The cosmological analysis of large X-ray galaxy cluster surveys

Abstract: Large samples of galaxy clusters collected in X-ray surveys are able to tighly constrain cosmological scenarios by probing the mass function of large structures and its evolution with time. Current projects with *XMM-Newton* (e.g. XMM-XXL) and the future *eROSITA* all-sky survey will deliver sizable samples (1,000-10^5) of objects displaying a wide range of signal-to-noise ratios in X-ray bands. We present here the CR-HR method, particularly suited to capturing the cosmological signal in these numerous samples. We demonstrate its applicability on the X-CLASS cluster sample, carefully selected in the *XMM* archive.

Context

Clusters trace the large-scale structure in the Universe and provide cosmological constraints by probing the halo mass function and its evolution through its most massive constituents. Because the mass function is steep, most sources display faint signal-to-noise ratios in the X-ray bands and require particular care in using them for cosmology.

Fig. 1: the 25 deg^2 XXL-North field observed by XMM-Newton at 10 ks depth [see talk of M. Pierre]

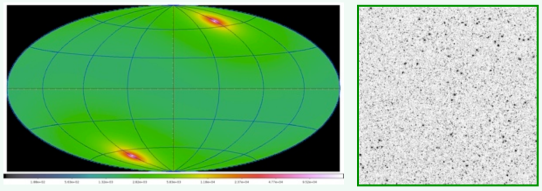

Fig. 2: the eRosita full-sky survey [launch 2015; Predehl et al. (2010)]. The exposure map shown on the left ranges from 2 ks to 100 ks (ecliptic poles). The right panel shows a simulated 3x3 deg^2 field at 4 ks depth with galaxy clusters and AGNs. About 10^5 galaxy clusters are expected in the 4-year time of survey.

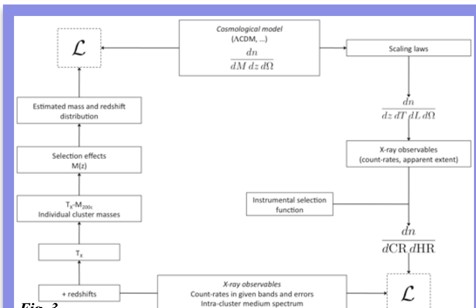

Fig. 3

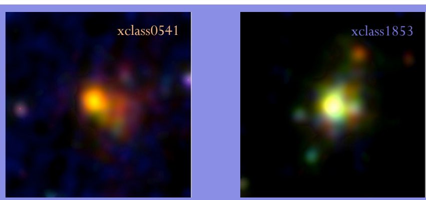

*Fig. 4: smoothed X-ray RGB images ([0.5-1], [1-2], [2-10] keV) of two clusters discovered in the X-CLASS survey with similar count-rates (**CR**=0.3 cts/s in the [0.5-2] keV band) and different hardness ratios (**HR**=0.5 and 1.1). Both **CR** and **HR** encode information on the cluster luminosity, temperature and redshift, hence on its mass.*

Method

Usual methods [e.g. Vikhlinin (2009)] rely on accurate mass computations and assumptions requiring high signal-to-noise observations (*bottom-top* on Fig. 3). The proposed method instead models forward the distribution of X-ray observables (*top-bottom*), namely the density of objects in the [0.5-2] keV count-rate (**CR**, closely related to the cluster X-ray flux) vs. [1-2]/[0.5-1] keV hardness ratio (**HR**) domain. It consistently accounts for selection biases, critical in the analysis. Cosmological parameters and scaling laws between mass and X-ray observables are constrained by fitting the observed distribution against the model.

Results

We applied the **CR-HR** method to 347 galaxy clusters serendipitously discovered in our tailored processing of XMM archive observations shrunk to 10 and 20 ks exposures. They form the 90 deg^2 X-CLASS cosmological sample [Clerc et al. (2012b) ; see also poster of J. Ridl] and have semi-automatic, multi-band, count-rates measurements (Fig. 5). The X-CLASS survey is made unique by its careful monitoring of selection effects, only possible thanks to extensive simulations of XMM extragalactic observations [Pacaud et al. (2006)].

