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THE NGC 4005 GROUP: A ROTATING SYSTEM OF GALAXIES?

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ABSTRACT

H I line observations with the Arecibo 305 m telescope were made of 23 galaxies within a 7 square degree region centered on the NGC 4005 group, a system of galaxies located in Zw 127-10 ($\alpha = 11^h53^m.0$; $\delta = +25°22'$). Accurate radial velocities and direct mass estimates derived from the 21 cm line profiles of the galaxies in this region are reported. A systematic trend in the radial velocities is found along the major axis of the NGC 4005 group. This correlation between position and velocity is fitted to a simple linear regression relation with a slope significantly different from zero.

One explanation for this effect is that the NGC 4005 group is rotating with a period no longer than 4×10^9 yr. Other possible interpretations of this systematic effect are discussed. The mass of the group is estimated by applying the harmonic law, the virial theorem, and the projected mass method. The masses obtained from the three methods are all consistent. The virial mass-to-light ratio of the group is 84 solar units, which is typical of small groups in general.

Subject headings: galaxies: clustering — galaxies: redshifts — radio sources: 21 cm radiation

I. INTRODUCTION

Many clusters of galaxies, including the well-studied Virgo, Coma, and Perseus clusters, appear as flattened systems. These elongated shapes, which probably reflect the three-dimensional distribution of galaxies within the clusters, are fairly common among the looser groups of galaxies (Rood 1979) as well as the compact groups (Sargent 1972; Hickson *et al.* 1984). Rotation, usually associated with flattened systems, cannot account for the ellipticity of most clusters and groups because there is no evidence of large-scale systematic motions in these systems. There are a few known examples of clusters that may rotate. Within 3° of the center of the Coma cluster, Gregory and Tifft (1976) have found some evidence for slow rotation along the cluster's major axis. The systematic redshift effect observed in the Coma I cloud (Gregory and Thompson 1977) has also been interpreted as rotational motion; however, the strongest evidence of rotation is found in the southern cluster SC 0316−44 (Materne and Hopp 1983). If the interpretation of rotation is correct, then this is the first example of a rich cluster where large-scale systematic motions are dynamically important.

The NGC 4005 group is a small system of galaxies identified by Nilson (1973) in his annotations; Gregory and Thompson (1978) are recognized for having formally named the association and for proposing a population much larger than that originally noted by Nilson (1973). The group is located within the medium-compact cluster Zw 127-10 ($\alpha = 11^h53^m.0$; $\delta = +25°22'$; Zwicky, Herzog, and Wild 1961). It appears to be relatively isolated and consists mostly of spiral members with $m_z \leq 15.2$. The galaxies in the NGC 4005 group are distributed on the plane of the sky so as to constitute an elongated system similar to groups observed in the Local Supercluster (de Vaucouleurs 1975; Tully 1982).

The optical properties of the galaxies in the NGC 4005 group and in the field out to 1°.5 from the group's center are summarized in § III. The data, which consist mainly of 21 cm hydrogen-line observations of galaxies in the group and in the surrounding region, are presented (§ IV). Evidence establishing a systematic variation of radial velocities along the major axis of the group is presented in § V and is discussed in terms of large-scale systematic motions and other interpretations. An analysis of the dynamical properties of the system follows in § VI.

II. OBSERVATIONS

The 21 cm spectral line observations were made during 1982 June and 1984 October with the NAIC[1] 305 m reflector at the Arecibo Observatory. The receiver used with the Arecibo telescope was a two channel, dual polarization, GaAs field effect transistor (FET) receiver with a system temperature ~50 K near the zenith. The central 210 m of the reflector were illuminated by the 12 m dual polarization line feed, giving a half-power beam of 3'.3. The orthogonal polarizations were detected independently and fed into a 1008 channel autocorrelation spectral line receiver which was operated as four banks of 252 channels. Each bank had a bandwidth of 10 MHz and a channel spacing of 39.1 kHz ≈ 8 km s^{-1}. With all banks centered at the frequency of the expected detection, the orthogonal polarizations were sampled simultaneously. When redshifts were unknown and searching was necessary, each polarization was split into two parts and fed into each bank which was offset by 7.5 MHz, producing a velocity coverage of ~7000 km s^{-1}. With the receiver tuned near 1390 MHz, the telescope and receiver provided a maximum sensitivity of ~8 K Jy^{-1}.

All observations were carried out in a position-switching mode, where 5 minute on-source integrations were differenced from 5 minute off-source integrations of a reference region located 6 minutes of right ascension away from the position of the program galaxies. The data were calibrated by comparing the noise tube signal with those of continuum point sources taken from the catalog by Bridle, Davis, and Fomalont (1972). The flux densities of each spectrum were correlated for frequency and zenith-angle variations in the system's sensitivity.

[1] The Arecibo Observatory is part of the National Astronomy and Ionosphere Center, operated by Cornell University under contract with the National Science Foundation.

III. OPTICAL PROPERTIES OF THE NGC 4005 GROUP

The NGC 4005 group has an angular size $\sim 30'$ and contains 10 galaxies brighter than $m_z = 15.2$. As is clearly shown in Figure 1 (Plate 1), the projected spatial distribution of the brighter members is flattened and can be approximated by an ellipse; the major axis of the distribution occurs along a position angle of $\sim 120°$. Applying Rood's (1979) ellipticity index, the group's axial ratio is measured to be ~ 0.53, which suggests a disklike system of galaxies.

