Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **412,** 2391–2395 (2011) doi:10.1111/j.1365-2966.2010.18062.x

Cluster X-ray luminosity–temperature relation at $z \gtrsim 1.5$

S. Andreon,* G. Trinchieri and F. Pizzolato

INAF – Osservatorio Astronomico di Brera, via Brera 28, 20121 Milano, Italy

Accepted 2010 November 23. Received 2010 November 22; in original form 2010 July 9

ABSTRACT

The evolution of the properties of the hot gas that fills the potential well of galaxy clusters is poorly known, since models are unable to give robust predictions, and observations lack a sufficient redshift leverage and are affected by selection effects. Here, with just two high-redshift, $z \approx 1.8$, clusters avoiding selection biases, we obtain a significant extension of the redshift range and we begin to constrain the possible evolution of the X-ray luminosity versus temperature relation. The two clusters, JKCS 041 at $z = 2.2$ and ISCS J1438+3414 at $z = 1.41$, are, respectively, the most distant and the second most distant clusters, overall, that can be used for studying scaling relations. Their location in the X-ray luminosity versus temperature plane, with an X-ray luminosity five times lower than expected, suggests at the 95 per cent confidence level that the evolution of the intracluster medium has not been self-similar in the last three-quarters of the age of the Universe. Our conclusion is reinforced by data on a third, X-ray-selected, high-redshift cluster, too faint for its temperature when compared to a sample of similarly selected objects. Our data suggest that non-gravitational effects, such as the baryon physics, influence the evolution of galaxy clusters. Precise knowledge of evolution is central for using galaxy clusters as cosmological probes in planned X-ray surveys, such as *WFXT* or *JDEM*.

Key words: galaxies: clusters: general – galaxies: clusters: individual: ISCS J1438+3414 – galaxies: clusters: individual: JKCS 041 – galaxies: clusters: intracluster medium – X-rays: galaxies: clusters.

1 INTRODUCTION

The observation of the diffuse, X-ray-emitting medium [also known as the intracluster medium (ICM)] of galaxy clusters provides quantities like its mass, temperature (T) and X-ray luminosity (L_X). The analysis of the scaling relation between these physical quantities gives considerable insight into the physical processes in the ICM (e.g. Rosati, Borgani & Norman 2002 and reference therein). On the other hand, the evolution of these scaling relations is difficult to predict theoretically (e.g. Norman 2010). The simplest model (Kaiser 1986), in which the ICM evolution is governed only by gravity, predicts an L_X–T relation shallower than observed (Markevitch 1998). This suggests that non-gravitational energy inputs, such as merger shocks or feedback from active galactic nuclei and star formation, need to be considered. More sophisticated models sensitively depend on the assumed physics of the baryons and their predictions can be tuned to be in good agreement with observed scaling relations (Kravtsov, Nagai & Vikhlinin 2005; Nagai, Kravtsov & Vikhlinin 2007; Bode, Ostriker & Vikhlinin 2009) measured in the nearby Universe, if one accepts an overprediction of the baryon fraction in stars by an order of magnitude (Gonzalez, Zaritsky & Zabludoff 2007; Andreon 2010).

The most direct way to probe ICM evolution is to measure the scaling relations over a wide range of redshifts. Here a difficulty arises: many cluster samples with known L_X and T are either X-ray-selected or heterogeneous collections of objects without a simple and accountable selection function. In both cases, neglecting the selection function may bias the L_X–T relation (Stanek et al. 2006; Pacaud et al. 2007; Nord et al. 2008), because, at a given temperature, clusters that are more luminous enter more easily in the sample (they can be seen on a larger volume, have smaller temperature errors and are more frequently found in archives and samples). Therefore, the mean L_X at a given T can be systematically overestimated, unless one accounts for the selection function (e.g. Gelman et al. 2004; Pacaud et al. 2007; Andreon & Hurn, in preparation). The requirement of a known selection function restricts the choice of the available samples and the redshift baseline makes it hard to detect deviations from a self-similar evolution for lack of extension at high redshift, for example, $z \leq 1.05$ for Pacaud et al. (2007) and $z < 0.2$ for Pratt et al. (2009).

