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NON-CIRCULAR VELOCITY FIELDS IN GALAXIES. A PRELIMINARY CLASSIFICATION AND SOME STATISTICAL PROPERTIES.

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ABSTRACT

The galaxies whose internal motions have hitherto been observed are about seventy in total, but among them those in which deviations from the circular motions at least in a local region, amount to about forty. The observed data are compiled and a preliminary classification is made according to the region where some non-circular motion appears.

Statistical correlations between the type of velocity field and other properties of galaxies are given with some inference on the origin of non-circular motion. Namely it is found that the radio luminosity and the nuclear brightness of galaxy have positive correlations with occurence of the non-circular motion, whereas no such correlation is ascertained for the total mass of galaxy and the mass of neutral hydrogen.

1. Introduction.

Non-circular velocity fields have been disclosed in many galaxies in the latest decade through the efforts for determining the rotation curves and masses of galaxies both in optical and 21-cm observations.*

We have now more than seventy galaxies for which the velocity fields have been observed in any degree of importance. Among these about forty galaxies exhibit appreciable deviation from regular circular motion. While the selection effect in observation has to be taken into account, the number forty among seventy would not be small as the fraction of galaxies having non-circular motion in any regions of galaxies. Moreover, it is notable that the velocity fields in these galaxies are in full of variety in its appearance. At a glance these evidences lead us to suppose that the origin of non-circular motion may be dispersed; some one reflects the effect of activity occured in the central region, while others reflect the external origin, and so on. Actually, however, it is as yet quite indecisive whether the origin is truely dispersed or there are some principal origins responsible for the high fraction of

* The survey of literature was concluded at December, 1968.

occurence and for its large variety.

The purpose of the present study is to investigate this problem from the statistical point of view. The observed data on the velocity field are compiled in the Appendix (Table A) from the references which are published mainly in the latest ten years. In Section 2 we give, for the galxies of Table A, a preliminary classification of the type of velocity field, paying our attention principally on the domain in which the non-circular motion occurs, and, subsequently, on the form of velocity field. Statistical correlations between the type of velocity field and other properties of galaxies will be delivered in Section 3. Some inference on the origin of non-circular motion will be obtained from the inspection of these statistical properties. Discussions will be given in the last section.

2. Preliminary Classification of Velocity Field.

When we consider the velocity fields in galaxies, we must bear in mind that it is principally the gas component of galaxies that participates to the non-circular motion and that the stellar component scarcely exhibits peculiar motion even in galaxies with violent activity such as M82. Moreover, it is fairly likely that the gas component in the central region is anyhow connected with the structure of nuclear region while the gas component in the outer region forms a part of the disk component of the galaxy. The different behaviour of ionized gases in both regions has been noticed in the emission spectra by Burbidge and Burbidge (1962) and Itoh and Kogure (1967). Concerning the origin of non-circular motion it is important as well to see if any difference of velocity field appears or not in different parts of the galaxy. Starting from this problem, we classify the velocity fields principally according to the domain in which the non-circular motion appears. The basic types of velocity field are as follows:

Type I. Non-circular motion in the central region of galaxy.
Type II. Peculiar velocity field in the outer region of galaxy.
Type III. Unusual rotation of the whole galaxy.
Type IV. Regular circular motion.

Each type is also divided into several sub-types according to the form of non-circular motion such as explosive motion, asymmetry of rotation curve and so on. In this way, the preliminary classification is made for the galaxies of Table A (in the Appendix)and is given in Table 1. The galaxies are arranged in the three groups of E galaxies, S and Ir galaxies, and SB ones. This is by the reason that E galaxies are distinguished from others in showing no appreciable rotation in their normal state and SB galaxies often reveal the special types of gas stream in the central bars. In classifying the Types I and II, the boundary of the central and outer regions is suitably taken here in the range of 1~2 Kpc. Although the boundary is not always so definitive, the classification has been made without difficulty except for several cases.

3. Statistical Relations.

In this section we prepare some statistical relations between the type of velocity field and the properties of galaxies. The data of the latter are compiled from the respective sources and are given in Table 2, which consists of the following contents:
Column 1. NGC number.

Table 1. Preliminary Classification.

Type of velocity field	Galaxy (NGC number) E	S,Ir	SB
I Non-circular motion in the central region			
(a) Central explosion	4486	1068 3034 7469	—
(b) Jet-like motion	4486	1275 3C305	—
(c) Infall motion	5128	2146	—
(d) Irregular motion in the central region	—	253 3556 4258 5194 7237	55 1097 1365
(e) Gas stream along the central bar	—	—	4027 4631 7479 7741 5383(?)
II Peculiar velocity field in the outer region			
(a) Asymmetry of rotation curve	—	925 1084 2146 4490(?) 5248 6181	—
(b) Local irregular motion (hump, dip, peculiar motion of HII clouds)	—	925 1808 2903 3310 3623 4736	—
(c) Irregular velocity field	—	3646 3038/9 4656(?)	613
(d) Large dispersion in the rotation curve ($\gtrsim \pm 50$km/s)	—	5005 7331	—
III Unusual rotation of the whole galaxy			
(a) No sign of rotation in S and Ir galaxies	—	IC1613	—
(b) Rapid rotation of E galaxies	4621 4697	—	—
(c) Rotation of nucleus in E galaxies	221 4278	—	—
(d) Spinning whorls arround the main body	—	2685	—
(e) Two gas components rotating separately	—	2782	—
(f) Center of rotation not coinciding with the nucleus of the galaxy	—	3310	—
IV Regular circular motion			
(a) E galaxy with no rotation	3379	—	—
(b) S, SB & Ir galaxies with regular rotation	—	157(O) 300(R) 598(O+R) 628(R) 681(O) 972(O)	672(R) 3359(R) 3504(O) 7640(R)?

Type of velocity field	Galaxy (NGC number)		
	E	S,Ir	SB
		1316(O)	
		1569(R)	
		1792(O)	
		2403(R)	
		3031(O)	
		3109(R)	
		3521(O)	
		4214(R)	
		4236(R)	
		4244(R)	
		4449(R)	
		4826(O)	
		5055(O+R)	
		5457(R)	
		6822(R)	
		6946(R)	
		IC10(R)	
		IC2574(R)	

Column 2. Hubble's morphological type.
Column 3. Type of velocity field given in Table 1.
Column 4. M_{gal}, the absolute magnitude of the whole galaxy.
Column 5. M_{nucl}, the absolute magnitude of the nucleus according to Vorontsov-Velyaminov (1966). The symbols in the parenthese indicate the following structural formation in the central region of galaxies :

L—the lens, a fairly thick structure with a gradual brightening toward the center.

B—the bulge, like a lens but with a greater sphericity and a more rapid decline in brightness toward the periphery.

N—the nucleus, like a bulge but being considerably smaller in size, even of stellar appearance.

