Demography of high-redshift AGN & SMBHs (and some other lowish-z stuff)

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Many thanks to
S. Puccetti, M. Brusa, F. Civano, A. Comastri, M. Elvis, C, Feruglio, A. Fontana, A. Grazian, A. Lamastra, R. Maiolino, S. Mathur, N. Menci, E. Piconcelli, P. Santini, M. Salvato, F. Shankar, C. Vignali

Two key questions:

- **When and how SMBH formed and grew up?**

  Can SMBHs be used to constrain

  - ***Scenarios for the formation of SMBHs***
  - AGN feeding/accretion physics
  - cosmological scenarios?

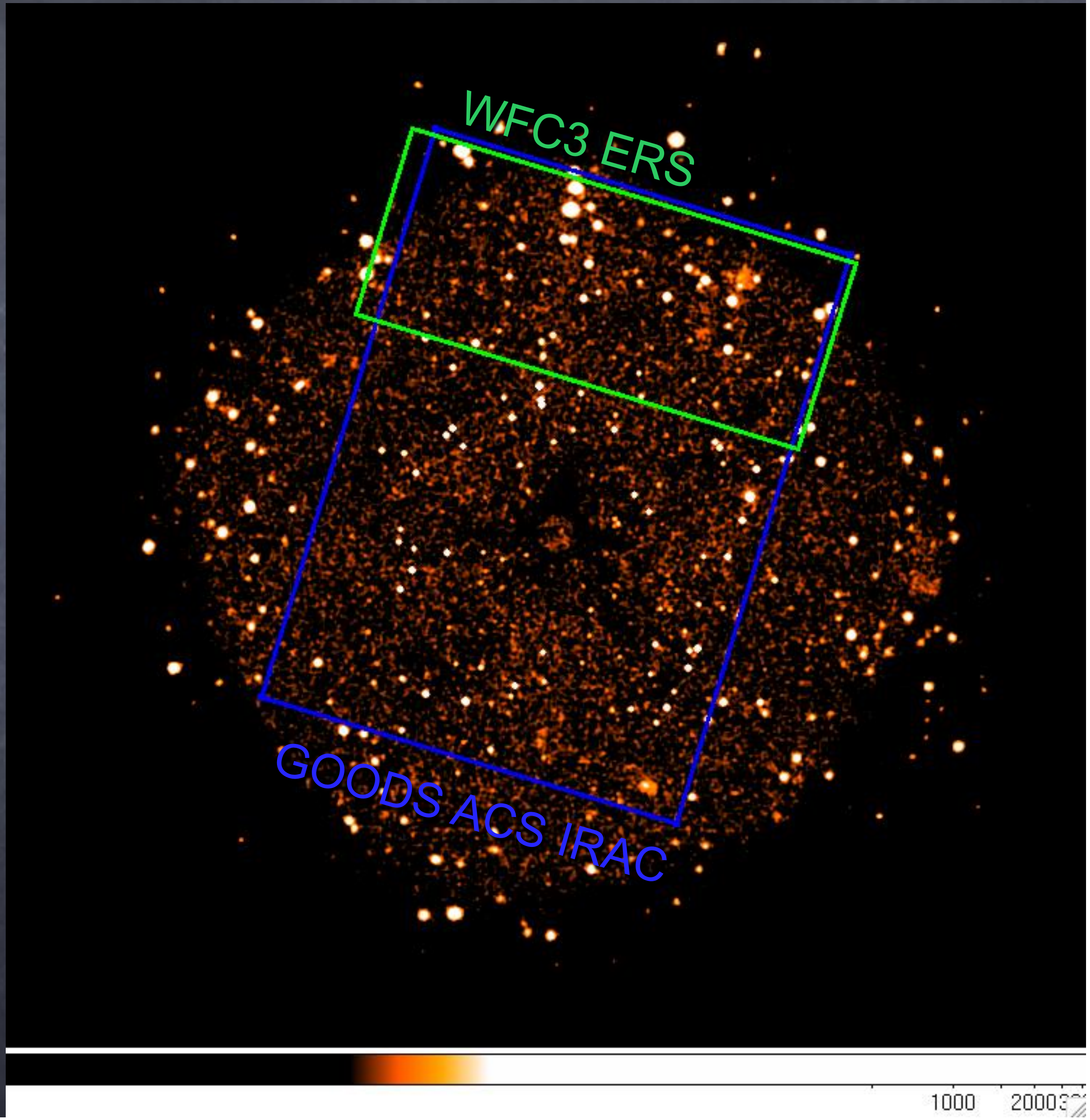
- **Why they suddenly light up to shine as QSOs?**

  - which is the *triggering mechanism?* Galaxy interaction? Galaxy internal dynamics? How can we discriminate?

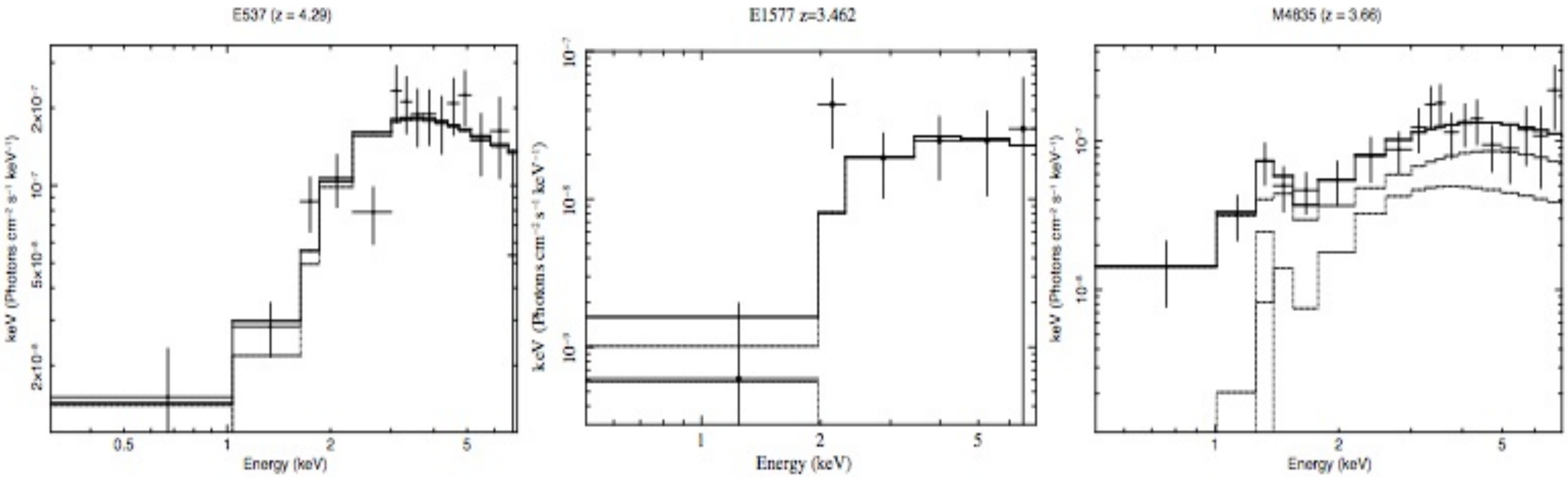
High-z AGN in the CDFS 4Msec field

Pilot program on the CDFS4Msec:

