A DYNAMICAL STUDY OF GALAXIES IN THE HICKSON COMPACT GROUPS

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ABSTRACT

To investigate dynamical properties of spiral galaxies in the Hickson compact groups (HCGs), we present rotation curves of 30 galaxies in 20 HCGs. We found as follows: (1) There is no significant relation between dynamical peculiarity and morphological peculiarity in HCG spiral galaxies. (2) There is no significant relation between the dynamical properties and the frequency distribution of nuclear activities in HCG spiral galaxies. (3) There are no significant correlations between the dynamical properties of HCG spiral galaxies and any group properties (i.e., size, velocity dispersion, galaxy number density, and crossing time). (4) Asymmetric and peculiar rotation curves are more frequently seen in the HCG spiral galaxies than in field spiral galaxies or in cluster ones. However, this tendency is more obviously seen in late-type HCG spiral galaxies. These results suggest that the dynamical properties of HCG spiral galaxies do not strongly correlate with the morphology, the nuclear activity, and the group properties. Our results also suggest that more frequent galaxy collisions occur in the HCGs than in the field and in the clusters.

Key word: galaxies: clusters: general — galaxies: interactions — galaxies: kinematics and dynamics

1. INTRODUCTION

The dynamical properties of a galaxy are basically governed by both the mass and angular momentum distributions in the galaxy. Since such dynamical properties are deeply related to the formation and evolution of galaxies, many dynamical studies have been done for various kinds of galaxies (e.g., Rubin et al. 1985; see for recent papers Rubin, Waterman, & Kenney 1999; Sofue et al. 1999). Dynamical properties also provide important information on the interaction between galaxies (Keel 1993, 1996; Chengalur, Salpeter, & Terzian 1994; Márquez & Moles 1996; Barton, Bromley, & Geller 1999) and on the galaxy environment, such as clusters of galaxies (Rubin, Whitmore, & Ford 1988; Rubin et al. 1999; Whitmore, Forbes, & Rubin 1988).

In addition to the central region of clusters of galaxies, compact groups (CGs) of galaxies are also useful laboratories to investigate violent interactions between or among galaxies because they are small isolated systems whose galaxy number densities are comparable to those in the center of a cluster of galaxies, e.g., $\sim 10^4-10^6$ galaxies Mpc$^{-3}$ (Shakhbazian 1973; Rose 1977; Hickson 1982, 1993). Among such CGs, the Hickson compact groups (HCGs) of galaxies have been studied extensively (Hickson 1982, 1993). Many galaxies in the HCGs show peculiar morphologies, such as tidal tails, tidal bridges, distorted isophotes, and shell structures (Mendes de Oliveira & Hickson 1994). It is also known that a number of early-type galaxies in the HCGs have unusually blue colors (Zepf, Whitmore, & Levison 1991; Moles et al. 1994). These observational results suggest that galaxies in the HCGs have experienced frequent dynamical interactions. Indeed, Rubin, Hunter, & Ford (1991) showed that rotation curves of many spiral galaxies in HCGs appear abnormal.

To investigate the effect of dynamical interactions in the CG environment, we recently conducted an optical spectroscopy program of HCG galaxies (Shimada et al. 2000, hereafter Paper I). This paper presents results of statistical studies with rotation curve properties of HCG spiral galaxies. We describe our observations and the data reduction in §2. Making the rotation curve, estimating rotation curve asymmetry, and classifying rotation curve shapes are described in §3. In §4, we compare the rotation curve properties of the HCG spiral galaxies with the optical morphologies, nuclear activities, and group properties (group size, velocity dispersion, galaxy number density, and crossing time). We compare the rotation curve properties between the HCG spiral galaxies and field ones in §5 and clusters ones in §6. In §7, we discuss our results.

We adopt a Hubble constant $H_0 = 100$ km s$^{-1}$ Mpc$^{-1}$ and a deceleration parameter $q_0 = 0$ throughout this paper.

2. OBSERVATIONS

We have obtained optical long-slit spectra along the major axis of 30 galaxies (mostly disk galaxies) in 20 HCGs. The sample galaxies were randomly selected from the HCG catalog (Hickson 1993). The optical spectroscopy was made using the new Cassegrain spectrograph with an S1Te 512 $\times$ 512 CCD camera attached to the 188 cm telescope at the Okayama Astrophysical Observatory (OAO) between 1996 February and 1997 January. A journal of the observations is listed in Table 1. Basic data of the observed galaxies from Hickson (1993) are summarized in Table 2. As for the morphology type, we preferentially adopted the Hubble type taken from de Vaucouleurs et al. (1991, hereafter RC3). For galaxies whose Hubble type is uncertain in RC3, we adopted the Hubble type taken from Hickson (1993).
the nucleus for each galaxy; i.e., \( V_{\text{obs}}(r) = c[\lambda_{\text{obs}}(r)/\lambda_0 - 1] \) where \( \lambda_{\text{obs}}(r) \) and \( \lambda_0 \) are the measured and the rest-frame wavelengths of H\( \alpha \), respectively. For each galaxy, we derive the rotation velocity curve, correcting for the inclination effect; i.e., \( V(r) = (V_{\text{obs}}(r) - V_0)/(1 + V_0/c \sin i) \), where \( V_0 \) is the heliocentric velocity of the galaxy center, \( c \) is the velocity of light, and \( i \) is the inclination angle of the galaxy \( (i = 0^\circ \) corresponds to the face-on view). Following Rubin et al. (1982), we estimate the inclination angle using the relation \( \sin i = 1.042^{+0.5}_{-2.0}(1 - 10^{-2x})^{0.5} \) where \( x = \log (R_{\text{maj}}/R_{\text{min}}) \) and \( R_{\text{maj}} \) and \( R_{\text{min}} \) are the semimajor and semiminor axes of the isophote at 25 mag arcsec\(^{-2} \) in the B band, respectively (Hickson 1993). The adopted values of \( \sin i \) are listed in Table 2. Distances \( r \) from the galactic nucleus, rotation velocities, \( V(r) \), and their 1 \( \sigma \) fitting errors, \( dV(r) \), are listed in Table 15. In Figure 1, we show the rotation velocity curves as a function of distance from the galactic nucleus in units of arcseconds for the observed galaxies.

### 3.2. Asymmetry of the Rotation Curve

It is known that galaxy collisions disturb the rotation curves of galaxies. The kinematical effect due to the tidal disturbance often differs between the side facing the colliding partner and the opposite side, and thus the rotation curve tends to show an asymmetric property (Barton et al. 1999 and references therein). Therefore, it is interesting to investigate the asymmetry of the rotation curve. To quantify the asymmetry of the rotation curve, we define an asymmetry parameter,

\[
A \equiv \left[ \frac{1}{N} \sum_{j=0}^{N} \left( \frac{V(r_j) - V(-r_j)}{V(r_j) + V(-r_j)} \right)^2 \right]^{1/2},
\]

where \( j \) is the bin number along the major axis and \( N \) is the total number of bins. Here we use the data between \( r = 0.2R_{25} \) and \( r = 0.5R_{25} \), where \( R_{25} \) is the length of the radius of the isophote at 25 mag arcsec\(^{-2} \) in the B band. The reason for this is as follows: The minimum radius, 0.2\( R_{25} \), is adopted to exclude the data in the central region of galaxies, where the tidal disturbance is expected to be negligibly small; i.e., if we include the data with \( r < 0.2R_{25} \), the difference of the asymmetry parameter among the galaxies could be less pronounced. On the other hand, the maximum radius, 0.5\( R_{25} \), is adopted to cover the observed rotation curves for most of the galaxies studied here. According to the definition of \( A \), galaxies with higher asymmetric rotation curves tend to have larger values of \( A \). The results are listed in Table 3. We cannot estimate \( A \) for six spiral galaxies (HCG 37b, 47a, 61c, 87a, 92c, and 96a) because of the few data points in their rotation curves.

### 3.3. Shape of the Rotation Curves

As shown in Figure 1, the observed velocity curves show various shapes. However, we simply adopt three shapes: (1) type f, for which the rotation velocity monotonically rises near the center and tends to be almost flat at \( r/R_{25} \leq 1 \) (note that most ordinary spiral galaxies have this type of rotation curve e.g., Rubin et al. 1985); (2) type fp, for which the rotation curve appears almost flat, but some dips and/or bumps are seen; (3) type p, for which the rotation curve shows a significantly peculiar shape. Rotation curves with a sinusoidal shape or a linearly rising shape are included in this type. The results of our classification are listed in Table 3. Note that rotation curves of two galaxies (HCG 37b and

### Table 1

**Journal of Observations**

| HCG  | Date       | Exposure (s) | P.A. (deg) |
|------|------------|--------------|------------|
| 7a   | 1996 Aug 19| 1800         | 159        |
| 7b   | 1996 Feb 21| 1800         | 77         |
| 7c   | 1996 Feb 21| 1800         | 15         |
| 5a   | 1996 Feb 20| 1800         | 93         |
| 5b   | 1996 Feb 20| 1800         | 18         |
| 5c   | 1996 Feb 20| 1800         | 23         |
| 3a   | 1996 Feb 25| 1800         | 18         |
| 3b   | 1996 Aug 18| 1800         | 0          |
| 3c   | 1996 Aug 18| 1800         | 56         |
| 3d   | 1996 Aug 18| 1800         | 132        |
| 3e   | 1996 Aug 18| 1800         | 31         |
| 3f   | 1996 Aug 18| 1800         | 31         |
| 3g   | 1996 Aug 18| 1800         | 71         |
| 3h   | 1996 Aug 18| 1800         | 57         |
| 3i   | 1996 Aug 18| 1800         | 137        |
| 3j   | 1996 Aug 18| 1800         | 140        |
| 3k   | 1996 Aug 18| 1800         | 143        |
| 3l   | 1996 Aug 18| 1800         | 98         |
| 3m   | 1996 Aug 18| 480          | 90         |

* HCG 7a and 92a are redshift discordant galaxies, and we exclude these galaxies from our statistical sample.
* HCG 87a is classified as a lenticular galaxy in RC3, and we exclude this galaxy from our statistical sample.

A long (5′) slit with a width of 1.8′ was used and put on each target galaxy with a position angle of the major axis. The 600 grooves mm\(^{-1} \) grating was used to cover a 6300–7050 Å region with a spectral resolution of 3.4 Å (≈ 157 km s\(^{-1} \) at 6500 Å). Two-pixel binning was made of the CCD along the slit, and thus the spatial resolution was 1.75′ per element. The typical seeing during the runs was 2′.