The optical properties of the brighter members are summarized in Table 1. The positions, accurate to within 5″, were obtained with the NRAO[2] (Charlottesville) Mann two-axis measuring engine and were measured directly from the blue Palomar Sky Survey (PSS) print. Morphological types in Table 1 were estimated by the author, who examined second editions of the blue and red PSS prints. Most angular sizes were taken from Nilson's (1973) catalog, but a few galaxies with angular sizes less than 1′ (the limit for inclusion in the UGC) had to be measured directly from the blue PSS print and then adapted to Nilson's system in a manner described by Williams (1983). The Zwicky magnitudes (m_z) were corrected for internal extinction by means of the inclination corrections,

$$\Delta m_i = 0.43(\sec i - 1) \quad \text{for types S0–Sb} ,$$

$$\Delta m_i = 0.28(\sec i - 1) \quad \text{for types Sbc, Sc}$$

(Peterson 1979). For inclinations greater than 75°, the maximum extinction is taken to be 1.33 mag for types S0–Sb and 1.03 mag for types Sbc and Sc (Peterson 1979). No correction is made if the galaxy's type is unknown. The following "K-correction" based on the work of Pence (1976) has been applied to the Zwicky magnitudes in Table 1 (de Vaucouleurs, de Vaucouleurs, and Corwin 1976):

$$\Delta m_K = z(4.5 - 0.75T) \quad \text{for} \quad 0 \leq T \leq 2 \text{ (S0/a–Sab)} ,$$

$$\Delta m_K = z(3.15 - 0.30T) \quad \text{for} \quad 3 \leq T \leq 10 \text{ (Sb–Ir)} ,$$

where z is the galaxy's redshift. When the morphological type is unknown, the adopted "K-correction" is taken to be $2.25z$, following Sullivan *et al.* (1981). The galactic extinction as determined by Burstein and Heiles (1978) is 0.0 mag in the direction of the NGC 4005 group. Entered in Table 1 are the fully corrected magnitudes (m_{cz}), along with the galaxy's inclination angle, which is calculated from

$$\cos^2 i = 1.042(B/A)^2 - 0.042 ,$$

where A and B are the major and minor blue diameters.

Within the 30′ diameter enclosing the 10 brightest members, the NGC 4005 group has a surface brightness of 27.8 mag arcsec^{-2} and a surface density enhancement of ~ 60 times the average density of "field" galaxies with $m_z \leq 15.2$ (the apparent magnitude of the faintest member having a measured radial velocity). The average surface density of "field" galaxies was estimated by adopting Abell's (1965) galaxy count (77 galaxies per square degree brighter than or as bright as 18.3 mag) and assuming a constant volume density.

The galaxies in the NGC 4005 group have a mean velocity of ~ 4600 km s^{-1} (Jaffe, Gavazzi, and Valentijn 1986), and therefore the group lies in front of the Coma/A1367 supercluster. At a distance of ~ 60 Mpc ($H_0 = 75$ km s^{-1} Mpc^{-1}), the size of the group is 0.5 Mpc, which is typical of the groups in the Local Supercluster (de Vaucouleurs 1975) and in the Coma/A1367 supercluster (Gregory and Thompson 1978). The NGC 4005 group is also very similar in terms of linear size, surface brightness, and density contrast to the IC 698 group of galaxies within the Coma/A1367 supercluster (Williams 1983).

The field surrounding the NGC 4005 group was searched for outlying members brighter than 15.7 mag. Many galaxies without measured redshifts were identified within $\sim 1°.5$ of the group's center. The optical properties of possible outlying members and other galaxies in this region are listed in Table 2, where the column headings are identical with those given in Table 1.

IV. H I PROPERTIES OF THE GROUP

The H I profiles of the galaxies in the NGC 4005 group and the surrounding field are presented in Figure 2. All profiles

[2] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

TABLE 1

OPTICAL PROPERTIES OF GALAXIES IN THE NGC 4005 GROUP

Galaxy (NGC)	α(1950)	δ(1950)	Type	$A \times B$[a]	m_z,[b] m_{cz} (mag)	i
3987	11ʰ54ᵐ46ˢ	25°28′23″	Sbc	2′.3 × 0′.40	14.4, 13.3	42°
3989	11 54 52	25 30 40	Sbc	0.7 × 0.30	15.7, 15.3	67
3993	11 55 03	25 31 08	Sbc	1.6 × 0.40	14.8, 13.7	81
3997	11 55 14	25 32 56	S(B)bc	1.6 × 1.30	14.3, 14.2	36
4000	11 55 23	25 25 24	Sc	1.1 × 0.20	15.2, 14.1	90
4005	11 55 36	25 24 00	Sb	1.1 × 0.60	14.1, 13.7	59
4011	11 55 51	25 22 35	Sb/Sbc	0.4 × 0.14*	15.7, 15.0	73
4018	11 56 06	25 35 46	Sc	1.8 × 0.30	14.7, 13.6	90
4015A	11 56 08	25 18 55	E	1.1 × 0.90	[14.5], 14.8	0
4015B	11 56 09	25 19 17	Irr	0.8 × 0.20	[15.7], 14.7	81
4022	11 56 27	25 39 05	S0	1.3 × 1.20	14.4, 14.3	23
4023	11 56 31	25 16 01	Sb	1.1 × 0.70	14.6, 14.3	52

[a] An asterisk following the galaxy's size indicates the author's measurement.

[b] A bracket indicates that apparent magnitudes of the component galaxies in a double system with known Zwicky magnitude were estimated by the author.

