A SEARCH FOR X-RAY BRIGHT DISTANT CLUSTERS OF GALAXIES

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ABSTRACT

We present the results of a search for X-ray luminous distant clusters of galaxies. We found extended X-ray emission characteristic of a cluster toward two of our candidate clusters of galaxies. They both have a luminosity in the *ROSAT* bandpass of $\simeq 10^{44}$ ergs s^{-1} and a redshift greater than 0.5; thus making them two of the most distant X-ray clusters ever observed. Furthermore, we show that both clusters are optically rich and have a known radio source associated with them. We compare our result with other recent searches for distant X-ray luminous clusters and present a lower limit of 1.2×10^{-7} Mpc^{-3} for the number density of such high-redshift clusters. This limit is consistent with the expected abundance of such clusters in a standard ($b = 2$) cold dark matter universe. Finally, our clusters provide important high-redshift targets for further study into the origin and evolution of massive clusters of galaxies.

Subject headings: galaxies: clusters of — X-rays: galaxies

1. INTRODUCTION

Clusters of galaxies are the largest gravitationally bound objects in the universe. They provide an ideal opportunity for studying the large-scale environment of galaxies and have provided important insights into the physics involved in the formation of both galaxies and clusters (see Sarazin 1986). Furthermore, clusters are key tracers of the large-scale structure in the universe, since their typical separation is ~ 10 Mpc[2]. This represents an efficient way of mapping the distribution of matter in the universe (e.g., Nichol et al. 1992; Guzzo et al. 1992).

The most detailed studies of clusters of galaxies, either as individual targets or mapping their distribution, have been carried out at relatively low redshifts ($z < 0.15$). This is due to the ease with which these objects can be observed. Clearly, it is important to probe the universe to higher, more cosmologically interesting, redshifts to increase the baseline over which evolutionary effects can be studied. The power of this approach was recently illustrated by the claims of strong evolution in the X-ray cluster luminosity function (Gioia et al. 1990; Henry et al. 1992). For the largest sample of X-ray clusters available prior to *ROSAT*, Henry et al. suggest that the number density of X-ray bright clusters ($\geq 10^{45}$ ergs s^{-1}) decreases rapidly as a function of lookback time, out to a redshift of 0.6. Some evidence for strong evolution has also been claimed by Edge et al. (1990) but for a much nearer sample of bright X-ray clusters ($z < 0.2$). If these results are true, they strongly suggest a hierarchical scenario of structure

formation in a high Ω_0 universe (Edge et al. 1990). Moreover, they indicate that high-redshift X-ray bright clusters are extremely rare objects and therefore, warrant detailed study since they provide us with vital information on the state of the universe at these large lookback times.

In this paper, we present the results of a search for such distant X-ray bright clusters of galaxies. The motivation behind this search was primarily to increase the number of such clusters known, thus allowing us to form the basis for a statistical sample. In addition, they would also provide important future targets for studying the universe at these earlier epochs. In § 2, we describe the methods used in finding these clusters, while in § 3 we detail the results of our search. In § 4, we discuss the consequences of our observations and other searches for high-redshift X-ray clusters.

2. OBSERVATIONS AND DATA ANALYSIS

Detecting clusters at high redshift is difficult. Optically, large areas of the sky have to be surveyed to faint limits, which is time consuming. Furthermore, the problems of phantom clusters, where field galaxies and/or groups of galaxies superposed along the line of sight give the impression of a rich cluster, become severe at these high redshifts (see Nichol 1992). In the X-rays, we are still in the early stages of X-ray survey astronomy with most of the observed distant X-ray clusters gained from either specific pointing observations, or, serendipitous discoveries. Therefore, we started a program to discover new distant X-ray bright clusters of galaxies using both unidentified extended radio sources and rich optical clusters selected from deep photographic plates as targets.

Most of the radio data used were taken from the survey of Hanish & Ulmer (1985), who surveyed an area of 3.4×10^{-3} sr

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[2] Throughout this paper, we use $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = \frac{1}{2}$.

around nearby clusters at a frequency of 1465 MHz using the VLA. Their original motivation was to identify wide-angled radio sources (WAR) with bright galaxies in the outskirts of these clusters and thus, measure the spatial extent of the hot gas. A WAR source is a classic signature of a hot intracluster medium being present, where the dynamical pressure from the supersonic motion of the radio galaxy through the medium gives rise to a characteristic U-shaped bow shock (Riley 1973). In addition to their many optically identified radio sources, they also discovered 17 faint resolved extended sources and two faint WAR sources, to a flux limit of 20 mJy, which were not identified with any object on the Palomar Observatory Sky Survey (POSS) photographic plates.

