Another X-ray–Discovered Poor Cluster of Galaxies Associated with CL 0016+16[1]

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ABSTRACT

We report optical spectroscopic observations of RX J0018.8+1602, a *ROSAT* X-ray source proposed to be a intermediate redshift cluster of galaxies. Our observations confirm the identification of RX J0018.8+1602 and provide measurements of its mean radial velocity ($z = 0.5406 \pm 0.0006$) and velocity dispersion ($\sigma_p = 180^{+620}_{-180}$ km s^{-1}). This is the second poor cluster that has been found to be a companion to CL 0016+16 ($z = 0.5455$), the other one being RX J0018.3+1618 ($z = 0.5506$). The 0.2–2 keV band source-frame X-ray luminosity summed over both companion clusters is 5×10^{44} ergs s^{-1}, which is a significant fraction $\sim$23% of the X-ray luminosity of the main cluster. The companions are located at angular distances of $10'$ to $25'$ (minimum physical scales of 5 Mpc to 12 Mpc) from CL 0016+16 and we propose that they represent a new large-scale component of the X-ray emission from clusters of galaxies. Similar low X-ray luminosity poor clusters surrounding nearby Abell clusters can explain the excess power observed in the angular cross-correlation function between Abell clusters and the X-ray background on inferred physical scales of 14–20 Mpc (Soltan et al. 1996).

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[1]Optical observations reported here were obtained at the Multiple Mirror Telescope, a joint facility of the Smithsonian Institution and the University of Arizona.

1. Introduction

In this article, we continue our studies of the environment of the moderately distant ($z = 0.5455$) rich cluster of galaxies CL 0016+16. This cluster was the prime target of a deep (43 ks) *ROSAT* X-ray pointing specifically intended for use in interpreting the Sunyaev-Zel'dovich effect (Hughes & Birkinshaw 1997). We have been following-up selected serendipitous sources in the imaging data (there are ∼80 field sources detected by the *ROSAT* standard processing) in order to investigate the large scale structure or supercluster believed to exist near CL 0016+16 (Koo 1981, 1986; Connolly et al. 1996). The length of the observation, plus the high sensitivity of the *ROSAT* position sensitive proportional counter (PSPC), offsets to some extent the low source fluxes of objects at these redshift. On the other hand the large redshift provides a clear advantage for studying structure: the roughly 1° field of view of the PSPC corresponds to large physical scales at the cluster's redshift: 30 Mpc or so.

Results to date corroborate the approach of using X-ray–selection to probe large scale structure. In a previous study (Hughes, Birkinshaw, & Huchra 1995) we reported the discovery, based on the *ROSAT* data, of a poor cluster, RX J0018.3+1618, some $9\overset{'}{.}5$ (4.6 Mpc) from CL 0016+16, which our optical spectroscopy revealed to be at very nearly the same redshift. Below we present new optical observations of a second X-ray source in this field, RX J0018.8+1602, which has been proposed as yet another galaxy cluster at roughly the same redshift (Connolly et al. 1996). Our observations confirm the identification of RX J0018.8+1602 as a galaxy cluster and provide the first accurate measurements of its redshift and velocity dispersion. It is indeed another companion to CL 0016+16, located ∼25′ (12 Mpc) nearly due south of the main cluster.

We consider the existence of these two companions to CL 0016+16 in light of the recently discovered extended, low surface brightness X-ray "halos" apparently associated with Abell clusters of galaxies (Soltan et al. 1996). The evidence for these X-ray halos comes from a cross-correlation between the positions of Abell clusters and the X-ray background as measured by the *ROSAT* All-Sky Survey (RASS), which was found to show significant amplitude on angular scales of $3\overset{\circ}{.}4$ for a cluster sample with mean redshift $\langle z\rangle = 0.063$ and on $1\overset{\circ}{.}3$ scales for a more distant, $\langle z\rangle = 0.128$, sample. Abell clusters are known to be highly clustered (see Nichol, Briel, & Henry 1994 and references therein) and are strong X-ray emitters, nevertheless the signal detected by Soltan et al. is a factor of three larger than the correlation function predicted from the known clustering properties of Abell clusters themselves, signifying that an additional, new component of sources, spatially correlated with Abell clusters, and displaying soft X-ray emission is required. The X-ray luminosities of the extended component in the two samples were 9.9×10^{43} ergs s^{-1} and 1.4×10^{44} ergs

