Black Hole growth at high redshift

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..what you should bring home..

- High-z Universe is a unique environment:
  - gas cooling is extremely efficient: $\sim(1+z)^6$
  - galaxy interactions are very common
  - interplay between structure formation and underlying Universe evolution (expansion rate etc.) is maximum
- BH are the structures with the fastest (exponential) growth rate
  - test accretion physics in extreme conditions and competing cosmological scenarios through the comparison of the observed high-z BH mass function with model predictions
- Hunting BH and AGN at high-z
  - multiwavelength surveys are necessary to obtain a complete BH census at high-z
  - X-rays play a major role (obscured AGN, low-L AGN)
  - push analysis of present X-ray survey, prepare for future surveys

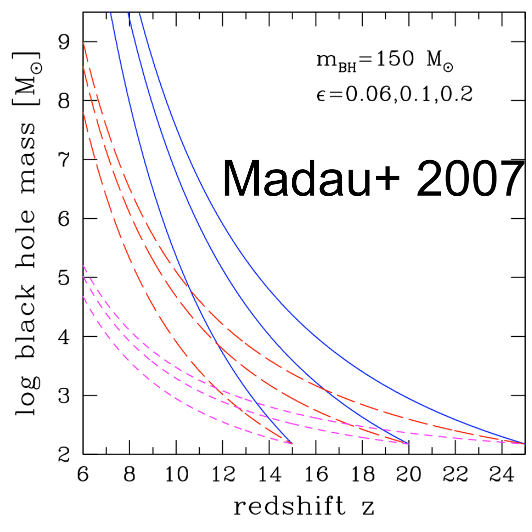
Formation of first galaxies/BH

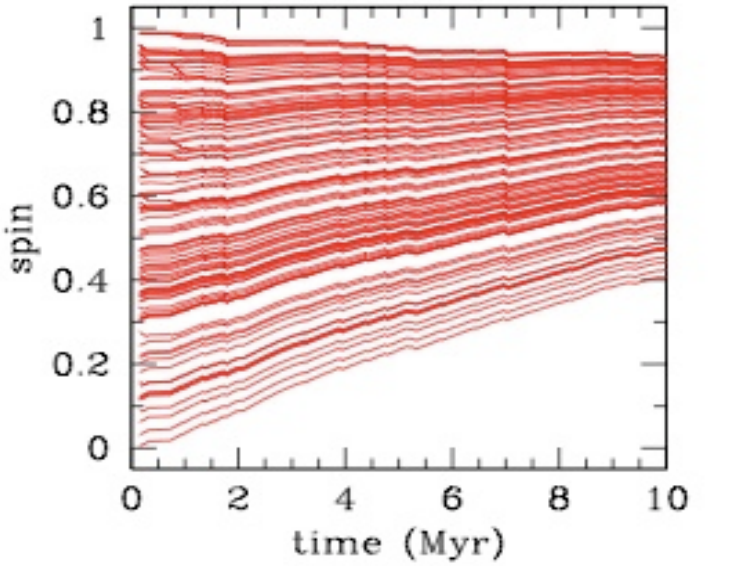
- ***SDSS QSO z>6 => M_{BH}~3-7×$10^9 M_{Sun}$***
- $\log M_{BH}=(8.2\pm0.1)+(1.1\pm0.1)(\log L_{K,bul}-10.9)$, $\log M_{BH}=(8.3\pm0.1)+(4.1\pm0.3)(\log\sigma-2.3)$

1. **Locally M_{BH}~0.001×M_{bulge} what happens at high-z?**
2. Early AGN activity can affect structure formation through IGM eating
3. Contribution to reionization.

- **Two additional key issues:**

4. If SMBH grow-up by hierarchical merging and accretion (hand in hand with galaxy formation and evolution), they can be used to probe the ***physics of accretion and BH feeding mechanisms***
5. Forming (enough) $10^{9-10} M_{Sun}$ BHs and $10^{11-12} M_{sun}$ bulges at z>6 is a challenge for models of structure formation. As well as forming metals and dust.
   SMBH can then used to:
   constrain cosmological scenarios





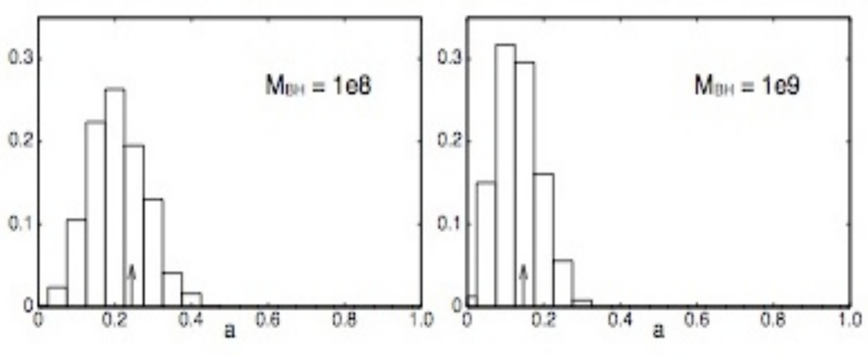
Physics of accretion

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; AGN accretion timescale; 3) cosmology.***

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

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

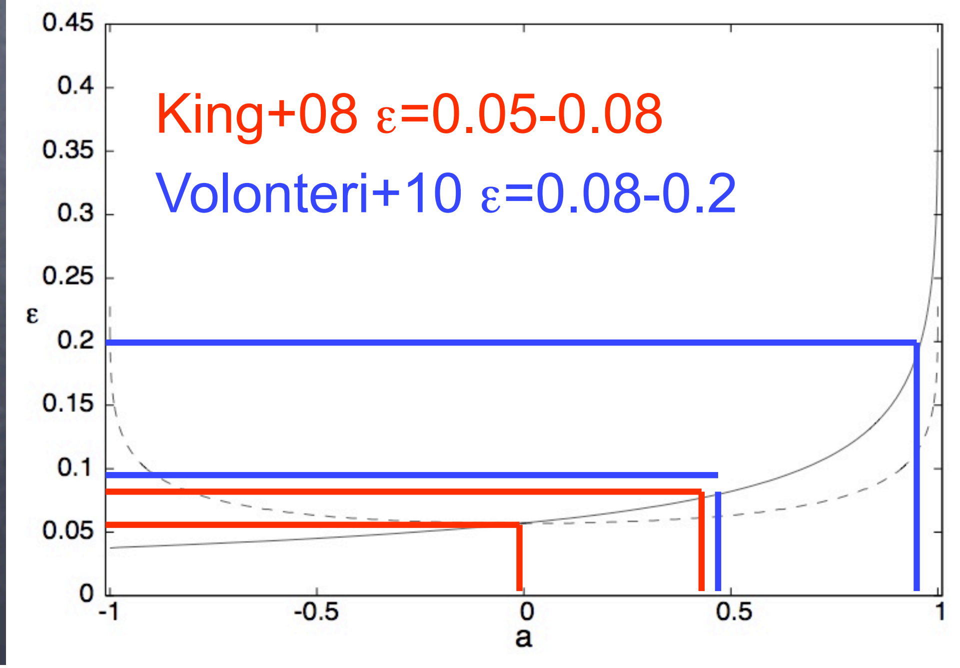
Volonteri2010, Dotti+2010 Spin evolution in gas-rich merger remnants (also see Fanidakis+2010)



King+ 2006,2008 “chaotic accretion”

J(disk)<2J(BH)