The data were analyzed using IRAF.\(^5\) We also used a special data reduction package, SNGRED (Kosugi et al. 1995), developed for the OAO new Cassegrain spectrograph data. The reduction was made with a standard procedure: bias subtraction, flat-fielding with the data of the dome flats, and cosmic-ray removal. Flux calibration was obtained using standard stars available in IRAF.

### 3. RESULTS

#### 3.1. Major-Axis Velocity Curves

We use the H\( \alpha \) emission line to construct a heliocentric velocity curve as a function of the radial distance, \( r \), from

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\(^5\) Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
HCG 92c cannot be classified because they have only a few data points.

4. THE ROTATION CURVE PROPERTIES OF HCG GALAXIES

4.1. Enlarged HCG Sample

Among the 30 galaxies observed by us, two galaxies are redshift-discordant galaxies in the HCGs (HCG 73a and HCG 92a). One of the remaining 28 galaxies is classified as an S0 in RC3 (HCG 87a). Therefore, our HCG sample contains 27 spiral galaxies. To enlarge the sample, we include HCG galaxies observed by Rubin et al. (1991) (see Table 4). Their sample contains 34 spiral galaxies. Excluding two unavailable galaxies (HCG 10a and HCG 37c) for which rotation curve data were not shown, two redshift-discordant galaxies (HCG 73d and HCG 78a), and five S0 galaxies classified in RC3 (HCG 16c, 16d, 23a, 34b, and 57e), we obtained the rotation curve data of the 25 HCG spiral galaxies from Rubin et al. (1991). For these 25 HCG spiral galaxies, we estimate the asymmetry parameter and classify the rotation curve shape using the same method for our HCG data. The results are also listed in Table 4. Twelve of these 25 spiral galaxies are commonly observed (HCG 31a, 31b, 31c, 37b, 40c, 44a, 44b, 44d, 79d, 88a, 88c, and 89a). The $A$ values of these twelve spiral galaxies are adopted from the average $A$. Finally, we obtain an enlarged HCG sample that contains 40 spiral galaxies. Hereafter, we discuss the rotation curves of HCG spiral galaxies with the enlarged HCG spiral sample containing 40 spiral galaxies.

4.2. Rotation Curve Properties versus Morphologies of Host Galaxies

Mendes de Oliveira & Hickson (1994) showed that about half the galaxies in HCGs have peculiar morphologies, such as tidal tails, tidal debris, or distorted isophotes, indicating galaxy collisions. On the other hand, Rubin et al. (1991) found that there is a loose correlation between peculiarity of rotation curve and peculiarity of morphology. In Table 5, we classified our HCG spiral galaxies into two categories based on the optical morphology from Mendes de Oliveira & Hickson (1994) and RC3. The spiral galaxies with or without optical peculiar morphologies are listed in Table 5. Without optical peculiar morphologies are listed in Table 5. We compare the shape of the rotation curves with the optical morphologies of host galaxies. The result is shown in Table 6. Although it is generally expected that spiral galaxies with normal rotation curves have normal morphology and those with peculiar rotation curves have peculiar morphology, there are galaxies with normal morphology that have peculiar kinematics, and galaxies with peculiar morphology that have normal kinematics. We adopted the null hypothesis that distribution for the HCG spiral galaxies with peculiar morphology is the same as that for those with normal morphology and applied the $\chi^2$ test. The result is shown in Table 6.
Figure 1.—Major-axis velocities with respect to the systemic heliocentric velocity for 30 HCG galaxies as a function of projected nuclear distance.
DISTANCE FROM NUCLEUS (arcsec)

Fig. 1.—Continued
TABLE 3
ASYMMETRY PARAMETERS AND THE SHAPE
PARAMETER OF THE ROTATION CURVES
FOR THE OBSERVED GALAXIES

| HCG | A   | Shape |
|-----|-----|-------|
| 7a  | 0.23| p     |
| 31a | 0.12| p     |
| 31b | 0.27| p     |
| 31c | 0.38| p     |
| 37b | ... | ?     |
| 38a | 0.07| fp    |
| 40c | 0.09| f     |
| 44a | 0.09| p     |
| 44c | 0.13| fp    |
| 44d | 6.55| p     |
| 47a | ... | p     |
| 53a | 0.06| f     |
| 61c | ... | fp    |
| 68c | 0.11| fp    |
| 71a | 6.23| p     |
| 73a | 0.18| p     |
| 79d | 0.84| p     |
| 80a | 0.40| p     |
| 87a | ... | p     |
| 87c | ... | p     |
| 88a | 0.26| p     |
| 88b | 0.49| p     |
| 88c | 1.21| p     |
| 88d | 0.15| p     |
| 89a | 0.14| fp    |
| 92a | 0.41| p     |
| 92c | ... | p     |
| 93b | 0.32| p     |
| 93c | 0.34| p     |
| 96a | ... | p     |

$P(\chi^2) = 0.818$. We find that there is no significantly
statistical difference between the HCG spiral galaxies with
peculiar morphology and those with normal morphology.

4.3. Rotation Curve Properties versus Nuclear Activities

It has often been considered that frequent galaxy colli-
sions trigger some nuclear activities (active galactic nuclei
or intense star formation) in HCG member galaxies. There-
fore, it is interesting to compare the kinematical properties
of the member galaxies with their nuclear activity. Using the
observed flux ratio of $[\text{N}\ II]$ to Hα, we classify the activities
of galaxies as active galactic nuclei (AGNs) and H II
nuclei (H II). Galaxies with $f([\text{N}\ II]) / f(\text{H}\alpha) \geq 0.6$
are classified as AGNs, and those with $f([\text{N}\ II]) / f(\text{H}\alpha) < 0.6$
are classified as H II (Ho, Filippenko, & Sargent 1997). We
classify the galaxy without emission-line activity as “Abs.”

The properties of the HCG galaxies are listed in Table 4. In Figure 2, we compare the
distributions of the asymmetry parameter $A$ between AGNs
and H II nuclei. We apply the Kolmogorov-Smirnov (KS)
test (e.g., Press et al. 1988). The null hypothesis is that the
distributions of $A$ of both the AGNs and the H II nuclei
come from the same underlying population. We obtain the
KS probability 0.947. This indicates that there is no di-
erence in the distribution of the asymmetry parameter $A$
between the HCG AGNs and the HCG H II nuclei. In
Figure 3, we show diagrams of the $[\text{N}\ II]/\text{H}\alpha$ ratio plotted
against the asymmetry parameter $A$. The left panel is the
diagram for early-type (S0/a–Sbc) and late-type (Sc and
later) spiral galaxies, and the right panel is the diagram for f,
fp, and p rotation curves. We adopt the null hypothesis that
the asymmetry parameter $A$ is not correlated with the
$[\text{N}\ II]/\text{H}\alpha$ ratio and apply the Spearman rank statistical
test for all the spiral galaxies shown in Figure 3. A sum-

TABLE 4
PROPERTIES OF HCG GALAXIES FROM RUBIN ET AL. 1991

| HCG | Hickson Type | RC3 Type | Adopted Type | $R_{25}$ (arcsec) | A | Rotation Curve Type |
|-----|--------------|----------|--------------|------------------|---|-------------------|
| 16a | S Bab        | SAB(rs)ab: pec | Sab | 34.9 | 0.04 | fp |
| 16b | Sab          | (R')Sa: pec | Sa | 49.4 | 0.03 | p  |
| 23b | S Bc         | (RSAB(r)a) pec | Sa | 46.1 | 0.04 | fp |
| 31a | Sdm          | Pec       | P | 32.3 | ... | p  |
| 31b | S M          | S?        | Sm | 26.1 | ... | p  |
| 31c | S M          | S?        | Sm | 18.3 | ... | p  |
| 33c | S d          | Sd        | Sd | 23.3 | 0.02 | p  |
| 34c | S Bd         | Sb        | Sd | 11.2 | 0.45 | p  |
| 37b | S Bc         | S7        | Sb | 51.9 | 0.08 | fp |
| 40c | S Bc         | SBr(s)b pec sp | Sb | 36.9 | 0.01 | f  |
| 40d | S Ba         | SBr(s)0/a pec: | S0/a | 23.9 | 0.06 | fp |
| 40e | S c          | SAB(s)a pec: | Sa | 17.8 | 0.03 | f  |
| 44a | S a          | S(A)sa pec sp | Sa | 100.7 | 0.07 | p  |
| 44b | S Bc         | (R)SBr(a) | Sa | 56.8 | 0.03 | fp |
| 44d | S d          | SBr(s)c pec | Sc | 67.7 | ... | p  |
| 57a | S b          | Sbr sp pec | Sab | 51.5 | ... | p  |
| 57b | S Bb         | SBr(s) | Sb | 30.0 | 0.01 | f  |
| 57d | S Bc         | SBr pec | Sb | 17.3 | 0.02 | f  |
| 79d | Sdm          | SBr(s)c sp | Sc | 28.1 | 0.2 | p  |
| 88a | S d          | SBr(s) | Sb | 45.1 | 0.10 | fp |
| 88e | S c          | SBr(s)b? | Sbe | 27.6 | 13.5 | p  |
| 89a | S c          | S?        | Sc | 29.1 | 0.04 | f  |
| 89b | S Bc         | S?        | Sc | 20.9 | 0.14 | p  |
| 100a | S b       | S0/a     | S0/a | 33.2 | 0.1 | p  |
| 100c | S Bc         | S?        | Sc | 22.1 | ... | p  |

* HCG 31a, 31b, 31c, 37b, 40c, 44a, 44c, 44d, 79d, 88a, 88c, and 89a are commonly observed galaxies.
investigated correlations between dynamics and other properties of group. The group size, velocity dispersion, galaxy number density, and crossing time from previous studies by Hickson, Kindl, & Huchra (1988), and Hickson et al. (1992) are listed in Table 5 for each HCG galaxy. Figure 4 shows relations between the asymmetry parameter $A$ and the group size (Hickson et al. 1992), velocity disper-

