XMM-NEWTON OBSERVATION OF THE CLUSTER Zw 1305.4+2941 IN THE FIELD SA 57

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ABSTRACT

We report the details of an XMM-Newton observation of the cluster of galaxies Zw 1305.4+2941 at the intermediate redshift \( z = 0.241 \), increasing the small number of interesting X-ray constraints on properties of \( \sim 3 \) keV systems above \( z = 0.1 \). Based on the \( \sim 45 \) ks XMM-Newton observation, we find that within a radius of \( 228 \) kpc the cluster has an unabsorbed X-ray flux of \( f_X = (2.07 \pm 0.06) \times 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\), a temperature of \( kT = 3.17 \pm 0.19 \) keV, in good agreement with the previous ROSAT determination, and an abundance of \( 0.93^{+0.24}_{-0.29} Z_\odot \). Within \( r_{500} = 723 \pm 16 \) kpc the rest-frame bolometric X-ray luminosity is \( L_X(r_{500}) = (1.25 \pm 0.16) \times 10^{44} \) erg s\(^{-1}\). The cluster obeys the scaling relations for \( L_X, T \), and the velocity dispersion \( \sigma \), derived at intermediate redshift for \( kT \leq 4 \) keV, for which we provide new fits for all objects in the literature. The mass derived from an isothermal NFW model fit is \( M_{\text{vir}} = (2.77 \pm 0.21) \times 10^{14} M_\odot \), with the concentration parameter \( c = 7.9 \pm 0.5 \).

Subject headings: galaxies: clusters: general — X-rays: general

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1. INTRODUCTION

The current generation of X-ray observatories, Chandra and XMM-Newton, is considerably extending the maximum redshift to which X-ray clusters can be identified and analyzed. In fact, the number of massive clusters detected at \( z > 1 \) is rapidly growing, thanks to the unprecedented XMM-Newton sensitivity (e.g., Mullis et al. 2005; Stanford et al. 2006; Bremer et al. 2006). On the other hand, they are also extending the minimum luminosity, i.e., the least massive structures, to which X-ray clusters can be detected and analyzed at intermediate redshifts. Galaxy groups and clusters with \( kT \leq 4 \) keV are starting to be routinely detected and analyzed in detail at \( 0.2 < z < 0.6 \) (Willis et al. 2005; Gaja et al. 2005; Jeltema et al. 2006; Puccetti et al. 2006), where few examples were known. They represent the population that Chandra and in particular XMM-Newton surveys (like the XMMLSS; Pierleoni et al. 2004) are sampling using typical exposures (\( 10–20 \) ks), as expected (Jones et al. 2002).

These objects are more likely to display the effects of non-gravitational energy into the intracluster medium (ICM) than hotter, more massive clusters (e.g., Ponman et al. 2003). The study of X-ray–extended objects over an extended temperature range at \( z > 0.2 \) will provide an important insight into the evolution of their X-ray–emitting gas and the deviation of X-ray–scaling relations from simple, self-similar expectations. Studies of objects in the redshift range \( 0.2 < z < 0.6 \) and with \( 2 < kT < 2.6 \) keV are already suggesting that at these redshifts these objects are less dynamically evolved than their counterparts at \( z = 0 \) (Mulchaey et al. 2006). Furthermore, clusters with masses in the range \( (3–5) \times 10^{14} M_\odot \) (\( 3 \) keV < \( T_X < 4 \) keV) will constitute the bulk of the cosmological constraining power of future Sunyaev-Zeldovich (SZ) surveys, because this is the range well above the nearly redshift-independent detection limit of these surveys (Haiman et al. 2001), therefore constituting the largest population in number count studies.

Here we present details of the XMM-Newton observation of the cluster \( Zw 1305.4+2941 \), also known as MS 1305+29, with \( kT \sim 3 \) keV at the redshift \( z = 0.241 \), observed during an exposure of the field SA 57. All distance-dependent quantities have been computed assuming \( H_0 = 70 \) km s\(^{-1}\) Mpc\(^{-1}\), \( \Omega_m = 0.3 \), and \( \Omega_{\Lambda} = 0.7 \). At the redshift \( z = 0.241 \), \( 1' \) corresponds to \( 228 \) kpc. All the errors quoted are at the 68% confidence limit.