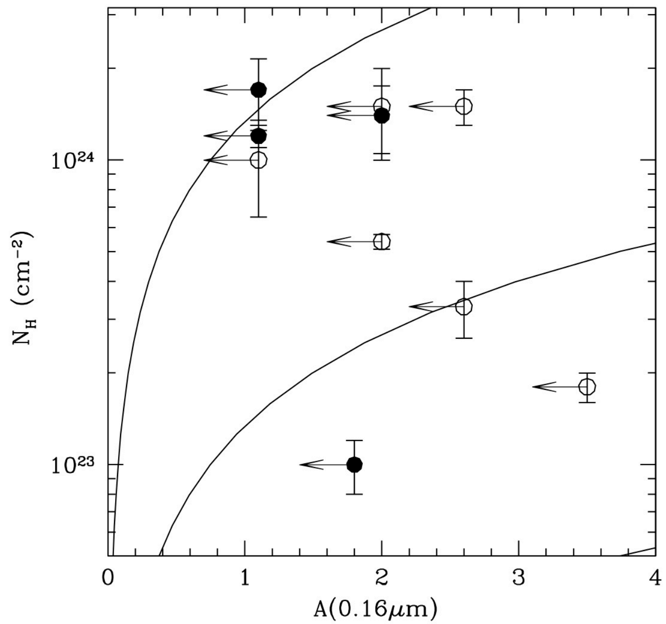
- Use ERS and GOODS-MUSIC galaxy catalogs and photo-z
- search the X-ray band that maximize the number of detected counts. ***ephot***, first step toward multi-dimensional source detection



Low-mid luminosity AGN

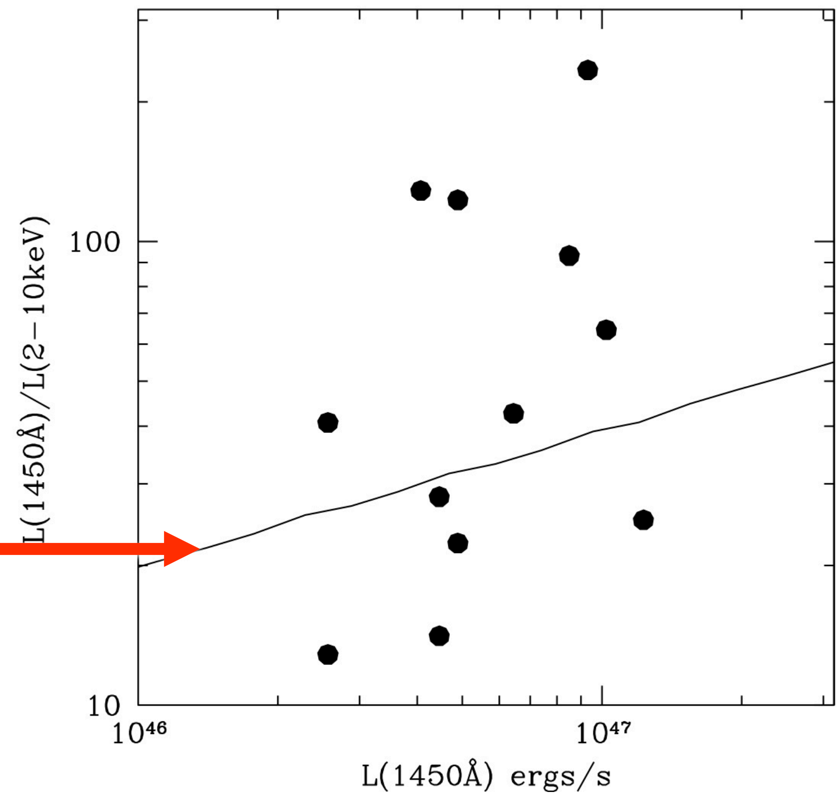


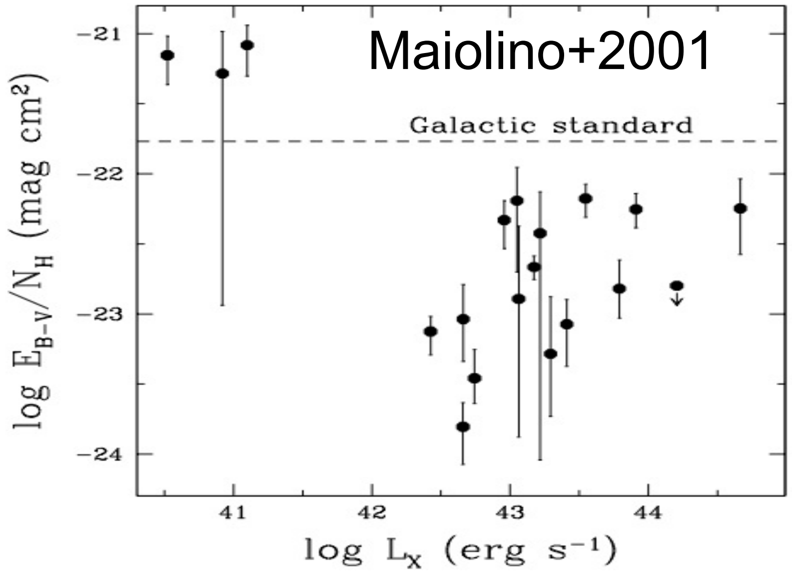
- Large fraction of X-ray obscured AGN at z>3:
  - 3/17 GOODS-ERS AGN are CT (18+17-10%)
  - 4/11 GOODS-MUSIC AGN with optical spectrocopy are CT
  - All with very low optical extinction



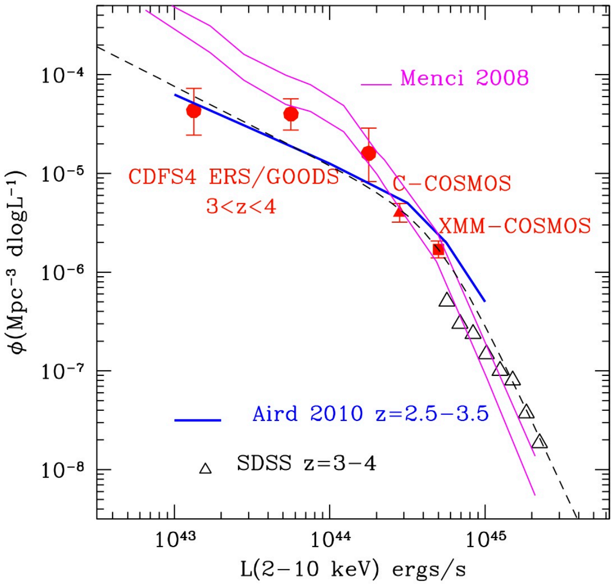
High luminosity QSOs

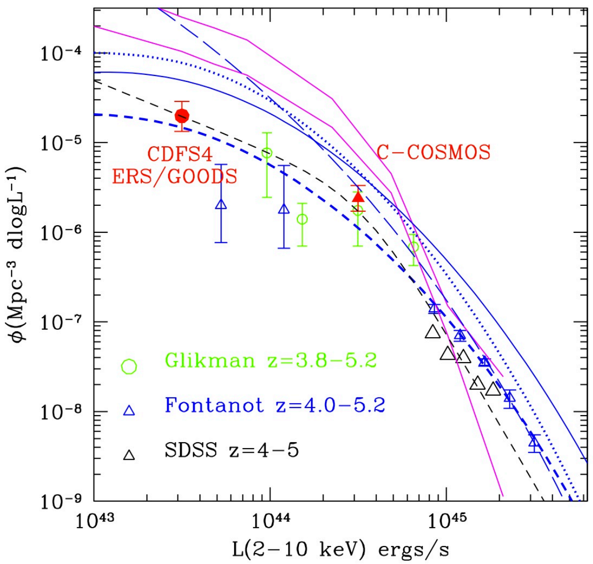
- Optically selected SDSS samples (Richards et al. 2006, Jiang et al. 2009).
- Compute X-ray luminosity using Marconi et al. luminosity dependent conversion factors.
- Test these factors with real data.
- No correction for dust extinction needed.
- Hopkins+2007 use large correction for dust extinction (adopt X-ray N_H distributon and galactic dust-to-gas ratio), and obtain very flat LF
- However, AGN E_{B-V}/N_H is usually smaller than galactic