### TABLE 5

**Environments and Nuclear Activities of HCG Galaxies**

| HCG | $N$ | log R (kpc) | log $\sigma_r$ (km s$^{-1}$) | log $\rho_N$ (Mpc$^{-3}$) | log $H_0^{*}$ | Peculiar Morphology | log $[f([\text{N II}])/f(\text{H}$ α)$]$ | Activity |
|-----|-----|-------------|-------------------------------|-----------------------------|--------------|---------------------|--------------------------------|----------|
| 7a  | 4   | 1.66        | 1.95                          | 4.00                        | -1.40        | Y                   | -0.31 $^{+0.05}_{-0.07}$ | H II     |
| 16a | 4   | 1.65        | 2.09                          | 4.03                        | -1.56        | Y                   | ...                            | ...       |
| 16b | 4   | 1.65        | 2.09                          | 4.03                        | -1.56        | Y                   | ...                            | ...       |
| 23b | 3   | 1.82        | 2.23                          | 3.65                        | -1.52        | Y                   | ...                            | ...       |
| 31a | 3   | 0.91        | 1.75                          | 6.23                        | -1.80        | Y                   | -0.77 $^{+0.03}_{-0.05}$ | H II     |
| 31b | 3   | 0.91        | 1.75                          | 6.23                        | -1.80        | Y                   | ...                            | H II     |
| 31c | 3   | 0.91        | 1.75                          | 6.23                        | -1.80        | Y                   | -1.10 $^{+0.07}_{-0.06}$ | H II     |
| 33c | 4   | 1.39        | 2.19                          | 4.81                        | -1.92        | N                   | ...                            | ...       |
| 34e | 4   | 1.19        | 2.50                          | 5.40                        | -2.44        | N                   | ...                            | ...       |
| 37b | 5   | 1.46        | 2.60                          | 4.67                        | -2.27        | Y                   | 0.10 $^{+0.27}_{-0.06}$ | AGN      |
| 38a | 3   | 1.77        | 1.11                          | 3.55                        | 0.88         | Y                   | -0.47 $^{+0.18}_{-0.18}$ | H II     |
| 40c | 5   | 1.18        | 2.17                          | 5.54                        | -2.12        | Y                   | -0.23 $^{+0.11}_{-0.11}$ | H II     |
| 40d | 5   | 1.18        | 2.17                          | 5.54                        | -2.12        | Y                   | ...                            | ...       |
| 44c | 4   | 1.18        | 2.17                          | 5.54                        | -2.12        | Y                   | ...                            | ...       |
| 44d | 4   | 1.18        | 2.17                          | 5.54                        | -2.12        | Y                   | ...                            | ...       |
| 47a | 5   | 1.56        | 1.63                          | 4.30                        | 0.66         | Y                   | ...                            | Abs      |
| 53a | 3   | 1.76        | 1.91                          | 3.31                        | -1.14        | N                   | 0.18 $^{+0.24}_{-0.06}$ | AGN      |
| 57a | 7   | 1.86        | 2.43                          | 3.71                        | -1.69        | Y                   | 0.14 $^{+0.19}_{-0.33}$ | AGN      |
| 57b | 7   | 1.86        | 2.43                          | 3.71                        | -1.69        | Y                   | ...                            | ...       |
| 57d | 7   | 1.86        | 2.43                          | 3.71                        | -1.69        | Y                   | ...                            | ...       |
| 61c | 3   | 1.46        | 1.94                          | 4.49                        | -1.60        | Y                   | -0.14 $^{+0.07}_{-0.06}$ | AGN      |
| 68c | 5   | 1.52        | 2.19                          | 4.51                        | -1.79        | Y                   | -0.11 $^{+0.04}_{-0.06}$ | AGN      |
| 71a | 3   | 1.70        | 2.62                          | 3.64                        | -2.04        | N                   | 0.31 $^{+0.03}_{-0.08}$ | AGN      |
| 79d | 4   | 0.83        | 2.14                          | 6.51                        | -2.43        | Y                   | -0.82 $^{+0.13}_{-0.22}$ | H II     |
| 80a | 4   | 1.40        | 2.43                          | 4.77                        | -2.16        | N                   | -0.14 $^{+0.01}_{-0.05}$ | AGN      |
| 87c | 3   | 1.49        | 2.08                          | 4.75                        | -1.56        | Y                   | -0.37 $^{+0.12}_{-0.15}$ | H II     |
| 88a | 4   | 1.83        | 1.43                          | 3.49                        | 0.94         | N                   | ...                            | AGN      |
| 88b | 4   | 1.83        | 1.43                          | 3.49                        | 0.94         | Y                   | 0.81 $^{+0.20}_{-0.39}$ | AGN      |
| 88c | 4   | 1.83        | 1.43                          | 3.49                        | 0.94         | N                   | -0.38 $^{+0.12}_{-0.22}$ | H II     |
| 88d | 4   | 1.83        | 1.43                          | 3.49                        | 0.94         | N                   | -0.33 $^{+0.09}_{-0.12}$ | H II     |
| 89a | 4   | 1.77        | 1.74                          | 3.66                        | -0.84        | N                   | -0.32 $^{+0.10}_{-0.14}$ | H II     |
| 89b | 4   | 1.77        | 1.74                          | 3.66                        | -0.84        | N                   | ...                            | ...       |
| 92c | 4   | 1.45        | 2.59                          | 4.62                        | -2.27        | Y                   | 0.16 $^{+0.03}_{-0.09}$ | AGN      |
| 93b | 4   | 1.85        | 2.32                          | 3.42                        | -1.59        | Y                   | -0.18 $^{+0.06}_{-0.09}$ | AGN      |
| 93c | 4   | 1.85        | 2.32                          | 3.42                        | -1.59        | Y                   | ...                            | AGN      |
| 96a | 4   | 1.48        | 2.12                          | 4.54                        | -1.76        | Y                   | -0.00 $^{+0.08}_{-0.10}$ | AGN      |
| 100a | 3   | 1.58      | 1.95                           | 4.27                      | -1.46        | Y                   | ...                            | ...       |
| 100c | 3   | 1.58      | 1.95                           | 4.27                      | -1.46        | N                   | ...                            | ...       |

### TABLE 6

**Comparison of Kinematical Properties with Morphological Peculiarities**

| Morphology | $f$ Rotation Curves | $fp$ Rotation Curves | $p$ Rotation Curves |
|------------|---------------------|----------------------|---------------------|
| Normal     | 2                   | 2                    | 8                   |
| Peculiar   | 4                   | 7                    | 16                  |

$P(X^2) = 0.818$

* The probability that rejects the null hypothesis.

4.4. Rotation Curve Properties versus Group Properties

Rubin et al. (1991) mentioned that there appears to be no correlation between normal or abnormal rotation curves and the velocity dispersion of the group. To confirm this, we investigated correlations between dynamics and other

### TABLE 7

**Summary of the Spearman Rank Test for the Correlations between Asymmetry Parameter $A$ and the [N II]/Hz Ratio**

| Galaxies | Number | Probabilities* |
|---------|--------|----------------|
| All     | 20     | 0.243          |
| S0/a–Sbc| 10     | 0.987          |
| Sc      | 10     | 0.907          |
| $f$     | 3      | 0.667          |
| $fp$    | 4      | 0.200          |
| $p$     | 13     | 0.566          |

* The probability that rejects the null hypothesis.
hypothesis that the asymmetry parameter $A$ is not correlated with each group property and apply the Spearman rank statistical test for all the correlations shown in Figure 4. A summary of the statistical tests is presented in Table 8. Although the probability of a relation between $A$ and group velocity dispersion for $f$ rotation curves is $4.8 \times 10^{-3}$, the 3 $\sigma$ confidence level is $1.3 \times 10^{-3}$. Therefore, for any spiral galaxy, it is found that there is no correlation between the asymmetry parameter $A$ and the group properties.

5. COMPARISON OF ROTATION CURVES BETWEEN HCG GALAXIES AND FIELD GALAXIES

5.1. Field Sample

To investigate how the dynamical properties of HCG galaxies are different from those of isolated galaxies, we need a reference sample of field galaxies. Rubin, Ford, & Thonnard (1980) and Rubin et al. (1982, 1985) published rotation curves for 60 spiral galaxies (16 Sa, 23 Sb, and 21 Sc galaxies). Excluding two Virgo spiral galaxies (NGC 4321 and NGC 4419) and two galaxies in groups (NGC 1353 and NGC 4448), we adopt 56 spiral galaxies (15 Sa, 21 Sb, and 20 Sc) as a field galaxy sample. The basic data of these field galaxies are summarized in Table 9.

Unfortunately, Rubin et al. (1980, 1982, 1985) show only average rotation velocity $V(|r|)$, the mean of velocities within the radial bins of both $r$ and $-r$, and 1 $\sigma$ error of the mean, $dV(|r|)$. It is hard to know how many data points either $r$ or $-r$ contains and to estimate $V(r)$ and $V(-r)$. Therefore, we simply assume that there is only one velocity data point in each bin of $r$ and $-r$. Making $V(r)$ and $V(-r)$ that data point here, we reconstruct $V(|r|)$ and $dV(|r|)$ of Rubin et al. (1980, 1982, 1985). Under this assumption, one finds that the rotation velocity at distance $r$ is $V(r) = V(|r|) + dV(|r|)\sqrt{2}$ and that the rotation velocity at distance $-r$ is $V(-r) = V(|r|) - dV(|r|)\sqrt{2}$. In this case we can define the asymmetry parameter $A$ as

$$A \equiv \frac{1}{\sqrt{2}} \left\{ \frac{1}{N} \sum_{j=1}^{N} \left[ \frac{dV(|r_j|)}{V(|r_j|)} \right]^2 \right\}^{1/2}.$$  (2)

The meaning of $j$ and $N$ are the same as in equation (1). Note that the asymmetry parameters $A$ for field spiral galaxies are all upper limits according to the above definition. We also classify the shape of rotation curves for field spiral

![Figure 2](image1.png)

**Fig. 2.** Comparisons of frequency distributions of the logarithmic asymmetric parameter ($\log A$) between the AGNs (top) and the H II nuclei (bottom).

![Table 8](image2.png)

**Table 8**

Summary of the Spearman Rank Test for the Correlations between Asymmetry Parameter $A$ and the Properties of the HCGs

| Galaxies       | Number | $\log R$ | $\log \sigma$ | $\log \rho_N$ | $\log H_0' \times_6$ |
|----------------|--------|----------|---------------|---------------|----------------------|
| All............| 34     | 0.737    | 0.355         | 0.748         | 0.804                |
| S0/a–Sbc......| 20     | 0.686    | 0.052         | 0.135         | 0.028                |
| Sc.............| 14     | 0.543    | 0.037         | 0.533         | 0.085                |
| $f$............| 6      | 0.329    | $4.81 \times 10^{-3}$ | 0.397         | 0.266                |
| fp.............| 8      | 0.955    | 1.000         | 0.867         | 1.000                |
| p..............| 20     | 0.701    | 0.519         | 0.762         | 0.565                |

* The probability that rejects the null hypothesis.

