A combined HST/CFH12k/XMM survey of X-ray luminous clusters of galaxies at $z \sim 0.2$

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We describe a project to study a sample of X–ray luminous clusters of galaxies at redshift $z \sim 0.2$ at several scales (with HST/WFPC2 and CFHT/CFH12k) and wavebands (optical and X–ray). The main aims of the project are (i) to determine the mass profiles of the clusters on scales ranging from $\sim 10 h^{-1}$ kpc to $\gtrsim 1.5 h^{-1}$ Mpc using weak and strong lensing, thereby testing theoretical predictions of a “universal mass profile”, and (ii) to calibrate the $M_{\text{total}}$–$T_X$ relation in view of future application in the study of the evolution of the cluster mass function at higher redshift.

1 Introduction

Current models describe the formation and evolution of large–scale structure in the Universe in a hierarchical, “bottom–up”, way. Since clusters of galaxies are the most massive gravitationally bound objects found in the Universe at the present time, their evolution is observable at low redshift, $z \lesssim 1$. Clusters of galaxies are therefore powerful probes for testing cosmological scenarios and determining cosmological parameters.

Two theoretical predictions are of particular interest. The first one concerns the evolution of the cluster mass function with redshift, which can be described using linear theory. As shown by Eke et al.$^1$, in a low matter density universe ($\Omega_M \sim 0.3$) we expect to see about 30 times as many clusters out to $z = 1$ as in a high matter density universe ($\Omega_M = 1$), using the current cluster abundance to normalize the density fluctuation power spectrum.

A second theoretical prediction concerns the internal structure of clusters. Numerical simulations suggest that dark matter haloes over a wide range of masses can be accurately described by a universal mass profile.$^2$ In the context of numerical simulations this is a very robust prediction, as the profile works over a wide range of masses, radii and cosmological parameters.
Other groups, however, find different behaviour of the mass distribution in their simulations, notably in the centres of haloes.

The observational tool of choice for investigating cluster mass profiles is gravitational lensing, which in principle permits to access the mass distribution directly (albeit a weighted sum of all the mass between the observer and the source plane).

Even given the large upcoming CCD mosaic cameras (such as MEGACAM), large–area cluster searches (necessary for testing predictions concerning the evolution of the cluster mass function) using their weak lensing signature will be difficult at best. More practical will be cluster searches from X–ray all–sky surveys. The temperature $T_X$ of the hot intracluster gas is directly related to the depth of the gravitational potential of the cluster if the gas is in hydrostatic equilibrium. In that case the cluster mass function can be transformed into a temperature function which retains the large separation between high– and low–$\Omega_M$ universes. However, current observations indicate that the $M_{\text{total}} – T_X$ relation differs from simple theoretical predictions, possibly related to pre–heating of the gas. Also the impact of substructure in the mass and gas distribution within clusters on the scatter around the $M_{\text{total}} – T_X$ relation has yet to be studied in a systematic way. It is therefore imperative to calibrate the shape of and the scatter around the $M_{\text{total}} – T_X$ relation observationally on a well–defined sample of clusters of galaxies before using it to test cosmological predictions.

Our project aims at studying a sample of massive galaxies at redshift $z \sim 0.2$ using HST and CFH12k observations in order to constrain mass profiles on length scales between $\sim 10h^{-1}$ kpc out to $\gtrsim 1.5h^{-1}$ Mpc and to relate the lensing masses to X–ray observables (notably $T_X$) from observations with XMM–Newton.

2 Sample selection

Our sample is drawn from the XBACs catalogue, a flux–limited catalogue of Abell clusters detected in the ROSAT All–Sky Survey. We apply limits in redshift space of $0.18 < z < 0.26$ in order to have an approximately luminosity–limited sample. It has been shown that X–ray luminosity is correlated with cluster mass and therefore, given the difficulty of measuring X–ray temperatures with current instruments, a luminosity–limited sample is the best approximation to a mass–limited sample. The redshift range has been chosen to maximize the lensing efficiency for a background galaxy population at $\langle z \rangle = 0.8$. Applying further limits in declination (for accessibility from CFHT), galactic latitude (to minimize contamination by stars) and hydrogen column density $N_H$ leads to a sample of 14 clusters (listed in table 1), 8 of which will be observed by HST under PI Kneib and 6 of which are available in the HST archive. Figure 1 shows that our sample covers the corresponding region in the XBACs catalogue well.