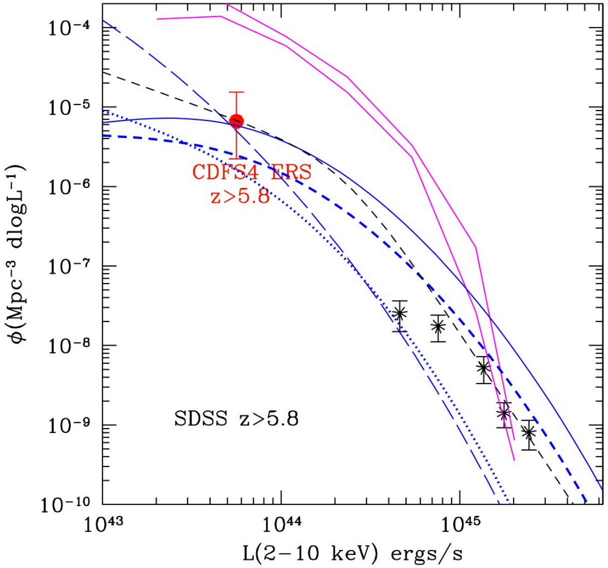




High-z AGN luminosity functions evolution



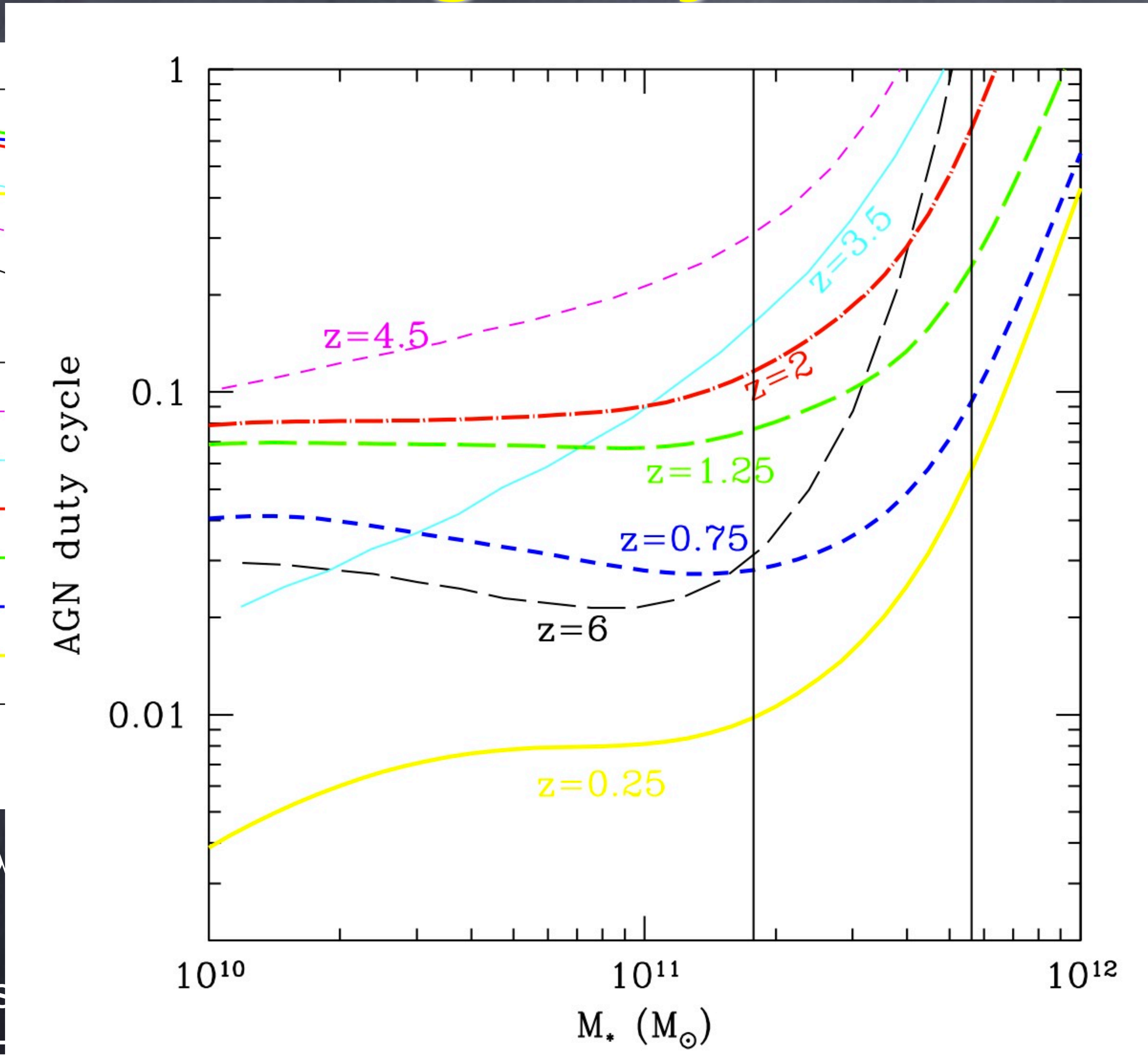


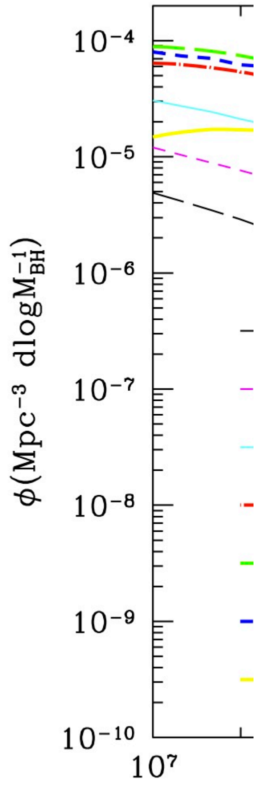


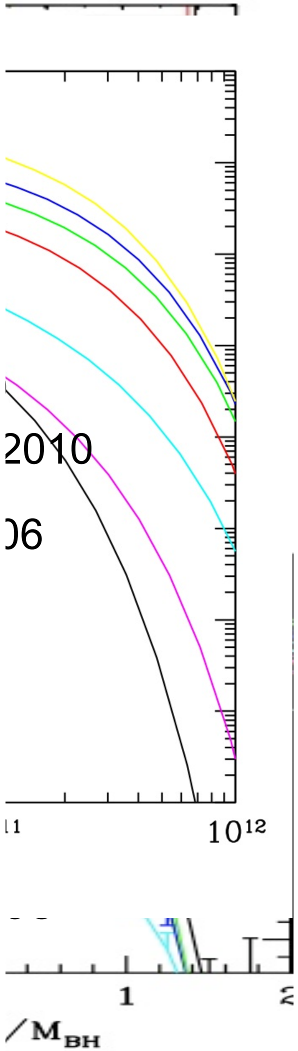
FF+2011

C-COSMOS Civano et al. 2010, Salvato et al. 2011
XMM-COSMOS Brusa et al. 2009, Salvato et al. 2009

