Multiwavelength perspective of AGN evolution

Fabrizio Fiore

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GOODS & COSMOS teams and in particular to
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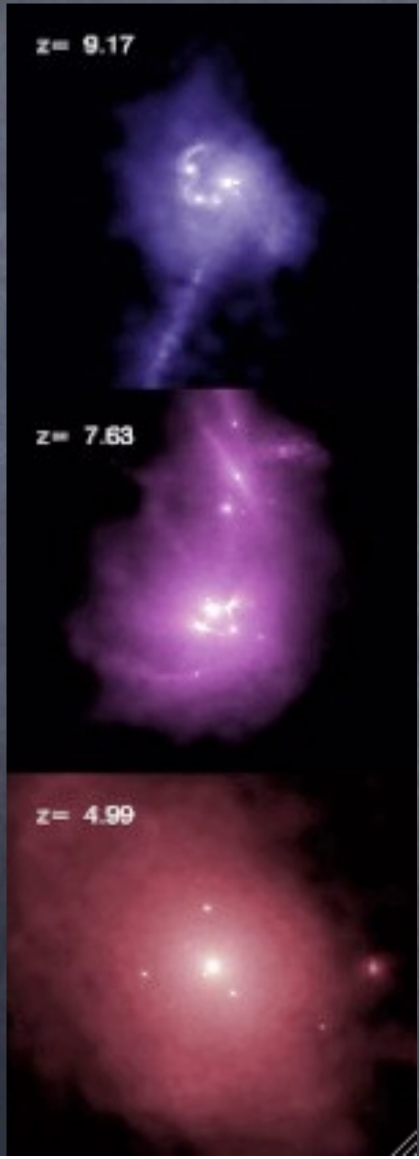
(A few) key questions:

- AGN feedback is often invoked to explain galaxy colors and ISM heating (see C. Jones talk). However systems are usually observed at the end of feedback processes. Can we probe feedback *when it is in action?*
    - Highly obscured AGN at z>1-2: witness of the still little known phase of common growth of SMBH and their host galaxies.
- Pushing toward higher z: the formation of first galaxies/BH
    - When? How? Which is the role of downsizing?
    - Are the SDSS QSOs representative of the z>5 AGN population? Which is the fraction of obscured AGN at z>3, z>5?
    - Can SMBHs be used to constrain AGN feeding/accretion physics and cosmological scenarios?
- The role of X-ray surveys in the JWST and ALMA era

AGN & galaxy co-evolutionary sequence

- **Early on**
  Strong galaxy interactions= violent star-bursts
  Heavily obscured QSOs
- **When galaxies coalesce**
  accretion peaks
  QSO becomes optically visible as AGN winds blow out gas.
- **Later times**
  SF & accretion quenched
  red spheroid, passive evolution



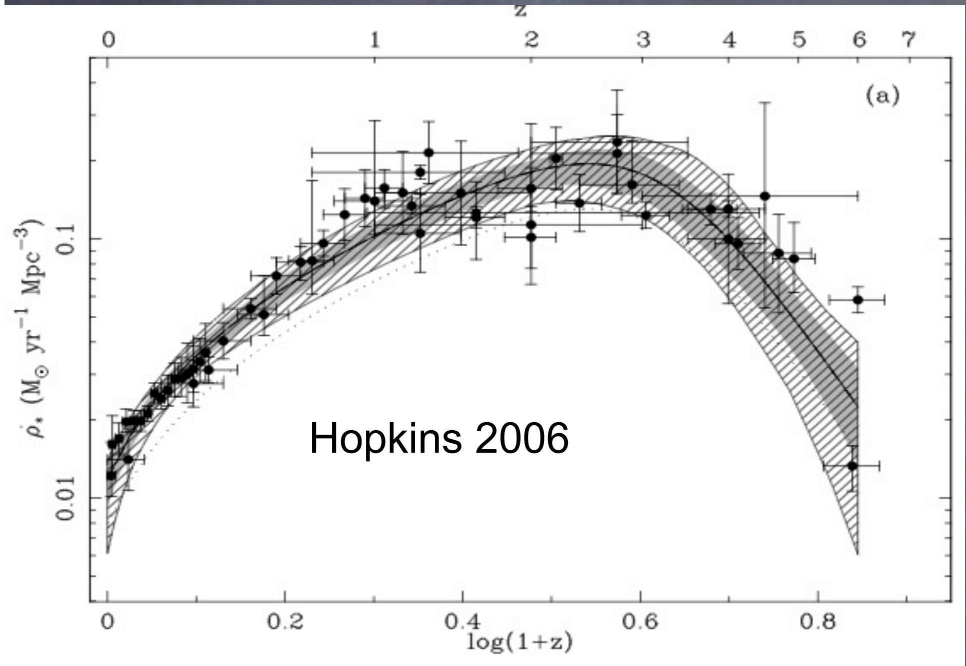
Time ↓

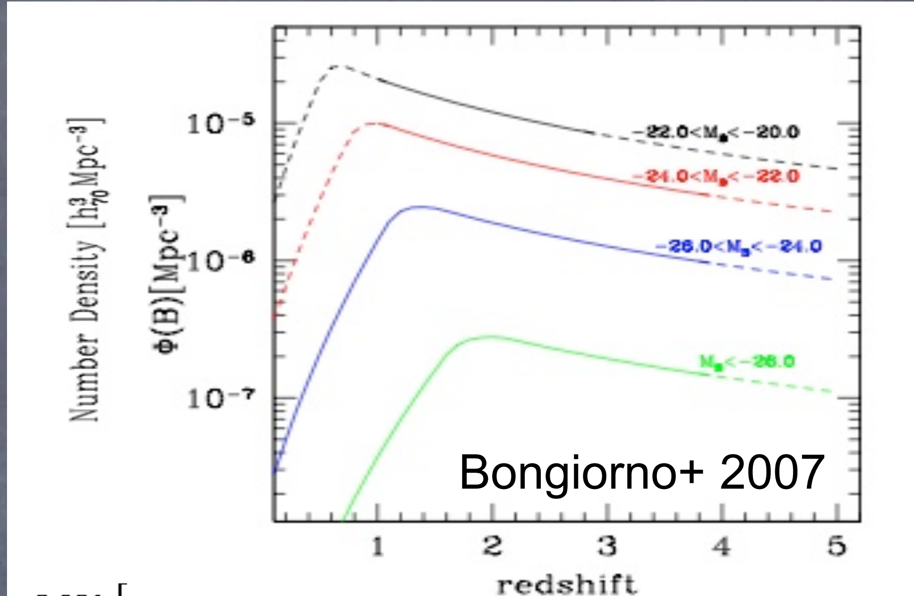
Galaxy: SF	Galaxy: Morph.	AGN: L/L_{EDD}	AGN: Obsc.
Strong	Disturbed	High	High
Moderate	Coalescing	Lower	Lower
Low	Relaxed	Lower	No

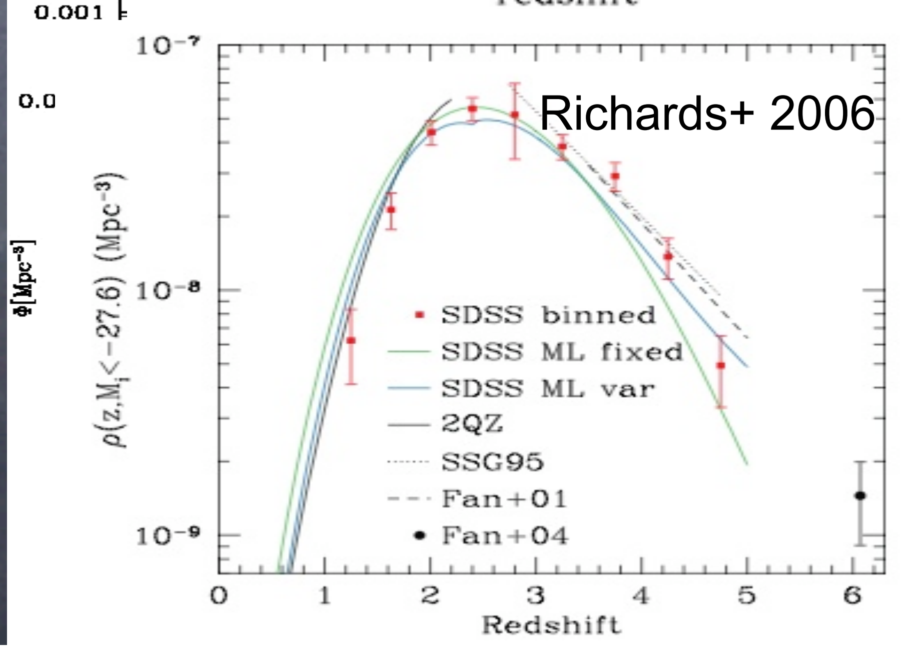
Timescales of these phases are little constrained (so far)