Only a handful of clusters are known at high z (four at $z > 1.4$). In this paper, we use only two clusters suitable for this study, namely JKCS 041, probably the most distant cluster known to date, and ISCS J1438+3414 (at $z = 1.41$, Stanford et al., 2005), the second

*E-mail: stefano.andreon@brera.inaf.it

most distant cluster that can be used for studying scaling relations. Note that the redshift of JKCS 041 is conservatively estimated at $z = 1.9$ in Andreon et al. (2009) and it has now a red-sequence-estimated redshift of $z = 2.20 \pm 0.11$ (Andreon & Huertas-Company 2011). Both are optically/near-infrared (near-IR) selected, that is, detected through their galaxies, and have been subsequently followed up in X-rays (see Andreon et al. 2009 for JKCS 041 and this paper for ISCS J1438+3414) to derive L_X and T for the gas. Though small, this sample is free from the biases that affect X-ray-selected samples, since these clusters are considered independent of their X-ray luminosity. By using them, we extend the redshift baseline to $z \sim 2$, where the self-similar model predicts a brightening 1.7 times larger than at $z = 1$.

We adopt the following cosmological parameters: $\Omega_\Lambda = 0.7$, $\Omega_m = 0.3$ and $H_0 = 70\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. The scale, at $z = 1.41$, is 8.4 kpc arcsec^{-1}. As point estimate and error measurements, we quote posterior mean and standard deviation when a Bayesian approach is explicitly mentioned, otherwise the usual profile likelihood-based estimates (e.g. XSPEC error, $-2\Delta \ln \mathcal{L} = 1$).

2 DATA AND ANALYSIS

2.1 *HST* observations

ISCS J1438+3414 has been observed with the Wide Field Camera of the Advanced Camera for Surveys (ACS, Ford et al. 1998, 2003) of the *Hubble Space Telescope* (*HST*) for 10 ks with the *F850LP* filter. These data are reduced following the procedure adopted in, for example, Andreon (2008): the raw ACS data were processed through the standard CALACS pipeline (Hack 1999) at the Space Telescope Science Institute. This includes overscan, bias and dark subtraction, as well as flat-fielding. Image combination has been done with the MULTIDRIZZLE software (Koekemoer et al. 2002). The data quality arrays enable masking of known hot pixels and bad columns, while cosmic rays and other anomalies are rejected through the iterative drizzle/blot technique. Fig. 1 shows the resulting image.

2.2 *Chandra* X-ray observations

ISCS J1438+3414 was observed by *Chandra* for 150 ks on 2009 October 4 and 9 (ObsID 10461 and 12003) using the ACIS-S detector. The data were reduced using the standard data reduction procedures and were checked for periods of high background. We found no differences between the data quality and the set-up of the instruments of the first and second observations. We therefore merged the two data sets for a total observing time of 143 ks, consistent with 150 ks originally requested. A preliminary examination of the data showed that the 0.3–2.0 keV energy band gave the maximum cluster signal-to-noise ratio for our image analysis. The image produced in this energy band is shown in Fig. 2. The image was then adaptively smoothed with the Ebeling, White & Rangarajan (2006) algorithm, available in the CIAO software, requesting a minimum significance of 3σ. Contours of this smoothed X-ray image are overlaid in Fig. 1 on the *HST F850LP* image. The X-ray morphology appears regular, but this could simply result from the relatively large kernel required by the low signal-to-noise ratio of the cluster emission ($\sigma \lesssim 20$ arcsec). Within a 1 arcmin radius from the cluster centre, there are 274 ± 60 photons in the 0.3–2 keV band (after subtraction of the background and exclusion of point sources).

