LETTERS TO THE EDITOR

A NEW DISTANT CLUSTER OF GALAXIES

Nebular redshifts up to $\Delta\lambda/\lambda_0 = 0.2$ have been reached by spectroscopic observations. The brightest galaxies in clusters with such a redshift are fainter than $m_p = 19$. The absorption features in the spectra of even fainter galaxies in more distant clusters are veiled to such an extent by the spectrum of the night sky that all attempts to reach larger redshifts have failed until now. It was obvious, however, that emission lines remain visible for much fainter galaxies than absorption lines and that the detection of galaxies with strong emission lines would therefore permit spectroscopic determination of very large redshifts (Humason, Mayall, and Sandage 1956).

The method of multicolor photoelectric photometry developed by Baum (1958) permits the measurement of redshifts for galaxies of normal color that are too faint to be accessible to spectroscopic observations. For two clusters near the limit of the 48-inch Schmidt telescope, red shifts of 0.29 and 0.35 have been found by Baum. Discovery of clusters of galaxies beyond the limit of the 48-inch Schmidt telescope is required to reach even larger redshifts.

It became clear that the investigation of radio sources offered a promising way of finding a galaxy with strong emission lines in a distant cluster of galaxies when the Cygnus A radio source was identified with a pair of colliding galaxies, showing strong emission lines, in a rich cluster of galaxies (Baade and Minkowski 1954). Such objects should occur mainly in clusters, and the discovery of distant objects of this type seemed possible, since sources of the intrinsic strength of Cyg A are observable at distances even beyond the reach of the 200-inch telescope.

The investigation of the source 3C 295 in the survey at 159 Mc/s by Edge, Shakeshaft, McAdam, Baldwin, and Archer (1959) has now led to the expected result. This source, with a flux density of 74×10^{-26} W m^{-2} (c/s)$^{-1}$ at 159 Mc/s ranks about fifteenth among sources more than 12° from the galactic plane in the northern hemisphere. When interferometric measures of its size showed the source to be smaller than 12″ (Morris, Palmer, and Thompson 1957), it was clear that this source, 70 times fainter and 10 times smaller than Cyg A (Jenison 1959), was likely to be a very distant analogue to Cyg A. A first attempt to identify the source failed because the accuracy of the best position then available (Shakeshaft, Ryle, Baldwin, Elsmore, and Thomson 1955) was inadequate. The attempt was repeated as soon as the precise position by Elsmore, Ryle, and Leslie (1959) and a confirming right ascension by Bolton were available.

Photographs with the 200-inch telescope showed the presence of a distant cluster of galaxies surrounding the position of the source. A plate covering the range λ 6300–6600 (Eastman 103*a*-E emulsion with Chance OR1 filter) is shown in Figure 1. About 60 galaxies with visual magnitudes in the range from 21 mag. to the limit of the 200-inch are in an area of about 3′ diameter in the center of the plate. Two galaxies near the center of the cluster stand out by their brightness. One with $m_v = 19.0$, 89 mm from the right edge and 75 mm from the top, stands out so much by its brightness that it could only be a foreground object. The other with $m_v = 20.9$, 90 mm from the right edge and 71 mm from the top, is noticeably brighter than all other members of the cluster but may be considered as the brightest member of the cluster. The position of this galaxy and the most precise positions of the source are given in Table 1. Excellent agreement is evident. Since the spectrum of this galaxy resembles that of Cyg A in showing an unusually strong emission line, there can be little doubt that it is the radio source.

