Stacking Analysis in the *Chandra*-COSMOS Survey: Hidden AGNs in low luminosity Early-type galaxies

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ABSTRACT: We present a stacking analysis of the *Chandra* data for the complete sample of Early Type Galaxies (ETGs) selected from the *Chandra* COSMOS survey to explore the relation between the X-ray luminosity of the hot gas halos ($L_{X,gas}$) and the K-band stellar luminosity of these sources (L_K) in the redshift range $0 < z < 1.5$. We subtract from the X-ray luminosities of the stacked signals the contribution of low mass X-ray binary populations, and compare our results with the relation observed in the local universe $L_{X,gas} \propto L_K^{4.5}$ that suggests the presence of generally virialized halos in nearby ETGs. We also compare our results with a recent analysis of X-ray detected ETGs in *Chandra* COSMOS survey indicating that, while most of the nearer and less luminous galaxies follow the $L_{X,gas}$- L_K relation of local universe ETGs, the more luminous ones tend to diverge from the local relation in these galaxies, implying significantly enhanced X-ray emission which can be due to the presence of hidden AGN, or the evolution of hot halos in the presence of nuclear and star formation feedback. The results of our stacking analysis confirm the existence of a population of ETGs with enhanced X-ray luminosities, far exceeding that expected from the local relation, with AGN contribution to the total X-ray luminosities suggested by increased hardness ratios with respect to the sources that follow the local relation. Using the relation between the stellar luminosity and the central black hole mass (M_{BH}) we evaluate for these sources $M_{BH} \sim 10^{7\text{-}8}\ M_O$ with accretion rates powering the excess X-ray emission of the order of $10^{-4}\ \dot{M}_{Edd}$.

SAMPLE AND METHODS

COSMOS photometric catalog by Ilbert et al. (2009):

- **sources classified as elliptical or S0 from their optical to near-infrared SED**
- **with reliable photometric redshift**
- **with Ultra-VISTA detection both in J and K bands → rest frame L_K**
- **excluded X-ray detected sources in C-COSMOS identification catalog (Civano et al. 2012)**

→ final sample of 6388 C-COSMOS ETGs.

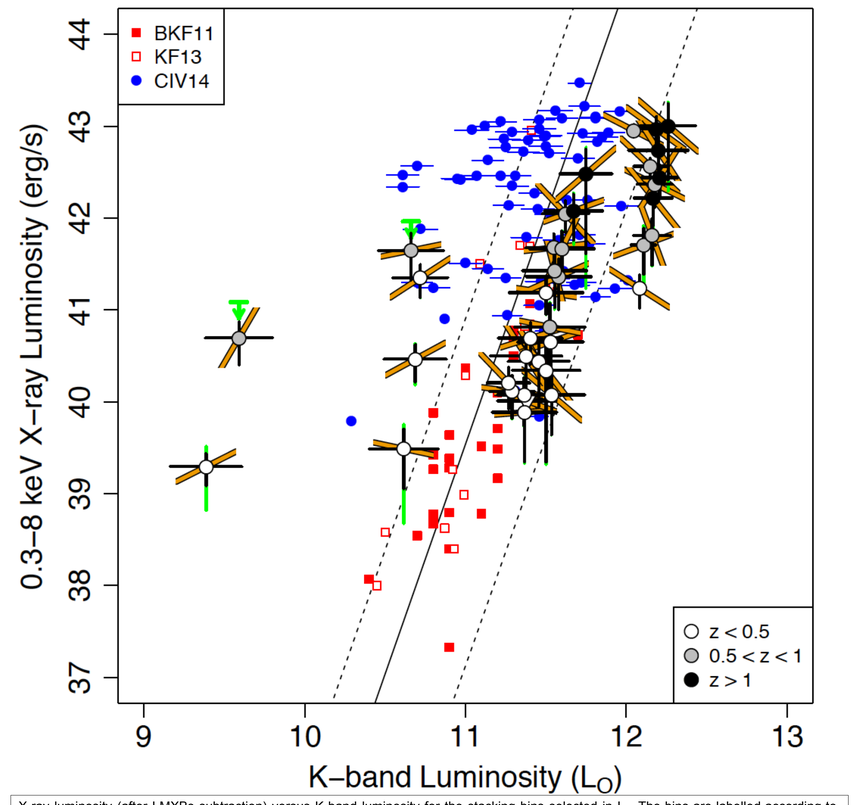
Source and background counts were evaluated from C-COSMOS observation excluding data nearby X-ray detected sources. The extraction radius was determined by the convolution between the *Chandra* PSF radius at the source position and the source semi-major axes from HST-ACS catalog (Leauthaud et al. 2007).

