A coordinated X-ray, SZ and optical survey for galaxy cluster cosmology

G.W. Pratt, H. Böhringer, R. Suhada, J.J. Mohr, J. Calrstrom, R. Kneissl, et al.

1 Introduction

In 2007 three major experiments, the South Pole Telescope (SPT), the Atacama Pathfinder EXperiment (APEX) and the Atacama Cosmology Telescope (ACT), opened a new survey window onto the Universe, aimed at producing the first extensive samples of galaxy clusters via the SZE. To fully understand the results to be obtained, and for their use for cosmological applications, a maximum of information on the detected clusters is needed (at least in an initial test field). These three SZ experiments (SPT, APEX and ACT) have thus agreed to focus their early efforts on a common test region of the sky that is also being surveyed by deep optical observations. To gain the deepest understanding of the SZ-cluster survey selection function, and to secure the best information on global structural parameters of the clusters, there is need of X-ray observations, as these still provide the best understood and most established way of surveying for clusters.

We have thus combined the SZ and optical survey efforts with X-ray data in a minimal test area, having been awarded an XMM-Newton Large Observing Programme (involving ~ 0.5 Million sec exposure time) allowing us to conduct an initial combined X-ray/optical/SZ survey in a 5 deg^2 area. XMM-Newton is the only instrument which can effectively provide such a survey and this program will be one of its legacy projects.

In this test area, we expect to clearly detect at least 50 galaxy clusters, more than 70% of which we estimate will also be detected in the SZ surveys. This number is sufficiently large for a first calibration and to establish observable scaling relations. It will also allow first cosmological tests, which will help to demonstrate the validity of the new approach, which has been flagged as one of the four most promising routes to observationally tackle the fundamental question of Dark Energy. Although these tests will not yet be competitive with previous observational results, the step is essential for further planning and funding of the SZ surveys.

2 Survey scope

The main aim of the project is to deepen our understanding the selection function of cluster surveys in the three different wavelength domains through an unprecedented intercomparison of the results. With the XMM-*Newton* survey we are bringing together all established (and some new) techniques for cluster selection in a single region of the sky, setting the foundation for future, larger solid-angle studies to achieve high precision cosmological constraints. There are no sizeable, existing X-ray fields that can be surveyed using these three leading SZE experiments.

The survey field fits into the overlap region of all three SZ experiments, and is complemented by a multi-band *griz* imaging survey with the MOSAIC camera on the 4m-class telescope BLANCO at Cerro Tololo, and by imaging at 3.6, 4.5, 5.8, and 8 μm with IRAC, on the *Spitzer* space observatory. The combined data-set will allow accurate photometric redshifts (i.e., with an uncertainty $\delta z < 0.05 \times (1 + z)$ for individual galaxies but equal to 0.04 for individual clusters) to be determined for red-sequence galaxies down to $L^\star$ (i.e., the characteristic luminosity in the luminosity distribution function of galaxies) all the way to $z = 1.5$. Moderately accurate photo-z's will be obtained up to $z = 2$. Furthermore, IRAC photometry will allow the contamination of the red-sequence by less-massive, dusty starburst galaxies to be investigated, starbursts being luminous at rest frame $\lambda \sim 3$–$8\ \mu$.

The geometry constraints of ACT are the most restrictive yielding a common survey area equal to a two degree strip. Our approach is to follow up initially a 6 deg^2 part of the field centered at (23hr30min, -52.4°). With a 6 deg^2 region, the expected SPT and XMM-*Newton* yield is $\sim$8 and $\sim$6 clusters at $z \geq 1$, respectively, and more than 50 clusters in total. This is a sizeable sample to study the survey selection model as a function of mass and redshift. Uniform X-ray and optical coverage on this scale will be a boon to all the mm-wave experiments, but each experiment has its own strategy and mixture of depth, resolution and solid angle. (APEX and ACT will survey total areas of $\sim$300 deg^2 at a resolution between 1 and 2 arcmin, while SPT will survey 4000 deg^2 south of $\delta = -30°$ with a 1 arcmin resolution. ACT and SPT will perform multi-frequency surveys, with SPT bands at 90, 150, 220 and 270 GHz.)