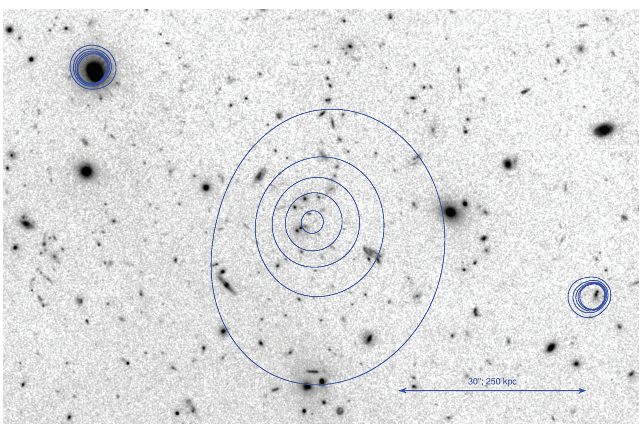

Figure 1. Contours from an adaptively smoothed *Chandra* image in the 0.3–2 keV energy band superposed on to an *Hubble Space Telescope* (*F850LP*) image of ISCS J1438+3414.

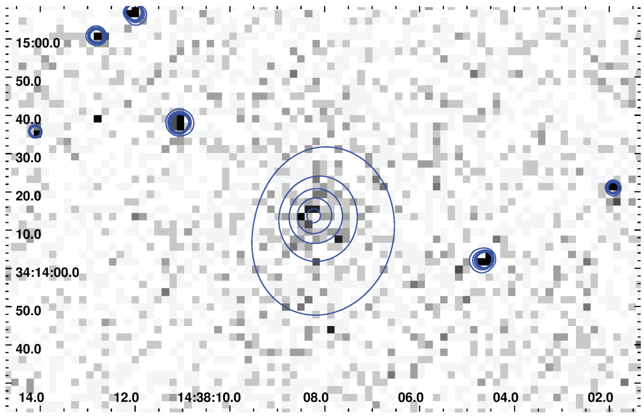

Figure 2. 0.3–2 keV *Chandra* X-ray image of ISCS J1438+3414, binned to 2 arcsec pixels. The image is overlaid with contours of the X-ray emission after adaptive smoothing so that all features are significant to at least the 3σ level. The faintest contour was chosen to closely approximate the region where the smoothing kernel contained a signal above the 3σ threshold on a scale of about 20 arcsec. North is up and east is to the left.

2.2.1 *X-ray image analysis*

To quantify the cluster surface brightness distribution, the *Chandra* image of ISCS J1438+3414 was fitted with a two-dimensional β profile (Cavaliere & Fusco-Femiano 1978) with an additive constant (on detector) component for the background.[1] The model was constrained to be circular. Point sources were masked out during the fitting process. We adopt the Bayesian approach of Andreon et al. (2008) with uniform priors except for β, taken to be a Gaussian, zeroed at $3\beta - 1/2 < 1$ (the β model must have a finite integral), centred on $\beta = 2/3$ and with width $\sigma_\beta = 0.2$; the latter is to account for the fact that clusters tend to have $\beta \approx 2/3$ (e.g. Maughan et al. 2008). The posterior probability distribution of β values resulting from the fit is displayed in Fig. 3 and compared to the assumed prior. We found $3\beta - 1/2 = 1.2 \pm 0.15$, but with a posterior distribution fairly different from a Gaussian (see Fig. 3). Its difference from the prior implies that the data

[1] We checked that consistent results are found whether we model the background with a constant on the detector or we modulate it through the telescope vignetting.

