OBSERVATIONS OF LOW REDSHIFT GROUPS AND CLUSTERS OF GALAXIES WITH MISTRAL AT OHP.

Q. Moysan[1], R. Cabanac[1], N. Clerc[1], L. Paquereau[2], F. Sarron[1] and G. Soucail[1]

Abstract.
We carried out an observing program with the low resolution spectro-imager MISTRAL at the T193 facility at Observatoire de Haute-Provence in order to measure redshifts of galaxy clusters selected in the X-CLASS sample. This program is motivated by the construction of a low-redshift sub-sample of the X-CLASS survey (the X-CLASS-LR sample) that aims to study the low-redshift ($0.07 \leq z \leq 0.2$), low-luminosity ($2 \times 10^{41} \leq L_X \leq 6 \times 10^{44}$ erg s^{-1}) and low-mass ($10^{13} \leq M_{tot} \leq 10^{15} M_\odot$) X-ray scaling relations.

The program is now complete and we managed to measure the redshift of 52 galaxy clusters and have completed the identification of the X-CLASS-LR sample, containing 154 clusters in total.

Keywords: clusters of galaxies, redshift, MISTRAL

1 Introduction

Galaxy clusters are the most massive virialized objects in the universe. Studying their number as a function of redshift and total mass, known as the halo mass function, is of prime importance to constrain the cosmological parameters in self-similar models of halo formation (Garrel et al. 2022; Ghirardini et al. 2024).

However, accurate estimates of their total mass and their redshift is crucial for this analysis. There are many methods to measure the total mass of galaxy clusters (see Pratt et al. (2019) for a review), one of which is the mass-observable relation, also known as scaling relations (Lovisari et al. 2015; Giles et al. 2016; Bahar et al. 2022). These scaling relations have been extensively studied for massive clusters (Mantz et al. 2010; Bulbul et al. 2019). However, they are less constrained for the low-mass ($M_{tot} \leq 10^{14} M_\odot$), low-luminosity ($L_X \leq 6 \times 10^{44}$ erg s^{-1}) and low-redshift ($z \leq 0.2$) ranges, hosting low mass clusters and groups.

In this context we constructed a sample that meets these conditions from the X-CLASS survey. X-ray temperature, luminosity and gas mass measurements are available and allow to constrain the low-mass galaxy clusters scaling relations. However we need the redshift to classify membership in the sample and to measure absolute quantities such as luminosity or gas mass. This is the main objective of the program that is presented.

2 The X-CLASS Survey

The *XMM* Cluster Archive Super Survey (X-CLASS, Koulouridis et al. (2021)) is a survey of 1646 galaxy clusters detected in the archives of XMM-Newton satellite. The detection was done on deep pointings of 10 and 20 ks to detect extended and low-flux sources. The survey covers an total area of 269 degrees^2 with a well defined selection function. The X-CLASS survey mostly consists of faint and previously unknown objects. A lot of them may correspond to nearby low-mass galaxy clusters while other sources are more massive and distant clusters. As an example X-CLASS can detect galaxy clusters of mass $M_{tot} < 10^{14} M_\odot$ up to a redshift $z = 0.3$. A substantial effort to identify the sources followed, with optical identification and redshift measurement, from the NED database and from SDSS-DR16 (Blanton et al. 2017) when available. Only about 60% of the X-CLASS galaxy clusters have a published spectroscopic redshift, for the others photometric redshift was collected when available.

[1] Institut de Recherche en Astrophysique et Planétologie (IRAP), Université de Toulouse, CNRS, CNES, 14 Avenue Belin, 31400 Toulouse, France
[2] Sorbonne Université, CNRS, Institut d'Astrophysique de Paris, 98 bis boulevard Arago, 75014 Paris, France