Column 6. P, the intrinsic radio power in units of 10^{19} W Hz^{-1} str^{-1} at 1415 MHz obtained at the Nançay Radio Observatory (Beaujardière et al, 1968).
Column 7. L, the radio luminosity in units of 10^{38} erg s^{-1} emitted in the radio-frequency region (10–10^4 MHz). The values are those compiled by Aizu et al (1964).
Column 8. $\mathfrak{M}/\mathfrak{M}_\odot$ the total mass of galaxy derived by the authors of spectroscopic observation in Table A.
Column 9. $\mathfrak{M}_{HI}/\mathfrak{M}_\odot$, the mass of neutral hydrogen derived by Epstein (1966) or by Whiteoak (1967 RRW'67*).
Column 10. the atlas number in the Atlas of Peculiar Galaxies by Arp (1966). This number also serves for the classification in morphological peculiarity of galaxies.
Column 11. membership in the system of galaxies. Following abbreviations are used:

H—Holmberg number of Double and Multiple Galaxies (Holmberg 1937).

P—Pair galaxy noted in the Reference Catalogue of G. and A. de Vaucouleurs (1964) with the additional following subclassification,

P(a) = non-interacting pair
P(b) = interacting pair
P(c) = colliding or strongly interacting pair

L.G.—the Local Group of galaxies.

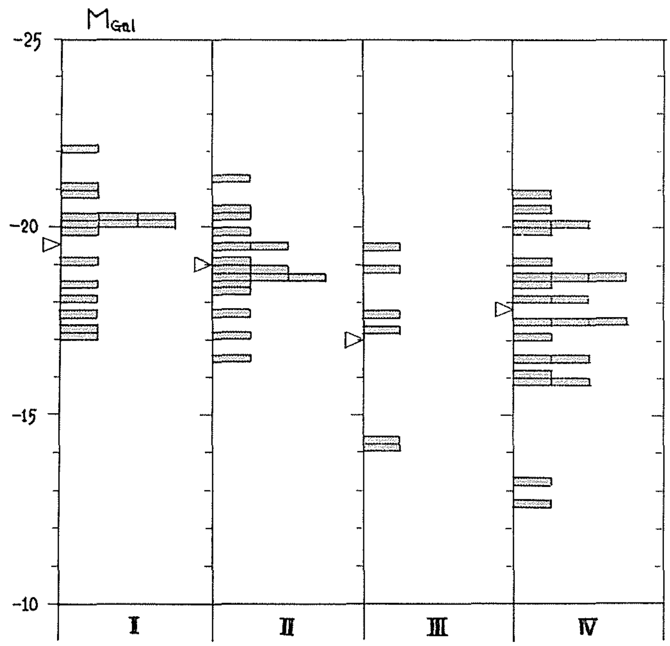

Fig. 1. Type of Velocity Field and Absolute Magnitude of Galaxy.

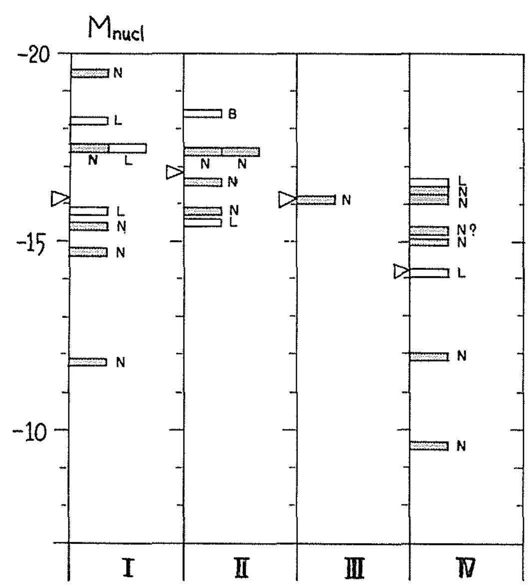

Fig. 2. Type of Velocity Field and Absolute Magnitude of Nucleus.
Structural formation of central region
L: lens B: bulge N: nucleus
according to VORONTSOV-VELYAMINOV (1966).

Table 2. Properties of galaxies.

NGC	Hubble type	Velocity field	M_{gal}	M_{nucl}	P	L	$\mathfrak{M}/\mathfrak{M}_{\odot}$	$\mathfrak{M}_{HI}/\mathfrak{M}_{\odot}$	No. Arp.	Membership
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
55	SB	I(d)	−18.08	—	—	0.35	$2.2—4.0\times10^{10}$	$2.0—3.1\times10^{9}$	—	Sculptor group
157	Sc	IV(b)	−19.85	−16.1(N)	137	6.4	4.5	—	—	
221	E2	III(c)	−14.26	—	—	—	—	—	168	P(a?) with NGC 224
253	Sc	I(d)	−19.79	—	41	2.5	24	—	—	Sculptor group
300	Sc	IV(b)	−16.50	—	—	—	1.4—8.0	2.1	—	Sculptor group
598	Sc	IV(b)	−17.12	−9.6(N)	—	0.053	3.4	1.3	—	L.G.
613	SBb	II(c)	−19.93	—	108	—	13—22	—	—	
628	Sc	IV(b)	−19.11	—	—	—	3.9—6.4	9.0	—	
672	SBc	IV(b)	—	—	—	—	—	—	—	Ho 46a, P(b?) with I1727 (Ho 46b)
681	Sa	IV(b)	−18.13	—	—	—	1.4	—	—	
925	Sc/SBc	II(a,b)	−17.62	—	—	—	4.5	4.4	—	NGC 1023 group
972	Sb	IV(b)	−18.68	—	—	—	1.2	—	—	
1068	Sb	I(a)	−19.91	−17.5(N)	780	52	2.7—1.9	—	37	NGC 1068 group
1084	Sc	II(a)	−18.87	−16.6(N)	50	7.0	1.6	—	—	
1097	SBb	I(d)	−20.05	−18.2(L)	140	8.1	0.54—1.34	—	77	
1275	Ir or Sp	I(b)	−20.94	—	—	2900 (core)	—	—	—	Perseus Cluster
1316	Sp or Ir	IV(b)	−20.54	—	—	2900	—	—	154	P(a) with NGC 1317, For I Cluster
1365	SBc	I(d)	−20.32	—	240	14	2.22—3.4	—	—	For I Cluster
1569	Ir	IV(b)	−12.79	—	1	0.037	—	—	210	L.G.?

