2000BASI...28..381N

Bull. Astr. Soc. India (2000) **28**, 381-383

Probes of superclusters at moderate redshifts

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Abstract. Detection of superclusters at z = 0.2 – 1.0 and determination of their mass provide constraints on the theories of structure formation in the Universe. A combination of the study of hot gas observed in X-rays, and the distribution of arcs (weak lensing of background galaxies) in optical can probe clusters of galaxies as well as superclusters. We have analysed the available X-ray and optical maps of a cluster pair of Abell 222 & Abell 223 at redshift $\simeq$ 0.2, separated by ~15' and where at least one arc has been reported. X-ray temperature of the gas in the two clusters is 4±2 keV and a bridge of hot gas at temperature of $\simeq$ 2keV connects them. The bridge is also seen in the optical indicating the presence of a supercluster structure.

Key words : clusters of galaxies, X-rays, gravitational lensing

Galaxy–clusters are the largest bound structures in the Universe. Most of them evolved into non–linear systems at least by redshift of 1 and the temperature of the order of 8 keV has been measured for the X-ray gas in some of the high redshift clusters (e.g. MG 2016+112 observations by Hattori et al. 1997). Detailed analysis of their structure (e.g. cooling flow, velocity maps, X-ray profile) indicates that some of them are relaxed while others are still evolving. Study of **clusters of galaxies** reveals "gross" properties of the Universe and places strong constraints on theories of large scale structure. It would be worthwhile to investigate **groups of galaxy–clusters** with a view to understand the evolution of large scale structures. This becomes specially relevant in view of the recent observations indicating that the universe could be anisotropic well upto hundreds of megaparsec scale. Some of the related important questions in Cosmology are : *When and how do structures at supercluster scales develop ? Is there evidence for bound objects at this scale ?*

The two reliable ways to answer these questions based on observations are :

1. Study of bound x-ray gas : An isothermal distribution of X-ray gas at a scale of ~10 Mpc should essentially be bound because time taken by the gas to escape will be comparable to the age of the Universe. Temperature of the gas will be an indication of the depth of the potential well that binds the gas. Linear scale derived from surface brightness measurements in X-rays

will give the mass of gas and thus will be indicative of the total gravitational mass. The column density of the gas, then, can be used to estimate the baryonic fraction of the mass. This method is limited mainly by the smallness of the column density and temperature of the X-ray gas in the extended features compared to the values within the cluster. Equally, the X-ray gas could be highly clumpy and any smoothing techniques are likely to miss the features of interest at the supercluster scale and consequently, an independent probe to the structures is required.

2. Study of Weak Lensing : The mass and size of a lensing supercluster can be inferred via weak lensing technique by studying (a) slight distortions in the shape of background objects due to the gravitational shear produced by the intervening mass, or (b) systematic gradients in the number density of background sources due to the differential magnification of areas in gravitational lensing. This method has the following limitation : Normally the lens action of the individual clusters will dominate over the lens action of the total mass distribution at the supercluster scale. The optical fields are very wide (≥ half a degree) and not very rich, thus conventional telescopes are not very useful, and *large format imaging cameras on large telescopes are required for imaging background objects down to* $V = 27$ *magnitude and at sub-arcsec seeing (< the width of arcs).*

The best strategy in these studies is to go for both sensitive X-ray imaging and spectroscopy, as well as wide field optical imaging. As an example, we have analysed the available X-ray and optical maps of a cluster pair consisting of Abell 222 & Abell 223 at redshift $\simeq 0.21$, separated by $\sim 15'$. Both the galaxy–clusters, classified to be of Bautz-Morgan type II-III and Richness class 3 have at least 150 member galaxies identified. Based on deep CCD imaging (limiting surface brightness of 26 mag arcsec^{-2} in V) of the core of Abell 222, a gravitational arc produced by the lens action of the cluster mass on a background galaxy has been observed (Smail et al. 1991).

We obtained the X-ray data from public archives of *ROSAT*, which observed this region for a total of 6780s at a spatial resolution of ~15"in the energy region of (0.1–2.0 keV). Substantial sub-structures are seen between Abell 222 and Abell 223, notably a faint bridge of hot gas connecting the two clusters separated by ~ 10*Mpc*. Best fitr values for X-ray temperature of the gas are : kT (A222 and A223) = 4±2 keV; kT (Bridge) ≃2keV. The X-ray temperature of the bridge is not any artefact of the analysis. X-ray contours overlaid on an optical image (size=18′x18′) taken from the Digitised Sky Survey are shown in Figure 1 (plate). At this resolution the individual galaxies in the field are barely resolved. Nevertheless, a concentration of galaxies can be discerned along the bridge. The existence of weak lensing and a bridge between A 222 and A 223 confirm the temperature of the hot gas in the bridge. Though the mass in the bridge cannot be estimated reliably in the absence of deeper X-ray images or weak lens observations, from the detection of gravitationally bound gas we would infer that structures extending over upwards of 5 Mpc and gravitational potential of at least 2 keV have become nonlinear by a redshift of 0.2. Deep 2-band optical images of the 40′x40′ region around the clusters should enable detection of the weak gravitational

