The X-ray Properties of Galaxy Clusters

P. Giles*, B.J. Maughan, H.Dahle, T. Hamana, S. Miyazaki, M. Bonamente, M. Birkinshaw, R. Ellis, C. Jones, M. Joy, R. Massey, S. Murray

*P.Giles@bristol.ac.uk

Abstract

We present work detailing the analysis of a complete, volume-limited sub-sample of 35 X-ray luminous galaxy cluster at $0.15 \le z \le 0.3$, from observations taken with the Chandra X-ray telescope. We construct scaling relations between various X-ray observables and find an offset in both the X-ray kT - Mgas and Yx - Mass when compared to previous published results. This cause is thought to be due to evolutionary effects between low and high redshift clusters, or selection effects, or a combination of both. We compare the X-ray mass estimates of our sample to weak lensing derived masses and find on average that the weak lensing masses are higher than those derived in the X-ray. We also present X-ray observations of clusters detected in a Subaru weak lensing survey. Comparing the luminosity-temperature relation of these weak lensing selected clusters to a large sample of X-ray selected clusters, preliminary results suggest no significant difference between weak lensing and X-ray selected clusters.

Properties of X-ray Selected clusters and Comparisons to Weak Lensing

Clusters of Galaxies are the largest gravitationally-collapsed structures in the Universe. The study of their number density and growth from the highest density perturbations in the early Universe offers insight into the underlying cosmology (e.g. Mantz et al., 2008; Vikhlinin et al., 2009). The study of galaxy clusters had been transformed with the launch of powerful X-ray telescopes such as Chandra and XMM, which have allowed the study of the X-ray emitting intracluster medium (ICM) with unprecedented detail and accuracy. One such study is that of radial temperature profiles of the ICM which allow us to probe the gravitational processes responsible for large scale structure and is an important ingredient in estimating the total cluster mass under the assumption of hydrostatic equilibrium of the ICM.

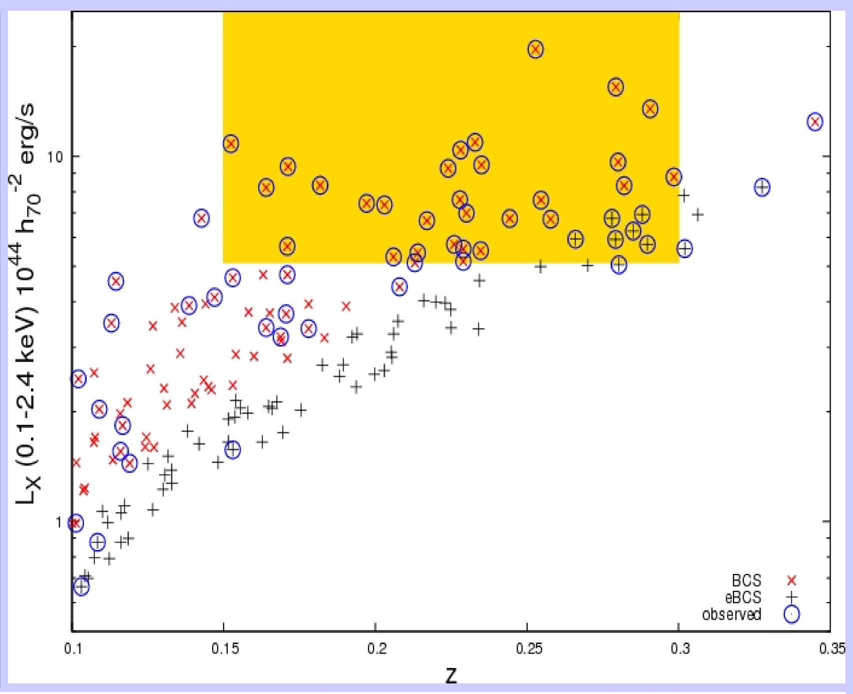
Observations using X-rays are a well established method of estimating masses, and indeed at the present time the most reliable. However, the assumption of hydrostatic equilibrium is not always valid as many clusters have complex structures due to processes such as merger events. This problem can be overcome by obtaining cluster masses through measurements of gravitational lensing (Dahle 2006; Hoekstra 2007). The gravitational potential of a cluster causes the deflection of light from background galaxies, causing small distortions in the galaxies' shapes, an effect known as weak gravitational lensing. Gravitational lensing offers the most direct probe of the cluster mass and does not rely on assumptions about the dynamical state of the cluster. However, weak-lensing techniques are susceptible to the possibility of projection effects of multiple structures along the line of sight, lending to overestimates of the cluster mass or false detections.

