THE ASTROPHYSICAL JOURNAL, 531:665–675, 2000 March 10

LUMINOSITY VERSUS PHASE-SPACE–DENSITY RELATION OF GALAXIES REVISITED

KEIICHI KODAIRA[1] AND NOBUNARI KASHIKAWA[1]
National Astronomical Observatory of Japan, 2-21-1 Osawa, Mitaka, Tokyo, 181-8588 Japan
AND
TORU MISAWA[2]
Department of Astronomy, School of Science, University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-0033 Japan
Received 1999 June 11; accepted 1999 November 26

ABSTRACT

We reexamined the correlation between the B_T magnitude and the phase-space–density parameter $w = (D_{25}^2 v_c)^{-1}$ of galaxies for the Virgo, the Coma, the Fornax, and the Perseus clusters in an effort to better understand the physical underpinning of the fundamental plane. A tight correlation ($B_T = a \log w + b$) common to different morphological types of galaxies (E, S0, S) was found for the Virgo and the Coma clusters, with $a = 1.87 \pm 0.10$ and 1.33 ± 0.11, respectively. An investigation using only E galaxies was made for the four clusters. The results indicated that the empirical linear relation might be common among the Coma, the Fornax, and the Perseus clusters, with the Virgo Cluster showing deviation. This relation, which is another way to project the fundamental plane, has an expression insensitive to the morphology and may be suitable for treating galaxies of different morphological types collectively.

Subject headings: galaxies: clusters: general — galaxies: kinematics and dynamics — galaxies: photometry — galaxies: structure

1. INTRODUCTION

Following the pioneering work by Brosche (1973), Watanabe, Kodaira, & Okamura (1985) applied the principal component analysis to an appropriate set of surface-photometric parameters of galaxies to identify significant independent variables that control the observed properties of galaxies of each morphological type. They found two principal components for S galaxies and one principal and one subordinate component for E galaxies. The two-dimensional surface that is spun by the two corresponding eigenvectors forms a plane in a multidimensional space of the surface-photometric parameters of galaxies. This plane was presented as the diameter versus surface-brightness diagram (DSBD) collectively for E, S0, and S galaxies by Kodaira, Okamura, & Watanabe (1983). More comprehensive analyses involving the spectroscopic parameters led to the concept of the fundamental plane (FP) for E galaxies by Dressler et al. (1987), Djorgovski & Davis (1987), and Faber et al. (1987).

The linear relations that are produced by nearly edge-on projections of this kind of planes toward certain directions had been recognized as the Faber-Jackson relation for E galaxies (Faber & Jackson 1976) and, similarly, as the Tully-Fisher relation for S galaxies (Tully & Fisher 1977), which were widely utilized to yield distance estimates. The D_n-σ relation for E galaxies (Dressler et al. 1987) was devised for the same application, based on the FP concept.

Another empirical relation was derived for E and S galaxies of the Virgo Cluster, by Kodaira (1989) as the luminosity versus phase-space–density (PSD) relation, not for the purpose of the distance estimate, but for better understanding of the physical meaning of the principal components defining galaxy properties. The PSD parameter was defined as $w \equiv (D^2 v)^{-1}$, where D was the photometric diameter and v was the central velocity dispersion (σ_0) for E galaxies or the rotation velocity represented by the H I line width (W_{20}) for S galaxies. Since quantity $(GD^2 v)^{-1}$ has a dimension of PSD of a single-particle ensemble in the virial equilibrium, w may represent a sort of an average PSD of a galaxy as a stellar ensemble.

Bender, Burstein, & Faber (1992) introduced the concept of the κ-space for E and S0 galaxies, a three-dimensional space that had coordinates along mass parameter (κ_1), mass to luminosity ratio parameter (κ_3), and $I_e^3 \times M/L$ parameter (κ_2), where I_e was the average surface brightness within the equivalent radius, r_e. The plane (κ_1, κ_2) in this κ-space was defined by the distribution of dynamically hot galaxies (Es and a part of S0s) in the Virgo Cluster and is close to being a face-on view of FP. Its nearly edge-on projection along the κ_2 axis was found to be $\kappa_3 = 0.15\kappa_1 + 0.36$, which was interpreted in the simple context of $L_B = M \times (L_B/M)$, with M being a kind of virial mass ($G^{-1} r_e \sigma_0^2$) under an inference of $M/L_B \propto M^{0.15}$. They suggested that the dynamically hot galaxies such as E and S0 might have been formed by dissipationless merging in keeping approximate relation $L \propto M$. This framework of the κ-space was later applied by Burstein et al. (1997) to S galaxies and, further, to other stellar systems such as groups and clusters of galaxies, and globular clusters (see also Djorgovski 1995).

As for S galaxies specifically, Chiba & Yoshii (1995) proposed a relation for disk galaxies to yield distance estimates by using the correlation of the radial scale length of the disk (r_d) with the specific combination of the central surface brightness (I_0) and the rotation velocity (v); $r_d \propto (v^2 I_0^{-1})^p$ with $p \sim 0.5$. Koda & Sofue (2000) have reported that they have found the plane equivalent to FP for S galaxies, which may degenerate to the luminosity versus specific angular momentum relation with the specific-angular-momentum parameter being Dv.

In the present paper we will reinvestigate the luminosity versus PSD relation by extending the sample to S0s in the Virgo Cluster, and to E, S0, and S galaxies in the Coma

[1] keiichi.kodaira@nao.ac.jp, kashik@zone.mtk.nao.ac.jp.
[2] misawatr@cc.nao.ac.jp.

