THE ASTROPHYSICAL JOURNAL, 265:632–642, 1983 February 15

THE $L \propto \sigma^n$ RELATION FOR THE BULGE COMPONENTS OF DISK GALAXIES

JOHN KORMENDY[1]
Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics
AND
GARTH ILLINGWORTH
Kitt Peak National Observatory[2]
Received 1982 March 12; accepted 1982 August 2

ABSTRACT

We reexamine the observed correlation between the luminosities L of galaxy bulges and their central velocity dispersions σ. Particular emphasis is given (i) to the use of accurate bulge-to-disk ratios, (ii) to a choice of bulges which have stellar populations like those in elliptical galaxies, (iii) to an exploration of possible differences between bulges in unbarred (SA) and barred (SB) galaxies, and (iv) to effects on the adopted distances of a Virgocentric flow field. Eleven new velocity dispersion measurements are given. These are used together with published data for a comparison of the central structure of 48 bulges with absolute magnitudes $-18.5 \geqslant M_B \geqslant -22$ and 43 ellipticals with magnitudes $-20 \geqslant M_B \geqslant -23$ ($H_0 = 50$ km s^{-1} Mpc^{-1}). The results are as follows.

1. The bulges of unbarred galaxies with negligible central disk contributions have essentially the same $L \propto \sigma^n$ relation as elliptical galaxies. We infer that the central dynamics and stellar content of bulges and ellipticals are similar, although the global dynamics differ in that rotation is more important in bulges than in bright ellipticals.
2. Unbarred S0 and Sa-bc galaxies have the same $L \propto \sigma^n$ relation.
3. One-third of the bulges of SB0-bc galaxies studied here have significantly smaller central dispersions than SA bulges of the same luminosity. We interpret this result as being consistent with the hypothesis that the bulges of many SB galaxies have been augmented by disk material transported inward by the bar.
4. At a given luminosity the bulges of nearly edge-on galaxies are observed to have larger velocity dispersions than bulges which are more face-on.

Our results extend recent conclusions of Whitmore, Kirshner, and Schechter that some bulges have lower central dispersions than ellipticals of similar luminosity. Evidently their sample included bulges which were contaminated by disk material and SB bulges which appear to be more disklike than the bulges of unbarred galaxies.

Subject headings: galaxies: evolution — galaxies: internal motions — galaxies: stellar content — galaxies: structure

I. INTRODUCTION

The observation that the luminosity L of an elliptical galaxy is related to its central velocity dispersion as $L \propto \sigma^n$, $n \approx 4$ (Faber and Jackson 1976) has well-known implications for the structure of elliptical galaxies. If $n = 4$, and if all ellipticals have the same characteristic surface brightness, then all ellipticals also have the same mass-to-light ratio M/L (Sargent *et al.* 1977). The observation by Whitmore, Kirshner, and Schechter (1979, hereafter WKS) and by Whitmore and Kirshner (1981, hereafter WK) that the bulge components of disk galaxies have a different $L \propto \sigma^n$ relation than ellipticals, with smaller σ at a given L, therefore implies that there exist differences in the structure or stellar populations of these components. Three other recent developments point to such differences. First, the brightness distributions of bulges and ellipticals are often recognizably different (Kormendy 1980; Boroson and Kormendy 1982). Some of this difference may be intrinsic, and some due to the potential of the disk. Second, the dynamics of bulges are dominated by rotation (Illingworth and Schechter 1982; Kormendy and Illingworth 1982, hereafter KI), while the structure of ellipticals is more varied and is often controlled by velocity anisotropies (see Illingworth 1981 for a review; contrast Davies *et al.* 1983). Finally, the bulges of barred galaxies show further differences from ellipticals: many

[1]Visiting Astronomer at Kitt Peak National Observatory.
[2]Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

are triaxial, like bars[3] (Kormendy and Koo 1982), and these rotate even more rapidly than SA bulges (Kormendy 1982*a*). All of these results refer to *global* dynamical differences between bulges and ellipticals. The $L \propto \sigma^n$ relation contains information about the *central* dynamics and stellar content. This may not directly be affected by the global dynamics. The purpose of this paper is to compare the $L \propto \sigma^n$ relations of bulges and elliptical galaxies to look for differences in central structure which may correspond to the global differences outlined above.

Specifically, we reexamine the observed correlation between $\log \sigma$ and the absolute magnitude M_B of the bulge, with the following points in mind.

1. Many of the "bulges" studied in WKS and in WK clearly contain Population I material. These do not resemble the features which have given rise to the general belief that bulges and ellipticals are similar. What is the $L \propto \sigma^n$ relation for a sample of bulges, like those of M31 and M81, which have as much as possible been selected to be free of disk material?

2. The bulges of many barred galaxies seem to be surprisingly disklike in their photometric and kinematic properties and in their tendency to show recent star formation. Kormendy (1982*a*) has found that many SB bulges appear to rotate more rapidly than dynamical models of rotationally flattened spheroids with isotropic residual velocities. He suggests that this may result from the inward transport of disk gas by the bar. The resulting star formation may add to the preexisting bulge an additional distribution of stars with high central concentrations but with disklike dynamics. Are the central velocity dispersions correspondingly smaller in barred galaxies than in unbarred galaxies?

3. Published studies of bulge dispersions have concentrated on providing the largest possible galaxy samples. As a result they have been forced to derive some ratios B/T of bulge-to-total light from rather poor photometry. Here we will use only well determined values of B/T.

4. Recent discussions of the velocity field of the local supercluster show that there are significant infall motions toward the Virgo Cluster (Schechter 1980; Tonry and Davis 1981; Aaronson *et al.* 1982). Neglect of this Virgocentric flow can introduce systematic errors into the $L \propto \sigma^n$ relations derived for samples of galaxies which have different distributions of redshift or position on the sky. Therefore we derive two sets of $L \propto \sigma^n$ relations, one assuming a uniform Hubble expansion, and the other using a plausible linear model for the Virgocentric flow.

[3] Even if bars and ellipticals are both triaxial, their dynamics are very different (see Kormendy 1981 for a review). Unlike ellipticals, bars are essentially as flat as disks. Also their stellar rotation velocities and their pattern angular velocities are both much higher than corresponding values in ellipticals.

The next section lists 11 new measurements of central velocity dispersions, nine of them in SB0 galaxies. These together with published data on a further 80 galaxies provide a sample large enough for an initial investigation of the above questions.

II. THE GALAXY SAMPLE: DATA ON BULGE MAGNITUDES AND CENTRAL DISPERSIONS

Tables 1 and 2 summarize the available data on magnitudes and central velocity dispersions of disk-galaxy bulges. All spiral and S0 galaxies are included for which σ is known and for which sufficiently accurate B/T values are available. New measurements are weighted means for radii $r \lesssim 2''$ of dispersion profiles given in Kormendy (1982*a*, *b*, *c*) and in Illingworth and Kormendy (1982). The observations were made with the High Gain Video Spectrometer and the KPNO 2.1 m and 4 m telescopes. The instrumental velocity dispersion was ~ 100 km s^{-1} for NGC 936, 2859, 2950, 3945, 4340, and 4596, and 60 km s^{-1} for NGC 488, 936, 1023, 4371, 7457, and 7743. Dispersions were derived with a Fourier-quotient program. Details of the measurement and reduction procedures are given in the above papers and in KI.