AGN feedback is likely to play a crucial role in the evolutionary sequence

AGN and galaxy co-evolution

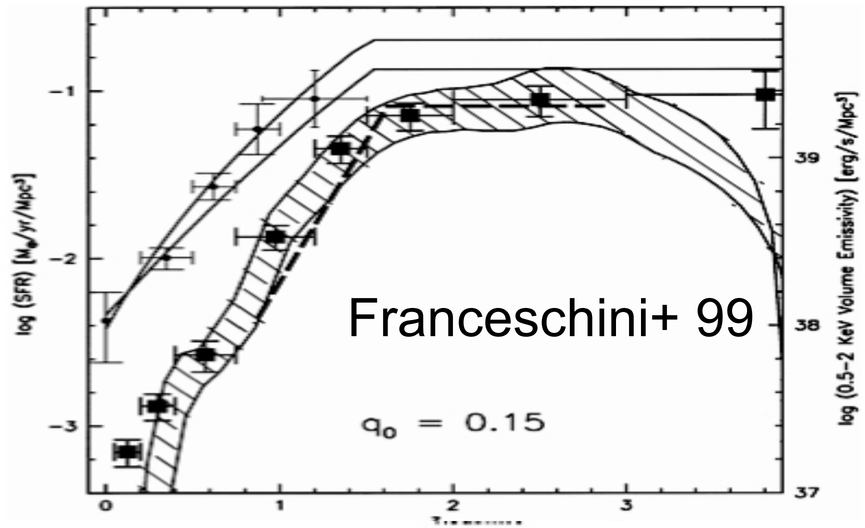


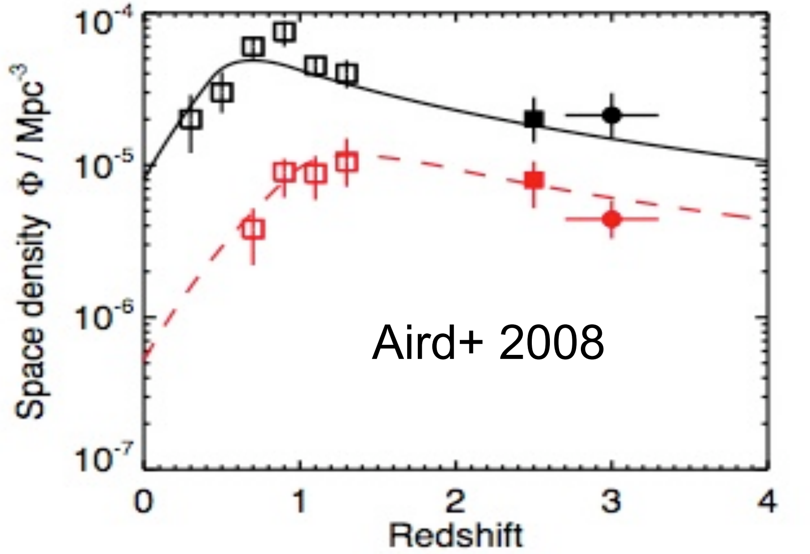


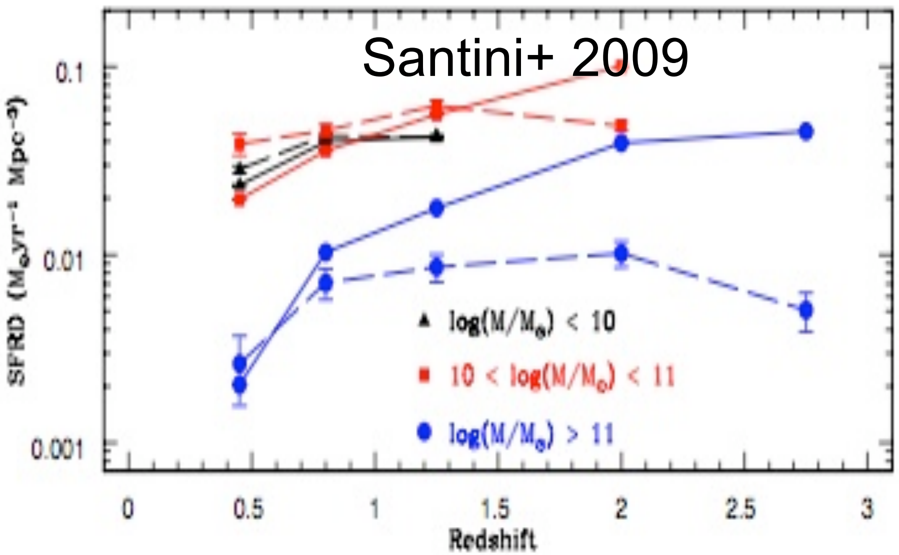


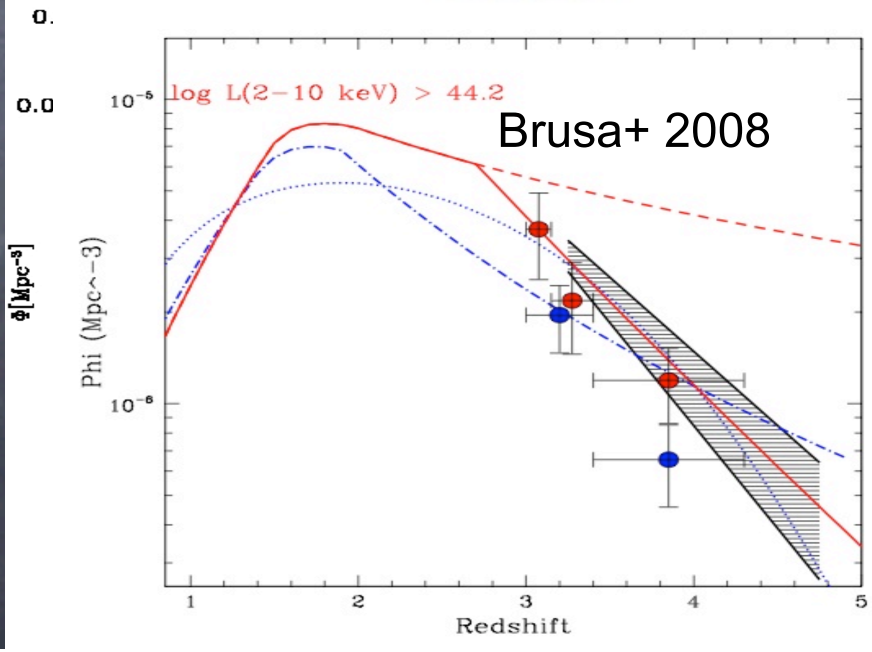
AGN and galaxy co-evolution

Downsizing



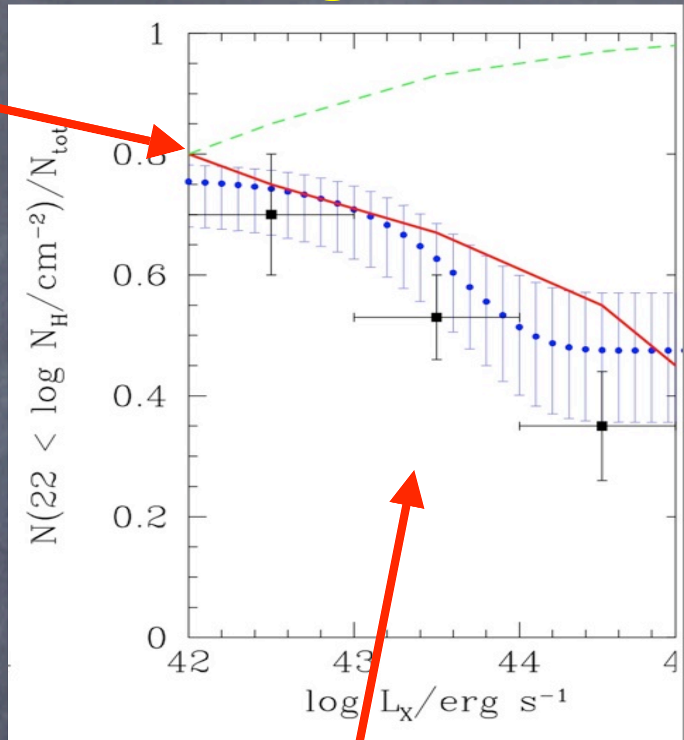




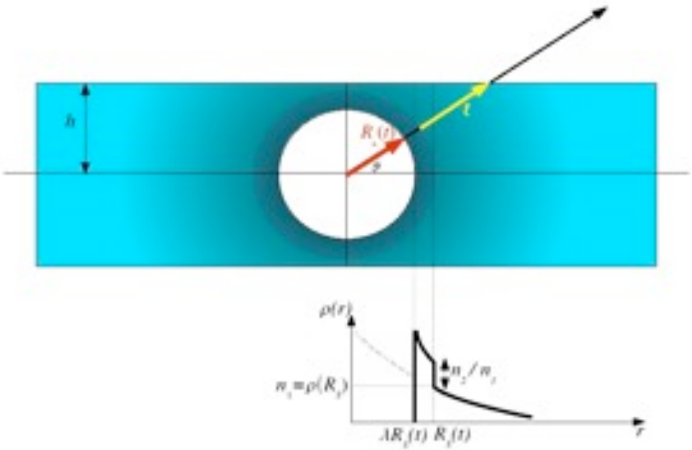


A working scenario for accreting BH

Powerful AGN clean their sight-lines more rapidly than low luminosity AGN, and therefore the fraction of obscured AGN can be viewed as a ***measure of the timescale over which the nuclear feedback is at work.***



Galactic cold gas available for accretion and obscuration increases at high z



Menci hierarchical clustering model,
Menci, Fiore, Puccetti, Cavaliere 2008

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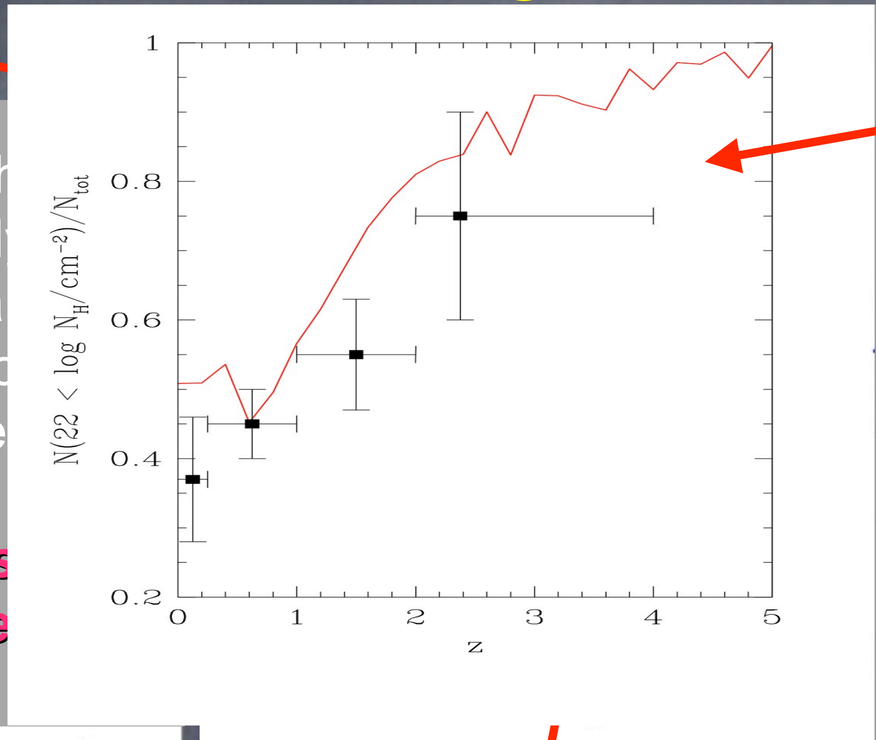

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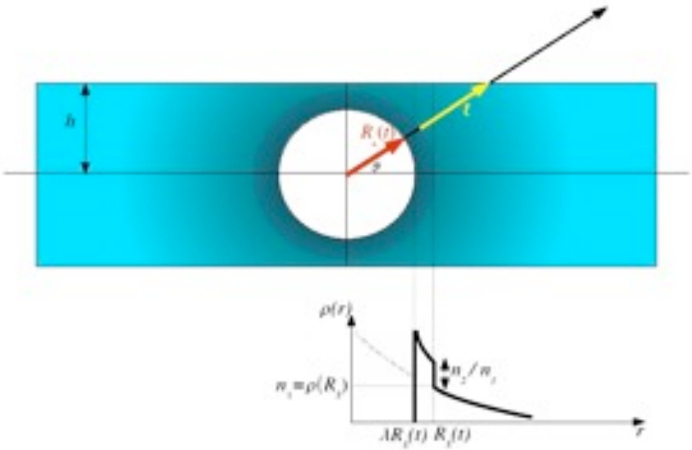

