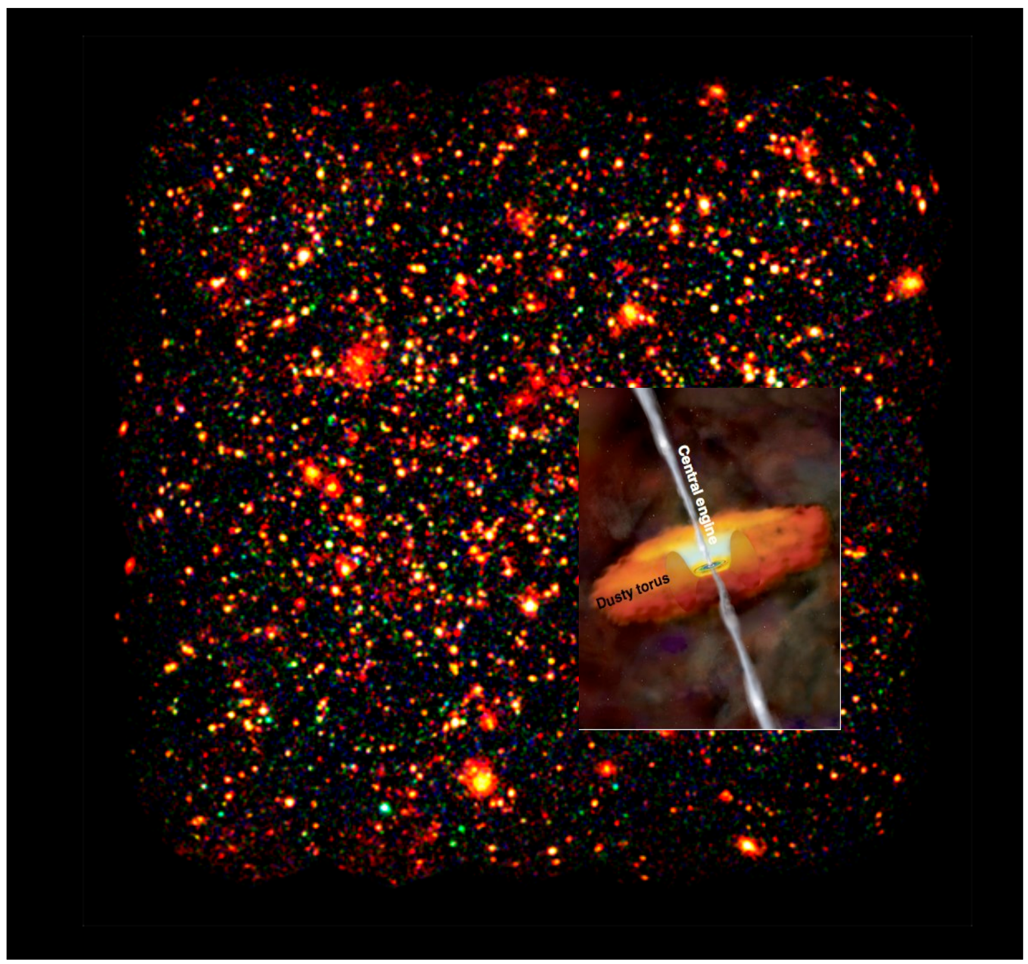

XMM view of the COSMOS field

AGN evolution and Supermassive black holes growth from large area and deep X-ray surveys

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INAF-Osservatorio Astronomico di Trieste 13/05/2009

Acknowledgements

XMM/Chandra COSMOS teams

CDFS/GOODS/MUSIC team

.. and in particular thanks to:

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F. Civano, G. Hasinger, K. Iwasawa, V. Mainieri, M. Mignoli, M. Salvato,
C. Vignali, G. Zamorani, A. Grazian, P. Santini

Outline

- Why should we care about evolution of AGN/SMBH population?
  - AGN-galaxy coevolution
  - Evolution of mass and accretion rate density (through Soltan argument)
- Tools: multiwavelength X-ray surveys
- Main results:
  - Anti-hierarchical growth/downsizing
  - Problem on complete AGN census (Compton Thick & high-z)
  - The host-galaxies of AGN and the BH-SFR connection
  - The evolution of the M_BH-M_star relation
- Implications:
  - Unified models revised
  - XRB and BH growth synthesis models (constraints on radiative efficiency)

Rationale: AGN evolution

MAIN ARGUMENTS:

1) AGN trace SMBH

SMBH ($M>10^6$ $M_\odot$) are powering Active Galactic Nuclei (AGN)

Source of power: accretion of material onto the SMBH through an accretion disc: the mass accreted is converted in energy and released as radiation (radiatively efficient)

SMBH are powering AGN over a wide range of Luminosities (Quasars and Seyfert); most of them (70-80%) are obscured by large amounts of gas and dust

Rationale: AGN evolution

MAIN ARGUMENTS:

1) AGN trace SMBH

2) (dormient) SMBH are ubiquitous in nearby galaxies

Chandra, HST, VLA/VLBI surveys of Palomar sample, AMUSE-VIRGO
(Elvis & Keel '84; Ho, Filippenko, Nagar, Wilson, Gallo etc. 1997-2007)

$n_{SMBH}(\mathrm{Log}\ M>5.5) \approx n_{AGN}(\mathrm{Log}\ L_X> 40.5) \approx n_{AGN}(\mathrm{Log}\ P_{core,5GHz}>18.8)$

→ AGN transient phase

Rationale: AGN evolution

MAIN ARGUMENTS:

1) AGN trace SMBH

2) (dormient) SMBH are ubiquitous in nearby galaxies

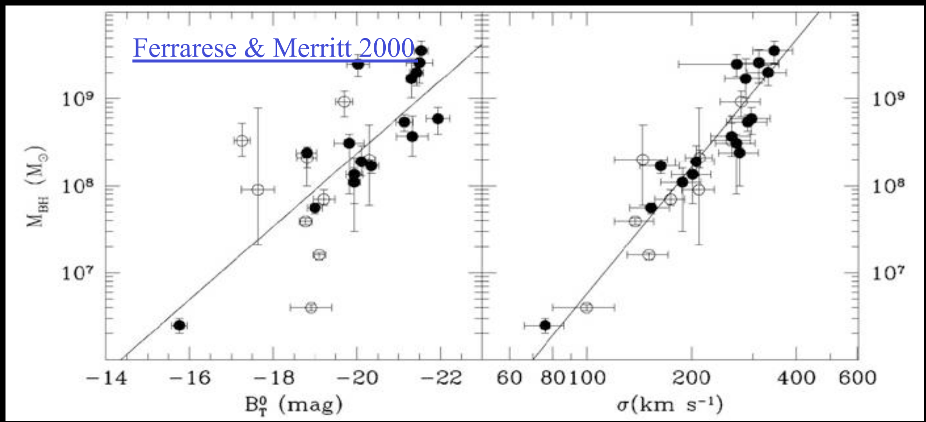
3) SMBH properties (mass) are related to host galaxy properties (e.g. velocity dispersion, bulge luminosity)

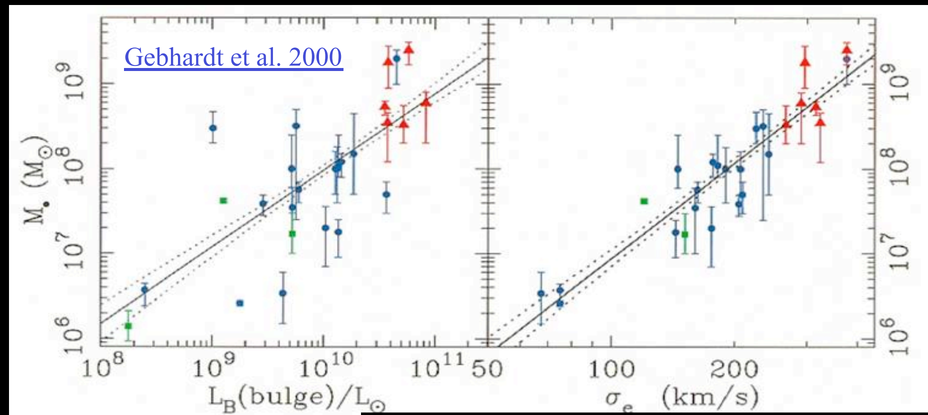
–

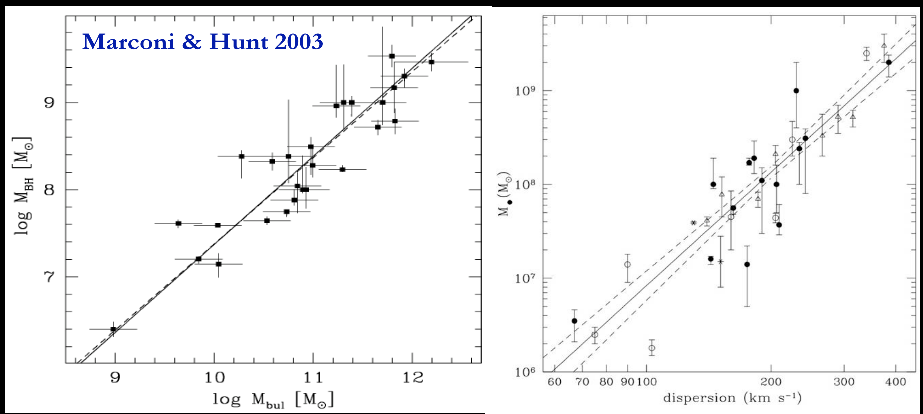
MAIN OBSERVATIONAL RESULT:

tight correlation between M_{BH} and bulge properties

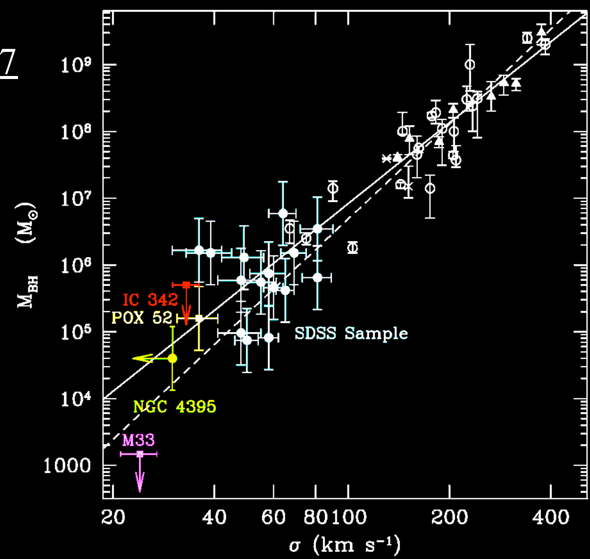
Large scale galaxies properties strongly depend on BH mass







Greene et al. 2007



Rationale: AGN evolution

MAIN ARGUMENTS:

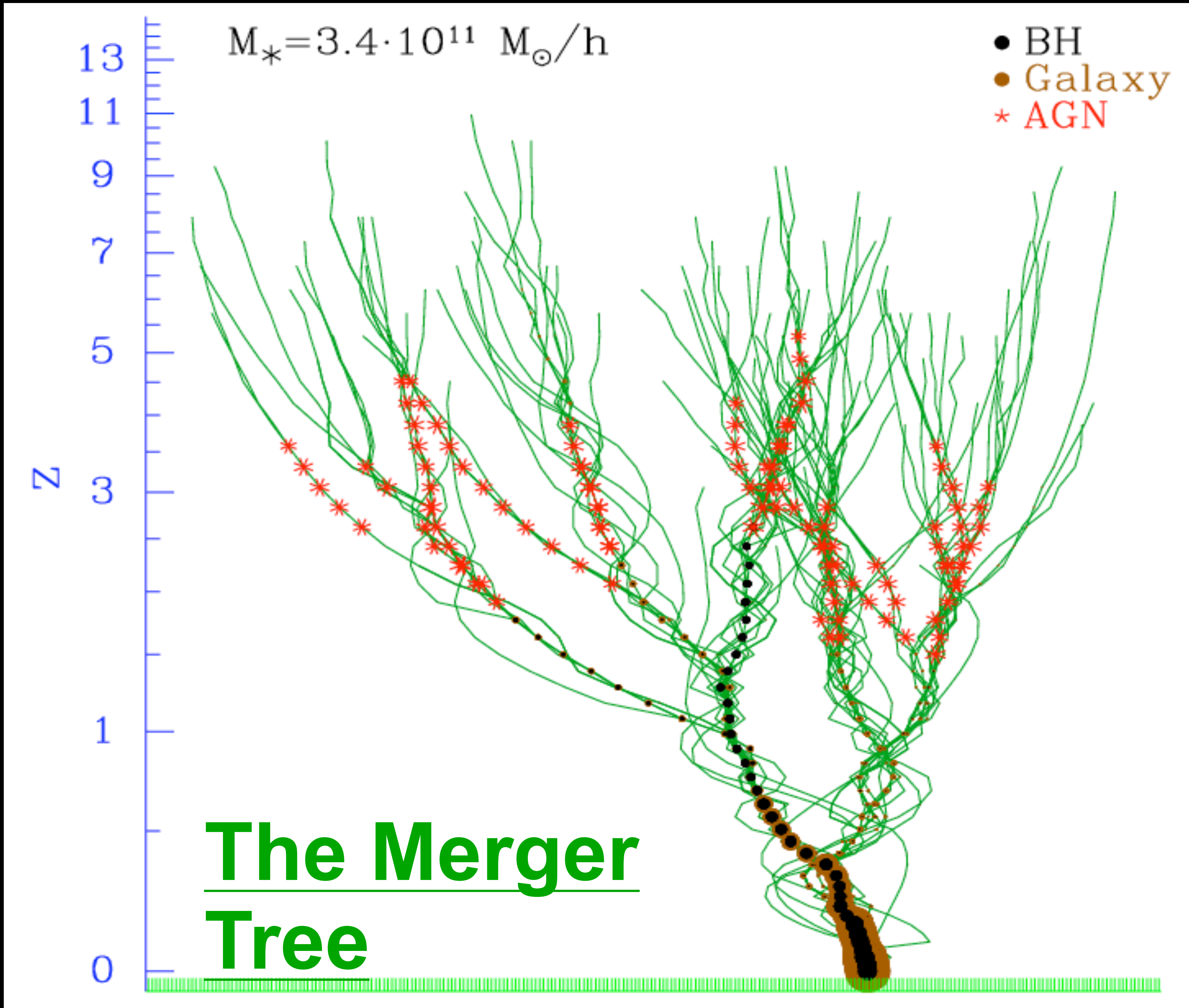
1) AGN trace SMBH

2) (dormient) SMBH are ubiquitous in nearby galaxies

3) SMBH properties (mass) are related to host galaxy properties (e.g. velocity dispersion, bulge luminosity)

AGN play a key role in galaxy evolution: “Feedback”

(e.g. Silk & Rees 1998, Granato et al. 2004, Di Matteo et al. 2005, King 2005, Hopkins et al. 2006)



Marulli et al. 2009, A&A

Extension of:

Croton+06
De Lucia+07
(SAM models based on Millennium sim)

Independent argument: Integral constraints (Soltan argument)

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

$$L_{\rm bol} = \epsilon \dot{M}_{\rm acc} c^2 = \epsilon \dot{M}_{\bullet} c^2 / (1 - \epsilon)$$

Radiative efficiency

Bolometric luminosity *Accretion rate* *BH growth rate*

IF all galaxies undergo an AGN phase and
IF dead SMBH observed today are the remnants/witnesses of this phase

→ The BH mass density obtained integrating the luminosity emitted by AGN over the cosmic time is expected to be similar to that measured in local bulges

$$\rho_{\bullet} \sim \rho\,(\text{direct}) \sim 4\text{-}5 \times 10^5\ M_{\odot}\,\text{Mpc}^{-3}$$

(e.g. Fabian & Iwasawa 1999, Yu & Tremaine 2002, Marconi et al. 2004, Shankar et al. 2008)

The main ingredients/actors

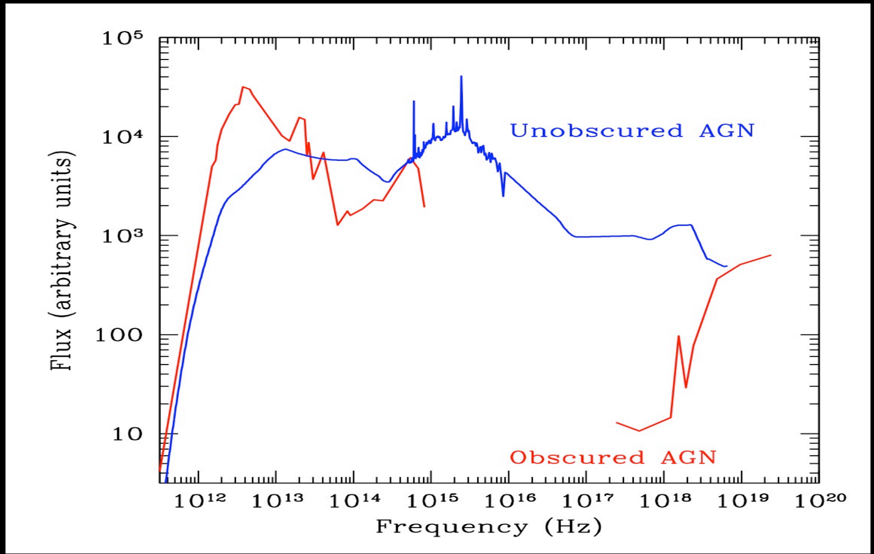
- Main observables needed to cope with models:
  - AGN bolometric luminosity functions + its evolution with redshifts
  - Masses and accretion rates distributions

- Main sources of uncertainty (from the observational side…):
  - z and L distributions, absorbed AGN fraction vs. L and z → estimate time scales and power
  - Compton Thick & high-z AGN → provide complete AGN census
  - Evolution of host galaxies properties and scaling relations → constrain models
  - […]
  - Bolometric corrections→ need SED to estimate "real" bolometric output
  - Role of environment in shaping LF

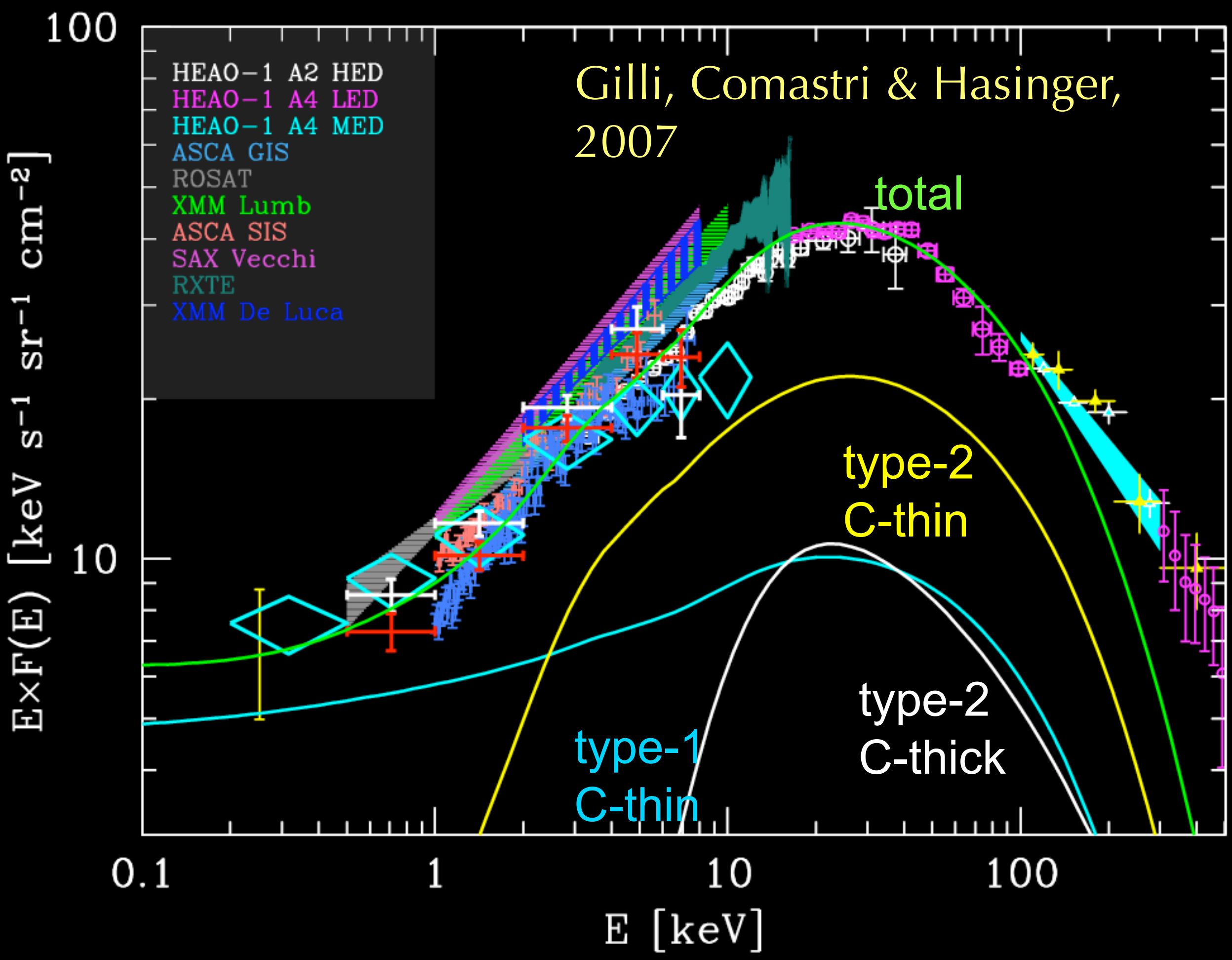
Tools: (hard) X-ray surveys

- Accretion Luminosity is emitted over a broad range of wavelengths, BUT the X-ray emission is the AGN fingerprint

