# Intermediate-Redshift Groups in the XBootes Survey


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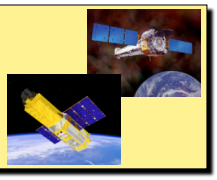

## MOTIVATION

Galaxy groups are key tracers of galaxy evolution, cluster evolution, and structure formation, yet they are difficult to study at even moderate redshift. We have undertaken a project to observe a flux-limited sample of intermediate-redshift ($0.15 < z < 0.35$) group candidates identified by the XBootes Chandra survey (Kenter et al. 2005). By exploiting the unique multi-wavelength coverage of the XBootes/NOAO Deep Wide Field Survey (NDWFS) field, we aim to:

(1) constrain non-gravitational processes that affect the energetics of the intragroup medium
(2) understand the connection between the X-ray and optical properties of groups

Of the 43 extended X-ray sources identified by the XBootes survey, 13 exceed our flux threshold of $4\times10^{-14}$ erg s$^{-1}$ cm$^{-2}$. This sample is listed in Table 1. Here we present deep *Suzaku*/XIS and *Chandra*/ACIS follow-up observations of the first four targets in this project.

**TABLE 1**
**XBOOTES GROUP OBSERVATIONS**

| Group | $z$ | $S14$ | Telescope | Date Obs. | ksec | |
|---|---|---|---|---|---|---|
| 7 | 0.194 | 4.7 | Suzaku | June 2007 | 42 | this work |
| 26 | 0.342 | 4.5 | Suzaku | June 2007 | 44 | this work |
| 30 | 0.222 | 4.1 | Suzaku | June 2007 | 39 | this work |
| 2 | 0.234 | 6.9 | Chandra | May 2007 | 38 | this work |
| 1 | 0.151 | 4.2 | Suzaku | Dec 2007 | 42 | scheduled |
| 24 | 0.131 | 9.7 | Chandra | GTO9 | 25 | scheduled |
| 10 | 0.280 | 3.3 | Chandra | GTO9 | 45 | scheduled |
| 23 | 0.130 | 22.1 | Chandra | | | for the future |
| 14 | 0.350 | 4.2 | Chandra | | | for the future |
| 33 | 0.242 | 6.3 | Chandra | | | for the future |
| 39 | ??? | 11.2 | Chandra | | | for the future |
| 25 | ??? | 6.2 | Chandra/Suzaku | | | for the future |
| 12 | ??? | 4.3 | Suzaku | | | for the future |
| 35 | ??? | 4.0 | Chandra/Suzaku | | | for the future |

$z$: spectroscopic redshift from AGES survey
$S14$: 0.5-7 keV flux in units of $10^{-14}$ erg s$^{-1}$ cm$^{-2}$, estimated from 5 ksec XBootes survey

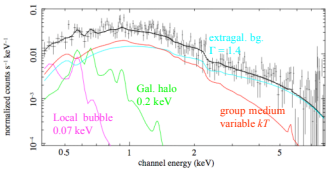


Figure 1. Emission model for *Suzaku*/XIS spectra, including X-ray background and group components.

**TABLE 2**
**GROUP EMISSION PARAMETERS**

| Group | $kT$ (keV) | abund. | $S_X$ | $L_X$ |
|---|---|---|---|---|
| 7 | 2.5 ± 0.4 | 0.3 ± 0.2 | 31 | 4.4 |
| 26 | 2.3 ± 0.3 | 0.3 ± 0.3 | 12 | 6.5 |
| 30 | 2.0 ± 0.3 | 0.4 ± 0.2 | 15 | 2.8 |
| 2 | 1.5 ± 0.5 | 0.7 ± 0.7 | 5.3 | 1.1 |

$S_X$ : 0.5-7 keV flux in units of $10^{-14}$ erg s$^{-1}$ cm$^{-2}$
$L_X$ : de-absorbed bolo. X-ray luminosity, $10^{43}$ erg s$^{-1}$

## THE $L_X$-$T_X$ RELATION FOR INTERMEDIATE-REDSHIFT GROUPS

Scaling relations identify divergence from self-similarity due to non-gravitational effects (pre-collapse heating, galactic/AGN feedback, radiative cooling). Evolution in scaling relations at group (rather than cluster) scales is a powerful diagnostic because these non-gravitational effects are more important at smaller mass scales. A small number of group have been observed at intermediate redshift with *XMM-Newton* (Willis et al. 2005, Pierre et al. 2006, Jeltema et al. 2006), and they show little if any evolution in the $L_X$-$T_X$ scaling relation.

The large intrinsic scatter in the $L_X$-$T_X$ relation requires a large sample of groups to distinguish between various models. Our full sample will double the number of groups observed in this redshift range. The first four groups have properties consistent with the observed $L_X$-$T_X$ relation (see Figure 3). They lie in a region on the faint end of the cluster population and bright end of the typical group population, similar to the sample of Jeltema et al. (2006).

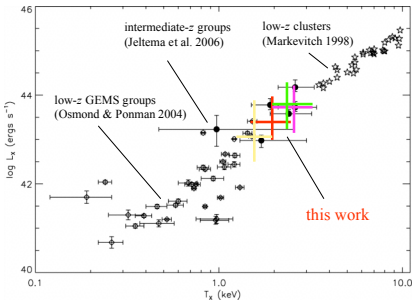


Figure 3. $L_X$-$T_X$ relation, from Jeltema et al. 2006.