The optical data consisted of many deep photographic plates, taken in several optical bandpasses, on 10 high-latitude fields (see Kron 1980; Windhorst, Kron, & Koo 1984). Each field has an effective radius of 25', thus giving an overall survey area of 1.7×10^{-3} sr. The 10 fields were visually scanned, on F, N, and J photographic plates, individually by R. G. K., S. Majewski, and R. Dreiser, and each observer compiled a separate list of possible deep optical clusters that were seen in all colors. These lists were then merged and the richest clusters, identified by all three observers, were added to our candidate cluster list.

Table 1 lists the details of the original sample of clusters we submitted as an AO-1 proposal for observations with *ROSAT*. Also indicated in this table is the total observing time we gained with the *ROSAT* PSPC for each of these cluster candidates. Four of our targets gained enough observing time for us to search for X-ray cluster emission. These included one WAR source, two distant optical clusters, and a resolved extended radio source. Another WAR source gained 1300 s, but this was too short an integration to detect any faint X-ray emission.

The X-ray data was processed using version 2.1 of PROS on a local Sparc2 workstation. The program DETECT was used to create a list of sources for each separate pointing. This was achieved using three different cell sizes; 30", 60", and 120", with a detection threshold of 3 σ. These were then merged into a single list of objects and in the case of multiple entries, the detection in the largest cell size was used for that source. Our next major goal was to assess the extent of these sources since this is the strongest indication of cluster X-ray emission. This was not a trivial task since the point-spread function (PSF) of the *ROSAT* PSPC increased dramatically with off-axis dis-
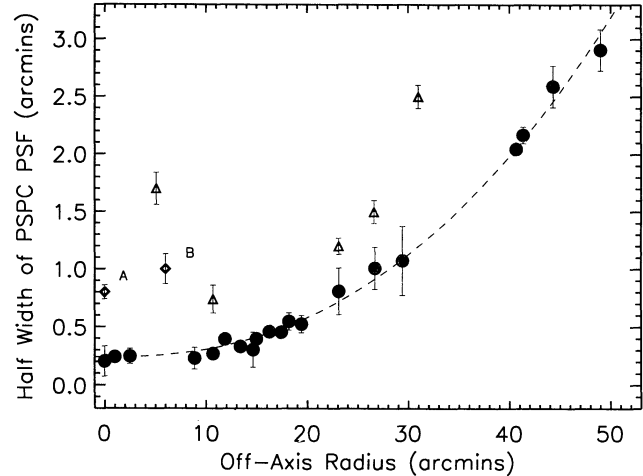

FIG. 1.—This figure shows the observed relationship between the width of the *ROSAT* PSPC PSF against off-axis angle. Filled circles (●) represent known stars used to calibrate this relationship. Error bars are plotted for all these points but some are smaller than the plotting symbol used. The best fit to this data is also shown as a dashed line (eq. 1 in the main text). The triangular symbols (△) are extended sources detected within all our PSPC pointings, while the diamond symbols (◇) are the two clusters reported in this paper. Point A is Cl 1719+49 and point B is Cl 0223−09.

tance. This was especially the case for pointing number one (Table 1), which contained two of our targets both 6' off axis.

We therefore, determined the width of the PSF for various off-axis distances using all X-ray sources positively identified in all our pointings with bright stars in the SIMBAD database (seven stars) and calibration data provided by the *ROSAT* team for the stars AR Lac and HZ 43; observed at several different positions within the PSPC (13 positions). We fit the radial profiles for these 20 stars with a Gaussian, which was the observed dominant component of the on-axis PSF gained from prelaunch tests (Hasinger et al. 1992). We assumed that the PSF was symmetrical and circular which from visual inspections of our data, was a fair representation out to large off-axis angles ($\simeq 40'$). A plot of the width of the fitted Gaussian to these stars against off-axis angle is shown in Figure 1. Also shown is a model fit to this data ($\chi^2 = 14$ for 17 d.o.f.) of the form:

$$\sigma(\text{PSF}) = (0.24 \pm 0.01) + (3.0 \pm 0.9 \times 10^{-4})R^{+2.35 \pm 0.08}, \quad (1)$$