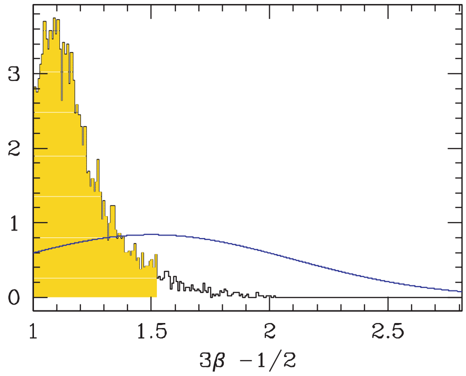

Figure 3. Posterior probability distribution for $3\beta - 1/2$. The black jagged histogram shows the posterior, marginalized over the other parameters. The jagging is due to the finite length of the chain sampled, that is, noise, not signal. The shaded (yellow) range shows the 95 per cent highest posterior credible interval. The blue smooth curve shows the assumed prior for the parameter. The data constrain $3\beta - 1/2$ to be small (e.g. $\beta < 2/3$ at 95 per cent confidence).

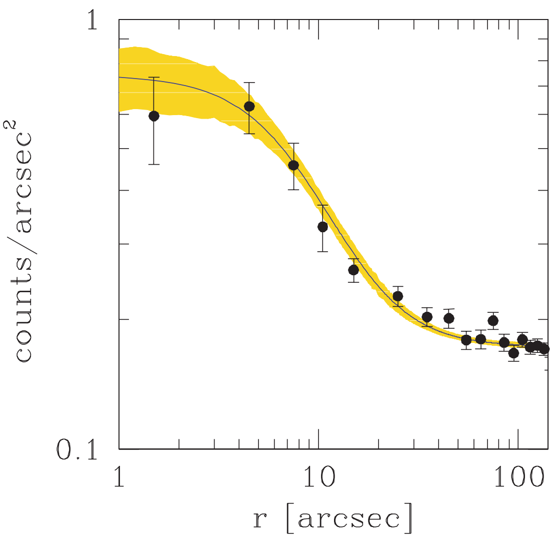

Figure 4. Radial profile of ISCS J1438+3414. The solid line marks the mean β model. The shaded region marks the 68 per cent highest posterior credible interval for the model. Error bars on the data points are heuristically computed and do not account, for example, for the intensity gradient across the bin, the uncertainty on the centre, etc. The shading, instead, does. This figure is simply for visualization purposes; the model was not fitted in this space.

carry information about the β parameter. Basically, the data constrain β to be small, $\beta \lesssim 2/3$ at 95 per cent confidence (with $\beta > 1/2$ to ensure a finite flux), but not its exact value.

Fig. 4 shows an azimuthally averaged radial profile of the data with heuristic error bars (for visualization purposes) and the mean two-dimensional model, with 68 per cent (highest posterior) error (shaded). The latter rigorously accounts for uncertainty and covariance of all modelled quantities. We emphasize that the model was not fitted in this space. The X-ray emission is manifestly extended with respect to the *Chandra* 0.5-arcsec point spread function. The fit coordinates of the X-ray emission of ISCS J1438+3414 are RA =14:38:08 ± 3 arcsec and Dec. = +34:14:14 ± 3 arcsec. We found a core radius of 9 ± 2 arcsec (75 kpc). We also compute the core radius with β fixed at 2/3, for comparison with other clusters, $r_c \sim 12 \pm 2$ arcsec (100 kpc). In either case, r_c is in the range of values observed for local clusters.

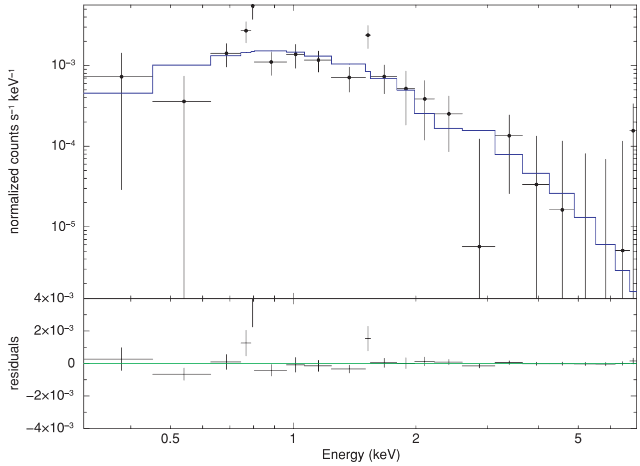

Figure 5. The *Chandra* X-ray spectrum and best-fitting model of ISCS J1438+3414 are shown in the top panel, with the residuals shown in the bottom panel. The spectrum is rebinned for displaying purposes, but is fitted on a minimally binned version.

