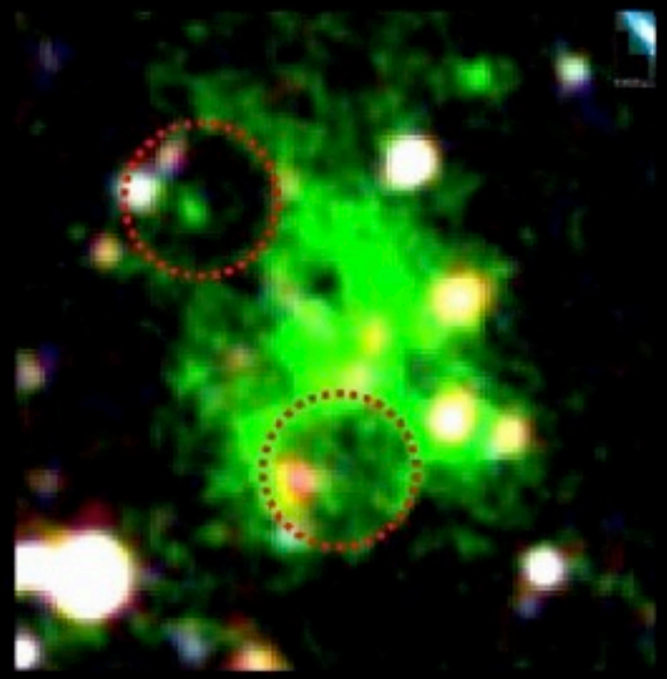
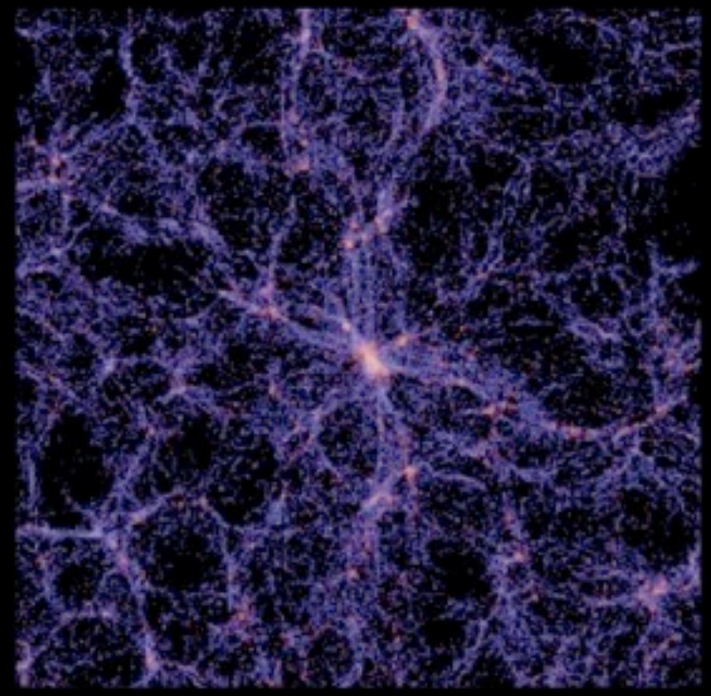
New Results From the *Chandra* Deep Protocluster Survey





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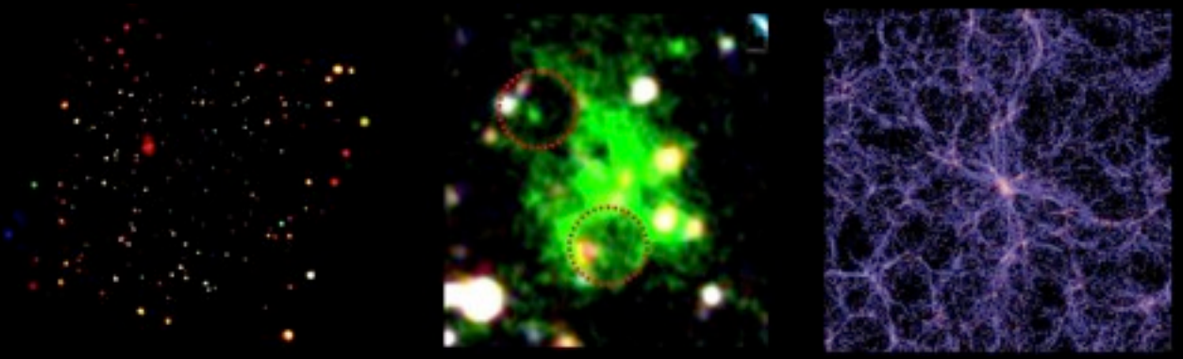
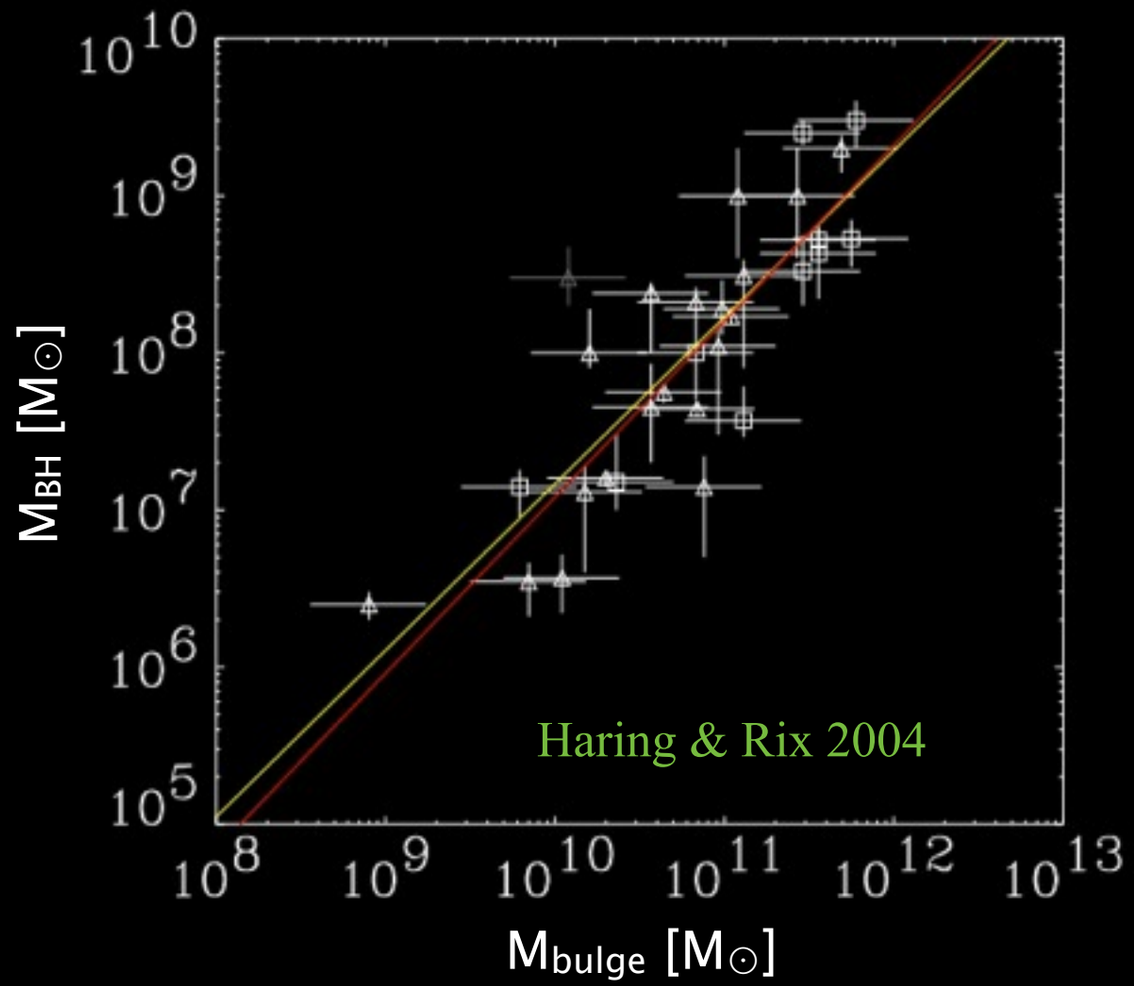
Motivation



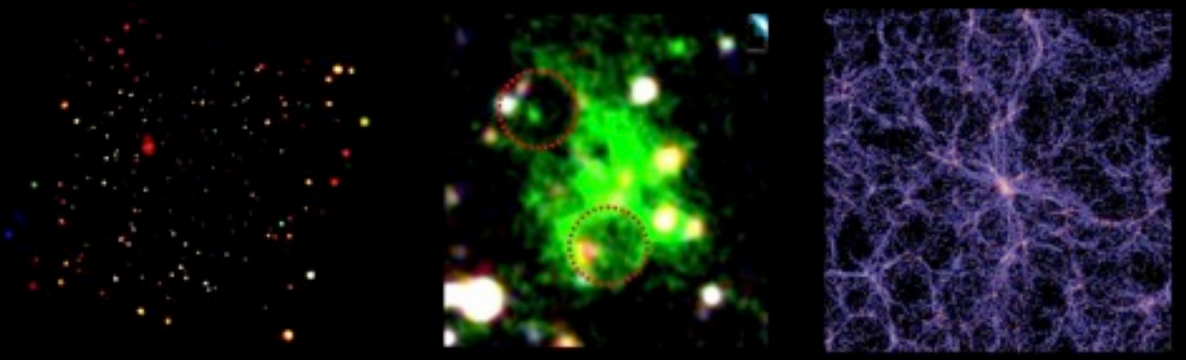
1. Locally $M_{BH}-M_{bulge}$ relation suggests a link between the growth of galaxies and their central supermassive black holes (SMBHs).

2. The oldest and most massive galaxies lie in high-density clusters, suggesting that these galaxies and their central SMBHs assembled relatively early in the cosmic timeline and with growth influenced by environment.

3. Want to better understand this environmental dependence through observations of high-redshift clusters in formation (protoclusters).



