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SPECTROSCOPIC STUDY OF THE DOUBLE GALAXY NGC 3395-3396

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ABSTRACT

Spectra of NGC 3395 and NGC 3396, a pair of interacting galaxies, show emission lines of H I, He I, [O II], [O III], [N II], and [S II]. In both galaxies the intensity of Hα is greater than that of [N II] λ6583, as in most Sc, irregular, and Seyfert galaxies. The intensity ratios Hα/Hβ = 5.1 in NGC 3395 and Hα/Hβ = 7.5 in NGC 3396 suggest that large amounts of dust may be present in the nuclei of the two galaxies. Within 1.5 kpc of the nucleus, NGC 3395 rotates as a solid body and has an approximate mass of $1.2 \times 10^9 M_\odot$. Velocities in NGC 3396 show no appreciable rotation. The general velocity field is consistent with the hypothesis that NGC 3396 rotates around NGC 3395.

I. INTRODUCTION

NGC 3395-3396 are an interesting, close pair of galaxies. The pair is listed as number 246 in the *Catalogue of Interacting Galaxies*, by Vorontsov-Velyaminov (1959), and as number 270 in the *Atlas of Peculiar Galaxies*, by Arp (1966). The angular separation of the two components is only 1′, and their appearance suggests that they are physically connected. The possibility of interaction is supported by Carpenter's observation (1957) of λ3727 emission in the region between the two galaxies and by the small difference in the observed systemic velocities (de Vaucouleurs and de Vaucouleurs 1964). Page (1952) and Mayall, Humason, and Sandage (1956) obtained spectra of the two galaxies and observed several emission lines and an early-type continuum. NGC 3395, which will be referred to as the main component of the pair, is classified Scd peculiar and NGC 3396 is classified Im in the revised system by de Vaucouleurs. In Arp's photograph the spiral pattern in NGC 3395 appears to be irregular. Arms apparently cross each other, and dust lanes and bright knots mark the central region. An arc of emission regions seems to trail from NGC 3395 to NGC 3396. In a short exposure by Morgan (1958), the nucleus of NGC 3396 is seen to have a noncircular form, with a single arm extending from it on the side away from NGC 3395.

II. OBSERVATIONS

Three spectra for each of the two galaxies in the spectral region 4300–6800 Å have been obtained with the DTM image-tube spectrograph attached to the 72-inch Perkins telescope of Ohio State and Ohio Wesleyan Universities at Lowell Observatory. The orientations of the spectrograph across the galaxies are shown in Figure 1, and position angles are listed in Table 2. The mean dispersion is 140 Å mm^{-1} for plates 1618, 1619, 1709, and 1762 and 42 Å mm^{-1} for plates 1701 and 1702. The slit was 1″.5 wide on the sky. This corresponds to 4.9 Å or 220 km sec^{-1} and 1.3 Å or 60 km sec^{-1} at Hα on the plates at low and high dispersion, respectively. Two spectra are shown in Figure 2 (Plate 1). In NGC 3395, the main component, we observe the emission lines Hβ; [O III] λλ4959, 5007; Hα; [N II] λ6583; and [O II] λ3727 in second order out of focus. The lines are not wider than the instrumental profile. The brighter part of the emission lines is shifted about 4″ NE of the center of the continuum strip. In NGC 3396 we observe Hγ; Hβ; [O III] λλ4959, 5007; He I λ5875; [N II] λλ6548, 6583; Hα; [S II] λλ6717, 6731; and [O II] λ3727 in second order out of focus. Comparable exposures show that the