s^{-1}, respectively. Soltan et al. offered two explanations for the halos: X-ray emission from either (1) a number of discrete sources associated with groups or poor clusters, or (2) a truly diffuse component of hot gas extended over tens of Megaparsecs. As we show below, the locations of the new clusters relative to CL 0016+16 and their X-ray luminosities and temperatures are broadly consistent with what is needed to explain the correlation function results in terms of discrete sources. We also remind the reader of several known pairs of clusters at low redshift that may represent other examples of this structure. The Perseus/AWM 7 system, in particular, may be a low redshift analog to the intermediate redshift CL 0016+16 system.

2. Observations

2.1. X-ray

We used the reprocessed (REV2) data from the 43 ks *ROSAT* PSPC observation of CL 0016+16 to study the X-ray properties of the proposed new cluster, RX J0018.8+1602. First we checked the accuracy of the attitude determination for the field using the optical positions for the same sources as in our earlier study (Hughes et al. 1995). In the case of the new REV2 data it was found that no boresight correction was necessary, since the agreement in X-ray and optical positions was better than $2''$.

RX J0018.8+1602 is approximately $25'$ off-axis, where the imaging resolution of the PSPC has a broad core ($\sim 2'$ FWHM) due to the off-axis aberrations of the *ROSAT* X-ray mirrors. This makes detailed analysis of the spatial structure difficult. Another complication arises from the presence of a second X-ray source about $3'$ to the southwest. Both sources can be seen clearly in Figure 1 (Plate L00) where the contour map shows the X-ray data.

We fit the X-ray imaging data within a $4'$ radius of RX J0018.8+1602 using a model consisting of background, a point source, and a cluster profile of the form $\Sigma = \Sigma_0[1 + (\theta/\theta_C)^2]^{-3\beta+0.5}$, which is commonly referred to as the isothermal-β model for galaxy clusters (Cavaliere & Fusco-Femiano 1976). For background we used the background image provided as part of the standard processing. The data strongly require, at about the 3-σ level, that the northern source be extended. However, the core radius parameter in the cluster model, θ_C is not well-constrained by the data due to the large image blur at the source's off-axis position. We choose to fix θ_C to the value $0\rlap{.}'44$ as found earlier for RX J0018.3+1618 (Hughes et al. 1995), the other companion cluster to CL 0016+16. In this case the central surface brightness and β of the candidate new cluster were found to be $\Sigma_0 \approx 1.1 \times 10^{-2}$ counts s^{-1} $arcmin^{-2}$ and $\beta \approx 0.75$. The position of the center of the isothermal-β model (from maximum likelihood fits to the image) is $00^h18^m47.9^s$, $16°02'22''$ (J2000) with an uncertainty of about $5''$ in each coordinate. In the spectral analysis presented next, we were careful to select the spectral extraction regions so that the X-ray emission from the two sources was kept separate.

The point-like X-ray source to the south has a count rate (within a radius of $1\farcm5$) of $(5.8 \pm 0.6) \times 10^{-3}$ PSPC counts s^{-1}. Although there are too few counts ($\lesssim 200$) to do a detailed spectral analysis, the hardness ratios are consistent with a low column density ($N_{\rm H} \lesssim 10^{19}$ cm^{-2}) and a spectrum that cuts-off above $\sim$1 keV, similar to that expected from a Galactic star. The unabsorbed X-ray flux is $\sim 3.3 \times 10^{-14}$ ergs cm^{-2} s^{-1}.

The northern source, i.e., the cluster candidate, has an observed count rate (within a radius of $1\farcm8$) of $(9.4 \pm 0.8) \times 10^{-3}$ PSPC counts s^{-1} based on a total of approximately 310 counts. The spectrum can be fit well by a thermal plasma model using the Galactic column density ($N_{\rm H} = 4.1 \times 10^{20}$ cm^{-2}) and fractional elemental abundances of 0.25 times cosmic values. Anticipating the results in §2.3 below, we set the redshift to 0.5406 and obtained a best-fit source-frame temperature of $kT = 1.4^{+0.7}_{-0.3}$ keV (1 σ uncertainty), in good agreement with Connolly et al. (1996). The unabsorbed X-ray flux is 1.5×10^{-13} ergs cm^{-2} s^{-1} over the 0.2–2 keV band.

