The X-ray Evolution of Early-Type Galaxies in the Extended Chandra Deep Field-South (E-CDF-S)

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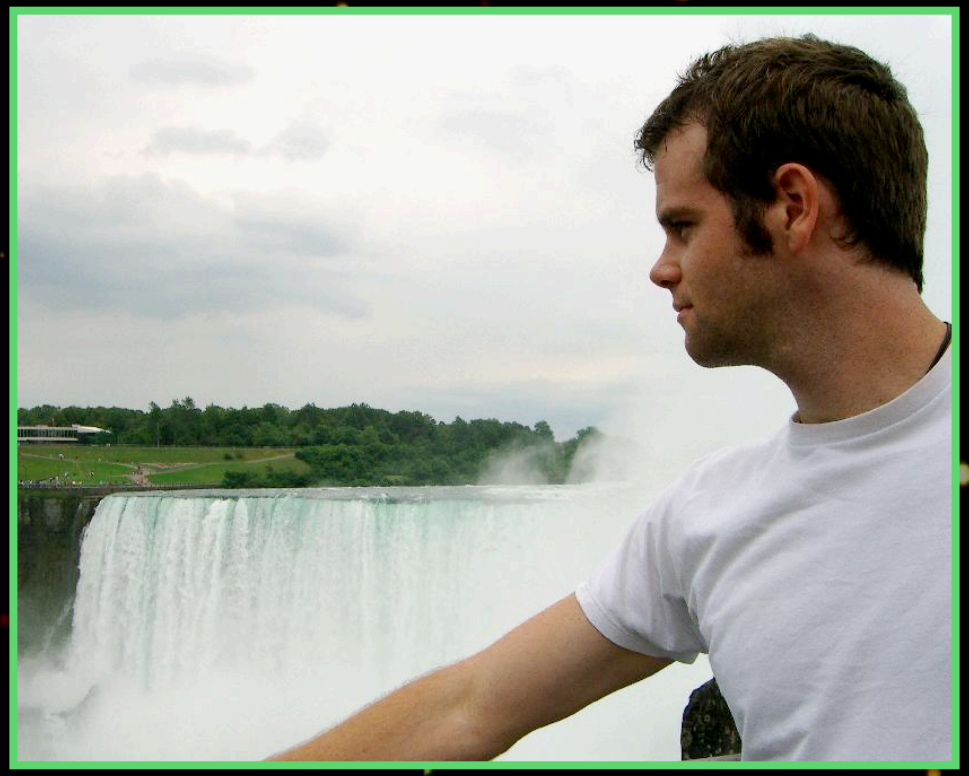
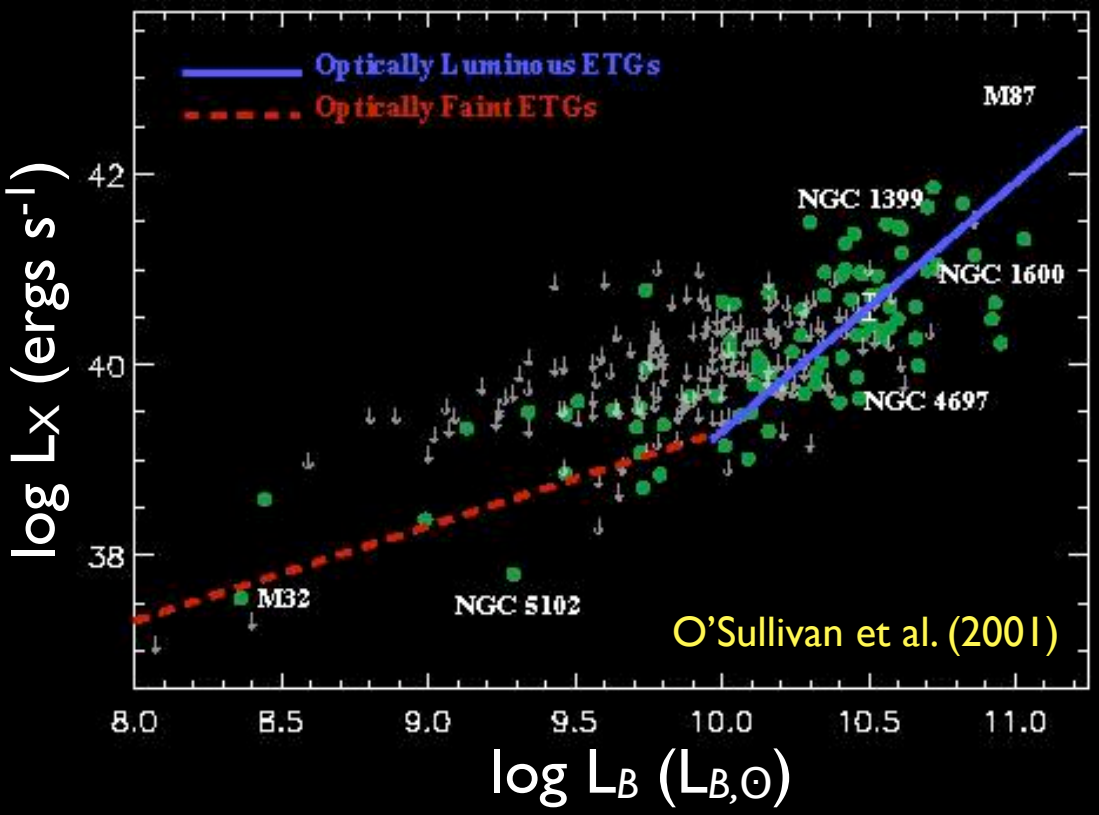
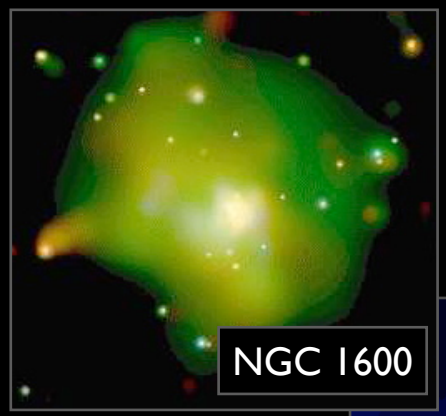