![Figure 3](image3.png)

**Fig. 3.** Relations between the logarithmic asymmetric parameter $A$ and the [N II]/H$\alpha$ ratio. Filled circles and open circles indicate the early-type (S0/a–Sbc) and the late-type (Sc and later) HCG spiral galaxies, respectively. Open squares, filled squares, and crosses indicate the $f$, fp, and p rotation curves, respectively.
5.2. Comparison of the Rotation Velocity between the HCG Spiral Galaxies and the Field Spiral Galaxies

In Figure 5, we show the rotation curves of our HCG spiral galaxies as a function of distance from the galactic nucleus in units of $R_{25}$. We also show expected rotation curves of the field galaxies calculated from synthetic rotation curves in Rubin et al. (1985). The rotation curves of the HCG spiral galaxies are different from those of the field spiral galaxies. Many spiral galaxies in HCGs have peculiar rotation curves.

By numerical simulations, Barton et al. (1999) found that galaxy collisions caused rising rotation curves. Some HCG spiral galaxies have such a rising rotation curve (e.g., HCG 61c and 88a). There are also spiral galaxies with higher rotation velocities (e.g., HCG 40c) and those with lower rotation velocities (e.g., HCG 88b and 88d) with respect to the field spiral galaxies with both the same Hubble type and the same luminosity.

Rubin et al. (1991) show that the HCG spiral galaxies tend to have lower rotation velocity than the field ones. For some HCG spiral galaxies, we found the same tendency. However, it is difficult to determine intrinsic inclination angles $i$ of HCG spiral galaxies showing peculiar morphologies. Although we estimated the inclination angles $i$ of the HCG spiral galaxies, there is an uncertainty of $i$. Most of the rotation curves of HCG spiral galaxies are too peculiar to discuss the mass distribution in the galaxies.

5.3. Comparison of the Asymmetry Parameter between the HCG Spiral Galaxies and the Field Spiral Galaxies

We compare the frequency distributions of $A$ between the HCG spiral galaxies and the field spiral galaxies in Figure 6. The comparison is carried out for all Hubble type, S0/a–Sbc type, and Sc and late-type galaxies. We include two field spiral galaxies with $A = 0$ in the smallest bin (NGC 2608 and IC 724). We find that $A$ values of the HCG spiral galaxies are generally larger than those of the field spiral galaxies for all the morphological types. In particular, we mention that the maximum value of $A$ for the field spiral galaxies is 0.06 (NGC 3054 and NGC 7171), while for 18 HCG spiral galaxies (53%), $A > 1.0$.

We apply the KS test. The null hypothesis is that the observed distributions of $A$ of both the HCG galaxies and the field ones come from the same underlying population. We obtain KS probabilities (see Table 10); $1.15 \times 10^{-11}$ for all the galaxies, $1.76 \times 10^{-6}$ for S0/a–Sbc galaxies, and $7.40 \times 10^{-7}$ for Sc and late-type spiral galaxies. Therefore, we conclude that the HCG galaxies tend to have asymmetric rotation curves with respect to the field galaxies. This is consistent with the result of Rubin et al. (1991).

For the HCG spiral galaxies, we find that the late-type (Sc and later) spiral galaxies have larger $A$ than the early-type (S0/a–Sbc) ones. Applying the KS test, we obtain a probability of $2.32 \times 10^{-3}$ between the $A$-distribution of early-type HCG spiral galaxies and that of late-type HCG spiral galaxies, while we obtain 0.792 for a comparison between the $A$-distribution of early-type spiral galaxies in the field and that of late-type spiral galaxies in the field (see Table 10). Therefore, it is suggested that the HCG late-type
| Name          | RC3 Type | Adopted Type | $R_{25}$ (arcsec) | $A$ | Rotation Curve Type | Reference |
|---------------|----------|--------------|------------------|-----|---------------------|-----------|
| NGC0701      | SB(rs)c  | Sc           | 73.6 0.02        | p   |                     | 1         |
| NGC0753      | SB(rs)bc | Sbc          | 75.4 0.02        | f   |                     | 1         |
| NGC0801      | Sc       | Sc           | 94.9 0.01        | f   |                     | 1         |
| NGC1024      | (R')SA(rs)ab | Sab    | 117 0.01        | fp  |                     | 3         |
| NGC1035      | SA(s)c   | Sc           | 67.2 0.02        | f   |                     | 1         |
| NGC1085      | SA(s)bc  | Sbc          | 88.5 0.01        | f   |                     | 2         |
| NGC1087      | SAB(rs)c | Sc           | 112 0.02         | f   |                     | 1         |
| NGC1325      | SA(s)bc  | Sbc          | 140 0.01         | f   |                     | 2         |
| NGC1357      | SA(s)ab  | Sab          | 84.6 0.03        | fp  |                     | 3         |
| NGC1417      | SAB(rs)b | Sb           | 80.8 0.01        | f   |                     | 2         |
| NGC1421      | SAB(rs)bc | Sbc       | 106 0.04         | f   |                     | 1         |
| NGC1515      | SAB(rs)bc | Sbc      | 157 0.02         | f   |                     | 2         |
| NGC1620      | SA(s)bc  | Sbc          | 86.5 0.01        | f   |                     | 2         |
| NGC2590      | SA(s)bc  | Sbc          | 67.2 0.01        | f   |                     | 2         |
| NGC2608      | SBSb:    | Sb           | 68.7 0.00        | fp  |                     | 1         |
| NGC2639      | (R)SA(s)a | Sa       | 54.6 0.01        | f   |                     | 3         |
| NGC2708      | SAB(s)bc | Sbc          | 78.9 0.01        | f   |                     | 2         |
| NGC2715      | SAB(rs)c | Sc           | 147 0.01         | f   |                     | 1         |
| NGC2742      | SA(s)c   | Sc           | 90.6 0.02        | f   |                     | 1         |
| NGC2775      | SAB(spec) | Sab      | 128 0.01         | f   |                     | 3         |
| NGC2815      | SB(rs)b: | Sb           | 104 0.01         | f   |                     | 2         |
| NGC2844      | SAB(s)a: | Sa           | 46.5 0.02        | f   |                     | 3         |
| NGC2998      | SAB(rs)c | Sc           | 86.5 0.01        | f   |                     | 1         |
| NGC3054      | SAB(rs)b | Sb           | 114 0.06         | fp  |                     | 2         |
| NGC3067      | SAB(rs)ab | Sab      | 73.6 0.01        | f   |                     | 2         |
| NGC3145      | SBSb:    | Sbc          | 92.7 0.02        | f   |                     | 2         |
| NGC3200      | SAB(rs)c | Sc           | 125 0.01         | fp  |                     | 2         |
| NGC3223      | SA(s)bc  | Sb           | 122 0.01         | fp  |                     | 2         |
| NGC3281      | SA(s)ab  | Sab          | 99.3 0.03        | fp  |                     | 3         |
| NGC3495      | Sd:      | Sd           | 147 0.02         | f   |                     | 1         |
| NGC3593      | SA(s)0/a  | S0/a        | 157 0.03         | ?   |                     | 3         |
| NGC3672      | SA(s)c   | Sc           | 125 0.04         | f   |                     | 1         |
| NGC3898      | SA(s)ab  | Sab          | 131 0.01         | f   |                     | 3         |
| NGC4062      | SA(s)c   | Sc           | 122 0.01         | f   |                     | 1         |
| NGC4378      | (R)SA(s)a | Sa       | 84.6 0.02        | fp  |                     | 3         |
| NGC4594      | SA(s)sp  | Sa           | 261 0.01         | fp  |                     | 3         |
| NGC4605      | SB(s)c:pec | Sc    | 173 0.03         | f   |                     | 1         |
| NGC4662      | SAB(s)cd | Scd          | 77.1 0.04        | f   |                     | 1         |
| NGC4698      | SA(s)ab  | Sab          | 119 0.02         | p   |                     | 3         |
| NGC4800      | SAB(rs)b | Sb           | 47.5 0.01        | f   |                     | 2         |
| NGC4845      | SA(s)absp | Sab     | 150 0.04         | f   |                     | 3         |
| NGC6314      | SA(s):sp | Sa           | 43.4 0.01        | f   |                     | 3         |
| NGC7083      | SA(s)bc  | Sbc          | 117 0.03         | f   |                     | 2         |
| NGC7171      | SB(rs)b  | Sb           | 78.9 0.06        | f   |                     | 2         |
| NGC7217      | (R)SA(s)bc | Sab | 117 0.01         | f   |                     | 2         |
| NGC7357      | SABbc:   | Sbc          | 67.2 0.02        | f   |                     | 2         |
| NGC7541      | SB(rs)bc | Sbc          | 104 0.02         | fp  |                     | 1         |
| NGC7606      | SA(s)b   | Sb           | 161 0.01         | f   |                     | 2         |
| NGC7664      | Sc:      | Sc           | 78.9 0.01        | f   |                     | 1         |
| IC467        | SAB(s)c  | Sc           | 97.1 0.03        | fp  |                     | 1         |
| IC724        | Sa       | Sa           | 70.3 0.00        | f   |                     | 3         |
| UGC02885     | SA(rs)c  | Sc           | 117 0.01         | fp  |                     | 1         |
| UGC03691     | SAc:     | Sdc          | 65.6 0.03        | f   |                     | 1         |
| UGC10205     | Sa       | Sa           | 43.4 0.02        | p   |                     | 3         |
| UGC11810     | SAB(rs)bc | Sbc      | 54.6 0.02        | fp  |                     | 2         |
| UGC12810     | (R')SAB(rs)bc | Sbc | 55.9 0.02 | f   |                     | 2         |

References.—(1) Rubin et al. 1980; (2) Rubin et al. 1982; (3) Rubin et al. 1985.
Fig. 5.—Major-axis velocities with respect to the systemic heliocentric velocity for 30 HCG galaxies as a function of nuclear distance in units of $R_{25}$, showing the approaching side (open circles) and the receding side (filled circles). In each panel, the middle line indicates the expected rotation curve of the field spiral galaxies with similar Hubble type and luminosity calculated from synthetic rotation curves in Rubin et al. (1985), and the top and bottom lines indicate the expected rotation curve of the field spiral galaxies with similar Hubble type that have luminosity 1 mag brighter and fainter, respectively.
Fig. 5.—Continued
spiral galaxies tend to have more asymmetric rotation curves with respect to the HCG early-type ones.