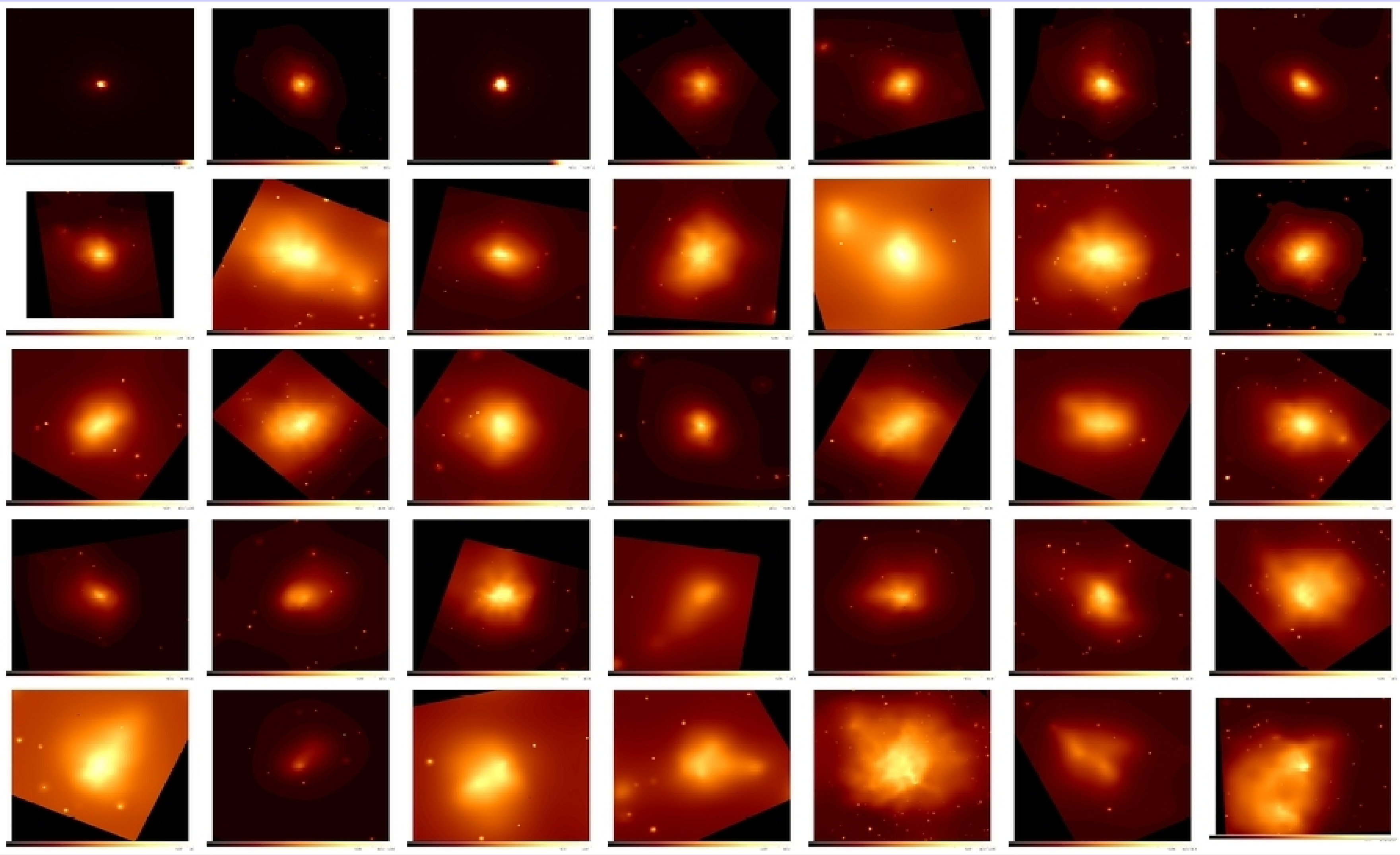
Sample and Aims

Our sample was constructed by selecting clusters from the BCS and eBCS (Ebeling et al., 1998 and 2000 respectively). The selection criteria was originally defined by Dahle et al (2002). Clusters were chosen to be in the redshift range $0.15 \le z \le 0.3$, and have a lower cut-off in X-ray luminosity of $L_{X,0.1\text{-}2.4\,keV} = 6 \times 10^{44}$ erg s^{-1}. This resulted in a sample of 35 clusters, shown in the figure opposite (yellow region).

Our aims are to:
1) Analyse Chandra observations of the full sample to study the clusters' X-ray properties.
2) Perform a full hydrostatic mass analysis on the most relaxed clusters.
3) Construct scaling relations of the relaxed clusters, and use these relations to estimate the masses of the remaining clusters.
4) Construct scaling relations between the X-ray and weak-lensing masses, and use the relations of the most relaxed clusters to calibrate the normalisation of the whole sample.

