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MKW 10: A GROUP OF GALAXIES WITH A COMPACT CORE

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ABSTRACT

MKW 10 is a poor cluster of galaxies identified by Morgan, Kayser, and White (1975). The system contains nine galaxies with $m_{pg} \leq 15.5$, five of which appear to form a compact subsystem. The Arecibo 305 m telescope was used to detect the eight spiral members in the 21 cm line of neutral hydrogen. H I line observations were also made of galaxies surrounding the group so that a complete redshift sample is now available for spiral galaxies ($m_{pg} < 15.6$) within a 10.2 deg^2 region. Galaxies within the compact subsystem show strong signs of tidal interaction, as inferred from their 4 m images and the anomalous shapes in the H I profiles. These are taken as evidence for a physical rather than an apparent compactness of the subsystem. The M_H/L ratio and the morphological type of the galaxies correlate with position and local galaxy density in MKW 10, i.e., the fraction of early-type ($\leq$Sb) to late-type ($\geq$Sc) spiral galaxies is higher in the compact subsystem than in the rest of the group.

The short dynamical friction time scale (7×10^8 yr) and the high collision rate (22 per galaxy per Hubble time) make it unlikely that the subsystem has been compact for a Hubble time. The core appears to be a transient (and probably bound) configuration of galaxies which will coalesce in $\sim 10^9$ yr.

MKW 10 has a virial mass-to-light ratio of ~ 70 solar units and is embedded in a much larger feature identified as a Geller-Huchra group at least 3° in diameter. Although this larger structure has a crossing time of less than 0.5 H_0^{-1}, the surface density contrast relative to the background is of order unity, making it difficult or impossible to separate this feature from the dispersed component of the Coma/A1367 supercluster.

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

I. INTRODUCTION

MKW 10 is one of the poor clusters of galaxies identified by Morgan, Kayser, and White (1975). It is located $\sim 12°$ from A1367 and is a system containing nine galaxies with $m_{pg} < 15.5$ within the medium-compact cluster Zw 68 − 21 ($\alpha = 11^h38^m.3$, $\delta = +10°24'$; Zwicky, Herzog, and Wild 1961). Five of the brightest members, concentrated toward the center of the group, form a subsystem that has been identified as a compact group of galaxies (No. 58; Hickson 1982). Although this subsystem marginally satisfies Hickson's (1982) isolation criterion for compact groups, it is not clearly isolated.

During a study of the three-dimensional distribution of spiral galaxies, several groups and clusters were identified in the southern extension of the Coma/A1367 supercluster (Williams and Kerr 1981). It was difficult to distinguish between the real and spurious clusters because the redshifts of only a few spirals in these suspected density enhancements were measured. Nearly complete H I line observations were then made of the brightest ($m_{pg} < 15.7$) spirals in several of these Zwicky clusters, e.g., the IC 698 group (Williams 1983), in order to determine which of these systems were physical groups of galaxies; Zw 68 − 21 is another of the observed clusters. After the first set of observations was made, it was discovered that the subsystem within MKW 10 is also one of Hickson's (1982) compact groups.

Previous studies of poor clusters have been based almost exclusively on optical (Oemler 1976; van den Bergh 1977; Stauffer and Spinrad 1978; Thomas and Batchelor 1978; Schild and Davis 1979; Bahcall 1980; Thuan and Romanishin 1981; Morbey and Morris 1983; Beers *et al.* 1984), X-ray (Schwartz, Schwarz, and Tucker 1980; Schwartz *et al.* 1980; Kriss *et al.* 1980, Kriss *et al.* 1983), and radio-continuum (White and Burns 1980; Burns, White, and Hanisch 1980; Burns, White, and Hough 1981) measurements. Radio spectral-line studies of these systems have concentrated mainly on the giant cD-like galaxies which so far have been undetected at 21 cm (Burns, White, and Haynes 1981; Valentijn and Giovanelli 1982). The spiral galaxies in poor clusters have been virtually neglected, despite the fact that these systems contain on the average a higher fraction of disk galaxies than do rich clusters (Bahcall 1980). MKW 12, part of the larger cluster Zw 74 − 23 ($\alpha = 14^h00^m.4$, $\delta = +09°49'$; Zwicky, Herzog, and Wild 1961), is the only other poor cluster for which spiral galaxies have been observed and detected in neutral hydrogen (Chincarini, Giovanelli, and Haynes 1979; Sullivan *et al.* 1981; Williams and Kerr 1981).

In this paper, H I line observations of the galaxies in MKW 10 are presented along with observations of spiral galaxies that lie within 1°.5 of the group. The physical compactness of the subsystem is analyzed by examining the observable effects of tidal interactions and collisions on the optical and H I properties of the spiral galaxies in the group. By using mainly the H I line observations, the dynamical stability of MKW 10 and of a larger ($\sim 3°$ in diameter) feature, which includes this group, is investigated. The time scale of dynamical friction and the expected collision rate are estimated and used to predict the degree of dynamical evolution that may have occurred in the group. These theoretical predictions are then compared with the available optical, X-ray, and H I properties of the group.

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

II. OBSERVATIONS

The spectral-line observations were made at 21 cm during 1982 June and 1983 October with the 305 m reflector at the Arecibo Observatory[2]. The front end of the radio telescope consisted of a cooled GaAs field effect transister (FET) receiver, which gave a system temperature of ~ 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 beamwidth of 3′.3. The two polarizations were detected independently and fed into a 1008 channel autocorrelation receiver, which was operated as four banks of 252 channels. Since many of the galaxies in the region had no previously known redshifts, each of the four banks was offset by 7.5 MHz, to produce a useful velocity coverage of ~ 7200 km s^{-1} when searching was needed. Each bank had a bandwidth of 10 MHz and a channel spacing of 39.1 kHz ≈ 8 km s^{-1}. With the receiver tuned near 1390 MHz, the telescope and receiver provided a sensitivity of ~ 8 K Jy^{-1} near the zenith. The observing procedure is identical to that described in an earlier article by Williams and Brown (1983).

III. MKW 10

a) Optical Properties

The nine brightest ($m_{n\sigma} < 15.7$) members of MKW 10 (Fig. 1 [Pl. 5]) are listed in Table 1, along with their magnitudes, sizes, and morphological types. The positions were obtained with the Mann two-axis measuring engine at NRAO (Charlottesville) and are accurate to within 5″. The angular sizes of the galaxies are taken directly from Nilson's (1973) catalog, except for Zw 68−044 and Zw 68−046. These two galaxies were not included in the catalog, so that their angular sizes had to be measured directly from the Palomar Sky Survey (PSS) print and then adapted to Nilson's system in a manner described by Williams (1983). The inclination angle i is calculated from

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

where A and B are the major and minor blue diameters listed in Table 1 and the true axial ratio is assumed to be 0.2.

The Zwicky magnitudes (m_Z) have been corrected for internal extinction (Peterson 1979). In the direction of MKW 10, the galactic extinction as determined by Burstein and Heiles (1978) is 0.0 mag. The following "K-correction" from the work of Pence (1976) has been applied to the magnitudes (de Vaucouleurs, de Vaucouleurs, and Corwin 1976):

$$\Delta m_K = 4.5z \text{ for ellipticals ,}$$

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

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

where z is the galaxy's redshift. The fully corrected magnitudes (m_{cz}) are also listed in Table 1. Unlike most of the poor clusters in the original list (MKW), there is no giant galaxy, i.e., c or cD, in MKW 10. The one elliptical galaxy in the group ranks only fifth in luminosity. NGC 3825 is considered the dominant galaxy (MKW), but it is nearly equal in brightness to NGC 3822.

The morphological types listed in Table 1 were estimated from a negative copy (Morbey 1984) of a Cerro Tololo Inter-American Observatory (CTIO) 4 m plate of the group (van den Bergh 1977). Enlarged reproductions of these images as they appear on the 4 m plate are presented in Figure 2 (Plates 6 and 7). Most of the galaxies have unusual images.

UGC 6647: This galaxy is a two-armed barred spiral of low surface brightness. The spiral structure appears clumpy and can be traced more than 180° around the nucleus. Near the edge of the disk, the arms do not continue to spiral but appear to bend at right angles to the axis formed by the bar.

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

TABLE 1

OPTICAL PROPERTIES OF THE GALAXIES IN MKW 10

Galaxy[a]	α(1950)	δ(1950)	Type	A × B	m_z / m_{cz} (mag)	i
U 6647	11ʰ38ᵐ29ˢ	+10°30′09″	SBc	1′.4 × 1′.20	15.5 / 15.4	32°
N 3817*	11 39 18	+10 34 54	SB0–a	1.1 × 0.80	14.4 / 14.2	44
N 3820*	11 39 30	+10 39 40	Scp	0.7 × 0.50	14.9 / 14.7	46
N 3819*	11 39 31	+10 37 42	E/S0	0.8 × 0.70	14.8 / 14.7	0
N 3822*	11 39 36	+10 33 17	Sbp	1.3 × 0.70	13.7 / 13.2	59
N 3825*	11 39 49	+10 32 26	Sap	1.4 × 1.10	13.8 / 13.6	39
N 3833	11 40 54	+10 26 22	Sc	1.5 × 0.70	14.7 / 14.3	64
Zw 68−044	11 40 55	+10 37 22	Sc	0.5 × 0.35	14.9 / 14.8	38
Zw 68−046	11 41 07	+10 31 21	Sc	0.4 × 0.25	14.9 / 14.6	53

[a] An asterisk by the name of the galaxy indicates that it is part of Hickson's 1982 compact group.