X-ray Properties of Local Early-Type Galaxies

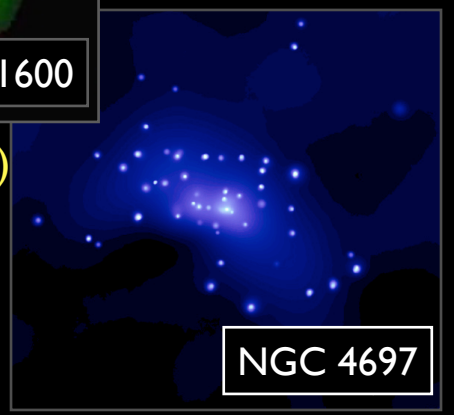
- X-rays originate from hot interstellar gas and LMXBs.
- Optically luminous ($L_B > 10^{10}\ L_{B,\odot}$) - hot gas dominated - $L_X \propto L_B^2$.
- Optically faint ($L_B < 10^{10}\ L_{B,\odot}$) - LMXB dominated - $L_X \propto L_B$.



O'Sullivan et al. (2001)



Sivakoff et al. (2004)



Sarazin et al. (2001)

Motivation and Goals of this Study

- Hot gas radiates powerfully but does not cool despite short inferred cooling timescales (10^8 yr).

- Cooling-flow models, which include heating from stellar winds and type Ia supernovae, overpredict the amount of cooled gas observed in the central regions of ETGs. (e.g., Mathews & Brighenti 2003)

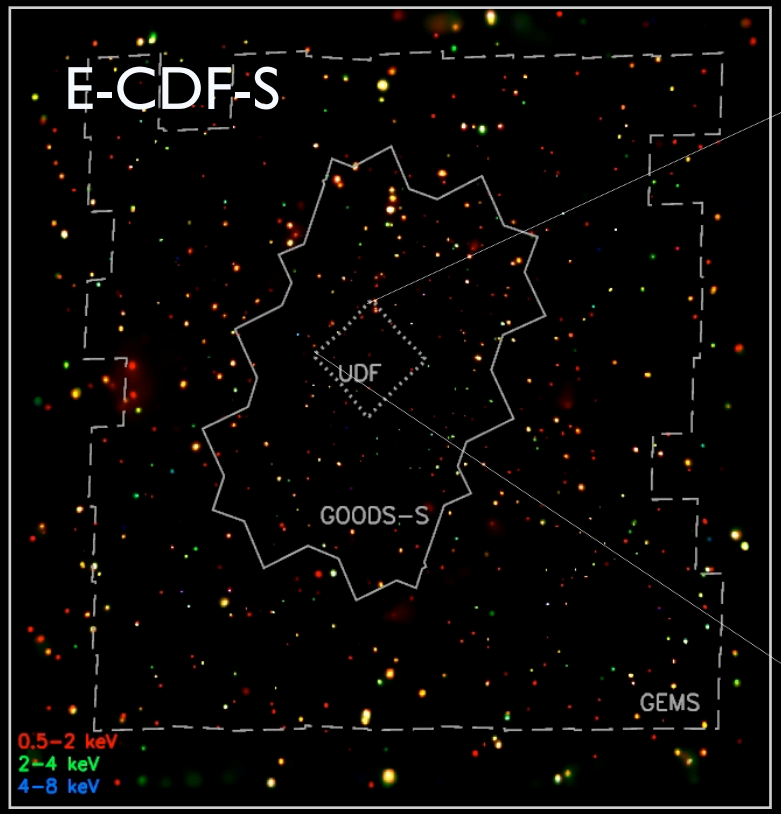
In this study, we aimed to address the following questions:

1. Has the average hot interstellar gas content within optically luminous ETGs evolved over the last ≈half of cosmic time? How does transient AGN activity contribute to this evolution?

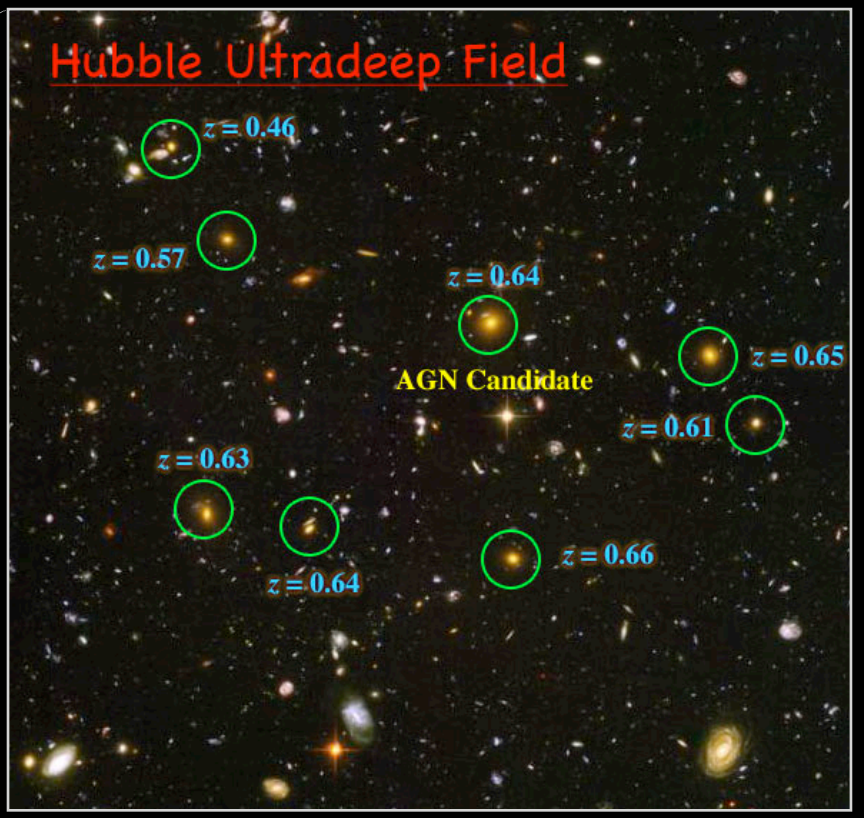
2. Have LMXB populations in optically faint ETGs evolved significantly since $z \approx 0.5$? What are the physical implications of such evolution?

Early-Type Galaxy Sample Selection

- Utilized multiwavelength coverage in the E-CDF-S to select > 500 ETGs over the redshift range $z \approx 0.1-0.7$.
- ETGs were selected using the combination of rest-frame red-sequence colors (COMBO-17) and Sersic indices (GEMS). (McIntosh et al. 2005)



Giacconi et al. (2002); Lehmer et al. (2005)