Cluster, and finally to E galaxies in the Fornax and the Perseus clusters. This study is undertaken in an effort further to elucidate the physical nature of the interrelation, rather than to develop an operating method for getting the distances of galaxies. The findings are discussed in § 3 in connection to FP and the structure of the multidimensional space for galaxy parameters.

2. B_T MAGNITUDE VERSUS PHASE-SPACE–DENSITY PARAMETER RELATION

In the present study we adopt the total B magnitude, B_T, as the luminosity parameter, the diameter at $\mu_B = 25$ mag arcsec^{-2}, D_{25} in units of 1″, as the size parameter, and the axial ratio of S galaxies at $\mu_B = 25$ mag arcsec^{-2}, $R_{25} \equiv b/a$, in place of the parameters defined in the V band, V_{26}, D_{26}, and R_{26} in Kodaira (1989). The adopted velocity data are the central velocity dispersion, σ_0, for E and S0 galaxies, and the H I 21 cm line width at 20% level, W_{20}, for S galaxies. As for S galaxies, the observational data, in particular the velocity data, are subject to the inclination effects, and the present S sample is limited to those of $30° \leq i \leq 65°$ in order to minimize the uncertainties in the inclination corrections, where i is to be derived through the conventional formula using R_{25} from de Vaucouleurs et al. 1991 (hereafter RC3) as adopted in Kodaira & Watanabe (1988). The inclination-corrected velocity for S galaxies is defined as 0.5 $W_{20}/\sin i$. For simplicity, no higher order corrections to other observational data, including those for the inisotropy of σ_0 and the triaxiality for E and S0 galaxies, are applied. As the velocity parameter to define the phase-space–density parameter, w, we adopt the circular velocity, $v_c \equiv \sqrt{3}\sigma_0/1.1$ or $v_c \equiv 0.5W_{20}/\sin i$ in units of km s^{-1}, which corresponds to the flat rotation velocity in the gravitational potential of an isothermal dark halo of a galaxy (see Shimasaku 1993). The additional factor of $\sqrt{3}/1.1 = 1.57$ introduced here corresponds to the factor of about 1.4 or $\sqrt{2}$, which was found empirically by Whitmore & Kirshner (1981) and derived theoretically by Binney & Tremaine (1987). Kodaira (1989) also derived the same factor to convert σ_0 into $0.5W_{20}/\sin i$ for the disk galaxies of the earliest morphological types.

The least-square fitting of a regression line in a form of $B_T = a \log w + b$ with $w \equiv (D_{25}^2 v_c)^{-1}$ will be carried out separately for E ($T \leq -3$), S0 ($-2 \leq T \leq 0$), and S ($T \geq 1$) galaxies. Note that no corrections due to the difference in the distance of individual galaxies in each cluster are applied to B_T or D_{25}; the distance difference within a cluster is regarded as negligible compared to the cluster distance. Thus we are using B_T as a luminosity parameter. The sample galaxies are listed in Appendix A with their data using the numbers in catalogs (N = NGC, I = IC, U = UGC, and Z = Zwickey Catalog). Since the photometric and velocity data are adopted from various sources, their systematic trends are investigated in Appendix B. Significant ones should be taken into account in comparing the results of the correlation analyses.

2.1. *Virgo Cluster*

Kodaira (1989) carried out the regression-line analysis for E and S galaxies in the Virgo Cluster, while S0 galaxies are included in the present study. The sample galaxies and their data are given in Appendix A (Tables 4–6). The data have been adopted from Binggeli, Sandage, & Tammann (1985) (T, B_T, D_{25}), Davoust, Paturel, & Vauglin (1985) (σ_0), and RC3 (W_{20}). The resulting regression lines are shown in Figure 1*a*, and their parameters are given in Table 1 with the number of sample galaxies (n) and the correlation coefficient. We find tight correlation also for S0 galaxies and notice that by adopting the circular velocity, v_c, the regression lines almost coincide each other among the three types of galaxies. We note that the values of a for E and S galaxies in the present study are different from those in Kodaira

TABLE 1

REGRESSION LINE ANALYSES $B_T = a \log w + b$ FOR THE VIRGO CLUSTER

Type	a	b	n	Correlation Coefficient
E…….	1.964	25.56	22	0.9886
S0……	1.769	24.35	37	0.9234
S…….	1.879	25.07	40	0.8630