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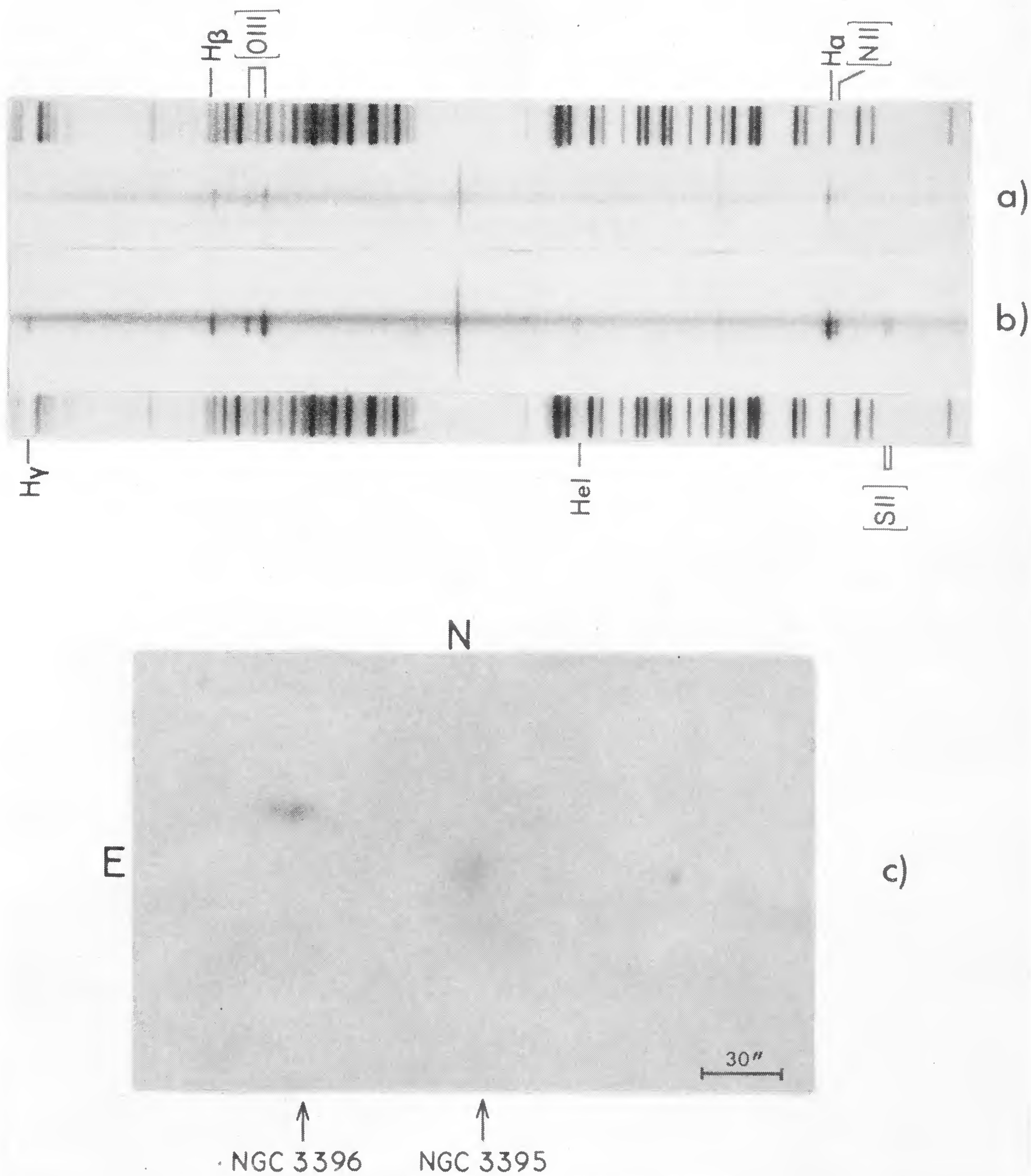

FIG. 2.—(*a*) Spectrum P1618, NGC 3395, exposure 32 min. (*b*) Spectrum P1709, NGC 3396, exposure 1 hour 25 min. DTM image-tube spectrograph attached to the 72-inch Lowell telescope. Phosphor surface photographed with IIa-O baked plates. Original dispersion 140 Å mm^{-1}. Scale perpendicular to the dispersion 39″ mm^{-1}. (*c*) Photograph of NGC 3395-3396, S20 image tube +100 Å bandpass Hα filter. NASA 36-inch telescope. Exposure 50 min. Note the two knots in the nucleus of NGC 3396, which were recorded also in spectrum P1709.