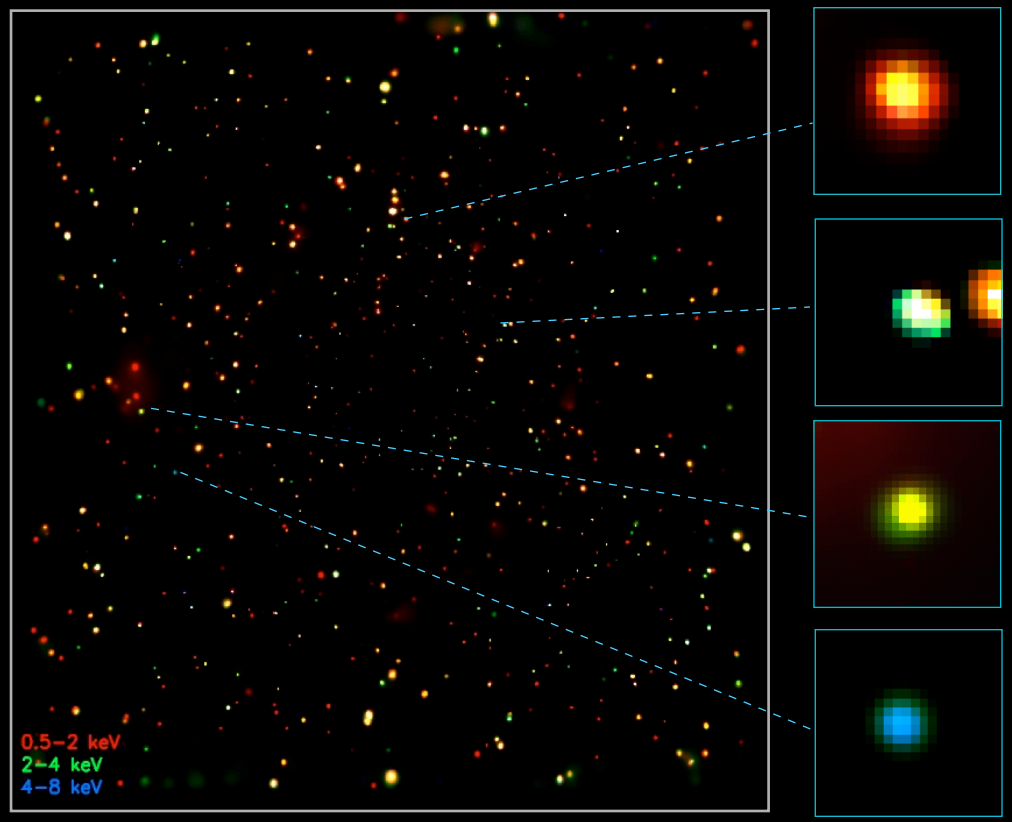


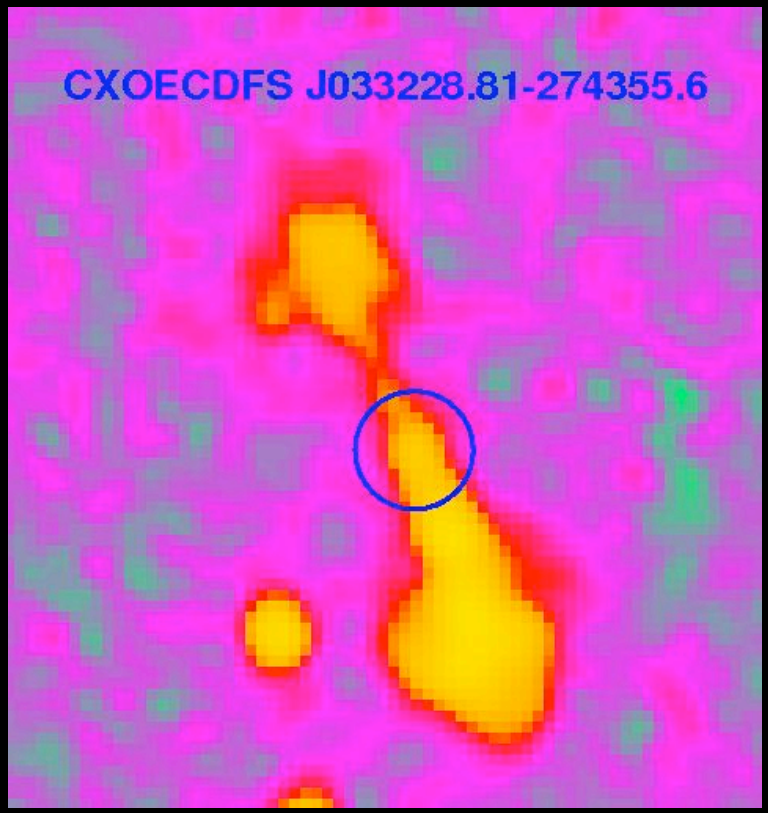
Beckwith et al. (2006)