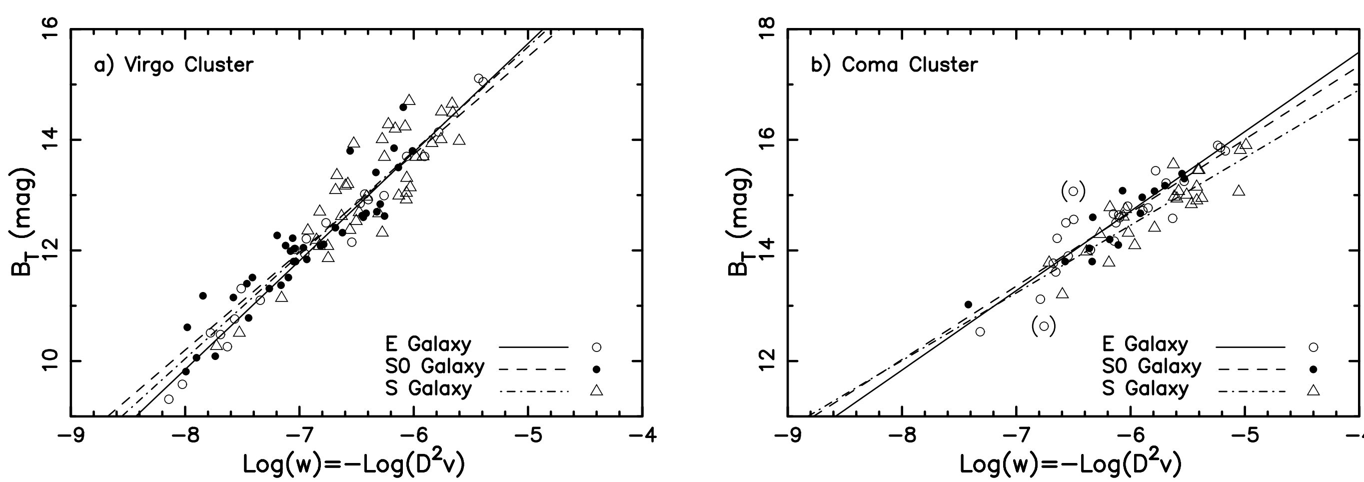

FIG. 1.—B_T magnitude vs. phase-space–density (w) relation. $w = (D_{25}^2 v_c)^{-1}$, with $v_c = \sqrt{3}\sigma_0/1.1$ for E and S0, and $v_c = 0.5W_{20}/\sin i$ for S galaxies. The coefficients of the regression lines are given in Tables 1, 2, and 3. The E regression lines for the Coma Cluster are for the case including the two deviating galaxies, which are marked by parentheses (see text). (*a*) Virgo Cluster (*b*) Coma Cluster: The data for S galaxies are plotted after the B_T transformation from Fukugita et al. (1991) to the RC3 system, based on the analysis in Appendix B. (*c*) E galaxies of the four clusters in the sample of Dressler et al. (1987): The regression lines are shifted corresponding to the distance of the Coma Cluster according to the distances, R, in Table 3.

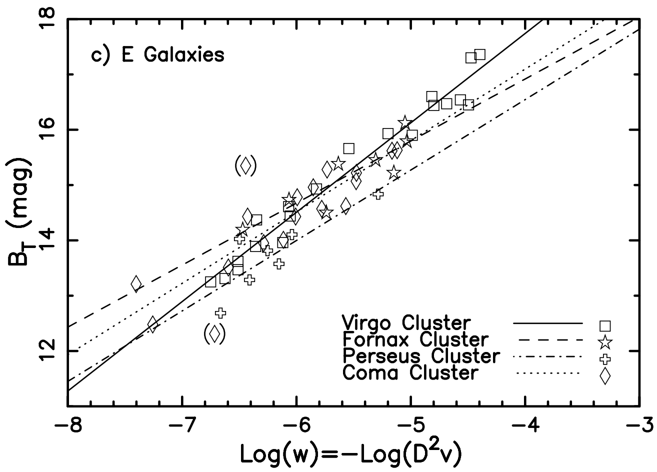

FIG. 1.—*Continued*

(1989) ($a = 1.50$ for E, 2.24 for S), largely because of the difference in the adopted photometric band.

By applying the Tully-Fisher relation, Yasuda, Fukugita, & Okamura (1997) suggested that S galaxies in the Virgo Cluster are distributed in a substantially extended region along the line of sight from 12 to 30 Mpc. Therefore, the present results, particularly for the Virgo S galaxies, need to be taken with caution although the B_T versus log w relation is rather insensitive to distance errors. We note that the faint S and S0 galaxies ($B_T \gtrsim 13.5$) show excess in the domain above the regression lines in Figure 1*a*. This may be partly due to the low accuracy of the photometric data for faint, small galaxies.

2.2. *Coma Cluster*

The sample galaxies for the Coma Cluster and their data are given in Appendix A (Tables 7–9), which have been adopted from RC3 (T for S, B_T for E and S0, D_{25}), Fukugita et al. (1991) (B_T and W_{20} for S), and Scodeggio, Giovanelli, & Haynes (1998a, 1998b) (T and σ_0 for E and S0). The stellar dispersion, σ_s, given in Scodeggio et al. (1998a, 1998b) was transformed into σ_0 as $\sigma_0 \equiv 1.1\sigma_s$ according to their empirical calibration. The S sample was adopted from Fukugita et al. (1991) who did not classify the subtypes. The type T from RC3 are not available for all of the adopted sample. The present S sample includes a galaxy of $T = -2$ (Z160067), which, however, does not show any clear deviation among the sample. The resulting regression lines are shown in Figure 1*b*, and the fitting parameters are given in Table 2.

In Figure 1*b* we notice that there are two E galaxies that show almost 3 σ deviations (N4874, N4872). The brighter one, N4874, is a CD galaxy ($T = -4$ in RC3) west to the other CD galaxy N4889 in the central part of the Coma Cluster, while the fainter one, N4872 ($T = -2$ in RC3), is located in the halo of N4874 with a few of other galaxies. The cause of the deviations might be a kind of photometric confusion. The fitting parameters for the E sample excluding these two deviators are given in Table 2. The regression line in Figure 1*b* is for the case including the two deviating galaxies. Since B_T in Fukugita et al. (1991) shows significant systematic deviation from that in RC3 (see Appendix B), the results for S galaxies that have been transformed into the RC3 system are given in Table 2 and are plotted in Fig. 1*b*).

