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3C 323.1: A QSO IN A RICH CLUSTER OF GALAXIES

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ABSTRACT

The QSO 3C 323.1 is at a projected distance of 6.′5 from the center of a compact Zwicky cluster and has the same redshift as the cluster. The cluster is investigated and found to be a typical cluster of richness 1 on Abell's scale. The probability of a chance coincidence is small.

The quasar 3C 323.1 lies 5.′2 east and 3.′4 south of the central giant galaxy in the compact cluster Zw Cl 1545.1+2104. We have obtained deep plates of the cluster region and spectral scans of the central galaxy in the cluster, from which the redshift and structural data on the cluster have been obtained. The cluster is of richness 1 on Abell's (1958) scale, and the redshift $z = 0.270 \pm 0.01$ of its central galaxy agrees well with that of the QSO ($z = 0.264$, Schmidt 1968).

The QSO has an absolute V-magnitude of -24.3 (assuming, of course, that it is at the distance indicated by the redshift, $H_0 = 60$ km s^{-1} Mpc^{-1} and $q_0 = 0$, though the cosmological corrections are small at this redshift) corresponding to its observed visual magnitude of 16.64 (Angione 1971) and a visual spectral index of -1.0 (Oke, Neugebauer, and Becklin 1970). It shows no violent activity in either the radio or the visible regions, though there is some evidence for a slowly increasing brightness in the visible (Hunter and Lü 1969).

The object shows some visible structure on the photograph, a Kodak 098-02 plate obtained in excellent seeing at the 200-inch (508-cm) telescope; the image is shown enlarged in the insert in figure 1 (plate L5). The protuberance to the NW is certainly real, and may represent a jet or a companion galaxy: spectral information would be exceedingly helpful, but will be difficult to obtain.

An averaged energy distribution for the central galaxy obtained from two scans with the multichannel spectrometer at the 200-inch Hale telescope is shown in figure 2, along with a fitted standard giant elliptical spectrum taken from Schild and Oke (1971). The fitted redshift is 0.270, with an estimated error of ± 0.01. The aperture was 7″, and the wavelength resolution is 80 Å in the blue ($\lambda < 5600$ Å) and 160 Å in the red. The projected diameter is 39 kpc for $H_0 = 60$, $q_0 = 0$, and the absolute luminosity contained in that circle corresponds to $M_v = -22.7$, a typical luminosity for the brightest cluster galaxy in a rich cluster.

The cluster is very much richer than that with which PKS 2251+11 (Gunn 1971) is associated. It is, on Abell's (Abell 1965) system, a regular cluster, and is dominated by a central cD galaxy.

An area of 1.1 square degrees around the cluster has been studied on the above-mentioned plate. The positions and magnitudes of most galaxies above the plate limit were measured, and the data are complete to at least 22.0. Magnitudes were determined by a method of photographic photometry which will be described in detail elsewhere (Oemler 1972). Grain noise limits the accuracy of photometry in this very faint cluster to 0.2 mag. Calibration is based on the scan of the central galaxy discussed above, and is probably accurate to 0.05 mag.

The redshift of the cluster is such that the emitted V band is shifted into the 6000–7000 Å passband of the plate. Magnitudes refer to total light within that isophote whose