2. X-RAY ANALYSIS

The object \( Zw 1305.4+2941 \) has been observed during an XMM-Newton pointing of the field SA 57 (Trevese et al. 2007), and it is located at \( 9.3' \) off-axis (see Fig. 1).\(^6\) The data were reduced with SAS version 7.0.0 using the tasks emchain and epchain. We considered only event patterns 0–12 for MOS and 0 for pn, and the data were cleaned using the standard procedures for bright pixels and hot column removal (by applying the expression FLAG = 0) and pn out-of-time correction. Periods of high background due to soft protons were filtered as in Gastaldello et al. (2007a); the observation was affected by flares at the end of the exposure, and \( \sim 20 \) ks were lost, resulting in a net exposure time of \( 47, 48, \) and 40 ks, respectively, for MOS1, MOS2, and pn.

For each detector, we created images in the \( 0.5–2 \) keV band with point sources detected using the task eva1e1t and masked using circular regions of \( 25'' \) radius centered at the source position. The images have been exposure-corrected, and a radial surface brightness profile was extracted from a circular region of \( 6' \) of radius centered on the cluster centroid. We account for the X-ray background by including a constant-background component. The data were grouped to have at least 20 counts per bin in order to apply the \( \chi^2 \) statistic. The fitted model is convolved with the XMM-Newton point-spread function (PSF). The joint best-fit \( b \)-model (Cavaliere & Fusco-Femiano 1976) has a core radius

\(^6\) The center of the pointing has been calculated as an effective area–weighted average of the optical axis of the three telescopes taken from the exposure map headers keywords Xcen and Ycen, as in Pacaud et al. (2006).
of $r_c = 57 \pm 8$ kpc ($14.9'' \pm 2.0''$) and $\beta = 0.54 \pm 0.02$ for a $\chi^2$/dof = 202/130, where “dof” is the number of degrees of freedom (see Fig. 2). Fits to the profiles of the individual detectors give consistent results within 1 $\sigma$ of the combined fit result and in the case of the MOS detectors are formally acceptable (20/24 MOS 1 and 41/39 MOS 2). The main contribution to the $\chi^2$ comes mainly from the pn, and its origin is instrumental; hence, there is no need for more complicated models.

For spectral fitting, we extracted spectra for each detector from a 1$'$ region centered on the centroid of the emission, to maximize the signal-to-noise ratio (S/N) over the background. Redistribution matrix files (RMFs) and ancillary response files (ARFs) were generated using the SAS tasks rmfgen and arfgen in extended source mode. Appropriate flux weighting was performed for RMFs and for ARFs, using exposure-corrected images of the source as detector maps (with pixel size of 1$''$), the minimum scale modeled by arfgen) to sample the variation in emission, following the prescription of Saxton and Siddiqui. The background was estimated locally using spectra extracted from a 2$''$–3$''$ annular region centered on the centroid of the emission. The spectra from the three detectors were rebinned to ensure a signal-to-noise ratio of at least 3 and a minimum of 20 counts per bin, and they were jointly fitted with an APEC thermal plasma modified by Galactic absorption (Dickey & Lockman 1990). The spectral fitting was performed with XSPEC (ver. 11.3.1, Arnaud 1996) in the 0.5–6 keV band, and quoted metallicities are relative to the abundances of Grevesse & Sauval (1998). The spectra are shown in Figure 3; the best-fit parameters are $kT = 3.17 \pm 0.19$ keV and $Z = 0.93^{+0.24}_{-0.26} Z_\odot$, for a $\chi^2$/dof = 241/222.