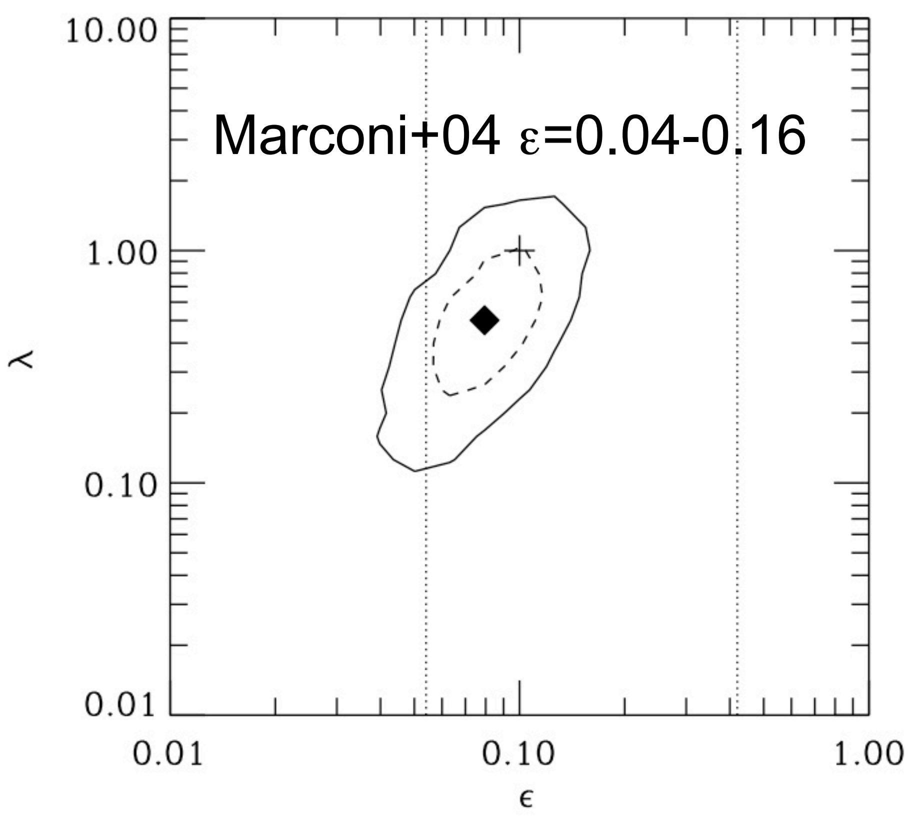
M(disk)<M(BH)$(R_S/R_d)^{0.5}$

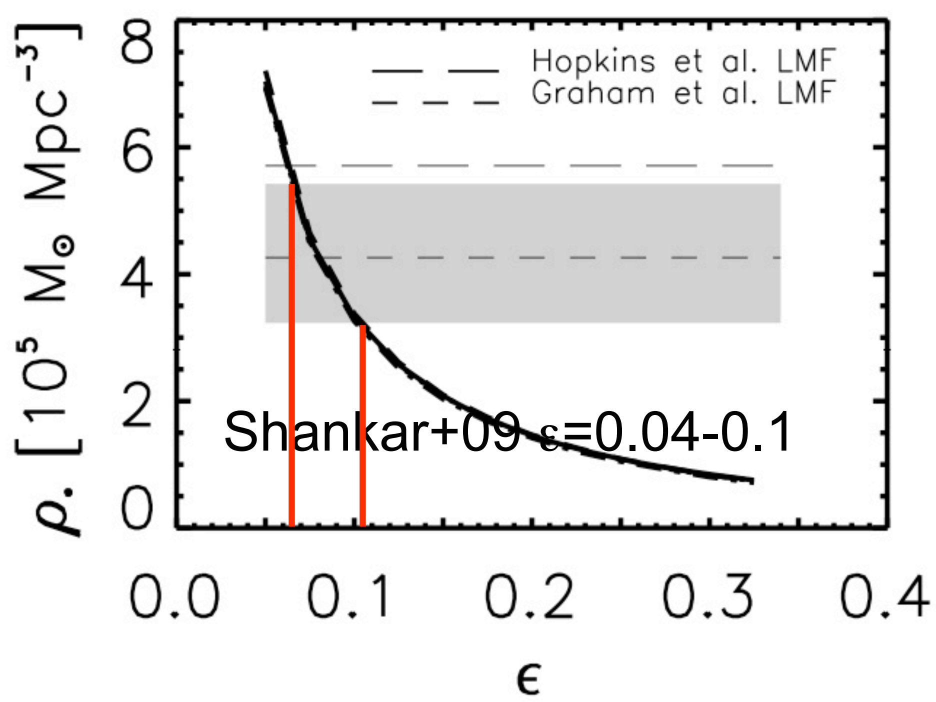


Physics of accretion low-z

Merloni & Heinz 2008 ε=0.065-0.07

Accretion efficiency 0.077-0.083



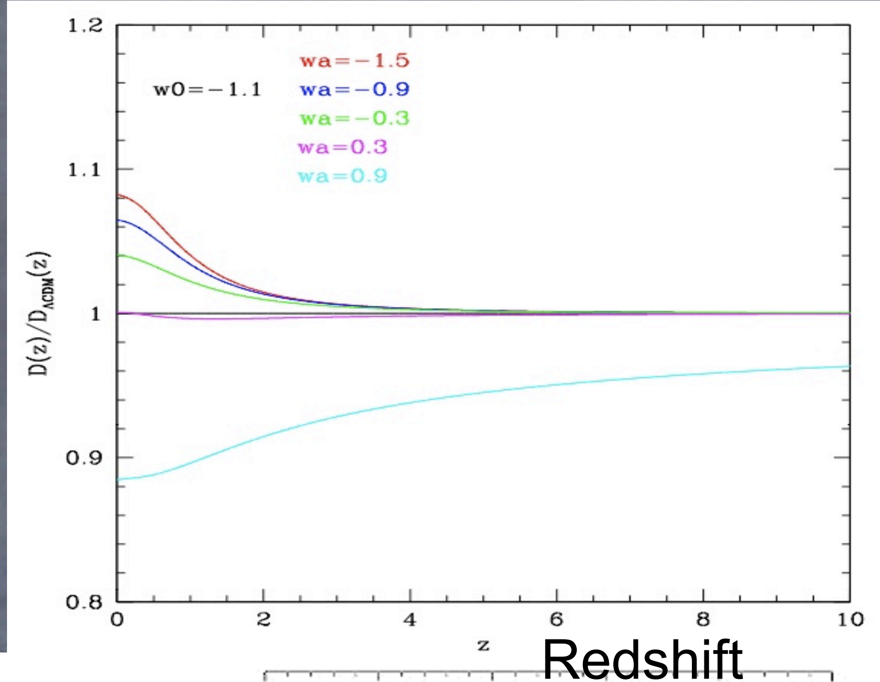


Cosmological models

ΛCDM

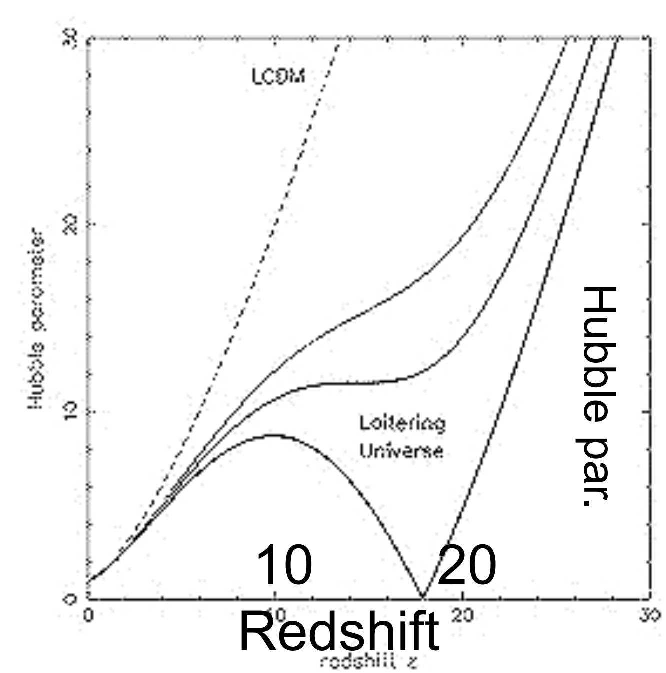
Quintessence models: the growth rate of primordial fluctuations is higher than in standard ΛCDM, i.e. the growth is anticipated with respect to ΛCDM

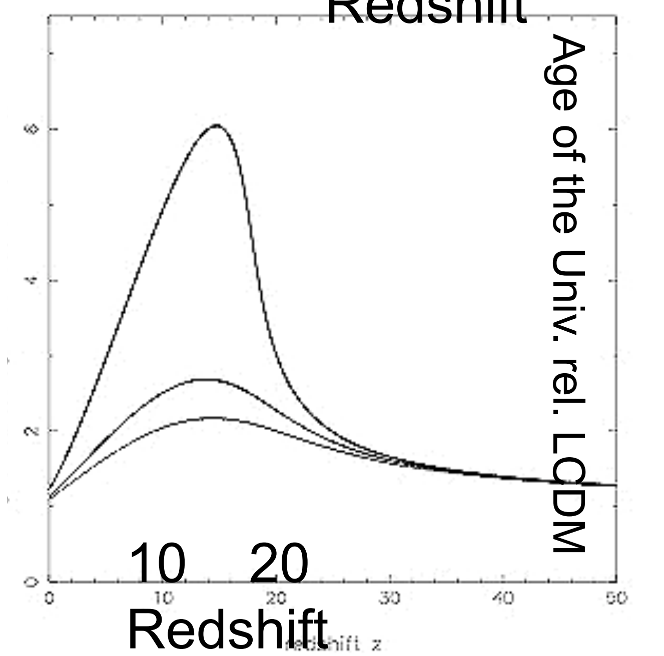
Braneworlds models: our observable Universe is a (3+1)-brane in a (4+1)-dimensional bulk space



Problem: how to disentangle and separate cosmological effects from accretion physics.

This may be done at high-z when differences are larger and BH accretion is maximal





Formation of high-z SMBH

BHs are the structures with the fastest (exponential) growth rate. BH growth due to both merging and accretion (triggered by merging).

Number of BH of mass $m_\bullet$ in haloes of mass M

Total probability of merging of halo of mass M

Accretion rate

$$\frac{\partial N_t(m_\bullet, M)}{\partial t} = -p(m_\bullet, M)\frac{\partial N_t(m_\bullet, M)}{m_\bullet}\dot{m}_\bullet dt$$

$$+ \int_0^{m_\bullet} dm_\bullet \int_{M_{min}}^{M} dM \; N(m_\bullet - \Delta m_\bullet, M)\frac{\partial^2 P(M \rightarrow M)}{\partial M \, \partial t} - N(m_\bullet, M)\int_M^{\infty} dM \frac{\partial^2 P(M \rightarrow M)}{\partial M \, \partial t}$$