2.2. Optical Imaging

The candidate cluster was observed at the Whipple Observatory 1.2-m telescope on 1996 July 17 under nonideal conditions. The focal plane detector (the so-called "AndyCam", a thinned, back-side illuminated, AR coated Loral 2048×2048 CCD) was binned to produce an effective pixel scale of $0\farcs64$. Three 600 s exposures in R were taken. Using standard IRAF tasks, we bias-subtracted the data, eliminated cosmic rays and bad pixels, and flat-fielded using dome flats. The positions of four *HST* guide stars were used to register the image to the celestial sphere; a positional uncertainty of $\lesssim 0\farcs5$ was obtained. Stellar images were about $1\farcs8$ [FWHM], which is not unusual for this telescope.

Figure 1 (Plate L00) shows a portion of the R-band image with contours of X-ray emission superposed. Numerous faint galaxies are associated with the diffuse X-ray emission, with a dominant bright galaxy (labeled 4) within $7''$ of the center of the X-ray emission. Toward the south there is a bright ($m_V = 8.6$) star (HD 1450) of spectral type F5 which is positionally coincident with the southern X-ray source. Using the flux quoted above, we estimate an X-ray to optical flux ratio for the star of $\log f_X/f_V \sim -4.7$ (using the relationship in Stocke et al. 1991), which is in the range expected for Galactic stars of spectral type B-F. We conclude that HD 1450 is the likely counterpart to the southern X-ray source.

DAOPHOT was run on the frame to detect objects and of order 300 were found. We used the sharpness parameter to discriminate between star and galaxies. There were 22 extended galaxy-like objects within $1\overset{'}{.}6$ of the central galaxy. Due to constraints associated with the aperture plate layouts, we were able to reserve slitlets for only 17 of these. Four additional objects that were within the $1\overset{'}{.}6$ radius but fell below the sharpness cutoff were included to fill otherwise blank positions. Finally, there were seven objects that passed the sharpness criteria but lay beyond a radius of $1\overset{'}{.}6$ from the central galaxy.

2.3. Optical Spectroscopy

We obtained optical spectra at the Multiple Mirror Telescope on 1996 November 12 and 13 using the Red Channel with aperture plates (Fabricant, McClintock, & Bautz 1991). Four aperture plates were machined several weeks before the run with slitlets (each $1\overset{''}{.}5 \times 22''$) cut for seven objects on each plate, and additional blocked slitlets were used for alignment on bright stars. The detector was a Loral 1200×800 CCD binned by 2 on the chip in the spatial (smaller) direction (for a scale of $\sim 0\overset{''}{.}6$ pixel^{-1}). We observed using a 270 line mm^{-1} grating blazed at 7300 Å, which provided a spectral resolution of $\sim$15 Å (FWHM) and a dispersion of 3.6 Å pixel^{-1}. All of the spectra included the wavelength range 5500 – 8500 Å.

The conditions were none too good when we started and they got progressively worse. On November 12, the first plate was exposed four times for 2700 s each and the second plate was exposed three times for the same duration. On the second night the weather had degraded to hazy and partly cloudy conditions. We exposed the third plate five times for 2700 s each and then the final plate was exposed twice for 2700 s of which only the initial frame was useful. He-Ne-Ar lamp exposures were done before and after each exposure and dome flats were done at the beginning or end of the night.

Standard IRAF routines were used for the data reduction. Cosmic rays were identified and removed through a comparison of frames. The bias level was subtracted and flat fields were applied. Task APEXTRACT was used to trace and extract the one-dimensional spectra. Wavelength calibration used $\sim$45 lines from the comparison lamp spectra fit to a cubic spline (root-mean-square residuals were $\sim$1.0 Å). We verified the wavelength of the 6300.2 Å night sky line in our spectra when the data were extracted without sky subtraction. Differences were ∼1 Å and our derived redshifts were corrected for this shift ($\Delta z \sim 0.0002$). Data from the separate frames were summed after wavelength calibration. To derive recessional velocities our reduced spectra were cross-correlated (task FXCOR) over the observed wavelength range 5600–7500 Å with a spectrum of the galaxy NGC 4486B redshifted to $z = 0.55$.