Using the best-fit model, the unabsorbed flux within the aperture of radius $r' = 228$ kpc is $(2.07 \pm 0.06) \times 10^{-13}$ erg s$^{-1}$ cm$^{-2}$ in the 0.5–2 keV band. This corresponds to an unabsorbed luminosity of $(3.33 \pm 0.15) \times 10^{43}$ erg s$^{-1}$ in the 0.5–2 keV and to a bolometric luminosity of $(8.66 \pm 0.98) \times 10^{43}$ ergs s$^{-1}$. The quoted errors on flux and luminosity are the mean and standard deviation of the distributions evaluated by repeating the measurements after 10,000 random selections of temperature, metallicity and normalization, drawn from Gaussian distributions with mean and standard deviation in accordance with the best-fit results.

To investigate possible spatial variation in the spectral parameters of the cluster, we extracted two annular regions of radii 0$''$–0.5$''$ and 0.5$''$–1.5$''$. The derived spectral parameters are $kT = 3.04 \pm 0.23$ keV and $Z = 0.93 \pm 0.45 Z_\odot$, with $\chi^2$/dof = 140/121 for the inner annulus and $kT = 3.47^{+0.22}_{-0.32}$ keV and $Z = 0.91^{+0.32}_{-0.35} Z_\odot$, with $\chi^2$/dof = 153/159 for the outer annulus. The widths of the bins have been chosen in order to avoid bias in the temperature measurement caused by scattered flux by the PSF (80% encircled energy fraction radius is 31$''$ for the pn at 1.5 keV and at the off-axis angle of the source). The cluster is therefore consistent with being isothermal over the explored radial range.

The cluster has regular X-ray isophotes and is centered on a dominant early-type galaxy (see § 3). These characteristics suggest that the cluster is relaxed and that hydrostatic equilibrium is a good approximation. The isothermal profile is not exceptional in a relaxed cluster, as Zw 1305.4+2941 seems to have properties very similar to the low-redshift cluster A2589 (Zappacosta et al.).
We calculated the total mass profile using two different models. First, we used the best-fit $\beta$-model for which the gas density and total mass profiles can be expressed by a simple analytical formula (e.g., Ettori 2000). We evaluated density and total mass profiles can be expressed by a simple analytical formula (e.g., Ettori 2000). We evaluated $r_{500}$ as the radius at which the density is 500 times the critical density and the virial radius as the radius at which the density corresponds to $\Delta_{\text{vir}}$, as obtained by Bryan & Norman (1998) for the concordance cosmological model used in this paper. To evaluate the errors on the estimated quantities, we repeat the measurements after 10,000 random selections of a temperature and parameters of the surface brightness profile, which were drawn from Gaussian distributions with mean and variance in accordance with the best-fit results. For $\Delta = 500$ we obtained $M_{r_{500}} = (1.37 \pm 0.15) \times 10^{14} M_\odot$ within $r_{500} = 723 \pm 16$ kpc; the virial mass is $M_{\text{vir}} = (2.81 \pm 0.30) \times 10^{14} M_\odot$, within the virial radius $r_{\text{vir}} = 1474 \pm 52$ kpc. Second, we fit the surface brightness profile with an isothermal Navarro, Frenk, and White (NFW; Navarro et al. 1997) model (Suto et al. 1998). We obtain a concentration parameter, $c = 7.9 \pm 0.5$, virial radius $r_{\text{vir}} = 1468^{+34}_{-41}$ kpc, and virial mass $M_{\text{vir}} = (2.77 \pm 0.21) \times 10^{14} M_\odot$, with $\chi^2$/dof = 197/130. The mass determinations using the two different models agree well within the 1 $\sigma$ errors. We calculate the gas mass using the procedure described in Ettori et al. (2004) and the $\beta$-model parameterization and deriving the central electron density from a combination of the surface brightness fit and the normalization of the spectral model (eq. [2] of Ettori et al. 2004). We obtained $M_{\text{gas,500}} = (1.37 \pm 0.14) \times 10^{13} M_\odot$. We calculate the entropy of the cluster using the standard definition $S = T_{\text{gas}} n_e^{3/2}$ and measure this quantity at $0.1 r_{200}$ and $r_{500}$ as done by Ponman et al. (2003). We find $S(0.1 r_{200}) = 168 \pm 12$ keV cm$^2$ and $S(r_{500}) = 1103 \pm 122$ keV cm$^2$, where $r_{200} = 1144 \pm 41$ kpc using the best-fit $\beta$-model. Finally, we have studied the sensitivity of our spectral results to various sources of systematic errors, which we summarize below.

