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CORRELATIONS BETWEEN LINE STRENGTHS AND FINE STRUCTURE IN ELLIPTICAL GALAXIES

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ABSTRACT

For 36 giant elliptical galaxies located mostly in the field and in groups, the strength of the nuclear Hβ absorption line at any given absolute magnitude increases systematically with the amount of fine structure (ripples, jets of luminous matter, X-structure, and boxy isophotes), while the strengths of the CN and Mg I + MgH features decrease. This effect is most likely due to systematic variations in mean age, rather than mean metallicity, of the stellar populations. We use the resulting correlations to estimate the contributions of age and metallicity variations to line-strength scatter and suggest that the elusive population of intermediate-age remnants of major disk-disk mergers may be found among ellipticals with much fine structure and enhanced Hβ absorption.

Subject headings: galaxies: evolution — galaxies: interactions — galaxies: stellar content — galaxies: structure

I. INTRODUCTION

For some time now, evidence has accumulated that the class of elliptical galaxies may not be as homogeneous as was thought two decades ago. Spectroscopic surveys paired with population syntheses suggest that Es contain various admixtures of intermediate-age stars (e.g., O'Connell 1976, 1980; Faber 1977; Pickles 1985; Bica and Alloin 1987). Also, the well-known correlations between metal-line strengths and absolute magnitude (Faber 1973) persistently show scatter in excess of observational errors, yet various attempts to correlate the line-strength *residuals* with other galaxy properties have failed (Faber 1987). Finally, a multitude of fine structures (ripples, plumes, boxy isophotes, disks, etc.) and kinematic anomalies (e.g., counterrotating cores) suggest increasingly that at least some ellipticals were either formed (Toomre 1977; Schweizer 1983; Barnes 1988) or structurally modified (Hernquist and Quinn 1988, 1989) by mergers in relatively recent times. In this context, the question arises whether at least the last major merger in the formation history of any given elliptical can be dated.

With such evidence and questions in mind, two groups among us authors undertook two largely independent surveys. The first two authors have been conducting a search for fine structure in a sample of 74 E and S0 galaxies (Schweizer and Seitzer 1988; Seitzer and Schweizer 1990), while the other four have been measuring line strengths in the spectra of some 400 early-type galaxies (Faber *et al.* 1985, 1989; Burstein *et al.* 1984). The present *Letter* discusses a first result obtained by combining the two data sets, namely the discovery of correlations between line strength residuals and fine structure measured in 36 Es common to both samples.

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II. FINE STRUCTURE AND LINE STRENGTHS

Ellipticals common to both samples are listed in Table 1, with types taken from Sandage and Tammann (1981). All lie north of $\delta = -20°$ and at $|b| > 20°$, have apparent magnitudes $B_T \leq 13.5$ in the RC2, and have recession velocities $v_0 <$ 4000 km s^{-1} (for details, see Schweizer and Seitzer 1988). The three galaxies marked by a "V" are members of the Virgo Cluster; all others are either field objects or in small groups. The absolute magnitudes (computed for $H_0 = 50$, without Virgocentric flow correction, and with group velocities where known) range between $M_B = -17.9$ and -22.4, with a median value of -21.0. Thus, these are giant ellipticals mostly in low-density environments.

For the study of fine structure, 74 E and S0 galaxies were imaged with the KPNO 0.9 m telescope plus CCD camera in the *R* passband. The imaged field measured 7'.3 × 4'.5 with the RCA1 chip and 6'.5 × 6'.5 with the Tektronix 1 chip. Typically, an image consisted of a series of five to 10 consecutive exposures totalling 40–60 minutes. All images were flat-fielded, cleaned, and masked with various derivative images obtained by convolution with $\sigma = 5''$ and $10''$ Gaussians (Schweizer and Ford 1985, hereafter SF85). Visual evaluation of these images and of contour plots yielded a catalog of the following types of fine structure in each galaxy: embedded disks, ripples, "jets" (our short form for plumes, streamers, or tails of luminous matter), twists, boxy isophotes, X-structure, and other, rarer forms of fine structure (Schweizer and Seitzer 1991, hereafter SS91).