## FUTURE WORK

- increase sample: observe all extended X-ray sources in XBootes field brighter than $4\times10^{-14}$ erg s$^{-1}$ cm$^{-2}$
- incorporate improved XIS calibration products available by end of 2007 (contamination, CTI, gain)
- point source contamination in *Suzaku* data: estimate contribution/cosmic variance, model point sources based on XBootes snapshot
- construct optically-selected group sample from NDWFS


**REFERENCES**

Jeltema et al. 2006, ApJ, 649, 649
Kenter et al. 2005, ApJS, 161, 9
Markevitch 1998, ApJ, 504, 27
Osmond & Ponman 2004, MNRAS, 350, 1511
Pierre et al. 2006, MNRAS, 372, 591
Willis et al. 2005, MNRAS, 363, 675


## SPECTRAL MODELING

The *Suzaku*/XIS group spectra were extracted from circular apertures of 1 Mpc radius at the group redshift. Point sources brighter than $10^{-14}$ erg s$^{-1}$ cm$^{-2}$ were masked out. Due to vignetting and non-uniform OBF contamination, the X-ray background was fit simultaneously to a region outside the group aperture, using the appropriately-weighted ARF. The full model is shown below in Figure 1 and included in the fits shown in Figure 2. Detector background was corrected using the accumulated *Suzaku* night Earth background data. The exposure-corrected flux maps are shown in contours on the NDWFS R-band images in Figure 2.

The *Chandra*/ACIS spectrum was extracted from a similarly-sized aperture, with a nearby region used as the background. Point sources were identified and masked by hand.

The diffuse group emission was modeled using the APEC plasma code with variable temperature and abundance. Fitting results are shown in Table 2. Group $kT$ ranges from 1.5-2.5 keV with abundances of 0.3-0.7 solar.

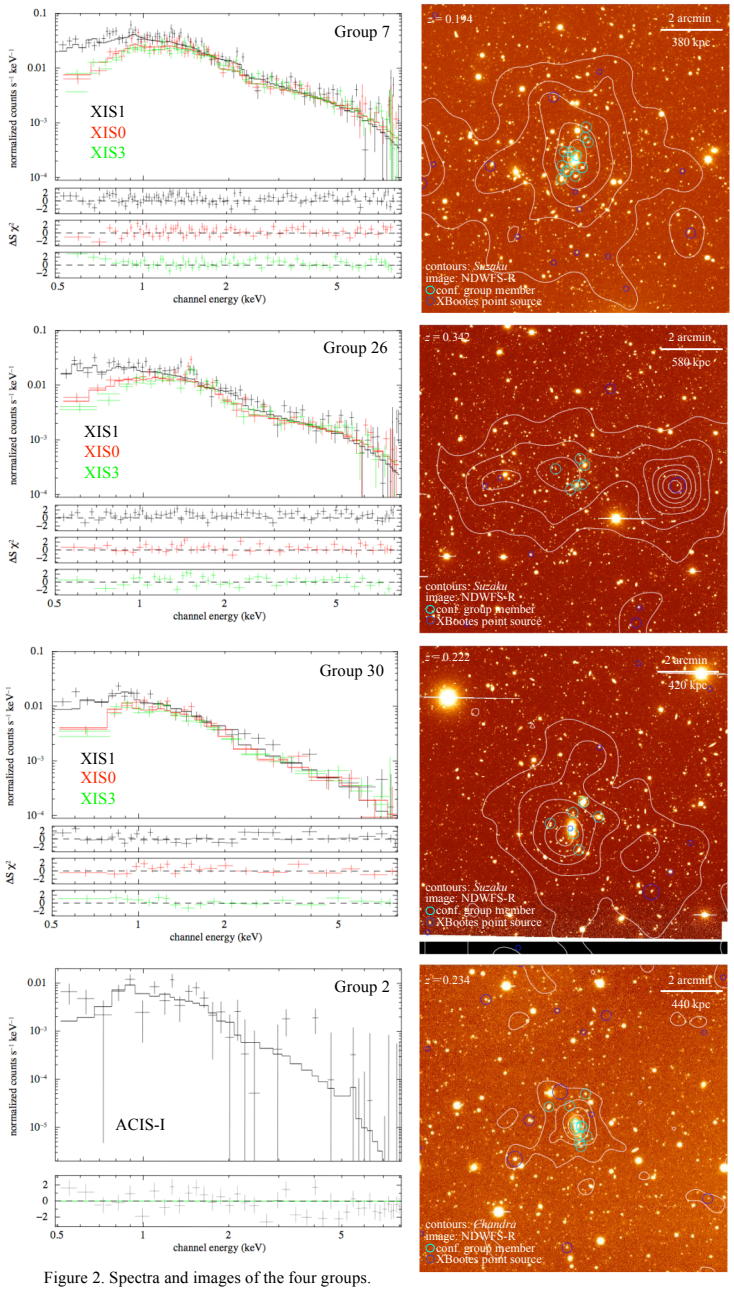


Figure 2. Spectra and images of the four groups.