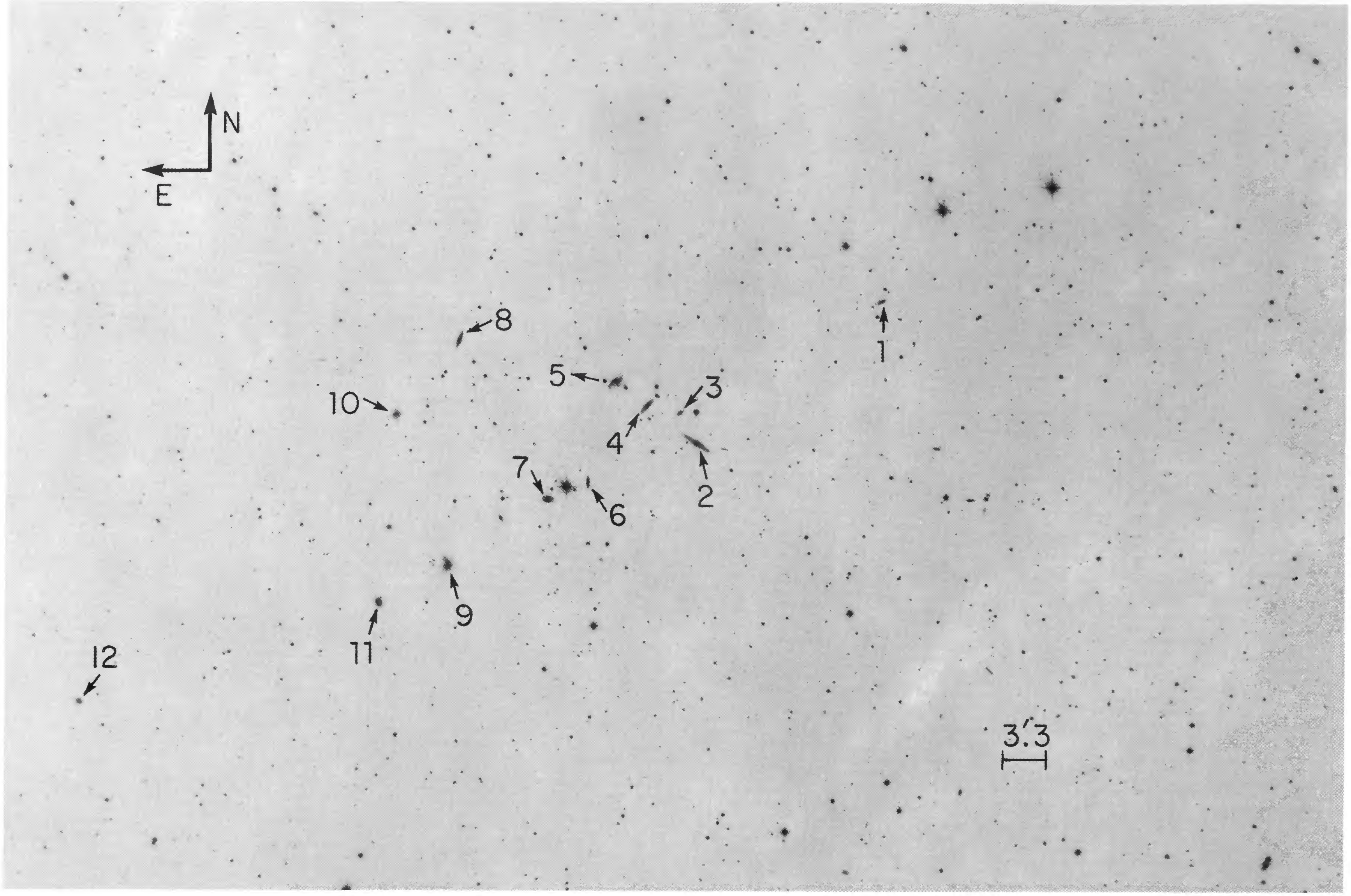

FIG. 1.—NGC 4005 group ($\alpha = 11^h55^m.6$, $\delta = +25°28'$) reproduced from the blue print of the Palomar Sky Survey. (© 1960 National Geographic Society–Palomar Sky Survey. Reproduced by permission of the California Institute of Technology.) Zw 127-109, N3987, N3989, N3993, N3997, N4000, N4005, N4018, N4015A, and N4015B, N4022, N4023, and Zw 127-133 are labeled *1–12*, respectively.

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TABLE 2

OPTICAL PROPERTIES OF GALAXIES IN THE FIELD SURROUNDING THE NGC 4005 GROUP

Galaxy	α(1950)	δ(1950)	Type[a]	$A \times B$[b]	m_z, m_{cz} (mag)	i
N3911	$11^h46^m47^s$	25°13′02″	Sc	1′.2 × 0′.90	15.4, 15.3	42°
U6806	11 47 45	26 14 20	>Sb	2.0 × 0.60	14.4, 13.3	77
U6861	11 50 36	25 42 57	Sc	1.0 × 0.70	15.1, 15.0	47
U6883	11 52 24	26 28 49	Sc	1.4 × 1.40	15.3, 15.3	0
Zw 127-105	11 53 08	25 11 56	Sc	0.7 × 0.15*	15.7, 14.6	90
I746	11 53 00	26 10 02	Sb	1.3 × 0.35	14.5, 13.1	79
Zw 127-107	11 53 15	25 24 35	Sbc	0.7 × 0.15*	15.7, 14.6	90
N3983	11 53 49	24 08 46	S0	1.2 × 0.30	14.8, 14.8	81
Zw 127-109	11 53 46	25 39 12	SB(bc)	0.8 × 0.25	15.7, 14.6	77
Zw 127-129	11 56 56	25 44 48	S...	0.5 × 0.20*	15.5, 15.1	69
Zw 127-131	11 57 10	25 53 57	S...	0.2 × 0.15*	15.7, 15.7	55
Zw 127-133	11 58 10	25 08 04	Sc	0.7 × 0 50*	15.3, 15.2	46

[a] S... means that the type is a spiral, but whether it is an early or late type spiral could not be determined from the PSS print.