5.4. Comparison of the Rotation Curve Shape between the HCG Spiral Galaxies and the Field Spiral Galaxies

We compare the rotation curve shapes between the HCG galaxies and the field ones. In Figure 7 we compare the frequency distributions of rotation curve shapes between the HCG spiral galaxies and the field ones for all galaxies, early-type spiral galaxies, and late-type spiral galaxies. We adopt the null hypothesis that the distribution for the HCG spiral galaxies is the same as that for the field ones and apply the $\chi^2$ test. The results are listed in Table 11. We find that there are significant statistical differences between the HCG spiral galaxies and the field ones.

Among the 39 HCG galaxies, 33 ($\approx 85\%$) galaxies have either fp or p rotation curves. It is remarkable that almost all the HCG late-type spiral galaxies ($\approx 93\%$) have p rotation curves. On the contrary, only 42% of the HCG early-type spiral galaxies have p rotation curves, and 21% of the HCG early-type spiral galaxies have f rotation curves. The probability from the $\chi^2$ test between the frequency distributions of the rotation curve shape of the early-type field spiral galaxies and that of late-type field spiral galaxies is 0.673, while that between the early-type HCG spiral galaxies and the late-type HCG spiral galaxies is $4.44 \times 10^{-3}$. Although the latter probability suggests a marginally sig-

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**TABLE 10**

| Galaxies | KS Probability$^a$ |
|----------|-------------------|
| All HCG vs. all field | $1.15 \times 10^{-11}$ |
| HCG S0a-Sbc vs. field S0a-Sbc | $1.76 \times 10^{-6}$ |
| HCG Sc vs. field Sc | $7.40 \times 10^{-7}$ |
| HCG S0a-Sbc vs. HCG Sc | $2.32 \times 10^{-3}$ |
| Field S0a-Sbc vs. field Sc | 0.792 |

$^a$ The probability that rejects the null hypothesis.

**TABLE 11**

| Shapes | All$^b$ | S0a-Sbc | Sc |
|--------|--------|--------|-----|
|        | HCGs   | Field  | HCGs | Field |
| f      | 15.4 (6) | 69.1 (38) | 20.8 (5) | 65.8 (25) | 6.7 (1) | 76.5 (13) |
| fp     | 23.1 (9) | 25.5 (14) | 37.5 (9) | 28.9 (11) | 0.0 (0) | 17.6 (3) |
| p      | 61.5 (24) | 5.5 (3) | 41.7 (10) | 5.3 (2) | 93.3 (14) | 5.9 (1) |
| $P(\chi^2)$ | $3.23 \times 10^{-9}$ | $2.55 \times 10^{-4}$ | $4.73 \times 10^{-6}$ |

$^a$ Numbers in parentheses are the actual values.

$^b$ "All" means the total sample of S0a–Sbc and Sc galaxies.

$^* The probability that rejects the null hypothesis.
The results are also listed in Table 12. We also classified the shape of the rotation curves for them. The asymmetry parameter $G$ was used to determine the shape of the rotation curves, although it has been shown that morphological deformation could be induced in outer parts of the galaxies. Therefore, it is interesting to compare the dynamical properties of the HCG spiral galaxies with those of cluster spiral galaxies.

6. COMPARISON OF ROTATION CURVES BETWEEN HCG SPIRAL GALAXIES AND CLUSTER SPIRAL GALAXIES

6.1. Cluster Sample

As we previously mentioned, the local galaxy number density of HCGs is comparable to that of cluster centers. Therefore, it is interesting to compare the dynamical properties of the HCG spiral galaxies with those of cluster spiral galaxies. We use a sample of cluster spiral galaxies taken from Amram et al. (1992, 1994, and 1995), who published rotation curves of 41 spiral galaxies in eight clusters. The basic data of these cluster galaxies are summarized in Table 12. Their morphological types were taken from RC3 if available (32 galaxies). For the remaining nine spiral galaxies without RC3, we adopt the morphological types taken from Bell & Whitmore (1989), Amram et al. (1995), and Gavazzi & Boselli (1996). Using equation (1), we calculated the asymmetry parameter $A$ of the cluster spiral galaxies. We also classified the shape of the rotation curves for them. The results are also listed in Table 12.

6.2. Comparison of the Asymmetry Parameter between the HCG Spiral Galaxies and the Cluster Spiral Galaxies

In Figure 6, we compare the frequency distribution of the asymmetry parameter $A$ between the HCG spiral galaxies and the cluster ones. The comparison is carried out for all Hubble type, S0/a–Sbc type, and Sc and late-type galaxies. The null hypothesis is that the observed distributions of $A$ of both HCG spiral galaxies and the cluster ones come from the same underlying population. Applying the KS test, we obtain the following KS probabilities (see Table 13); $6.64 \times 10^{-4}$ for all the galaxies, $4.50 \times 10^{-2}$ for the S0/a–Sbc spiral galaxies, and $8.48 \times 10^{-4}$ for the Sc and late-type spiral galaxies. We find that the $A$ values of HCG spiral galaxies tend to be larger than those of the cluster ones for all galaxies.

6.3. Comparison of the Rotation Curve Shape between the HCG Spiral Galaxies and the Cluster Spiral Galaxies

We show the frequency distribution of the rotation curve shape for the HCG, the field, and the cluster spiral galaxies in Figure 7. We compare the two distributions for all Hubble type, S0/a–Sbc type, and Sc and late-type spiral galaxies. The null hypothesis is that the observed distributions of the rotation curve shape of both the HCG spiral galaxies and the cluster ones come from the same underlying population. Applying the $\chi^2$ test, we obtain the following probabilities (see Table 14); $9.28 \times 10^{-7}$ for all the galaxies, $3.84 \times 10^{-3}$ for the S0/a–Sbc spiral galaxies, and $3.23 \times 10^{-5}$ for the Sc and late-type spiral galaxies. These results suggest that the HCG spiral galaxies tend to show more peculiar shapes in their rotation curves.

7. DISCUSSION

In this paper, we have investigated the asymmetry and the shape of the rotation curves of spiral galaxies in HCGs. Table 15 lists the distances from the galactic nucleus, $r$, in units of arcseconds and $R_{25}$, the rotation velocities, $V'(r)$, at $r$, and their 1 $\sigma$ errors $dV'(r)$ for each observed HCG spiral galaxy.

First, we investigated the relation between the morphological peculiarity and dynamical peculiarity of HCG spiral galaxies. We found that there is no statistical difference between them (Table 6), which is consistent with the finding by Rubin et al. (1991). It is likely that the HCG spiral galaxies with both the morphological peculiarity and the dynamical peculiarity have experienced recent galaxy collisions. However, there are galaxies of normal morphology with peculiar dynamical properties and ones of peculiar morphology with normal dynamical properties. That there is no correlation between the dynamical peculiarity and the morphological peculiarity suggests that the dynamical properties of the HCG spiral galaxies may be governed by galaxy collision parameters such as the difference of masses and the orbital parameters. While morphological peculiarities such as tidal tails, tidal bridges, and asymmetry are more clearly seen in the outer regions of galaxies, the dynamical peculiarities probed by the Hβ line emission are observed in inner regions ($r < 0.5R_{25}$) of galaxies (see Fig. 5). The morphological peculiarity can be more easily induced by galaxy collisions than the dynamical peculiarity. Thus, weak galaxy collisions could not perturb the galaxy rotation curves, although it has been shown that morphological deformation could be induced in outer parts of the galaxies.
TABLE 12

| Galaxy       | Cluster | RC3 Type | Adopted Type | \(R_{25}\) (arcsec) | A    | Rotation Curve Type | Reference |
|--------------|---------|----------|--------------|----------------------|------|---------------------|-----------|
| NGC0668 ...... | A262    | Sb       | Sb           | 55.9                 | 0.04 | f                   | 1         |
| NGC0669 ...... | A262    | Sab      | Sbc          | 97.1                 | 0.11 | p                   | 1         |
| NGC0688 ...... | A262    | (R’SAB(rs)b | Sb          | 75.4                 | 0.03 | fp                  | 1         |
| UGC01347..... | A262    | SAB(rs)c | Sc           | 39.5                 | 0.07 | f                   | 1         |
| NGC0753 ...... | A262    | SAB(rs)bc| Sbc          | 78.9                 | 0.04 | fp                  | 1         |
| UGC01493..... | A262    | SBB?     | Sab          | 97.2                 | 0.04 | f                   | 1         |
| UGC03269..... | A539    | Sbc      | Sbc          | 27.4                 | 0.02 | f                   | 2         |
| UGC03282..... | A539    | SBBd?    | Scd          | 33.7                 | 0.11 | f                   | 2         |
| Z119 – 051    | Cancer  | ...      | Sb           | 16.4                 | 0.03 | f                   | 1, 3      |
| Z119 – 043    | Cancer  | ...      | Im           | 18.1                 | 0.04 | p                   | 2, 3      |
| UGC04329...... | Cancer  | SAB(rs)cd| Scd          | 62.7                 | 0.11 | p                   | 1         |
| NGC0688 ...... | A262    | SAB(rs)bc| Sbc          | 54.6                 | 0.01 | f                   | 2         |
| NGC0691 ...... | A262    | SAB(rs)bc| Sbc          | 97.1                 | 0.03 | fp                  | 1         |
| UGC0691 ...... | A539    | SAB(rs)bc| Sbc          | 78.9                 | 0.04 | fp                  | 1         |
| Z119 – 053    | Cancer  | ...      | S0a          | 20.9                 | 0.04 | f                   | 2, 3      |
| UGC04386...... | Cancer  | Sb       | Sb           | 57.2                 | 0.07 | p                   | 2         |
| UGC2595 ...... | Cancer  | SAB(rs)c | Sc           | 97.1                 | 0.05 | f                   | 2         |
| NGC3861 ...... | A1367   | SAB(rs)b | Sb           | 68.7                 | 0.06 | fp                  | 1         |
| NGC3883 ...... | A1367   | SAB(rs)b | Sb           | 88.5                 | 0.05 | f                   | 1         |
| UGC08161..... | Coma    | S?       | Sb           | 32.2                 | ...  | ?                   | 1, 3      |
| NGC4848 ...... | Coma    | SBB: sp  | Sab          | 48.7                 | 0.07 | f                   | 2         |
| Z160– 058     | Coma    | S?       | Sbc          | 31.4                 | 0.02 | f                   | 2, 3      |
| NGC4911 ...... | Coma    | SAB(r)bc | Sbc          | 43.4                 | 0.05 | f                   | 2         |
| NGC4921 ...... | Coma    | SBB(r)bc | Sbb          | 73.6                 | 0.10 | p                   | 2         |
| Z130– 008     | Coma    | S?       | Sc           | 12.8                 | 0.03 | f                   | 2, 3      |
| IC1179 ....... | Hercules| SBr(s)cd | Scd          | 17.7                 | 0.13 | f                   | 1         |
| NGC6050 ...... | Hercules| SA(s)c   | Sc           | 26.1                 | 0.01 | f                   | 1         |
| NGC6054 ...... | Hercules| (R)SAB(s)b | Sb         | 20.8                 | 0.04 | f                   | 1         |
| UGC10085..... | Hercules| SAcd:    | Scd          | 31.4                 | 0.08 | f                   | 2         |
| NGC6045 ...... | Hercules| SB(s)c sp | Sc           | 40.5                 | 0.12 | f                   | 2         |
| NGC7591 ...... | Pegasus | SBBc     | Sbc          | 59.9                 | 0.02 | f                   | 1         |
| NGC7536 ...... | Pegasus | SBBc     | Sbc          | 59.9                 | 0.05 | f                   | 2         |
| NGC7593 ...... | Coma    | S?       | Sc           | 31.4                 | 0.02 | f                   | 2         |
| UGC12498...... | Pegasus | Sb       | Sb           | 42.4                 | 0.05 | f                   | 2         |
| NGC7631 ...... | Pegasus | SA(r)b:  | Sb           | 55.9                 | 0.02 | f                   | 2         |
| NGC7643 ...... | Pegasus | S?       | Sc           | 43.4                 | 0.02 | f                   | 2         |
| IC4755 ....... | DC1842–63| S?      | Sa           | 39.4                 | 0.05 | fp                  | 4, 5      |
| IC4764 ....... | DC1842–63| S?      | Sa           | 39.6                 | 0.06 | fp                  | 4, 5      |
| IC4770 ....... | DC1842–63| S?      | Sa           | 26.1                 | 0.10 | fp                  | 4         |
| IC4771 ....... | DC1842–63| SAB(rs)c | Sbc          | 36.9                 | 0.06 | f                   | 4         |
| IC4769 ....... | DC1842–63| SAB(rs)b pec | Sbc    | 61.3                 | 0.08 | fp                  | 4         |
| IC4759 ....... | DC1842–63| ...     | ...          | 22.5                 | 0.14 | f                   | 4, 5      |
| IC4741 ....... | DC1842–63| SA(r)ab | Sab          | 46.5                 | 0.02 | f                   | 4         |