**Galactic column density and bandwidth**.—If $N_{\text{HI}}$ is allowed to vary, the fit in the 1$'$ aperture does not improve, and the best-fit column density is consistent at 1 $\sigma$ with the Galactic value; the other parameters are unchanged. Restricting the energy band to the 0.5–5 keV band returned practically unchanged values, $kT = 3.15 \pm 0.23$ keV and $Z = 0.91 \pm 0.29 Z_\odot$, whereas using a 0.4–5 keV band has the effect of slightly increasing the values, $kT = 3.24 \pm 0.12$ keV and $Z = 1.06^{+0.34}_{-0.12} Z_\odot$, but still with systematic errors less than the statistical ones.

**Background.**—For comparison with the results obtained with the local background, we used the standard blank-background fields (Read & Ponman 2003), finding good agreement between the two methods in the 1$'$ aperture, $kT = 3.20 \pm 0.12$ keV and $Z = 0.87 \pm 0.23 Z_\odot$. In the 0.5$'$–1.5$'$ outer annulus the results obtained with the background template are in agreement within 1 $\sigma$ with the local background method, $kT = 3.41^{+0.25}_{-0.19}$ keV and $Z = 0.70^{+0.22}_{-0.19} Z_\odot$.

**Plasma code.**—We investigated the sensitivity of our results to the plasma code using the MEKAL model. The quality of the
3. OPTICAL ANALYSIS

Zw 1305.4+2941 is a Bautz-Morgan type I cluster at $z = 0.24$. The optical map with overplotted X-ray contours from XMM-Newton 0.5–10 keV data is shown in Figure 4. Optical photometry of the field SA 57 was obtained from $U$, $B_r$, $F$, and $N$ plates taken at the KPNO 4 m Mayall telescope (Koo et al. 1986). A foreground cluster was recognized in the two-color diagram calibrated with the spectroscopic redshifts available in the field (Koo et al. 1988). The cluster is elongated, with a major-axis position angle $\theta_c = 57^\circ \pm 6^\circ$. The central cD galaxy has a position angle $\theta_{cD} = 61^\circ$ and an axial ratio $b/a = 0.78$, both measured at 3.5 mag fainter than the central surface brightness and with a $\approx 10\%$ error. In Koo et al. (1988) the galaxy number density profiles, as deduced, respectively, in circular or elliptical annuli and statistically corrected for background, were fitted with both a projected Emden isothermal profile $\sigma(b) = \sigma_{\text{iso}}(b/b_c)$ and projected King profile $\sigma_r(b) = \sigma_{K}(1+(b/R_c)^{1.5})^{-1}$ following the procedure of Sarazin (1980). The parameters are the core radius $R_c = 3 b_c = 3 \sigma_r/(4\pi G n_0)^{1/2}$, the central surface density, and the surface density of the background; $\sigma_r$ is the dispersion of the radial velocities, $n_0$ is the central value of the volume density of galaxies, and $m$ is the average galaxy mass. The results of the fit are reported in Table 2B of Koo et al. (1986).