[b] An asterisk following the galaxy's size indicates the author's measurement.

have been smoothed to a velocity resolution of 32 km s^{-1}, and most have the single- or double-peaked features characteristic of rotationally supported H I disks viewed at various inclination angles. The following galaxies have abnormal H I profiles that could be caused by confusion in the main beam or asymmetries in the galaxy's velocity field due to tidal interactions.

a) *Notes on Galaxy Profiles*

UGC 6806.—The profile's shape is asymmetric with respect to the systemic velocity. Nilson (1973) notes that the galaxy is "disturbed" and paired with UGC 6807, which is 2′ away. The anomalous shape is probably caused by both the tidal interaction with UGC 6807 and confusion within the beam.

NGC 3989.—The angular separation between the centers of this galaxy and NGC 3987 is less than 3′.3. Given the size and position angle of NGC 3987, confusion is suspected in the main beam. From the profile's shape, intensity, and systemic velocity, it is likely that the emission detected at the position of NGC 3989 is associated with the receding end of NGC 3987 and not with NGC 3989.

NGC 3997.—As noted by Nilson (1973), this galaxy is "distorted." Its spiral arms are too open for a galaxy seen at an inclination angle of 36°, so that they appear to lie above and below the plane defined by the bar.

NGC 4015.—This double system, also referred to as Arp 138 (Arp 1966) and VV 216 (Vorontsov-Vel'yaminov 1959) are two partially superposed galaxies seen in projection along the line of sight. The fainter irregular companion, viewed edge-on, partially obscures the elliptical galaxy. The H I emission detected at the position of NGC 4015 (Fig. 2) is probably associated with the irregular galaxy and not the brighter elliptical companion, which has an optical velocity of 4341 km s^{-1} (Huchra *et al.* 1983) very close to that of the H I emission. The broad ($\Delta v \approx 800$ km s^{-1}) H I profile, though unusual for isolated galaxies, is typical for interacting systems.

b) *Observed and Derived Quantities of the Detected Galaxies*

The quantities observed directly from the H I profile and those that have been derived are given in Table 3, which contains the following information for each galaxy:

Col. (*1*).—Source name.

Col. (*2*).—Top row: heliocentric radial velocity estimated at the midpoint between the velocities at which the flux density is 20% of the peak intensity in the H I profile. Middle row: the H I velocity corrected for the velocity of the Sun relative to the Local Group (de Vaucouleurs, de Vaucouleurs, and Corwin 1976):

$$V_{\rm LG} = V_{\odot} + 300 \text{ km s}^{-1} \sin l \cos b \, .$$

Bottom row: estimate of the error in the radial velocity due to the uncertainty in the determination of the 20% level in the flux density.

Col. (*3*).—Top row: observed velocity width at 20% of the peak intensity. Second row: velocity width corrected for inclination and for the redshift effect,

$$\Delta V_c = \Delta V_{\rm obs}/(1 + z) \sin i \, .$$

Col. (*4*).—Top row: observed integrated hydrogen flux $\int S\,dv$. Middle row: Integrated hydrogen flux corrected for the effects of partial resolution (Sullivan *et al.* 1981). Bottom row: estimate of the error in the flux due to the rms noise variation of the baseline.

Col. (*5*).—Neutral hydrogen mass determined from the relation

$$M_{\rm H\,I}/M_{\odot} = 2.36 \times 10^5 D^2 \int S\,dv \, ,$$

where D is the distance to the galaxy or to the NGC 4005 group ($D = 60$ Mpc). The distance to the group was determined from the average radial velocity of the members (§ V) and the nominal value for H_0 of 75 km s^{-1} Mpc^{-1}. The 21 cm self-absorption corrections were made following the precepts given by Heidmann, Heidmann, and de Vaucouleurs (1971).

Col. (*6*).—Total mass within a Holmberg (photometric) radius determined from the relation

$$M_{\rm opt} = 5000 D a_{\rm H}(0) \Delta V_{20}^2 \, ,$$

where $a_{\rm H}(0)$ is the face-on Holmberg diameter in arcminutes and D is the galaxy's or group's distance in Mpc. Holmberg

TABLE 3

H I AND INTEGRAL PROPERTIES OF GALAXIES IN THE NGC 4005 GROUP AND THE SURROUNDING FIELD

Galaxy[a] (1)	$V_{\odot}$ V_{LG} $\pm\sigma(V)$ (km s^{-1}) (2)	ΔV_{obs}[b] ΔV_c (km s^{-1}) (3)	$Flux_{obs}$ $Flux_c$ ε (Jy km s^{-1}) (4)	M_H (10^9 $M_{\odot}$) (5)	M_{opt}[c] (10^9 $M_{\odot}$) (6)	L (10^9 $L_{\odot}$) (7)	M_H/L ε ($M_{\odot}/L_{\odot}$) (8)	M_{opt}/L ($M_{\odot}/L_{\odot}$) (9)	M_H/M_{opt} (10)
N 3911	5958 5913 16	207 303	4.95 5.65 0.27	8.29	70.4	6.6	1.25 0.06	10.6	0.12
U 6806	3760 3715 16	265: 269:	4.14: 4.80: 0.40	2.98:	42.9:	16.5	0.18: 0.02	2.6:	0.07:
U 6883	5150 5113 16	59 58	3.92 4.84 0.07	5.31	(35.0)	5.0	1.07 0.02	7.0	-
I 746	5030 4992 16	310 311	6.70 7.20 0.62	8.16	53.1	35.8	0.23 0.02	1.5	0.15
Zw 127-107	6458 6417 20	86 84	0.54 0.55 0.15	1.14	(104.3)	14.9	0.08 0.02	7.0	-
Zw 127-109*	4731 4675 20	284† 287	2.54 2.64 0.57	2.44	29.7	7.4	0.33 0.07	4.0	0.08
N 3987*	4501 4461 16	577 568	7.87 9.10 0.75	9.33	246.8	24.6	0.38 0.03	10.0	0.04
N 3989	4713: 4673: 20	374: 400:	2.01: 2.09: 0.75	1.87:	53.6:	4.3	0.44: 0.16	12.6:	0.04:
N 3993*	4828 4788 16	372 371	4.28 4.71 0.41	4.47	79.9	17.0	0.26 0.02	4.7	0.06
N 3997*	4765 4726 16	295 494	8.73 10.84 0.35	9.33	183.7	10.7	0.87 0.30	17.1	0.05
N 4000*	4562 4522 16	318 313	2.29 2.40 0.41	2.46	41.2	11.8	0.21 0.04	3.5	0.06
N 4005*	4458 4418 20	402 462	1.97 2.16 0.76	1.86	108.7	17.0	0.11 0.04	6.4	0.02
N 4018*	4482 4443 16	369 364	7.73 8.55 0.52	8.76	82.8	18.6	0.47 0.03	4.4	0.11
N 4015B*	4347 4307 16	815 813	2.32 2.40 0.49	2.27	(18.2)	2.7	0.84 0.17	7.0	-
N 4023*	4408 4368 16	221 276	1.43 1.58 0.44	1.36	40.2	9.8	0.14 0.04	4.1	0.03
Zw 127-133*	4667 4627 16	164 224	1.32 1.39 0.16	1.20	18.9	4.3	0.28 0.03	4.4	0.06