For the purposes of this *Letter*, we define a *fine-structure parameter* Σ based on the four types of fine structure that were found to correlate with line-strength residuals:

$$\Sigma = S + \log(1 + n) + J + B + X , \qquad (1)$$

where S is our visual estimate of the strength of the most prominent ripples (S = 0–3), n is the number of detected ripples (n = 0–17), J is the number of "jets" (J = 0–4), B is a visual estimate of the maximum boxiness of isophotes (B = 0–3), and X indicates the absence or presence of an X-structure (X = 0 or 1; see: SF85; Whitmore and Bell 1988; Hernquist and Quinn 1989). The values of Σ for the present sample of Es are

TABLE 1

DATA FOR 36 ELLIPTICAL GALAXIES

Galaxy	RSA Type	$-M_B$ (mag)	Σ	ΔHβ (Å)	ΔCN (mag)	ΔMg_2 (mag)
N0596.........	E0	21.26	4.60	0.24	−0.037	−0.047
N0636.........	E1	20.59	1.48	0.44	−0.004	−0.002
N1052.........	E3[a]	20.94	1.78	−4.79[b]	0.099	0.044
N1453.........	E2	22.29	1.48	−0.60	0.027	0.016
N1700.........	E3	22.24	3.70	0.63	−0.037	−0.035
N2300.........	E3	21.54	2.85	0.42	0.050	0.029
N2974.........	E4	21.22	0.00	−0.80	0.038	0.014
N3156.........	E5:	19.77	1.70	2.36	−0.139	−0.153
N3193.........	E2	20.05	0.00	−0.02	0.020	0.039
N3377.........	E6	19.51	1.48	0.04	0.014	0.019
N3379.........	E0	20.18	0.00	−0.32	0.050	0.047
N3605.........	E5	18.34	2.70	0.29	0.004	−0.018
N3608.........	E1	19.90	0.00	−0.35	0.086	0.055
N3610.........	E5	21.23	7.60	0.44	−0.040	−0.031
N3640.........	E2	20.95	6.85	0.42	−0.036	−0.025
N3818.........	E5	19.54	1.30	−0.02	0.068	0.077
N4125.........	E6	22.33	6.00	0.17	−0.004	0.005
N4168V.......	E2	19.71	3.00	−0.36	0.004	0.004
N4261.........	E3	21.78	1.00	−0.23	0.040	0.041
N4278.........	E1	19.87	1.48	−2.92[b]	0.061	0.037
N4283.........	E0	17.89	0.00	−0.18	0.026	0.050
N4374V.......	E1	21.53	2.30	−0.60	0.030	0.014
N4589.........	E2	21.22	0.00	−0.57	0.030	0.030
N4660V.......	E5	19.47	0.00	−0.59	0.065	0.060
N4697.........	E6	21.63	0.00	−0.33	0.001	0.008
N4915.........	E0	20.89	5.48	0.01	0.007	0.005
N5018.........	E4	22.16	5.15	0.88	−0.085	−0.105
N5198.........	E1	20.96	1.85	−0.13	0.014	0.032
N5322.........	E4	22.05	2.00	0.30	0.007	−0.017
N5557.........	E2	23.38	2.78	0.40	−0.018	−0.001
N5576.........	E4	20.76	2.30	−0.19	−0.035	−0.027
N5687.........	E3	20.99	0.30	0.38	−0.002	−0.003
N5831.........	E4	20.33	3.60	0.24	0.045	0.020
N5982.........	E3	21.90	2.04	0.17	−0.001	−0.006
N7619.........	E3	22.34	0.00	−0.03	0.027	0.032
N7626.........	E1	22.35	2.60	−0.33	0.018	0.029

[a] Transition type E3/S0.
[b] Strong Hβ emission.

given in the fourth column of Table 1 and cover the range $\Sigma = 0$–7.6.

