



# Cosmological evolution of SMBH: Clues about AGN feedback from multiwavelength surveys

Andrea Merloni  
MPE

# The theoretical necessity of AGN feedback for galaxy evolution: a history of failures

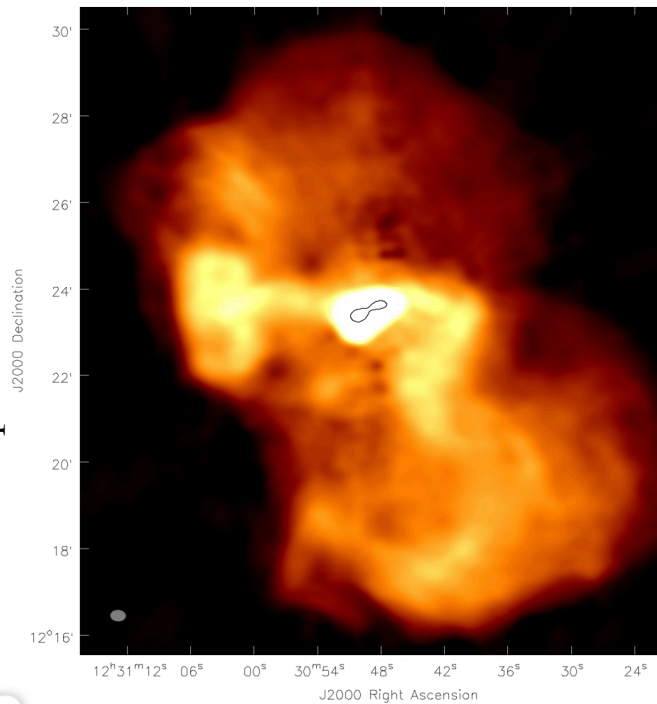
1. Maintain the observed close connection between the growth of SMBH and the growth of galaxies
2. Ensure a tight relation between black hole mass and galaxy mass/velocity dispersion
3. Help establishing the color-bimodality of galaxies
4. Prevent too massive galaxies from forming
5. Solve the cooling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

# Feedback for real

We need to classify AGN output according to:

- 1) Global energetics (mechanical power in Eddington units)
- 2) Covering factor/duty cycle
- 3) Impact on the gaseous phase of their host galaxies/structures
- 4) Redshift and mass distribution of the liberated energy

De Gasperin et al. 2012



LOFAR M87 map @ 150 MHz

(c) Interaction/"Merger"



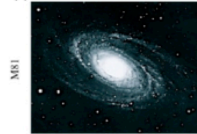
- now within one halo, galaxies interact & lose angular momentum
- SFR starts to increase
- stellar winds dominate feedback
- rarely excite QSOs (only special orbits)

(b) "Small Group"



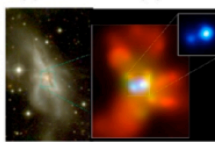
- halo accretes similar-mass companion(s)
- can occur over a wide mass range
- $M_{\text{halo}}$  still similar to before
- dynamical friction merges the subhalos efficiently

(a) Isolated Disk



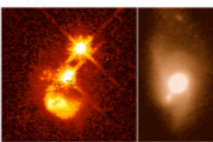
- halo & disk grow, most stars formed
- secular growth builds bars & pseudobulges
- "Seyfert" fueling (AGN with  $M_{\text{BH}} > 23$ )
- cannot redden to the red sequence

(d) Coalescence/(U)LIRG



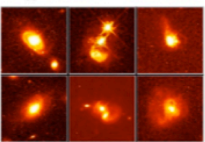
- galaxies coalesce: violent relaxation in core
- gas inflows to center: starburst & buried (X-ray) AGN
- starburst dominates luminosity/feedback, but, total stellar mass formed is small

(e) "Blowout"



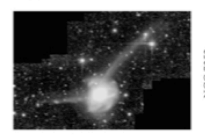
- BH grows rapidly: briefly dominates luminosity/feedback
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- get reddened (but not Type II) QSO: recent/ongoing SF in host
- high Eddington ratios
- merger signatures still visible

(f) Quasar



- dust removed: now a "traditional" QSO
- host morphology difficult to observe: tidal features fade rapidly
- characteristically blue/young spheroid

(g) Decay/K+A

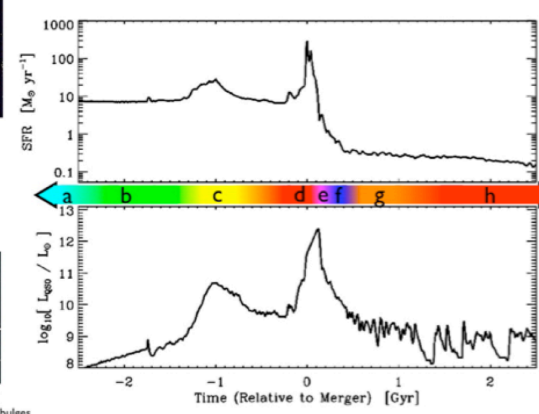


- QSO luminosity fades rapidly
- tidal features visible only with very deep observations
- remnant reddens rapidly (E+A/K+A)
- "hot halo" from feedback
- sets up quasi-static cooling

(h) "Dead" Elliptical



- star formation terminated
- large BH/spheroid - efficient feedback
- halo grows to "large group" scales: mergers become inefficient
- growth by "dry" mergers



Di Matteo, Hernquist, Hopkins+, 2005

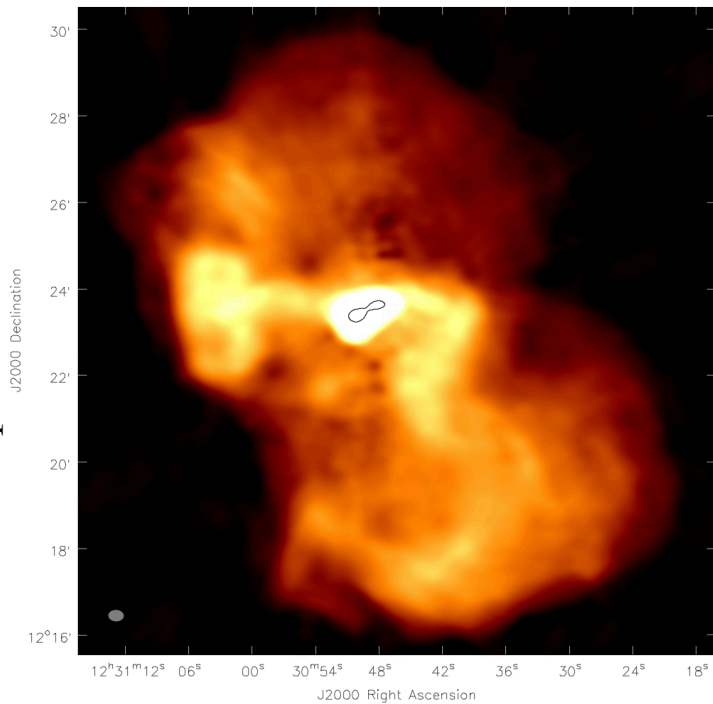


# Feedback for real

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De Gasperin et al. 2012



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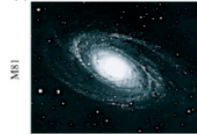
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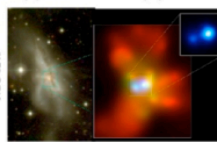
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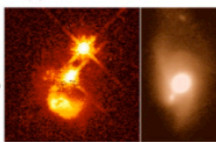
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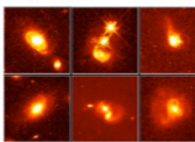
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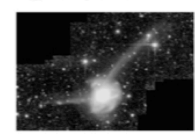
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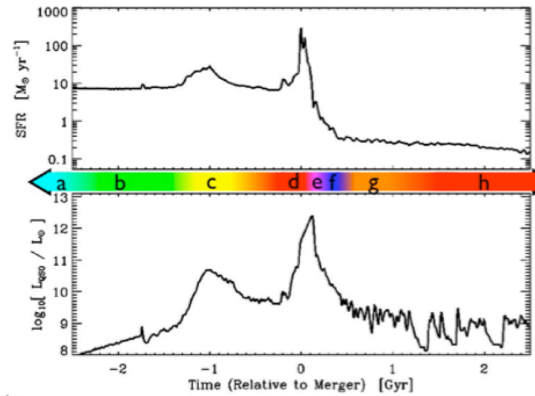