The **CR-HR** method applied to this sample (Fig. 6) constrains basic cosmological parameters (Ω_m, σ_8) without any redshift information on clusters (Fig. 7). Moreover the luminosity-temperature (L_X-T_X) is found to evolve with redshift at a rate weaker than predicted by self-similar scaling. This result is confirmed in an independent analysis of a sample of 52 galaxy clusters with spectroscopic redshifts collected over 11 deg^2 in the XMM-LSS field [Clerc et al. (2014, subm.)]. It is consistent with trends identified in the XMM-XXL brightest cluster sample (see talk of P. Giles) and heterogeneous collections of clusters [Reichert et al. (2011)]. This finding has a critical impact on the number of clusters detected in X-ray surveys at high redshifts.

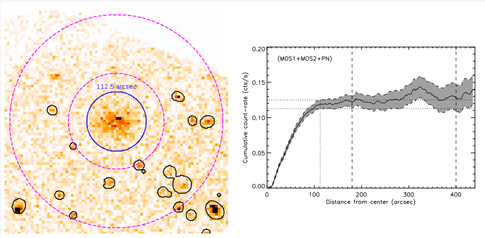

*Fig. 5: an example of count-rate measurement for a galaxy cluster found in the X-CLASS survey. This observable directly enters the **CR-HR** diagram of the sample (Fig. 6).*

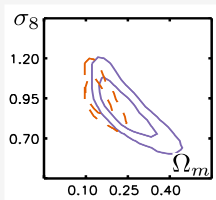

*Fig. 7: constraints from the X-CLASS sample and **CR-HR**, with two assumptions on the local L_X-T_X.*

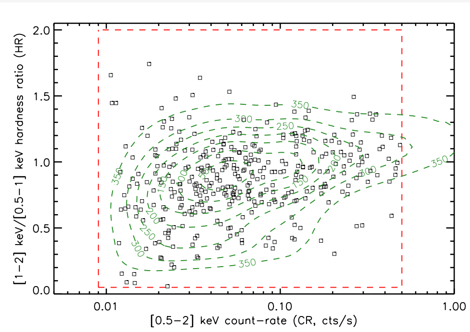

*Fig. 6: the **CR-HR** method in practice. Distribution of clusters from the X-CLASS sample (black squares), overlaid is the best-fit model as derived from a cosmological model and a set of scaling relations.*

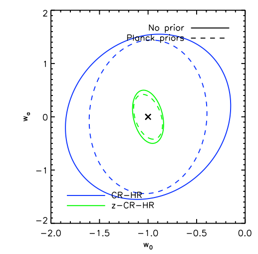

*Fig. 8: Fisher matrix forecasts for the eRosita full-sky survey. The dark energy equation of state is tightly constrained by the **z-CR-HR** method, i.e. adding redshift information on each cluster.*

Outlook

With ~10^5 objects predicted over the full sky [Merloni et al. (2012)], the eRosita cluster survey requires a well-matched methodology in order to constrain cosmological parameters, intra-cluster gas physics and their cosmic evolution. **CR-HR** and extensions are powerful and flexible in this respect (Fig. 8). As a demonstration, we will apply the **z-CR-HR** method – using photometric redshifts – on the X-CLASS sample (see poster J. Ridl).

References: *Clerc et al. 2012a, MNRAS, 423, 3545 • Clerc et al. 2012b, MNRAS, 423, 3561 • Merloni et al. 2012 arXiv1209:3114 • Pacaud et al. 2006, MNRAS, 372, 578 • Predehl et al. 2010, SPIE, 7732, 23 • Reichert et al. 2011, A&A, 535, 4 • Vikhlinin et al. 2009, ApJ, 692, 1033*

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