THE ASTROPHYSICAL JOURNAL, 207:L9–L12, 1976 July 1

THE CLUSTER OF GALAXIES ABELL 2255

M. TARENGHI*
Steward Observatory, University of Arizona
AND
JOHN S. SCOTT
Kitt Peak National Observatory†
Received 1976 January 26; revised 1976 April 5

ABSTRACT

New redshifts for nine galaxies in the field of the cluster Abell 2255 are reported, and are discussed together with six other redshifts of galaxies in the literature. The distribution of redshifts indicates that we may have observed two superposed clusters (although we have analyzed the data on both one-cluster and two-cluster hypotheses). If this is so, the data presented here and new *Ariel* X-ray data tend to invalidate claims of correlation between ΔV and L_x. Dynamics of the cluster combined with radio data allows inferences to be made concerning particle lifetimes. Under either the one-cluster or a two-cluster hypothesis, the data indicate that *in situ* particle acceleration occurs in the radio components after they exit from the parent galaxy.

Subject headings: radio sources: general — galaxies: cluster of — galaxies: intergalactic medium

I. INTRODUCTION

The study of radio tail objects is significant mainly because (1) the tails allow inferences of the time evolution of expelled radio components; and (2) studies of effects of the interaction of the expelled components with the intracluster medium may lead to conclusions regarding the nature of that medium.

Recent theoretical models (Jaffe and Perola 1973; Pacholczyk and Scott 1975) stress the importance of dynamic considerations in the interpretation of these objects. Of particular importance in these theories are (1) the distance to the cluster containing the radio tail, and (2) the relative velocity of the tail object with respect to the center of mass of the cluster.

With this in mind we have obtained 10 spectra of galaxies in the cluster Abell 2255 (including the radio tail galaxy 4CT 64.20.1 A). We have combined these data with six spectra from the literature (Zwicky 1971; Sargent 1970) in an attempt to find the above mentioned quantities.

The cluster A2255 (Zw Cl 1710.4+6401) is interesting in itself since it is composed primarily of compact galaxies, 48 of which are listed in the Zwicky catalog (1971). The mean magnitude of galaxies listed by Zwicky is $\langle m_p \rangle = 18.3$. A2255 is a cluster of richness 2 and distance class 3 in Abell's catalog (Abell 1958). Rood and Sastry (1971) classify A2255 as a core-halo cluster. Two galaxies, A and B in the Zwicky list, dominate the central region.

In addition to the radio tail object, the cluster contains three distinct radio galaxies associated with the radio sources 4CT 64.20.1 B, 4CT 64.20.1 C, and 4CT 64.20.1 S (cf. Slingo 1974*a*, *b*).

* On leave from Lab. Fis. Cosmica e Tecnologie Rel., C.N.R., Milano, Italy.

† Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

II. OBSERVATIONS

All spectra were taken with the Steward Observatory 90 inch (229 cm) Cassegrain spectrograph with an RCA image tube. A 300 line mm^{-1} grating was used, giving dispersion of about 240 Å mm^{-1}. Exposure time on unbaked IIa-O plates ranged from 20 to 50 min. A He-Ar comparison source was used. All the spectra were unwidened.

The spectra were measured in both the forward and reverse direction by one of us (J. S.) using the one coordinate Grant engine of the Kitt Peak National Observatory. The reduction was made using the FORTRAN program written by N. B. Sanwal.

No emission lines were found in any galaxy, and the redshift values came from measurements of H and K lines and the G band with different weight for the different galaxies. A mean error of ± 150 km s^{-1} is representative of the internal errors. To obtain an estimate of the internal error, we obtained two spectra for galaxy 5 (see Table 1) with a difference in velocity of 107 km s^{-1}.

Table 1 lists the relevant data for all galaxies in our sample. Column (1) gives a progressive number. Column (2) gives the Zwicky number if the object is a compact galaxy. Columns (3), (4), and (5) give the right ascension, declination (1950.0), and m_p, respectively, as listed in Zwicky (1971) or as estimated from an inspection of the Palomar Sky Survey if the galaxy is not listed in the Zwicky catalog. Column (6) gives the redshift in km s^{-1} reduced to the Sun, and column (7) the reference of previously published redshifts (S = Sargent 1971; Z = Zwicky 1971).

From Table 1 the mean velocity with respect to the Sun is 23,666 km s^{-1}. The corresponding dispersion in the line-of-sight velocities, σ_v, is 1234 km s^{-1}. If the mass-weighted space velocity dispersion of the cluster is $3^{1/2}\ \sigma_v$ and the harmonic mean radius $\langle R\rangle \approx 1$ Mpc,[1] then the "virial theorem mass" is $M_{\rm VT} = 6\sigma_v^2 \langle R\rangle/G \approx 10^{15}\ M_\odot$.