Mahdavi & Geller (2001) report a velocity dispersion value $\sigma_{v}$ of $\sim 813$ km s$^{-1}$, citing the paper of Wu et al. (1999), but this value is not attributed in an unequivocal way to the cluster MS 1305.4+2941. Mushotzky & Scharf (1997) used velocity dispersion data from Fadda et al. (1996), Carlberg et al. (1996), and Fabricant et al. (1991), none of which contains $\sigma_r$ for MS 1305.4+2941. On the basis of the redshifts found using the NASA Extragalactic Database (NED), mostly derived by the spectroscopic survey of the field by Munn et al. (1997), we have determined the velocity dispersion of the cluster by considering circular areas of increasing radius, centered on the cD galaxy. The results are shown in Figure 5, where the redshifts as a function of the angular distance from the cluster center are also reported. The velocity dispersion is roughly constant between 1 and 3.5' and progressively rises beyond 4'. This may be due to the inclusion of galaxies not belonging to the cluster or to incomplete virialization. The X-ray surface brightness falls below 3% of the central value at a radius of 3.3' (see Fig. 2), which corresponds to about $r_{500}$, and becomes practically undetectable. Therefore, we adopt $\sigma(3.3') = 568 \pm 125$ km s$^{-1}$ (based on 10 members), which corresponds to $\sigma_{\text{spec}} = \mu \sigma_{v}(kT)^{-1/2}$ for $T = 3.17$ keV and $\mu = 0.6$. This value of $\sigma_{\text{spec}}$ is not much different from the value of $\sigma_{\text{spec}}$ derived from the X-ray brightness distribution $0.54 \pm 0.02$. Moreover, $\sigma_{\text{spec}} < 1$ is also consistent with the X-ray image that in the central region seems to show a quite relaxed cluster. A value of $\sigma_{\text{spec}}$ lower than 1 may be due to the transfer from orbital to internal energy occurring in galaxy merging, thus cooling the galaxy velocity distribution, despite the counteracting effect of the cluster gravitational potential (Fusco-Femiano & Menci 1995). Finally, the fraction of blue galaxies $f_b \sim 0.1$ derived within $\sim 1.4'$ from (see their Fig. 8) Koo et al. (1988) for this cluster is consistent with the relationship between cluster velocity dispersion and blue fraction within $r_{200}/4$ obtained by Andreon et al. (2006), although not definitely conclusive.

4. DISCUSSION

In this section we discuss the properties of Zw 1305.4+2941 in relation to those of objects with $kT \leq 4$ keV at the intermediate redshift $0.2 < z < 0.6$. In particular, we investigate the scaling relations between $L_X$, $T_X$, and the velocity dispersion $\sigma_3$ for the six objects at intermediate redshift ($0.29 < z < 0.44$) in the XMM LSS survey (Willis et al. 2005), the six objects ($0.23 < z < 0.59$) in the sample of Jeltema et al. (2006), and Zw 1305.4+2941, together with the recently discovered cluster XMMU J131359.7-162735, with $kT = 3.57 \pm 0.12$ keV, presented in Gastaldello et al. (2007b). We made a first attempt at investigating quantitatively these relations (in a simple power-law representation) in its normalization and slope by performing a linear regression $Y = a \log X + b$ between two sets of measured quantities $Y$ and $X$. We employ the bisector modification of the BCES method (i.e., bivariate correlated errors with intrinsic scatter) described by Akritas & Bershady (1996) that takes into account both any intrinsic scatter and errors on the two variables considered symmetric. We performed the BCES fitting using software kindly provided by M. Bershady. The uncertainties on the best-fit results are obtained from 100 bootstrap resamplings. The results on the best-fit normalization and slope for the scaling laws here investigated are quoted in Table 1, together with total and intrinsic scatter (measured using eq. [2] of Buote et al. 2007), and they are shown as black solid lines in Figure 6.

We first investigate the $L_X-T_X$ relation. For Zw 1305.4+2941, the aperture of 228 kpc used for spectroscopy encloses 70% of the flux within $r_{500}$, assuming the cluster emission profile follows the $\beta$-model of Figure 2. The derived bolometric luminosity

$9$ See http://www.astro.wisc.edu/~mab/archive/stats/stats.html.
within $r_{500}$ is $L_{500} = (1.26 \pm 0.16) \times 10^{44}$ ergs s$^{-1}$; errors in the luminosity were determined by including both the spectral errors and the uncertainties in the $\beta$-model parameters. The temperature derived with XMM-Newton is in good agreement with the previous Röntgensatellit (ROSAT) determination ($2.98^{+0.52}_{-0.41}$ keV, 2 $\sigma$ errors; Mushotzky & Scharf 1997). In the top panel of Figure 6 we plot the results for the intermediate-redshift groups/poor clusters compared to the best-fit regression lines for the low-redshift groups of the GEMS sample (Osmond & Ponman 2004), for the clusters of Horner (2001) as quoted in Osmond & Ponman (2004), removing cool ($T_X < 2$ keV) low-luminosity ($L_X < 2 \times 10^{43}$ ergs s$^{-1}$) objects, and for the cluster sample of objects with $T_X > 3$ keV of Markevitch (1998). With the caveat of the large error bars in the measured slope due to the still rather large errors in both luminosity and temperature and the small size of the sample, the relation is consistent with that found for local clusters. Given the angular resolution of the data, it has not been possible to correct for the effect of central cool cores, which tend to reduce the scatter and produce flatter slopes (Allen & Fabian 1998; Markevitch 1998).