NOTE.—A colon means that the value is uncertain because of confusion in the beam with emission from a neighboring galaxy.

[a] An asterisk following the name of the galaxy indicates that it is part of the NGC 4005 group.

[b] A dagger following the velocity width indicates that the profile width was estimated at 50% of the peak intensity because of the higher rms noise per channel.

[c] Parentheses indicate that the mass was estimated by using a mass-to-light ratio of 7 solar units.

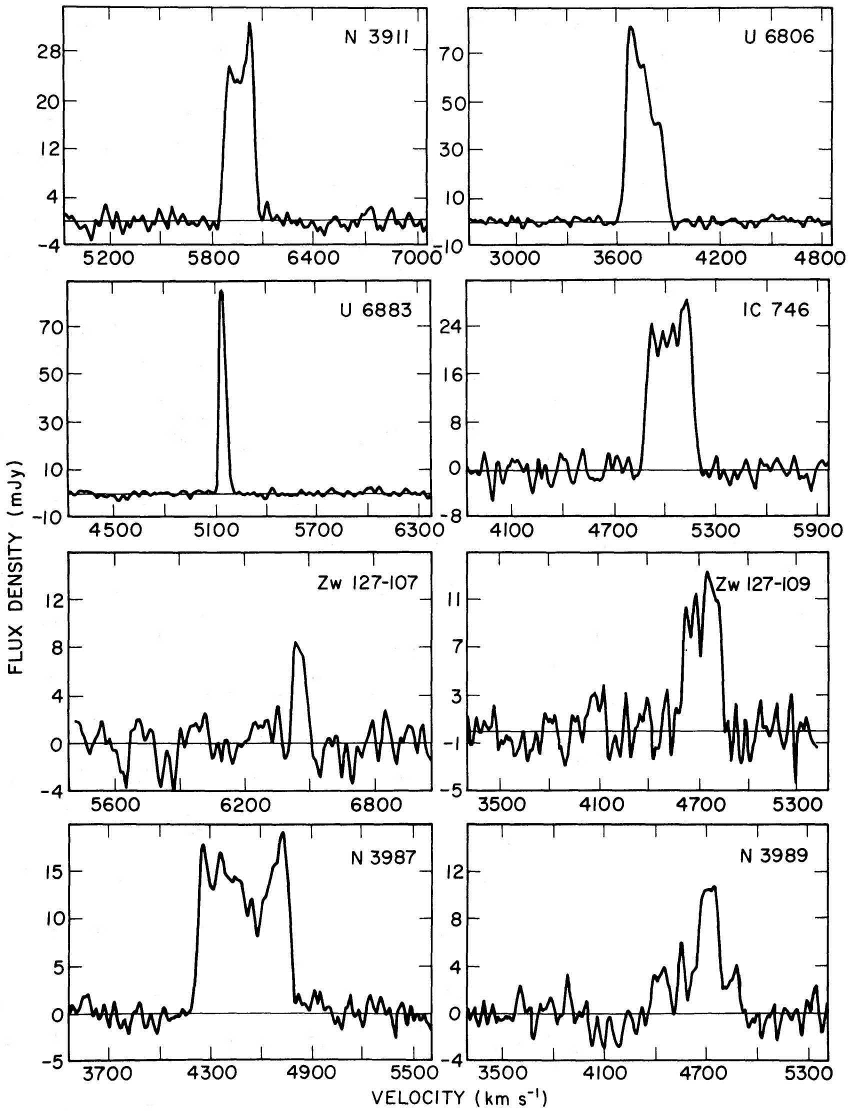

FIG. 2.—H I profiles of the galaxies in and surrounding the NGC 4005 group

diameters are computed from the Nilson (1973) diameters through relations given in Sullivan *et al.* (1981), who modified the previous transformations of Rood and Dickel (1978).

Col. (8).—Ratio of hydrogen mass to luminosity.

Col. (9).—Ratio of total mass to luminosity.

Col. (10).—Ratio of hydrogen mass to total mass.

V. KINEMATIC PROPERTIES OF THE GROUP

The mean radial velocity of the 10 brightest ($m_{cz} \leq 15.2$) members (Table 1) in the NGC 4005 group is 4469 km s^{-1}, and the radial velocity dispersion about this value is 167 km s^{-1}. All but two of the radial velocities used to compute the average velocity of the group are H I determinations contained in Table 3. Although observed at 21 cm, NGC 4022 was not detected at its optical velocity of 4390 km s^{-1} (Huchra *et al.* 1983). NGC 4015, the double system, was detected at 21 cm, but the H I emission is probably associated with NGC 4015B rather than NGC 4015A, the elliptical companion. The optical velocities of NGC 4015A and NGC 4022 were used in the determination of the mean radial velocity. All of the galaxies that were observed but not detected in the 21 cm line are listed in Table 4.

