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RADIO AND OPTICAL OBSERVATIONS OF THE ALLEGED OPTICAL JET IN DA 240

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ABSTRACT

Radio (continuum and H I line) and optical (continuum and line) observations have been made in an attempt to clarify the nature of the so-called optical jet in the giant radio galaxy DA 240. No 21, 6, or 2 cm continuum ($\gtrsim 1$ mJy) was detected from the jet using the VLA. In the optical, our blue images suggest that the jet (henceforth called the low-velocity system or LVS) might be a spiral galaxy. This interpretation is consistent with the spectrum of the LVS, which possibly shows stellar absorption features at the redshift of the emission lines detected by Burbidge, Smith, and Burbidge. Further evidence for this interpretation is provided by the discovery by Dr. A. G. de Bruyn (private communication) that an adjacent galaxy has nearly the same redshift as the LVS, suggesting that both are members of a small foreground group at several thousand km s^{-1} lower redshift. No H I in the LVS was detected in absorption against the nuclear radio source of DA 240 at a level $\tau_{\mathrm{H\,I}} \lesssim 0.06$. The similarities of the LVS in DA 240 to the "high-velocity system" (HVS) in NGC 1275 (Burbidge *et al.*) appear to be strengthened, but in the opposite sense to that proposed by these authors: In both cases there is now strong circumstantial evidence that both the DA 240 LVS and NGC 1275 HVS are foreground (spiral) galaxies rather than jets indicative of explosive outflow.

Subject headings: galaxies: individual — galaxies: jets — galaxies: structure — radio sources: galaxies — radio sources: 21 cm radiation

I. INTRODUCTION

The giant radio source DA 240 is one of the largest known (1.3 Mpc for $H_0 = 75$ km s^{-1} Mpc^{-1}, Willis, Strom, and Wilson 1974). Its associated galaxy MCG 9-13-57[8] (redshift 0.0354; Burbidge, Smith, and Burbidge 1975, hereafter BSB I) has been reported to have an extended, knotty, and relatively blue feature which is aligned with the nucleus. This feature shows emission lines which are blueshifted by 3386 ± 24 km s^{-1} relative to the nucleus (Burbidge, Smith, and Burbidge 1978, hereafter BSB II). BSB I and BSB II interpreted it as a "jet" emanating from the nucleus of MCG 9-13-57.

If this were correct, this jet in DA 240 would have some unique properties: (*a*) Its direction is misaligned by about 60° from the main radio source axis, in contrast to other optical jets in radio galaxies or quasars (e.g., Butcher, van Breugel, and Miley 1980). (*b*) The jet appears embedded within "a weaker, more extended asymmetric halo of nebulosity" (BSB I, p. L137), again unlike the other optical jets.

To clarify the nature of this blue feature we have reinvestigated its radio and optical properties. To avoid bias we henceforth refer to this jetlike feature as the

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[8] BSB I and BSB II have inadvertently confused the name of the parent galaxy (MCG 9-13-57, Willis *et al.*) with MCG 9-13-66, which has the same redshift but is located near the eastern lobe of DA 240 (see Willis *et al.*).

low-velocity system (LVS), by analogy with the high-velocity system (HVS) in NGC 1275, a system which the MCG 9-13-57 + LVS system of DA 240 resembles (BSB II).

We have made the following new observations:

1. With the Very Large Array (VLA), 2 cm, 6 cm, and 21 cm continuum observations were made with high resolution. The aim was to search for radio continuum from the LVS and to try to resolve the radio nucleus. The former would show whether the LVS is a radio continuum source with a spectrum similar to those of other optical jets; the latter, whether or not the nuclear radio source is extended in the direction of the LVS.

2. With the Westerbork telescope, 21 cm H I line observations were made to search for absorption against the nuclear radio source at the redshift of the LVS. Such absorption might be expected if the LVS were a foreground spiral galaxy.

3. Optical imaging was undertaken using the Video Camera on the Kitt Peak 4 m telescope. Broad-band blue images were obtained to show the morphologies of the LVS and the parent galaxy better and to estimate the flux densities at optical wavelengths of the knots in the LVS.

4. Optical long-slit spectroscopy was undertaken using the High-Gain Video Spectrometer (HGVS) and Cryogenic Camera on the Kitt Peak 4 m telescope. These observations, made with better sensitivity and dynamic range than previously possible (BSB I, BSB II), were intended to show the nature and extent of the emission-line gas and whether the LVS contains stars.

The observations and results are described in § II and discussed in § III. Our most important conclusions are summarized in § IV.

II. OBSERVATIONS AND RESULTS

Table 1 gives the most important properties of the various telescopes and instruments. We will discuss the observations and results briefly.

a) Radio Continuum

The core region of DA 240 was observed at 2 cm, 6 cm, and 21 cm wavelengths with the VLA in its A configuration (Thompson *et al.* 1980). The source was observed at each wavelength over a large range of hour angles to ensure optimum sampling of any source structure. Four to five scans of 10–15 minutes were made at the different wavelengths, interspersed with short observations of the secondary calibrator 0804+499 to monitor instrumental and atmospheric phase and amplitude fluctuations. The primary flux density calibrator was 3C 286. Details are given in Table 2.

After editing, calibration, and Fourier transformation, the maps were self-calibrated (using the nucleus of DA 240 as a reference) and CLEANed using standard reduction techniques at the VLA (see, for example, Bridle, Fomalont, and Cornwell 1981). Self-calibration only marginally improved dynamic range; the effective noise in the maps (see Table 2) was dominated by confusion from the bright northeastern hot spot, at 11′ from the field center. No radio emission from the LVS was detected at a level above 3 times these values.

The nucleus of DA 240 was detected in all three wavelengths. The flux density and size of the nuclear

TABLE 1

OBSERVATIONAL PARAMETERS

Parameter	Radio Imaging: Continuum	Radio Imaging: H I Line	Optical Imaging: Continuum	Optical Spectroscopy: Red	Optical Spectroscopy: Blue
Observatory	NRAO	NFRA	KPNO	KPNO	KPNO
Telescope	VLA	WSRT	4 m	4 m	4 m
Instrument or telescope configuration	A configuration	1.5 km	Video Camera	Cryogenic Camera	HGVS
Wavelengths	2, 6, 21 cm	21 cm	4000–5000 Å	4550–7890 Å	3700–5600 Å
Bandwidth	50, 50, 25 MHz	2.5 MHz	~900 Å	...	...
Spatial or spectral resolution	0″.12, 0″.37, 1″.2	34 km s^{-1}	~1″	15–25 Å	17 Å
Map size or slit position angle	8″, 26″, 1′.7 sq.	21′ radius	~70″ × 70″	4°	1°
Observing date	1981 Feb	1979 Dec	1978 Nov	1981 Dec	1979 Nov
Purpose of the observations	Is the LVS thermal or nonthermal? Is the nucleus resolved and directed toward the LVS?	H I absorption against nucleus at the redshift of the LVS	morphology of the galaxy and the LVS	stellar and emission-line features in LVS	stellar and emission-line features in LVS

NOTE.—NRAO = National Radio Astronomy Observatory, NFRA = Netherlands Foundation for Radio Astronomy, KPNO = Kitt Peak National Observatory.