The spectrum of the bright central galaxy (# 4) is shown in Figure 2. The 4000 Å break, as well as absorption features due to Ca II H and K, the G-band, and Mg_2, are all clearly visible. Our redshift $z = 0.5413 \pm 0.0007$ is consistent with the recent value of 0.541 ± 0.004 presented by Connolly et al. (1997). Strong correlations ($R > 4.0$) were obtained for all the 15 galaxies listed in Table 1, which turn out to be all absorption line objects. We point out object g in the table, which is the radio galaxy 54W084 (Windhorst, Koo, & Kron 1984). Connolly et al. (1996) quote a redshift of $z = 0.544$ for this galaxy (the original source being a private communication from R. Windhorst). In a separate communication, R. Windhorst claims that this value is not highly accurate (having been estimated at the telescope from night sky lines and comparison arcs) and thus should not be judged inconsistent with our measurement.

We were unable to identify or determine redshifts for the remaining 13 objects on the various plates. Our "success" rate was highly correlated with the weather conditions. On the first night 10 out of 14 of our observed spectra resulted in redshift measurements, while on the second night only 5 out of 14 did. Of the 21 objects observed within 1.′6 of the cluster center, 12 were identified as galaxies and 8 are members of the cluster. On the other hand, all of the identified galaxies beyond 1.′4 have radial velocities that are inconsistent with cluster membership.

Now a few words about our quoted uncertainties. The formal velocity uncertainties generated by FXCOR from the width of the correlation function vary from galaxy to galaxy over the range 100 km s^{-1} to 250 km s^{-1}. We also include an estimate of the velocity uncertainty due to sky subtraction, obtained by carrying out the reduction twice using slightly different parameters of the fitting function for the sky and taking the difference between the resulting redshift values as the additional uncertainty. In general this quantity is comparable in magnitude to the previous uncertainty; we find values ranging from 80 km s^{-1} up to 330 km s^{-1}. We also include an uncertainty of 60 km s^{-1} due to wavelength calibration and an uncertainty of 90 km s^{-1}, due to variation of the parameters of the cross-correlation, e.g., the order of the continuum fits and the wavelength range over which the cross-correlation was done. The final uncertainty quoted in Table 1 is the root-sum-square of the individual components.

3. Discussion

The mean redshift of the new cluster based on the eight galaxies indicated as members in Table 1 is 0.5406 ± 0.0006 and the radial component of its velocity dispersion is 180^{+620}_{-180} km s^{-1} (1 σ uncertainties), calculated using the formulae in Danese, De Zotti, & di Tullio (1980). Although galaxies b, f, and g in the lower part of the table have redshifts near 0.5, they are unlikely to be members of the cluster because they lie at the outskirts of the cluster (more than $1\farcm5$ from the central galaxy), and their redshifts are more than 8 σ away from the mean of the cluster. They are possibly related to the sheet of galaxies identified by Connolly et al. (1996).

The X-ray luminosity of RX J0018.8+1602 is 3×10^{44} ergs s^{-1} over the 0.2–2 keV band in the source frame. From the measured temperature, the imaging results, and the standard assumption of a symmetric, isothermal cluster in hydrostatic equilibrium, we estimate the cluster's mass within a 2 Mpc radius to be 3×10^{14} $M_{\odot}$. The ratio of gas mass to total mass within this same radius is 33%. These values are similar to those of the other poor cluster, RX J0018.3+1618 (Hughes et al. 1995) associated with CL 0016+16 and in Table 2 we present a comparison between the observed and physical characteristics of the two new clusters. (Note that the temperature of RX J0018.3+1618 was determined for this article from a joint fit of *ROSAT* PSPC and *ASCA* GIS data.) The luminosity of CL 0016+16 is 2×10^{45} ergs s^{-1}, which is 4 times the combined X-ray emission from the companions.