NGC 3989, 3999, 4011, and 4021 are the fainter galaxies which lie within the area of the group as defined by the brighter ($m_{cz} \leq 15.2$) members listed in Table 1 and shown in Figure 1. These galaxies are all comparable in brightness and have an average angular size of 0'.40 (2.5 σ lower than the mean angular size of the brighter members). An unpublished Center for Astrophysics optical redshift measurement for NGC 4021 was provided by D. Latham (1985, private communication). In the

TABLE 4

UNDETECTED GALAXIES

Galaxy	rms (mJy)	Velocity Range (km s^{-1})
U6861	1.2	3400–10400
Zw 127-105	2.0	3400–10400
N3983	1.8	3400–10400
N4011	2.0	3400–10400
N4022	2.0	3400– 5400
Zw 127-129	3.0	3400–10400
Zw 127-131	3.0	3400–10400

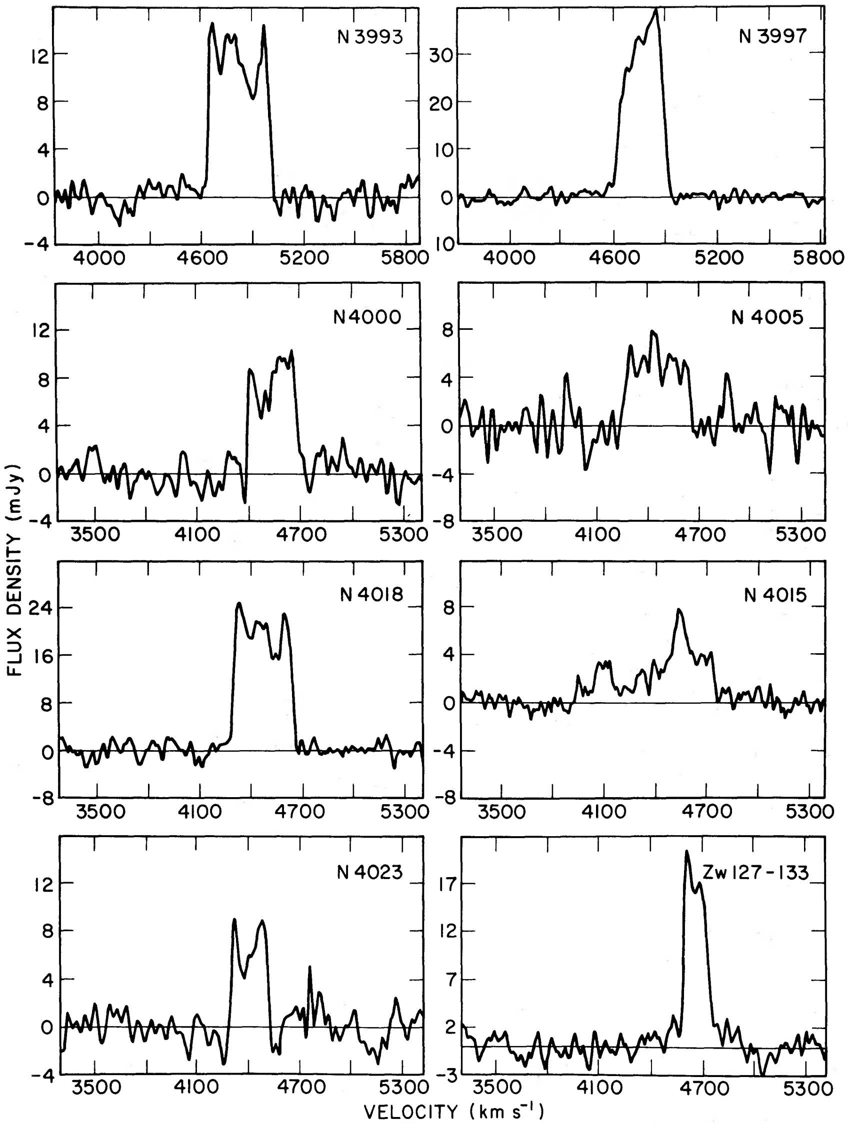

Fig. 2—*Continued*

optical spectrum, three absorption lines were detected at 10,064 $\pm$ 30 km s^{-1} (heliocentric). Because the other three galaxies are similar in size and brightness to NGC 4021, they may also be at the same redshift and therefore would not belong to the NGC 4005 group.

Along the major axis of the NGC 4005 group, an interesting trend is observed in the distribution of the galaxies' velocities. In the western region of the group, most members have radial velocities that are $\sim$200 km s^{-1} larger than the radial velocities of the galaxies in the eastern part. To test this correlation, a rectangular coordinate system was defined arbitrarily through the position of NGC 4023. The perpendicular distances x_i of all galaxies to this y-axis were calculated, so that the member's radial velocity v_i could be determined as a function of x_i. The position angle of the y-axis was allowed to vary between 0° and 170° in increments of 10°.

The best least-squares fit to the data is given by the relation

$$v_i = 15 \pm 4(\text{s.e.})x_i + 4255 \pm 44(\text{s.e.}) ,$$

where v_i is in km s^{-1} and x_i is in arcminutes. The correlation coefficient is 0.8, which represents a good fit to the data along a position angle of 130° $\pm$ 10°. The significance of the linear regression relationship was assessed by using the analysis-of-variance technique to test the null hypothesis that the gradient is zero. From the F-value, there is evidence at the significance level 0.01 that the gradient is not equal to zero. A quadratic equation was also fitted to the data, but it did not provide a significantly better fit than the straight line at the 5% level.