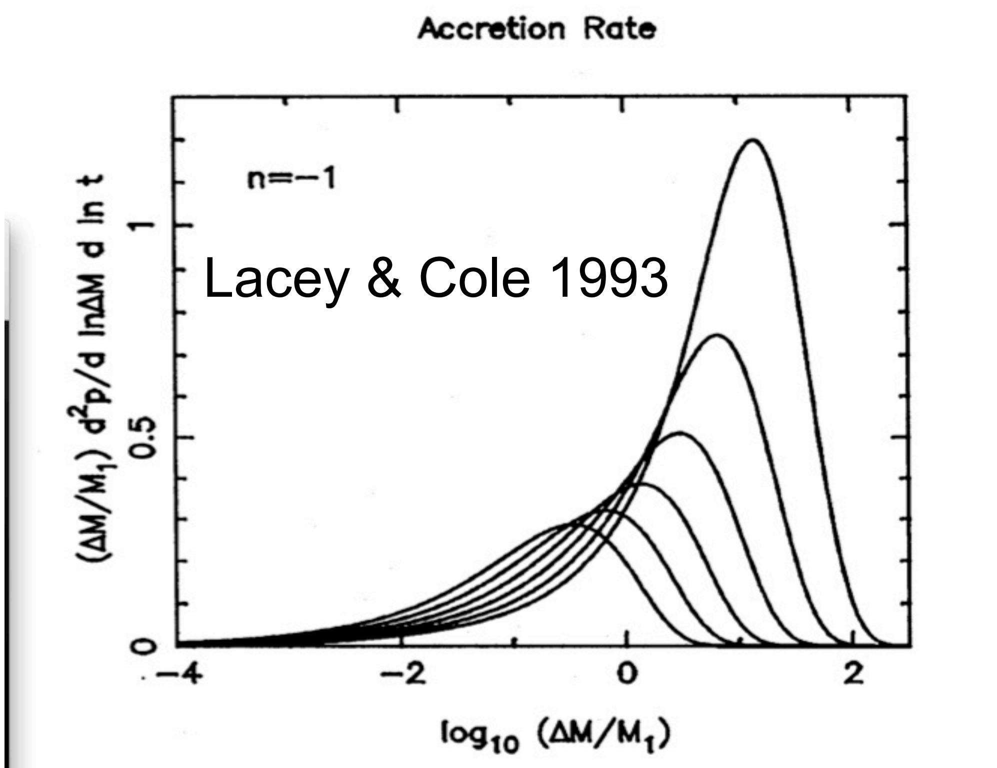
Hierarchical merging

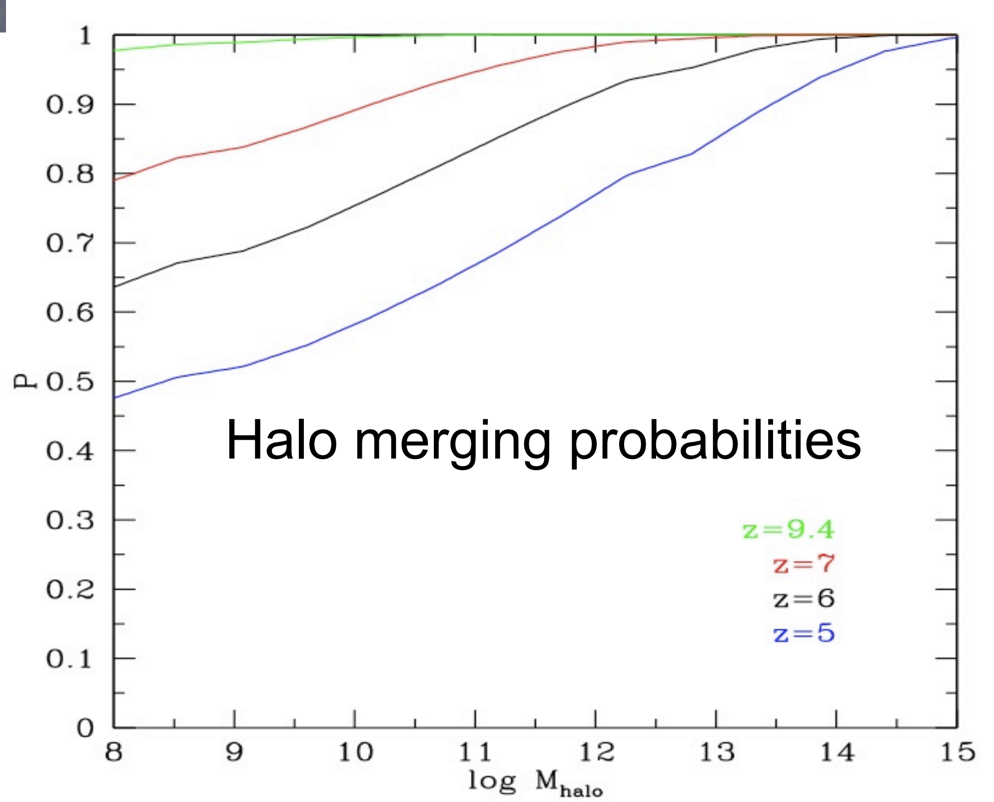
Halo merging probability

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

The physics of accretion enters in $dm_\bullet/dt$ Lamastra+ 2010

Analytic model of BH growth

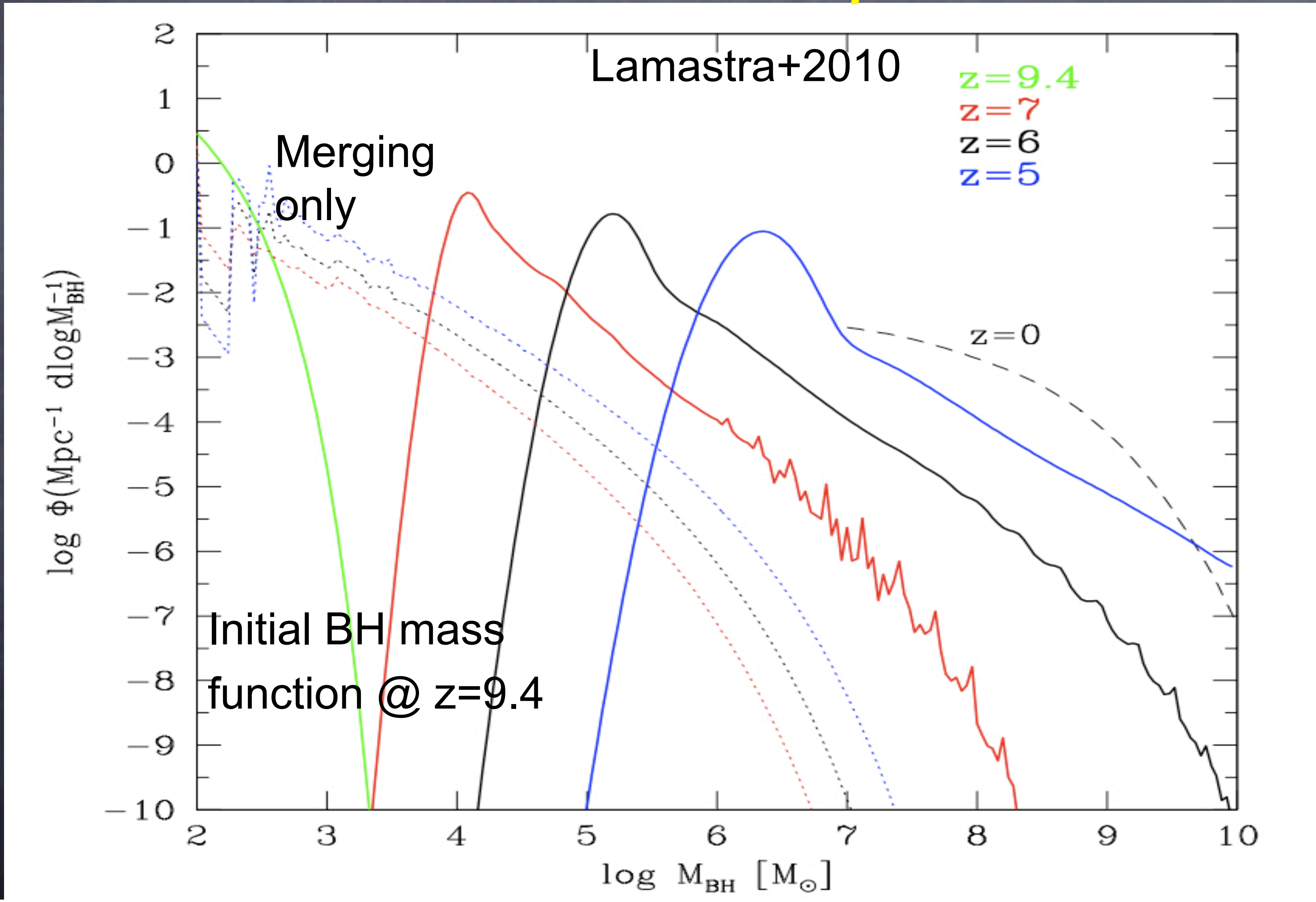




Halo accretion rates as a function of the halo mass contrast. Only halo merging with $0.01<\Delta M/M<100$ are assumed to trigger BH gas accretion. After a merging event cold gas settles into a rotationally supported disk with radius r_d~1-5kpc, rotation velocity v_d~100km/s. BH accretion is assumed to proceed for a time $\tau \sim r_d/v_d \sim 10^7$yr and always at Eddington rate.