We find again common distribution among E, S0, and S galaxies. The gradient of the regression line is $a = 1.33 \pm 0.11$ for the Coma Cluster, which is different from $a = 1.87 \pm 0.10$ for the Virgo Cluster. There seems to be a fine difference in the value of coefficient, a, among different types of galaxies in a cluster, indicating a tendency of a(E) $\gtrsim$ a(S0) $\gtrsim$ a(S), when the results for the Virgo S galaxies are taken into account with a lower weight.

2.3. *E Galaxies of the Virgo, Coma, Fornax, and Perseus Clusters*

In this section we confine our sample to E galaxies in the Fornax and the Perseus clusters, in addition to the Virgo and the Coma clusters. Their data are adopted from Dressler et al. (1987), except for D_{25}, which are adopted from RC3. The adopted samples and their data are given in

TABLE 2

REGRESSION LINE ANALYSES $B_T = a \log w + b$ FOR THE COMA CLUSTER

Type	a	b	n	Correlation Coefficient
E.......	1.437	23.33	26	0.8844
	1.404	*23.13*	*24*	*0.9309*
S0......	1.327	22.64	14	0.9217
S.......	1.223	21.79	25	0.8755

NOTE.—The data for E in italics are for the regression-line fitting without the two galaxies showing large deviation in Fig. 1*b*. The data for S are for the regression-line fitting after the transformation of B_T from the Fukugita et al. 1991 system to the RC3 system.

TABLE 3

REGRESSION LINE ANALYSES $B_T = a \log w + b$ FOR THE E GALAXIES OF THE FOUR CLUSTERS IN DRESSLER ET AL. 1987

Cluster	a	b	n	Correlation Coefficient	R (km s^{-1})
Virgo	1.616	24.20	20	0.9827	1333
Fornax	1.121	21.40	8	0.8879	1422
Perseus	1.273	21.64	7	0.8443	6050
Coma	1.291	22.26	18	0.8371	7461
	1.246	*21.98*	*16*	*0.9359*	

NOTE.—The data for the Coma cluster in italic are for the regression-line fitting without the two galaxies showing large deviation in Fig. 1*c*. R is the distance expressed as recession velocity in Faber et al. 1989.

Appendix A (Table 10), and the regression lines are shown in Figure 1*c*, with the fitting parameters given in Table 3. The resulting regression lines for E galaxies of the Virgo and the Coma clusters in the present subsection are different from those obtained in §§ 2.1 and 2.2. These differences are mostly caused by the fact that the samples and the data in this subsection are different from those adopted in the preceding subsections (see Appendices A and B). In the case of the Coma Cluster, the parameters for the fitting without the two deviating galaxies are indicated in italic in Table 3. The regression line for the Coma Cluster in Figure 1*c* is for the case including the two deviating galaxies. The gradient of the regression line is similar among the sample clusters ($a = 1.21 \pm 0.09$) with deviation of the Virgo Cluster ($a = 1.62$).

For convenience of comparison, the plots for the different clusters are overlapped in Figure 1*c* by applying the distance correction to each cluster relative to the Coma corresponding to the distance, *R*, in Table 3, which were given by Faber et al. (1989) based on the D_n-σ relation. We notice that the Perseus galaxies appear to deviate systematically from the others toward the lower side in Figure 1*c*. Another distance scale such as was proposed by Jerjen & Tammann (1993) or by Hudson et al. (1997) leads to a difference of the distance modulus between the Coma and the Perseus clusters $\Delta(m - M) = 0.57$ or 0.72, respectively, in contrast to $\Delta(m - M) = 0.45$ in Table 3, improving the overlapping of the galaxies of the two clusters in Figure 1*c*.

We also notice that the upward deviator on the bright end in Figure 1*c* is the third brightest galaxy in the present sample of the Coma Cluster in Table 10, N4839. This galaxy is classified as S0 in Table 8 and is located at the center of the southwest subcluster. Recent X-ray observation from *ASCA* (see Watanabe et al. 1999) has revealed that this subcluster may have a separate halo structure from the main halo of the Coma Cluster. The deviation of N4839 in Figure 1*c* might be related to this fact.

3. SUMMARY AND DISCUSSION

Although the analyzed sample is limited, we may draw some inferences as follows.

For the Virgo and the Coma clusters:

1. The B_T versus log *w* relation ($B_T = a \log w + b$) is valid for a wide range of galaxy types, E, S0, and S. The coefficient *a* appears to show a tendency of $a(\mathrm{E}) \gtrsim a(\mathrm{S0}) \gtrsim a(\mathrm{S})$.

For E galaxies of the Virgo, the Fornax, the Perseus, and the Coma clusters:

2. The coefficient *a* is almost common among the clusters, with the Virgo Cluster showing deviation.

In addition we note as follows:

3. The coefficients of the regression lines are depending upon the data sources as Appendix B indicates. One must be careful in discussing the physical meaning of the empirical relations using the nominal values of the fitting coefficients.

4. The values of the coefficients of the regression lines depend upon the adopted photometric band. Some of the apparent properties of the empirical relations as are pointed out above may be subject to modification if photometric bands other than the *B* are applied.

In summary, we have found that the B_T versus log *w* relation can be regarded as a tight empirical relation that is almost common to a wide range of galaxy types in each cluster. The relation might be common for majority of nearby clusters, though the Virgo Cluster may show possible deviation. Since the Virgo Cluster is the nearest among the sample clusters and is suspected to have a widespread complicated structure, further studies are needed to confirm its actual deviation.