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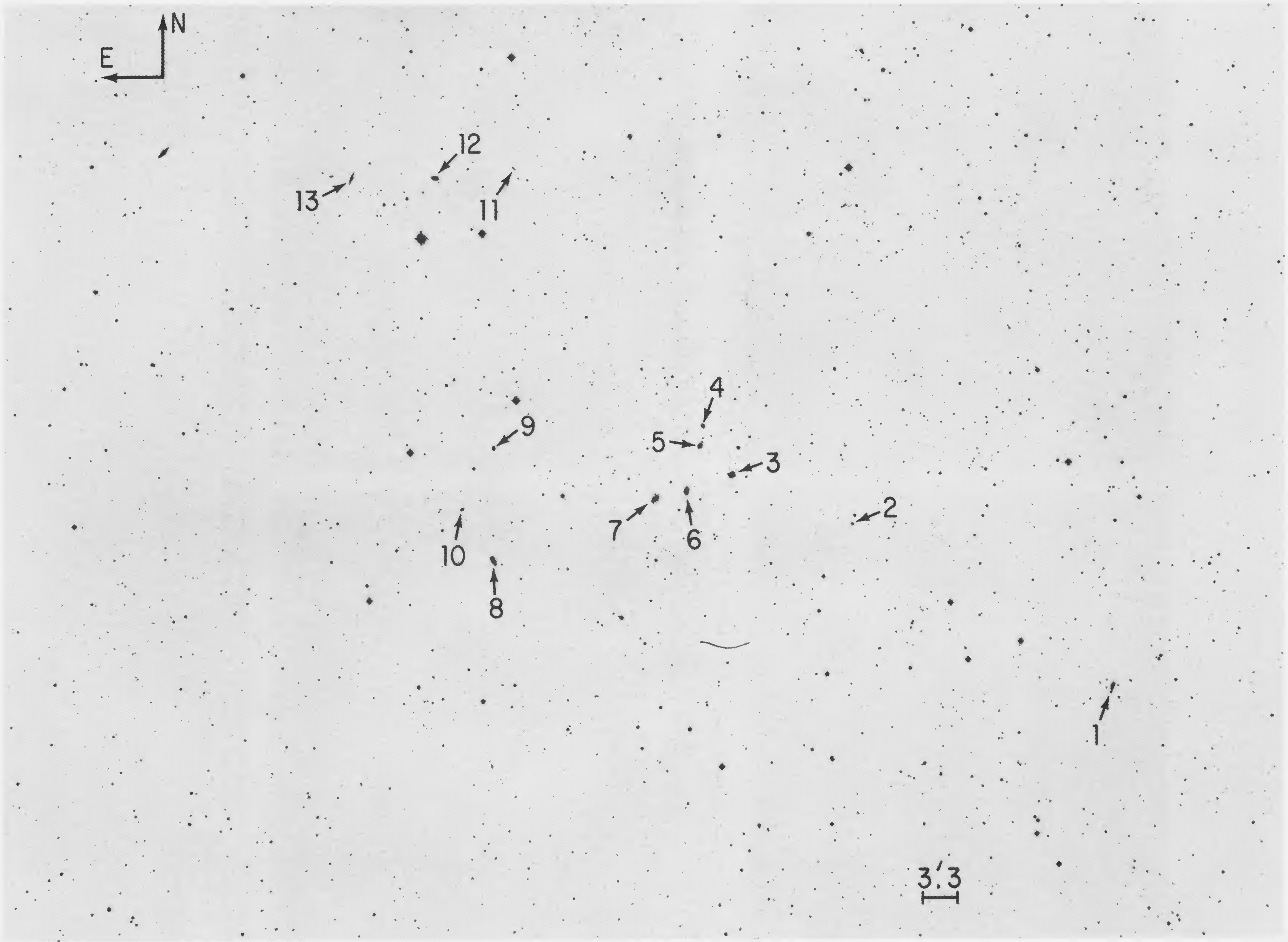

FIG. 1.—Zw 68−21 ($\alpha = 10^h38^m.3$, $\delta = +10°24'$) reproduced from the red print of the Palomar Sky Survey (© 1960 National Geographic Society—Palomar Sky Survey. Reproduced by permission of the California Institute of Technology). This cluster includes MKW 10 (*2–10*) and Hickson's compact group (*3–7*). U 6617, U 6647, N 3817, N 3820, N 3819, N 3822, N 3825, N 3833, Zw 68−044, Zw 68−046, Zw 68−042, U 6700, and IC 727 are labeled 1–13, respectively.

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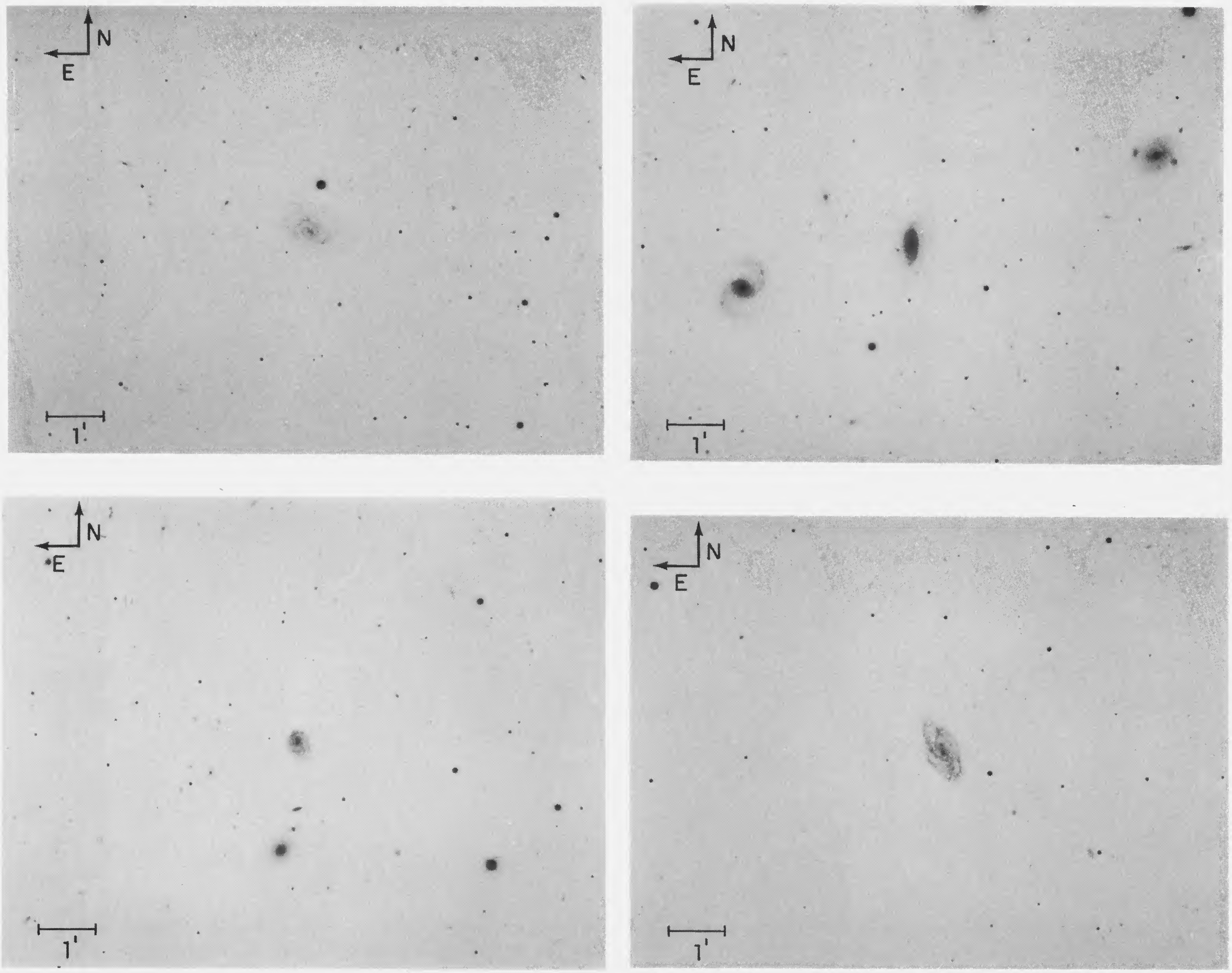

FIG. 2.—(*a*) UGC 6647. All reproductions [(*a*)–(*f*)] were made from a negative copy (kindly provided by Dr. Christopher Morbey) of a CTIO 4 m plate of the group (van den Bergh 1977). (*b*) From west to east, NGC 3817, NGC 3822, and NGC 3825. (*c*) From north to south, NGC 3820 and NGC 3819. (*d*) NGC 3833. (*e*) Zw 68 − 044. (*f*) Zw 68 − 046.

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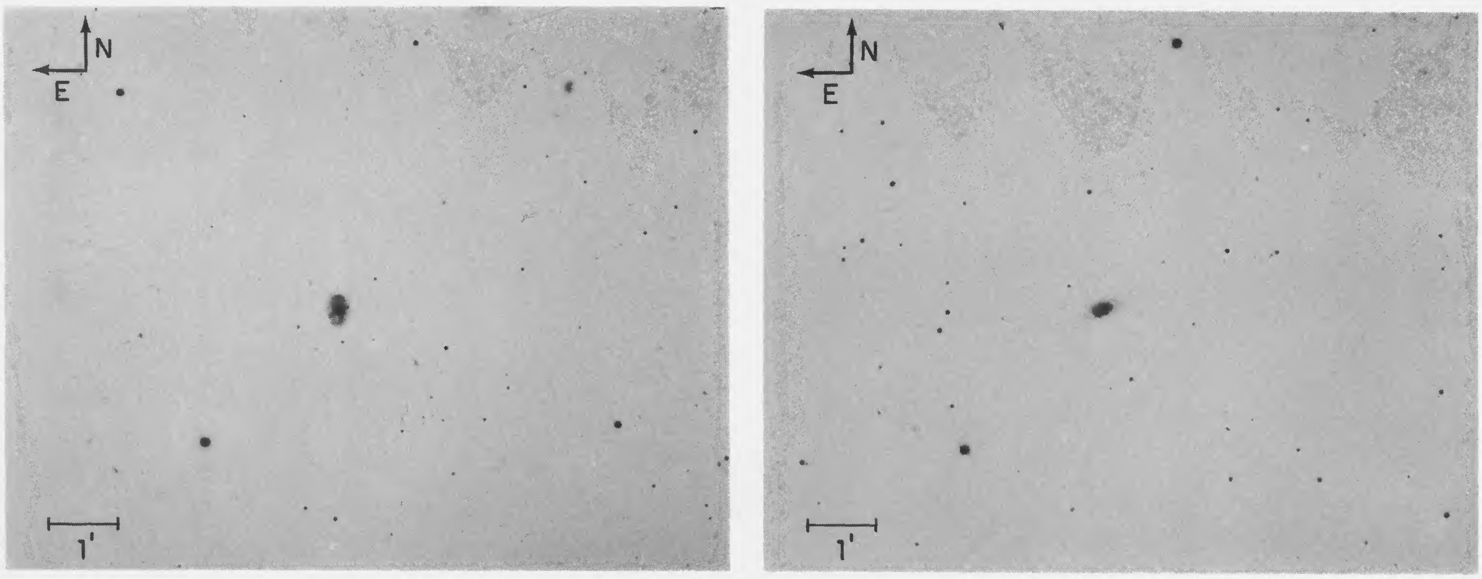

FIG. 2.—*Continued*

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NGC 3817: The nucleus, bar, and lens can be easily resolved in Figure 2*b*. The envelope surrounding the nucleus is generally smooth except for an absorption arc appearing northeast of the bar and a faint spiral feature in the southern part of the lens. There are two small companions within 24″ of the galaxy's nucleus. A description of each companion can be found in Nilson's (1973) catalog. The apparent magnitude in Table 1 includes both companions. A faint wisp of material can be seen emanating $\sim 1\rlap{.}'5$ from the southwest companion, which appears to be spiraling into the disk of NGC 3817.

NGC 3819: Using the 4 m CTIO plate, van den Bergh (1977) identified a slightly extended envelope around NGC 3819 and classified the galaxy as either an E1 or an S0–a. The image reproduced in Figure 2*c* shows a fuzzy outer envelope but the nucleus and the lens cannot be distinguished at the inner region. On the NRAO (Charlottesville) copy of the PSS print, the image is too exposed to even detect the outer envelope. On the Arecibo copy of the PSS print (Fig. 3 [Pl. 8]), the nucleus and the extended envelope are seen as two distinct features.

NGC 3820: The disk can be resolved into spiral arms and dust lanes (Fig. 2*c*). In the southern part of the image, the spiral arms consist of broken segments which end abruptly at the point where they just begin to bend around the galaxy. In the northern half of the image, a continuous spiral arm can be traced more than 90° around the nucleus, but this feature also ends abruptly in the southern part of the disk. Although none of the spiral structure can be resolved at the scale of the PSS print, Nilson (1973) noted that the image of NGC 3820 is "disturbed." At the resolution of the PSS print, the disk appears asymmetric with more luminous material observed on the side of the minor axis near NGC 3819. Despite the fact that NGC 3820 appears peculiar, its low surface brightness, dust lanes, spiral structure, and small nucleus are all characteristic of late-type spirals, particularly the Sc's.