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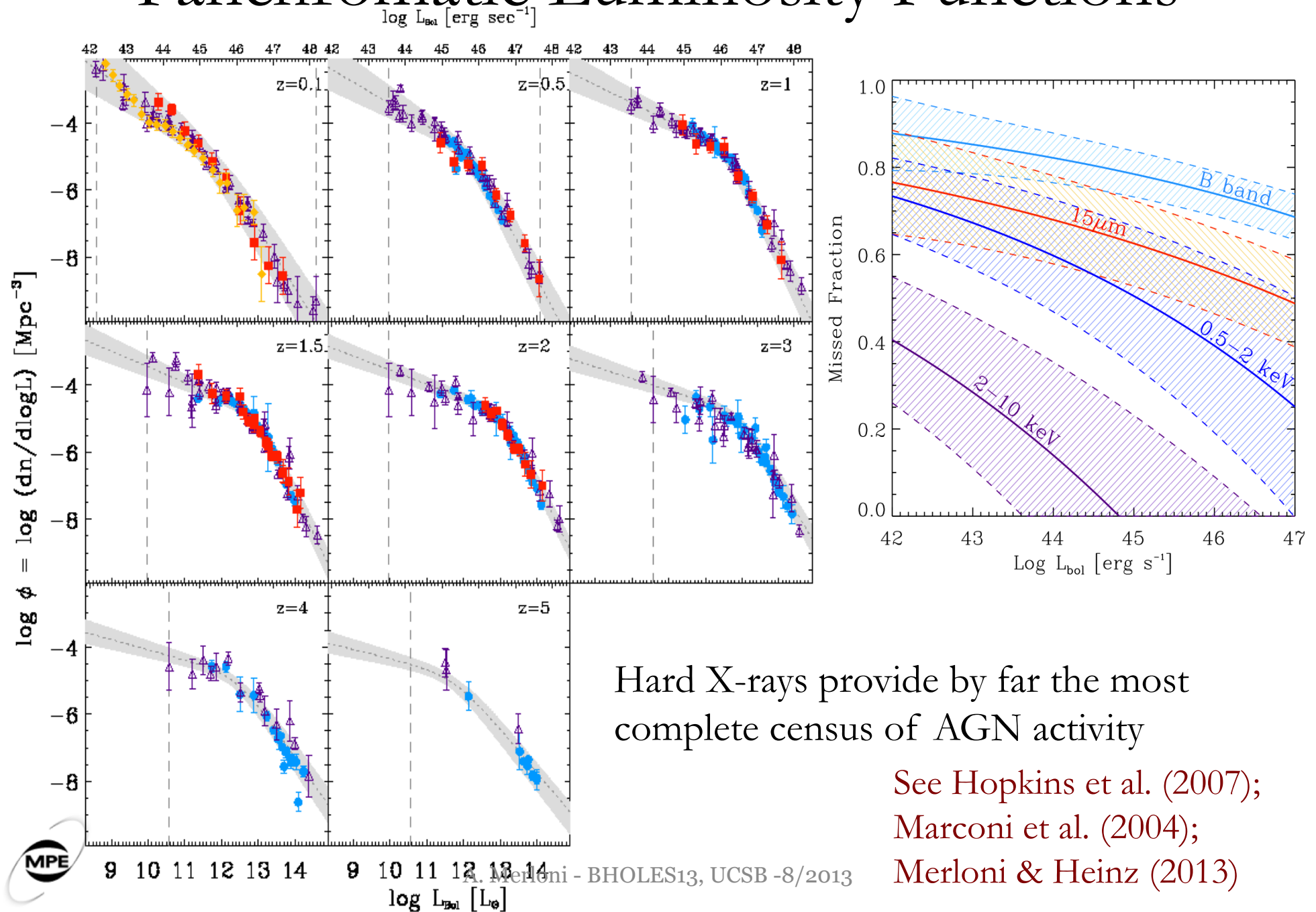
# Outline of this talk

- A. From multi-wavelength surveys to the history of accretion
- B. The properties of AGN host galaxies in COSMOS
- C. The incidence of obscuration in AGN



# From multi-wavelength surveys to the history of accretion

# 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)



# Cosmological evolution: Integral constraints

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

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

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

Fabian and Iwasawa (1999)  $\epsilon \sim 0.1$ ; Elvis, Risaliti and Zamorani (2002)  $\epsilon > 0.15$ ;

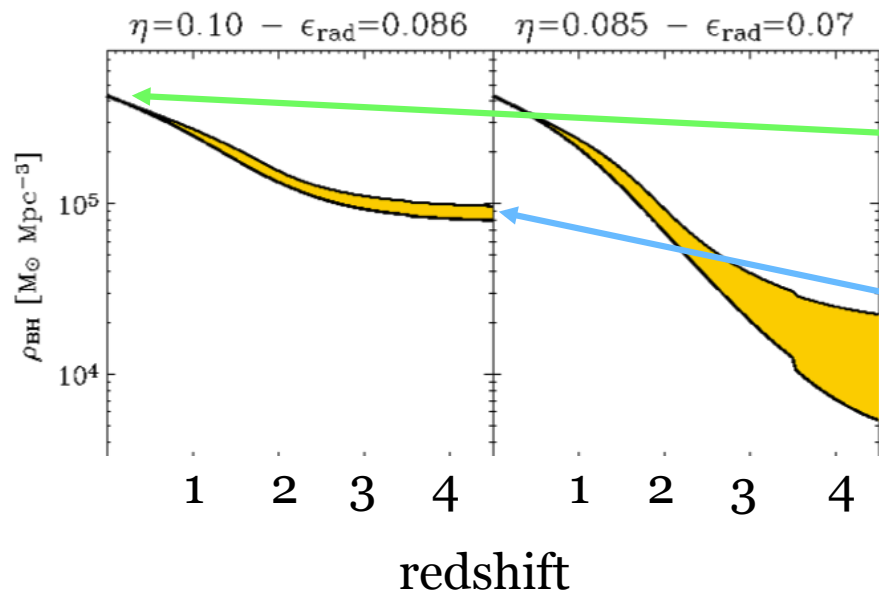
Yu and Tremaine (2002)  $\epsilon > 0.1$ ; Marconi et al. (2004)  $0.16 > \epsilon > 0.04$ ;

Merloni, Rudnick, Di Matteo (2004)  $0.12 > \epsilon > 0.04$ ; Shankar et al. (2007)  $\epsilon \sim 0.07$





# Constraints on radiative efficiency $\langle \epsilon_{\text{rad}} \rangle$



$$\xi_0 = \rho_{\text{BH},0} / (4.2 \times 10^5)$$

$$\xi_i = \rho_{\text{BH}}(z=z_i) / \rho_{\text{BH},0}$$

(Input from seed BH formation models needed!)

$$\xi_{\text{CT}} = \rho_{\text{BH,CT}} / \rho_{\text{BH},0}$$

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

$$\xi_{\text{lost}} = \rho_{\text{BH,lost}} / \rho_{\text{BH},0}$$

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

$$\langle \epsilon_{\text{rad}} \rangle / (1 - \langle \epsilon_{\text{rad}} \rangle) \approx 0.075 / [\xi_0 (1 - \xi_{\text{CT}} - \xi_i + \xi_{\text{lost}})]$$

Merloni and Heinz 2008

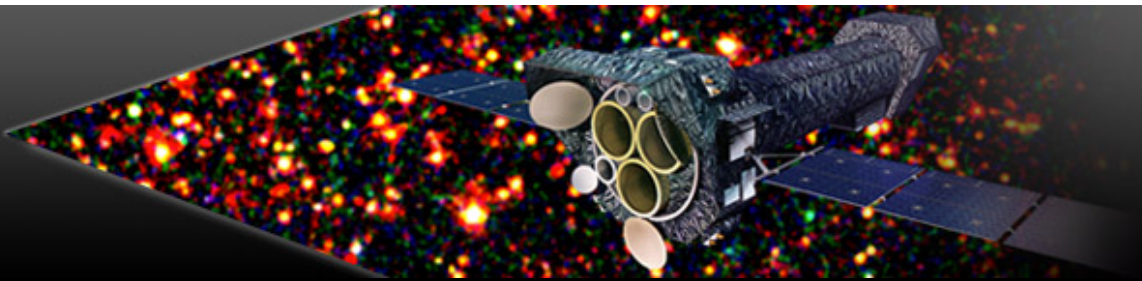
Volonteri et al. 2013



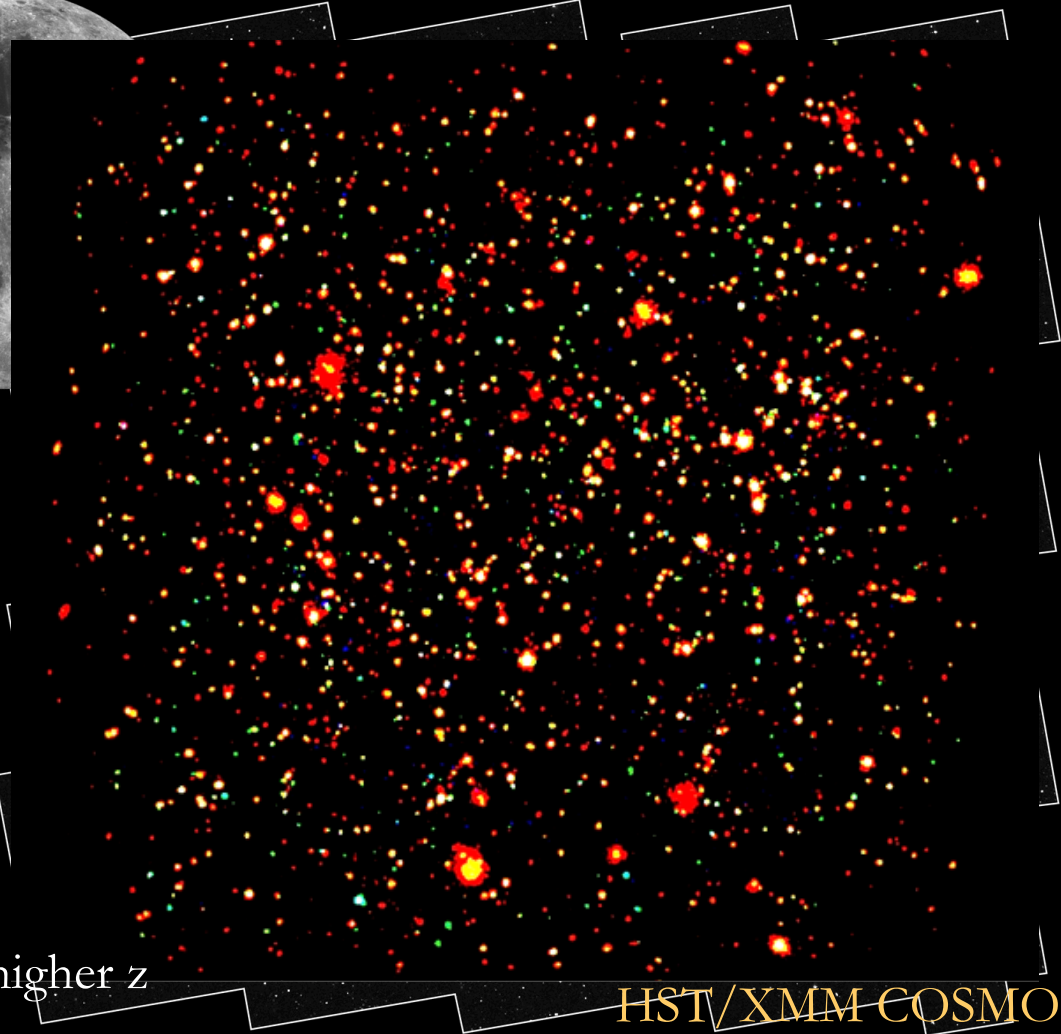
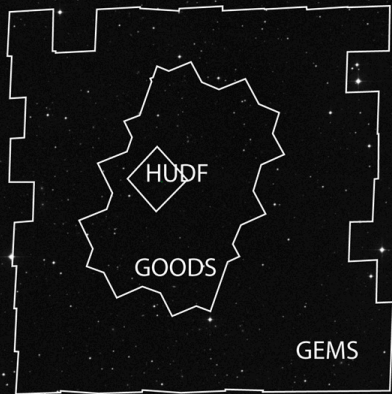
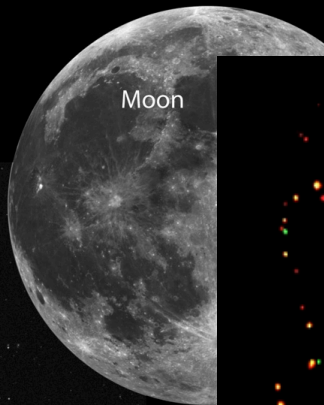
# The properties of AGN host galaxies in COSMOS