TABLE 2

VLA Observations
(Pointing Position: R.A. [1950] = $07^h44^m35^s.1$, Decl. [1950] = 55°56′27″.8)

A. DA 240 Core Region

Wavelength (cm)	Frequency (MHz)	Bandwidth (MHz)	Resolution (arcsec²)	On Source Observing Time (minutes)	Effective[a] rms Noise (mJy per beam)
21	1413	25	1.2	82	2.4
6	4885	50	0.37	75	0.3
2	15035	50	0.12	50	0.8

B. Calibrators Used

Wavelength (cm)	3C 286 (Primary Calibrator) Flux Density (Jy)	0804+499 (Secondary Calibrator) Flux Density (Jy)
21	14.77	0.87
6	7.41	1.64
2	3.44	1.48

[a] Mainly due to confusion from the bright eastern lobe.

source at each wavelength was determined using a one-component Gaussian fitting program. These, and other values available from the literature, are listed in Table 3. The nucleus has a straight and relatively steep spectrum with a spectral index α (defined by $S_\nu \sim \nu^{-\alpha}$) between 2 cm and 49 cm of $\alpha_{49}{}^2 = 0.47 \pm 0.02$. The model fits suggest that the nucleus is marginally resolved at 2 and 6 cm. Plots of the visibility amplitude as a function of baseline length confirm this; i.e., the source is resolved at the maximum baseline (~35 km) by ~20% and ~8% at 6 cm and 2 cm, respectively. These results are consistent with very long baseline interferometry (VLBI) measurements (see Table 3). At 2 cm, the Gaussian model fit suggests a position angle for the major axis of the nucleus of ~105° ± 20°, i.e., nearly perpendicular to the LVS but perhaps also misaligned with the major axis of the radio source. It is desirable to confirm this position angle using higher resolution observations (i.e., using VLBI).

TABLE 3

DA 240 Radio Core Parameters
(Position: R.A. [1950] = $07^h44^m34^s.98 \pm 0^s.001$
Decl. [1950] = 55°56′28″.14 ± 0″.01)

Wavelength (cm)	Flux Density (mJy)	Angular Size (arcsec)	Ref.
49	267 ± 7	<30	1
21	217 ± 12	<0.9	2
18	<100	>0.003	3
6	111 ± 1	~0.07	2
6	39 ± 6	≳0.05	4
2	59 ± 2	0.06 × 0.03	2

References.—(1) Willis, Strom, and Wilson 1974 (WSRT observation). (2) This paper, using one-component Gaussian model fits. The formal uncertainties in the angular sizes are ±0″.01 (at 2 and 6 cm). The position angle for the major axis appears to be 105° ± 20° (at 2 cm). (3) Shaffer and Marscher 1979 (VLBI observation). (4) Graham, Weiler, and Wielebinski 1981 (VLBI observation).

b) H I *Line*

The Westerbork synthesis radio telescope (WSRT) was used to search for H I in absorption from the LVS. The configuration of the spectrometer was optimized to search for narrow (≲100 km s^{-1}) features located within ±250 km s^{-1} of the mean velocity of the optical emission lines in the LVS (BSB II). Such a strategy was suggested by the optical spectroscopy of BSB II, which showed the emission-line gas in the LVS to be kinematically quiescent, and by comparison with the H I absorption detected from the HVS associated with NGC 1275 (De Young, Roberts, and Saslaw 1973; van Gorkom and Ekers 1983). Our observations were thus designed to check the hypothesis that the LVS in DA 240 is a late-type foreground galaxy.

DA 240 was observed using three "cuts" of about 1 hr duration each at different hour angles. The visibility data (for each velocity channel) were calibrated and Fourier transformed to the map plane following standard procedures. For each channel map the flux density of the nuclear radio source was determined. No features (either in absorption or emission) are seen at a 3 rms level of 10 mJy. For an absorption feature, this limit corresponds to a limit on the optical depth of absorbing material of $\tau_{\rm H\,I} < 0.06$. (Van Gorkom, private communication, has made similar observations with the VLA and finds $\tau_{\rm H\,I} \leq 0.05$ at the velocity of the LVS.) This limit, in turn, is related to the column density of H I ($n_{\rm H\,I}$) through the H I spin temperature ($T_{\rm spin}$) and the line width of the absorption feature in km s^{-1} (Δv) by

$$n_{\rm H\,I} \approx 1.8 \times 10^{18} T_{\rm spin} \Delta v \tau_{\rm H\,I} \ {\rm cm}^{-2} .$$

For $\tau_{\rm H\,I} \leq 0.06$ and $\Delta v \leq 100$ km s^{-1} this implies $n_{\rm H\,I} < 10^{21}$ cm^{-2}. Were the LVS a normal spiral galaxy, we would expect any H I absorption to be unresolved in velocity ($\Delta v \lesssim 34$ km s^{-1}), implying $n_{\rm H\,I} \leq 3 \times 10^{20}$ cm^{-2}.

c) *Optical Imaging*

Optical images of DA 240 were obtained with the KPNO Video Camera system on the 4 m telescope using a broad-band blue filter. The standard reduction techniques have been described, for example, by Butcher, van Breugel, and Miley (1980). The standard star EG 26 (Oke 1974) was observed to obtain absolute flux calibration to within ~25%.

The blue image is shown in Figures 1*a* and 1*b* (Plates 1 and 2). Clearly, the galaxy MCG 9-13-57 has a complex brightness distribution. A "loop" south of the galaxy can best be seen in Figure 1*a*, while Figure 1*b* shows the central region of the galaxy. In this latter figure one can recognize absorption patches to the east, west, and south of the nucleus. Perhaps the east and west features are due to a faint dust ring encircling the nucleus of DA 240. Such rings have been found in several other galaxies (e.g., Kotanyi and Ekers 1979). Extinction by dust in the nucleus could also account for the $U-B$ and $B-V$ colors (BSB I), which are quite red, even for an elliptical galaxy (see de Vaucouleurs and de Vaucouleurs 1972). The southern absorption patch (and the others as well, of course) may be related to the LVS, obscuring part of the background galaxy.

To show the structure of the LVS more clearly and to estimate the flux density of its various features, we subtracted a model for MCG 9-13-57 by using an elliptically symmetric Hubble profile which best fitted the data. Because of the dust, the central part of the galaxy was not well represented by such a model, but everywhere else the model subtraction was successful. A slight oversubtraction was made on purpose, in order to be conservative with respect to the structure of the LVS. This resulted in a slight "bowl," visible as a lighter region in the northern half of Figures 2*a* and 2*b* (Plates 3 and 4). Figure 2*a* best shows the loop, or spiral arm, while Figure 2*b* best shows the two knots of the LVS. The central part of MCG 9-13-57 (also central in the figures) is "black" near the nucleus, surrounded by "white" patches to the east and west. These are due to the improper fit of the Hubble profile at the nucleus and the obscuration patches. The (blue) flux densities of various components of the LVS are given in Table 4.

d) *Optical Long-Slit Spectroscopy*

We obtained long-slit spectroscopic data on the LVS using the 4 m telescope at KPNO with two different detectors. In the blue we used the High-Gain Video Spectrometer (HGVS), and in the red we used the Cryogenic Camera (CC). The configurations used for both systems are described in Table 1. The observations and the calibration and reduction of the data were all done in a standard way described in detail elsewhere (e.g., Heckman *et al.* 1981; Balick and Heckman 1983).

i) *Continuum/Absorption-Line Spectra*

In Figures 3*a* and 3*b* the blue and red spectra of the LVS are exhibited. These spectra refer to the southerly blue knot (some 14″ ± 1″ south of the nucleus of MCG 9-13-57) since it is here that the spectrum of the LVS can be most clearly discerned. The data are quite noisy, particularly in the blue. Nonetheless, we can tentatively identify a number of absorption features in the blue spectrum at the redshift of the emission-line gas as given by BSB II ($z = 0.024$). In Table 5 we give line strengths (or upper limits) estimated for the strongest stellar absorption lines expected if the LVS is a galaxy. One would expect that the Balmer lines would dominate in late-type galaxies and the metal lines in early-type galaxies.