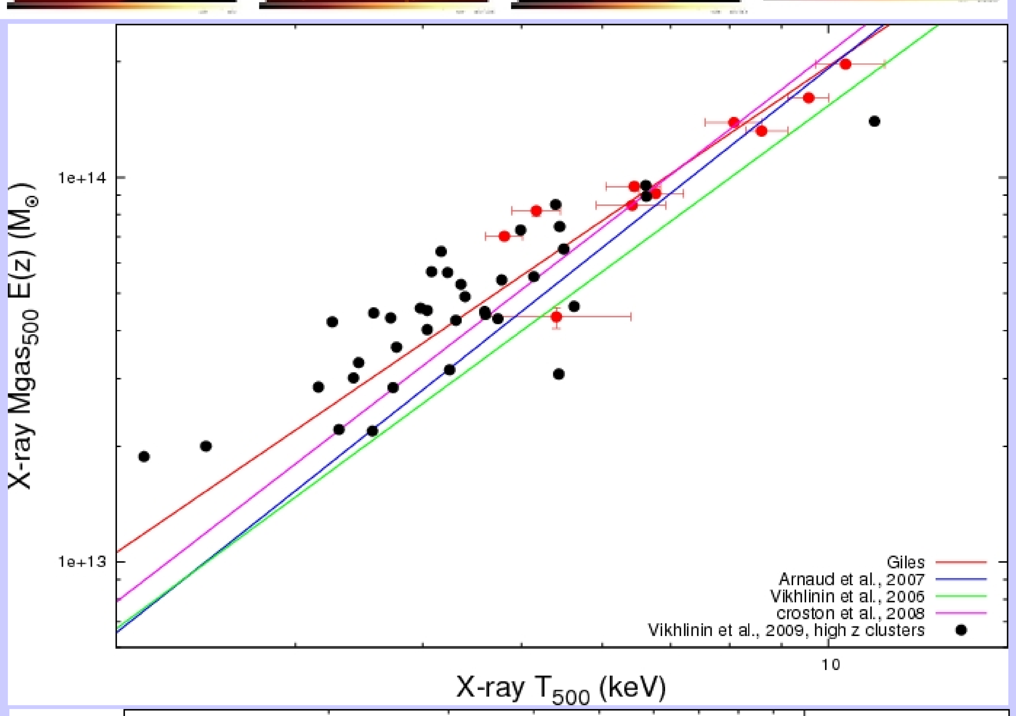
The mosaic figure below shows our sample of clusters arrange in order of relaxed-to-unrelaxed.