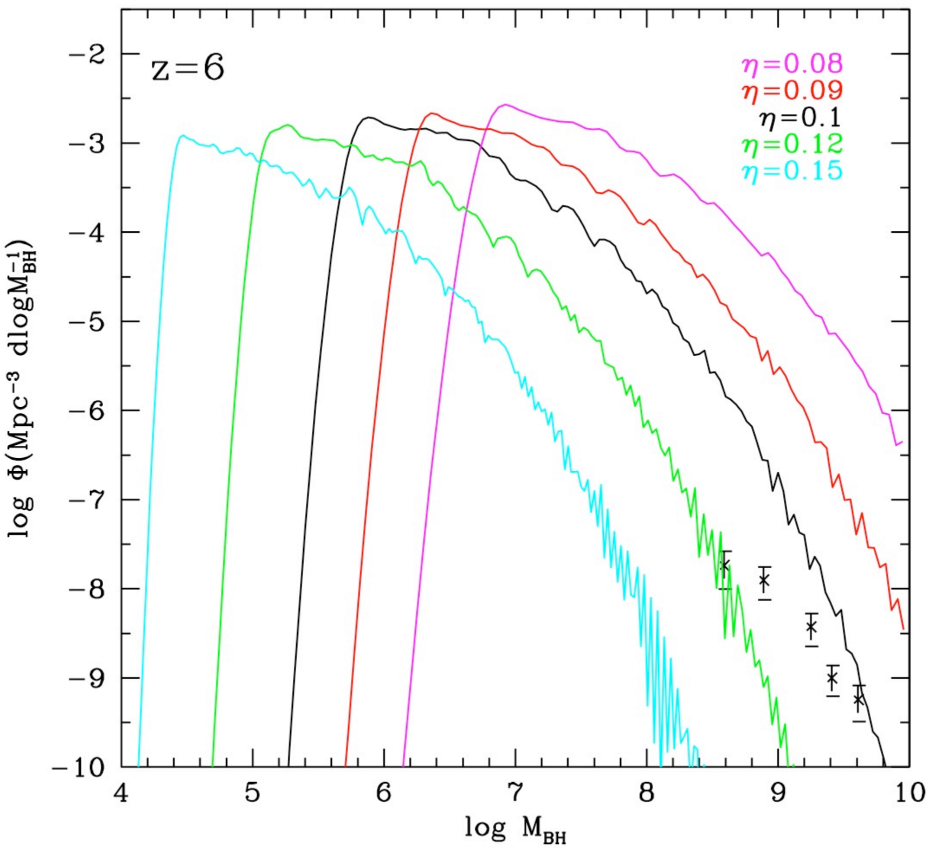
BH growth models

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

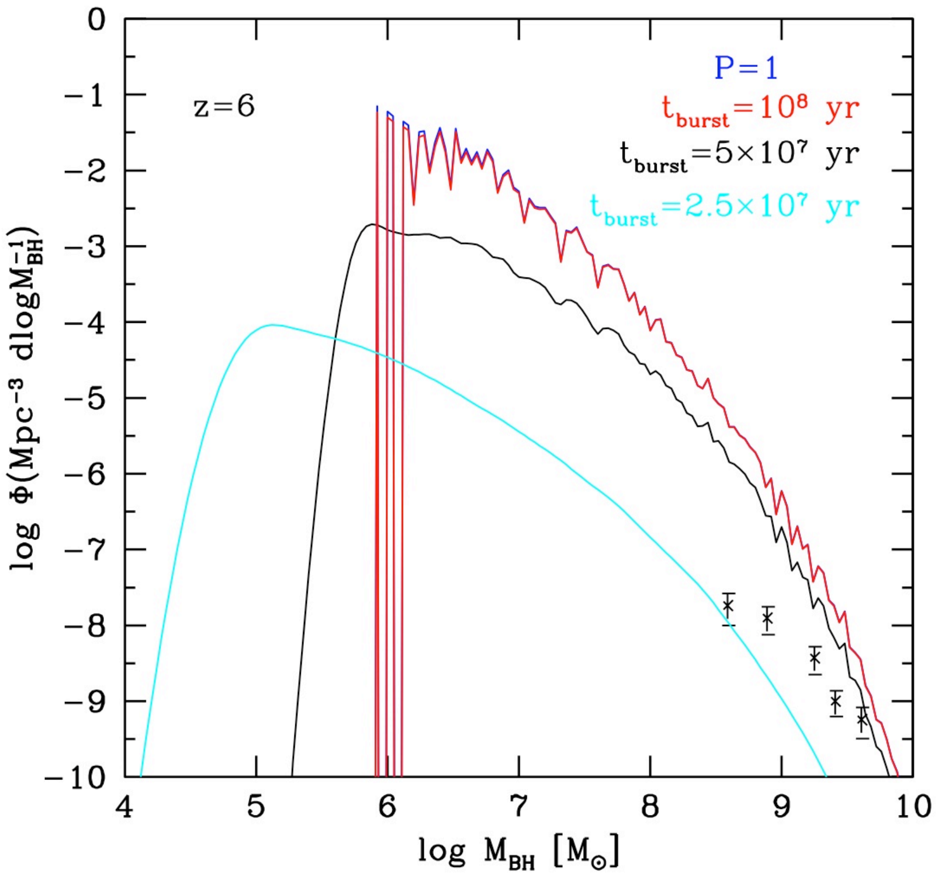


BH growth models:ΛCDM

BH mass functions vs. η

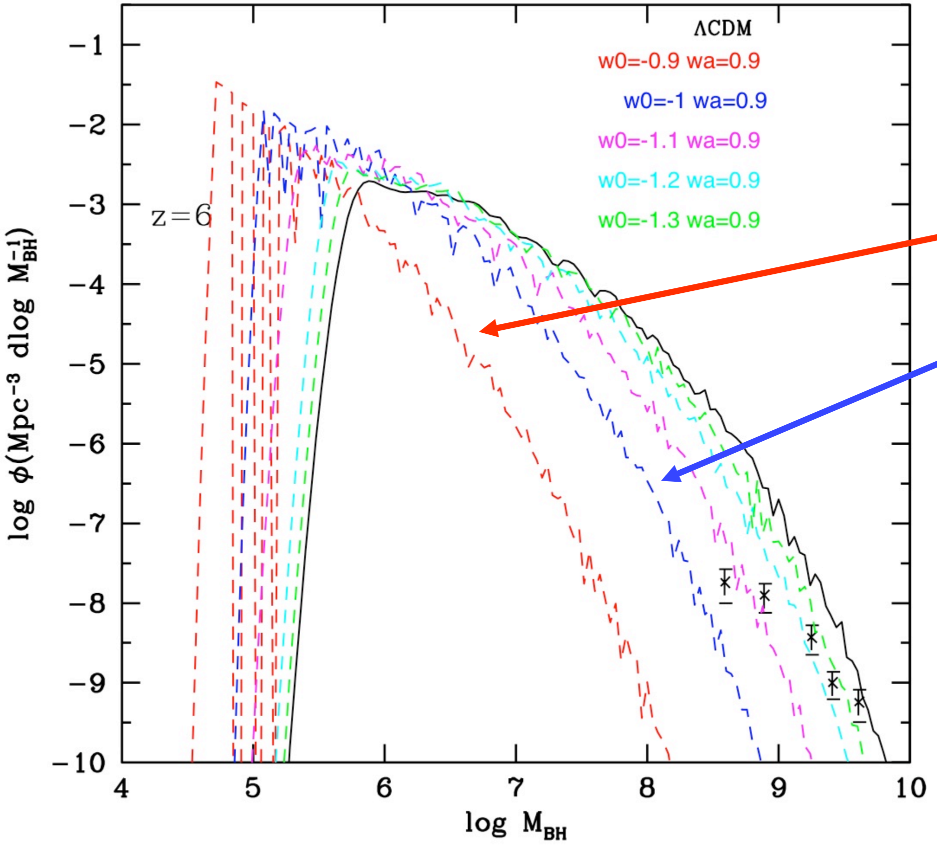


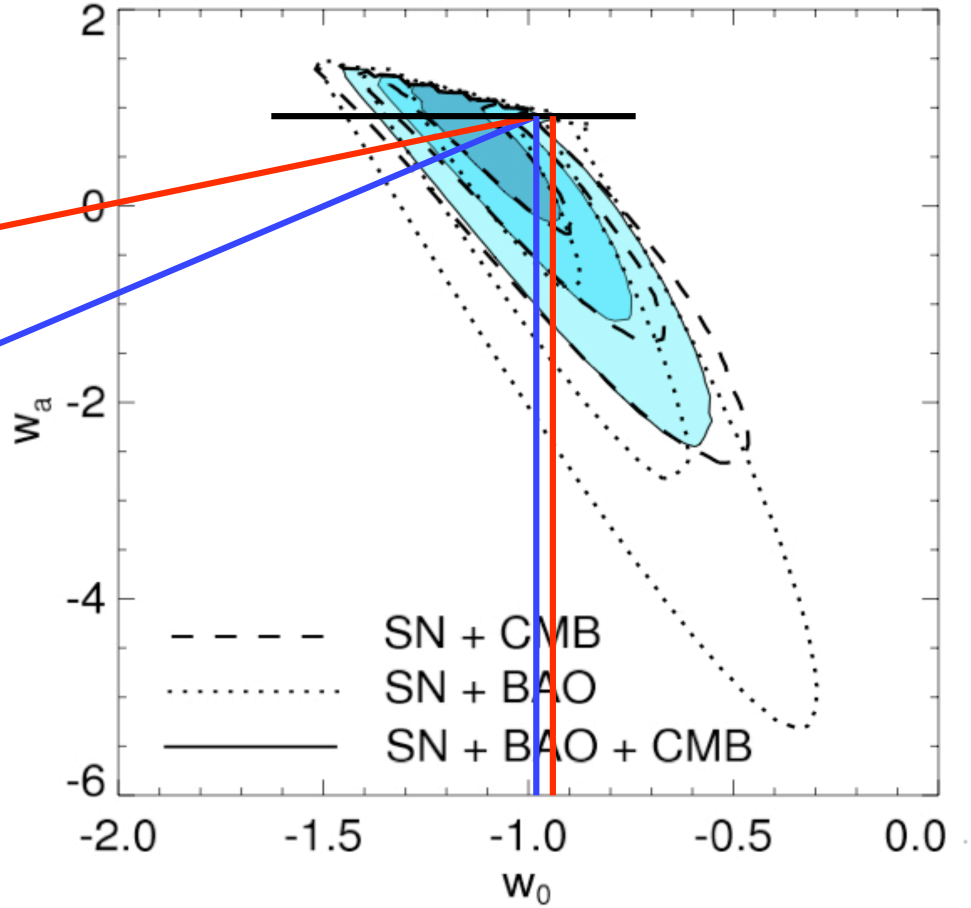
BH mass functions vs. AGN timescale



BH mass function vs. Quintessence models

η=0.1 fix



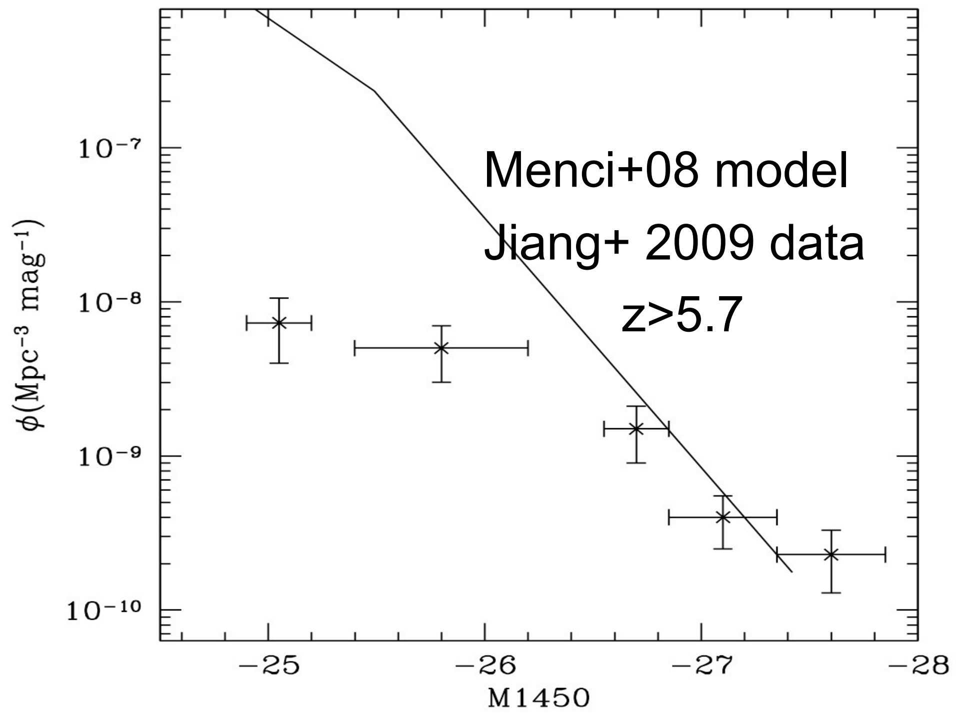


$w(z) = p/\rho$ DE pressure and energy density

$$w(z) = w_0 + w_a \frac{z}{1+z}$$

High-z AGN

Optical (SDSS) surveys found **~30 luminous, unobscured QSO z>5.5.** Are they the tip of the iceberg of the high-z SMBH population? There could be many more lower L and highly obscured AGN. X-rays may help in unveiling this population.



