A Purely Photometric Fundamental Plane ?

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1 Economical Distance Indicators

The Tully–Fisher (TF) and Fundamental Plane (FP) relation are the most commonly used distance-indicator relations. Observationally, their ingredients are analogous: magnitudes, radii and surface brightnesses require relatively easy to obtain optical photometric data. Rotational widths and velocity dispersions are instead more demanding, both in terms of telescope aperture and of longer exposures. An economical distance-indicator, based entirely on photometric parameters, would be an extremely valuable tool for observational cosmology, if it were to achieve an accuracy comparable to those of the TF and FP relations.

The Kormendy (1977) relation between r_e and μ_e is one such candidate. The scatter in the relation is fairly large, but this disadvantage can be partly offset, when the relation is applied to clusters of galaxies, by the availability of a large number of objects, that can statistically compensate for the large scatter in the derivation of the cluster distance. In Fig.1a we present the Kormendy relation for 405 E and S0 galaxies in the Coma, A1367, and A2634 clusters. The rms scatter in $\log R_e$ is 0.19, equivalent to an uncertainty of 0.95 mag. in the distance modulus of a single galaxy. However, the residuals from the Kormendy relation are not random: they correlate very well with the galaxy magnitude, or, equivalently, with the galaxy velocity dispersion, as shown in Fig.1b. Because of the combination of a large scatter and of residuals correlated with the galaxy luminosity, the Kormendy relation is severely affected by the cluster population incompleteness bias (Sandage 1994, and references therein): both the zero-point and the observed dispersion depend on the limiting magnitude of the sample. It is therefore very important to derive accurate bias corrections before using the Kormendy relation for cosmological applications.

Other economical photometric distance indicators are based on the determination of a characteristic magnitude for a cluster sample. Sandage & Hardy (1973) have used the luminosity of the first ranked galaxy in a cluster, that they measured to be approximately constant, with a dispersion of only 0.28–0.32 magnitudes. A modified version of this method was proposed by Hoessel (1980), and has been used most recently by Lauer & Postman (1994). The uncertainty associated with this method is approximately 16%, or 0.35 magnitudes (Lauer & Postman 1994). Also luminosity functions (LF) have been used as distance indicators. Globular clusters and planetary nebulae LF (Jacoby et al. 1992, and references therein) have been used to derive redshift-independent distances for

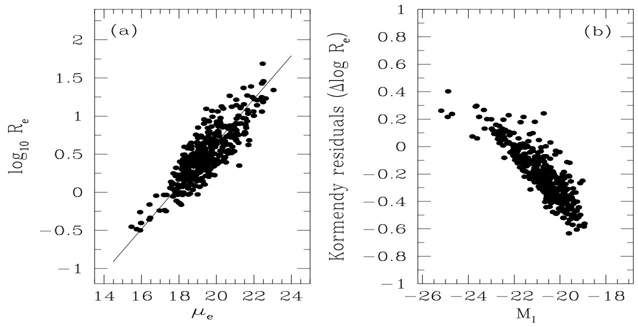

Fig. 1. (a) The Kormendy relation between effective radius and effective surface brightness. (b) The residuals from the Kormendy relation, as a function of the galaxy magnitude. The photometric parameters in this and the following figure have been derived from I band CCD observations obtained with the 0.9m telescope at KPNO.

individual galaxies. The same technique can be applied to the galaxy LF in a cluster, provided that such LF is to a large extent a universal one. Since giant E and S0 galaxies and spiral galaxies have been shown to have a Gaussian LF (Sandage et al. 1985), these galaxies would provide the most accurate determination of a characteristic magnitude, through the measurement of the peak of the Gaussian.

2 The Photometric Fundamental Plane

Here we propose to use jointly the Kormendy relation and one of the methods that can provide a characteristic magnitude for a cluster sample, to derive a modified version of the FP relation, based entirely on photometric parameters. We define for each galaxy ΔM as the difference between the galaxy's magnitude and the sample characteristic magnitude, and use ΔM, a distance–independent parameter, in substitution of the velocity dispersion in the FP relation. We illustrate the characteristics of such a Photometric Fundamental Plane (PFP), using the peak of the Gaussian LF of E and S0 galaxies to derive the characteristic magnitude. We combined the sample of 405 galaxies already used in Fig.1, assuming the clusters have negligible peculiar motions, and derived a Gaussian LF using a maximum likelihood method. Figure 2a shows the edge-on projection of such a PFP. The rms scatter in $\log R_e$ about the PFP plane is 0.096, which is approximately half the scatter in the Kormendy relation, and very similar to the scatter shown by the FP relation. This scatter, however, is not the only source of uncertainty in the determination of a cluster distance with the PFP, because the uncertainty in the determination of the characteristic magnitude introduces a systematic uncertainty in the determination of the PFP zero-point. For large samples this systematic uncertainty becomes the dominant source of error in a cluster distance determination. However, because the ΔM coefficient α_M in the PFP is significantly smaller than 0.2 (0.13 for the sample used here), the effect of this systematic uncertainty on the distance determination is reduced by the ratio $\alpha_M/0.2$, which is $\simeq$0.65 in our case. A comparison of the accuracy in a distance determination that can be obtained using the Fundamental Plane, the PFP, and the Kormendy relation, as a function of sample size, is shown in Fig. 2b. If the characteristic magnitude can be measured with an uncertainty of 0.3 magnitudes or less, the PFP can offer an accuracy in distance measurements comparable to that of the FP, for a typical FP cluster sample, requiring only one fifth to one tenth of the telescope time.

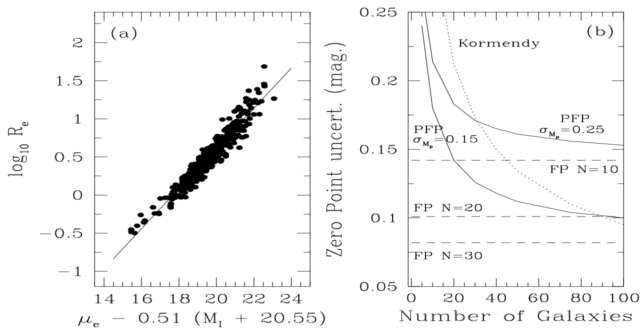

Fig. 2. (a) Edge-on projection of the PFP. (b) Comparison of the accuracy that can be obtained using the PFP, Kormendy, and FP relation, vs sample size. The horizontal dashed lines give the accuracy achieved using the FP (fixed sample size, assuming a scatter in the FP of 0.085, or 0.43 mag.). The solid line curves give the accuracy achieved using the PFP, for two different values of the uncertainty in the determination of the characteristic magnitude. The dotted line gives the accuracy obtained with the Kormendy relation.

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