Energy considerations were used by Hughes et al. (1995) to show that CL 0016+16 and RX J0018.3+1618 were not unlikely to form a bound system: on the assumption of random projections of the separation vector and relative velocity vector of these clusters, and using the mass estimates out to radii of 2 Mpc, the *a priori* probability that these two clusters form a bound system is about 38%. We have repeated this calculation taking into account the extra kinetic and potential energies contributed by RX J0018.8+1602. The *a priori* probability that all three clusters form a bound system can be shown to be about 11%. This is smaller than previously calculated, because RX J0018.8+1602 contributes less to the potential than the kinetic energy — it is rapidly moving relative to and distant from the center of mass of the composite system for most choices of projection angles. If CL 0016+16 is taken, instead, to have a radius of 5 Mpc, then the mass increases by a factor 2.5 and the probability that the entire system is bound rises to about 30%. These *a priori* probability estimates are likely to be pessimistic about the chances that the overall system is bound, since they ignore the indications of further clumped masses in the field of CL 0016+16 (based on optical material: Connolly et al. 1996).

If we assume that the projection angles of the companion clusters relative to CL 0016+16 are less than 60° (i.e., the three clusters lie within a sphere of radius ∼25

Mpc centered on CL 0016+16), then a conservative lower limit to the local space density of clusters is $N \sim 5 \times 10^{-5}$ Mpc^{-3}. This is 2 orders of magnitude larger than the space density of Abell clusters with $L_X \gtrsim 2 \times 10^{44}$ ergs s^{-1} from a complete sample of clusters over several hundred square degrees at high Galactic latitude (Briel & Henry 1993).

Notwithstanding this large local space density of clusters, it is our opinion that the CL 0016+16 system is not particularly exceptional but may merely represent an intermediate redshift example of essentially similar nearby systems. We offer two pieces of evidence in support of this. One is the high frequency of pairs observed in the X-ray flux-limited sample of low redshift ($z < 0.2$) clusters from Lahav et al. (1989). The other is the presence of extended, low surface brightness X-ray haloes associated with Abell clusters mentioned in the Introduction. We discuss each of these below.

Out of the roughly 50 clusters in their all-sky compilation of the brightest X-ray clusters, Lahav et al. (1989) find 5 close pairs with physical separations of 20 Mpc or less: A401/A399, Perseus/AWM7, A754/Hydra A, A3558/A3562, and A2052/A2063. The X-ray luminosities of the pairs (corrected to correspond to the 0.2–2 keV band) vary from being nearly equal (A2052/A2063 and A3558/A3562) to differing by a factor of 1.6 (A754/Hydra A and A401/A399) to differing by as much as a factor of ∼7 (Perseus/AWM7). The latter example is particularly instructive. The 0.2–2 keV band luminosities of Perseus and AWM7 are 8.8×10^{44} erg s^{-1} and 1.3×10^{44} erg s^{-1} and their mean gas temperatures are 5.5 keV and 3.6 keV (Edge et al. 1990). AWM7 is some $4^\circ\!.7$ away from Perseus for a projected linear separation of 8.6 Mpc and the difference in redshift, if interpreted as being due purely to the Hubble flow, suggests a radial separation of 6.2 Mpc. In almost all respects then, the Perseus/AWM7 system bears a remarkable resemblance to the CL 0016+16/RX J0018.3+1618 system. Whether additional unidentified poor clusters await detection in the Perseus/AWM7 system is an open question. It is unlikely that a cluster similar to AWM7, which has a 2–10 keV X-ray flux of $f_X \sim 10^{-10}$ erg cm^{-1} s^{-1} and a luminous central cD galaxy, could have been missed. On the other hand, a poor cluster that lacks a central cD (like the two near CL 0016+16) with a temperature of ∼1 keV and a corresponding luminosity $L_X \sim 10^{43}$ ergs s^{-1} might have escaped identification.

The second piece of evidence for structure on ten Megaparsec scales associated with nearby clusters of galaxies comes from a cross-correlation between the angular positions of Abell clusters and the intensity of the soft X-ray background as measured by *ROSAT* (Soltan et al. 1996). To explain their cross-correlation results Soltan et al. need a new component of X-ray emission from structure on scales 20–30 times larger than the size of the cluster itself, or physical scales of 18–23 Mpc. The spectral character of the emission needs to be softer than the X-ray background in general, due to limits set by the *Ginga* satellite over the higher energy 4–12 keV band (from the auto-correlation function of the X-ray background, Carrera et al. 1991, 1993). Sources with little emission above $\sim$4 keV are required and thermal spectra with $kT \lesssim 5$ keV would be consistent with this limit. And as mentioned in the Introduction the mean luminosity of the extended component is $L_X \sim 10^{44}$ ergs s^{-1}.