The relation, $B_T = a \log w + b$, is one of the nearly edge-on projections of FP and almost equivalent to the relation $\kappa_3 = \alpha\kappa_1 + \beta$ in the κ-space of Bender et al. (1992), as is shown below. Both can be transformed into the relation in which the effective radius (r_e) is expressed as a function of distance-independent parameters, the velocity (v), and the mean surface brightness within r_e (I_e). The κ relation is rewritten by the definition of κ_1 and κ_3 as

$$\log r_e = \gamma \log v + \delta \log I_e + \text{const.}, \quad (1)$$

with $\gamma \equiv 2(2 - \sqrt{6}\alpha)/(2 + \sqrt{6}\alpha)$ and $\delta \equiv -2/(2 + \sqrt{6}\alpha)$, while the B_T versus log *w* relation is transformed into

$$\log r_e = p \log v + q \log I_e + p \log \{f^{-1}(AI_{25}/I_e)\} + \text{const.}, \quad (2)$$

with $p \equiv a/(5 - 2a)$, $q \equiv 2.5/(2a - 5)$, and I_{25} being the surface brightness corresponding to $\mu = 25$ mag arcsec^{-2}. In deriving equation (2), we have assumed that the surface-brightness profile of a galaxy along the major axis is a monotonous function, $I(r) = I_0\, f(r/r_0)$, with I_0 and r_0 being the representative surface brightness and radial scale; $f^{-1}(I_{25}\, A/I_e) = r_{25}/r_0$ with definition of $A \equiv I_e/I_0$. If we stipulate $\gamma = p$, the difference Δ between the right terms of the two expressions (1) and (2) becomes

$$\Delta \equiv p[-0.75 \log I_0 + \log \{f^{-1}(I_{25}/I_0)\}] + \text{const.}, \quad (3)$$

with *p* being the same coefficient as in equation (2) and of O(1) for the range of *a* obtained in the present paper. As the value of α is 0.15 for E galaxies and larger than this for S galaxies (say 0.30) (see Burstein et al. 1997), the condition $\gamma = p$ leads to $a = 1.83$ for E and a value slightly smaller than that for S (1.60), which are comparable to the *a* values found in the present paper. The term in the square brackets in equation (3) varies monotonously and its absolute value remains almost constant at 0.93 ± 0.23 for $18.5 \lesssim \mu_{0,B} \lesssim 22.5$ in the case of $f(x) = \exp\{-x^{1/4}\}$, and at 0.60 ± 0.30 for $19.5 \lesssim \mu_{0,B} \lesssim 23.5$ in the case of $f(x) = \exp\{-x\}$. These ranges of $\mu_{0,B}$ for E and S galaxies are estimated from the *V*-band surface photometry (Kodaira, Watanabe, & Okamura 1986; Kodaira et al. 1990) by assuming $B-V = 1.0$ and 0.6 for E and S, respectively. In conclusion, the B_T versus log *w* relation is almost equivalent to the κ_1 versus κ_3 relation as a nearly edge-on projection of FP and has an expression insensitive to the difference of the morphological type of galaxies. The concept of PSD, therefore, may be suitable for collective study of galaxies in connection to FP.

When we regard a galaxy to be a relaxed dynamical ensemble of stellar particles imbedded in a relaxed dark halo, the global properties of the galaxy and the dark halo may well be characterized by their mass and the average PSD. The physical process involved in the galaxy formation and evolution such as mass loss, merging, or dissipation may ideally be investigated on the mass versus average PSD plane. In practice, however, we directly observe not the mass but the luminosity for stars, and indirectly estimate the effective virial mass including both stars and dark halo. The observed luminosity in a certain photometric band, L_λ, is related to the stellar mass, m_s, with a mass/luminosity ratio $(m_s/L_\lambda) = (m_s/L)(L/L_\lambda)$, which is generally dependent on the evolution of galaxies. As we are mainly concerned with normal and giant galaxies at the present epoch, m_s approximately represents the barion mass of a galaxy. When we take the total mass, including the mass of the dark halo, m_T, into account, we have to consider a relation $L_\lambda = m_T(m_s/m_T)(L/m_s)(L_\lambda/L)$. When we study galaxies collectively on a mass versus PSD plane, we need more detailed consideration about the factor m_s/m_T, which may be significantly affected by the formation and the initial-phase evolution of galaxies.

The mass m_T and PSD of the total system are better investigated with help of X-ray data. Fritsch & Buchert (1999) introduced a concept of FP for clusters of galaxies using the optical and X-ray data. The involved parameters are the total B-band luminosity L_O, the total X-ray luminosity L_X, and the half-light radii R_O(optical) and R_X(X-ray) of each cluster. Their nearly edge-on projection of the cluster FP is represented by relation $\log L_O = 0.84 \log R_O + 0.21 \log L_X + \text{const.}$, and the deviation from the relation is suggested to be an indication of the unrelaxed dynamical system. If there are differences in the large-scale structure of the dark halo embedding a cluster of galaxies, they may have consequences upon the local structure of the dark halo of each member galaxies, leading to differences in the B_T versus $\log w$ relation among different clusters, such as is suspected for the Virgo Cluster. The results of the present study indicate that the relaxed clusters may show the common B_T versus $\log w$ relation. It is desirable to include also the optical spectroscopic parameters in this kind of cluster studies. Using future X-ray data of higher resolution, we may do similar studies of individual galaxies, involving both optical and X-ray data to better understand the physical underpinning of the galaxy FP.