AGN and galaxy evolution







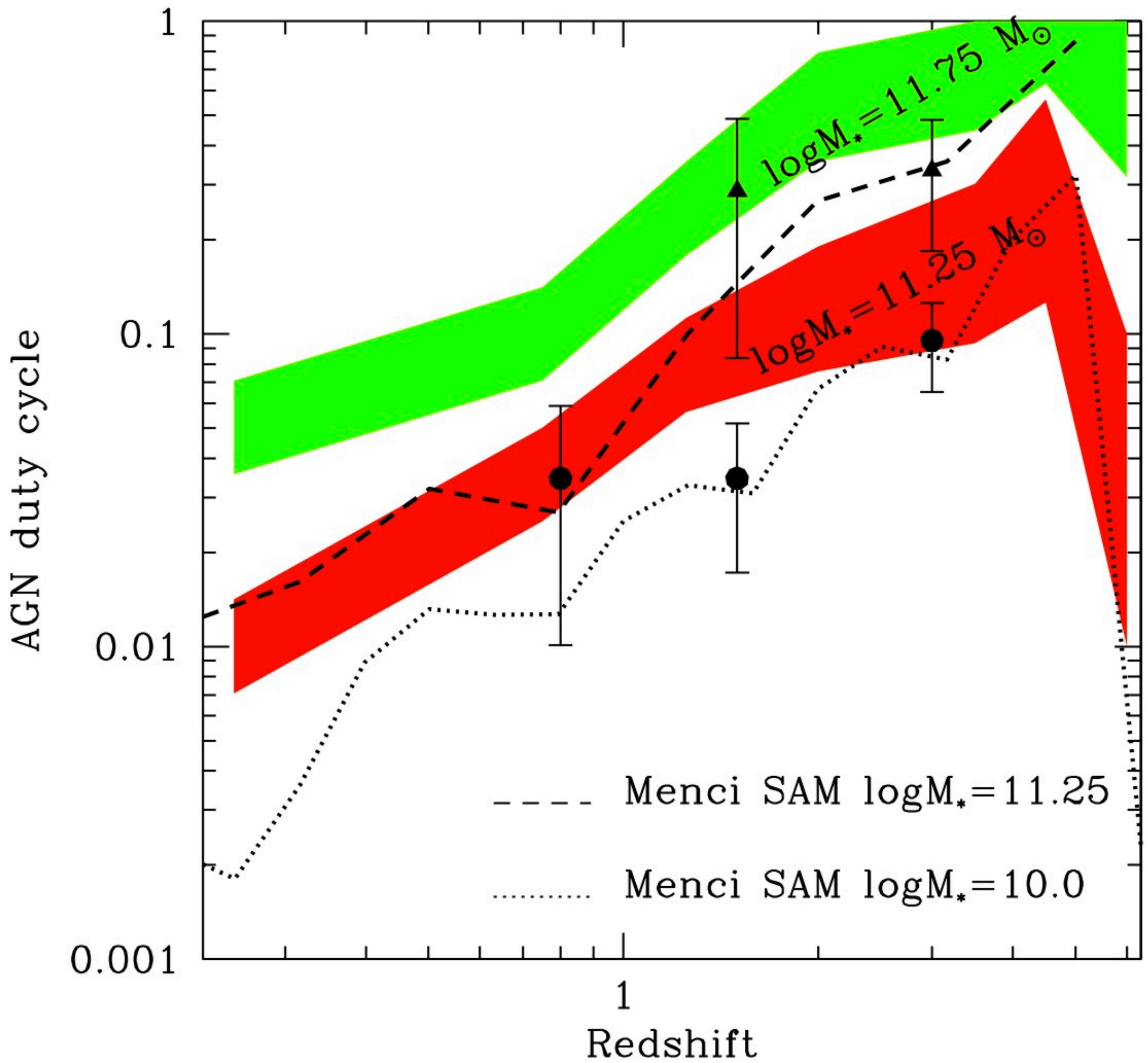
AGN LF + λ
BHMF ==>
nucleus ass
AGMF/GMF

Evolution of AGN duty cycle

AGN timescale and duty cycle are determined by AGN triggering mechanism. The comparison of the model prediction with the evolution of AGN duty cycle can constrain AGN triggering models:

- Galaxy encounters
- Galaxy dynamics
- Stellar mass losses
- Etc.

FF+2011



Different triggering mechanisms

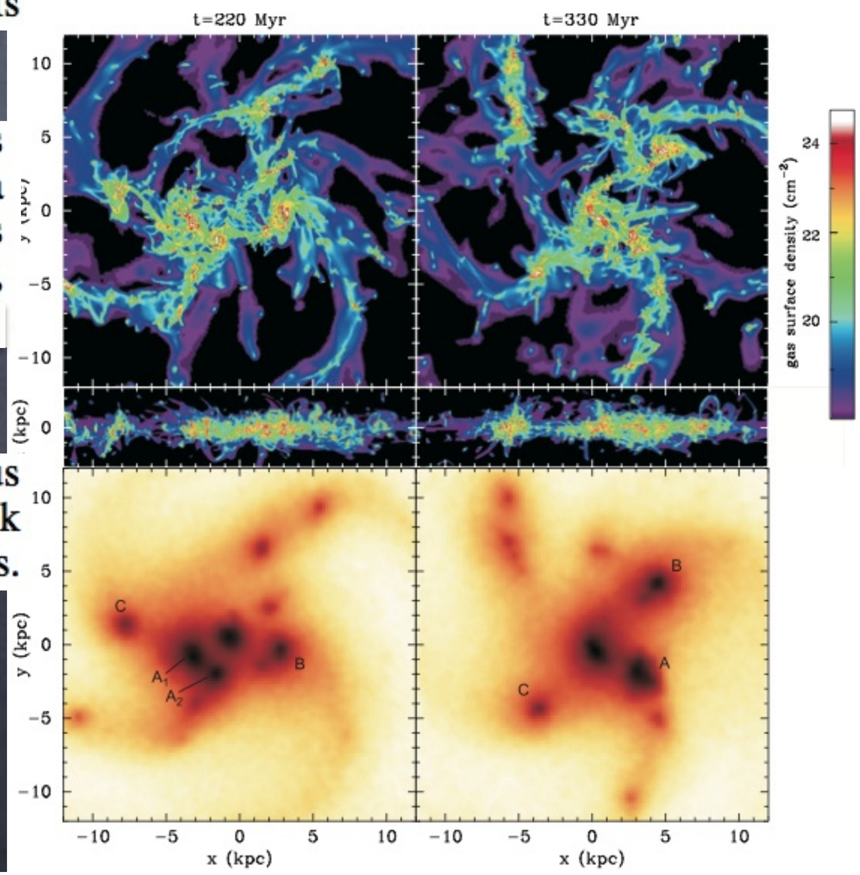
The corresponding bolometric luminosity is 2×10^{44} erg s^{-1}. With typically 1%–5% in X-rays, we estimate on average $L_X \sim 10^{42}$–10^{43} erg s^{-1}, scaling with galaxy mass and with $(1+z)^{2.5}$. While the average luminosity would be modest, short episodes of higher accretion rate, possibly up to the Eddington level, occur during the central coalescence of migrating giant clumps—which could also bring with them seed BHs

Disk instability at $z \sim 2$ can thus funnel half of the disk gas toward the center in 2 Gyr. This is similar to the mass inflow in a major merger (Hopkins et al. 2006), but spread over a 10 times longer period, resulting in a lower average AGN luminosity, with higher duty cycle, and high obscuration.