REFERENCES.—(1) Amram et al. 1994; (2) Amram et al. 1992; (3) Gavazzi & Boselli 1996; (4) Amram et al. 1995; (5) Bell & Whitmore 1989.

Second, we investigated the relation between the properties of the rotation curves and the properties of the nuclear activity. Since it has often been suggested that the galaxy collisions trigger nuclear activities such as AGNs and nuclear starburst phenomena (Kennicutt & Keel 1984; Keel 1996), it is expected that such nuclear activities would be more often observed in HCG galaxies. However, we found that there is no significant statistical difference in the distribution of the asymmetry parameter \(A\) among the nuclear activities (Fig. 2). We also found that there is no correlation between the asymmetry parameter \(A\) and \([\text{N II}]/\text{H}a\) ratio (Fig. 3). All these findings indicate that galaxy collisions do not always trigger the nuclear activity.

Third, we investigated the relation between the dynamical properties of HCG spiral galaxies and properties of compact groups such as group size, velocity dispersion of member galaxies, galaxy number density, and crossing time (see Fig. 4 and Table 8). In compact groups with higher number densities with smaller sizes, more frequent galaxy collision would occur, and thus spiral galaxies in such galaxies. On the other hand, minor mergers could perturb the rotation curve in the inner regions of galaxies without causing global morphological peculiarities.

TABLE 13

Results of KS Test for Distributions of the Asymmetry Parameter between the HCG Spiral Galaxies and the Cluster Spiral Galaxies

| Galaxies                   | KS Probability* |
|----------------------------|-----------------|
| All HCG vs. all clusters   | 6.64 \times 10^{-4} |
| HCG S0/a–Sbc vs. cluster S0/a–Sbc | 4.50 \times 10^{-2} |
| HCG Sc vs. cluster Sc      | 8.48 \times 10^{-4} |
| HCG S0/a–Sbc vs. HCG Sc    | 2.32 \times 10^{-3} |
| Cluster S0/a–Sbc vs. cluster Sc | 0.183 |

* The probability that rejects the null hypothesis.
TABLE 14

|          | ALL | S0a–Sbc | Sc |
|----------|-----|---------|----|
|          | HCGs | Clusters | HCGs | Clusters | HCGs | Clusters |
| \( f \)  | 15.4 (6) | 70.7 (29) | 20.8 (5) | 64.3 (18) | 6.7 (1) | 84.6 (11) |
| \( f_\theta \) | 23.1 (9) | 17.1 (7) | 37.5 (9) | 25.0 (7) | 0.0 (0) | 0.0 (0) |
| \( p \)   | 61.5 (24) | 12.2 (5) | 41.7 (10) | 10.7 (3) | 93.3 (14) | 15.4 (2) |
| \( P(X^2)^p \) | \( 9.28 \times 10^{-7} \) | \( 3.84 \times 10^{-3} \) | \( 3.23 \times 10^{-5} \) |

a Numbers in parentheses are the actual values.
b “All” means the total sample of S0a–Sbc and Sc galaxies.
c The probability that rejects the null hypothesis.

groups would show more asymmetric rotation curves. However, we found that there are no significant correlations between the asymmetry parameter \( A \) and any group properties. There may be two interpretations for this finding: (1) Many compact groups containing spiral galaxies are false groups, i.e., a pair of galaxies with a few field galaxies (Mamon 1986, 1992, 1994, 1995; Hernquist, Katz, & Weinberg 1995). (2) The projected size and the observed velocity dispersion of the compact groups are significantly different from the real (i.e., three dimensional) ones. (Tovmassian & Chavushyan 2000; Tovmassian, Martinez, & Tiersch 1999). As mentioned in § 5.4, 85% of HCG spiral galaxies are peculiar and 93% of the late-type HCG spiral galaxies are peculiar. This high rate of peculiarity seems inconsistent with the false-group hypothesis. However, these two possibilities will be taken into account in future studies.

Finally, we compared the dynamical properties of spiral galaxies in the field, the clusters, and the HCGs. We found that the HCG spiral galaxies tend to have more asymmetric and more peculiar rotation curves with respect to the field and the cluster spiral galaxies (see Figs. 6 and 7 and Tables 10, 11, 13, and 14). It is interesting to note that these are the significant differences in the distributions of the \( A \) and the rotation curve morphologies between the HCG early-type spiral galaxies and the HCG late-type ones, although we found no such difference between the field early-type spiral galaxies and the field late-type ones. This may be attributed to the stabilization of a disk by a large bulge of early-type spiral galaxies (Mihos & Hernquist 1994; Velázquez & White 1999). Since a small bulge cannot stabilize the disk, late-type spiral galaxies are more sensitive to galaxy interactions than early-type spiral galaxies are, and they are expected to show the peculiar kinematical properties for a longer duration.

Table 15 lists the distances \( r \) from the galactic nucleus in units of arcseconds and \( R_{25} \), the rotation velocities, \( V(r) \), at \( r \), and their 1 \( \sigma \) errors, \( dV(r) \), for each observed HCG spiral galaxy.

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### TABLE 15

Velocities for Spiral Galaxies in Hickson Compact Groups

| r (arcsec) | V(r) (km s\(^{-1}\)) | dV(r) (km s\(^{-1}\)) |
|------------|-----------------|-------------------|
| HCG 7a     |                 |                   |
| –28.00     | –0.49           | –128              |
| –26.25     | –0.46           | –144              |
| –24.50     | –0.43           | –150              |
| –22.75     | –0.40           | –135              |
| –21.00     | –0.37           | –133              |
| –19.25     | –0.34           | –127              |
| –17.50     | –0.31           | –133              |
| –5.25      | –0.09           | –145              |
| 3.50       | –0.06           | –133              |
| –1.75      | 0.00            | –86               |
| 0.00       | 0.00            | 0                 |
| 1.75       | 0.03            | 116               |
| 3.50       | 0.06            | 209               |
| 5.25       | 0.09            | 238               |
| 7.00       | 0.12            | 193               |
| 7.50       | 0.28            | 192               |
| 19.25      | 0.34            | 205               |
| 21.00      | 0.37            | 228               |
| 22.75      | 0.40            | 226               |
| 24.50      | 0.43            | 210               |
| 26.25      | 0.46            | 243               |
| 28.00      | 0.49            | 230               |
| 29.75      | 0.52            | 222               |
| HCG 31a    |                 |                   |
| –14.00     | –0.43           | 85                |
| –12.25     | –0.38           | 69                |
| –10.50     | –0.33           | 52                |
| –8.75      | –0.27           | 60                |
| –7.00      | –0.22           | 58                |
| –5.25      | –0.16           | 52                |
| –3.50      | –0.11           | 37                |
| –1.75      | –0.05           | 9                 |
| 0.00       | 0.00            | 1                 |
| 3.50       | 0.11            | –30               |
| 5.25       | 0.16            | –49               |
| 7.00       | 0.22            | –54               |
| 8.75       | 0.27            | –65               |
| 10.50      | 0.33            | –81               |
| 12.25      | 0.38            | –93               |
| 14.00      | 0.43            | –88               |
| 15.75      | 0.49            | –84               |
| 17.50      | 0.54            | –50               |
| HCG 31b    |                 |                   |
| –21.00     | –0.80           | –50               |
| –17.50     | –0.67           | –50               |
| –15.75     | –0.60           | –56               |
| –14.00     | –0.54           | –39               |
| –12.25     | –0.47           | –32               |
| –10.50     | –0.40           | –34               |
| –8.75      | –0.34           | –35               |
| –7.00      | –0.27           | –34               |
| –5.25      | –0.20           | –31               |
| –3.50      | –0.13           | –13               |
| –1.75      | –0.07           | –15               |
| 0.00       | 0.00            | 0                 |
| 1.75       | 0.07            | 12                |
| 3.50       | 0.13            | 25                |
| 7.00       | 0.27            | 60                |

