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NEW OBSERVATIONS OF THE NGC 1275 PHENOMENON

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ABSTRACT

From a study of new spectroscopic and plate material of the peculiar galaxy NGC 1275, we make the following observations: (1) The main galaxy ($V = 5200$ km s^{-1}) has a smooth luminosity profile and is of type E or S0. (2) Immediately south of the nucleus, this galaxy exhibits an early-type spectrum; immediately north of the nucleus, the stellar population is obscured. (3) Further north of the nucleus, the stellar continuum ($V = 5200$ km s^{-1}) is of later type. In regions where optical obscuration is seen photographically, spectra show that the underlying continuum from the low-velocity galaxy is generally obscured, and strong emission from the high velocity is seen instead. There is generally a correlation in position between the obscuring knots and the high velocity emission. (4) The Balmer decrement is significantly steeper in the low-velocity emission lines than in the high-velocity system. (5) No absorption lines nor continuum are found in association with the high-velocity knots. (6) There is a smooth variation of velocity across the high-velocity region, which is consistent with a picture of a rotating galaxy seen almost edge-on, with $V_{max} = 150(\sin i)$ km s^{-1}.

We believe that the most straightforward interpretation of these observations is that an intervening late-type galaxy, $V = 8200$ km s^{-1}, is seen along the line of sight to the main galaxy, $V = 5200$ km s^{-1}.

Subject headings: galaxies: individual — galaxies: internal motions — galaxies: structure

We have obtained new spectroscopic and plate material of the peculiar galaxy NGC 1275 = Perseus A = 3C 84. From these observations we infer that an intervening late-type galaxy, $V = 8200$ km s^{-1}, is seen close to edge-on along the line of sight to the underlying galaxy, $V = 5200$ km s^{-1}. The presence of the high-velocity galaxy is unrelated to the extensive filaments seen in the low-velocity galaxy (Lynds 1970). While the two galaxies may be sufficiently close to each other that the distant filaments from the underlying galaxy are intermingled with the late-type galaxy, it is unlikely that the two main masses are interacting. This model naturally explains the narrow 21 cm absorption observed at $V = 8120$ km s^{-1} by De Young, Roberts, and Saslaw (1973). The details of these observations are presented more fully below:

1. The classification of NGC 1275 has been uncertain. Broad-band blue photographs show a region of absorption strings and knots to the northwest (Figs. 1*a*, 1*b* [Pl. 14]; Burbidge and Burbidge 1965; Minkowski 1968; Sandage 1971). A narrow-band continuum red photograph (Fig. 1*c* [Pl. 14]) taken in a spectral band free of emission lines in both velocity systems ($\lambda_0 = 6558 \pm 46$ Å; $\lambda_{5200} = 6446 \pm 45$ Å; $\lambda_{8200} = 6384 \pm 45$ Å) shows that the luminosity of the main galaxy decreases smoothly outward from the nucleus. A tracing across the galaxy image in an east-west direction to avoid the obscuration in the north gives a luminosity profile which is typical of a spheroidal system (Fig. 2). No discontinuity (e.g., see Freeman 1970) in the luminosity profile is seen out to $r = 60''$ (=30 kpc, for an adopted distance of 100 Mpc). Hence the main galaxy is not a spiral, but is either an elliptical or an S0 galaxy. Interior to $r = 4''$, an unresolved source rises above the theoretical curve derived from dynamical models which have been shown to closely match the luminosity profiles of spheroidal systems (King 1966).

2. Two emission-line systems in NGC 1275 were discovered spectroscopically by Minkowski (1955; 1957), and were studied extensively by Burbidge and Burbidge (1965). However, it has been uncertain whether the high-velocity system extends into the nucleus. A spectrum (M357, Table 1) taken with the 4 meter KPNO image-tube spectrograph shows that the high-velocity excited gas does not extend into the nucleus (Fig. 3*a* [Pl. 15]). Even more striking, however, is the appearance of the continuous spectrum (M1010) immediately off the nucleus (Fig. 3*b* [Pl. 15]). Away from the high-velocity gas toward the southeast, the continuum is crossed by an early-type absorption spectrum at $V = 5200$ km s^{-1}, with Balmer lines Hγ