3 The X-ray survey

For our XMM-Newton survey we have adopted an "Olympic symbol" mosaic observation strategy with offsets of 20 arcmin between adjacent fields. Covering the 5 deg^2 region with a two degree-width requires a mosaic of 6×7 (minus one) pointings with an exposure of 12 ks per pointing. By combining the MOS and pn exposures in this exposure pattern, we reach a maximum effective MOS1 exposure of 45 ks and a mean exposure of 27 ks (this includes the effects of the recent loss of one MOS chip). In our survey region, these exposures correspond to 50 photon flux limits in the 0.5–2 keV band of 6.5×10^{-15} erg s^{-1} cm^{-2}. For extended sources like clusters, our experience with the XMM-Newton archive search for distant clusters suggests that about 50-60% of the photons are detected under these conditions, owing to the low surface brightness of the outer parts of clusters. Including a typical background in a simulation indicates that clusters with fluxes of $\sim 1 \times 10^{-14}$ erg s^{-1} cm^{-2} and an effective solid angle of 1 arcmin^2 are detectable at high statistical significance ($>5\sigma$) anywhere in the survey region. Our experience with cluster finding gives us confidence that with 50 photons we can reliably differentiate extended from point sources anywhere in the XMM field.

Our XMM survey should in principle provide an X-ray detection for 100% of the SZE selected clusters at $z < 0.85$ (and still more than half at $z = 1$), allowing accurate tests of the SZE selection function (see Fig. 1. This SZE and X-ray cluster matching requirement sets the XMM exposure. On the scales of interest for clusters ($\sim$ 1 arcmin^2 or greater) the exposure is very uniform; this enables a high completeness cluster selection in X-rays. Figure 3 illustrates a map of the effective exposure as a function of position over a portion of the survey region.

4 Current status

Currently we have data for the first 20 fields (out of 42 fields in total). These fields have been reduced and source detection applied using the same SAS-based pipeline as the XDCP. The total useful exposure time is slightly less than 60% of the total nominal time, mainly due to soft proton flares (the first 7 fields were rendered entirely unusable for science purposes and have been re-proposed). A mosaic image of 19 of the 20 currently available fields is shown in Fig. 3.

The current total number of sources detected in the single band detection scheme (0.35 - 2.4 keV) of at least at 3 sigma detection significance level is 1315. Of these, there are 68 extended sources detected with at least a 2.5 sigma extent significance, meaning $\sim$ 5.2% of the total detected sources are of this type, and we have 1-3 cluster candidates per field (as expected).

5 Future prospects, relevance to XXL survey

After a successful start of these SZ surveys, we expect that future XMM-Newton AOs will allow us to extend the X-ray survey area to 12.5 deg^2, as originally advocated in our successful XMM-Newton proposal. This next step is essential in order to exploit the expertise developed on a larger area, allowing competitive cosmological constraints to be established. Combination with a future XXL survey would obviously be desirable, especially given the area coverage of the SZ instruments (300-4000 deg^2). Such a project would be a desirable precursor to the *Planck* All Sky Survey.