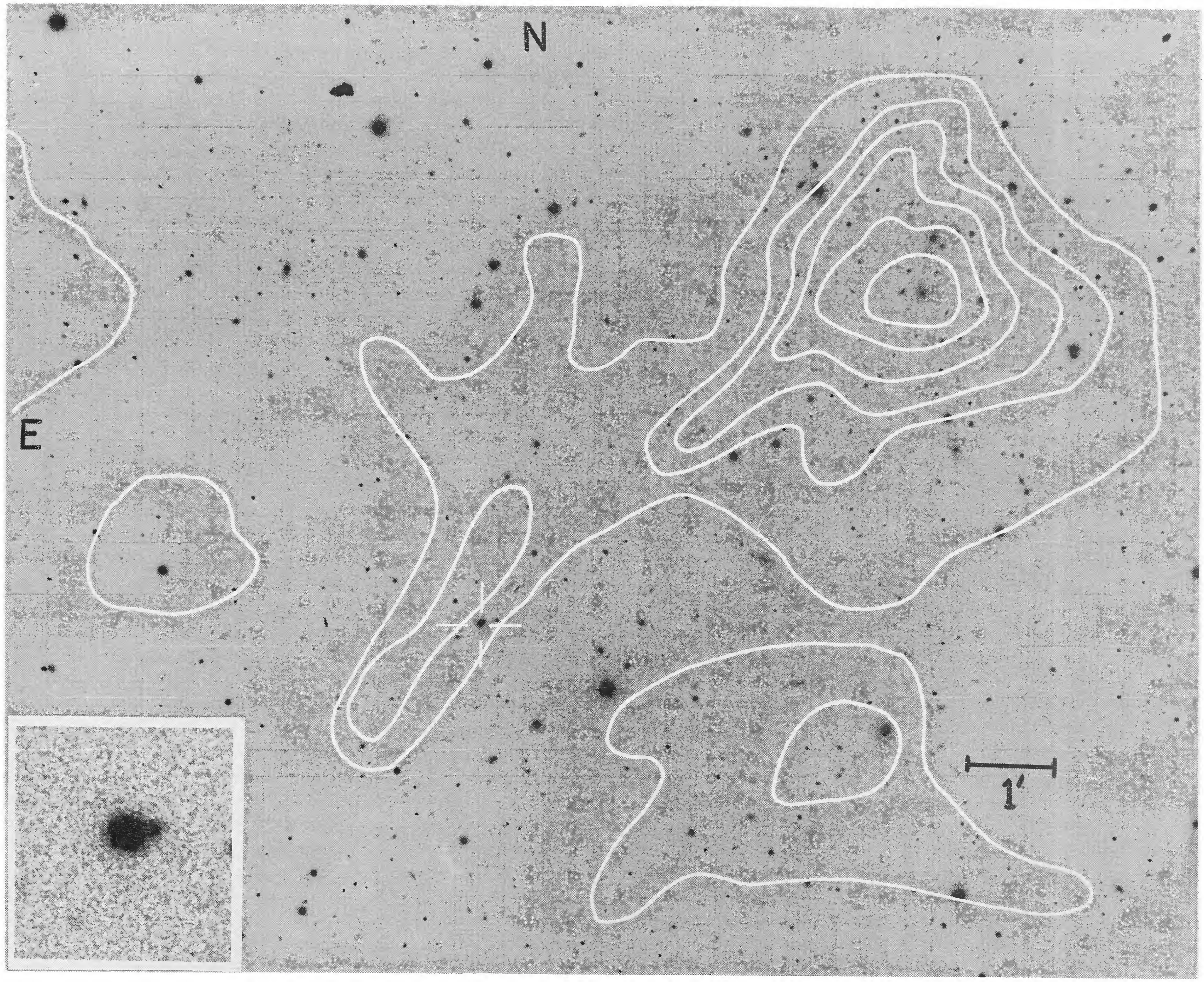

FIG. 1.—The central supergiant galaxy is near the center of the NW contours while the QSO is marked by four lines. The lines are smoothed count contours, the contour interval being 200 galaxies per square degree above the background brighter than 22.0 mag. *Inset*, an enlargement of the QSO image showing the peculiar jetlike protuberance. The plate is a 30-minute exposure on hypersensitized Eastman 098-02 obtained at the prime focus of the 200-inch telescope with the f/3.67 Ross corrector behind 3 mm of RG-1. The plate was calibrated with spot sensitometry.

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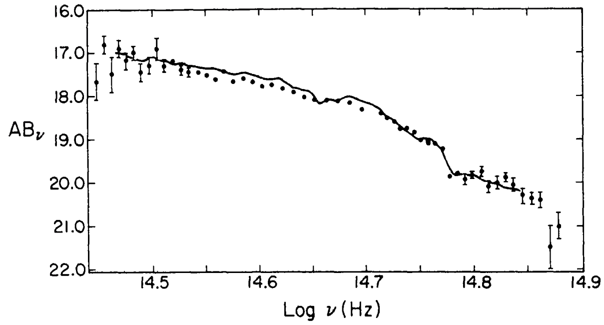

FIG. 2.—The spectral energy distribution of the central galaxy, as obtained with the multichannel spectrometer on the 200-inch telescope. The measuring aperture was 7″. Error bars are shown for all points which have formal errors in excess of 0.05 mag. *Solid line*, the standard giant elliptical distribution of Schild and Oke (1971).

surface brightness at the earth is 23.00 mag per square second of arc. In the rest frame of the cluster the surface brightness of this isophote is higher by an amount

$$\Delta S = 2.5 \log [(1 + z)^3] = 0.75 \text{ mag} . \quad (1)$$

Therefore, all apparent magnitudes given refer to luminosity in the emitted V band within the 22.25 isophote of the galaxy. Eight galaxies were, because of their size, classified as foreground objects and were discarded. The distribution of the remaining 313 galaxies is presented in figure 1. Each contour represents a number density above the background of 200 galaxies per square degree.

