THE ASTROPHYSICAL JOURNAL, 226: L119–L123, 1978 December 15

VLA OBSERVATIONS OF NGC 1265 AT 4886 MHz

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Received 1978 July 10; accepted 1978 August 25

ABSTRACT

Observations are presented of the head-tail radio galaxy NGC 1265, made with the VLA at 4886 MHz. The total intensity brightness distribution has a resolution of $1'' \times 1''.5$ and an rms noise of $\sim$150 μJy/beam area. These observations, combined with data at 2695 and 8085 MHz on a 35 km baseline in Green Bank, show that the nuclear component is less than $0''.1$ and has a slightly inverted spectrum.

The VLA map reveals a narrow continuous stream of emission leading away from the nucleus and out into the lower-surface-brightness tail. Several small knots are superposed on the stream. This brightness distribution is compared with the independent-blob model of Jaffe and Perola. We find that the brightness distribution predicted by this model does not agree well with the observed brightness distribution. We suggest that a hot interstellar medium in the galaxy may be necessary to explain the complex structure.

Subject headings: galaxies: structure — interferometry — interstellar: matter — radio sources: extended

I. INTRODUCTION

Head-tail radio galaxies are now generally understood to result from the motion of a radio galaxy through the hot external medium found in clusters of galaxies. However, a clear picture of the physical processes producing the radio tail is still lacking. Ever since Ryle and Windram (1968) mapped NGC 1265 with the 1 mile (1.67 km) telescope, this source has been the most closely studied of the head-tail radio galaxies (e.g., Riley 1973; Miley 1973; Miley, Wellington, and van der Laan 1975). The well-determined X-ray and optical properties of the Perseus cluster (e.g., Malina *et al.* 1978) also give us a good picture of the surrounding medium. Thus at present NGC 1265 probably provides the best opportunity for studying the head-tail radio galaxy phenomenon in detail. In this *Letter* we present a new, higher-resolution map of NGC 1265 obtained with the VLA at 4886 MHz. The comparison of these data with current theoretical ideas about head-tail sources may suggest some new approaches to the subject.

II. OBSERVATIONS AND RESULTS

The observations were made on 1977 November 5 at 4886 MHz with seven 25 m antennas of the Very Large Array (VLA) now under construction near Socorro, New Mexico (see Heeschen 1975). The seven antennas were all located on the southwest arm (azimuth 236°). Table 1 summarizes the positions of the antennas for this experiment. The maximum baseline for this experment was 10.1 km Each antenna used two oppositely circularly polarized channels with bandwidths of 50 MHz. No useful polarization data were obtained. The system temperatures were $\sim$50 K. All 21 baselines were correlated; however, the shortest baseline, $\sim$100 m, was excluded from the final map due to instrumental problems. Thus our observations are sensitive only to structure $\lesssim 10''$ in size.

NGC 1265 was observed over hour angles from -6 to $+6$ hours. Every 15 minutes 3C 84 was observed for 1 minute to calibrate the complex instrumental gain as a function of time. The calibrated data were tied by way of 3C 286 to the Kellermann, Pauliny-Toth, and Williams (1969, hereafter KPW) flux density scale. After calibration the data were Fourier transformed and the resulting map cleaned. The rms noise on the final map is $\sim$150 μJy.

In Figures 1 (Plate L11) and 2 we display the resulting map as a radiograph and contour map, respectively. The radiograph brightness scale (Fig. 1) has been clipped so that only levels ≤ 5 mJy are shown. The central component (the elliptical bright spot in the center C1) is actually about 4 times as intense as any other part of the structure at this resolution. The "clean" restoring beam for both maps is an elliptical Gaussian $1''.43 \times 0''.99$ in extent at P.A. = 124°.

The optical image of NGC 1265, according to Bertola and Perola (1973), can be traced out to about 100″ from the center of the galaxy. If this is the case, then the entire field shown in Figures 1 and 2 is within the low-surface-brightness halo of NGC 1265.

