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EMISSION-LINE INTENSITIES AND RADIAL VELOCITIES IN THE INTERACTING GALAXIES NGC 4038–4039*

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ABSTRACT

Spectrograms of eighteen emission regions in the peculiar extragalactic system NGC 4038–4039 show emission lines of Hβ; [O III] λλ4959, 5007; He I λ5876; [O I] λ6300; [N II] λλ6548, 6583; Hα; and [S II] λλ6717, 6731. The value of the Hα/Hβ intensity ranges from 6 to 14. The helium-to-hydrogen abundance is 0.16 (uncorrected for reddening) or 0.071 (corrected for reddening by using the Hα/Hβ theoretical intensity ratio).

From a discussion of the sizes of the luminous regions, the systemic velocity, the magnitude of the brightest stars, and the magnitude of the 1921 supernova, a distance of 9 ± 3 Mpc is estimated.

The line-of-sight velocities show a spread of only 235 km sec^{-1} over all the emission regions. The velocity field exhibits a systematic variation from knot to knot, which can be interpreted as due to two rotating, interacting galaxies.

I. INTRODUCTION

NGC 4038–4039 is a peculiar galaxy described by Shapley and Paraskevopoulos (1940). It is number 244 in Arp's (1966) *Atlas of Peculiar Galaxies*, where other similar galaxies are also shown. Interest in NGC 4038–4039 was revived when Minkowski (1957) interpreted it as a pair of colliding galaxies coincident with a radio source. A kinematic study of the object has been made by Burbidge and Burbidge (1966), in whose paper additional photographs and earlier references can be found. We show in Figure 1 (Plate 1) a reproduction of a plate taken in 1921 by Lampland with the Lowell 42-inch reflector. Short-exposure photographs show a continuous loop of bright emission-like knots in the galaxy, embedded in a smooth, luminous background. No resolution into stars is seen. On long-exposure photographs, the emission knots are mostly hidden in two uniformly luminous ovals with major axes in position angles 55° and 100°, and thus inclined about 45° to each other. The two galaxies intersect at the east end of the major axes. From this point two tails of low-luminosity material extend away from the galaxies more than 0°.25, bending in opposite directions. In this paper we present emission-line ratios and radial velocities for eighteen of the emission knots.

II. RELATIVE LINE STRENGTHS

a) *Spectral Observations*

We have obtained spectrograms of NGC 4038–4039 with the DTM image-tube spectrograph attached to the Kitt Peak 84-inch telescope, and to the 72-inch telescope of the Ohio State and Ohio Wesleyan Universities at Lowell Observatory. The spectra were taken with the aid of a RCA cascaded image tube (type C33011). The dispersions were

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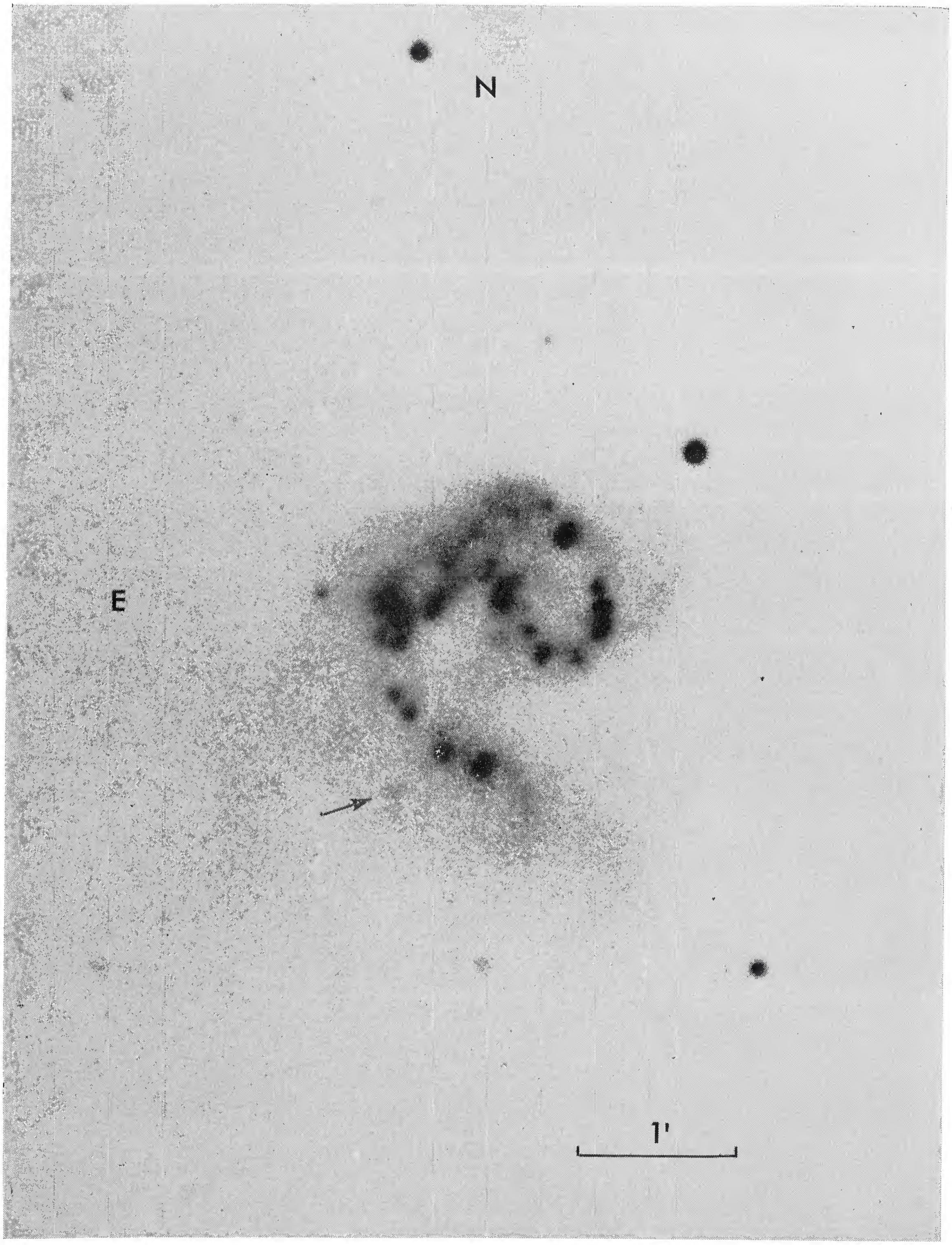