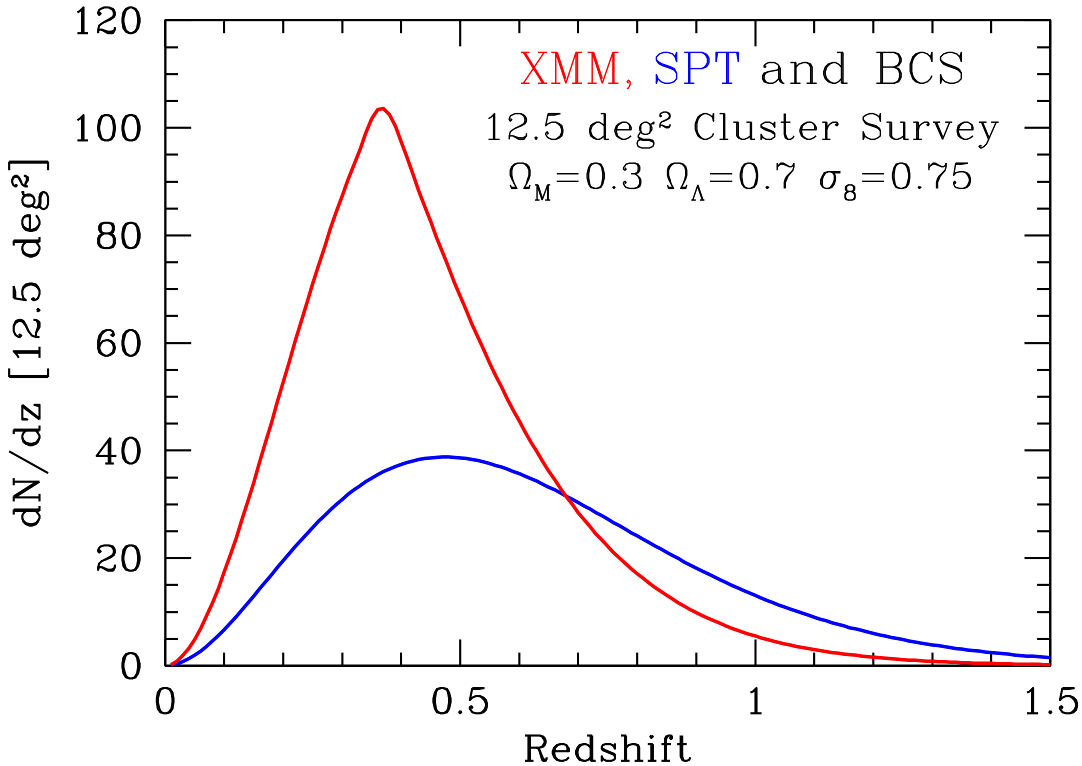

Figure 1: Expected number of detected clusters for the SPT experiment and for XMM in the proposed 12.5 deg^2 survey region in redshift bins of $\delta z = 0.1$ (we count only clusters with $M > 10^{14}$ $M_\odot$ for SPT). The Blanco MOSAIC *griz* survey (BCS) will deliver cluster photometric redshifts to $z = 1$ (∼85% of the full SZE sample). The uniform coverage of the 5 deg^2 region (as well as of the originally proposed one) provides two advantages: (1) we can use X-ray cluster finding to calibrate our model of the SZE cluster selection, and (2) we can combine the data of all three cluster finding techniques to lower the detection threshold for each of the methods and increase the number of detections.

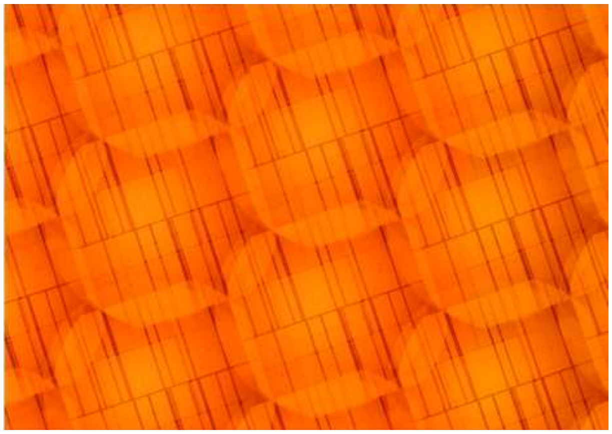

Figure 2: Zoom into a simulated exposure map for the XMM survey that includes both MOS and the pn detectors. Adjacent fields are offset by 22.8 arcmin, leading to a very uniform exposure over the entire survey region. We proposed for a 9×9 mosaic with 12 ks exposures (including overheads) for the original 12.5 deg^2 region; the granted 5 deg^2 region requires 486 ks of XMM time. The mean effective MOS1 exposure time is 25.6 ks, corresponding to a 50 photon flux limit of 6.5×10^{-15} erg s^{-1} cm^{-2}. The uniformly exposed, large solid angle field enables very clean X-ray source finding and studies of the angular clustering of the sources. In combination with the deep optical *griz* band and mm-wave data from APEX, ACT and SPT, this XMM survey field will be the premier testbed for cluster finding in cluster cosmology.