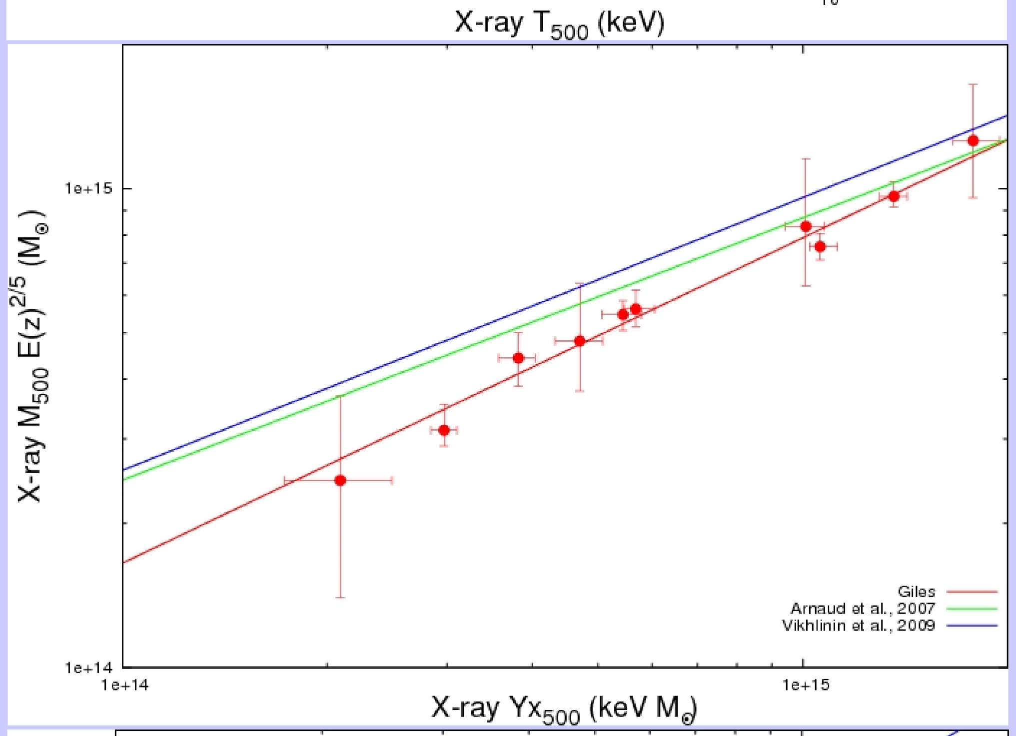
KT-Mgas relation

The top plot to the right shows the kT-Mgas relation for our 10 most relaxed clusters (red circles). Our kT and Mgas values are measured within R500 with the core excluded for for kT. Our relaxed clusters were deemed so by a centroid shift method and choosing the 10 smallest centroid shift values. We fit a power law relation of the form Mgas*E(z) = A*(T / 7 keV)$^{\alpha}$. We find a slope of 1.81 and a normalisation of 1.02E14 at 7 keV. We plot on here for comparison the relations found in Vikhlinin et al., (2006), Arnaud et al., (2007) and Croston et al., (2008). We find a slight offset in the normalisation of our relation as compared to these results, which is a result of these relations being determined based upon samples of low redshift clusters. Vikhlinin et al., (2009) measured temperatures and gas masses for a sample of high redshift clusters, which are plotted for comparison with our data (black points). We find much better agreement with our results and conclude the difference we see between our sample and low redshift samples could be due to evolutionary effects or selection effects.



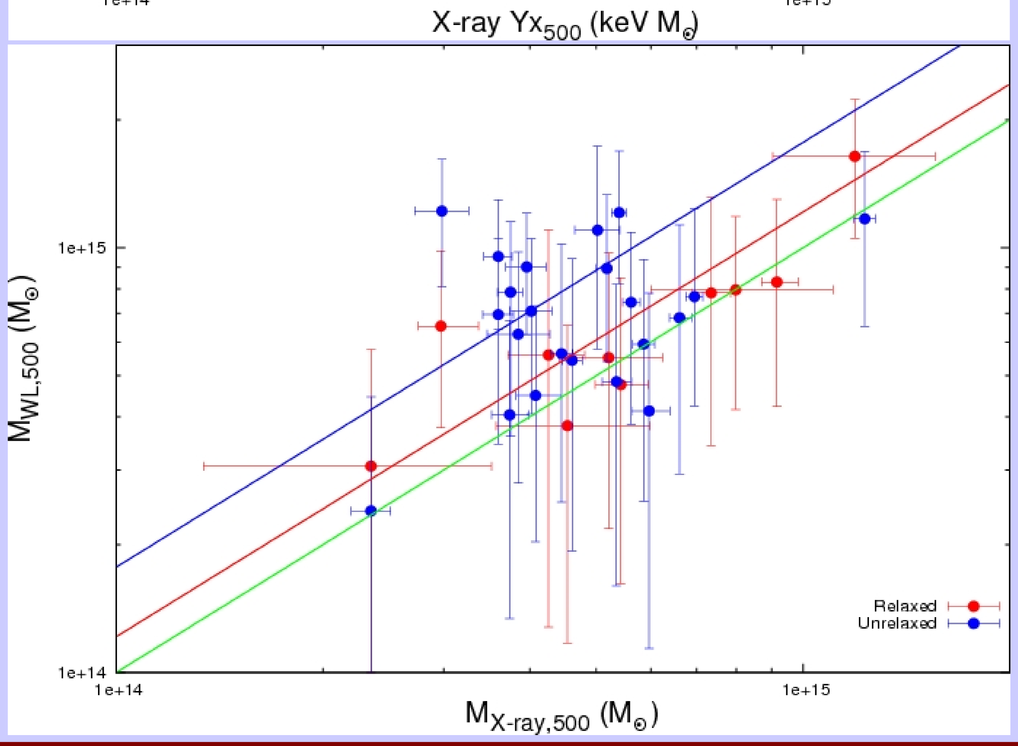
Yx – Mass relation

The middle plot to the right shows the Yx – Mass relation for our sample relaxed clusters. Yx is defined as kT*Mgas. We determine the hydrostatic masses by following the method outlined in Vikhlinin et al., (2006). Comparing results to Arnaud et al., (2007) and Vikhlinin et al., (2009), we again see an offset between our sample of clusters and these relations. The offset is consistent with the offset found in the kT-Mgas relation and having a common cause. We note that we will be able to test selection bias as our sample is statistically complete.



Mx – Mwl relation

The bottom plot to the right shows the Mx – Mwl relation for our sample of 35 clusters. The weak lensing masses were derived by NFW profile fitting to the weak lensing shear profiles (Dahle et al., 2006) determined from images taken by the Nordic optical telescope and the University of Hawaii telescope. The WL masses were derived with the X-ray determined r500 and at the X-ray determined centroid of the cluster. We fit a power law relation to the data for both the relaxed and unrelaxed clusters, noting that we fix the slope at unity due to the large uncertainties in the WL masses. These preliminary results show on average the WL masses are higher than those derived from X_ray observations with a larger difference in the unrelaxed case.