We then investigate the relationship between the velocity dispersion of the group member galaxies and the X-ray temperature, excluding from the sample of Willis et al. (2005) XLSSC 013, for which no velocity dispersion was quoted, and XMMU J131359.7–162735, for which we do not have optical spectroscopy. For the sample of Jeltema et al. (2006), we used the updated velocity dispersions presented in Jeltema et al. (2007). In the middle panel of Figure 6 we show the $\sigma_T$-$T_X$ relation compared to the best fit of the GEMS groups (Osmond & Ponman 2004), the cluster data of Horner (2001) as quoted in Osmond & Ponman (2004), and the cluster sample of Girardi et al. (1996). As discussed in Jeltema et al. (2006), there is a large scatter with few groups, which appears to have significantly low velocity dispersions for their temperature, similar to that found in the GEMS sample at lower X-ray luminosities and temperatures. A well-known observational effect could be a possible explanation, due to the fact that velocity dispersions may be artificially low when based on relatively small numbers (e.g., Zabludoff & Mulchaey 1998; Girardi & Mezzetti 2001). Or velocity dispersions could be really reduced; Helsdon et al. (2005) propose several possible mechanisms for this effect, including dynamical friction, tidal heating, and orientation effect (see also discussion in § 3). The former explanation holds for many of the objects in the sample of Jeltema et al. (2006). For example, RX J1334.9+3750 increased its velocity dispersion from $121^{+38}_{-59}$ km s$^{-1}$, based on six members (Mulchaey et al. 2006), to $246^{+44}_{-26}$ km s$^{-1}$, based on 17 members (Jeltema et al. 2007); RX J1648.7+6019 increased its velocity dispersion from $130^{+14}_{-46}$ km s$^{-1}$, based on eight members, to $417^{+118}_{-86}$ km s$^{-1}$, based on 22 members. Deeper spectroscopy to increase the robustness of the determination of the velocity dispersion and deeper X-ray observations are therefore

| Relation ($Y$) | $a$ | $b$ | $\sigma_Y$ | $\sigma_Y^{\text{stat}}$ |
|---------------|-----|-----|------------|---------------------|
| $L_X$-$T_X$    | 3.10 ± 1.77 | 42.7 ± 0.6 | 0.39 | 0.37 |
| $\sigma_T$-$T_X$ | 0.86 ± 0.85 | 2.37 ± 0.27 | 0.14 | 0.12 |
| $L_X$-$\sigma_T$ | 2.82 ± 0.75 | 36.2 ± 2.0 | 0.36 | 0.33 |

