The XMM/Megacam-VST/VIRMOS
Large Scale Structure Survey

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Abstract. The objective of the XMM-LSS Survey is to map the large scale structure of the universe, as highlighted by clusters and groups of galaxies, out to a redshift of about 1, over a single 8 × 8 sq.deg area. For the first time, this will reveal the topology of the distribution of the deep potential wells and provide statistical measurements at truly cosmological distances. In addition, clusters identified via their X-ray properties will form the basis for the first uniformly-selected, multi-wavelength survey of the evolution of clusters and individual cluster galaxies as a function of redshift. The survey will also address the very important question of the QSO distribution within the cosmic web.

1 Context

As the largest gravitationally bound entities, clusters of galaxies play a key role in our understanding of the universe. In particular, the redshift evolution of both their individual properties and global space distribution are essential to constrain cosmological scenarios. Since clusters originate from high amplitude initial density fluctuations, they are rare events and dedicated search programmes are necessary to provide homogeneous samples suitable for statistical studies (the mean cluster/group number density is of the order 5 × 10⁻¹⁶ Mpc⁻³ [1]). A notable sample is the Abell (ACO) catalogue [2] which enabled the first measurement of the local cluster power spectrum [3]. Optical catalogues are, however, severely hampered by projection effects and galaxy density contrasts with respect to the background become marginal beyond z ≈ 1, unless detailed multi-color information is available, together with sophisticated detection algorithms. In this context, the X-ray wave-band represents much more than a useful alternative: it is a secure and straightforward approach. A high latitude galactic field observed at medium sensitivity (≈ 10¹³ erg/s/cm²) shows basically two types of objects: QSO (pointlike) and clusters (extended), the cluster X-ray emission being due to the hot diffuse gas trapped in the cluster potential. Moreover, the X-ray temperature and luminosity can be related to the cluster total mass, provided the physics of the

¹ We assume H₀ = 50 km/s/Mpc and q₀ = 0.5 throughout this paper
intra-cluster medium (ICM) is properly modelled. From ROSAT and ASCA observations, the current status of the X-ray cluster research can be summarized as follows: there is no significant evolution in the cluster luminosity function out to \( z \sim 0.8 \) \cite{4}, or in the \( L_X - T_X \) relationship out to \( z \sim 0.5 \) \cite{5}; the power spectrum of the local X-ray cluster population is remarkably similar to that of galaxies, with a higher scaling \cite{6}. Due to its unrivalled sensitivity (Fig. 1), its large field of view (30') and good PSF (FWHM = 6" on-axis), XMM opens a new era for cluster studies, and will not be superseded for many years to come.

![Fig. 1. The XMM effective area as a function of energy compared to other X-ray satellites. (AXAF = Chandra)](image)

We have, thus, designed an XMM wide area survey with the aim of tracing the large scale structure of the universe out to a redshift of \( z \sim 1 \), as underlined by clusters and QSOs: THE XMM LARGE SCALE STRUCTURE SURVEY (XMM-LSS) (Fig. 2).

The wide scope of the project has motivated the set-up of a large consortium in order to facilitate both the data reduction/management and the scientific analysis of the survey. The XMM-LSS Consortium comprises the following institutes: Saclay (Principal Investigator), Birmingham, Bristol, Copenhagen, Dublin, ESO/Santiago, Leiden, Liege, Marseille (LAM), Milan (AOB), Milan (IFCTR), Munich (MPA), Munich (MPE), Paris(IAP), Santiago (PUC).

2 X-ray and follow-up observations

The survey design

The survey consists of adjacent 10 ks XMM pointings and will cover a region...
Fig. 2. An artist view of the XMM-LSS. Transversal distances are in comoving units. QSOs should be discovered out to a redshift of $\sim 4$. Some 300 sources per sq.deg. are expected, out of which about one tenth will be galaxy clusters. For the first time, a huge volume of the distant universe will be uniformly sampled.

A SLICE OF THE UNIVERSE AS SEEN BY XMM

The histogram of the predicted cluster redshift distribution is shown on Fig. 3.

Fig. 3. The predicted XMM-LSS cluster redshift distribution, computed using the local cluster luminosity function and properties; redshifted thermal spectra convolved with the XMM response were simulated, source number counts computed and finally compared to the survey sensitivity limit. Three detection bands are shown ($[2-10]$, $[0.6-8]$ and $[0.4-4]$ keV, from bottom to top respectively). The $[0.4-4]$ keV band is the most sensitive for clusters, whereas the hardest one is quite inefficient since the majority of the cluster/group population has a temperature of the order of 2-3 keV (restframe). Up to 800 clusters are expected out to $z = 1$ and of the order of 100 between $1 < z < 2$ (if there is no evolution).
Basic follow-up
In order to ensure the necessary identification and redshift measurement of the X-ray sources, we have started an extensive multi-wavelength follow-up programme. Optical and NIR imaging has been initiated at CFHT and CTIO and will be then uniformly performed by the 2nd generation of wide field imagers such as Megacam/WFIR (CFHT) and VST (ESO). Subsequent spectroscopic identifications and redshift measurements will be performed by the VLT/VIRMOS instrument and other 4-8m class telescopes to which the consortium has access. Entire coverage of the region by the VLA is underway at 90 and 400 cm.