1792	Sc	IV(b)	−18.75	—	—	—	1.8×10^{10}	$—\times10^{9}$	—	
1808	Sb	II(b)	−18.28	—	50	3.7	2.7	—	—	
1832	Sb	IV(b)	−18.9	—	—	—	3.5	—	—	
2146	Sap	I(c), II(a)	−19.07	—	100	14	1.8	—	—	P(b?) with NGC 2146-A
2403	Sc	IV(b)	−18.06	−14.2(L)	—	0.37	1.7—4.3	4.6	—	M 81 group
2685	SOp	III(d)	−17.82	−16.1(N)	—	—	—	—	336	
2782	Ir	III(e)	−19.52	—	—	—	14—22	—	215	P(b?) with anon. SB(s)
2903	Sbc	II(b)	−17.56	−15.8(N)	50	2.3	3.7	—	—	
3031	Sc	IV(b)	−15.87	−16.6(L)	—	0.35	19	1.5—2.9	—	M 81 group
3034	Ir	I(a)	−17.85	—	140	3.5	1—2.5	1.8	337	M 81 group
3109	Ir/Sb	IV(b)	−16.14	—	—	—	0.6—1.6	2.2	—	
3227	S	I(d)	−18.5	—	—	—	2.6	—	94	
3310	Sb	II(b), III(f)	−18.82	—	50	5.1	1.4	—	217	
3359	SBc	IV(b)	−18.57	−15.3(N)	—	—	7.7	—	—	
3379	Eo	IV(a)	−18.28	—	—	—	10	—	—	Ho 212a=P(a)?, Leo group
3504	SBb	IV(b)	−18.72	—	100	9.2	9	—	—	P(a) with NGC 3512
3521	Sb	IV(b)	−18.73	−16.4(N)	50	2.6	8.1	—	—	
3556	Si or Ir	I(d)	−19.04	—	—	—	1.1—1.7	—	—	
3623	Sa	II(b)	−18.68	−15.5(L)	—	—	20	—	—	Ho 246b, P(a) with 3627 Leo group
3646	Sb	II(c)	−21.27	—	—	—	20—30	—	—	P(a) with NGC 3649
4027	SB	I(e)	—	—	—	—	—	—	22	P(a?) with NGC 4038-39
4038/9	Ir+Sc	II(c)	−20.23	—	30	13	—	—	244	P(c)=colliding system, P(a?) with NGC 4027
4214	Ir	IV(b)	−17.50	—	—	—	0.33—2.0	0.98	—	UMa I group

NGC	Hubble type	Velocity field	M_{gal}	M_{nucl}	P	L	$\mathfrak{M}/\mathfrak{M}_\odot$	$\mathfrak{M}_{HI}/\mathfrak{M}_\odot$	No. Arp.	Membership
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
4236	Sc	IV(b)	−16.61	—	—	0.075	2.3×10^{10}	$—\times10^{9}$	—	Ho 357a, P with amon. (Ho 357b)
4244	Sc	IV(b)	−16.99	−11.9(N)	—	1.3	5.3—7.1	2.0	—	
4258	Sb	I(d)	−19.63	−15.8(L)	22	1.1	8.2—15.8	—	—	Ho 363a, P with NGC 4248
4278	El	III(c)	−17.21	—	40	3.0	—	—	—	Ho 369a, P with NGC 4283
4449	Ir	IV(b)?	−17.43	—	—	0.74	2.1	2.4	—	UMa I group
4486	Eo	I(a,b)	−19.62	—	—	1300	—	—	152	Virgo cluster
4490	Sc	II(a)	−18.60	—	82	2.4	2.7	—	269	Ho 414a, P(b) with NGC 4485, UMa II group
4621	Es	III(b)	—	—	—	—	—	—	—	Virgo Cluster
4631	Sc or SB	I(e)	−17.74	−11.8(N)	100	3.0	2.4—7.7	3.8—4.0	281	Ho 442a, P(b) with NGC 4627, UMa II group
4656	Ir	II(c) ?	−16.48	—	—	0.19	0.81	1.4—1.5	—	P(c)? (NGC 4038/a-type), UMa I group
4697	E5	III(b)	—	—	—	—	—	—	—	P(b) with anon. SAB
4736	Sb	II(b)	−20.56	—	6	0.28	1.1—3.0	—	—	UMa I group
4826	Sbp	IV(b)	−20.91	—	—	1.3	10	—	—	
5005	Sb	II(d)	−18.73	−17.4(N)	30	3.1	10	—	—	
5055	Sb	IV(b)	−18.65	—	11	1.4	22	—	—	UMa II group
5128	Ep	I(c)	−20.25	—	—	—	7.6	—	153	
5194	Sc	I(d)	−17.03	−14.7(N)	65	2.3	3.2—5.8	0.84(94/95)	85	Ho 526a, P(b) with NGC 5195
5248	Sc	II(a)	−19.48	−17.4(N)	50	3.8	3—7	—	—	
5383	SBb	I(e)	−20.00	(−17.4)(L)	—	—	5	—	—	P(a) with faint anon. SB (s)

5457	Sc	IV(b)	−20.05	−15.0(N)	13	1.2	16—18×10[10]	10.3×10[9]	26	M 101 group
6181	Sc	II(a)	−19.16	—	—	—	4.8	—	—	
6822	Ir	IV(b)	−13.43	—	—	0.0087	0.14	0.14	—	L. G.
6946	Ir	IV(b)	−17.54	—	20	2.9	1.9—19	2.2	29	L. G. ?
7237	SO	I(d)	−20	—	—	—	—	—	—	P(b) ? (Pair of distorted E or SO)
7331	Sb	II(d)	−19.45	−18.4(N)	50	8.9	14	—	—	Ho 795a (a.b.c.d.f.g.h)
7469	Sa	I(a)	−20.20	−19.5(N)	720	28	0.39	—	298	Ho 803a, P(a) with IC 5283 (Ho 803 b ?)
7479	SBb	I(e)	−21.00	−15.4(N)	—	—	2.2	—	—	
7640	SBc	IV(b)	−17.49	—	—	—	8.3	—	—	
7741	SBc	I(e)	—	—	—	—	—	—	—	
IC 10	Ir	IV(b)	—	—	1	—	0.1—0.2	0.2	—	L. G. ?
IC 1613	Ir	III(a)	−14.1	—	—	—	0.026	0.056	—	L. G.
IC 2574	Ir	IV(b)	−15.8	—	—	—	1.1—2.1	1.4	—	M 81 group
3C 305	Sa	I(b)	−22.0	—	—	—	—	—	—	

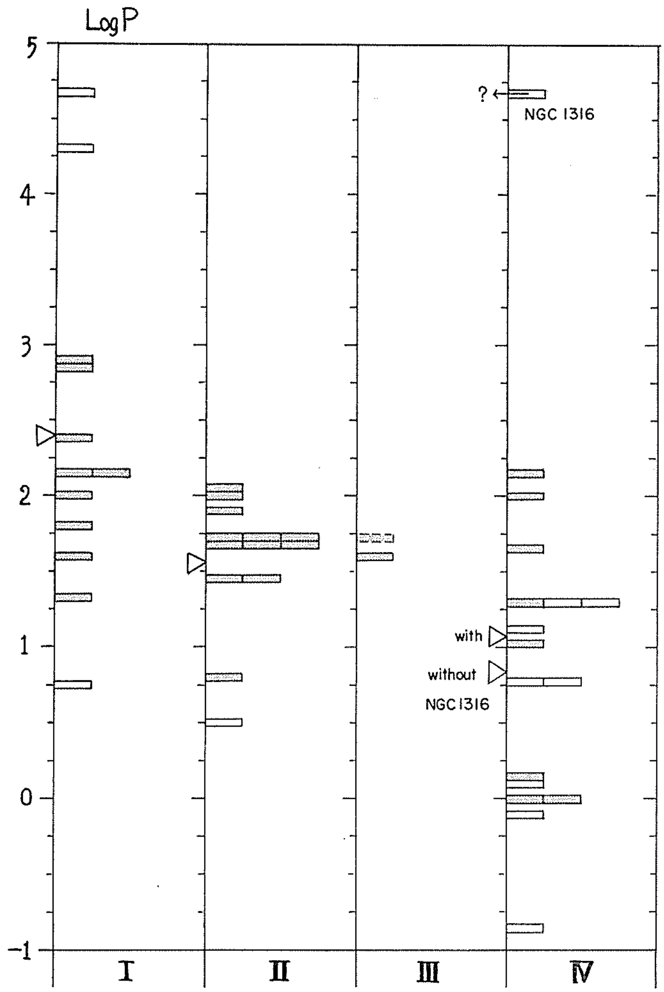

Fig. 3. Type of Velocity Field and Intrinsic Radio Power.