NGC 3822: The disk, which appears amorphous on the PSS print, is resolved into dust lanes and tightly wound spiral arms of high surface brightness (Fig. 2*b*). The nucleus still cannot be distinguished from the luminous clump in the central regions. A faint tail proceeding from the northern part of the image can be traced almost 180° around the side of the image away from NGC 3825.

NGC 3825: The bright nucleus and lens dominating the image are characteristic of early-type systems (Fig. 2*b*). This galaxy appears to be a normal two-armed spiral, yet the axial ratio of the central region (nucleus and lens) is different from that of the entire image, which is defined by the angular extent of the spiral arms (Fig. 2*b*). The inclination angle determined from the spiral arms is close to face-on, whereas the bulge appears inclined nearly 50°, according to its axial ratio. Two bright spots on either end of the major axis mark the beginning of the spiral arms. The structures of the two arms appear different on the blue and red PSS prints. On the red image, both arms are smooth and well developed and have nearly the same angular extent. On the blue PSS print and the 4 m plate (Fig. 2*b*), the arm nearer to NGC 3822 resolves into luminous clumps (H II regions) that can be traced along two-thirds of the arm's length. The far arm appears less developed on the blue image; fewer H II regions are seen along the inner half of the spiral arm.

NGC 3833: This galaxy is a classic Sc type and is the largest in the group. Its image reveals a small, bright nucleus, dust lanes, and well-defined spiral arms decorated with many H II regions.

Zw 68–044: The spiral structure is ill defined and cannot be traced as single arms. There appears to be a faint bar whose ends mark the beginnings of two broken spiral arms. The extremely small nucleus and dust patches visible in the disk indicate that the galaxy is a late-type spiral.

Zw 68–046: Two thick, luminous arms can be traced more than 180° around the large, bright nucleus. These arms do not spiral into the nucleus but appear to begin at bright spots tangent to the edge of a central lens. Because the galaxy is inclined, the spiral arms give the impression of an external ring around the nucleus. Very faint spiral arms can be seen branching away from the two dominant arms in the disk.

Located ~7° from the IC 698 group (Williams 1983), MKW 10 is one of several small groups belonging to the Coma/A1367 supercluster (Gregory and Thompson 1978, Williams and Kerr 1981). The MKW 10 group has an estimated total blue magnitude of 11.9 mag and a surface brightness of 28.5 mag arcsec^{-2} within the ~40′ diameter enclosing all of the brightest ($m_{pg} <$ 15.7) members. At the distance of the Coma/A1367 supercluster, MKW 10 has a linear size of ~1 Mpc for a Hubble constant of 75 km s^{-1} Mpc^{-1}. The nine galaxies in the group represent a surface density contrast of ~16 times the average density of "field" galaxies equal to or brighter than 15.5 mag (the apparent magnitude of the faintest member in the group). The average surface density of "field" galaxies was determined by assuming a constant volume density and adopting Abell's (1965) galaxy count (77 galaxies per square degree brighter than or equal to 18.3 mag).

The projected spatial distribution of galaxies in MKW 10 is inhomogeneous, with more than half the galaxies clumped toward the center of the group (Fig. 1). The central subsystem has an estimated surface brightness of 25.6 mag arcsec^{-2} within the $8\rlap{.}'8$ diameter enclosing the five brightest members. This represents a surface density contrast of ~420 times the average density of "field" galaxies with $m_{pg} \leq 14.9$ (the apparent magnitude of the faintest member in the subsystem). The galaxies in this subsystem have an apparently compact configuration; the average projected angular separation between pairs is $5\rlap{.}'5$ (~3 times their average Holmberg angular diameter) and their rms angular projected separation is $\pm 2'$.

Photoelectric *UBV* measurements have been reported in the literature for the three brightest galaxies in the group. The corrected (galactic extinction, *K*, and aperture) $B-V$ colors of NGC 3817, 3822, and 3825 are 1.05, 0.91 and 0.98 (Schild and Davis 1979) respectively. These colors are significantly redder ($> 3\ \sigma$) than the average $B-V$ colors for normal early-type spirals (de Vaucouleurs 1977).

Several galaxies lie within ~45″ of MKW 10 (1, 11, 12, and 13; Fig. 1). Their angular diameters and apparent magnitudes are similar to those of the galaxies in MKW 10. The optical properties of these galaxies and other spirals within $\sim 1\rlap{.}^\circ 5$ of the group (Fig. 4 [Pl. 9]) are listed in Table 2. The morphological types are taken from Nilson (1973) unless otherwise noted.

b) H I *Properties*

All the spiral galaxies in MKW 10 were detected at 21 cm. Their H I profiles, presented in Figure 5, have been smoothed to a velocity resolution of 32 km s^{-1}. The observational results and other derived quantities 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

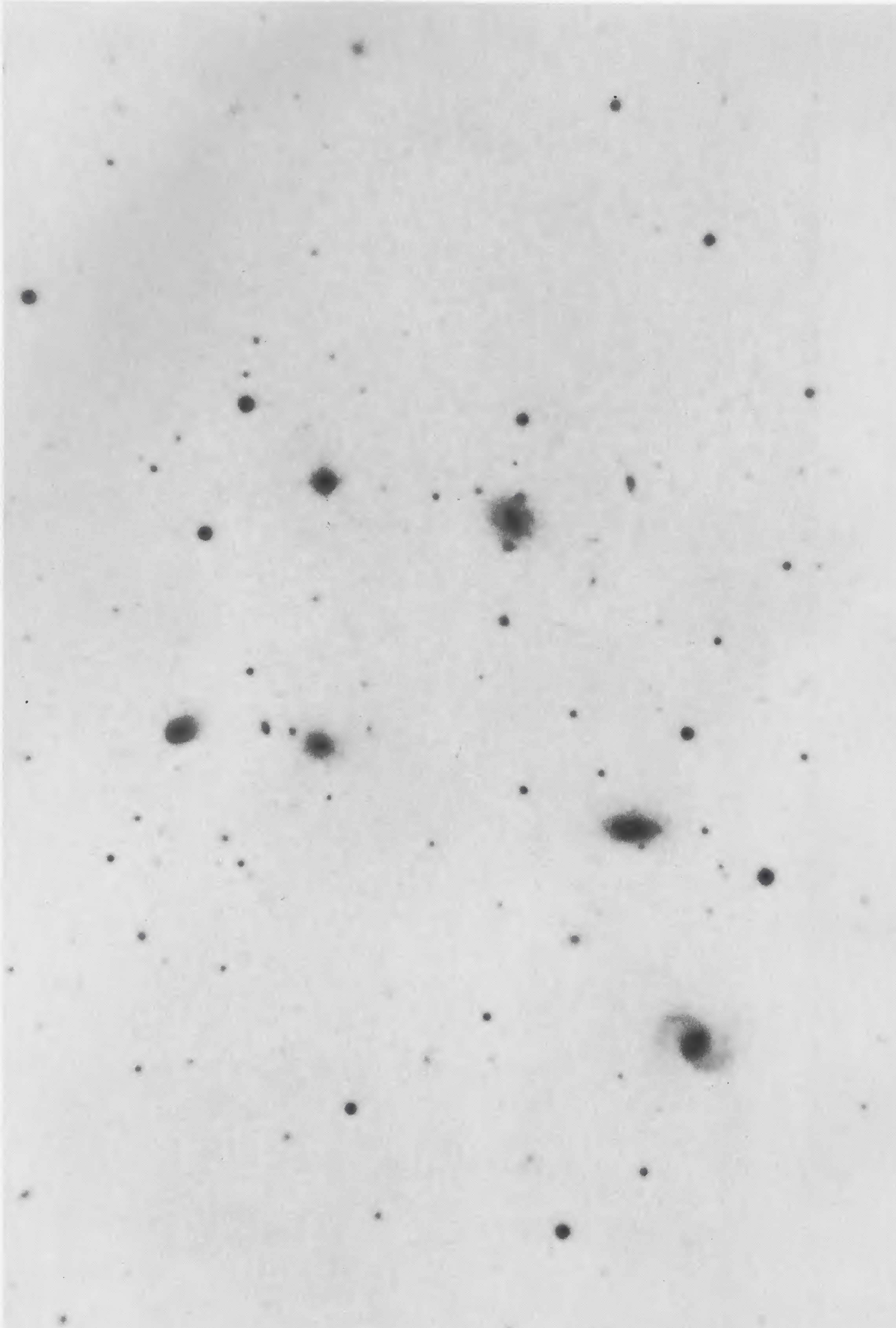

FIG. 3.—This reproduction is an enlargement of the blue print of the Palomar Sky Survey at the Arecibo Observatory (© 1960 National Geographic Society—Palomar Sky Survey. Reproduced by permission of the California Institute of Technology).

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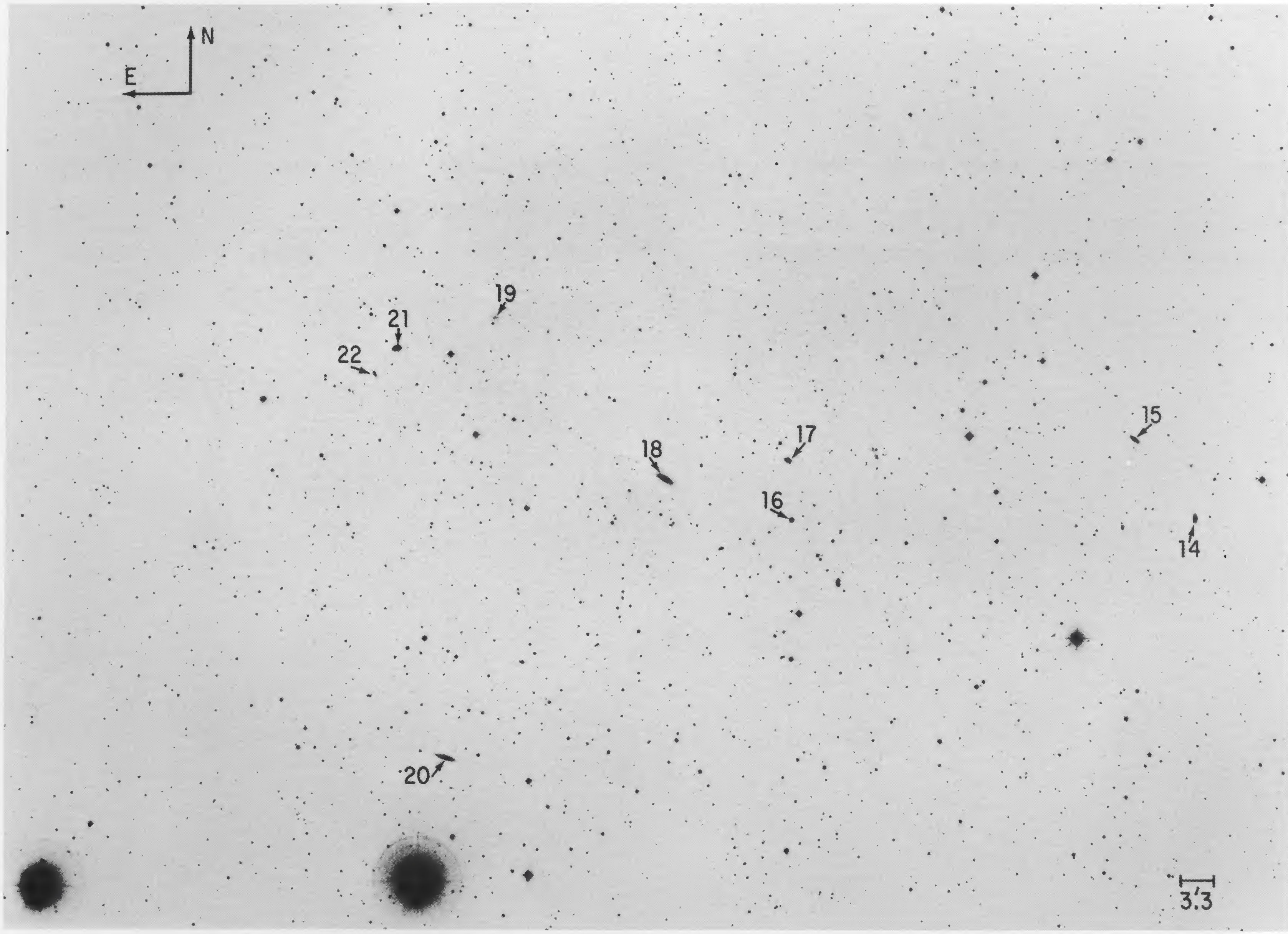