3 Observations

To date (June 2000) five clusters have been observed with HST, three more are scheduled for observation before the end of 2000; six cluster observations are available in the HST archive. The observations are done with the WFPC2 through the F702W filter, three orbits are allocated for each cluster. The excellent spatial resolution of these images allows precise modelling of the mass distribution in the cluster centres ($\lesssim 100h^{-1}$ kpc) due to their strong lensing effects. For most of the clusters in our sample no giant arcs were known previous to these observations. Therefore, they will constitute a valuable sample for investigating the probability of formation of giant arcs which depends strongly on the cosmological parameters, in particular $\Omega_\Lambda$.

On larger scales, observations with the CFH12k camera on CFHT will be used to determine mass profiles out to $1.5 \ldots 2h^{-1}$ Mpc using the systematic distortion of the background galaxies due to weak lensing by the cluster potential. CFH12k observations were finished in June 2000.
During three observing runs (7 nights) 11 clusters were observed in three bands (B, R, I), typically reaching a limiting magnitude of 25 in R. Photometry in three filters allows robust discrimination between cluster members and background galaxies.

Seven of our eight core sample clusters have been allocated XMM time in category B under PI Kneib, with integration times between 20 and 30 ksec. All the other clusters will be observed by XMM under different PIs. The observations will be done with the EPIC camera with a field of view of 3.8 Mpc at $z=0.2$; images will allow study of the morphology of the X–ray surface brightness and detection of significant substructure, spectra will permit precise measurement of X–ray temperatures and temperature profiles.

These core observations will be supplemented by spectroscopy of giant arcs and cluster galaxies, as well as miscellaneous observations in different wave bands, notably in the near infrared in order to permit determination of photometric redshifts in the central cluster regions.

4 Conclusions

At the time of writing (June 2000), most of the optical observations have been finished and are currently being reduced. A first paper describing and modelling several arcs and multiple image systems in Abell 383 is in preparation. Previously unknown arcs have already been found in Abell 68, 383, 773, 963 and 1835. X–ray observations will begin after the end of the XMM calibration phase and should be finished by mid– to end–2001. Further projects studying similar cluster samples at redshifts $\sim 0.1$ and $\sim 0.4$ are in preparation.
Table 1: Physical data for our sample. Note that the temperatures given are estimated\(^6\). The first eight clusters are observed with HST under PI Kneib, observations of the remaining six clusters are available in the HST archive.

| Cluster  | \(z\)   | \(L_X[10^{44}\text{erg/s}]\) | \(T_X[\text{keV}]\) |
|----------|---------|-------------------------------|---------------------|
| Abell 68 | 0.1889  | 8.36                          | 7.7                 |
| Abell 209| 0.2060  | 13.75                         | 9.6                 |
| Abell 267| 0.2300  | 13.32                         | 9.4                 |
| Abell 383| 0.1871  | 8.03                          | 7.5                 |
| Abell 773| 0.2170  | 12.52                         | 9.2                 |
| Abell 963| 0.2060  | 10.23                         | 8.4                 |
| Abell 1763| 0.2279 | 14.23                         | 9.7                 |
| Abell 1835| 0.2528 | 38.34                         | 15.1                |
| Abell 1689| 0.1840 | 20.74                         | 10.8                |
| Abell 2218| 0.1710 | 8.99                          | 6.7                 |
| Abell 2219| 0.2281 | 19.80                         | 11.2                |
| Abell 2261| 0.2240 | 18.06                         | 10.8                |
| Abell 2390| 0.2329 | 21.25                         | 11.6                |
| Abell 665 | 0.1818  | 16.22                         | 8.3                 |

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