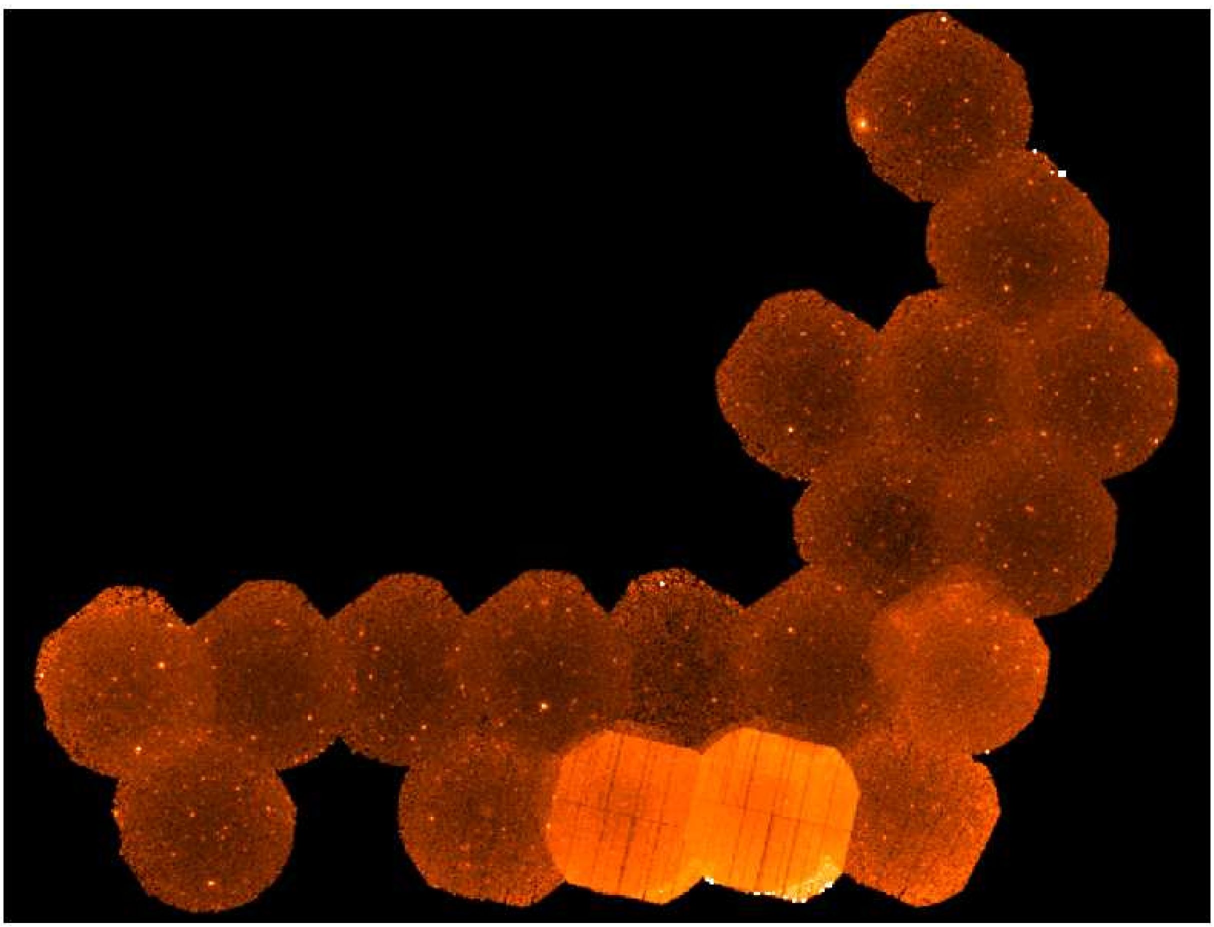

Figure 3: Current status of the X-ray survey survey (19 pointings, ~ 3.6 deg^2) Brighter pointings are scientifically unusable due to proton flare contamination.