FIG. 1.—NGC 4038–4039 from a plate by Lampland, taken with the Lowell Observatory 42-inch reflector, 1921 May 3. Exposure time 1 hr. Seed 30 plate. Supernova discovered by Hubble in 1939, from 100-inch plates taken by Curtis in 1921 March and April, is indicated. It was noted as "new star" on plate envelope by Lampland.

RUBIN ET AL. (*see* page 801)

130 and 270 Å mm^{-1}, and the resolution on the plates corresponded to about 6 and 12 Å, respectively. Details of the observations are given in Table 1. We show in Figure 2 (Plate 2) spectrograms taken at two different position angles. Also included in the figure are photographs of NGC 4038–4039 printed at the same scale as the spectra, showing the orientation of the slit across the knots in the galaxies.

Emission lines of Hβ; [O III] λλ4959, 5007; He I λ5876; [O I] λ6300; [N II] λλ6548, 6583; Hα; and [S II] λλ6717, 6731, are observed in various knots in the galaxy, plus [O II] λ3727 out of focus in the second order. These lines appear no broader than the nightsky lines, as can be noted in Figure 2. The plates were calibrated by a step wedge exposure. Peak intensities were used, as the width is the same for all the lines. The calculated intensities have been corrected for extinction and spectral response of the equipment. We estimate the uncertainties in the listed intensities to be less than 25 percent. The He I, [O III], and [O I] lines have not been detected in previous spectroscopic observations of the two galaxies. The intensity ratios among the lines and the strengths of the continuous spectra show a large range of variations from knot to knot.

TABLE 1

OBSERVATIONS OF NGC 4038–4039

Spectrum	Date	Position of angle of slit	Dispersion (Å mm^{-1})	Exposure (min)	Notes
L 1198	1966 December 17	119°	270	120	Slit 10″ NE of star*
L 1207	1966 December 18	119°	270	120	Slit 8″ SW of star
L 1229	1966 December 21	119°	130	94	Through star
KP 1262	1967 March 7	119°	130	120	Through star
KP 1270	1967 March 8	49°	130	90	
KP 1275	1967 March 9	35°	130	~ 45	
KP 1277	1967 March 10	0°	130	~ 45	

* Star NW of NGC 4038.

