Stellar Populations and Peculiar Velocities of Elliptical Galaxies

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Abstract.
The estimated distances of elliptical galaxies, as determined by the $D_n - \sigma$ technique, can be affected by stellar population variations and perhaps also dynamical effects due to mergers, leading to spuriously large positive peculiar velocities.

1. Measuring Peculiar Velocities

When extragalactic astronomers speak about peculiar velocities, they usually mean the difference between a galaxy's measured radial velocity and the velocity it would have if it were at rest with respect to the general Hubble expansion or $V_{pec} = V_{rad} - V_{dist}$. A radial-velocity-independent distance estimate is needed to determine V_{dist}. Presently, the best distance estimators are the infrared Tully-Fisher relation (Aaronson, *et al.* 1979) for spirals and the $D_n - \sigma$ method (Dressler *et al.* 1987) for ellipticals. In determinations of cluster distances, both have an advertised accuracy of 10-20% (Dressler *et al.* 1987; Aaronson *et al.* 1989).

The $D_n - \sigma$ relation relies on the correlation between the central velocity dispersion σ and a photometric diameter D_n, defined as the diameter of a circular aperture within which the blue surface brightness is 20.75 mag/arcsec^2. The velocity dispersion is nearly independent of distance while D_n simply scales as distance^{-1}. The displacement of a galaxy in the D_n direction from a fiducial $D_n - \sigma$ relation (usually the Coma cluster) is a measure of its relative distance.

Using the $D_n - \sigma$ distance estimator, Faber *et al.* 1989 determined peculiar velocities for ~ 400 ellipticals and found evidence for a large scale streaming motion through our part of the universe, of amplitude 600 km s^{-1} toward l=307°, b=9°, in very rough agreement with the microwave background dipole. This result has been generally supported by other studies, whether involving ellipticals (Lucey & Carter 1988) or spirals (Aaronson *et al.* 1989; Mathewson *et al.* 1991). Lynden-Bell *et al.* (1988) attribute the streaming motion to the gravitational influence of a "Great Attractor" located at a distance corresponding to ~ 4500 km s^{-1}.

2. Fine Structure Results of Schweizer *et al.*

In a seemingly unrelated study, Schweizer *et al.* (1990, S90) studied the "fine structure" of elliptical galaxies and its correlation with various line strength residuals. Fine structure is any measurable deviation from elliptical isophotes, such as shells, jets, boxy isophotes, or X-structure. All of these features are interpreted by S90 as phenomena resulting from mergers. The amount of fine structure is parametrized in a semi-quantitative way in S90 with an index Σ which ranges from 0 to 7.6 in their sample of 36 ellipticals (see S90 or Schweizer & Seitzer, this conference, for details). Larger Σ presumably implies a more recent or more traumatic merger event.

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S90 show that in their sample of ellipticals, Σ is correlated with the residuals of Mg_2, $H\beta$, and CN formed from the mean relation with absolute magnitude defined by a large sample of $\sim$ 400 ellipticals (Faber *et al.* 1991). Galaxies with larger Σ have more negative residuals of Mg_2 and CN and positive residuals of $H\beta$. They interpret this as differences in the mean ages of the ellipticals due to merger induced star formation, though except for a time dependence of some of the ingredients of the Σ index and the likelihood of star formation accompanying mergers, the correlations could be explained equally well by metallicity variations. Whether