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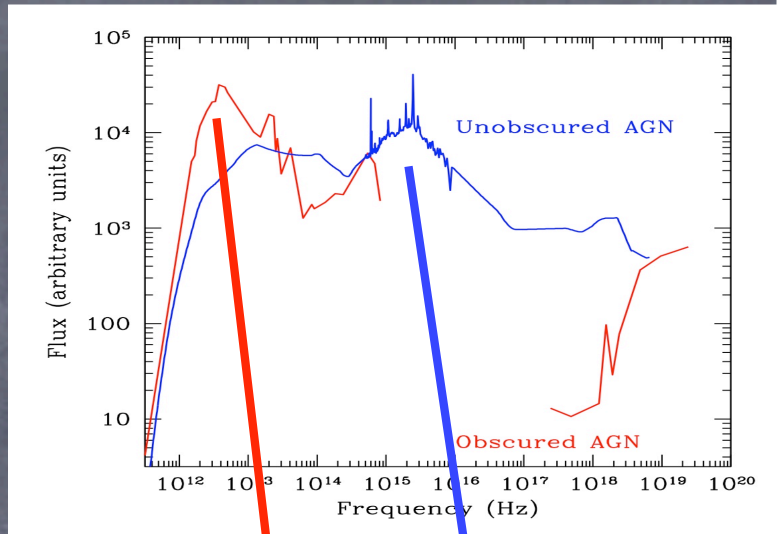
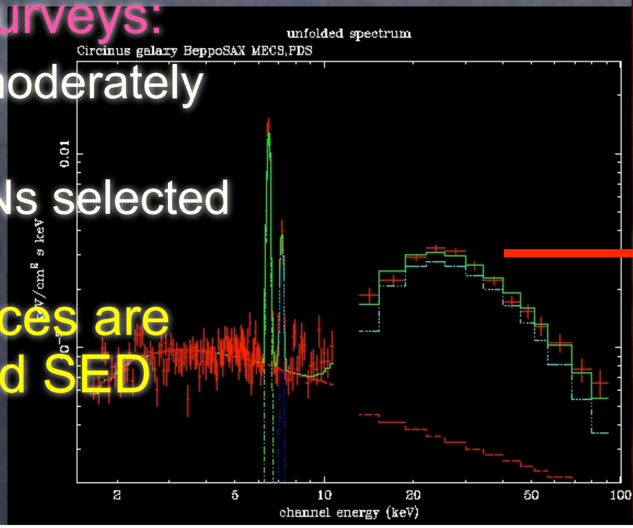
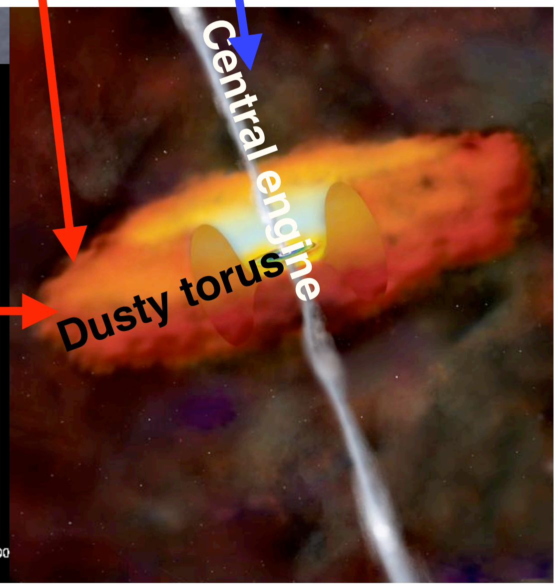
Probing the phase of SMBH and galaxy common growth: Highly obscured AGN @ z>1-2

- X-ray surveys:
  - very efficient in selecting unobscured and moderately obscured AGN
  - Miss most highly obscured AGN
- IR surveys:
  - AGNs highly obscured at optical and X-ray wavelengths (CT) shine in the MIR thanks to the reprocessing of the nuclear radiation by dust
- Use both X-ray and MIR surveys:
  - Select unobscured and moderately obscured AGN in X-rays
  - Add highly obscured AGNs selected in the MIR
- Simple approach: Differences are emphasized in a wide-band SED analysis



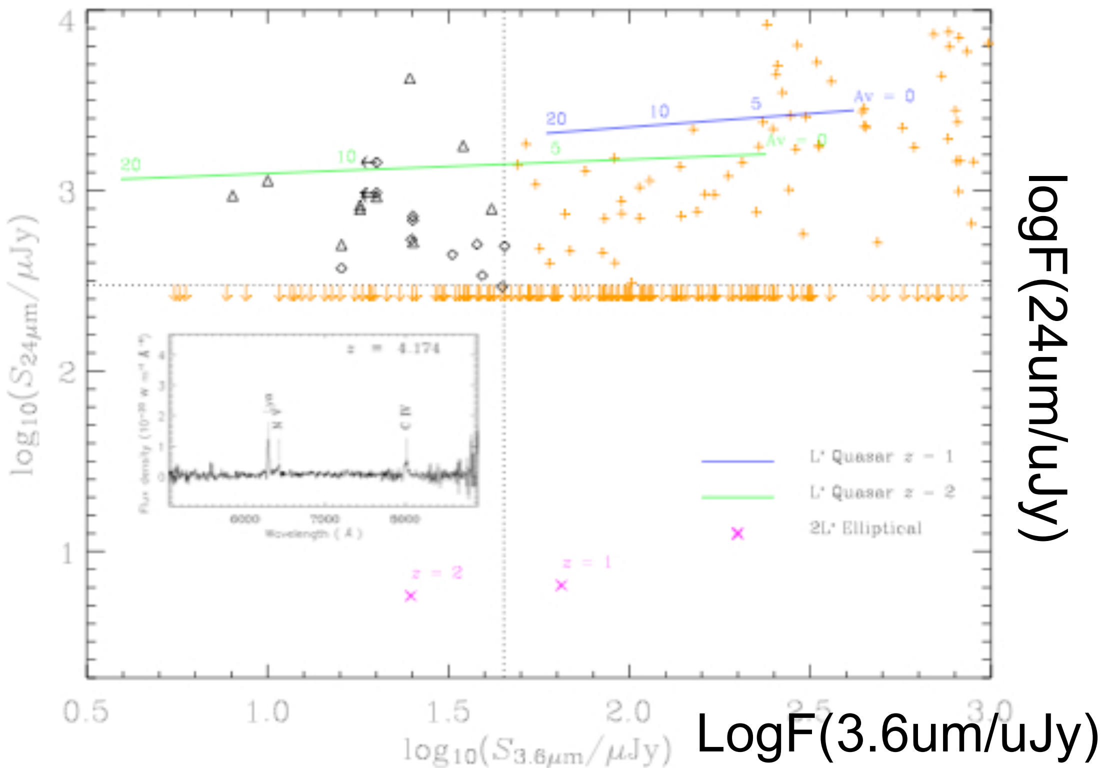




IR selected CT AGN

Efficient strategy: target sources with AGN luminosity in the MIR but faint (and red) optical counterparts.
First used by Martinez-Sansigre (2005)

Application to COSMOS:

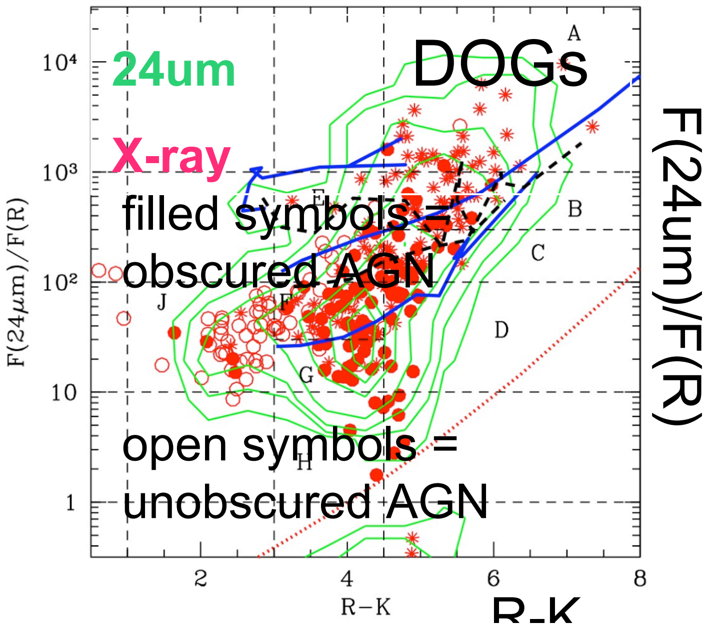


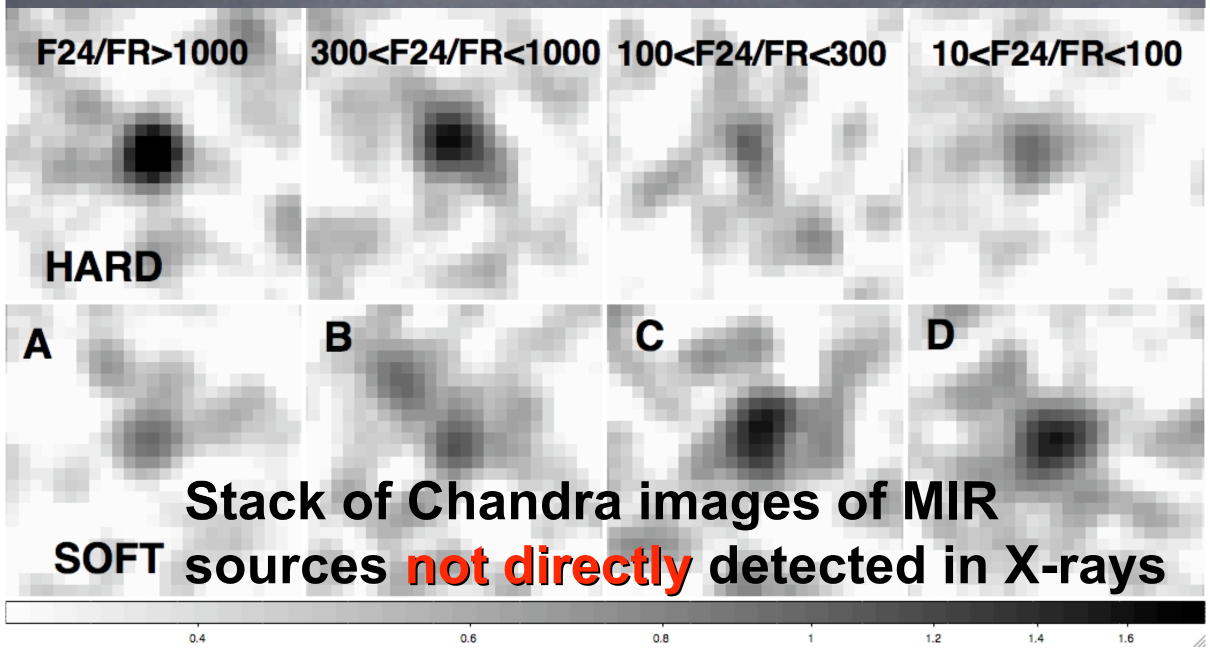
Chandra-COSMOS area:
0.9 deg^2
200 ks equivalent expo.

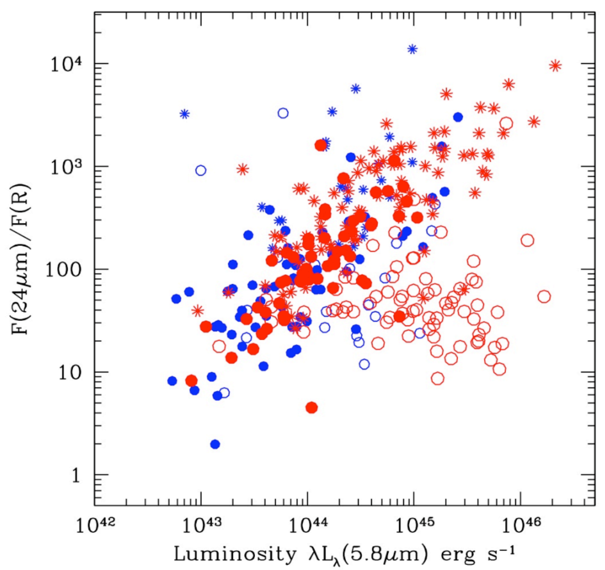
~900 MIPS sources with **F(24um)>550uJy**