TABLE 1

ORIGINAL CLUSTER CANDIDATE LIST SUBMITTED FOR *ROSAT* OBSERVATIONS

Pointing Number (1)	Name (2)	R.A. (J2000) (3)	Decl. (J2000) (4)	*ROSAT* Total Observation Time (5)	Radio Flux (mJy) (6)	Optical Cluster (7)
1...............	WAR1	02h23m32.7	−08°57'43"	13797	93	No
1...............	EXT1	02 23 10.0	−09 08 45	13797	39	No
2...............	DOC1	17 19 31.0	+49 59 06	33579	2*	Yes
3...............	WAR2	03 03 31.7	+41 22 33	1300	88	No
4...............	DOC2	08 49 15.1	+44 28 37	15703	...	Yes
5...............	EXT2	12 38 46.1	+03 23 20	0	32	No

NOTES.—The first two columns give the original priority and names of our targets. The names signify: WAR, wide-angled radio source; EXT, a resolved extended radio source; and DOC, a distant optical cluster. The coordinates are the observed centroids of these objects. Col. (5) is the total amount of *ROSAT* PSPC observing time gained for that specific pointing, while col. (6) gives the radio fluxes quoted by Hanish & Ulmer 1985, except for DOC1, which has a published radio source (Windhorst et al. 1984). Finally, the last column indicates whether a optical cluster was known in that direction before the *ROSAT* observations.

where $\sigma(\text{PSF})$ is the radius of the Gaussian fitted and R is the radial angle from the center of the PSPC (both in arcminutes). The zero point of this relationship agrees well with the on-axis PSF quoted by Hasinger et al. (1992) of $\simeq 0\rlap{.}'2$ over the energy passband of *ROSAT*. This model, therefore, provided us with a means of determining the extent of any object detected in our PSPC data. For each pointing, we plotted the radial fits for all detected objects and compared them with this relationship. We defined all sources that were greater than 3σ above this model as extended.

After we had determined the extent of the detected sources, their total counts were measured using an aperture on the source and either an annulus around this or a nearby area devoid of sources to determine the background. The angular size of these apertures and annulli was determined empirically and varied in size depending on the proximity of other sources. In almost all cases, the apertures were much larger than the observed angular extent of the sources and therefore, it is fair to assume that our measured source counts are close to the total X-ray flux from the object in the *ROSAT* bandpass (see below).

The measured background-corrected counts were converted to count rates using the exposure maps provided with each pointing from the *ROSAT* SASS software. For each source, the average exposure time within the same aperture described above was calculated and used instead of the total observing time given for the whole field. Finally, the hardness ratio (HR) for all detected sources was derived using the same apertures. The hardness ratio was defined as; $\text{HR} = (B - A)/(B + A)$, where B was the background subtracted counts in the range $0.07 \rightarrow 0.4$ keV and A was background subtracted counts in the range $0.4 \rightarrow 2.5$ keV. This is the same definition as used by the standard *ROSAT* SASS software.

As stated above, we are only interested in extended X-ray emission, since this is characteristic of a cluster of galaxies. The results of our search for extended emission are summarized in Figure 1; where we find seven of our detected sources are extended compared to equation (1). These sources include two of our distant cluster candidates (marked A and B), three known Abell clusters (A348, A350, A351: Abell 1958) and two large nearby galaxies seen in the $1719+49$ field. The X-ray details of the two detected distant cluster candidates are presented in Table 2 and are discussed in detail below, while the other extended sources will be presented in a subsequent paper.

3. RESULTS

We have positively detected extended X-ray emission toward two of our distant cluster candidates and the X-ray

details of these two clusters are presented in Table 2. The observed hardness ratios of our clusters can be compared to the hardness ratios of other detected objects in our *ROSAT* pointings. For example, they differ significantly ($>4\sigma$) from those of identified stars and the two nearby galaxies with extended emission mentioned above. Furthermore, the hardness ratios of our candidate clusters are consistent with the observed ratio of A348 ($z = 0.274$, HR $= 0.59$), which is detected at high signal-to-noise in our data. Finally, the hardness ratios of our candidates are inconsistent with the X-ray colors quoted by Kim, Fabbiano, & Trinchieri (1992) for active galactic nuclei.

The optical data we have obtained shows the existence of rich optical clusters of galaxies coincident with the X-ray emission. The probability of a chance coincidence of an extended X-ray source with our cluster candidates can be derived from the surface density of extended sources in our fields. Using the central $40'$ region of the PSPC, the probability of an extended X-ray source, by chance, being within $30''$ of the optical cluster is $\simeq 10^{-4}$. This distance corresponds to the largest observed uncertainty on the positions of both the optical and X-ray centroids. Therefore, these observations combined strongly suggest that we have detected extended X-ray cluster emission. We will discuss the two detected clusters individually below. We note here that we did not detect any statistically significant X-ray emission, extended or not, toward the remaining observed cluster candidates; although we did reach a flux sensitivity level of 1×10^{-14} ergs cm^{-2} s^{-1} in the hard *ROSAT* energy passband for pointing number four. We will no longer discuss this candidate since only an upper limit on the X-ray flux can be obtained.