2.2.2 *X-ray spectral analysis*

Our spectral analysis procedure was chosen to match that of Pacaud et al. (2007) to allow direct comparison with their L_X–T relation. In summary, a cluster spectrum was extracted from an aperture of radius 30 arcsec (252 kpc) (with minor masking of a single point source falling just outside the boundary), chosen to maximize the signal-to-noise ratio. A background spectrum was extracted from two regions around the cluster, sufficiently separated to exclude any cluster emission (mean background radius: 125 arcsec, 1050 kpc at the cluster distance), and chosen to be included in the same chip, but avoiding gaps and bad columns. The resulting cluster spectrum contains ∼280 net photons in the 0.3–7.0 keV band used for spectral fitting. The source spectrum was fitted with an absorbed APEC (Smith et al. 2001) plasma model, with the absorbing column fixed at the Galactic value (0.98×10^{20} cm^{-2}, Dickey & Lockman 1990), the metal abundance fixed at 0.3 relative to solar and the redshift of the plasma model fixed at 1.41. The spectrum was grouped to contain a minimum of five counts per bin, and the source and background data were fitted within the XSPEC spectral package using the modified C-statistic (also called W-statistic in XSPEC). Simulations in Willis et al. (2005) confirm that this methodology is reliable.

The best-fitting spectral model (plotted in Fig. 5) gives $kT = 4.9^{+3.4}_{-1.6}$ keV, which results in an unabsorbed bolometric X-ray flux of 1.4×10^{-14} erg cm^{-2} s^{-1}.

In order to measure X-ray scaling relations, we need $L_X < r_{500}$ and therefore we need to estimate r_{500}, which is derived from the cluster temperature, using the scaling relation of Finoguenov, Reiprich & Böhringer (2001) as given in equation 2 of Pacaud et al. (2007). For the best-fitting temperature, $r_{500} = 0.48$ Mpc, but temperature has errors, which we need to account for. We use a Bayesian approach: for each temperature (we used a chain of 1000 samples drawn from the temperature likelihood), we compute 1000 estimated values of r_{500}. For each r_{500} and for each sampling of the posterior distribution of the parameters of the β model (a chain of 2000 values), we compute the ratio between the flux in the spectral aperture and within the estimated r_{500}, including correction for

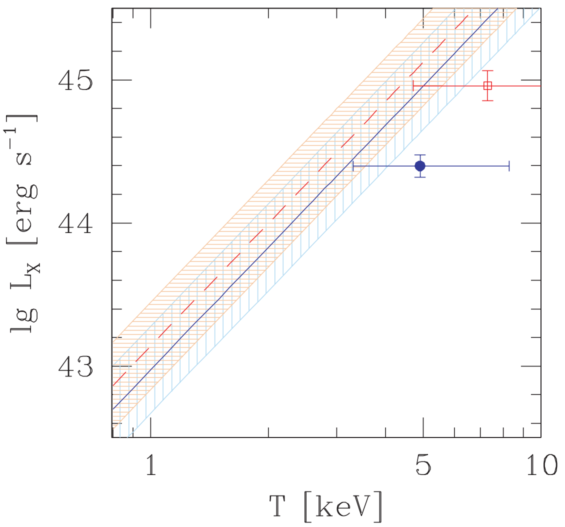

Figure 6. Locations of ISCS J1438+3414 at $z = 1.41$ (lower closed point) and JKCS 041 at $z \sim 2.2$ (upper open point) in the L_X–T plane. The blue solid (red-dashed) line marks the $z = 0.33$ L_X–T scaling relation self-similarly evolved to $z = 1.41$ ($z = 2.2$). We shaded the region within one intrinsic scatter from the mean model: the red, horizontal, shading refers to $z = 2.2$, whereas the blue, vertical, shading refers to $z = 1.41$. Both clusters are approximately five times too faint for their X-ray temperature if the L_X–T scaling relation evolves self-similarly.