While the low signal-to-noise ratio in the spectrum precludes any detailed analysis, the spectrum is more consistent with that of the nuclei of late-type galaxies (e.g., Heckman 1980*a*). In such nuclei, nebular Balmer emission and stellar Balmer absorption are competing processes. The absorption lines all have roughly the same strength, while the relative strengths of the emission lines decline sharply from the red to the blue. Thus, emission dominates in the red lines (e.g., Hα and Hβ), while absorption dominates in the blue lines (e.g., Hϵ, H8, H9). This is consistent with the spectrum of the LVS. Higher signal-to-noise data in the blue are desirable to confirm the tentative line identifications we have made here.

As noted by BSB I, the spectrum of MCG 9-13-57 is typical of the nuclei of early-type galaxies (Table 5). Strong absorption lines indicative of a cool stellar population are readily detected (e.g., Ca II H and K, the G band, Mg I λ5174, Na I λ5892), while the Balmer lines are quite weak. The absorption lines have the same redshift as the emission lines in MCG 9-13-57, as reported by BSB I. The difference between the spectra of the LVS and MCG 9-13-57 is also evident in the slope of

TABLE 4

LVS BLUE FLUX DENSITIES

Component	Distance from DA 240 Nucleus (arcsec)	Area (arcsec^2)	Flux Density (μJy)	Apparent Magnitude (m_B)
Knot 1	9	3.5 × 3.5	25	20
Knot 2	15	3.5 × 3.5	21	20

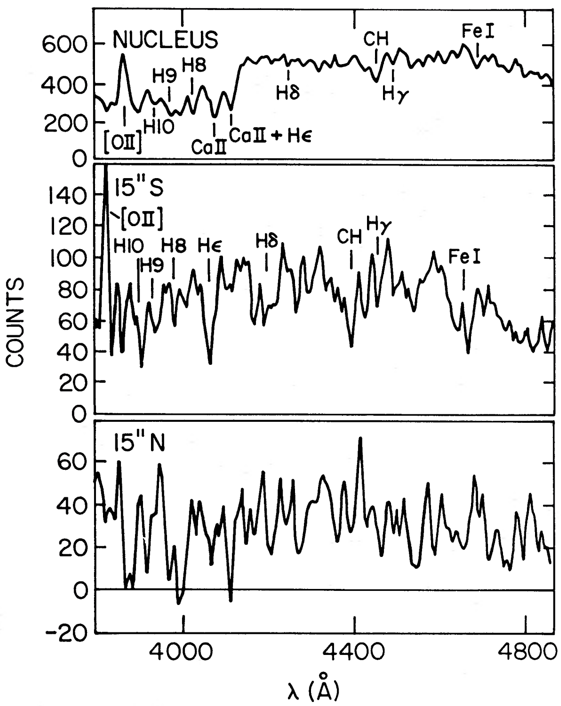

FIG. 3*a*

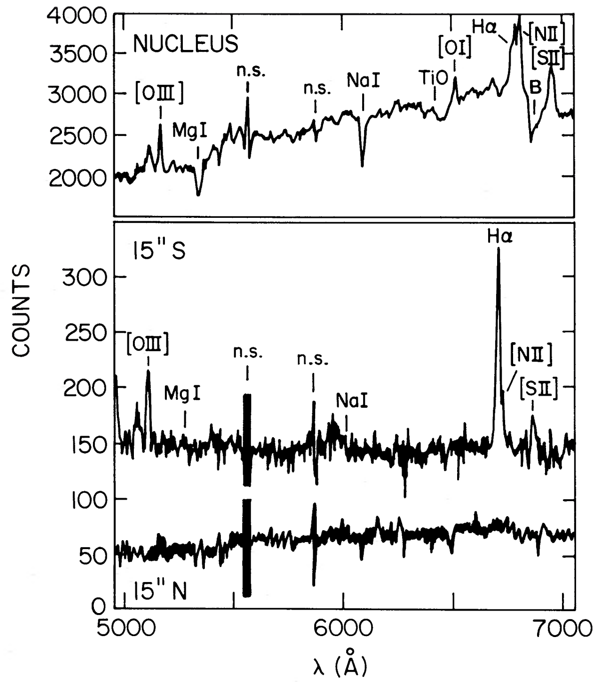

FIG. 3*b*

FIG. 3.—(*a*) The blue (HGVS) spectra at three positions. The top spectrum is at the position of the nucleus of MCG 9-13-57. The middle spectrum is at the position 15″ south of the nucleus, where the LVS can be most clearly discerned. For comparison, the bottom spectrum is at a position 15″ north of the nucleus, where only weak radiation from the outer part of MCG 9-13-57 can be seen. The horizontal axis is the wavelength as observed on the Earth. The units of the vertical axis are arbitrary (the data were not flux calibrated). Note that the zero point and scale for the vertical axis are different for the three different spectra. The [O II] λ3727 and various stellar absorption lines expected in a galaxy spectrum are marked for $z = 0.0354$ (*top*) and $z = 0.0241$ (*middle*). (*b*) The red (CC) spectra at three positions. The top spectrum is at the position of the nucleus of MCG 9-13-57. The middle spectrum is at the position 15″ south of the nucleus, where the LVS can be most clearly discerned. The bottom spectrum is at a position 15″ north of the nucleus (weak signal from MCG 9-13-57). The vertical and horizontal axes are as in Fig. 3*a*, except that the two bottom spectra share a common zero point and scale in the vertical axis. Various expected emission and absorption features are marked for the two redshifts as in Fig. 3*a*. Some improperly subtracted night-sky lines are marked "n.s," and the atmospheric B band is also indicated.

TABLE 5

EQUIVALENT WIDTHS OF ABSORPTION LINES

	EQUIVALENT WIDTH (Å)			
LINE	LVS	MCG 9-13-66	Late[a]	Early[a]
H10	5 ± 5	2 ± 3	7	<2
H9	5 ± 5	4 ± 3	7	<2
H8	5 ± 5	4 ± 3	7	<2
Ca II λ3934	0 ± 5	10 ± 3	3	11
Hε + Ca II λ3969	14 ± 5	12 ± 3	10	10
Hδ	11 ± 5	1 ± 3	7	1.5
CH λ4300	10 ± 5	6 ± 3	3	6
Hλ	5 ± 5	2 ± 3	6	1
Fe I λ4529	10 ± 5	3 ± 3	3	5
Hβ	emission	0 ± 1	6	1
Mg I λ5174	0 ± 3	6 ± 1	2	6
Na I λ5892	0 ± 3	6 ± 1	1	6
Hα	emission	emission	5	1

[a] Typical galactic nuclei from Heckman *et al.* 1981 corrected for emission lines.