D'ODORICO (*see* page 3)

emission lines are stronger than in NGC 3395. In the plate at higher dispersion, Hα is about 80 km sec^{-1} wide. No absorption lines are apparent on the continuum. In the spectrum P1709, reproduced in Figure 2 (Plate 1), the emission is concentrated in two knots. Enlarged isophotes of some emission lines from this spectrum have been obtained by using the automatic isodensitracer at Kitt Peak National Observatory and are shown in Figure 3 (Plate 2). One concentration is associated with the strong continuum while the other is about 7″ east of it. In the other two spectra, taken at position angles of 95° and 100°, this second concentration is not so prominent. We have obtained, in Figure 2*c* (Plate 1), an image-tube photograph of the system through a 100 Å bandpass filter centered at Hα with the 36-inch NASA telescope at Greenbelt, Maryland. In agreement with the spectra, the photograph shows in the nucleus of NGC 3396 two emission regions aligned at a position angle of about 85°.

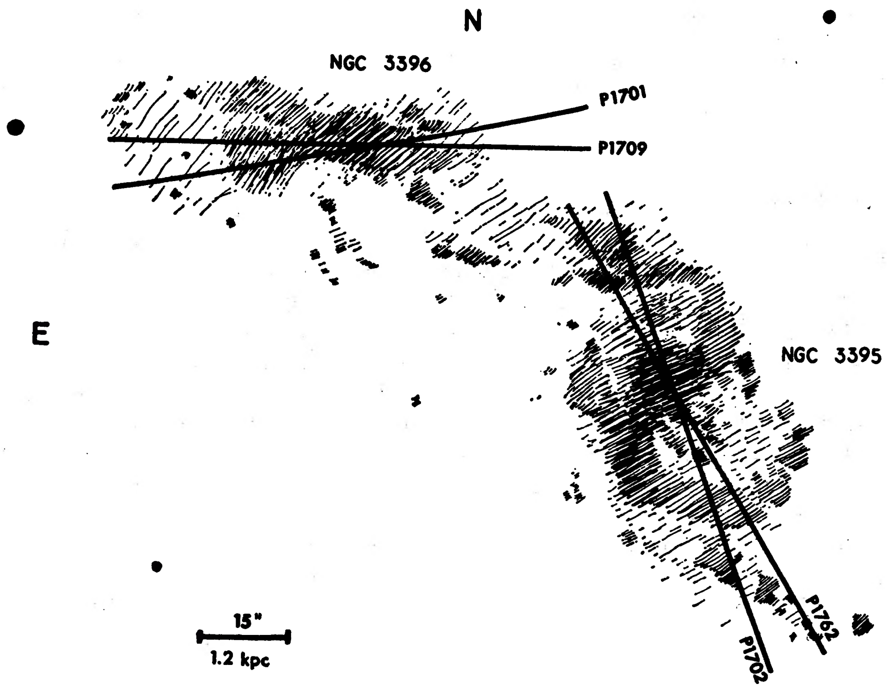

FIG. 1.—Sketch of NGC 3395 and NGC 3396 showing position of the spectra through the galaxies. Spectrum P1619, at an intermediate position angle between P1701 and P1709, and spectrum P1618, almost coincident with P1702, have not been omitted for clarity.

III. RELATIVE LINE INTENSITIES

Relative intensities for emission lines in the two galaxies have been obtained from microphotometer tracings of the central part of the spectra and are listed in Table 1. We have used wedge calibration plates that were developed together with the galaxy spectra to derive the line intensities, and applied a correction for extinction and spectral response of the spectrograph–image-tube system. No correction has been applied for reddening. No intensities have been derived for [N II] λ6548, which is weak and difficult to separate in the tracings from Hα, and for Hγ, because in that region the spectral response is not well determined. The uncertainty of the derived intensities is estimated within 15 percent from the scatter of the values for a line from different plates. Weak lines such as He I λ5876 and [S II] λλ6717, 6731 in NGC 3396, can be affected by larger errors.