In order to determine line-strength indices w_i, spectra of ~400 early-type galaxies and of a host of stars were obtained from 1972 to 1982 with the red-sensitive image-dissector scanner and Cassegrain spectrograph of the 3 m Shane telescope at Lick Observatory. These spectra cover the wavelength interval 4000–6300 Å with a resolution of 9 Å. The spectra were acquired through a 1″.4 × 4″ aperture centered on the nucleus or star, with a second aperture at 21″ or 35″ distance used for sky subtraction. Details about the reduction procedures and definitions of the indices are given in Burstein *et al.* (1984), Faber *et al.* (1985), and Faber *et al.* (1991, hereafter FBDG91). Of the four best determined indices, Hβ, CN, and Mg_2 yield interesting correlations with Σ and will be discussed here, while the *G* band index shows mostly scatter and will be ignored.

Figure 1 shows the Mg_2 index of 169 ellipticals plotted versus M_B, and two linear least-squares (LSQ) fits. Comparison between the data and the error cross suggests that the scatter around any mean relation exceeds the observational errors; the same holds true for the Hβ and CN indices when plotted versus M_B. The question we now pose is to which extent the line-strength residuals Δw_i (i.e., the deviations of the indices w_i from mean relations) correlate with fine structure in the 36 ellipticals with known Σ.

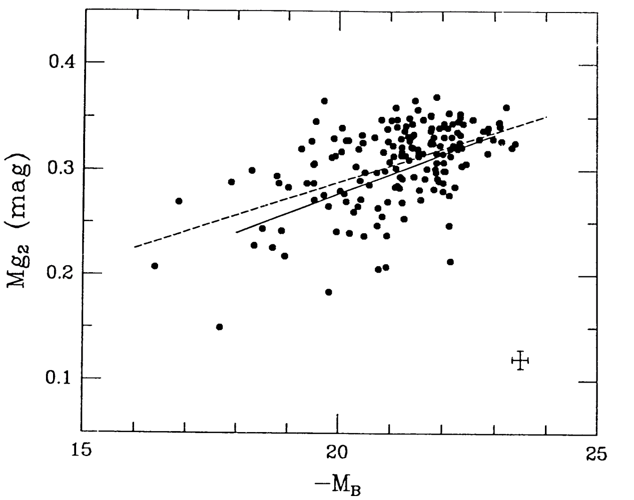

FIG. 1.—Line-strength index Mg_2 of 169 elliptical galaxies plotted versus absolute magnitude; cross indicates mean observational errors ($\pm 1\ \sigma$ bars). Two linear least-squares fits are shown: one for all Es (*dashed*) and the other for 241 E+S0 galaxies with $18 < -M_B < 23$ (*solid line*; S0 data points not shown). The latter fit was adopted to form the line-strength residuals presented in this *Letter*.

To derive such residuals, we performed linear LSQ fits for various subsamples of the galaxies observed by FBDG91 and found that all sets of residuals yielded similar results. The procedure finally adopted was to perform linear LSQ fits of w_i versus M_B for 241 E+S0 galaxies with $18 < -M_B < 23$ and $v_0 \leq 8000$ km s^{-1}. For the 36 Es with measured Σ, Table 1 gives the residuals ΔHβ, ΔCN, and ΔMg_2 obtained by subtracting from the observed indices the LSQ fit values at the appropriate M_B.

III. CORRELATIONS Δw_i-Σ

Figure 2 shows the three line-strength residuals plotted versus the fine-structure parameter Σ. Note that there are nine galaxies at $\Sigma = 0$, where points crowd. Clearly, ΔHβ correlates with Σ, whereas both ΔCN and ΔMg_2 anticorrelate.

