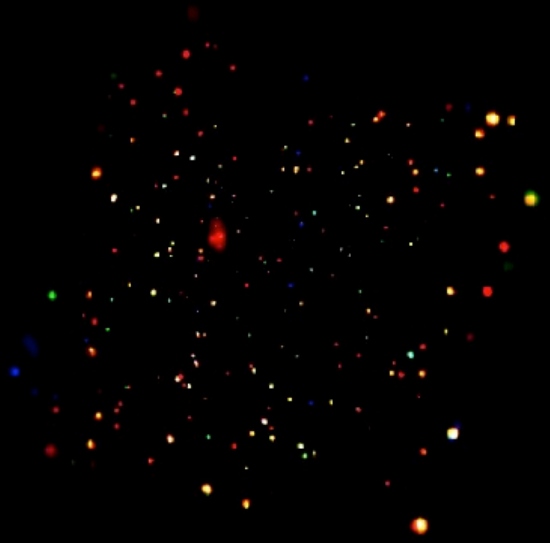
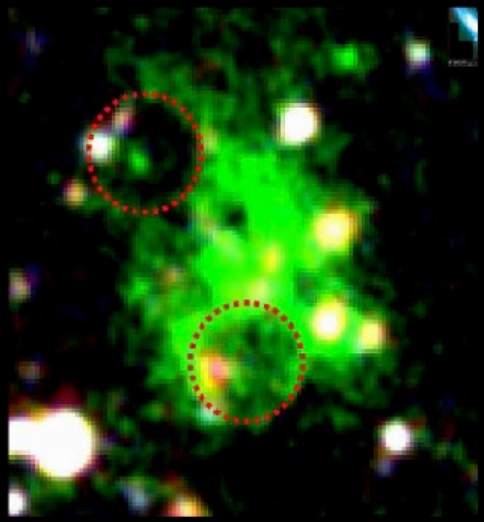
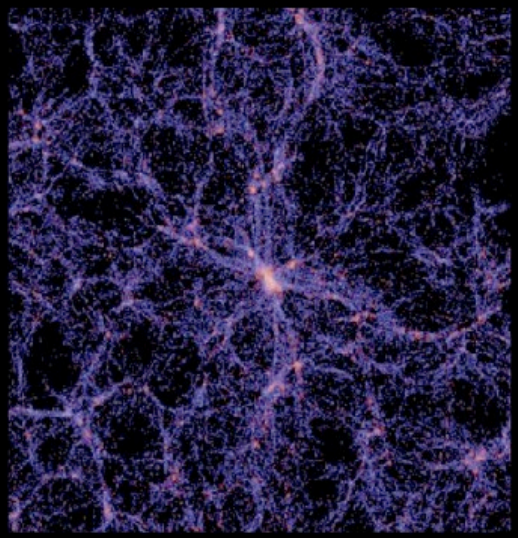
Growth of black holes in distant overdense environments