The authors acknowledge that Kazuhiro Shimasaku and Naoki Yasuda kindly made their observational data available to the present analyses. They wish to thank anonymous referee for his constructive advice to clarify the purpose of this paper and to present the mathematical connection of the PSD relation to the FP concept.

APPENDIX A

DATA LIST

The sample galaxies and their data for the present regression-line analyses are summarized in the following Tables 4–10.

TABLE 4

VIRGO CLUSTER E GALAXIES

Galaxy	T	B_T	$\log D_{25}$	$\log v_c$	$-\log w$
N4168	−5	12.21	2.23	2.48	6.94
N4239	−5	13.70	2.03	2.01	6.06
N4261	−5	11.31	2.37	2.77	7.51
N4318	−5	14.14	1.79	2.21	5.78
N4365	−5	10.51	2.57	2.64	7.78
N4374	−5	10.26	2.48	2.67	7.63
N4387	−5	13.02	2.05	2.33	6.43
N4434	−5	12.99	1.98	2.30	6.26
N4458	−5	12.92	2.08	2.24	6.40
N4464	−5	13.70	1.84	2.23	5.90
N4467	−5	15.05	1.63	2.14	5.39
N4472	−5	9.31	2.73	2.69	8.14
N4473	−5	11.10	2.43	2.49	7.34
N4478	−5	12.15	2.09	2.37	6.54
N4486B	−5	15.11	1.46	2.52	5.43
N4486	−5	9.58	2.64	2.75	8.02
N4550	−5	12.50	2.32	2.13	6.77
N4551	−5	12.85	2.08	2.31	6.47
N4564	−5	12.02	2.27	2.50	7.04
N4621	−5	10.76	2.49	2.59	7.57
N4636	−5	10.48	2.57	2.56	7.69
N4660	−5	11.94	2.22	2.52	6.95

TABLE 5

VIRGO CLUSTER S0 GALAXIES

Galaxy	T	B_T	log D_{25}	log v_c	$-$ log w
N4200	−2	13.85	2.03	2.12	6.17
N4259	−2	14.59	1.84	2.42	6.09
N4262	−2	12.41	2.12	2.45	6.69
N4267	−2	11.80	2.32	2.41	7.05
N4281	−2	12.27	2.27	2.66	7.20
N4292	0	13.50	2.10	1.94	6.13
N4296	−2	13.80	2.03	2.50	6.56
N4324	−1	12.60	2.17	2.11	6.44
N4339	−2	12.32	2.15	2.33	6.62
N4340	−1	12.03	2.39	2.27	7.04
N4350	−2	11.99	2.28	2.52	7.08
N4371	−2	11.80	2.37	2.30	7.03
N4377	−2	12.67	2.04	2.34	6.42
N4379	−2	12.62	2.10	2.06	6.26
N4382	−2	10.09	2.63	2.48	7.74
N4406	−2	10.06	2.65	2.60	7.90
N4417	−2	12.08	2.34	2.14	6.81
N4429	−2	11.15	2.52	2.54	7.58
N4435	−2	11.84	2.25	2.44	6.93
N4442	−2	11.40	2.44	2.58	7.46
N4459	−2	11.37	2.36	2.45	7.16
N4461	−1	12.09	2.35	2.43	7.12
N4468	0	13.80	1.96	2.10	6.01
N4477	−2	11.31	2.38	2.51	7.26
N4489	−2	12.84	2.12	2.06	6.29
N4526	−2	10.61	2.64	2.71	7.98
N4528	−2	12.70	2.04	2.25	6.32
N4552	−2	10.78	2.40	2.65	7.45
N4578	−2	12.22	2.34	2.38	7.06
N4596	−1	11.51	2.37	2.36	7.10
N4598	−2	13.41	2.08	2.18	6.33
N4608	−2	12.05	2.28	2.41	6.97
N4638	−2	12.11	2.23	2.33	6.79
N4649	−2	9.81	2.64	2.72	7.99
N4733	−2	12.63	2.15	2.16	6.45
N4754	−2	11.51	2.45	2.52	7.41
N4762	−2	11.18	2.72	2.41	7.85

TABLE 6

VIRGO CLUSTER S GALAXIES

Galaxy	T	B_T	log D_{25}	R_{25}	log v_c	− log w
I3021	1	14.70	2.04	0.62	1.96	6.04
I3033	5	14.65	1.88	0.66	1.91	5.66
I768	5	14.28	2.00	0.50	2.23	6.22
N4165	1	14.20	1.96	0.66	2.25	6.16
I769	3	13.17	2.18	0.68	2.24	6.60
N4193	5	13.20	2.14	0.51	2.30	6.58
N4212	5	11.86	2.26	0.62	2.23	6.75
N4237	5	12.53	2.14	0.65	2.23	6.50
N4246	5	13.36	2.18	0.54	2.32	6.67
I776	6	14.01	2.11	0.60	2.06	6.28
N4260	1	12.70	2.20	0.50	2.43	6.82
N4273	5	12.37	2.14	0.65	2.28	6.56
N4298	5	12.08	2.28	0.56	2.20	6.75
N4334	2	13.93	2.16	0.48	2.21	6.53
I3259	5	14.24	2.03	0.55	2.02	6.08
N4353	5	13.94	1.89	0.63	2.07	5.84
N4351	5	13.04	2.09	0.68	1.89	6.06
N4370	1	13.69	1.99	0.52	2.28	6.26
N4376	6	13.69	2.00	0.62	1.98	5.98
N4380	2	12.36	2.35	0.55	2.23	6.93
N4405	5	12.99	2.08	0.65	1.97	6.13
N4413	4	12.97	2.17	0.65	2.08	6.41
I3356	9	14.49	2.00	0.59	1.66	5.69
N4420	5	12.67	2.13	0.48	2.05	6.31
N4424	1	12.32	2.35	0.50	1.58	6.28
N4451	5	13.31	1.95	0.65	2.17	6.06
I3414	5	13.70	2.01	0.60	1.90	5.92
N4480	3	13.09	2.20	0.51	2.29	6.68
N4498	5	12.62	2.29	0.54	2.06	6.63
I797	5	14.01	1.88	0.69	2.00	5.76
N4501	4	10.27	2.62	0.54	2.49	7.73
N4535	5	10.51	2.61	0.71	2.31	7.53
I3517	7	14.51	1.97	0.63	1.82	5.79
I3521	9	13.98	1.85	0.69	1.91	5.63
N4567	5	12.08	2.25	0.68	2.33	6.83
N4595	5	12.92	2.04	0.65	1.99	6.07
N4606	1	12.69	2.22	0.50	2.04	6.48
N4630	4	13.14	2.01	0.71	2.01	6.03
N4639	3	12.19	2.24	0.68	2.37	6.85
N4654	5	11.14	2.45	0.58	2.26	7.16