- AGN come in 2 flavours: unobscured and obscured; obscuration affects mostly the soft X-ray and optical wavelengths → **Hard (>2 keV)** X-ray surveys (unbiased)



The X-ray Background: fossil AGN radiation



hard X-ray surveys still miss the highest obscured sources (don't directly sample XRB peak)

See
Comastri 2004
Worsley et al. 2005
Hickox et al. 2007

Tools: (hard) X-ray surveys

- Accretion Luminosity is emitted over a broad range of wavelengths, BUT the X-ray emission is the AGN fingerprint

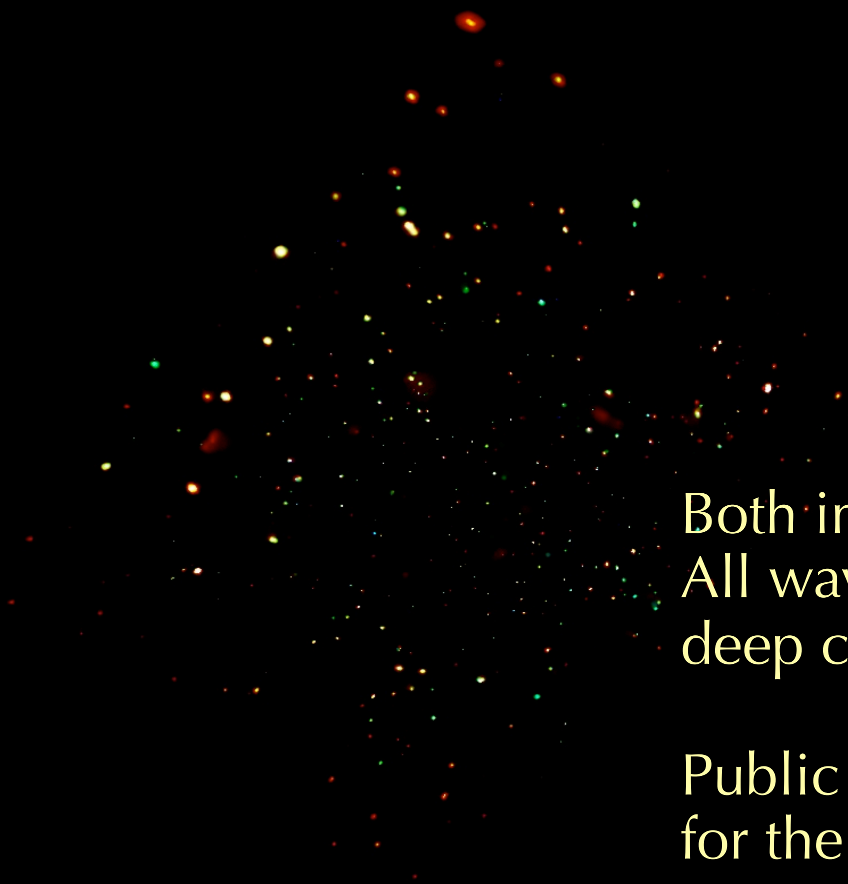
- AGN come in 2 flavours: unobscured and obscured; obscuration affects mostly the soft X-ray and optical wavelengths → **Hard (>2 keV)** X-ray surveys (unbiased)

- Multiwavelength coverage to assure identification, redshift determination, SED studies, host galaxy properties, and alternative AGN selection

The deepest X-ray sky

Chandra Deep Field Surveys → 4 Megaseconds exposures

HDFN
(Alexander+ 2003)



CDFS
(Giacconi+ 2002, Luo+ 2008)

Both in GOODS:
All wavelengths, very
deep coverage available

Public fields, resource
for the community

COSMOS field

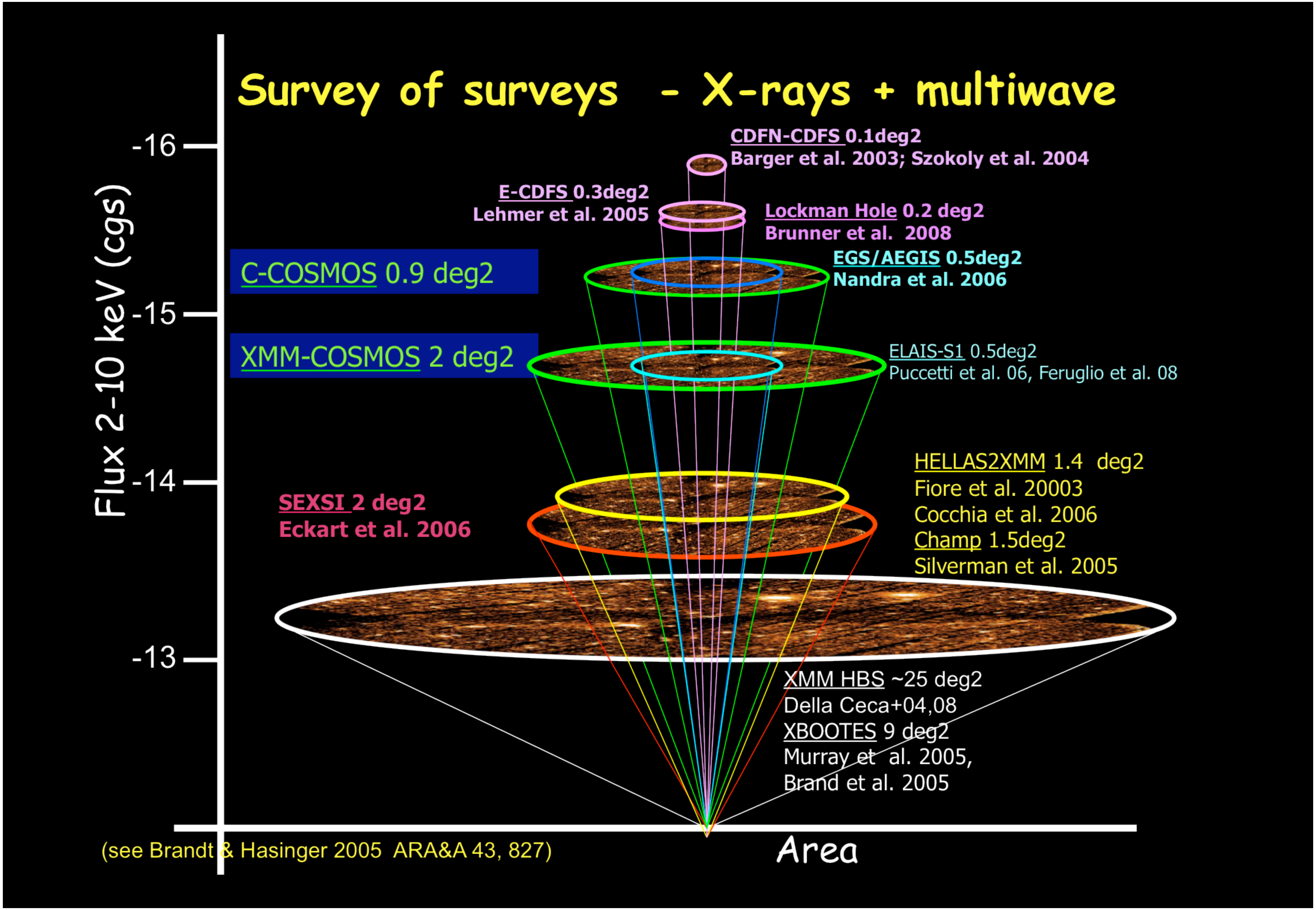
XMM 1.55 Ms 2 deg^2
(Hasinger+07, Cappelluti+07,09)

Chandra 1.8 Ms
0.9 deg^2
(Elvis+09)

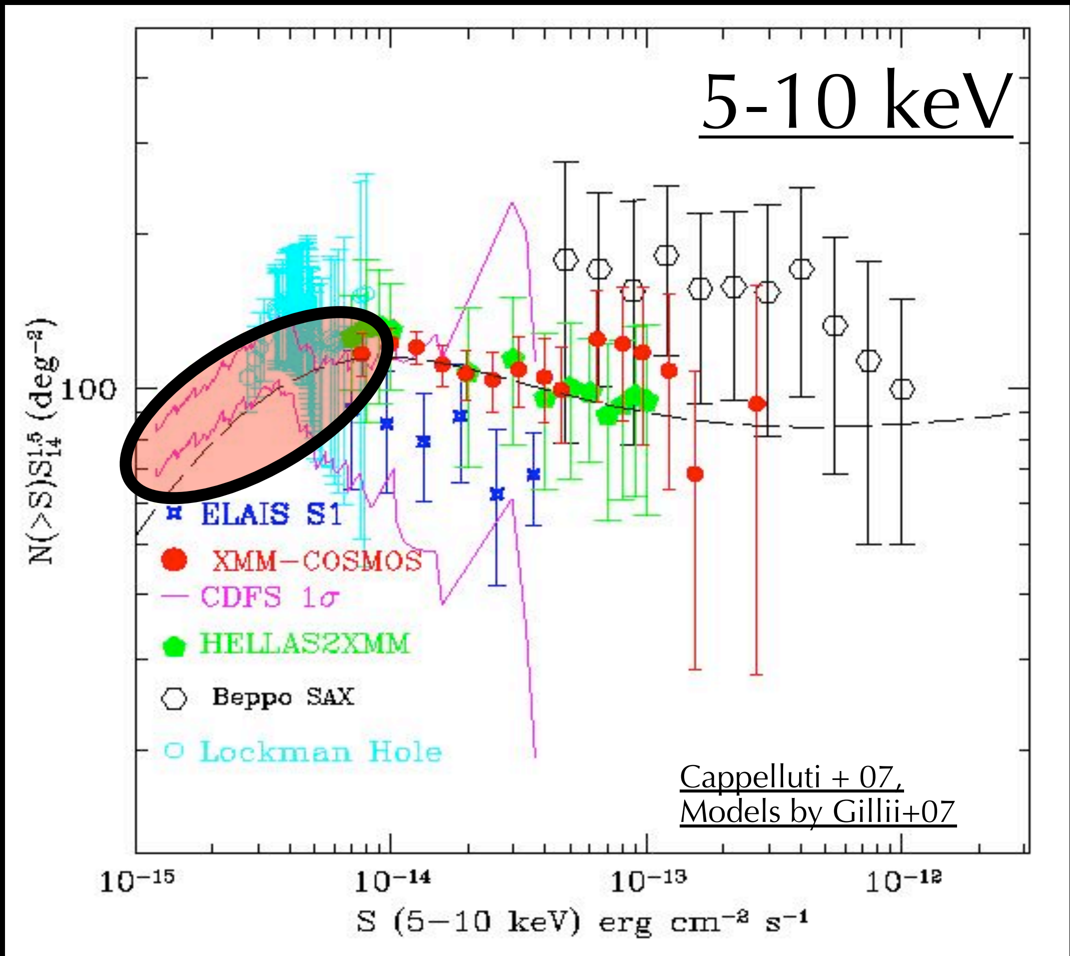
All wavelengths, deep coverage available

Public field, resource for the community

http://www.astro.caltech.edu/cosmos/


Survey of surveys - X-rays + multiwave
Flux 2-10 keV (cgs)
-16
-15
-14
-13
Area
CDFN-CDFS 0.1deg2
Barger et al. 2003; Szokoly et al. 2004
E-CDFS 0.3deg2
Lehmer et al. 2005
Lockman Hole 0.2 deg2
Brunner et al. 2008
C-COSMOS 0.9 deg2
EGS/AEGIS 0.5deg2
Nandra et al. 2006
XMM-COSMOS 2 deg2
ELAIS-S1 0.5deg2
Puccetti et al. 06, Feruglio et al. 08
HELLAS2XMM 1.4 deg2
Fiore et al. 20003
Cocchia et al. 2006
Champ 1.5deg2
Silverman et al. 2005
SEXSI 2 deg2
Eckart et al. 2006
XMM HBS ~25 deg2
Della Ceca+04,08
XBOOTES 9 deg2
Murray et al. 2005,
Brand et al. 2005
(see Brandt & Hasinger 2005 ARA&A 43, 827)

COSMOS 5-10 keV logN-logS



5-10 keV
[~250 sources]

In between previous determinations in the flux range $8x10^{-15}$- $5x10^{-12}$ cgs and in excellent agreement with models predictions

Fainter fluxes to be explored exploiting

2+3 (proposed) Ms Chandra observations on CDFS (PI: N. Brandt)

3 Ms XMM on CDFS (PI: A. Comastri)

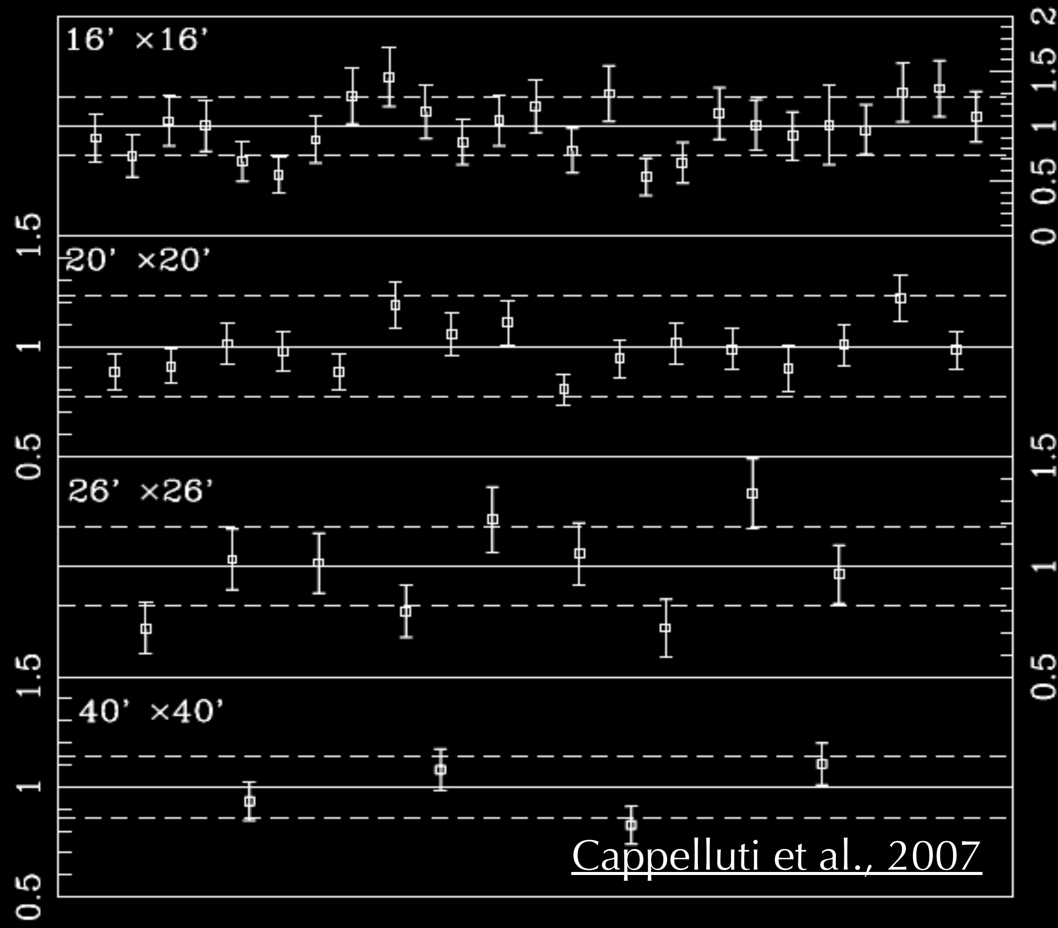
COSMOS counts: Cosmic Variance

Large area → investigate the relative contribution of LSS and Poissonian noise to source counts fluctuations

Summary of the 0.5–2 keV sample variance in the COSMOS field. Prediction and observation at a flux limit $S_{lim}=5\times10^{-15}$ erg cm^{-2} s^{-1}

Area[a] arcmin^2	σ_{obs}[b]	σ_p[c]	σ_{cl}[d]	σ_{exp}[e]	χ^2/d.o.f.[f]
$40' \times 40'$	0.09±0.04	0.10	0.09	0.13	4.21/3
$26' \times 26'$	0.20±0.05	0.15	0.10	0.19	8.93/8
$20' \times 20'$	0.21±0.04	0.20	0.11	0.23	16.63/1[illegible]
$16' \times 16'$	0.24±0.02	0.25	0.12	0.28	25.15/2[illegible]

[a] Size of the independent cells.
[b] The observed standard deviation.
[c] The predicted Poissonian standard deviation σ_p.
[d] The predicted standard deviation due to clustering σ_{cl}.
[e] The total predicted standard deviations.
[f] Value of the fitted χ^2/d.o.f.



→ Cosmic or Sample variance have been reduced to 5% in studying X-ray source counts at the depth and area of XMM-COSMOS

Main results (and key questions behind)

- AGN "downsizing"

- Evolution of high-z population (z>3)

- Compton Thick AGN census

- Interplay between AGN and SF

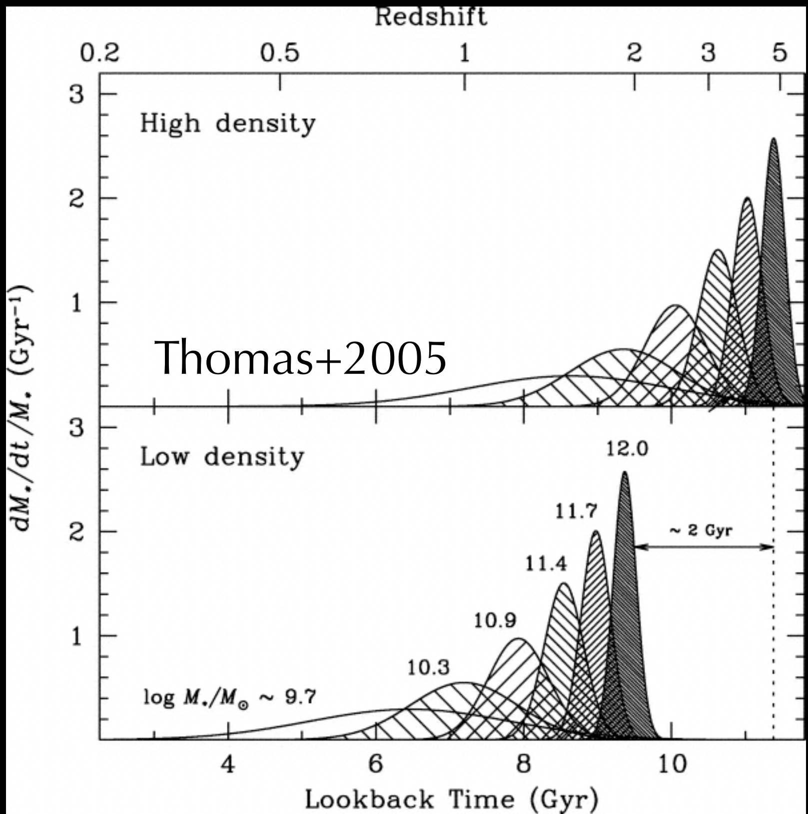
- BH mass / accretion rate evolution

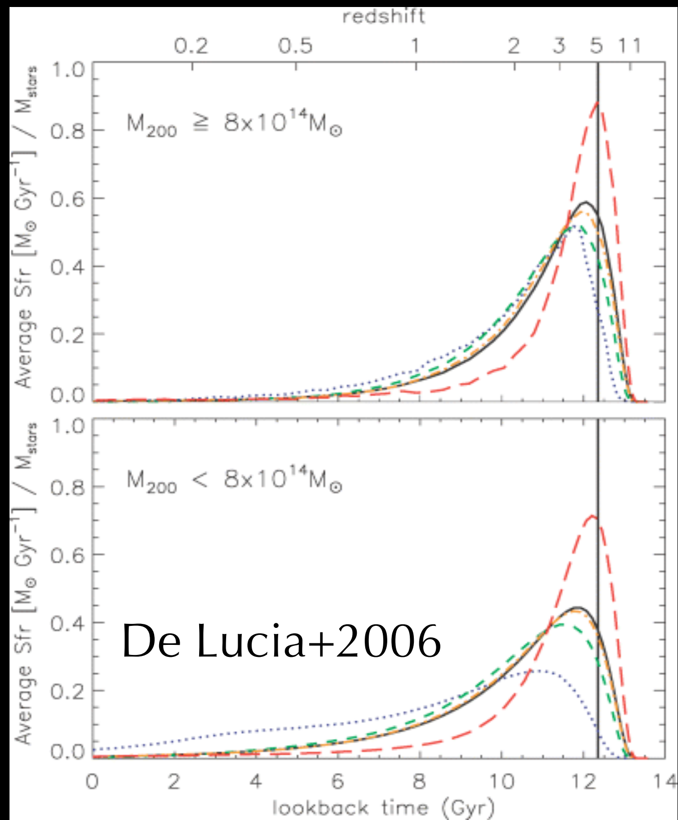
AGN “downsizing”

Cosmic downsizing: the larger, the faster..