FIG. 4.—Galaxies in the field just south of MKW 10. IC 718, IC 719, Zw 68 − 038, IC 722, IC 724, U 6717, U 6730, U 6734, and U 6722 are labeled 14–22, respectively. IC 720, Zw 68 − 049, and Zw 68 − 056 are in the field but are unlabeled (© 1960 National Geographic Society—Palomar Sky Survey. Reproduced by permission of the California Institute of Technology).

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TABLE 2

OPTICAL PROPERTIES OF THE SPIRAL GALAXIES IN THE FIELD SURROUNDING MKW 10

Galaxy	α(1950)	δ(1950)	Type[a]	A × B	m_z m_{cz} (mag)	i
IC 2941	11ʰ33ᵐ35ˢ	10°19′56″	Sb*	0′.9 × 0′.90	15.0 15.0	0°
U 6617	11 36 43	10 14 23	S...	0.9 × 0.30	14.5 13.3	74
IC 718	11 37 18	09 09 10	Irr	1.2 × 0.45	14.6 14.6	71
IC 719	11 37 44	09 17 12	S...	1.3 × 0.35	13.6 12.6	79
Zw 68−038	11 40 08	09 09 02	S...	0.6 × 0.55	15.3 15.2	24
IC 722	11 40 09	09 15 06	S...	0.8 × 0.60	14.9 14.8	42
Zw 68−042	11 40 48	11 04 46	Sb*	0.7 × 0.20	15.6 14.2	90
IC 724	11 41 00	09 13 10	Sa	2.5 × 1.00	13.8 13.0	69
U 6700	11 41 20	11 03 46	S...	1.0 × 0.50	13.6 13.3	62
Zw 40−036	11 41 48	08 27 11	S...	0.95 × 0.35	14.9 14.4	72
Zw 68−049	11 41 48	08 39 55	S...	0.50 × 0.30	15.6 15.4	55
IC 727	11 41 54	11 03 43	Sb	1.6 × 0.25	15.0 13.6	90
Zw 68−052	11 42 02	11 03 53	Sb*	0.8 × 0.20	15.6 14.2	90
U 6717	11 42 11	09 29 25	dwarf	1.6 × 1.60:	17.0 17.0	0
U 6722	11 42 32	08 44 51	Sb–c	2.8 × 0.60	14.0 12.9	86
IC 720	11 37 48	09 08 15	S...	0.7 × 0.30	15.5 15.1	67
U 6730	11 42 52	09 26 19	Sa–b	1.1 × 0.80	13.4 13.2	44
Zw 68−056	11 42 56	10 00 23	Sb*	0.9 × 0.50	15.3 14.9	58
U 6734	11 43 02	09 23 45	Sb	1.6 × 0.30	15.4 14.0	90
U 6740	11 43 14	10 45 17	S...	1.1 × 0.55	14.8 14.5	62
Zw 68−061	11 43 38	10 52 22	S...	0.7 × 0.50	14.6 14.5	46

[a] An asterisk by the galaxy type indicates that the morphological classification was done by the author.

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):

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

(*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. (*middle row*) Velocity width corrected for inclination and for the redshift effect as in Williams (1983).

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 variation of the baseline.

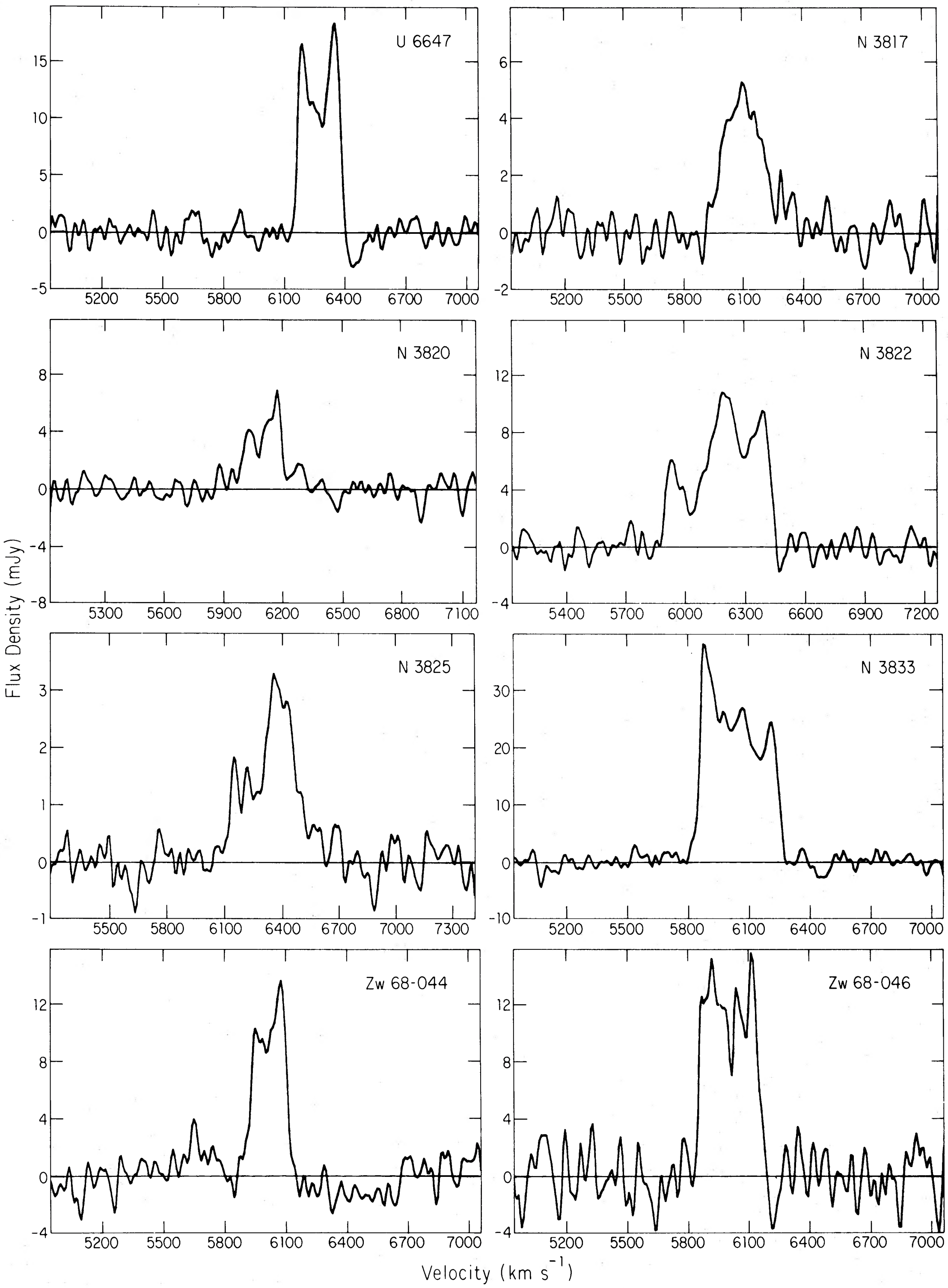

FIG. 5.—H I profiles of galaxies in MKW 10

TABLE 3

H I AND INTEGRAL PROPERTIES OF GALAXIES IN MKW 10

Galaxy[a] (1)	$V_{\odot}$ V_{LG} $\pm\sigma_{(v)}$ (km s^{-1}) (2)	ΔV_{obs} 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} (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)
U 6647	6277	231	3.00	5.48	46.4	6.2	0.88	7.4	0.12
	6160	226	3.61				0.06		
	16		0.27						
N 3817*	6079	326	1.09	1.85	152.0	18.9	0.10	8.1	0.01
	5963	460	1.22				0.02		
	25		0.23						
N 3820*	6090	219	0.90	1.44	44.2	11.9	0.12	3.7	0.03
	5975	298	0.95				0.02		
	18		0.18						
N 3822*	6166	559	3.63	6.18	315.0	47.4	0.13	6.6	0.02
	6050	639	4.08				0.02		
	18		0.51						
N 3825*	6323	393	0.80	1.44	333.0	32.8	0.04	10.2	0.004
	6207	612	0.95				0.02		
	18		0.15						
N 3833	6055	417	10.28	18.40	174.0	17.2	1.07	10.1	0.11
	5940	455	11.70				0.05		
	16		0.62						
Zw 68 − 044	6013	214	2.04	3.19	43.8	10.9	0.29	4.0	0.07
	5898	341	2.12				0.05		
	19		0.31						
Zw 68 − 046	6009	322	3.72	5.76	47.9	11.9	0.48	4.0	0.12
	5894	395	3.80				0.05		
	18		0.68						

[a] An asterisk by the name of the galaxy indicates that it is part of the compact subsystem (Hickson 1982).

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 adopted distance to MKW 10 ($D = 80.5$ Mpc), determined from the average radial velocity of the members and a 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 arc minutes and D is the group's distance in Mpc. Holmberg diameters are computed from the relations given in Sullivan *et al.* (1981), who modified the previous transformations of Dickel and Rood (1978).

Col. (7).—Luminosity of the galaxy calculated from the corrected Zwicky magnitude (Bothun and Schommer 1982). The photographic luminosity of the Sun is taken as 5.37 mag (Stebbins and Kron 1957).

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.

The H I profiles of spiral galaxies surrounding MKW 10 are given in Figures 6 and 7. The integrated flux in the H I line, profile width, and systemic velocity of these galaxies are listed in Table 4, along with other derived quantities. The column headings are the same as those given in Table 3.