In Figure 3, *a*, we show a sketch of NGC 4038–4039 that identifies the individual knots. Table 2 summarizes the observed emission-line intensities for each knot. For the brighter knots, line intensities relative to Hα have been measured and are listed in columns (2)–(10). In columns (11), (12), and (13) the intensity ratios Hα/Hβ, Hα/[N II], and [S II] λ6717/6731 are tabulated. The final column contains comments on the intensity of the continuum.

b) Hα/Hβ *Intensity Ratio*

The intensity ratio Hα/Hβ ranges from 6 to 14 for eight regions. These values are clearly larger than the intensity ratio predicted by the recombination theory, but are similar to the values observed in some Seyfert galaxies (Osterbrock and Parker 1965; Rubin and Ford 1968) and in other galaxies (Peimbert and Spinrad 1969; D'Odorico 1970). Using the theoretical value of 2.84 given by Clarke (quoted by Aller and Liller 1968) for case B with $n_{\rm coll} = 20$ and the reddening curve tabulated by Seaton (1960), we compute a mean absorption of 3.5 mag at Hβ. If correct, this high absorption would indicate a large dust content in the galaxy; the galactic component of the absorption is only of the order of 0.3 mag at the latitude ($l^{\rm II} = +42°$) of NGC 4038–4039. This interpretation is supported by direct observations of the object. One does see a great deal of dust, particularly in the region between knot J and northeast of knot A.

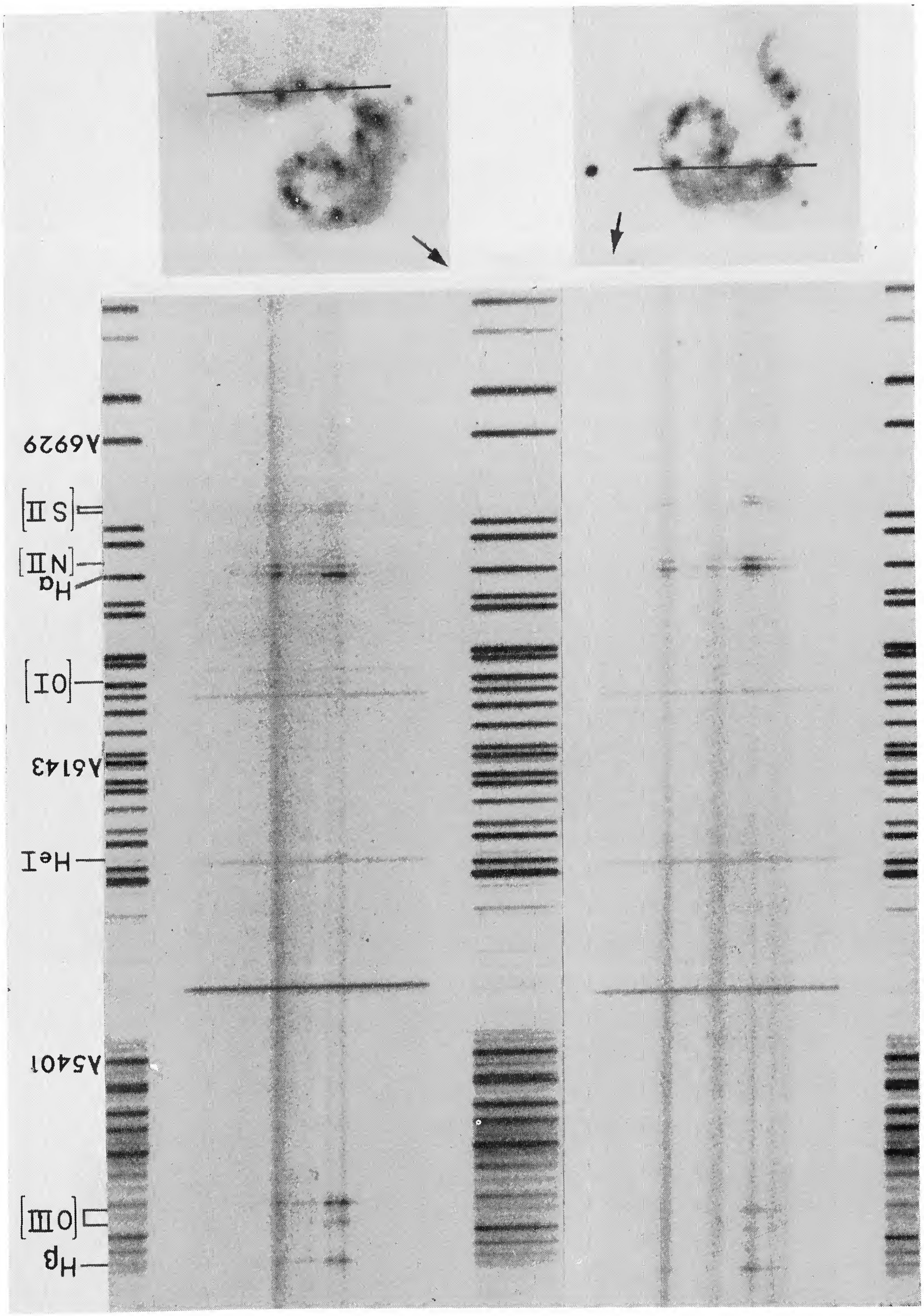

FIG. 2.—Two spectra of NGC 4038–4039, showing emission lines in spectra of knots A through H. *Upper spectra*, plate 1270; *lower spectrum*, plate 1262. Original dispersion 130 Å mm^{-1}. Photographs at right show orientation of slit across galaxy; arrow indicates north.