The dispersions in Tables 1 and 2 have been measured with round or rectangular apertures centered on the nucleus and $2''$–$6''$ in radius (typically hundreds of parsecs). We assume that contamination from any separate nuclear component like that in M31 is small. Two arguments suggest that this is so. First, available velocity dispersion profiles of bulges and ellipticals generally do not show large gradients indicative of separate nuclear features. Second, the nucleus of M31 would not contribute significantly to measurements made with apertures similar in size to those used for the rest of the sample ($2''$–$6''$ for a Virgo Cluster galaxy is equivalent to $40''$–$120''$ at M31). In fact the dispersion in the nucleus is difficult to determine even in M31 (Whitmore 1980). Our adopted dispersion for M31 applies to the bulge outside the nucleus but still within one core radius of the center.

Adopted velocity dispersions in Tables 1 and 2 are unweighted means of all published measurements. Values in parentheses are not used. Some of these are preliminary data listed in WK but not yet corrected for instrumental resolution effects. Tonry and Davis (1981, hereafter TD) remark that flexure and other effects produce occasional large errors in their measurements; when their values or other authors' values disagree strongly with the remainder of the data, the discrepant values are discarded. Also, the present measurements made at 60 km s^{-1} instrumental dispersion are given high weight. Apart from this editing we have used the available data as published; both published tests and our own show that different papers are on similar dispersion scales. Nevertheless, there are a number of

TABLE 1

DISPERSIONS AND ABSOLUTE MAGNITUDES FOR SPIRAL GALAXIES

Galaxy NGC (1)	Type (2)	Dist. (Mpc) H_0=50 (3)	Dist. (Mpc) w=300 (4)	B/T (5)	Source (6)	M_T (7)	M_B H_0=50 (8)	M_B w=300 (9)	Adopted σ (km s^{-1}) (10)	Adopted $\varepsilon(\sigma)$ (km s^{-1}) (11)	Sources of σ WKS+WK (km s^{-1}) (12)	Sources of σ Other (km s^{-1}) (13)
224	SAb	0.65	0.65	0.24	1	-20.11	-18.57	-18.57	148	8	151±16	145±10[P78]
488	SAb	46.7	33.5	0.17	2	-22.42	-20.52	-19.80	194	(10)	(234)	194±10[IK]
2655	SAB0/a	32.5	28.8	0.55	2	-22.00	-21.36	-21.10	162	(25)	162±25	...
2775	SAab	19.3	20.1	0.55	2	-20.49	-19.84	-19.93	162	...	162	...
2841	SAb	11.9	12.0	0.24	2	-20.53	-18.99	-19.00	202	...	202	...
3031	SAab	3.6	3.6	0.21	3	-20.31	-18.61	-18.61	161	9	157±17	165±10[P78]
3351	SBb	15.4	11.0	0.2	14	-20.63	-18.88	-18.14	101	(16)	101±16	...
3368	S(B)ab	15.4	10.8	0.44	2	-21.03	-20.12	-19.34	115	(17)	115±17	...
4378	SAa	25.4	19.8*	0.5	4	-19.95	-19.20	-18.66*	164	(20)	164±20	...
4548	SBb	21.7	20.3	0.15	5,6	-20.90	-18.84	-18.70	155	(14)	155±14	...
4594	SAa	19.3	16.7*	0.92	7	-22.39	-22.30	-21.98*	258	15	260±20	256±22[KI]
4725	S(A)ab	18.7	20.0*	0.19	2	-21.59	-19.77	-19.92*	166	(15)	166±15	...
4736	S(B)ab	6.8	4.8	0.22	2	-20.53	-18.88	-18.09	134	(17)	134±17	...
7217	SAab	24.5	18.7	0.28	2	-21.39	-20.01	-19.42	185	(18)	185±18	...
7331	SAbc	22.0	16.7	0.52	2	-21.85	-21.15	-20.54	176	(18)	176±18	...

NOTES TO TABLES 1 AND 2

Col. (2), a simplified morphological type, from the RC2. Parentheses indicate that a transition type has been rounded. (B) also identifies oval galaxies.

Col. (3), distances derived from group velocities and a Hubble constant of $H_0 = 50$ km s^{-1} Mpc^{-1} (see the text).

Col. (4), distances based on linear Virgocentric flow model with $w = 300$ km s^{-1} (Schechter 1980) and $D_{\rm Virgo} = 20.3$ Mpc. Triple-valued distance solutions are indicated by an asterisk; the adopted distance is the middle one. The distance to M81 is taken from Aaronson, Mould, and Huchra 1980.

Col. (5), ratio of bulge to total light in the B bandpass.

Col. (6), sources of B/T: (1) de Vaucouleurs 1958. (2) Boroson 1981. (3) Boroson and Kormendy 1982. (4) Rubin *et al.* 1978. (5) Benedict 1976. (6) Whitmore and Kirshner 1981. (7) van Houten 1961. (8) Type, according to RC2 and Sandage and Visvanathan 1978; see text. (9) Kormendy 1977*b*. (10) Kormendy 1981. (11) Barbon and Capaccioli 1975. (12) Tsikoudi 1979. (13) Burstein 1979. (14) Bulge strength in Kormendy 1979. (15) Okamura 1978.

Cols. (7)–(9), total and bulge absolute magnitudes from B_T and A_B values in RC2. Col. (8) M_B values are based on distances in col. (3), while col. (9) M_B values are from Virgocentric flow distances in col. (4).

Cols. (10)–(11), adopted velocity dispersion and estimated error. Multiple measurements that are not listed in parentheses in cols. (12)–(15) are averaged with equal weight. The dispersion of the measurements is given as $\varepsilon(\sigma)$. Thus the mean $\varepsilon(\sigma)$ calculated in this way estimates the external consistency of σ. On occasion $\varepsilon(\sigma)$ is unrealistically small, particularly when only two measurements are available. For these cases the internal error estimates are combined in the usual inverse-square sense to give more realistic errors.

Cols. (12)–(15), sources of σ: D81, Davies 1981; FJ, Faber and Jackson 1976; I+82, Illingworth, Mould, and Skillman (1982); for NGC 4762, Illingworth and McElroy 1982; for NGC 7457, Illingworth and Kormendy 1982; K82, Kormendy 1982*a*; KI+IK, Kormendy and Illingworth 1982 and Illingworth and Kormendy 1982; P78, Pritchet 1978; S80, Schechter 1980; S^{2}BS, Sargent *et al.* 1977; TD, Tonry and Davis 1981; V74, de Vaucouleurs 1974; WKS+WK, Whitmore, Kirshner, and Schechter 1979 and Whitmore and Kirshner 1981.

potentially serious problems with the dispersion measurements that will affect the analysis of § III.