the optical continuum. Our Cryogenic Camera and GHVS data indicate that the LVS is bluer than MCG 9-13-57: by $\sim 40\%$ over the wavelength range 5000–7000 Å and by $\sim 70\%$ in the range 4000–5500 Å, respectively. This is consistent both with the character of the continuum as inferred from the possibly detected absorption lines and with the optical morphologies of the two objects—LVS: blue, hot stars, late-type galaxy; MCG 9-13-57: red, cool stars, early-type galaxy.

ii) *Emission Lines*

Our data confirm the existence of two emission-line redshift systems: one centered on the nucleus of the parent galaxy (MCG 9-13-57, $cz = 10{,}600$ km s^{-1}) and one associated with the LVS ($cz = 7200$ km s^{-1}). The high-redshift gas (nucleus) is confined to a region $\lesssim 5''$ in size. As can be seen in Figures 3*a* and 3*b* the strength of such emission lines as [O I] λ6300, [N II] λ6584, and [S II] $\lambda\lambda$6717, 6731 relative to Hα indicates that this high-redshift gas cannot be excited by normal hot stars (Baldwin, Phillips, and Terlevich 1981; Heckman 1980*b*) but presumably is excited by processes reflecting the active state of the nucleus. While the lines are unusually strong in MCG 9-13-57, qualitatively similar emission-line spectra are commonly observed from the nuclei of early-type galaxies (Heckman 1980*b*).

The emission-line spectrum of the LVS (Figs. 3*a*–3*b*) is quite different in character. No [O I] λ6300 is detected, [O III]/H$\beta \sim 1$, and Hα is $\gtrsim 5$ times stronger than either [N II] λ6584 or [S II] $\lambda\lambda$6717, 6731. The precepts of Baldwin, Phillips, and Terlevich (1981), Heckman (1980*a*), and Stauffer (1982) classify this emission-line spectrum as one produced in gas ionized by hot stars. Such an emission-line spectrum is typical of the nuclei of late-type galaxies (Heckman 1980*a*). The LVS emission-line gas is more widely dispersed along P.A. 4°: we find detectable Hα emission extending over at least 15″ (from 7″ to 22″ south of the nucleus of DA 240). The intensity of the LVS line emission peaks sharply $\sim 15''$ south of the nucleus at the position of the more southerly of the two blue knots evident in Figure 2*b*. At this position, the Hα line has an equivalent width of ~ 30 Å.

The high- and low-redshift emission-line systems are disjoint in two ways. First (at least in P.A. $\approx 4°$), there is no spatial overlap between the two systems. Second, we find no detectable emission lines at redshifts intermediate between the two systems. Any emission line at such intermediate redshifts must be at least 5 times weaker than the LVS lines and at least 12 times weaker than the lines from the nucleus of the parent galaxy.

III. DISCUSSION

We now consider the data presented in the previous section in the light of three hypotheses to explain the low-velocity system in DA 240.

1. It is a jet, i.e., material ejected toward the observer from the active nucleus of the parent galaxy at velocities in excess of 3400 km s^{-1}.

2. It is an unrelated foreground galaxy; i.e., both MCG 9-13-57 and the LVS are at the Hubble distances implied by their velocities and, hence, are separated from one another by many megaparsecs.

3. It is a galaxy associated with the active parent galaxy. The association may or may not be related to the activity which led to the formation of the large-scale radio emission. The anomalous redshift of the LVS may or may not have a kinematic origin (e.g., Burbidge 1981; Arp 1982; Tifft 1980).

Hypothesis 1 was invoked by BSB II to explain the LVS in DA 240 and the HVS in NGC 1275. Hypothesis 2 was favored by Rubin *et al.* (1977) to explain the HVS in NGC 1275.

a) Jet

The sample of optical continuum/emission-line jets in active galaxies is rapidly expanding (e.g., Butcher, van Breugel, and Miley 1980; van Breugel and Heckman 1982). This sample can serve as a basis for comparison in order to evaluate the possibility that the LVS in DA 240 is a jet.

First consider how the LVS resembles such optical jets:

1. The two bright knots are approximately colinear with the nucleus of DA 240.

2. The emission-line gas and the region of continuum emission are roughly coextensive. This is also the case in the optical jets of M87 (Ford and Butcher 1979) and 3C 277.3 (Miley *et al.* 1981).

3. If the obscuration east and west of the nucleus of MCG 5-13-57 is taken to be a dust lane (viewed nearly edge-on), then the orientation of the LVS almost perpendicular to this (Fig. 1*b*) could support the jet hypothesis. Dust lanes are frequently perpendicular to the axes of radio sources, i.e., the presumed axes of jets in active galaxies (Kotanyi and Ekers 1979). Since the LVS and the major axis of DA 240 are grossly misaligned, this interpretation requires a drastic change of ejection axis of the nucleus of MCG 5-13-57 since the lobes of DA 240 were formed. One might infer some evidence for this from the misalignment of the individual lobes with the nucleus (Willis, Strom, and Wilson, 1974; Strom and Willis 1982).

We now summarize the ways in which the LVS is different from currently known optical jets:

1. The morphology of the LVS is strongly reminiscent of a spiral galaxy.

2. The orientation of the LVS relative to the nucleus of MCG 5-13-57 is misaligned by a very large angle ($\sim 60°$) with respect to the fundamental radio source axis (see also point 3 above).

3. There is no detectable radio continuum emission from the LVS. While all other known optical jets are characterized by a radio/optical continuum with a spectral index $\alpha_{RO} \approx 0.7$, the results of § II imply that $\alpha_{RO} \leq 0.24$ for the LVS if the optical continuum is entirely nonthermal.

4. The optical continuum is not featureless (as expected for a nonthermal jet) but instead possibly exhibits absorption lines.

5. The spectrum of the LVS emission-line gas

resembles that of an ordinary H II region, i.e., gas photoionized by hot stars.

6. The velocity of the LVS with respect to the parent galaxy would be ~ 10 times larger and the velocity width ~ 10 times smaller than in all the other optical jets with optical line emission (i.e., 3C 277.3, Miley *et al.* 1981; Cen A, Graham and Price 1981).

b) Foreground/Background Galaxy

Following the format of the previous section we first list the evidence in favor of the hypothesis that the LVS MCG 9-13-57 system is an optical, but not physical, pair of galaxies.

1. As was noted by BSB I, there are several galaxies near MCG 9-13-57. A finding chart, reproduced from a IIIa-J Schmidt plate taken by Dr. A. G. de Bruyn, is shown in Figure 4 (Plate 5). Dr. de Bruyn (private communication) has also obtained spectra of ten galaxies near DA 240. Most appear to form a group, including MCG 9-13-57. Two others are a considerable distance to the south and probably belong to the nearby cluster Zw 0756.1+5616. However, one of the galaxies close to MCG 9-13-57 (see Fig. 4) has a redshift (z) of 0.026, which is close to $z = 0.024$ for the LVS. This suggests that the LVS is a member of a small group of galaxies in the foreground of DA 240.