Bongiorno et al. 2012, MNRAS, 427, 3103

# COSMOS



Relative Sizes of HST ACS Surveys



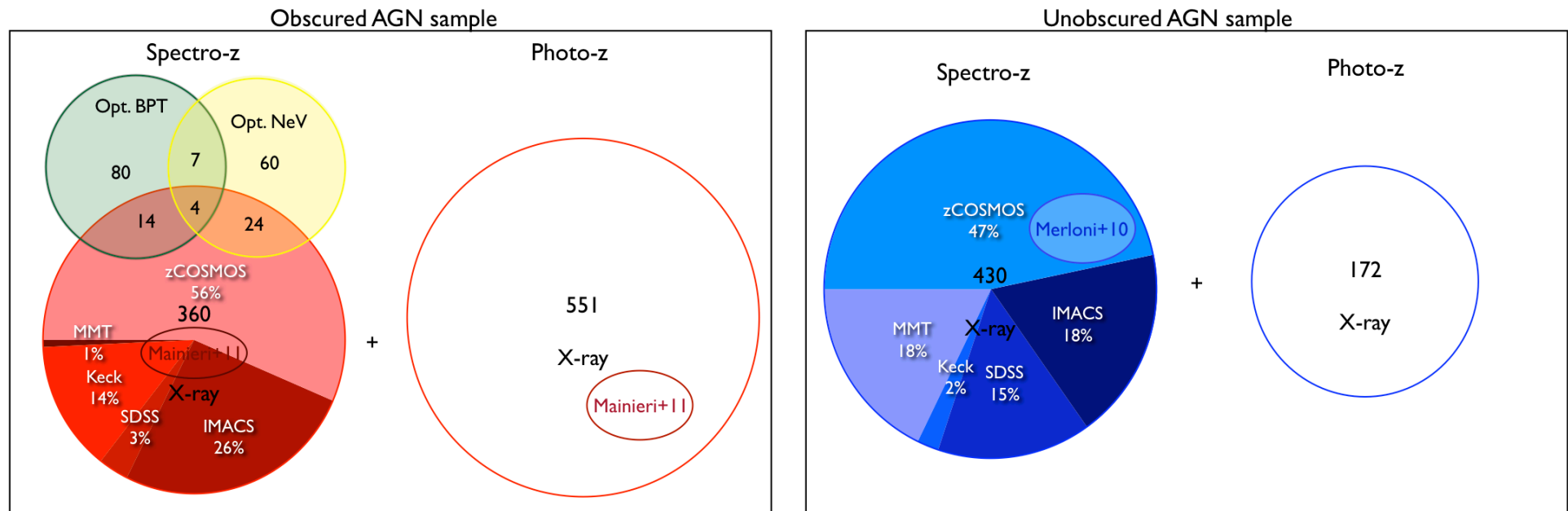
2 deg<sup>2</sup> equatorial  
HST treasury project  
Deep: ACS  $i_{AB} < 27$   
Similar volume as ~~SDSS~~<sub>30</sub>, but fainter and higher  $z$   
Extensive multi- $\lambda$  coverage

HST/XMM COSMOS  
[Scoville, Hasinger]



# A complete, X-ray selected, AGN sample

- 1555 X-ray selected AGN (XMM;  $f_{\text{lim}} \sim 5 \times 10^{-16} [0.5-2]; 3 \times 10^{-15} [2-10]$ )
- **100% redshift complete** (54% specz; 46% photoz)
- 602 Unobscured (71% specz; 29% photoz)
- 953 Obscured (42% specz; 58% photoz)
- **Parent sample** of  $\sim 200\text{k}$  IRAC galaxies (photoz,  $M_*$ ; Ilbert et al. 2010)



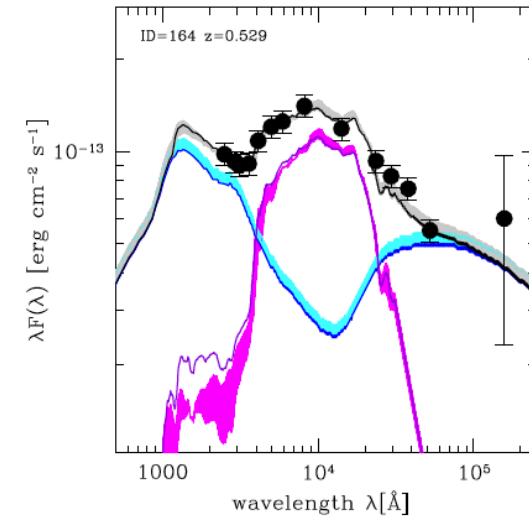
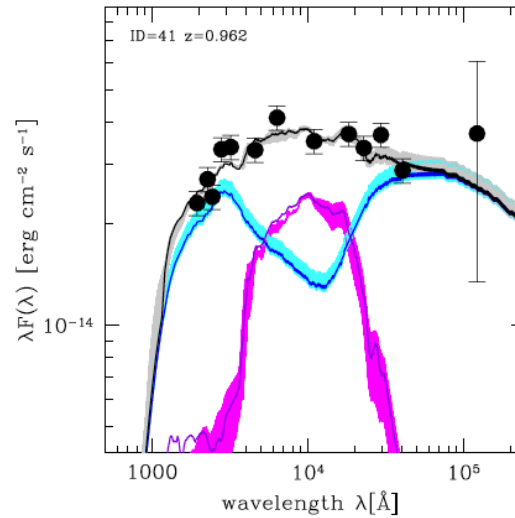
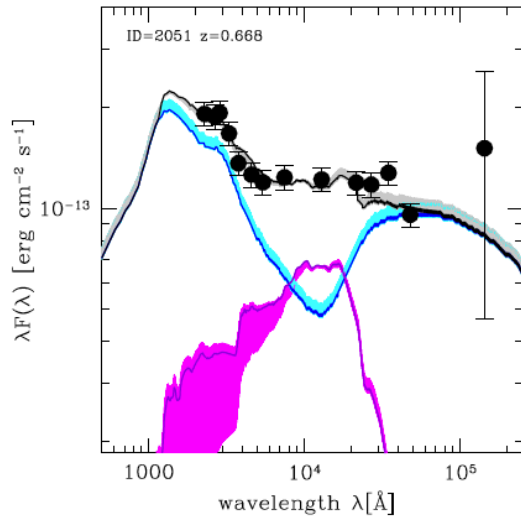
Bongiorno et al. 2012

See also Brusa et al. 2010; Salvato et al. 2009; Lusso et al. 2011, 2012

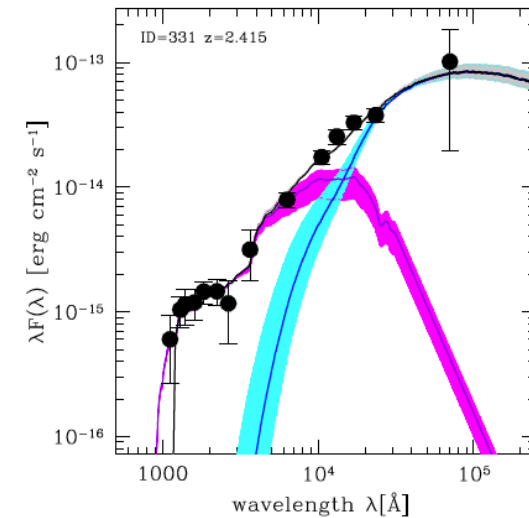
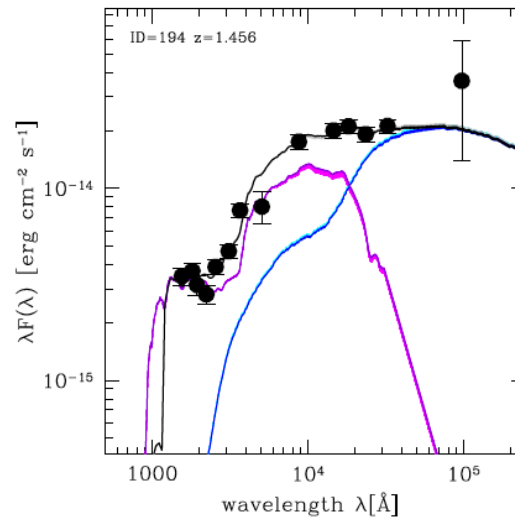
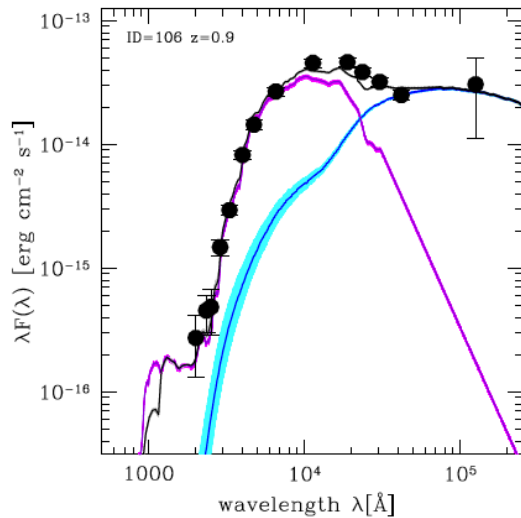