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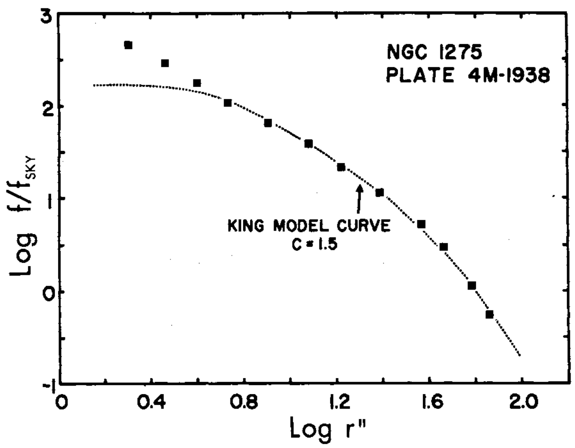

FIG. 2.—Luminosity profile of NGC 1275 from a 4 m direct plate (Fig. 1*c*) in a narrow band ($\lambda_0 = 6558 \pm 46$ Å) which includes no emission lines from either velocity system. The plate was traced in an east-west direction and the profile fit with a theoretical curve from King (1966). Interior to 4″, there is an additional unresolved source.

through H13 prominent in *absorption*, and Hα and Hβ strong in emission. No high-velocity gas is seen southeast of the nucleus. In contrast, just off the nucleus to the northwest, toward the high-velocity gas, the continuum is weaker, and Balmer lines Hα through Hζ are observed in *emission* in both velocity systems. In the low-velocity system, H and K are present, and a weak Hε in emission sits in the broad Ca II absorption. This weakened continuum in the region toward the high-velocity gas we take as evidence that the high-velocity system is located between the observer and the underlying E or S0 galaxy; absorption in this system obscures the underlying galaxy.

The early-type spectrum near the nucleus of NGC 1275 has been mentioned by Minkowski (1968), and south of the nucleus by van den Bergh (1972). The sudden change across the nucleus has not previously been noted.

3. Further north of the nucleus, in the region of the strongest absorption knots, there is additional evidence that the absorbing material consists of high-velocity knots which lie in front of the main galaxy. We show in Figures 4*a* and 4*b* (Plate 16) spectra taken with the slit aligned through stars A and E (spectra M583, M991). Here, high-velocity emission is generally coincident with absorption knots. This can be seen by comparing the locations of the high-velocity emission with the optical photographs. Especially striking are the horizontal stripings in the spectra (Figs. 4*a* and 4*b*). Where the underlying continuum is strong, there is generally emission from the low-velocity system and little high-velocity emission. In contrast, where the continuum is obscured, the emission from the high-velocity knots is most intense. The obscuring knots in the northwest region are between the observer and the underlying galaxy and have $V = 8200$ km s^{-1}. South of the nucleus, where no absorption patches are observed, no high-velocity gas is found. The association of visible absorption patches, high-velocity emission, and obscuration of the underlying (low-velocity) continuum seems now well established.

In the northwest region of the high-velocity knots, a stellar continuum is observed in regions where the obscuration is not intense. Absorption lines of Ca II H and K, the Morgan-Osterbrock (1969) metallic line blends at 3834 and 4385 Å, the G-band, and the Na I D-lines are observed, all with $V = 5200$ km s^{-1} (Fig. 4*c*). This change from an early spectral type near the nucleus to a late-type stellar spectrum at greater distances for the underlying galaxy is reminiscent of the less-pronounced change in spectral type across M82 (Burbidge, Burbidge, and Rubin 1964). A burst of star formation near the nucleus of NGC 1275 could have been triggered at the epoch of the expulsion of the outer filaments, as suggested by van den Bergh (1972).