Summary

We have analysed Chandra observations of a statistically complete sample of 35 galaxy clusters. Using the most relaxed clusters, generated scaling relations between X-ray observables and hydrostatic masses to use to calculated the masses of the whole sample. Comparing these masses to those derived through weak lensing NFW profile fitting we find on average that the masses derived via weak lensing are higher than X-ray mass estimates.

X-ray Properties of Weak Lensing Selected Clusters

In order to use clusters as a cosmological probe three essential tools are required: (a) an efficient method to find clusters over a wide redshift range, (b) an observational method of determining cluster mass, and (c) a method to compute the selection function or the survey volume in which clusters are found. A variety of observational techniques have been brought to bear on requirements (a-c), each with different strengths and weaknesses.

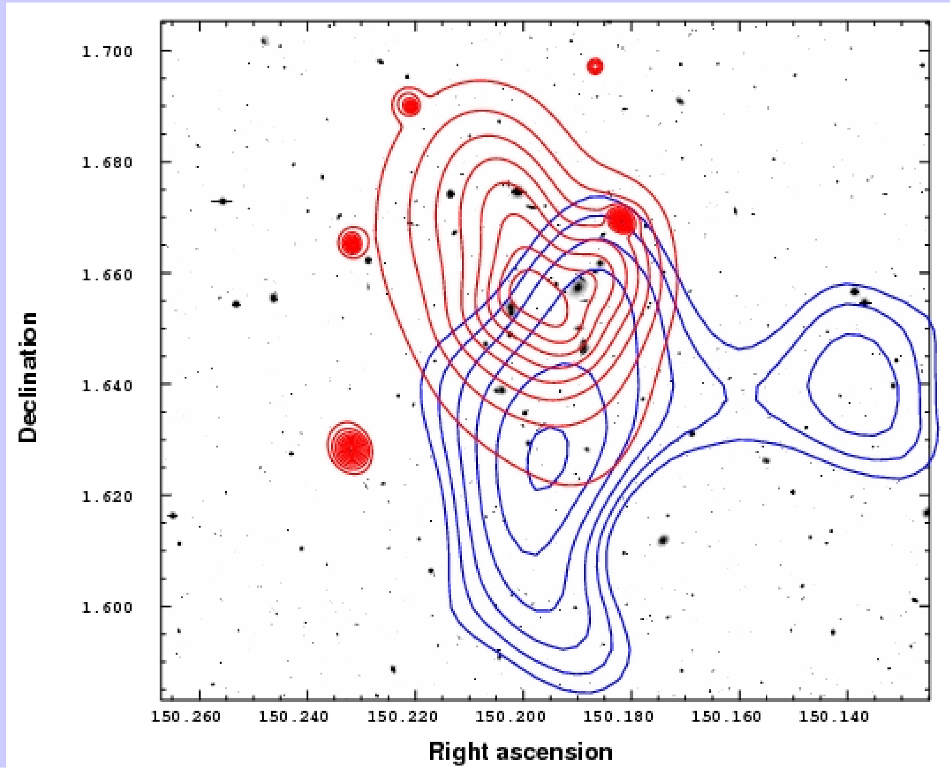
Early samples of clusters were based upon selecting clusters optically, however these samples have traditionally suffered from projection effects. Very recently, the first clusters have been detected in blind surveys using the Sunyaev-Zel'dovich effect (SZE; Staniszewski et al ., 2009; Marriage et al., 2010). This method holds much promise due to the redshift independence of the SZE, though this technique is still in its infancy. The most effective method of building large, well defined cluster samples has been via X-ray selection. The high X-ray luminosities of clusters make it relatively easy to detect and study clusters out to high redshifts, and X-ray cluster studies have provided a means to impose tight constraints on various cosmological parameters.