RUBIN ET AL. (*see* page 802)

TABLE 2

OBSERVED EMISSION-LINE RATIOS AND CONTINUUM OBSERVATIONS OF KNOTS IN NGC 4038–4039

Knot (1)	Hβ λ4861 (2)	[O III] λ4959 (3)	[O III] λ5007 (4)	He I λ5876 (5)	[O I] λ6300 (6)	Hα λ6563 (7)	[N II] λ6583 (8)	[S II] λ6717 (9)	[S II] λ6731 (10)	Hα/Hβ (11)	Hα/[N II] (12)	λ6717/λ6731 (13)	Continuum (14)
AA (tail)	...	...	...	...	...	P	<Hα	...	...	...	> 1	...	v. weak
A*	1.4	0.6	1.6	0.29	0.9	10	6.4	3.5	2.4	7.1	1.6	1.4	strong
B	1.6	...	1.7	...	...	10	3.5	1.6	1.4	6.3	2.9	1.2	v. weak
C†	1.3	0.8	3.3	0.24	...	10	2.5	1.1	0.8	7.7	4.0	1.4	weak
D†	0.7	0.6	2.8	0.15	...	10	1.5	0.4	0.3	14	6.7	1.1	weak
E	P	...	=Hβ	...	...	10	4.4	...	...	...	2.3	...	weak
F†	0.9	0.2	0.6	0.10	...	10	2.3	0.6	0.4	11	4.3	1.6	weak
G	0.9	...	0.4	...	...	10	3.0	1.0	0.8	11	3.3	1.4	mod., strong in blue
H	P	...	≪Hβ	...	...	10	2.8	...	...	...	3.6	...	weak
J	P	...	≪Hβ	...	...	10	6.6	4.0	2.5	...	1.5	1.6	mod., strong in blue
K	1.7	0.3	0.4	...	...	10	3.6	1.5	1.1	5.9	2.8	1.3	mod., v. strong in blue
L	P	...	≪Hβ	...	...	10	3.3	1.2	0.9	...	3.0	1.4	v. weak
M	0.9	0.3	0.5	...	...	10	3.5	1.2	1.0	11	2.9	1.3	v. weak
N	P	...	>Hβ	...	...	10	P	...	...	...	∼ 3	...	mod., strong in direction SE
P	P	...	<Hβ	...	...	P	P	...	...	...	∼ 3	...	weak
Q	P	...	<Hβ	...	...	P	P	...	...	...	∼ 3	...	weak
R	P	...	<Hβ	...	...	P	P	P	P	...	∼ 3	...	v. weak
S	P	...	<Hβ	...	...	P	P	P	P	...	∼ 3	...	weak
T	P	...	≪Hβ	...	...	P	P	P	P	...	∼ 3	...	v. weak

NOTE.—P = present; v = very.

* [O II] λ3727 moderate.

† [O II] λ3727 strong.

c) Hα/[N II] λ6583 *Intensity Ratio*

[N II] λ6583 is weaker than Hα in all regions. However, in knots A and J, the ratio of the intensities of the two lines approaches unity. Both of these knots have strong continua, as does knot K, and are identified as the nuclei of NGC 4039 (A) and NGC 4038 (J + K). This is consistent with the observation that, in the nuclei of late-type spirals, [N II] λ6583 is as strong as or stronger than Hα (Burbidge and Burbidge 1965). This ratio is less than unity in emission regions in spiral arms and in Irregular galaxies.