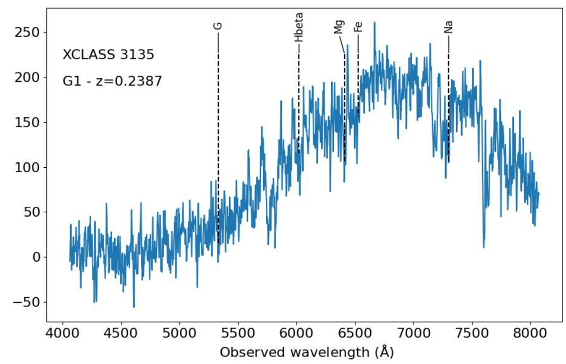
3 The MISTRAL program

In order to better constrain the mass-luminosity relation and other scaling relations for clusters in the low-mass regime, we extracted a sub-sample of 154 clusters from the X-CLASS database with potentially low redshift, with the following criteria: $0° \leq \delta \leq 90°$ and $0.07 \leq z \leq 0.2$. In this so-called X-CLASS-LR sample, only $\sim 65\%$ of the clusters have a spectroscopic redshift available, so in order to complete the sample of spectroscopically confirmed clusters, we started an observing program with the low resolution spectro-imager MISTRAL at the T193 facility at Observatoire de Haute-Provence. The survey was split into 7 runs between October 2021 and February 2025 for a total of 23 nights. We consider that over the 23 nights of observation, 2/3 of the time was spent in acceptable observing conditions (clear sky and seeing lower than 4").

All the clusters with no spectroscopic redshift in the X-CLASS-LR sample were observed with MISTRAL. Additional clusters with higher estimated redshift (photometric or by eye) up to $z_{est} \leq 0.3$ were included as fillers during the observing runs, leaving a total of 60 clusters. Among these 60 clusters we mostly observed galaxies that have a r-band magnitude limited to $r < 19$.

We used the standard definition of a "confirmed" spectroscopic redshift for a cluster: either it comes from the measurement of three consistent galaxy redshifts or the redshift of the Brightest Cluster Galaxy (BCG) is measured. In the first case we take as redshift for the cluster the mean value of the redshift of the three galaxies and in the second case we take the redshift of the BCG as the redshift of the cluster. We also included in this study some spectroscopic measurements of galaxies already available in surveys like the SDSS-DR18 (Almeida et al. 2023) or the DESI-DR1*.

3.1 Data reduction and redshift measurement



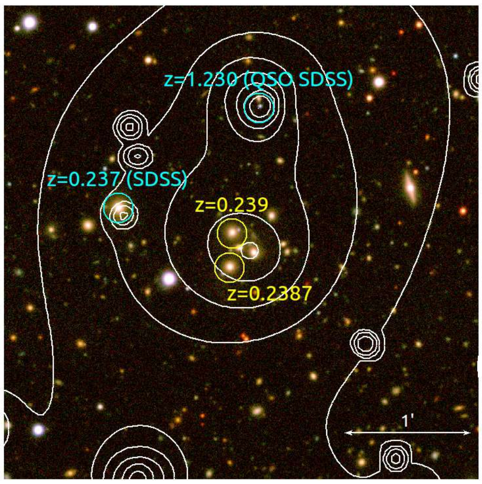


Fig. 1. Left : MISTRAL spectrum of a galaxy in the cluster xclass3135 at redshift $z = 0.2387$ with the identified absorption lines. **Right** : DESI Legacy optical image and XMM X-ray contours in the field of xclass3135. Yellow circle : Redshift of the galaxies measured with MISTRAL, Cyan circle : Redshift of the galaxies measured by other surveys.

We developed a semi-automatic end-to-end pipeline to reduce and extract the spectra. We used the PyRAF environment, a Python-based command language for IRAF†, and standard procedures for long slit spectroscopy.

Nearly all the galaxies observed in the program are early-type passive galaxies that were selected to be the brightest members of the groups and clusters. Therefore, the spectra are dominated by absorption line features, which are more difficult to detect in low signal-to-noise ratio spectra (Figure 1).

We used a combined approach to measure the redshift on the final spectra for each galaxy. First, we used the cross-correlation module in PYRAF (`noao.rv.fxcor`), which computes a Fourier cross-correlation as defined by Tonry & Davis (1979). We used templates distributed by the CfA‡, especially the elliptical type ones. In

*`https://data.desi.lbl.gov/public/dr1/`
†`https://iraf-community.github.io/pyraf.html`
‡`http://tdc-www.harvard.edu/iraf/rvsao/templates/`

parallel, for confirmation by eye, we also used the Marz software[§] (Hinton et al. 2016) available through an online graphical interface. In order to improve the identification of the "true" spectral features in the spectra we included a slight smoothing of the data. The global redshift accuracy is $\delta z \sim 0.001$ with this low-resolution spectrograph. There is excellent agreement between both approaches for more than 85 % of the galaxies, for which the absolute difference between the two redshifts is less than 0.001. When available we added redshifts already published in the litterature to complete our data and get a final redshift identification of the clusters (Figure 1).