III. DISCUSSION

a) General Morphology

Figures 1 and 2 cover only the very innermost part of Miley's (1973) map of NGC 1265 at 5 GHz. As on the

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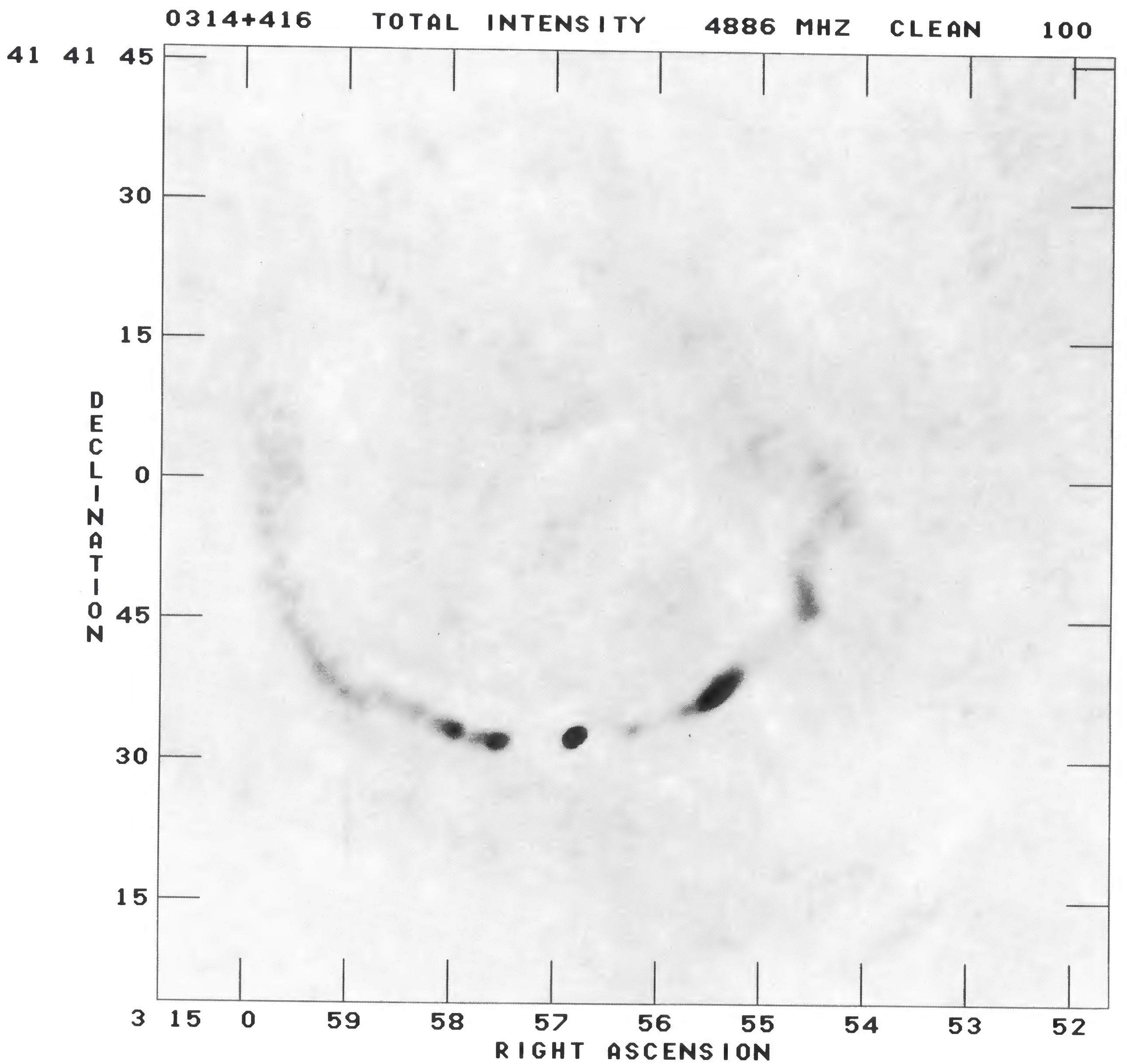

FIG. 1.—Radiograph of NCG 1265 at 4886 MHz. The radiograph has been truncated at 5 mJy in order to show the fainter features. The beam is the same as Fig. 2.