The H I profiles of the galaxies in the subsystem have unusual features and shapes which are not characteristic of rotationally supported H I disks. NGC 3817 has a Gaussian-shaped profile, yet the galaxy is inclined almost 45° to the plane of the sky. If the H I gas is rotating in the disk of NGC 3817, then a double-peaked profile is expected. The 21 cm profile of NGC 3820 is more characteristic of normal spirals, although its shape is asymmetric with respect to the systemic velocity. NGC 3822 has the most anomalous profile of any observed in the group. It is difficult to explain the three emission peaks (Fig. 5) using the simple model of a rotating disk. The H I spectrum of NGC 3825 is also asymmetric in that the blue wing of the line profile is lower than the narrow redshifted feature near 6400 km s^{-1}.

Complex profiles such as those described above can be produced by the superposition of normal profiles if there is confusion in the beam. The angular separations between the members in the subsystem are shown in Figure 8. Near 10° declination, the HPBW is measured to be 3′.2 ± 0′.1 (Krumm and Salpeter 1979). The first null in the modeled antenna pattern for the circular feed (Briggs *et al.* 1980) occurs at 3′.6 and the first sidelobe at 5′.8. The separation between most of the spiral galaxies is larger than the radius of the first null. Since the average response of the first sidelobe relative to the main beam is 0.08 (Krumm and Salpeter 1979) and the sources are all very weak (< 6 mJy for NGC 3817, 3820, and 3825 and < 12 mJy for NGC 3822), the contribution from the sidelobes

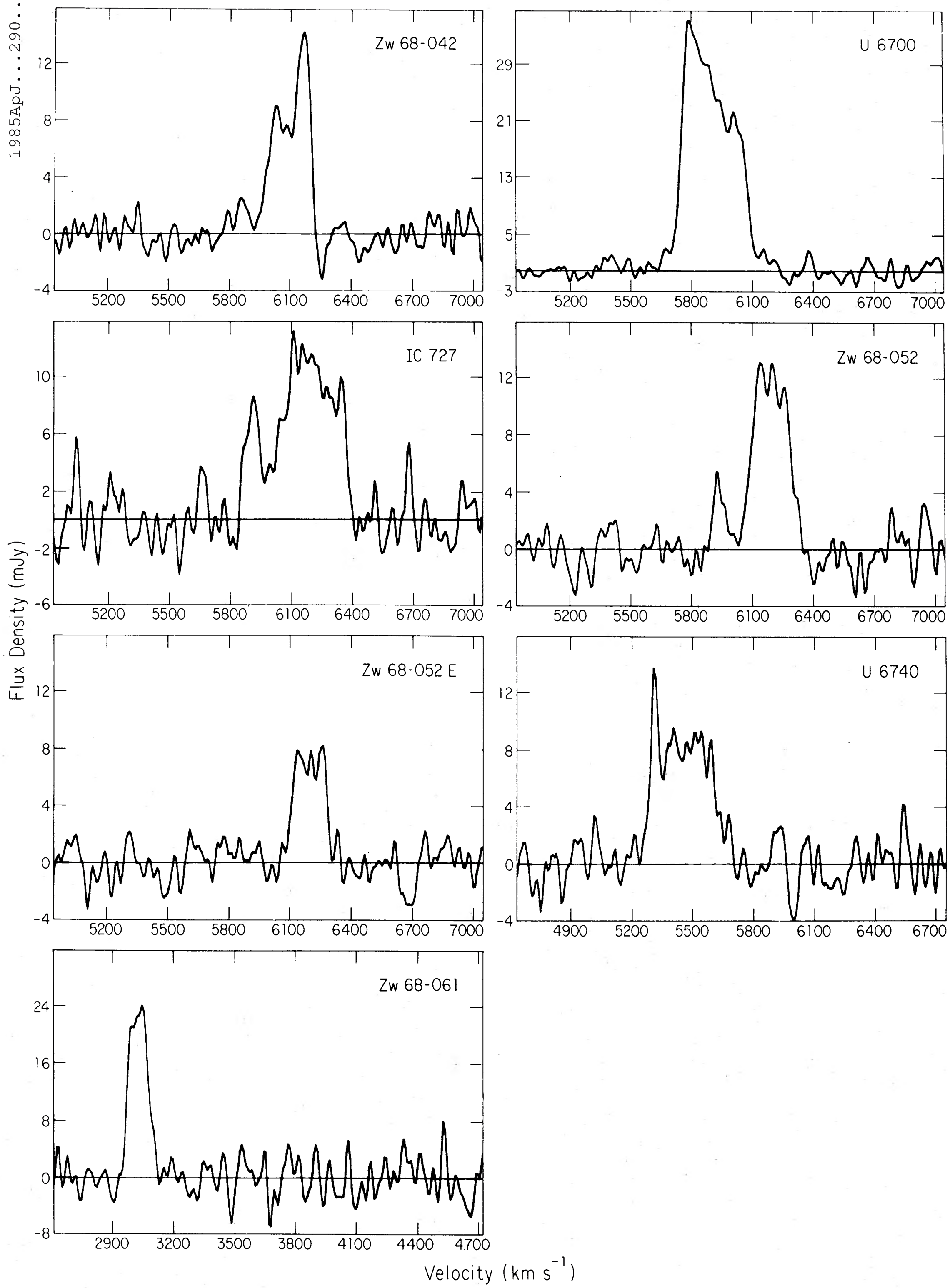

FIG. 6.—H I profiles of the galaxies north of MKW 10

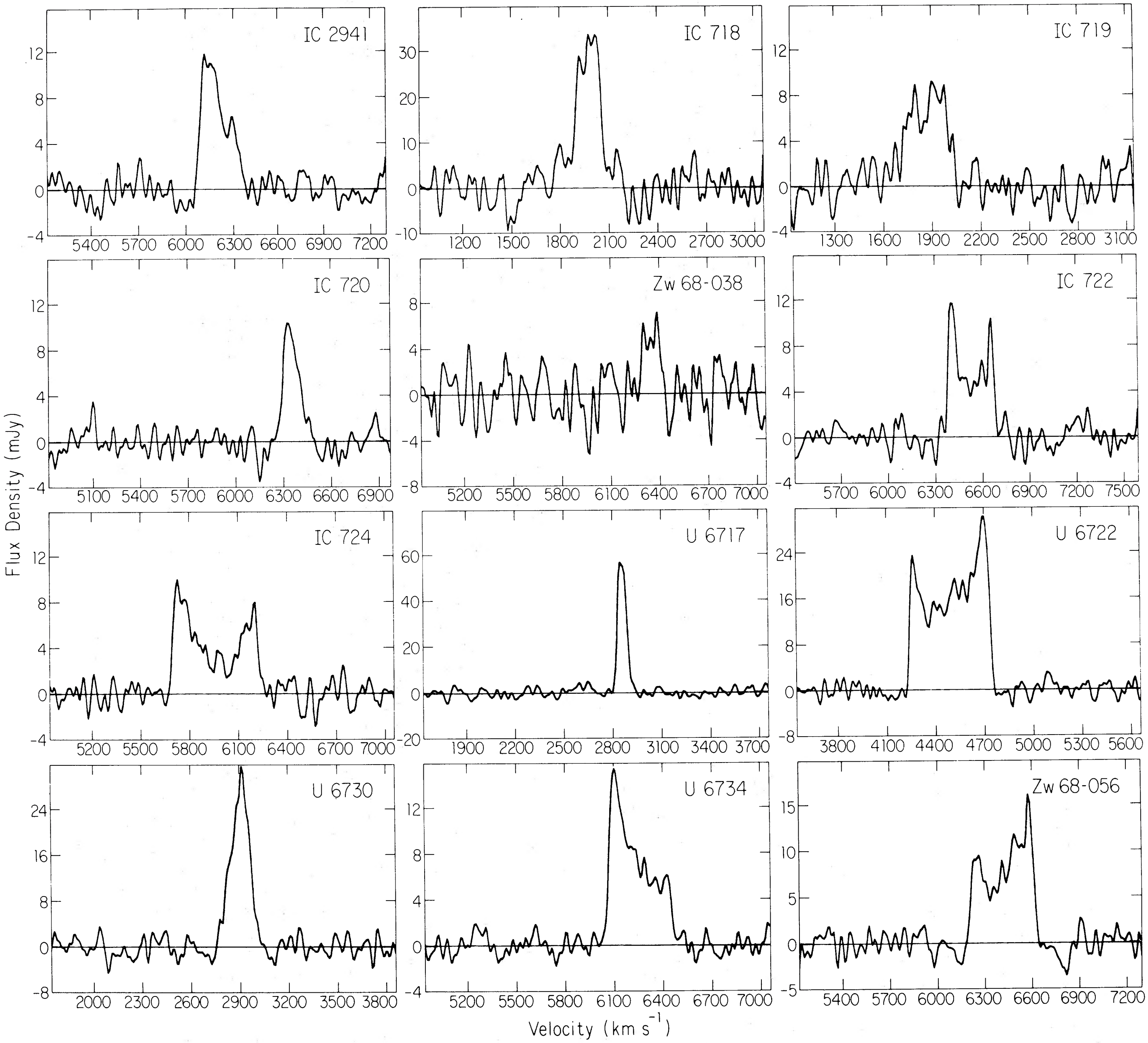

FIG. 7.—H I profiles of the galaxies south of MKW 10

is negligible, i.e., less than the rms noise fluctuations per channel.

Confusion in the main beam needs to be considered for NGC 3822 and 3825 because they are separated by only 3'.3. The optical image of NGC 3825 lies between 2'.6 and 4'.0 from the center of NGC 3822. The antenna pattern (circular feed) modeled by Briggs *et al.* (1980) gives a maximum response relative to the main beam of ~ 0.06 between 2'.6 and 4'.0. Since the first null occurs at 3'.6, the minimum response is zero in this interval. The peak H I flux density measured for NGC 3825 is ~ 3.5 mJy (Fig. 5). When the beam is centered on NGC 3822, a 3.5 mJy source positioned 2'.6 away would contribute at most a flux density of 0.21 mJy, which is less than the rms noise fluctuations measured in the spectrum of NGC 3822. This argument assumes that the H I extent is comparable to the optical diameter. If the assumption about the H I diameter is correct, then contamination caused by NGC 3825 in the spectrum of NGC 3822 is insignificant and can be neglected.