2. There are several indications that the LVS is a late-type galaxy viewed nearly face-on: its morphology (also noted by BSB I), the quiescent kinematics of the emission-line gas (which is in accord with that expected of a spiral galaxy seen at low inclination angles), the possible detection of absorption lines at the same redshift as the emission lines, the relatively blue color, the spectral resemblance to normal H II regions, and the coextension of the regions with optical line and continuum emission. Also, the strength of the Hα emission line suggests that the LVS is a late-type spiral galaxy. The Hα equivalent width is ~ 30 Å in the southerly blue knot of the LVS, compared with median values of 5 Å and 20 Å for the nuclei of Sbc and Scd galaxies, respectively (Stauffer 1982). The absolute blue magnitude of the LVS, derived from m_B in Table 4 and assuming a distance of ~ 96 Mpc ($H_0 = 75$ km s^{-1} Mpc^{-1}), is $M_B = -17$. Such low-luminosity galaxies are quite common (e.g., the SMC has $M_B \approx -16$, the LMC has $M_B \approx -17$, and M33 has $M_B \approx -18$). The lack of detectable radio continuum is to be expected for such a low-luminosity late-type galaxy at a distance of ~ 100 Mpc (e.g., Hummel 1981).

The evidence against the above hypothesis is as follows:

1. The morphology of the LVS, while resembling a spiral galaxy, is somewhat peculiar in that it exhibits two blue knots (H II regions or nucleus + H II region?) of roughly equal brightness (Table 4) located $\sim 6''$ (~ 3 kpc) apart and collinear with the nucleus of an active galaxy (MCG 9-13-57). The *a posteriori* statistical chance of such a curious alignment of unrelated objects can be made arbitrarily low, so that the jet hypothesis might seem more attractive.

2. An intervening late-type spiral galaxy would be expected to show absorbing H I. In the sample of Balkowski (1973) the percentage of galaxies with $N_{\rm H\,I} \lesssim 3 \times 10^{20}$ cm^{-2} declines smoothly with Hubble type: 47% for Sa, 33% for Sb, 17% for Sc, and 4% for Sd. Since many of the arguments given above favor interpreting the LVS as a late-type spiral galaxy, the lack of H I absorption may be somewhat unexpected. However, H I may be quite patchy, and we sample only one small area of the outer part of a nearly face-on galaxy in searching for absorption against the nuclear core of MCG 9-13-57.

c) Associated Galaxy

The evidence for the associated galaxy hypothesis is essentially identical to that for the foreground/background galaxy hypothesis. We therefore confine further evaluation to the ways in which the associated galaxy hypothesis circumvents the above objection to the foreground/background galaxy hypothesis:

1. If the LVS and the parent galaxy are physically associated, most *a posteriori* statistical arguments are not relevant.

2. The lack of H I in absorption could be attributed to the location of the LVS *behind* MCG 5-13-57.

3. If the LVS is a galaxy interacting with MCG 9-13-57, a peculiar morphology may be expected.

The associated galaxy hypothesis has some major problems not shared with the other hypotheses:

1. If the LVS and MCG 5-13-57 are interacting (possibly triggering the activity in MCG 5-13-57 and star formation in the LVS), then it is surprising to find the LVS so quiescent (the gas velocity is constant to within ~ 50 km s^{-1}).

2. The association of two galaxies differing in velocity by ~ 3400 km s^{-1} is physically unlikely according to all but a few astronomers (e.g., Arp 1982; Burbidge 1981; Tifft 1980). While this is not a fundamental objection to the hypothesis in itself, it causes the practical problem of convincing a large (more conservative?) majority of astronomers to accept a radical change in their perspective of the universe.

IV. CONCLUSIONS

We have presented new radio and optical observations intended to elucidate further the nature of the low-velocity system in the parent galaxy of DA 240 (MCG 9-13-57). We have considered several possible explanations for this feature and conclude that it is most likely a spiral galaxy that is a member of a small group of galaxies in the foreground of DA 240. The most important evidence for this can be summarized as follows: (*a*) Its morphology resembles that of a spiral galaxy. (*b*) It bears a spectroscopic resemblance to a late-type galaxy in terms of its emission lines, and possibly in its absorption lines as well. (*c*) At least one galaxy near MCG 9-13-57 has a redshift comparable to that of the LVS, suggesting that the LVS is a member of a small group of galaxies seen in projection against MCG 9-13-57. (*d*) It is not a radio continuum source.

To interpret the LVS as a jet, i.e., evidence for a collimated energy flow from the nucleus of MCG 9-13-57, appears to us much more contrived. As a jet it would have many unusual features, most notably its complex morphology, misalignment with the radio source, the lack of radio continuum, and the possible presence of optical absorption lines.

As noted by BSB II, the LVS in DA 240 in some ways resembles the high-velocity system in NGC 1275. They proposed that both these features are the results of collimated ejections of gas from active galactic nuclei. However, for NGC 1275 there is now also quite strong evidence that the HVS is an intervening, late-type, spiral galaxy (e.g., Rubin *et al.* 1977; Kent and Sargent 1979; van Gorkom and Ekers 1983). Some may consider the existence of two such "accidental projections" too much of a coincidence, and a further *statistical* study of the occurrence of such objects may be useful.

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REFERENCES

Arp, H. 1982, *Ap. J.*, **256**, 54.
Baldwin, J. A., Phillips, M. M., and Terlevich, R. G. 1981, *Pub. A.S.P.*, **93**, 5.
Balick, B., and Heckman, T. M. 1983, *Ap. J.* (*Letters*), **265**, L1.
Balkowski, C. 1973, *Astr. Ap.*, **29**, 43.
Bridle, A. H., Fomalont, E. B., and Cornwell, T. J. 1981, *A.J.*, **86**, 1294.
Burbidge, E. M., Smith, H. E., and Burbidge, G. R. 1975, *Ap. J.* (*Letters*), **199**, L137 (BSB I).
———. 1978, *Ap. J.*, **219**, 400 (BSB II).
Burbidge, G. 1981, in *Tenth Texas Symposium on Relativistic Astrophysics*, ed. R. Ramaty and F. C. Jones (*Ann. NY Acad. Sci.*, Vol. **375**), p. 123.
Butcher, H. R., van Breugel, W. J. M., and Miley, G. K. 1980, *Ap. J.*, **235**, 749.
de Vaucouleurs, G., and de Vaucouleurs, A. 1972, *Mem. R.A.S.*, **77**, 1.
De Young, D. S., Roberts, M. S., and Saslaw, W. C. 1973, *Ap. J.*, **185**, 809.
Ford, H. C., and Butcher, H. R. 1979, *Ap. J. Suppl.*, **41**, 147.
Graham, D. A., Weiler, K. W., and Wielebinski, R. 1981, *Astr. Ap.*, **97**, 388.
Graham, J. A., and Price, R. M. 1981, *Ap. J.*, **247**, 813.
Heckman, T. M. 1980*a*, *Astr. Ap.*, **87**, 142.
———. 1980*b*, *Astr. Ap.*, **87**, 152.
Heckman, T. M., Miley, G. K., Butcher, H. R., and van Breugel, W. J. M. 1981, *Ap. J.*, **247**, 603.
Hummel, E. 1981, thesis, University of Groningen.
Kent, S. M., and Sargent, W. L. W. 1979, *Ap. J.*, **230**, 667.
Kotanyi, C. G., and Ekers, R. D. 1979, *Astr. Ap.*, **73**, L1.
Miley, G. K., Heckman, T. M., Butcher, H. R., and van Breugel, W. J. M. 1981, *Ap. J.* (*Letters*), **247**, L5.
Oke, J. B. 1974, *Ap. J. Suppl.*, **27**, 21.
Rubin, V. C., Ford, W. K., Peterson, C. J., and Oort, J. H. 1977, *Ap. J.*, **211**, 693.
Shaffer, D. B., and Marscher, A. P. 1979, *Ap. J.* (*Letters*), **233**, L105.
Stauffer, J. 1982, *Ap. J. Suppl.*, **50**, 517.
Strom, R. G., and Willis, A. G. 1982, Proc. of a Workshop on Optical Jets in Galaxies (ESA SP-162), p. 83.
Thompson, A. R., Clark, B. G., Wade, C. M., and Napies, P. J. 1980, *Ap. J. Suppl.*, **44**, 151.
Tifft, W. G. 1980, *Ap. J.*, **236**, 70.
van Breugel, W. J. M., and Heckman, T. M. 1982, in *IAU Symposium* 97, *Extragalactic Radio Sources*, ed. D. S. Heeschen and C. M. Wade (Dordrecht: Reidel), p. 61.
van Gorkom, J. H., and Ekers, R. D. 1983, *Ap. J.*, **267**, 528.
Willis, A. G., Strom, R. G., and Wilson, A. S. 1974, *Nature*, **250**, 625.