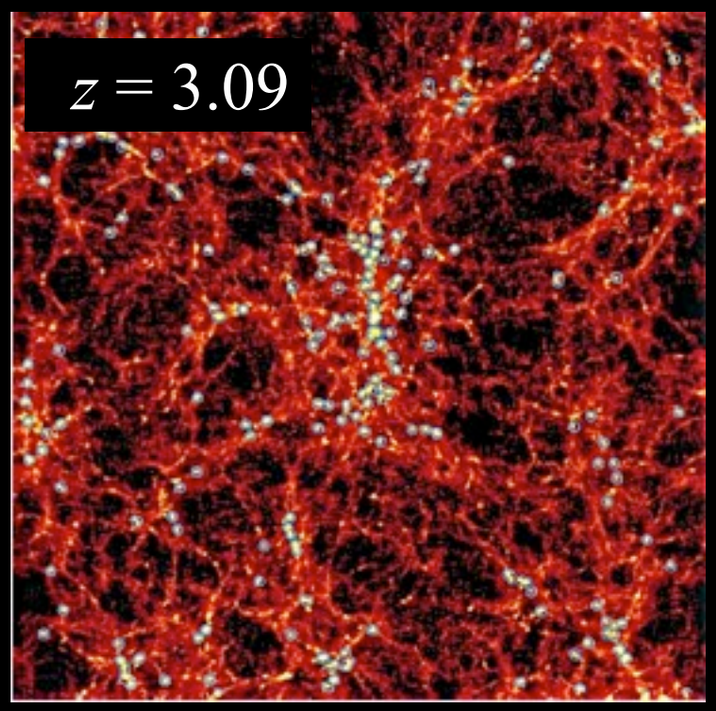
SSA22 Protocluster

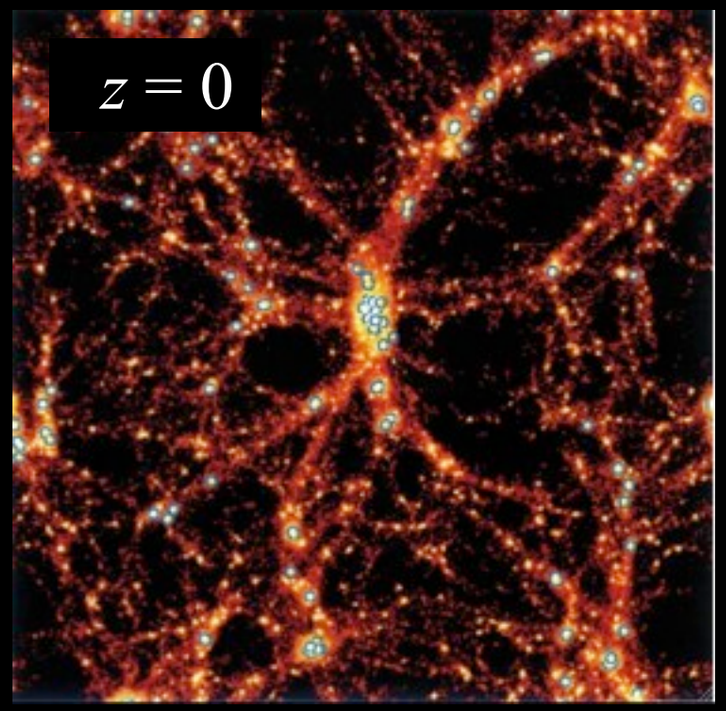


• Identified as a factor of ~6 overdensity of LBGs and LAEs at z =3.09 in the SSA22 field (Steidel+1998; Hayashino+2005; Matsuda+2005).

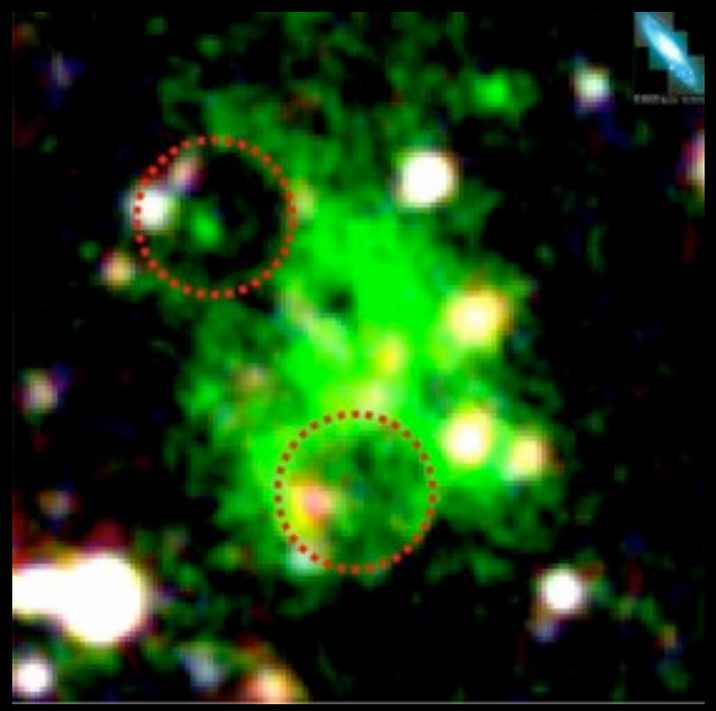
• Measured constraints and simulations of the source populations suggest that the structure will collapse to form a rich cluster (e.g., Coma) by z = 0.

• Several (29) extended Lyα-emitting blobs (LABs) have been identified in SSA22 surrounding massive galaxies (Matsuda+2004) At present, these objects are not well understood physically.