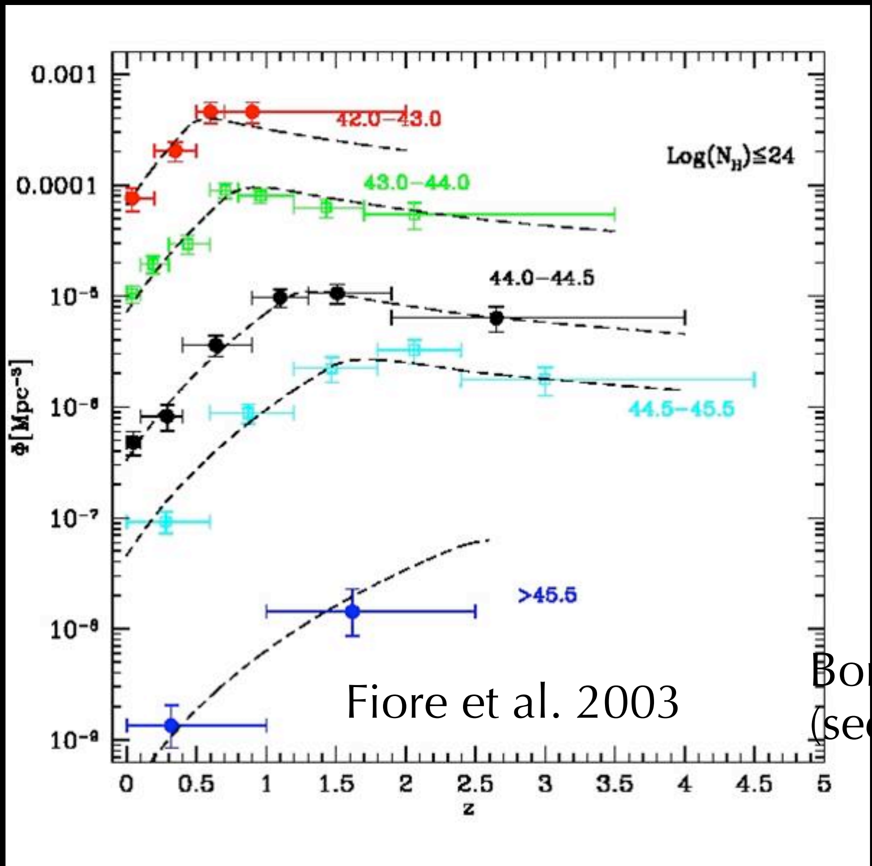
Definition of "downsizing" (Cowie et al. 1996):

".. galaxy formation took place in "downsizing", with more massive galaxies forming at higher redshift.."

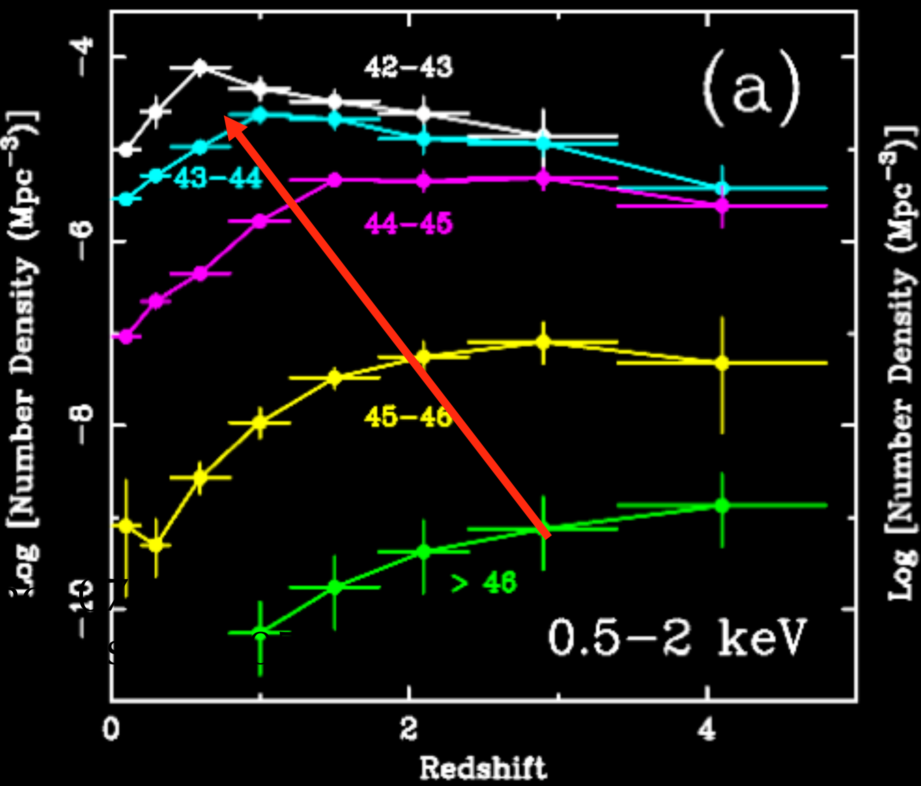




AGN/SMBH downsizing



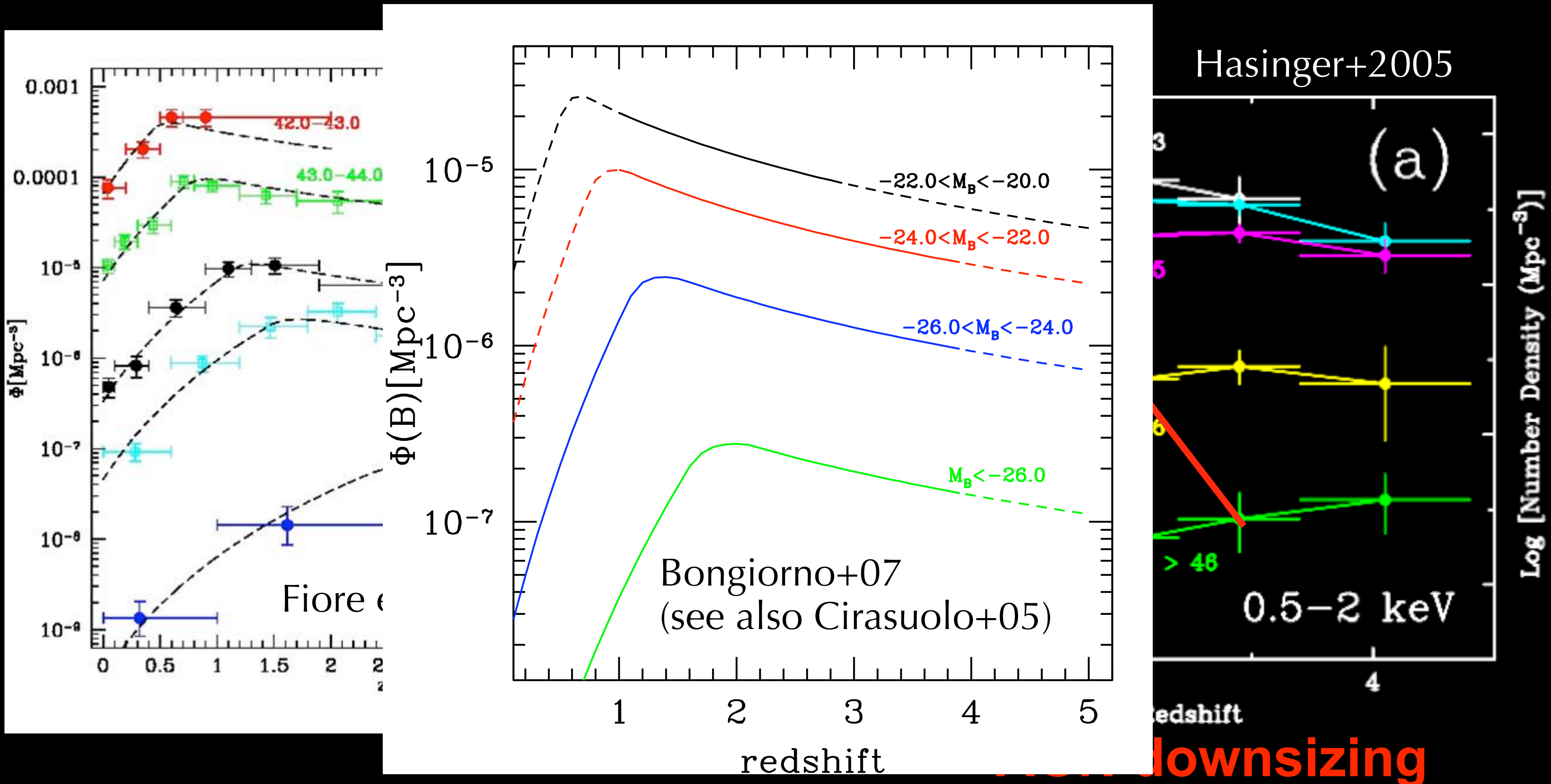
Hasinger+2005



AGN downsizing

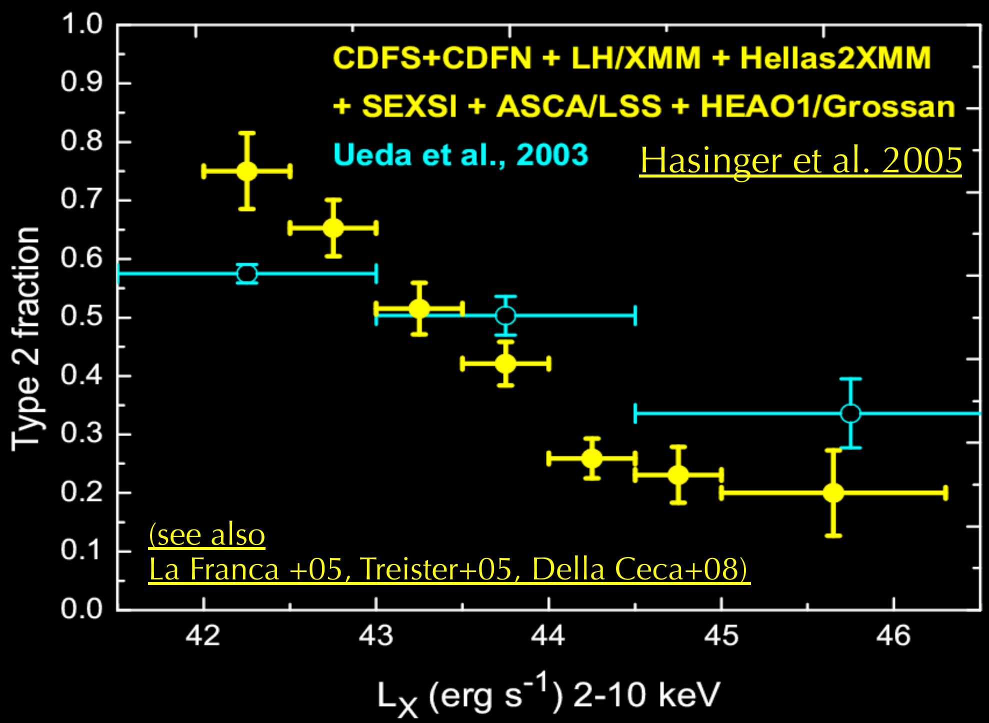
Ueda+03; Fiore+03; Barger+05; Hasinger+05, Della Ceca+08, Miyaji+ in preparation

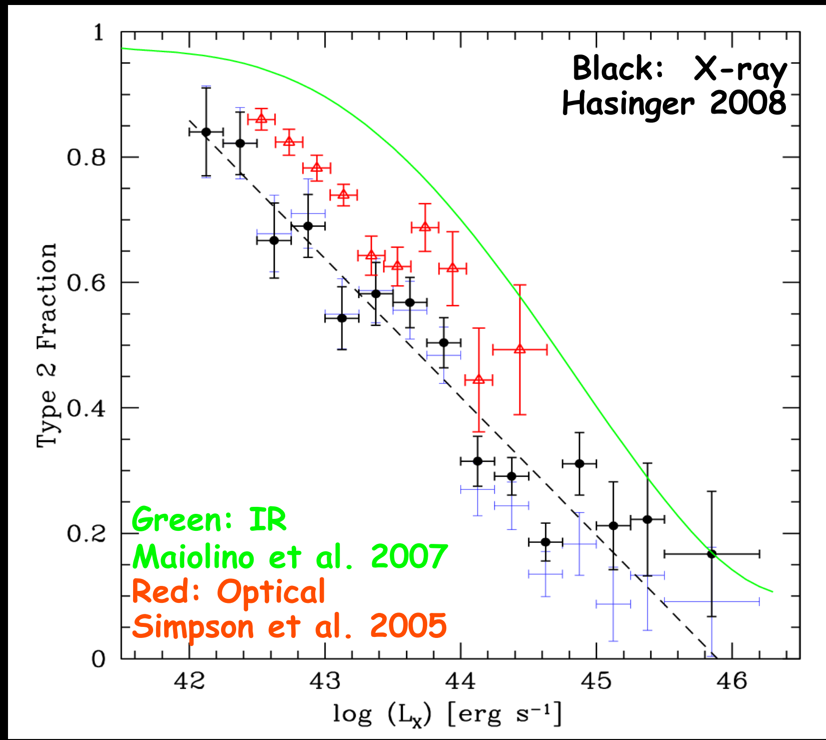
AGN/SMBH downsizing



Ueda+03; Fiore+03; Barger+05; Hasinger+05, Della Ceca+08, Miyaji+ in preparation

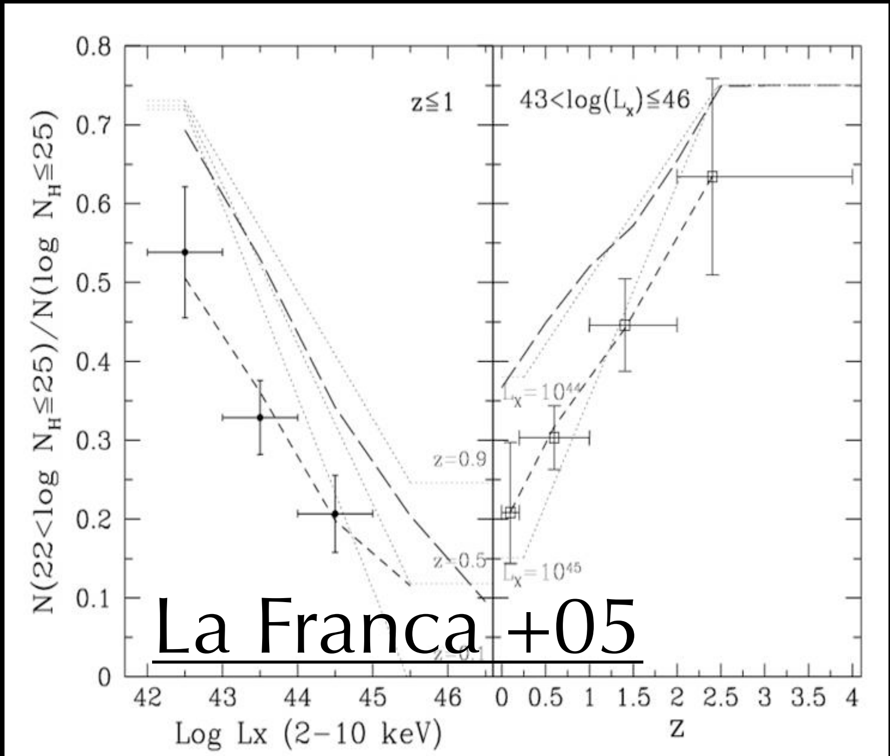
Fraction of absorbed sources: Luminosity dependence

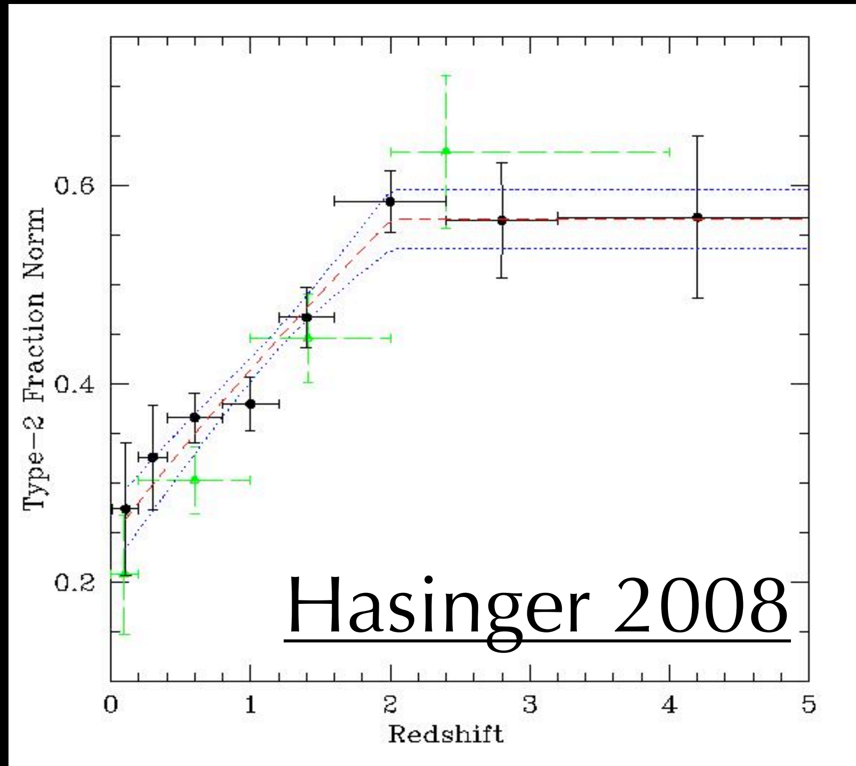




- fraction of obscured AGN is a strong function of L: most luminous, less obscured
- Same result in DIFFERENT bands despite the very different selections!!