OWEN *et al.* (*see* page L119)

TABLE 1

DISTANCE OF EACH ANTENNA FROM THE NOMINAL ARRAY CENTER ALONG THE SW ARM (azimuth 236°)

Antenna	Position (m)
1	385
2	484
3	1590
4	3188
5	5223
6	7659
7	10473

map of Riley and Pooley (1975) with a resolution of $2'' \times 3''$, the central component dominates the map. Our observations with the 35 km baseline at 2695 and 8085 MHz in Green Bank show that this component has a flat spectrum ($\alpha \sim 0$) and is less than 0″1 in extent. If the source is optically thick and limited by Compton cooling to $T_b \sim 10^{12}$ K (e.g., Burbidge, Jones, and O'Dell 1974; O'Dell *et al.* 1978), the source should have a characteristic angular size

$$\theta \text{ (milli-arcsec)} \sim 10^{-3} S^{1/2} \text{ (mJy) } \lambda\text{(cm)} .$$

For 20 mJy at 6 cm, $\theta \sim 0.03$ milli-arcsec. For a Hubble parameter of 75 km s^{-1} Mpc^{-1}, this implies a linear size $\sim$0.01 pc.

Besides the nuclear component, Cl, a continuous narrow brightness distribution with several bright spots can be traced most of the way from the nucleus out into the more diffuse structure which makes the radio tail. At the resolution shown in Figures 1 and 2, the source is not symmetric in detail. Much more symmetry is apparent in the lower-resolution maps (e.g., Miley 1973). The three brightest spots outside of the nucleus (E1, E2, W1) all have a peak brightness $\sim$4 mJy per beam area. E1 and E2 are both unresolved and thus $\lesssim$0″5 in extent.

Assuming a spectral index of $\alpha = -0.8$ ($S \propto \nu^{\alpha}$), a distance of 72 Mpc for the Perseus cluster, an upper