The only significant difference in the two galaxies is that the hydrogen lines are slightly stronger in NGC 3395, compared with the [O III] lines. The intensity ratio $H\alpha$/[N II] $\lambda6583$ has an approximate value of 6 in both galaxies. This value is typical of irregular galaxies and H II regions in spiral arms. In elliptical and S0 galaxies, the ratio is <1; in Sa and Sb galaxies, values >1 and <1 are observed in nearly the same proportion; and in Sc galaxies, the ratio is mostly ≥ 1 (Burbidge and Burbidge 1962, 1965). $H\alpha$ is also stronger than [N II] $\lambda6583$ in the Seyfert galaxies NGC 1068 (Osterbrock and Parker 1965), NGC 4151 (Oke and Sargent 1968), and NGC 3227 (Rubin and Ford 1968). Additional data on the strength of emission lines in galaxies will be needed in order to understand the significance of this similarity among late spiral, irregular, and Seyfert galaxies.

We obtain the intensity ratio $H\alpha/H\beta = 5.1$ for NGC 3395 and $H\alpha/H\beta = 7.5$ for NGC 3396. These values are high in comparison with the theoretical values as computed by Clarke (in Aller and Liller 1968). We assume for the moment that the departure from the theory is entirely due to reddening in the nuclei of the two galaxies. If we use for the intensity ratio $H\alpha/H\beta$ the value 2.84 given by Clarke for case B with $n_{\rm coll} = 20$, and the reddening curve tabulated by Seaton (1960), we compute an absorption of 1.8 and 2.9 mag at $H\beta$ for NGC 3395 and NGC 3396, respectively.

TABLE 1

RELATIVE INTENSITIES OF EMISSION LINES

Galaxy	$H\beta$	[O III] $\lambda4959$	[O III] $\lambda5007$	He I $\lambda5875$	$H\alpha$*	[N II] $\lambda6583$	[S II] $\lambda6717$	[S II] $\lambda6731$
NGC 3395..	100	50	137	...	512	87	...	...
NGC 3396..	100	87	313	26	752	149	56	45

* Corrected for the contribution of [N II] $\lambda6548$.

The galactic component of absorption is very small at the position of NGC 3395-3396 ($b^{\rm II} = +67°$). The heavier absorption obtained for NGC 3396 is in agreement with the fact that NGC 3396 is redder than NGC 3395 (de Vaucouleurs and de Vaucouleurs 1964), while irregular galaxies are usually very blue objects. It must be pointed out, however, that the values computed for the absorption are quite approximate, because we have not observed other Balmer or Paschen lines. In addition, it may be questioned whether the theory considers all the physical processes which take place in the nuclei of galaxies. Despite the large number of spectra collected in the past years, Balmer decrements are usually not given for emission-line galaxies, because the plates are uncalibrated and the spectral response unknown. Recently, using a photoelectric-scanning technique, Peimbert (1968) observed intensity ratios $H\alpha/H\beta = 2.82$ and $H\gamma/H\beta = 0.45$ in M81, and Peimbert and Spinrad (1970) observed $H\alpha/H\beta = 13.9$ and $H\gamma/H\beta = 0.20$ in M82. The high values for the Balmer decrement obtained for M82 were attributed to reddening which takes place in the nucleus of the galaxy. Steep Balmer decrements have been observed for the Seyfert galaxies NGC 1068 and NGC 3227 and in some Haro objects and quasi-stellar sources (Wampler 1968). Osterbrock (1968) discussed different mechanisms for the formation of the lines but was not successful in eliminating the discrepancy between theory and observations. A very strong reddening, possibly with a different wavelength dependence, could explain the observed values, but it should also affect the adjacent continuum. Wampler (1968) observed a case in which the continuum was unreddened. This suggests that reddening may not be responsible for the steep Balmer decrement at least in some objects. Finally, the presence of underlying Balmer absorption lines due to the stellar content tends also to increase the $H\alpha/H\beta$ intensity ratio.