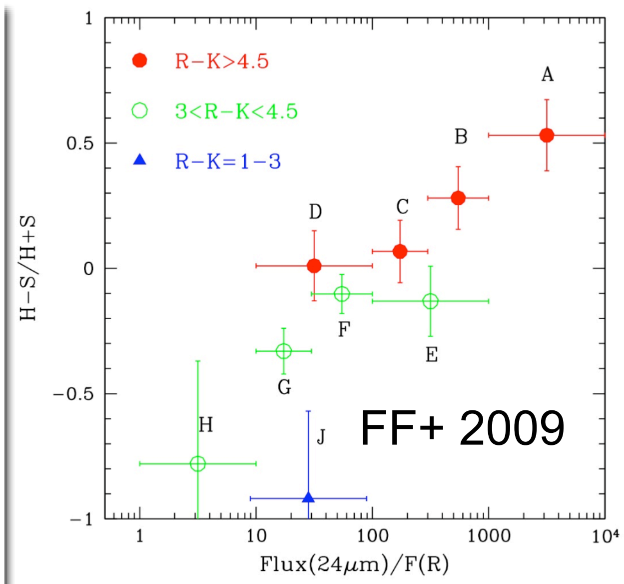
~250 MIPS sources with X-ray detection

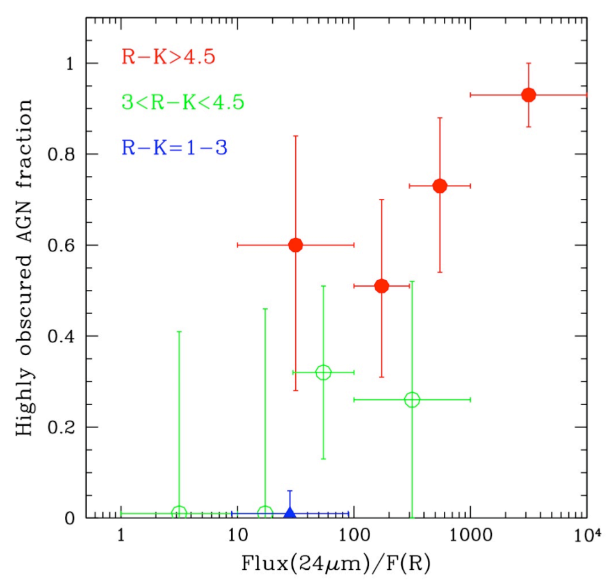
COSMOS MIR AGN







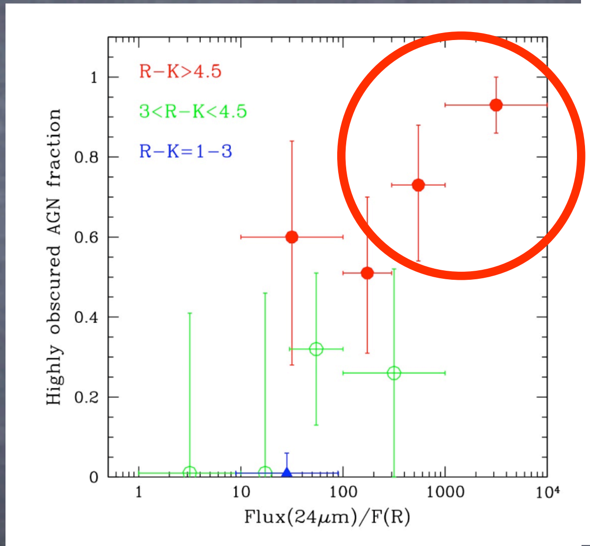


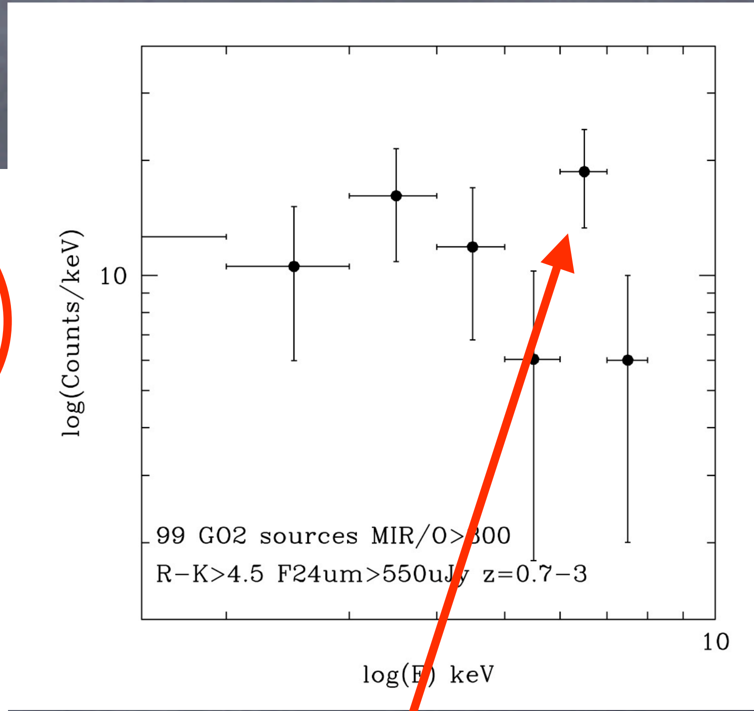


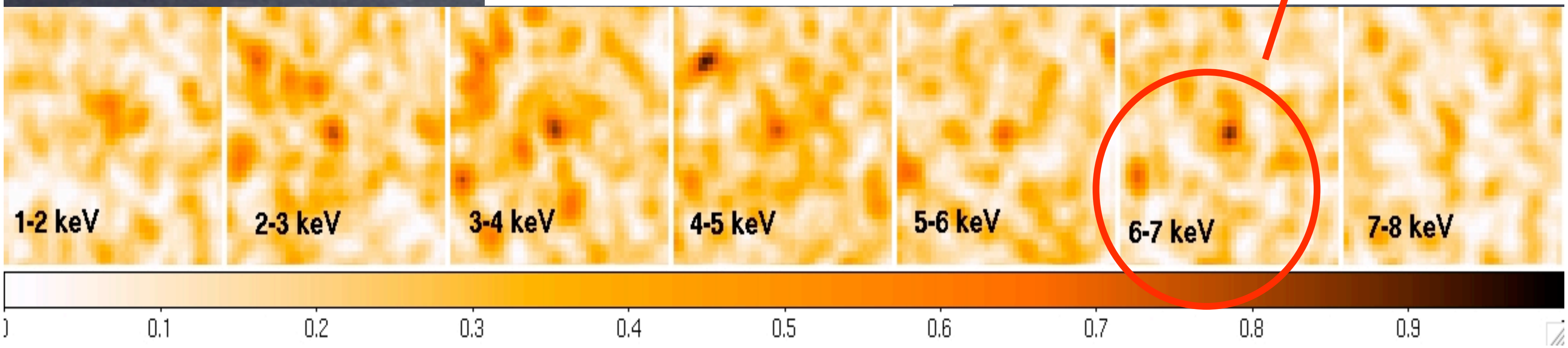
Chandra stack rest frame

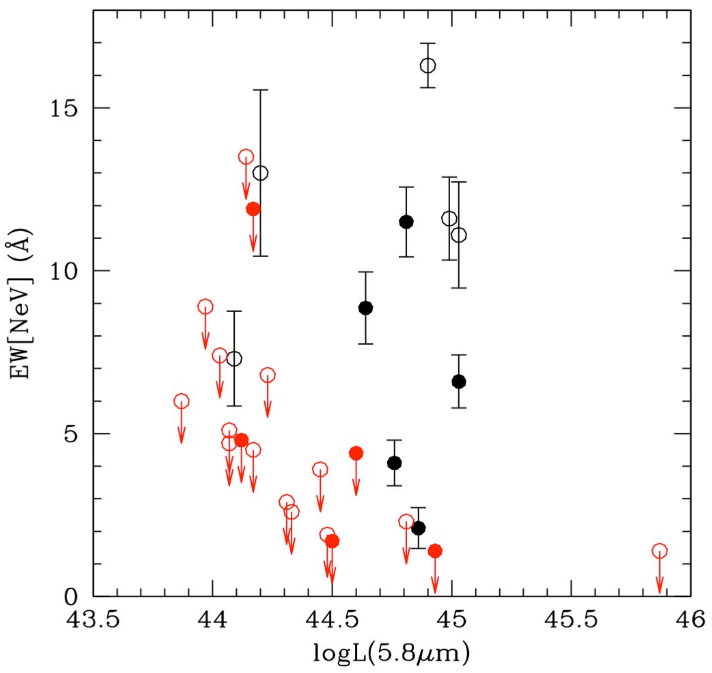
Bright DOGs

99 sources with:
F24um>550uJy
MIR/O>300
R-K>4.5
0.7<z<3



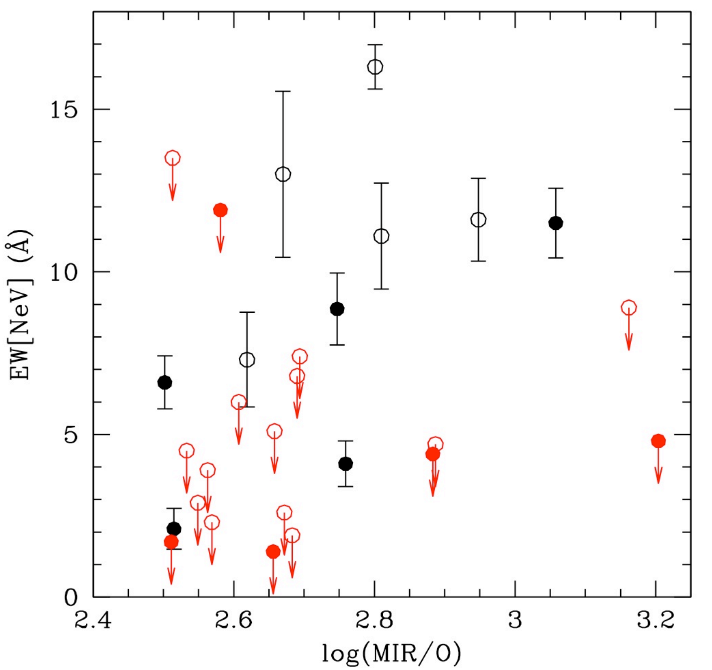


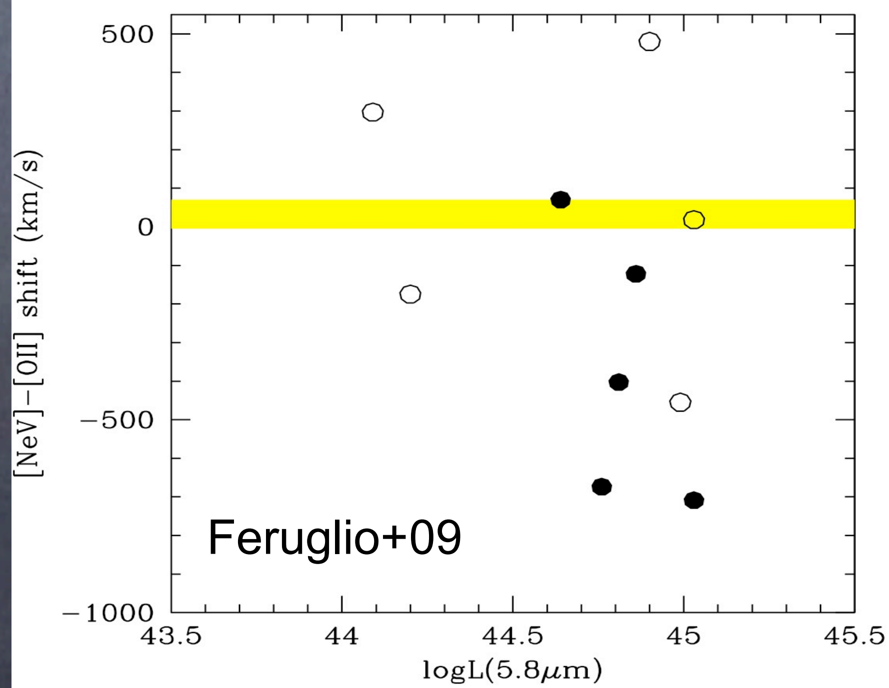




[NeV] detection in DOGs

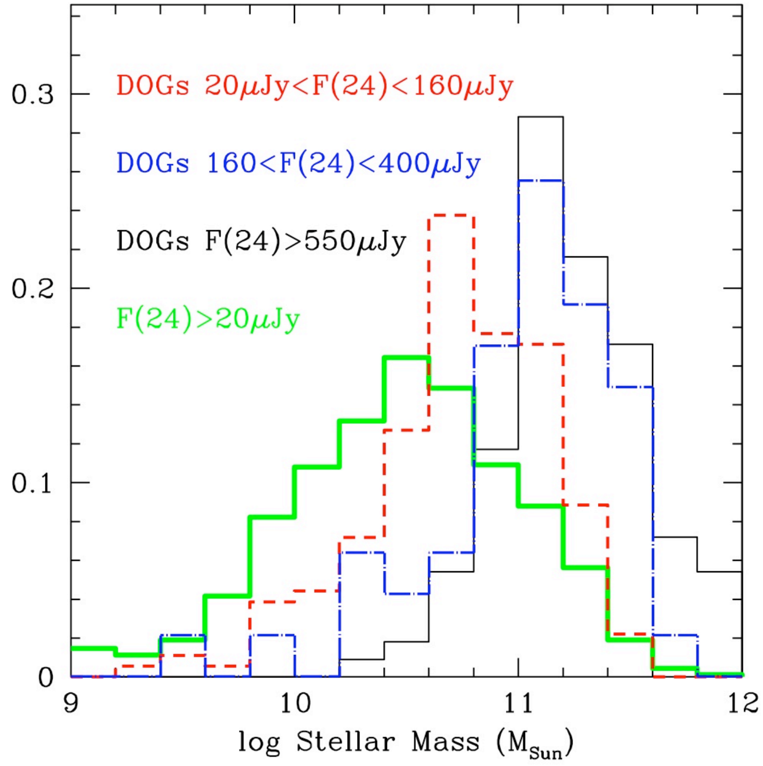
29 spectra of MIPS sources with F(24um)>550uJy, 300<MIR/O<1500, 10 [NeV] detections, 5 in sources without an X-ray detection. logN_H of X-ray sources >22. [NeV] often blueshifted with respect to [OII]: ***outflows!!!*** More VLT/Keck spectra coming soon