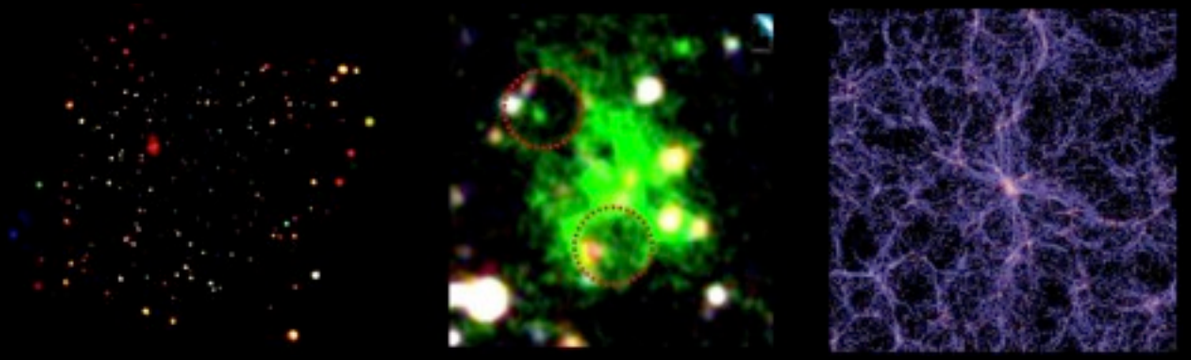


Governato+1998



Matsuda+2005

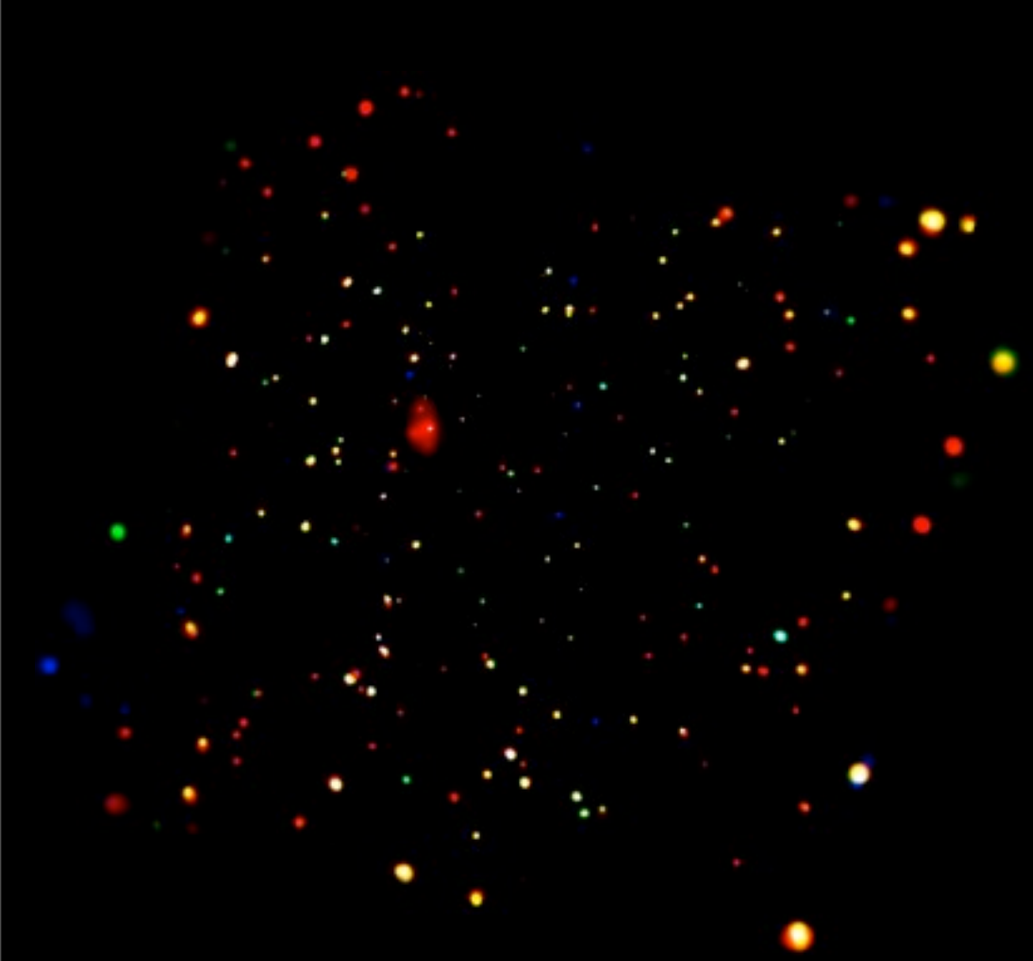
Chandra Observations

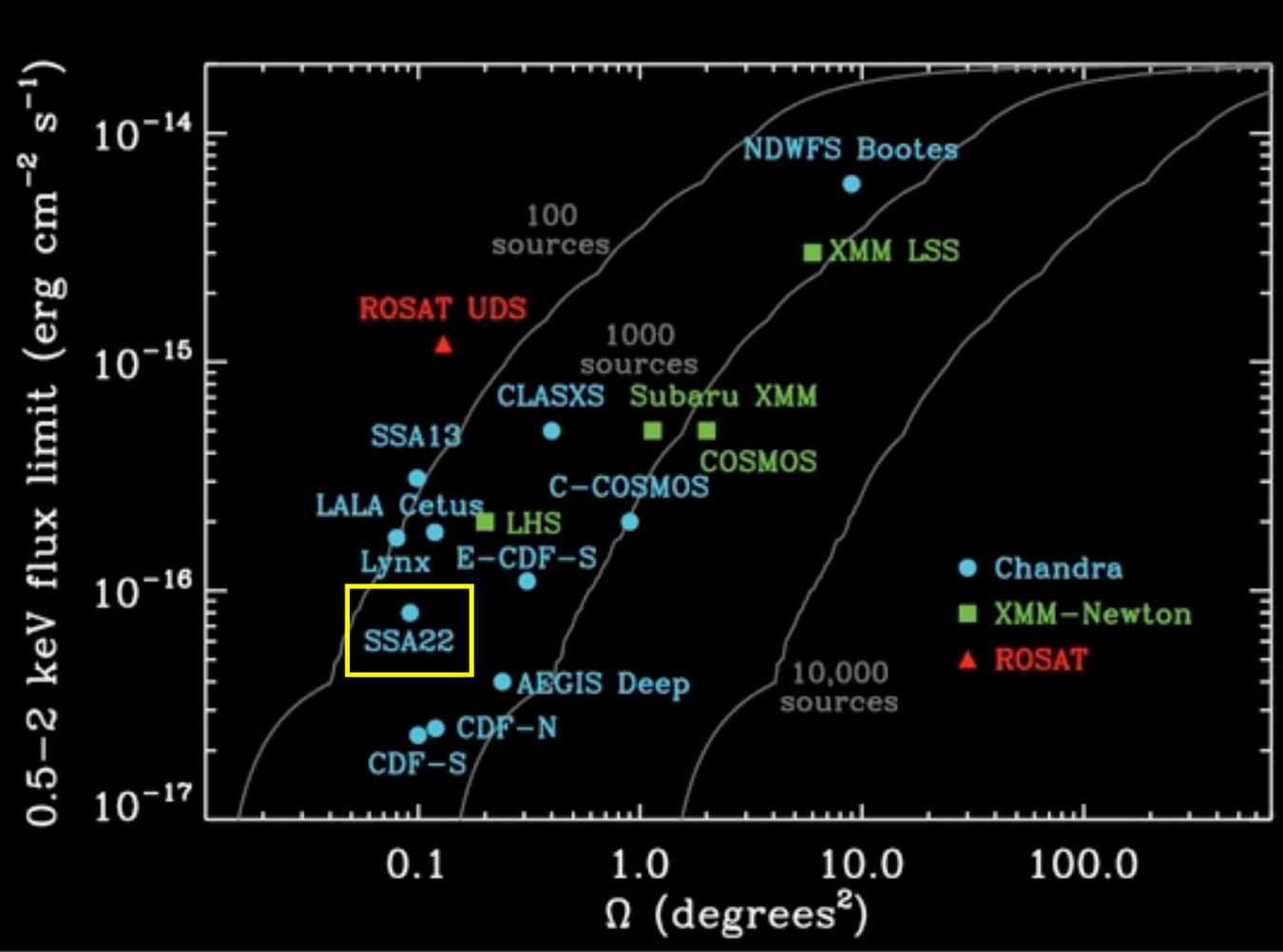


- To better understand the role of SMBH accretion in the protocluster, we have conducted a deep 400 ks *Chandra* (Lehmer+2009) centered on SSA22.

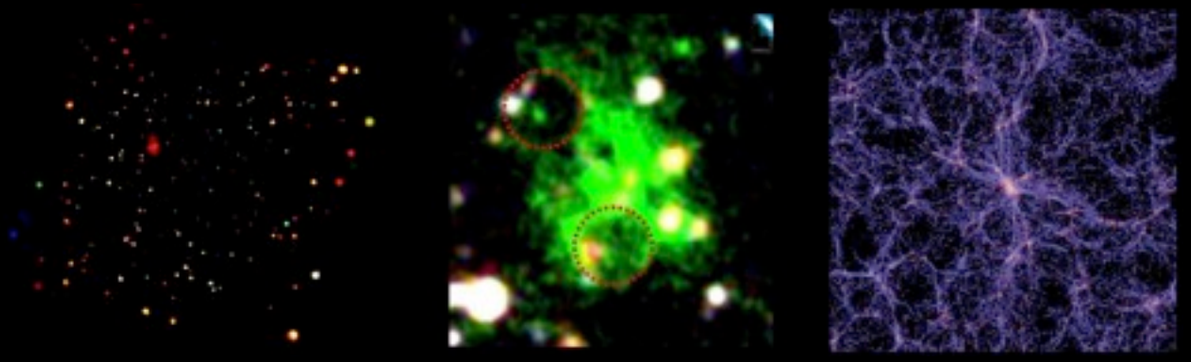
- 297 X-ray sources are detected down to an X-ray flux limit corresponding to $L_X = 10^{43}$ ergs s^{-1} at $z = 3$ (Seyfert-type AGNs); fourth deepest survey yet!

- Several multiwavelength observations are available: *Spitzer* (IRAC and 24um MIPS), *HST,* VLA, SCUBA and Laboca (submm), Subaru (optical), UKIRT (near-IR).





Science Projects



X-ray catalogs and data products available publicly (Lehmer et al. 2009a; MNRAS, in-press, astro-ph/0907.4369). A variety of science topics can benefit from these observations:

1.—The AGN activity in protocluster galaxies versus $z = 3$ field galaxies (Lehmer et al. 2009b; ApJ, 691, 687).

2.—Identifying the power source driving emission from Lyman-α emitting blobs (Geach et al. 2009; ApJ, 700, 1).

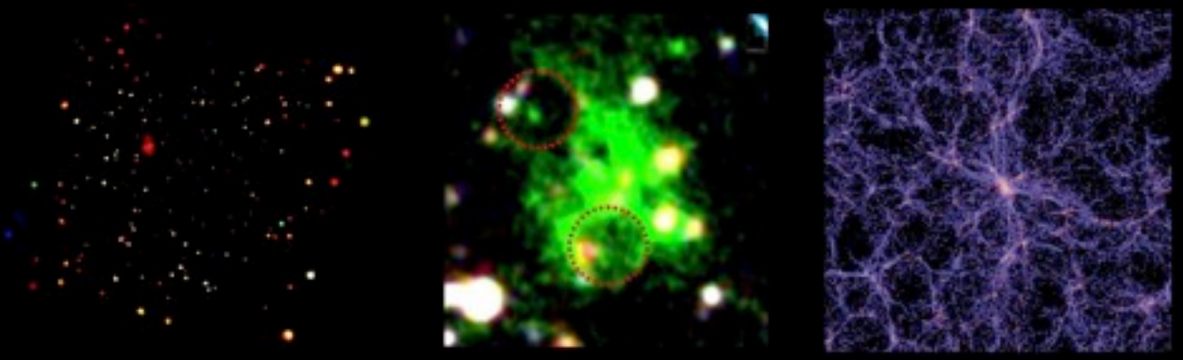
3.—The evolution of AGN activity and their absorption properties over $z = 0-5$.

4.—Evolution of the X-ray emission from normal galaxies (e.g., X-ray binaries, hot gas, supernovae and remnants) out to $z = 0.8$.

5.—X-ray emission from groups and poor clusters.

6.—X-rays from Galactic stars

Science Projects



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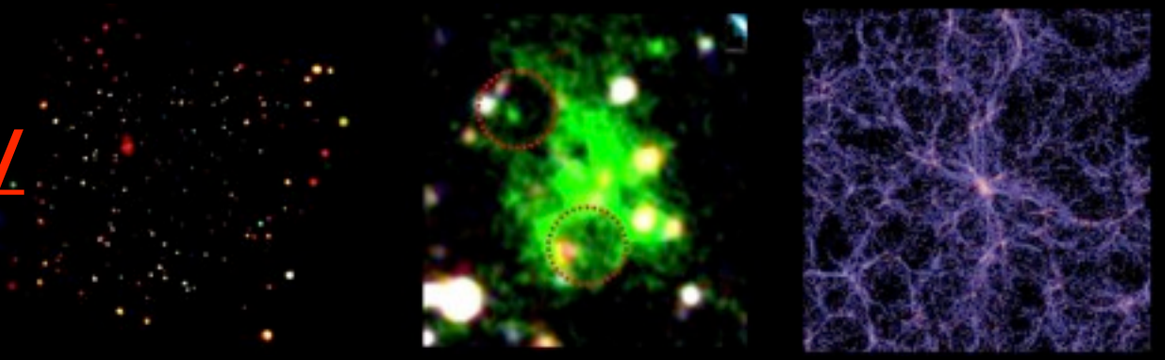
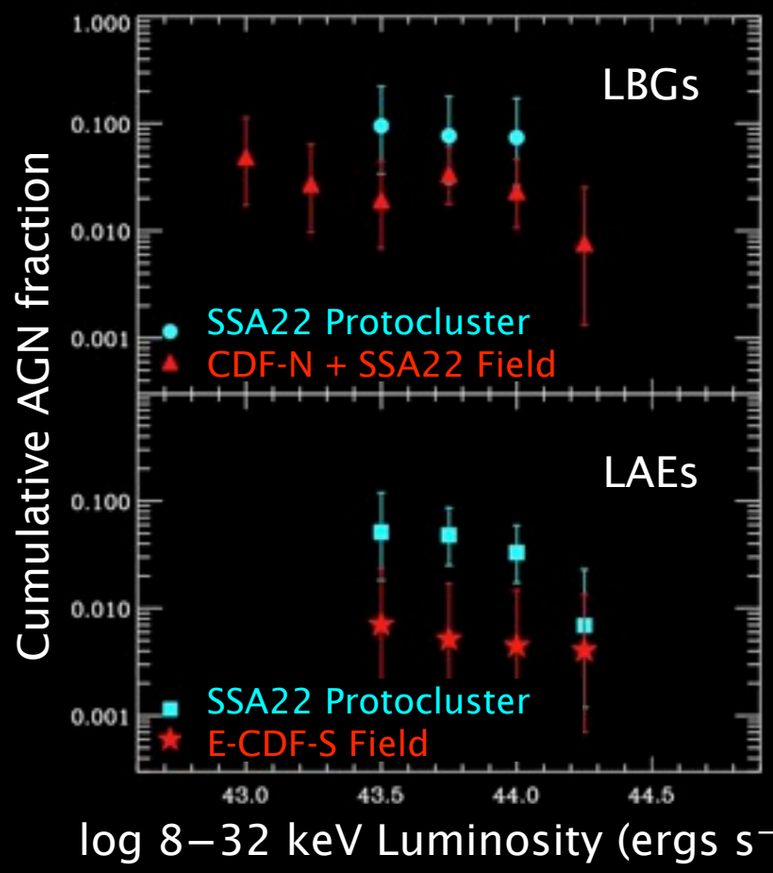
Protocluster AGN Activity

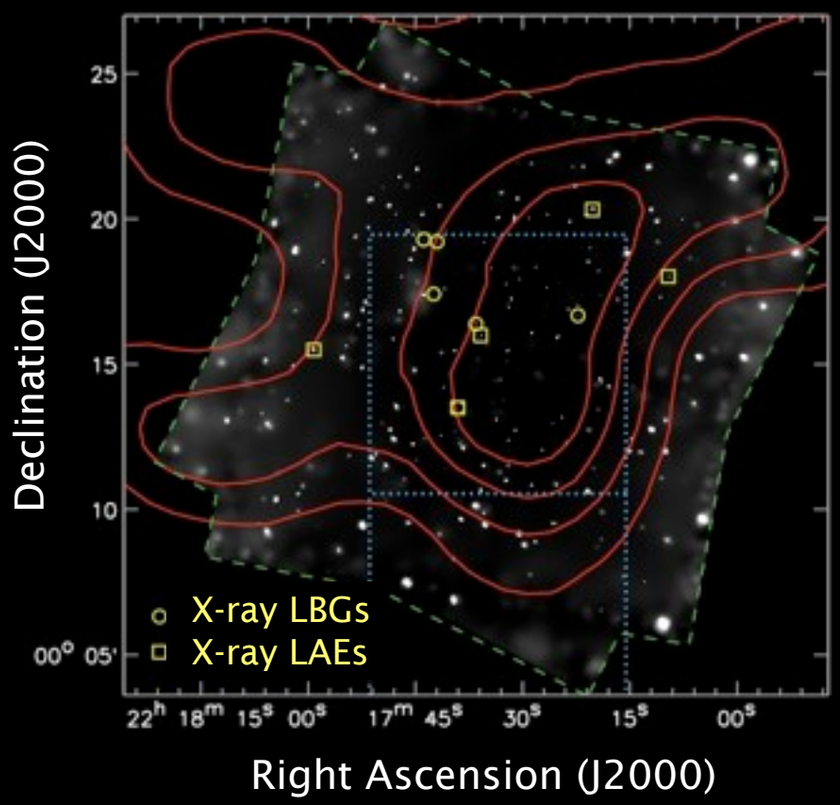
(Lehmer et al. 2009; ApJ, 691, 687)

