Session 4: Large Scale Hot Plasmas and Their Relation with Dark Matter

X-RAY LARGE SCALE STRUCTURE AND XMM

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1. Introduction

The formation of Large Scale Structures (LSS) in the universe was first studied at optical wavelengths as the galaxy spatial distribution appeared to be far from homogeneous. Considerable effort has been invested in semi-analytical approaches and in numerical simulations (DM + hot gas) to explain the observed structures, given some set of initial conditions and using additional constraints provided by the COBE results. It is now clear however, that these two extreme data set are not sufficient to discriminate between the possible remaining cosmological scenarios. It is thus timely to investigate LSS at a much higher redshift than the present survey limits *both* in the optical and in other wavebands. In this context, the X-ray band will certainly become a hot field with the advent of the XMM observatory. The next section briefly summarizes what is known about LSS from optical wavelengths and simulations. Sect. 3 reviews the particular points that can be addressed in the X-ray band. Last section presents realistic prospects for mapping LSS with XMM.
Throughout the paper we assume $H_o = 50$ km/s/Mpc and $q_o = 1/2$.

2. Present knowledge

Optical - up to what "scale"?

Some 10 years ago, the CfA redshift survey revealed the "bubbly" structure of the local universe ($z_{max} \sim 0.03$) [1]. The Las Campanas Redshift Survey - the largest galaxy survey to date - largely confirms this topology out to $z_{max} \sim 0.2$ [2]. Its power spectrum indicates a characteristic scale of ~ 100 Mpc, which is reminiscent of the "periodicity" of 128 Mpc found in deep

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pencil beam surveys at the galactic poles [3]. A similar scale (120 Mpc) was also recently found in the galaxy cluster distribution [4].

N-body simulations - down to what "depth"?

Constraining the initial spectrum to be compatible with the COBE results leaves still room for "tilted" CDM models (e.g. Λ CDM, SDM, ODM, τ [5]). Large N-body simulations are quite succcessful in reproducing the characteristics of the local observed network. Moreover, they clearly show model dependent identifiable features at $z \sim 3$ and suggest that it will still be possible to discriminate among the various models at $z \sim 1$ but certainly not later. More precisely, hydrodynamical simulations show that filaments begin to form in both the dark matter and the gas by $z \sim 4$, with material flowing over large distances (> 10 Mpc) along the filaments to reach forming clusters [6]. These timescales are in global agreement with independent recent observations of galaxies [7] and thus, with the overall evolutionary picture in "bottom-up" models where accretion or merging is an integral part of formation processes on all scales.

A realistic goal for the next generation of LSS surveys should be to investigate scales of the order of 100 Mpc at $z \sim 1$

3. X-ray implications for the LSS

High galactic latitude fields observed at medium sensitivity ($\sim 10^{-14}$ erg/s/cm^2 in the [2-10] keV band) contain basically two types of objects: clusters of galaxies (extended) and AGNs (pointlike). In all that follows it is assumed that coordinated optical (photometry & spectroscopy) observations are available.

Galaxy clusters

Clusters are the largest bound entities in the universe, they are located at the intersection of filaments and, thus, constitute key objects for investigating LSS. Systematic cluster searches in the optical ($22 < I < 25$) are a difficult task as the cluster galaxy density contrast above field galaxy counts becomes marginal beyond $z \sim 1$ [8]. Fine-tuned multicolour photometry (on 8-10 m class telescopes) seems to be efficient but requires large amounts of telescope time. On the other hand, the X-ray band is ideally suited to the detection of high redshift clusters, as it is free from projection effects. Moreover, X-ray data readily provide information about the cluster potential depth and relaxation state (L_X, T_X, morphology). Mapping large areas in X-ray should, therefore, provide a unique view of the topology of the deep potential wells of the universe out to $z \sim 2$.

Filaments

Hydrodynamical simulations predict the existence of a "cool", low density gas trapped in the filaments connecting clusters. This tenuous component has so far not been detected unambiguously and a proper measurement would be of prime interest for our understanding of the formation of LSS. Moreover, combining X-ray observation of filaments with the analysis of weak lensing in the optical (caused by the underlying DM [9]) would provide invaluable information on bias mechanisms in low density structures.