In all direct observational aspects: spatial scale, low X-ray temperature, and soft X-ray luminosity, the companion clusters to CL 0016+16 satisfy the observational requirements demanded of the extended halo emission component. Our results therefore strongly suggest that the origin of the extended halos around Abell clusters can now be explained as arising from physically associated discrete sources, specifically poor clusters or groups of galaxies, rather than a truly diffuse extended halo of hot gas.

Although the case of CL 0016+16 is compelling, clearly other examples of this phenomenon, particularly at lower redshift, need to be found. Following-up X-ray–detected sources in the vicinity of known galaxy clusters from the RASS is probably the best approach to further research in this area. It is essential that a range of luminosities for the main cluster be sampled in order to investigate effects of system richness on the properties of the companions. CL 0016+16 is a very rich, massive cluster, which, some may argue, makes it and its companions unique and therefore inappropriate to use as a paradigm for explaining the correlation function results. Along this line of argument we note that the ratio of L_X between CL 0016+16 and its companions is much larger ($\sim$4) than the ratio indicated by the cross-correlation results. There the extended component emission is dominant: the main cluster L_X is merely 0.4–0.6 times that of the extended component. However, the luminosities of the CL 0016+16 companions ($2 - 3 \times 10^{44}$ erg s^{-1}) are not exceptional when compared to the luminosities of the weaker member of the cluster pairs mentioned above, which vary over $1 - 6 \times 10^{44}$ erg s^{-1}. Thus the high ratio of main to extended cluster L_X in the CL 0016+16 system is due to the exceptional luminosity of its main cluster and not to a deficiency in its companions. This may indicate that the L_X distribution of the poor clusters that make up the halo emission is quite different from the L_X distribution of Abell clusters.

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Table 1. Spectroscopic Results

n	Position (J2000) α	Position (J2000) δ	z
	RX J0018.8+1602 Cluster Members		
1	$0^h18^m52.9^s$	$16°02'08''$	0.5392 ± 0.0007
2	50.7^s	$01'42''$	0.5419 ± 0.0007
3	48.2^s	$03'10''$	0.5384 ± 0.0007
4	47.7^s	$02'15''$	0.5413 ± 0.0007
5	47.3^s	$02'19''$	0.5416 ± 0.0010
6	45.8^s	$02'09''$	0.5396 ± 0.0012
7	43.9^s	$02'16''$	0.5418 ± 0.0008
8	42.0^s	$01'59''$	0.5406 ± 0.0009
	Probable Non-members		
a	$0^h18^m57.7^s$	$16°01'37''$	0.1594 ± 0.0006
b	55.5^s	$02'12''$	0.5509 ± 0.0007
c	46.7^s	$02'41''$	0.3864 ± 0.0007
d	45.8^s	$01'29''$	0.6243 ± 0.0009
e	45.2^s	$00'49''$	0.2097 ± 0.0006
f	43.8^s	$03'46''$	0.5484 ± 0.0010
g[a]	41.4^s	$02'10''$	0.5491 ± 0.0012

[a]Radio galaxy 54W084 (Windhorst, Koo, & Kron 1984)

Table 2. Clusters Associated with CL 0016+16 [a]

Parameter	RX J0018.3+1618	RX J0018.8+1602
z	0.5506 ± 0.0012	0.5406 ± 0.0006
σ_P (km s^{-1})	540^{+260}_{-120}	180^{+620}_{-180}
kT (keV)	$3.1^{+2.8}_{-1.4}$	$1.4^{+0.7}_{-0.3}$
F_X[b] (erg cm^{-2} s^{-1})	1.1×10^{-13}	1.5×10^{-13}
L_X[c] (erg s^{-1})	2×10^{44}	3×10^{44}
$M_{\rm gas}(< 2\,{\rm Mpc})$ $(M_\odot)$	9×10^{13}	1×10^{14}
$M_{\rm tot}(< 2\,{\rm Mpc})$ $(M_\odot)$	5×10^{14}	2×10^{14}
Distance from CL 0016+16		
Angular	$9\farcm5$	$24\farcm2$
Projected linear (Mpc)	4.6	11.7

