Decoupling Cosmological and Evolutionary Effects

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Traditionally, cosmological tests and studies of galaxy evolution have employed observables, such as size and magnitude, that are affected both by curvature and (potentially) evolution. Because of this ambiguity, studies of galaxy evolution should focus particular attention on observables that are independent of cosmology, such as surface-brightness, color, and image structure. Below I sketch an example of how size and magnitude alone are insufficient to probe galaxy evolution at moderate depths (z$\sim$0.3, I=20.5). I then demonstrate that there is a reasonable correlation between average surface-brightness and color in the near-infrared. This correlation, as well as the bivariate distribution (in a comoving sense) can be used as a sensitive probe of galaxy evolution because (1) both observables are cosmologically independent, and (2) the observables are sensitive to changes in density and composition of stellar populations.

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1 Size and Luminosity

It has long been known that there exists a very strong correlation between the optical size and luminosity of local galaxies (Holmberg 1975, RC2, Huchra 1977). The strength of this correlation could in principle be due in part to a selection effect, e.g. against galaxies with very low surface-brightness (undetected), or very high surface-brightness (stellar appearance). However, deeper surveys find this correlation persists for galaxies selected well above the detection limit (Bershady 1993), as illustrated in figure 1 for galaxies at z_{median}=0.15 from the sample of Bershady *et al.* (1994). [Colless *et al.* (1994) have shown a similar result holds for galaxies at z$\sim$0.3.] This correlation also holds in the near-infrared, as illustrated in figure 1. Interestingly, the correlation is somewhat weaker, i.e. galaxies in this B_J selected sample have a larger range in K band surface-brightness. We return to this point below.

The strong correlation between size and luminosity makes it straightforward to model the apparent size and magnitude distribution in magnitude-limited samples because one can translate the luminosity function into a size function in a simple and reliable way. One recent illustration of this application that also takes advantage of HST data is illustrated in figure 2, as adapted from Phillips *et al.* (1994; other studies of this nature using HST data can be found in the proceedings of this conference, e.g. see contributions from Ellis, Griffiths, Windhorst, and references therein). In our study, we found that a non-evolving model fit the apparent size-magnitude distribution to I=20.5 remarkably well, assuming q_0=0.1. However, had we assumed q_0=0.5 (also illustrated in figure 2), our result would have been qualitatively unchanged. If there has been evolution in the galaxy population at these depths (z_{median}~0.3) than it is subtle and comparable to the effects of changing the assumed cosmology. To make further progress towards detecting unambiguously the presence of galaxy evolution, the observables need to be unaffected by cosmology.

2 Surface-brightness and color

Many of the observables that are independent of cosmology, e.g. profile shape, concentration, or spectroscopic line-widths, are demanding in terms of telescope time required for observations at large redshift. Here we explore just two observables that are relatively easy to measure, namely color and average surface-brightness. In figure 3 the *rest-frame* V and K band surface-brightness is plotted against *rest-frame* V-K color (for the same sample as in figure 1). There is a moderately strong correlation between the K band surface-brightness and V-K color, not present for the V band surface-brightness. This is somewhat a reflection of the effect found in figure 1: these galaxies have a larger range in surface-brightness in the near-infrared than the optical, with the lower-surface-brightness objects being preferentially at lower luminosities. This, combined with color-luminosity effects, is then qualitatively consistent with what is seen in figure 3.

Although not as strong as the size-luminosity correlation, the optical–near-infrared color–surface-brightness correlation should be sufficient to provide a diagnostic tool to explore galaxy evolution. For example, constraints can be placed on the increase in the merger rate as a function of look-back time. The critical point is that the comoving distribution of galaxies in this color–surface-brightness plane will be unaffected (except in total number) by cosmology. Merger-induced galaxy evolution should produce changes in this distribution, as