Fraction of absorbed sources: Redshift dependence





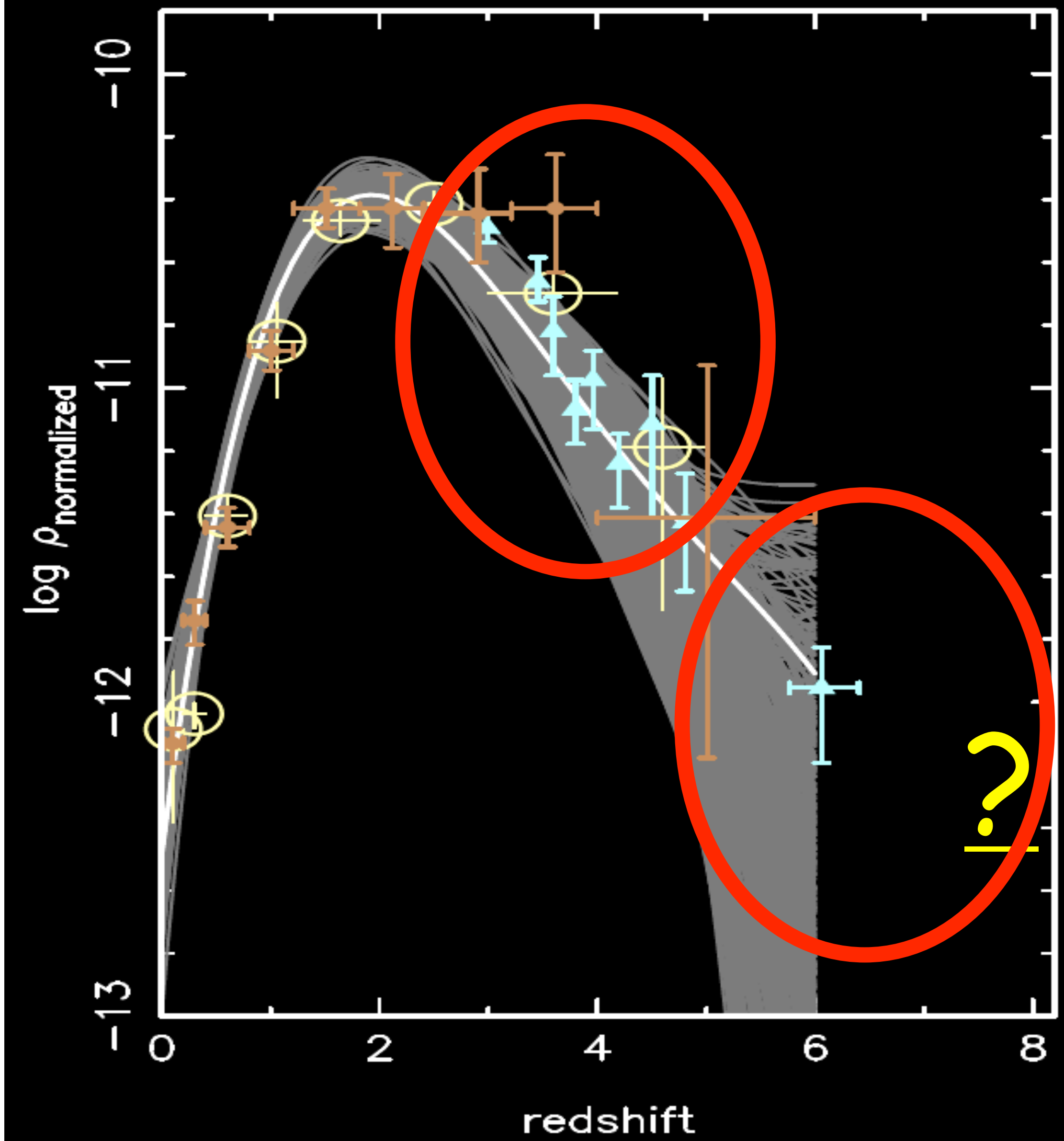
Seen in (some) data [e.g. La Franca+05, Treister+06, Hasinger08],

not seen in others (Ueda+03, Dwelly&Page 2006),

not needed in XRB models (Gilli+07) but expected/predicted in feedback models (Menci+08)

The high-z (z>3) QSOs

The population of z>3 QSOs



Radio QSO [Wall et al., 2005]

Optical QSOs
[Schmidt+95, Fan+01,04, Richards+06 SDSS]
[Cristiani+04, Fontanot+07, GOODS]

Exponential decline in space density at z=2.7

X-ray QSOs:
[ROSAT/Chandra/ XMM
Hasinger, Miyaji & Schmidt 2005
Silverman et al. 2005/2008]

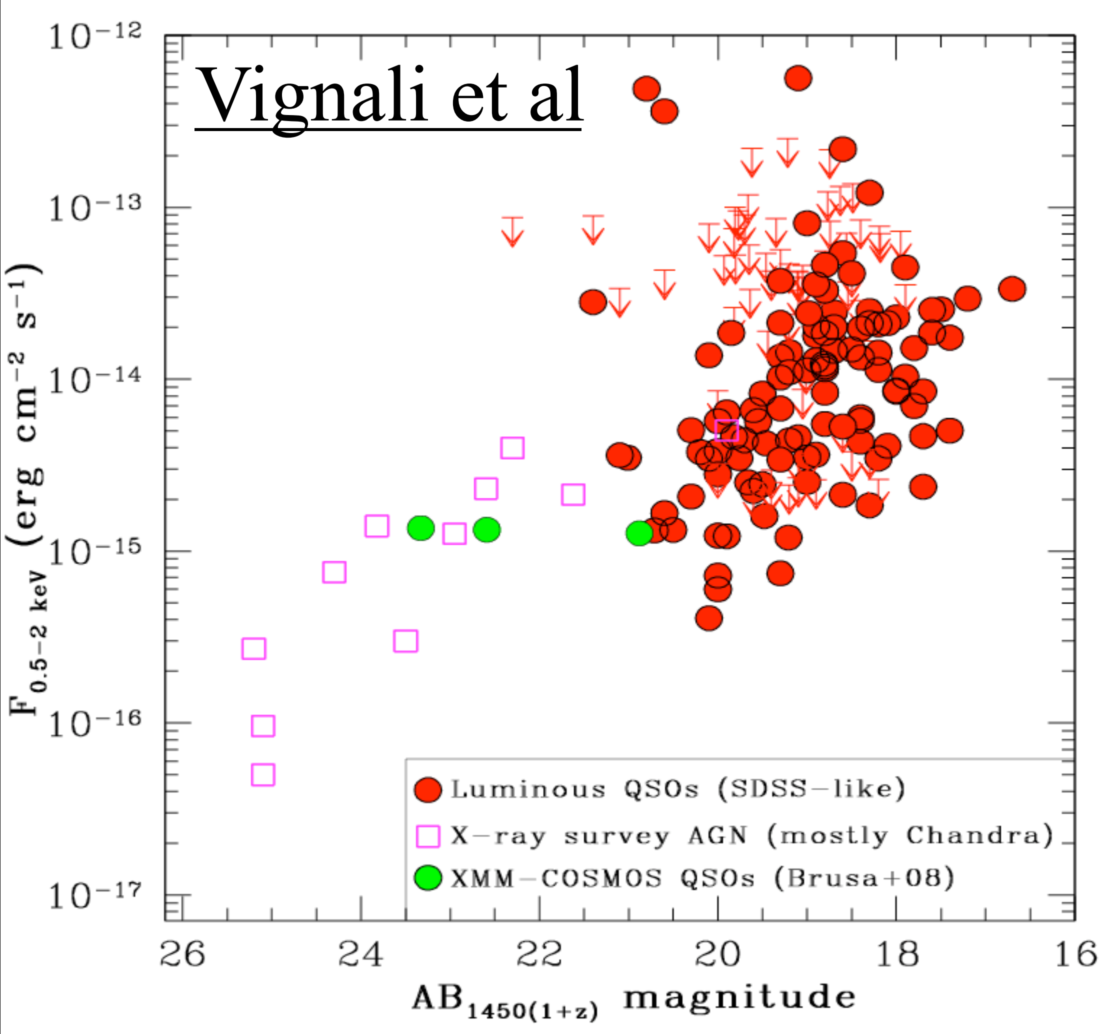
statistics still low at z~3-5
(NO statistics at z>6)

X-rays from high-z Quasars

1990-1994:
pioneering works with ROSAT
Wilkes+92,Elvis+94, Bechtold+94
(record QSO z=4)

2002-2005:
Chandra/XMM contribution
Follow-up of optically SDSS QSOs
Brandt+02, Mathur+02,Vignali+03,05
(record QSO z=6.4)

X-rays needed to get the LF faint end



The number of high-z AGN detected so far

	SDSS*	X-ray sel.$
z > 3	8000	50
z > 4	1500	11
z > 5	150	2
z > 6	10	0

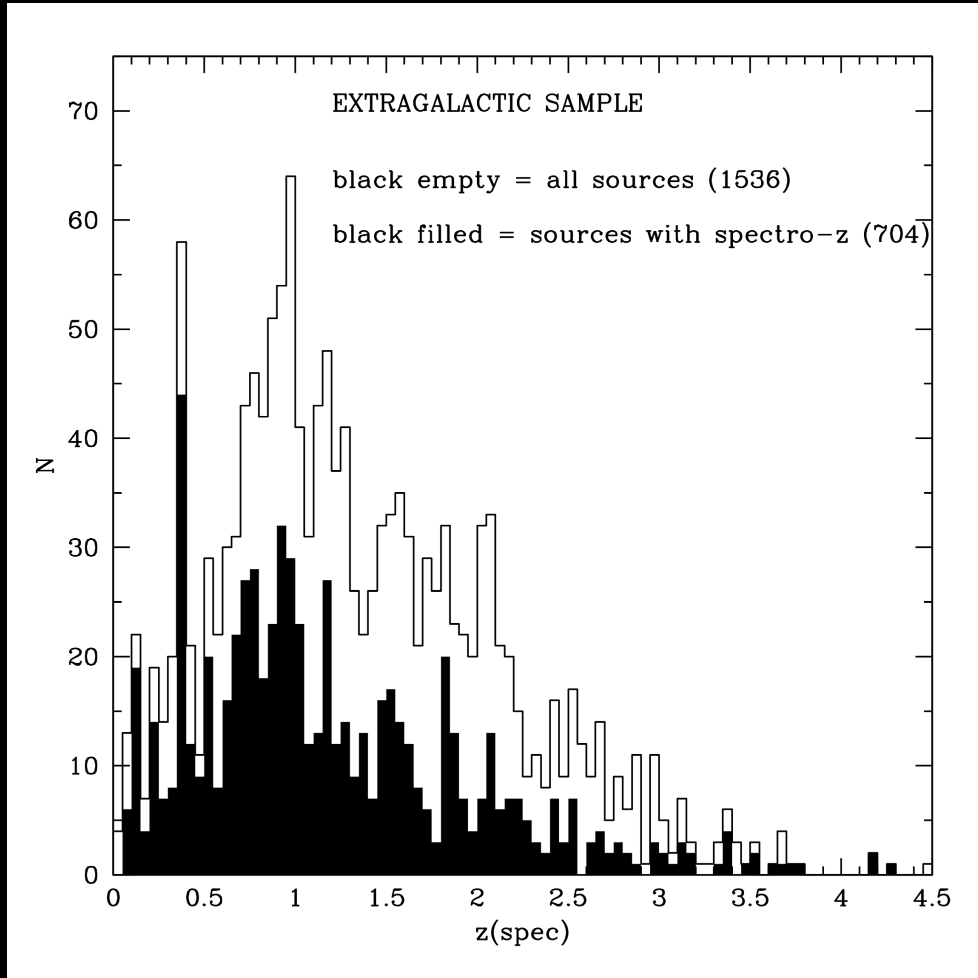
XMM-COSMOS sources redshifts

compilation from ongoing spectroscopic projects [IMACS/Magellan+VLT/ESO + SDSS + literature data]

- Flux limited sample (50% of the area coverage in at least one band) at 10^{-15} cgs
- 1651 XMM sources

  <10% problematic ID thanks to

  IR+Chandra info
- ~700 “secure” spectroscopic redshifts (45%)
- ~900 “good” photometric redshifts (Salvato et al. 20009)



(Adapted from Brusa et al. 2007, ApJ)

XMM-COSMOS sources redshifts

compilation from ongoing spectroscopic projects [IMACS/Magellan+VLT/ESO + SDSS + literat

- Flux limited sa
area coverage i
at 10^{-15} cgs

- 1651 XMM sou

<10% problem

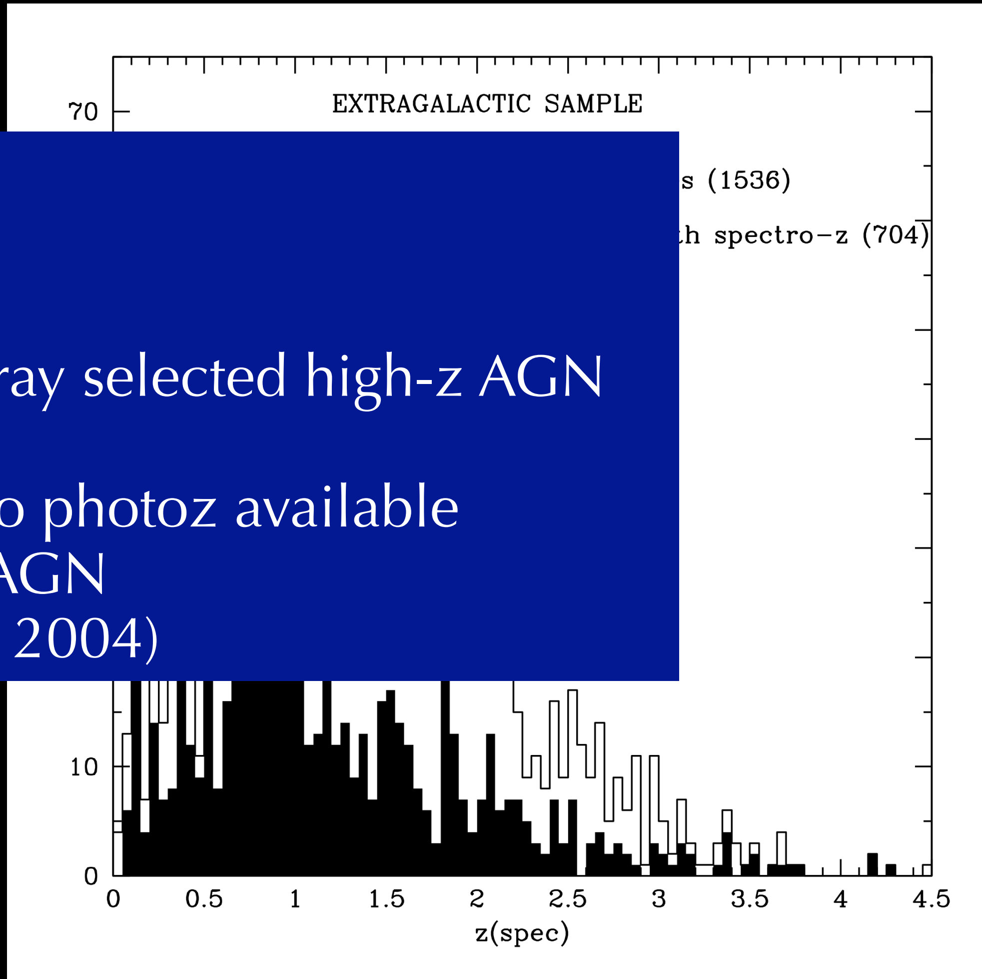
IR+Chandra info

- ~700 "secure" spectroscopic redshifts (45%)

- ~900 "good" photometric redshifts (Salvato et al. 20009)

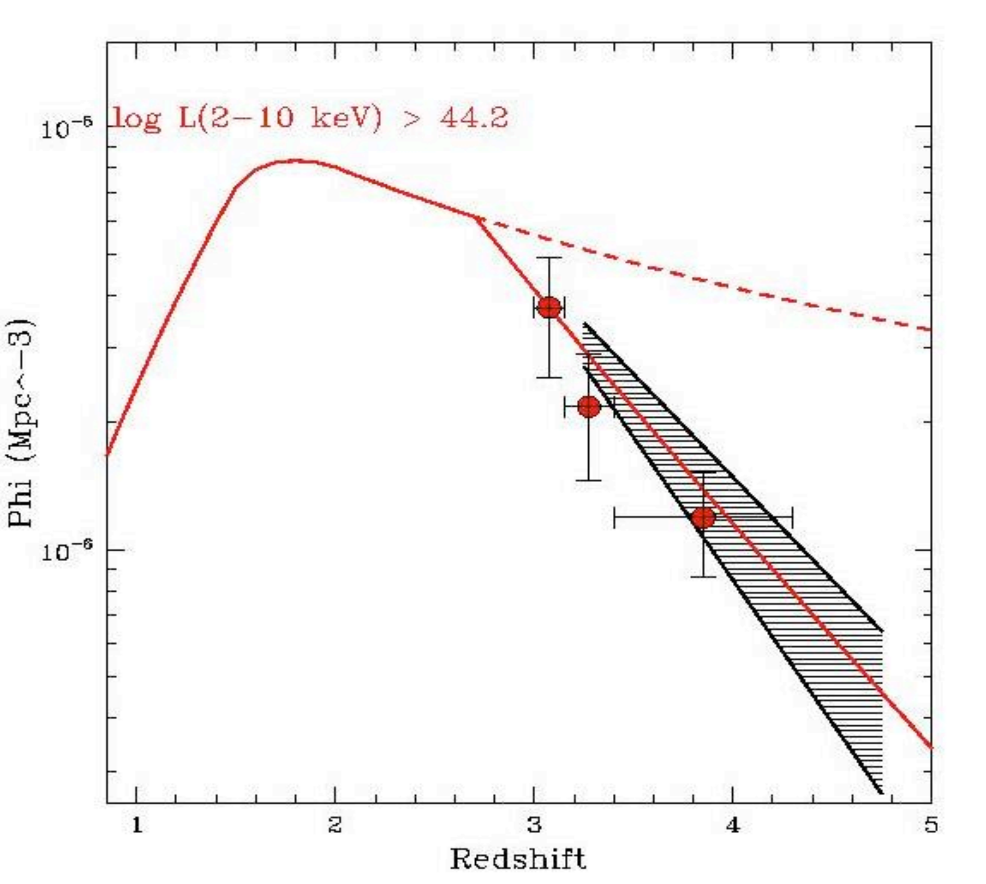
z>3 sample:
40 objects
(22 specz + 18 photoz)
The largest sample of X-ray selected high-z AGN

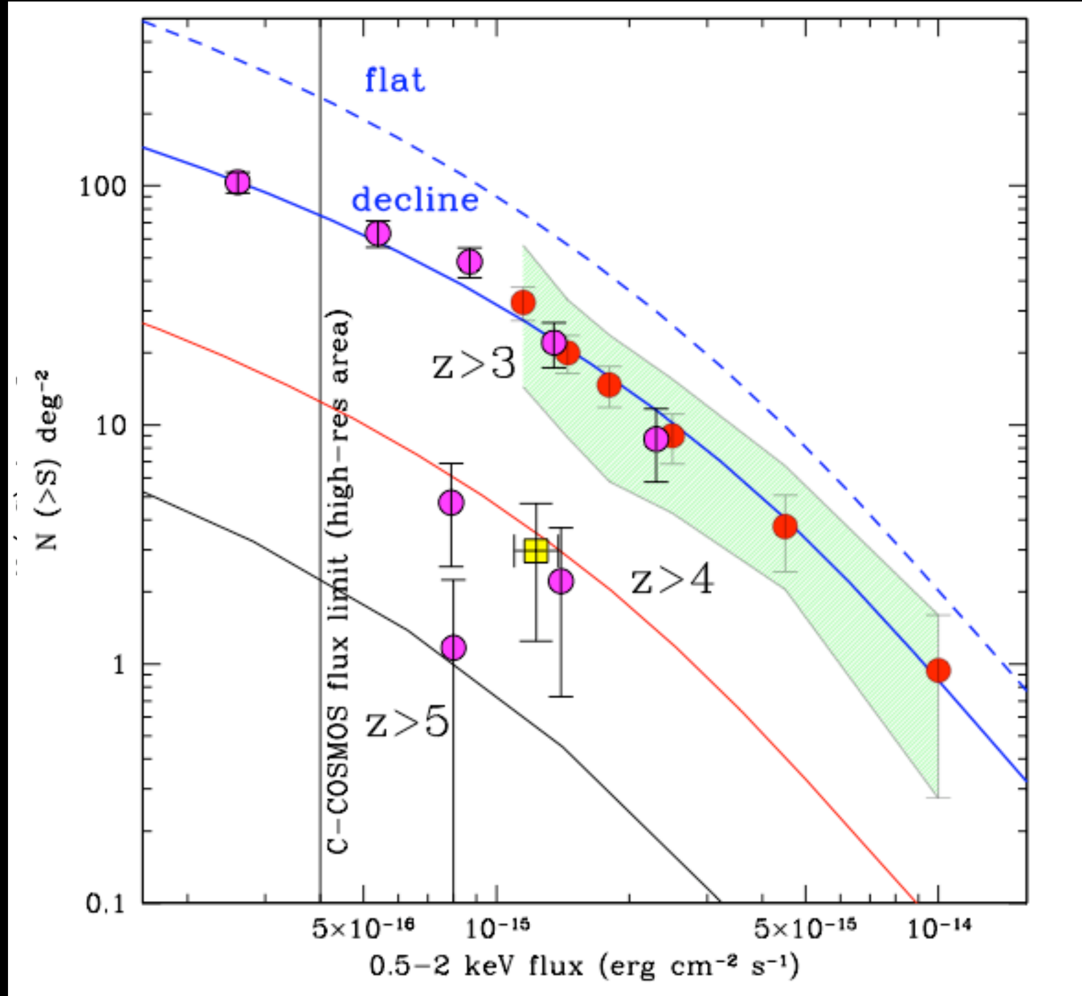
Additional 14 objects, no photoz available
Candidates very high-z AGN
(EXOs, Koekemoer et al. 2004)