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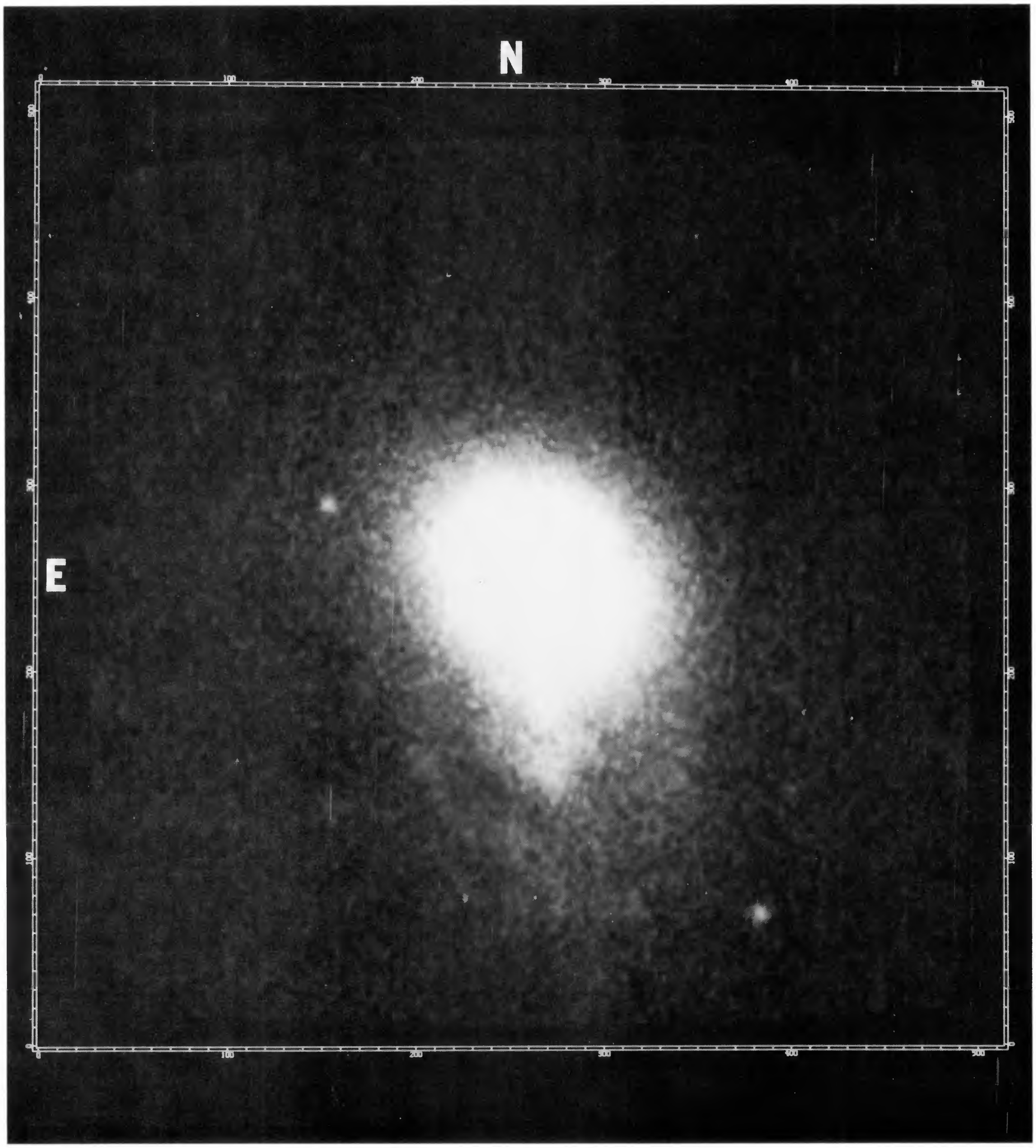

FIG. 1*a*.—Blue image (75″ × 75″) of the parent galaxy (MCG 5-13-57) of DA 240. The low-velocity system is the feature extending southward of MCG 5-13-57. North is upward; east is to the left.

VAN BREUGEL *et al.* (*see* page 64)

