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DETECTION OF AN APPARENT, DISTANT CLUSTER OF GALAXIES ASSOCIATED WITH THE RADIO-TAIL QSO 3C 275.1

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ABSTRACT

Based on the suggestion that QSOs with distorted radio structures are likely to be members of clusters of galaxies (Hintzen and Scott), we have obtained deep direct observations of the fields containing 3C 270.1 and 3C 275.1, the most reliably substantiated cases of wide-angle radio tails associated with QSOs. Our 75″ square field centered on 3C 275.1 ($z=0.557$) contains over three-dozen objects, many of which are nonstellar, between $m_R=19.8$ and $m_R=23.5$. The quasar itself lies at the center of an elliptical nebulosity. The size of this nebulosity and the magnitude distribution of the surrounding objects are consistent with the interpretation that the QSO is the nucleus of a giant elliptical galaxy which is a member of a cluster of galaxies at $z\sim0.55$. Our observations of 3C 270.1 ($z=1.519$) show no definitive evidence of an associated cluster of galaxies, which is consistent with the cosmological interpretation of QSO redshifts.

Subject headings: galaxies: clusters of — quasars — radio sources: extended

I. INTRODUCTION

In order to determine the nature of the QSO phenomenon and the origin of QSO redshifts, attempts to detect clusters of galaxies associated with QSOs have been pursued for well over a decade. In spite of extensive efforts, only a half-dozen such cluster–QSO associations have been identified (Butcher *et al.* 1976; Phillips 1980; Wyckoff *et al.* 1980). We have therefore suggested observations of QSOs associated with distorted radio sources, since radio galaxies displaying such distortions are normally found in clusters of galaxies (Hintzen and Scott 1978). Meanwhile, spectroscopic observations of associations between QSOs and individual galaxies have greatly strengthened the case for the cosmological interpretation of QSO redshifts (Stockton 1978). If the cosmological interpretation prevails and if QSOs with certain types of distortions in their radio maps prove to be members of clusters of galaxies, "radio-distorted" QSOs should be of great use in studies of galaxy evolution. Since the redshifts of QSOs may be measured and their radio structures mapped out to very great distances, deep direct observations of distorted QSOs would provide a sample of distant clusters of galaxies at known redshifts (the QSOs').

While morphological distortions of extragalactic radio sources vary in type and degree, "radio-tail" distortions are the most reliable indication of cluster membership identified to date among radio galaxies. Thus far, all radio galaxies exhibiting tail-like distortions have been found to be cluster members. The best-documented examples to date of tail-like radio sources associated with QSOs are the wide-angle radio tails 3C 270.1 and 3C 275.1 (Jenkins, Pooley, and Riley 1977; Riley and Pooley 1978). In order to determine whether those QSOs are indeed associated with clusters of galaxies, we obtained deep direct observations of these objects. Assuming the QSOs' redshifts are cosmological, a cluster of galaxies associated with 3C 275.1 ($z=0.557$) should be detectable, since Coleman, Wu, and Weedman (1980, hereafter CWW) predict apparent R magnitudes ~20 for the brightest members. A cluster of galaxies associated with 3C 270.1 ($z=1.519$) would probably not be definitively detected; CWW predict $m_R\sim23.5$ for the brightest members, although evolutionary effects might render this estimate unduly pessimistic (Tinsley 1977). Of course, if a substantial portion of the QSOs' redshift is noncosmological, a cluster associated with 3C 270.1 would be considerably brighter.

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II. THE OBSERVATIONS

The observations were obtained on the KPNO 4 m telescope using the video camera in its normal mode (Butcher and Oemler 1978). A series of 13.6 minute integrations in the *R* bandpass (KP 1097, effective wavelength 6425 Å) was taken for each of these objects. Nine frames of the 3C 275.1 field were taken in good seeing (1″.5). Only six frames were obtained for 3C 270.1, but since the seeing was excellent (1″.1) the limiting magnitude attained was comparable to that for 3C 275.1 ($m_R \sim 23.5$). A field in M92 containing several faint photometric standards was also observed (Christian 1980). These data were processed at KPNO using standard reduction procedures (Butcher and Oemler 1978) and the various frames for each object were combined. Photographic reproductions of the reduced data for the QSO fields are provided in Figures 1 and 2 (Plates L1 and L2).