3.1. Cl 0223−09

The centroid of the observed extended X-ray emission is only $8'$ away from the WAR source presented in Table 1 and well within the boundary of this emission.[3] To verify the existence of this cluster, we obtained a deep large-format CCD frame of this area in 1992 December with the Isaac Newton Telescope (the observations were kindly carried out by Stuart Lumsden and Tom Broadhurst). A rich cluster of galaxies is evident with its optical centroid ($\alpha = 02^h23^m32\rlap{.}^s1$ $\delta = 08°57'48''$ J2000 with an optical astrometrical uncertainty of $3''$) within $13''$ of the X-ray centroid given in Table 2. Furthermore, the WAR source quoted in Table 1 is only $4''$ (again with a $3''$

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[3] In the pointing mode, the aspect solution of the PSPC is specified to be better than $6''$, with a systematic error of $2\rlap{.}''5$. For the weakest sources, a statistical error of $7''$ is expected (UK *ROSAT* Announcement of Opportunity 1991).

TABLE 2

THE TWO CLUSTERS POSITIVELY DETECTED IN X-RAYS FROM LIST OF
CANDIDATES PRESENTED IN TABLE 1

Name (1)	R.A. (J2000) (2)	Decl. (J2000) (3)	Raw Net Counts (4)	Flux (ergs cm^{-2} s^{-1}) (5)	Luminosity (ergs s^{-1}) (6)	Hardness Ratio (7)	Observed Extent (8)	Corrected Extent (9)	$\log_{10}(N_H)$ (atoms cm^{-2}) (10)	Exposure (s) (11)
WAR1......	$02^h23^m33\rlap{.}^s0$	$-08°57'50''$	94 ± 13	9.2×10^{-14}	2.3×10^{44}	0.95 ± 0.26	$62'' \pm 7''$	$57'' \pm 9''$	20.49	13499
DOC1......	17 19 29.6	$+49$ 59 18	139 ± 16	7.3×10^{-14}	1.4×10^{44}	0.64 ± 0.10	$48'' \pm 6$	$45'' \pm 8$	20.37	30792

NOTES.—For the remaining candidates, no X-ray source was seen within $60'$ of the quoted candidate position. Col. (1) is the candidate name given in Table 1. The coordinates in cols. (2) and (3) are the X-ray centroid of the emission seen. Col. (4) presents the raw net counts, and the error, measured in the energy band $0.5 \rightarrow 2.4$ keV. Cols. (5) and (6) are the X-ray flux and luminosity calculated in the full *ROSAT* bandpass ($0.07 \rightarrow 2.5$ keV). The hardness ratios are given in col. (7). Col. (8) gives the full observed extent of the cluster, followed by the implied cluster extent after the contribution from the PSPC PSF has been removed (assuming a Gaussian profile for the cluster and PSF). The errors on these extents are also presented. Cols. (10) and (11) are the hydrogen column density from the Stark et al. 1992 data and the specific *ROSAT* exposure time gained by the object which includes the effects of vignetting.

astrometrical error) away from the brightest optical galaxy seen within the cluster region (Fig. 2 [Plate 4]). If we assume this galaxy is a cluster member, then this observation justifies our original motivation for observing unidentified WAR sources as candidate distant clusters. The optical background-corrected richness of the cluster is 51 galaxies to the limit of the CCD frame ($R \simeq 22.0$) and within a 3' radius on the optical centroid. A more robust richness estimate of Cl 0223−09 will require deeper optical observations.

We have no measured redshift for this cluster. However, using the imaging data and the fact that it is not seen on the POSS plates, we can estimate its redshift assuming little or no evolution in the cluster optical luminosity function (Scaramella et al. 1991). First, using the universal cluster luminosity function of Colless (1989) for rich optical clusters and redshifting it, with suitable K-corrections (Shanks et al. 1984), the cluster must be at a $z > 0.5$ to shift even the brightest cluster member below the plate limit ($R \simeq 20$). Second, from the CCD image of the cluster, we have estimated the magnitude of the 10th brightest member (m_{10}) to be $R \simeq 21.5$, which corresponds to an estimated redshift of 0.68; using the best available determination of the $m_{10} - z$ relationship (see Nichol 1992).