1. The photon-counting reticon systems used to obtain most of the data seem to have serious stability problems (WKS, WK, TD). It is not clear that these are adequately removed by corrections made in the above papers. In any case, there are probably a few values in the tables which are seriously in error but which cannot be identified without repeating the measurements.

2. The slit sizes used for much of the data are very large, i.e., $3'' \times 10''$ in WKS and WK, and $3'' \times 12''$ in Schechter (1980) and TD. The measured dispersion is then smaller than that of the galaxy core by an amount which depends on the form of the surface brightness and dispersion profiles.

3. The slit of the Mount Hopkins reticon system is always oriented east-west. Rotation can therefore contribute to the dispersion when the galaxy major axis is oriented nearly east-west. The data from the Mount Hopkins reticon have been compared to true central dispersions when these are available (see Tables 1 and 2); there are signs that rotation sometimes contributes to σ but the effect is not very large. To some extent, the errors introduced by problems (2) and (3) are mutually compensating; a global σ is generally smaller than a central value, while including rotation increases the measured dispersion. We retain measurements made with large slits, but regard the results as preliminary.

4. Given the limited instrumental resolution and the stability problems of some of the data, it is possible that many dispersions in the range $50 \lesssim \sigma \lesssim 150$ km s^{-1} have been overestimated. Since these occur at low luminosities, the data from Tables 1 and 2 may yield $L \propto \sigma^n$ relations with powers n which are too large. All of these

1983ApJ...265..632K

TABLE 2

DISPERSIONS AND ABSOLUTE MAGNITUDES FOR S0 GALAXIES

Galaxy NGC (1)	Type (2)	Dist. (Mpc) H_o=50 (3)	Dist. (Mpc) w=300 (4)	B/T (5)	Source (6)	M_T (7)	M_B H_o=50 (8)	M_B w=300 (9)	Adopted σ (km s^{-1}) (10)	Adopted ε(σ) (km s^{-1}) (11)	Source of σ: WKS+WK (km s^{-1}) (12)	Source of σ: TD (km^{-1}) (13)	Source of σ: Other (km s^{-1}) (14)	Source of σ: Other (km s^{-1}) (15)
524	SA0	51.9	37.6	0.88	3,8	-22.30	-22.16	-21.46	228	13	237	219±52	...	...
679	SA0	103.1	77.3	0.71	9	-22.18	-21.80	-21.18	288	(19)	...	288±19	...	...
936	SB0	28.5	20.3	0.4	10	-21.43	-20.44	-19.70	187	(13)	(191)	(233±24)	187±13[K82]	...
1023	SB0	13.4	10.6	0.51	11	-20.95	-20.21	-19.69	204	(15)	...	(247±15)	204±15[K82]	...
1172	E1/SA0	31.0	21.9	0.90	8	-19.82	-19.71	-18.96	98	(12)	...	...	...	98±12[S2BS]
1400	E1/SA0	27.1	19.9	0.90	8	-20.34	-20.23	-19.56	272	13	...	270±16	273±25[S80]	...
2859	SB0	29.3	28.7	0.6	10	-20.91	-20.36	-20.32	167	16	(197)	178±13	156±14[K82]	...
2950	SB0	29.0	27.8	0.4	10	-20.72	-19.73	-19.64	196	20	...	210±14	182±17[K82]	...
3065	SA0	43.2	37.6	0.44	9	-20.55	-19.66	-19.36	173	(16)	...	173±16	...	...
3115	S0/	9.5	7.8	0.84	12	-20.10	-19.91	-19.48	249:	31	295±17	...	230[V74] 235[FJ]	235±16[D81]
3384	SB0	15.4	10.6	0.59	13	-20.26	-19.68	-18.86	179	30	200±19	157±16	...	...
3412	SB0	15.4	10.4	0.4	14	-19.68	-18.68	-17.82	115	16	104±14	126±24	...	...
3489	S(B)0	11.8	7.7	0.5	14	-19.41	-18.65	-17.73	145	9	146±10	144±22	...	...
3945	SB0	26.8	26.6	0.4	10	-20.88	-19.89	-19.87	161	(13)	...	...	161±13[K82]	...
4203	S(A)0	18.7	19.3*	0.33	13	-19.99	-18.79	-18.86*	182	(14)	182±14	...	...	...
4281	S0/	43.4	42.2	0.38	13	-21.18	-20.14	-20.08	290	(12)	...	290±12	...	...
4340	SB0	20.3	20.3	0.4	10	-19.71	-18.72	-18.72	117	10	...	115±16	119±12[K82]	...
4350	S0/	20.3	20.3	0.40	13	-19.82	-18.83	-18.83	195	23	...	211±15	...	179±14[I+]
4371	SB0	20.3	20.3	0.4	10	-19.83	-18.84	-18.84	108	(9)	...	(160±24)	108± 9[K82]	...
4377	SA0	20.3	20.3	0.53	13	-19.07	-18.38	-18.38	139	(17)	...	139±17	...	...
4382	SA0	20.3	20.3	0.88	8	-21.62	-21.48	-21.48	193	16	186±16	212±10	...	...
4429	SA0	20.3	20.3	0.3	13	-20.63	-19.33	-19.33	156	(13)	...	(221±15)	...	156±13[I+]
4442	SB0	20.3	20.3	0.6	14	-20.44	-19.89	-19.89	225	39	252±19	197±15	...	...
4459	SA0	20.3	20.3	0.83	13	-20.37	-20.17	-20.17	174	22	163±18	160±22	...	200 [FJ]
4526	S(A)0	20.3	20.3	0.59	13	-21.15	-20.58	-20.58	217	(17)	...	(322±12)	...	217±17[I+]
4570	S0/	20.3	20.3	0.36	13	-20.03	-18.91	-18.91	180	(18)	...	...	...	180±18[I+]
4578	SA0	20.3	20.3	0.53	13	-19.46	-18.77	-18.77	153	(15)	...	153±15	...	...
4596	SB0	20.3	20.3	0.39	5	-20.26	-19.24	-19.24	143	9	...	139±39	147± 9[K82]	...
4636	E0/(SA0)	25.4	19.2*	0.95	8	-21.73	-21.67	-21.06*	232	26	...	...	213±17[S80]	250±21[D81]
4762	SB0/	20.3	20.3	0.2:	13	-20.61	-18.87	-18.87	172	22	...	156±11	...	187±14[I+]
6703	SA0	53.1	43.2	0.88	8	-21.67	-21.54	-21.09	189	14	...	179±30	199±11[S80]	...
7457	SA0	15.8	11.8	0.37	9	-19.73	-18.65	-18.01	57	(4)	...	(129±49)	...	57± 4[I+]
7743	SB0	38.1	27.2	0.39	15	-20.96	-19.93	-19.20	86	(11)	...	...	86±11[K82]	...

problems should be kept in mind in the following sections.