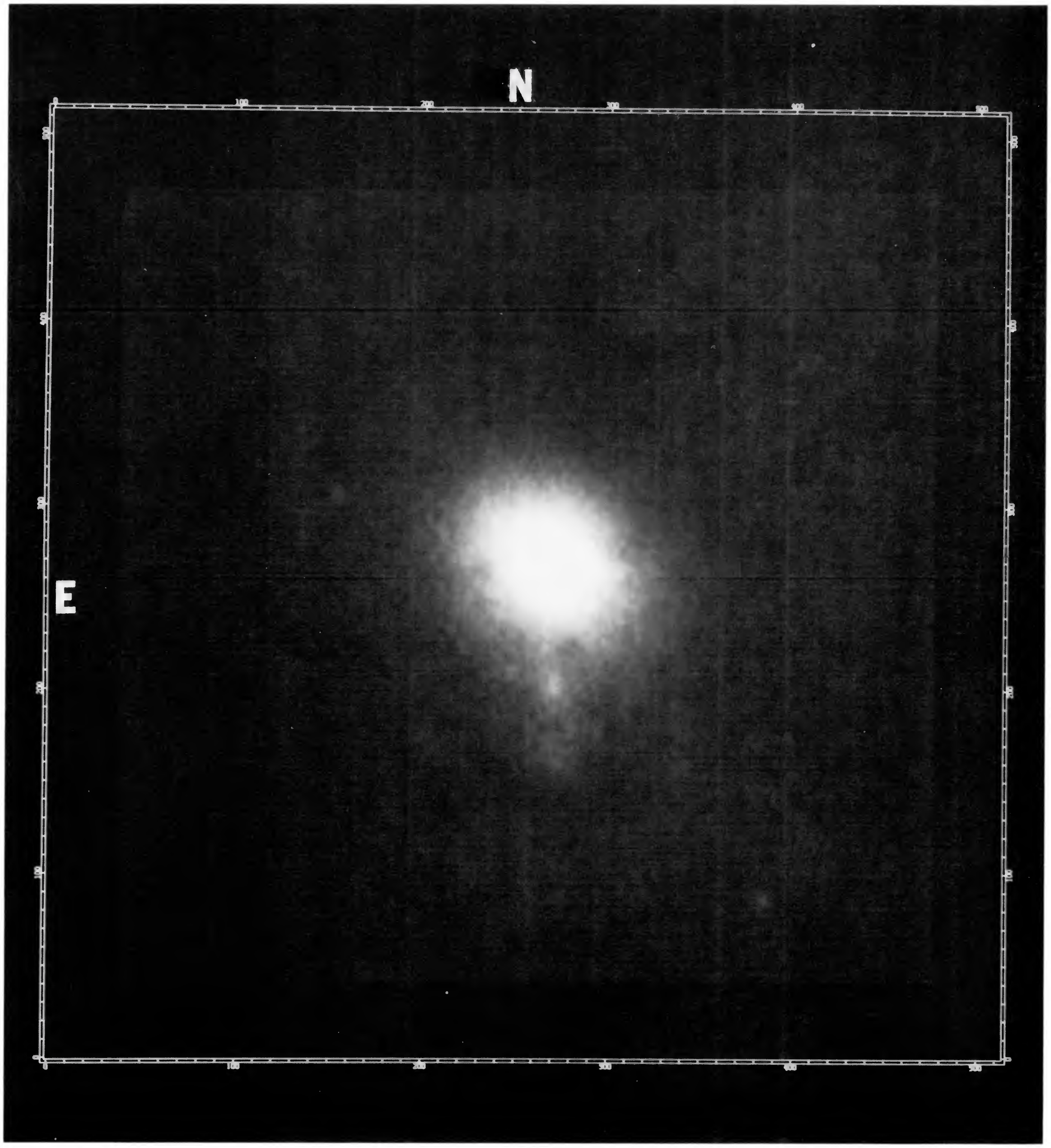

FIG. 1*b*.—The same image as in Fig. 1*a* but with a different brightness transfer function to show the various absorption patches and the knottiness of the LVS.

VAN BREUGEL *et al.* (*see* page 64)

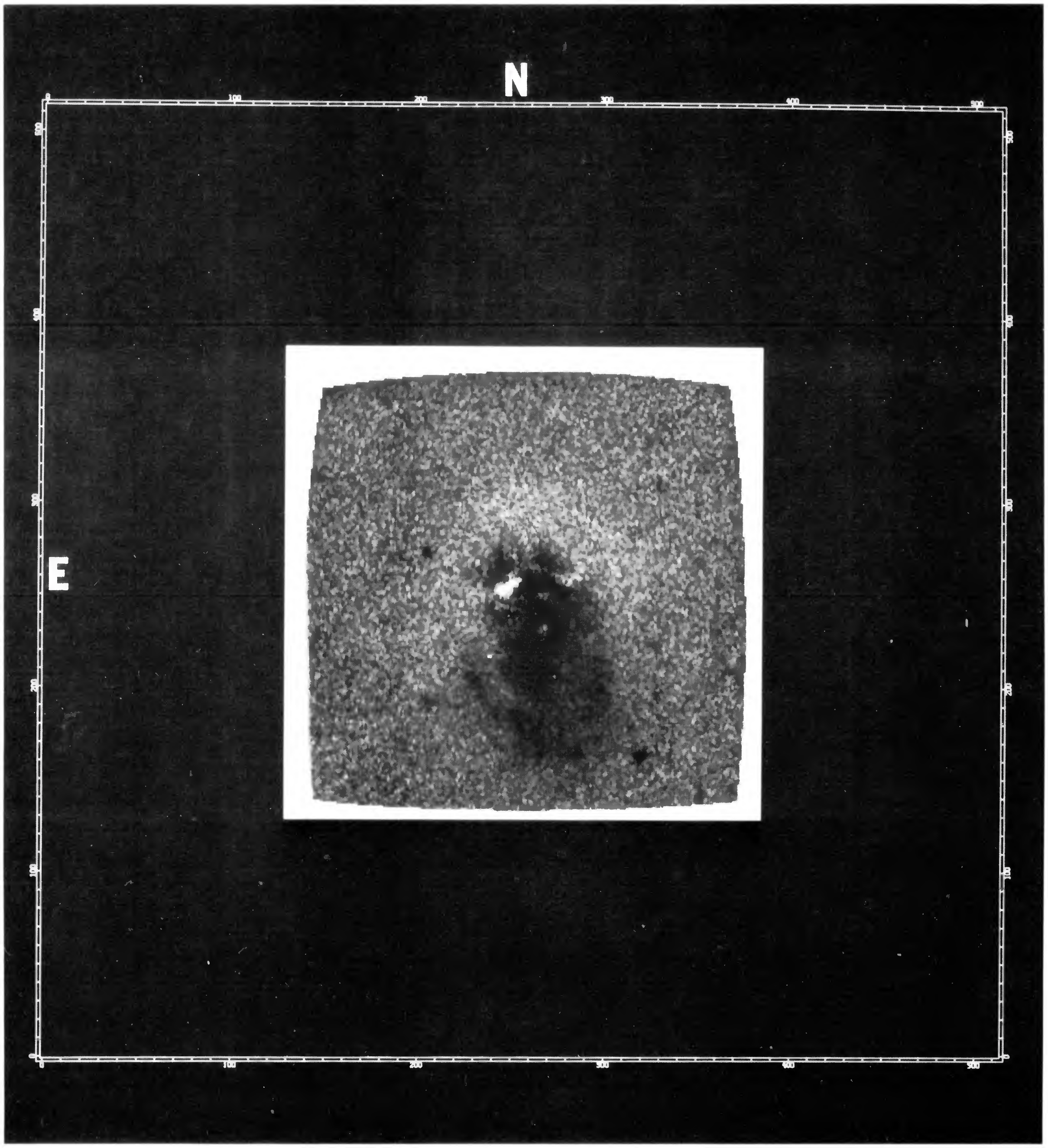

FIG. 2*a*.—The same field as in Fig. 1*a* but with a galaxy model for MCG 5-13-57 subtracted (see § II*c*). The brightness contrast is optimized to show the loop structure south of the LVS. The lighter region north of the LVS is due to the, intentional, oversubtraction of the galaxy model. The white patches in the nuclear region of MCG 5-13-57 are caused by oversubtraction of the galaxy model near obscured regions (see Fig. 1*b*).

VAN BREUGEL *et al.* (*see* page 64)