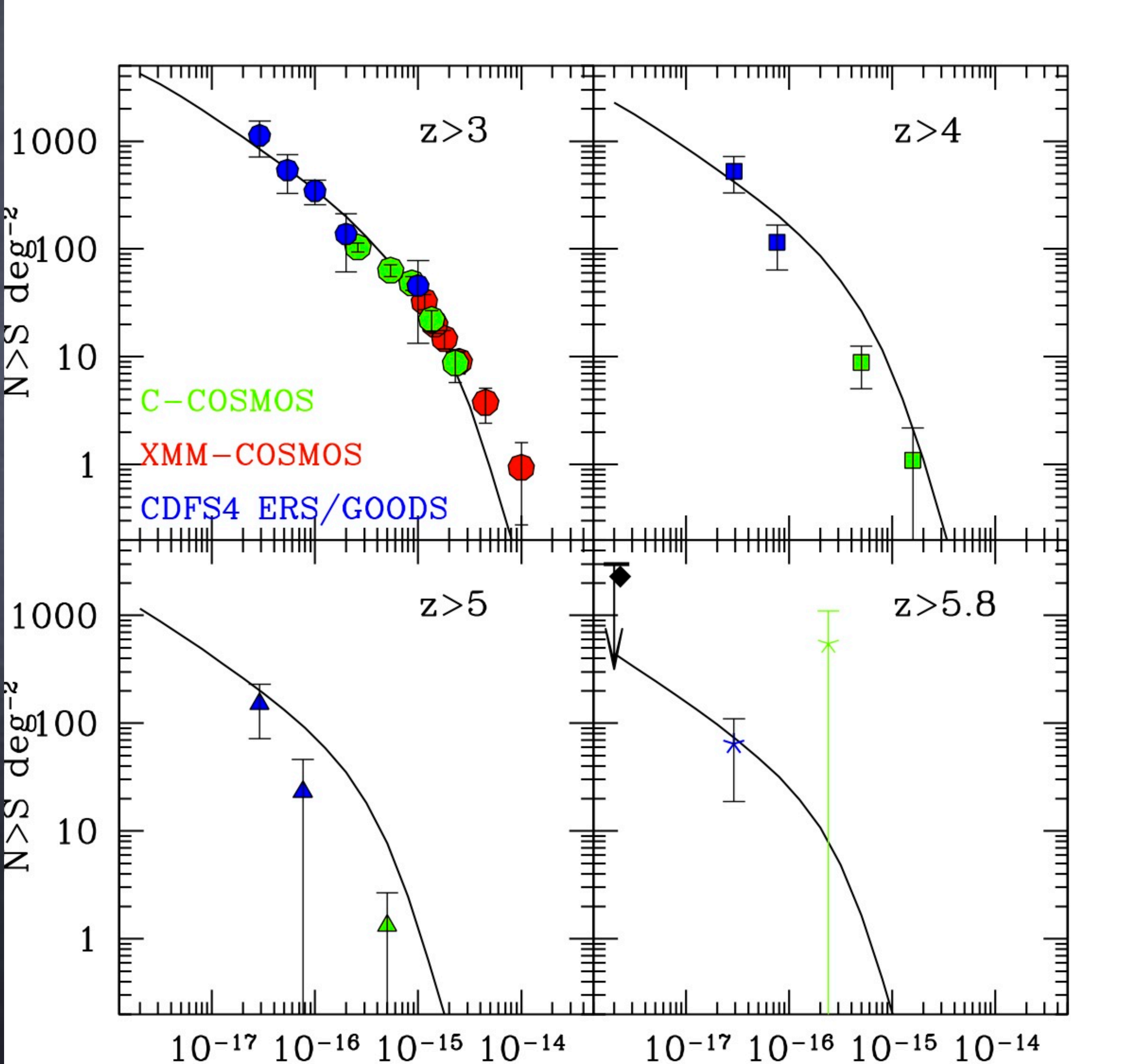
The main prediction is thus that many high-z AGNs should be hosted by star-forming disk galaxies, composed of clumpy disks and growing spheroids.

Cold flows (similar to minor mergers)

Dekel+ 2009, Bournaud+ 2011



High-z AGN number counts



Formation of high-z SMBH

BHs are the structures with the fastest (exponential) growth rate.
They may be used to probe both accretion physics and cosmological scenarios

Canonical scenario for structure formation:

- collapse of overdense regions of DM primordial density field

BHs grow through *both merging and accretion*

Merging rate depends critically on the growth factor D(t)

All processes are pushed to the maximum, to maximize number of SMBH at each given mass

- No delay between DM haloes merging and BH merging
- Accretion occurring at Eddington rate for whole cosmic time from z~10 to z=6

The cosmological model enters in $N(m_\bullet,M)$ and $P(M \rightarrow M)$

The physics of accretion enters in $dm_\bullet/dt$ Lamastra+ 2011

SMBH formation scenarios

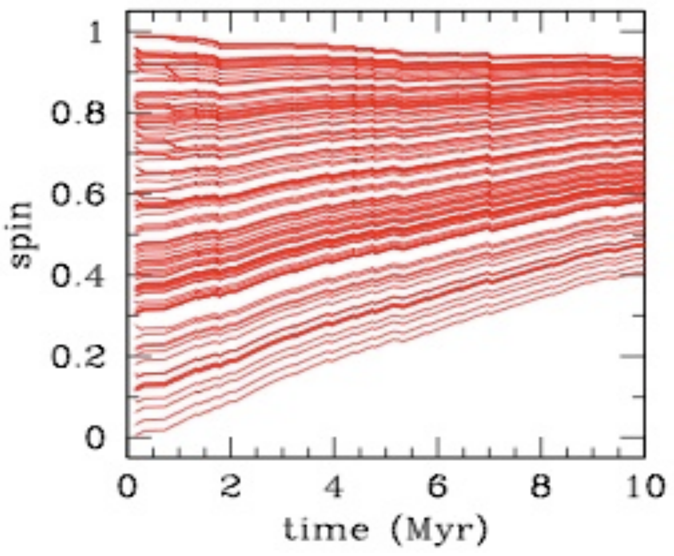
- BH seeds from PopIII stars:

These would collapse from a metal-free gas leading to a top-heavy IMF, corresponding to very massive stars with masses >100 $M_\odot$. Stars with M<300 $M_\odot$ will produce pair-instability SNae, and their stellar cores would be entirely disrupted leaving no remnants. Stars with M>300$M_\odot$ will produce BHs with 100-150 $M_\odot$. The primordial generation of stars could form at redshifts z~20 in DM haloes with $M>10^7$ $M_\odot$, corresponding to populating the peaks above 2.5σ corresponding to a cosmic density of seed BHs: ρ_{BH}~10 $M_\odot$ Mpc^{-3}

- BH seed from direct collapse of gas clouds

Gas clouds with $M=10^3$-10^6 $M_\odot$ can directly collaps to BH if fragmentation of the gas cloud can be avoided i.e., high UV flux to avoid cooling and low-metallicities. The latter condition would be incompatible with the presence of nearby luminous galaxies. These seeds are rarer: a peak density of 0.1 Mpc^{-3} at $z \simeq 12$