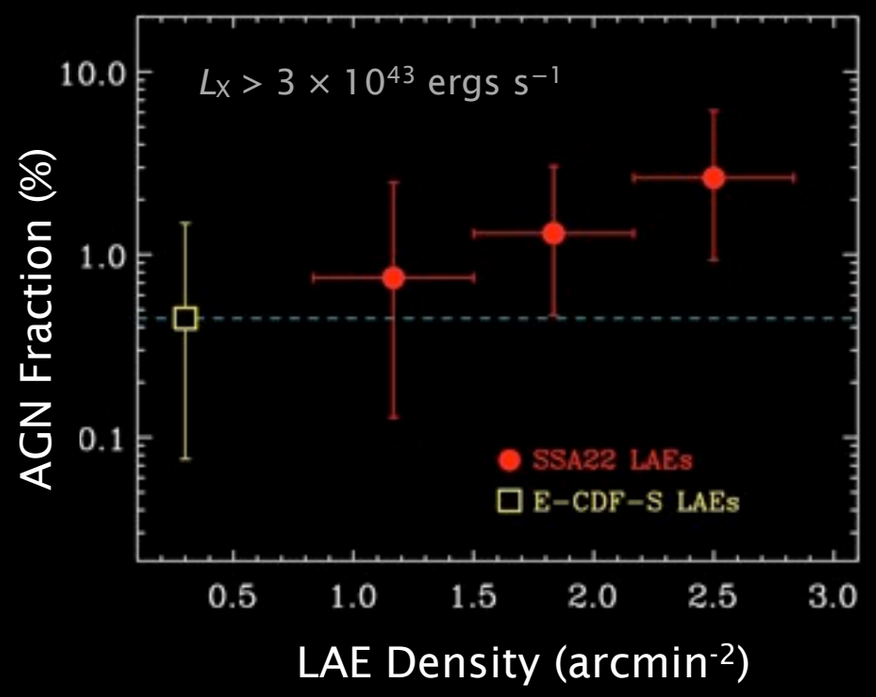


GOAL: To measure how AGN activity in protocluster LBGs and LAEs compares to similar $z \sim 3$ galaxies found in blank-field surveys (CDF-N and E-CDF-S).

- We created a PROTOCLUSTER SAMPLE of ~30 LBGs and ~150 LAEs confirmed to lie at $z = 3.09$ (SSA22) and a FIELD SAMPLE of ~130 LBGs and ~250 LAEs confirmed to lie in field environments (SSA22, CDF-N, and E-CDF-S).
- In total, 6 protocluster and 8 field galaxies were X-ray detected AGNs. The AGN fraction is ~2−15 times larger in protocluster galaxies than field galaxies.

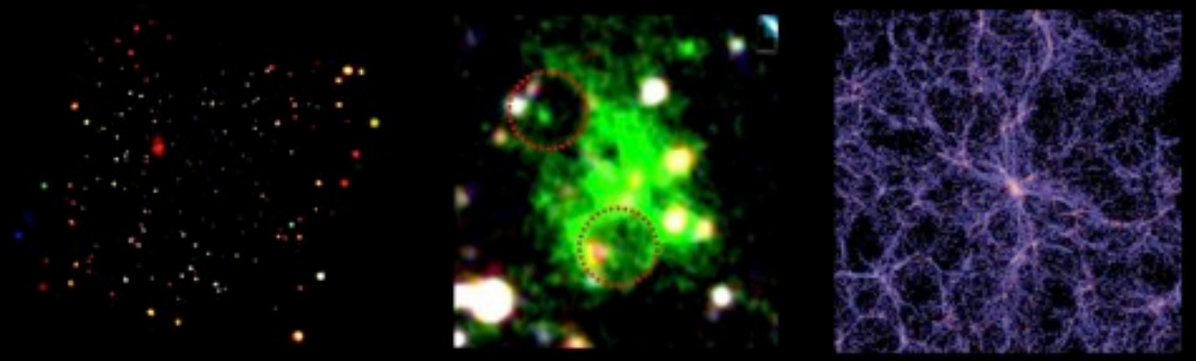






Physical Interpretation

(Lehmer et al. 2009; ApJ, 691, 687)



• Theoretical studies predict that merger activity in SSA22 galaxies will peak around $z = 3-4$, leading to enhanced growth of galaxies and SMBHs in these environments (e.g., Volonteri+2003).

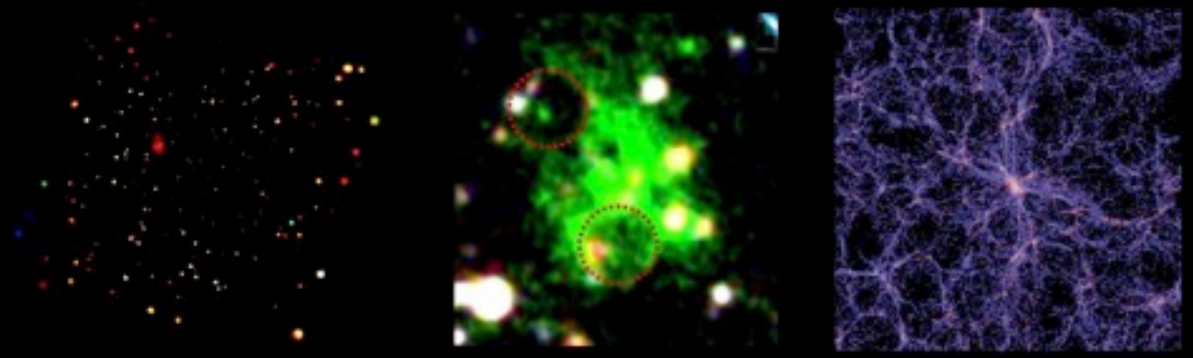
• An enhancement in the AGN fraction in the protocluster compared to the field may be due to:

(a) An enhancement in the average accretion rate (i.e., larger L/L_{Edd}) or accretion event frequency (e.g., via mergers).

(b) The presence of more massive galaxies and SMBHs in the protocluster.

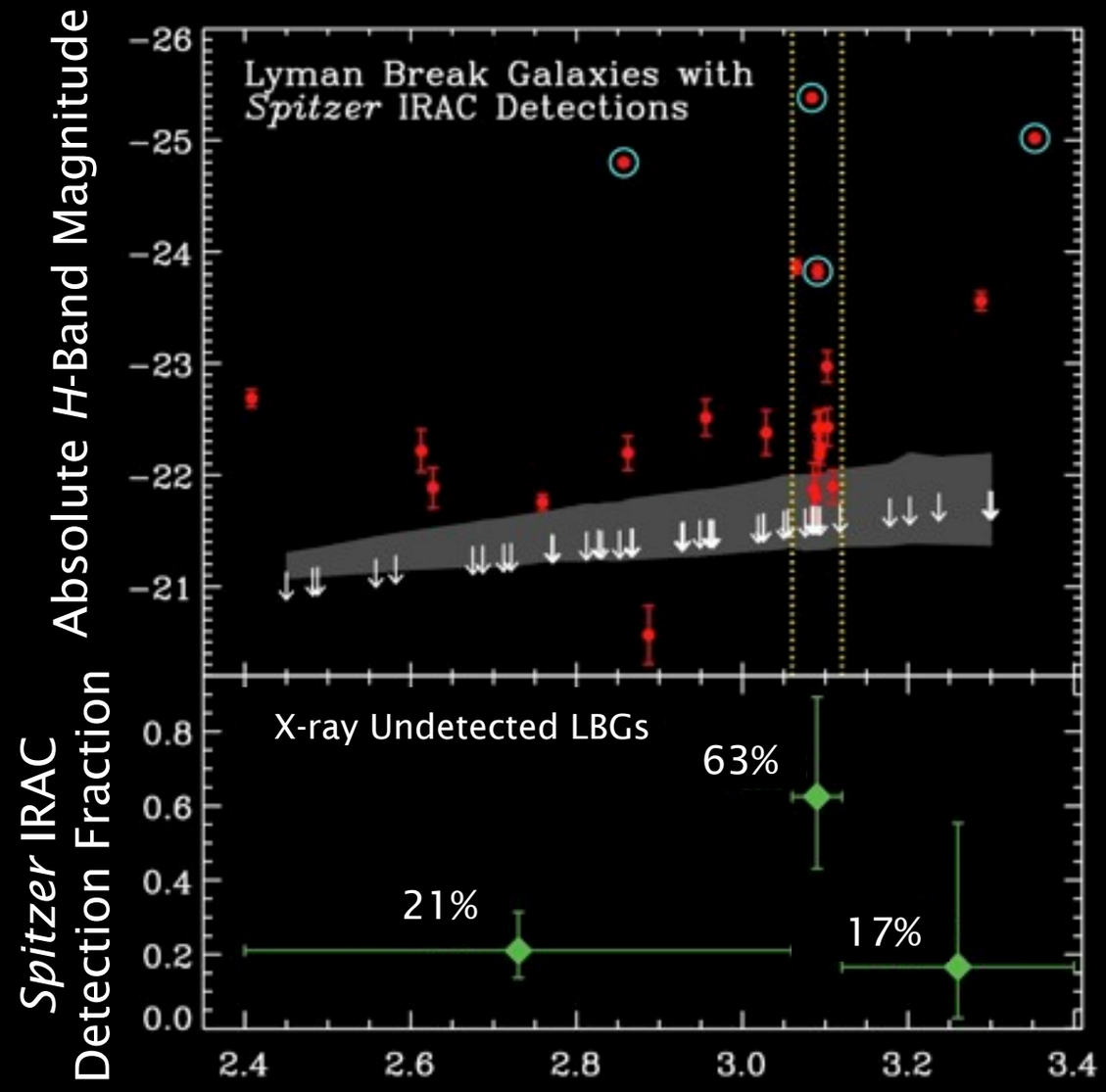
Enhancement of Galaxy and SMBH Masses?