We then subtracted the LMXBs contribution using the relation from Fragos et al. (2013). This luminosity is expected to mainly include the emission from the hot gaseous halos, with possible contribution from AGN harbored in these ETGs.

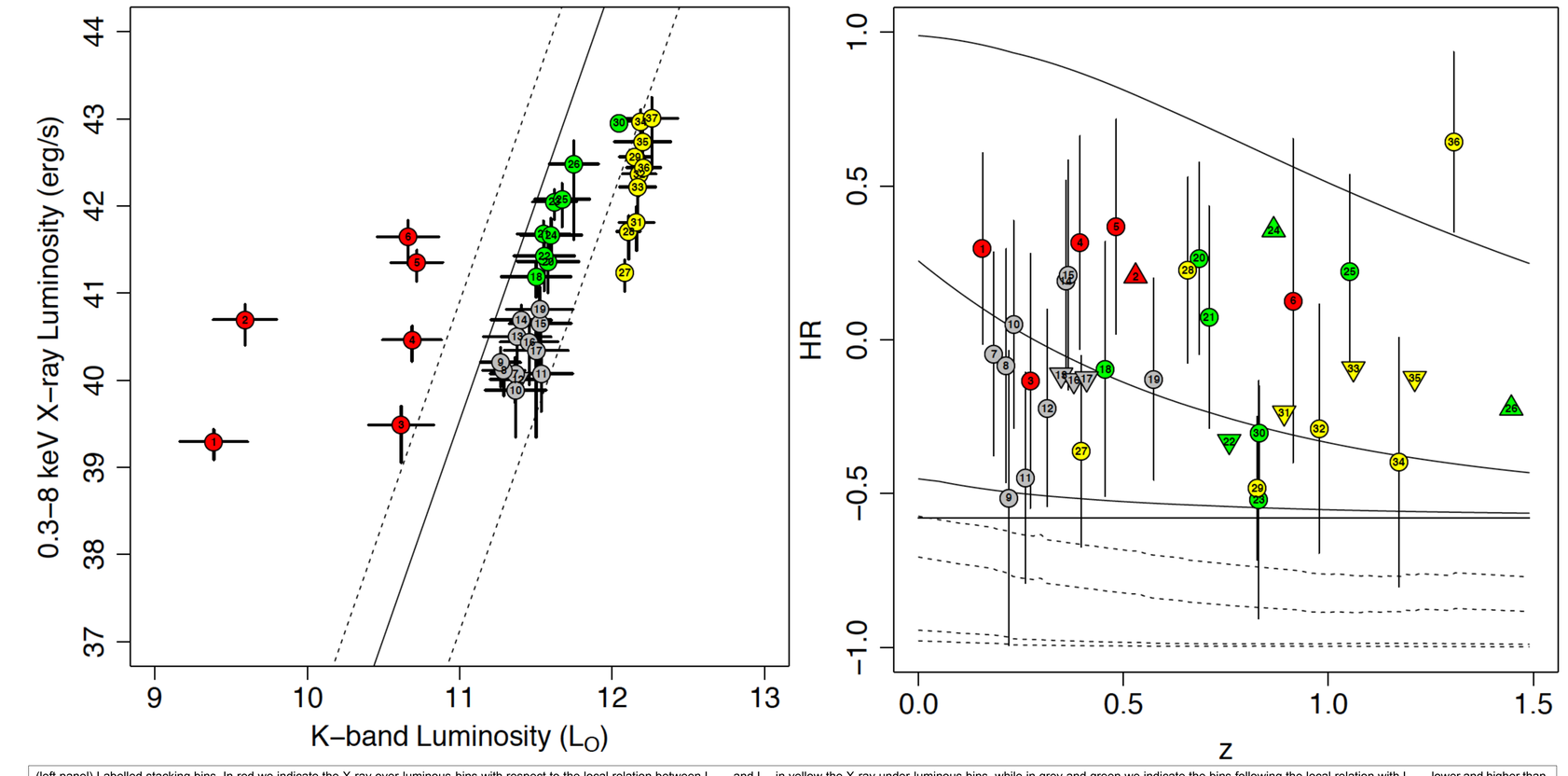
COMPARISON WITH LOCAL RELATION

While most of the detected signals are compatible with the local relation (BKF11; KF13), a number of detections appear to be over or under-luminous in X-ray with respect to their L_K.