X-ray Detected Sources

- E-CDF-S sufficient to detect luminous normal ETGs out to $z \geq 0.7$.
- Detected 49 ETGs in X-rays: 17 normal galaxies and 32 AGN candidates.
- AGNs were identified using:

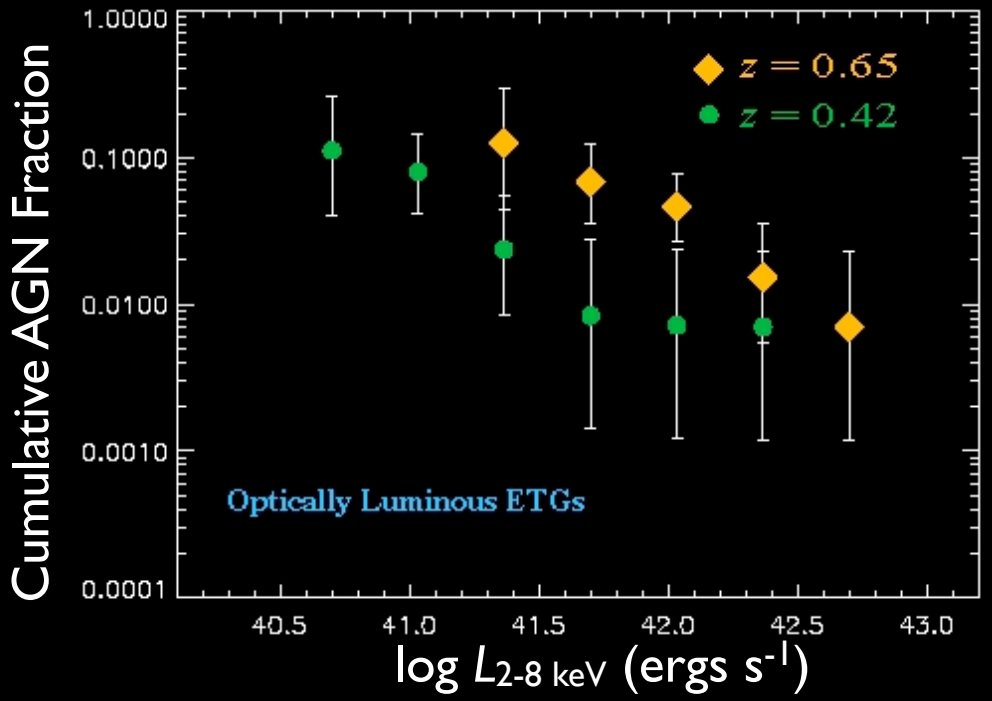
  1. Hard X-ray Emission (2−8 keV/0.5−2 keV band ratio)
  2. X-ray−to−optical flux ratios (f_X/f_R)
  3. Radio−to−optical flux ratios ($f_{1.4\ GHz}/f_R$)