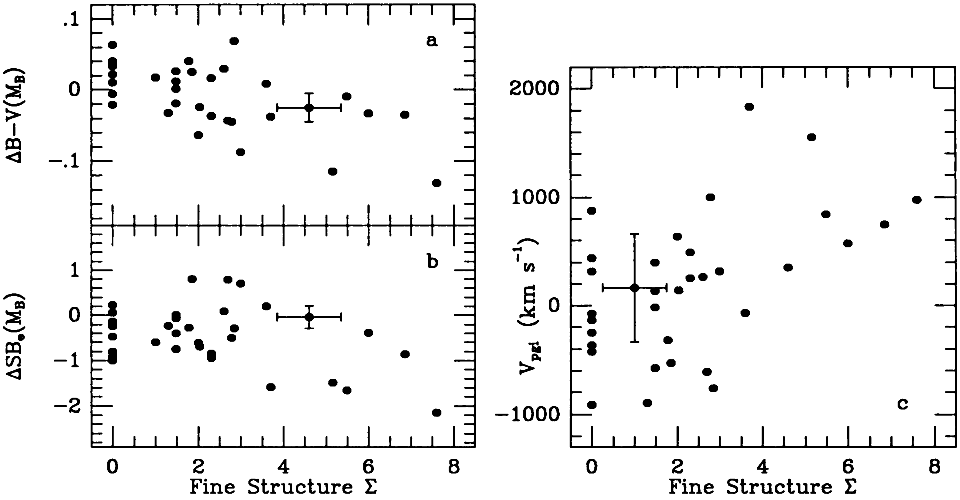

Fig. 1. Color and surface brightness residuals and peculiar velocity trends with the fine structure parameter Σ.

age or metallicity is responsible for the correlations, there should also exist trends with color and perhaps surface brightness. Using the data of Burstein *et al.* 1988, mean linear relations of $B - V$ and effective surface brightness, SB_e, versus absolute blue magnitude were defined. The residuals $\Delta(B - V)$ and ΔSB_e from these mean relations have been determined for 35 of the fine structure ellipticals. Figures 1a & b show the resulting correlations between the residuals and Σ. There is a clear trend for high Σ galaxies to be bluer, with somewhat higher surface brightness.

3. Effects on Distance Estimates

The determination of accurate distances to elliptical galaxies using the $D_n - \sigma$ relation requires a universal and tight correlation between D_n and $\log(\sigma)$. Yet the fine structure results paint a picture of common galaxy mergers and associated star formation, which must alter the relation between central velocity dispersion and D_n through mass-to-light differences due to mean age differences of the galaxies. Young stars in the high Σ galaxies lower M/L which inflates D_n, in turn causing an underestimate of the distance. This should result in systematically large positive

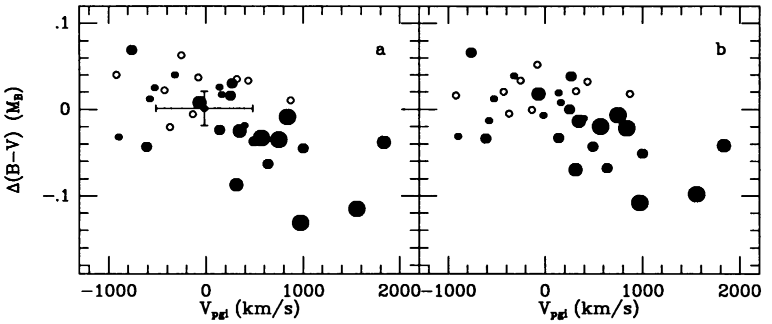

Fig. 2. Residuals of B − V from the mean relations with M_B and log(σ) for the fine structure galaxies, symbols scaled to Σ. See text for details.

peculiar velocities for the high Σ objects. To search for this effect, define a measure of peculiar velocity $V_{pgi} = V_{cmb} - R_e$ where V_{cmb} is the velocity of the group or cluster of which the individual galaxy is a member with respect to the microwave background (from Faber *et al.* 1987) and R_e is the *individual* $D_n - \sigma$ distance estimate, expressed as a velocity (computed using data in Burstein *et al.* 1988, Davies *et al.* 1988, and equation 3.1 of Lynden-Bell *et al.* 1988). This definition of peculiar velocity maximizes sensitivity to stellar population effects. Figure 1c shows the correlation obtained between Σ and V_{pgi}. The distances to the high Σ galaxies have been underestimated either because of stellar population variations or dynamical effects which alter the relation between D_n and σ.