The situation in the X-ray band is much poorer. Direct identification of sources in X-ray catalogs:
1 z~5AGN in the CDFN
4 4.5<z<5.5 AGN in CCOSMOS

A different approach: search for X-ray emission at the position of known high-z galaxies:

- reach fainter X-ray fluxes
- optimize the X-ray band

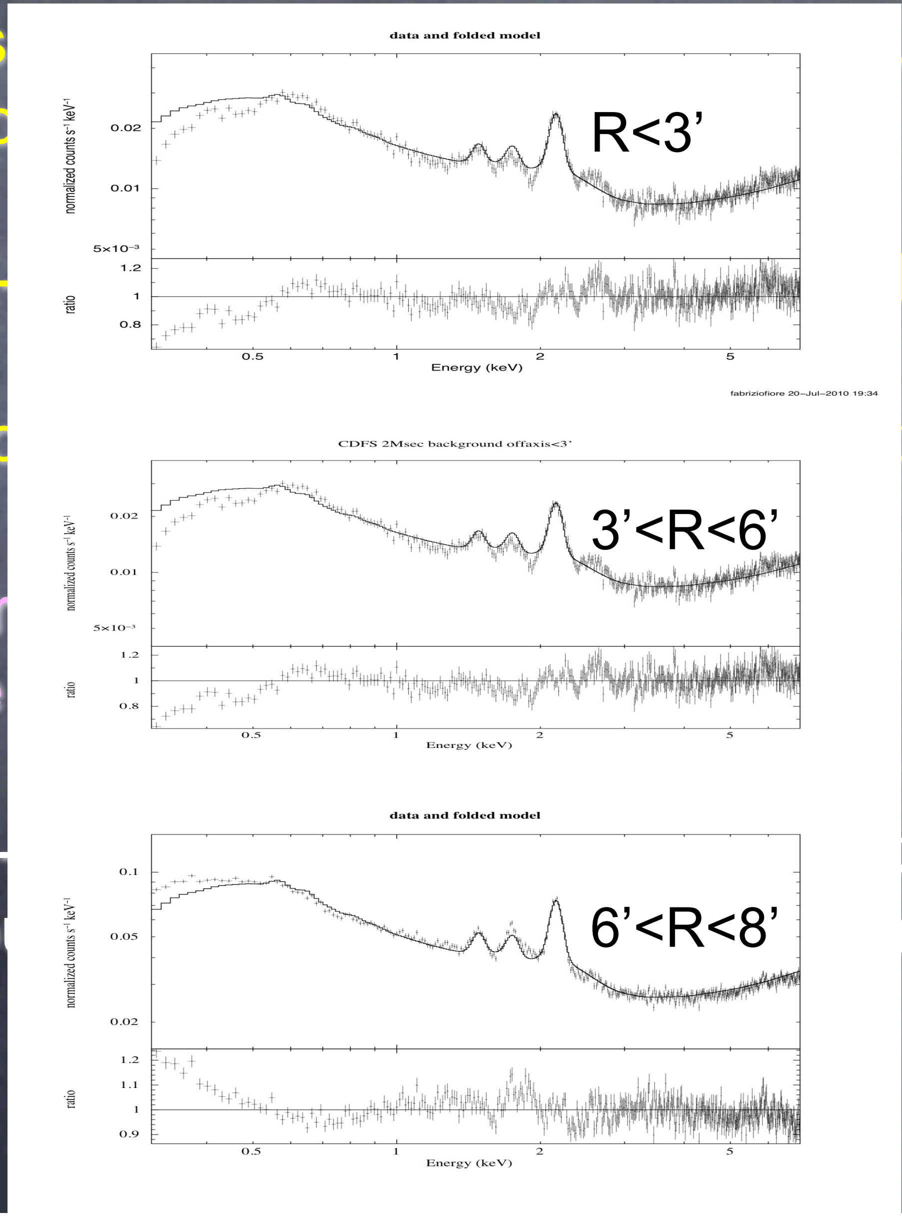
Pilot program on the CDFS2Msec:

- Use GOODS-MUSIC galaxy catalog and photo-z
- Use dropouts

A new X-ray detection algorithm: ePhot

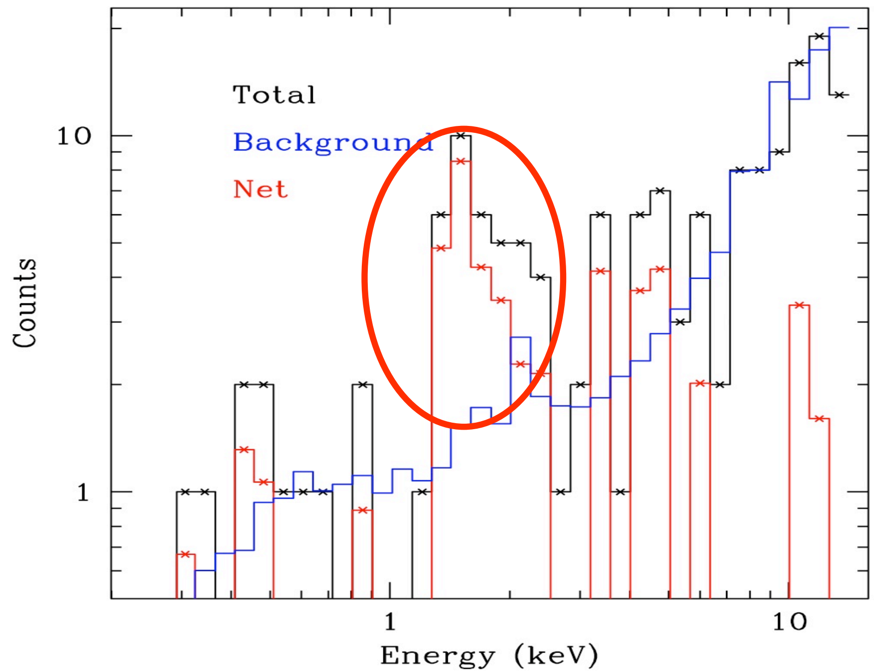
Adaptive filter to s ... unts in a multidimensio

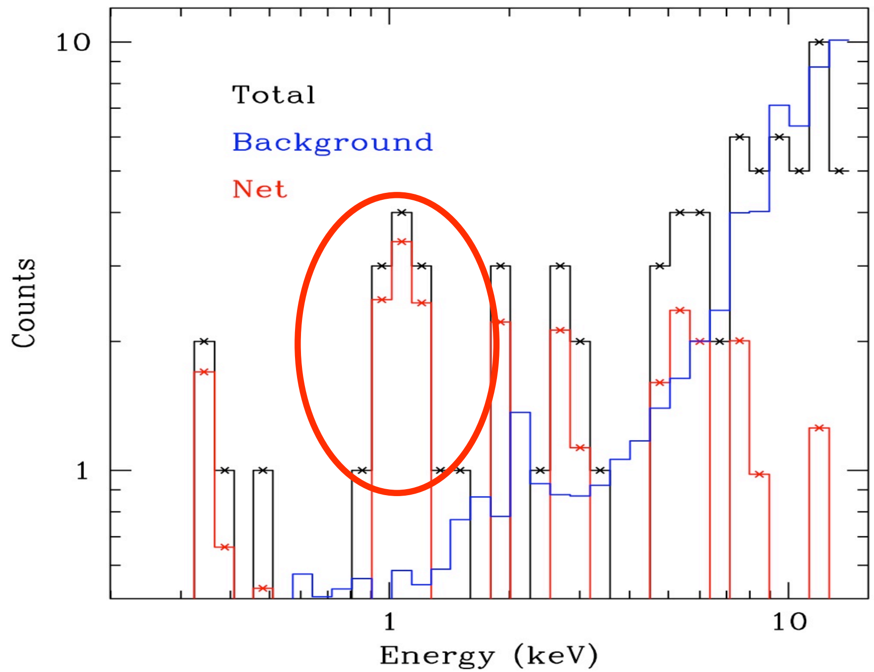
1. Search the X- ... N of the detected counts.
2. Search the sc ... ximize the S/N
3. Model backgr ... maximize S/N and minimize
4. Use GOODS- ... z and B, V dropouts to bu ... te list.



High-z AGN in the CDFS 2Msec field

FF+2010



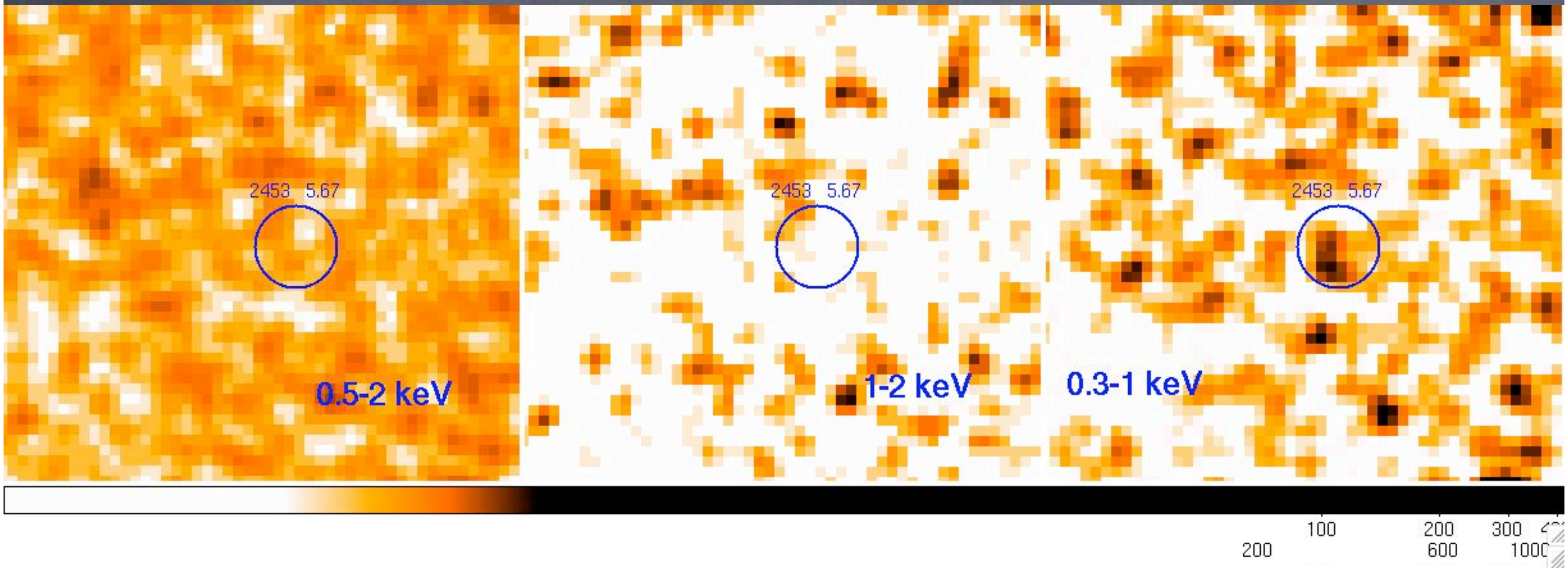


- GOODS-MUSIC galaxy catalog: photo-z
- B, V, I, z, Y ACS, WFC3, Hawk-I dropouts to build up a high-z galaxy candidate list.