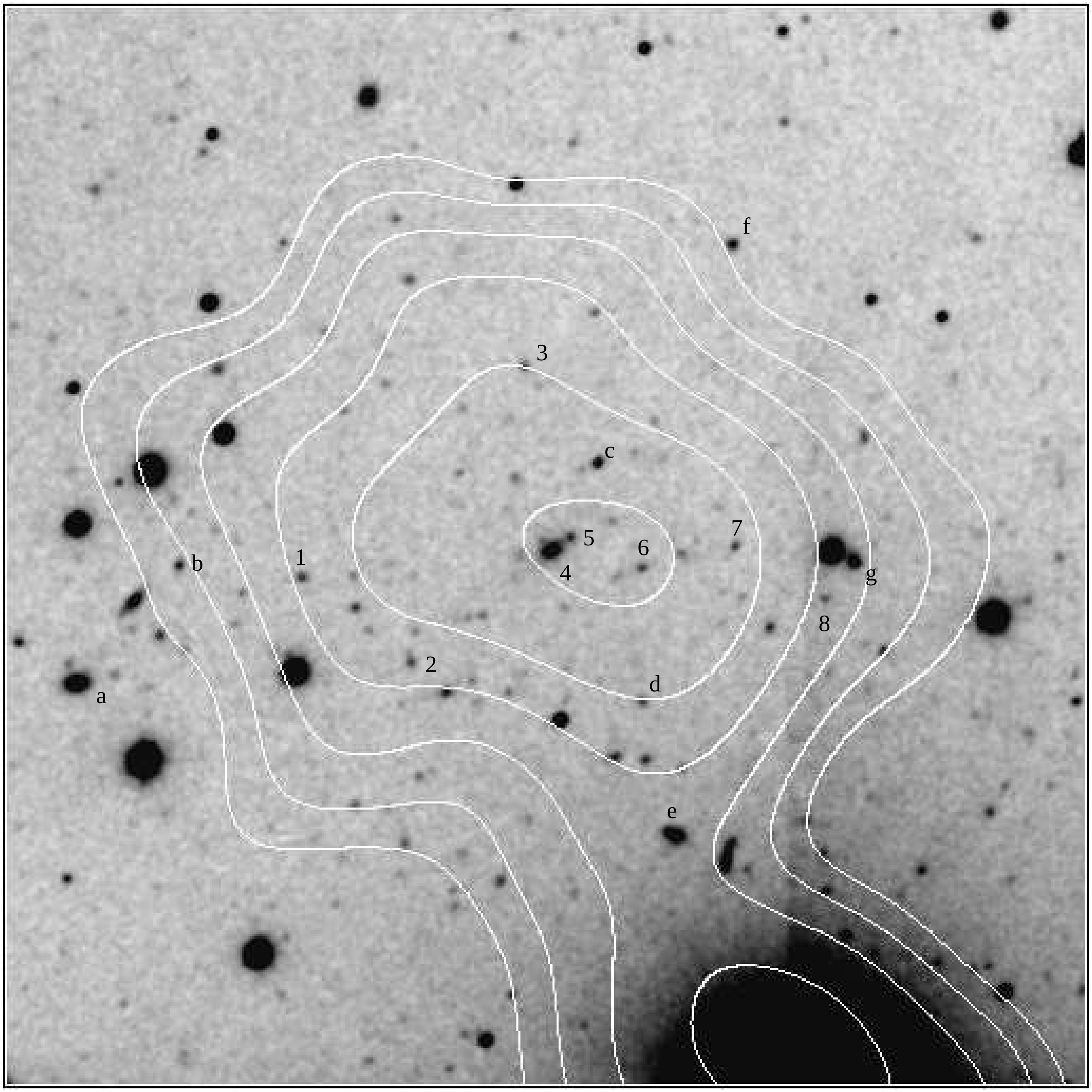
[a]Uncertainties quoted at the 1 σ confidence level

[b]Unabsorbed flux over 0.2–2 keV band (observed frame)

[c]Over 0.2–2 keV band (source frame)