Currently the quantity whose availability most limits the samples in Tables 1 and 2 is the bulge fraction B/T. In general it is necessary to be much more precise in deriving B/T values for spirals than for S0's. In spirals B/T is small, and hence difficult to measure. It also varies over essentially the complete range $0 \leq B/T \lesssim 1$. We have retained in Table 1 only those galaxies for which well-determined B/T values are available. In particular, we have excluded from the WKS and WK samples any galaxies with unreliable photometry. In contrast to spirals, S0 galaxies have a more restricted range of bulge strengths, $\sim 0.3 \lesssim B/T \lesssim 1$ (Burstein 1979). As pointed out in WK, we can therefore retain (although with reservations) rather more crudely determined values. B/T values quoted to two significant figures are fairly accurate (although not accurate to two significant figures). They were given in the sources quoted or are derived from published photometry by the iterative bulge-disk decomposition procedure of Kormendy (1977*b*). Values quoted to one significant figure are based on poor photometry or on a comparison of photographs of the objects with photographs of galaxies with accurate B/T values. In a number of S0's it is clear from published photometry (Kormendy 1977*a*, *b*, *c*; King 1978; Burstein 1979; Tsikoudi 1979) or assumed from published classifications that the disk contributes $\lesssim 10\%$ of the light. For these we arbitrarily assume B/T values as follows. If the galaxy is classified S0 both in the RC2 (de Vaucouleurs, de Vaucouleurs, and Corwin 1976) and in Sandage and Visvanathan (1978), we adopt $B/T = 0.88$ (cf. NGC 3115: $B/T = 0.84$, Tsikoudi 1979; NGC 524: $B/T = 0.87$, Boroson and Kormendy 1982). If the galaxy is classified S0 by one of the above references and E by the other, $B/T = 0.90$. Finally NGC 4636 is classified E by both of the above references, although a detailed examination of the profile suggests that there is a weak disk (Kormendy 1977*b*). For NGC 4636 we adopt $B/T = 0.95$. The above values are unlikely to be in error by much more than 5%. In general the adopted B/T values should yield bulge magnitudes accurate to $\lesssim 0.3$ mag.

It would not be surprising if galaxies with almost negligible disks had the same $L \propto \sigma^n$ relation as ellipticals. In § III we therefore derive separately the $L \propto \sigma^n$ relations for all bulges, and for bulges which contribute $\leqslant 85\%$ of the light of the galaxy.

Edge-on spiral galaxies have been discarded from Table 1. They suffer so much absorption in the disk that a nuclear velocity dispersion cannot be measured. Edge-on S0's (S0/) are included, but will be discussed separately from the other galaxies. In S0/ galaxies the path length through the disk is so long, and the disk is therefore so bright, that its contribution to the nuclear dispersion is not necessarily negligible. Detailed photometry is available for all of the edge-on galaxies and suggests that the dispersions (which are all measured with small apertures) are in fact largely measurements of the bulge. Nevertheless, it seems prudent to discuss these galaxies separately. In any case, it is usually impossible to reliably distinguish barred and unbarred edge-on galaxies, and we will see that this distinction is important.

We also discuss separately those galaxies in which the morphology or spectrophotometry suggest that there is Population I material in the "bulge." An excellent example is NGC 4736. Although this galaxy has the extreme central concentration and high central surface brightness characteristic of a bulge (Boroson 1981), dust and spiral structure are visible even in the nucleus (Chincarini and Walker 1967; see also Kormendy 1980). Evidently the central regions contain large amounts of disk material. This is confirmed by the spectrophotometry of Pritchet (1977), which shows the presence of A stars and gas. Further confirmation is provided by the extremely rapid rotation discovered by Pellet and Simien (1982; see the discussion in Kormendy 1982*a*). NGC 4736 is in fact a prototypical oval galaxy (Bosma 1978; Kormendy and Norman 1979; Kormendy 1980); the nonaxisymmetry is entirely comparable to that produced by a bar. Among barred galaxies, NGC 3351 also clearly has Population I material near its nucleus (Vorontsov-Vel'yaminov and Savel'eva 1974). We will discuss the $L \propto \sigma^n$ relation for barred and oval galaxies separately from that of unbarred galaxies.

Finally, we derive separate distances and $L \propto \sigma^n$ relations assuming (i) a uniform Hubble flow and (ii) a linear Virgocentric flow model (cf. Schechter 1980). Distances in column (3) of both Tables 1 and 2 are derived using individual or group velocities and a Hubble constant of 50 km s^{-1} Mpc^{-1}. Distances in column (4) of both tables are derived using the same velocities as those in column (3), but with the linear Virgocentric flow model. We assume an infall velocity at the position of the Galaxy of $w = 300$ km s^{-1} and adopt the same distance to Virgo as in the uniform flow model, i.e., $D_{\rm Virgo} = 20.3$ Mpc. This allows us to compare the $L \propto \sigma^n$ solutions from the two models directly (see § III*d*). Group memberships are derived from de Vaucouleurs (1975), including the subdivisions of the Virgo Cluster area described by de Vaucouleurs (1961). Additional group memberships are given by Schechter (1980) and are derived from the RC2 listings of positions and velocities. For groups nearer than the Virgo Cluster, we have averaged the group velocities given by de Vaucouleurs (1975) and by Sandage and Tammann (1975). The distance of M31 is adopted from de Vaucouleurs (1978), and that of M81 from Aaronson, Mould, and Huchra (1980). Galactic absorption corrections are taken from the RC2. No corrections are made for internal absorption; since we are mainly interested in bulges which are free of Population I material, these corrections should be small.

The above restrictions, particularly those on B/T values, leave us with only a small sample. The following discussion will be based on 33 usable S0's (15 SA0's, 13 SB0's, and 5 S0/ galaxies) and 15 spirals (10 SAs and 5SBs). In addition, mean σ values and total absolute magnitudes were derived by the above procedures for 43 elliptical galaxies, from dispersion data in Faber and Jackson (1976), Sargent *et al.* (1977). Young *et al.* (1978), Schechter and Gunn (1979), Whitmore, Kirshner, and Schechter (1979), Schechter (1980), Davies (1981), and Whitmore and Kirshner (1981). These provide a sample of elliptical galaxies analyzed in the same way as the disk galaxies.

III. THE $L \propto \sigma^n$ RELATION

The major conclusion reached by Whitmore, Kirshner, and Schechter (1979) and by Whitmore and Kirshner (1981) was that the bulges of S0 galaxies have the same $L \propto \sigma^4$ relation as ellipticals, but that spiral-galaxy bulges have smaller velocity dispersions than ellipticals of the same luminosity. In this section we examine the $L \propto \sigma^n$ relations of various ellipsoidal components in more detail. In particular, we allow the exponent n to be a free parameter, and we discuss separately the $L \propto \sigma^n$ relations for barred and unbarred galaxies. In § III*d* we verify that neglect of the Virgocentric flow does not significantly affect our conclusions.