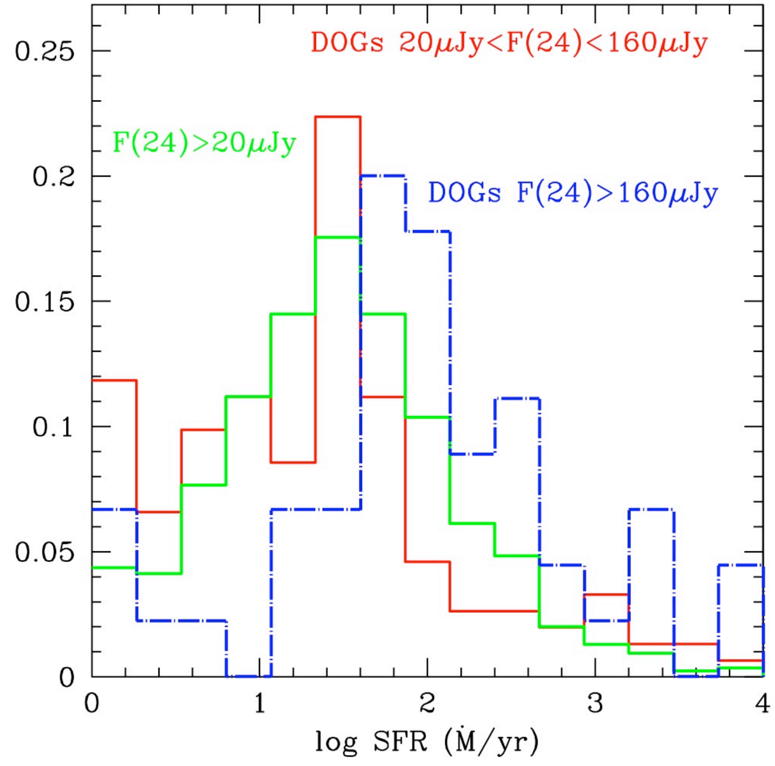




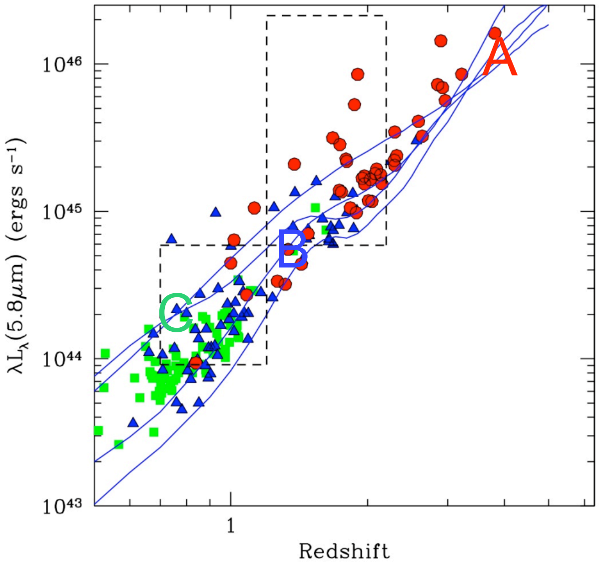
Why DOGs are so interesting

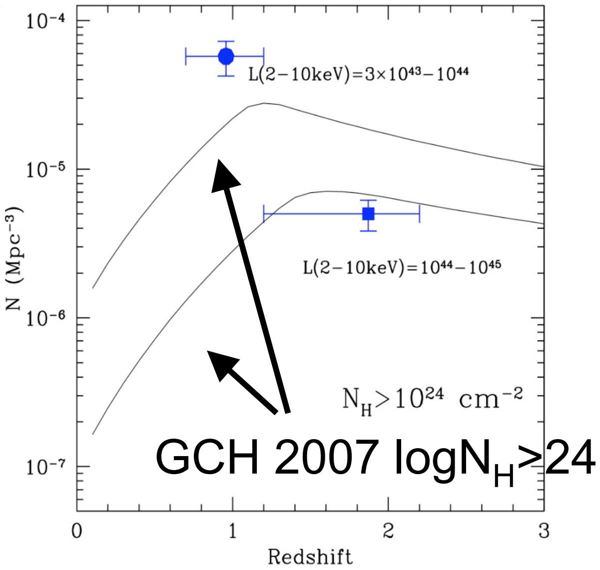
- Massive, young, strongly star-forming
- May witness the AGN/galaxy co-evolution phase associated to the onset of AGN feedback
- May be a crucial evolutionary phase in the assembling of passive spheroids, hosting unobscured AGN or relic SMBH .

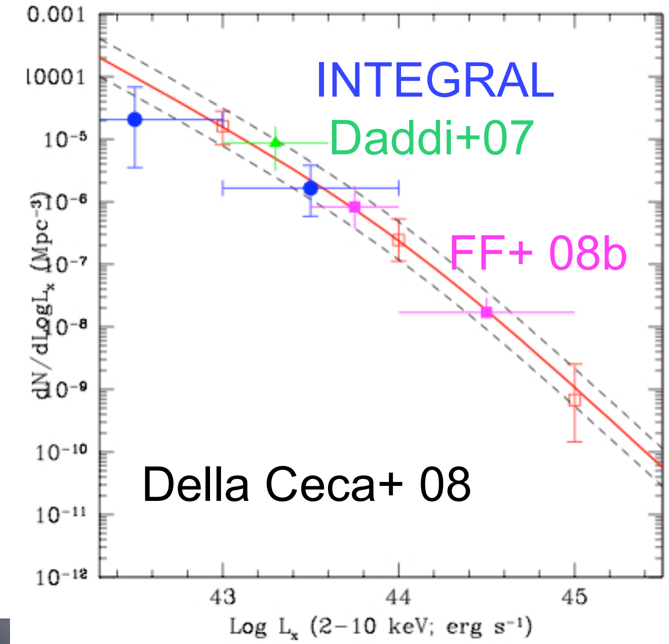




CT AGN volume density







z=1.2-2.2 $\log L_X$=44-45: density IR-CT AGN~45% density X-ray selected AGN

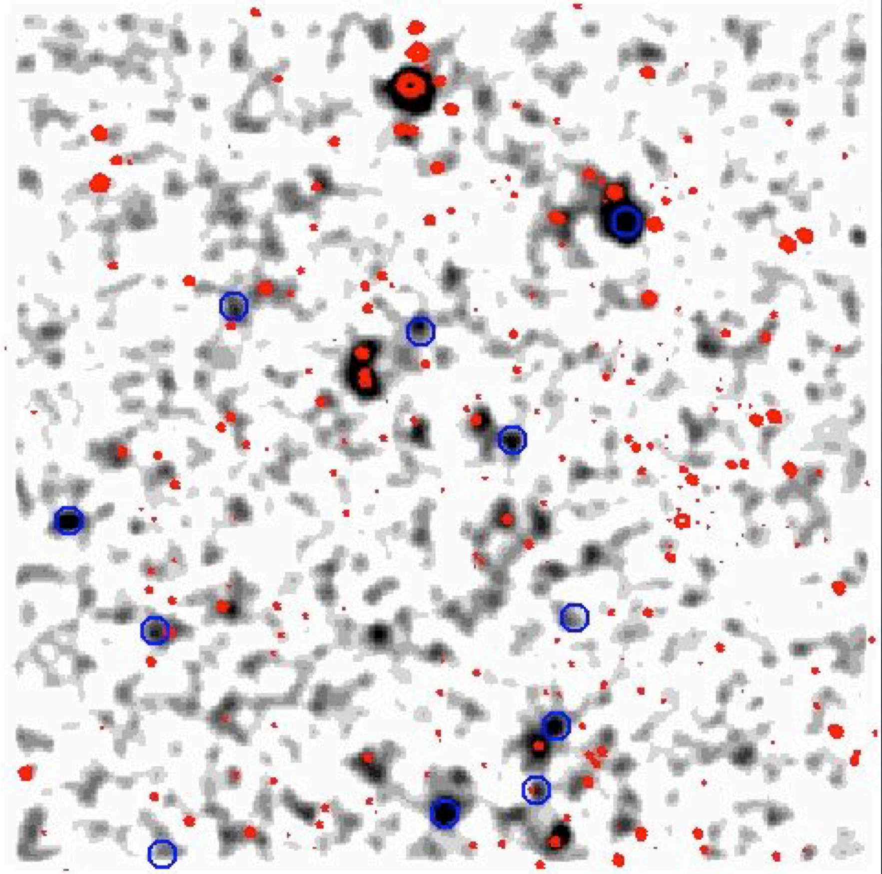
z=0.7-1.2 $\log L_X$=43.5-44: density IR-CT AGN ~100% density X-ray selected AGN