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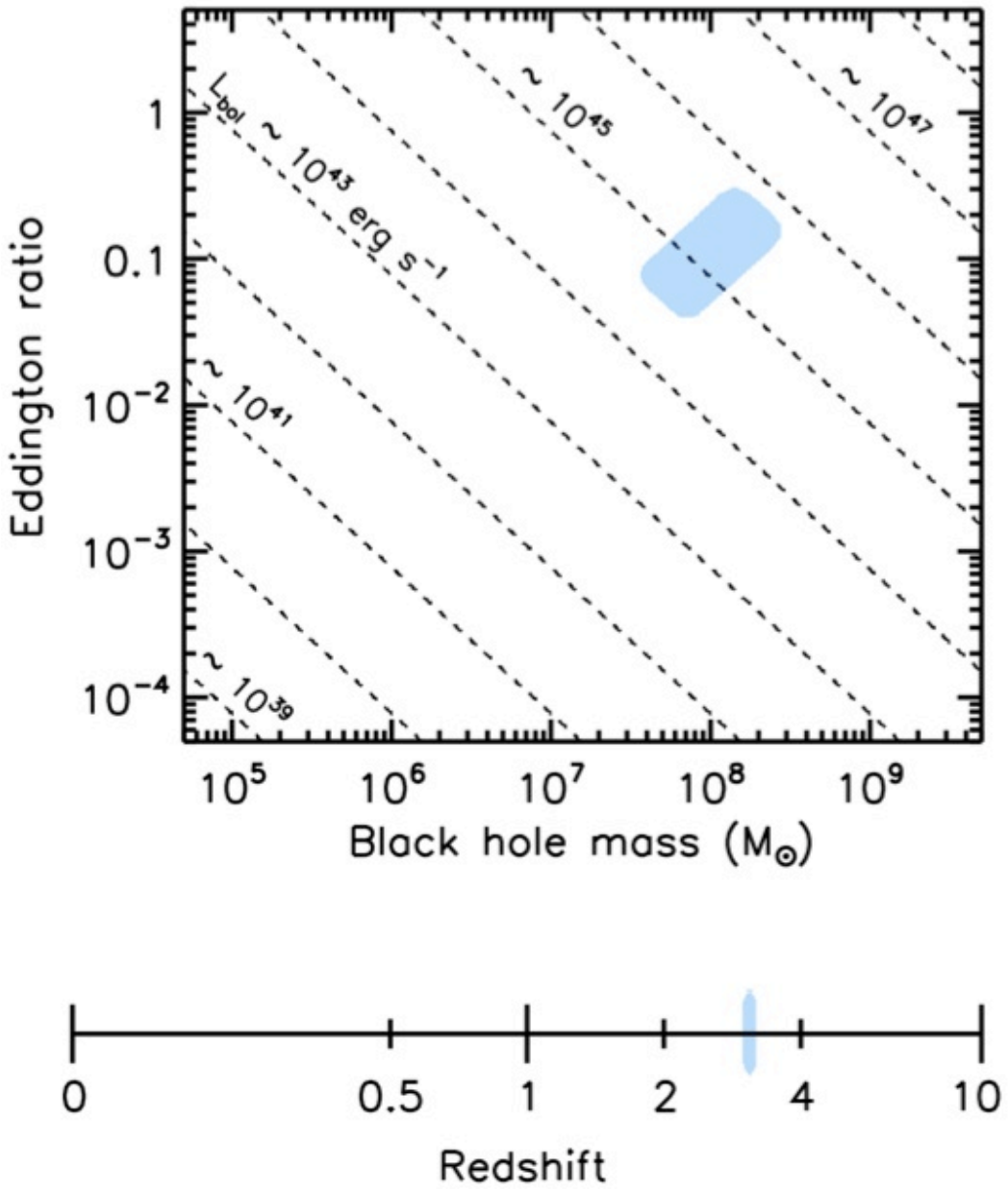
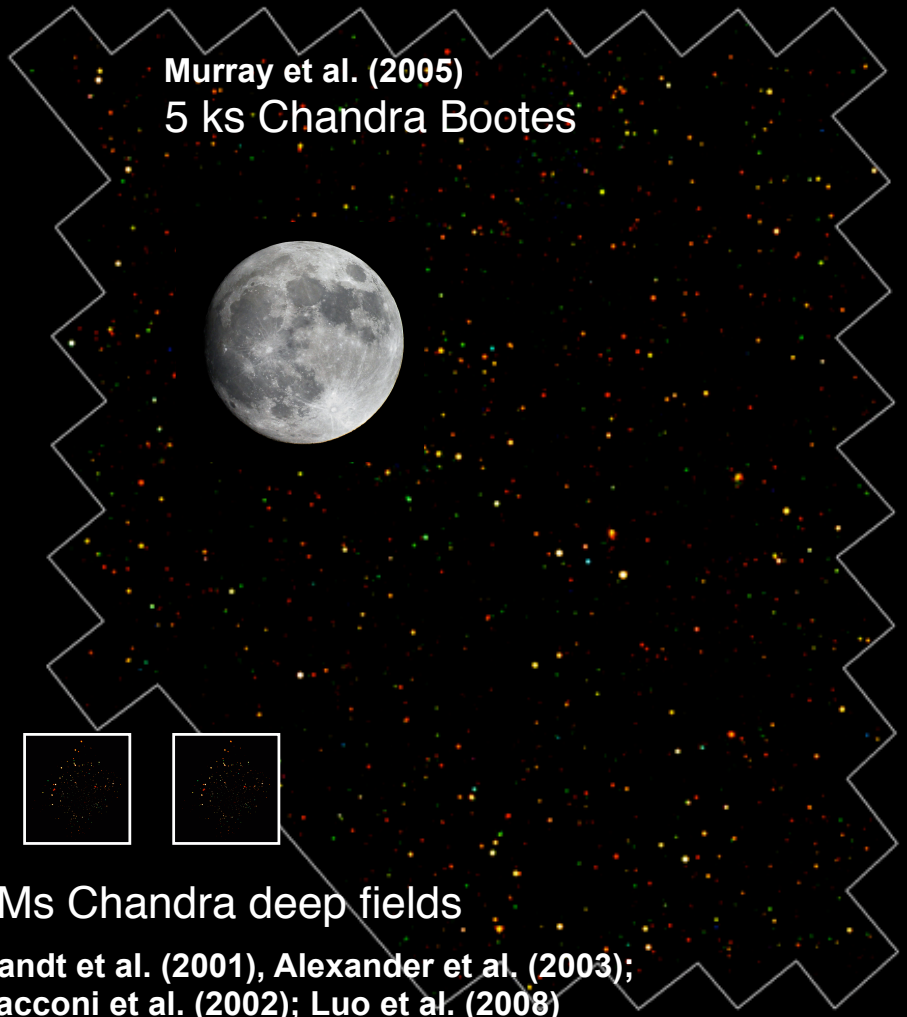