(Adapted from Brusa et al. 2007, ApJ)

COSMOS: XMM and Chandra z>3 QSOs



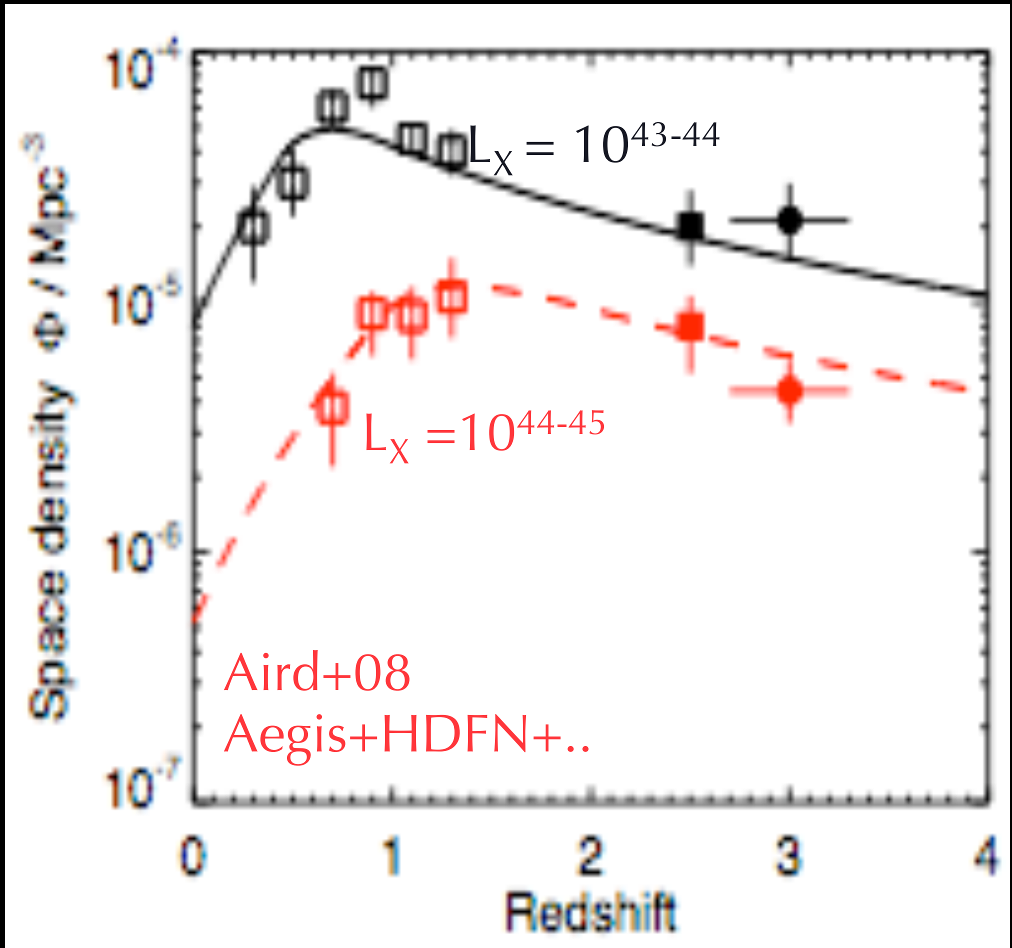


Lg(Lx)>44 QSO: same behaviour of opticaly selected bright QSOs

Brusa, Comastri et al. 2009, ApJ

To have same statistics of SDSS: need to survey >200 deg2 at COSMOS depth

X-ray from LBG in deep surveys



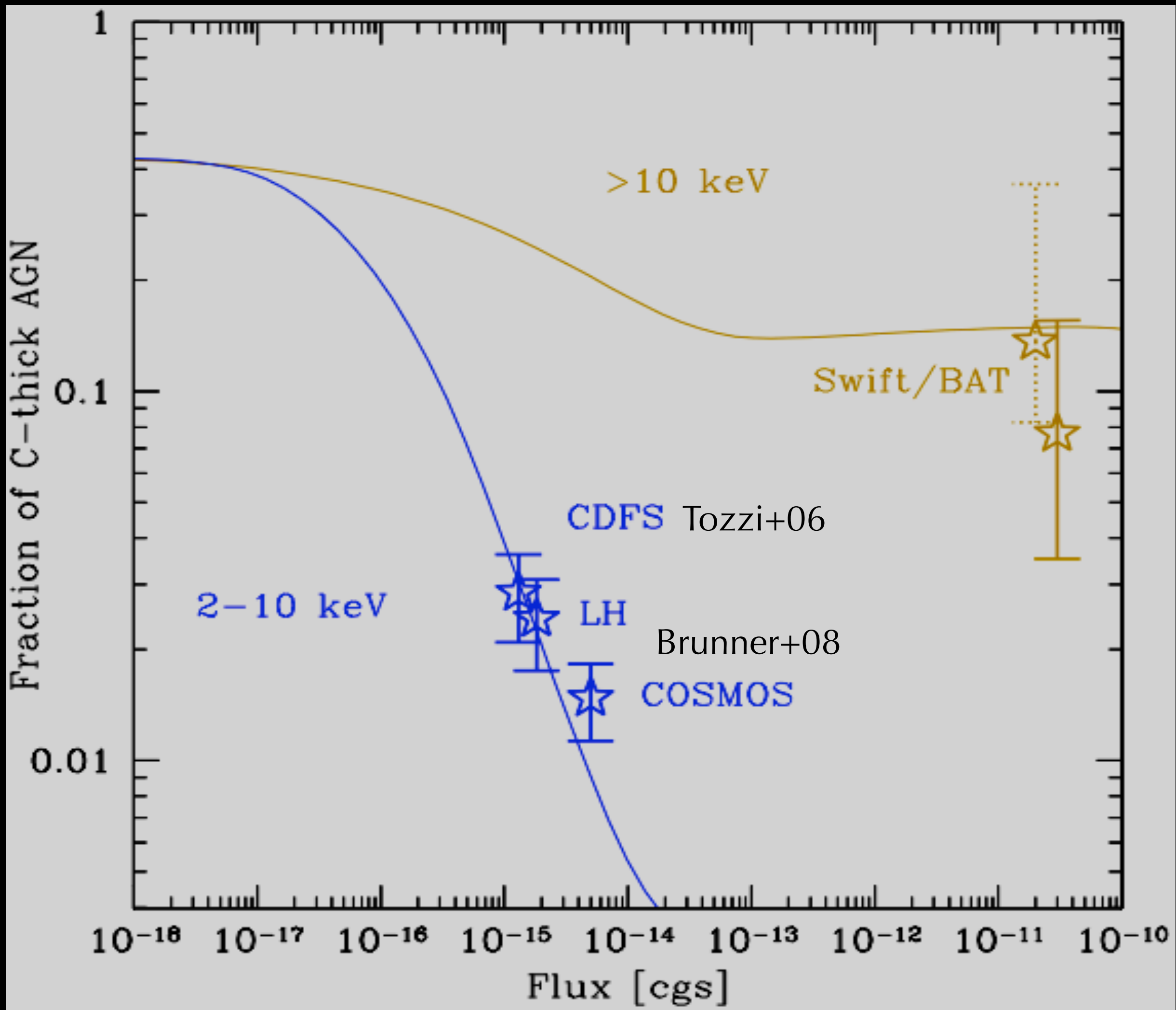
Select high-z objects through well-known optical criteria (dropouts)
[Steidel+97….Vanzella+09]

Study X-ray emission (subthreshold)
[Nandra+02,05 Laird+06, Aird+08]

COSMOS (preliminary)
~100 X-ray detections
(over 3000 LBG galaxies)
AGN luminosities, absorption in 40%

The Compton Thick AGN population

Compton Thick sources in X-ray Surveys



CT AGN (logNH>24 cm-2)

only barely sampled
by deep Chandra
and XMM surveys

Relative fraction
steeply increasing

Hard (> 10 keV)
surveys more efficient

Redshift distribution
<z> ~ 0 @ 10^{-11}
<z> ~ 1 @ 10^{-15}

Unveiling obscured accretion

- X-ray surveys: very efficient in selecting unobscured and moderately obscured AGN but miss most highly obscured AGN (e.g. Worsley et al. 2005)

- IR surveys: AGNs highly obscured at optical and X-ray wavelengths shine in the MIR thanks to the reprocessing of the nuclear radiation by dust

- Goal: combining X-ray and IR surveys to get the SMBH census and compile bolometric luminosity function for AGN (with no incompleteness for Compton Thick sources)

- Select candidate luminous obscured AGN in the IR:

  Several criteria recently proposed (since Spitzer launch)

  [e.g. Lacy+04, Stern+05, Martinez-Sansigre+05, Yan+05,Pope+08,Dey+08, Donley+08 etc….]

CDFS: Selection of CT AGN at z~2

Criterion:

24 micron bright fluxes (luminous) +

optically faint red sources (optically obscured)

→ high MIR/O ratio +

R-K>4.5

GOODS CDFS field

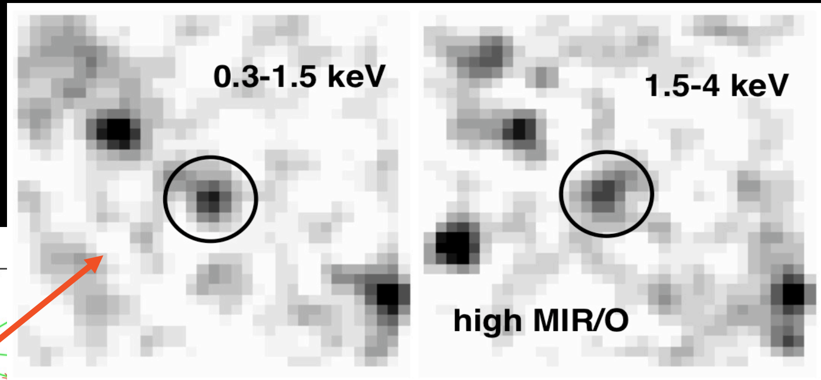
\+

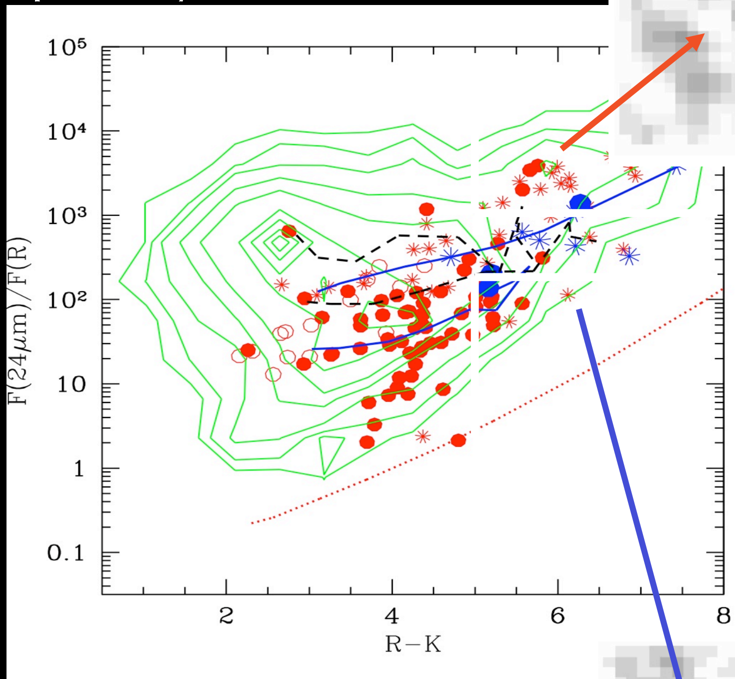
MUSIC MW catalog

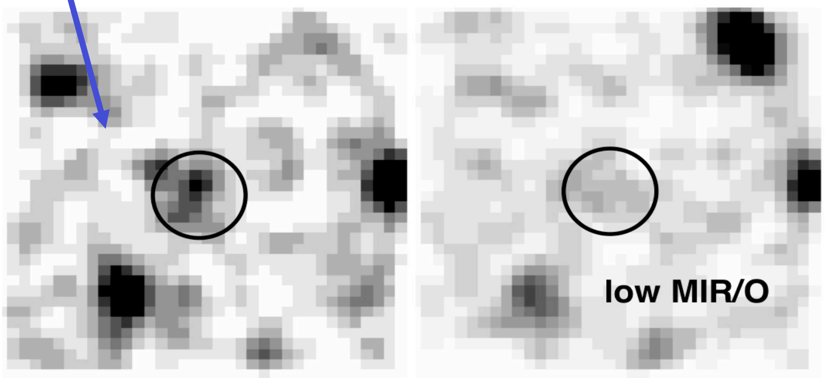
(Spitzer+HST+VLT)

~110 obscured AGN candidates

Stack of Chandra images excluding X-ray detections in two different MIR/O and R-K bins