TABLE 7

COMA CLUSTER E GALAXIES

Galaxy	T	B_T	log D_{25}	log v_c	$-$log w
N4789	−5	13.12	2.06	2.67	6.79
N4807	−5	14.50	1.78	2.57	6.13
N4872	−5	13.90	1.94	2.67	6.55
N4841A	−5	13.77	2.01	2.66	6.68
N4840	−5	14.72	1.63	2.64	5.89
N4841B	−5	13.61	2.03	2.60	6.65
N4850	−5	15.22	1.60	2.49	5.69
N4860	−5	14.56	1.92	2.66	6.50
I3957	−5	15.80	1.38	2.41	5.17
I3960	−5	15.90	1.38	2.48	5.24
I3959	−5	15.25	1.50	2.53	5.53
N4864	−5	14.58	1.55	2.54	5.63
N4867	−5	15.44	1.60	2.58	5.78
N4865	−5	14.64	1.75	2.61	6.10
N4869	−5	14.77	1.65	2.55	5.85
N4872[a]	−5	15.07	1.97	2.56	6.50
N4874[a]	−5	12.63	2.07	2.62	6.76
N4881	−5	14.59	1.77	2.56	6.10
N4886	−5	14.80	1.81	2.41	6.02
N4889	−5	12.53	2.24	2.84	7.32
I4021	−5	15.86	1.39	2.44	5.21
N4895	−5	14.22	2.04	2.57	6.64
N4908	−5	14.66	1.80	2.55	6.15
I4051	−5	14.17	1.78	2.59	6.14
N4931	−5	14.50	2.01	2.55	6.57
N4957	−5	14.01	1.86	2.63	6.35

[a] Galaxies showing a large deviation in Fig. 1*b*.

TABLE 8

COMA CLUSTER S0 GALAXIES

Galaxy	T	B_T	log D_{25}	log v_c	$-$log w
N4798	−2	14.20	1.86	2.47	6.18
N4816	−2	13.80	1.89	2.56	6.34
N4839	−2	13.02	2.38	2.66	7.42
Z160065	−2	14.10	1.80	2.51	6.11
N4859	−2	14.60	1.88	2.57	6.33
N4871	−2	15.17	1.62	2.46	5.70
N4873	−2	15.07	1.69	2.41	5.79
N4876	−2	15.39	1.52	2.51	5.55
I4041	−2	15.30	1.60	2.33	5.53
I4045	−2	14.96	1.67	2.56	5.90
N4919	−2	15.08	1.81	2.45	6.07
N4923	−2	14.67	1.68	2.56	5.91
N4926	−2	14.04	1.85	2.66	6.36
N4944	−2	13.80	2.02	2.54	6.57

TABLE 9

COMA CLUSTER S GALAXIES

Galaxy	T	B_T	log D_{25}	R_{25}	log v_c	− log w
I821	4	14.32	1.83	0.85	2.36	6.02
I826	...	14.90	1.60	0.76	2.22	5.42
I842	...	14.61	1.85	0.50	2.37	6.06
I854	...	14.94	1.68	0.58	2.24	5.60
I3913	...	15.45	1.63	0.63	2.15	5.41
I4210	...	15.07	1.67	0.68	2.24	5.58
N4735	...	15.15	1.54	0.67	2.35	5.42
N4921	2	13.20	2.17	0.86	2.26	6.60
N4966	...	14.09	1.78	0.55	2.41	5.96
N4979	...	14.41	1.80	0.60	2.19	5.79
N5000	4	13.78	2.01	0.77	2.17	6.19
N5032	3	13.78	2.10	0.54	2.52	6.71
N5041	6	13.98	2.00	0.79	2.39	6.39
U7890	...	15.00	1.60	0.71	2.31	5.51
U7978	6	14.75	1.87	0.57	2.31	6.04
U8229	3	14.30	1.93	0.66	2.41	6.27
U8259	...	14.78	1.92	0.46	2.34	6.18
Z130006...........	...	14.95	1.56	0.81	2.26	5.38
Z130008...........	...	15.06	1.41	0.73	2.24	5.05
Z159090...........	...	15.45	1.73	0.50	1.94	5.40
Z159101...........	...	15.90	1.40	0.83	2.19	4.99
Z160067...........	−2	15.81	1.40	0.74	2.24	5.04
Z160080...........	...	14.84	1.72	0.79	2.03	5.47
Z160127...........	...	15.56	1.75	0.65	2.13	5.63
Z160139...........	...	14.97	1.76	0.53	2.10	5.62