To evaluate the significance of these correlations, we performed linear LSQ fits of Δw_i versus Σ, excluding the most deviant galaxy (NGC 3156 at $\Sigma = 1.7$) and, in the case of ΔHβ, also two galaxies with strong Hβ emission (NGC 1052 and 4278, outside plot area). The resulting mean relations, shown in Figure 2, are

$$\langle \Delta H\beta \rangle = -0.25 + 0.110(\pm 0.026)\Sigma\ , \quad (2)$$

$$\langle \Delta CN \rangle = 0.040 - 0.0112(\pm 0.0025)\Sigma\ , \quad \text{and} \quad (3)$$

$$\langle \Delta Mg_2 \rangle = 0.035 - 0.0108(\pm 0.0022)\Sigma\ , \quad (4)$$

with units of Å, mag, and mag, respectively. The corresponding correlation coefficients are $r = 0.58$, -0.60, and -0.64, respectively, and the slopes are significant at the 4.2 σ, 4.5 σ, and 4.9 σ level. Clearly, each of the three correlations is significant.

Could these correlations, though formally significant, be artifacts caused by the specific procedure used to derive the Δw_i? To answer this question, we derived residuals in four different manners. The first fit of the indices was made against M_B, the absolute magnitude based on a strictly linear distance-velocity relation (§ II). The second fit was against $M_B(R)$, an absolute magnitude based on fully corrected distances R derived by Faber *et al.* (1989). The third fit was against log σ_v, where σ_v is the velocity dispersion and is distance-independent. Finally, the fourth "fit" consisted of simply computing

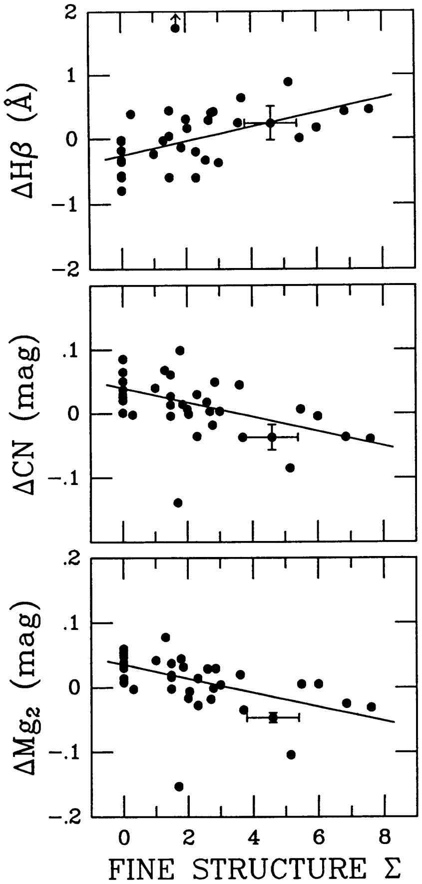

FIG. 2.—Correlations between line-strength residuals and fine-structure parameter Σ for 36 E galaxies. Straight lines mark least-squares fits; crosses indiate mean observational errors. Note that $\Delta H\beta$ correlates with Σ, whereas ΔCN and ΔMg_2 anticorrelate.

residuals Δw_i against the mean index $\langle w_i \rangle$. All four fits yielded good correlations between the Δw_i and Σ for our sample of 36 Es, with slopes significant at the 3–5 σ level. Thus, the Δw_i-Σ correlations are both significant and robust.

IV. DISCUSSION

What causes the correlations between line-strength residuals and fine structure? Two possibilities to be considered are metallicity and age variations. Unfortunately, the separation of age effects from metallicity effects via stellar population synthesis has proved difficult (see the excellent review by O'Connell 1986). Despite some recent progress (§ I), the spectroscopic signature of younger stars in old stellar populations has yet to be identified conclusively. To illustrate the problem in the present case, the $\lambda\lambda$4000–6300 spectra of Es with high Σ mimic those of lower luminosity, weak-lined Es along the general line-strength sequence (e.g., NGC 5018 is nearly a carbon copy of M32). Thus, we remain unable to determine, from spectroscopic evidence alone, whether intermediate-age stars are or are not present in our sample of ellipticals.