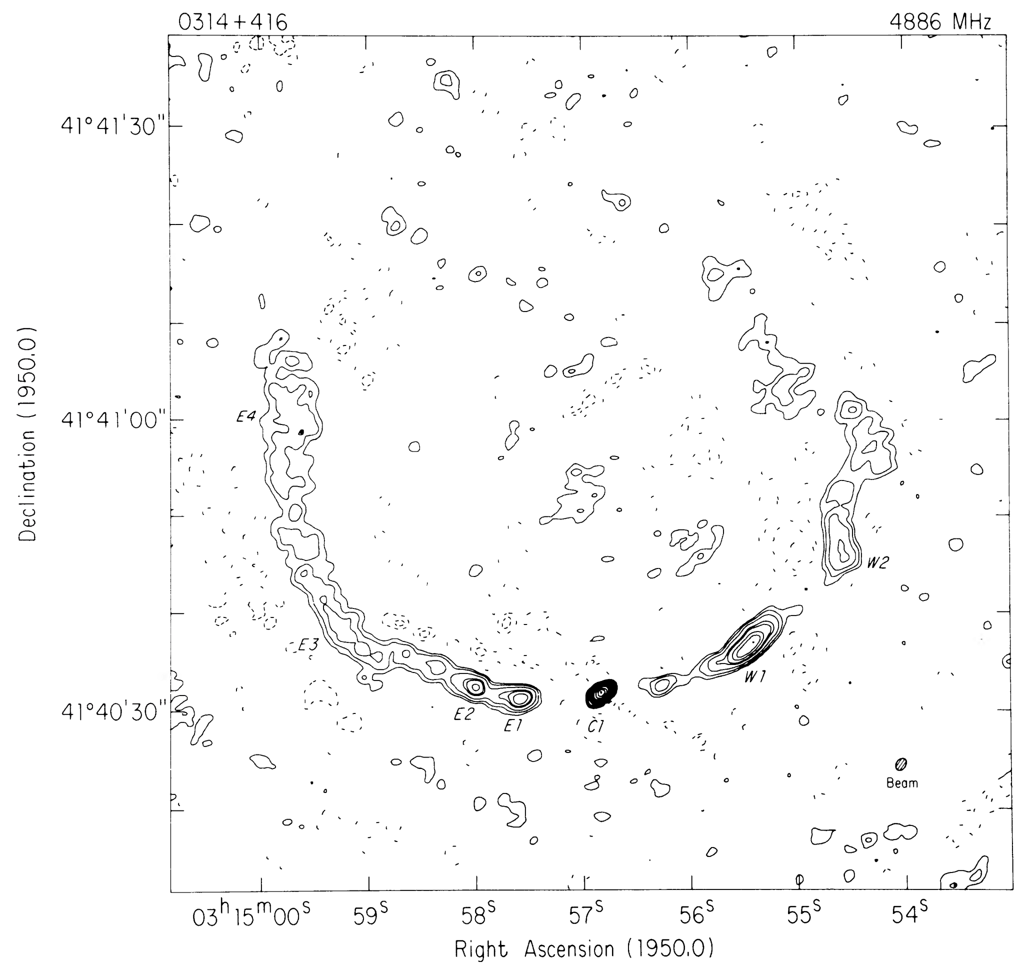

FIG. 2.—Total intensity contour map of NGC 1265 at 4886 MHz. The contour levels are 20, 16, 12, 8, 6, 5, 4, 3, 2, 1.6, 0.8, 0.4, 0.2, −0.2, −0.4, and −0.8 mJy per clean beam area. The shaded ellipse represents the half-power contour of the clean beam.

spectra cutoff of 10 GHz, and equal total energies in protons and electrons, a minimum energy density of 2×10^{-10} ergs cm^{-3} is required in knots E1, E2, and W1. Thermal pressure from an external gas of density $\sim 10^{-3}$ cm^{-3} and temperature $\sim 10^8$ K is too small to confine blobs of this energy density. Dynamic confinement of the blobs can be accomplished, however, for ejection velocities $\gtrsim 10^4$ km s^{-1}. No change in the above assumed parameters consistent with Miley (1973) will significantly lower this energy density. A number of different assumptions could raise the actual energy density.

b) Possible Models

The independent-blob model for head-tail sources was first discussed in detail by Jaffe and Perola (1973). In this model the galaxy ejects symmetric pairs of blobs of plasma and magnetic field into the intracluster "wind" which blows by the galaxy due to its motion through the cluster. The blobs are decelerated with respect to the rest frame of the intracluster medium by the dynamic pressure they encounter as they move out into the wind. Eventually they expand, come to rest, and reach equilibrium with the thermal gas in the cluster. The role of hydrodynamic instabilities (Cowie and McKee 1975) and subsequent turbulent acceleration in the blobs (Pacholczyk and Scott 1976) have been examined by these authors for their effect on the brightness and spectral index distributions.

In the independent-blob model, the shape of the trajectory is a sensitive function of the ejection velocity and the blob mass (see Jaffe and Perola 1973). This is a serious constraint for the independent-blob models; each blob ejection must be the same as the rest if a continuous stream is to be formed.

As shown in Figure 3, a model trajectory using an initial ejection velocity of 9000 km s^{-1}, at an angle defined in the figure of 8°, and a mass $m_{\rm blob} = 5 \times 10^3$ $M_\odot$ was found to fit the observed distribution. The result was obtained by numerical integration of the