point sources. This gives the wanted posterior distribution of the conversion factor. It turns out to have a (near to) lognormal shape, that is, it is normal after moving to log units. We found $\log c = 0.16 \pm 0.06$ dex, that is, the conversion factor has a 14 per cent uncertainty. This uncertainty is larger than the uncertainty on the flux in the spectral aperture alone (10 per cent) and therefore cannot be neglected. Not accounting for the temperature error also induces a bias almost as large as the flux error in the spectral aperture. To summarize, the bolometric luminosity within r_{500} is $L_X(<500) = (2.5 \pm 0.5) \times 10^{44}$ erg s^{-1}. We emphasize that this is the luminosity within the angular aperture of radius r_{500}.

Finally, the temperature of ISCS J1438+3414 can be used to estimate the cluster's mass. Under the (strong) assumption that the temperature–mass relation presented in Finoguenov et al. (2001) self-similarly evolves (doubtful, but adopted for lack of anything more suitable) from $z = 0$ to 1.4, and neglecting all (at this point negligible) statistical subtleties, we found $M_{500} = 2.0^{+2.6}_{-0.9} \times 10^{14}$ M$_\odot$.[2]

3 A FIRST LOOK AT THE L_X–T SCALING RELATION AT $z \approx 1.8$

Fig. 6 shows the position of the two clusters in the X-ray luminosity, $L_X(<r_{500})$, versus X-ray temperature T plane relative to the L_X–T relation self-similarly evolved at the redshift of the two clusters. Because of the slightly revised redshift from the publication of Andreon et al. (2009), JKCS 041 data have been reanalysed with the updated redshift. We find $L_X(<500) = (9.1 \pm 2.5) \times 10^{44}$ erg s^{-1} and $kT = 7.3^{+6.7}_{-2.6}$ keV. Once the large temperature errors have been taken into account, it is plausible to find a cluster, such as JKCS 041, in the volume surveyed in Andreon et al. (2009) in a standard Λ cold dark matter universe.

The relation is derived from data presented in Pacaud et al. (2007). In their paper, the authors account for the selection function, but did not publish the value of the parameters of the L_X–T scaling. We obtained the selection function in electronic form directly from the authors. Through a Bayesian analysis (Andreon & Hurn, in preparation), we recomputed the L_X–T scaling at the median redshift of their sample, $z = 0.33$, and we checked that our results are entirely consistent with theirs. The scatter amplitude uses as prior the Stanek et al. (2006) measurements. The relation, self-similarly evolved at $z = 1.41$ (solid blue line) and $z = 2.2$ (dashed red line), is shown in Fig. 6.

Both clusters are located below the self-similar expectation, too faint by 0.73 dex (ISCS J1438+3414) and by 0.68 dex (JKCS 041), that is, by a factor of 5, for their (best-fitting) temperature. On the other hand, they are about only '1σ' away from the predicted scaling relation, given their relatively large errors on T. The probability to observe two points '1σ' or more away from the expected relation and on the same side is 5 per cent ($= 0.32*0.32/2$), that is, our claim is statistically significant at 95 per cent confidence (in the above, p-value, sense). A more advanced analysis will not prove very useful: (i) the influence of a redshift uncertainty for JKCS 041 is negligible: using the previous value of $z = 1.9$ (3σ away from the present value) makes JKCS 041 0.70 dex too faint (versus 0.68 dex) and still 1σ away from the predicted scaling relation; and (ii) we performed a preliminary account for the fact that points are not exactly '1σ' away and for the covariance between regressed quantities (T, on the abscissa, also enters in the ordinate, via r_{500}), but the ultimate limit is given by the sample size, not by the precise treatment of errors, and to improve the former more data are needed, not a better statistical analysis.