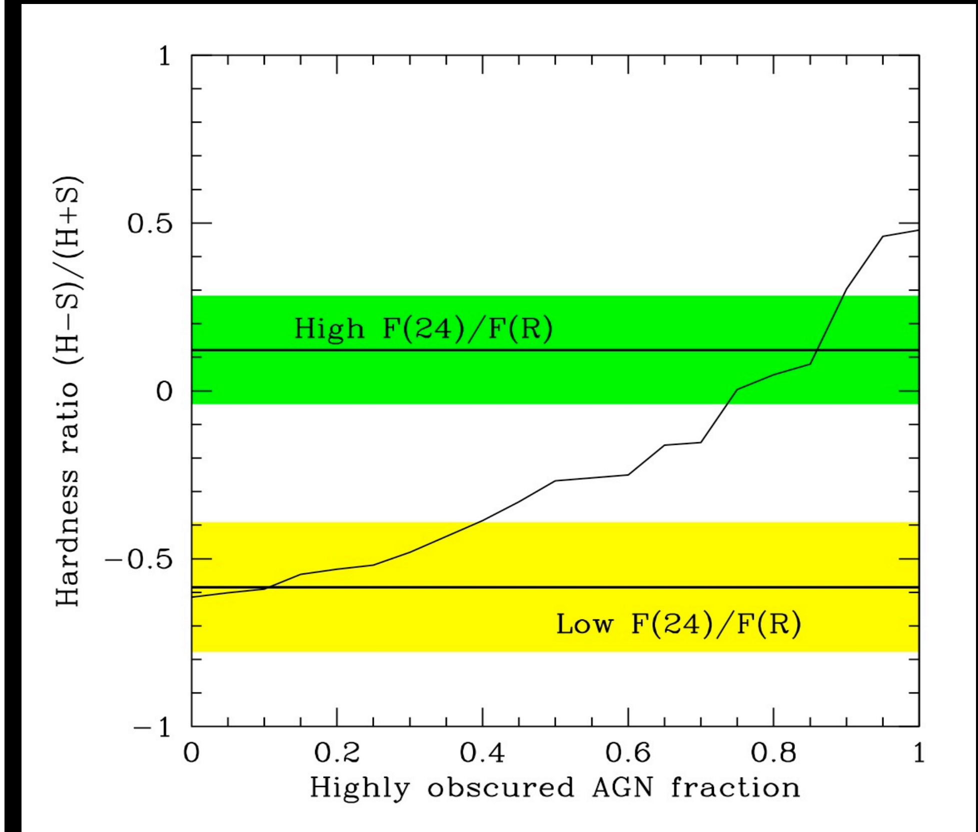


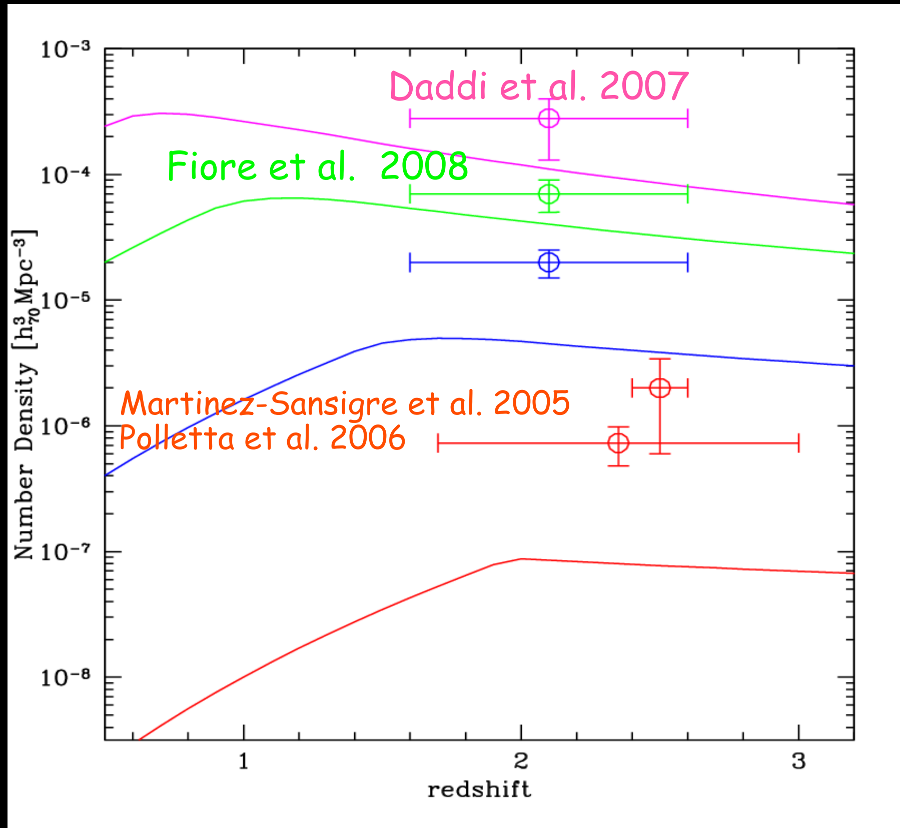


Fiore et al. 2008

See also Daddi et al. 2007

CDFS: Selection of CT AGN at z~2

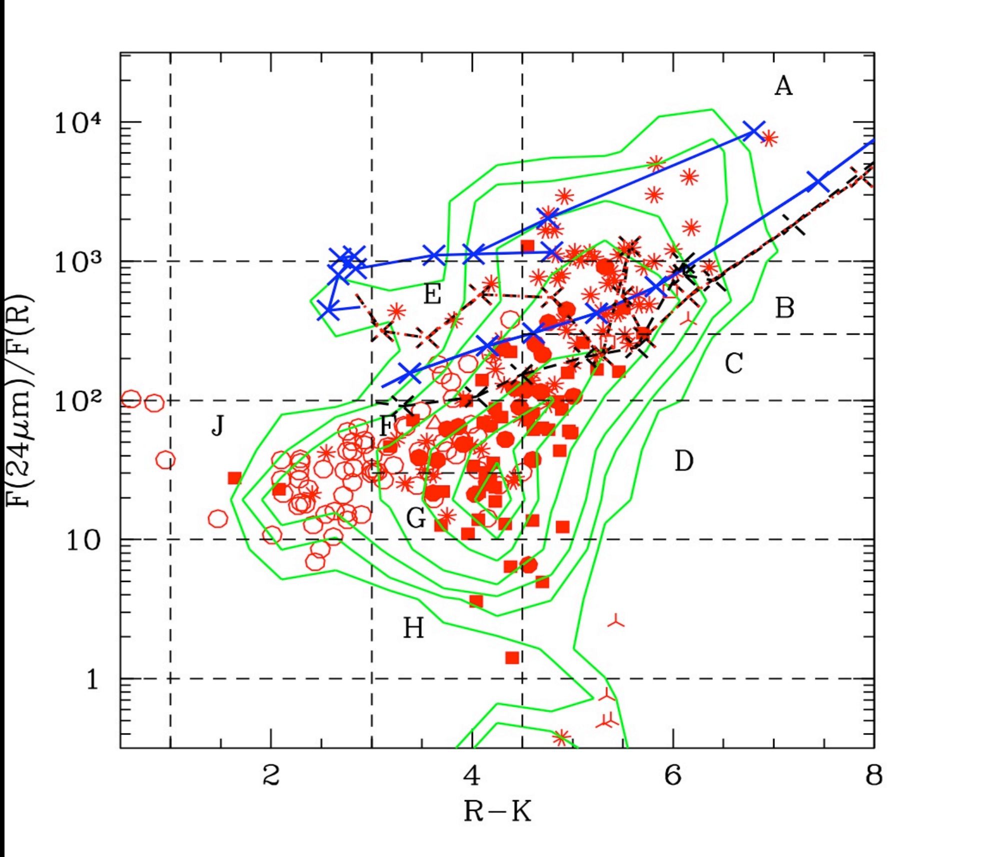


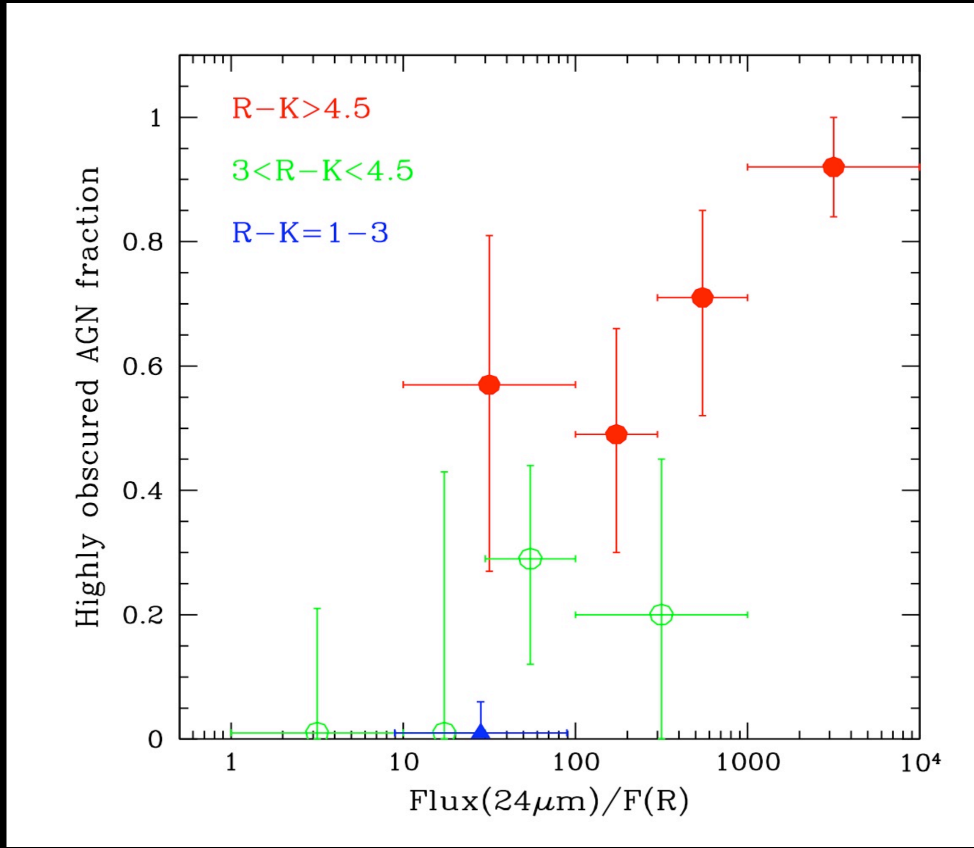


The observed MIR luminosity and the observed HR imply (unobs) Lx>43 and NH>24 for ~80% of the sources

Curves: model predictions from Gilli, Comastri & Hasinger 07 for L> 42, 43, 44, 45

COSMOS CT AGN at z~2



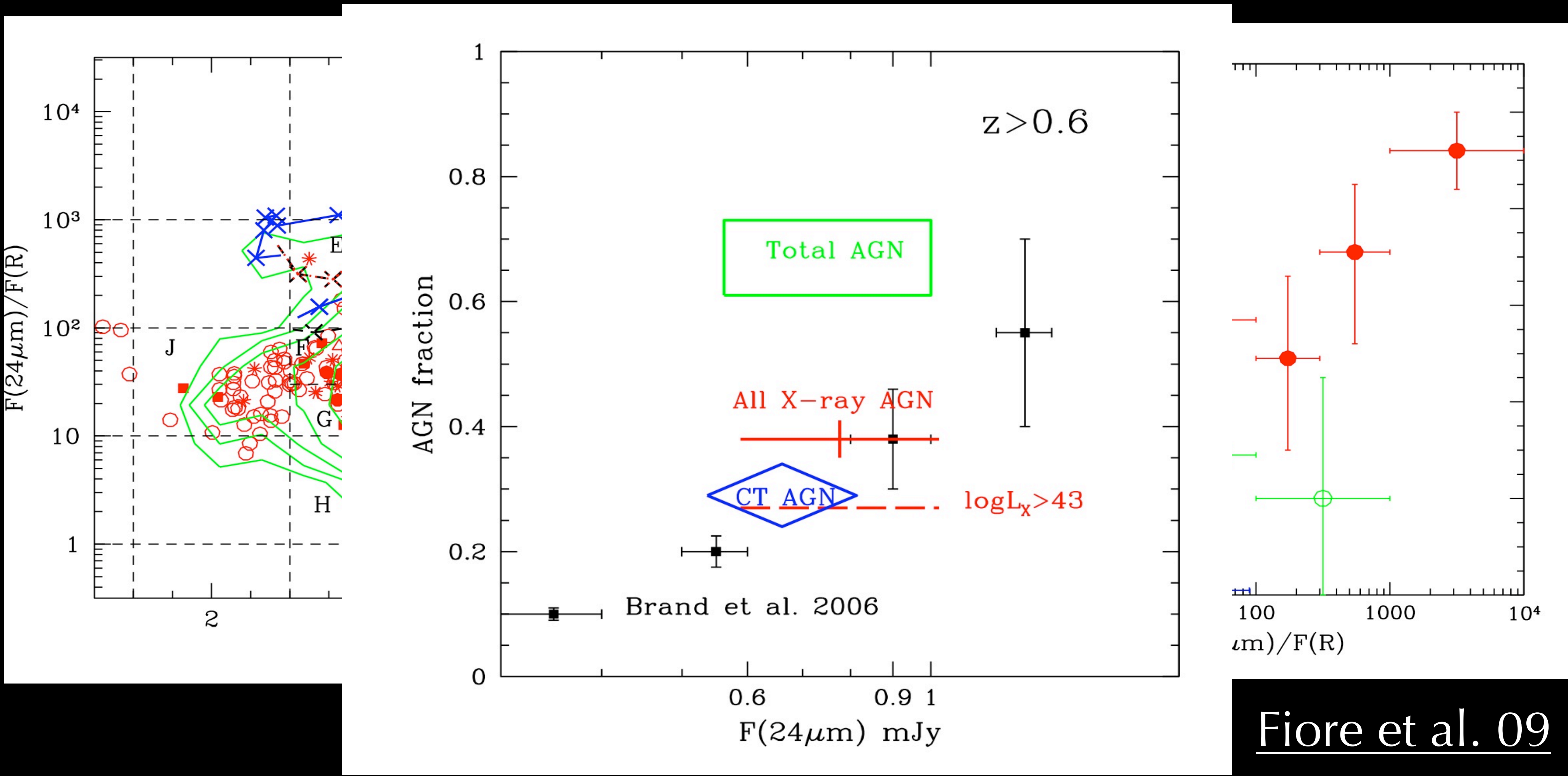


Fiore et al. 09

High AGN fraction (~65%) in MIPS selected samples (higher than Brand+06)

(deeper X-ray data + more comprehensive analysis)

COSMOS CT AGN at z~2



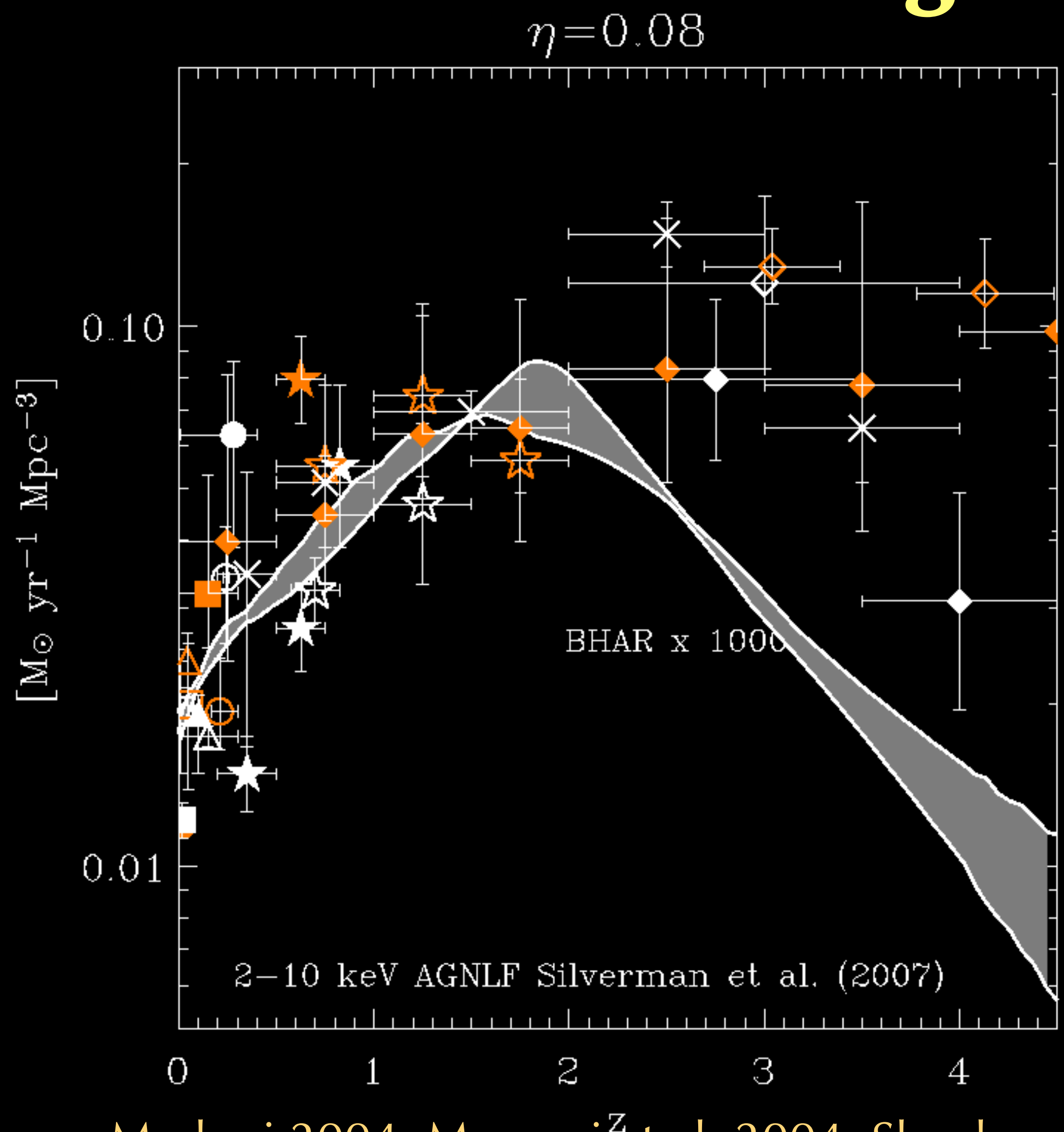
Fiore et al. 09

High AGN fraction (~65%) in MIPS selected samples (higher than Brand+06)

(deeper X-ray data + more comprehensive analysis)

The host galaxies of high-z AGN: the BH-SFR connetcion

Coeval Starforming and AGN activity



SMBH growth traces SFR (same downsizing)

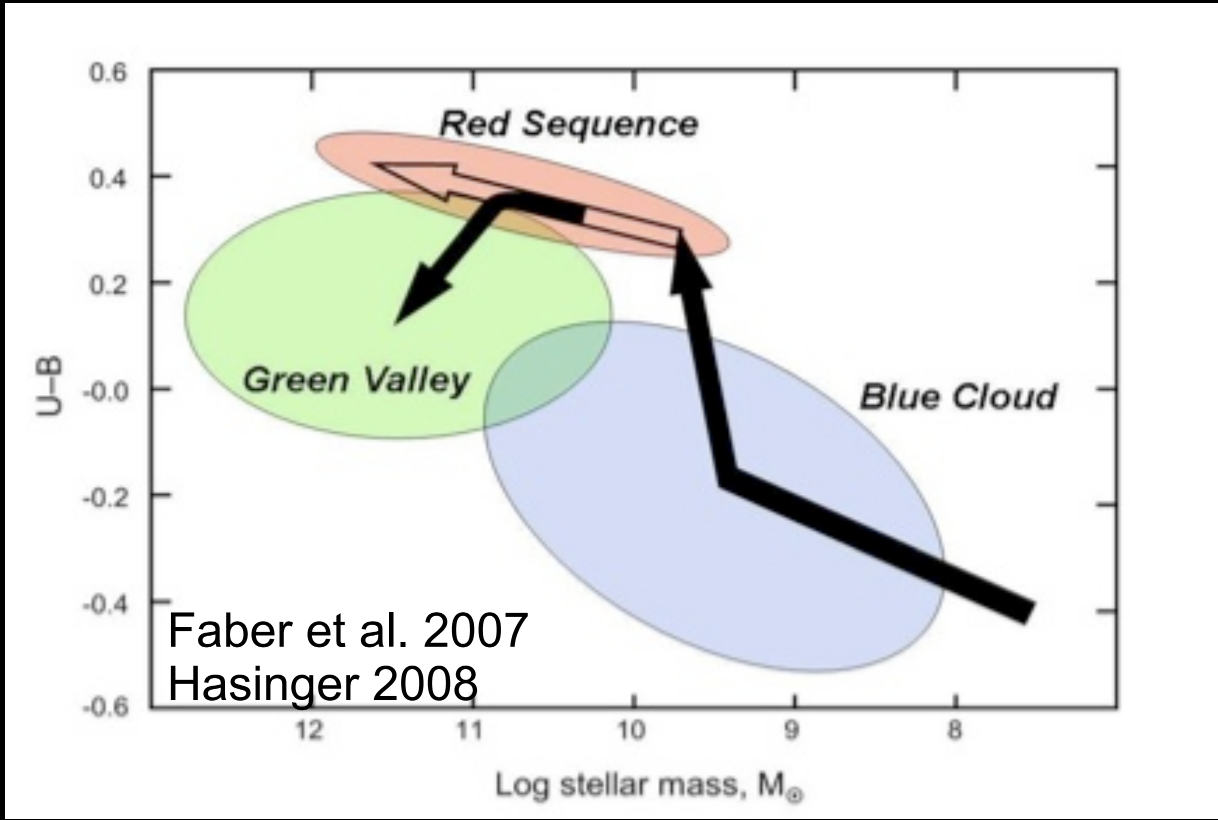
Well determined from XLF of AGN (modulo uncertainties in N_H distribution vs. z and Compton Thick sources)

See e.g. Merloni 2004; Marconi et al. 2004; Shankar et al. 2007; Merloni & Heinz 2008

AGN and host galaxies colors

At low-z (z<0.3, SDSS) AGN reside in massive, early type galaxies
(Kauffmann et al. 2003)

At intermediate redshifts z<1
X-ray selected AGN populate the "green valley" (Nandra et al. 2005, Silverman et al. 08)



What about z>1? Can we see/measure coeval SF and AGN activity?

Obscured AGN in the CDFS

Framework:
CDFS/GOODS/MUSIC area
143 arcmin2
(Grazian et al. 2006, Santini et al. 2009)

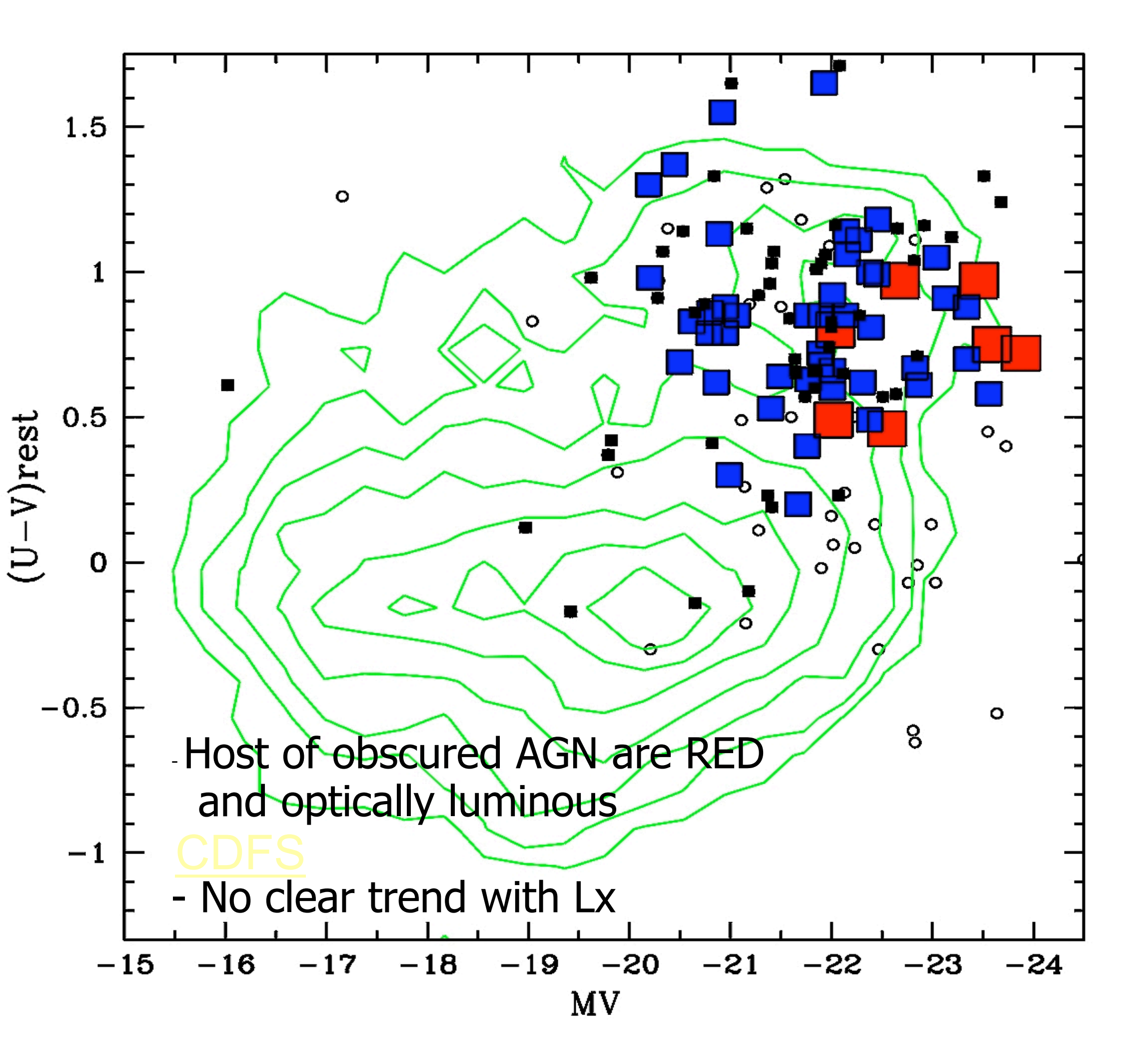
179 1 Ms X-ray sources
From Alexander+03
(vs. 460 in 2 Ms area,
vs. ~950 in 2Ms + ECDFS)

110 obscured AGN isolated from
Morphological + X-ray analysis
Spectro-z + (good) photoz