As can be seen, the cluster is roughly circular, with an extension to the southeast in the direction of the quasar. The apparent magnitude of the brightest galaxy is 17.85 and that of the third brightest 19.4. Within 2 mag of the latter, and within an Abell radius (Abell 1958) of size

$$r = 4.12 \times 10^5/cz \text{ minutes of arc} = 5'.2 \quad (2)$$

there are 54 cluster members, making this a cluster belonging to richness class 1. It should be noted that even at this redshift, cosmological corrections to the angular diameter are not insignificant, and even for $q_0 = 0$, the radius corresponding to equation (2) for nearby clusters should be increased to $7'.4$, so the richness of the cluster is somewhat underestimated in this analysis. The QSO falls neatly within the corrected radius, though, of course, the Abell radius is not by any means at the "edge" of a cluster, so the significance of this fact is not great. The luminosity function for the cluster members is presented in figure 3. It is very similar to that found for Coma and other nearby clusters (Abell 1962). Using Rood and Baum's (1968) brightness profiles to convert the magnitude of the Coma cluster galaxies to our system, we find the central galaxy in our cluster to be 0.1 mag brighter than NGC 4889, the brightest galaxy in Coma, in keeping with the known small dispersion in the brightness of these objects (Sandage 1968).

There is no question that the QSO at a projected distance of 2.3 Mpc is an "outlying" member if it is connected with the cluster at all. Is a chance superposition likely? One can answer this question only with the usual strong reservations about arguing probabilities after the fact. The density of rich clusters (richness 1 and greater) is estimated by Abell (1965) (with our value of H_0) to be about 1.2×10^{-6} Mpc^{-3}. The QSO, as we have seen, is quite close to the "Abell radius" from the center of the cluster, and it seems reasonable to take this radius as approximately the maximum tolerable. The velocity range corresponding to our precision of ± 0.01 in z is ± 3000 km s^{-1}, large compared with the velocity dispersion in most clusters; it is reasonable to require agreement to at least

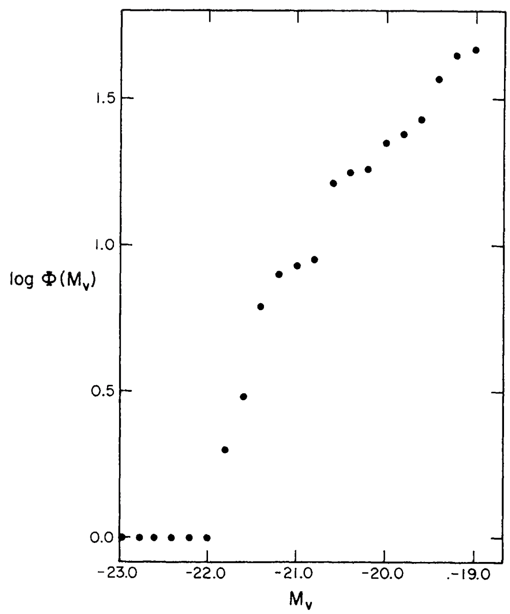

FIG. 3.—Luminosity function for Zw Cl 1545.1+2104

this precision as a criterion of cluster membership. We can then ask what the probability is of finding a cluster within 6$'$.5 of an arbitrary point in the sky and within 0.01 in z of 0.263. The corresponding volume is about 1200 Mpc^3, so the probability is 1.4×10^{-3}.

This is subject to a few "fudge factors," the application of which is very subjective. By far the least well known of these is the number of trials, a number which can be determined with certainty only after the present survey of QSOs with $z < 0.36$ is completed. The present score stands at approximately one-half of the sample of 28 QSOs with suspected companion groups. Three out of five redshift determinations yield agreement with the QSOs (counting Ton 256, Gunn 1971); the other two yield no redshift. There have been no "failures" as yet, but the selection of what to measure is obviously biased toward those cases which "look best." Any discussion of the statistics under these conditions is premature; we defer such discussion until later and assume here that the association is real.

This case seems to break the trend, known for some time, that QSOs seem not to be associated on the sky with rich clusters of galaxies. Even here, however, the QSO is not central, and one is still tempted to assert categorically that QSOs are not found in the central regions of greater regular clusters.

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