(Lehmer et al. 2009; ApJ, 691, 687)

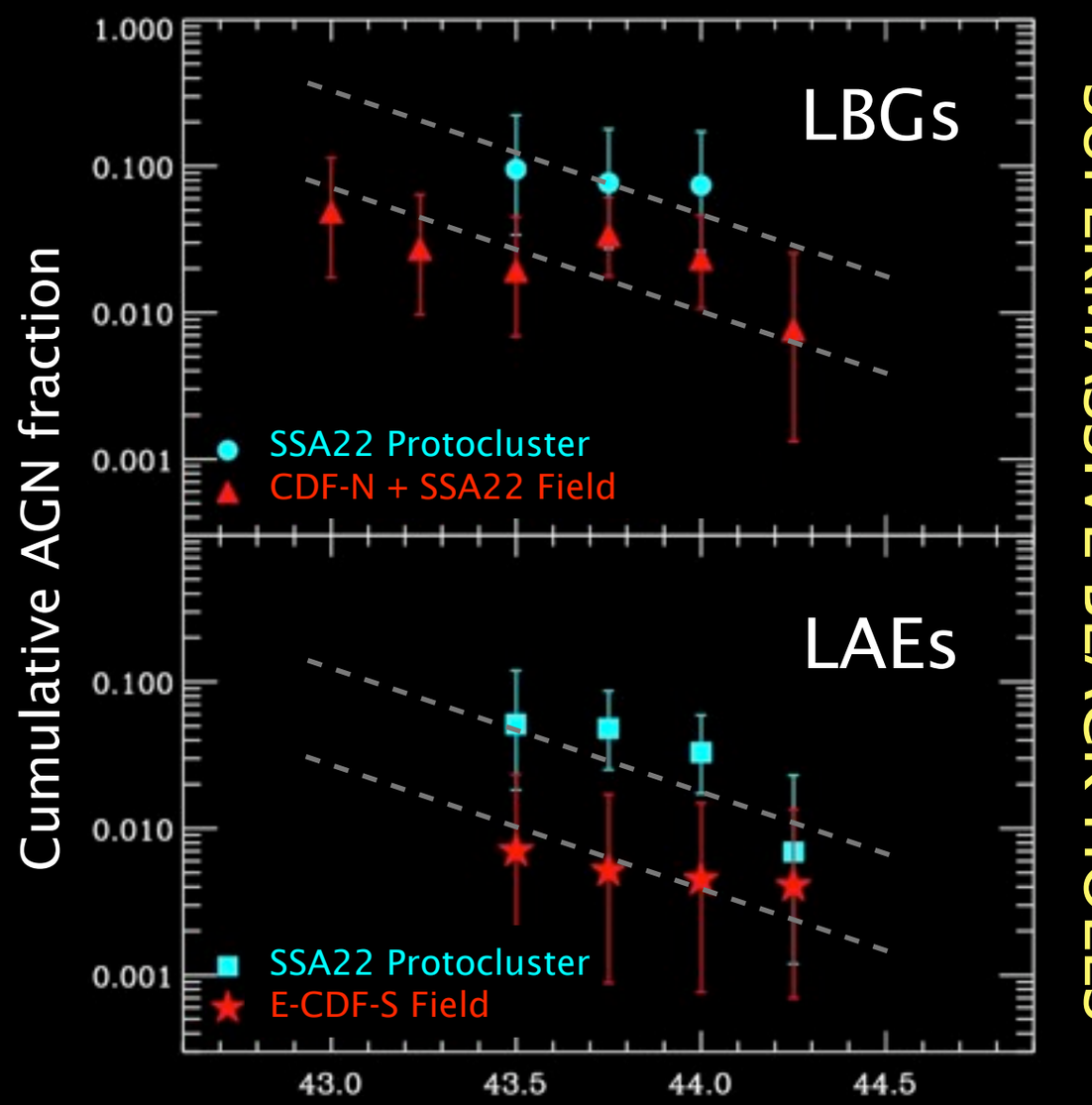


- Using our multiwavelength data, we measure median host luminosities (proxy for stellar mass) to be ≥1.2−1.8 larger in the protocluster versus the field.
- If the AGN fraction is larger in the protocluster simply due to more massive SMBHs, then the SMBHs would have to be at least ≈3−10 times more massive.

GALAXIES

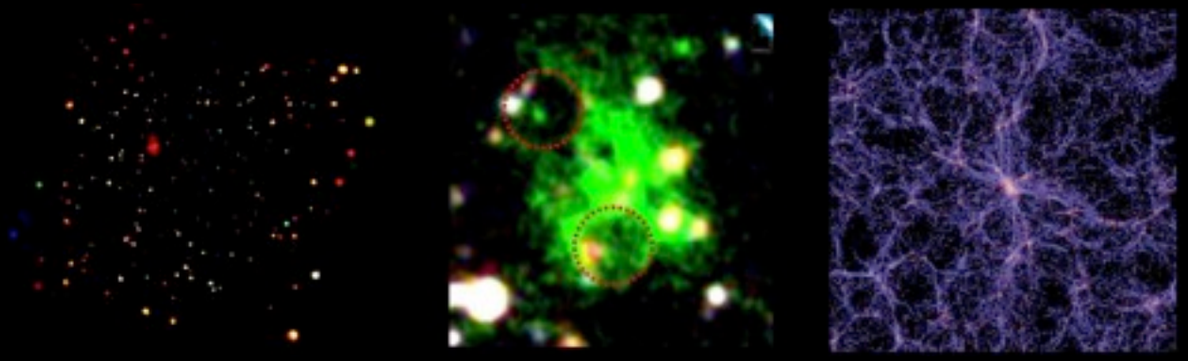


SUPERMASSIVE BLACK HOLES



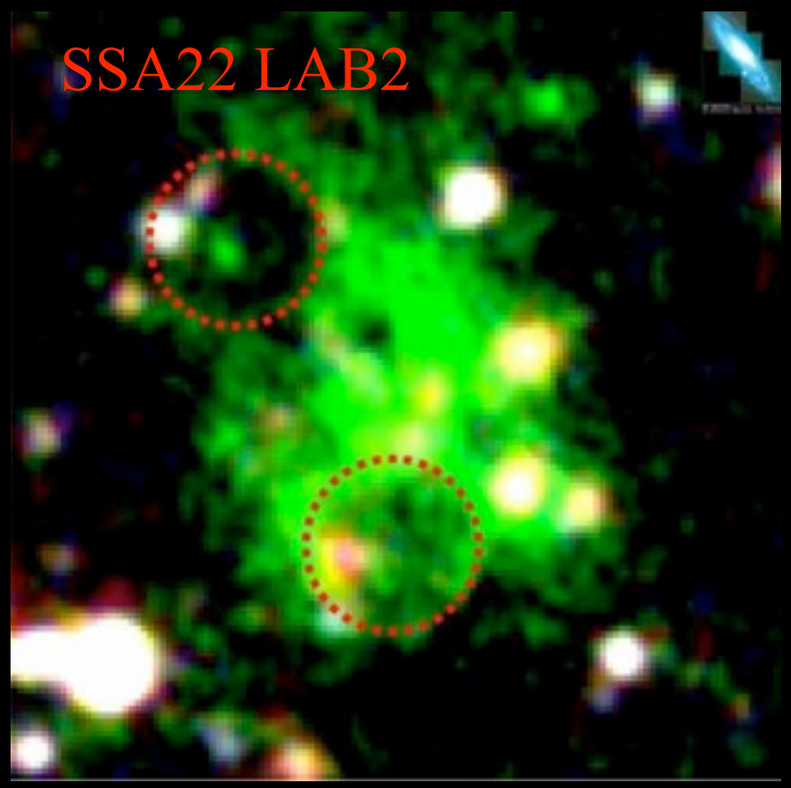
Lyman-α Blobs (LABs)

(Geach et al. 2009; ApJ, 700, 1)

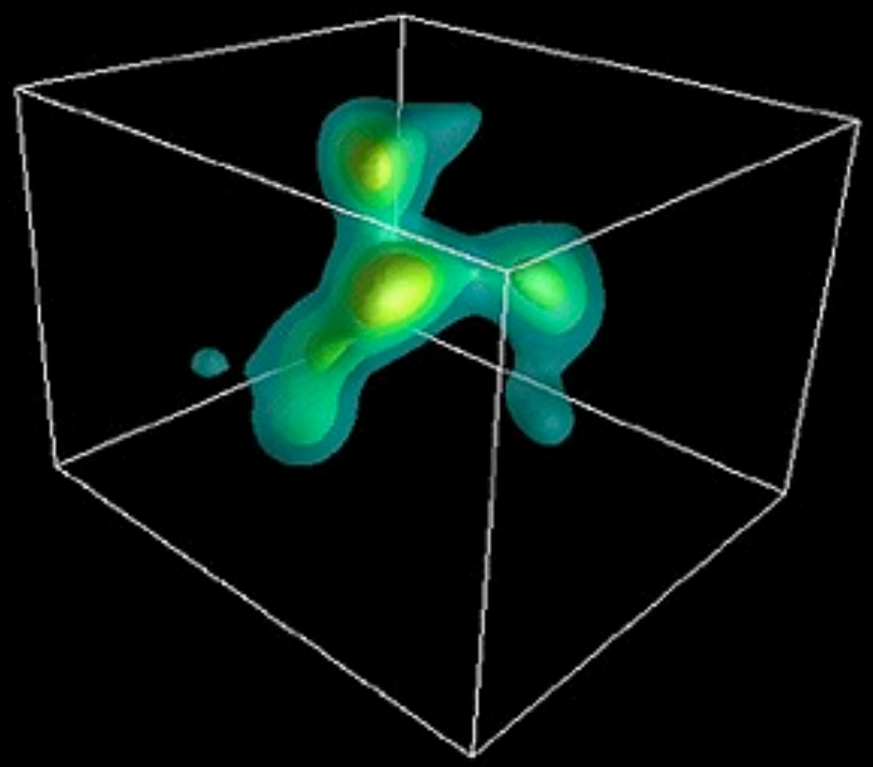


- Lyα-emitting blobs appear to be a common high-redshift phenomenon associated with cluster formation. Within the *Chandra*−observed regions in SSA22, there are 29 extended LABs with average sizes of ~30−113 kpc.
- LABs may form as gas cools through 10^4 K in the process of forming galaxies; however, these structures may be maintained by AGNs or SF feedback.

GOAL: To constrain the role of AGNs and SF activity in LAB production.