Statistical relations between the type of velocity field and the other properties in Table 2 are illustrated in Figures 1–5.

Figure 1 gives the relation to the absolute magnitude of whole galaxy. The average value of M_{gal} for each type is as follows:

$$\langle M_{gal} \rangle = \begin{cases} -19.5 & \text{for Type I galaxies} \\ -19.0 & \text{for Type II} \\ -17.0 & \text{for Type III} \\ -17.7 & \text{for Type IV.} \end{cases}$$

These values are also marked by the arrows in Figure 1.

Figure 2 yields the relation to the absolute magnitude of nucleus. The average value of M_{nucl} for each type is given as

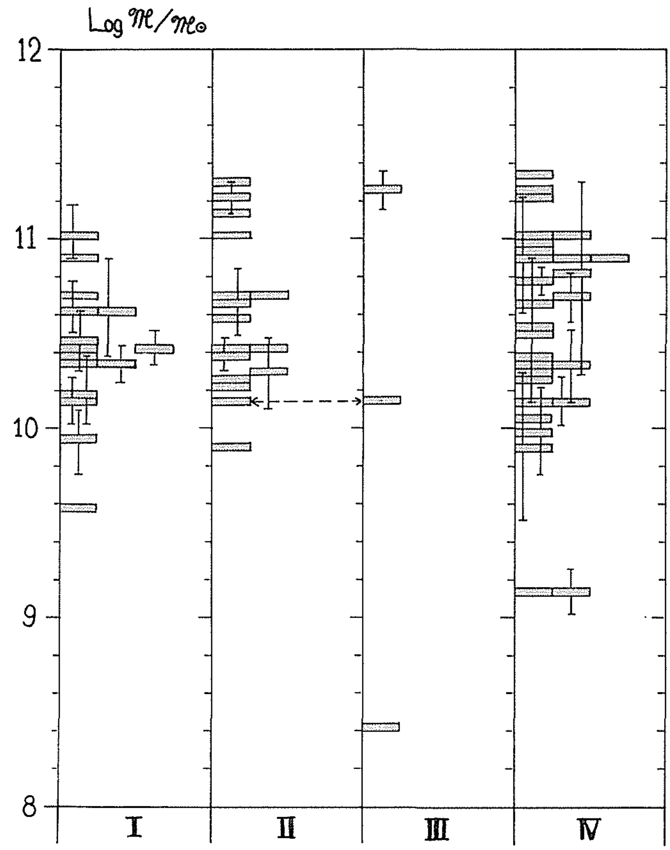

Fig. 4. Type of Velocity Field and Total Mass of Galaxy.

$$\langle M_{nucl} \rangle = \begin{cases} -16.1 & \text{for Type I galaxies} \\ -16.8 & \text{for Type II} \\ -16.1 & \text{for Type III} \\ -14.2 & \text{for Type IV} \end{cases}$$

In calculating these averages, attention is drawn for the nuclear formation of Vorontsov-Velyaminov's designation. Namely, we give the weight 2 for N-type nuclei while the weight unity for the others. This is because we have supposed that the N-type of nuclei mostly concerns with the violent activity occuring in the nuclei.

The relation in Figure 3 indicates the intrinsic radio power for every type of velocity field. The shaded marks denote the values of P by Nançay group expressed in units of 10^{19} W Hz^{-1} str^{-1} at 1415 MHz and the unshaded marks are those transformed from the values of L of Aizu et al. The average value for each type is as follows:

$$\langle \log P \rangle = \begin{cases} 2.40 & \text{for Type I galaxies} \\ 1.56 & \text{for Type II} \\ 1.65 & \text{for Type III} \end{cases}$$

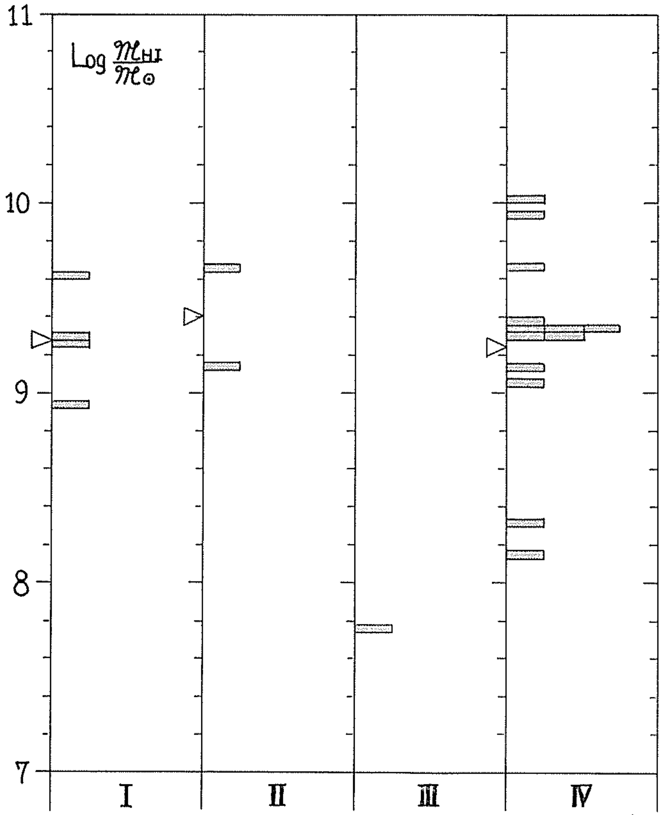

Fig. 5. Type of Velocity Field and Mass of Neutral Hydrogen.

and

$$\langle \log P \rangle = \begin{cases} 1.07 & \text{when NGC 1316 is included} \\ 0.84 & \text{when NGC 1316 excluded} \end{cases}$$

for galaxies of Type IV. The two values of $\langle \log P \rangle$ for the latter galaxies are dependent on the inclusion of NGC 1316. It is to be noticed that NGC 1316 has a high possibility to be classified as Type I. That is, NGC 1316 is a strong radio source (For A) whose radio power is two orders of magnitude higher than any other galaxies of Type IV. Other galaxies with strong radio sources usually exhibit the velocity field of Type I. Moreover, the observation of the velocity field in NGC 1316 is of poor quality (weight 1.5 in Table A). Particularly we have little information on the structure of its nucleus. In this way the value of $\langle \log P \rangle = 0.84$ may be more preferable for the galaxies of Type IV.