Using the estimated redshift above ($z = 0.68$), the cluster has an estimated X-ray luminosity (k-corrected) in the full passband of ROSAT ($0.07 \rightarrow 2.5$ keV) of 2.3×10^{44} ergs s^{-1} within an angular aperture of radius 4 arcminutes. As mentioned above, this is significantly larger than the observed angular extent of the cluster and corresponds to a spatial diameter of 3.8 Mpc at the estimated redshift of the cluster. This would therefore, give us nearly 90% of the cluster luminosity assuming a core radius of 0.3 Mpc and a King model with a $\beta = \frac{2}{3}$. We make no correction to the observed luminosity for the size of our aperture since the correction factor is much smaller than the overall uncertainty in the cluster redshift and gas temperature (see below).

The luminosity derived above was obtained using FIT and XFLUX within PROS using the rebinning facility to account for the small number of counts in our objects. The advantages of this procedure are that, for any given X-ray spectrum, it directly corrects for the K-correction, photoelectric absorption by the interstellar medium and the response function of the satellite. However, it does require the user to specify the form of the spectrum for the cluster. In the above calculation, the spectrum, in the rest frame of the source, was assumed to be a Raymond-Smith (R-S) thermal plasma with a temperature of 7 keV and 25% cosmic abundance of heavy elements. We recalculated its luminosity for a number of different combinations of redshift ($z = 0.4 \rightarrow 0.7$), model spectra (i.e., bremsstrahlung), temperatures (4–13 keV) and abundance of heavy elements. The range in luminosities we derived from these combinations was 9.0×10^{43} ergs s^{-1} to 3.0×10^{44} ergs s^{-1} in the ROSAT bandpass. We have not quoted statistical errors on this result simply because the potential systematic changes due to the unknown redshift and properties of our distant cluster are much greater.

3.2. Cl 1719+49

Figure 3 (Plate 5) is a photograph of the original cluster visually found by Kron and his collaborators on their KPNO prime-focus 4 m photographic plates. The centroid of the X-ray emission is shown and is 24" away from the optical centroid given in Table 1. The radio source 53W062, published by Windhorst et al. (1984), is also shown in Figure 3 and is 13"

and 34" away from the optical and X-ray centroid, respectively; as well as appearing to be coincident with a galaxy within the cluster.

This cluster has a measured redshift of $z = 0.61$, based on unpublished Cryogenic Camera observations of three galaxies that are likely to be cluster members, plus the published radio source 53W062 (Windhorst, Kron, & Koo 1984). Hamilton (1985) observed another galaxy at the same redshift within the same region. Using a RS model as above for the X-ray spectrum, this cluster has an X-ray luminosity of 1.4×10^{44} ergs s^{-1} in the ROSAT passband and within an angular aperture of radius 3'.5. The luminosity of this cluster changed by less than 5% for different combinations of model spectra and temperatures as discussed above for Cl 0223−09. No correction has been made for the finite size of the detection aperture since it is once again large compared to the observed extent of the cluster.

This cluster has a background-corrected count of 32 galaxies within the magnitude range $19 < I < 21$ and a radius of 3'. This corresponds to an absolute magnitude range of $M^* - 2$ to M^* and a projected area of 6 Mpc^2 around the cluster centroid. In comparison, Coma has only eight cluster members within this magnitude range and area (Thompson & Gregory 1980), thus suggesting, if we assume no significant evolution of the optical cluster luminosity function, that Cl 1719+49 is a very rich optical cluster.

4. DISCUSSION

The original targets shown in Table 1 represent the most likely candidates, based either on their galaxy richness or the presence of a WAR source, for being the most luminous X-ray clusters in our optical and radio survey regions. Despite this, the X-ray luminosities of our two clusters are consistent with the mean observed luminosity of nearby X-ray clusters (Kowalski et al. 1984). To extend this analysis further and place constraints on the luminosity function of high redshift X-ray bright clusters would require detailed knowledge of our obviously complicated selection function (i.e., what fraction of X-ray bright clusters do not possess a WAR source and is this a function of luminosity?). Furthermore, there are still other X-ray cluster candidates in our optical and radio survey regions that have not been observed in X-rays. This therefore, greatly hinders us from accurately determining our observed number density of distant X-ray clusters, however, our search for X-ray luminous distant clusters is qualitatively consistent with the scenario advocated by Henry et al. (1992). They suggest that the number density of bright X-ray clusters decreases with lookback time, and we have surveyed $\simeq 16$ degrees^2 to faint flux limits in the optical and radio passbands but have yet to discover any distant X-ray bright clusters ($L_x \geq 10^{45}$ ergs s^{-1}).