# AGN/Galaxy SED decomposition

Type 1 (unobscured)



Type 2 (obscured)



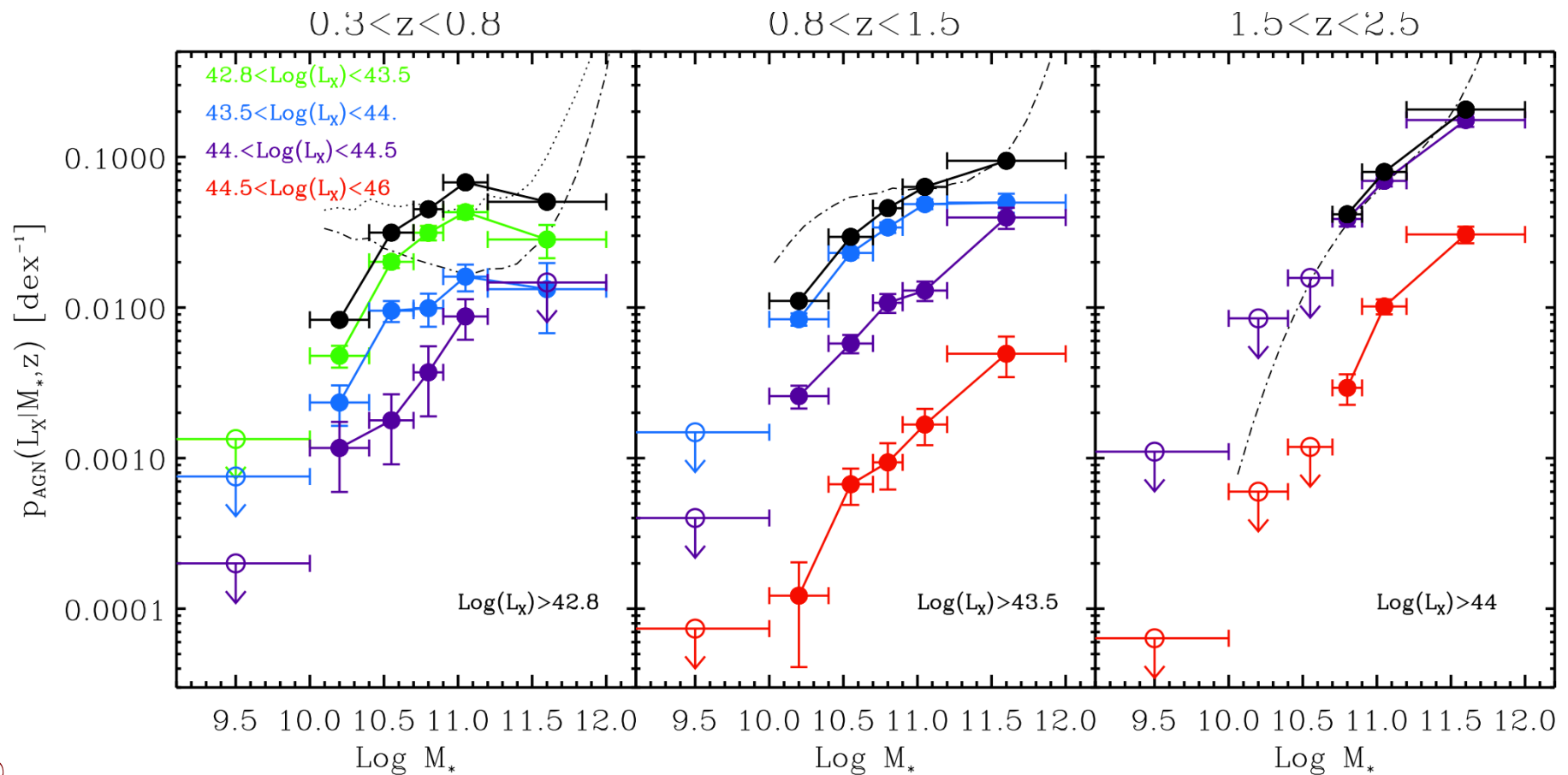
# Scientific Questions

- Statistically robust assessment of AGN demographics:
  - Which galaxies host (which) AGN?
  - AGN triggering: under which conditions do SMBH grow?
- Does AGN activity affect galaxies' properties (at the population level)
  - Location of AGN in color-magnitude plots, etc.
  - Smoking guns of AGN feedback?

See e.g. Nandra et al. 2008; Silverman et al. 2009; Brusa et al. 2010; Xue et al. 2011; Schavinski et al. 2011; Rosario et al. 2012; Alexander & Hickox 2012; Mullaney et al. 2012; Santini et al. 2012; Page et al. 2012; Rovilos et al. 2012; Harrison et al. 2012; etc.



# AGN fractions ( $M_*$ , $L_X$ )



Bongiorno et al. 2012

1: The probability of a galaxy to host an AGN growing at a given  $L_X$  strongly depends on stellar mass. Similar at all luminosities!  
 Narrow range of  $L_X/M_*$  clearly ruled out (Merloni & Heinz 2008)

