X-ray emission from RX J1720.1+2638 and Abell 267: a comparison between a fossil and a non-fossil system

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We present the XMM-Newton X-ray analysis of RX J1720.1+2638 and Abell 267, a non-fossil and a fossil system, respectively. The whole spectrum of both objects can be explained by thermal emission. The luminosities found for RX J1720.1+2638 and Abell 267 in the 2-10 keV band are $6.20^{+0.04}_{-0.02} \times 10^{44}$ and $3.90^{+0.10}_{-0.11} \times 10^{44}$ erg s$^{-1}$, respectively. The radial profiles show a cool core nature for the non-fossil system RX J1720.1+2638, while Abell 267 shows a constant behaviour of temperature with radius. Metallicity profiles have also been produced, but no evidence of any gradient was detected due to the large uncertainties in the determination of this parameter. Finally, density and mass profiles were also produced allowing to derive $M_{500}$ for RX J1720.1+2638 and Abell 267. The masses obtained are high, in the range of $(5\sim7)\times10^{14} M_{\odot}$. The X-ray properties obtained for both systems are not always in good agreement with what is expected: cool cores are expected for fossil systems, as Abell 267, considering them as and relaxed systems. However, the decrement of the temperature in Abell 267 could start at lower radii. Also the presence of a recent merger in Abell 267, already suggested in the literature, could have increased the central temperature. The non-fossil system RX J1720.1+2638 actually exhibits a cool core profile, but also evidence of a recent merger has been reported.

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1 Introduction

Fossil systems (Harrison et al. 2012) are systems of galaxies dominated by a single and isolated massive elliptical galaxy. The classification as a fossil system requires a gap in the R-band magnitude of two or more for the two brightest galaxies (Aguerri et al. 2011; Mendes de Oliveira et al. 2003; Onghia et al. 2005; von der Linden et al. 2004). The current theory suggests that these objects collapsed in the early Universe with enough time to be able to merge the more massive galaxies (Jones et al. 2003; Khosroshahi et al. 2004; Khosroshahi et al. 2007) and that are the most undisrupted systems of galaxies. This scenario is supported by both observational studies (Harrison et al. 2012; Jones et al. 2003; Khosroshahi et al. 2004; Khosroshahi et al. 2007) and cosmological simulations (D’Onghia et al. 2005; von Benda-Beckmann et al. 2008). Alternatively, other studies show that these systems actually present a deficit of L* galaxies (Aguerri et al. 2011; Mendes de Oliveira et al. 2006; Mulchaey & Zabludoff 1999). According to both observations and simulations, there is therefore no clear scenario for the physical origin of fossils. Here, we present the EPIC XMM-Newton data analysis of the two clusters RX J1720.1+2638 and Abell 267 selected from Santos et al. 2007 and classified as fossil systems of galaxies. A detailed analysis of optical data (J. L. Aguerri, private communication) showed that RX J1720.1+2638 cannot be classified as a fossil system according to its optical photometric and spectroscopic properties. However the general properties of both systems (i.e. $\sigma \sim 1100$ km s$^{-1}$ for both systems, Girardi et al. 2013, in preparation) are very similar and therefore this study consists of a good comparison between a fossil and a non-fossil system.

2 Data reduction and analysis

The XMM-Newton observations of RX J1720.1+2638 (ObsID: 0500670201) and Abell 267 (ObsID: 0084230401) were processed using SAS, v11.0 and using the most updated calibration files available in November 2011. Event lists from EPIC detectors were filtered to ignore periods of high background flaring following Piconcelli et al. (2004). The net exposures for RX J1720.1+2638 and Abell 267 are 23.4 and 12.7 ks, respectively. Background spectra were extracted from blank sky event files, provided by the XMM-Newton EPIC Background Blank Sky team (Carter & Read 2007). The blank sky event files were requested using the same criteria of the observations (filter, mode). Source and background spectra, along with associated response matrices and ancillary response files were obtained with SAS. We simultaneously fitted the pn and MOS spectra using Xspec v12.7.1. The spectral analysis was performed in the 0.3-8 keV band with a Hubble constant of $70$ kms$^{-1}$Mpc$^{-1}$ and $\Omega_{M} = 0.3$ and $\Omega_{\Lambda} =$...
The goodness of the fit was \( \chi^2/dof=416/292 \). The absorbed fluxes measured in the 0.5-2 (2-10) keV bands were \( 5.22 \pm 0.02 (8.56^{+0.06}_{-0.03}) \times 10^{-12} \, {\text{erg cm}^{-2} \text{s}^{-1}} \) and the corresponding unabsorbed luminosities were \( 3.97 \pm 0.02 (6.20^{+0.04}_{-0.02}) \times 10^{44} \, {\text{erg s}^{-1}} \). The higher temperature component accounts for 70% of the bulk of the soft emission and up to 90% goes to hard emission. Abell 267 spectrum was satisfactorily fitted with two thermal components, \( kT_{\text{high}} = 11^{+10}_{-8} \, \text{keV} \) and \( kT_{\text{low}} = 1.4 \pm 0.3 \, \text{keV} \) and associated metallicities of \( Z_{\text{high}} \lesssim 0.3 \) and \( Z_{\text{low}} = 0.05 \pm 0.4 \) times the solar metallicity. The goodness of the fit was \( \chi^2/dof=166/120 \). The absorbed fluxes measured in the 0.5-2 (2-10) keV bands were \( 1.40 \pm 0.02 (2.44^{+0.06}_{-0.10}) \times 10^{-12} \, {\text{erg cm}^{-2} \text{s}^{-1}} \) and the corresponding unabsorbed luminosities were \( 2.27 \pm 0.03 (3.90^{+0.10}_{-0.11}) \times 10^{44} \, {\text{erg s}^{-1}} \). The higher temperature component accounts for 70% of the bulk of the soft emission and up to 95% of the hard emission. No absorption above the Galactic value has been found for any of the two spectra. Figure[1] shows the observed spectra, the best fit model, and the residuals for RX J1720.1+2638 and Abell 267.