We can compare our result with other recent searches for X-ray emission from distant clusters of galaxies and combine these data to obtain more stringent constraints. For example, Castander et al. (1994) has published the findings of their search for X-ray luminous clusters from the Gunn, Hoessel, & Oke (1986) sample of distant optical clusters. They selected the six highest redshift clusters from this database ($z \sim 0.5 \rightarrow 0.9$) for observation with the ROSAT PSPC. Their results are in good agreement with ours in that they only find statistically significant X-ray emission from three of their clusters; all of which have a X-ray luminosity of $\simeq 10^{44}$ ergs s^{-1} in the ROSAT bandpass.
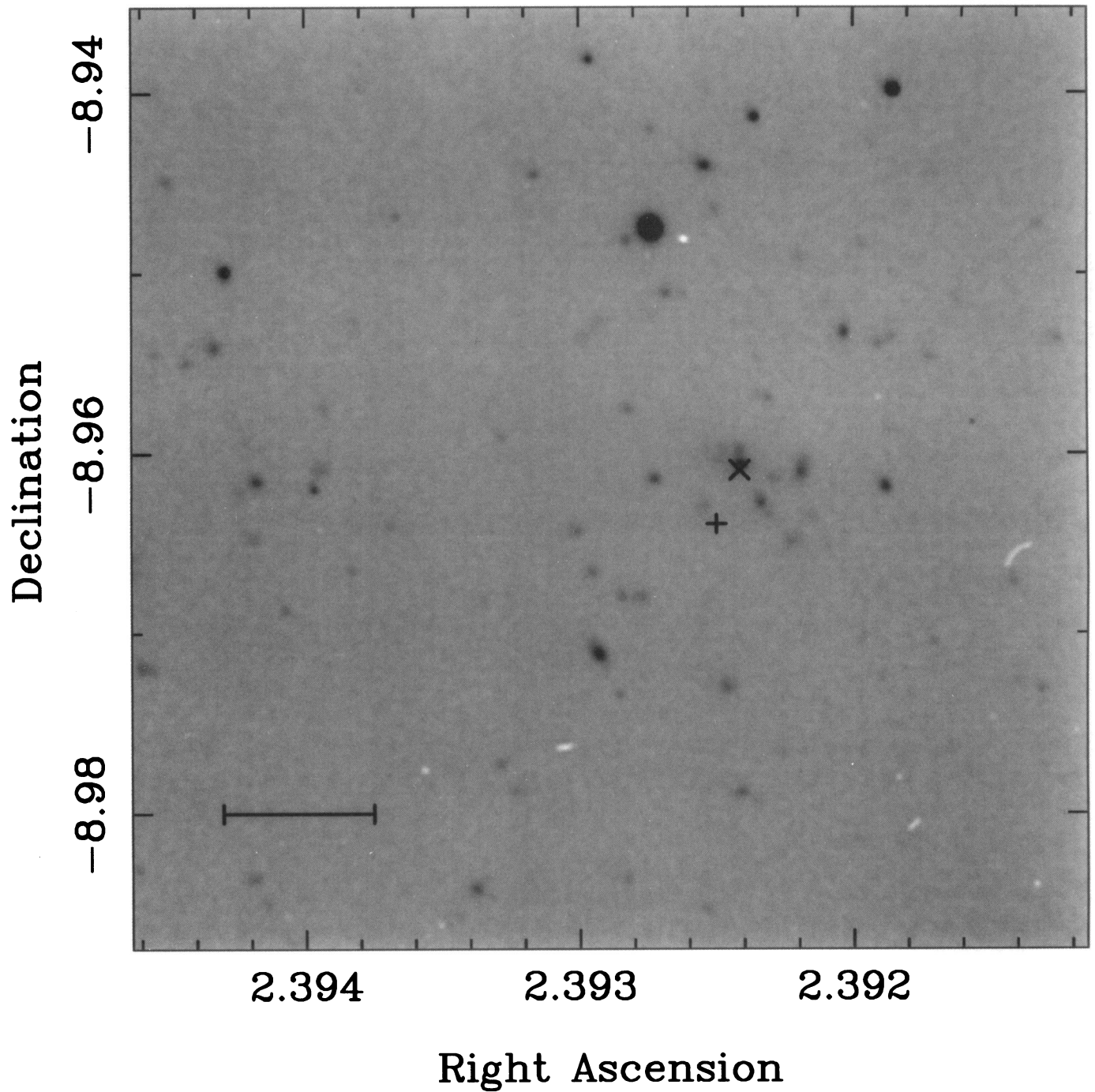
PLATE 4