Eddington ratio
1
0.1
10^{-2}
10^{-3}
10^{-4}
$L_{bol} \sim 10^{43}$ erg s^{-1}
$\sim 10^{45}$
$\sim 10^{47}$
$\sim 10^{41}$
$\sim 10^{39}$
10^5
10^6
10^7
10^8
10^9
Black hole mass ($M_\odot$)
0
0.5
1
2
4
10
Redshift

Blank-field X-ray surveys and studies of z<1 clusters

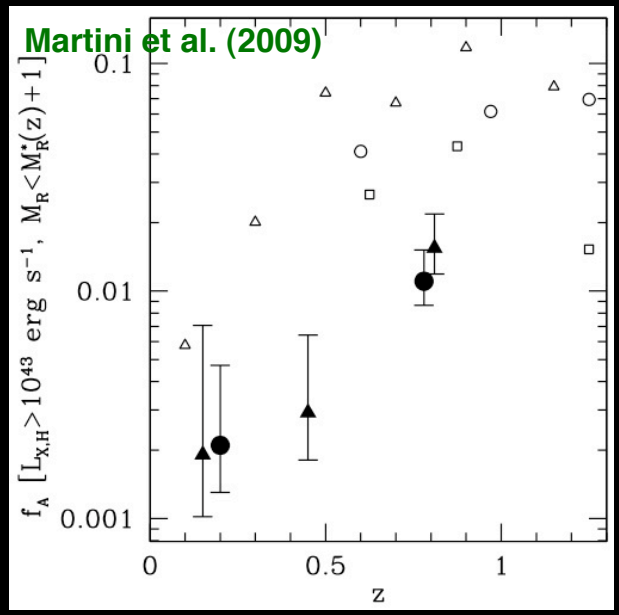


Murray et al. (2005)
5 ks Chandra Bootes

2 Ms Chandra deep fields

Brandt et al. (2001), Alexander et al. (2003); Giacconi et al. (2002); Luo et al. (2008)

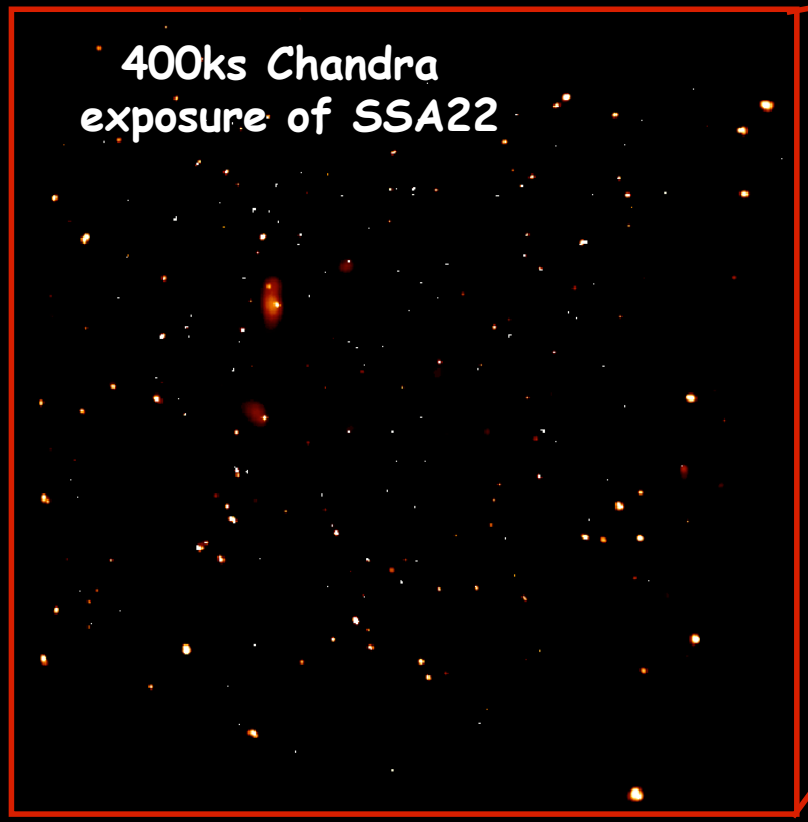
Blank-field X-ray surveys: very efficient at identifying AGNs in *typical* environments at z<1