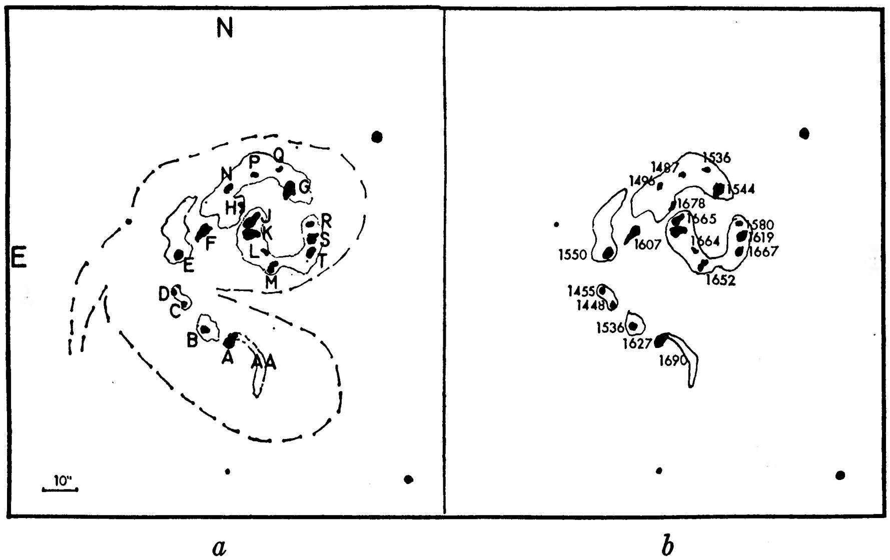

FIG. 3.—(*a*) Sketch of NGC 4038–4039, showing designations of knots used in this paper; dashed line indicates outer envelope of galaxies on long-exposure photographs. (*b*) Line-of-sight velocities, reduced to the Sun, of individual knots.

d) *The* He/H *Abundance Ratio*

The line of neutral helium at λ5876 is observed in four of the knots. We can estimate the helium abundance by comparing the strength of this line with that of Hβ. Following Peimbert and Spinrad (1969), we find that, for $T_e = 10000°$, the ratio of helium (neutral atoms plus ionized atoms) to hydrogen is

$$\frac{N_{\rm He}}{N_{\rm H}} = 1.2\,\frac{N_{\rm He^+}}{N_{\rm H^+}} = 0.89\,\frac{I(5876)}{I(4861)}\,. \qquad (1)$$

The factor 1.2 follows from the assumption that all the hydrogen is ionized but that the amount of neutral helium is 20 percent that of the ionized helium. This value comes from the values observed in other external galaxies by Peimbert and Spinrad (1970).

In Table 3 we have listed for each knot the observed $I(5876)/I(4861)$ ratio, the same ratio corrected for the reddening calculated for each knot, and the N(He)/N(H) ratio corrected for reddening. Since this value depends strongly on the adopted reddening correction, we also list the N(He)/N(H) ratio derived from the uncorrected intensities. This value can be considered an upper limit to this ratio. We derive mean values of 0.071 (corrected for reddening) and 0.16 (uncorrected for reddening) for the relative helium abundance in NGC 4038–4039. This can be compared with values ranging from 0.10 to 0.13 found by Peimbert and Spinrad for five external galaxies.

The low abundance derived for knot F can be explained by a lower degree of ionization and, therefore, a higher percentage of neutral helium in the knot. This is suggested by the fact that [O III] λ5007 is weaker than Hβ in F, the reverse being true for knots A, C and D. Knots A, C, D, and F, where He I λ5876 is observed, are those with the stronger spectra. It is, therefore, most likely that the line is not seen in the other knots only because it is below the limit of detectability.

e) [O I], [O III] *and* [S II] *Intensities*

In knot A, the nucleus of NGC 4039, we observe the high-ionization lines of [O III], together with low-ionization lines of [O I] and [S II]. All lines are relatively stronger with respect to Hα than the average. It seems likely that regions with different degrees of ionization contribute to the observed spectrum of this knot. Since such variations have been found in galactic H II regions (Peimbert and Costero 1969), it is quite natural to expect them in extended knots in external galaxies. In knots C and D, which have well-exposed spectra, [O I] λ6300 is not seen, and the [S II] lines are relatively weak while the [O III] lines are very strong. These knots present the highest degree of ionization.

For all knots, the ratio λ6717/λ6731 of [S II] ranges from 1.1 to 1.6, and has a mean value of 1.4. This implies a low electron density. For $T \simeq 10000°$ K, $N_e \simeq 100$.

TABLE 3

THE He/H ABUNDANCE RATIO

Knot	$I(5876)/I(4861)$ Uncorrected for Reddening	$I(5876)/(4861)$ Corrected for Reddening	C*	$N(\mathrm{He})/N(\mathrm{H})$ Corrected for Reddening	$N(\mathrm{He})/N(\mathrm{H})$ Uncorrected for Reddening
A................	0.207	0.108	1.11	0.096	0.184
C................	0.184	0.092	1.25	0.082	0.163
D................	0.214	0.074	1.94	0.066	0.190
F................	0.111	0.046	1.64	0.041	0.098

* Logarithmic reddening correction.