Quantities more directly influenced by stellar populations than Σ provide a more sensitive test for effects on distance estimates. Figure 2a shows the trend of V_{pgi} with $\Delta(B - V)$, as defined above. Open circles are galaxies with $\Sigma = 0$; filled circles are scaled roughly with Σ. Objects with zero fine structure show no trend whatsoever with V_{pgi} while the other objects exhibit a clear effect, with the largest Σ galaxies tending to be at larger negative residuals and more positive peculiar velocities. Similar trends are found for surface brightness and Mg_2. The M_B used to generate these residuals are based on $D_n - \sigma$ distances, thus any distance errors will result in *positive* correlations in these diagrams, opposite to the trends seen. Because these plots show that the $D_n - \sigma$ distances *are* in error, the real effect is *larger* than demonstrated here because the distance errors work to weaken the correlations.

The results of Figure 2a are not dependent on using M_B as the independent variable to generate the residuals. In Figure 2b, residuals from the $\log(\sigma) - (B - V)$ relation are plotted against V_{pgi} for the fine structure galaxies, symbols the same as for Figure 2a. Here too, distance errors work against the trend seen. The correlations in Figure 2b are not as strong as in Figure 2a. This is due possibly to an effect demonstrated in the N-body simulations of Balcells & Quinn which show that a merger involving a small galaxy and a large elliptical can produce a dip in the central velocity dispersion of $\sim 40\,\mathrm{km\,s^{-1}}$. So even though an underestimate of

$\log(\sigma)$ will cause an underestimate of distance of the same magnitude as the stellar population inflation of D_n, it may not be manifested in Figure 2b because a decrease in color may be partly compensated for by a decrease in $\log(\sigma)$. That is, mergers cause galaxies to move along lines roughly parallel to the "unperturbed" $\log(\sigma) - (B - V)$ relation. That $\log(\sigma)$ is systematically too low for the high Σ objects can be demonstrated by calculating the residuals of $\log(\sigma)$ on M_B for the fine structure sample. All but 1 of the 9 objects with $\Sigma > 3$ have negative $\log(\sigma)$ residuals.

4. Discussion

How much of the large scale streaming motion can be explained away by stellar population effects? Little or none, probably, because both the spirals and the CMB dipole show rough qualitative agreement with the ellipticals. Faber *et al.* 1988 have also wisely bullet-proofed themselves against such effects by adopting the median $D_n - \sigma$ distance to groups and clusters, rather than relying on averages, though there may still be problems if too few objects in a group are measured or have young populations. However, taking stellar population effects into account, if only as a way of eliminating galaxies from a data set, will certainly result in smoother velocity fields which may facilitate modeling and help resolve some of the outstanding disagreements among the various large scale flow studies. One might be able to explain some of the rather large discrepancies between $D_n - \sigma$ and Tully-Fisher estimated distances to various groups and clusters (Mould *et al.* 1991).

Finally, the sensitivity of $D_n - \sigma$ to young stellar populations can be reduced by using R, I, or infrared bandpasses instead of B to define a fiducial diameter to correlate with $\log(\sigma)$.

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DISCUSSION

Terlevich: In a recent paper with J. Lucey and D. Carter we examined the properties of the fundamental plane (FP) with new improved data in Coma cluster including objects up to 5° away from the core, to check for environmental effects. The main conclusion is that the FP is very thin, all the scatter is consistent with observational errors. Furthermore, the FP is the same at all radii, *i.e.*, is independent of local density that changes by x100.

Gregg: Yes, the Coma cluster ellipticals do appear to be very well behaved in all this.

Faber: I just wish to point out that we have made an extensive test of the variation of fundamental-plane zero point for the whole sample in Burstein, Faber, & Dressler (*Ap. J.* 1989). There, we plotted V_{pec} (group) vs. richness and included also field galaxies. There was no correlation with R or offset for field galaxies. This suggests there is no wholesale problem with the 7S distances, which is what you said.

Djorgovski: The effects you discussed add to the growing body of evidence that differences in formation histories (which may vary systematically with the environment) can modify galaxian properties in a way which would masquerade as false peculiar velocities. One particularly instructive example is a direct comparison of the peculiar velocities for clusters, measured with the Tully-Fisher relation and with the $D_n - \sigma$ relation (*c.f.* Mould *et al. Ap. J.*, in press): there is no correlation whatsoever.

Gregg: I have seen the Mould *et al.* results. I would say there is some correlation present, but it is very poor. This is an intriguing state of affairs and should be worrisome to those who measure peculiar velocities.