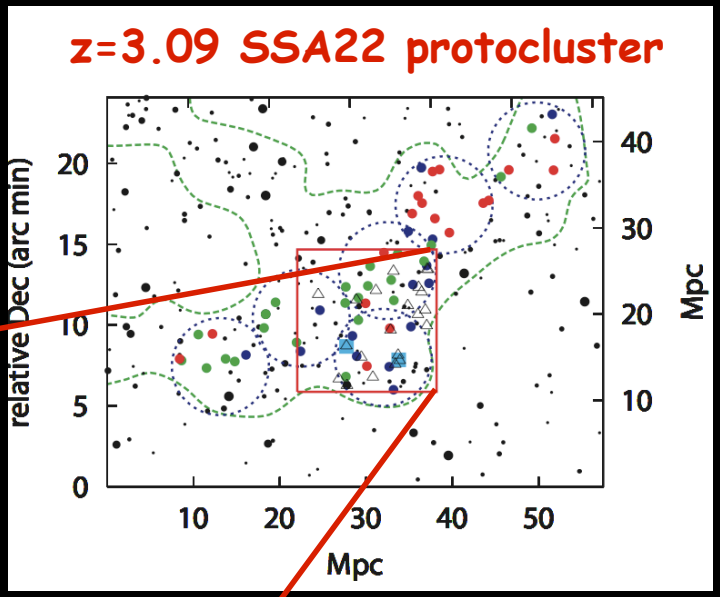


X-ray studies of z<1 galaxy clusters show decreasing AGN fraction - but these systems *must* have been more active in the past

What about black-hole growth (AGN activity) in distant overdense environments?

A key laboratory of black-hole growth mechanisms: a distant protocluster?