The KPNO "Mountain Photometry" code was used to determine *R* magnitudes for objects in both the 3C 270.1 and 3C 275.1 fields (Mould *et al.* 1980). An "aperture" 7 pixels in radius (4″.1 in diameter) was used for these photometric measurements, which are presented in Table 1. Identification charts for the objects measured are provided in Figures 3 and 4. Root-mean-square internal errors in the resulting magnitudes are 0.03 mag at $m_R = 21.5$, rising to 0.09 mag at $m_R = 22.5$ and 0.20 mag at $m_R = 23.5$. We estimate that the zero-point calibration for each field, determined from our standard star observations in M92, is uncertain by about 0.20 mag.

III. DISCUSSION

As can be seen in Figure 1, the lower-redshift QSO, 3C 275.1, is surrounded by dozens of objects, all of which are fainter than the Palomar Sky Survey limit. The QSO itself is surrounded by a faint, elliptical nebulosity. On the other hand, our data for 3C 270.1, the higher-redshift QSO, provide no strong evidence of an associated cluster, although several very faint objects are present within a few arc seconds of the QSO.

In order to evaluate the significance of these data, we require an estimate of the number of "background" galaxies expected in each field. Since magnitudes were determined only for those objects we judged to be definitely detected, the histograms in Figure 5 provide a conservative estimate of the limiting magnitude of our observations ($m_R \sim 23.5$). From the histogram for 3C 275.1 it appears that all objects brighter than $m_R = 23$ have been detected. Excluding the QSO, the 3C 275.1 field, 75″ square, contains 32 objects brighter than $m_R = 23$. The 3C 270.1 field contains only nine such objects. Available data (Butcher and Oemler 1978; Bahcall and Soneira 1980) indicate a mean background density of 5.4 galaxies and stars brighter than $m_R = 23$. We therefore expect about eight background objects in each field.

Since the number of objects in the 3C 270.1 field does not significantly exceed this level, we find no statistical evidence of a cluster associated with this QSO. This result is consistent with the cosmological interpretation of QSO redshifts as noted above: We would expect only the brightest cluster members to be detectable at $z = 1.5$.

TABLE 1

PHOTOMETRY OF OBJECTS IN THE 3C 275.1 AND 3C 270.1 FIELDS

3C 275.1								3C 270.1	
Object	Δα[a]	Δδ[a]	m_R	Object	Δα	Δδ	m_R	Object	m_R
1[b]......	0″.0	0″.0	17.98	20	+15″.0	+22″.2	22.90	1[b]......	17.83
2.......	+2.5	−5.4	21.17	21	+9.5	+16.7	21.56	2.......	22.34
3.......	+15.2	+8.5	19.81	22	−1.5	+16.3	21.76	3.......	22.59
4.......	+7.2	−15.5	19.81	23	+0.3	+19.9	22.68	4.......	23.49
5.......	−5.6	+4.3	20.19	24	−16.8	+18.9	22.62	5.......	20.31
6.......	−15.4	−25.1	20.30	25	−18.6	+25.0	23.49	6.......	23.71
7.......	−0.8	−29.8	21.57	26	−20.1	+12.6	23.42	7.......	23.50
8.......	+8.1	−34.1	21.16	27	−17.4	+7.5	22.96	8.......	20.94
9.......	+15.1	−33.5	22.33	28	−16.9	+5.1	22.56	9.......	21.43
10.......	+16.8	−31.0	21.99	29	−24.0	+5.8	22.64	10.......	22.82
11.......	+23.7	−35.2	22.88	30	−34.3	+3.8	22.94	11.......	21.89
12.......	+21.1	−27.0	22.44	31	−21.6	+0.7	22.07	12.......	23.31
13.......	+26.7	−27.2	20.98	32	−20.1	−6.8	21.81	13.......	23.58
14.......	+24.6	−4.2	21.87	33	−18.6	−10.3	22.83	14.......	22.90
15.......	+27.0	+5.9	22.01	34	−30.4	−15.8	22.41	15.......	22.76
16.......	+9.6	−0.6	23.10	35	−31.6	−29.7	21.33		
17.......	+3.6	−17.7	22.47	36	+3.1	+8.2	23.53		
18.......	+8.6	−21.8	22.64	37	+4.6	−34.2	22.91		
19.......	−3.8	−10.5	22.30						

[a] R.A. and decl. offsets from the QSO, in arc seconds. Object positions cannot be measured directly from the print because of geometric distortion in the video camera field.