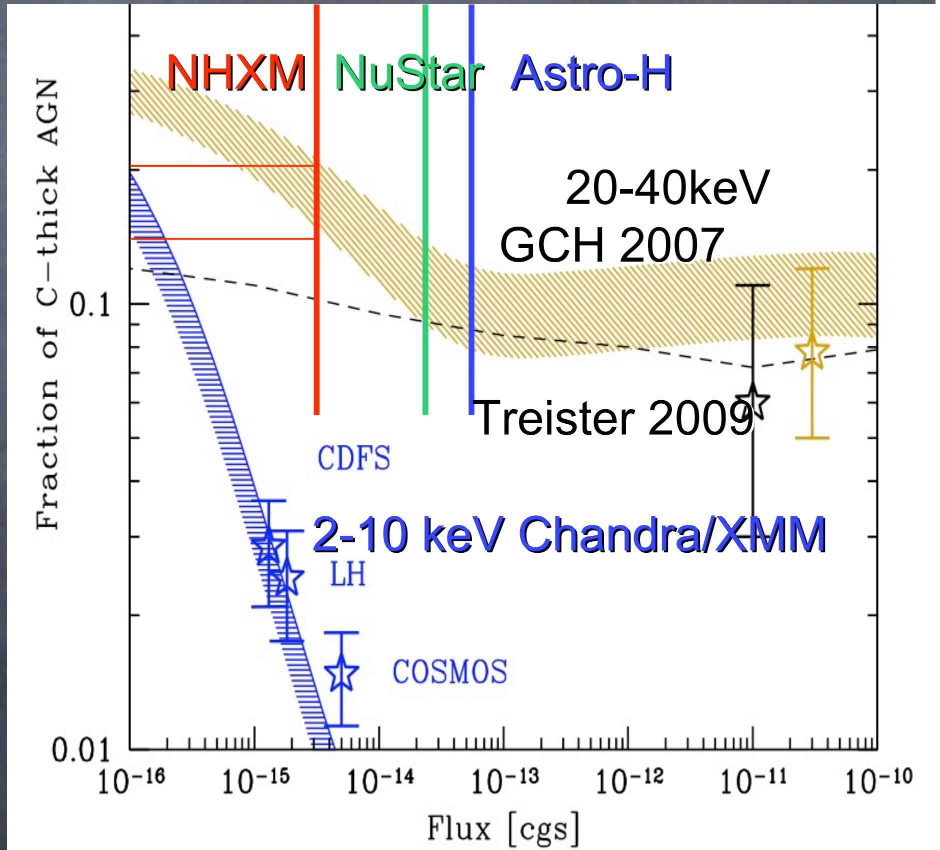
The correlation between the fraction of obscured AGN and their luminosity holds including CT AGN, and it is in place by z~2

Similar results on CT AGN obtained by Treister+ 2009, Georgantopoulos + 2009 etc.

New hard-Xray mission

IR selected AGN, how big is the obscuration? Only high energy X-ray observations tell, thus assessing the real power of the active nucleus and probing the BH growth in these galaxies and its feedback. CDFS 1 Msec NHXM simulations 10-40 keV, PSF HED=20”. Chandra sources (red contours); IR selected CT AGN at z=0.5-2 (blue circles) assuming NH=10^{24} cm^{-2} and a reasonable IR/X-ray luminosity ratio. See Pareschi talk.

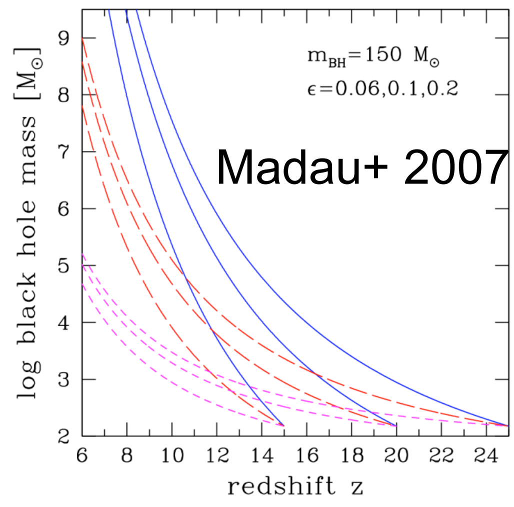




Formation of first galaxies/BH

- ***SDSS QSO z>6 => M_{BH}~3-7×$10^9 M_{Sun}$***
- $\log M_{BH}=(8.2\pm0.1)+(1.1\pm0.1)(\log L_{K,bul}-10.9)$, $\log M_{BH}=(8.3\pm0.1)+(4.1\pm0.3)(\log\sigma-2.3)$
- **Locally M_{BH}~0.001×M_{bulge} what happens at high-z?**
- Early AGN activity can affect structure formation through eating of the IGM.
- Contribution to reionization.
- **Two additional key issues:**
  - 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***
  - Forming (enough) $10^{9-10} M_{Sun}$ BHs and $10^{11-12} M_{sun}$ bulges at z>6 can be a challenge for models of structure formation. As well as forming metals and dust. SMBH can then be used to:

constrain cosmological scenarios



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

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.,M) and P(M→M)

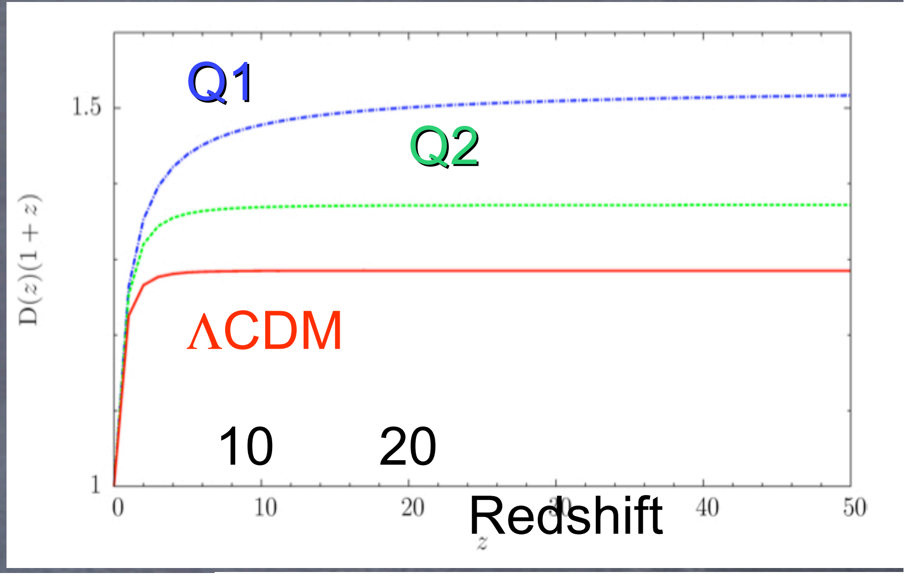
The physics of accretion enters in dm./dt   Lamastra+ 2009

Cosmological models

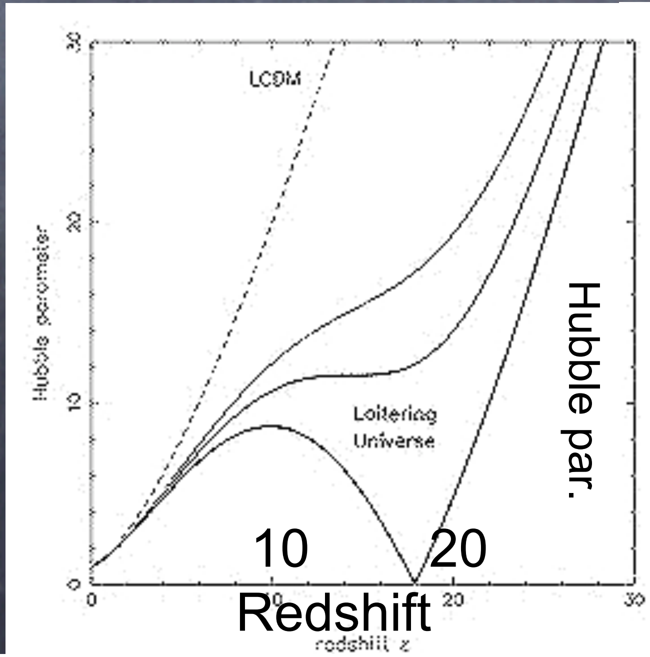
ΛCDM

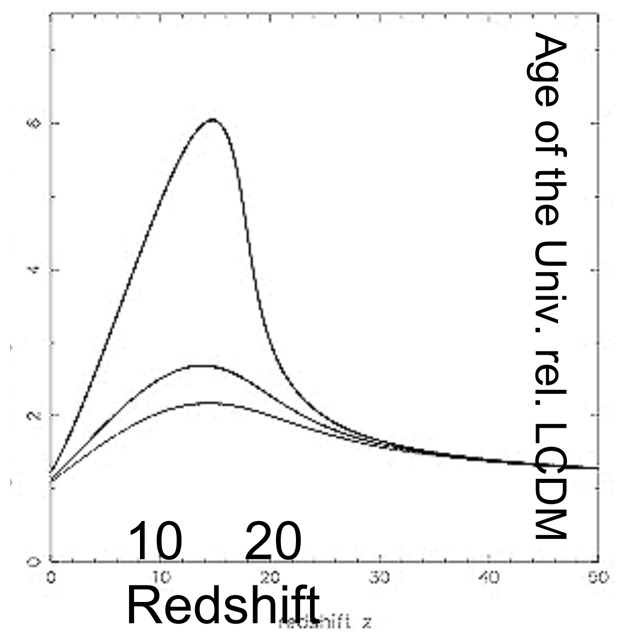
Quintessence models: the growth rate of primordial fluctuations is higher than in standard ΛCDM, i.e. the growth is anticipated with respect to ΛCDM

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

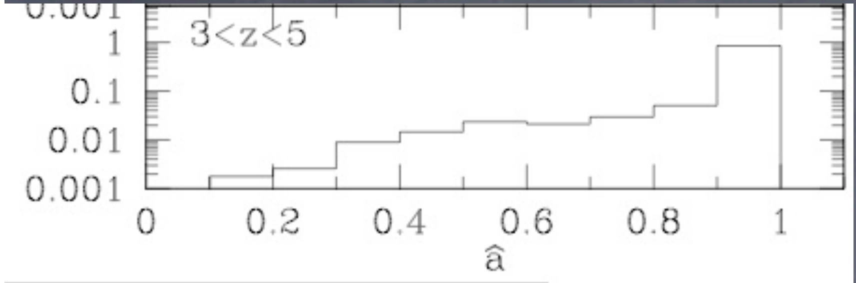


Problem: how to disentangle and separate cosmological effects from accretion physics.
This may be done at high-z when differences are larger and BH accretion is maximal

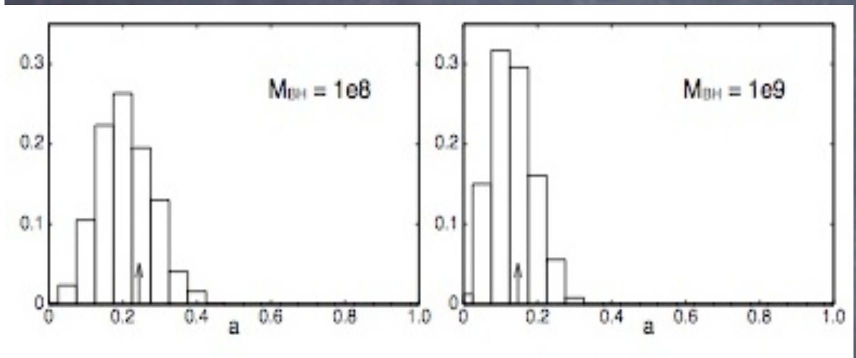




Physics of accretion



Volonteri+2005 J(disk)>>J(BH)