When the beam is centered on the optical position of NGC 3825, its response along the major axis of NGC 3822 is nearly constant because the position angle of the galaxy is 178° (Nilson 1973). The maximum response expected at NGC 3822 is ~ 0.02 (Fig. 5 in Briggs *et al.* 1980) relative to that at the beam's center. The maximum flux density measured at NGC 3822 is ~ 11.5 mJy. A 11.5 mJy source 3'.3 away from NGC 3825 would contribute at most 0.23 mJy to the flux measurement at the beam's center. The rms fluctuations per channel in the spectrum of NGC 3825 are only 0.37 mJy. Unless the gal-

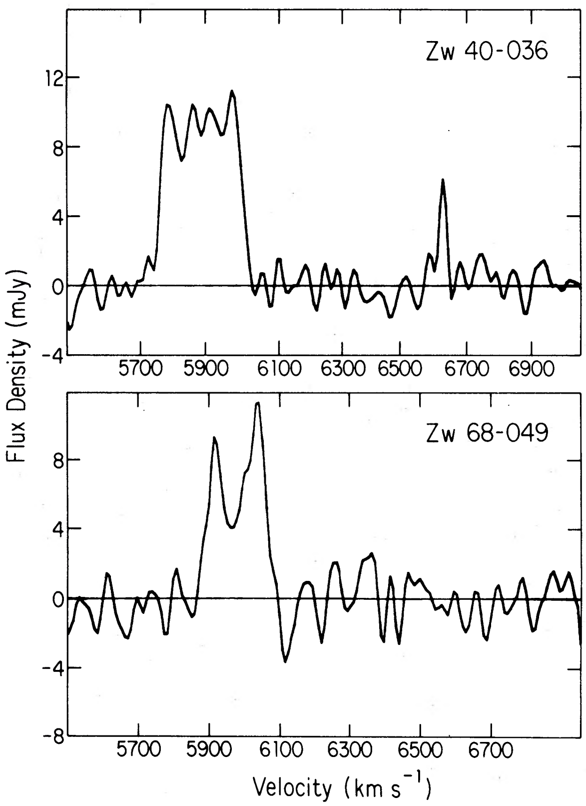

FIG. 7.—*Continued*

axies have extensive H I disks, i.e., 2–3 times the Holmberg diameter, the contribution to the flux caused by confusion is too small to explain the asymmetric shapes in the H I profiles. Rarely is neutral hydrogen detected at radii of 2–3 times the Holmberg diameter in isolated galaxies (Bosma 1978; Briggs *et al.* 1980); however, close companions nearly comparable in mass like NGC 3822 and 3825 are more likely to have extended regions of neutral hydrogen because of tidal interactions (Weliachew, Sancisi, and Guelin 1978; Haynes, Giovanelli, and Roberts 1979). High-resolution VLA observations are needed in order to determine whether the asymmetries in the H I profiles of NGC 3822 and 3825 are a manifestation of the gasdynamics or whether the abnormal profiles result from superposition of H I emission within the single-dish beam.

Accurate optical velocities (Table 5) are available for all the members in the compact subsystem of MKW 10. Despite the fact that the H I spectra are abnormal, there is good agreement between the H I and optical determinations, except in the case of NGC 3825. The systemic velocity of the neutral hydrogen detected when the beam was centered on NGC 3825 differs by ~ 150 km s^{-1} from that measured for the stars in this galaxy. Because the angular separation between NGC 3825 and 3822 is comparable to the half-power beamwidth, it is not possible to ascertain which galaxy is associated with the H I emission detected at the optical position of NGC 3825 (Fig. 5). It could be that the neutral hydrogen detected at this position is not associated with any galaxy. The source of this H I emission, particularly the narrow feature near 6400 km s^{-1}, could be an isolated intergalactic cloud similar to those observed in other compact groups of galaxies (Allen and Sullivan 1980; Peterson and Shostak 1980; Shostak, Sullivan, and Allen 1983; Schneider *et al.* 1983).

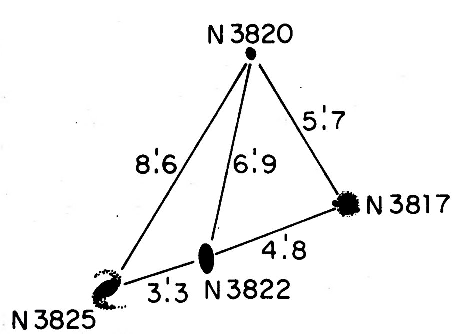

FIG. 8.—Angular separation between the spiral galaxies in the compact core.

The M_H/L ratios measured for the four spirals in the subsystem are between 0.04 and 0.13 solar units. These ratios agree with the average values obtained by Bottinelli, Gouguenheim, and Paturel (1980) and Zong-yun and Ru-liang (1981) for the nearby sample of early-type spirals. The M_H/L ratios of the galaxies in the subsystem are not measurably different from the M_H/L ratio of IC 724 (Table 4), an Sa-type spiral galaxy located more than 1° from MKW 10 and at nearly the same radial velocity as that of the group. Note that NGC 3820 is a late-type spiral galaxy, yet its M_H/L is more similar to the M_H/L values of the other earlier type galaxies in the subsystem. The value given in Table 3 is 1 σ lower than the mean M_H/L ratio obtained for the nearby Sc galaxies.

The four galaxies in the halo have much larger M_H/L ratios. The values measured for Zw 68-044 and 68-046 are consistent with the average M_H/L ratio obtained for Sc's, whereas UGC 6647 and NGC 3833 have M_H/L ratios $\sim 2\ \sigma$ larger than this mean. There is a significant difference in M_H/L of the spiral galaxies in the central subsystem and the M_H/L of the galaxies near the outer regions of MKW 10. Except in the case of the NGC 3820, this correlation is expected given the distinct segregation between early- and late-type spiral galaxies within MKW 10.

The surface number density of galaxies brighter than $m_{pg} = 15.7$ averaged over the smallest circle that contains the compact subsystem is ~ 150 Mpc^{-2} (where $H_0 = 75$ km s^{-1} Mpc^{-1}), which is comparable to that measured in some rich clusters (Dressler 1980). The local surface number density was estimated by taking the four nearest neighbors ($m_{pg} < 15.7$) to each galaxy in the group and dividing by the area of the smallest circle containing these neighbors. In the field surrounding MKW 10, the local surface density was also estimated around the spiral galaxies with radial velocities in the range 5000–7000 km s^{-1} as a comparison. Apparent neighbors ($m_{pg} < 15.7$) with measured radial velocities outside this range were treated as contaminating galaxies and subtracted from the local surface density surrounding MKW 10. The three galaxies in the field without known radial velocities were taken as members of the Coma/A1367 supercluster and included as part of the local surface density surrounding the group.

The relationship between M_H/L and the local surface density is shown in Figure 9. At the local surface densities greater than 20 galaxies Mpc^{-2}, no large values (> -0.6) of log M_H/L are observed (Fig. 9) for galaxies in the subsystem, though one of the spirals is a relatively late type. In the field surrounding MKW 10 where the local density is typically less than 10 galaxies Mpc^{-2}, the M_H/L ratios are as small as the values for the spirals found in the central subsystem and as large as some of those in the outer regions of the MKW 10.

TABLE 4

H I AND INTEGRAL PROPERTIES OF SPIRAL GALAXIES WITHIN ~1°.5 OF MKW 10

Galaxy (1)	$V_{\odot}$[a] 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)
IC 2941	6216	278	2.05	3.56	(37.2)	9.3	0.38	7.0	-
	6096	272	2.29				0.02		
	19		0.10						
U 6617	6229*	[455]	<2.30	<3.50	(311.0)	44.4	<0.08	7.0	-
	6117								
	28*								
IC 718	1982	191	5.12	0.84	8.3	1.2	0.67	6.7	0.10
	1859	201	5.54				0.10		
	16		0.85						
IC 719	1865	322	2.27	0.34	20.4	6.9	0.05	3.0	0.02
	1743	326	2.44				0.01		
	16		0.56						
Zw 68-038	6374	99†	0.65	1.12	(56.9)	8.1	0.14	7.0	-
	6253	-	0.69				0.07		
	16		0.36						
IC 722	6535	317	2.04	3.78	128.4	12.4	0.31	10.4	0.03
	6414	464	2.19				0.05		
	16		0.36						
Zw 68-042	6098	254	2.22	4.09	25.1	18.7	0.22	1.3	0.16
	5985	249	2.28				0.03		
	16		0.30						
IC 724	5972	551	2.70	5.18	400.0	54.0	0.10	7.4	0.01
	5851	579	3.45				0.02		
	18		0.68						
U 6700	5910	366	9.33	14.60	97.8	40.2	0.36	2.4	0.15
	5798	406	10.04				0.02		
	16		0.46						
Zw 40-036	5890	275	2.43	3.76	42.5	14.4	0.26	2.9	0.09
	5766	284	2.57				0.05		
	18		0.53						
Zw 68-049	5971	195	1.35	1.99	19.3	5.9	0.34	3.3	0.10
	5848	233	1.39				0.09		
	16		0.36						
IC 727	6121	539	4.30	8.42	211.0	32.8	0.26	6.4	0.04
	6009	528	4.67				0.07		
	18		1.19						
Zw 68-052	6200	273	2.56	4.89	31.9	19.4	0.25	1.6	0.15
	6088	268	2.64				0.04		
	16		0.47						
U 6717	2869	82	3.76	1.54	(2.1)	0.3	5.14	7.0	-
	2750	81	4.86				0.18		
	16		0.17						
U 6722	4491	525	9.30	10.80	232.0	33.0	0.33	7.0	0.05
	4369	518	11.38				0.02		
	16		0.80						
IC 720	6371	196	1.21	2.14	20.1	8.9	0.24	2.3	0.11
	6248	208	1.26				0.05		
	17		0.23						
U 6730	2903	173	4.05	1.48	20.3	10.2	0.15	2.0	0.07
	2784	247	4.54				0.01		
			0.34						
Zw 68-056	6407	419	3.63	6.45	141.0	10.8	0.59	13.0	0.05
	6291	484	3.88				0.10		
	19		0.64						

TABLE 4—Continued

Galaxy (1)	$V_\odot$ [a] / 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)
U 6734	6257 6138 16	397 389	3.36 3.66 0.39	6.89	117.0	23.7	0.29 0.03	4.9	0.06
U 6740	5483 5370 24	412 458	3.10 3.37 0.75	4.22	124.0	11.4	0.37 0.08	10.9	0.03
Zw 68-061	3038 2925 16	154 212	2.68 2.83 0.51	1.02	10.9	3.4	0.30 0.05	3.2	0.09

[a] Asterisk indicates that velocity is from Huchra *et al.* 1983.
[b] Bracket indicates that the velocity width was estimated from the galaxy's luminosity using the expression

$$\log \Delta V(0) = 0.29 \log L_{pg} - 0.43$$

(Sullivan *et al.* 1981) for a Hubble constant of 75 km s^{-1} Mpc^{-1}.
[c] Parentheses indicates that the mass was estimated by using a mass-to-light ratio of seven solar units.
[d] Profile width estimated at 50% of peak intensity because of the higher rms noise per channel.

c) *Is the Subsystem Physically Compact?*

Compact cores could be formed if several members of a loose group are projected fortuitously close to each other. It is unlikely that projection effects can explain the high density of galaxies near the center of MKW 10, because the core and halo populations are significantly different in morphological type and hydrogen content per luminosity; moreover, there are signs of tidal interaction in the core which imply a physical rather than apparent compactness.

The faint tail proceeding from NGC 3822 is one of the relics predicted in computer-simulated collisions between galaxies (Toomre and Toomre 1972). Within their photometric diameters, NGC 3825 and 3822 are nearly equal in mass (Table 3), which is not surprising since the galaxies have nearly the same apparent brightness. In numerically simulated collisions between galaxies of comparable masses, a tidal tail forms on the far side of the companion, as observed in the image of NGC 3822. This feature can be taken as evidence of a close encounter.

TABLE 5

OPTICAL VELOCITIES OF GALAXIES IN MKW 10

Member	$V_\odot$ (km s^{-1})	Source
N 3817	6100 ± 27	CfA
N 3819	6232 ± 15	JT
	6270 ± 27	JH
N 3820	6052 ± 23	JH
N 3822	6123 ± 32	CfA
N 3825	6487 ± 24	JH
	6466 ± 47	MK

SOURCES.—CfA = Huchra *et al.* 1983. JT = J. Tonry (1984, private communication). JH = J. Huchra (1984, private communication). MK = Malumuth and Kriss (1984, private communication).