III. DISTANCE OF NGC 4038–4039

a) Size of Emission Regions

In a preliminary calibration, Sandage (1962) established that the linear diameter of the largest H II region in an Sc or Irregular galaxy is 245 ± 20 pc and the mean of the five largest such regions is 178 ± 33 pc. We can estimate the distance of NGC 4038–4039 from the angular dimensions of the H II regions observed in the galaxy. For each of the eighteen emission knots an angular size has been measured from the extent of the emission on the spectrum. The results are listed in Table 4. On the plates, the scale perpendicular to the dispersion is 40″ mm^{-1}, while the resolution corresponds to 1″.6. During the exposure, guiding is done on an offset star to ensure that this spatial resolution is maintained.

Because the slit of the spectrograph was oriented along three or four knots for each observation, it is likely that the observations were not made along the maximum diameter of each knot, which would make the measured diameters too small. On the other hand, there is a tendency for the extent of the brighter spectral lines to be overestimated due to image buildup at the ends of the lines. Hence the measured extent should be a fair estimate of the true size. This has been confirmed by comparing measurements of the emission-line extent with direct measurements of the knot sizes on the plates of Lampland.

In making the computation, we have excluded knots A, G, and J + K because their strong continuum and their line intensities suggest that they may be galactic nuclei. We obtain a distance of 5.4 ± 1 Mpc from the mean of the five largest knots and 6.6 ± 0.5 Mpc from the largest knot. Adopting the mean value, we get a distance modulus of 28.9 ± 0.2. This distance derivation cannot avoid certain criticism. While the calibration itself and the measurements should not introduce very large errors, the question arises of whether we can use for the H II region in NGC 4038–4039 a calibration based on M33 and the Large Magellanic Cloud.

TABLE 4

OBSERVED ANGULAR DIAMETERS AND VELOCITIES OF EMISSION KNOTS IN NGC 4038–4039

			Velocity (km sec⁻¹) Reduced to Sun					
Knot	Plate	Extent (Sec. of arc)	Hα	[N II] λ6583	[S II] λ6717	[S II] λ6731	Other	Mean*
AA	1270	Tail	+1690	...	...	...	...	+1690
A	1270	6.5	1618	+1648	+1624	...	...	1627 ± 9
B	1270	6.0	1536	...	...	...	...	1536
C	1270	6.7	1458	1456	1421	+1442	...	1447 ± 8
D	1270	7.1	1459	1448	...	...	...	1455 ± 5
E	1262	5.2	1547	1541	...	...	...	...
	1207	7.6	1564	...	...	...	...	1550 ± 6
F†	1262	12.5†	1592	1588	1571	1573	...	...
	1207	10.2†	1619	...	...	...	...	...
	1229	11.9†	1645	1647	1613	1598	λ5007: +1565 λ6548: +1610	1604 ± 9
G	1262	9.1	1530	...	...	...	...	...
	1229	> 6.3‡	1558	...	...	...	...	1544 ± 14
H	1262	5.7	1668	...	...	...	...	...
	1229	5.5	1685	...	...	...	...	1676 ± 8
J	1275	2.3	1665	...	...	...	...	1665
K	1275	3.7	1625§	1633	...	...	...	1628 ± 4
L	1275	5.4	1658	1675	...	...	...	1664 ± 8
M	1275	4.3	1647§	1662	...	...	...	1652 ± 7
N	1198	5.1	1485§	...	...	...	...	...
	1275	2.2	1502	...	...	...	...	1496 ± 8
P	1198	5.2	1487	...	...	...	...	1487
Q	1198	4.2	1536§	...	...	...	...	1536
R	1277	3.5	1593§	1555	...	...	...	1580 ± 18
S	1277	4.7	1623	1611	...	...	...	1619 ± 5
T	1277	5.0	+1658§	+1685	...	...	...	+1667 ± 13

* 130 Å mm measures = weight 2; Hα measures = weight 2 × other lines.

† Three contiguous knots.

‡ At edge of slit.

§ Velocity gradient across knot ≥ 50 km sec⁻¹.

b) *Kinematic Distance*

The mean of the systemic velocities of NGC 4038 and 4039 is +1636 km sec^{-1} with respect to the Sun, which corresponds to a velocity of +1464 km sec^{-1} corrected for a rotation of the Sun about the center of the Galaxy of $V = 250$ km sec^{-1}. The direct application of a Hubble constant of 75 km sec^{-1} kpc^{-1} implies a distance of 19.5 Mpc, which corresponds to a distance modulus of 31.0. However, for such a low value of the redshift, the effects of anisotropy in the velocity field make the determination of distance by means of the Hubble constant unreliable. We can estimate the distance by using a model for the kinematics of the supercluster proposed by de Vaucouleurs (1958). Adopting the constants $Rw = 500$, $R\epsilon = 1200$, and $R_1 = 10$ Mpc, we obtain an order-of-magnitude distance of 10 Mpc and a distance modulus of 30. Because the model is only a preliminary one, the uncertainty in the distance is high even though the approach is preferable to the use of the Hubble constant.