Physics of accretion

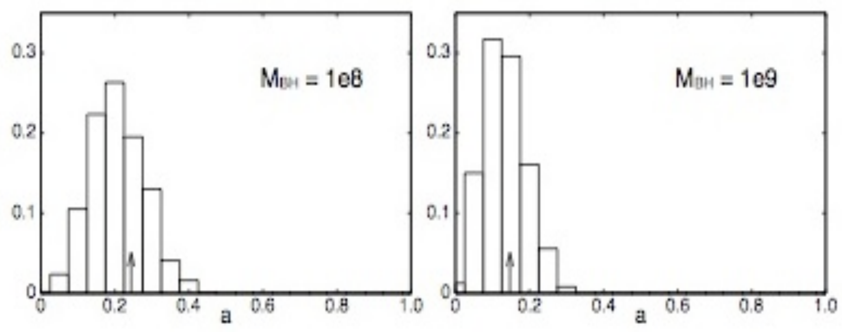


BH growth at z=6. λ=1; nearly continuous accretion from z~10 on ~100M_{Sun} seed BHs; ***LF and MF depend on: 1) accretion efficiency; 2) AGN accretion timescale; 3) cosmology.***

$$\frac{dM}{dt} = \frac{\lambda(1-\varepsilon)}{\varepsilon}\frac{M}{\tau} \qquad \lambda = \frac{L_{bol}}{L_{Edd}} = 1 \qquad \tau \sim \frac{Mc^2}{L_{Edd}}$$

$$M(t) = M(0)\exp\left(\frac{1-\varepsilon}{\varepsilon}\frac{t}{\tau}\right)$$

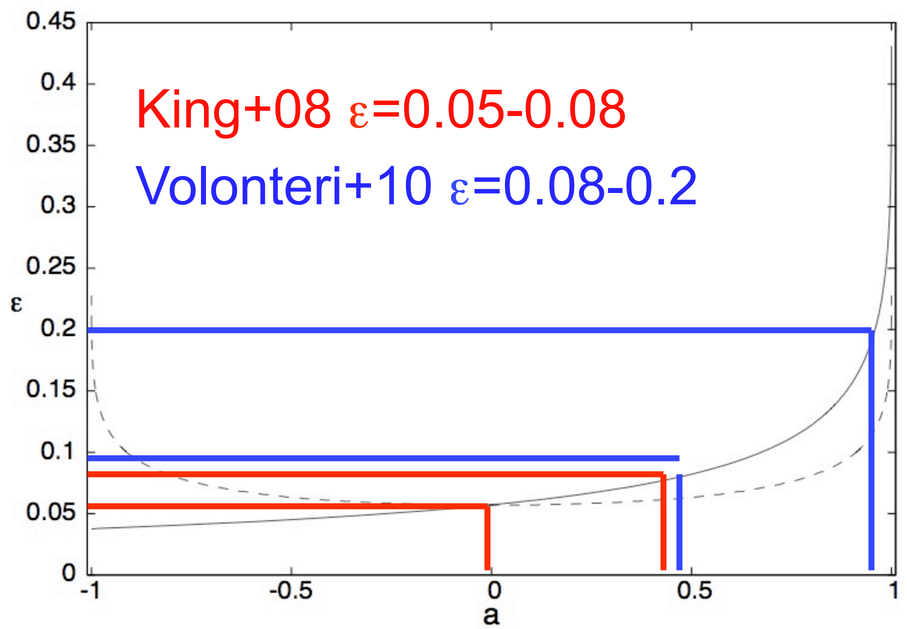
Volonteri2010, Dotti+2010 Spin evolution in gas-rich merger remnants (also see Fanidakis+2010)



King+ 2006,2008 “chaotic accretion”

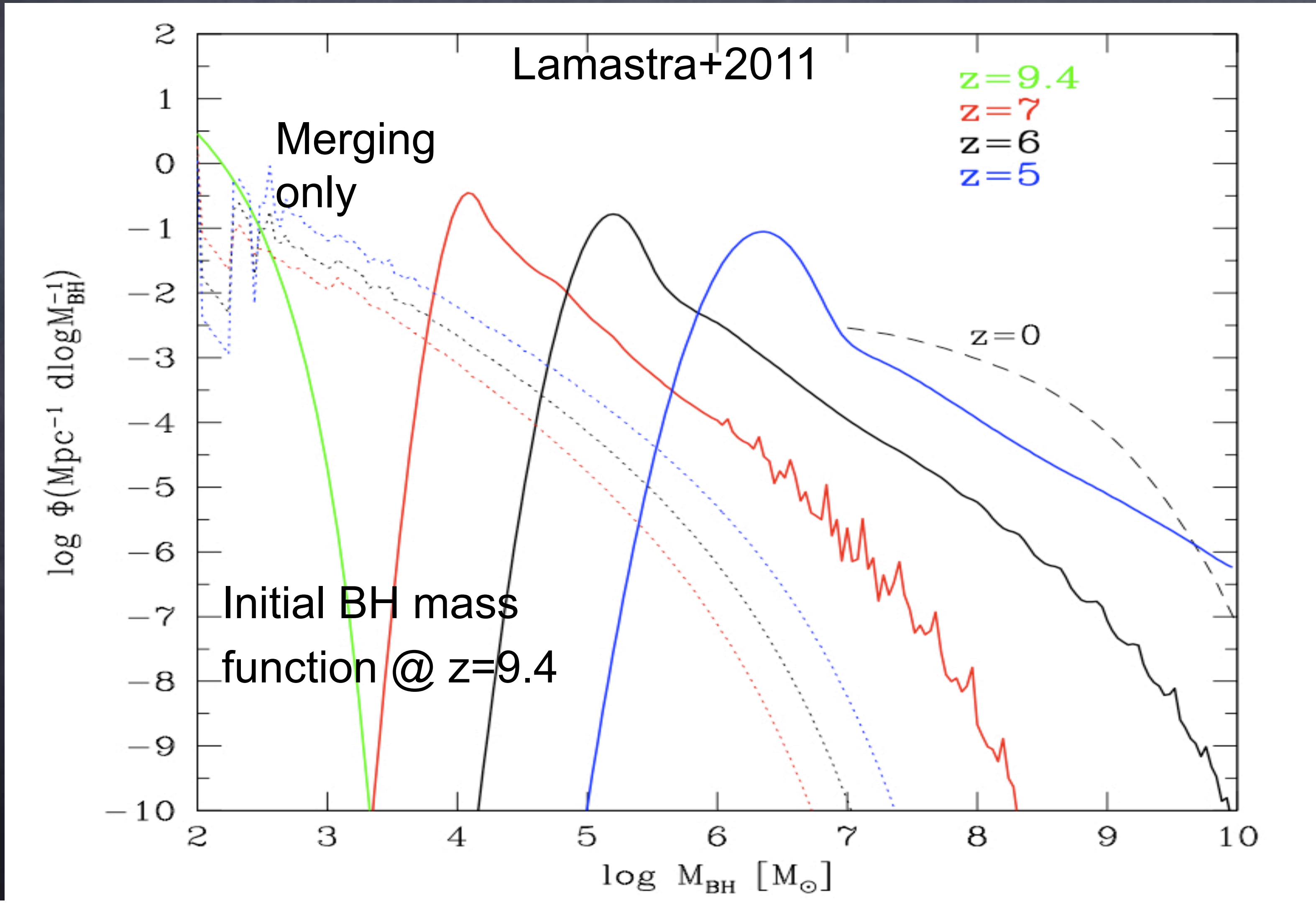
J(disk)<2J(BH)