4. Additional support for the conclusion that the high-velocity gas is located in front of the low-velocity galaxy comes from the difference in the Balmer decrements for the emission lines in the two velocity systems. The Balmer decrement is steeper for the low-velocity system than for the high (Fig. 4). In both velocity systems, Hα is of approximately equal intensity, but Hβ is notably weaker, and higher members of the Balmer series are almost absent in the low-velocity gas. Differing excitation mechanisms or differing internal dust contents could produce different Balmer decrements; however, placing the high-velocity gas in front of the lower naturally explains the steep Balmer decrement in the latter by absorption in the high-velocity system.

5. A search for H and K and the Balmer lines in absorption in the high-velocity system has been unsuccessful (Fig. 4*c*). We conclude that either there is no

TABLE 1

RECORD OF SPECTRAL OBSERVATIONS

Plate	Date	Dispersion (A mm^{-1})	Exposure* (minutes)	Spectral Region	Slitwidth (arcsec)	Seeing (arcsec)	Position Angle (degrees)
M357....	1974 Sept. 8	26	85	Red	1.1	1.25	110 through stars AF
M583....	1975 Jan. 15	53	230	Red	1.1	1.5	92 AE
M991....	1975 Nov. 4	47	210	Blue	1.3	2.5	92 AE
M1010...	1975 Nov. 8	94	35	Blue	1.1	1.25	110 AF

* IIIa-J, N_2-baked, preflashed plates (M357 not preflashed); scale perpendicular to dispersion = 25″ mm^{-1}. Transfer optics f/2, except f/1.75 for M583. No Moon for all exposures.

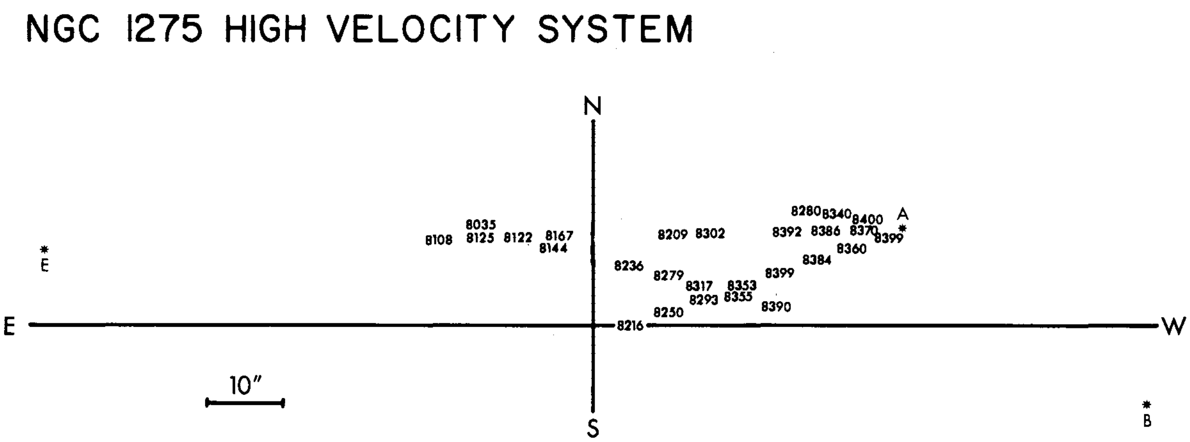

FIG. 5.—Velocity field for high-velocity excited gas seen along line of sight to NGC 1275, from 4 m spectra. Nucleus of underlying galaxy is located at origin. Note regular pattern of variation from 8100 km s^{-1} at east to 8400 km s^{-1} at west edge of emission. This pattern is consistent with velocities expected from an almost edge-on galaxy rotating with maximum velocity given by $V_{max} \approx 150(\sin i)$ km s^{-1}.

stellar continuum associated with the $V = 8200$ km s^{-1} knots, or the obscuration associated with the high-velocity knots is sufficient to hide the high-velocity stellar population. We know from the observations discussed above that it is sufficient to hide the continuum from the underlying main galaxy. Infrared observations in the region of the high-velocity system would be of value in identifying an obscured nucleus.