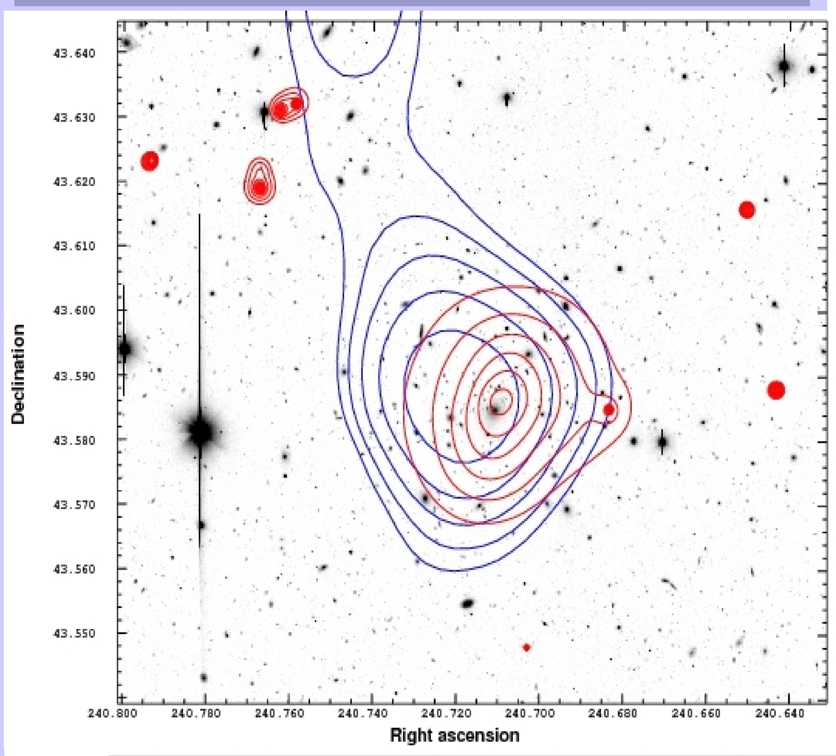
A common weakness of the three techniques outlined above is that the clusters are selected based on the properties of their minority baryonic material. However, cosmological constraints from those clusters are based on their masses, dominated by dark matter. This gives rise to complications in both the mass estimation and in the determination of sample selection functions. These selection functions depend crucially on the form and scatter of the relationship between the observable used to detect clusters, and the cluster mass.

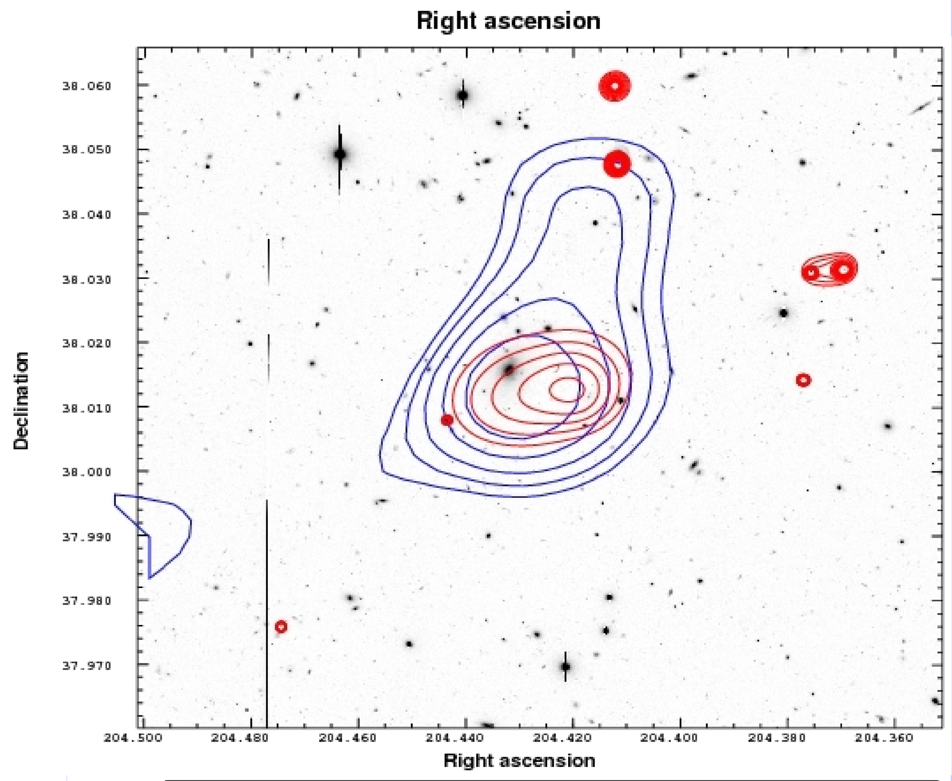
In principle, these complications may be avoided by defining cluster samples through gravitational lensing, the most direct observational probe of cluster masses. The development of weak lensing (WL) techniques has enabled the construction of WL selected cluster surveys.