FIG. 2.—This is a deep CCD image taken in 1992 December of cluster Cl 0223−09. The size of the image shown is 3 arcminutes square and reaches a limiting magnitude of $R \simeq 22.0$. A rich cluster of galaxies is evident near both the X-ray centroid (+) and the wide-angled radio source (×). The bar shown represents 30″.
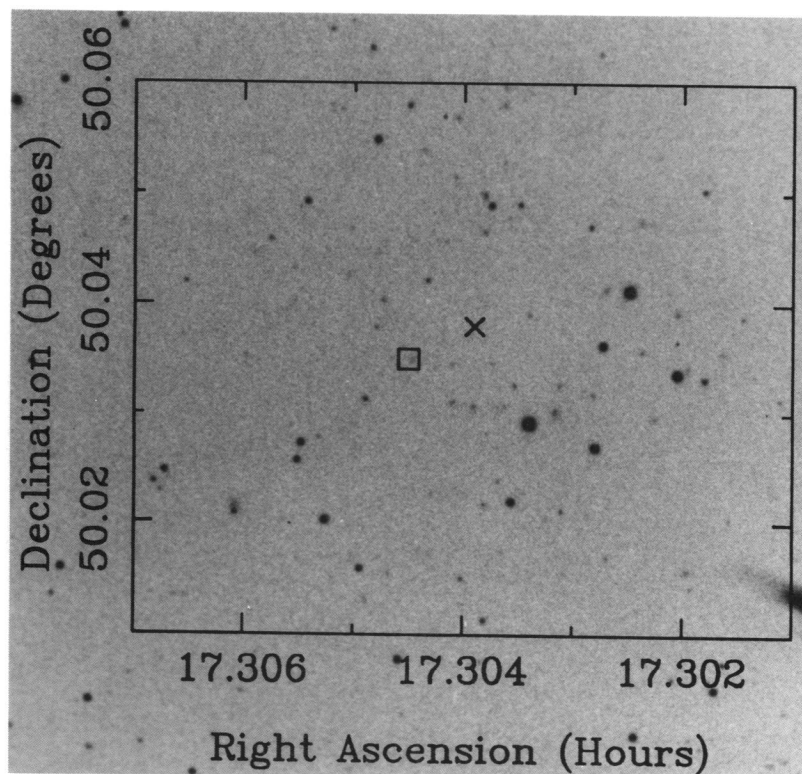
NICHOL et al. (see 432, 467)

PLATE 5

FIG. 3.—This is a photograph of the distant optical cluster originally discovered by Richard Kron and his collaborators. The whole region shown is 11′ by 7′ taken from the *N*-band photographic plate. The X-ray centroid (×) and radio source 53W062 (□) are marked and are clearly coincident with the rich optical cluster.

NICHOL et al. (see 432, 467)

Therefore, combining the Castander et al. data and ours, we have positive detections of five clusters in the redshift shell $z = 0.6 \rightarrow 0.9$ with an X-ray luminosity of $\simeq 10^{44}$ ergs s^{-1} in the *ROSAT* bandpass. The maximum possible volume surveyed by the two independent searches (assuming a flat selection function and no evolution) can be obtained by integrating the formula;

$$\frac{dV}{dz} = 4 \, d\Omega \left(\frac{c}{H_0}\right)^3 \frac{(z - \sqrt{1 + z} + 1)^2}{(1 + z)^{7/2}}, \qquad (2)$$

($q_0 = \frac{1}{2}$; Kolb & Turner 1990) over the entire redshift shell ($z = 0.6 \rightarrow 0.9$) of our searches, with $d\Omega$ being the total area covered by the two surveys (6.2×10^{-3} sr). This, therefore, implies an absolute lower limit of 1.2×10^{-7} Mpc^{-3} to the number density of such clusters.

This lower limit provides an important normalization for future models of structure formation since it is a direct observation of the underlying mass distribution at these high redshifts, which then evolves to form the nearby structures. This is illustrated in the simulations of Frenk et al. (1990) where the number density of clusters in a standard cold dark matter (hereafter CDM; Davis et al. 1985) universe drops by an order of magnitude between now and a redshift of $z = 0.7$. The lower limit quoted above is consistent with the predicted abundance of our clusters at a $z = 0.7$ in this CDM model ($b = 2$; Frenk et al. 1990, Castander et al. 1994). However, as discussed above, this is the absolute lower limit on the abundance of such clusters and if future observations uncover yet more clusters at these high redshifts with similar X-ray luminosities, this would provide strong evidence for a lowering of the biasing parameter for CDM models; which has already been advocated by other authors from observations of distant clusters (i.e., Evrard 1989).