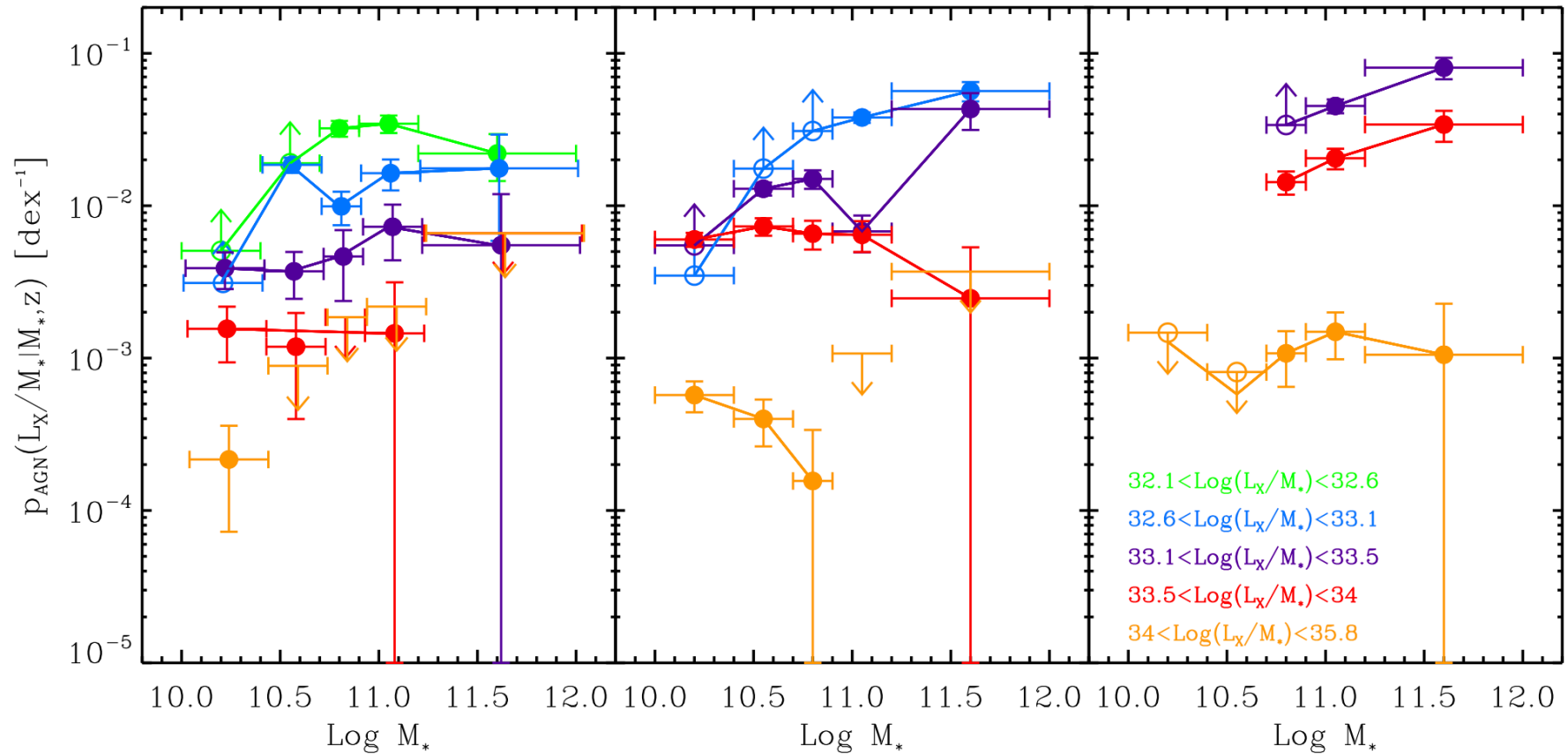


# AGN fractions ( $M_*$ , $L_X$ )

$0.3 < z < 0.8$

$0.8 < z < 1.5$

$1.5 < z < 2.5$



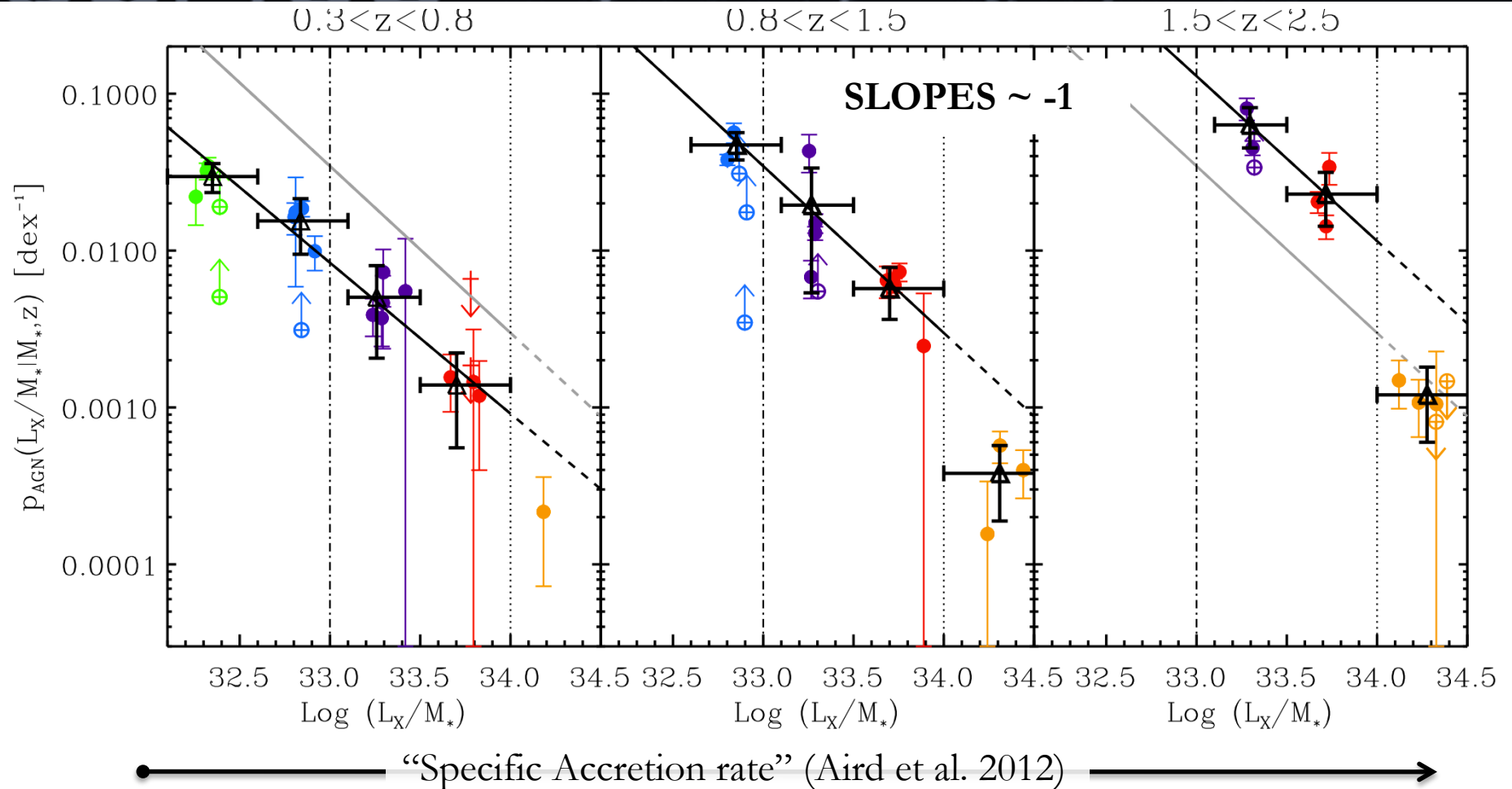
Bongiorno et al. 2012

2: AGN fraction at fixed  $L_X/M_*$   $\sim$  independent on galaxy mass!





# Specific accretion rate distributions

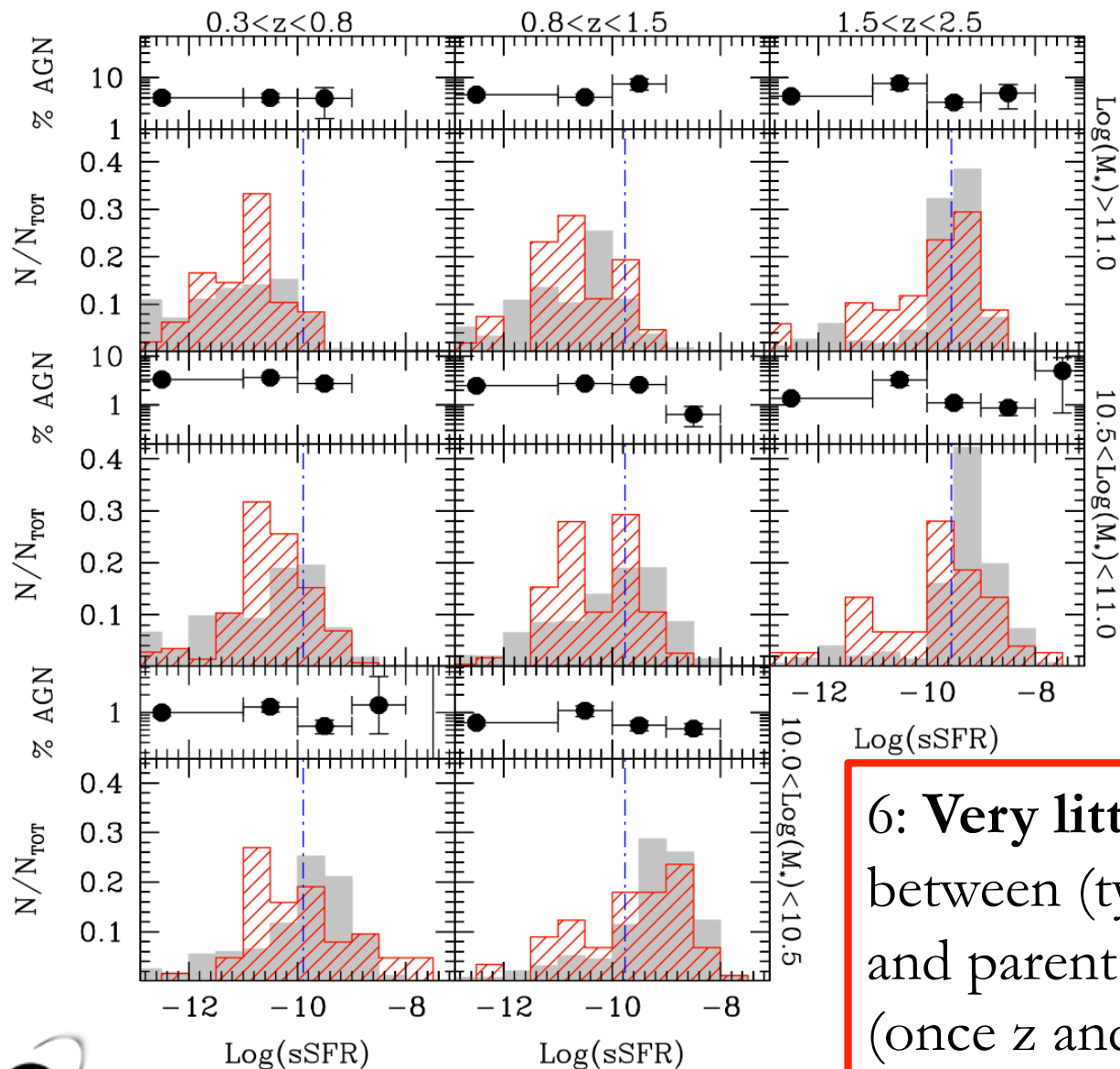


Bongiorno et al. 2012

- 3: AGN fraction at fixed L/M ~independent on galaxy mass!
- 4: Its normalization increases as  $\sim(1+z)^4$  [cfr. sSFR density]
- 5: There appears to be a break consistent with  $\sim$ **Eddington limit**



# Obscured AGN in sSFR-Mass plane



Bongiorno et al. 2012

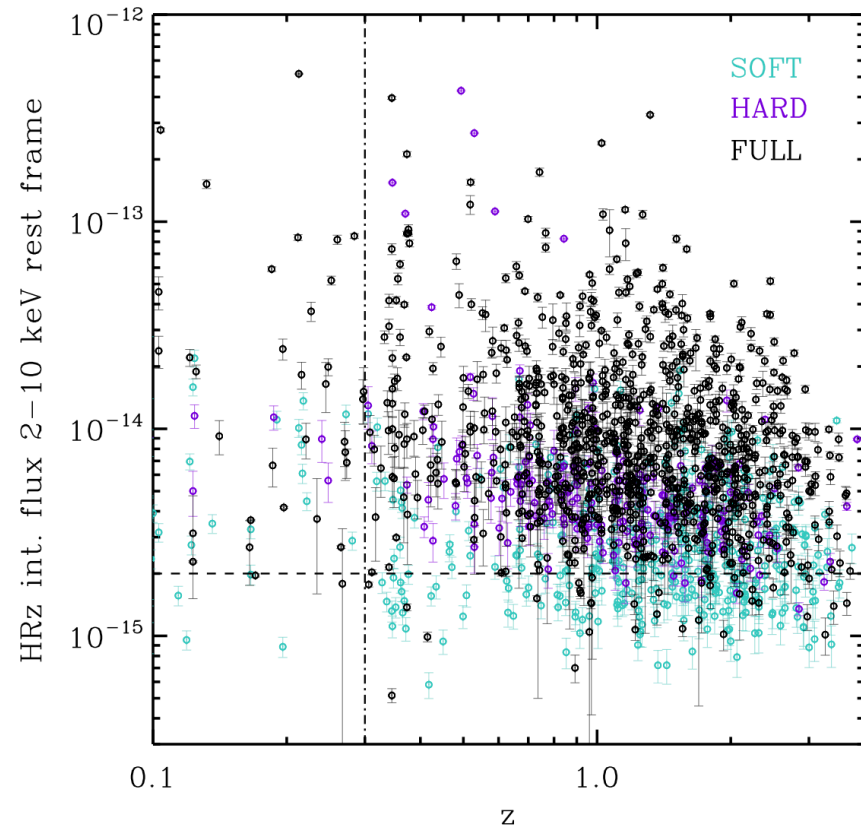
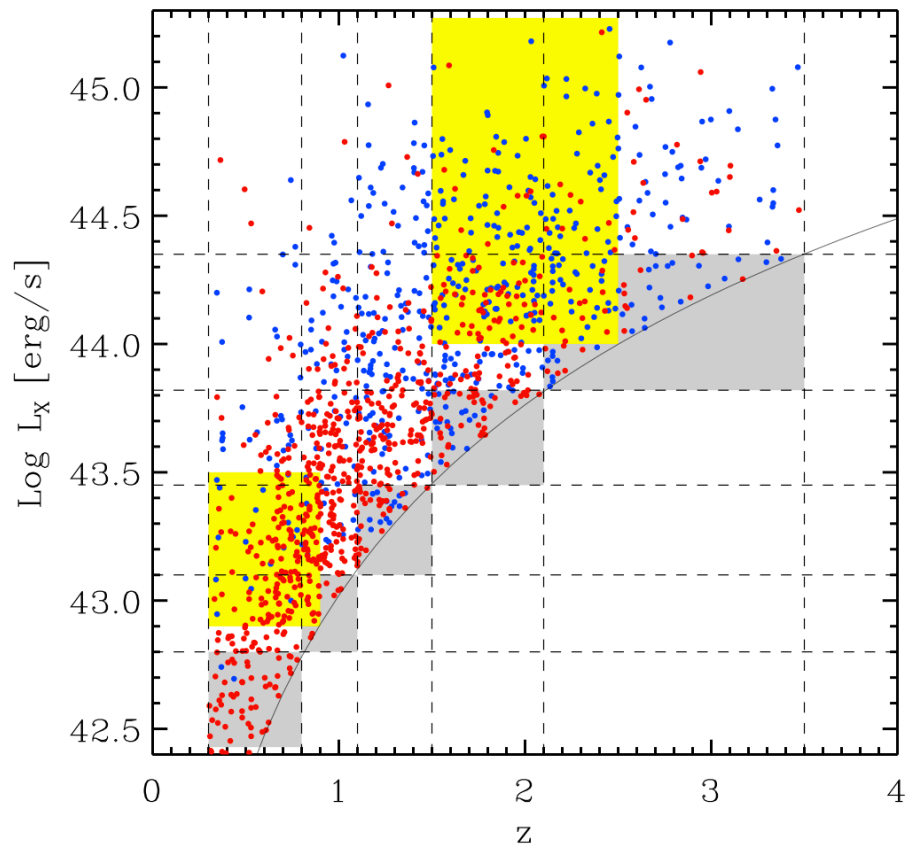
6: Very little difference between (type 2) AGN hosts and parent sample in sSFR (once  $z$  and  $M_*$  factored out)