### TABLE 15—Continued

| r (arcsec) | V(r) (km s\(^{-1}\)) | dV(r) (km s\(^{-1}\)) |
|------------|-----------------|-------------------|
| 8.75       | 0.34            | 55                |
| 12.25      | 0.47            | 70                |
| HCG 31c    |                 |                   |
| –21.00     | –1.15           | 23                |
| –19.25     | –1.05           | 51                |
| –17.50     | –0.96           | 18                |
| –15.75     | –0.86           | 8                 |
| –12.25     | –0.67           | 28                |
| –8.75      | –0.48           | 27                |
| –7.00      | –0.38           | 11                |
| –3.50      | –0.19           | 1                 |
| –1.75      | –0.10           | –5               |
| 0.00       | 0.00            | 0                 |
| 1.75       | 0.10            | –3               |
| 3.50       | 0.19            | –8               |
| 5.25       | 0.29            | –17              |
| 8.75       | 0.48            | –34              |
| 10.50      | 0.57            | –34              |
| 12.25      | 0.67            | –40              |
| 14.00      | 0.77            | –12              |
| 15.75      | 0.86            | 24                |
| HCG 37b    |                 |                   |
| –24.50     | –0.47           | 163               |
| –17.50     | –0.34           | 82                |
| –3.50      | –0.07           | 230               |
| –1.75      | –0.03           | 97                |
| 0.00       | 0.00            | 0                 |
| 1.75       | 0.03            | –139              |
| 3.50       | 0.07            | –266              |
| 5.25       | 0.10            | –67               |
| HCG 38a    |                 |                   |
| –14.00     | –0.63           | 181               |
| –12.25     | –0.55           | 181               |
| –10.50     | –0.48           | 141               |
| –8.75      | –0.40           | 131               |
| –7.00      | –0.32           | 151               |
| –5.25      | –0.24           | 114               |
| –3.50      | –0.16           | 123               |
| –1.75      | –0.08           | 38                |
| 0.00       | 0.00            | 0                 |
| 1.75       | 0.08            | –68               |
| 3.50       | 0.16            | –73               |
| 5.25       | 0.24            | –146              |
| 8.75       | 0.40            | –147              |
| 10.50      | 0.48            | –133              |
| 12.25      | 0.55            | –80               |
| 14.00      | 0.63            | –145              |
| HCG 40c    |                 |                   |
| –22.75     | –0.62           | 186               |
| –21.00     | –0.57           | 187               |
| –19.25     | –0.52           | 201               |
| –17.50     | –0.47           | 189               |
| –15.75     | –0.43           | 177               |
| –14.00     | –0.38           | 168               |
| –10.50     | –0.28           | 177               |
| –7.00      | –0.19           | 159               |
| –5.25      | –0.14           | 108               |
| –3.50      | –0.09           | 102               |
| \( r \) (arcsec) | \( r/R_{25} \) | \( V(r) \) (km s\(^{-1}\)) | \( dV(r) \) (km s\(^{-1}\)) |
|----------------|-------------|----------------|----------------|
| -1.75 .......... | -0.05       | 39             | 14             |
| 0.00 ..........  | 0.00        | 0              | 9              |
| 1.75 ..........  | 0.05        | -30            | 10             |
| 3.50 ..........  | 0.09        | -54            | 8              |
| 5.25 ..........  | 0.14        | -105           | 11             |
| 7.00 ..........  | 0.19        | -112           | 10             |
| 8.75 ..........  | 0.24        | -185           | 8              |
| 10.50 .......... | 0.28        | -202           | 7              |
| 12.25 .......... | 0.33        | -198           | 7              |
| 14.00 .......... | 0.38        | -209           | 9              |
| 15.75 .......... | 0.43        | -231           | 16             |
| 17.50 .......... | 0.47        | -236           | 16             |
| 19.25 .......... | 0.52        | -239           | 16             |
| HCG 44a        |             |                |                |
| -49.00 ..........| -0.49       | -196           | 29             |
| -45.50 ..........| -0.45       | -95            | 51             |
| -28.00 ..........| -0.28       | -274           | 27             |
| -19.25 ..........| -0.19       | -66            | 39             |
| -8.75 .......... | -0.09       | -143           | 34             |
| -5.25 .......... | -0.05       | -181           | 29             |
| -3.50 .......... | -0.03       | -168           | 28             |
| -1.75 .......... | -0.02       | -65            | 28             |
| 3.50 ..........  | 0.03        | 208            | 27             |
| 5.25 ..........  | 0.05        | 242            | 34             |
| 7.00 ..........  | 0.07        | 196            | 29             |
| 8.75 ..........  | 0.09        | 271            | 29             |
| 12.25 .......... | 0.12        | 388            | 42             |
| 22.75 .......... | 0.23        | 233            | 27             |
| 24.50 .......... | 0.24        | 222            | 28             |
| 26.25 .......... | 0.26        | 220            | 26             |
| 28.00 .......... | 0.28        | 236            | 26             |
| 29.75 .......... | 0.30        | 242            | 27             |
| 31.50 .......... | 0.31        | 241            | 30             |
| HCG 44c        |             |                |                |
| -38.50 ..........| -0.68       | -177           | 15             |
| -36.75 ..........| -0.65       | -139           | 9              |
| -35.00 ..........| -0.62       | -135           | 10             |
| -33.25 ..........| -0.59       | -157           | 16             |
| -31.50 ..........| -0.55       | -151           | 14             |
| -29.75 ..........| -0.52       | -145           | 14             |
| -28.00 ..........| -0.49       | -124           | 29             |
| -5.25 .......... | -0.09       | -86            | 24             |
| -3.50 .......... | -0.06       | -71            | 9              |
| -1.75 .......... | -0.03       | -75            | 4              |
| 0.00 ..........  | 0.00        | 0              | 3              |
| 1.75 ..........  | 0.03        | 83             | 5              |
| 3.50 ..........  | 0.06        | 102            | 6              |
| 5.25 ..........  | 0.09        | 125            | 12             |
| 35.00 .......... | 0.62        | 87             | 29             |
| 36.75 .......... | 0.65        | 159            | 20             |
| 38.50 .......... | 0.68        | 147            | 22             |
| 40.25 .......... | 0.71        | 177            | 14             |
| 42.00 .......... | 0.74        | 164            | 20             |
| HCG 44d        |             |                |                |
| -36.75 ..........| -0.54       | 86             | 18             |
| -35.00 ..........| -0.52       | 95             | 10             |
| -33.25 ..........| -0.49       | 123            | 10             |
| -31.50 ..........| -0.47       | 99             | 10             |
| -29.75 ..........| -0.44       | 97             | 10             |
| -28.00 ..........| -0.41       | 79             | 11             |
| $r$ (arcsec) | $r/R_{25}$ | $V(r)$ (km s$^{-1}$) | $dV(r)$ (km s$^{-1}$) |
|-------------|-----------|---------------------|---------------------|
| $-14.00......$ | $-0.20$ | $-243$ | $32$ |
| $-12.25......$ | $-0.18$ | $-245$ | $33$ |
| $3.50......$ | $0.05$ | $106$ | $41$ |
| $10.50......$ | $0.15$ | $149$ | $43$ |
| $14.00......$ | $0.20$ | $207$ | $34$ |
| $15.75......$ | $0.23$ | $222$ | $32$ |
| $17.50......$ | $0.25$ | $226$ | $32$ |
| $19.25......$ | $0.28$ | $241$ | $33$ |
| $21.00......$ | $0.30$ | $264$ | $32$ |
| $22.75......$ | $0.33$ | $210$ | $34$ |
| $24.50......$ | $0.35$ | $228$ | $33$ |
| $26.25......$ | $0.38$ | $216$ | $37$ |
| $28.00......$ | $0.40$ | $237$ | $33$ |
| $29.75......$ | $0.43$ | $212$ | $35$ |
| $31.50......$ | $0.45$ | $211$ | $33$ |
| $33.25......$ | $0.48$ | $248$ | $33$ |
| $35.00......$ | $0.50$ | $226$ | $35$ |
| $36.75......$ | $0.53$ | $272$ | $37$ |
| $47.25......$ | $0.68$ | $278$ | $37$ |

**HCG 61c**

| $r$ (arcsec) | $r/R_{25}$ | $V(r)$ (km s$^{-1}$) | $dV(r)$ (km s$^{-1}$) |
|-------------|-----------|---------------------|---------------------|
| $-19.25......$ | $-0.37$ | $-197$ | $35$ |
| $-17.50......$ | $-0.34$ | $-226$ | $10$ |
| $-15.75......$ | $-0.30$ | $-186$ | $9$ |
| $-14.00......$ | $-0.27$ | $-168$ | $7$ |
| $-12.25......$ | $-0.24$ | $-165$ | $7$ |
| $-10.50......$ | $-0.20$ | $-161$ | $8$ |
| $-8.75......$ | $-0.17$ | $-136$ | $9$ |
| $-7.00......$ | $-0.14$ | $-140$ | $11$ |
| $-5.25......$ | $-0.10$ | $-127$ | $9$ |
| $-3.50......$ | $-0.07$ | $-102$ | $9$ |
| $-1.75......$ | $-0.03$ | $-63$ | $9$ |
| $0.00......$ | $0.00$ | $0$ | $9$ |
| $1.75......$ | $0.03$ | $66$ | $9$ |
| $3.50......$ | $0.07$ | $92$ | $11$ |
| $5.25......$ | $0.10$ | $156$ | $17$ |
| $7.00......$ | $0.14$ | $195$ | $18$ |

**HCG 68c**

| $r$ (arcsec) | $r/R_{25}$ | $V(r)$ (km s$^{-1}$) | $dV(r)$ (km s$^{-1}$) |
|-------------|-----------|---------------------|---------------------|
| $-63.00......$ | $-0.82$ | $172$ | $51$ |
| $-61.25......$ | $-0.80$ | $184$ | $32$ |
| $-43.75......$ | $-0.57$ | $190$ | $18$ |
| $-42.00......$ | $-0.55$ | $188$ | $16$ |
| $-33.25......$ | $-0.43$ | $156$ | $26$ |
| $-31.50......$ | $-0.41$ | $193$ | $23$ |
| $-29.75......$ | $-0.39$ | $209$ | $21$ |
| $-28.00......$ | $-0.37$ | $172$ | $18$ |
| $-26.25......$ | $-0.34$ | $217$ | $23$ |
| $-5.25......$ | $-0.07$ | $228$ | $44$ |
| $-3.50......$ | $-0.05$ | $147$ | $23$ |
| $-1.75......$ | $-0.02$ | $41$ | $8$ |
| $0.00......$ | $0.00$ | $0$ | $6$ |
| $1.75......$ | $0.02$ | $-28$ | $8$ |
| $3.50......$ | $0.05$ | $-81$ | $21$ |
| $21.00......$ | $0.27$ | $-137$ | $16$ |
| $22.75......$ | $0.30$ | $-184$ | $21$ |
| $24.50......$ | $0.32$ | $-162$ | $14$ |
| $26.25......$ | $0.34$ | $-156$ | $21$ |
| $28.00......$ | $0.37$ | $-176$ | $20$ |
| $29.75......$ | $0.39$ | $-166$ | $20$ |
| $31.50......$ | $0.41$ | $-161$ | $13$ |
| $33.25......$ | $0.43$ | $-179$ | $15$ |
| $35.00......$ | $0.46$ | $-164$ | $14$ |
| $36.75......$ | $0.48$ | $-180$ | $15$ |
| \( r \) (arcsec) | \( r/R_{25} \) | \( V(r) \) (km s\(^{-1}\)) | \( dV(r) \) (km s\(^{-1}\)) |
|------------------|-------------|-----------------|-----------------|
| 3.50             | 0.14        | -107            | 7               |
| 5.25             | 0.21        | -72             | 21              |