X-ray over-luminous bins tend to have positive HR, while the opposite is true for the under-luminous bins. For the sources following the local relation we see that the less X-ray luminous bins show generally lower HR ratios with respect to the more X-ray luminous bins.



X-ray luminosity (after LMXBs subtraction) versus K-band luminosity for the stacking bins selected in L_K. The bins are labelled according to their redshift, with the HR indicated by the slope of the orange segments. The horizontal black segments indicate the uncertainty on L_K, while the vertical black segments represent the uncertainty on $L_{X,gas}$ due to the errors on the counts. An additional green vertical segment indicates the uncertainty on $L_{X,gas}$ due to redshift spread in each bin.



(left panel) Labelled stacking bins. In red we indicate the X-ray over-luminous bins with respect to the local relation between $L_{X,gas}$ and L_K, in yellow the X-ray under-luminous bins, while in grey and green we indicate the bins following the local relation with $L_{X,gas}$ lower and higher than 10^{41} erg/s, respectively. (right panel) HR of the stacking bins shown in the left panel. Triangles pointing up and down represent lower and upper limits on HR, respectively. The dashed lines represent simulated HR from thermal models with increasing temperature form bottom to top 0.7, 1, 2 and 3 keV. The full lines represent simulated HR from power-law models with fixed slope $\Gamma = 2$ and increasing intrinsic absorption form bottom to top 0, 10^{21}, 10^{22} and 10^{23} cm^{-2}.

SPECTRAL ANALYSIS

X-ray over-luminous bins show high HRs, pointing to the presence of hidden AGNs with $N_H \sim 10^{22}$ cm^{-2} significantly contributing to the X-ray emission.
Bins following the local relation with $L_{X,gas} < 10^{41}$ erg/s show generally lower HRs, indicating a less important AGN contribution. Instead, many bins with $L_{X,gas} > 10^{41}$ erg/s show HRs incompatible with a thermal model, with the higher redshift bins showing HRs compatible with $N_H \sim 10^{23}$ cm^{-2}, indicating the possibility for these galaxies to harbor highly obscured AGNs.
The X-ray under-luminous bins show generally softer spectra compatible with a thermal emission, with the exception of bin 36 that shows an exceptionally hard spectrum compatible with a power-law with $N_H > 10^{23}$ cm^{-2}.

QUIESCENT BLACK HOLES?

We compare our results with the models proposed by Volonteri et al. (2011) that predict the X-ray luminosity of quiescent BHs (also) in ETGs, both for radiatively efficient and inefficient accretion flows.
The X-ray over-luminous bins are roughly compatible with radiatively inefficient accretion flow models as well as the more luminous bins following the local relation. We evaluate for these hidden AGNs accretion rates $\dot{m} \sim 10^{-4}$.
On the other hand, the less luminous bins following the local relation are fainter than expected for the emission to be due to AGN.

X-ray luminosity (after LMXBs subtraction) versus BH mass for the stacking bins selected in L_K. The bins are color-labelled according to their average M_*. The horizontal segments indicate the uncertainty on M_{BH} due to the scatter in Graham's relation, while the vertical segments represent the uncertainty on $L_{X,gas}$ due to the errors on the counts. An additional black vertical segment indicates the uncertainty on $L_{X,gas}$ due to redshift spread in each bin. Colored lines represent the predictions of Volonteri et al. (2011) models for various M_* (with the same color code of the stacking bins), where full symbols refer to radiatively efficient accretion flows and empty symbols refer to radiatively inefficient ones.

CONCLUSIONS

- **We find evidence of hidden AGNs powering the X-ray emission of X-ray undetected ETGs in C-COSMOS survey**
- **The spectral analysis indicates an increasing AGN contribution for the bins following the local relation with increasing $L_{X,gas}$**
- **The X-ray emission from these hidden AGNs is roughly compatible with theoretical prediction of quiescent massive BHs with $M_{BH} \sim 10^{7\text{-}8}\ M_O$ accreting at $\dot{m} \sim 10^{-4}$**

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