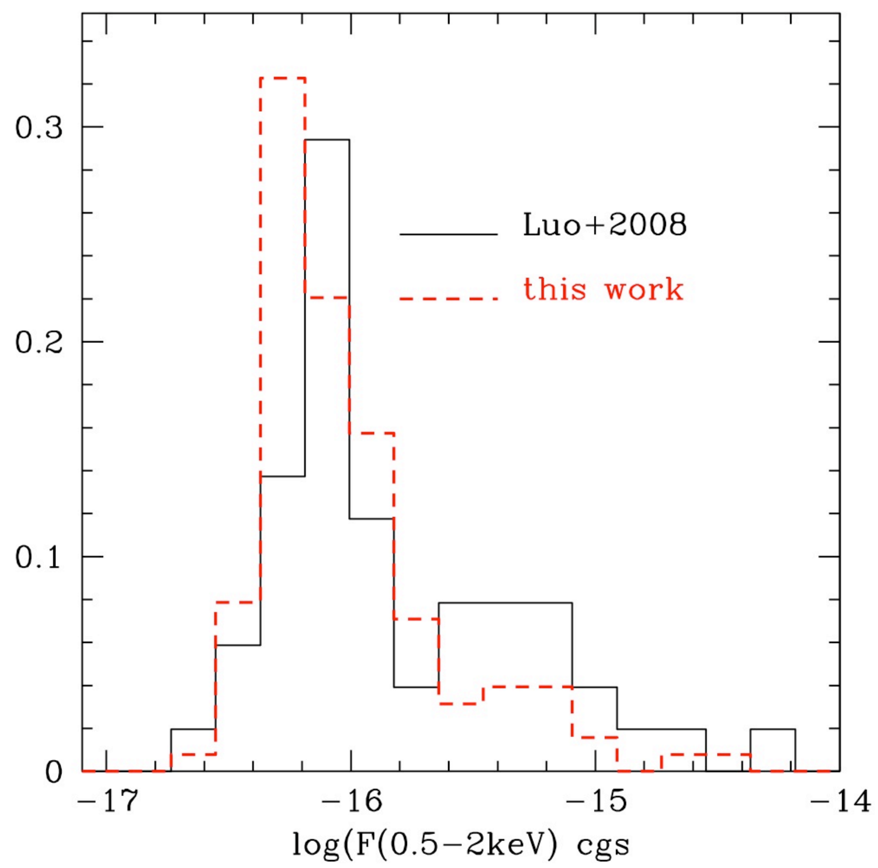
39 z>3 AGN; 6 z>4.5 AGN, 1z>6 AGN

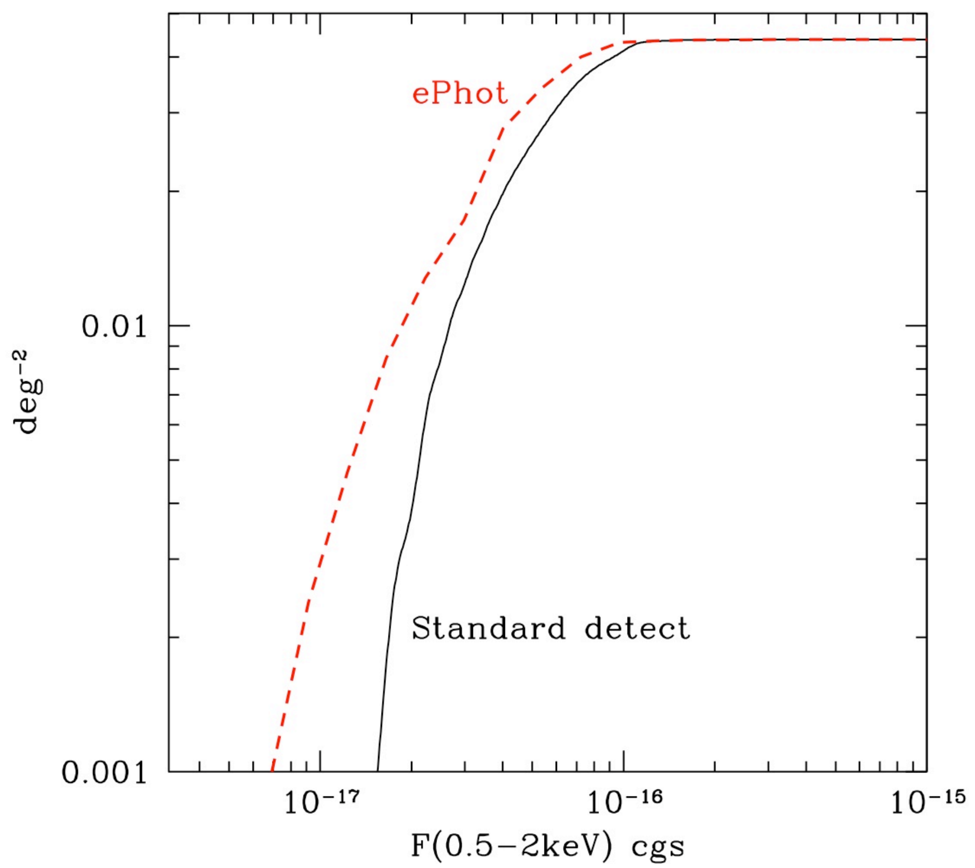
19 (50%) *NOT* in Luo et al. catalog

High-z AGN in the CDFS 2Msec field



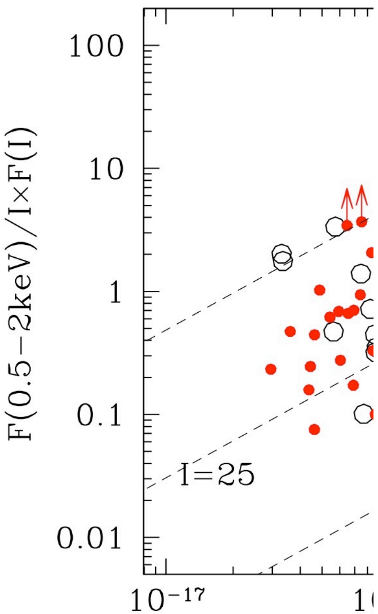
ePhot application to CDFS2Msec

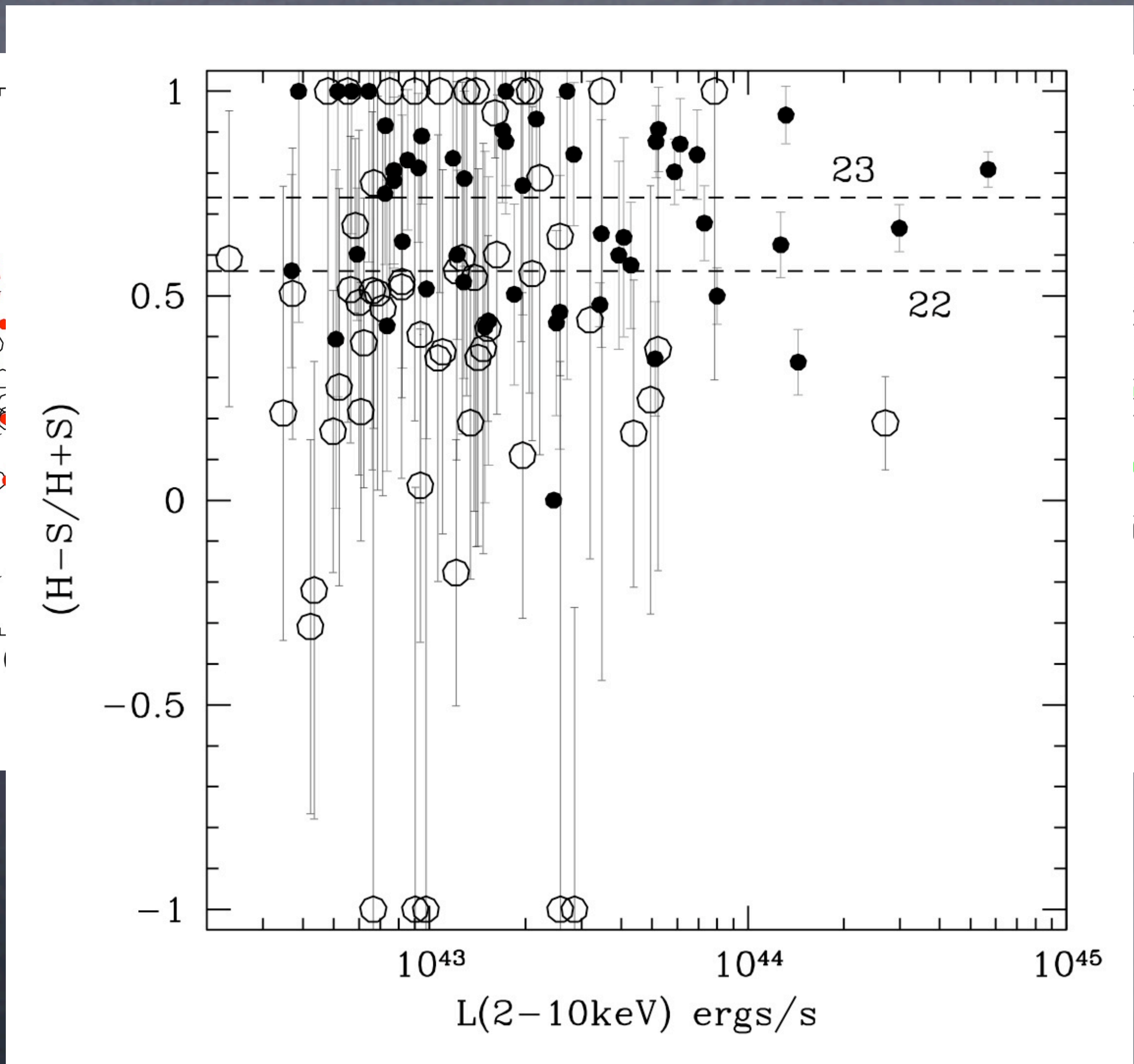


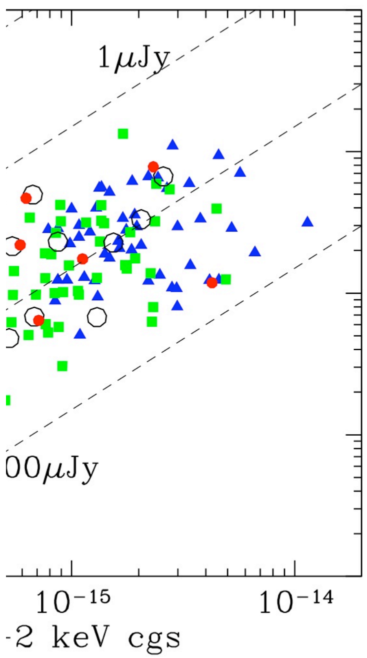


Threshold set to get ≤1 spurious detection in the sample

High z AGN in the CDFS 2Msec field



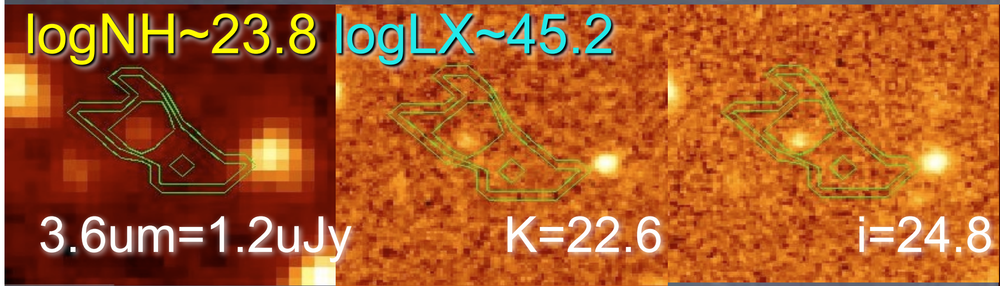


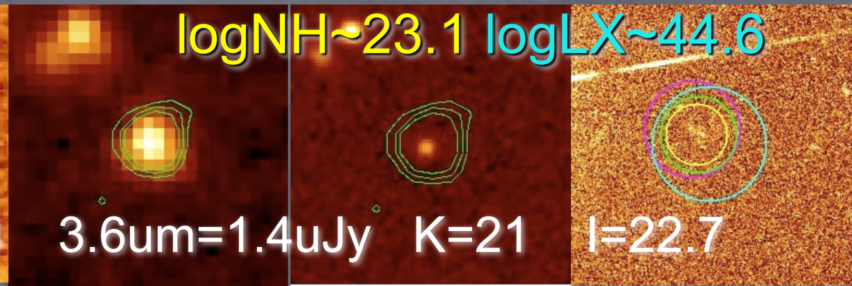


z>4.5 X-ray selected AGN

C-COSMOS 125 z=5.441 logFS=-15.04 | 781 z=4.660 logFS=-15.07

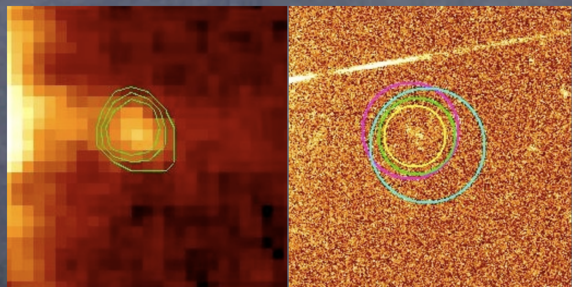
logNH~23.8 logLX~45.2 | logNH~23.1 logLX~44.6