We have not included in our analysis the only remaining cluster at $z > 1.4$ for which a measure of L_X and T is available, namely XMMXCS J2215.9−1738 at $z = 1.46$ (Stanford et al. 2006), because this cluster is X-ray selected and its (X-ray) selection function is unpublished. As already noted by Hilton et al. (2010), this high-redshift cluster is too faint for its temperature when compared to a sample of similarly selected objects from Maughan et al. (2006) and when the selection function is ignored. If we assume that the X-ray selection factors out (i.e. it is benign), our suggestion of a breaking of the self-similar evolution is reinforced and its statistical significance increased.

4 CONCLUSIONS AND DISCUSSION

The large redshift leverage considered in this paper has provided direct, though not yet compelling, evidence that clusters do not evolve self-similarly in the last 10.6 Gyr, about three-quarters of the present age of the Universe. We remark that our result relies on a large redshift leverage, rather than on a detailed analysis of small effects on large samples at lower redshift. If confirmed, the trend we have found implies that non-gravitational effects, such as baryon physics, began long ago to shape the clusters' scaling relations. In particular, the observed evolution is in line with the predictions of simulation that include high-redshift pre-heating and radiative cooling in addition to shock heating, such as those in Short et al. (2010). They predict that our clusters should be a factor of 3 to 4 fainter than self-similar evolution, while we observe a factor of 5. Instead, their models that include feedback directly tied to galaxy formation or that incorporate gravitational heating only strongly disagree with our observations. This conclusion should not be overemphasized,

[2] Although not as clearly stated as in this work, the mass of JKCS 041 quoted in Andreon et al. (2009) has also been derived by self-similarly evolving the relation.

because we are still a long way from having the numerical resolution required to really implement these mechanisms (e.g. Norman 2010), for example, to follow the formation of stars, whose feedback is deemed important for the evolution of the gas properties.

It is of utmost importance to extend the sample of non-X-ray-selected clusters to $z > 1.4$ to confirm the modulation provided by non-gravitational phenomena in the cluster evolution. We emphasize the need of non-X-ray-selected samples: X-ray-selected samples should be treated with caution when used in this context, because the probability that an object is in the sample is not random in L_X at a given T. Optically/near-IR-selected samples should instead be used, since their selection is not due to their X-ray properties, unless we are able to predict their individual X-ray luminosities relative to the average X-ray luminosity at a given T in the absence of X-ray data and we are to make use of this information to select the objects.

If confirmed, the breakdown of the self-similar evolution would have important consequences for the cosmological studies. Indeed, the estimate of cosmological parameters is very sensitive to the evolution with redshift of the scaling relations (e.g. Albrecht et al. 2006 and references therein). A proper assessment of the intrinsic processes shaping the scaling relations is fundamental for the use of galaxy cluster surveys, such as the planned *WFXT* (Conconi et al. 2010) and *JDEM* (Sholl et al. 2009), as probes of the cosmological parameters.

ACKNOWLEDGMENTS

We thank Ben Maughan for his encouragement at the start of this work, Florian Pacaud for giving us the selection function of his sample in electronic form and the anonymous referee for useful suggestions. This paper is based on observations obtained by *Chandra* (ObsID 10461 and 12003) and the *HST* (ObsID 10496). We acknowledge financial contribution from the agreement ASI-INAF I/009/10/0.