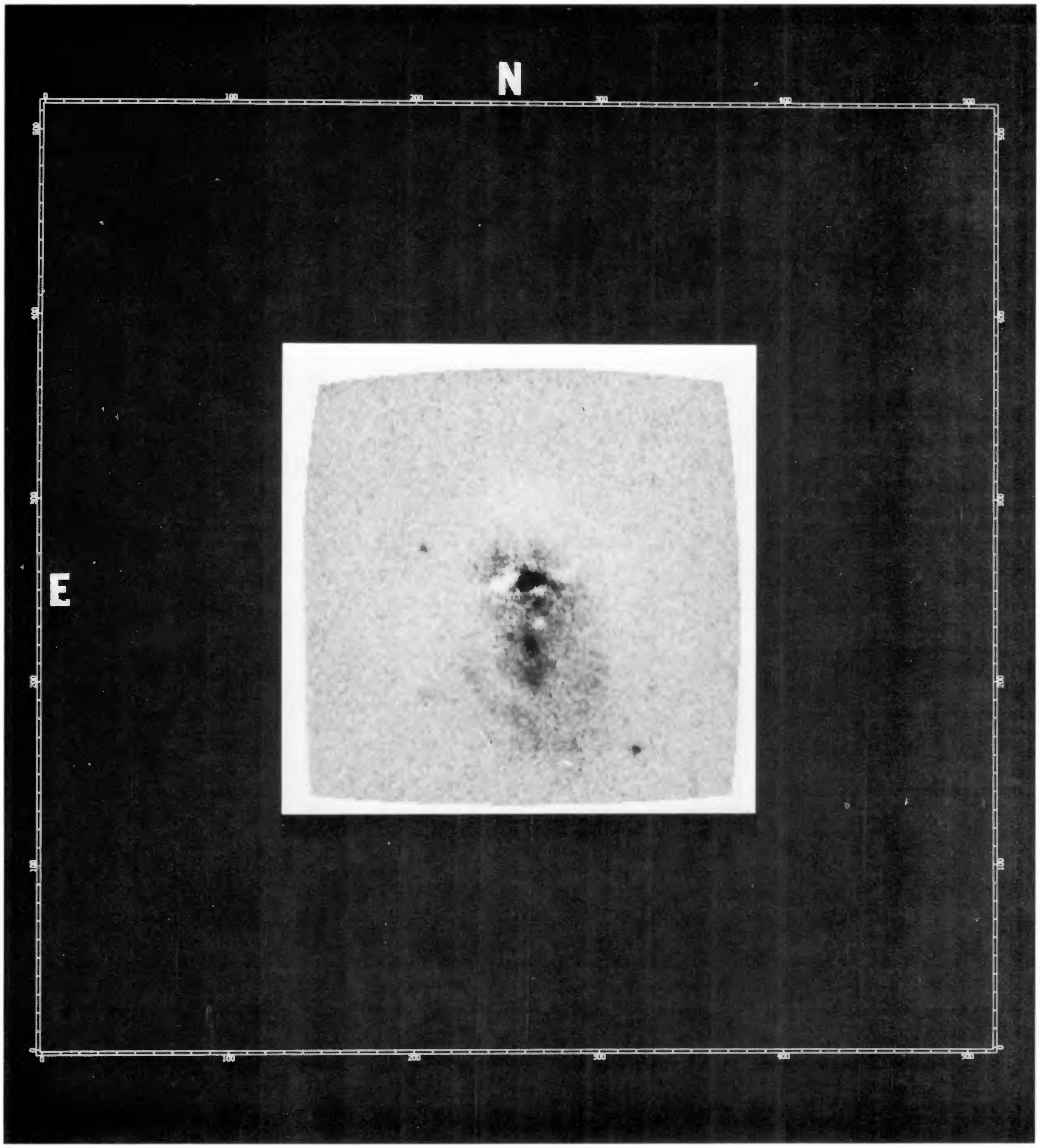

FIG. 2b.—The same image as shown in Fig. 2a but with a brightness transfer function which shows better the knottiness of the LVS (dark) and the obscured regions (white) near the nucleus of MCG 5-13-57 (black, northernmost region).

VAN BREUGEL *et al.* (*see* page 64)

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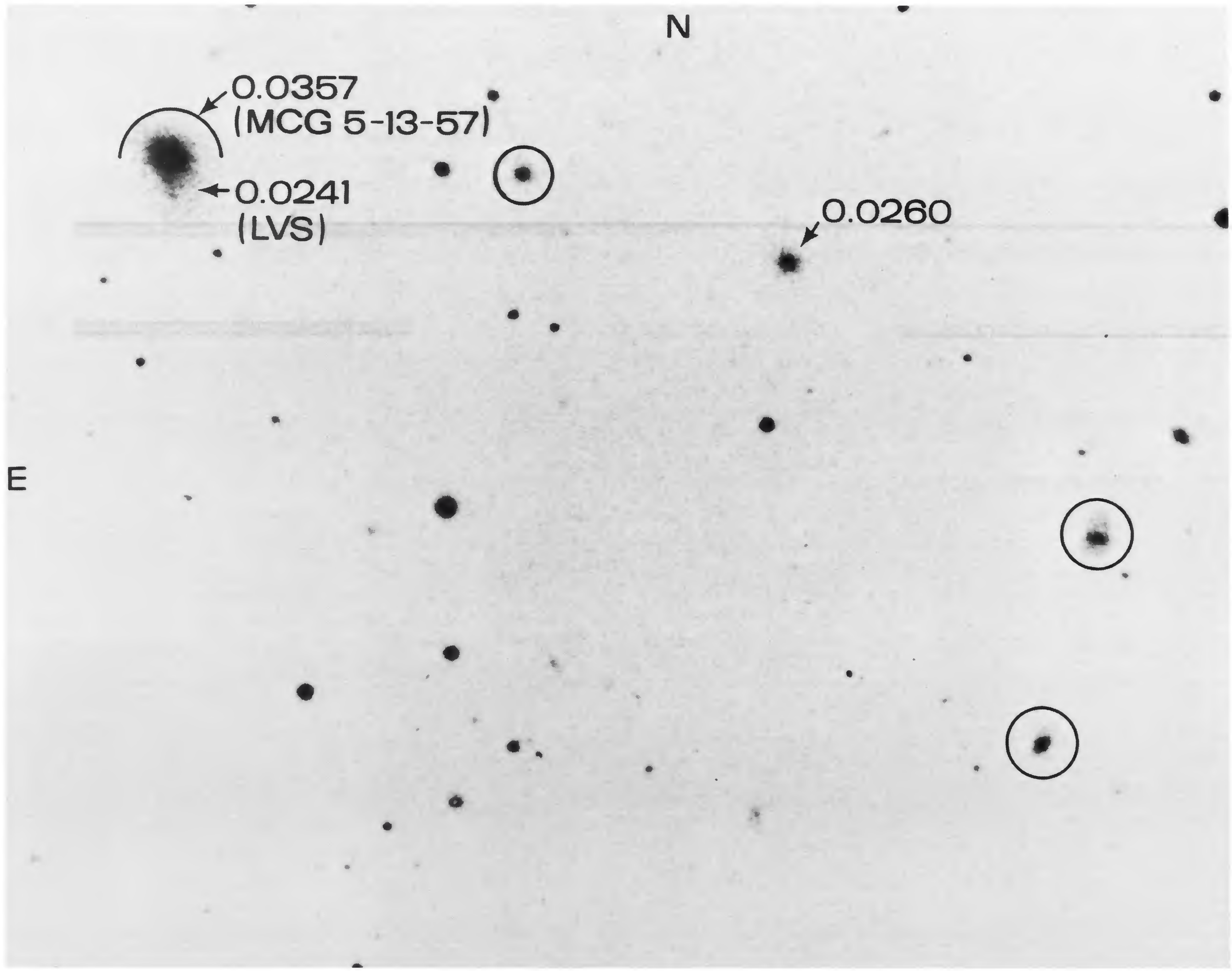

FIG. 4.—Finding chart for galaxies near the center of DA 240. Members of the DA 240 group, including the parent galaxy MCG 9-13-57, are circled ($0.033 < z < 0.037$). Systems with $z \approx 0.025$ (the LVS and one western galaxy) are indicated by arrows. (The plate and most redshifts were taken by Dr. A. G. de Bruyn, private communication; observations by us with the Multiple Mirror Telescope showed that the circled galaxy west of MCG 5-13-57 also belongs to the DA 240 group.)

VAN BREUGEL *et al.* (*see* page 67)