c) Brightest Stars

No stars are resolved in the galaxies in the photographs by Zwicky (Arp 1966) or Burbidge and Burbidge (1966). If we use for the magnitude of the brightest stars the value $M_{BS} = -9.3 \pm 0.2$ (Sandage 1962) and adopt the smaller distance modulus of 28.9 derived from the H II regions, an absorption of about 3.1 mag might explain the absence of bright supergiants. It is interesting to recall that M82 also has no resolved stars, although it is a member of the M81 groups of galaxies and there are resolved stars in other galaxies in that group.

d) The 1921 Supernova

Hubble (1939) discovered in 1939 a supernova in NGC 4039 from a plate taken by Duncan on 1921 March 7 with the 100-inch telescope. Curiously, Duncan (1923) published a reproduction of this plate in the *Astrophysical Journal*, but the prominent supernova long escaped detection. A search of the plate collection at Lowell Observatory revealed that Lampland had taken plates of NGC 4038–4039 every year with the 42-inch reflector starting in 1917, including plates dated 1920 May 20 and 1921 May 3. On the envelope for the 1921 plate he wrote, "new star." As Lampland was actually searching for proper motions in the nebula he believed to be galactic, he apparently ignored the discovery of the "new star" and did not mention it elsewhere. Figure 1 (Plate 1) is a reproduction of the Lampland plate of 1921 May, with the supernova indicated.

Although supernovae may be used as distance indicators, the procedure is not of value for NGC 4038–4039 because of the many uncertainties involved. From the Duncan (1923) reproduction we estimate that in 1921 March the photographic magnitude of the supernova was near 16. However, it is not known how much earlier the maximum was reached. Also, the appearance of dust lanes in the region of the galaxy in which the supernova appeared (NE of knot B) suggests that the absorption correction may be as high as that derived for the emission knots from the observed $H\alpha/H\beta$ intensity ratio. A supernova of Type II, with $M = -16.3$, would appear as $m = 12.6$ at a distance $D = 6$ Mpc, or as $m = 14.2$ at $D = 13$ Mpc, before correcting for absorption.

e) Conclusions

To summarize, we obtain a distance of 6 Mpc from the sizes of H II regions and a distance of 10 Mpc from kinematic considerations. Neither the criterion of brightest stars nor that of supernovae can give certain results because of the unknown amount of absorption, and these criteria only suggest that 6 Mpc and 13 Mpc may be limiting values. We conclude that $D = 9 \pm 3$ Mpc is the best estimate we can give. De Vaucouleurs and de Vaucouleurs (1968) obtained 12.5 ± 2.5 for the nearby galaxy NGC 4027, from diameter and magnitude considerations. It is likely that NGC 4027 and NGC 4038–4039 are a physical group, even though there is a large uncertainty in both distance determinations. At a distance of 9 Mpc, 1″ equals 44 pc. The maximum extension across the loop of knots is 4.1 kpc; the maximum diameter of NGC 4038–4039 on long-exposure photographs, including the luminous background, is 8.7 kpc; and the total extent of the outer faint tails is 40 kpc.

IV. THE VELOCITY FIELD

The spectra were measured on a Mann two-dimensional measuring machine, and the procedure used was that described by Rubin and Ford (1968). Velocities as a function of distance along the slit were derived from the emission lines Hα, [N II] λ6583, and

[S II] λλ6717, 6731. In Table 4 we list for each knot the line-of-sight velocity with respect to the Sun. When more than one velocity is determined for a knot, a mean value is computed. For the systemic velocities of the two systems we take $V = 1636$ km sec^{-1} with respect to the Sun. This is the mean of the velocities for knots A and J + K, which are probably the nuclei of NGC 4039 and 4038. In Figure 3, *b*, we show a sketch of the galaxy with the distribution of line-of-sight velocities. Our spectra are at a higher dispersion than are those taken by Burbidge and Burbidge (1966); ours also cover the northern portion of the galaxy (knots N, P, Q) which they did not observe. The agreement with their velocity measurements for spectra taken at the same position angle is excellent.