Figure 1 shows the correlation observed between log σ and the absolute magnitude M_B for ellipticals and for bulges of disk galaxies. Distances are derived assuming a uniform Hubble flow. It is clear that ellipticals and SA bulges have similar log σ-M_B correlations, and that SB bulges do not satisfy this correlation. These statements are made more quantitative in the rest of this section.

a) *Discrepant Galaxies*

Several galaxies do not satisfy the rather tight log σ-M_B correlation observed for unbarred galaxies. In particular, the central dispersions of NGC 7457 ($\sigma = 57$ km s^{-1})[4] and NGC 1172 ($\sigma = 98$ km s^{-1}) are anomalously small for their bulge magnitudes. The unusually small dispersion of NGC 1172 has been noted previously by Terlevich *et al.* (1981). Since only a single measurement is available (Sargent *et al.* 1977), it is conceivable that the value is in error. Such a hypothesis is less probable for NGC 7457, which we have measured with good resolution ($\sigma_{\rm instrumental} \approx 60$ km s^{-1}) on two different occasions. The fact that the log σ-M_B correlation otherwise has small scatter suggests that these two galaxies are discrepant because of real physical anomalies. This is slightly surprising in the case of NGC 7457, because this galaxy has very ordinary photometric properties (Kormendy 1977*a*, *b*) and stellar content (Sparke, Kormendy, and Spinrad 1980). We note the anomalies and omit both NGC 1172 and 7547 from the least squares fits.

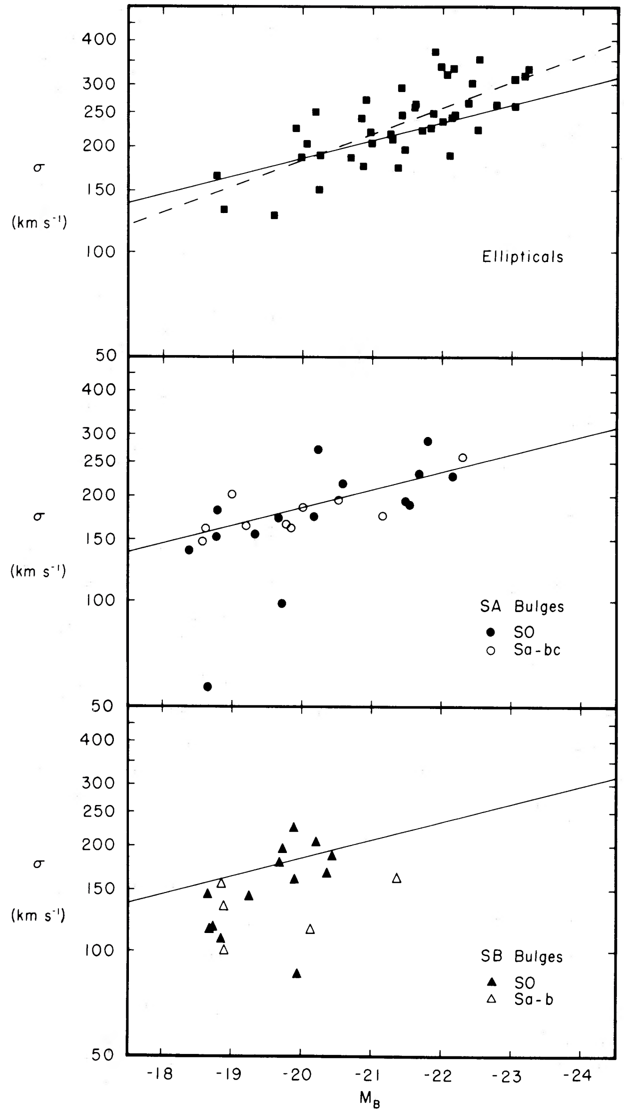

FIG. 1.—Correlation between central velocity dispersion σ and absolute magnitude M_B for elliptical galaxies (*top panel*) and for bulges of unbarred (*middle panel*) and barred (*bottom panel*) disk galaxies. Edge-on galaxies are omitted. The solid line is in each case the combined $L \propto \sigma^n$ relation for unbarred S0-bc galaxies which are not edge-on ($n = 7.8$; $\sigma_{21} = 208$ km s^{-1}; solution 4 of Table 3). The dashed line is solution 1 for elliptical galaxies ($n = 5.4$; $\sigma_{21} = 217$ km s^{-1}).

[4]Schechter (1983) has measured $\sigma = 80 \pm 7$ km s^{-1} for NGC 7457, higher than our preliminary value quoted here. Even with $\sigma = 80$ km s^{-1} NGC 7457 is still discrepant since its central dispersion is much smaller than expected for its bulge luminosity.

The dispersion $\sigma = 273$ km s^{-1} measured for NGC 1400 is slightly high for its absolute magnitude $M_B = -20.2$ (see also Schechter 1980). We retain NGC 1400; tests show that the least squares solutions derived below are not altered significantly if this galaxy is omitted.

b) The Exponent of the $L \propto \sigma^n$ Relation for Unbarred Galaxies

Table 3 gives parameters for least squares fits of straight lines to various subsets of the galaxies in Figure 1. These solutions routinely yield the exponent n and the zero point of the $L \propto \sigma^n$ relation, which is conveniently taken to be σ_{21}, the velocity dispersion at $M_B = -21$. We consider first solutions 1–7, which allow n to be a free parameter.

Our solution 1 for elliptical galaxies is virtually the same as that derived by Schechter (1980). In particular, we obtain $n = 5.4^{+0.9}_{-0.7}$, while Schechter derives $n = 5.4^{+1.3}_{-0.9}$. Our zero point $\sigma_{21} = 217$ km s^{-1} is slightly smaller than Schechter's value $\sigma_{21} = 236$ km s^{-1}, possibly reflecting our neglect of the Virgocentric flow (Schechter's $L \propto \sigma^n$ relation arises from a Virgocentric flow solution in which w is found to be 190 km s^{-1}). We will see in § III*d*, below, that our conclusions regarding the $L \propto \sigma^n$ relations are unchanged if we derive distances from a reasonable Virgocentric flow model ($w = 300$ km s^{-1}, Aaronson *et al.* 1982). Furthermore, none of the above results are changed if we include as elliptical galaxies those S0's which have $B/T \geq 0.88$. Our value of n is larger than those obtained by Tonry and Davis (1981) and Davies *et al.* (1982) because these authors include more low luminosity ellipticals. Tonry (1981) has shown that the $L \propto \sigma^n$ relation curves towards smaller n at low luminosities.