The asymmetry in the spiral arms of NGC 3825 and in the distribution of luminous knots or H II regions therein may have been induced by the tidal forces between the galaxies. Given the axial ratio of the bulge, the spiral arms of NGC 3825 are too open; it is as if the bulge and arms lie in slightly different planes. This could occur if the spiral arms were

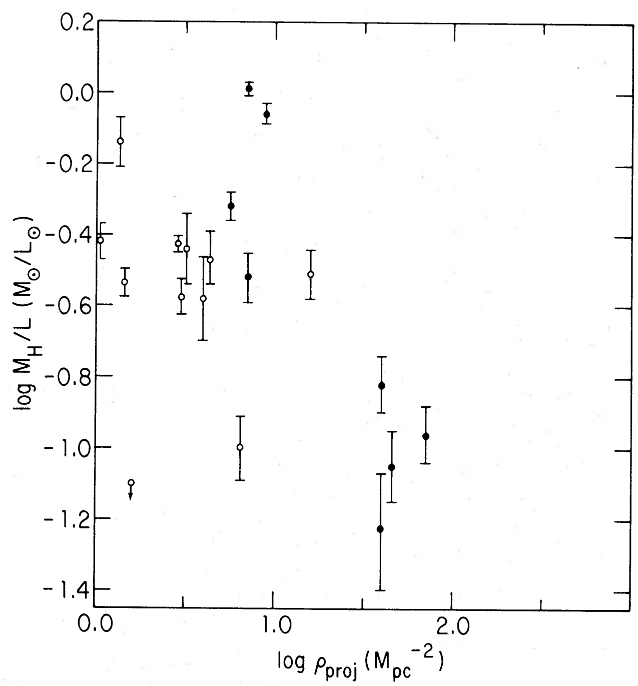

FIG. 9.—Log M_H/L vs. local galaxy surface density for spirals in MKW 10 (*closed circles*) and for the surrounding spirals (*open circles*) with radial velocities between 5000 and 7000 km s^{-1}. Error bars ($\pm\sigma$) are the uncertainty in M_H/L caused by errors in determining the hydrogen mass.

warped out of the plane by the tidal encounter between NGC 3822 and 3825.

NGC 3820 shows obvious signs of tidal damage and is disturbed perhaps by NGC 3819, as Nilson (1973) suggests. The hydrogen content per luminosity of NGC 3820 is significantly smaller than that measured in any of the other late-type spiral galaxies in the group. Neutral hydrogen may have been removed during the tidal interaction that produced the asymmetry in the optical image. NGC 3817 does not appear to be interacting with any of the bright members, but the wisp of material emanating from the faint companion less than 24″ from the nucleus of NGC 3817 may indicate tidal interaction on a smaller scale.

The evidence for tidal interaction seen in the images is strengthened by the anomalies in the shape of the H I profiles. Because line shapes are known to be more sensitive to perturbations in the velocity field of a galaxy than to the H I distribution of the neutral hydrogen, it is more likely that the abnormalities observed in the H I profiles are generated by irregularities in the velocity field caused by the tidal interaction between members. If confusion in the main beam is negligible, all spiral galaxies in the subsystem have H I line shapes that are more asymmetric than normal. A measure of the asymmetry in the profile's shape is given in Table 6; the asymmetry index A (Peterson and Shostak 1974) is defined as $|(b - a)/(b + a)|$, where a and b are the areas under the profile on either side of the systemic velocity (Table 3). The indices measured for UGC 6647, NGC 3833, Zw 68−044, and Zw 68−046 are within 1 σ of 0.05, the average index of 50 normal Scd galaxies (Peterson and Shostak 1974). When compared to the same sample, the remaining galaxies, all in the central subsystem, have asymmetry indices which range from 1.6 to 3.8 σ above this mean. The asymmetry indices of the galaxies in the subsystem are comparable to the mean index obtained by Peterson and Shostak (1974) for a sample of Arp's (1966) peculiar galaxies.

The asymmetry index of NGC 3817 is closer to the average index of normal galaxies than that of any other galaxy in the subsystem. It is worth noting that while the profile is nearly symmetric, its Gaussian shape is unusual for a rotating disk inclined $\sim 45°$ to the plane of the sky. The H I evidence for tidal interaction between NGC 3822 and 3825 is less convincing, however, if confusion within the main beam can account for the large asymmetry indices measured for the two galaxies. This could probably be determined from VLA observations of the group. In any case, the argument for tidal interaction between NGC 3822 and 3825 does not suffer because the H I evidence is ambiguous; the optical evidence alone is quite convincing.

TABLE 6

ASYMMETRY INDICES OF THE H I PROFILES

Galaxy	A
U 6647	0.04
N 3817	0.13
N 3820	0.18
N 3822	0.23
N 3825	0.24
N 3833	0.10
Zw 68−044	0.10
Zw 68−046	0.07

IV. GROUP DYNAMICS AND VIRIAL ANALYSIS

a) MKW 10 and Surrounding Galaxies

It is difficult to find a system of galaxies that is clearly isolated in the field containing MKW 10. The luminous aggregate of bright galaxies (Hickson 1982) near the center of the group (Fig. 1) is surrounded by a partial ring of galaxies and just barely meets Hickson's (1982) isolation criterion for inclusion into his sample of compact groups.

The mean velocity of MKW 10 is 6040 km s^{-1}, and the velocity dispersion about this value is 152 km s^{-1}, where the optical velocity of NGC 3825 (Table 5) is taken as the true measure of its systemic velocity. (The velocity dispersion of the group would be only 116 km s^{-1} if the H I velocity is taken as the systemic velocity of NGC 3825.) Given the large mean projected separation between group members (18′) and the large dispersion ($\pm 11'$) in this value, there are five galaxies, UGC 6617, Zw 68−042, UGC 6700, IC 727, and Zw 68−052, within 0°.5 of at least one member of MKW 10 (Fig. 1). These galaxies have radial velocities that are very close to the mean velocity of MKW 10 and probably should be included in the dynamical analysis of the system. Adding these galaxies to MKW 10, the mean velocity becomes 6020 km s^{-1} and the velocity dispersion becomes 144 km s^{-1}. The a-test (Yahil and Vidal 1977) shows that the velocity distribution of this larger system is still consistent with an underlying Gaussian distribution law.

The potential and kinetic energy of MKW 10 is defined as

$$\Omega = -2/\pi G \sum_{\text{pairs}} M_i M_j / r_{ij} , \tag{1}$$

$$T = \tfrac{3}{2} \sum_i M_i \Delta v_i^2 , \tag{2}$$

respectively, where r_{ij} is the projected linear distance between galaxies with masses M_i and M_j, and Δv_i is the line-of-sight velocity of the galaxy relative to that of the group's center of mass.

The most probable value of the potential and kinetic energy are found to be -2×10^{59} ergs and 10×10^{59} ergs respectively. (The mass of NGC 3819 was estimated by assuming a mass-to-light ratio of seven solar units, and the optical velocity of NGC 3825 is taken as its systemic velocity.) The relative line-of-sight velocities have been corrected for the observational errors in the radial velocity measurement of each galaxy, following Materne (1974) and Rood and Dickel (1976). The uncertainty in the kinetic and potential energies given above is influenced more by the errors in the determination of the masses than in the observational errors in the radial velocity. Since nearly all of the individual masses were determined from $M_{\text{opt}} \propto D\Delta v_{20}^2$, errors in the masses are dominated by uncertainties in the distance and the velocity width of the H I profiles. Taking these two parameters as the major source of error in the masses, the fractional uncertainty in the kinetic and potential energies given above are 20% and 39% respectively. The fractional uncertainty in the kinetic energy caused by the observational errors in the line-of-sight velocity, $\sigma(T)/T$ (Williams 1983), is only $\sim 7\%$.

Because the total energy of the MKW 10 is positive, the derived galaxy masses within the Holmberg radii appear to be insufficient to bind the group. If the five outlying galaxies, UGC 6617, Zw 68−042, UGC 6700, IC 727, and Zw 68−052 (Fig. 1), are taken as members, then the potential and kinetic energy would increase by nearly a factor of 1.5 and 1.3 respec-

TABLE 7

DYNAMICAL PARAMETERS

Parameters[a]	Compact Subsystem	MKW 10	MKW 10 + Surrounding Galaxies ($\delta > 10°$)
N	5	9	14
$\langle v \rangle$	6093 ± 162 km s^{-1}	6040 ± 152	6020 ± 144
t_c	0.03 H_0^{-1}	0.10	0.21
V	281 km s^{-1}	291	258
R	0.47 Mpc	0.67	1.2
M_v	$8.7 \times 10^{12}\ M_\odot$	13.0×10^{12}	18.0×10^{12}
M_v/L	69	77	60

[a] N = number of galaxies, $\langle v \rangle$ = average velocity of the system, t_c = crossing time, V = mass-weighted velocity dispersion, R = virial radius, M_v = virial mass, L = total luminosity.

tively. (Since the H I profiles of IC 727 and Zw 68−052 are confused and UGC 6617 was not detected, their masses were estimated by assuming a mass-to-light ratio of seven solar units.) If the compact subsystem within MKW 10 is considered an independent system, then its potential energy and kinetic energy would be $\sim -1.6 \times 10^{59}$ ergs and 7.2×10^{59} ergs respectively. The compact subsystem appears to have a positive total energy that is not significantly different from that of MKW 10.

From the relation

$$t_c = 2/\pi(\langle r \rangle / \langle v \rangle)\,, \quad (3)$$

where $\langle r \rangle$ is the mean projected distance of the group members from the center of mass, and $\langle v \rangle$ is the average absolute value of the velocities relative to the center of mass of the group, a crossing time of 0.10 H^{-1} is calculated for MKW 10. Because the crossing time of the group is short compared to the Hubble time, this suggests that MKW 10 must be bound; otherwise it would have dispersed by now. If the group were unbound it would have had to begin its expansion less than 1.4×10^9 yr ago, which is small compared to the probable age of its galaxies (10^{10} yr).

If it can be assumed that MKW 10 is a gravitationally bound system, then the virial theorem can be applied to derive the group's mass. The virial theorem can be written

$$M_v = V^2 R/G\,, \quad (4)$$

$$V^2 = 2T/M\,, \quad (5)$$

$$R = -GM^2/\Omega\,, \quad (6)$$

where M is the sum of the individual masses of the spiral galaxies (Table 2) and the one elliptical galaxy, NGC 3819. Table 7 gives the virial masses of MKW 10, the compact subsystem, MKW 10 including the five peripheral galaxies, and other relevant dynamical parameters. The mean fractional error (Rood and Dickel 1976) in the virial mass caused by uncertainties in the radial velocities is less than 20%, while the uncertainty in the mass-weighted velocity dispersion V is smaller than 17 km s^{-1}. Within the uncertainties, there is no difference in the virial mass-to-light ratio of MKW 10 with or without the five outlying galaxies. Although the crossing time of the group is short ($< 0.25\ H^{-1}$), the mass as derived from the virial theorem is ~ 10 times larger than the sum of the individual masses associated with the disks of the galaxies. Estimates of the mass-to-light ratios have been made for six other poor clusters (Beers *et al.* 1984). MKW 10 has a mass-to-light ratio that is comparable to those of MKW 1, MKW 12, and AWM 1.

b) *The Geller-Huchra Group 89*

In a 10.2 deg^2 area including MKW 10, the radial velocities, mostly H I determinations, are complete for the spiral galaxies brighter than $m_{pg} = 15.6$ (Fig. 10). The brightest ($m_{pg} \le 14.5$) galaxies in the field (Fig. 10) have been identified as group 89 (Geller and Huchra 1983; hereafter GH). Seven of the galaxies listed as members include the three brightest spirals in MKW 10. It appears as if Zw 68−21 and MKW 10 are part of a larger system which has an angular extent of at least $\sim 3°$.