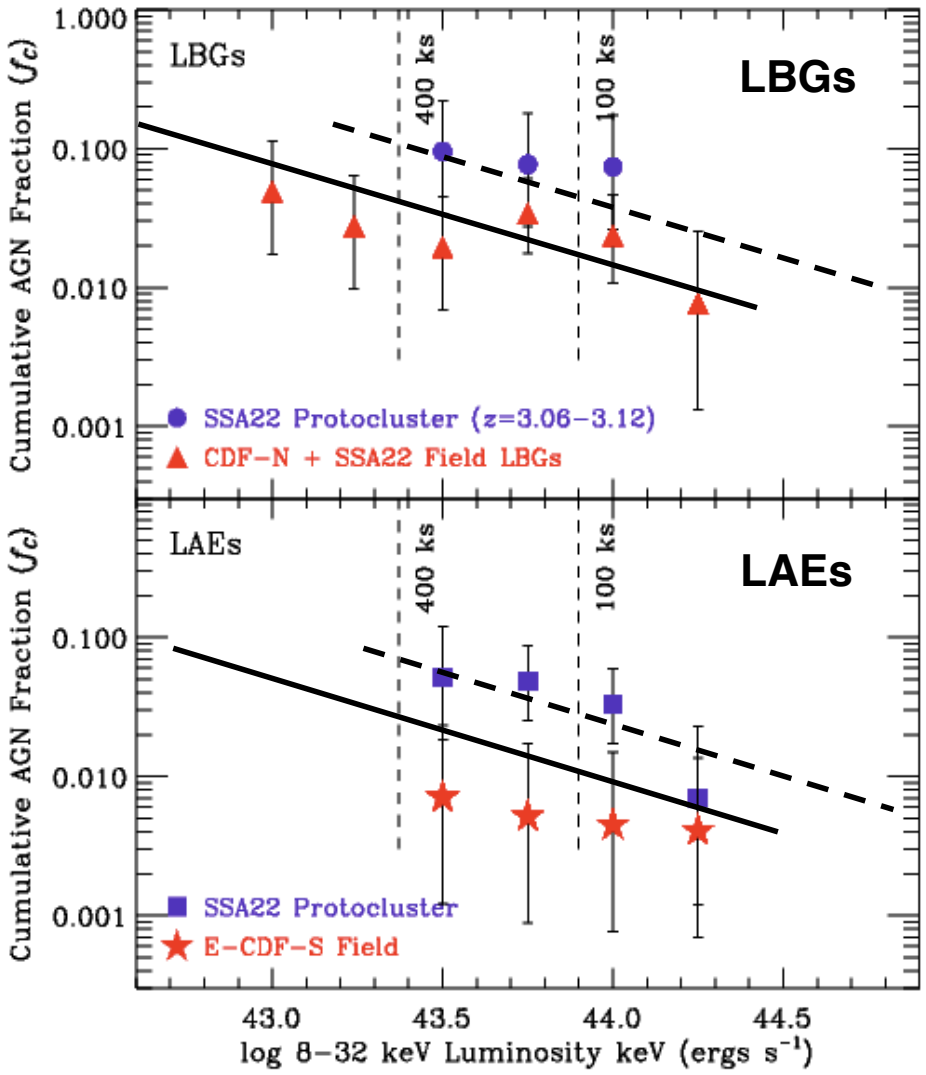




The galaxy density is ~6x higher than the field already at z~3.09

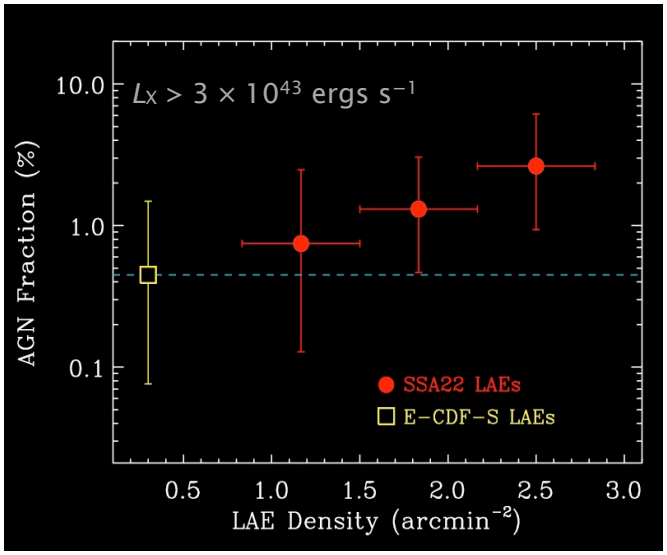
Enhanced black-hole growth compared to the field

Lehmer et al. (2009a)



- The AGN activity per galaxy is larger in the protocluster compared to the field by a factor of $6.1^{+10.3}$ (enhanced at the 95% confidence level) for AGNs with $L_X > 3 \times 10^{43}$ ergs s^{-1}.

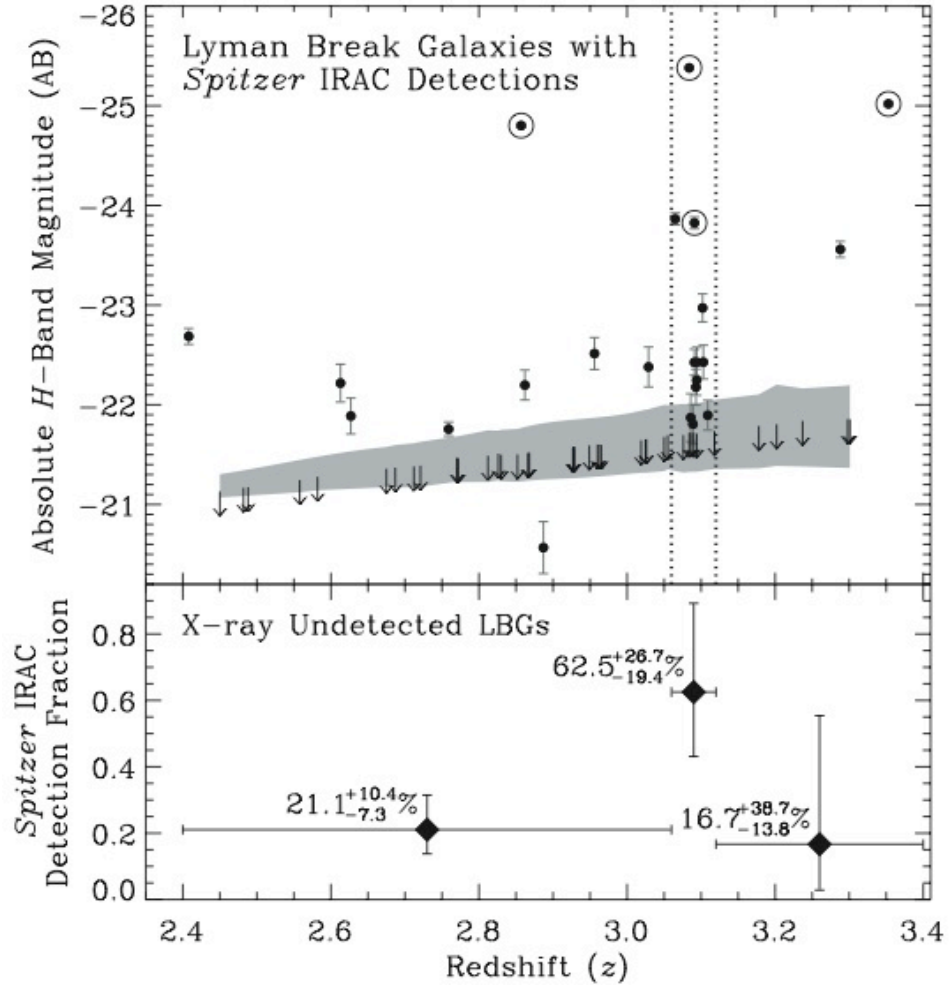
- Fraction of LAEs hosting AGNs appears to be positively correlated with the local LAE density (96% confidence level).



Lehmer et al. (2009b)

More massive black holes active at earlier times?