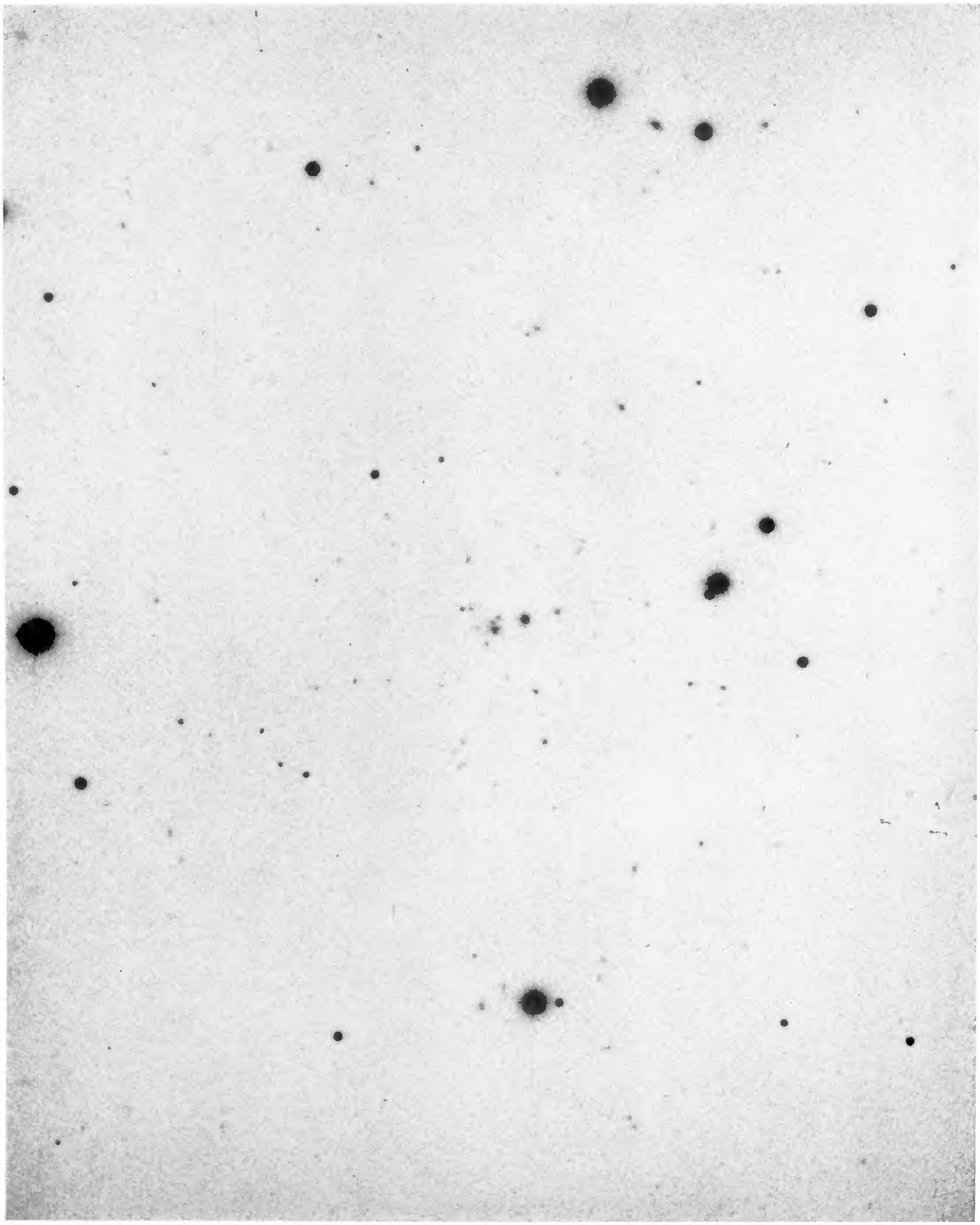

Fig. 1.—Cluster of galaxies at $14^{h}09^{m}.5$, $+12°26'$ (1950)