M(disk)<M(BH)$(R_S/R_d)^{0.5}$



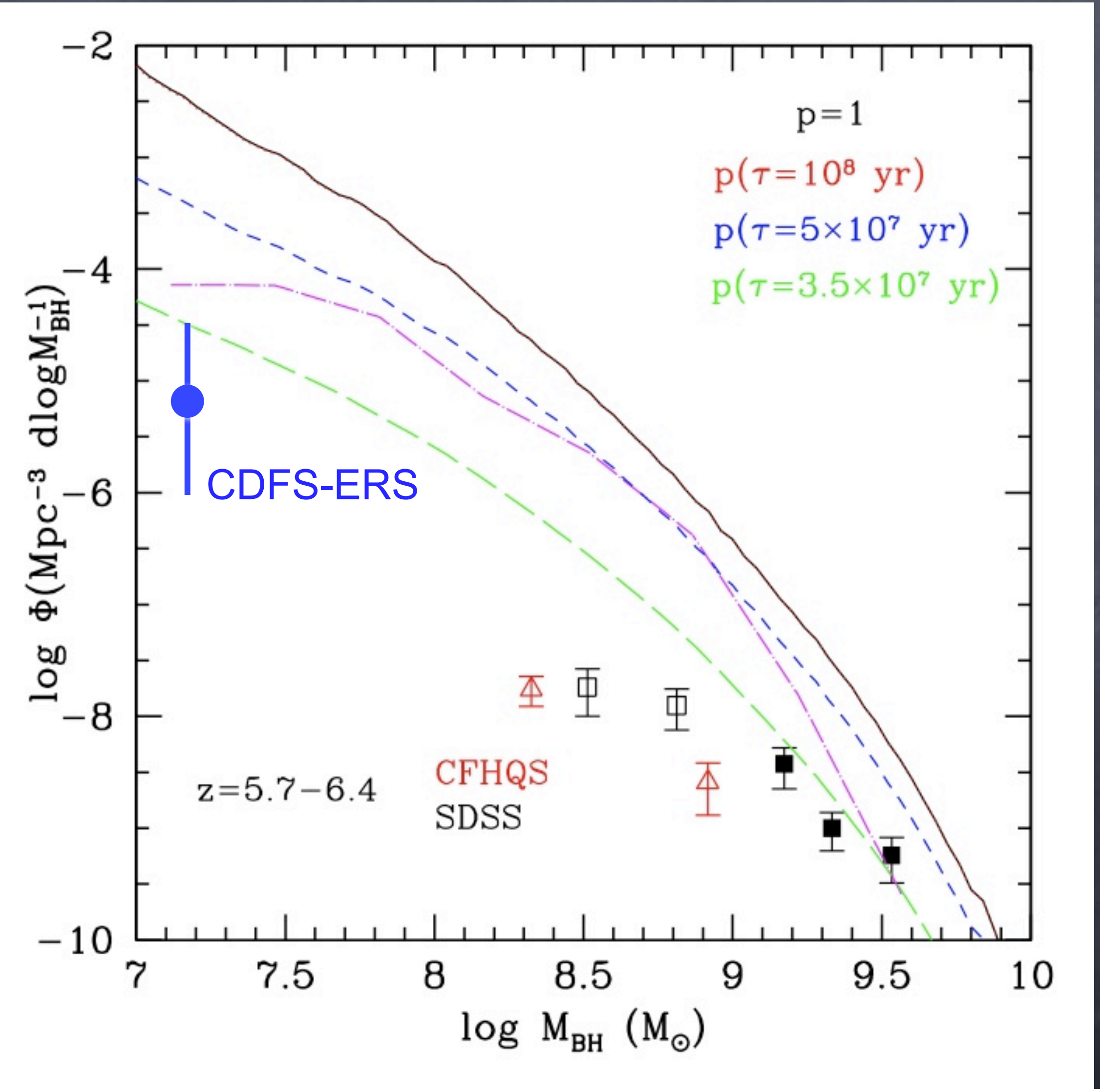
BH growth models

Initial condition: $M_{BH}=M_{halo}/10^6 > 100M_{Sun}$. BH accretion only would rigidly shift the initial BH mass function to higher masses. ***ε=0.1 fix***



BH growth models: ΛCDM

BH mass functions vs. AGN timescale (duty cycle)