Host galaxies appear more massive in protocluster



Lehmer et al. (2009a)

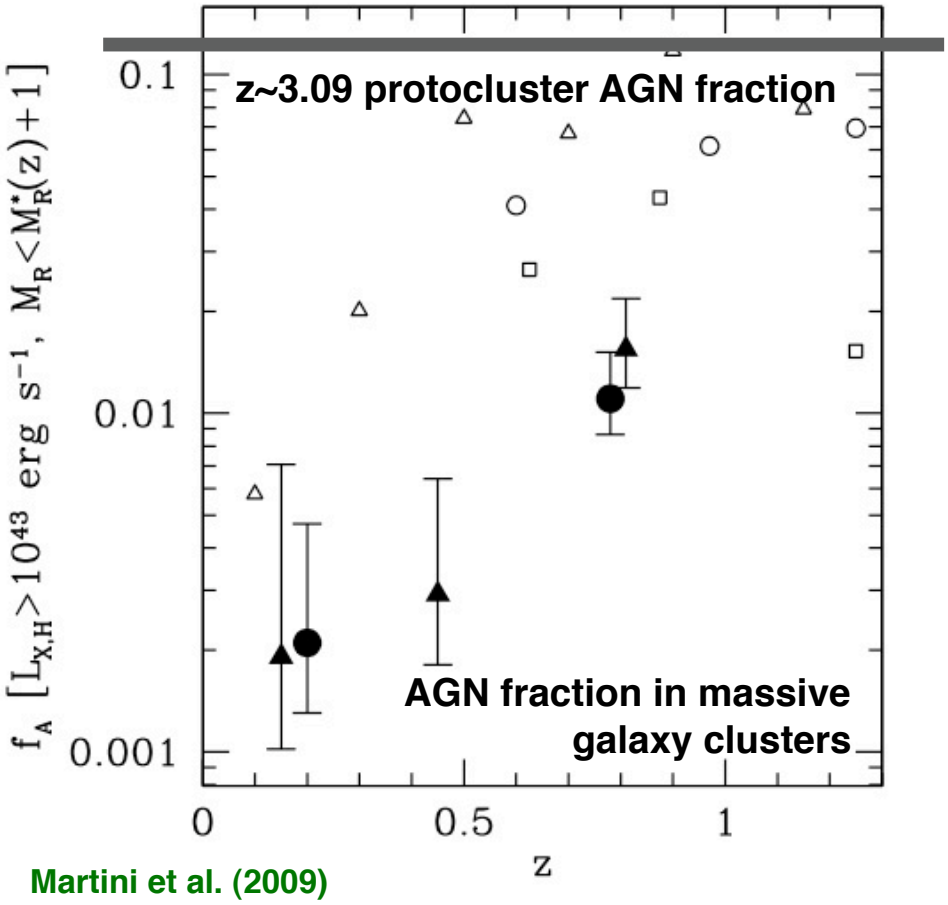
- If the AGN fraction is larger in the protocluster simply due to the presence of more massive SMBHs, then an average protocluster AGN would be more luminous than an average field AGN by the same factor

- For this to be the case, the SMBHs would have to be ≈3−10 times more massive in the protocluster than the field: likely 10^8-10^9 solar masses rather than 10^7-10^8 solar masses

Good agreement with that found for a z=2.3 protocluster (Digby-North et al. 2010)

Implication: the characteristic X-ray luminosity and "active" black-hole mass appears to be a function of environment as well as redshift

And AGN fraction declines to lower redshifts



Martini et al. (2009)

- Significant drop (1-2 orders of magnitude) in AGN fraction for similarly overdense regions at z<1
- AGN activity has been "switched off" in galaxy clusters/protoclusters since z~3 to z<1
- Need to trace this out from z~2-8 with X-ray observations of more protoclusters/overdense regions

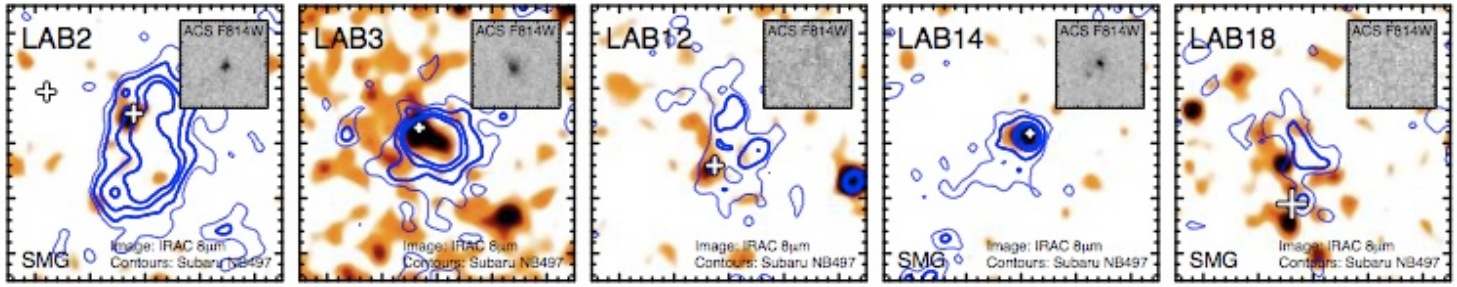
Require more constraints for more protoclusters, particularly at high redshift