REFERENCES

Albrecht A. et al., 2006, Report of the Dark Energy Task Force (arXiv:astro-ph/0609591)
Andreon S., 2008, MNRAS, 386, 1045
Andreon S., 2010, MNRAS, 407, 263
Andreon S., Huertas-Company M., 2011, A&A, 526, A11
Andreon S., De Propris R., Puddu E., Giordano L., Quintana H., 2008, MNRAS, 383, 102
Andreon S., Maughan B., Trinchieri G., Kurk J., 2009, A&A, 507, 147
Bode P., Ostriker J. P., Vikhlinin A., 2009, ApJ, 700, 989
Cavaliere A., Fusco-Femiano R., 1978, A&A, 70, 677
Conconi P., Campana S., Tagliaferri G., Pareschi G., Citterio O., Cotroneo V., Proserpio L., Civitani M., 2010, MNRAS, 405, 877
Dickey J. M., Lockman F. J., 1990, ARA&A, 28, 215
Ebeling H., White D. A., Rangarajan F. V. N., 2006, MNRAS, 368, 65
Finoguenov A., Reiprich T. H., Böhringer H., 2001, A&A, 368, 749
Ford H. C. et al., 2003, in Blades J. C., Siegmund O. H. W., eds, Proc. SPIE Vol. 4854, Future EUV/UV and Visible Space Astrophysics Missions and Instrumentation. SPIE, Bellingham, p. 81
Ford H. C. et al., 1998, in Bely P. Y., Breckinridge J. B., eds, Proc. SPIE Vol. 3356, Space Telescopes and Instruments V. SPIE, Bellingham, p. 234
Gelman A., Carlin J., Stern H., Rubin D., 2004, Bayesian Data Analysis, Chapman & Hall/CRC, Boca Raton, FL
Gonzalez A. H., Zaritsky D., Zabludoff A. I., 2007, ApJ, 666, 147
Hack W., 1999, CALACS Operation and Implementation, Instrument Science Report ACS 99-03, STScI, Baltimore
Hilton M. et al., 2010, ApJ, preprint (arXiv:1005.4692)
Kaiser N., 1986, MNRAS, 222, 323
Koekemoer A. M., Fruchter A. S., Hook R. N., Hack W., 2002, The 2002 HST Calibration Workshop: Hubble after the Installation of the ACS and the NICMOS Cooling System. STSci, Baltimore, p. 337
Kravtsov A. V., Nagai D., Vikhlinin A. A., 2005, ApJ, 625, 588
Markevitch M., 1998, ApJ, 504, 27
Maughan B. J., Jones L. R., Ebeling H., Scharf C., 2006, MNRAS, 365, 509
Maughan B. J., Jones C., Forman W., Van Speybroeck L., 2008, ApJS, 174, 117
Nagai D., Kravtsov A. V., Vikhlinin A., 2007, ApJ, 668, 1
Nord B., Stanek R., Rasia E., Evrard A. E., 2008, MNRAS, 383, L10
Norman M. L., 2010, preprint (arXiv:1005.1100)
Pacaud F. et al., 2007, MNRAS, 382, 1289
Pratt G. W., Croston J. H., Arnaud M., Böhringer H., 2009, A&A, 498, 361
Rosati P., Borgani S., Norman C., 2002, ARA&A, 40, 539
Sholl M. J. et al., 2009, in MacEwen H. A., Breckinridge J. B., eds, Proc. SPIE Vol. 7436, UV/Optical/IR Space Telescopes: Innovative Technologies and Concepts IV. SPIE, Bellingham
Short C., Thomas P., Young O., Pearce F., Jenkins A., Muanwong O., 2010, MNRAS, 408, 4
Smith R. K., Brickhouse N. S., Liedahl D. A., Raymond J. C., 2001, ApJ, 556, L91
Stanek R., Evrard A. E., Böhringer H., Schuecker P., Nord B., 2006, ApJ, 648, 956
Stanford S. A. et al., 2005, ApJ, 634, L129
Stanford S. A. et al., 2006, ApJ, 646, L13
Willis J. P. et al., 2005, MNRAS, 363, 675

This paper has been typeset from a TEX/LATEX file prepared by the author.