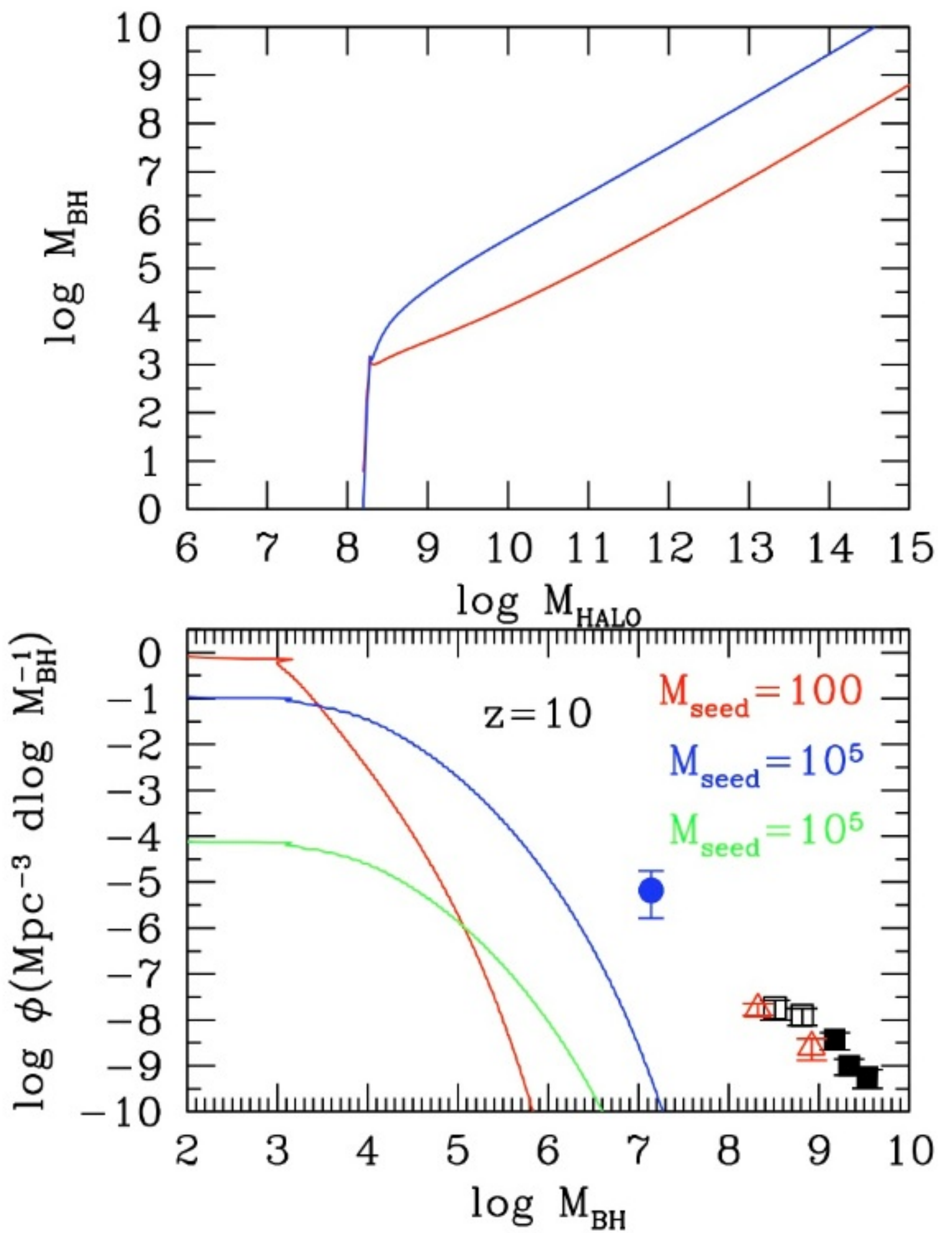


BH mass functions

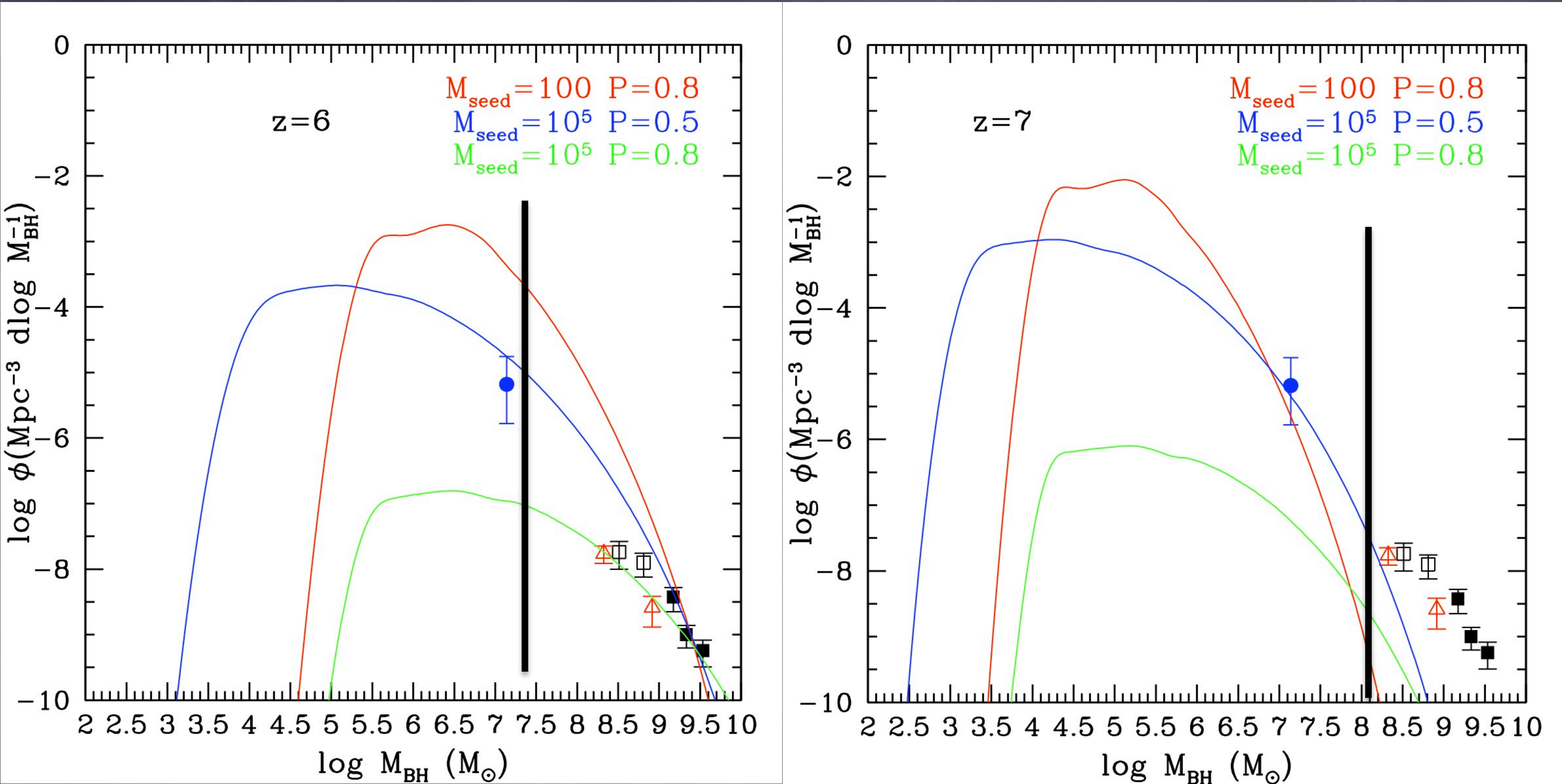
2 scenarios:

1. PopIII star seeds: z=15 M_{BH}=100 M_{sun} in halos with T>10^3 K, M_H>2×10^6 M_{Sun}
2. Direct collaps of 10^5 M_{Sun} gas clouds in halos with T>10^4K, M_H>8×$10^7$$M_{Sun}$

Evolution through merging only up to z~9-10, then merging+accretion



High-z BH mass functions



P=fraction of Cosmic time with Eddington accretion

fseed=1 fseed=0.1 fseed=0.0001 fseed = fraction of halos with BH seed

Sy-like AGN at z=6 and QSO-like AGN at z=7 can distinguish between models

Predictions for Chandra deep surveys

- Present: CDFS 4Msec, CDFN 2Msec, EGS 3Msec, COSMOS 1.8Msec (~12Msec total)
  - ~100 AGN z>3, 20 AGN z=4-5, ~10 AGN z=5-6, ~2-4 AGN z>6 (no spectroscopic confirmation so far)
- Future Chandra deep coverage on all CANDELS fields (130arcmin^2 deep, 670 arcmin^2 wide, 5 Msec total). Deep NIR coverage (H≥26.5) is needed to ensure sufficient completeness of counterpart identifications):
  - 30-100 AGN z=4-5, 10-30 AGN z=5-6, 3-10 AGN z>6

Prediction for future deep surveys

TABLE II: **Predicted number of faint, high-z X-ray sources**

Mission concept	PSF HPD arcsec	Mosaics	total FOV deg^2	z=4–5 LX(z=5)	z=5–5.8 LX(z=6)	z> 5.8 LX(z=7)
Athena*	10	60x0.2Msec	10	940 >43.3	480 >43.5	250 >43.6
Athena*	5	6x2Msec	1.0	360 >42.5	210 >42.6	125 >42.8
Athena	5	40x0.3Msec	7.0	1100 >43	650 >43.1	360 >43.2
WFXT*	10	24x0.5Msec	24	2300 >43.2	1300 >43.4	600 >43.5
WFXT*	5	4x3Msec	4	1200 >42.5	700 >42.6	400 >42.8
WFXT	5	60x0.2Msec	60	6000 >43.35	3200 >43.4	1600 >43.5
S-Chandra	2	6x2Msec	0.6	310 >42.2	185 >42.3	110 >42.5
S-Chandra	2	24x0.5Msec	2.4	390 >43	220 >43.1	125 >43.2
S-Chandra	1	2x6Msec	0.2	175 >41.8	100 >42.0	65 >42
S-Chandra	1	6x2Msec	0.6	350 >42.1	210 >42.2	120 >42.4

* close to confusion limit (40 beams per source).

Chandra	1	24x2Msec	2.4	200 >42.8	150 > 43.0	60 >43.1
Chandra	1	12x4Msec	1.2	200 >42.5	100 >42.6	60>42.7

Predictions for future surveys

- Comuving volume @ z=6-7 is $10^{6.9}$ Mpc^3/ deg^2, thus 10^{-6} AGN/ Mpc^3 translate in ~8 AGN/deg^2