In conclusion, until the theory is better tested and all the effects can be correctly evaluated, we think that some caution has to be applied in ascribing all the deviations from the predicted ratios to reddening.

IV. DYNAMICS OF THE SYSTEM

Radial velocities relative to the Sun were determined from measurements of the stronger lines as described by Rubin and Ford (1968) and are listed in Table 2 as a function of the distance from the center. The estimated accuracy of a single measurement is of the order of 10 km sec^{-1}. Equal weight was given to all the places, because those of 42 Å mm^{-1} have a smaller scale perpendicular to the dispersion. For NGC 3395, the velocity at the center of the continuum from the symmetry of the observed points is $V = 1622$ km sec^{-1} with respect to the Sun. We take it as the systemic velocity. This value is not significantly different from the mean of the measured velocities at the center,

TABLE 2

MEASURED VELOCITIES RELATIVE TO THE SUN IN NGC 3395 AND NGC 3396 AS A FUNCTION OF DISTANCE FROM THE CENTER

A. NGC 3395

Distance (sec of arc)	Velocity (km sec^{-1}) Hα	[O III] λ5007	Hβ	Distance (sec of arc)	Hα Velocity (km sec^{-1})	Distance (sec of arc)	Hα Velocity (km sec^{-1})
	P1618, P.A. 31°				P1702, P.A. 32°		P1762, P.A. 20°
NE 11.9	1691	...	...	NE 17.4	1687	NE 11.9	1660
7.9	1662	...	...	13.0	1672	7.9	1634
4.0	1624	1608	1615	8.7	1645	4.0	1637
0	1575	1631	1620	4.3	1631	0	1621
4.0	1576	1630	1597	0	1627	4.0	1608
7.9	1602	...	...	4.3	1610	7.9	1606
11.9	1609	...	...	8.7	1603	11.9	1579
SW 15.9	1588	...	...	SW 13.0	1570	15.9	1552
						SW 19.9	1553

B. NGC 3396

Distance (sec of arc)	Velocity (km sec^{-1}) [N II] λ6583	Hα	[O III] λ5007	Hβ
	P1619, P.A. 95°			
E 11.9	...	1733	...	...
7.9	...	1704	1660	...
4.0	1653	1705	1681	1678
0	1684	1711	1763	1740
4.0	...	1727	1734	...
W 7.9	...	1745	...	...
	P1701, P.A. 100°			
E 8.4	...	1688	...	...
4.3	1680	1684	...	...
0	1701	1709	...	...

Distance (sec of arc)	Velocity (km sec^{-1}) [N II] λ6583	Hα	[O III] λ5007	Hβ
	P1709, P.A. 90°			
E 15.9	...	1726	...	...
11.9	...	1673	1700	1659
7.9	1654	1672	1682	1641
4.0	1717	1687	1687	1673
0	1755	1691	1694	1673
4.0	...	1728	1725	1702
7.9	...	1723	1743	...
11.9	...	1709	...	...
W 15.9	...	1661	...	...

which is 1615 ± 20 rms. De Vaucouleurs and de Vaucouleurs (1964) give 1656 km sec^{-1} as the weighted mean of the determinations of Page (1952) and Mayall *et al.* (1956).

NGC 3395-3396, as a member of a subgroup of the Leo II complex, is at an estimated distance of 16 Mpc (de Vaucouleurs 1970). We adopt 20° as the position angle of the major axis and estimate the angle between the normal to the plane of the galaxy and the line of sight as 50° from the axis ratio given in the *Reference Catalogue* (de Vaucouleurs and de Vaucouleurs 1964). Rotational velocities were then computed and are plotted in Figure 4. In the region studied, the rotation curve can be approximated with a straight line obtained by a least-squares solution of the observed points. From this, the maximum rotational velocity is $V_{rot} = 80$ km sec^{-1} at 1.5 kpc, which is the outermost point observed. Using these values and considering the central part of the galaxy as a spheroid (Burbidge, Burbidge, and Prendergast 1959) of $c/a = 0.2$, we derive a mass of the galaxy within $R = 1.5$ kpc of 1.2×10^9 $M_\odot$ and a density of 0.38 $M_\odot$ pc^{-3}.