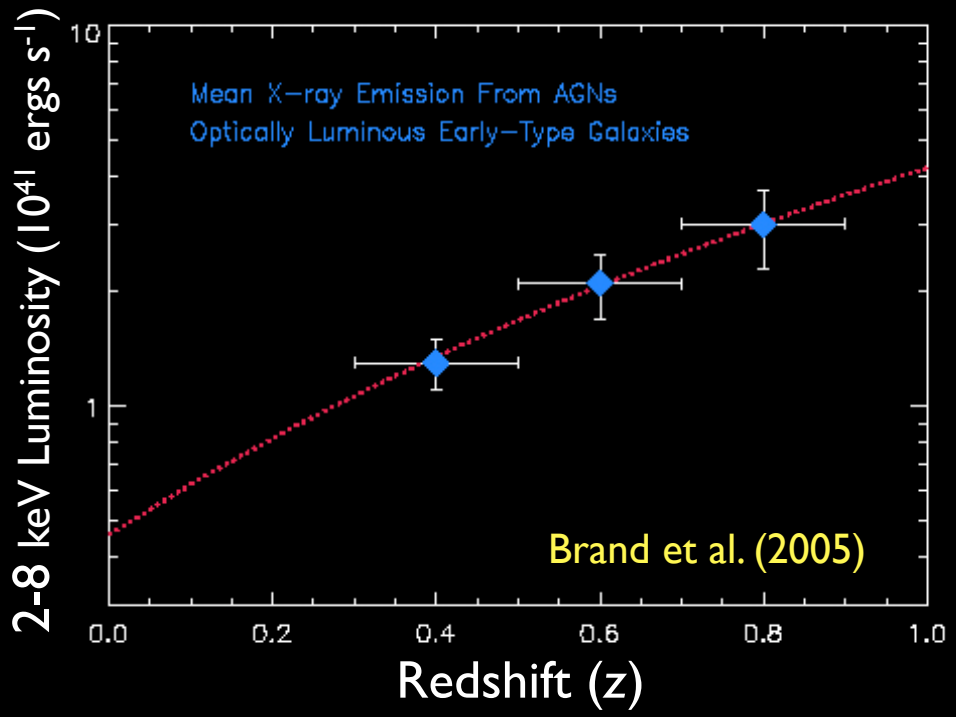




AGNs in Early-Type Galaxies

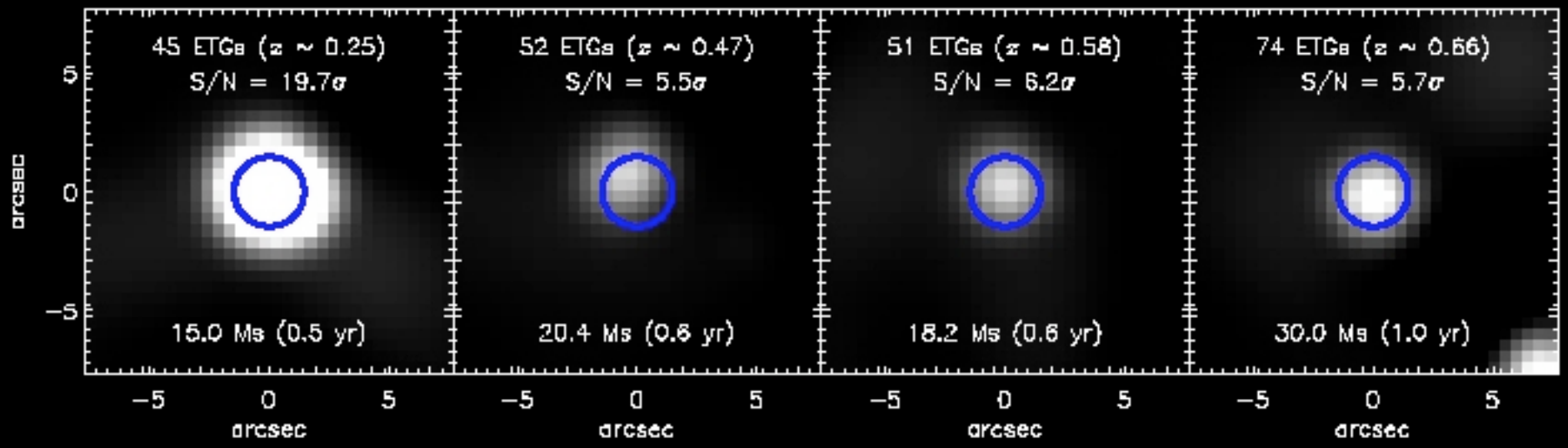
- Majority of AGN candidates are in optically luminous ETGs.
- The AGN fraction for optically luminous ETGs evolves strongly with redshift (*below left*).
- This is consistent with $(1+z)^3$ evolution observed in the Brand et al. (2005) X-ray stacking analyses of ~3300 $z \approx 0.3-0.9$ ETGs (*below right*).