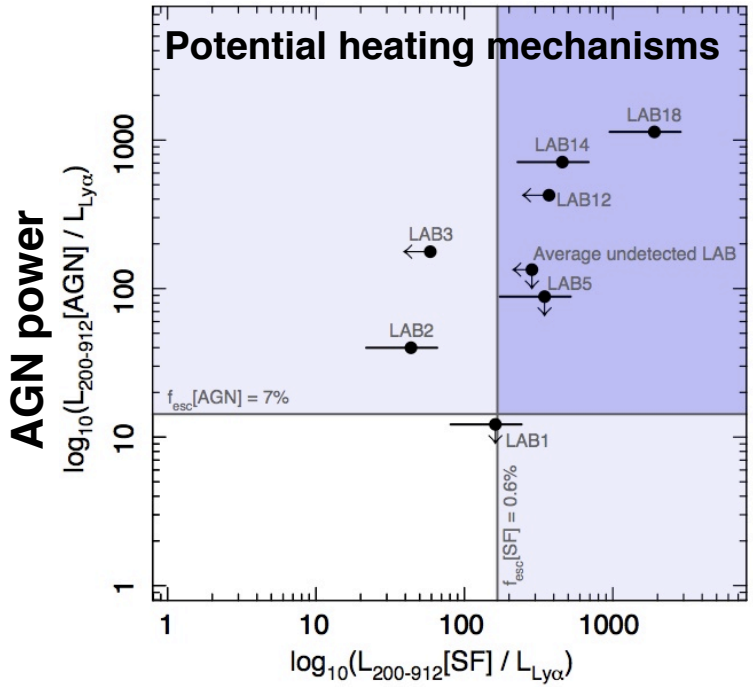
Need deep X-ray observations of other overdense regions
Need wider area X-ray surveys to cover full range of environments

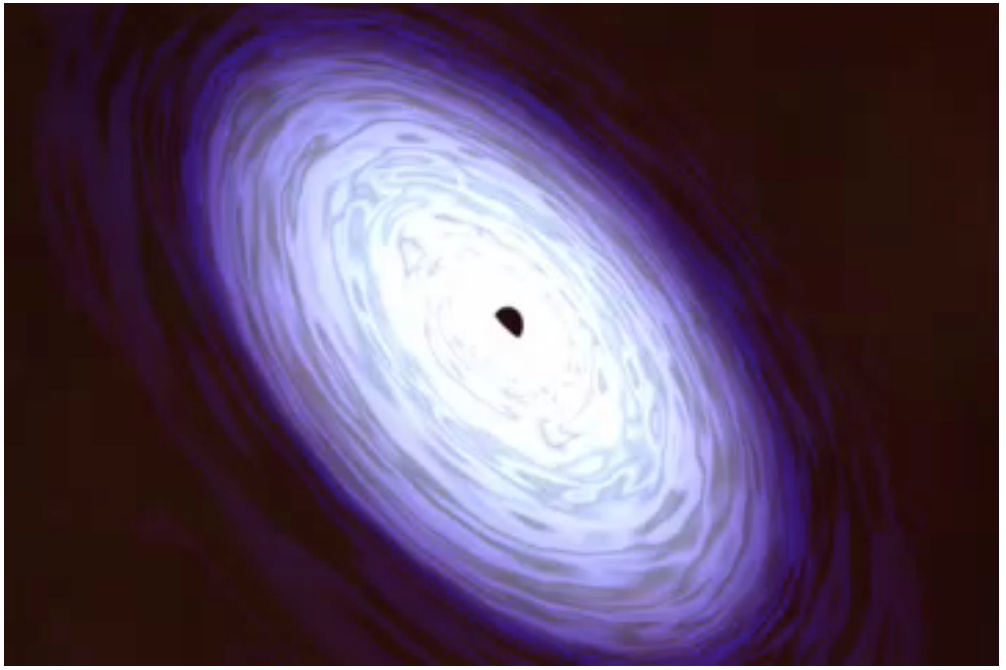
Has heating of the ICM tentatively started?

Geach et al. (2009)

