Distant Clusters in X-rays

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ABSTRACT

In recent years several clusters at high redshift (z > 0.75) have been discovered through their X-ray emission in different X-ray surveys. Follow-up observations with X-ray telescopes, and deep imaging from the ground and from HST, have shown that massive bound structures at high redshift exist and are not as rare as was once believed. Weak lensing techniques applied to these X-ray selected clusters have provided masses of the order of several 10^{14}-10^{15} $M_\odot$. I will present results on high-z clusters extracted from the *Einstein Medium Survey* (EMSS) and the *ROSAT* NEP survey. These clusters present a filamentary structure in the optical, and a corresponding resolved morphology in X-rays. They are objects of special importance because their X-ray emission and weak lensing signals imply that they are massive, comparable to low redshift examples, and their existence is problematic for some theories of structure formation.

1. Introduction

In hierarchical theories of structure formations clusters of galaxies form from the high peaks in the original density field, thus they provide crucial constraints on the shape, amplitude, and temporal evolution of the primordial mass fluctuation spectrum. Despite their importance, the statistics of the abundance of high-z (>0.5) clusters are poor since they are so difficult to find. Optical surveys of distant galaxy clusters are well known to have serious statistical shortcomings such as effects of superpositions of unvirialized systems (i.e. Frenk et al. 1990; Van Haarlem, Frenk & White). Therefore, the selection of high-z clusters by means of their X-ray emission is one of the cleanest ways to avoid sample contaminations, and it is based on simple physical quantities such as X-ray luminosity and temperature. X-ray surveys are sensitive enough to detect distant clusters. Examples include MS1137+6625, at z=0.78, and MS1054.5−0321 at z=0.83 in the Medium Survey (Gioia & Luppino 1994; see also the detailed study on MS1054.5−0321 by Donahue et al. 1998). Other X-ray surveys being conducted with ROSAT archive data are also finding distant clusters, for example the WARPS cluster at 0.83 (RXJ0152.7-1357, Ebeling et al. 1998) or the clusters discovered in the RDCS survey (Rosati et al. 1995 and Rosati et al. 1998).

2. Clusters of galaxies at z > 0.5 in the EMSS and NEP surveys

In Table 1, five examples of clusters with z > 0.5 from the EMSS and one from the NEP surveys are listed. L_X is given in the 0.3−3.5 keV band in units of $\times 10^{44}$ erg s^{-1}, T_X is in the 2−10 keV band and $N_{0.5}$ gives an indication of the richness of the cluster. In addition to their high X-ray luminosity, the six clusters possess lensed arcs (those marked with an "s" in column 3), strong shear signal (those marked with a "w" in column 3), high temperature and high values of the velocity dispersion. Recently Donahue et al. 1998 have published a detailed study on **MS1054−0321**, the most distant cluster in the EMSS, and among the most distant X-ray selected clusters known. MS1054.5−0321 is filamentary in optical with an elongation of galaxies in the E-W direction (see Fig. 1) and with X-ray emission extended in the same direction as the optical galaxies. The cluster is extremely rich and quite hot (ASCA measures a T_X=$12.3^{+3.1}_{-2.2}$ keV, Donahue et al. 1998). A strong shear signal at 6σ level is detected by Luppino & Kaiser 1997. The total mass (within 1 Mpc) from X-rays and from weak lensing are consistent (2-6$\times 10^{14} h_{50}^{-1}$ M$\odot$ vs 3-30$\times 10^{14} h_{50}^{-1}$ M$\odot$). Donahue et al. 1998 have shown that the high temperature in such a distant cluster is a powerful evidence that Ω is less than 1.

Gioia et al. 1998 have recently studied the distant cluster **RXJ1716.6+6708** at z=0.809 found in the North Ecliptic Pole (NEP) survey. Our group at the Institute for Astronomy in Hawai′i has been involved for several years in the optical identification of all the sources found in 84.7 deg^2 centered at the NEP of the ROSAT All-Sky Survey (Voges et al. 1996). We reported in Henry 1997 the discovery data of RXJ 1716.6+6708, from only 33 net photons. This weak detection revealed a very interesting object. The spectroscopy in hand at the time of the Henry 1997 paper was limited to only 12 cluster members but there was already an indication that the galaxies in the inverted S-shaped filament (see Fig. 2) were all part of the X-ray cluster. The new data presented in Gioia et al. 1998 allow a determination of the velocity dispersion. The cluster has a low temperature, T_X=$5.7^{+1.37}_{-0.58}$ keV, and a very high velocity dispersion σ =1522^{+215}_{-150} km s^{-1} h_{50}^{-1}. While the temperature is commensurate with its X-ray luminosity of (8.19±0.43)$\times 10^{44}$ h_{50}^{-2} erg s^{-1} (2−10 keV rest frame), its velocity dispersion is much higher than expected from