6. Spectroscopic evidence that the northwest knots can be emission regions in the outer parts of a late-type spiral or irregular galaxy comes from the velocity pattern, from the upper limit to H I in the system, and from the emission-line ratios. In the high-velocity gas, there is a fairly smooth transition from velocities near $V = 8100$ km s^{-1} in the east to velocities of $V = 8400$ km s^{-1} in the west (Fig. 5). This velocity pattern is consistent with that expected from a late-type galaxy seen almost edge on at inclination i, and rotating with a maximum velocity $V_{max} = 150(\sin i)$ km s^{-1}. There exist many galaxies which have morphological characteristics not unlike that which we are proposing for the intervening galaxy—a fairly regular pattern of emission knots, much gas and dust, and no obvious nucleus. One of these is another Perseus cluster member, a knotty irregular showing no obvious nucleus, which lies only 3′.5 NE of NGC 1275. The only galaxies of this morphological type for which we know there exist kinematical data are the members of the pair NGC 4038–4039 (Rubin, Ford, and D'Odorico 1970); these galaxies also show a smooth velocity variation.

The range of velocities in the high-velocity system is also consistent with the 21 cm absorption observed (De Young, Roberts, and Saslaw 1973) at a velocity of $V = 8120$ km s^{-1}. Reobservations by Ekers, van der Hulst, and Miley (1976) with the Westerbork telescope reveal that the absorption takes place in a region less than 6″ east-west and less than 9″ north-south around a position within 1″ of the small-diameter nuclear source. De Young, Roberts, and Saslaw discuss two alternative interpretations: absorption by a superposed second galaxy, or ejection from the nucleus. In the latter case, the gas is being ejected by one of the compact core components and is seen in absorption against another compact component, situated behind it. The only component sufficiently bright at 21 cm to explain the great depth of the absorption would be one of the "decimeter-wave" components found by Purcell (quoted by Pauliny-Toth *et al.* 1976). Though De Young, Roberts, and Saslaw suggest two mechanisms that might confine the ejection velocities to a narrow range, it seems doubtful whether under actual conditions a velocity range as small as 6 km s^{-1} could be maintained.

Interpretation as absorption by a cloud in an intervening galaxy seems more natural. The nucleus of NGC 1275 is so compact (about 10 pc) and contains so large a fraction of the total radio emission of the central region that a single cool interstellar cloud in the superposed galaxy could cause the deep absorption and would explain its small width of 6 km s^{-1}. From the velocity pattern, neutral hydrogen associated with the late-type galaxy would be expected to have a velocity less than or near 8200 km s^{-1} in the vicinity of the NGC 1275 nucleus. Additionally, Ekers *et al.* (1976) have placed an upper limit of 10^{10} $M_{\odot}$ for the neutral hydrogen in the 8200 km s^{-1} system, which is consistent with a late-type galaxy of average mass.

The emission-line ratios observed in the high-velocity gas (Fig. 4) offer supporting evidence for a late-type intervening galaxy. They are typical of large low density, high-excitation H II regions excited by hot stars at large radial distance from the nucleus of a late-type or irregular galaxy: $I(\mathrm{H}\alpha) \gg I([\mathrm{N\,II}])$; $I([\mathrm{O\,III}]) > I(\mathrm{H}\beta)$; $I([\mathrm{N\,II}]) \approx I([\mathrm{S\,II}])$; and $I([\mathrm{O\,II}]\,\lambda3729) > I([\mathrm{O\,II}]\,\lambda3726)$. Especially notable is the relatively low [N II]/[S II] intensity ratio, which is a reflection of the N/S abundance ratio. This low ratio implies that the intervening galaxy has recycled only a low mass of gas through nucleogenesis (Smith 1975). This is in marked contrast to the higher [N II]/[S II] intensity ratio in the low-velocity gas, both near and at some distance from the nucleus, which implies a later evolutionary state for the main galaxy.

We cannot rule out the possibility that the excitation mechanism in the late-type galaxy is related to its proximity to NGC 1275. Polarization measurements by Walker (1968) suggest the presence of optical synchrotron radiation and, as pointed out by Shields and Oke (1975), this could be sufficiently strong in the far-ultraviolet to ionize the outer filaments in the low-velocity system observed by Lynds (1970) extending out to $r \sim 50$ kpc. Additionally, alternative excitation mechanisms—e.g., collisional excitation due to the high velocity of this galaxy relative to the intracluster gas, or excitation due to the general X-ray radiation in the cluster—may well complicate the interpretation of the line ratios. However, the interpretation of the high-velocity system as a late-type intervening galaxy is consistent with the observed ratios.