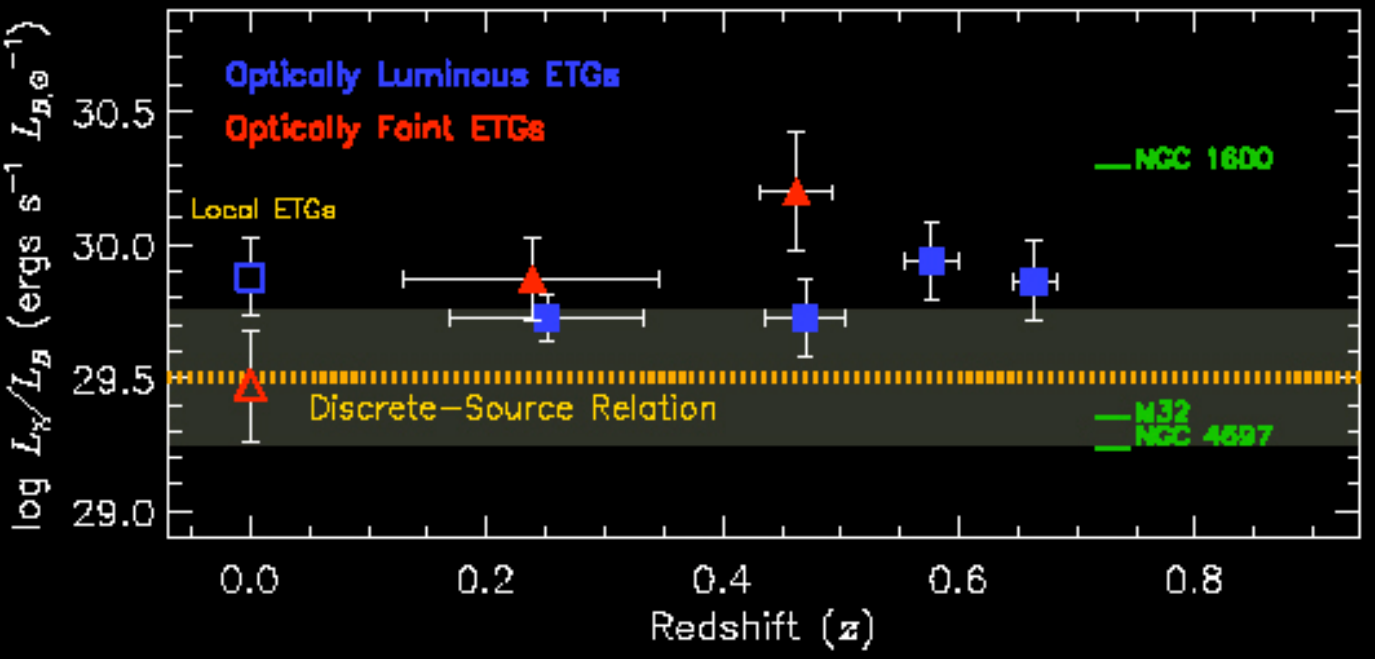
Normal Early-Type Galaxies

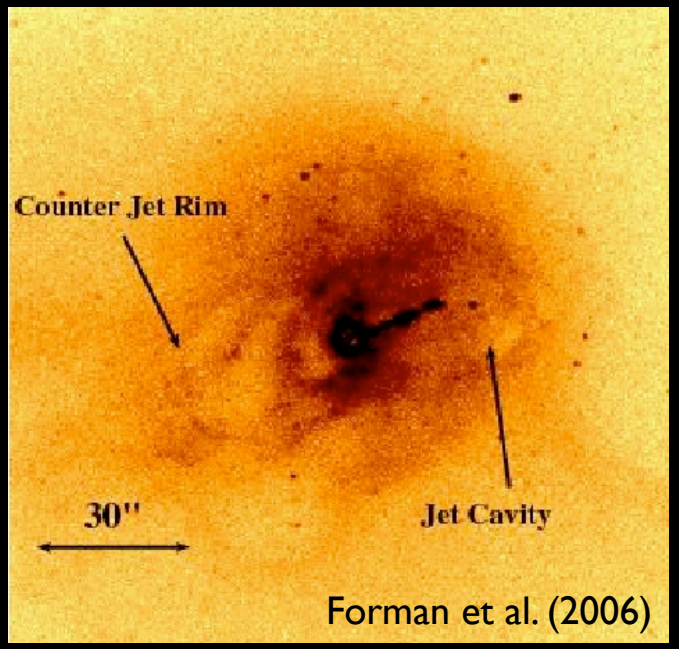
- We used X-ray stacking analyses to study the mean X-ray properties of the normal galaxies in our ETG sample.
- We stacked separately optically luminous and faint ETGs in redshift bins ranging from z = 0.1−0.7.
- All samples are detected significantly in 0.5−2 keV and two samples are detected in 2−8 keV. The latter two samples have X-ray colors consistent with normal galaxies.



Results on the X-ray Evolution of Normal ETGs

- X-ray emission from optically luminous ETGs does not evolve, which we interpret to be due to a balance between the heating and cooling of hot gas.
  - If this balance is primarily due to transient AGN activity, then ~1–5% of the bolometric luminosity contributes to heating the gas.
  - Evolution of AGN heating efficiency? Other heating sources dominant?
- We find suggestive evidence for evolution in the X-ray emission from optically faint ETGs. Evolution in LMXB populations? Downsizing?