Figure 4 yields the relation to the total mass of galaxies, the average values being as follows:

$$\langle \log \mathfrak{M}/\mathfrak{M}_\odot \rangle = \begin{cases} 10.46 & \text{for Type I galaxies} \\ 10.69 & \text{for Type II} \\ 10.26 & \text{for Type III} \\ 10.50 & \text{for Type IV.} \end{cases}$$

In Figure 5 we give the relation to the total mass of neutral hydrogen. The average values are

$$\langle \log \mathfrak{M}_{\mathrm{HI}}/\mathfrak{M}_{\odot} \rangle = \begin{cases} 9.2 & \text{for Type I galaxies} \\ 9.3 & \text{for Type II} \\ - & \text{for Type III} \\ 9.2 & \text{for Type IV.} \end{cases}$$

The relation to the morphological peculiarities is given in Table 3 for galaxies which are found simultaneously in Table A and in the Atlas of Peculiar Galaxies by Arp (1966). The classification in column 1 and the atlas number in the second column are due to Arp and the type of velocity field in column 3 is that of ours. The NGC numbers are given in the last column.

Finally the relation to the membership in the system of galaxies is summarized in Table 4 from the data of Table 2. The galaxies are arranged by the NGC number in every type of velocity field. The galaxies in bracket in the multiple system, P(a) ~P(c), are those whose membership is not given in the de Vaucouleurs' catalogue but confirmed by other reference sources. For these galaxies the subclass, a, b or c, is suitably estimated here.

4. Discussions.

In our preliminary classification, the velocity fields in galaxies are primarily

Table 3. Relation with morphological peculiarity

Morphological peculiarity by Arp.		Type of Velocity Field	NGC
Classification	No. of Arp's Atlas		
Spiral Galaxies			
One heavy arm	26	IV(b)	5457
	29	IV(b)	6946
Companions on arm			
Low surface-brightness comps.	37	I(a)	1068
Small, high surface-br. comps.	77	I(d)	1097
Large, high surface-br. comps.	85	I(d)	5194
Galaxies			
With jets	152	I(b)	4486(Vir A)
Disturbed with interior absorption	153	I(c)	5128(Cen A)
	154	IV(b)	1316(For A)
Diffuse counter tails	168	III(c)	221
Irregularities, absorption and resolution	210	IV(b)	1569
Adjacent loops	215	III(e)	2782
	217	II(b)/III(f)	3310
Appearance of fission	244	II(c)	4038/9
	269	II(a)	4490
Double Galaxies			
Connected arms	269	II(a)	4490
Infall and attraction	281	I(e)	4631
	298	I(a)	7469
(Peculiar form with whorls)	336	III(d)	2685
Internal explosion	337	I(a)	3034(M82)

divided into four types (Types I to IV) according to the domain in which non-circular motion occurs. Although each of the type is also classified into several sub-types due to the form of motion, we shall confine ourselves in this paper to the consideration of primary types, for the latter subtypes are so much dispersed and their origins seem also dispersing.

In the preceding section, some statistical properties are prepared on the primary types of the velocity fields. It is of course to be mentioned that these materials are not fully appropriate for detailed statistics, since they are strongly affected by the selection effect in observation and the homogeneity of material is lacking as well, as seen in the large variety of weight in Table A. Nevertheless, some inference on

Table 4. *Relation with membership of the system of galaxies.*

	Type of velocity field			
	I	II	III	IV
P(c)		4038/9 4656 ?		
P(b)	2146 4631 5194 (7237)	2146 4490	2782 4697	672
P(a)	(1097) 4027 (4258) 5383 7469	3623 3646 (7331)	221 4278	1316 (3379) 3504 (4236)
Group of Galaxies	55 253 1068 3034	925 4736	IC1613	300 598 1569 2403 3031 4214 4449 5055 5457 6822 6946? IC 10 IC 2574
Cluster of Galaxies	1275 1365 4486		4621	
Field Galaxy	3556 5128 7479 7741	613 1084 1808 3310 2685 3310 5005 5248 6181		157 628 681 972 1792 3109 3359 3521 4244 4826 7640

Note: P(a) non-interacting pair.
P(b) interacting pair.
P(c) colliding or strongly interacting pair.

the origin of velocity fields may be drawn from the following discussions.

Let us first enumerate the possible origins of non-circular motion in a galaxy:

(A) Interior origin	A–1.	Activity in the nucleus
	A–2.	Instability in the disk
	A–3.	Effect of galaxy formation
(B) Exterior origin	B–1.	Interaction with nearby galaxies
	B–2.	Interaction with intergalactic medium

The contents of each term are obviously very ambiguous and we shall use these terms only in the following broad sense: origin A–1 indicates the effect of any explosive phenomena in the nucleus, origin A–2 is related to certain effect of gravitational, thermal, or other dynamical instabilities occuring in the outer thin gas layer, while origin A–3 is responsible for young galaxies by some effect of turbulence or inhomogeneous gravitational contraction surviving from the period of galaxy formation. Among the cases of exterior origins, origin B–1 implies some interaction with nearby galaxies in the form of tidal effect or in the collision of galaxies, whereas origin B–2 is an effect of intergalactic medium which gives rise to some disturbance on the disk matter after falling into the galaxy.

(1) If the non-circular motions are of interior origin, some correlation must appear between the non-circular velocity field and the properties of galaxies such as shown in Table 2. The relations are illustrated in Figures 1 to 5, among which Figure 1 (M_{gal}) and Figure 4 ($\mathfrak{M}/\mathfrak{M}_\odot$) concern with the whole structure of galaxies. Figure 1 shows that the galaxies of Types I and II are somewhat brighter than the galaxies of Type IV, but such a tendency can not be found in Figure 4. This discrepancy may be explained if we suppose that the non-circular velocity field is essentially independent of the whole structure of galaxies and that the tendency in Figure 1 could be attributed to the brightness of nuclear regions of galaxies.

(2) The above supposition is confirmed from the inspection of Figure 2 (M_{nucl}) and Figure 3 (P), both of which may be taken as indicators of activity in the nuclei. When compared with galaxies of regular field (Type IV), galaxies of Types I and II reveal the definite elevation of levels in the brightness of nuclei and in the radio power. Particularly one may notice that the radio power is highest in the Type I galaxies and is followed by Type II and Type III galaxies. If we suppose that the radio power is a true indicator of nuclear activity and moreover it reaches its maximum at some early stage followed by gradual decline, then Figure 3 suggests that when the radio power is high the non-circular motions are confined in the central regions of galaxies and when its power is weakened the peculiar motions spread into the outer regions of galaxies, and finally in the weakest stage of radio power, non-circular motions disappear. This tendency is not so clear in the brightness of nuclei, this is partly owing to unresolved components of stars and thermal or non-thermal gases.

(3) The neutral hydrogen mass in galaxies shows no reliable relation with the type of velocity field as shown in Figure 5. This infers that the velocity field is independent of the amount of gas component and of any instabilities in the category of A–2.

(4) The relation between the velocity field and the Arp's morphological peculiarity is shown in Table 3. Although the number of galaxies in Table 3 is not enough to make the statistics, one may state that the galaxies with morphological peculiarity in any form have high fraction to be classified as Type I to III. Particularly, when morphological peculiarities appear in the central region of galaxies,

e.g., Nos. 152, 153, 281, 298, and 337 in Arp's Atlas, those galaxies are prevalently classified as Type I.