NGC 1275 lies in the densest part of the Perseus cluster (Chincarini and Rood 1971; Bahcall 1974). While the probability of having a second galaxy along the line of sight is large, about 1/8, there are only a few late-type galaxies in the nuclear region of the cluster; however, we do not regard this as a strong objection to our model. Moreover, the velocity dispersion in the relevant part of the cluster is so high that this velocity difference is not unusual.

For all of the above reasons, we believe that there is good evidence that part of the NGC 1275 phenomenon can be explained by a superposition of a spheroidal and a late-type galaxy. On this model, the origin of the low-velocity filaments associated with the underlying galaxy is unrelated to the presence of the intervening galaxy. The model thus requires that we observe a galaxy along the line of sight to a galaxy which has previously undergone an explosive event, but the probability that this is the case is not prohibitively low at the center of the Perseus cluster.

Earlier models have ascribed the NGC 1275 phenomenon to the collision of two spiral galaxies (Minkowski 1957); to a nuclear explosion which has ejected the high-velocity material which would now be located beyond the galaxy (Burbidge and Burbidge 1965); or to the superposition of two galaxies (Shields and Oke 1975). De Young, Roberts, and Saslaw (1973) have discussed models with both one or two galaxies. Shields and Oke made spectrophotometric observations of the nucleus of NGC 1275 (low-velocity system only) and proposed a model of two superposed galaxies similar to the model presented here. From our kinematic and spectroscopic evidence extending out to include the high-velocity region, we believe that there is compelling evidence that the high-velocity system is located along the line of sight to an underlying spheroidal galaxy. We believe that the observations can most simply be interpreted as an almost edge-on late-type rotating system superposed on NGC 1275. Although the morphology of the intervening galaxy is somewhat unusual, any alternative model seems so contrived as to be practically unacceptable. Models with two superposed galaxies have been suggested before; we wish to emphasize that this interpretation now rests on a firm observational foundation.