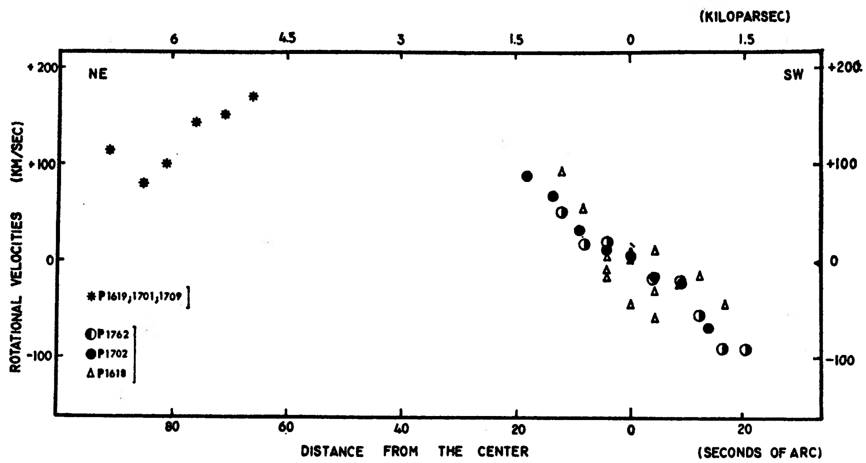

FIG. 4.—Rotation curve of central part of NGC 3395. Isolated points on NE part of curve have been derived from the mean values of the observed velocities in NGC 3396, under the assumption that NGC 3396 lies in the principal plane of NGC 3395. Linear scale based on distance of 16 Mpc.

The velocities northeast of the center show a steeper and more regular gradient. If we use only these velocities, we obtain a systemic velocity $V = 1603$ km sec^{-1}, a maximum of $V_{rot} = 112$ km sec^{-1} at $R = 1.4$ kpc. This would give a mass of 2.2×10^9 $M_\odot$ and a mean density of 0.95 $M_\odot$ pc^{-3} for the central spheroid of an axis ratio of 0.2.

NGC 3396 has the characteristic aspect of an irregular-type galaxy. Apparently, it is seen edge-on, but the plane of symmetry and the position of the nucleus are not well determined. We take as the center of the galaxy the region where the continuum is stronger, and this corresponds to the brighter, eastward concentration in the Hα photograph. The mean radial velocity with respect to the Sun measured there is $V = 1712 \pm 29$ km sec^{-1} rms. The difference between this value and that given in the *Reference Catalogue*, 1643 km sec^{-1}, can be partly explained by the fact that the strong emission knot that is not associated with the continuum visible on spectrum P1709 has a mean velocity of 1662 km sec^{-1}. This could have led to an underestimation of the systemic velocity of the system in the previous low-dispersion determinations. Because the orientation of the major axis is not known with accuracy and because the difference in position angle for our spectra is small, we have plotted in Figure 5 all the observed velocities as a function of the distance from the center. The average position angle is 95°. No systematic velocity differences are noted in the spectra within the accuracy of our measurements. The outermost points come only from Hα measurements in P1709 and therefore have lower weight. There are several ways to interpret the observed velocity field. We briefly discuss here three possible models. First, we can consider the small velocity gradient as due to rotation of the system, seen edge-on and not strongly interacting with NGC 3395. If we use a distance of 16 Mpc, we derive a maximum rotational velocity of 32 km sec^{-1} at 0.6 kpc. This would give for a central spheroid of $c/a = 0.2$ a mass of 0.8×10^8 $M_\odot$. A galaxy in which the velocity maximum of the rotation curve is so low and so close to the nucleus has never been observed. We conclude that NGC 3396 shows no appreciable rotation and probably has very small mass.