(5) In order to see if there is any possibility of exterior origins, one may refer the relationship in Table 4, where the galaxies in every type of velocity field are arranged in the order of suspected strength of interaction with nearby galaxies. As properly expected, the Type II galaxies may be mostly concerned with the exterior origins, particularly, when the galaxies compose a system of strong interaction as P(c) in Table 4. The relation in Table 4 is not inconsistent with this expectation, since the two galaxies showing strong interaction belong to Type II. However, the evidence that a large fraction of Type II galaxies are field galaxies makes this possibility to be inconclusive. As for the galaxies of other types of velocity field Table 4 reveals no appreciable tendency suggesting external origins of peculiar velocity field. In this way one may state that the external effects are restricted if exist only in some special cases of Type II galaxies.

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APPENDIX

The data on the velocity field in galaxies are compiled in Table A, the content of each column is as follows:

Column 1. NGC number
Column 2. Hubble's morphological type.
Column 3. Short description on the main feature of velocity field.
Column 4. Weight of observation in optical (O) and 21-cm (R) regions.
Column 5. Type of velocity field due to the present classification(see Table1).
Column 6. References on optical (O) and 21-cm (R) observation. The short descriptions of velocity field in column 3 are those summarized from the references in column 6.

It is to be mentioned that the velocity fields in galaxies have not so far been the first subject of observation except several cases. This implies that the quality of information on this subject differs a great deal in every reference. In the compilation of data we have taken into account this qualification in the form of weight given in column 4. This weight, ranging from 0 to about 10 in optical (O) and 21-cm (R) observations, respectively, is suitably estimated by making use of the number of position angles and slit length in spectroscopic observation, or of the distribution of observed points in the case of 21-cm observation. For example, when spectroscopic

Table A. Main Features of Velocity Field in Galaxies.

NGC	Hubble type	Velocity field			
		Weight O+R	Main feature	Class	Reference
55	SB	1.5+6	Possible velocity dispersion of ionized gas in the central region($\lesssim 1' \approx 0.5$Kpc), and regular rotation of HI gas.	I(d)	O=de V'61 de V'64* R=RD'64 SW'65* RD'66
157	Sc	4+0	Regular rotation. Linear part of the rotation curve is somewhat longer than the usual.	IV(b)	O=BBP'61
221 (M32)	E2	2+0.5	Rotation of nucleus ($\lesssim$10 pc). Insignificant rotation outside. HI gas undetected.	III(c)	O=W'62 EP'64*
253	Sc	6.5+0.5	Large scale irregular motion of ionized gas in the central region($\lesssim 80'' \approx 1.2$Kpc). 21-cm emission is very weak.	I(d)	O=BBP'62 R=R'62*
300	Sc	0+2	Regular rotation of HI gas.	IV(b)	R=SR'67 SW'65*
598 (M33)	Sc	8+4	Regular rotation of ionized and HI gases. Arms rotate slightly faster (~15km/sec) than the disk.	IV(b)	O=MA'42 WM'42 B'65 CCGMP'68 R=V'59 R'62*
613	SBb	5+0	Regular rotation ($<20'' \approx (1.5)$ Kpc). Possible irregular motion in the outer region, asymmery of rotation curve and large derivation in the velocity of bright knots.	II(c)	O=BBRP'64
628	Sc	0+2.5	Regular rotation of HI gas.	IV(b)	R=R'62* RRW'67*
672	SBc	0+2	Regular rotation of HI gas.	IV(b)	R=RRW'67*
681	S(B)ab	3+0	Regular rotation of ionized gas up to$\sim 47'' \approx$ (3.9) Kpc. Velocity dispersion not exceeds $\pm$50km/sce. Rotation curve is similar with NGC 1084.	IV(b)	R=BPP'65
925	Sc/SBc	5+4	Irregular rotation of ionized and HI gases. Unusually small rotation and strong asymmetry of rotation curve in optical galaxy ($\lesssim$4Kpc), and very steep velocity features in outer HI region(at about $8' \approx 16$Kpc on either side).	II(a) II(b)	O=RBB'64 R=HR'65 RRW'67*
972	Sb	4+0	Regular rotation of ionized gas ($\lesssim 36'' \approx (3.9)$ Kpc).	IV(b)	O=BBP'65 D'65
1068	Sb	10+0	Explosion of ionized gas in the nucleus. A combination of circular motion and radial motion. Regular rotation in the outer region ($>30'' \approx 1.6$ Kpc)	I(a)	O=BBP'59 D'65* W'68
1084	Sc	4+0	Asymmetry of rotation curve in the outer region ($>30'' \approx 2.1$ Kpc).	II(a)	O=BB'63
1097	SBb	2+0.5	Peculiar motion in the nuclear region with annular structure ($<15'' \approx 0.87$ Kpc). HI gas undetected.	I(d)	O=BB'60 R=Ep'64*
1275	Irr or Sp	9+0	(Violent jet-like motion of gas from the center. Radial filaments exist.) Strong radio source. Seyfert galaxy.	I(b)	O=BB'65

NGC	Hubble type	Velocity field			
		Weight O+R	Main feature	Class	Reference
1316	Sp or Irr	1.5+0	Regular rotation. The central region not confirmed. Strong radio source (For A) exists in the disk plane.	IV(b)	O=S′65 BBS′63*
1365	SBc	6+0	Non-circular motion (radial or Z-axis directed) in the nucleus ($\lesssim 15'' \approx 1.1$Kpc).	I(d)	O=BB′60 BBP′62
1569	Irr	0+2	Regular rotation of HI gas.	IV(b)	R=RRW′67*
1792	Sc	6+0	Regular rotation of ionized gas ($\lesssim 65'' \approx 3.3$ Kpc)	IV(b)	R=RBBP′64
1808	Sb	2+0	Large scale local departure from circular motion in the region $30'' \sim 60''$($1.1 \sim 2.2$Kpc).	II(b)	O=BB′68
1832	Sb	6+0	Regular rotation of ionized gas ($\lesssim 48.7'' \approx 3.6$ Kpc)	IV(b)	O=BB′68
2146	Sap	5+0	Falling motion of ionized cloud, and asymmetry of rotation curve in the outer region.	I(c) II(a)	O=BBP′59
2403	Sc	0+2	Regular rotation of HI gas.	IV(b)	R=R′62* SW′65*
2685	SOp	3.5+0	Unusual rotation (main body and surrounding whorls rotate separately).	III(d)	O=Dm′65
2782	Irr	3+0	Two gas components (HII gas and [OIII] gas) rotate separately with regular rotation curves.	III(e)	O=D′65
2903	Sbc	4+0.5	Local disturved motion of ionized gas, and large velocity dispersion in the outer region. HI gas undetected.	II(b)	O=BBP′60 R=Ep′64*
3031 (M81)	Sc	0.5+0	Possible regular rotation of HII regions.	IV(b)	O=M′59
3034 (M82)	Irr	9+0	Explosive motion of ionized gas in the central region, and regular rotation of stellar component.	I(a)	O=BBR′64
3109	Irr/Sb	0+8	Regular rotation of HI gas.	IV(b)	R=D′66
3227	S	4+0	Large dip (-175 km/s) in the rotation curve and velocity split into a few components in the nuclear region ($\lesssim 5'' = 0.28$ Kpc). Seyfert galaxy.	I(d)	O=RF′68
3310	Sb	3+0	Possible disturbed motion of ionizd gas, and unusual rotation (center of roation not coinciding with the nucleus).	II(b) III(f)	O=CW′67
3359	SBc	0+2	Regular rotation of HI gas.	IV(b)	R=RRW′67*
3379 (M105)	EO	2+0	Regular E-galaxy with no appreciable rotation.	IV(a)	O=BBF′61
3504	SBb	5+0	Regular rotation of ionized gas. Outer arms may be elliptical or not coplanar with the main body if the arms are circular.	IV(b)	O=BBP′60
3521	Sb	5+0	Regular rotation of ionized gas ($\gtrsim 180'' \approx$ (5.6),(7.4)Kpc). Steep rise to near-maximum velocity, followed by a long fairly flat portion.	IV(b)	O=BBCRP′64
3556 (M108)	Sc or Irr	4+2	Flat rotation curve over wide range of central region, suggesting turbulent motion of ~ 50 km/sec. Regular rotation of HI gas.	I(d)	O=BBP′60 R=RRW′67*
3623 (M65)	Sa	5.5+0	Bright knots in outer region show large deviation (~ 150km/sec) from circular motion.	II(b)	O=BBP′61
3646	Sb	6+0	Large scale irregular motion. Dynamically	II(c)	O=BBP′61