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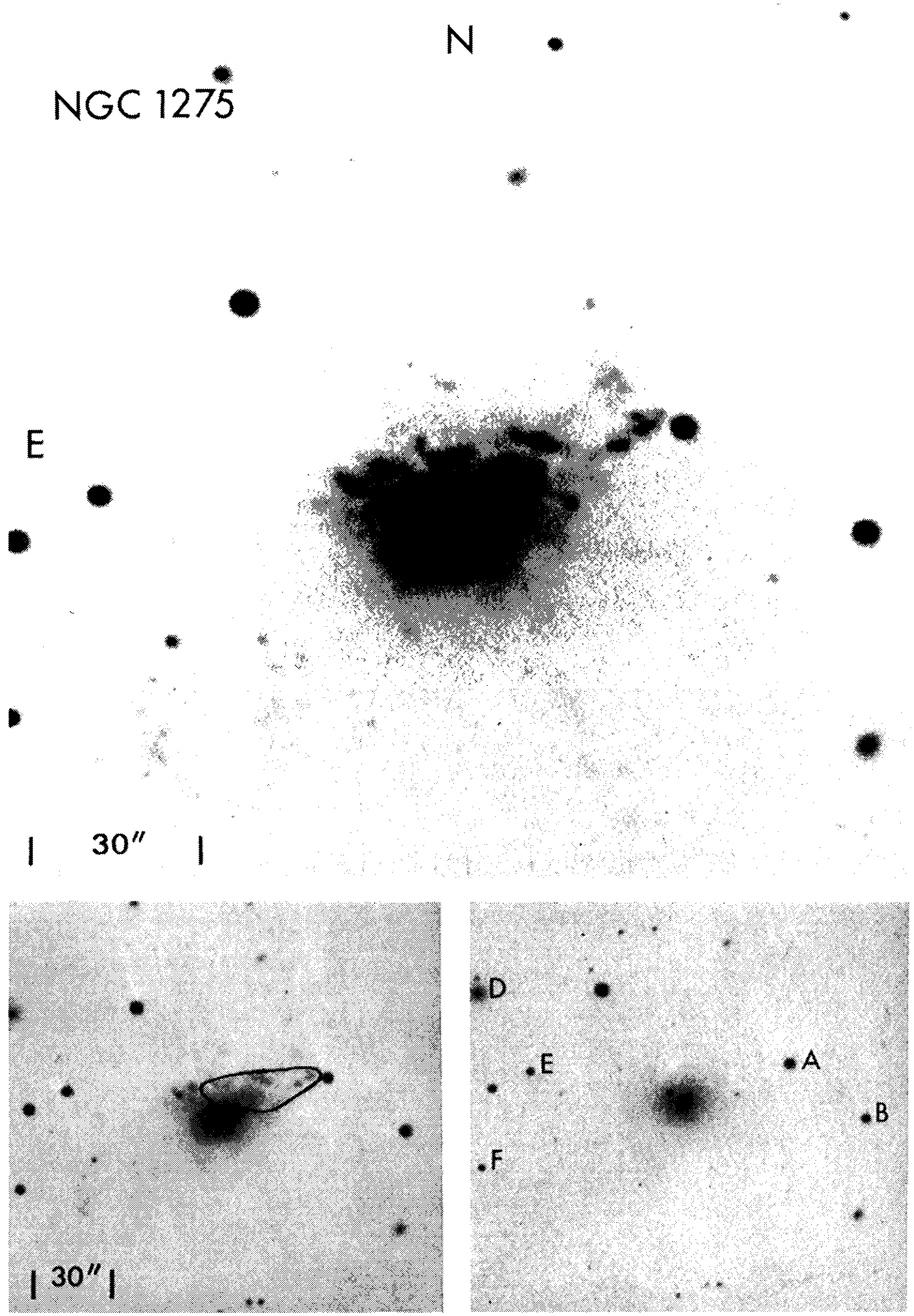

FIG. 1*a*.—NGC 1275, 4 m prime focus plate taken by Dr. S. Strom. N_2-baked IIIa-J plate + UG 2 filter, exposure time 2^h15^m, 1975 October 29.

b) 4 m prime focus plate, N_2-baked IIIa-J plate + UG 2 filter, exposure time 55^m, 1975 November 9. For both plates, the effective wavelength 3400–4000 Å includes emission from [O II] λ3727 of both velocity systems. The region containing all of the known high-velocity material is outlined.

c) 4 m prime focus plate, N_2-baked 098-02 + λ6558 interference filter (92 Å FWHM), exposure time 2^h, 1976 February 3. No emission lines in either velocity system are contained in the defined wavelength band. This continuum photograph of NGC 1275 illustrates the spheroidal nature of the underlying galaxy.