# The incidence of obscuration in AGN

Merloni et al. 2013, MNRAS, submitted

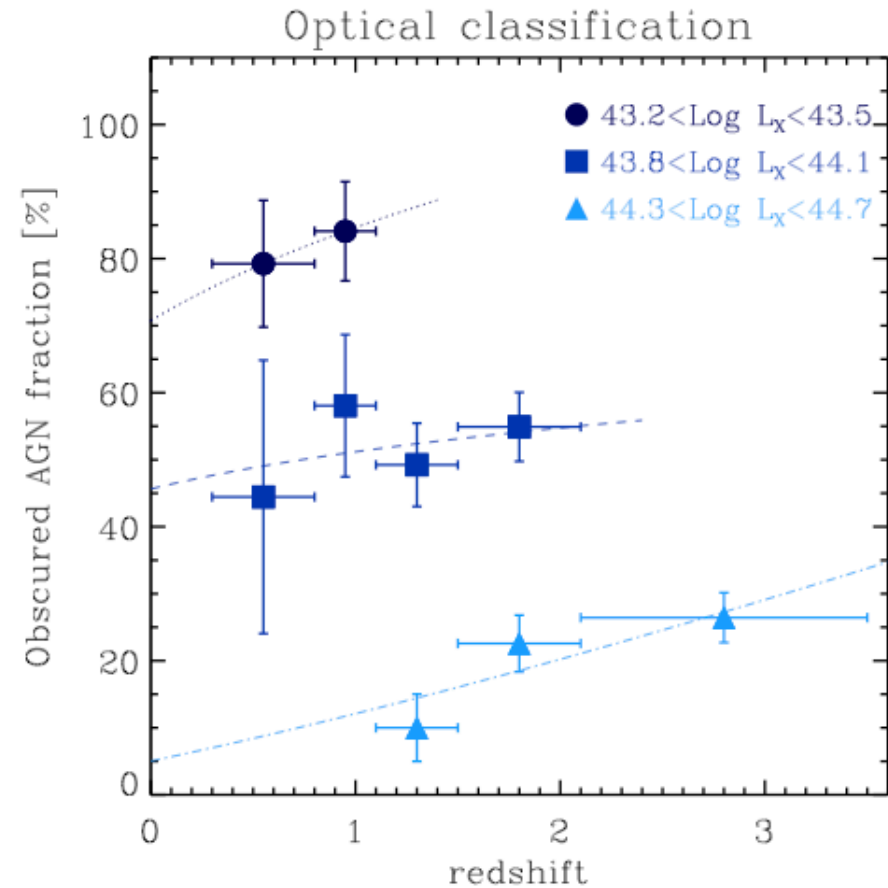
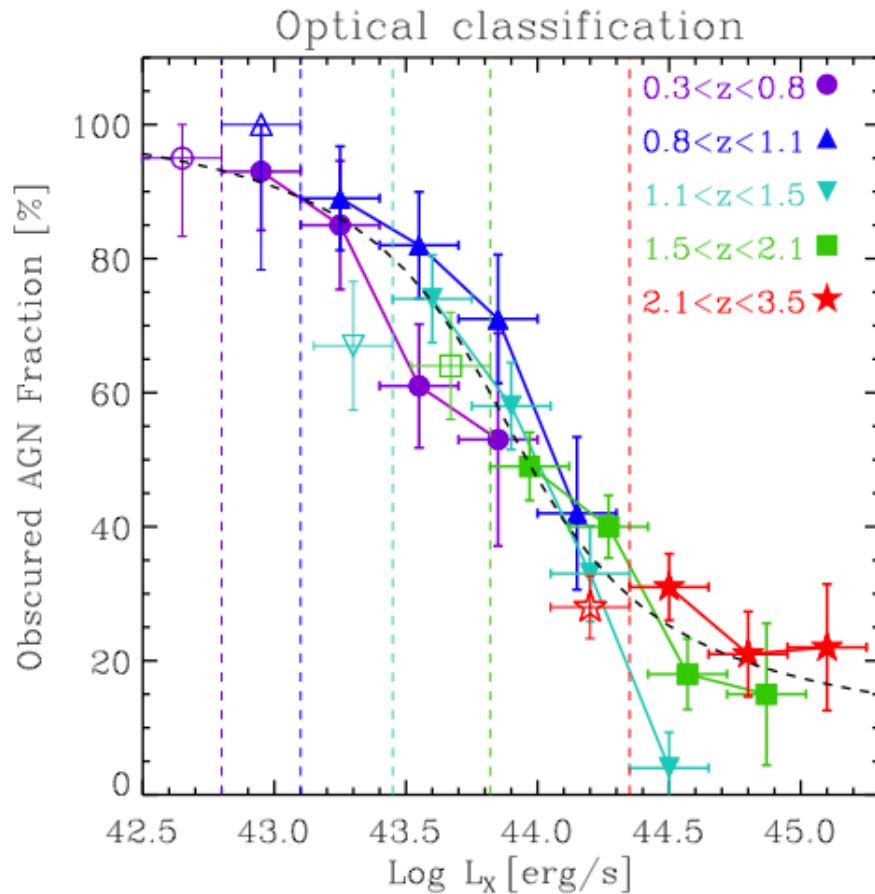
# A 2-10 keV rest-frame selected sample



- 1310 X-ray selected AGN ( $f_{\text{lim}} \sim 2 \times 10^{-15}$  erg/s/cm<sup>2</sup> [2-10 keV])
- Redshift information allows a 'clean' rest-frame selection based on the intrinsic (absorption corrected) X-ray flux



# Optical Obscuration

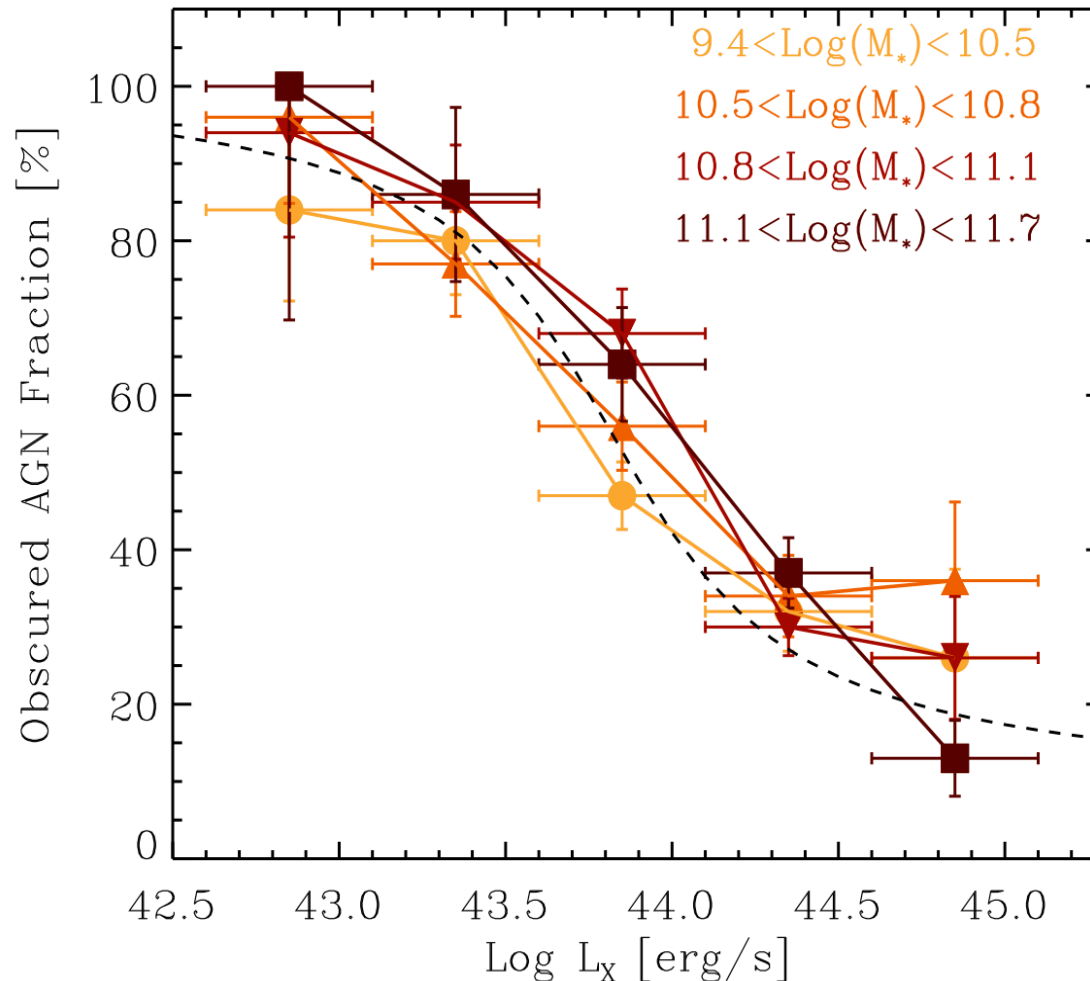


Merloni et al. 2013

7: The fraction of Optically obscured AGN depends on the nuclear luminosity, and on redshift only for the most luminous