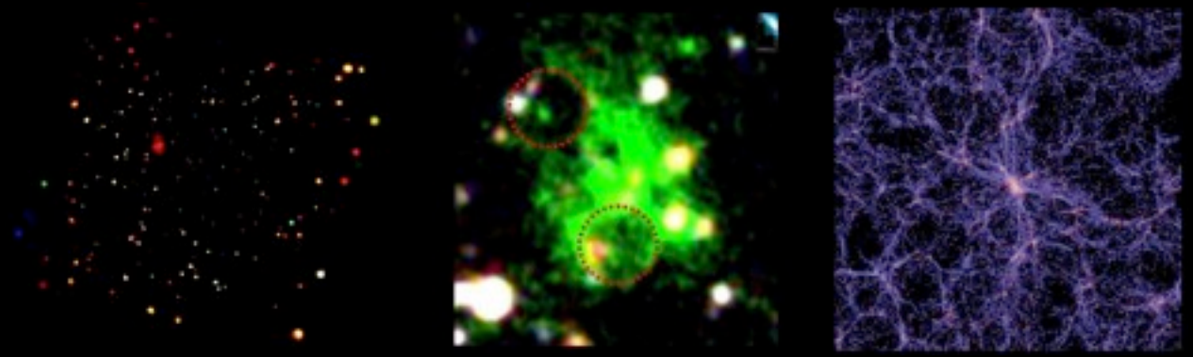


Matsuda+2005



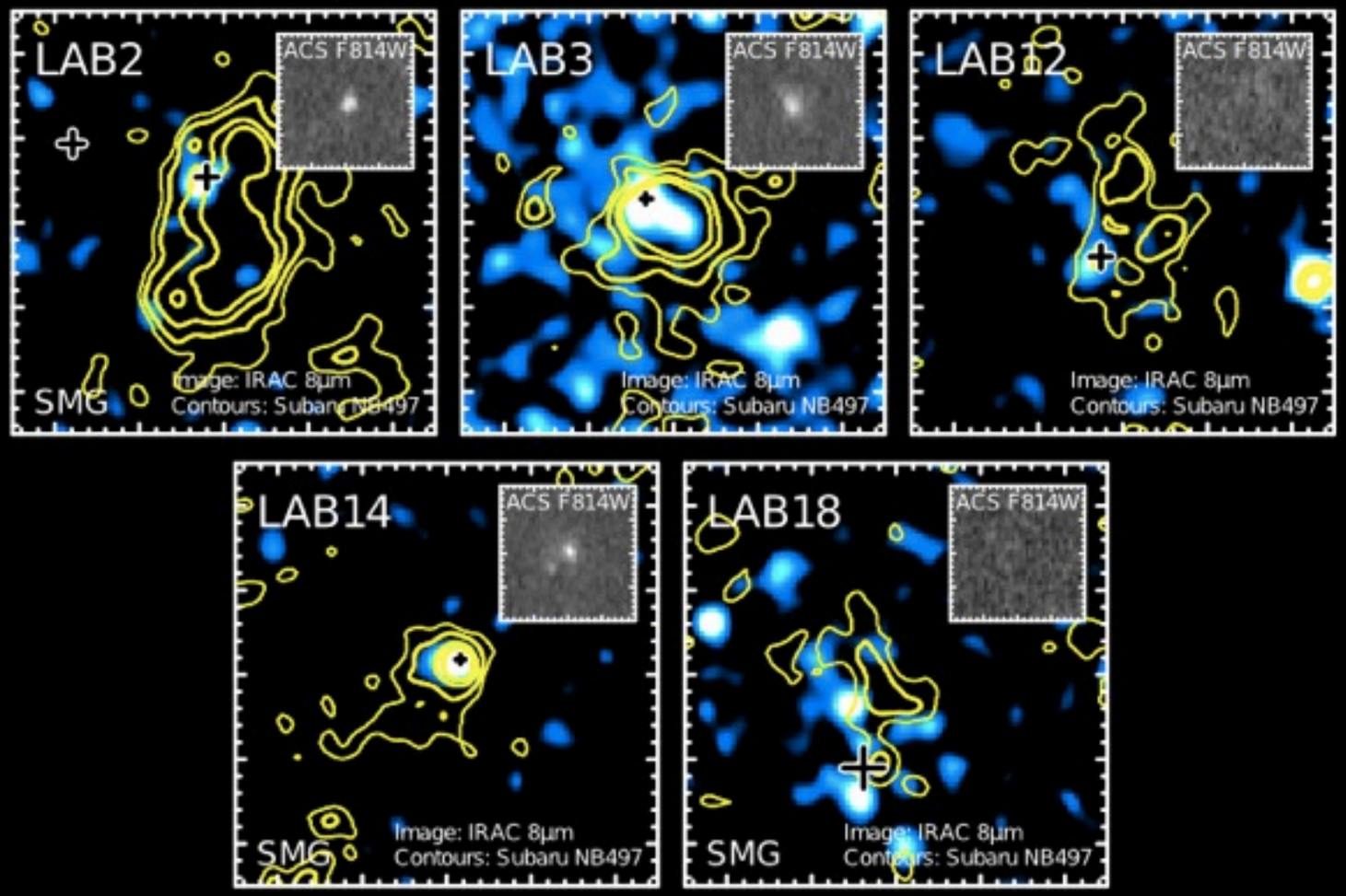
X-rays from LABs

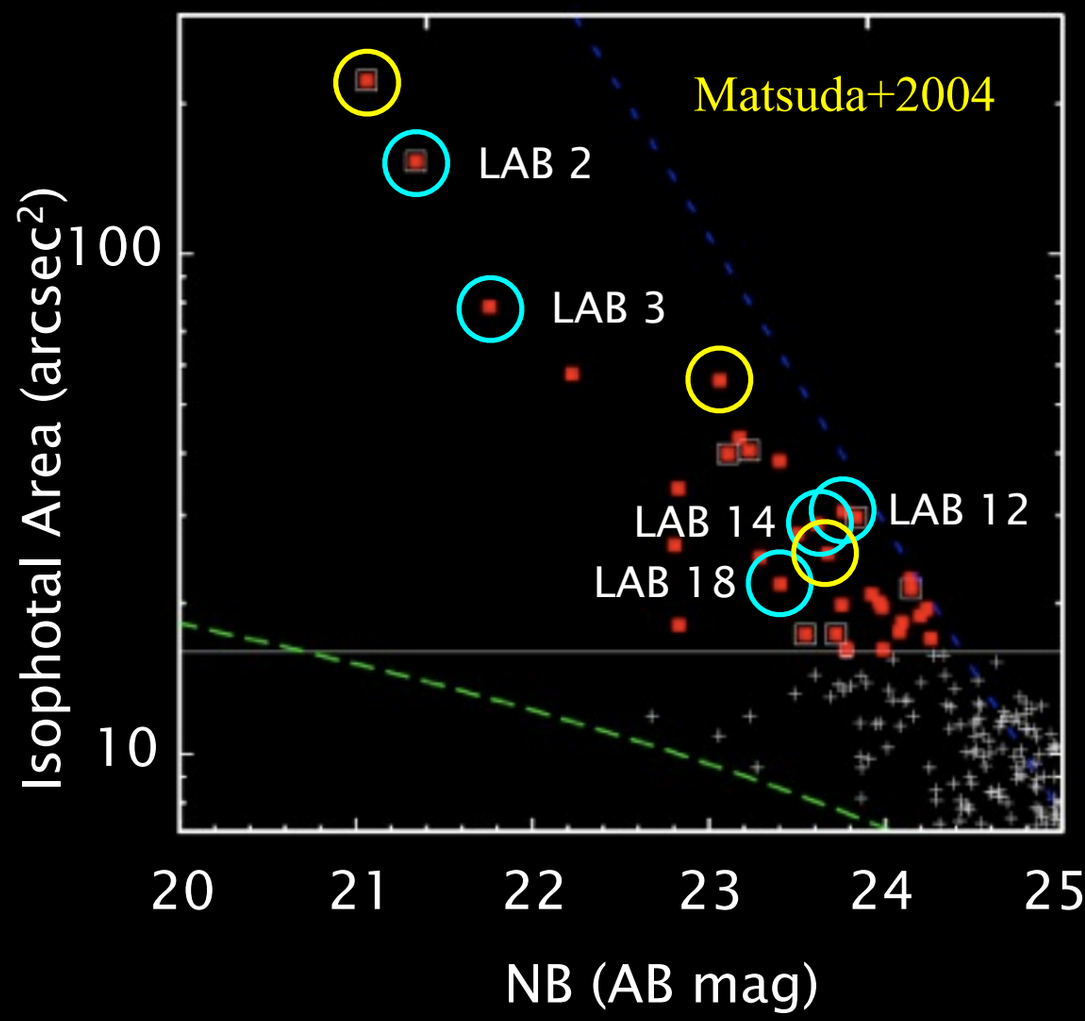
(Geach et al. 2009; ApJ, 700, 1)



- Of the 29 LABs, we found five X-ray AGNs with significant X-ray absorption present. An additional three LABs have counterparts with infrared evidence for obscured AGN activity.

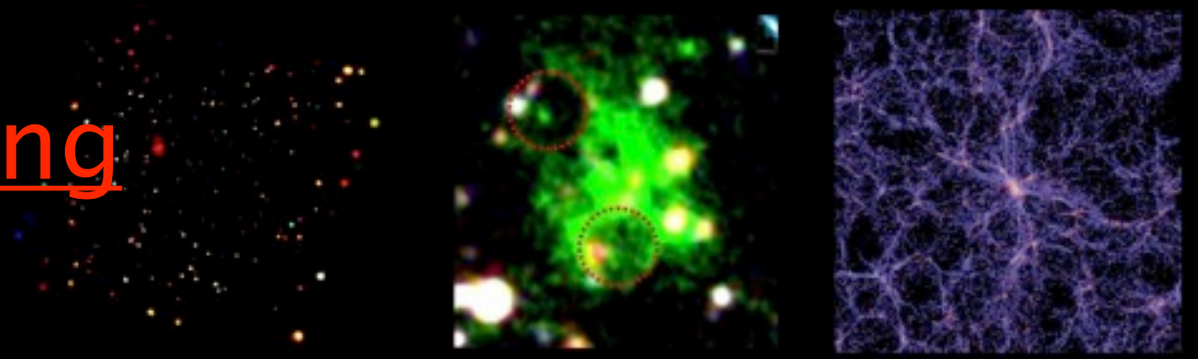
- The relatively large AGN fraction (~20−40%) indicates a potential connection between the production of LABs and AGN activity.