Yet, the new element introduced by the present work is the parameter Σ, which measures globally four types of fine structure thought to be caused by mergers (Hernquist and Quinn 1988, 1989). This parameter is, in some sense, a measure of dynamical youth since at least the ripples and jets (which together carry most of the correlation signal) are relatively short-lived. The striking combination of a $\Delta H\beta$-Σ correlation with ΔCN-Σ and ΔMg_2-Σ anticorrelations (Fig. 2) may then provide a clue: Metallicity variations seem unlikely to produce these combined correlations, while admixtures of intermediate-age stars to an old population, or variations in the mean population age, can reproduce them quite naturally.

Our main objection to metallicity variations as an explanation for these correlations is that mergers, as traced by a high Σ, should be metallicity-blind. That is, they should occur among galaxies of *all* metallicities and should not lead to preferentially metal-poor remnants, as a metallicity interpretation of Figure 2 would require. In fact, more merging and star formation would tend to *raise* the mean stellar metallicity, not lower it. Thus, metallicity variations seem unlikely to drive the Δw_i-Σ correlations.

On the other hand, *mean age variations explain the Δw_i-Σ correlations in a natural manner:* Adding A or F stars to an old population enhances the Balmer lines while weakening the metal lines, especially in the blue. If these A or F stars belong to an aging starburst induced by a merger, one may also expect the presence of morphological signatures such as those measured by Σ. This same mechanism may also explain the fact that, of the 74 E + S0 galaxies imaged by SS91, the 12 with the most fine structure ($\Sigma \geq 4$) are all luminous, $M_B \leq -20.8$, which is consistent with their luminosities having been boosted through mergers (Schweizer 1990).

To test this merger hypothesis for line-strength variations quantitatively, we computed simple models of evolving starbursts superposed on old populations (Bica, Alloin, and Schmidt 1990), using as ingredients star clusters of uniform metallicity (Bica and Alloin 1987). Families of models were computed for three different metallicities of the (evolving starburst, underlying old population): $[Z/Z_\odot] = (0,0)$, (0.6, 0.6), and (0, 0.6). Each family contains evolutionary tracks for starbursts with mass ratios relative to the old population of $\mu = 0.01, 0.02, 0.04, \ldots, 0.32$. The resulting equivalent widths of Hβ, CN, and Mg I + MgH on the Bica-Alloin system were transformed to indices on the Faber *et al.* (1985) system via 36 galaxies observed in common, and model "residuals" were formed by subtracting the line indices of the old population from those of the mixed population.

Figure 3 shows as an example a $\Delta H\beta$-ΔMg_2 diagram with evolutionary tracks from the $[Z/Z_\odot] = (0, 0.6)$ model family superposed. Note that after $\sim 10^8$ yr the evolutionary tracks converge and slope roughly in the same direction as the data points do. Thus, the observed anticorrelation between $\Delta H\beta$ and ΔMg_2 (and similarly that between $\Delta H\beta$ and ΔCN), which traditionally has been explained as primarily a metallicity effect (Burstein *et al.* 1984), can at least partially also be explained by aging starbursts embedded in old, metal-rich populations.

To estimate the relative contributions of age and metallicity variations to $\Delta H\beta$ and ΔMg_2, we have divided the galaxies in Figure 3 into three groups depending on their Σ. Note that the systematic shifts between the different Σ groups are comparable to the scatter within each group itself. This suggests that the influence of age variations on the residuals $\Delta H\beta$ and ΔMg_2 may be as important as that of metallicity variations.

In fact, a detailed analysis of the scatter in the Δw_i-Σ relations (Fig. 2) supports this first guess. Under the simplifying assumptions that (1) the mean relations in Figure 2 (eqs. [2]–[4]) measure roughly the age-dependent components $\Delta w_{i,\mathrm{age}}$ of the Δw_i, (2) the remaining scatter is due to a combination of observational errors and metallicity variations, and (3) the