3 Expected science
The XMM-LSS has been designed such as to enable, for the first time, the determination of the cluster 2-point correlation function in two redshift bins \((0 < z < 0.5, \ 0.5 < z < 1)\), with an accuracy better than 10% for the correlation length. Considered on a more qualitative (topological) point of view, we shall obtain a 3D map of the deep potential wells of the universe within an unprecedented volume. Both aspects will have profound cosmological implications. Beside this main goal, thanks to the unique data set to be collected, several other fundamental aspects will be addressed.

- First of all, as apparent on Fig. 3, we shall be in a position to test the existence of massive clusters out to a redshift of \(\sim 2\). This is also of key importance for constraining cosmological scenarios.
- We shall compute, to a high degree of accuracy, the QSO 2-point correlation function out \(z \sim 4\).
- The study of the combined X-ray/optical/radio evolution of clusters and QSOs, of their galaxy content and of their environment is an obvious “by-product” of the XMM-LSS. This aspect is to be especially important at redshifts beyond 1, where merger and star formation are expected to be significantly more active than in the local universe. Indeed, preheating and shocks are thought to influence the ICM properties of forming clusters, i.e. before they reach a relaxed state. Moreover, these effects are redshift dependent since cluster sizes, densities and temperatures are expected to vary as a function of redshift, on a purely gravitational basis. Although there is both theoretical and observational evidence for traces of feedback in the low redshift cluster population \([2] \& [3]\), its influence needs to be assessed and quantified at earlier times \([4]\). The radio data will provide an important source of complementary information for our understanding of merger processes, as well as the presence of energetic particles and magnetic fields which are likely to also affect the state of the ICM.
- Finally, it will be possible to see how the QSO population fit into the LSS network defined by the cluster/group population. This “external view” of the QSOs is a fundamental complement to the “internal view”, i.e. the unified
AGN scheme; indeed, this latter approach alone neither explains the observed strong QSO clustering, nor the fact that BL Lac objects, for instance, are preferentially found in clusters or groups [1]. The environmental properties of AGNs is thus crucial for the understanding of their formation (mergers, initial density perturbations of a peculiar type, etc.). The XMM-LSS data set will also provide decisive statistical information regarding the effect of gravitational lensing on QSO properties.

**Advanced follow-up**

Subsequently to the core programme science, further detailed follow-up will be undertaken for objects that appear as especially relevant. For instance, deep XMM pointings will be used to study high-z forming cluster complexes [10]. Also, the expected high density of QSOs in the survey may form the basis of high-resolution optical spectroscopy within a sub-area, in order to map the Ly-forest and, thus, obtain a detailed 3D picture of the structures where most of the baryons are expected to be located [12].

The deep and high quality optical coverage of the entire 64 sq.deg. area by Megacam will enable an unprecedented weak-lensing analysis [13]. Its cosmological implications will be directly compared to the constraints derived from the XMM-LSS cluster sample.

Finally, Sunyaev-Zel’dovich observations (S-Z) are also foreseen. In a first step, individual XMM-LSS clusters will be observed; together with the X-ray, optical and radio observations, this will enable a truly statistical analysis of the physics of the ICM as a function of redshift. On the long term, S-Z mapping of part or of the entire XMM-LSS area should provide invaluable information on the low density structures such as cluster outskirts as well as their connections to the cosmic filaments.

**4 Simulations**

We illustrate, by two examples, the characteristics of the XMM-LSS (Fig. 4 & Fig. 5). The captions outline some of the major impacts of the project.

**5 Conclusion**

The ultimate goal of the XMM-LSS survey is to map the matter distribution out to $z = 1$ over a $8 \times 8$ sq.deg. area, using three different methods:
- X-ray clusters and QSOs
- weak-lensing analysis
- Sunyaev-Zel’dovich effect.

A detailed description of the XMM-LSS project (consortium, multi-λ follow-up, data management and analysis, status of the observations) can be found at http://vela.astro.ulg.ac.be/themes/spatial/xmm/LSS/index_en.html
The 3D cluster distribution

**Fig. 4.** Simulation of the XMM-LSS cone, using the Hubble Volume Lightcone cluster catalogue for a $\Lambda$CDM model $^{[14]}$. Symbol sizes indicate cluster masses. Together with Fig. 2, this wedge diagram shows, in a striking manner, how the XMM-LSS will provide the next hierarchical step as compared to traditional galaxy surveys. Points are now galaxy clusters which are the carriers of a cosmologically significant parameter: their mass. Predicted numbers of clusters in the $0 < z < 0.5, 0.5 < z < 1$ bins are given in brackets. **Left:** the cluster distribution; cosmic evolution can be appreciated from the decrease of the number density of massive clusters at high redshift. **Right:** convolution by the XMM-LSS selection function: only massive clusters are detectable at high redshift.

**An XMM-LSS field**

**Fig. 5.** Simulation of a 10 ks XMM-LSS field, encompassing a cosmic filament at $z = 0.5$, whose properties have been estimated from high resolution hydrodynamical simulations. **Left:** The filament photon image alone. Three galaxy groups are conspicuous (masses of $1.7, 3.2, 3.5 \times 10^{14} \, M_\odot$), but not the diffuse filamentary medium linking the collapsed objects. **Right:** same field with the back/foreground QSO population now added; the image has been filtered using a multi-resolution wavelet algorithm. The groups clearly show up as diffuse objects. In the XMM-LSS Survey, it will be possible to infer the existence of cosmic filaments through the presence of chains of groups and clusters; then, subsequent weak-lensing analysis will probe the gravitational properties of the underlying dark matter. Details on the XMM simulations of the cosmic network can be found in $^{[10]}$. 


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