TABLE 10

E GALAXIES IN THE VIRGO, FORNAX, PERSEUS AND COMA CLUSTERS IN THE SAMPLE OF DRESSLER ET AL. 1987

Cluster	Galaxy	B_T	log D_{25}	log v_c	− log w
Virgo	N4239	13.56	2.03	1.91	5.97
	N4365	10.63	2.62	2.61	7.85
	N4374	10.15	2.59	2.68	7.85
	N4387	12.86	2.03	2.26	6.31
	N4406	9.88	2.73	2.55	8.01
	N4434	12.80	1.93	2.21	6.06
	N4458	12.73	2.02	2.15	6.18
	N4464	13.62	1.81	2.28	5.89
	N4472	9.51	2.79	2.67	8.25
	N4473	11.19	2.43	2.47	7.32
	N4478	12.16	2.06	2.37	6.48
	N4486	9.57	2.70	2.73	8.12
	N4489	12.71	2.01	1.98	5.99
	N4551	12.70	2.04	2.22	6.29
	N4552	10.87	2.49	2.59	7.56
	N4564	11.92	2.33	2.38	7.04
	N4621	10.70	2.51	2.54	7.55
	N4636	10.22	2.56	2.50	7.62
	N4649	9.73	2.65	2.71	8.01
	N4660	12.19	2.12	2.46	6.70
Fornax	N1339	12.52	2.06	2.38	6.49
	N1344	11.13	2.56	2.39	7.51
	N1374	11.85	2.17	2.41	6.75
	N1379	11.62	2.16	2.27	6.59
	N1399	10.59	2.62	2.67	7.91
	N1404	10.90	2.30	2.58	7.18
	N1427	11.78	2.34	2.40	7.07
	I2006	12.19	2.10	2.28	6.47
Perseus	N1260	13.65	1.84	2.55	6.22
	N1270	13.57	1.95	2.78	6.68
	N1272	12.23	2.09	2.67	6.85
	N1274	14.38	1.50	2.47	5.47
	N1278	12.83	1.97	2.66	6.59
	N1282	13.36	1.93	2.58	6.44
	I310	13.12	1.89	2.56	6.34
Coma	N4839	13.21	2.38	2.65	7.40
	N4926	13.95	1.85	2.59	6.29
	I3959	15.07	1.50	2.48	5.48
	I3957	15.63	1.38	2.36	5.12
	N4869	14.57	1.65	2.48	5.78
	N4876	15.22	1.52	2.44	5.48
	N4874[a]	12.31	2.07	2.58	6.72
	N4872[a]	15.35	1.97	2.51	6.44
	N4867	15.28	1.60	2.54	5.73
	I4051	14.01	1.78	2.56	6.11
	N4889	12.48	2.24	2.78	7.26
	N4886	14.78	1.81	2.38	5.99
	N4864	14.62	1.55	2.47	5.57
	I4045	14.96	1.67	2.52	5.85
	I4021	15.62	1.39	2.39	5.16
	N4860	14.43	1.92	2.59	6.43
	N4881	14.43	1.77	2.47	6.01
	N4841A	13.51	2.01	2.58	6.60

[a] Galaxies showing a large deviation in Fig. 1*c*.

APPENDIX B

COMPARISON OF DATA SOURCES

The data used in the present study are adopted from various sources and may be subject to systematic anomalies bound to the individual sources. In order to make the comparisons among the different types of galaxies and among the different clusters of galaxies, we try to find out the formula of transformation among the data from the different sources. The formula of the transformation are derived by the regression-line analyses ($Y = AX + C$) using the data from RC3 (B_T, log D_{25}, log W_{20}) and from Dressler et al. (1987) (log σ_0) as the standard references (X). The resulting coefficients (A and C) are given in Table 11 with the number of sample (N) and the correlation coefficient. The numbers in the sample in Table 11 (N) are different from those in Tables 1, 2, and 3 (n), because we use all galaxies available in common to the respective two data sources in question. An outstanding deviation is found for B_T in Fukugita et al. (1991), and its transformation to the RC3 system is applied in § 2.2. No other transformations are applied, for they do not affect the essential features of the present analyses.

TABLE 11

REGRESSION LINE ANALYSES $Y = AX + C$ FOR THE TRANSFORMATION AMONG DIFFERENT DATA SOURCES

	B_T			log D_{25}	log W_{20}	log σ_0	
X	RC3	RC3	RC3	RC3	RC3	DLB	DLB
Y	BST	DLB	FOT	BST	FOT	DPV	SGH
N	93	38	17	99	40	20	18
A	0.9615	0.9693	0.8003	0.8947	0.9117	0.9006	0.9772
C	0.4685	0.3183	2.7307	0.1680	0.2376	0.2705	0.1069
Correlation Coefficient......	0.9870	0.9979	0.9489	0.9769	0.9463	0.9851	0.9827

NOTE.—RC3: de Vaucouleurs et al. 1991; DLB: Dressler et al. 1987; BST: Binggeli et al. 1985; FOT: Fukugita et al. 1991; DPV: Davoust et al. 1985; SGH: Scodeggio et al. 1998a, 1998b.

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