NGC	Hubble type	Velocity field			
		Weight O+R	Main feature	Class	Reference
			unstable structure (acute-angle structure and wavy structure) in the outer part.		
4027	SB	2+0	Gas stream along the central bar (Magellanic type).	I(e)	O=de V'64*
4038/9	Ir+Sc	7+0	Large negative velocities in the dusty disturbed area (explosive phenomena ?)	II(c)	O=BB'66
4214	Irr	0+2	Regular rotation HI gas.	IV(b)	R=SW'65*
4236	Sc	0+2	Regular rotation HI gas.	IV(b)	R=RRW'67*
4244	Sc	0+3.5	Regular rotation HI gas.	IV(b)	R=R'62* SW'65* RRW'67*
4258	Sb	5+0	Irregular motion of ionized gas in the central region (explosive motion ?).	I(d)	O=BBP'63 CW'67 D'65* R=Ep'64*
4278	El	2.5+0	Rotation of ionized gas in the central region of E galaxy.	III(c)	O=O'60
4449	Irr	0+2	Regular rotation of HI gas.	IV(b)?	R=RRW'67*
4486 (M87)	EO	5+0.5	Outflow of ionized gas relative to stellar component and jet-like ejection of non-thermal gas. HI gas undetected.	I(a) I(b)	O=Os'60 BBS'63* WH'67 R=Ep'64*
4490	Sc	0+2	Possible irregular rotation of HI gas (asymmetry and large dispersion of rotation curve).	II(a)	R=RRW'67*
4621 (M59)	E5	1+0	E-galaxy with appreciable rotation (tilt angle 5:0=13 km/s/sec of arc=22 km/sec/100 pc).	III(b)	O=KM'66
4631	Sc or SB(s)m	4+3	Large scale gas stream in the central part. Regular rotation of HI gas.	I(e)	O=deVV'63 BBP'64 R=R'62* RRW'67* Rb'68
4656	Irr	0+1	Possible non-circular motion of HI gas.	II(c)?	R=Rb'68
4697	E5	1+0	E-galaxy with appreciable rotation (tilt angle $11° \pm 1°$=29km/s/sec of arc=50km/s/100 pc).	III(b)	O=KM'66
4736 (M94)	Sb	5+2	Possible irregular motion in the outer region (HI and ionized gas.)	II(b)	O=BB'62 CW'67 R=RRW'67*
4826 (M64)	Sbp	5+0.5	Regular rotation of ionized gas in the inner part ($\lesssim$2Kpc). Neither OB star groups nor HII region in the outer arms. HI gas undetected.	IV(b)	O=RBBP'65 R=Ep'64*
5005	Sb	3+0	Rotation curve (up to$\sim$87″$\approx$4.6 (6.1) Kpc) contains various peculiarities. Large velocity dispersion of ionized gas in 20″$\sim$50″ and a break of Hα velocity curve at 48″.	II(d)	O=BBP'61
5055	Sb	3+2	Regular rotation of ionized gas and HI gas.	IV(b)	O=BBP'60 R=RRW'67* Ep'64*
5128	Ep	7+0.5	Falling motion of gas relative to stellar component, wigh large irregular gas motion. Strong radio source (Cen. A). HI gas undetected.	I(c)	O=BB'59 BB'62 BBS'63* R=Ep'64*

NGC	Hubble type	Velocity field			
		Weight O+R	Main feature	Class	Reference
5194	Sc	10+3	Large scale irregular motion in the central region ($\lesssim 40'' \approx 760$ (600) pc), Regular rotation in outer region and of HI gas.	I(d)	O=BB'64 R=H'61 R'62* RRW'67*
5248	Sc	4+0	Large scale deviation from rotation curve of ionized gas in the outer region ($50'' \sim 65'' \approx 3.5 \sim 4.9$ Kpc).	II(a)	O=BBP'62
5383	SBb	5+0	Possibility of large scale Z-motion in the central bar ($\lesssim 7'' \approx 1.0$ Kpc).	I(e)	O=BBP'62
5457 (M101)	Sc	0+2	Regular rotation of HI gas.	IV(b)	R=R'62* RRW'67*
6181	Sc	5+0	Asymmetry of rotation curves at these position angles, a "hump" at SE $8'' \sim 13'' \approx 0.96 \sim 1.6$ ($1.3 \sim 2.1$) Kpc. Gas stream along the central bar ?	II(a)	O=BBP'65
6822	Irr	0+2	Regular rotation of HI gas.	IV(b)	R=RRW'67* VH'61*
6946	Irr	0+2	Regular rotation of HI gas.	IV(b)	R=RRW'67*
7237	SO	0.5+0	High velocity gas in the nucleus. Strong radio source (3C442).	I(d)	O=BBS'63* G'62*
7331	Sb	6+0	Large scale velocity dispersion in the outer retion of $143'' \sim 250'' \approx 7.4 \sim 8.0$ Kpc.	II(d)	O=RBBCP'65
7469	Sa	3+0	Explosive phenomena (Seyfert galaxy) in the nucleus ($\lesssim 1''.4 \approx$ (340) pc). Regular rotation of ionized gas in the outer region. ($1.4 \sim 11'' \approx 340 \sim 2700$ pc).	I(a)	O=BBP'63
7479	SBb	4+0	Possible gas stream along the bar. Extremely long bar up to ~ 9 Kpc.	I(e)	O=de V'64*
7640	SBc	0+2	Regular rotation of HI gas (slightly disturbed).	IV(b)	R=RRW'67*
7741	SBc(s)	1+0	Gas stream along the central bar.	I(e)	O=de V'64*
IC10	Irr	0+3	Regular rotation of HI gas. HI rich high velocity cloud at the nucleus.	IV(b)	R=R'62 Ep'64* RRW'67*
IC 1613	Irr	0+4	No sign of rotation.	III(a)	R=VH'61*
IC 2574	Irr	0+2	Regular rotation of HI gas.	IV(b)	R=RRW'67*
3C 305	Sa	2+0	Possible jet-motion from the nucleus. Strong radio source.	I(b)	O=S'66

observation is made in a position angle of major or minor axis with the slit length extending to the ends of the galaxy in both sides, we count the weight 2 in optical observation. The values of weight are adjusted, though rather arbitrarily, so as that it rea ches up to about 10 when the measurement is made along several position angles enough to cover the main part of the galaxy. Because of the crudeness of weight estimation, we have not taken into account the further observational conditions, such as the dispersion of spectrograms and/or the instrumentation.