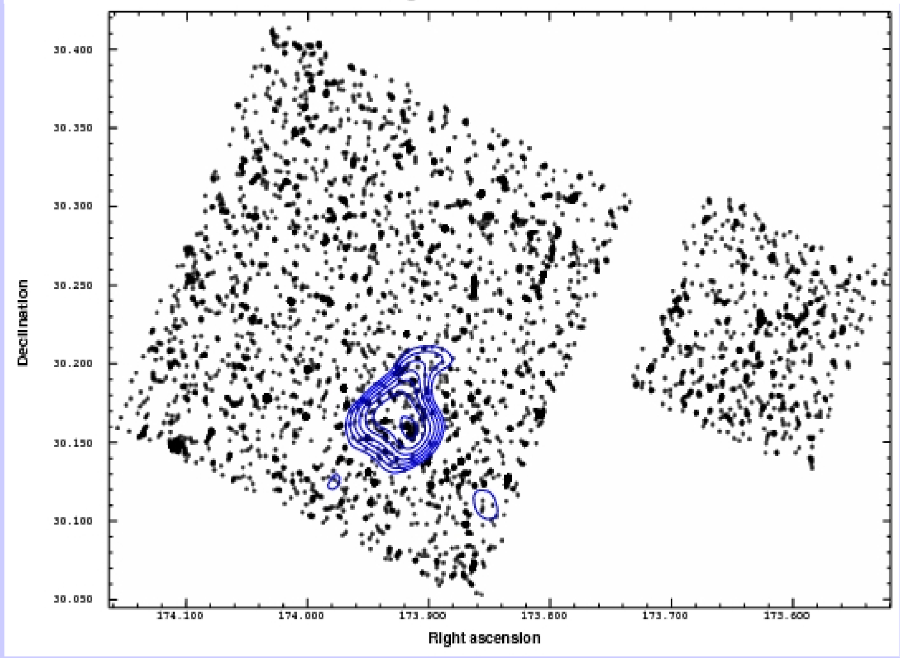
Sample and Aims

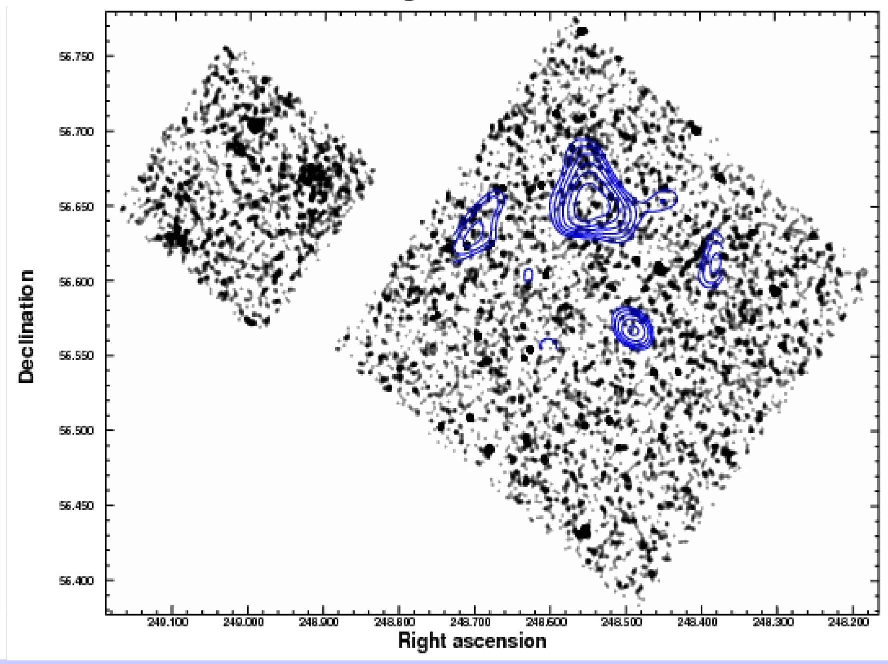
The target clusters are taken from our Subaru Weak Lensing Survey (Miyazaki et al., 2007), which is unique in terms of its survey depth, spectroscopic follow up and image quality. Hamana et al. (2009) presented results of a multi-object spectroscopic follow up of cluster candidates to determine plausible optical counterparts to the WL signals, and to determine cluster redshifts. For 36 WL cluster candidates we obtained 15-32 galaxy redshifts per cluster cluster, 28 of the candidates were securely identified as clusters. We then defined a subset of 10 "clean" clusters whose velocity dispersion could be evaluated from at least 12 spectroscopic member galaxies, and whose WL mass estimation was not affected by a neighbouring system or field boundary. These WL selected clusters were then observed with Chandra to perform the first comprehensive study of the X-ray properties of WL selected clusters. We present here the X-ray and WL detections of a sample of these WL selected clusters showing X-ray contours (red contours) and WL mass contours (blue contours) plotted on the Subaru images. The images further below show the WL mass contours plotted on the Chandra images which have very weak detections.