**Notes:**—Best-fit results for the scaling relations discussed in the text. The total scatter $\sigma_Y$ on $Y$ is measured as $\sigma_Y = \sqrt{\sum_{i=1}^{N} (Y_i - \alpha - \beta \log X_i)^2/N}$. The intrinsic scatter is estimated as $\sigma_Y^{\text{stat}} = \sqrt{\sum_{i=1}^{N} (1/\sigma^2_{Y,i})}$, where $\sigma_{Y,i}^{\text{stat}} = \sqrt{\sum_{i=1}^{N} (1/\sigma^2_{Y,i})}$.
crucial to clarify the nature of these systems. In the cluster regime there seems to be a consensus for a slight departure from a pure gravitational collapse, $\sigma_{\text{cl}} \propto T^{0.5}$ (e.g., Lubin & Bahcall 1993; Bird et al. 1995; Girardi et al. 1996; Xue & Wu 2000), whereas the evidence for groups is more controversial, with some authors (e.g., Mulchaey 2000; Xue & Wu 2000) finding that groups fall on the cluster trend and others (Helsdon & Ponman 2000a, 2000b) finding that the relation steepens. As discussed in Osmond & Ponman (2004), the large nonstatistical scatter mentioned above contributes to the controversy. Again with the caveat of large error bars, the objects in the intermediate-redshift sample seem to indicate an intermediate slope between clusters and low-temperature groups (but see Ortiz-Gil et al. [2004] for an even steeper slope, 1.00 ± 0.16, for a large REFLEX cluster sample). It is interesting to quote the results we would obtain if we had used the velocity dispersions based on fewer members for the sample of Jeltema et al. (2006) reported in Mulchaey et al. (2006), a slope of 0.89 ± 1.18 and intercept 2.30 ± 0.18.

Finally, we investigate the $L_X$-$\sigma_{\text{cl}}$ relation for the same objects considered above, shown in the bottom panel of Figure 6. The cluster relation slope is consistently found by many investigations close to the purely gravitational expectation of 4 (e.g., Girardi & Mezzetti 2001; Popeo et al. 2005; Ortiz-Gil et al. 2004; see the latter reference for a thorough comparison with previous determinations). There is disagreement at the group scale between studies that find that groups are consistent with the cluster relation (e.g., Helson & Ponman 2000b; Mahdavi & Geller 2001) and those that find significantly flatter relations (e.g., Xue & Wu 2000; Osmond & Ponman 2004). The results from the intermediate-redshift sample point to a flatter trend compared to the cluster results. But we can see that this is mainly due to the same low-velocity dispersion objects that have not only $L_X$, but also $L_X$, higher compared to the expectations. Clearly, these are not the X-ray underluminous optically selected objects found both at the cluster (e.g., Popeo et al. 2007) and group scale (e.g., Rasmussen et al. 2006) that are believed to be systems that are collapsing for the first time, and it is therefore likely that a better determination of $\sigma_{\text{cl}}$ in these X-ray-selected objects will bring these objects into closer agreement with the cluster scaling relations (modulo the effects described, for example, in Helson et al. 2005).

In fact, for example, had we used the velocity dispersions based on fewer members reported in Mulchaey et al. (2006), we would have obtained a flatter slope of $2.07 ± 1.21$ and the intercept $38.3 ± 3.2$.

We checked that the values for slope and intercept of the regression lines do not depend on the choice of the pivot point: we fitted the relation $\log Y/Y_0 = \sigma_1 \log X/X_0 + b_1$ with $L_0 = 10^{43.3}$ ergs s$^{-1}$, $T_0 = 2.0$ keV, and $\sigma_0 = 300$ km s$^{-1}$ at the center of the data point cloud in the three relations, obtaining results identical to the ones in Table 1.

The entropy for Zw 1305.4+2941, measured at the two directions, $E_0$ and $E_2$, with $E_0 = H_0/H_0 = \left(\Omega_m(1+z)^3 + \Lambda\right)^{1/2}$ to account for the variation of the mean density within a given overdensity radius with redshift, we find $E_0^{1/3}S(0.1\sigma_{200}) = 232 ± 16$ keV cm$^2$ and $E_2^{1/3}S(1.0\sigma_{200}) = 1522 ± 168$ keV cm$^2$, which can be compared with the plots in Figures 12 and 13 of Jeltema et al. (2006), showing good agreement with the local relation.