The signal-to-noise of the data allows a radial spectral analysis for both sources. We therefore extracted the spectra for annular regions from the highest emission peak to the maximum extension radius. In order to be able to perform a spectral analysis with enough signal-to-noise to derive well-defined parameters, we extracted annular regions with at least 2000 counts, after background subtraction for Abell 267: five annuli have been extracted. For RX J1720.1+2638, we extracted the same annuli as in Mazzotta et al. (2001) in which the authors analysed Chandra data (obsid 1453) to allow comparison. Table[1] shows for both sources the inner and outer radius of the annuli extracted and the parameters of the fitted model, \( zwabs\cdotmekal \) for Abell 267 and \( zwabs\cdotraymond-smith \) (for comparison with Mazzotta et al. 2001 work). In order to obtain the properties of the sources in a 3D space from the 2D spectrum projected, we use the deprojection technique known as \textit{onion peeling} (Ettori 2002). Goodness of the fits are also shown in Table[1]. Using these values, we obtained temperature and metallicity profiles for each source in order to investigate the presence of a cool core and/or a metallicity gradient. In this sense, we found that while in Abell 267 the .
temperature remains constant at all radii, the temperature decreases to the centre of cluster RX J1720.1+2638, as it can be seen in Figure 2 (left panel). Unfortunately, the accuracy on the determination of the metallicities is poor and therefore nothing can be said about the radial behaviour of this quantity (see Figure 2, right panel). However, a subtle increment towards the inner radii can be appreciated in the metallicity profile of RX J1720.1+2638. The deprojected temperatures found for RX J1720.1+2638 are compatible with those found by Mazzotta et al. (2001) from the Chandra observation (obsid 1453) only for annuli 1 to 5. For the last three annuli, the temperatures found by Mazzotta et al. (2001) are higher by 2-3keV. We re-analysed the Chandra data following the standard method for extended sources of this observation and another available in the archive, obsid. 4361. We find deprojected temperatures lower but compatible with those of Mazzotta et al. (2001) for all annuli. In particular, XMM-Newton deprojected temperatures are fully compatible with those obtained from Chandra observation 4361, except for the last point. We inspected the XMM-Newton spectrum of this last annulus and we noticed a very large background emission above 2 keV which we suspect is responsible of mimicking the measured low temperature. We therefore decided to remove in the following the last point from our further analysis.

Based on the definition of the normalisation of the thermal emission model, it is possible to determine the electron density of the media. Therefore, a density profile has also been constructed for both sources. Figure 3 shows the obtained density profiles for RX J1720.1+2638 and Abell 267. Assuming spherical symmetry, we fitted a $\beta$-model to the density profile. The fit allowed us to determine the mean central density and the radius of the nucleus: $n_0=0.05$ cm$^{-3}$, $r_0=80$ kpc and $\beta = 0.38$ for Abell 267. It is also possible to derive the mass profile of the systems by assuming hydrostatic equilibrium, a spheric mass distribution, constant temperature of the intracluster gas, and a NFW (Navarro et al. 1995) profile for the distribution of the density $\rho_m$ of the media. In particular, we derived for RX J1720.1+2638 and Abell 267 the values of $M_{500}$ and $r_{500}$. We obtained $M_{500} = (7 \pm 2) \times 10^{14} M_\odot$ and $r_{500} = 900 \pm 4100$ kpc for the first and for Abell 267, we found that $M_{500} = (4.7 \pm 1.8) \times 10^{14} M_\odot$ and $r_{500} = 780 \pm 400$ kpc. The mass of Abell 267 found is compatible with the value reported in Zhang et al. (2008) within 2-$\sigma$. We have also used the M-T relationships in Chen et al. 2007 and Finoguenov et al. 2001 to derive the masses of the systems. For Abell 267 the calculated $M_{500}$ range (7-9) $\times 10^{14} M_\odot$ is fully compatible with what was found using the NFW profile. For RX J1720.1+2638, excluding the cool core annuli, we obtain masses varying in the range of (6-8) $\times 10^{14} M_\odot$, in good agreement with the results form the NFW profile.