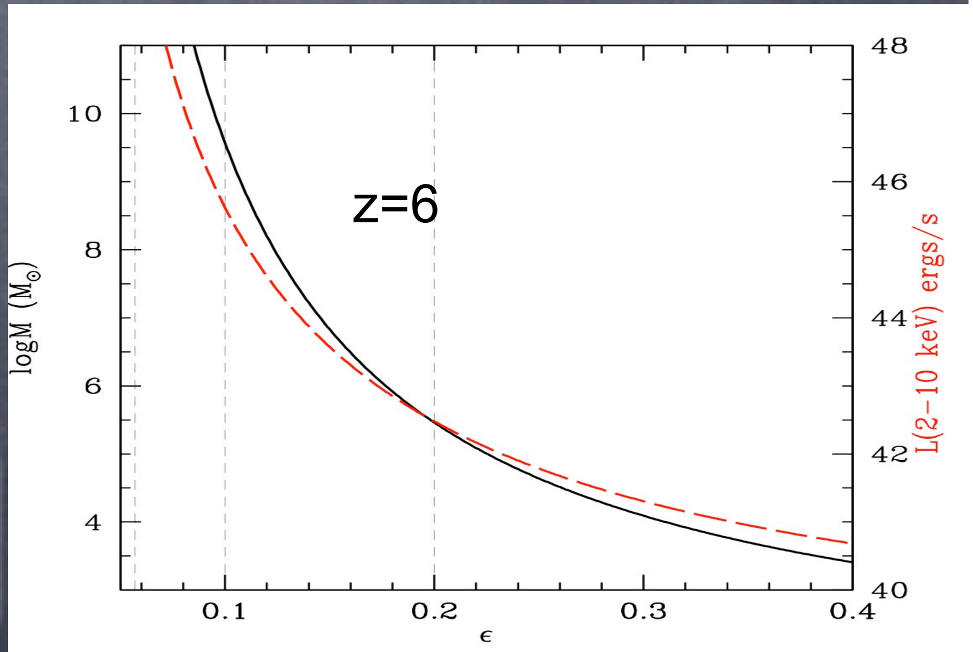
King+ 2005,2008 J(disk)<2J(BH)

See Miniutti, McClintock, Gallo talks

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

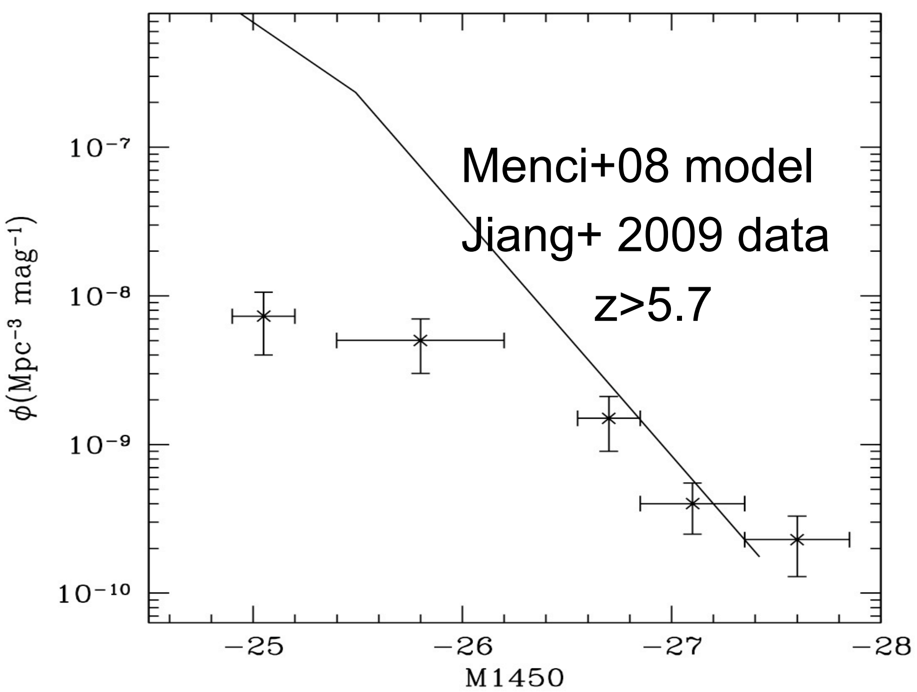
BH growth at z=6. λ=1; continuous accretion from z=30 on a 150MSun seed BH; M and L dependence on ε is extremely steep ⇒ **the shape of the high-z LF is mainly produced by the distribution of ε**

- ***LF slope gives ε distribution***
- ***LF normalization can be used to constrain the cosmology***



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

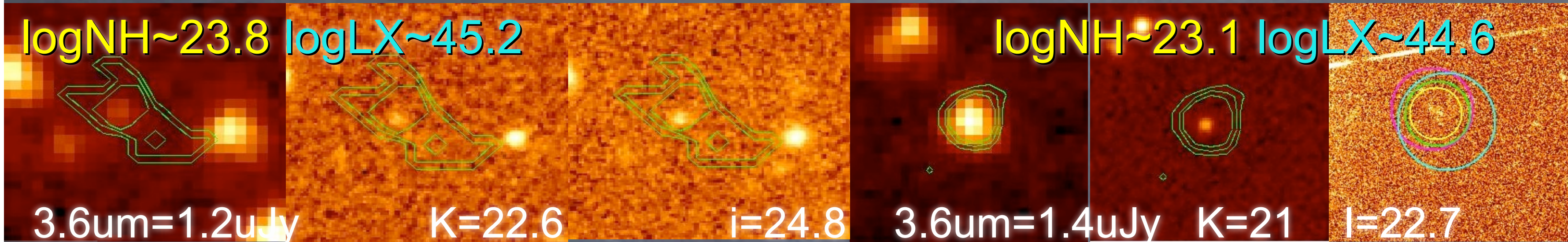
Pilot program on the CDFS2Msec:
- Use GOODS-MUSIC galaxy catalog and photo-z
- search the X-ray band that maximize the number of detected counts. First step toward multi-dimensional source detection

~30z>3 AGN; 3 z>4.5 AGN

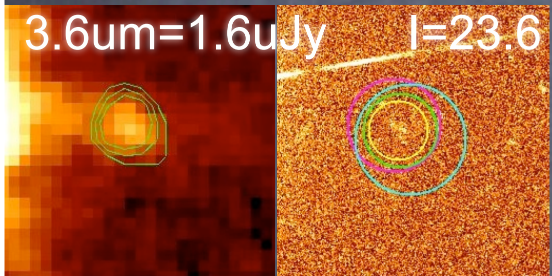
z>5 X-ray selected AGN

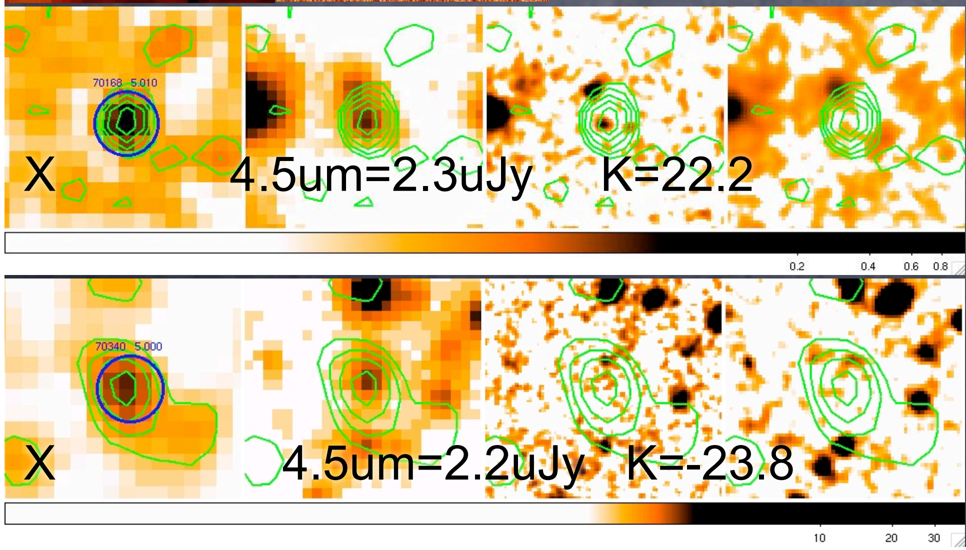
C-COSMOS 125 z=5.441 logFS=-15.04

781 z=4.660 logFS=-15.07



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





zm=26.0

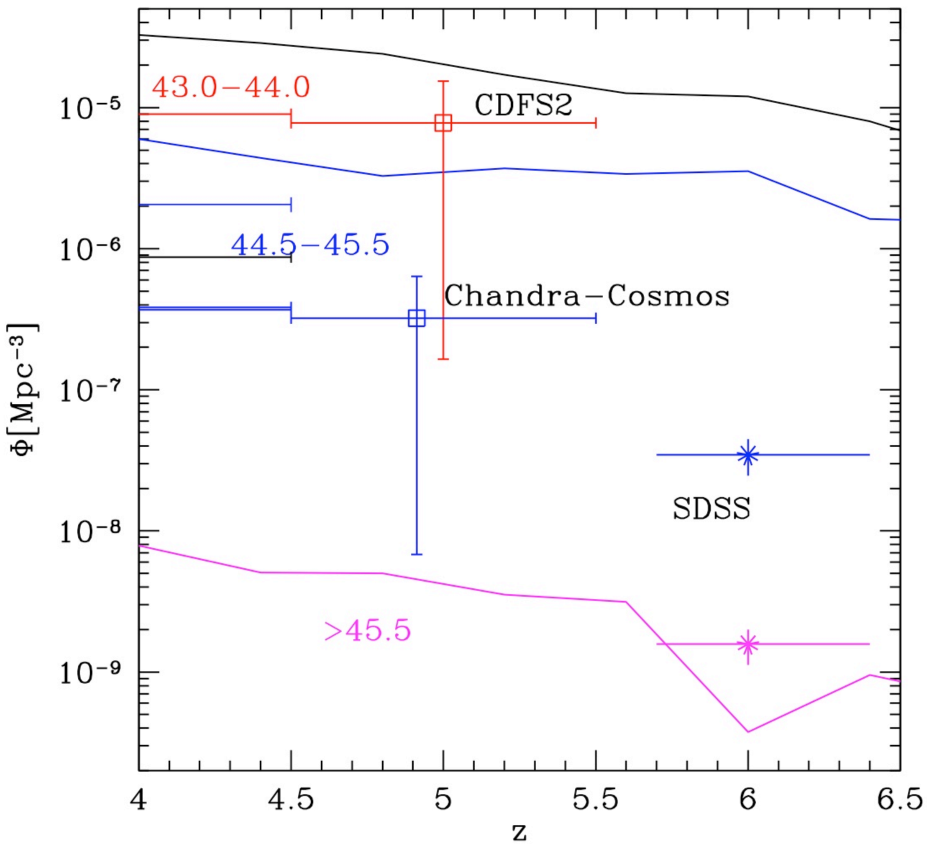
zm=-27.6

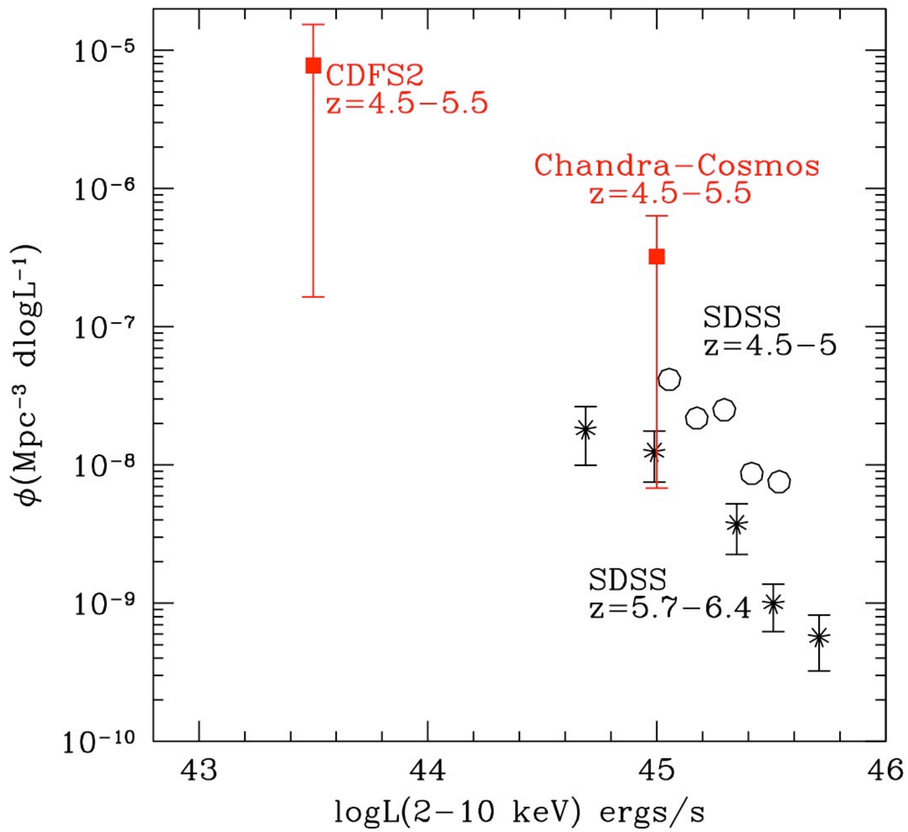
CDFS_70168 z~5
logFS=-16.05 LX~43.8
logNH~23.5