A plot of v_i versus x_i along this position angle is shown in Figure 3. The maximum correlation between v_i and x_i shows up along a line which is nearly coincident with the projected major axis (position angle $\sim$120°) of the NGC 4005 group. This could be interpreted as a possible indication of the group's rotation, with the northwest side receding.

The velocity difference between the galaxies from one end of the major axis to the other is $\sim$370 km s^{-1}. If the group is a dislike system, as its axial ratio suggests, then the rotational period can be estimated from the group's size (0.5 Mpc) and rotational velocity. In the outer regions, a lower limit of $\sim$185 km s^{-1} can be set on the velocity of the group relative to its

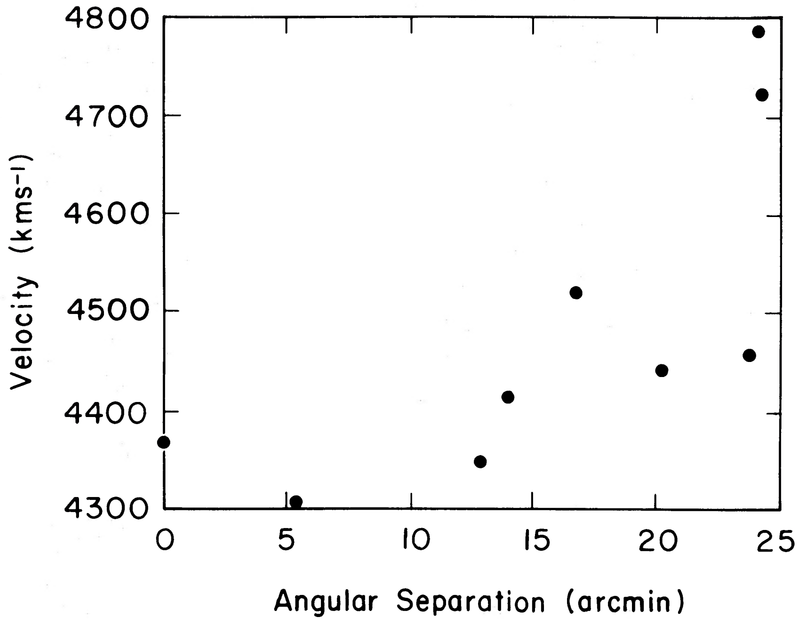

FIG. 3.—A plot of radial velocities (galactocentric) vs. angular distances from an origin passing through the position of NGC 4023 along a position angle of 130°

center. Because the inclination angle of the disklike system is unknown, only an upper limit of $\sim 4 \times 10^9$ yr can be set on the rotational period of the NGC 4005 group. This value is much less than the period of rotation for the Local Supercluster (de Vaucouleurs 1958), the Coma cluster (Gregory and Tifft 1976), and the southern cluster SC 0316−44 (Materne and Hopp 1983).

The systematic trend in the radial velocities along the major axis of the NGC 4005 group could also be explained if the group is in the process of either expanding or contracting. The dynamical stability of the NGC 4005 group (§ VI) could determine which condition (expansion or contraction) is more likely. The other possibility, that there are two groups which are superposed on the sky and which have nearly identical mean velocities, cannot be eliminated. It does seem likely that the redshift distribution of the NGC 4005 group is an effect in a single group and not a composite one, because the velocity dispersion (167 km s^{-1}) is typical of small groups of galaxies.

VI. DYNAMICAL PROPERTIES OF THE GROUP

The smallest circle that contains the 10 brightest ($m_{cz} \leq 15.2$) members of the NGC 4005 group is not clearly isolated. Although faint, Zw 127-109 and 127-133 (labeled *1* and *12*, respectively in Fig. 1) lie within 1° of the group's center, have radial velocities (Table 3) very close to the mean velocity of the NGC 4005 group, and are probably physically associated with the system. The radial velocity of Zw 127-109 follows the systematic trend of redshifts along the major axis of the group. Zw 127-133, the farthest galaxy from the center of the NGC 4005 group, has a radial velocity that deviates most from this trend. Including these galaxies does not change the group's velocity dispersion but increases its angular size to $\sim 70'$. The largest concentric circle which contains no galaxies brighter than 15.3 mag is more than twice as large than the smallest circle (70′) which contains the NGC 4005 group. This system, which includes Zw 127-109 and 127-133, is well isolated from other bright galaxies.

Although the total energy of the group is positive (see below), the crossing time defined as

$$t_c = (2/\pi)(\langle r \rangle / \langle v \rangle)$$

(Rood and Dickel 1978), where $\langle r \rangle$ is the mean projected distance of the members from the center of mass and $\langle v \rangle$ is the average absolute value of the velocities relative to the center of mass, is only 10^9 yr. This value is comparable to that measured for most groups of galaxies. If the system were unbound, as its total energy indicates, then the group would have to have begun its expansion relatively recently ($\sim 10^9$ yr ago).

The mass contained within the Holmberg diameter, M_{opt} (Table 3), was taken as the total mass for nine of the 12 members in the group. Because of the broad H I emission associated with NGC 4015A and NGC 4015B, their masses along with that of NGC 4022 were estimated by assuming a mass-to-light ratio of 7 solar units. The mass-weighted space-velocity dispersion of the NGC 4005 group is $V = 268$ km s^{-1}; its virial radius, R, is 0.73 Mpc. Application of the virial theorem (cf. Williams 1985) to this group of 12 members gives a mass $M_v = V^2R/G = 1.1 \times 10^{13}\ M_\odot$. This yields a virial mass-to-light ratio of 84 ± 6 solar units, which is typical for small groups of galaxies.