III. DISCUSSION

From an inspection of Table 1 (and Fig. 1) it may easily be seen that the velocity distribution of our 15 galaxies is far from a normal distribution. A possible explanation, besides a statistical effect of the small number of galaxies observed, can be made in terms of a two-overlapping-clusters hypothesis. Following this idea we will call the two clusters A2255 A (that one containing the galaxy "A" in the Zwicky list) and A2255 B (that one containing the galaxy "B" in the Zwicky list). The A2255 A cluster has a mean velocity of 21,828 km s^{-1} and a velocity dispersion of 475 km s^{-1}.

The second cluster, A2255 B, has a mean velocity of 24,334 km s^{-1} and σ = 469 km s^{-1}. Using H_0 = 50 km s^{-1} Mpc^{-1}, a distance of 50 Mpc between the two clusters is obtained.

The suggestion that two overlapping clusters are present is strengthened by the fact that the two brightest members of the cluster, galaxies A and B in the Zwicky list (Nos. 4 and 15 in Table 1) show a difference of velocity relative to each other of 2775 km s^{-1}. These two galaxies lie very close to each other and are clearly the dominant galaxies present. It therefore seems reasonable to obtain mass constraints under a binary galaxy hypothesis. In a picture of a binary system of galaxies we obtain a lower limit to the mass $M > 1.2 \times 10^{14}\ M_\odot$. This extremely large mass seems to indicate that these galaxies are not physically associated.

We may also regard the evidence from calculated M/L values as an indication that we are observing two separate clusters. Using the values of velocity dispersions mentioned above to obtain masses, and luminosities from Zwicky's (1971) magnitudes, we obtain

$$M/L|_{1\ \rm cluster} \sim 1500$$

and

$$M/L|_{2\ \rm clusters} \sim 200\ .$$

The second value is much closer to "normal" values for such clusters.

The radial velocity distribution, the binary galaxy

[1] Typical order of magnitude for rich clusters.

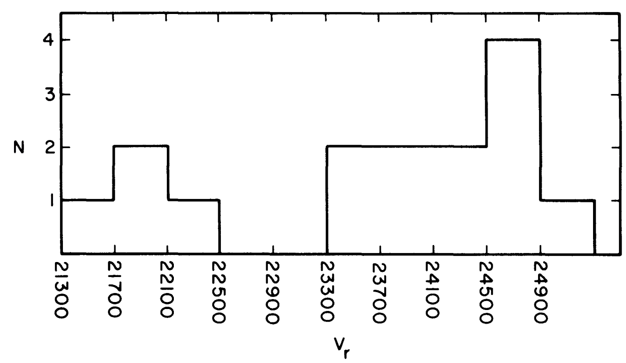

FIG. 1.—Histogram of measured radial velocities

TABLE 1

NEW REDSHIFTS

n	Zwicky No.	α	δ	m_p	v (km s^{-1})	Notes
1......	...	17ʰ11ᵐ7	64°10′	18–17.8	24,493	
2......	15	17 12.0	64 06	17.6	21,761	
3......	17	17 12.0	64 05	17.1	23,922	Radio source 4CT 64.20.1 A (Slingo 1974*b*)
4......	B	17 12.2	64 08	17.4	24,561	
5......	24	17 12.7	64 11	17.3	24,292	Mean value of two spectra: v_{01}=24345, v_{02}=24238; Radio source 4CT 64.20.1 B (Slingo 1974*b*)
6......	31	17 12.9	64 08	17.5	24,938	
7......	35	17 13.0	64 08	17.5	23,994	
8......	...	17 13.0	64 07	17.5	22,460	Galaxy southeast of No. 35
9......	...	17 13.2	64 06	17.4	23,682	Radio source 4CT 64.20.1 C (Slingo, 1974*b*)
			Other Objects			
10.....	3	17 10.9	63 56	18.1	23,615	S
11.....	4	17 10.7	64 05	18.2	24,730	Z
12.....	5	17 10.9	64 03	18.6	21,306	S
13.....	7	17 11.0	64 14	18.4	24,683	Z
14.....	9	17 11.2	63 54	18.7	24,858	S
15.....	A	17 12.1	64 08	16.8	21,786	S

argument, and the M/L ratio all seem to indicate the presence of two overlapping clusters. The probability, P, of a chance overlapping of this nature is

$$P = \frac{(\text{angular cluster radius})^2}{\text{angular area of sky}}$$

$$\times \text{ number of clusters with proper redshift} .$$

The number of rich clusters in the proper redshift range ($22{,}000 \pm 2000$ km s^{-1}) is of the order of 50, but there may be an order of magnitude more "groups" of galaxies with the richness needed here and with the proper redshifts. Thus $P \approx 10^{-2}$–10^{-3}.