CDFS_70340 z~5
logFS=-16.1 LX~43.4
logNH~22.5

CDFS_5835 z~4.6
logFS=-16.2 LX~43
logNH~22.5

High-z AGN luminosity functions and density evolution





High-z AGN

Today constraints are too loose to constrain accretion physics and cosmology (handful of AGN at z>4.5 only).

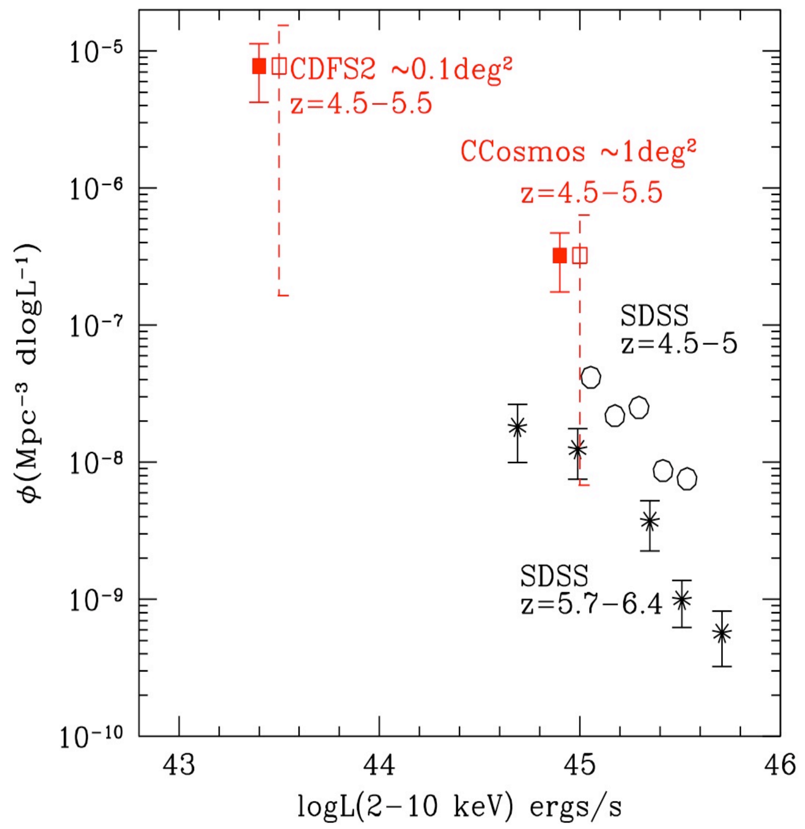
Both IXO and WFXT can provide breakthroughs in this field

!!!provided that a PSF with HPD<5" is achieved!!!

However, these programs will not see light before 2020!

In the meantime, the problem can be attacked by dedicated Chandra Legacy programs AND by aggressive multiband data analysis strategies exploiting synergies with HST, Spitzer, JWST and ALMA.

Tripling today z>4.5 sample can already provide errorbars comparable to SDSS ones, thus allowing us to measure the LF over >2 decades. This can start putting constraints on accretion physics and cosmology. Feasible by doubling today expo on CDFS and COSMOS

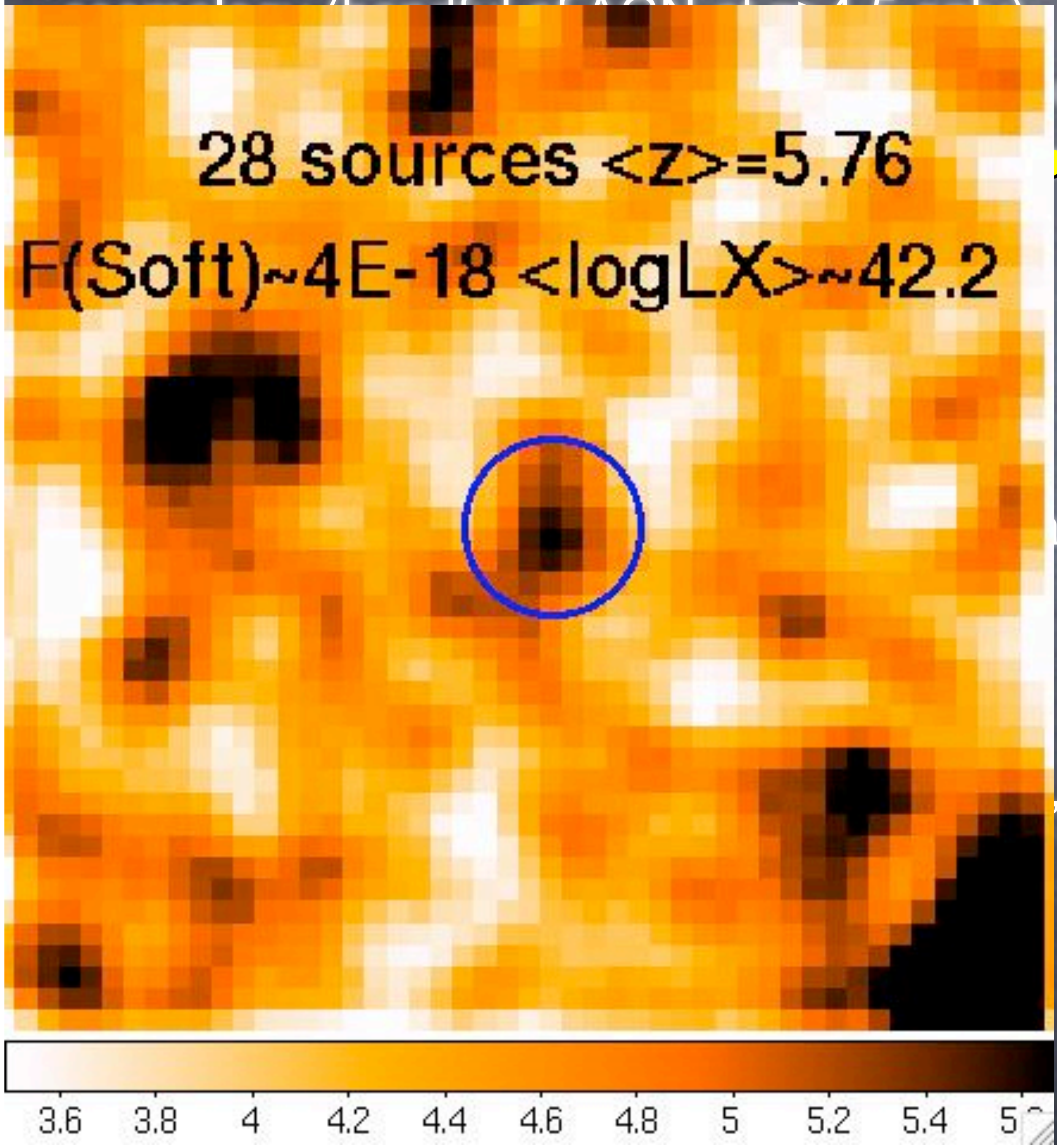


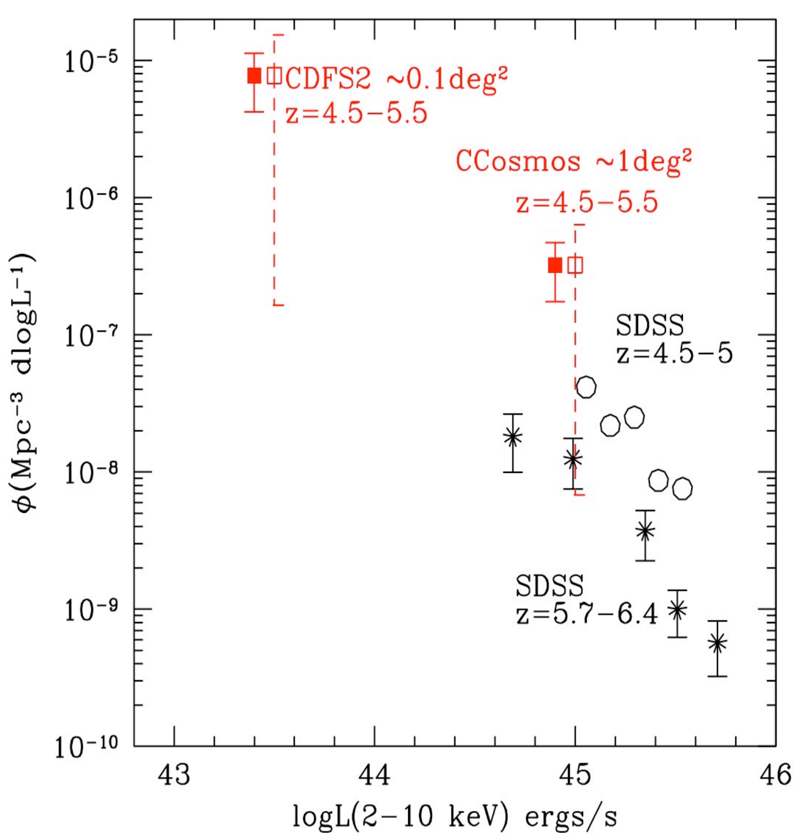
High-z AGN

Today constraints are too loose to constrain accretion physics and

ughs in this field

D<5" is achieved!!!





Summary

- Obscured AGN: probe of early galaxy evolution phases, when feedback must be in action
  - DOGs: massive, star-forming galaxies hosting active (and highly obscured) nuclei. Only high-E X-ray observations can measure the accretion luminosity, thus probing the BH growth in these galaxies.
- High-z, completing the AGN census is essential to probe accretion physics, BH feeding and cosmological scenarios:
  - eROSITA will find 30-50 $\log L_X \geq 45$ AGN at $z>5$
  - New Chandra legacy surveys: doubling the present Chandra exposure on CDFS, COSMOS should find ~20 AGN at $z>4.5$ and $42.5<\log L_X<45$ First constraints on ε distribution. We may start excluding the most extreme cosmological scenarios.
  - ALMA/JWST will detect LIRGs @ $z \leq 10$, regardless of the presence of an AGN and its obscuration. AGN identifications complex but feasible through HCN and HCO+ lines and/or IR spectroscopy. X-rays essential to get AGN total power $\Rightarrow$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)