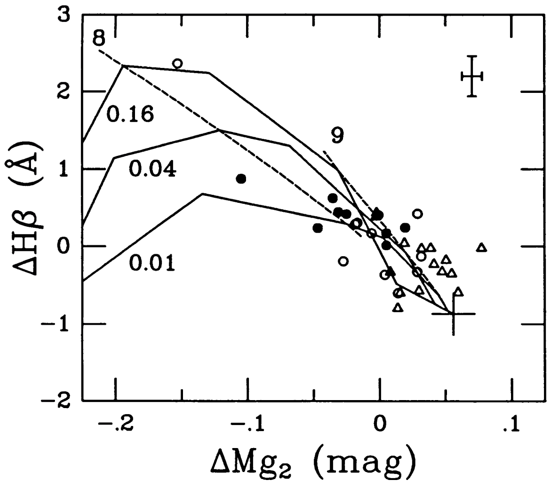

FIG. 3.—Two-residual diagram for $\Delta H\beta$-ΔMg_2. Data for 34 ellipticals without strong $H\beta$ emission are compared with evolutionary tracks (*solid lines*) of aging starbursts superposed on an old, metal-rich population; the three tracks show starbursts of mass ratio $\mu = 0.01, 0.04$, and 0.16 relative to the old population. Dashed lines mark isochrones at 10^8 and 10^9 yr. The zero point for the model residuals (*cross*) can be shifted arbitrarily. Data points for Es are coded according to fine structure as follows: $0 \leq \Sigma \leq 1.5$ (*triangles*), $1.5 < \Sigma \leq 3$ (*open circles*), and $\Sigma > 3$ (*filled circles*). Notice the general alignment of the data points with the converging model tracks and the segregation of points as function of Σ, suggesting that the residuals $\Delta H\beta$ and ΔMg_2 depend not only on metallicity, but also on age.

errors, $\Delta w_{i,\mathrm{age}}$, and metallicity-dependent components $\Delta w_{i,\mathrm{met}}$ are statistically independent, one can estimate the relative importance of $\Delta w_{i,\mathrm{age}}$ and $\Delta w_{i,\mathrm{met}}$. We find rms values $\Delta w_{i,\mathrm{age}}/\Delta w_{i,\mathrm{met}} = 0.23/0.20$ Å for $\Delta H\beta$, 0.028/0.023 mag for ΔCN, and 0.025/0.026 mag for ΔMg_2. These rough estimates seem to confirm that *age and metallicity variations contribute comparable amounts to the line-strength scatter in the* $H\beta$-M_B, CN-M_B, *and* Mg_2-M_B *diagrams* (see Fig. 1).

What kinds of starbursts may have produced the age-dependent part of the scatter? Unfortunately, the convergence of model tracks in Figure 3 makes it difficult to distinguish between weak, recent starbursts and strong, older starbursts. In the past, the case for four to 10 minor mergers ($m/M \lesssim 0.1$) per giant elliptical and Hubble time has been made from observed frequencies and estimated lifetimes of ripples (Schweizer 1983). Yet, two new lines of evidence suggest that fewer, but major, mergers may be involved instead: (1) The above-mentioned fact that the 12 E+S0 galaxies with $\Sigma \geq 4$ are all luminous suggests that the same events that created the fine structure also increased $-M_B$ by $\sim$1–2 mag at present. Only mergers between disk galaxies of comparable mass seem capable of raising the luminosity by that amount after a few Gyr have elapsed (Larson and Tinsley 1978). (2) Spectral observations of the 1–2 Gyr old merger remnants NGC 3921 and 7252 place these suspected protoellipticals (Toomre 1977; Schweizer 1990) just beyond the three point sequences of Figure 2, namely at $\Sigma \approx 9$–10, $\Delta H\beta \approx 2.5$, $\Delta CN \approx -0.2$, and $\Delta Mg_2 \approx -0.2$, thus supporting the notion that such *remnants of disk-disk mergers move roughly along the regression lines of Figure 2 as they age.* This evidence seems to favor the view that at least among ellipticals with high Σ, there probably are remnants of major mergers between disk progenitors of comparable mass.