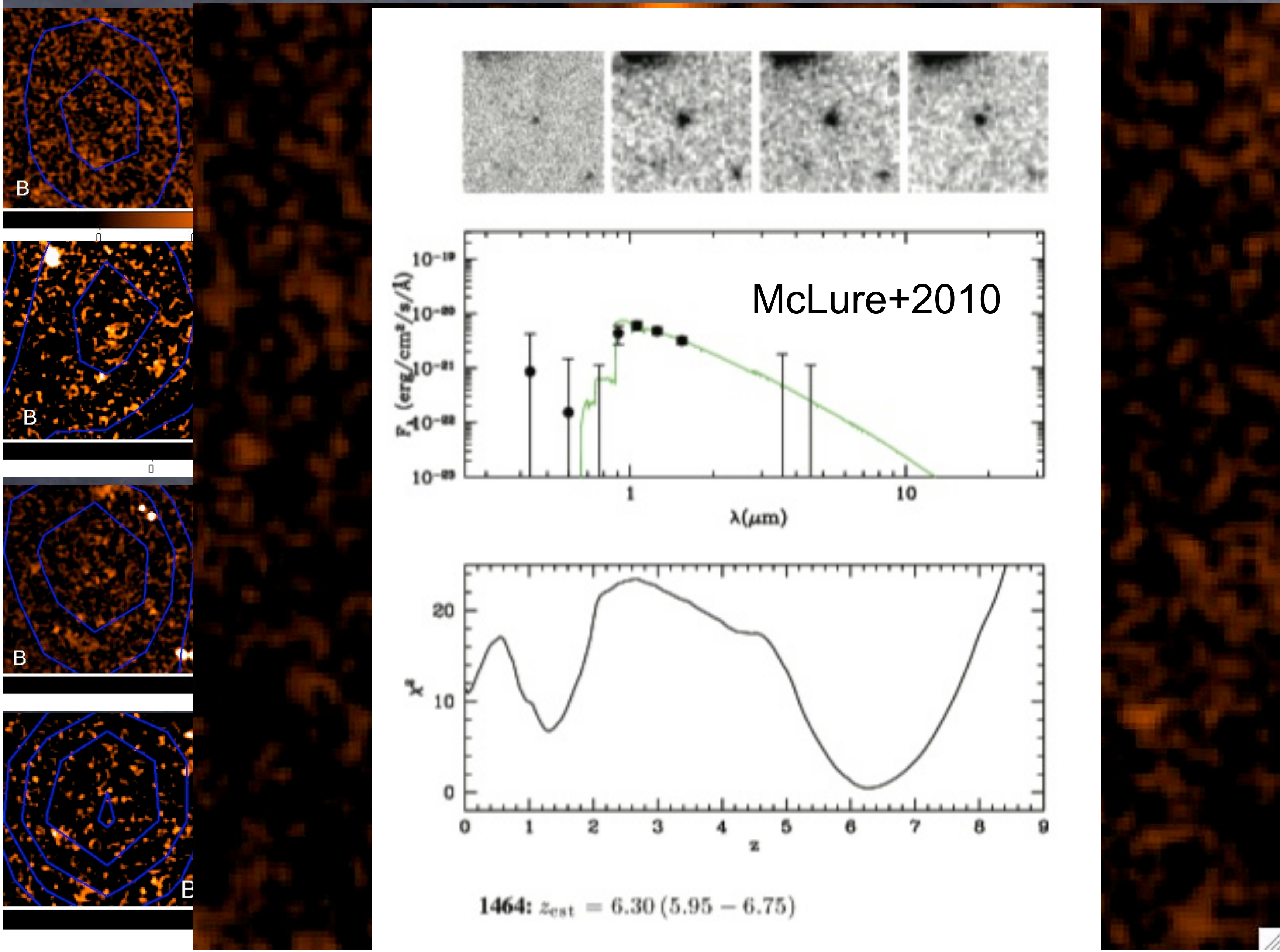


CC 931 z=4.913 logFS=-15.1 logNH~23.6 logLX~45

3.6um=1.6uJy I=23.6



z>4.5 X-ray selected AGN



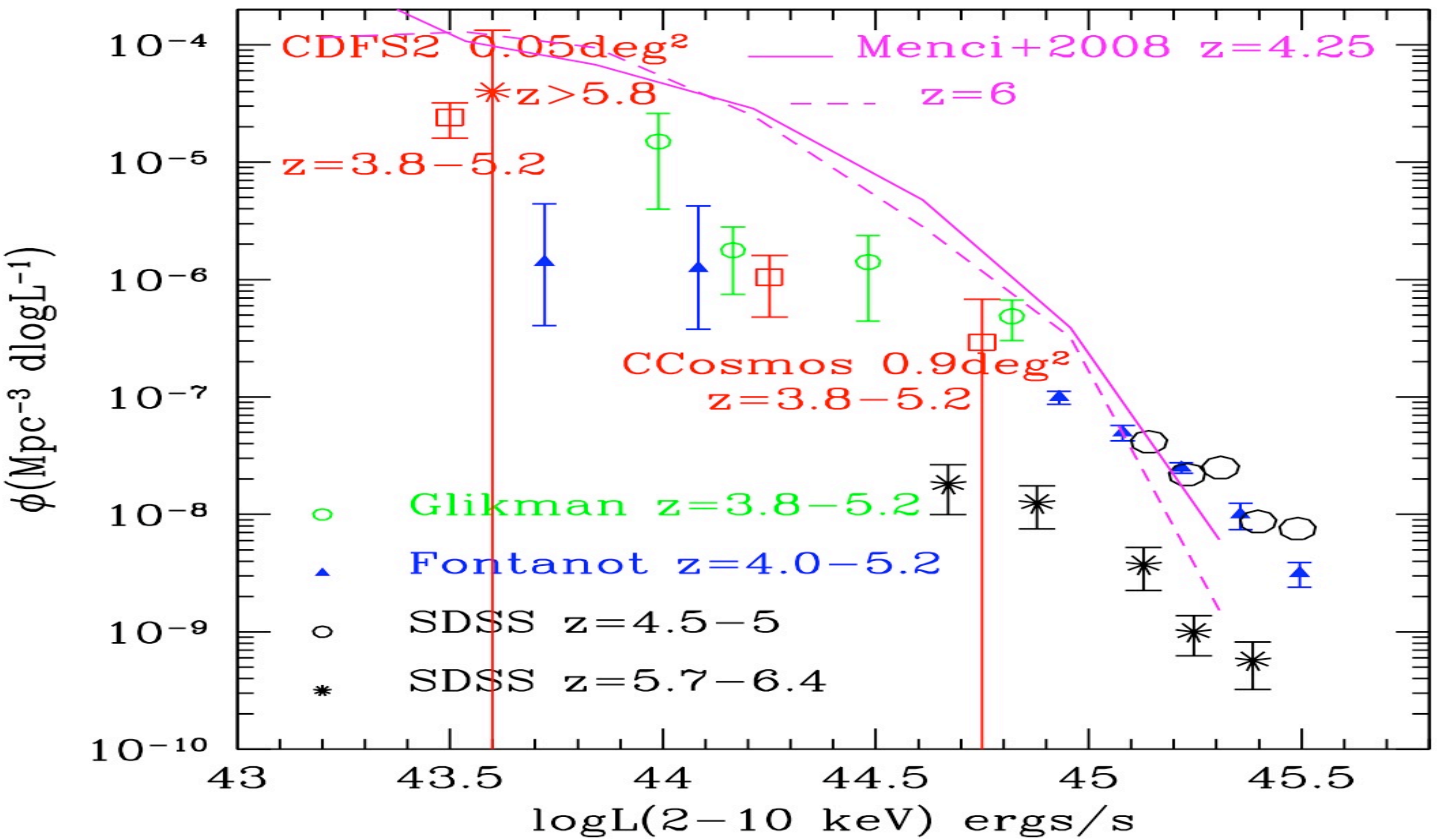
~5.7
-43.5

z~4.8
-43

z~5
X~43.4

z~5
LX~43.8

High-z AGN luminosity functions and density evolution



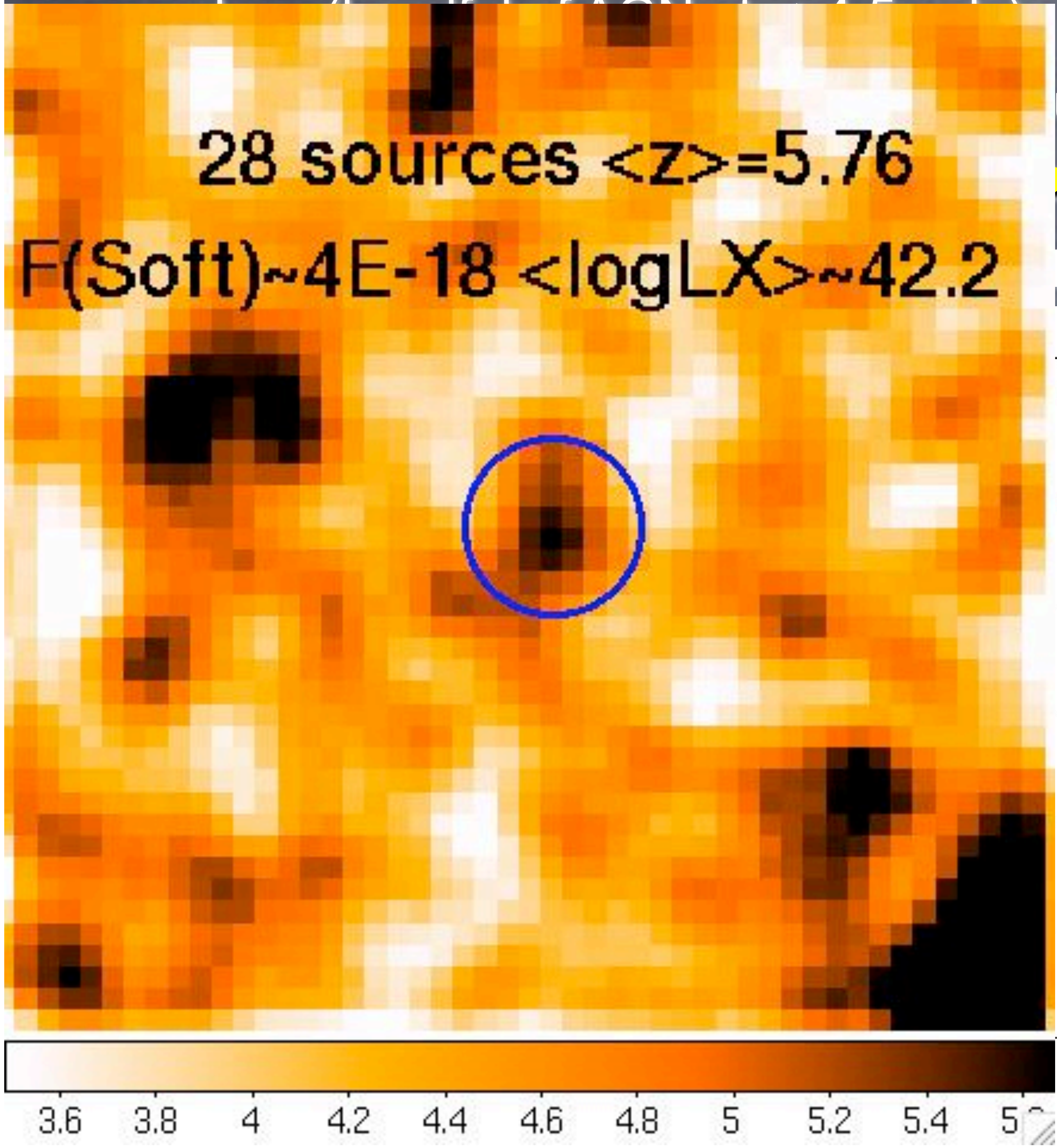
High-z AGN

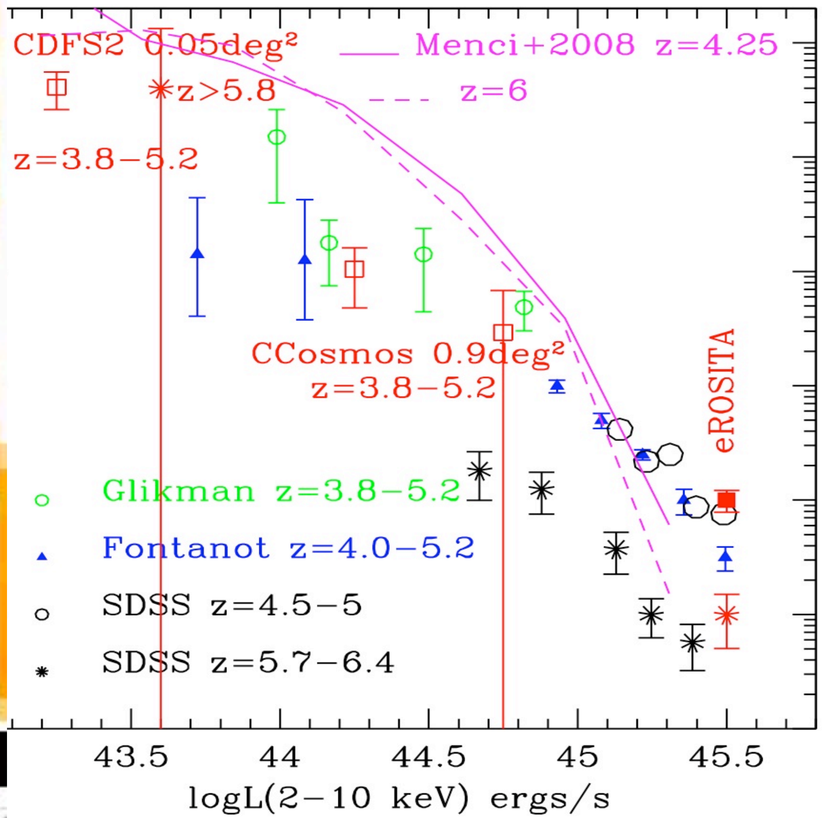
Today constraints are too loose to constrain accretion physics and

ughs in this field

'D<5" is achieved!!!

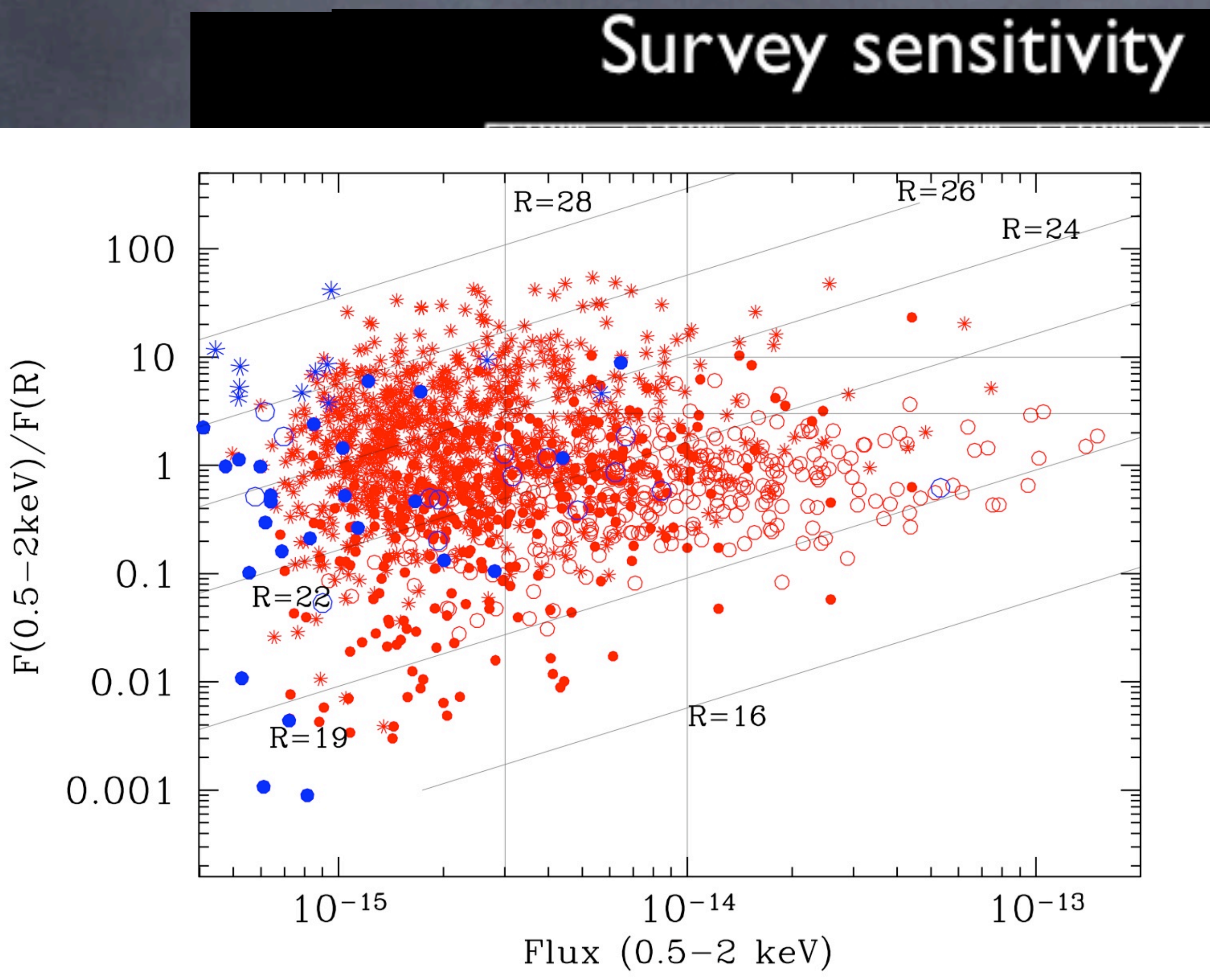
before 2020!!!!





Xray high-z AGN

eROSITA



- PSF 30-40 arcsec
- F(0.5-2keV)>3×10^{-15}

~400 deg^2 =>30-50 z>5 AGN LX>10^{45}

Identification complex!

- ~80% of counterparts will have R<24 ~90% R<25

Pan-STARRS

- ~20% of counterparts will have F3.6um>0.1mJy

WISE

SWIRE fields?

Spitzer warm survey?
Janus J~19.5 all sky Survey, VISTA
Redshifts with VLT/KecK *and* ALMA at high-z

Summary

- Completing the AGN census at high-z is crucial to probe accretion physics, BH feeding and cosmological scenarios in the early Universe.
  - Chandra legacy surveys + aggressive data analysis (ePhot): ~20 AGN at $z>4.5$ and $42.5<logLX<45$, a few $z>6$.
  - eROSITA will find 30-50 $logLX\geq45$ AGN at $z>5$, 5-10 $z>6$: LF bright end
  - First constraints on $z>5$ LF slope. We may constrain AGN accretion time and start excluding the most extreme cosmological scenarios.
- ALMA will detect LIRGs @ $z\leq10$, regardless of the presence of an AGN and its obscuration.
  - Redshifts will be (relatively) easy
  - AGN identifications complex but feasible through HCN and HCO+ lines and/or IR spectroscopy.
  - X-rays crucial to get AGN total power ⇒SMBH luminosity and mass functions.
- IXO, WFXT: large samples of high-z AGN ***if PSF $<5''$***. Identification complex, should rely on Spitzer (large fields) JWST, ALMA (small fields)