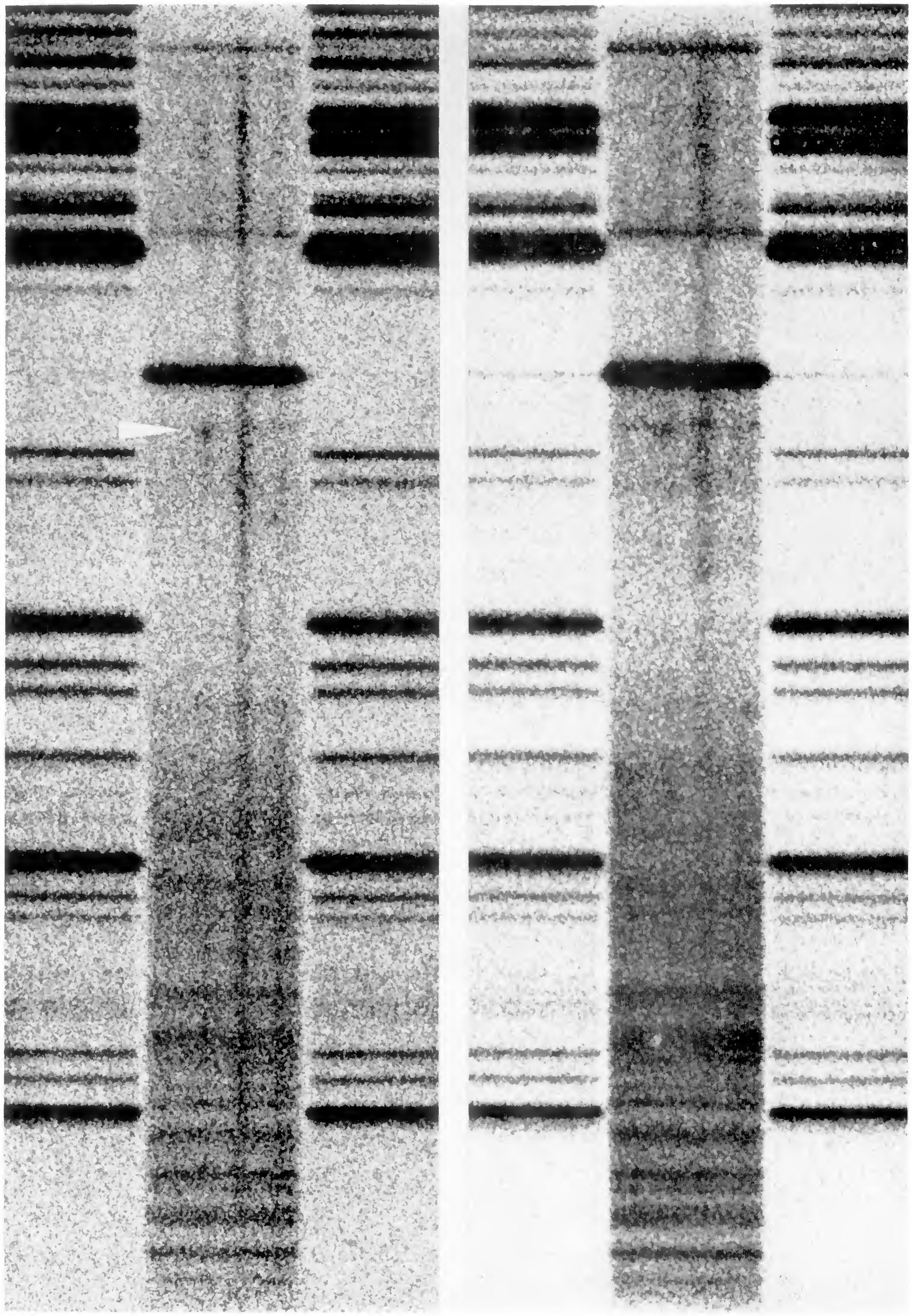

FIG. 2.—Spectrograms of galaxies. *Top:* exposure 4.5 hours, good seeing. *Bottom:* exposure 9 hours, mediocre seeing

Two spectrograms of both galaxies described above were obtained with the nebular spectrograph at the prime focus of the 200-inch telescope, one with an exposure of 4.5 hours with good seeing, the other with an exposure of 9 hours with mediocre seeing, using a dispersion of 700 A/mm and the Eastman 103*a*-D emulsion; both spectra are shown in Figure 2. The slit was rotated so that both galaxies could be observed simultaneously. The long lines extending over the length of the slit are night-sky lines. Just below the center of the spectrum is the continuous spectrum of the bright (foreground) galaxy. Just above the center of the spectrum is the spectrum of the brightest cluster galaxy; it shows a faint continuous spectrum and a strong emission line, marked by the white pointer. Near the lower edge of the spectrum appears a faint trace of a third galaxy, south-preceding of the foreground galaxy, which fell on the edge of the slit. The spectrum of this galaxy, with $m_v = 21.1$, the second brightest in the cluster, is continuous; strong emission lines would be observable but are absent.