3 Results and Conclusions

Here in this work, we analysed the EPIC XMM-Newton data of the fossil system Abell 267 and the non-fossil system RX J1720.1+2638. Firstly, global X-ray properties have been derived for both systems. The integrated spectra of both sources can be explained by pure thermal emission with mean temperatures of $\sim 5$-6 keV for both sources. This values are typical of massive clusters of galaxies. Metallicities range from 0.1 to 0.5 $Z_\odot$, also compatible with what was found by Balestra et al. 2007 for a sample of 56 clusters at these distances observed with Chandra. The luminosities found for RX J1720.1+2638 and Abell 267 in
the 2-10 keV band are $6.20^{+0.04}_{-0.02} \times 10^{44}$ and $3.90^{+0.10}_{-0.11} \times 10^{44}$ erg s$^{-1}$, respectively. Fossil systems show an excess in X-ray luminosity of about one order of magnitude compared to non-fossil systems for a given total optical luminosity (Jones et al. 2003; Khosroshahi et al. 2007; see also Harrison et al. 2012). The observed R-band magnitudes for RX J1720.1+2638 and Abell 267 are very similar, -24.3 and -24.9, respectively. According to this result, we would expect a higher X-ray luminosity for Abell 267 than for RX J1720.1+2638 but interestingly the measured values are of the same order of magnitude. Moreover, the luminosities of the two clusters scale with their mass as expected. A relatively boosted luminosity of Abell 267, due to its cooling core, is expected. However, the non-detection of a cool core in RX J1720.1+2638, shows a decrement in temperature for inner radius, visible below $0.1 r_{500}$ (i.e. $\sim 180$ kpc). This value is in good agreement with what was found for a sample of 15 nearby clusters observed with XMM-Newton (Pratt et al. 2007). A similar decrement was found by Mazzotta et al. (2001) using Chandra data. For Abell 267, the temperature remains constant within the errors for all radii. In this sense, and assuming the theory in which fossil systems are considered as the end product of galaxy merging, then no recent merger could have occurred (on average, only one galaxy has been accreted since $\sim 1$, von Benda-Beckman et al. 2007). This, in term, translates to an absence of any heating source to prevent the decrement in temperature at inner regions of the fossil system. Due to this relaxed nature of fossil systems, the presence of cool cores is expected. However, the non-detection of a cool core in Abell 267 could be due to several causes. One possibility is that for some reason, the decrement in temperature for fossil systems begins at lower radii than in normal clusters, i.e. $\leq 0.1 r_{200}$. Unfortunately, this possibility could not be tested due to the limited signal-to-noise of our data. Another possibility is that the core of the system is being heated. One alternative is that the source of heating is an AGN. However, no evidence of any hidden AGN was detected. One other possibility is that the heating could be due to a recent major merger. Zhang et al. 2008 stated that Abell 267 has actually a disrupted morphology. Mazzotta et al. (2001) also suggest the presence of a merger in RX J1720.1+2638, which supports the non-fossil nature of this system. We also produced the electron density and mass profiles for both systems. The derived values of $M_{500}$ are of the order of $(5-8) \times 10^{14} M_\odot$. Proctor et al. (2011) found that fossil systems have masses comparable to those of clusters, and Harrison et al. 2012 showed that the brightest galaxy of fossils are among the most massive galaxies in the Universe. However, even taking into account these considerations the values found for the masses of the systems are very high. Moreover, both sources present evidence of a recent merger, and therefore our assumption of spherical symmetry could be introducing uncertainties in the mass determinations.

In summary, we presented the results on the analysis of two clusters: RX J1720.1+2638 classified as a non-fossil system with the presence a cool core but interestingly with evidence of a recent merger; and the fossil system Abell 267 with no evidence of cool core. The results obtained for both objects are therefore unexpected for their nature and an evidence that the current scenario for fossil systems as relaxed systems, end products of galaxy mergers is not directly applicable to all fossil systems, as it is the well-studied case of Abell 267.

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