A second approach is to assume that NGC 3396 lies in the principal plane of NGC 3395 and rotates around it as a "broken" arm. The mean observed velocities in NGC 3396 have been therefore projected on the major axis of NGC 3395, corrected for inclination, and plotted in Figure 4 together with the rotational velocities in the inner part of NGC 3395. With the distance scale previously adopted, NGC 3396 would fall at 6 kpc from the center of NGC 3395, which is within the dimension of an Sc galaxy. If we extrapolate the rotation curve of NGC 3395 to 6 kpc, we would expect rotational velocities slightly lower than those we have computed for NGC 3396. However, the agreement

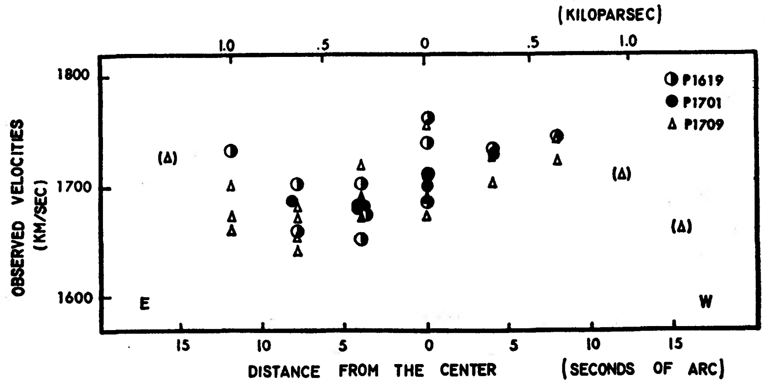

FIG. 5.—Radial velocities with respect to the Sun in NGC 3396, from three different spectra and measurements of [N II] λ6583, Hα, [O III] λ5007, and Hβ. Points in parentheses come only from Hα in spectrum P1709. Linear scale based on distance of 16 Mpc.

can be improved by assuming that NGC 3396 follows an orbit slightly inclined to the principal plane of NGC 3395. The hypothesis that the center of gravity of the double system coincides approximately with NGC 3395 is also supported by the value of the radial velocity of H I associated with the pair. The value of 1605 km sec^{-1} (Roberts 1969) refers to both components not resolved in the beam and is much closer to the systemic velocity of NGC 3395. The principal objection to this one-galaxy model is the asymmetric distribution of luminous matter in the system. It would be interesting to extend the observations farther from the nucleus of NGC 3395 and, by comparing the two sides of the rotation curve, check whether there is any asymmetry also in the mass distribution.

Finally, we can explore the possibility that NGC 3396 is the result of some violent event which took place in the nucleus of NGC 3395. Bertola (1966) has produced evidence of dynamic instability in the double system NGC 4490–85. Arp (1969) studied six spirals with companions at the end of an arm and concluded that the satellites have probably been expelled from the larger galaxies and are themselves centers of violent activity. The differences in the radial velocities of the components of the pair were very similar to the value we observe, $\Delta V = 90$ km sec^{-1}. A dissimilarity with Arp's sample is that NGC 3395, the main galaxy, is only 0.5 mag brighter than NGC 3396 (de Vaucouleurs and de Vaucouleurs 1964), the differences between the two components being usually 1 mag or more. On the other hand, NGC 3395 is a late-type spiral, as are all systems studied by Arp (1969). Its nucleus has a peculiar shape, evident both in Morgan's (1958) photograph and in our Hα exposure. The spiral pattern is irregular and brighter on the side opposite NGC 3396. The smaller concentration near the nucleus of NGC 3396, recorded both in the Hα photograph and in spectrum 1709, can be interpreted as a secondary ejection, mentioned by Arp (1969). All these facts, however, only suggest that violent activity is taking place or had taken place in the recent past in NGC 3395-3396, but they are clearly not convincing evidence that NGC 3396 was expelled from NGC 3395.

In conclusion, since the velocities observed in the companion galaxy, NGC 3396, do not differ significantly from the velocities predicted at that point from the rotation curve of NGC 3395, an explosive origin of NGC 3396 need not be invoked to explain the observed velocity field. The hypothesis that NGC 3396 is gravitationally bound to NGC 3395 and rotates around it seems the most plausible.

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