Lyα images of some protocluster AGNs





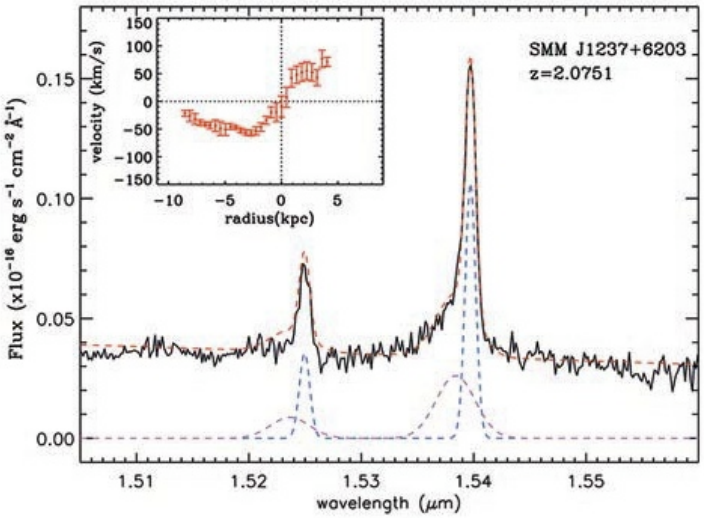


NASA press conference movie; see Geach poster 2.9

~17% of extended Lyα emitters host luminous AGN in the z~3.09 protocluster; AGNs are luminous enough to power the 10-100 kpc extended Lyα emission

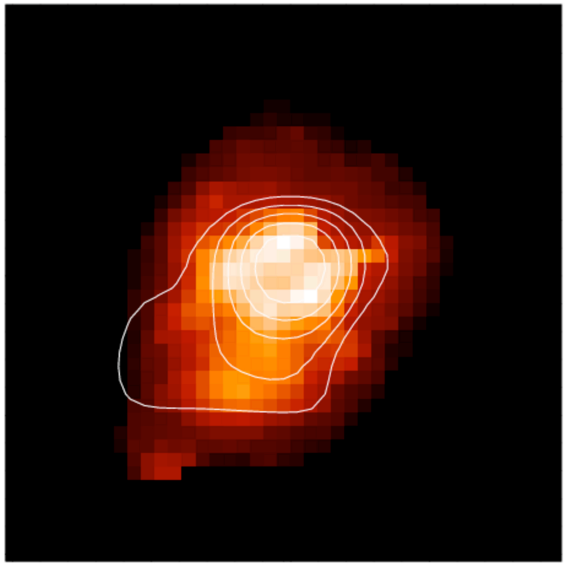
Tentative evidence for feedback inducing blow out?

Collapsed IFU spectrum of z~2.07 SMG

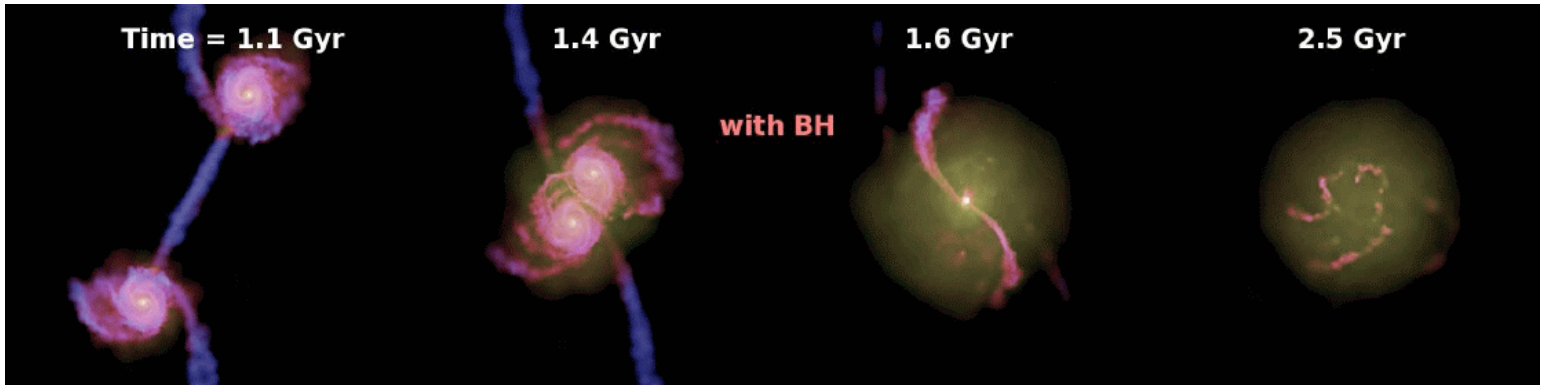


Broad (800 km/s) high-velocity (200-500 km/s) [OIII] gas

~4-8 kpc extent of broad [OIII gas]



Alexander et al. (2010); see Nesvadba and Mullaney talks for further observational constraints



Di Matteo et al. (2005) simulation

Summary

- Deep 400ks Chandra observations of the z=3.09 SSA22 protocluster

- Environmental dependencies on black-hole growth: AGN fraction increases in z~2-3 protoclusters than compared to field - result is seen for both lyman-break galaxies and Lyα emitters

- Galaxies in the protocluster appear to be more luminous than those in the field - this suggests the host galaxies and hence the black holes are also more massive

- AGN fraction significantly decreases compared to field at z<1 - possibly due to gas depletion or heating

- AGN activity in z~3 protocluster is luminous enough to power 10-100 kpc Lyα halos - early evidence for ICM heating?

See Lehmer et al. (2009a,b) and Geach et al. (2009) for the first papers