The results obtained by applying the virial theorem to GH 89 are given in Table 8. The mass-to-light ratio has been derived by using the seven members listed in the GH catalog and by including 17 fainter ($m_{pg} \le 15.6$) galaxies that lie in the same region and have similar radial velocities (Fig. 10). The 24 galaxies for which redshifts have been measured provide a better sampling to study the system's dynamics than do the seven galaxies. GH 89 appears to be gravitationally unbound,

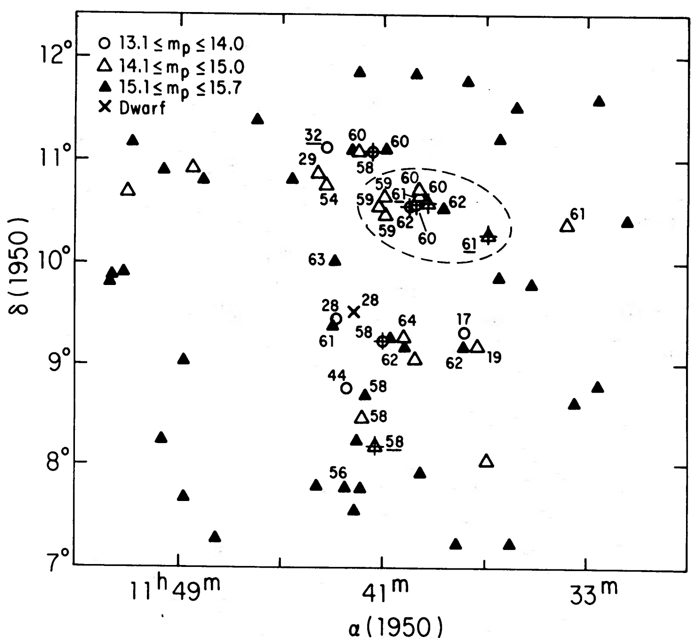

FIG. 10.—Positions, magnitudes, and radial velocities (with respect to the Local Group and in units of 100 km s^{-1}) of galaxies brighter than or equal to 15.7 mag in the direction of Zw 68−21. This Zwicky cluster is indicated by the dashed ellipse. All radial velocities are the author's H I determinations except the four optical velocities that are *underlined*. The profile of Zw 40−039 ($\alpha = 11^h42^m\!.4$, $\delta = +07°47'$) is published in Williams and Kerr (1981). The seven crossed symbols indicate the members of the GH group 89.

TABLE 8

DYNAMICAL PARAMETERS OF GH 89

Parameters[a]	GH 89	GH 89 + fainter members ($m_{pg} \leq 15.6$)
N	7	24
T	20×10^{59} ergs	34×10^{59}
Ω	-1.5×10^{59} ergs	-4.1×10^{59}
$\langle v \rangle$	5990 ± 207 km s^{-1}	6041 ± 187
t_c	$0.36\ H_0^{-1}$	0.40
V	335 km s^{-1}	315
R	1.8 Mpc	2.2
M_v	$47 \times 10^{12}\ M_\odot$	51×10^{12}
M_v/L	173	101

[a] See note to Table 7. T = kinetic energy, Ω = Potential energy.

although its crossing time is less than half the Hubble time. Including the faint members in the dynamical analysis has the effect of reducing the virial mass-to-light by about a factor of 2.

One of the methods used to identify a group of galaxies is to observe a surface number density contrast relative to the uniform background number density, σ_{bg}. GH 89 subtends an area $\sim 8.48 \times 10^7$ arcsec^2. The surface density σ of galaxies ($m_{pg} \leq 15.6$) in the group is $\sim 24/8.48 \times 10^7$ arcsec^2 or 2.83×10^{-7} arcsec^{-2}. Assuming a uniform distribution, the average surface density of "field" galaxies σ_{bg} equal to or brighter than 15.6 is 1.44×10^{-7} arcsec^{-2}. The surface density enhancement or contrast, σ/σ_{bg}, is ~ 2. This value is too close to unity to discriminate between a physical group and the underlying background distribution. GH 89 may be an extremely large group with a short crossing time ($\langle 0.5\ H_0^{-1}$) or simply part of the dispersed component of the Coma/A1367 supercluster (Williams and Kerr 1981).

V. DYNAMICAL EVOLUTION OF MKW 10

The time scale for the loss of orbital energy by dynamical friction for a galaxy moving in a homogeneous background distribution of galaxies is given by

$$t_{DF} = v^3/4\pi G^2 m\rho \ln(d_{max}/d_{min}) \quad (7)$$

(cf. White 1982), where v is the galaxy's velocity through the system, m is the galaxy's mass, ρ (virial mass per volume) is the background density, and d_{max} (group's size) and d_{min} (galaxy's size) are the effective upper and lower limits of the integration over the impact parameter. If it can be assumed that MKW 10 is bound, then its dynamical friction time is $\sim 4.5 \times 10^{10}$ yr, which is larger than the Hubble time. If the compact configuration is a bound system, then its dynamical friction time is 7×10^8 yr. The galaxies could not have existed in a compact state for a Hubble time, but must have developed this dense core only recently ($< 7 \times 10^8$ yr ago).

The number of collisions expected for each galaxy in a group is given by

$$N_c = n\sigma v t\ , \quad (8)$$

where n is the number density of the *other* galaxies, σ is the interaction cross section (radius is taken as 20 kpc), v is $\sqrt{6}$ times the observed line-of-sight velocity dispersion, and t is the group's lifetime. Suppose that the average number density has remained nearly constant over a Hubble time; then the galaxies in MKW 10 have not had the opportunity to experience one collision. This low estimate of the collision rate is consistent with the optical and H I properties of the outer galaxies in MKW 10, but not with those of the inner galaxies which appear to have experienced at least one collision. If the inner galaxies have been in a compact configuration for a Hubble time, then the number of collisions expected is ~ 22 per galaxy. At this high collision rate, the inner galaxies should have lost enough neutral hydrogen to appear deficient, yet only one galaxy in the subsystem is marginally deficient for its morphological type. The possibility that the subsystem is bound and has been compact for a Hubble time can be eliminated because the dynamical friction time is too short and the expected collision rate is too high to be consistent with the H I observations.

MKW 10 probably formed as a loose grouping of galaxies and has existed in this state for nearly a Hubble time. N-body simulations performed on loose groups in which the galaxies are treated as point masses show that physically compact configurations occasionally form within a loose system, but generally disperse after a crossing time (Rose 1979). The relative velocity between galaxies in MKW 10 is ~ 380 km s^{-1}. Actual galaxies with their finite sizes in the compact core of MKW 10 can experience slow hyperbolic encounters which increase the internal energy of the galaxies at the expense of their orbital motion (Roos and Norman 1979; Gutowski and Larson 1976; Lauberts 1974). Taking into account these inelastic collisions, the compact configuration would not disperse but would evolve into an increasingly compact state as a result of the merging process induced by the close encounters (Carnevali, Cavaliere, and Santangelo 1981). The time scale for complete merging is $\sim 1/(n\sigma v)$, or $\sim 10^9$ yr $\approx t_{DF}$. The galaxies in the core of MKW 10 could be a transient compact configuration which will disappear in $\sim 10^9$ yr.

A lower limit to the lifetime of the compact configuration can be estimated from the fact that each galaxy in the core appears to have experienced at least one collision. Substituting 1 for N_c and solving for t in equation (8) requires the configuration to be compact for at least 6×10^8 yr, which is comparable to the derived upper limit for its lifetime, t_{DF}.

Very little dynamical evolution appears to have occurred in the core of MKW 10. There is evidence for close encounters between the galaxies, i.e., peculiarities in the optical images and perturbations in the velocity fields associated with the H I, but apparently none of the galaxies have suffered enough collisions to appear significantly deficient in neutral hydrogen. NGC 3820 is just marginally deficient, while the H I content of the other galaxies is normal for their morphological types.

The X-ray characteristics of the compact core confirm that the group must be in an early evolutionary phase. Clusters in this stage are expected to have highly clumped, weak X-ray emission that is bound to individual galaxies. The X-ray emission is indeed weak ($L_x = 4.8 \times 10^{41}$ for $H_0 = 75$ km s^{-1} Mpc^{-1}; Kriss *et al.* 1983) and is associated with NGC 3825 rather than extended throughout the subsystem.

VI. CONCLUSIONS

MKW 10 contains a core of galaxies that are physically in a compact configuration. This core appears to be a transient configuration (probably bound) that will coalesce in $\sim 10^9$ yr. It is apparent from the optical and H I properties of the galaxies that tidal encounters and collisions have occurred between members in the core while the galaxies in the halo show no similar effects.

A strong correlation between morphological type and M_H/L with local galaxy density resembles Dressler's (1980) relationship between galaxy types and density. Bhavsar (1981) has shown that this relationship is continuous from rich clusters through the groups to the field galaxies. In the case of MKW 10, there is a strong suggestion that the relationship is continuous within the general class of spirals, i.e., early types ($\leq$Sb) are found in the high-density region of the core, and late types ($\geq$Sc) are located in the low-density regions of the halo. The morphological segregation of spiral galaxies as a function of local surface density has been observed in other clusters. In a sample of 10 different clusters, Sullivan (1984) finds that the fraction of late-type to early-type spiral galaxies correlates with projected local density within the clusters in the same sense as that observed in MKW 10.

Dressler's (1980) relationship is believed to exist because of initial conditions at the time galaxies formed, or environmental effects that are present after the galaxies' formation, or both. The evidence suggests that MKW 10 probably formed as a loose group of galaxies that only recently ($<10^9$ yr ago) developed a dense core. Since the estimated lifetime of the compact core is $<10^9$ yr, it is difficult to understand how the correlation between galaxy type and densities could have been present when the group condensed into galaxies ($\sim 10^{10}$ yr ago). If the correlation observed in MKW 10 is real, then it follows from the argument given above that the morphology-density relation would have to have been established after the formation of the galaxies. In this case, the correlation between morphology and density must be the result of some *other* environmental process that occurred since the galaxies' formation.

Like most of the poor and rich clusters that have been studied, there is not enough mass within the photometric radii of the galaxies in MKW 10 to bind the cluster. The virial mass is a factor of 10 larger than the sum of the individual masses. The group is not isolated but is part of a Zwicky cluster which also appears to be gravitationally unbound. Both MKW 10 and the Zwicky cluster are embedded in a larger feature identified as a GH group. This feature has a surface density contrast of 2 relative to the background density and is probably part of the dispersed component of the Coma/A1367 supercluster (Williams and Kerr 1981).

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