Table 1: X-ray Selected Clusters with z > 0.5

Name	redshift	lensing	L_X (erg/s)	T_X (keV)	$N_{0.5}$	σ (km/s)
MS0015.9+1609	0.546[a]	w	14.6[b]	8.4[c]	66±6[d]	1324[a]
MS0451.6−0305	0.550[e]	sw	20.0[b]	10.4[f]	47±5[d]	1371[g]
MS1054.5−0321	0.826[b]	w	9.3[b]	12.3[h]	82±10[i]	1360[h]
MS1137.5+6625	0.782[b]	sw[n]	7.6[b]		56±6[d]	850[m]
MS2053.7−0440	0.583[e]	sw	5.8[b]		20±5[d]	
RXJ1716+6708	0.809[l]	w[n]	5.2[l]	5.7[l]	52±7[l]	1522[l]

[a]Dressler & Gunn 1992 [b]Gioia & Luppino 1994 [c]Furuzawa *et al.* 1994 [d]Luppino & Gioia 1995 [e]Maccacaro *et al.* 1994 [f]Donahue 1996 [g]Carlberg *et al.* 1994 [h]Donahue *et al.* 1998 [i]Luppino & Kaiser 1997 [l]Gioia *et al.* 1998 [m]Donahue *et al.* in preparation [n]Clowe *et al.* 1998

the $\sigma - T_X$ relationship of present-day clusters. The dynamical state of RXJ 1716.6+6708 may be in large part dominated by infall or merging and consequently the velocity dispersion is not representative of the virial temperature of the cluster. If RXJ 1716.6+6708 is actually composed of two or more distinct gravitational components, the situation should be apparent from the velocity histogram, unless the separation of the cluster components is so small to be statistically of little significance. As with MS1054.5−0321, it is unlikely that RXJ1716+66 is in virial equilibrium. If there is any fraction of infalling galaxies which are bound to the cluster but not yet virialized, they could inflate the velocity dispersion. These galaxies in the cluster would be moving on radial orbits rather than following the bulk motion towards the cluster center. It is intriguing that the morphology of MS1054.5−0321 and RXJ1716+66 is filamentary with the X-rays coming from the center, as often described in theories of the initial formation of protoclusters (Bond *et al.* 1996) where matter is flowing along filaments with the X-rays coming from the midpoint of the filaments. The optical and X-ray morphologies of RXJ 1716.6+6708 support this picture.

Identifications of high-z clusters provide useful observational constraints to cosmological models. As more accurate observing capabilities become available, the number of distant known clusters will steadily increase, and the counts may severely constrain cosmological models. Other techniques, besides X-ray surveys, are succesfully isolating clusters. Clustering around radio galaxies at redshift equal or greater than 1 has been reported (see among others 3C 184, z=0.996, Deltorn et al. 1997; 3C 294, z=1.786, Crawford & Fabian 1996; 3C 324, z=1.206, Smail & Dickinson 1995.) A new promising technique which is currently providing interesting results is the search for distant clusters in the near-IR (see ClG J0848+4453 at z=1.3, Stanford et al. 1997). Even if we are still far from having large complete samples of high-z clusters to test the predictions of cosmic structure formation theories at these redshifts, there are already indications that the number of high-z massive clusters predicted by standard CDM, or other mixed Dark Matter models, is too low with respect to the number of clusters observed. The existence of even the single most distant cluster in the EMSS at z=0.83, MS1054.5−0321, with its large gravitational lensing mass, high temperature, and large velocity dispersion argue strongly that Ω_o is much less than 1.

I am grateful to my colleagues at the Institute for Astronomy in Honolulu and to M. Donahue at STScI for suggestions and advice. This work has received partial finacial support from NSF AST95-00515, NASA grants NASA-STScI GO-5402.01-93A, NASA-STScI GO-05987.02-94A, NAG5-2594 and CNR-ASI grants.