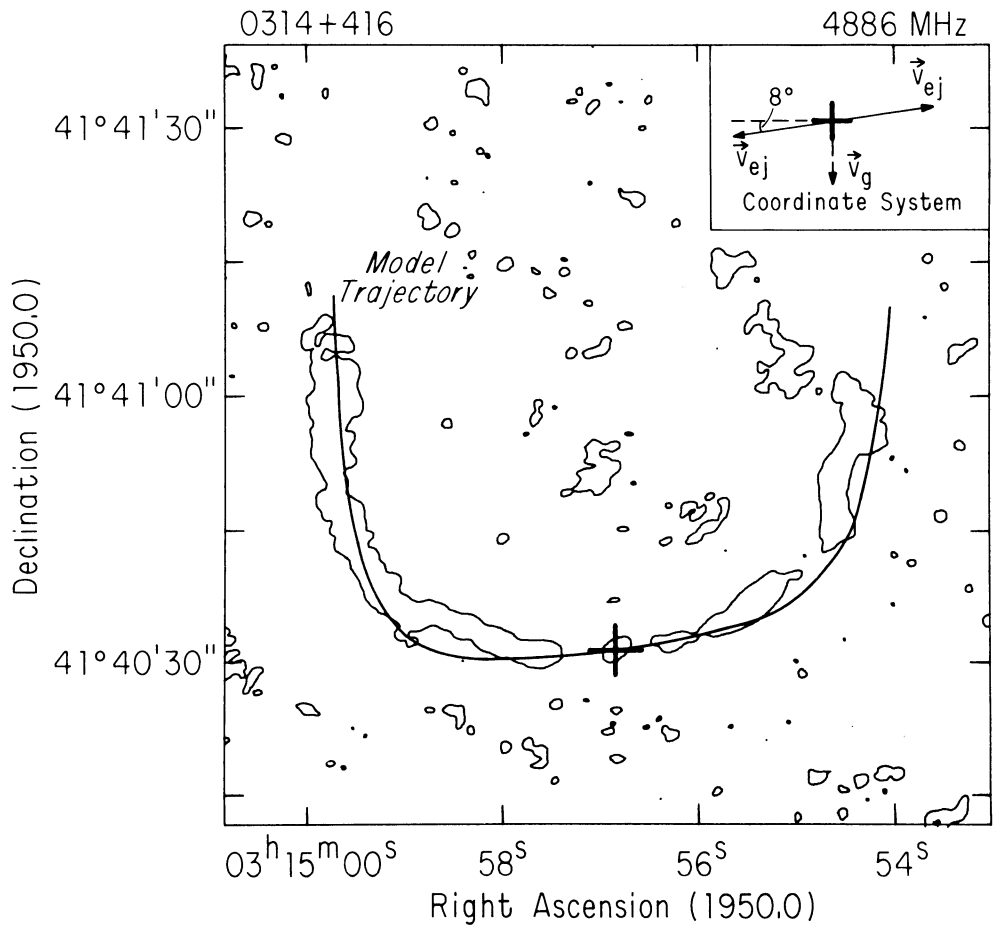

FIG. 3.—Schematic illustration of the independent-blob model trajectory described in the text. The contour plotted is at a level of 0.2 mJy per clean beam area. The cross marks the position at which the model computations began; the east and west trajectories were solved for independently The coordinate system used in constructing the model and the associated definition of the ejection angle (8°) are displayed in the upper right-hand corner.

equation of motion

$$\frac{d^2\mathbf{r}}{dt^2} = -\frac{GM_g(r_g)}{|\mathbf{r}_g|^3}\mathbf{r}_g - \frac{GM_{\rm cl}(r)}{|\mathbf{r}|^3}\mathbf{r} - \xi\frac{\pi R_{\rm blob}{}^2}{m_{\rm blob}}\rho_{\rm ext}(r)(\mathbf{v}-\mathbf{v}_g)|\mathbf{v}-\mathbf{v}_g| \,, \quad (1)$$

where $\mathbf{r}[\mathbf{r}_g]$ is the distance of the blob from the center of the cluster [galaxy], and $\mathbf{v}[\mathbf{v}_g]$ is the velocity of the blob [galaxy] with respect to the cluster center. $M_g(r_g)$ and $M_{\rm cl}(r)$ are the mass functions obtained by integrating the King (1966) galaxy and cluster density distributions, using total galaxy and cluster masses of 5×10^{11} $M_\odot$ and 5×10^{14} $M_\odot$, respectively. The density and temperature of the intracluster medium were calculated from a hydrostatic model (e.g., Lea 1975; Bahcall and Sarazin 1977), using central values $\rho_{\rm ext}(0) \sim 2 \times 10^{-27}$ g cm^{-3}(2×10^{-3} cm^{-3}) and $T_{\rm ext}(0) \sim 10^8$ K. A space velocity $v_g = 3000$ km s^{-1} with respect to the intracluster medium was assumed (Chincarini and Rood 1972; Miley *et al.*). The drag coefficient ξ was taken to be $\langle\text{cosine}\rangle^2 = \frac{1}{2}$, averaged over the blob surface. The deceleration in the above expression is valid for a spherical blob moving hypersonically through the surrounding medium. When the blob slows to near the sound speed of the external gas, the dynamic pressure increases slightly (e.g., Landau and Lifshitz 1959). This subsonic domain was ignored, however, since the resulting error is small with respect to other uncertainties in the assumed blob and galaxy parameters.