[b] These objects are the QSOs.

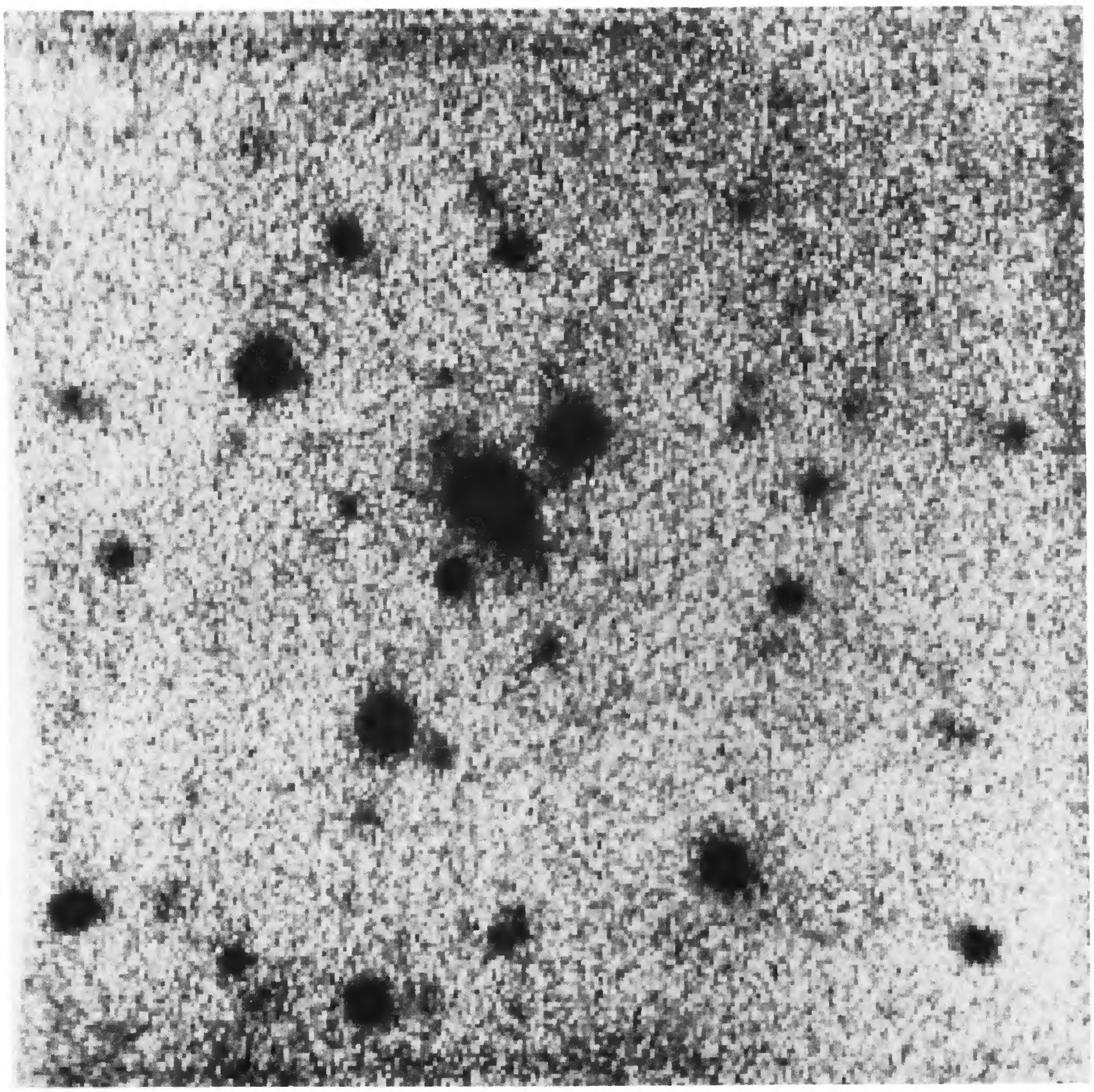

FIG. 1.—The 3C 275.1 field, observed for 122 minutes through an *R* filter in 1".5 seeing. The field is 75" square, with north at the top and east to the left.