The high iron abundance for this cluster is consistent with the trend of increasing metallicity with decreasing temperature found at intermediate and high redshift by Balestra et al. (2007) in Chandra and XMM-Newton data and in the sample of Baumgartner et al. (2005) with the Advanced Satellite for Cosmology and

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Astrophysics (ASCA) data. Particularly relevant is the comparison with objects such as Zw 0024.0+1652 and V1416+4446 in the sample of Balestra et al. (2007), which at $z = 0.395$ and $0.400$ have $kT = 4.38 ± 0.27$ keV, $Z = 1.09^{+0.25}_{-0.25}$ $Z_\odot$ and $kT = 3.50 ± 0.18$ keV, $Z = 1.34^{+0.31}_{-0.24}$ $Z_\odot$, respectively, after their solar abundances were converted from Asplund et al. (2005) to Grevesse & Sauval (1998) by scaling for 0.89. In addition, these objects, which are observed with Chandra and for which an analysis in two annuli is performed, do not show a clear enhancement of the iron abundance in the inner regions (Balestra et al. 2007), displaying the same behavior as Zw 1305.4+2941. These data seem to suggest therefore that the higher abundance is not due to the presence of a particularly iron-rich cool core. Zw 1305.4+2941 is present in the sample of Baumgartner et al. (2005) based on the results of Horner (2001): the ASCA abundance determination is high (0.92±0.96), while the XMM-Newton abundance determined by Anders & Grevesse [1989] to Grevesse & Sauval [1998] by scaling for 1.48) and in good agreement with the XMM-Newton measurement. This trend of metallicity with temperature, still poorly understood, needs to be investigated with better data (it should be remarked that the constraints on the metallicity of Zw 1305.4+2941 are interesting, but not tight; it is consistent with $\sim 0.3 Z_\odot$ at the 2$\sigma$ level).

The measured concentration parameter $c$, multiplied by the expected dependence $1 + z$ (Bullet et al. 2001), is consistent with a relaxed, early forming object in a $\Lambda$CDM model with $\sigma_8 = 0.9$ and with the observational results of relaxed, low-z objects (Buote et al. 2007). In Figure 7 we show the data points corresponding to Zw 1305.4+2941 and XMMU J131359.7−162735 overplotted on the $c$-$M$ data points and best-fit relation discussed in Buote et al. (2007). It should be kept in mind that these two data points have been derived under a very simple and restrictive isothermal assumption, whereas all the low-z data points have been derived with a detailed investigation of the density, temperature, and abundance profiles.

5. CONCLUSIONS

We present results for an XMM-Newton observation of the cluster Zw 1305.4+2941, for which we derive $kT = 3.17 ± 0.19$ keV, an abundance of $0.93^{+0.25}_{-0.29} Z_\odot$ for an unabsorbed bolometric...
luminosity of \( (8.86 \pm 0.98) \times 10^{13} \) ergs s\(^{-1}\) within an aperture of 1' (228 kpc at \( z = 0.241\)). Under the assumption of isothermality and assuming that the cluster follows the best-fit model to the surface brightness profile, we derive luminosity, entropy, and mass at various overdensities. We measure a velocity dispersion of \( 568 \pm 125 \) km s\(^{-1}\) within 3.3'. These interesting constraints increase the small number of well-studied ~3 kV objects above \( z = 0.1\).

We provide new fits of scaling relations for all \( kT \leq 4 \) keV objects in the intermediate-\( z \)-range in the literature. The cluster obeys the scaling relations thus derived. Concentration and mass for this object agree with the local \( c-M \) relation.

The prospects for increasing the sample size and improving the description presented here are promising. \textit{XMM-Newton} and \textit{Chandra} are dramatically expanding our previously little knowledge of \( X \)-ray–emitting low-temperature clusters and groups of galaxies beyond the present epoch. Surveys such as \textit{XMM LSS} (Pierre et al. 2004) and \textit{COSMOS} (Finoguenov et al. 2007) will provide large samples of \( X \)-ray–selected groups and poor clusters out to redshift \( z \sim 0.6 \) or higher. Together with very large redshift surveys, optically selected groups in large quantities at moderate redshifts (e.g., Wilman et al. 2005a, 2005b) will be obtained, characterizing in great detail this population and investigating some initial suggestion of group downsizing. More massive groups could still be in the process of virializing at intermediate redshift, while this process is restricted to much less luminous (and thus less massive) systems at the present day (Mulchaey et al. 2006). \( X \)-ray follow-up with \textit{Chandra} could allow going beyond the simple isothermal \( \beta \)-model used so far in these studies.

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