# Optical Obscuration: no $M_*$ -dependence

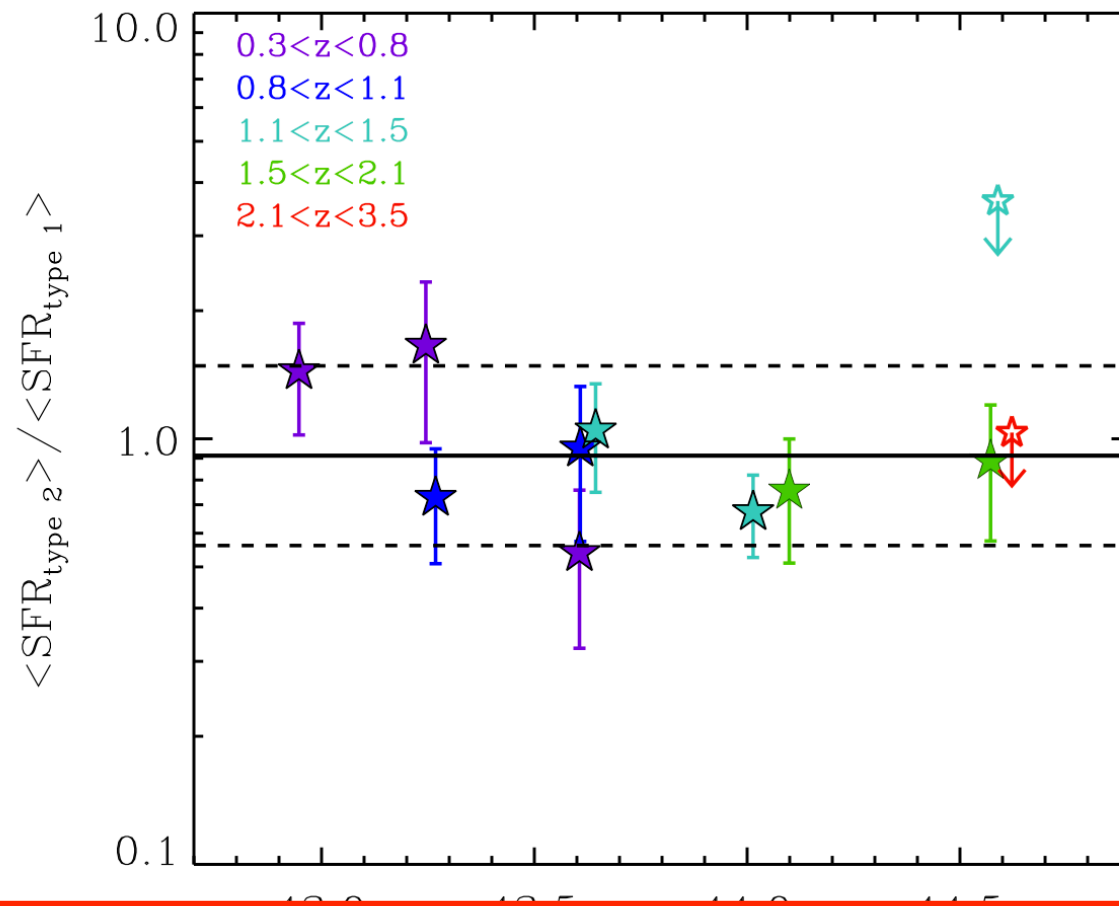


Merloni et al. 2013

8: The fraction of Optically obscured AGN does NOT depend on the host stellar mass



# No link of AGN obscuration with SFR



9: The Galaxy-wide SFR of AGN hosts does not correlate with the properties of the obscuring medium

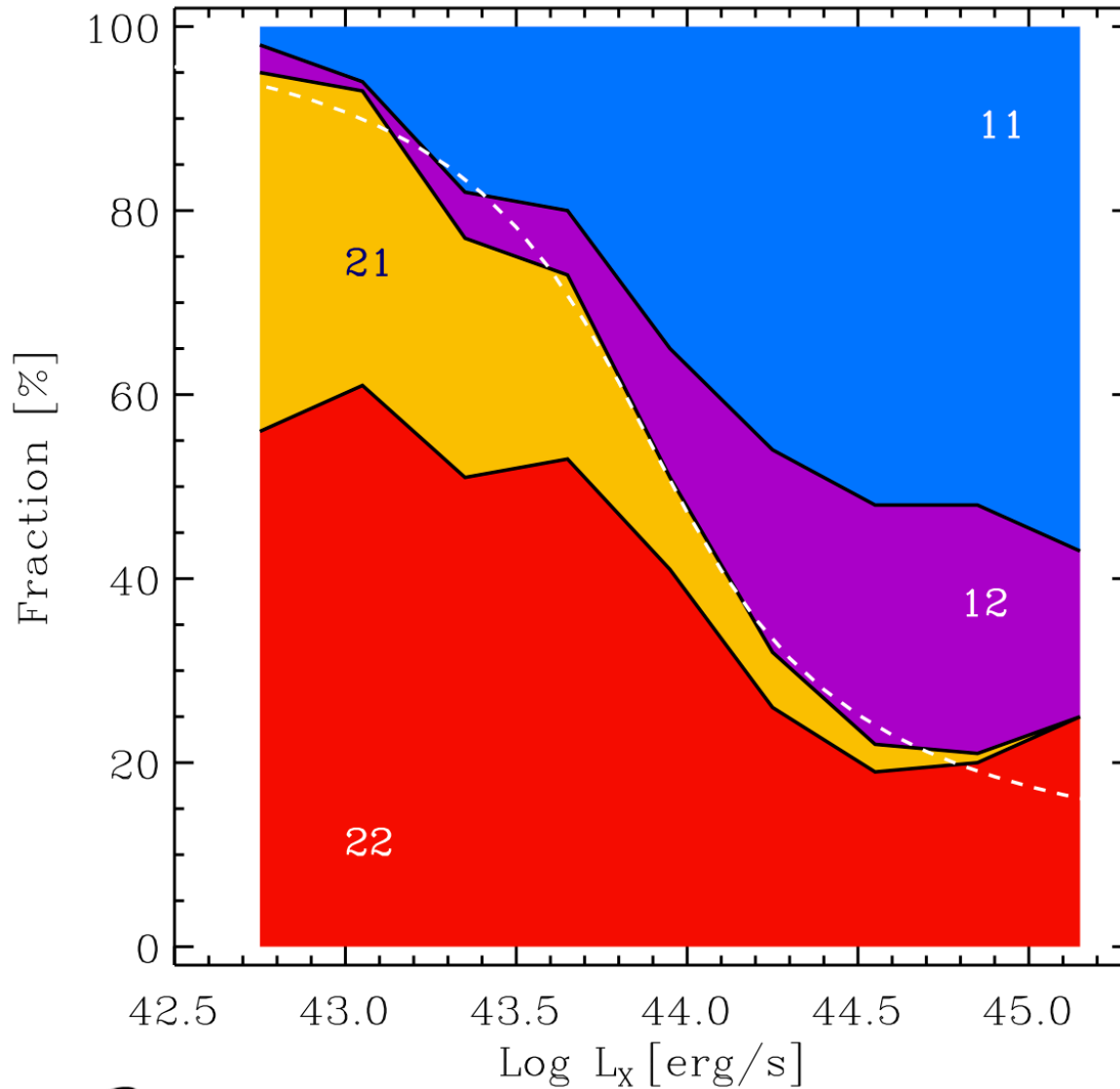
Merloni et al. 2013

Lutz, Rosario, Santini, Magnelli, Berta, ...