This number is not so small as to invalidate the assumption of chance superposition of two clusters, though it does raise the possibility of two distinct clusters which are gravitationally bound to each other. This also seems unlikely, however, since if the clusters are both bound and superposed, the velocity vectors of the clusters must lie predominantly in the plane of the sky. If, for example, the radial velocity is roughly one-third of the true space velocity (a reasonable value in light of the above mentioned projection effect), the mass of these clusters would then be $\sim 10^{16} M_\odot$.

The conclusions regarding both the radio tail object and the cluster itself depend to some extent on whether or not the galaxies associated with A2255 actually comprise one or two clusters. Although we favor the two-cluster hypothesis, we will therefore consider two cases:

a) *One Cluster*

The cluster's mean redshift implies a distance of $R \approx 473$ Mpc (assuming $H_0 = 50$ km s^{-1} Mpc^{-1}). The velocity dispersion of the cluster, $\Delta V = 3^{1/2} \sigma_v$, is very large: $\Delta V \approx 2137$ km s^{-1}.

The cluster is not listed as an X-ray source in the *Uhuru* catalog (Giacconi *et al.* 1974), but an upper limit for its intrinsic X-ray luminosity, L_x, may be calculated from the *Uhuru* detectability limit and the above quoted distance: $L_x \leq 1.5 \times 10^{45}$ ergs s^{-1}. Recently the satellite *Ariel*-5 has observed the area of sky around A2255 and found a source with a flux of 1.5 ± 0.6 *Ariel* counts s^{-1}, corresponding to an X-ray luminosity of $\sim 7.0 \times 10^{44}$ ergs s^{-1} (Cooke and Maccagni, private communication).

These values are consistent with the L_x–Δv relation (see Fig. 2) suggested by Solinger and Tucker (1972). The distance of the cluster and the radio data of Slingo (1974*b*) imply that the intrinsic radio luminosity of 4CT 60.20.1 A is slightly less than that of either 3C 129 or NGC 1265.

The projected length of the tail is $\sim$180 kpc (as compared with 625 kpc for 3C 129 [Spinrad 1975]). Under the one-cluster hypothesis the projected length is approximately equal to the true tail size since the galaxy's velocity is probably directed at $\sim 80°$ to the line of sight. This is evidenced by the fact that the radial velocity of the tailed galaxy is very close to the average radial velocity of the cluster ($v_{RT} - \langle v \rangle \approx 0.1\, \Delta V$). Thus the unprojected space velocity of the galaxy, which has a high probability of being near ΔV, must be exhibiting a strong projection effect.

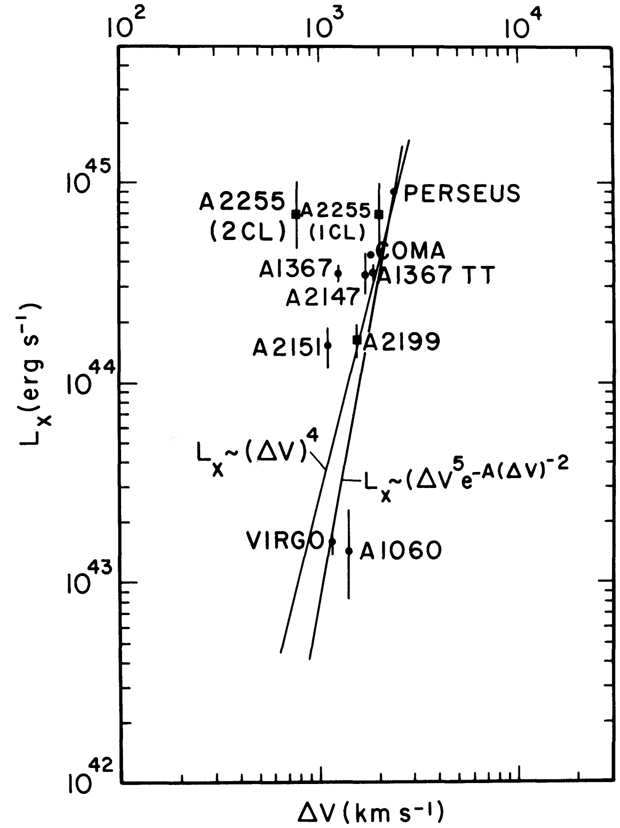

FIG. 2.—The X-ray luminosity versus velocity dispersion relation. A2255 is plotted for both the one- and two-cluster hypotheses. Note that the two-cluster hypothesis (which we feel is more likely) point on the diagram destroys any possible correlation between the plotted quantities. A1367 is from Tifft and Tarenghi (1975). All other points are taken from Cooke and Maccagni (1976). The solid lines are two theoretical relations suggested by Solinger and Tucker (1972).