If the NGC 4005 group is a disk system viewed nearly edge-on, then another estimate of the group's mass can be made from the orbital period of the outermost members. Most of the luminous mass in the group is contained within an ellipse that has a major axis of $\sim 30'$. The adopted value of the group's radius over which the systematic trend in radial velocities occurs is 0.24 Mpc. At this distance from the group's center, the orbital period of the galaxies is $\leq 4 \times 10^9$ yr. Using the harmonic law gives a mass of at least $10^{13}\ M_\odot$, which is comparable to the mass derived from the virial theorem.

The projected mass estimate described by Heisler, Tremaine, and Bahcall (1985) can also be applied to the NGC 4005 group. This method yields a group mass of $1.7 \times 10^{13}\ M_\odot$, which is consistent with the virial mass and the mass derived from the

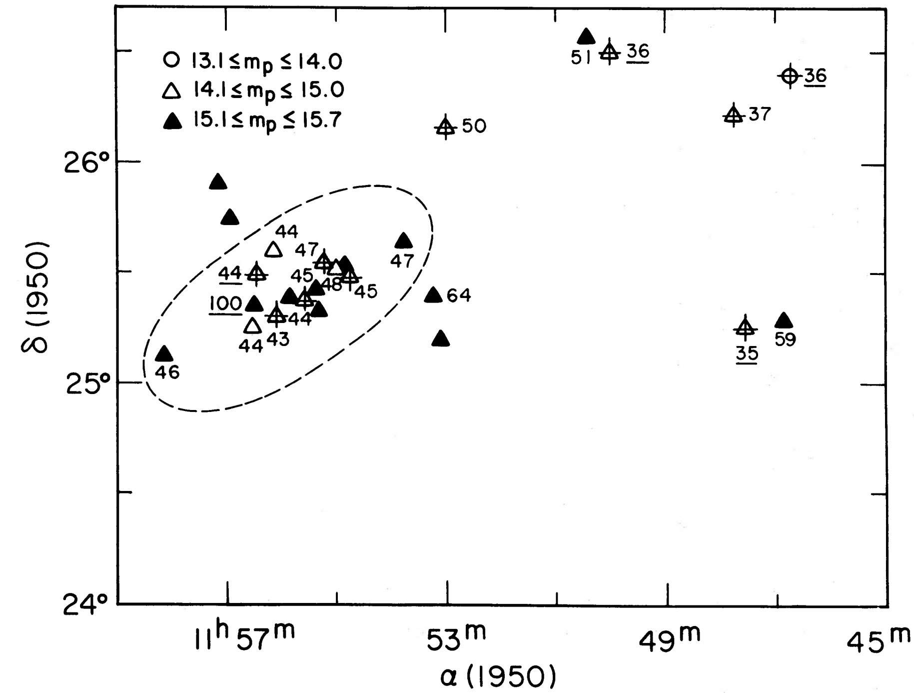

FIG. 4.—Positions, magnitudes, and radial velocities (with respect to the Local Group and in units of 100 km s^{-1}) of galaxies brighter than or equal to 15.7 mag in the direction of Zw 127-10. This Zwicky cluster is indicated by the dashed ellipse. All radial velocities are the author's H I determinations, except for the five optical velocities that are underlined. The 10 symbols that are crossed indicate the members of Geller-Huchra group 92.

harmonic law. The median and average mass estimates (Heisler, Tremaine, and Bahcall 1985) of the NGC 4005 group are a factor of 2–3 smaller than the mass derived from the other three methods.

VII. GELLER-HUCHRA GROUP 92

The NGC 4005 group may be part of a larger system of galaxies identified as group 92 (Geller and Huchra 1983, hereafter GH). The galaxies in GH 92 cover an area $\sim 10^8$ $arcsec^2$ and tend to cluster only in the region of the sky defined by the NGC 4005 group (Fig. 4). Ten of the brightest galaxies listed as members of GH 92 include NGC 3987, 3997, 4005, 4015, and 4022. The fainter galaxies within the NGC 4005 group have similar velocities and should also be included as members of GH 92.

The mass-to-light ratio was derived by applying the virial theorem to GH 92, including the eight fainter ($m_z \leq 15.6$) galaxies identified in the NGC 4005 group. The 18 galaxies for which redshifts have been measured provide a better sampling of this system's dynamics than do only the brighter members. The virial mass-to-light ratio for GH 92 is ~ 550 solar units. Because of this high mass-to-light ratio and the low surface density enhancement relative to the background (~ 1), it is very likely that GH 92 is part of the underlying background distribution of galaxies, and not a physical association as is the NGC 4005 group.

VIII. CONCLUSIONS

A systematic variation of radial velocities along the major axis of the NGC 4005 group is reported. This trend in velocities can be fitted very well by a simple linear regression relation with a slope significantly different from zero at the 0.01 significance level. The most interesting explanation for this effect is that the NGC 4005 group is rotating about its minor axis with a period of $\leq 4 \times 10^9$ yr. If the interpretation of rotation is correct, this would mean that the random motions of the members relative to the group's center of mass are eclipsed by the overall systematic motions. This may be the first known example of a small group of galaxies where rotation is dynamically important.

A disk model is adopted for the system. This model is not inconsistent with the observations of groups of galaxies. In the literature there are other possible examples of disk systems, such as Shakhbazian I (Robinson and Wampler 1973), the NGC 1023 group (Tully 1980), and the IC 698 group (Williams 1983). These systems have anomalously small velocity dispersions (< 80 km s^{-1}), which are expected if they are seen face-on and if most of the galaxy's motion lies in the plane of their disks.

A more prosaic interpretation for the orderly motions in the NGC 4005 group is that the system is expanding; this is in accordance with its positive total energy. If the group is in the process of dispersing, then its expansion age must be less than 10^9 yr. Alternatively, the systematic effect in the NGC 4005 group could be produced by two systems superposed on the sky. As in most groups of galaxies, there is not enough luminous mass to bind the system. Its virial mass-to-light ratio is a factor of 10 larger than that measured for the individual galaxies.

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