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X-RAY ASPECTS OF THE DAFT/FADA CLUSTERS

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Abstract. We have undertaken the DAFT/FADA survey with the aim of applying constraints on dark energy based on weak lensing tomography as well as obtaining homogeneous and high quality data for a sample of 91 massive clusters in the redshift range [0.4,0.9] for which there are HST archive data. We have analysed the XMM-Newton data available for 42 of these clusters to derive their X-ray temperatures and luminosities and search for substructures. This study was coupled with a dynamical analysis for the 26 clusters having at least 30 spectroscopic galaxy redshifts in the cluster range. We present preliminary results on the coupled X-ray and dynamical analyses of these clusters.

Keywords: Cosmology, Galaxy clusters, Survey, Substructures

1 Introduction

It has been half a century since the observation of the first X-ray source outside the Solar System. Since then, X-ray astronomy never ceased to provide new means of study for large scale structures as well as for point sources, and space instruments have been steadily improving, with increasing sensitivity and spatial resolution, allowing ever deeper and more accurate observations. Today, the three main X-ray satellites are XMM-Newton, Suzaku and Chandra, and we used primarily data from XMM-Newton to try detecting substructures in all the clusters of the DAFT/FADA survey for which such data were available (about half of the sample).

The DAFT/FADA survey (PIs: M. Ulmer, C. Adami, and D. Clowe) is based on the study of 91 rich (masses $> 10^{14} M_\odot$) and distant (redshifts $0.4 < z < 0.9$) clusters, all with HST data available. This survey has two main objectives. The first one is to constrain dark energy using weak lensing tomography on galaxy clusters. The second one is to build a database of rich distant clusters to study their properties.

The chosen redshift range is interesting in the study of galaxy clusters because it is situated just after the predicted end of the galaxy cluster formation (estimated around $z = 1.0$ within the current cosmological concordance model). At this redshift, the galaxy cluster formed and the groups that it has accreted have different scales, implying different mechanisms than during initial cluster formation. The dynamical state of clusters can be probed by detecting substructures, either in the galaxy distribution or in the intra cluster medium (ICM). The search for substructures in this redshift range will thus allow us to search for traces of this accretion mechanism inside galaxy clusters. First results of the DAFT/FADA survey can be found in Guennou et al. (2010).

In this framework, we applied the Sherpa tools to the X-ray images to bring out substructures detected in XMM-Newton data, and we used the Serna & Gerbal (1996) hierarchical program (based on spectroscopic redshifts and V band magnitudes) to detect optical substructures. This double detection will allow us to ascertain the existence (or not) of substructures in the galaxy clusters considered. We present hereafter in section 2 the data and methods used in this study, followed in section 3 by the results and discussion.

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2 Data and method

We retrieved XMM-Newton data from the archive and kept the 42 clusters with data of sufficient quality. We also obtained deep optical imaging for most of the 91 clusters in several bands, with various telescopes, reaching a total of around 70 nights of observing time on 4m to 10m telescopes (Blanco, WIYN, GTC, Gemini, SOAR). We retrieved all the galaxy redshifts available in NED in a 5 arcmin region around each cluster center, and added some redshifts that we obtained during several observing runs with 8m telescopes (42 redshifts obtained with GMOS on the GEMINI telescope and 27 obtained with FORS2 on the VLT).

The XMM-Newton data were analysed using the SAS (Science Analysis System from XMM-Newton team) tool from the Heasarc package to do the main part of the reduction. After this we applied the program created by Andy Read to remove flares, using a 3σ clipping technique, and calibrated the images. The X-ray images, with a pixel size of 4.1", were then fit with an azimuthally symmetric elliptical β-model, representing a simulated relaxed cluster with a homogeneous gravitational potential, applying the Sherpa tool from CIAO. The residuals were computed as the difference between the image and the fit, allowing us to bring out any perturbations from a homogeneous gravitational potential due to the substructures that are not completely merged with the cluster yet. An example is displayed in Fig. 1, showing the case of LCDCS 504 (z=0.7943).

Note that in some residual images it was difficult to distinguish substructures from point sources. In order to check this point, we plan to use Chandra data when available and/or to perform optical spectroscopy on the objects as shown in Fig. 2.