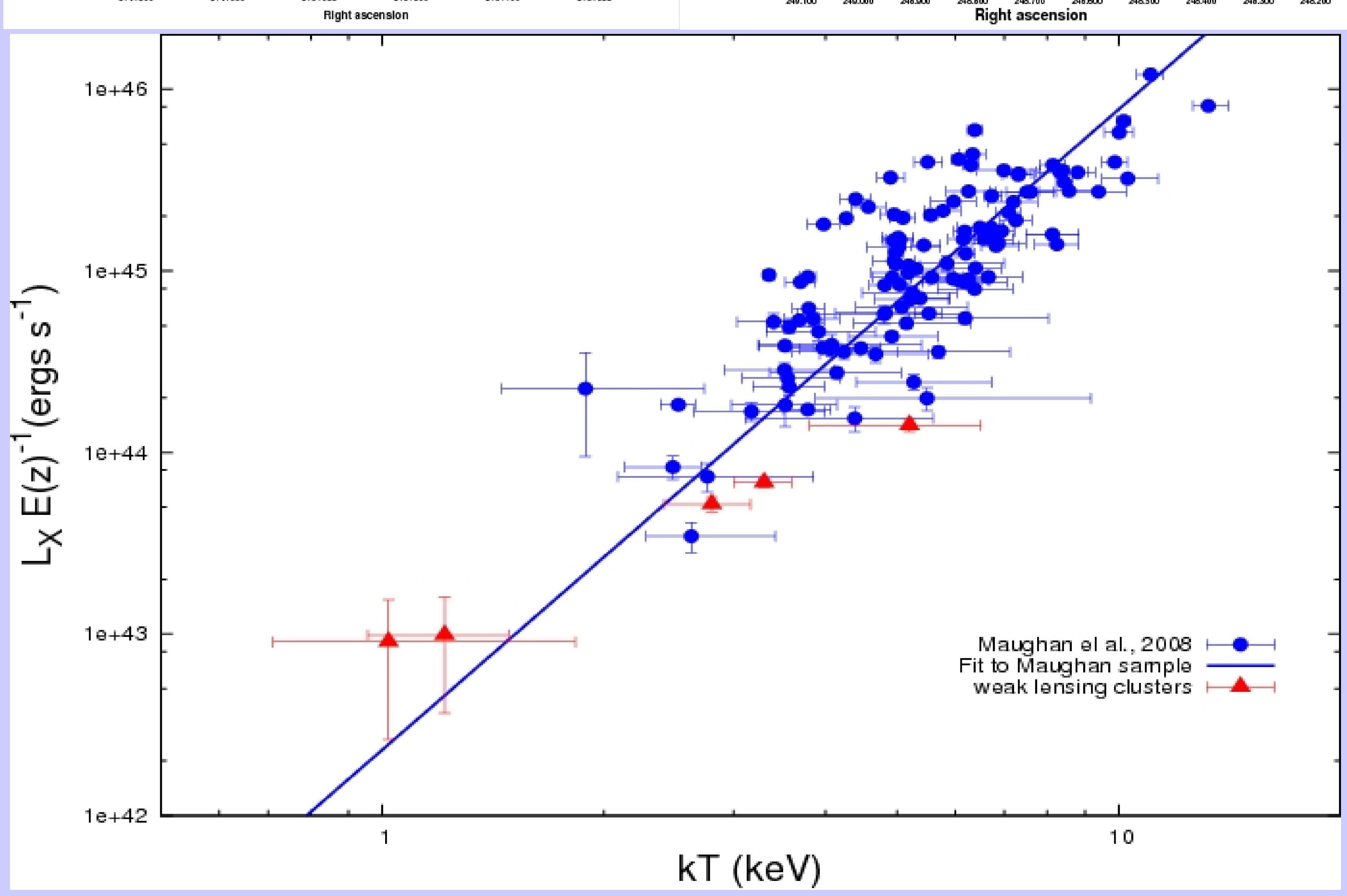












X-ray Luminosity-Temperature relation

Plotted above is the Lx-kT relation of 115 X-ray selected clusters from Maughan et al., 2008 (blue circles). We plot on here the results from our Chandra observations of five WL selected clusters (red triangles). These are preliminary results based on half of the sample, which so far suggest the WL selected clusters do not differ significantly from the LT relation of X-ray selected clusters. For further analysis we will compare the a WL selected LM relation to that of X-ray selected clusters from well defined cluster samples such as the Dahle et al., (2006) sample opposite, the REXCESS sample and the 400d sq sample.

Summary

We have performed follow-up observations of Subaru weak lensing selected clusters in order to determine X-ray properties of a sample of 10 weak lensing selected clusters. Preliminary results suggest that there is no significant difference in the X-ray luminosity-temperature relation for weak lensing selected clusters to that of X-ray selected clusters. Further work will compare to other well defined cluster samples.

BRISTOL PHYSICS

Monsters, Inc.: Astrophysics and Cosmology with Galaxy Clusters – Santa Barbara 2011

University of BRISTOL