AGNs and QSOs

QSOs are known to be strongly correlated [10], but the origin of the signal and what fraction of the amplitude is due e.g. to lensing are still unclear [11]. AGNs and QSOs will constitute by far the largest source population for XMM at medium sensitivity (up to 90%). As their spatial distribution will appear unambiguously on top of the 3-D cluster network, it will be possible to isolate "true" QSO clustering, quantitatively study the AGN formation process and its relation to high density fluctuations (e.g. BL-LAC in clusters) or, alternatively, with the presence of filaments or voids.

4. Investigating LSS with XMM [12]

XMM ([0.1-10] keV) is one of ESA's cornerstones for the next millenium and is expected to be launched by the end of 1999. With a collecting area of some 6500 cm^2 at 1.5 keV it is by far the most sensitive X-ray telescope of the next generation, and is thus best suited for large scale investigations. It has a field of view of 30', an on-axis FWHM of $\sim$ 15" and, in imaging mode, a spectral resolution of 10 % at 1.5 keV [13].

Taking a canonical value of 500 kpc for cluster characteristic sizes ($R_c = 250$ kpc), XMM will readily flag clusters as extended sources out to $z \sim 1-2$ (R_c = 12"), provided enough photons are detected. We have performed detailed simulations in order to estimate the cluster population that can be seen by XMM as a function of sensitivity assuming: (1) the local $F(L_X)$ and $T_X - L_X$ relationship hold out to $z = 2$; (2) a King luminosity profile for clusters with $\beta = 0.75$ and $R_c = 250$ kpc; (3) Raymond-Smith type spectra, with $N_H = 5\ 10^{20}\ \mathrm{cm}^{-2}$; (4) a folding of the spectra with XMM response; (5) a detection limit set to $n\sigma$, for a given energy band and exposure time, within $1.5R_c$ (60 % of the flux) with respect to the background.

Predictions at medium sensitivity are displayed in Fig.1. Clusters are best detected in the soft energy band; this is easily understandable since low luminosity (i.e "cool") objects are the most numerous and, in addition, are seen with redshifted spectra. In a 5 × 5 sq. degree area (perfectly adapted for probing the 100 Mpc scale at $z \sim 1$) some 320 clusters are expected out to $z = 2$. Out of these, about 1/4 will be beyond $z > 1$, which, in addition, should provide strong constraints on any cluter evolution theory.

Preliminary calculations seem to indicate that it will not be possible to detect filaments with XMM, despite its large collecting area; the truly dif-

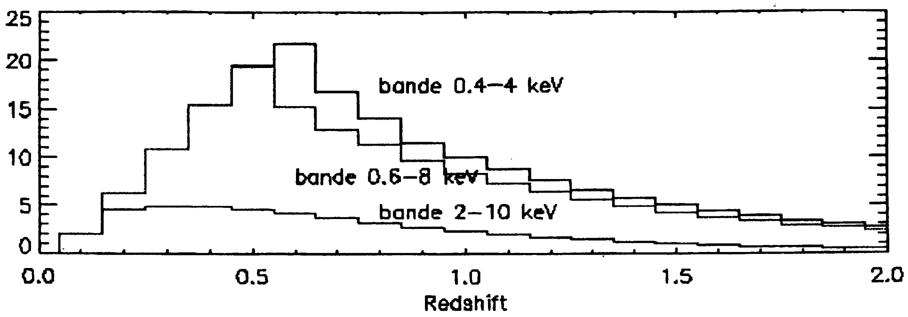

Figure 1. Expected cluster population seen by XMM, for a 15 sq. deg. area and 20 ks exposure. Detection at the 5σ level ($\sim 10^{-14}$ erg/s/cm^2). For exposure times of $\sim$ 100 ks, the distribution peaks around $z = 0.8$, with $\sim$ 1.5 times as many clusters.

fuse medium is expected to have a mean temperature well below the XMM range and to be too tenuous (e.g. [14]) for producing a significant signal. Hydrodynamical simulations are, however improving significantly and, in the near future, they will be able to resolve the small galaxy groups supposed to be embedded within the filaments, a population that will be detectable by XMM. This will enable a detailed confrontation with theory.

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