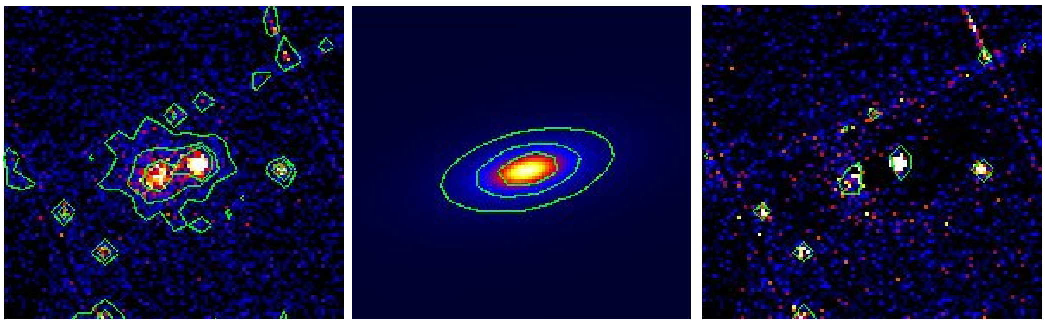

Fig. 1. Example of the method used to detect substructures using Sherpa on X-ray data for LCDCS 504. The let panel shows the cluster image, the middle panel shows the azimuthally averaged $\beta-$model applied, and the right panel shows the residual image obtained when we subtract the model from the cluster.

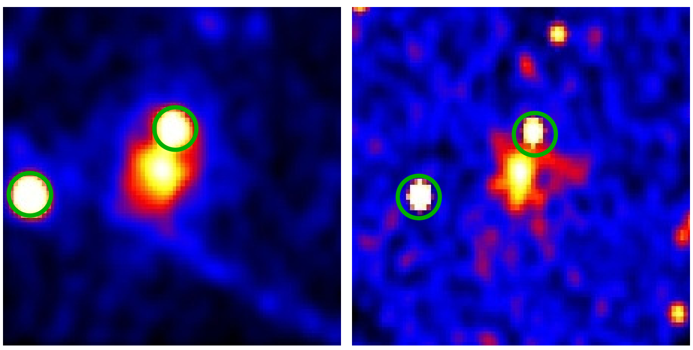

Fig. 2. An example of the help Chandra will provide in the detection of point source objects. The left panel shows the image obtained with XMM. The right panel shows the image obtained with Chandra. We can see that the point sources circled in green can be detected more easily with Chandra.

For each cluster with more than 30 galaxy redshifts available in the cluster range, we applied the Serna & Gerbal (1996) analysis to search for substructures. This method calculates the relative binding energy between galaxies and allows us, from the galaxy positions, redshifts and magnitudes, to detect and characterize substructures on a line of sight. A dendogram is created, representing the binding potential energy between galaxies (see Fig. 3). The number of substructures and their corresponding masses can thus be estimated, assuming a value for the mass to luminosity ratio.

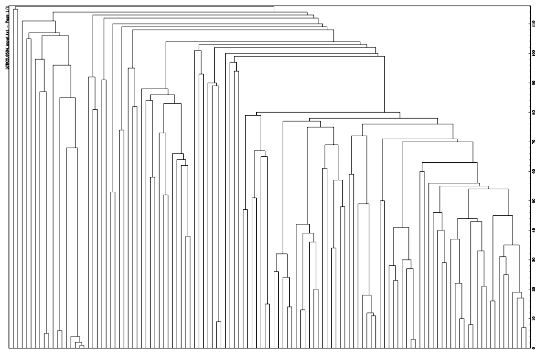

Fig. 3. Dendogram obtained by the Serna & Gerbal (1996) method applied to the optical spectroscopic redshifts and V magnitudes of LCDCS 504. Each vertical line represents a galaxy, and the scale on the vertical axis corresponds to the relative binding energy between galaxies (in arbitrary units). Several substructures are clearly visible.