3.2 Observations of xclass3135 as an example

Since the clusters are distant, the magnitudes of the objects to be observed are sufficiently high that positioning the spectrograph slit on the galaxies is a long and difficult process. In particular, it required individual exposures of 30 seconds to 1 minute to be able to detect the galaxies along the slit between each control of the slit position. All in all, a typical duration of 20 to 30 minutes was required between science exposures on two different targets. On-target integration times were chosen to 1 hour typically or more in case of poor observing conditions, split into individual exposures of 30 minutes. The efficiency of the program was therefore reduced compared to more standard stellar programs because of these long overheads. We acknowledge that we have pushed the instrument to its limits on a 2-meter telescope !

Fig. 2. Left : 30 seconds exposure image used for the slit positioning **Right** : DESI Legacy Surveys optical image of the field of view of xclass3135 for comparison.

We choose the cluster xclass3135 as an example to illustrate the difficulties encountered in aligning two galaxies in the slit (Figure 2). Finally in this specific cluster we measured the redshift of 2 new galaxies. We also included the redshift of another galaxy from the SDSS survey that is consistent with the 2 others. In this cluster there is no dominant BCG so we take the mean of the 3 redshifts to measure the cluster redshift, at $z = 0.238$.

4 Results of the MISTRAL program

We measured the redshifts of 144 individual galaxies and used these to derive new redshifts for 52 galaxy clusters. These high-statistics measurements provide us with the quantitative data needed to present the final performance of MISTRAL. Figure 3 shows the distribution of the measured redshift and r-band magnitude for the 144 galaxies. These results confirm that MISTRAL is well suited to spectroscopy of faint objects up to a redshift of 0.25 and a r-band magnitude of 19.

[§]https://samreay.github.io/Marz/

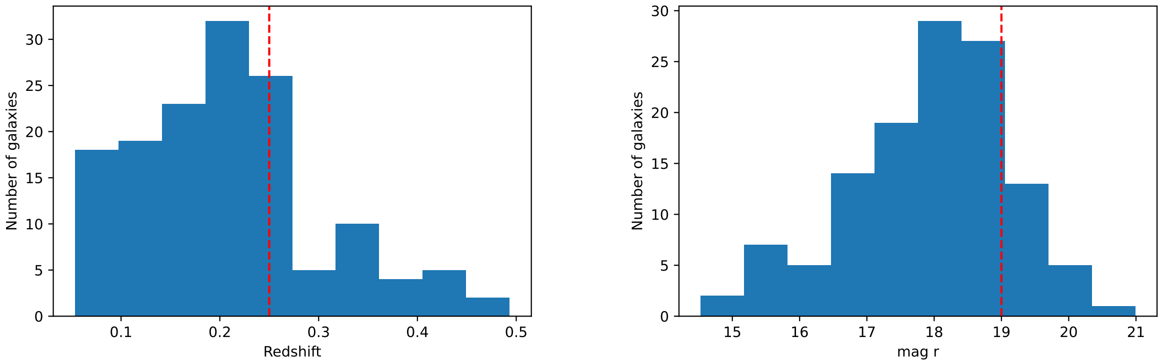


Fig. 3. Left: Distribution of the 144 measured redshift of the individual galaxies. **Right:** Distribution of the r-band magnitudes (from the DESI Legacy survey DR9) for the galaxies observed with MISTRAL.

5 Conclusions : completion of the X-CLASS-LR sample

With the spectro-imager MISTRAL at OHP we measured the spectroscopic redshift of 52 low-redshift galaxy clusters from the X-CLASS survey. We were thus able to complete the X-CLASS-LR sample, which is now complete in redshift and comprises 154 clusters located in the low-mass ($10^{13} \leq M_{tot} \leq 10^{15} M_{\odot}$), low-luminosity ($2 \times 10^{41} \leq L_X \leq 6 \times 10^{44}$ erg s^{-1}) and low-redshift ($0.07 \leq z \leq 0.2$) range. This will enable us to measure quantitative values for cluster parameters such as X-ray absolute luminosity, temperature, metallicity and gas mass. A detailed analysis of the detection conditions of the clusters in the X-CLASS-LR survey is also necessary in order to adjust scaling relations by controlling detection biases and measurement errors. The interest of the sample lies in the fact that it concerns low-redshift and low-mass clusters in a mass range that is poorly explored and more difficult to understand (Moysan et al. in prep).

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