Knowing the length of the tail at a given frequency, l_ν, and assuming that the parent galaxy is moving relative to the cluster medium at speed $\sim \Delta V$, and that the ejected components come to rest in this medium, the age of the oldest ejection is

$$\tau = l_\nu / \Delta V . \quad (1)$$

If this lifetime is determined by synchrotron and inverse Compton losses (Pacholczyk 1970), then

$$\tau = \frac{1}{2.4 \times 10^{-13} (H + 4 \times 10^{-6})^2 E} , \quad (2)$$

where H is the mean magnetic field and E is the energy of the electrons which are emitting at frequency ν. Furthermore (cf. Pacholczyk 1970),

$$\nu = 6.27 \times 10^{18} HE^2 . \quad (3)$$

We may solve simultaneously equations (1)–(3). No solutions exist for $H > 0$. This implies physically that inverse Compton losses alone are severe enough that the predicted tail length is shorter than it is observed to be!

If one allows for replenishment of particle energy by some form of *in situ* particle acceleration, the actual tail length can be larger than the loss time length by a factor α:

$$l_\nu = \alpha \tau \Delta V \,. \tag{4}$$

Such acceleration has been suggested by Pacholczyk and Scott (1976). For the tail in A2255 discussed here, in order to get a value of $H \sim 2 \times 10^{-6}$ gauss (a typical value from Pacholczyk and Scott) then $\alpha = 3$ (i.e., $\Delta E/E$ due to acceleration $\sim$2). This seems to indicate the need for *in situ* acceleration. The factor of 3 necessary to give the proper tail length (and a reasonable field strength) could, however, be explained as being due to inaccuracies in our estimates of l_ν and the relative velocity of the galaxy and the cluster.

There is also the possibility that the factor of 3 may be due to the fact that the electrons are still visible three e-folding times past the critical lifetime calculated above. This is very unlikely, however, for several reasons. Radio tails often show high and regularly varying polarization near the end of the tail, indicating a nearly uniform field. We are therefore viewing electrons within a small range of pitch angles. In such a case, the high-frequency cutoff is exponential, i.e., $F \propto \exp(-\nu/\nu_c)$, where ν_c is the frequency at which the cutoff appears at time τ. Since $\nu_c \propto t^{-2}$ (Pacholczyk 1970), the flux at the beginning and end of the tail would have to be different by a factor $F/F_{(\mathrm{end})} = \exp(3^2) \sim 10^4$, in order to explain the factor $\alpha = 3$ as being due to remnant emission. Even if the field is not uniform, the same argument holds. This is because physical conditions in most astrophysical plasmas (Wentzel 1976) and certainly in radio tails (Jaffe and Perola 1973) lead to streaming instabilities which constantly scatter the particles in pitch angle. When particles are emitting synchrotron radiation and scattering in pitch angle, this leads to $F(\nu > \nu_c) \propto \exp(-\nu/\nu_c)$, even for the homogeneous field case (Christianson 1975). This would again require $F/F_{(\mathrm{end})} \sim 10^4$, contrary to observations.

b) Two Clusters

Given the distribution of radial velocities reported here, the calculated values of M/L, and the binary galaxy calculation given above, we feel the two-cluster hypothesis is somewhat more likely.

In this case the low velocity dispersion (467–475 km s^{-1}) of the X-ray cluster, and the *Ariel* X-ray luminosity, place A2255 in a position on the oft discussed Δv–L_x plot which tends to argue against any significant correlation between these two quantities (see Fig. 2).

In this case $v_{\mathrm{RT}} - \langle \bar{v} \rangle \approx \Delta V$, and we infer that the tangential velocity of the radio tail object is small. A shortening effect of order $\frac{1}{2}$ or $\frac{1}{3}$ is likely, and this implies that the tail has a length comparable to that of either 3C 129 or NGC 1265. With a length of 400 kpc (projection factor $\sim\frac{1}{2}$) and again assuming the relative velocity of the parent galaxy and the cluster medium to be $\sim\Delta V$, a repetition of the simultaneous solution to equations (1)–(3) gives $\alpha \approx 100$. Even with the true length being equal to the projected length ($\sim$200 kpc), $\alpha \approx 27$. We feel this constitutes strong evidence for *in situ* particle acceleration.

One of us (M. T.) would like to acknowledge ESRO for fellowship support. We would also like to acknowledge helpful discussions with P. Hintzen, F. Owen, and L. Thompson.

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John S. Scott: Kitt Peak National Observatory, Box 26732, Tucson, AZ 85726

M. Tarenghi: Steward Observatory, University of Arizona, Tucson, AZ 85721