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Using Distant X-ray Luminous Galaxy Clusters as Dark Energy Probes

The XMM-Newton Distant Cluster Project (XDCP)

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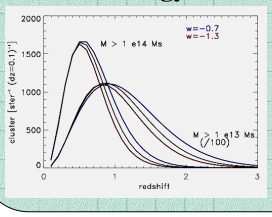
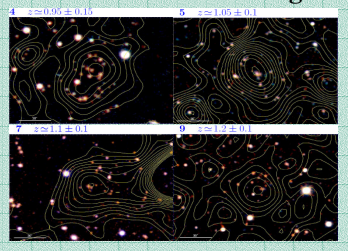
Abstract: Measurement of the number density evolution of galaxy clusters directly probes cosmological structure growth and has been identified as one of the most promising tools for Dark Energy studies. Achieving the sensitivity for distinguishing different Dark Energy scenarios rests largely on cluster abundance measurements at high redshifts (z>0.8) (see box I). However, this method is currently limited by (i) the low number of known systems at z>1, and (ii) systematic effects due to a limited knowledge of the astrophysics of these high-z objects, and in particular the scaling relations that relate observables to the total cluster mass.
In order to make progress on both fronts we have initiated the XMM-Newton Distant Cluster Project (XDCP), a new generation serendipitous X-ray survey focused on the most distant X-ray luminous galaxy clusters, with a final goal to compile a cosmologically useful study sample of ~40 X-ray selected z>1 clusters. The identification of high-z X-ray clusters is based on the selection of ~250 distant cluster candidates (extended X-ray sources) from the XMM archive, followed by two-band imaging for the identification and redshift estimation and the ongoing final spectroscopic confirmation (box II).
For the use of galaxy clusters as cosmological probes, the selection process has to be well understood and quantified, for which extensive simulations are performed (box III). We are aiming to better understand the systematics of cluster selection in different wavebands by following a multi-wavelength cross-comparison approach in X-rays, SZE, and optical/NIR (box IV). In addition, we also perform in-depth studies of confirmed high-z clusters to gain new insight in the formation process and evolution of the intracluster medium and the cluster galaxy populations (box V).

I. Cluster Number Density Evolution as Dark Energy Test

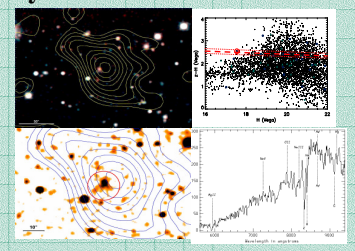


Expected differential redshift evolution of the galaxy cluster abundance for two mass thresholds ($10^{14}M_{\odot}/10^{13}M_{\odot}$) in a concordance comology for different Dark Energy scenarios (black w=-1, blue w=-0.7, red w=1.3). The highest leverage for DE studies is achieved at redshifts of z>1.

II. Identification of High-z X-ray Clusters

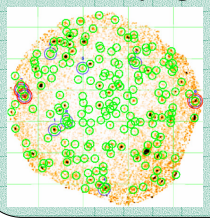


Four examples of photometrically identified high-redshift galaxy clusters. The images show 2.5'x2' z+H band color composites with X-ray contours overlaid in yellow. The photometric redshift estimates are based on a new z-H red sequence technique (Fassbender, 2007).



Top left: 2.5'x2' z+H color composite of a newly discovered galaxy cluster at z=1.11 with X-ray contours overlaid in yellow. Top right: The z-H color magnitude diagram shows the red-sequence (dashed line) which yielded an initial photometric redshift estimate of z~1.05±0.1. Bottom: Zoom on the BCG (left, red circle) in an apparent merging state. The BCG spectrum is shown in the right panel.

III. Quantifying X-ray Selection



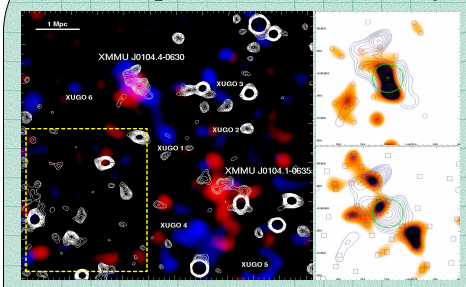
In order to quantify the cluster selection process in X-rays, we are currently performing extensive simulations of the survey fields by means of inserted beta-model cluster sources and additionally more sophisticated hydro-simulated clusters (see also poster 41 by Martin Mühlegger).

The image shows the source detection results of one XMM field with detected point sources indicated in green, and the extended cluster candidate sources marked by blue und red circles.

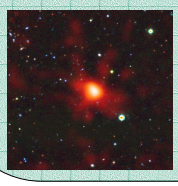
IV. Multi-Wavelength Approach & Cross Calibration

A precise understanding of the different selection techniques in X-rays, SZE, optical, and IR is a pre-requisite to effectively use distant clusters as cosmological tools. We are aiming to better understand the different systematics by pursuing a multi-wavelength approach of the subsample of XDCP fields located in the South Pole Telescope (SPT) survey region for future cross-comparison analyses. In addition to the existing deep X-ray data, this subsample of about 10 square degrees will soon have full coverage in SZE and multi-band optical/NIR data in griz+H.

V. In-depth Studies of Distant Systems



Left: Red (red-sequence ±0.15mag) and blue (0.3mag bluer) galaxy overdensities in the 14'x14' field surrounding the spectroscopically confirmed cluster XMMU J0104.4-0630 at z=0.95 (Fassbender et al., 2008) encoded with the corresponding color; X-ray contours are overlaid in white. XMMU J0104.4-0630 and its probable associated superlcluster member XMM J0104.1-0635 correspond to 7-sigma overdensity peaks in the red population.
Right: 3'x3' view on the red (top) and bluer (bottom) galaxy population of XMMU J0104.4-0630. A galaxy color transition at cluster-centric distances of 1-2 core radii (green circle, 150kpc) is clearly visible.
This system and its surrounding large-scale structure environment is currently followed-up with extensive spectroscopy using VIMOS at the VLT.



XMMU J2235.3-2557 at z=1.393 (Mullis et al., 2005) is currently one of the most massive z>1 clusters known. Multi-wavelength follow-up data have allowed a detailed study of the system (Rosati et al., to be submitted)

Another rich galaxy clustersat z=0.976 has been studied in detail by Santos et al. (to be submitted).

VI. Prospects

The XDCP survey is currently in a state where new X-ray cluster confirmations at z>0.8 become routine, with available spectroscopic data of more than two dozen clusters and imaging data of about 200 cluster candidates at hand. However, a more detailed understanding of the high-z cluster population will take time. Considering the current progress of many other (distant) cluster surveys at different wavelengths and upcoming large projects (e.g. eROSITA), the future of distant cluster cosmology and the applications to Dark Energy studies looks very bright.

References:

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