In addition to the observed number density of distant clusters, detailed study of such systems at high redshift is vital to our understanding of the state of the universe at these large lookback time. For example, the galaxy population of Cl 1719+49 appears red similar to that observed for the famous Cl 0016+16 cluster. A detailed analysis, similar to that performed by Butcher & Oemler (1984), puts the blue fraction (f_B) of the cluster at $f_B = 0.25 \pm 0.24$. This large error is primarily due to the F photographic plate not being deep enough to give a well determined f_B. However, if subsequent photometric studies of this cluster verify our qualitative assessment of the color of Cl 1719+49 it is important to understand such red clusters at high redshift, since they conflict with the scenario advocated by Butcher & Oemler (1984); i.e., the fraction of blue galaxies in clusters increases substantially with lookback time. Furthermore, it is imperative to study known X-ray distant clusters as the relationship between the X-ray–emitting gas and the Butcher-Oemler effect still remains relatively unknown (see Wang & Stocke 1993). Clearly, as the number of known clusters at high redshift increases we will be able to create statistical samples of such objects which will then provide us with important insights into the nature of the universe at these significant lookback times.

REFERENCES

Abell, G. O. 1958, ApJS, 3, 211
Butcher, H., & Oemler, A. 1984, ApJ, 285, 426
Castander, F. J., Ellis, R. S., Frenk, C. S., Dressler, A., & Gunn, J. E. 1994, ApJ, 424, L79
Colless, M. 1989, MNRAS, 237, 799
Davis, M., Efstathiou, G., Frenk, C. S., & White, S. D. M. 1985, ApJ, 292, 371
Edge, A. C., Stewart, G. C., Fabian, A. C., & Arnaud, K. A. 1990, MNRAS, 245, 559
Evrard, A. E. 1989, ApJ, 341, L71
Frenk, C. S., White, S. D. M., Efstathiou, G., & Davis, M. 1990, ApJ, 351, 10
Gioia, L., Henry, J. P., Maccacaro, T., Morris, S. L., Stocke, J., & Wolter, A. 1990, ApJ, 356, L35
Gunn, J. E., Hoessel, J., & Oke, J. B. 1986, ApJ, 306, 30
Guzzo, L., Collins, C. A., Nichol, R. C., & Lumsden, S. L. 1992, ApJ, 393, L5
Hamilton, D. 1985, ApJ, 297, 371
Hanish, R. J., & Ulmer, M. P. 1985, AJ, 90, 1407
Hasinger, G., Jan Turner, T., George, I. M., & Boese, G. 1992, ROSAT Calibration Memo
Henry, J. P., Gioia, L., Maccacaro, T., Morris, S. L., Stocke, J., & Wolter, A. 1992, ApJ, 386, 408

Kim, D. W., Fabbiano, G., & Trinchieri, G. 1992, ApJS, 80, 32
Kolb, E. W., & Turner, M. S. 1990, The Early Universe (Redwood City, CA: Addison-Wesley)
Kowalski, M. P., Ulmer, M. P., Cruddace, R. G., & Wood, K. S. 1984, ApJS, 56, 403
Kron, R. G. 1980, ApJS, 43, 303
Nichol, R. C. 1992, Ph.D. thesis, University of Edinburgh
Nichol, R. C., Collins, C. A., Guzzo, L., & Lumsden, S. L. 1992, MNRAS, 255, 21p
Riley, R. 1973, MNRAS, 156, 252
Sarazin, C. L. 1986, Rev. Mod. Phys., 58, 1
Scaramella, R., Zamorani, G., Vettolani, G., & Chincarini, G. 1991, ApJ, 101, 342
Shanks, T., Stevenson, P. R. F., Fong, R., & MacGillivray, H. T. 1984, MNRAS, 206, 767
Stark, A. A., Gammie, C. F., Wilson, R. W., Balley, J., Linke, R. A., Heiles, C., & Hurwity, M. 1992, ApJS, 79, 77
Thompson, L. A., & Gregory, S. A. 1980, ApJ, 242, 1
Wang, Q., & Stocke, J. T. 1993, ApJ, 408, 71
Windhorst, R., et al. 1984, A&AS, 39, 58

Note added in proof.—We recently measured the redshift for 3 galaxies in the direction of cluster Cl 0223−09 using the Mayall 4 m telescope at Kitt Peak. The mean redshift observed was $z = 0.41$, which is significantly different from the estimated redshift of this cluster quoted in this paper.