Solutions 2 and 3 show that *the bulges of unbarred S0 and Sa-bc galaxies have the same $L \propto \sigma^n$ relation.* This result differs somewhat from the conclusions of Whitmore and collaborators (WKS, WK). The difference may partly be due to the fact that SB bulges are included in the solutions of WKS and WK; we will see in § III*e* that these often have smaller dispersions than SA bulges. However, the main reason that Whitmore and collaborators find small dispersions for spiral galaxy bulges is probably that they include many late-type galaxies which have faint bulges that clearly contain Population I or disk material. An example is NGC 4321 (Sbc) where the spectrophotometry of Turnrose (1976) clearly reveals the presence of young stars. Such faint, patchy, and disk-dominated "bulges" bear little resemblance to S0 bulges or ellipticals; it is not surprising that they have small dispersions. When we retain only those spiral galaxy bulges which are morphologically similar to S0 bulges, we obtain an $L \propto \sigma^n$ relation which is similar to that describing S0 bulges. Given this result, we will compare to elliptical galaxies a combined solution 4 which describes all the SA0-bc galaxies.

There are indications that the $L \propto \sigma^n$ exponent $n = 7.8^{+1.9}_{-1.3}$ for disk-galaxy bulges is larger than $n = 5.4^{+0.9}_{-0.7}$ for ellipticals. This result may prove to be spurious. The number of disk galaxies in the solution is still rather small. More important, the smaller dispersions may have systematically been overestimated due to problems discussed in § II. This would result in a spuriously large value of n. The hint that n is larger for bulges than for ellipticals is worth further investigation, but it is not convincing at present.

Therefore, *the present data are consistent with the hypothesis that disk galaxy bulges have the same $L \propto \sigma^n$ relation as ellipticals.* If the relations turn out to be different, the difference is more likely to lie in the exponent n than in the zero point, which is closely the same for solutions 1–4. We recall that this result is derived for bulges with $-18.5 \geq M_B \geq -22$ and ellipticals with $-20 \geq M_B \geq -23$ ($H_0 = 50$ km s^{-1} Mpc^{-1}).

The above conclusions do not depend on the fact that we have included S0 galaxies with almost negligible disk (i.e., S0 galaxies which may be almost the same as ellipticals, and which may therefore prejudice any comparison with ellipticals). Such galaxies are omitted in solutions 6 and 7. The S0 sample in solution 6 is reduced to only eight galaxies, so the results are somewhat unstable. However, solutions 2 and 6 and solutions 4 and 7 are mutually consistent.

c) The Zero Point of the $L \propto \sigma^n$ Relation for Unbarred Galaxies

Solutions 1–4 suggest that the zero point σ_{21} of the $L \propto \sigma^n$ relation is the same for ellipticals and for bulges of S0 and spiral galaxies. If σ_{21} is smaller for spiral galaxy bulges, the difference is marginal. A more detailed comparison between the various zero points can be made by fixing the exponent n. However this comparison must be made very carefully, because the bulges and ellipticals have different average luminosities (Fig. 1). If an incorrect exponent is used, then an incorrect value of the zero point difference will be derived. For this reason it is convenient to choose as the zero point the dispersion at $M_B = -21$. This is approximately the average of the absolute magnitudes of typical bulges and typical ellipticals in Figure 1. Therefore calculation of σ_{21} requires the least amount of extrapolation of the various $L \propto \sigma^n$ relations. We can illustrate the need to use the correct exponent n by adopting a value which is too small, namely $n = 4$ (Faber and Jackson 1976). We then obtain $\sigma_{21} = 216 \pm 6$ km s^{-1} for ellipticals, and $\sigma_{21} = 227 \pm 13$ km s^{-1} for S0's. Given the fact that the ellipticals are brighter than the bulges, smaller values of n yield smaller values of σ_{21} for ellipticals as compared with σ_{21} for S0s.

Since the exponent n may be different for bulges and ellipticals, we give in Table 1 sets of solutions computed both for $n = 5.4$ (derived for ellipticals) and for $n = 7.8$

TABLE 3

$L \propto \sigma^n$ RELATIONS

Solution Number (1)	Sample (2)	N (3)	a (4)	b (5)	r (6)	n (7)	σ_{21} (km s^{-1}) (8)	$\varepsilon(\sigma)$ (km s^{-1}) (9)
1	Ellipticals	43	0.78±0.23	−0.074±0.011	0.74	$5.39^{+0.90}_{-0.68}$	217	38
2	SA0s, omit 7457, 1172, /	13	1.20±0.31	−0.054±0.015	0.73	$7.45^{+3.0}_{-1.7}$	211	34
3	SAa-bc galaxies	10	1.37±0.27	−0.045±0.014	0.75	$8.95^{+4.0}_{-2.1}$	201	23
4	SA0-bc galaxies omit 7457, 1172, /	23	1.24±0.20	−0.051±0.010	0.74	$7.80^{+1.9}_{-1.3}$	208	28
5	SB0-b galaxies	18	0.87±0.62	−0.066±0.032	0.44	$6.06^{+5.6}_{-2.0}$	180	42
6	SA0s, omit 7457, /, all B/T > 0.85	8	0.66±0.29	−0.081±0.015	0.92	$4.94^{+1.09}_{-0.75}$	231	23
7	SA0-bc galaxies, omit 7457, /, all B/T > 0.85	17	1.12±0.26	−0.057±0.013	0.75	$7.00^{+2.1}_{-1.3}$	210	24
8	Ellipticals	43	0.78±0.08	−0.075	...	5.39	217± 6	38
9	SA0s, omit 7457, 1172, /	13	0.78±0.07	−0.075	...	5.39	218±10	36
10	SAa-bc galaxies	10	0.78±0.06	−0.075	...	5.39	217± 9	29
11	SA0-bc galaxies, omit 7457, 1172, /	23	0.78±0.06	−0.075	...	5.39	218± 7	32
12	SB0-b galaxies	18	0.71±0.10	−0.075	...	5.39	185±10	45
13	Ellipticals	43	1.27±0.08	−0.051	...	7.80	222± 6	41
14	SA0s, omit 7457, 1172, /	13	1.25±0.07	−0.051	...	7.80	211± 9	32
15	SAa-bc galaxies	10	1.23±0.05	−0.051	...	7.80	205± 7	22
16	SA0-bc galaxies omit 7457, 1172, /	23	1.24±0.06	−0.051	...	7.80	208± 6	23
17	SB0-b galaxies	18	1.16±0.10	−0.051	...	7.80	172±10	42
18	SA0-c/ galaxies	5	1.34±0.07	−0.051	...	7.80	259±18	40
19	SA0-c and SB0-c galaxies with i < 27°	13	1.29±0.07	−0.051	...	7.80	234±10	37

NOTE.—Col. (2), / denotes galaxies which are edge-on. Col. (3), number of galaxies in sample. Cols. (4)–(5), coefficients in a least squares solution of the form $\log \sigma = a + bM_B$. Formal least square error estimates are given for the parameters neglecting errors in the independent variable M_B. All galaxies are given equal weight. Col. (6), correlation coefficient. Col. (7), power n of the $L \propto \sigma^n$ relation is $n = -(2.5b)^{-1}$. Col. (8), adopted zero point of the $L \propto \sigma^n$ relation, i.e., the velocity dispersion for a bulge or elliptical galaxy of absolute magnitude $M_B = -21$. Col. (9), formal error estimate for *individual* σ measurements used in the solution, from the observed scatter in Fig. 1. The values quoted include both measuring errors and any intrinsic dispersion in the $\log \sigma$-M_B correlation. Generally, $\varepsilon(\sigma) \lesssim 25$ km s^{-1} implies that the scatter is consistent with the measuring errors, while $\varepsilon(\sigma) \gtrsim 35$ km s^{-1} suggests that a significant real dispersion is present.