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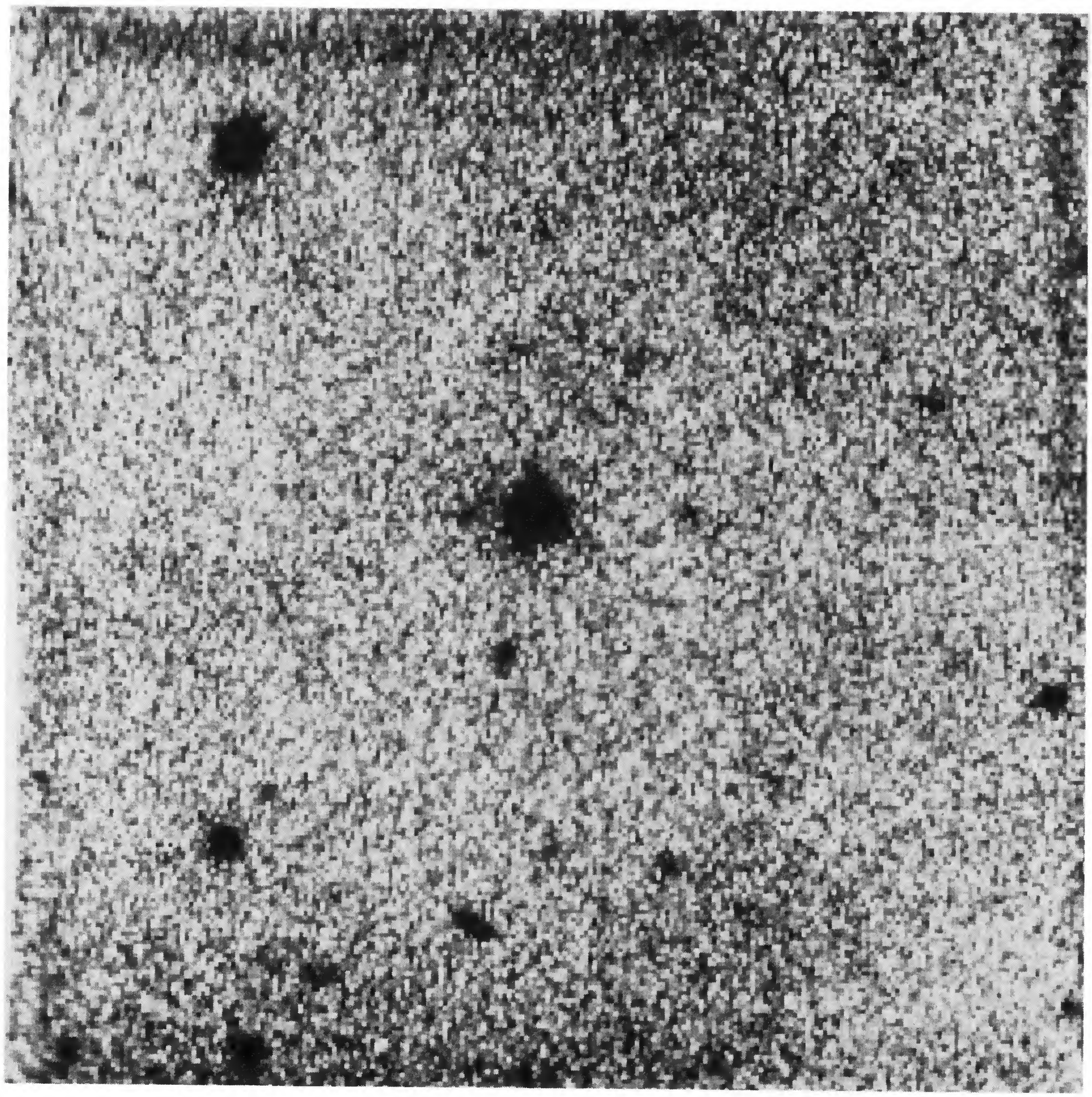

FIG. 2.—The 3C 270.1 field, observed for 82 minutes through an R filter in 1".1 seeing. The field is 75" square, with north at the top and east to the left.