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Fig. 1.— Subarray I image of MS1054−03 taken with the Tek 2048 CCD camera at the UH2.2m

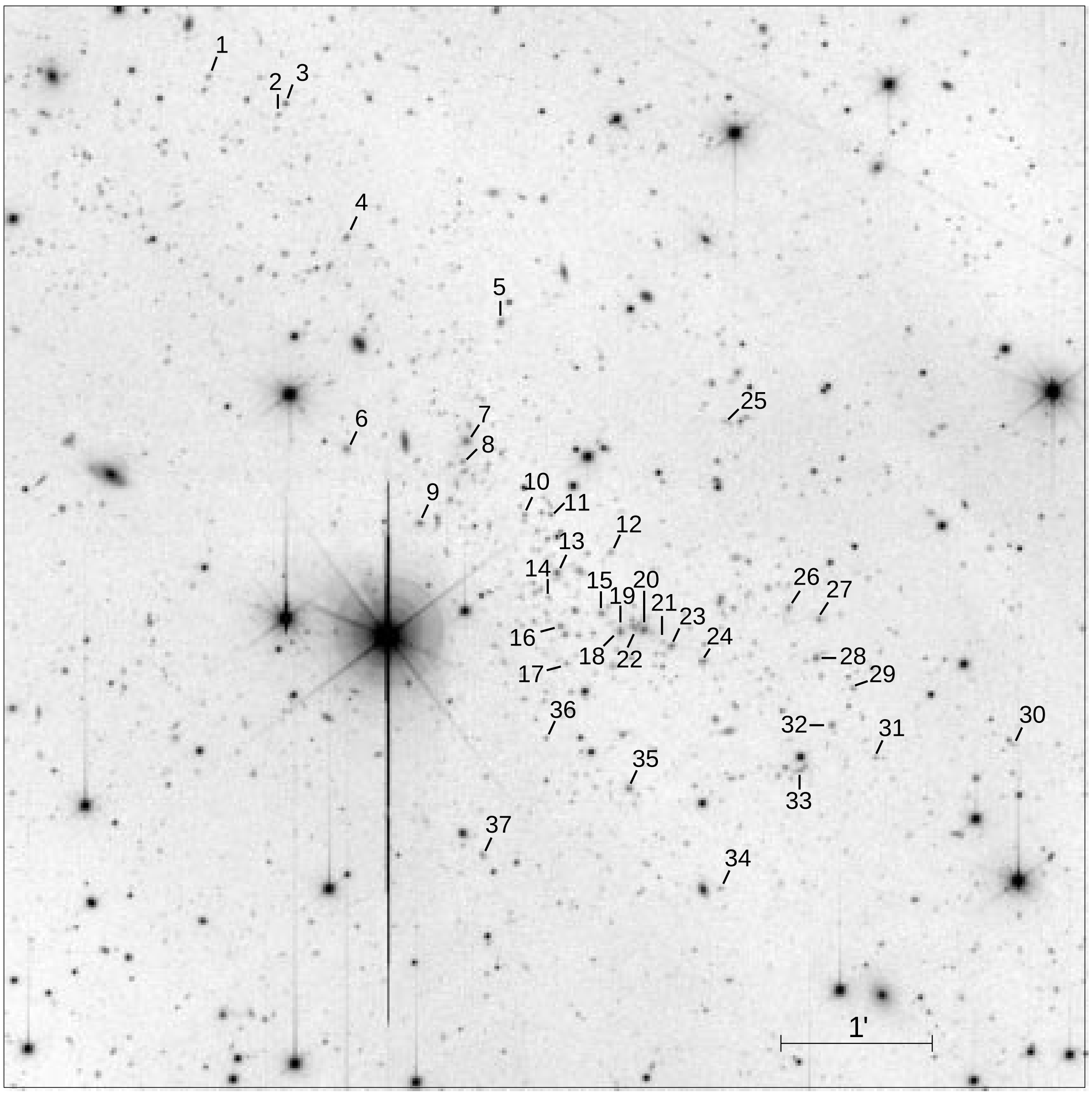

Fig. 2.— Subarray I image of RXJ1716.6+6708 taken with the UH 8K×8K CCD mosaic camera on the CFHT prime focus with 37 cluster members marked.

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