Forecasting cosmological parameter constraints with the *XCS*: *XMM Cluster Survey*

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on behalf of the XCS Collaboration (http://xcs-home.org)

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Introduction

The evolution of the number density of galaxy clusters with redshift has been used to obtain direct estimates for both σ_8, the dispersion of the mass field smoothed on a scale of 8 h^{-1} Mpc, and Ω_m, the present mean mass density of the Universe. Furthermore, such data could be used to constrain the present energy density of a dark energy component and its equation of state, or more simply the present vacuum energy density associated with a cosmological constant, $\Omega_\Lambda = \Lambda/3H_0^2$. Others have suggested using galaxy clusters to constrain particle physics beyond the Standard Model, or modified-gravity models (for references see [1]).

The cluster X-ray temperature is one of the best proxy observables in lieu of mass, and galaxy clusters are also most unambiguously identified in X-ray images. This makes galaxy cluster surveys based on X-ray data those with the most accurately determined selection function. For these reasons, we have undertaken to construct a galaxy cluster catalogue, called *XCS: XMM Cluster Survey*, based on the serendipitous identification of galaxy clusters in public data obtained with the *XMM - Newton* satellite [2].

The XCS project is ongoing, with already more than 1800 *XMM* pointings analyzed, yielding a cluster candidate catalogue numbering almost 2000 entries. So far, the XCS covers a combined area of 170 square degrees suitable for cluster searching. With a mission lifetime extending to 2013, a conservative estimate for the final XCS area is 500 square degrees.

Aims & Method

The work presented here is described in more detail in [1]. The main objective is the estimation of the expected constraints on σ_8, Ω_m and the parameters that characterize the galaxy cluster luminosity – temperature (hereafter L – T) relation on the X-rays, that could be obtained from XCS data. We restrict our analysis to galaxy clusters with redshifts $0.1 < z < 1$, and temperatures 2 keV $< T <$ 8 keV. We also require them to have more than 500 photon counts (^{500}XCS identifies such XCS sample hereafter), so that we can be sure to estimate X – ray temperatures with reasonable accuracy using only archival data.

The analysis builds upon previous efforts in several ways, and to a large extent constitutes the first coherent treatment of effects and methods previously only considered separately. Specifically, we combine all the following characteristics: (i) we use a Monte Carlo Markov Chain approach and can thus characterize all parameter degeneracies exactly; (ii) we include scatter in the cluster scaling relations; (iii) we include a detailed simulated cluster selection function; (iv) we consider the effect of realistic and catastrophic photometric redshift errors, as well as temperature measurement errors, partly based on detailed simulations of *XMM* observations, including the propagation of the redshift errors to the temperature; (v) we investigate quantitatively the effect on cosmological constraints from systematic errors in the assumed cluster scaling relations and measurement error characterization.

We work within the standard Cold Dark Matter (CDM) paradigm, where large-scale structure arises from a spectrum of primordial, adiabatic, Gaussian, and scale-invariant, density perturbations. For our fiducial cosmological model we assume Ω_m = 0.3, Ω_Λ= 0.7, σ_8 = 0.8, Ω_{baryon} = 0.044 and H_0 = 75 km s^{-1} Mpc^{-1}, and restrict our analysis to the case of a flat universe.

Results & Discussion

In Fig. 1 is shown, for our fiducial cosmological model, the predicted redshift distribution and the total number of clusters in ^{500}XCS, under different assumptions regarding the L – T relation. For a given temperature, the cluster luminosity increases with redshift for self-similar evolution, thus leading to an higher number of detected clusters than in the case of no evolution. On the other hand, intrinsic scatter in the relation between cluster luminosity and temperature (or mass) will effectively increase the observed number of galaxy clusters above any X-ray luminosity (or flux) threshold, relative to the case without scatter. This results from the steepness of the cluster mass function, due to which significantly more clusters have their X-ray luminosity scattered up than down across any given luminosity threshold.

We find that somewhere in the range of 250 – 700 clusters will be present in ^{500}XCS, for its projected area of 500 deg^2. This corresponds to around 20 per cent of the 1500 - 3300 total number of clusters we would expect to detect (with effectively a 50-photon cut-off). This full set of XCS clusters will constitute a significant sample (relative to previous studies), representing around a quarter to a third of the actual 7000 to 10000 clusters present in the observed fields. Going to higher redshifts, we roughly estimate that a minimum of 250 clusters will be found at z>1, of which at least 10 should have more than 500 photons.