Only one absorption line, at λ 5260 $\pm$ 2, could be seen and measured on both spectrograms of the foreground galaxy. Only on the plate obtained with good seeing, a broad absorption seems to be at about λ 4910 and a faint line at λ 5102; the relatively stronger night-sky spectrum on the plate with poor seeing would hide these features, if they are real. It seems possible to interpret the feature at λ 4910 as the blend of Ca II H and K,

TABLE 1

POSITIONS OF 3C 295

α (1950)	δ (1950)	Frequency (Mc/s)	Reference*
$14^h09^m33^s.4 \pm 1^s.5$	$+52°26'30'' \pm 90''$	178	1
$14^h09^m33^s.2 \pm 0^s.3$	....	960	2
$14^h09^m33^s.3 \pm 0^s.2$	$+52°26'12''.4 \pm 3''$	Optical	3

* The references are as follows:
1. B. Elsmore, M. Ryle, and Patricia R. R. Leslie, *Mem. R. Astr. Soc.*, **68**, 61, 1959.
2. T. A. Matthews, D. Morris, and R. B. Reed, unpublished.
3. T. A. Matthews, unpublished.

with a redshift $\Delta\lambda/\lambda_0 = 0.243$; the line at λ 5102 as H with $\Delta\lambda/\lambda_0 = 0.244$; and the line at λ 5260 as λ 4226, Ca I, with $\Delta\lambda/\lambda_0 = 0.245$. A redshift of 0.244 is consistent with the brightness of the foreground galaxy, but the interpretation is not beyond doubt.

The emission line in the spectrum of the brightest cluster galaxy is undoubtedly to be interpreted as [O II] λ 3726/29, the most common emission line in the spectra of galaxies. It is by far the strongest line in the spectrum of Cyg A; on a spectrogram on which it would appear as strong as here, none of the other lines would be observable. One might consider the possibility that the [O II] line is hidden by the strongest night sky line [O I] λ 5577 and that the emission line is one of the fainter lines of the Cyg A spectrum—but such an interpretation can be ruled out because it would require the presence of additional lines with observable intensity. The measured wave length of the emission line is 5447.8 $\pm$ 0.9; the stated error is the deviation of the two individual values from their mean. On the assumption that the unshifted wave length of the [O II] blend has the value 3727.7 valid for low density (Seaton and Osterbrock 1957), the redshift is $\Delta\lambda/\lambda_0 = 0.4614 \pm 0.0002$.

Using multicolor photoelectric photometry, Baum has derived a redshift of 0.44 $\pm$ 0.03 for two galaxies that are probable members of the cluster. This establishes that the galaxy with the strong emission line is indeed a member of the cluster. It is not unusual that the brightest galaxy in a cluster is of outstanding brightness. If the analogy to Cyg A is complete, the galaxy should be double and therefore brighter than the single galaxies. Preliminary comparisons of the color with the colors of other galaxies suggest that the color is anomalous, both red and blue being relatively bright. This might indicate the presence of a substantial contribution of synchrotron radiation to the optical emission; in that case the brightness of the galaxy could not be compared directly with that of normal galaxies.

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AVERAGE MASSES AND MASS-LUMINOSITY RATIOS OF THE DOUBLE GALAXIES

Radial velocities are now known for 97 pairs of galaxies in double and multiple systems, 20 of them measured by Page (1952), 73 of them by Humason, Mayall, and Sandage (1956), and 15 more by Page (1959). Treating each as a pair of point masses in a circular relative orbit yields, as Holmberg (1954) has shown, a regression of the square of the differential radial velocity, $(\Delta V_i)^2$, on a function of the projected separation, with slope proportional to average mass, $\bar{M}$.

In a paper presented before the Fourth Berkeley Symposium on Mathematical Statistics and Probability, Page (in press) has derived the proper weights, W_i, to be assigned, computed the root-mean-square error of $\bar{M}$, and extended the statistical theory to derive a regression of the following form, involving the average ratio of mass to luminosity, $\langle M/L\rangle$ (in solar units):

$$(\Delta V_i)^2 - \frac{\sigma_\Delta^2}{W_i} = \frac{2.96}{h}\frac{M}{L}\left[\left(10^{-4}\frac{V_i}{S_i}\right) + 0.19\times 10^{-8} V_i^2\right]\sum_{j=1}^{N_i} 10^{0.4(20.26-m_j)},$$

where σ_Δ^2 is the mean-square error in ΔV for weight $W = 1$; h is the ratio of the Hubble constant to 100 km/sec/megaparsec, V_i is the average radial velocity of the ith pair; S_i is the separation of the ith pair, in minutes of arc; m_j ($j = 1, 2, \ldots N_i$) are the apparent photographic magnitudes, corrected for galactic absorption; N_i is the number of galaxies involved in the ith pair, some pairs being formed of one close pair and a distant companion or a close group and a distant companion; $i = 1, 2, \ldots n$, and n = number of pairs.

Of the 97 pairs, 31 are rejected as of trapezium type to which the 2-point-mass model