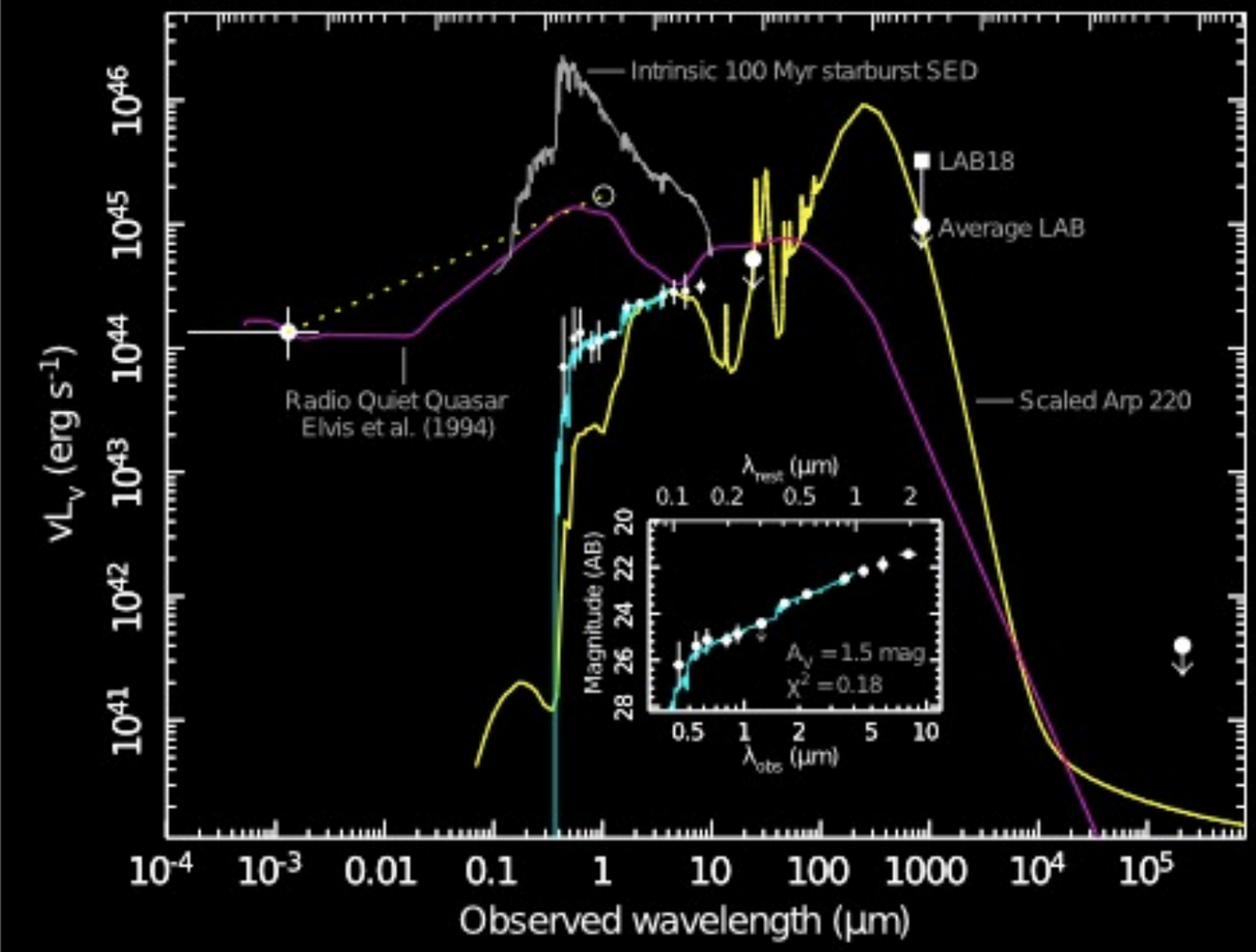
Powering LABs via Heating

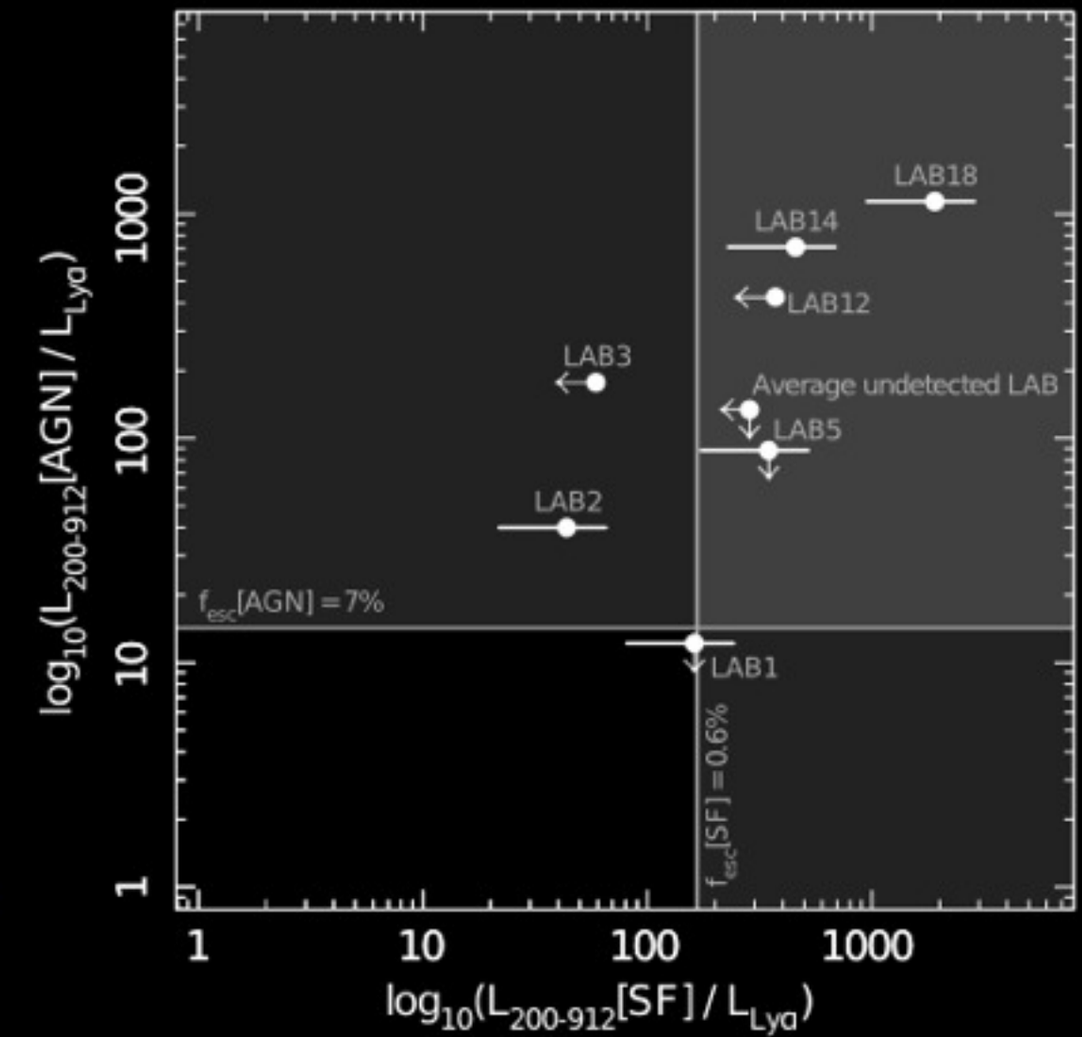
(Geach et al. 2009; ApJ, 700, 1)



- X-ray and submm constraints indicate AGNs and star-formation in LAB host galaxies produce plenty of ionizing radiation to power the Lyα emission.

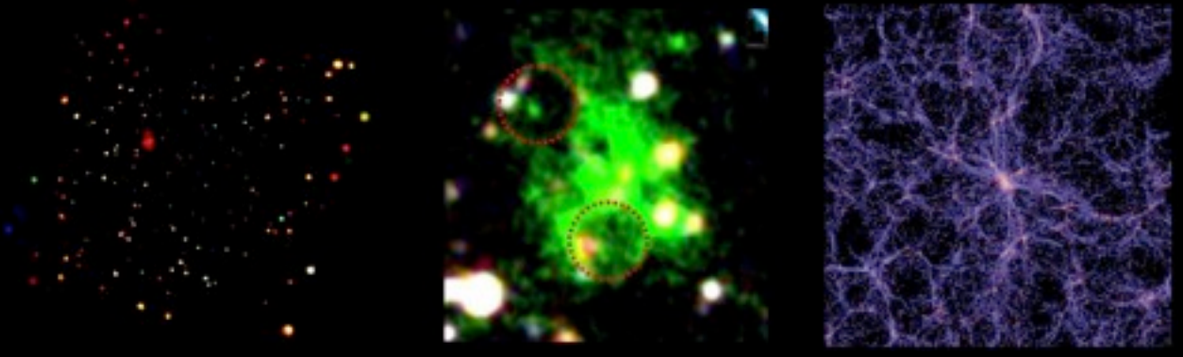
- Additionally, mechanical heating from supernovae and AGN winds are also expected to contribute to ionization.





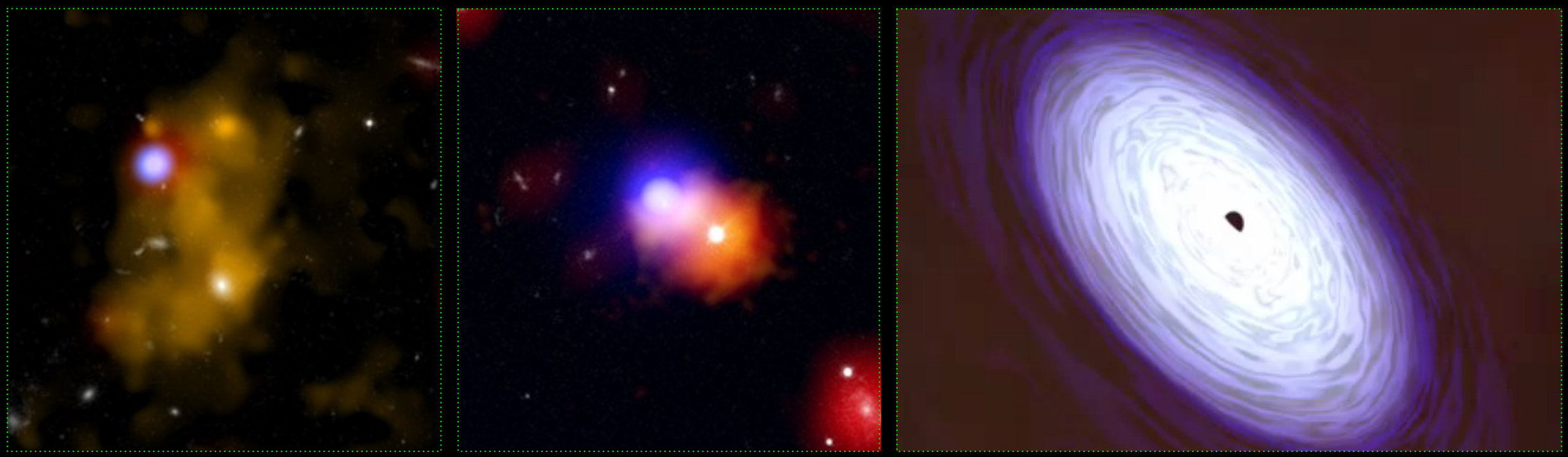
Physical Interpretation

(Geach et al. 2009; ApJ, 700, 1)



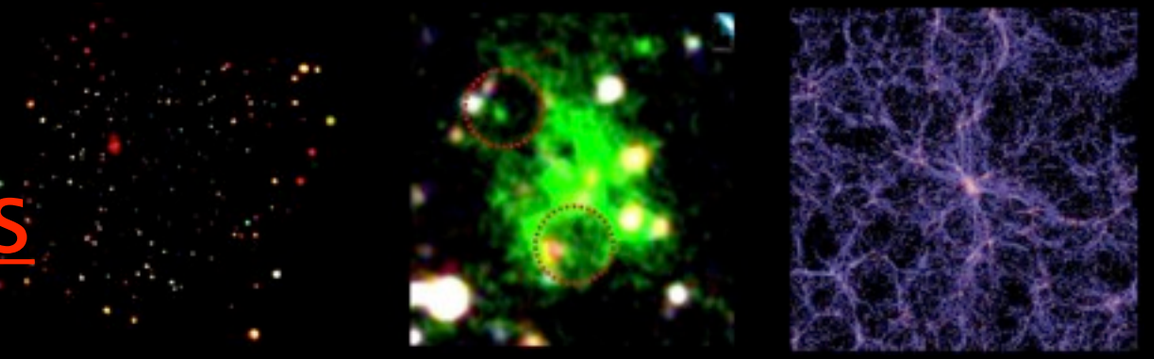
• LABs are likely cooling debris left over from galaxy formation: smaller LABs may be cocoons with galaxies forming inside, while larger X-ray luminous LABs likely represent an advanced stage in galaxy evolution where surrounding gas is being illuminated by starburst and AGN feedback.