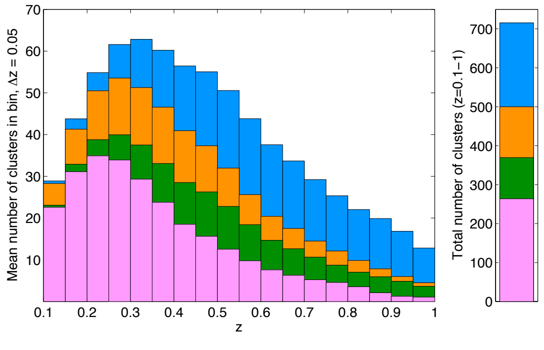

Figure 1 - Expected ^{500}XCS redshift distribution for four different assumptions regarding the redshift evolution and scatter of the cluster X-ray luminosity - temperature relation: pink – no evolution and no scatter; green – self-similar evolution and no scatter; orange – no evolution and scatter; blue – self-similar evolution and scatter.

We find that jointly fitting for the cosmological parameters and the L - T relation, we will be able to measure σ_8 and Ω_m to within respectively 6 and 10 per cent (at 1σ) using the ^{500}XCS data, under our assumptions. The marginalized Ω_m – σ_8 likelihood distributions are shown in Fig. 2, and the full set of likelihood distributions can be found in [1] (see Fig. 13). These constraints are for a photon-count threshold of 500. If all clusters detected by the XCS could be used in the analysis, with temperatures know with errors similar to the ^{500}XCS clusters (through follow-up observations with e.g. *XMM or XEUS*), we find that 1D constraints would improve by about 40 per cent. The ^{500}XCS data will be able to constrain the L - T normalization and slope to within respectively 6 and 13 per cent (at 1σ). But unfortunately, the self-calibration procedure is not able to jointly constrain the scatter and redshift evolution of the L- T relation significantly.

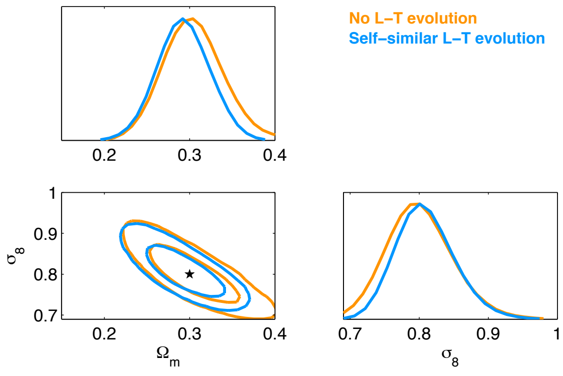

Figure 2 - Expected 68 and 95 per cent parameter constraints for ^{500}XCS, without measurement errors.

Including redshift and X-ray temperature measurements errors in the analysis introduces scattering of clusters across the redshift and temperature cut-offs. As the cluster distribution is not symmetric with respect to these cut-offs, there may be a net change in the expected number of clusters as a result (a type of Malmquist bias). Furthermore, the measurement error distributions may also be asymmetric, as is our temperature error distribution (for more details on the temperature and redshift error distributions considered see [1]). We find that the effect on derived cosmological constraints from measurement errors in X-ray temperature and redshift, as long as they are known accurately, is small. This is the case even with temperature or redshift errors of an unrealistically large magnitude. As such, we expect the broadening of constraints due to measurement errors to be a minor effect compared to the effects of possible systematic errors. Furthermore, we find that even imperfect knowledge of the variances of measurement errors, or the presence of catastrophic photometric redshifts, should not produce significant bias in the cosmological constraints, in all but the most extreme scenarios. We conclude that, under these assumptions, even ignoring the expected realistic measurement errors in the data analysis will provide a reasonable estimate of the true constraints.

In our analysis, we assumed we knew perfectly the relation between cluster X-ray temperature and mass (hereafter T - M relation). The reason why is because there isn't enough information in the XCS to allow for a joint constraining of cosmological parameters and both the L- T and T - M relations. We assumed the self-similar prediction for the redshift dependence of the T – M relation to hold for any combination of cosmological parameters, The constant of proportionality was set by demanding that our fiducial cosmological model reproduces the local abundance of galaxy clusters. And the intrinsic scatter was assumed to have a Gaussian distribution with a redshift - independent dispersion of 0.10 about the logarithm of the temperature.

In order to determine the sensitivity of our derived constraints to the assumed characteristics of the T - M relation, we estimated the impact of incorrect assumptions about such characteristics when analyzing the data: in most situations we considered significant bias occurred, with the constraints becoming displaced by more than 3σ from the fiducial model (see [1] for details). This stresses the importance of knowledge of the behaviour of the cluster scaling relations, in the form of self-calibration and/or separate follow-up information. For this, accurate knowledge of the selection function is necessary, so that scaling-relation scatter and evolution can be correctly distinguished.

Our next objective is to determine to what extent the information in ^{500}XCS can be used to constrain the equation of state of the dark energy, under the assumption of a flat universe. Previous work [3,4] would suggest that, if such equation is assumed to be constant with redshift, then it should be possible to constrain it, jointly with σ_8, Ω_m and the L - T relation, to within 20 to 30 per cent (at 1σ) using the ^{500}XCS data.

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