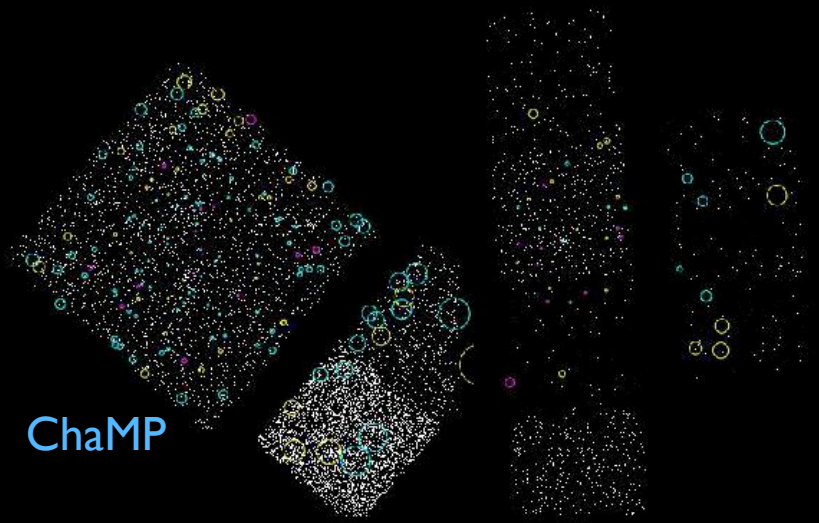


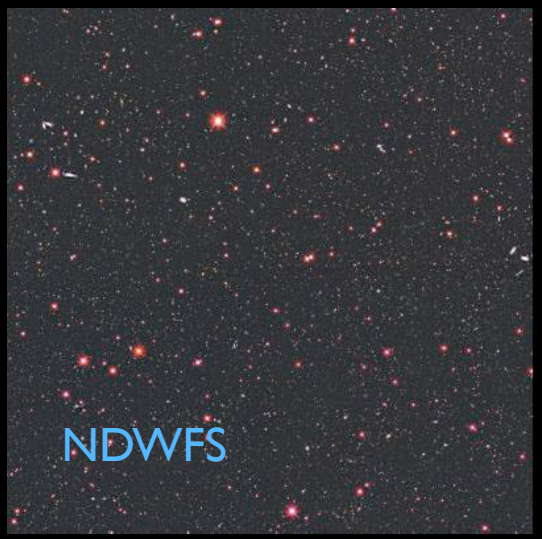


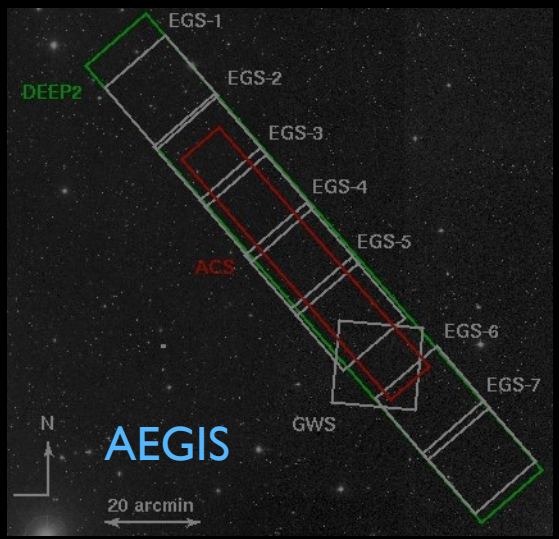
Potential for Future Work

- Test and constrain better the AGN fraction and X-ray evolution of normal ETGs using additional available and forthcoming survey fields.
  - $z = 0-0.2$: NOAO Deep Wide-Field Survey (NDWFS; Murray et al. 2005)
  - $z = 0.1-0.5$: All-wavelength Extended Groth Strip International Survey (AEGIS; e.g., Davis et al. 2006)
  - $z = 0.4-1$: 2 Ms *Chandra* Deep Field-North (CDF-N; Alexander et al. 2003)
  - COSMOS, ChaMP, etc.

- Future deep *Chandra* observations (most notably in the CDF-N) would enable studies of ETG progenitors at redshifts $z > 1$ (e.g., DRGs, EROs, and submm galaxies).







Summary and References

- Used sample of > 500 early-type galaxies to investigate the X-ray evolution of ETGs in the E-CDF-S.
- We find evolution in the AGN fraction of optically luminous ETGs, consistent with other studies.
- We do not observe significant X-ray evolution of normal optically luminous ETG populations. We interpret this to indicate a general balance between the heating and cooling of the hot interstellar gas; AGNs can provide up to 1−5% of their bolometric luminosity in this heating.
- We find suggestive evidence for evolution for our optically faint ETGs, possibly due to the evolution of LMXB; however, due to statistical limitations, this result is presently marginal.

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