HCG 87a

| \( r \) (arcsec) | \( r/R_{25} \) | \( V(r) \) (km s\(^{-1}\)) | \( dV(r) \) (km s\(^{-1}\)) |
|------------------|-------------|-----------------|-----------------|
| -31.50           | -0.79       | 335             | 29              |
| -29.75           | -0.75       | 310             | 15              |
| -28.00           | -0.70       | 294             | 14              |
| -26.25           | -0.66       | 269             | 16              |
| -24.50           | -0.62       | 265             | 16              |
| -22.75           | -0.57       | 237             | 15              |
| -21.00           | -0.53       | 214             | 14              |
| -19.25           | -0.48       | 204             | 14              |
| -17.50           | -0.44       | 187             | 16              |
| -15.75           | -0.40       | 175             | 15              |
| -14.00           | -0.35       | 151             | 17              |
| -12.25           | -0.31       | 135             | 14              |
| -10.50           | -0.26       | 118             | 16              |
| -8.75            | -0.22       | 84              | 15              |
| -7.00            | -0.18       | 68              | 14              |
| -5.25            | -0.13       | 62              | 15              |
| -3.50            | -0.09       | 27              | 15              |
| -1.75            | -0.04       | 22              | 16              |
| 0.00             | 0.00        | 0               | 9               |
| 5.25             | 0.13        | -111            | 18              |
| 7.00             | 0.18        | -100            | 21              |

HCG 87c

| \( r \) (arcsec) | \( r/R_{25} \) | \( V(r) \) (km s\(^{-1}\)) | \( dV(r) \) (km s\(^{-1}\)) |
|------------------|-------------|-----------------|-----------------|
| -10.50           | -0.49       | -228            | 40              |
| -8.75            | -0.41       | -166            | 13              |
| -7.00            | -0.33       | -137            | 8               |
| -5.25            | -0.25       | -110            | 8               |
| -3.50            | -0.16       | -92             | 9               |
| -1.75            | -0.08       | -57             | 8               |
| 0.00             | 0.00        | 0               | 9               |
| 5.25             | 0.16        | 75              | 8               |
| 7.00             | 0.25        | 97              | 9               |
| 8.75             | 0.33        | 127             | 19              |
| 10.50            | 0.41        | 94              | 11              |
| 12.25            | 0.49        | 89              | 10              |
| 14.00            | 0.57        | 99              | 12              |
| 15.75            | 0.65        | 125             | 11              |

HCG 87a

| \( r \) (arcsec) | \( r/R_{25} \) | \( V(r) \) (km s\(^{-1}\)) | \( dV(r) \) (km s\(^{-1}\)) |
|------------------|-------------|-----------------|-----------------|
| -21.00           | -0.47       | 254             | 29              |
| -19.25           | -0.43       | 88              | 28              |
| -17.50           | -0.39       | 212             | 28              |
| -15.75           | -0.35       | 213             | 29              |
| -14.00           | -0.31       | 189             | 31              |
| -12.25           | -0.27       | 169             | 29              |
| -10.50           | -0.23       | 172             | 30              |
| -8.75            | -0.19       | 152             | 31              |
| -7.00            | -0.16       | 135             | 31              |
| 1.75             | 0.04        | -177            | 33              |
| 3.50             | 0.08        | -215            | 38              |
| 5.25             | 0.12        | -229            | 33              |
| 7.00             | 0.16        | -290            | 30              |
| 8.75             | 0.19        | -304            | 29              |
| 10.50            | 0.23        | -310            | 29              |
| 12.25            | 0.27        | -311            | 30              |
| 14.00            | 0.31        | -318            | 29              |
| 15.75            | 0.35        | -324            | 32              |
TABLE 15—Continued

| r (arcsec) | r/R_{25} | V(r) (km s^{-1}) | dV(r) (km s^{-1}) |
|------------|----------|------------------|------------------|
| HCG 89a    |          |                  |                  |
| -17.50     | -0.60    | 159              | 22               |
| -15.75     | -0.54    | 136              | 19               |
| -14.00     | -0.48    | 110              | 18               |
| -12.25     | -0.42    | 114              | 18               |
| -10.50     | -0.36    | 75               | 19               |
| -5.25      | -0.18    | 142              | 24               |
| -3.50      | -0.12    | 127              | 20               |
| -1.75      | -0.06    | 49               | 15               |
| 0.00       | 0.00     | 0                | 14               |
| 1.75       | 0.06     | -92              | 17               |
| 3.50       | 0.12     | -121             | 19               |
| 5.25       | 0.18     | -148             | 22               |
| 7.00       | 0.24     | -153             | 24               |
| 8.75       | 0.30     | -125             | 26               |
| 15.75      | 0.54     | -131             | 23               |
| 17.50      | 0.60     | -152             | 22               |
| 19.25      | 0.66     | -152             | 21               |
| 21.00      | 0.72     | -143             | 20               |
| 22.75      | 0.78     | -146             | 22               |
|            |          |                  |                  |
| HCG 92a    |          |                  |                  |
| -43.75     | -0.63    | -128             | 28               |
| -42.00     | -0.60    | -136             | 24               |
| -28.00     | -0.40    | -77              | 33               |
| -24.50     | -0.35    | -121             | 29               |
| -22.75     | -0.33    | -90              | 26               |
| -21.00     | -0.30    | -104             | 24               |
| -19.25     | -0.28    | -107             | 23               |
| -17.50     | -0.25    | -117             | 23               |
| -10.50     | 0.15     | -100             | 28               |
| -7.00      | 0.10     | -62              | 27               |
| -5.25      | 0.08     | -47              | 25               |
| -3.50      | -0.05    | -47              | 25               |
| -1.75      | -0.03    | -45              | 26               |
| 3.50       | 0.05     | -7               | 24               |
| 5.25       | 0.08     | 11               | 24               |
| 7.00       | 0.10     | -13              | 29               |
| 8.75       | 0.13     | 28               | 24               |
| 10.50      | 0.15     | 48               | 31               |
| 15.75      | 0.23     | 19               | 27               |
| 17.50      | 0.25     | 35               | 28               |
| 19.25      | 0.28     | 37               | 23               |
| 21.00      | 0.30     | 45               | 24               |
| 22.75      | 0.33     | 57               | 24               |
| 24.50      | 0.35     | 89               | 25               |
| 26.25      | 0.38     | 58               | 24               |
| 28.00      | 0.40     | 55               | 23               |
| 29.75      | 0.43     | 40               | 23               |
| 31.50      | 0.45     | 34               | 23               |
| 33.25      | 0.48     | 42               | 23               |
| 35.00      | 0.50     | 46               | 23               |
| 36.75      | 0.53     | 26               | 25               |
|            |          |                  |                  |
| HCG 92c    |          |                  |                  |
| -7.00      | -0.13    | -320             | 42               |
| -5.25      | -0.10    | -259             | 41               |
| -3.50      | -0.07    | -142             | 19               |
| -1.75      | -0.03    | -17              | 7                |
| 0.00       | 0.00     | 0                | 7                |
| 1.75       | 0.03     | -36              | 9                |
| 3.50       | 0.07     | -127             | 26               |
| 19.25      | 0.36     | -178             | 45               |

TABLE 15—Continued

| r (arcsec) | r/R_{25} | V(r) (km s^{-1}) | dV(r) (km s^{-1}) |
|------------|----------|------------------|------------------|
| HCG 93b    |          |                  |                  |
| -14.00     | -0.24    | 91               | 10               |
| -12.25     | -0.21    | 93               | 4                |
| -10.50     | -0.18    | 25               | 6                |
| -8.75      | -0.15    | 8                | 4                |
| -7.00      | -0.12    | 7                | 4                |
| -5.25      | -0.09    | -28              | 4                |
| -3.50      | -0.06    | 7                | 7                |
| -1.75      | -0.03    | 4                | 4                |
| 0.00       | 0.00     | 0                | 5                |
| 1.75       | 0.03     | -83              | 10               |
| 5.25       | 0.09     | -23              | 29               |
| 7.00       | 0.12     | -97              | 16               |
| 8.75       | 0.15     | -119             | 4                |
| 10.50      | 0.18     | -162             | 4                |
| 12.25      | 0.21     | -198             | 4                |
| 14.00      | 0.24     | -195             | 4                |
| 15.75      | 0.27     | -214             | 9                |
| 17.50      | 0.30     | -217             | 19               |
| 19.25      | 0.34     | -217             | 19               |
|            |          |                  |                  |
| HCG 93c    |          |                  |                  |
| -10.50     | -0.29    | 154              | 50               |
| -5.25      | -0.15    | 111              | 36               |
| -1.75      | -0.05    | 33               | 41               |
| 1.75       | 0.05     | -152             | 44               |
| 3.50       | 0.10     | -266             | 42               |
| 5.25       | 0.15     | -298             | 39               |
| 17.50      | 0.49     | -339             | 38               |
|            |          |                  |                  |
| HCG 96a    |          |                  |                  |
| -3.50      | -0.11    | -276             | 151              |
| -1.75      | -0.05    | -23              | 38               |
| 0.00       | 0.00     | 0                | 29               |
| 1.75       | 0.05     | 66               | 46               |
| 3.50       | 0.11     | 84               | 50               |
| 5.25       | 0.16     | 96               | 62               |
| 7.00       | 0.21     | 94               | 53               |
| 10.50      | 0.32     | 130              | 74               |
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