In this scenario, ellipticals with much fine structure and large line-strength residuals contain embers of a variety of starbursts triggered by mergers. The most spectacular mergers may have formed protoellipticals as in NGC 3921 and 7252, while lesser mergers may have been accretions of the type presently observed in "E galaxies with shells." The latter are a collection of E, S0, and Sa galaxies, of which 15%–20% show enhanced Balmer lines indicative of recent starbursts (Carter *et al.* 1988). If this scenario is correct, then the Δw_i-Σ correlations may help us find the elusive population of intermediate-age (2–7 Gyr), postmerger ellipticals that King (1977) asked Toomre (1977) to reveal.

REFERENCES

Barnes, J. 1988, *Ap. J.*, **331**, 699.
Bica, E., and Alloin, D. 1987, *Astr. Ap. Suppl.*, **70**, 281.
Bica, E., Alloin, D., and Schmidt, A. 1990, *M.N.R.A.S.*, **242**, 241.
Burstein, D., Faber, S. M., Gaskell, C. M., and Krumm, N. 1984, *Ap. J.*, **287**, 586.
Carter, D., Prieur, J. L., Wilkinson, A., Sparks, W. B., and Malin, D. F. 1988, *M.N.R.A.S.*, **235**, 813.
Faber, S. M. 1973, *Ap. J.*, **179**, 731.
———. 1977, in *The Evolution of Galaxies and Stellar Populations*, ed. B. M. Tinsley and R. B. Larson (New Haven: Yale University Observatory), p. 157.
———. 1987, in *Nearly Normal Galaxies*, ed. S. M. Faber (New York: Springer), p. 175.
Faber, S. M., Burstein, D., Dalle Ore, C., and Gonzalez, J. 1991, in preparation (FBDG91).
Faber, S. M., Friel, E. D., Burstein, D., and Gaskell, C. M. 1985, *Ap. J. Suppl.*, **57**, 711.
Faber, S. M., Wegner, G., Burstein, D., Davies, R. L., Dressler, A., Lynden-Bell, D., and Terlevich, R. J. 1989, *Ap. J. Suppl.*, **69**, 763.
Hernquist, L., and Quinn, P. J. 1988, *Ap. J.*, **331**, 682.
———. 1989, *Ap. J.*, **342**, 1.
King, I. R. 1977, in *The Evolution of Galaxies and Stellar Populations*, ed. B. M. Tinsley and R. B. Larson (New Haven: Yale University Observatory), p. 418.
Larson, R. B., and Tinsley, B. M. 1978, *Ap. J.*, **219**, 46.
O'Connell, R. W. 1976, *Ap. J.*, **206**, 370.
———. 1980, *Ap. J.*, **236**, 430.
———. 1986, in *Stellar Populations*, ed. C. A. Norman *et al.* (Cambridge: Cambridge University Press), p. 167.
Pickles, A. J. 1985, *Ap. J.*, **296**, 340.
Sandage, A., and Tammann, G. A. 1981, *A Revised Shapley-Ames Catalog of Bright Galaxies* (Washington: Carnegie Institution of Washington) (RSA).
Schweizer, F. 1983, in *IAU Symposium 100, Internal Kinematics and Dynamics of Galaxies*, ed. E. Athanassoula (Dordrecht: Reidel), p. 319.
———. 1990, in *Dynamics and Interactions of Galaxies*, ed. R. Wielen (Heidelberg: Springer), p. 60.
Schweizer, F., and Ford, W. K. 1985, in *New Aspects of Galaxy Photometry*, ed. J.-L. Nieto (Berlin: Springer), p. 145 (SF85).
Schweizer, F., and Seitzer, P. 1988, *Ap. J.*, **328**, 88.
———. 1991, in preparation (SS91).
Seitzer, P., and Schweizer, F. 1990, in *Dynamics and Interactions of Galaxies*, ed. R. Wielen (Heidelberg: Springer), p. 270.
Toomre, A. 1977, in *The Evolution of Galaxies and Stellar Populations*, ed. B. M. Tinsley and R. B. Larson (New Haven: Yale University Observatory), p. 401.
Whitmore, B. C., and Bell, M. 1988, *Ap. J.*, **324**, 741.

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