# X-ray vs. Optical obscuration

$0.3 < z < 3.5$



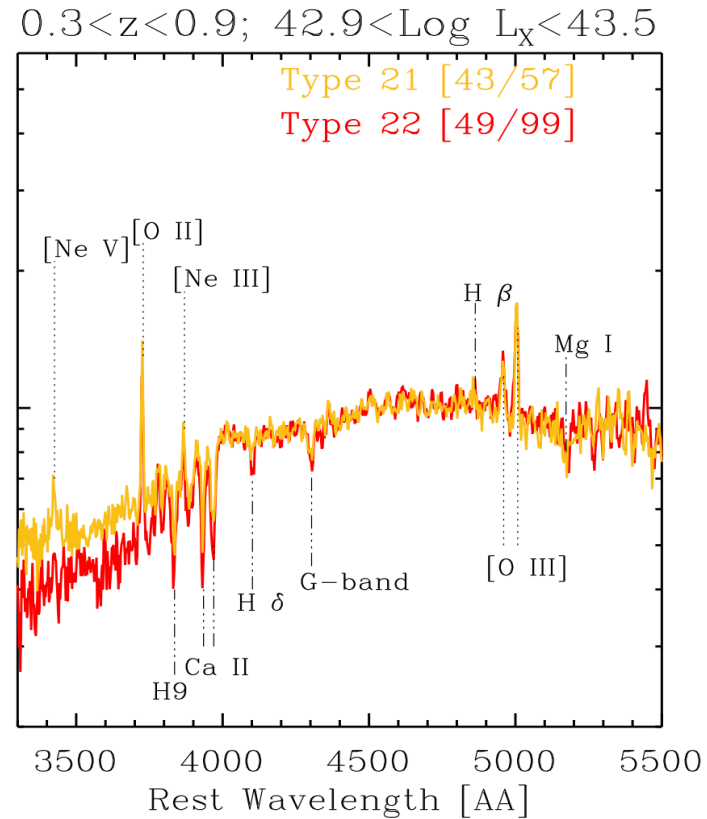
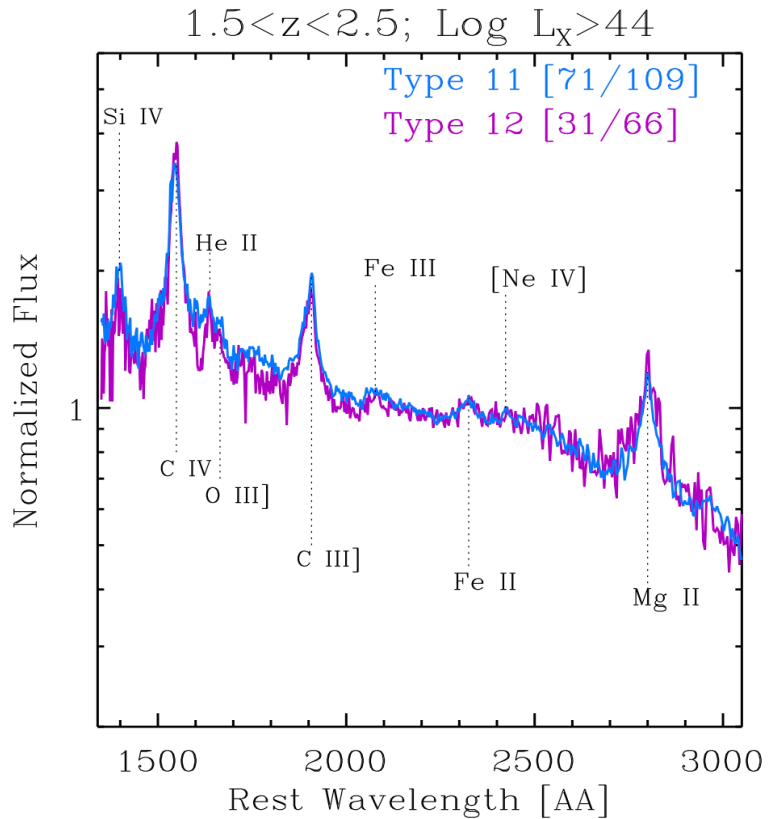
**Blue: X-ray & Optical type 1**  
**Red: X-ray & Optical type 2**  
**Yellow: X-ray type1, no BL**  
**Purple: BLAGN,  
X-ray obscured**

Merloni et al. 2013

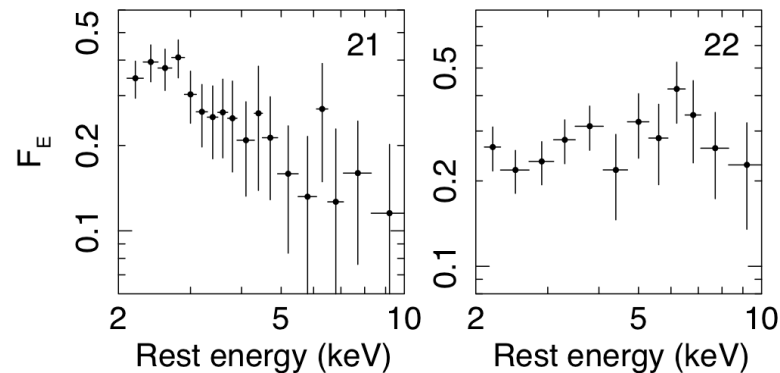
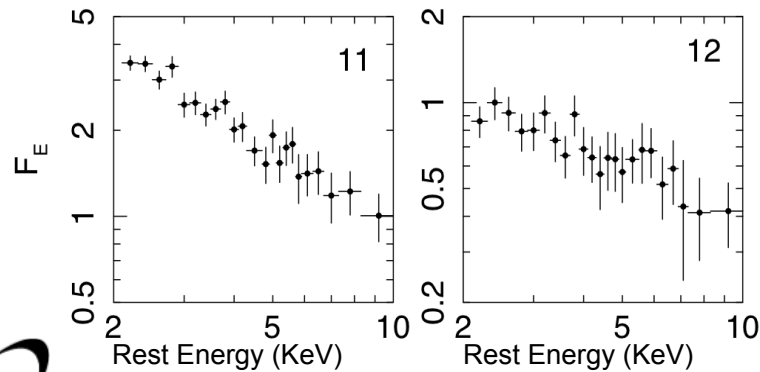




# Stacked rest-frame spectra



Optical

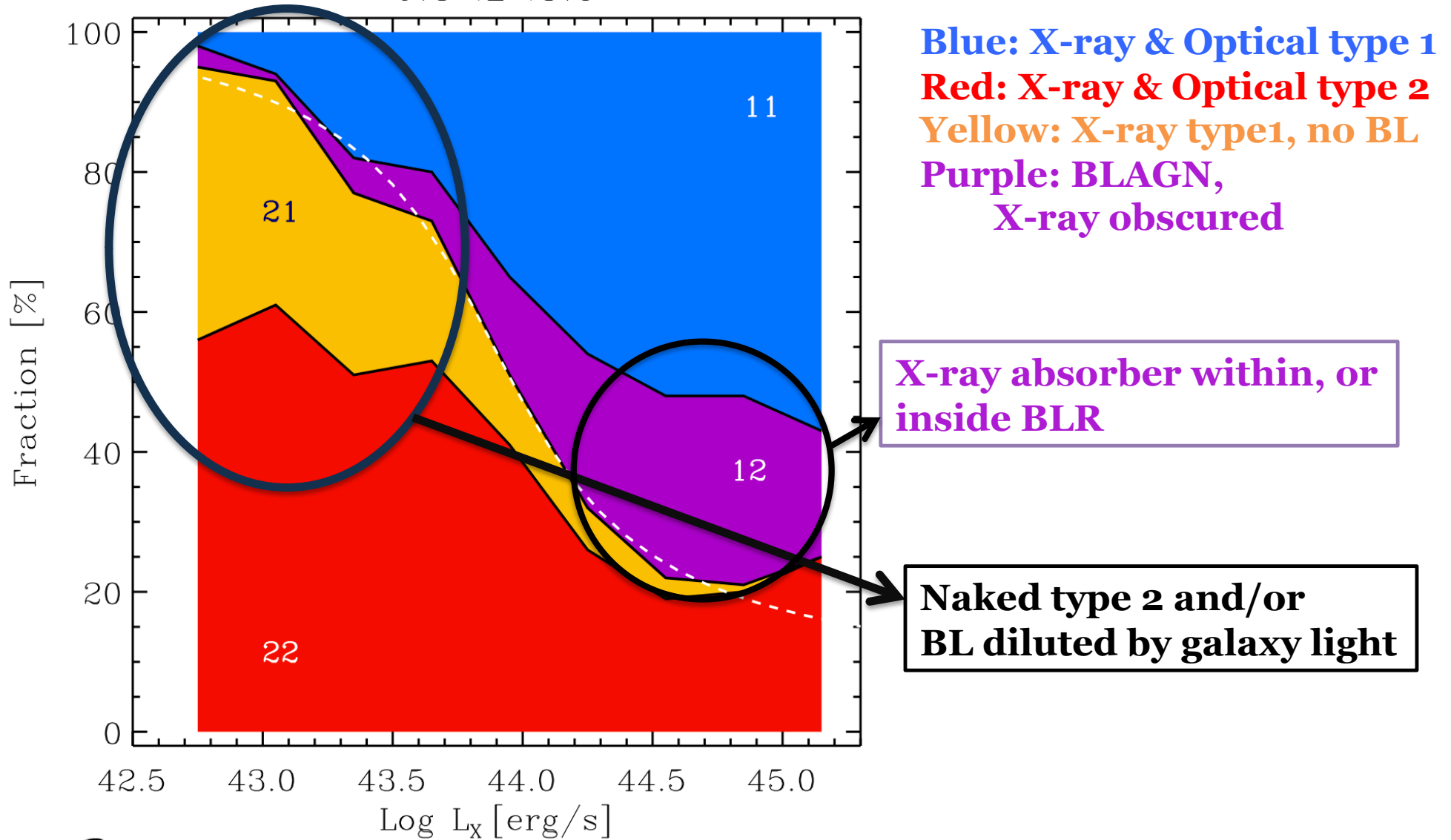


X-ray



# X-ray vs. Optical obscuration

$0.3 < z < 3.5$



Merloni et al. 2013



# Summary

1. The probability of a galaxy to host an AGN growing at a given specific accretion rate is (almost) **independent of stellar mass**
2. Power-law distribution of Eddington ratios  $\rightarrow$  stochasticity of accretion
3. AGN fraction normalization increases  $\sim (1+z)^4$  [ $\sim$  sSFR density]
4. The AGN fraction distribution shows a break consistent with **Eddington limit**
5. Very little difference between (type 2) AGN hosts and parent sample in sSFR (once  $z$  and  $M_*$  factored out). **Where is AGN feedback smoking gun?** ( $t_{\text{AGN}} \not\gg t_{\text{quench}}$ )
6. Nuclear obscuration (AGN-gas interaction on pc scale) is clearly complex, and affected by the **AGN radiative output**, but not on any measured galaxy property (stellar mass or star formation rate)





Thank you