Fig. 1.— R-band image from the Mount Hopkins 1.2 m telescope of a portion of the field containing the X-ray–discovered cluster, RX J0018.8+1602. The field of view is approximately $5\overset{\prime}{.}5$ square and is centered on position $00^{h}18^{m}16.8^{s}$, $16^{\circ}19'18''$ (J2000); north is up and east is to the left. Contours of constant X-ray surface brightness are overlaid. Contours increase in multiplicative steps of 1.476 from a minimum value of 2.0×10^{-4} PSPC counts s^{-1} arcmin^{-2} to a maximum value of 1.4×10^{-3} PSPC counts s^{-1} arcmin^{-2}. The 8 galaxies with measured redshifts in the range $0.538 - 0.542$ (Table 1) are numbered. Galaxies labelled a to g have spectroscopic redshifts outside this range and are believed to foreground or background objects.

Fig. 2.— Optical spectrum of the brightest galaxy in the new cluster RX J0018.8+1602. The 4000Å break, as well as absorption lines characteristic of late type stellar spectra are clearly visible. We indicate with filled circles features in the galaxy spectrum due to Ca II K and H, the G-band, Fe I λ4383.6, Mgb, and Fe I λ5269.6. Tellaric absorption from the O_2 B and A bands are noted with $\oplus$ symbols. For this display only, the spectrum was smoothed with a 15Å [FWHM] gaussian, which is approximately the spectral resolution.



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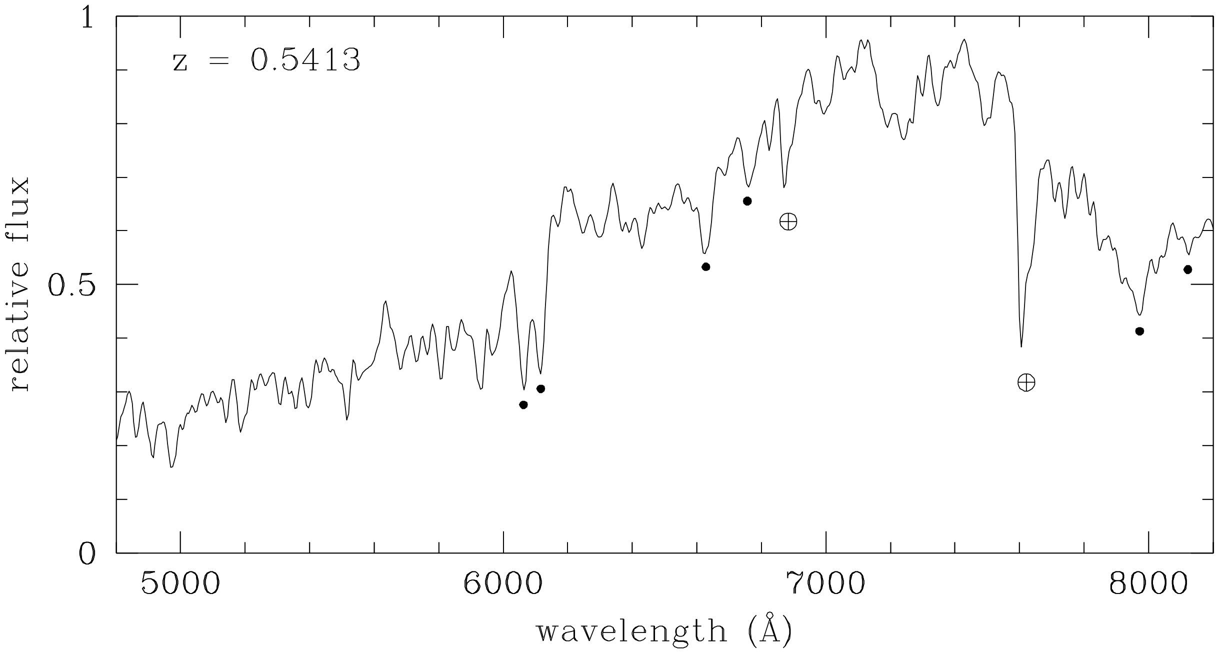
3
c
7
5
6
4
b
1
g
8
2
d
a
e


z = 0.5413
relative flux
wavelength (Å)
0
0.5
1
5000
6000
7000
8000