An important question concerning the application of the Serna & Gerbal (1996) method is how the incompleteness in the galaxy optical spectroscopy can affect the results. In order to estimate how important this problem is, we considered a well observed cluster, Abell 851, for which 194 spectroscopic redshifts are available in the cluster redshift range, and we observed the changes in the results depending on the completeness of the input catalogue. To perform this task, we considered between 100% and 10% of the complete catalog and for each step we ran the Serna-Gerbal and checked the results to detect differences as the incompleteness grew. In this way, we can observe the impact of the incompleteness on our results and its damages on the results depending on the richness of the substructures. Results are shown in Fig. 4, where we observe that substructures with few members quickly disappear when the incompleteness increases, and the mass of these "light" substructures also strongly varies. On the other hand, substructures with many members (i.e. large substructures), remain visible even with a high incompleteness, and their mass remains quite constant. In short, the heaviest and biggest substructures are still detected, even with a low completeness, while smaller substructures disappear.

These tests allow us to think that the large and massive substructures will still be detected by the Serna-Gerbal program, even if we cannot estimate accurately the completeness of our redshift catalogs. Since we are also using X-ray data, where large substructures are primarily detected using the Sherpa tools, we are confident that we can apply both methods and assess in two different ways the presence or absence of substructures in these clusters.

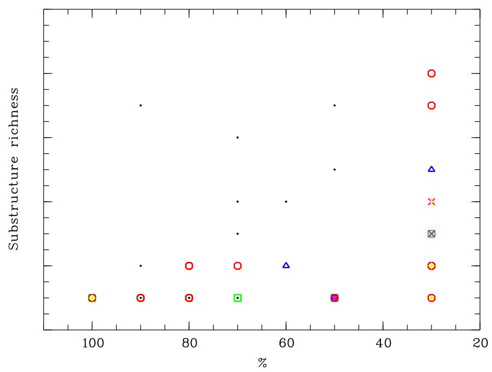

Fig. 4. Effects of the incompleteness of the input spectroscopic catalogue on the Serna & Gerbal (1996) method. The points show the richness of the galaxy group versus the percentage of completeness until which the group exists for 6 clusters, each represented with a different symbol and color.

3 Results and discussion

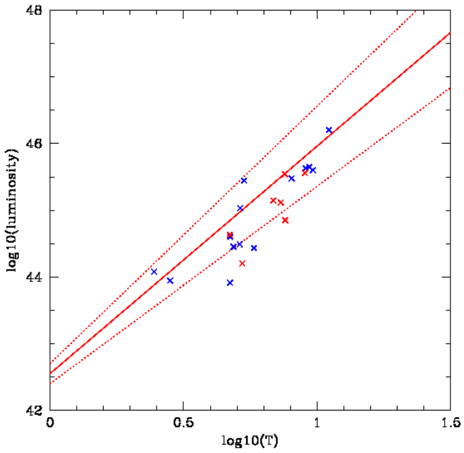

Fig. 5. Relation between temperature and luminosity for our clusters. The red line represents the $L_X - T_X$ relation found by Takey et al. (2011). The blue and red points represent galaxies with redshifts respectively lower and higher than 0.6.

Out of our initial sample of 42 DAFT/FADA clusters with XMM-Newton data, we were able to analyse spatially 30 clusters, to which we applied the Sherpa tools to detect possible substructures inside the clusters. Out of these 30 clusters, only 23 had deep enough X-ray data for a robust analysis. Out of these 23, we find that only 6 clusters clearly possess substructures, while 13 may have some and only 4 clusters seem completely relaxed.

We also assessed the quality of our X-ray data and analysis by plotting an $L_X - T_X$ diagram for our clusters (see Fig. 5) and comparing our data with the $L_X - T_X$ relation found by Takey et al. (2011) for clusters with a redshift smaller than 0.6. For this purpose, we modified our energy interval, initially chosen between 0.5 and 8.0 keV, to the one used by Takey et al. (2011), by applying the PIMMS software, and considered the r_{500} spatial zone. We can see that our points roughly agree with the relation found by Takey et al. (2011).

We also compared the substructures detected in X-rays with those detected with the hierarchical method to confirm or invalidate the existence of substructures inside the clusters. The analysis of all the clusters for which sufficient data are available will be the subject of a future paper (Guennou et al., in preparation).

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