Host galaxies properties available
(SFR, masses, etc)
Santini et al. 2009, A&A

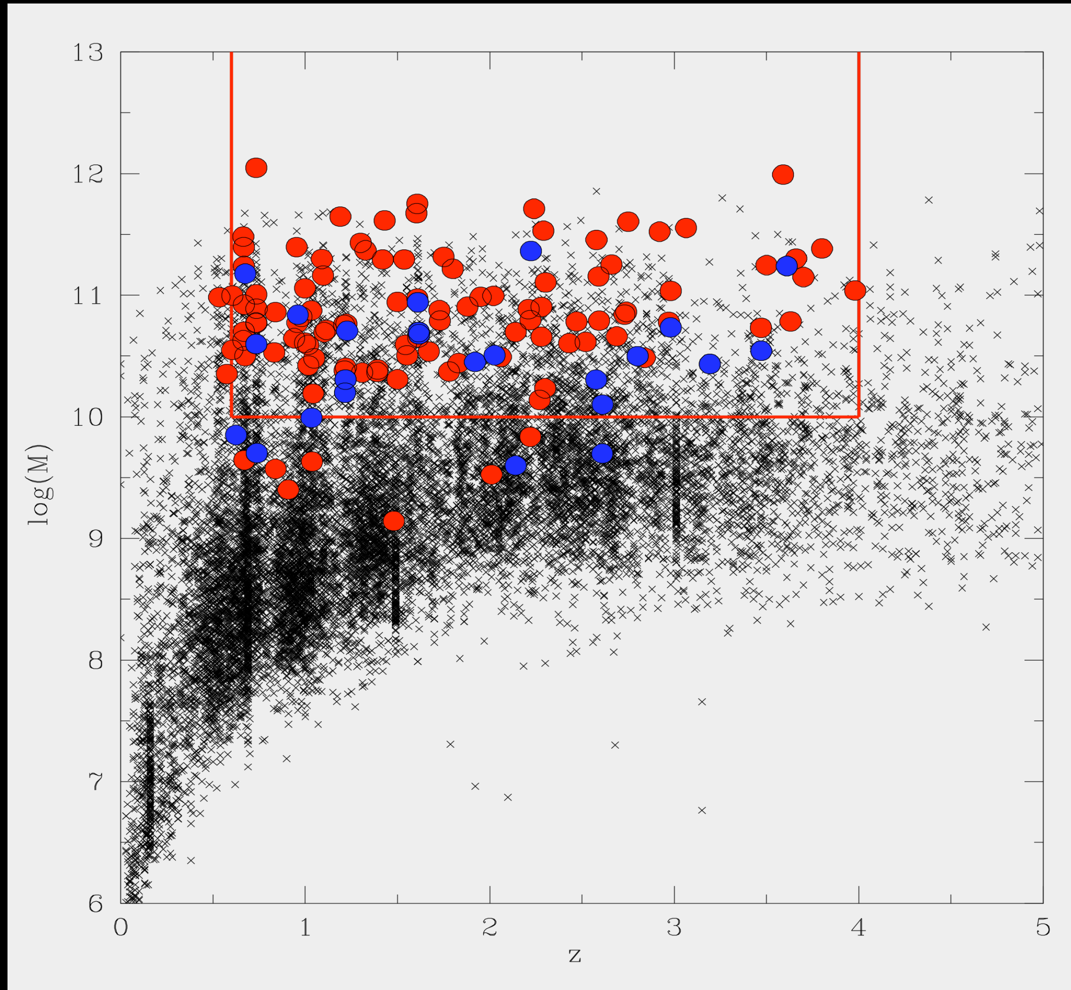
Brusa, Fiore et al. 2009, A&A submitted

Lx range Black = 42-43, Blue = 43-44 Red >44
Green contours: Field population



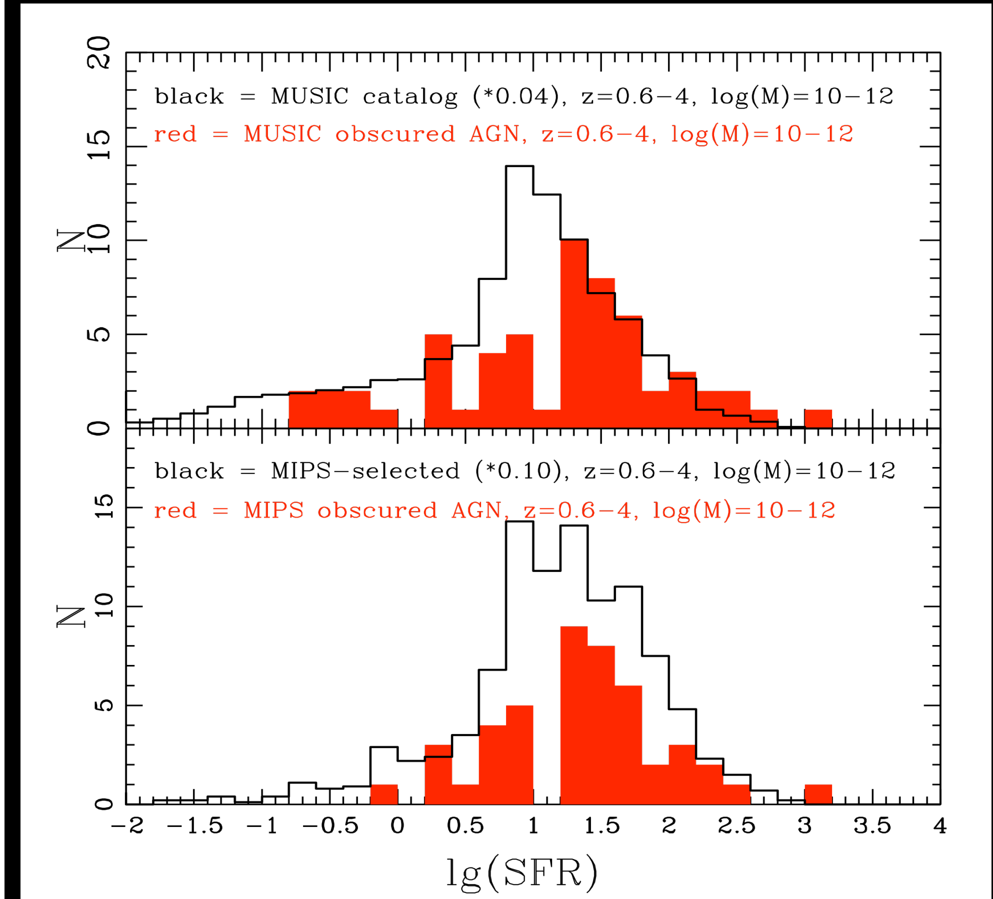
AGN host galaxies: masses

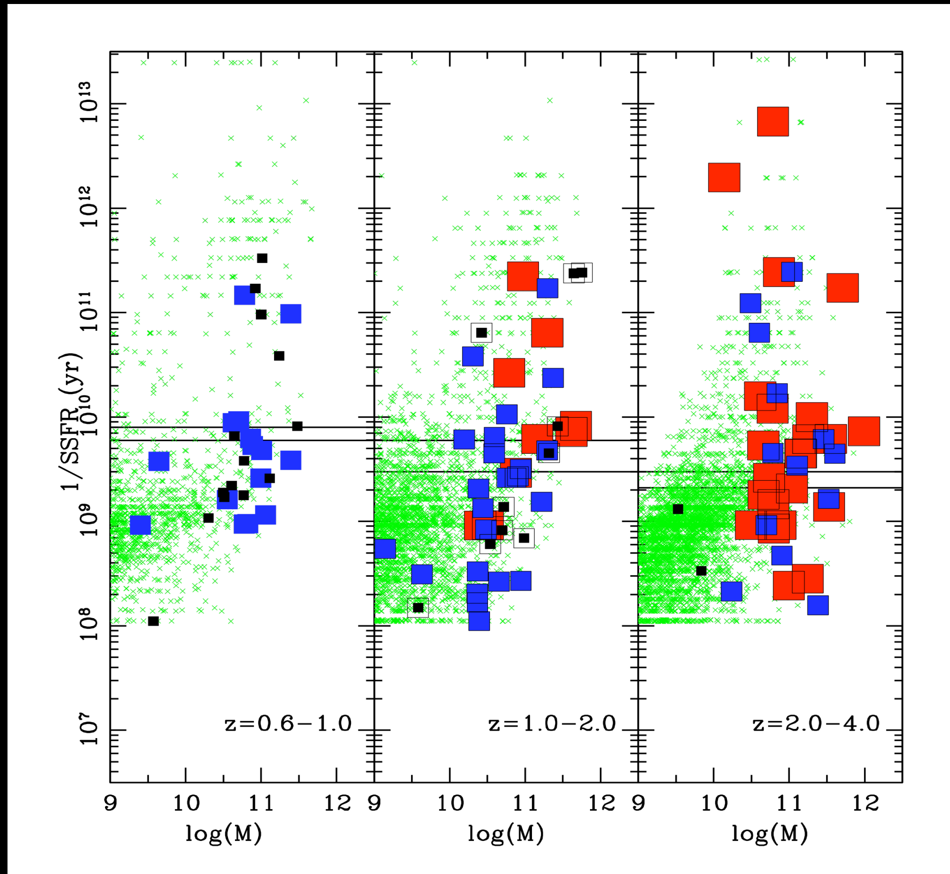
- Most X-ray selected
- obscured AGN live in
- RED massive galaxies



Brusa et al. 2009, A&A submitted

SFR and SSFR distributions



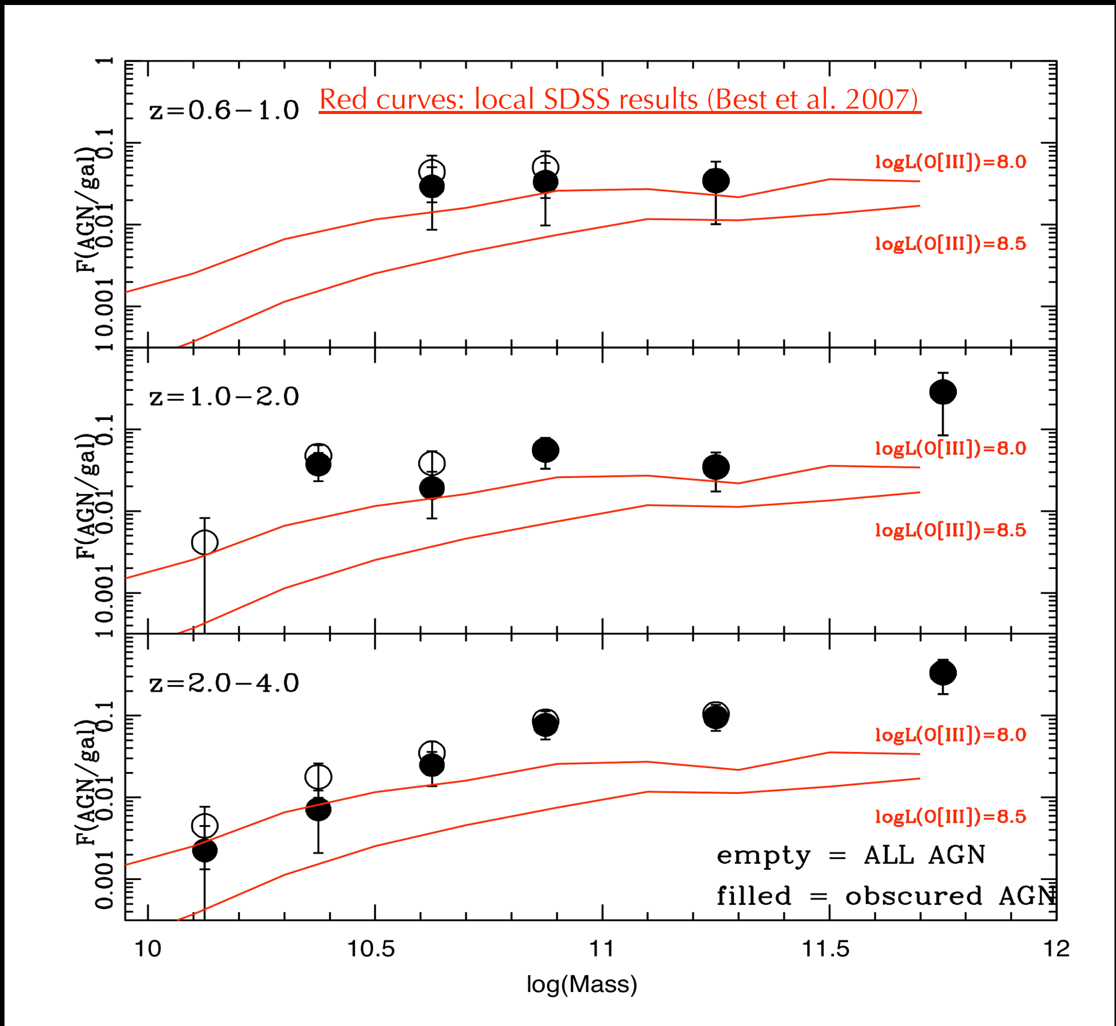


- Most X-ray selected obscured AGN live in red DUSTY STARFORMING gal

~50% live in galaxies with SFR>10M_{Sun}/yr or with 1/SSFR<t(Hubble)

Brusa et al. 2009, A&A submitted

AGN fraction in mass selected samples



AGN fraction increases with stellar mass:
<1% at logM<10.5
>10% at logM > 11

Higher than what observed in the local Universe at ~same L (Best et al. 2007)

→ Enhanced AGN activity

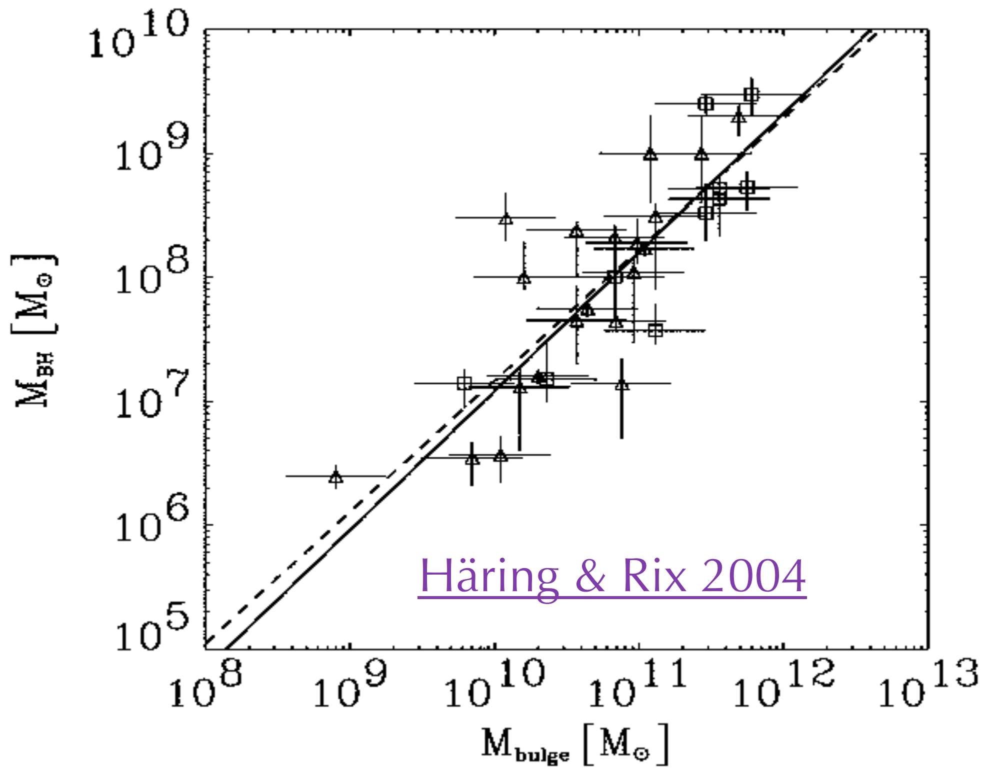
Brusa et al. 2009, A&A submitted

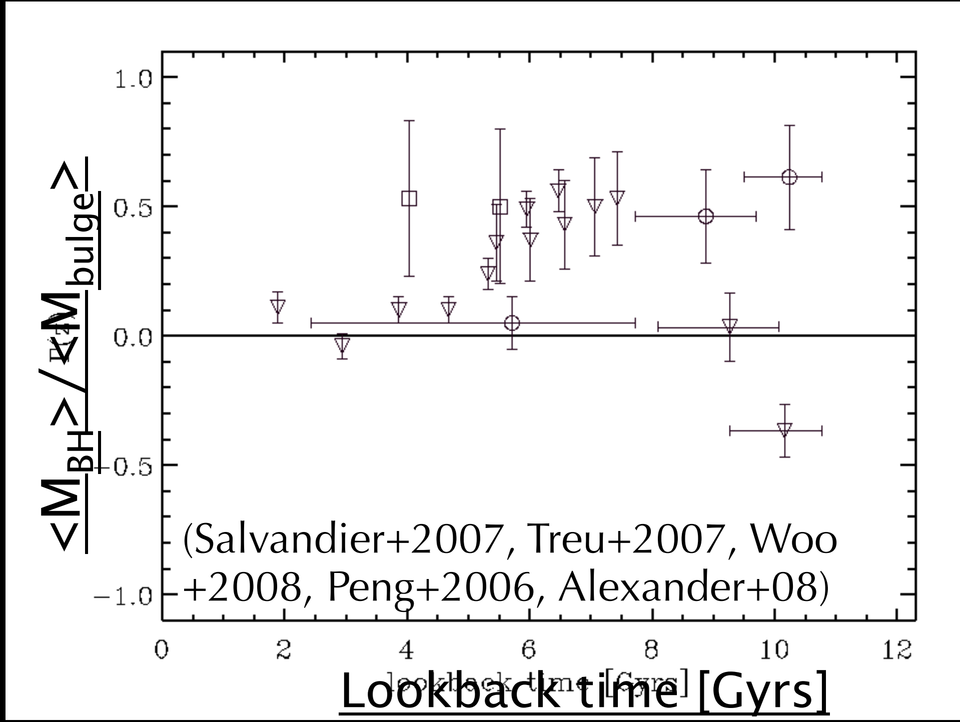
The evolution of the scaling relations

Studying the evolution of black hole-galaxy scaling relations

Local Universe

Evolution?





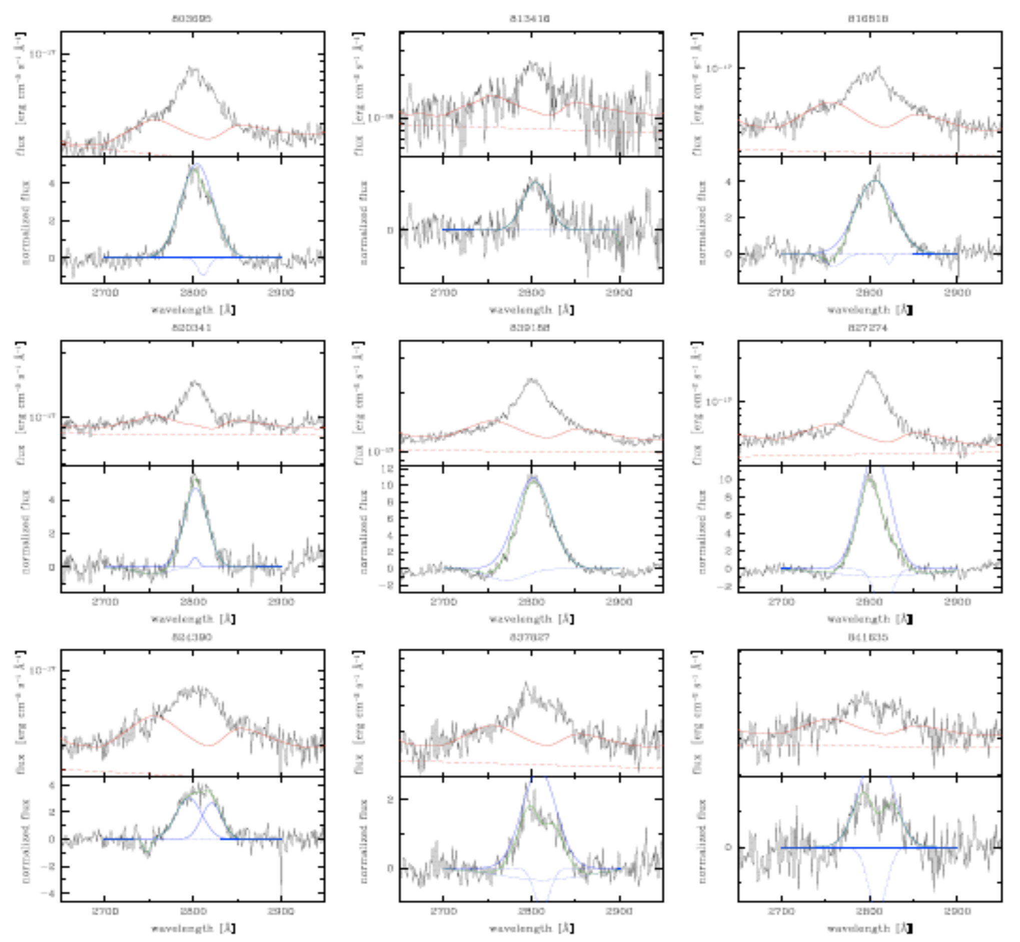
A large number of feedback models have been proposed and can reasonably well reproduce them (e.g. Silk & Rees 1998, Granato et al. 2004, King 2005)