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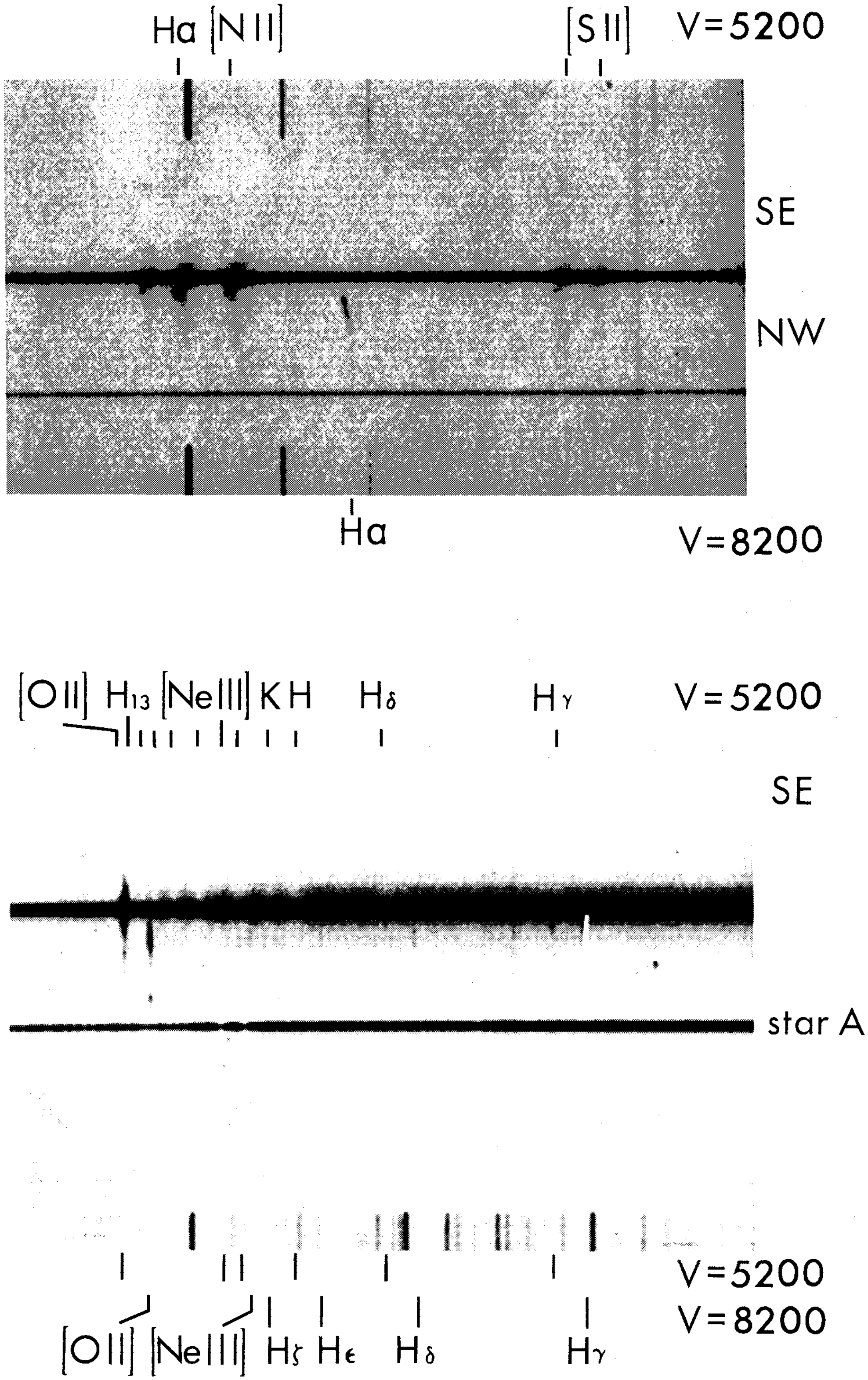

FIG. 3.—Spectra of the nuclear region of NGC 1275. (*a*) Plate M357, showing emission lines of Hα, [N II], [S II] at $V = 5200 \text{ km s}^{-1}$ crossing the nucleus while Hα at $V = 8200 \text{ km s}^{-1}$ does not extend into the nucleus. Original dispersion 26 Å mm^{-1}; scale perpendicular to the dispersion $25'' \text{ mm}^{-1}$; position angle 110° through stars A and F. (*b*) Plate M1010, P.A. 110°, dispersion 94 Å mm^{-1}, showing early-type Balmer *absorption* spectrum southeast of nucleus, $V = 5200 \text{ km s}^{-1}$. Northwest of nucleus toward star A, Balmer *emission* at both $V = 5200$ and $V = 8200 \text{ km s}^{-1}$ is present, and underlying stellar continuum is weaker.