TABLE 4

$L \propto \sigma^n$ RELATIONS: VIRGOCENTRIC FLOW

Solution Number (1)	Sample (2)	N (3)	a (4)	b (5)	r (6)	n (7)	σ_{21} (km s^{-1}) (8)	$\epsilon(\sigma)$ (km s^{-1}) (9)
1	Ellipticals..........	43	0.75±0.23	-0.077±0.011	0.75	$5.19^{+0.84}_{-0.64}$	231	40
2	SA0s, omit 7457, 1172, /....	13	1.19±0.40	-0.055±0.020	0.64	$7.29^{+4.2}_{-2.0}$	219	39
3	SAa-bc................	10	1.30±0.31	-0.049±0.016	0.74	$8.24^{+3.9}_{-2.0}$	209	24
4	SA0-bc, omit 7457, 1172, /....	23	1.21±0.25	-0.054±0.013	0.68	$7.48^{+2.3}_{-1.4}$	216	32
5	SB0-b.................	18	0.92±0.54	-0.065±0.028	0.50	$6.17^{+4.7}_{-1.9}$	191	45

NOTE.—Column explanations as for Table 3. Virgocentric flow solution based on linear model (Schechter 1980) with $w = 300$ km s^{-1}. The adopted distance modulus of the Virgo Cluster is $(m - M)_0 = 31.54$, giving $D_{\text{Virgo}} = 20.3$ Mpc for consistency with Table 3. For $(m - M)_0 = 30.98$ (Mould, Aaronson, and Huchra 1980), σ_{21} values in col. (8) should be multiplied by $(1.67)^{1/n}$.

(derived for bulges). Solutions 8–11 and 13–16 show that σ_{21} does not depend critically on the value of n adopted. We conclude that the zero point $\sigma_{21} \approx 210$–220 km s^{-1} is the same for bulges and ellipticals. Any tendency for spiral galaxy bulges to have comparatively small values of σ_{21} is currently masked by measurement errors and by the intrinsic dispersion of the $L \propto \sigma^n$ relation.

d) *Effect of the Virgocentric Flow*

It now seems well established (Tonry and Davis 1981; Aaronson *et al.* 1982), that the Hubble expansion within the Local Supercluster is perturbed by a field of infall velocities directed toward the Virgo Cluster. Neglect of this effect could introduce systematic errors in the parameters of the $L \propto \sigma^n$ relations if significant differences exist in the spatial distributions of our galaxy samples. Accordingly we have reevaluated fits 1–5 using distances based on a linear Virgocentric flow model (Schechter 1980) with a Local Group component towards Virgo of $w = 300$ km s^{-1} (Aaronson *et al.* 1982). The results are given in Table 4. For ease of comparison with previous sections we continue to use a distance of 20.3 Mpc for the Virgo Cluster. If the more probable distance of 15.7 Mpc is adopted (Mould, Aaronson, and Huchra 1980), then all zero points in Table 4 are increased by a factor of $(1.67)^{1/n}$, i.e., by 1.10 if $n = 5.4$ or 1.07 if $n = 7.8$. The zero points for ellipticals derived using the two Virgo distances bracket Schechter's (1980) value $\sigma_{21} = 236$ km s^{-1}. We note that a choice of the distance to Virgo affects only the zero-point scale in Table 4; it *does not* affect the comparison of zero points for different galaxy samples.

Comparison of Tables 3 and 4 shows that systematic effects of the Virgocentric flow on differences between $L \propto \sigma^n$ parameters derived for different galaxy samples are small enough to be unimportant. The remainder of this paper will therefore be based on distances derived by assuming a uniform Hubble expansion.

e) *Barred Galaxies*

The correlation between velocity dispersion and absolute magnitude is quite different for the bulges of barred and oval galaxies than it is for the above SA objects (see Fig. 1). Approximately two-thirds of the SB bulges satisfy the $L \propto \sigma^n$ relation for SA bulges. However, *one-third of the SB bulges have significantly smaller velocity dispersions than SA bulges of the same luminosity*. As a result, the scatter in the log σ-M_B diagram is large, and the correlation coefficient between log σ and M_B is small: $r = 0.44$ in solution 5, compared with 0.74 for SA bulges. The average zero point for SB bulges, $\sigma_{21} = 180 \pm 10$ km s^{-1}, is significantly smaller than $\sigma_{21} = 210 \pm 7$ km s^{-1} for SA bulges. The inclusion of SB bulges contributes to the relatively small values of σ found in WKS and in WK.

At first sight one may want to attribute the relatively small σ_{21} values for barred galaxies directly to rotation. Kormendy (1981, 1982*a*) has, in fact, found that triaxial SB bulges rotate more rapidly than normal bulges. However, there are two problems with this approach. First, we know (Illingworth and Schechter 1982; KI) that normal bulges rotate significantly faster than the ellipticals in Figure 1, yet they have the same $L \propto \sigma^n$ relation as ellipticals, within the uncertainties. Second, it is not obvious why a global dynamical property such as rotation should directly influence a relationship between the *total* luminosity and the *central* dispersion.

Now Kormendy and Koo (1982) have shown that many SB bulges are triaxial, like bars. Also, SB bulges are in general very highly flattened. These observations and the very rapid rotation found by Kormendy (1981, 1982*a*) suggest that SB bulges differ dynamically from SA bulges. Kormendy (1981, 1982*a*) has suggested that the bulges of some SB galaxies have been augmented by disk gas transported into the center by the bar. Both theoretical and observational arguments indicate that this gas transfer is an efficient process. The resulting star formation may well add to the bulge the dynamically cooler or lower M/L material needed to explain the difference seen here between the SB and SA galaxies. It is noteworthy that all spiral SB bulges fall below the $L \propto \sigma^n$ relation for SA bulges, but that not every SB0 galaxy has an anomalously small velocity dispersion. Any gas transport in an S0 may have been switched off early enough (when the gas was depleted or removed) so that the material added to the bulge was not significant in every case. Gas transport should be more important in spirals because they contain gas for a longer time. Two distinct effects may then produce different L-σ relations in SB0 and SBa-bc galaxies: the latter may have suffered larger dynamical modification and they may also have smaller M/L values than the SB0 bulges, which have had more time to age.

f) *Edge-On Galaxies*

Whitmore and Kirshner (1981) note that the central velocity dispersion in the edge-on S0 galaxy NGC 3115 is anomalously high for its bulge absolute magnitude. We now have σ and B/T measurements for five edge-on S0's. Figure 2 shows that the bulges of all five of these galaxies have velocity dispersions larger than the prediction of the overall $L \propto \sigma^n$ relation. In fact, they have $\sigma_{21} = 259 \pm 18$ km s^{-1} (solution 18 of Table 3), compared to the overall value of $\sigma_{21} = 208 \pm 6$ km s^{-1}. The edge-on bulges have higher dispersions despite the fact that one of the galaxies (NGC 4762) is almost certainly barred, and several more are likely to be barred.