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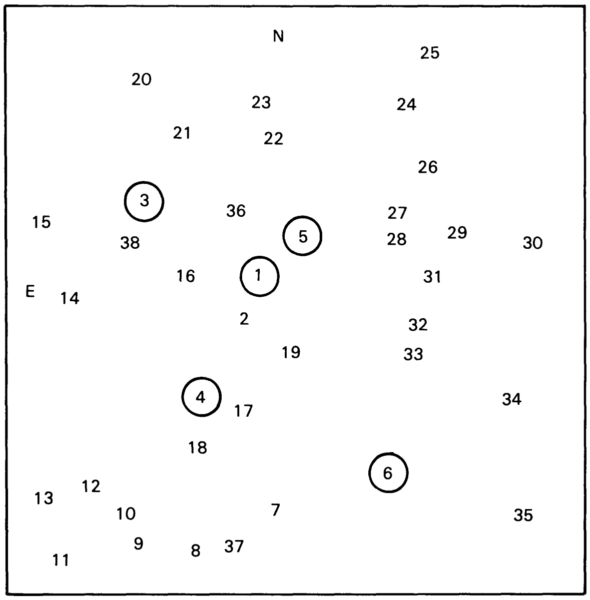

FIG. 3

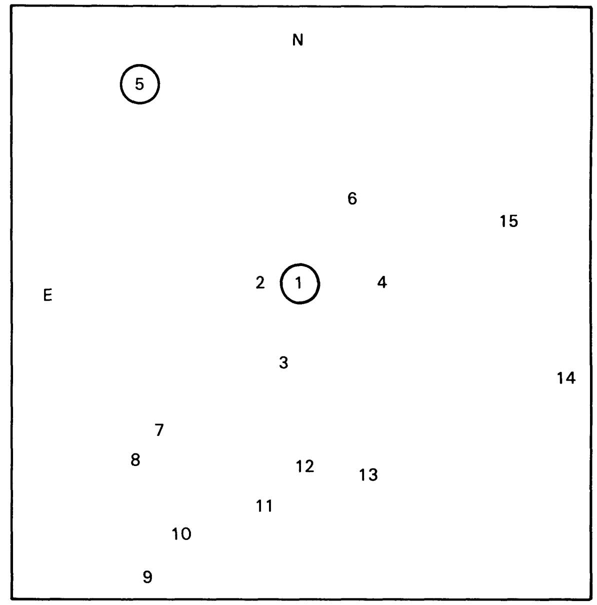

FIG. 4

FIG. 3.—A finding chart for the 3C 275.1 field. The numbering system in Table 1 is used, with objects brighter than $m_R = 20.5$ circled. The QSO is object number 1.

FIG. 4.—A finding chart for the 3C 270.1 field. The numbering system in Table 1 is used, with objects brighter than $m_R = 20.5$ circled. The QSO is object number 1.

The presence of several very faint objects ($m_R > 23$) within a few arc seconds of the QSO, including one object which is partially blended with the north edge of the QSO image, should provide motivation for further observations, preferably with a CCD.

By contrast, the density of objects in the 3C 275.1 field far exceeds the expected background density, and the apparent cluster is almost certainly a physical association.

Measurements of image sizes provide evidence that the cluster in the 3C 275.1 field is indeed composed of galaxies. The QSO image provides an upper limit on the seeing during our observations of the 3C 275.1 field. The FWHM of 3C 275.1 is 1".6 ± 1".2, where the error estimate is half the difference between the row and column measurements. The FWHM's of the 2d through 16th brightest objects in the field vary from 1".4 to 2".6 with measuring errors averaging 0".2. While merged images and the noisy profiles of fainter objects may contribute to the variation of image sizes, it does appear that an appreciable portion of the objects in the 3C 275.1 field are extended.