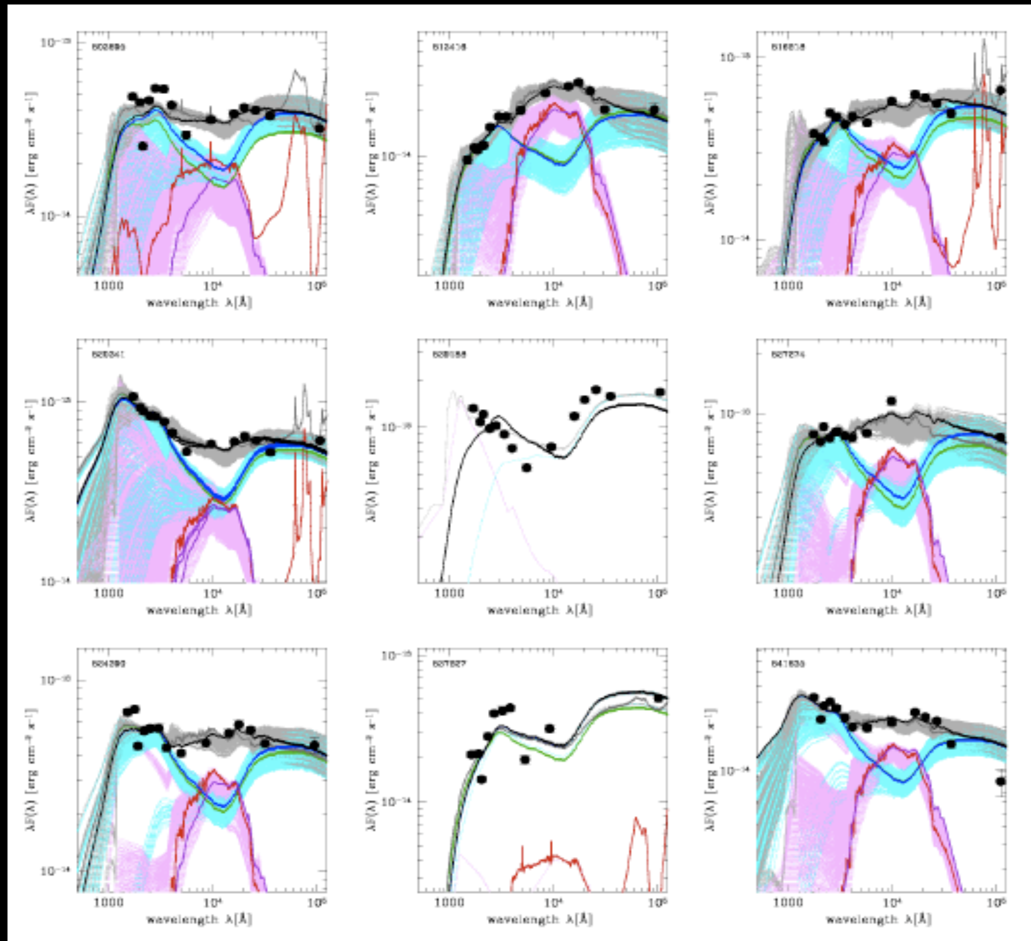
Hint for positive evolution: Hosts are undermassive compared to the central BH

Scarce data, large uncertainties

Black Holes in COSMOS

SAMPLE: 89 type-1 AGN at 1<z<2 (with MgII line) from the zCOSMOS survey



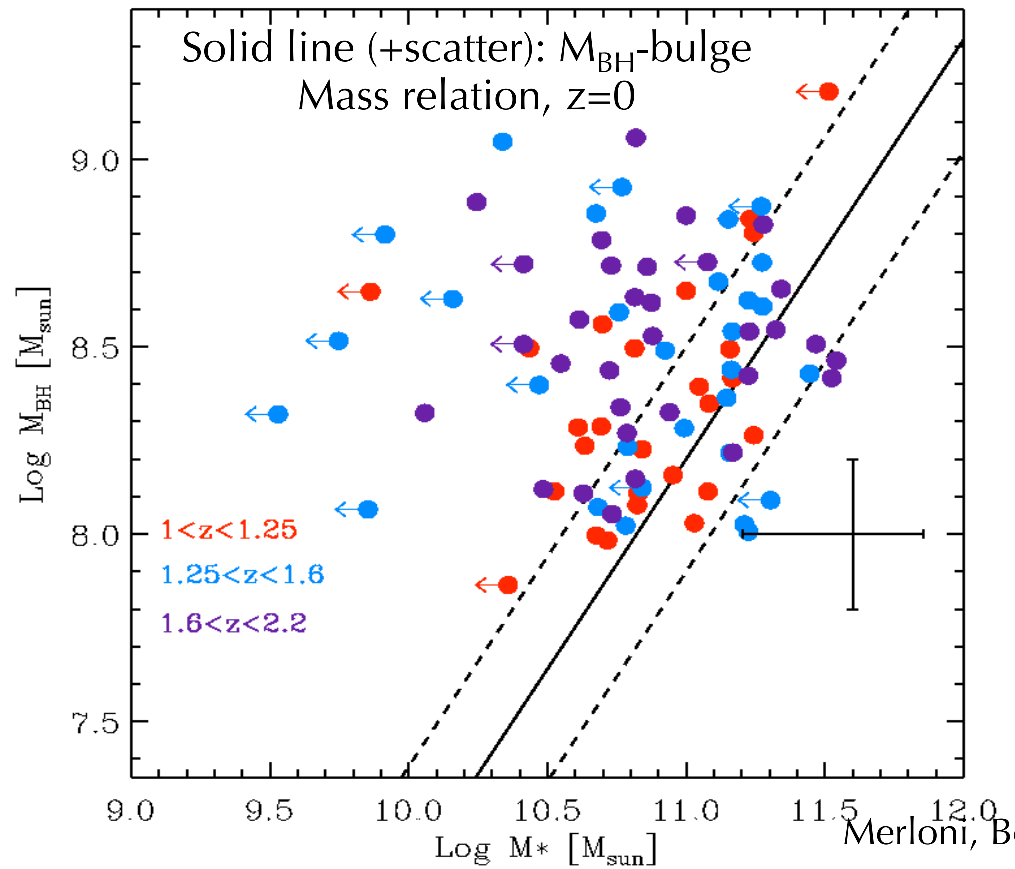


Black Hole mass: Virial Method
[e.g. Peterson et al. 2004]

Host galaxy mass: SED fitting
(AGN/host galaxy decomposition)

Merloni, Bongiorno et al. 2009

RESULTS: The black hole-galaxy scaling relation at 1<z<2

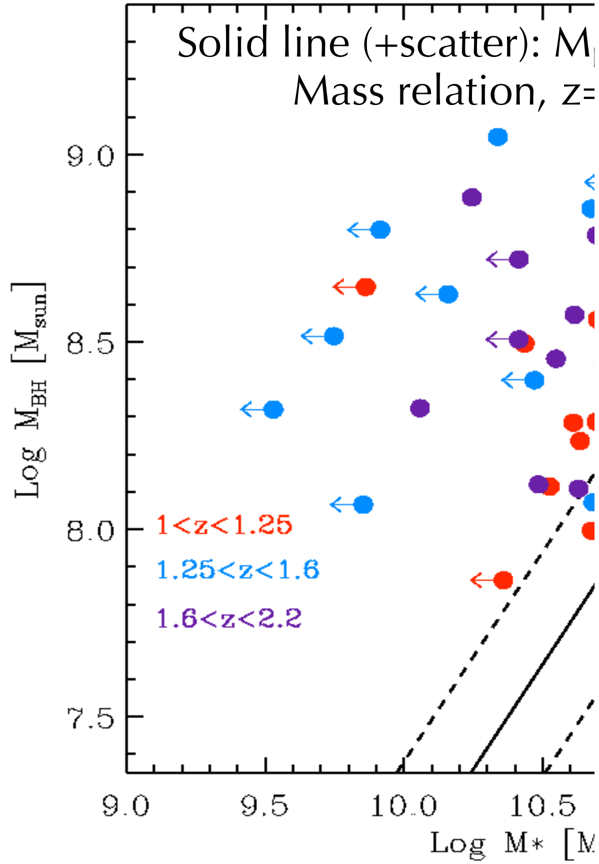


Merloni, B

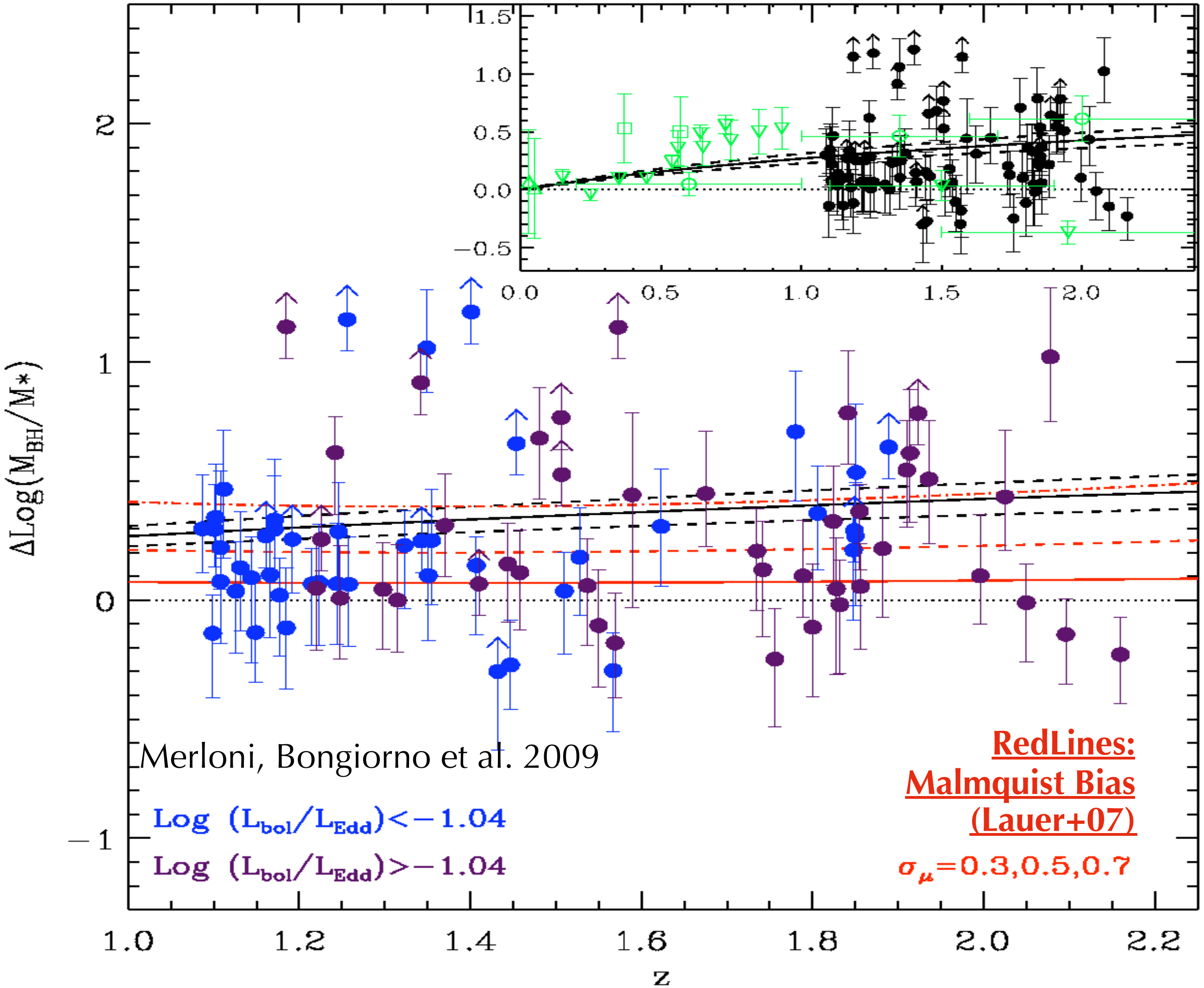
Substantial offset from the local relation

RESULTS: The black hole-galaxy scaling relation at 1<z<2

Black line: fit -> Δ Log M_{BH}/M_{*} $\propto(1+z)^{0.89}$



Substantial offset
local relati



Implications and conclusions

AGN and galaxy co-evolution

- Early on

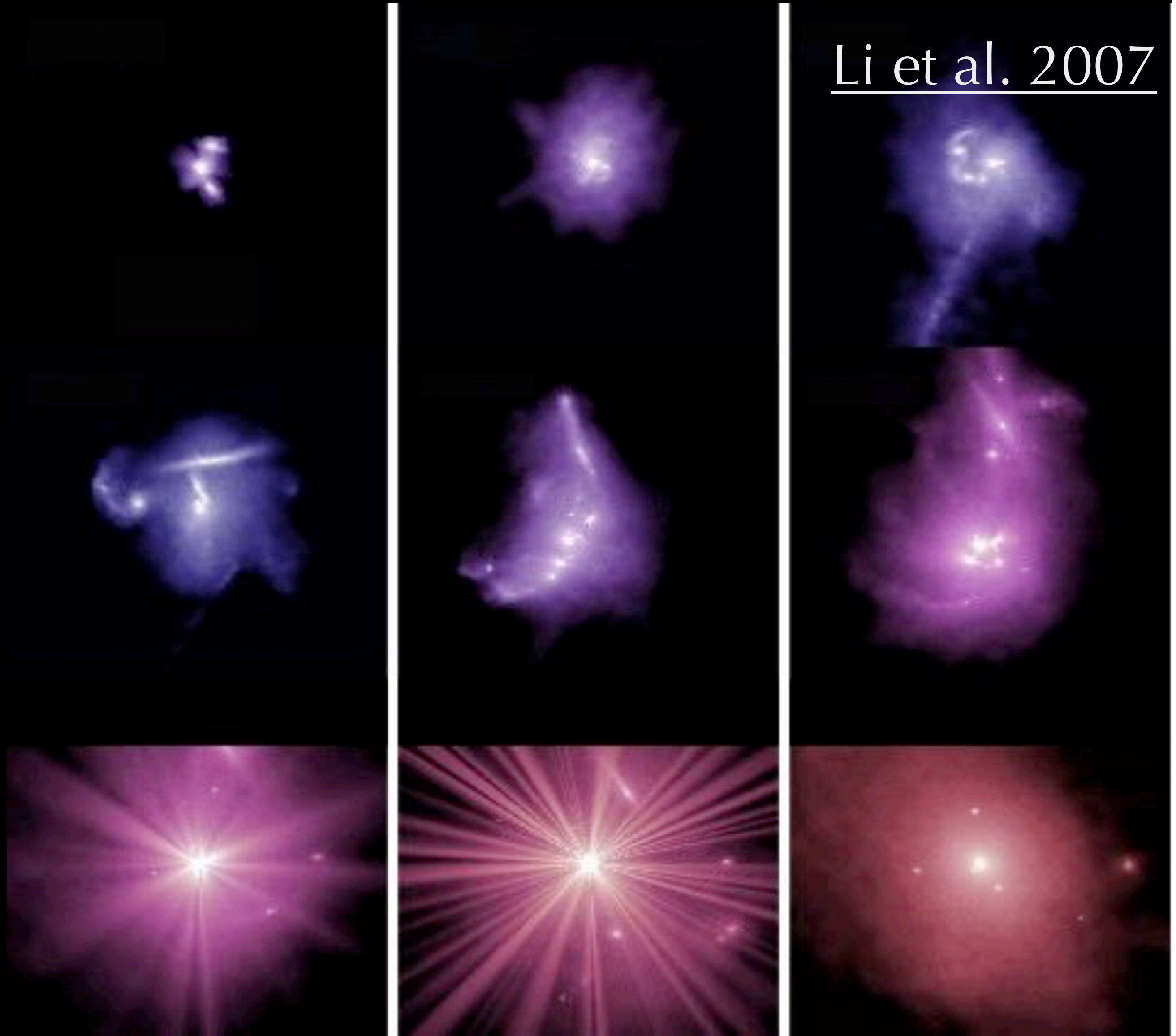
Strong galaxy interactions; Mergers between gas rich galaxies drive gas which fuel both SF and BH activity; Violent starbursts episodes; Heavily obscured BH growth

- When galaxies coalesce

Accretion peaks; SMBH becomes optically “visible” (QSO phase) as AGN winds blow out gas

- Later times

SF & BH accretion quenched; Dead quasars (or slowly accreting BH) in red galaxies (passive evolution)



[see also Granato et al. 2004, Di Matteo, Springel & Hernquist, 2005, Croton+06, Bower+06, Hopkins et al. 2006,2008]

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

$\rho_{BH} c^2 = (1-\varepsilon)/\varepsilon * U_T$

Bolometric

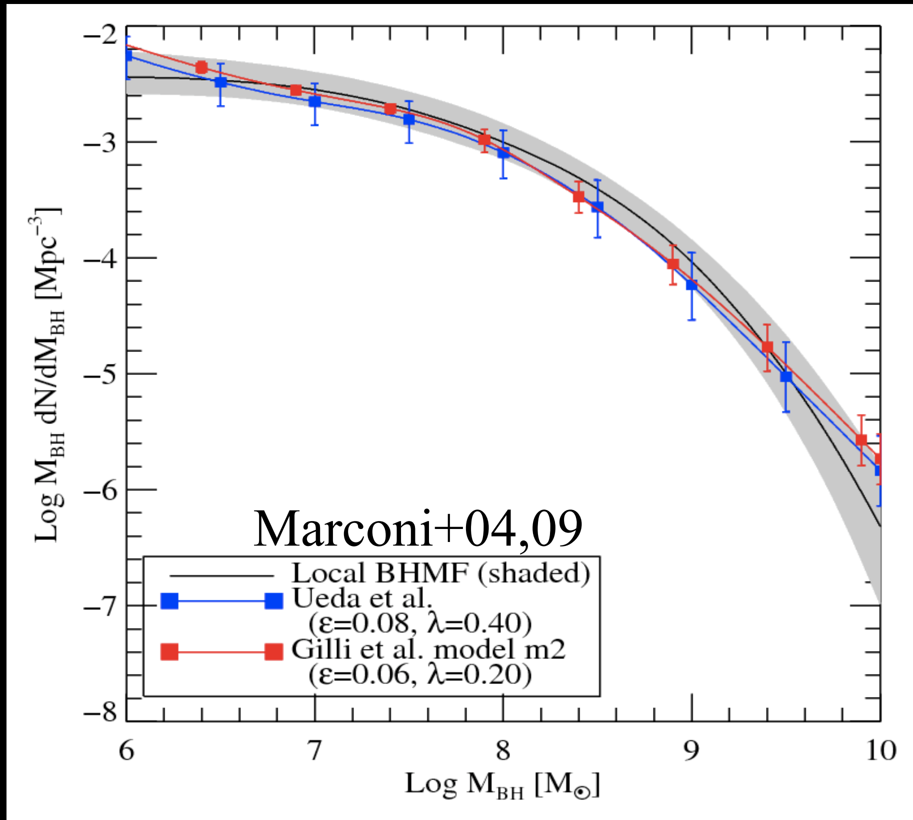
$U_T = \int dt \int L_{bol} F(L_{bol}) dL_{bol}$

XLF

$U_T = k_{bol} \int dt \int L_X F(L_X) dL_X$

XRB

$U_T = k_{bol} 4 \pi I_0 / C * (1 + \langle z \rangle)$



Matching the mass accreted to the local BH mass density it is possible to derive the radiative efficiency

Iwasawa & Fabian (1999) ε~0.1; Elvis, Risaliti & Zamorani (2002) ε >0.15; Yu & Tremaine (2002) ε>0.1; Marconi et al. (2004) 0.16> ε >0.04; Merloni et al. (2004) 0.12> ε >0.04; Marconi et al. (2009) 0.1> ε >0.06; Shankar et al. (2007) ε ~0.07, Merloni & Heinz (2008) ε ~0.07

Conclusions (I)

- AGN downsizing is an important, independent evidence that our general BH-galaxy coevolution picture is correct

- High-z, X-ray selected, moderate luminous AGN show the same decline in the space density as the more luminous SDSS QSO

  → Aim at having "SDSS statistic" in the X-ray to put SMBH light up and evolution in a full context (eROSITA)

- Obscured/CT SMBH (at z~2) can be revealed through stacking and are as numerous as the directly detected Type 2 AGN

  → Ultra deep XMM / Chandra and deep IXO fields will reveal heavily obscured SMBH up to high redshifts

Conclusions (II)

- Host galaxies of obscured AGN at z>1 show high, dust obscured starformation (in about half of the cases)

  → A truly multiwavelength approach is mandatory (Herschel, ALMA, JWST, …)

- BH-galaxy scaling relations evolve positively with redshift: at earlier tmes the BH were "larger" wrt galaxy mass than today

- Most of SMBH growth occurred in radiatively efficient episodes of accretion. Very strong constraint on rad. efficiency