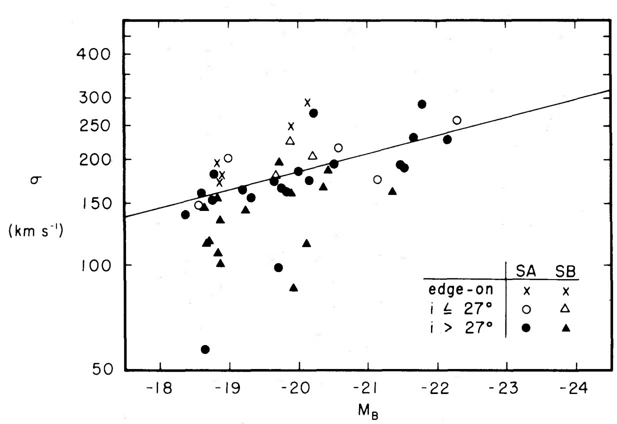

FIG. 2.—Correlation between σ and M_B for bulges which are edge-on, nearly edge-on, and more face-on than $i = 27°$. The solid line is solution 4 of Table 3, as in Fig. 1.

To better determine whether this is a statistical accident or a general property of bulges we identify in Figure 2 the galaxies which are almost edge-on. Open circles in Figure 2 refer to bulges which have inclinations $i \leqslant 27°$. This angle is chosen as follows. The observed velocity dispersion contains contributions $\sigma_r \cos i$ from the radial velocity dispersion σ_r and $\sigma_z \sin i$ from the axial dispersion σ_z. If $\sigma_r \approx \sigma_z$, the contribution of σ_z becomes small (i.e., $\sin i/\cos i < 0.5$) for $i < 27°$. Thus, open symbols and crosses in Figure 2 refer to bulges whose measured dispersions are dominated by σ_r. We see that the highly-inclined galaxies generally have larger central dispersions than nearly face-on galaxies. More quantitatively, $\sigma_{21} = 234 \pm 10$ km s^{-1} for all 13 bulges with $i \leqslant 27°$ (solution 19 of Table 3), which is also marginally larger than σ_{21} for non–edge-on galaxies.

It is unlikely that the above effect is due to internal absorption or to any contribution of the disk to the observations. Both of these effects would tend to decrease the measured dispersion. Also, photometry is available for all five of the edge-on bulges, and shows that the central surface brightness of the disk is at least 2 mag arcsec^{-2} below the central brightness of the bulge. It is also unlikely that general bulge rotation is contributing to the dispersion, because all of the edge-on and many of the highly inclined galaxies were measured with small apertures.

Possible reasons for the apparently high dispersions in nearly edge-on galaxies include the following.

1. The velocity dispersion may be slightly anisotropic, with $\sigma_z \approx 0.84\sigma_r$. This is not implausible in principle, but the degree of anisotropy conflicts with the near-isotropy ($\sigma_z \gtrsim 0.97\sigma_r$) implied by the rapid rotation of bulges (Kormendy and Illingworth 1982).

2. A nuclear mass concentration distinct from the bulge might produce very rapid central rotation that could masquerade as a high velocity dispersion. However, there is no other evidence for such a mass concentration.

3. The edge-on galaxies may have abnormally high central surface brightnesses. Simple arguments can be used to show that $M/L \propto \sigma^2/(RI_0)$ (Rood *et al.* 1972), where I_0 and R are characteristic surface brightness and radius scales. Central surface brightnesses μ_0, corresponding to I_0, are in fact available for all five edge-on galaxies, from Tsikoudi (1979) and Burstein (1979). NGC 3115 ($\mu_0 = 15.2$ B mag arcsec^{-2}) and to a lesser extent NGC 4762 ($\mu_0 \approx 16.4$ B mag arcsec^{-2}) have slightly higher central brightnesses than the average $\langle \mu_0 \rangle = 17.6 \pm 0.2$ B mag arcsec^{-2} for the other 13 galaxies with measurements available. But the other three edge-on galaxies have $\langle \mu_0 \rangle \approx 17.4 \pm 0.2$ B mag arcsec^{-2}, which is in no way unusual.

We therefore have no clear-cut interpretation for the suggestion of Figure 2 that nearly edge-on bulges have higher central velocity dispersions than more face-on objects.

IV. SUMMARY

We have compared the observed correlations between luminosity and central velocity dispersion in elliptical galaxies and in the bulge components of disk galaxies. The ellipticals studied mostly have absolute magnitudes $-20 \geq M_B \geq -23$, while the bulges are slightly fainter; $-18.5 \geq M_B \geq -22$.

1. We conclude that the $L \propto \sigma^n$ relations for ellipticals and for the bulges of spiral and S0 galaxies are not significantly different. There is weak evidence that the exponent n is larger in bulges than in ellipticals. However, the central dynamics and stellar populations of ellipticals and ordinary bulges are basically similar, although the global dynamics differ in the sense that bulges rotate more rapidly than the present ellipticals.

2. The bulges of many barred and oval galaxies do not satisfy the above $L \propto \sigma^n$ relations. One-third of the SB bulges studied here have significantly smaller velocity dispersions than SA bulges of the same luminosity. These bulges therefore have smaller mass-to-light ratios and/or more disklike dynamics than their SA counterparts. Both of these effects may result from an inward radial transport of disk gas by the bar or oval disk, which could augment an existing bulge with a younger subpopulation of relatively disklike material (Kormendy 1982*a*).

3. There are indications that nearly edge-on bulges are observed to have higher central velocity dispersions than bulges which are more face-on.

R. Davies kindly provided a computer program to calculate distances using the Virgocentric flow model. New velocity dispersions reported here were calculated using a Fourier-quotient program originally written by P. Schechter and expanded and maintained by J. Fried and D. McElroy. The *CECAM Workshop on Formation, Structure, and Evolution of Galaxies* held at the Institut d'Astrophysique in Paris during August, 1981 provided a stimulating and pleasant environment for some of the work on this paper. We are grateful to Jean Audouze, Carl Moser, and Colin Norman for organizing this workshop.

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GARTH ILLINGWORTH: Kitt Peak National Observatory, P.O. Box 26732, Tucson, AZ 85726

JOHN KORMENDY: Dominion Astrophysical Observatory, 5071 West Saanich Road, Victoria, B. C. V8X 4M6, Canada