If we therefore assume that objects 2 through 37 are members of a distant cluster of galaxies, the R magnitudes of these objects can be used to estimate the redshift of the cluster using the precepts of Schecter and Press (1976, hereafter SP). From Figure 5 it appears that our sample in the 3C 275.1 field is complete to about $m_R = 23.0$. We therefore choose a conservative limiting magnitude for our sample, $m_{\rm lim} = 22.66$. Excluding the QSO, there are 24 objects in the field brighter than this limit. Using equation (9) of SP, we derive an average magnitude $\overline{m_R} = 21.27$ for our sample of $N = 24$ objects. From our value of $m_{\rm lim} - \overline{m_R}$ and Table 1 of SP, we find

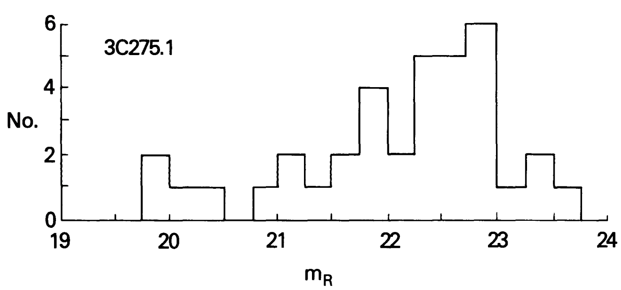

FIG. 5a

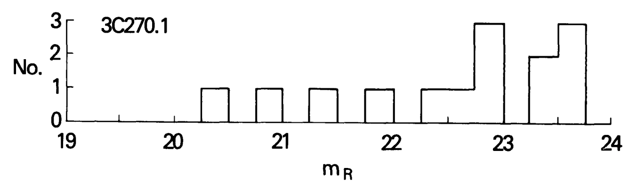

FIG. 5b

FIG. 5.—Histograms of the photometric data for the two fields observed

that $m_R^*=20.44$ for $N=24$. With $H_0=50$ km s^{-1} Mpc^{-1} and $q_0=0$ (values adopted for the remainder of this section), equation (2) of SP gives $M_V^*=-21.43$. Assuming $V-R=0.87$ at zero redshift, typical of nearby elliptical galaxies (Coleman, Wu, and Weedman 1980; Sandage 1973), we adopt $M_R^*=-22.30$. The resulting distance modulus estimate for $N=24$ is $m_R^*-M_R^*=42.74$.

If we assume that 3, 4, 5, and 6 are foreground objects, the remainder of our sample brighter than $m_R=22.66$ yields $m_R^*-M_R^*=44.22$. This case also results in a cluster richness parameter $n^*=36\pm4$. Since we have presumably observed only the central portion of the cluster, our value for n^* is only a lower limit for the $N=20$ case. The cluster may therefore qualify as "rich" by the criterion of SP ($n^*>30-50$). We therefore used Table 2 of SP to calculate a distance modulus for $N=20$ under the "rich cluster" hypothesis and obtained $m^*-M_R^*=45.26$.

If the cluster consists primarily of elliptical and S0 galaxies, and if evolutionary effects are not important, the "old stellar population" K-corrections of CWW (see their Tables 6 and 7) are appropriate. Using these values, we derive redshifts of $z=0.40$, $z=0.55$, and $z=0.70$ for the three distance moduli above (the $N=24$, $N=20$, and "rich cluster" $N=20$ cases, respectively). These redshift estimates are all within 30% of the redshift of 3C 275.1 ($z=0.557$).

The images of the QSOs themselves are also of considerable interest. The image of 3C 270.1 is stellar, with FWHM of 1".1 and no evidence of an underlying galaxy. As noted previously, we would expect to detect neither an underlying galaxy nor the postulated associated cluster of galaxies if the redshift of 3C 270.1 ($z=1.519$) is cosmological.

On the other hand, our data for 3C 275.1 ($z=0.557$) show a definite elliptical nebulosity surrounding the quasar. This nebulosity, which is centered on the quasar, measured 14" by 7" (the latter number is a lower limit). If the quasar's redshift is cosmological, the nebulosity's semimajor axis is 87 kpc, typical of the larger gE galaxies (Oemler 1976). In fact, considering its apparent position at the center of the cluster, this object may be a cD.

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