Although the fit to the trajectory is not particularly good in detail, the general shape is consistent, given the assumptions made for the equation of motion. The gravitational terms in equation (1) actually have little effect; a similar trajectory was derived analytically ignoring these terms. The dynamic pressure is sufficient to confine the blobs based upon the minimum energy density of the blobs derived earlier. The observed increase in angular size of the stream is also in reasonable agreement with the model predictions ($r_b = 0''.25$ at El and $r_b \sim 1''$ at E4). However, one point presents a serious problem for this model. As can be seen on earlier maps (e.g., Miley *et al.*), just north of $\delta = 41°41'$ the tail abruptly widens. In a simple independent-blob model the tail should retain a constant width when it has reached a velocity less than the equivalent thermal velocity. This should occur near the turning points E3 and W2 shown in Figure 1. Because of the rapid increase in tail width, we must reject this model.

The sudden flaring out suggests that some change in the physical conditions in the external medium occurs over the path from the nucleus out into the tail. Qualitatively this could be the situation if the galaxy possesses a significant interstellar medium.

On the simplest grounds it seems likely that an elliptical galaxy would have a significant interstellar medium due to the remnants of mass loss occurring during ordinary stellar evolution. It might seem curious that observations have thus far failed to detect a significant interstellar medium in ellipticals. Faber and Gallagher (1976) have discussed this point and suggest that a hot, interstellar wind is responsible for removing the debris from the galaxy. However, as they and Gisler (1976) point out, very massive ellipticals may have trouble maintaining a wind. Lea and DeYoung (1976) and Gisler (1976) have both discussed mass loss from galaxies in clusters due to ablation as the galaxy moves through the intracluster medium. Although both papers conclude that most of the interstellar medium is lost in this process, Lea and DeYoung find that a significant part of the interstellar medium remains with the galaxy. Characteristic dimensions $\sim$10 kpc for the region enclosed by the contact surface between the interstellar medium and intracluster medium are suggested by these calculations. Interstellar equilibrium temperatures $\sim 10^7$ K and densities $\sim 10^{-2}$ cm^{-3} are typical of their results. As discussed by Faber and Gallagher, such a medium would be difficult to detect optically.

In NGC 1265, the dimensions of the thin stream region and the derived minimum energy densities seem to be consistent with such a medium. Since the particle density is higher, the ejection velocity necessary to confine the plasmoids is somewhat lower than in the above calculation but is still supersonic. The thermal pressure inside the galaxy would be similar to that of the intracluster medium. The more diffuse structure further back in the tail (Miley *et al.*) would then be due to the injection of the relativistic gas into the turbulent wake of the galaxy. Such a picture including possible mechanisms to bend the tail is discussed in more detail by Jones and Owen (1979).

The authors wish to thank Eric Greisen for help with the observations and reduction of these data. We also thank D. DeYoung, J. Eilek, and P. Hardee for critically reading the text.