The nearest galaxies M31, LMC, SMC, and our Galaxy are excluded from our survey, for the details of observation for these galaxies sometimes make difficult to compare them with other galaxies, and our attempt is limited to the overall feature of velocity field in galaxies.

One point is noticed in Table A that the spectroscopic and 21-cm observations have so far been made almost exclusively with each other. This is easily seen in the values of weight: of 75 galaxies, only 5 galaxies have the weight equal or greater than 2 both in spectroscopic and 21-cm observations, whereas 61 galaxies are of weight 0 either in spectroscopic or in 21-cm observation. It is therefore most desirable further observations to be made from both sides of optical and radio observations parallelly.

Reference for individual galaxy in Table A

NGC	Abbreviation	Reference
55	de V'61	Vaucouleurs, G. de. 1961, Ap. J., **133**, 405.
	RD'64	Robinson, B. J. & Damme, van. K. J. 1964, IAU-URSI Symp. No. 20. 1966, Aust. J. Phys., **19**, 111.
157	BBP'61	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1961, Ap. J., **134**, 874.
221	W'62	Walker, M. F. 1962, Ap. J., **136**, 695.
253	BBP'62	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1962, Ap. J., **136**, 339.
300	SR'67	Shobbrook, R. R. & Robinson, B. J. 1967, Aust. J. Phys., 20131.
598	MA'42	Mayall, N. U. & Aller, L. H. 1942, Ap. J., **95**, 55.
	WM'42	Wyse, A. B. & Mayall, N. U. 1942, Ap. J., **95**, 55.
	B'65	Brandt, J. C. 1965, M. N. **129**, 309.
	CCGMP'68	Carranza, G., Courtes, G., Georgelin, Y. & Monnet, G. 1968, Ann. d'Ap., 31, 63.
	V'59	Volders, L. 1959, B. A. N., **14**, 323.
613	BBRP'64	Burbidge, E. M., Burbidge, G. R., Prendergast, K. H. & Rubin, V. C. 1964, Ap. J., **145**, 85.
681	BBP'65	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1965, Ap. J., **142**, 154.
925	RBB'64	Rubin, V. C., Burbidge, E. M. & Burbidge, G. R. 1964, Ap. J., **140**, 94.
	HR'65	Höglund, R. & Roberts, M. S. 1965, Ap. J., **142**, 1366.
972	BBP'65	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1965, Ap. J., **142**, 649.
	D'65	Demoulin, M. 1965, Publ. de L'obs. de Haute-Provence **8**, No. 1.
1068	BBP'59	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1959, Ap. J., **130**, 26.
	W'68	Warker, M. F. 1968, Ap. J., **151**, 71.
1084	BBP'63	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1963, Ap. J., **137**, 376.
1097	BB'60	Burbidge, E. M. & Burbidge, G. R. 1960, Ap. J., **132**, 30.
1275	BB'65	Burbidge, E. M. & Burbidge, G. R. 1965, Ap. J., **142**, 1351.
1316	S'65	Searle, L. 1965, Nature, **207**, 1282.
1365	BB'60	Burbidge, E. M. & Burbidge, G. R. 1960, Ap. J., **132**, 30.
	BBP'62	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1962, Ap. J., **136**, 118.
1792	RBBP'64	Burbidge, E. M., Burbidge, G. R., Prendergast, K. H. & Rubin, V. C. 1964, Ap. J., **140**, 80.
1808	BB'68	Burbidge, E. M. & Burbidge, G. R. 1968, Ap. J., **151**, 99.
2146	BBP'59	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1959, Ap. J., **130**, 739.
2685	Dm'65	Demoulin, M. 1965, Publ. de L'obs, de Haute-Provence **7**, No. 44.
2903	BBP'60	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1960. Ap. J.,

	132, 640.
3031 M'59	Münch, G. 1959, P. A. S. P., **71**, 102.
3034 BBR'64	Burbidge, E. M., Burbidge, G. R. & Rubin, V. C., 1964, Ap. J., **140**, 942.
3109 D'66	van Damme, K. J. 1966, Aust. J. Phys., **19**, 687.
3310 CW'67	Chincarini, G. & Warker, M. F. 1967, Ap. J., **147**, 416.
3379 BBF'61	Burbidge, E. M., Burbidge, G. R. & Fish, R. A. 1961, Ap. J., **134**, 251.
3504 BBP'60	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1960, Ap. J., **132**, 661.
3521 BBCRP'64	Burbidge, E. M., Burbidge, G. R., Prendergast, K. H., Rubin, V. C. & Crampin, 1964, Ap. J., **139**, 1058.
3556 BBP'60	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1960 Ap. J., **131**, 549.
3623 BBP'61	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1961, Ap. J., **134**, 232.
3646 BBP'61	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1961, Ap. J., **134**, 237.
4038/9 BB'66	Burbidge, E. M. & Burbidge, G. R. 1966, Ap. J., **145**, 661.
4258 BBP'63	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1963, Ap. J., **138**, 375.
CW'67	Chincarini, G. & Warker, M. F. 1967, Ap. J., **149**, 487.
4278 O'60	Osterbrock, D. E. 1960, Ap. J., **132**, 323.
4486 Os'60	Osterbrock, D. E. 1960, Ap. J., **132**, 323.
WH'67	Warker, M. F. & Hayes, S. 1967, Ap. J., **149**, 481.
4621 KM'66	King, I. R. & Minkowsky, R. 1966, Ap. J., **143**, 1002.(L)
4631 de VV'63	Vaucouleurs, G. de. & Vaucouleurs, A. de. 1963, Ap. J., **137**, 363.
BBP'64	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1964, Ap. J., **140**, 1620. (Note)
Rb'68	Roberts, M. S. 1968, Ap. J., **151**, 117.
4656 Rb'68	Roberts, M. S. 1968, Ap. J., **151**, 117.
4697 KM'66	King, I. R. & Minkowsky, R. 1966, Ap. J., **143**, 1002.(L)
4736 BB'62	Burbidge, E. M. & Burbidge, G. R. 1962, Ap. J., **135**, 366.
CW'67	Chincarini, G. & Warker, M. F. 1967, Ap. J., **147**, 407.
4826 RBBP'65	Rubin, V. C., Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1965, Ap. J., **141**, 885.
5005 BBP'61	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1961, Ap. J., **133**, 814.
5055 BBP'60	Burbidge, E. M., Burbidge, G. R. & Prendergast, K. H. 1960, Ap. J., **131**, 282.
5128 BB'59	Burbidge, E. M. & Burbidge, G. R. 1959, Ap. J., **129**, 271.
5194 BB'64	Burbidge, E. M. & Burbidge, G. R. 1964, Ap. J., **140**, 1445.
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