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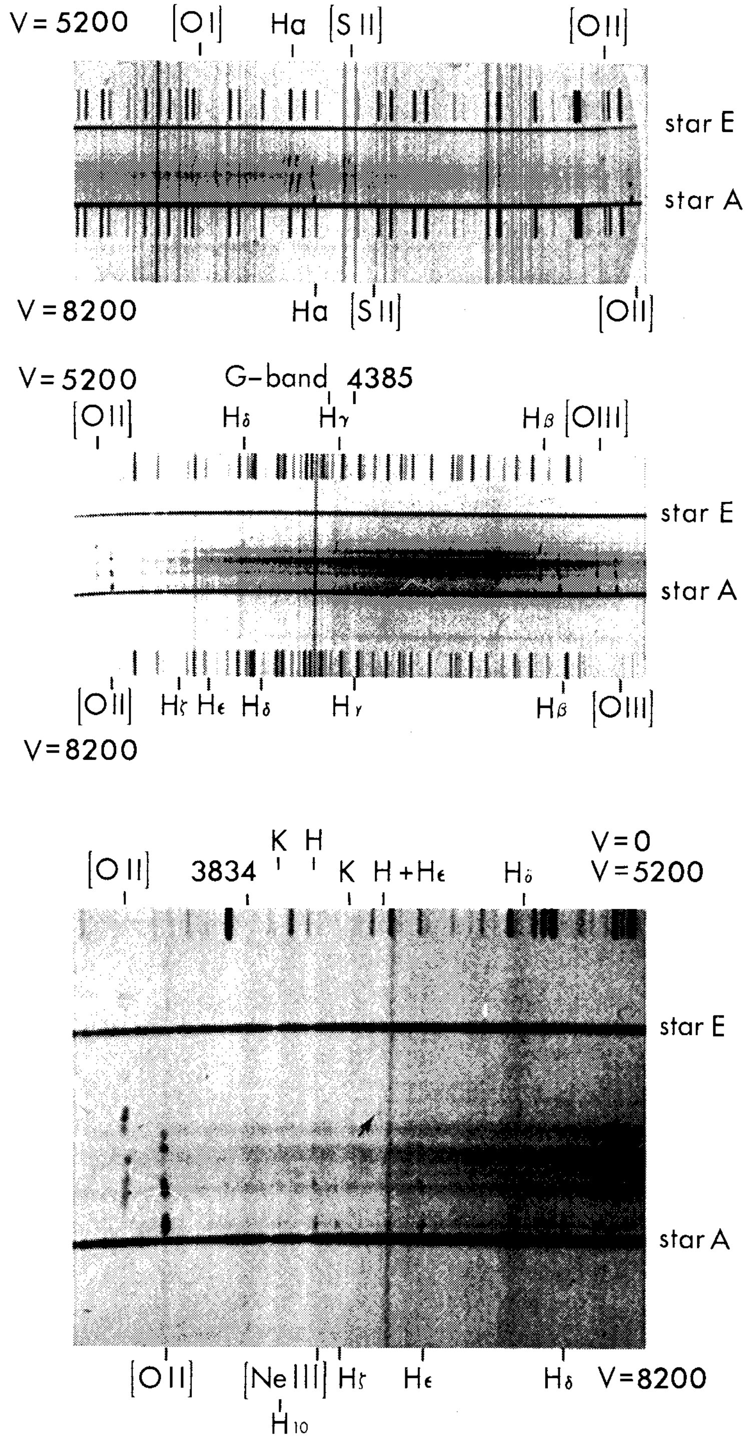

FIG. 4.—Spectra with slit aligned through stars A and E; dispersion 50 Å mm^{-1}. (*a*) M583, red spectral region, showing emission lines of Hα, [N II], [S II], and [O I] in high- and low-velocity systems. [O II] is seen in second order. (*b*) M991, yellow-blue spectral region, showing [O III], Balmer emission lines, [O II], and H and K in night sky and in galaxy, with $V = 5200$ km s^{-1}. Note steep Balmer decrement and weak [O III] λ5007 in $V = 5200$ system. Continuum arises from 5200 stellar population; striping is due to obscuration from intervening $V = 8200$ galaxy. Note that 8200 emission is often strong where background continuum is obscured. (*c*) Detail of H and K region in M991, showing H and K in night sky and H and K redshifted by $V = 5200$ km s^{-1}. Note narrow Hε in emission ($V = 5200$ km s^{-1}) at arrow. No absorption feature corresponding to location of Ca II H line redshifted by $V = 8200$ km s^{-1} is seen. Hε, $V = 8200$ km s^{-1}, is present in emission.

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