• Such Feedback processes may be important in keeping the gas from forming stars, which would otherwise make the galaxies more massive than is actually observed (e.g., Croton+2006; Bower+2006).



June 24, 2009 CXC Press Release: http://chandra.harvard.edu/press/09_releases/press_062409.html

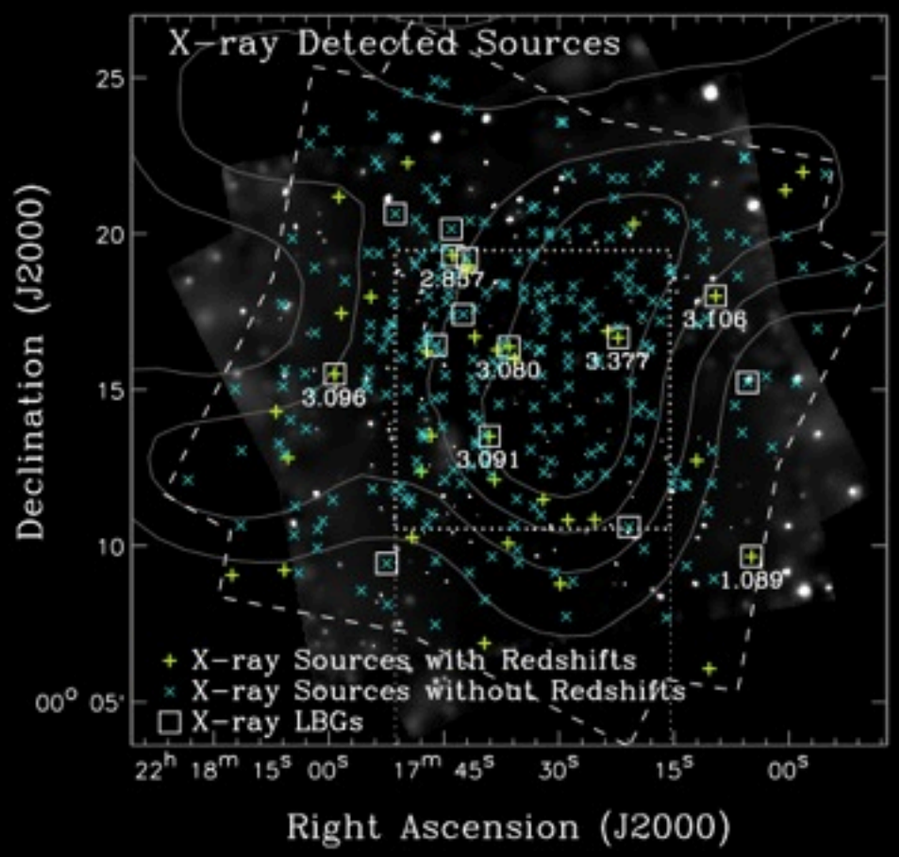
Future SSA22 Constraints

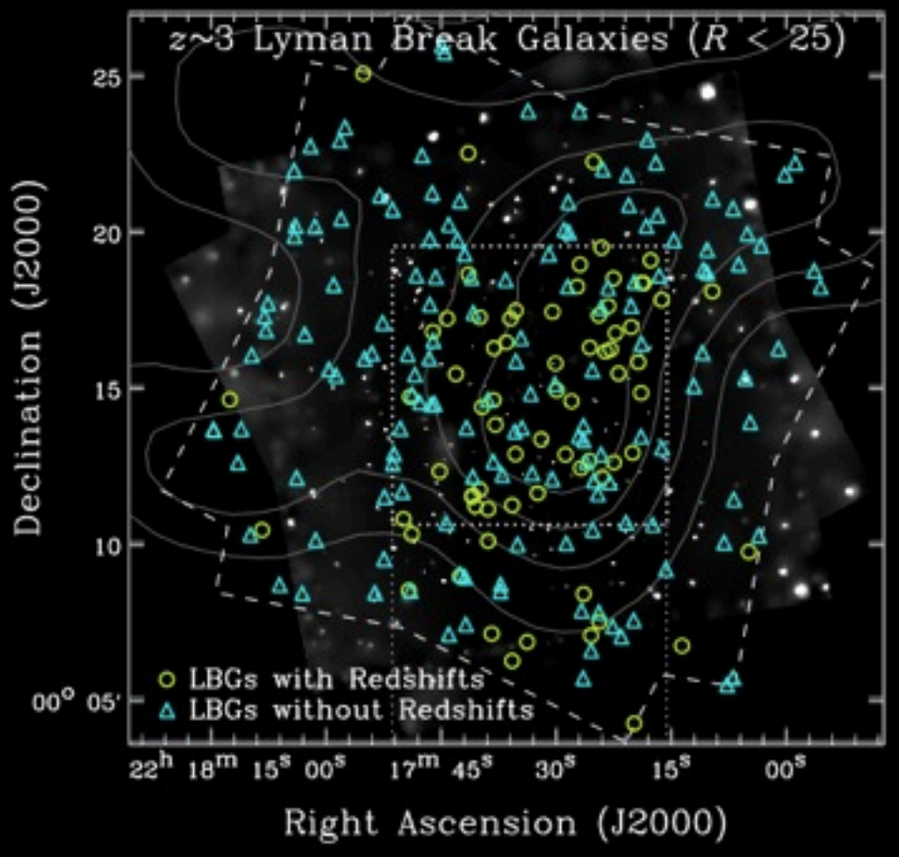


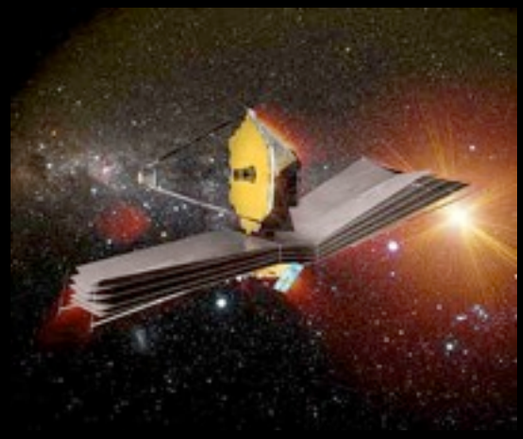
- Loads of science still to be done!!! Currently lack spectroscopic redshifts for 88% of X-ray sources and 75% of moderately bright LBGs!

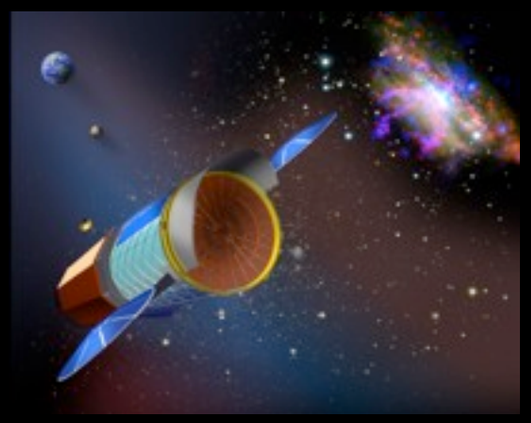
- Near-IR Observations with *HST* and in the future *JWST* will allow us to spatially measure merger rates and place tighter constraints on stellar mass. These observations will be crucial in identifying what drives black hole growth.

- Future observatories such as *JWST* and *IXO* will hopefully place constraints on outflows from starburst and AGNs constraining mechanical feedback at $z \sim 3$.

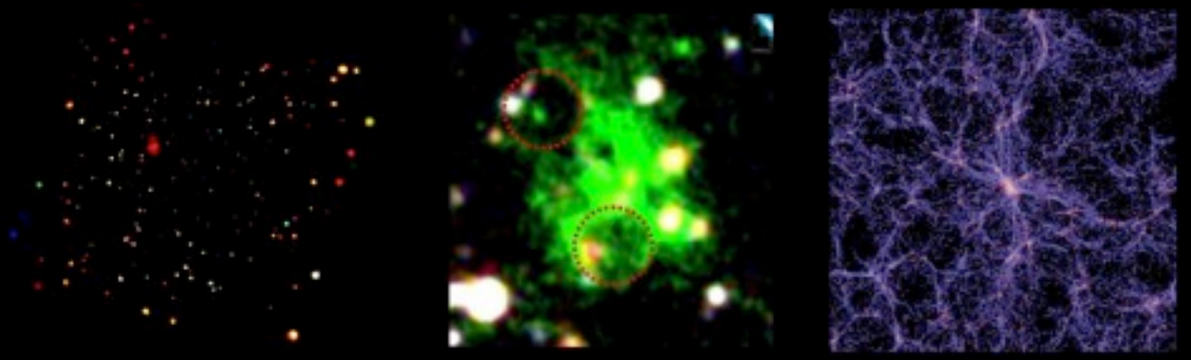








Summary



• X-ray catalogs and data products will be released soon in a forthcoming paper (Lehmer et al. 2009; MNRAS, in-press). Future multiwavelength observations and studies of SSA22 are currently underway ...

• We find that the AGN fraction of LBGs and LAEs is enhanced by a factor of ~6 in the $z = 3.09$ SSA22 protocluster compared to the lower-density field population at $z \approx 3$. This is possibly due to the presence of more massive SMBHs and galaxies and/or enhanced accretion activity (duty cycle, accretion efficiency) (see Lehmer et al. 2009; ApJ, 691, 687).

• Lyman-α blobs are commonly associated with massive galaxies and often AGNs. The AGN and SF activity in typical LABs is more than sufficient to power the Lyman-α suggesting heating is likely important in LAB production (Geach et al. 2009; ApJ, 700, 1).

• Additional deeper and/or wider multiwavelength surveys can help quantify how AGN activity at $z \approx 3$ depends on environment and future telescopes (e.g., *JWST*, *Herschel*, *IXO*) will enable the study of detailed properties of the AGNs and galaxies and their growth.