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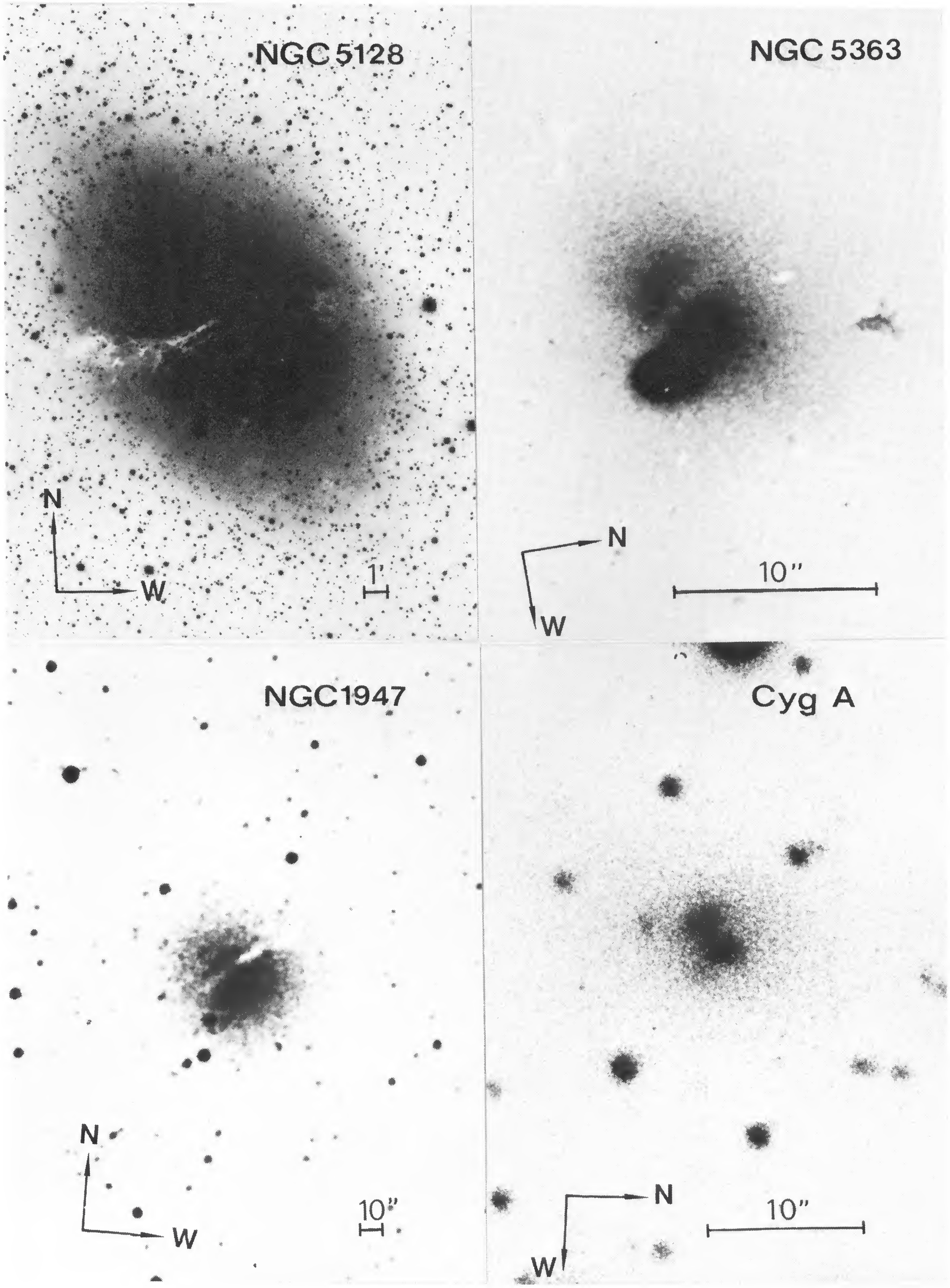

FIG. 1.—Photographs of NGC 5128, 5363, 1947, and Cyg A, showing the elongated structure crossed along the minor axis by a dust lane. NGC 5128 is from a deep IIIa-J plate taken with the 4 m CTIO telescope by Graham; NGC 5363 is from a plate taken by Hubble with the 100 inch (2.54 m) Hooker telescope; NGC 1947 is from the ESO B Atlas; and Cyg A is from a plate taken by Baade with the 200 inch (5.08 m) Hale telescope.

BERTOLA AND GALLETTA (*see* page L115)