It is not a simple matter to understand the velocity field in NGC 4038–4039. Those galaxies appear on long-exposure plates as two interacting galaxies, both of approximately equal size and luminosity. The smooth background in which the bright knots are embedded becomes very prominent and indicates the presence of a relatively strong component of Population II stars. It is in the low-luminosity region of NGC 4039 that the 1921 supernova was discovered. Clearly, NGC 4038 and NGC 4039 are not Magellanic-type Irregulars, because the emission knots are arranged in a very patterned fashion, even though the pattern is not a typical spiral one. Similarly, the velocities are also distributed in a highly regular fashion. Starting at the north with knot N, which has a velocity of -150 km sec^{-1} with respect to the nucleus J + K, and going clockwise along the loop, the velocities increase steadily to a value of $+20$ km sec^{-1} near the nucleus J + K. On the other side, the velocities decrease from $+30$ (knot H) to -100 km sec^{-1} at knot E. From knots D and C through A there is a steady increase in velocity.

Burbidge and Burbidge (1966) suggested that the excess negative velocities were the result of an explosion with two centers, and that large regions of dust in the galaxy prevented them from seeing the far side of this explosion. This model cannot be rejected on the basis of our new velocities. However, the highly regular nature of the velocities, suggestive of velocity gradients in normal spiral galaxies, the fact that the velocity spread over all knots is only 235 km sec^{-1}, plus the appearance of a double system, lead us to look for a model involving two interacting galaxies.

In NGC 4039, the velocity gradient from knots A through D is 235 km sec^{-1} over a distance of 3000 pc, which is comparable to the velocity gradient observed along the major axis of a typical spiral galaxy. Hence we can interpret the line-of-sight velocities in NGC 4039 as arising in a rotating galaxy with major axis in position angle $\sim 50°$, with the NE region of the galaxy approaching the observer.

In NGC 4038, too, there is a gradient in the velocities from northeast to southwest. This would imply that NGC 4038 is rotating about an axis which lies at right angles to the line joining knot G and J + K. If there is a nucleuslike structure here, it is hidden by heavy obscuration. Photographs in the infrared spectral region would be valuable to see if such structure can be detected. In the confused region common to the two galaxies, the gradient of the velocities is less systematic, as would be expected because of the gravitational interaction. Such a model explains satisfactorily the main features of the velocity field. On the basis of the available velocities, it appears unwarranted to search for a more detailed model of the two galaxies.

V. CONCLUSIONS

In the spectra of eighteen emission knots in NGC 4038–4039, we detected lines of [O I], [O III], and He I, in addition to lines previously observed. The average intensity ratio Hα/Hβ is 9. If this high value is entirely attributed to reddening, it implies an absorption of the order of 3.5 mag at Hβ. With this value, the abundance ratio of helium to hydrogen is 0.074. A distance of 9 ± 3 Mpc is derived from various distance indicators. The velocity field exhibits a systematic variation of line-of-sight velocities from knot to knot, which leads us to infer a model of two rotating, interacting galaxies.

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REFERENCES

Aller, L. H., and Liller, W. 1968, in *Stars and Stellar Systems*, ed. B. H. Middlehurst and L. H. Aller (Chicago: University of Chicago Press), p. 483.
Arp, H. 1966, *Atlas of Peculiar Galaxies* (Pasadena: California Institute of Technology).
Burbidge, E. M., and Burbidge, G. R. 1965, *Ap. J.*, **142**, 634.
———. 1966, *Ap. J.*, **145**, 661.
D'Odorico, S. 1970, *Ap. J.* (in press).
Duncan, J. C. 1923, *Ap. J.*, **53**, 137.
Hubble, E. 1939, *Carnegie Yrb.*, **38**, 27.
Minkowski, R. 1957, *I.A.U. Symposium No. 4*, ed. H. C. van de Hulst (Cambridge: Cambridge University Press), p. 107.
Osterbrock, D. E., and Parker, R. A. 1965, *Ap. J.*, **140**, 892.
Peimbert, M., and Costero, R. 1969, *Bol. Obs. Tonantzintla y Tacubaya*, **5**, 3.
Peimbert, M., and Spinrad, H. 1970, *Ap. J.*, **159**, 809.
Rubin, V. C., and Ford, W. K., Jr. 1968, *Ap. J.*, **154**, 431.
Sandage, A. 1962, in *Problems of Extra-Galactic Research*, ed. G. C. McVittie (New York: Macmillan Co.), p. 359.
Seaton, M. G. 1960, *Rep. Progr. Phys.*, **23**, 313.
Shapley, H., and Paraskevopoulos, J. S. 1940, *Proc. Nat. Acad. Sci.*, **26**, 31.
Vaucouleurs, G. de. 1958, *A.J.*, **63**, 253.
Vaucouleurs, G. de, Vaucouleurs, A. de, and Freeman, K. B. 1968, *M.N.R.A.S.*, **139**, 425.