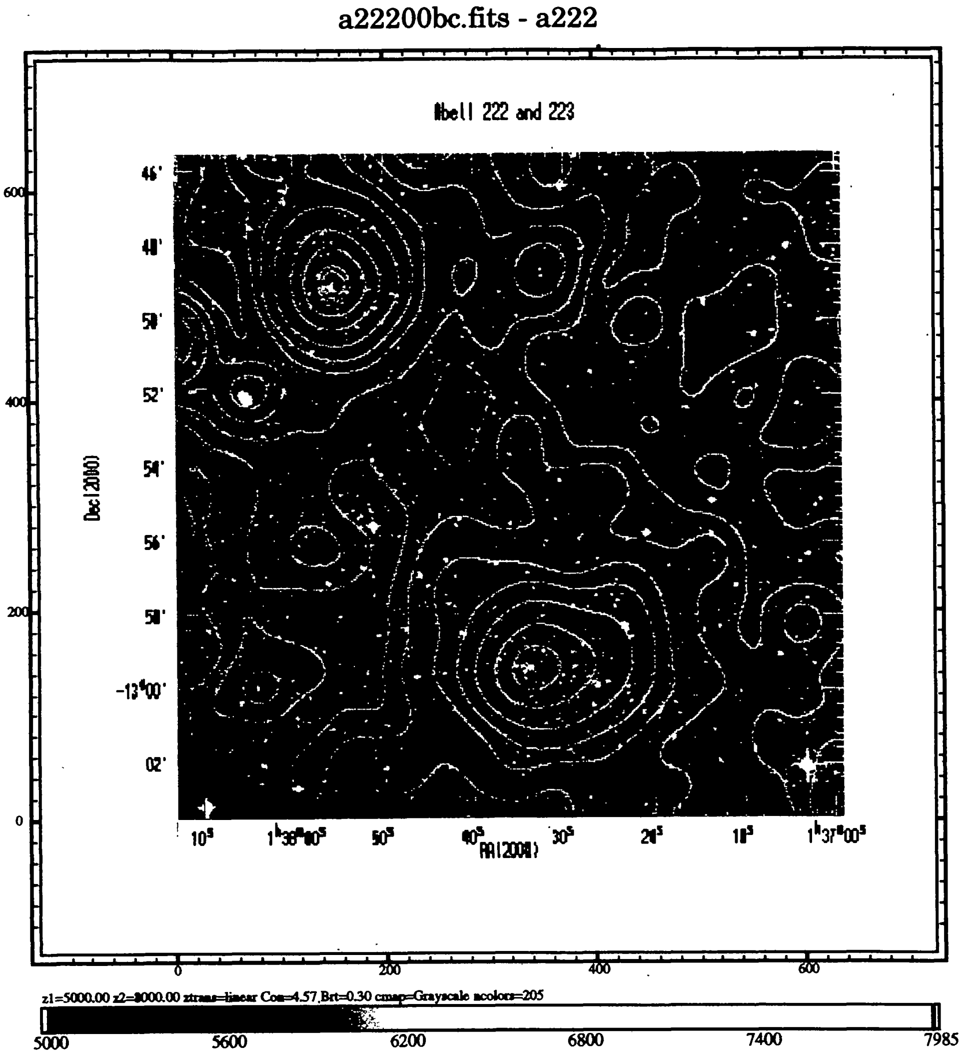

Figure 1. X-ray intensity contours from A222 and A223 as observed with the ROSAT PSPC, after smoothing with a Gaussian ($\sigma = 75''$) and overlaid on the optical image (black and white) obtained from the Digitised Sky Survey. X-ray contour levels are 0.084, 0.117, 0.167, 0.251, 0.335, 0.502, 0.837, 1.172, 1.501 and 1.590 cts/pixel (1 pixel = $15'' \times 15''$). The hashed contour shows a local minimum. East of it lies the X-ray "bridge" connecting A222 and A223 along an arc which follows the galaxy concentration. The mean (integrated) value of X-ray intensity along the bridge is more than 6σ above the background.

lens features. Large format imaging cameras on large telescopes are capable of this task by imaging background objects down to V = 27 magnitude and at sub–arcsecond seeing (< the width of arcs).

References

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