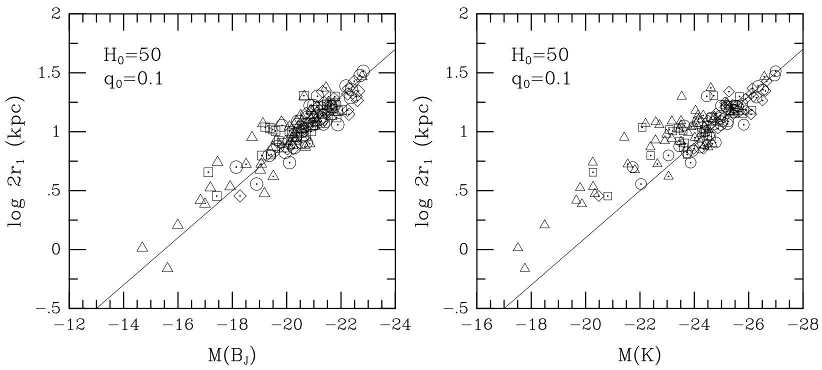

Figure 1: Size vs. luminosity in the optical B_J and near-infrared K bands. Lines at constant surface-brightness are drawn for reference. The size measure is equal to twice the first radial moment of the light profile ($2r_1$). The sample is statistically representative to B_J=20.5.

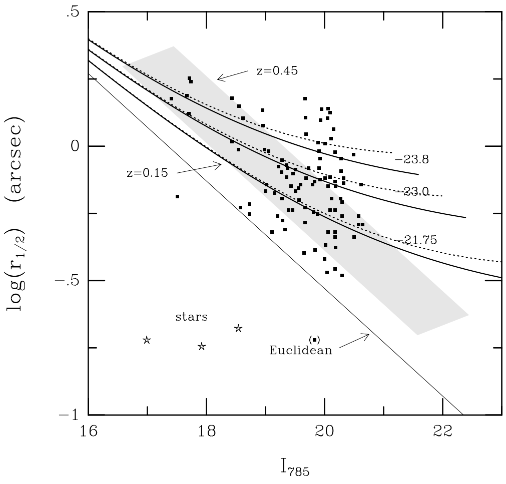

Figure 2: Apparent size (half-light radius) vs. I (F785LP) magnitude distribution to I∼20.5 from Phillips *et al.* (1994; a bright galaxy sample from the HST Medium Deep Survey). The three solid curves represent tracks in redshift for the upper-, median, and lower-quartile luminosities and rest-frame sizes, predicted by a non-evolving model (q_0=0.1, H_0=50; see Phillips *et al.* 1994 for details); 50% of the galaxies should be within these three tracks. The shaded area is the expected location in redshift (along the tracks) of the median half of galaxies, i.e. 50% of the galaxies should be within this shaded area. The dashed lines are luminosity-size tracks assuming q_0=0.5.

anticipated by the merger models of Mihos and Hernquist (1994a,b).

3 Discussion

I recall two comments made at the end of this presentation which were particularly useful in that they underscored the above points.

Ofer Lahav emphasized that it was not only the correlation between observables (such as color and surface-brightness) that was interesting, but also the statistical distribution. This is an important point since the shape of any distribution function of observables (in a comoving volume) is also a cosmologically independent quantity. Therefore changes in the *shape* (but not normalization) of a distribution function can be used as a measure of evolution. The most commonly explored distribution function has been luminosity, but there is no reason not to use other distribution functions. Multivariate distribution functions offer more leverage if the observables are chosen correctly to probe different physical conditions of galaxies, e.g. luminosity, color, surface-brightness (or alternatively, size), image structure, etc.

Myungshin Im pointed out that size and apparent magnitude could be used to rule out certain evolutionary models, even though these observables are cosmologically dependent quantities. This is certainly true as long as the evolutionary models predict sufficiently drastic changes in rest-frame size and luminosity so as to dwarf the effects of space-time curvature. However, if galaxy evolution is a subtle phenomenon, as suggested by some work (e.g. Koo & Kron 1992, Koo this conference), then it is not clear that such observables will be sufficient to discern the effect – at least at intermediate redshifts. The example given above showed that for $0.15<z<0.45$ the size and apparent magnitude distribution of galaxies brighter than 0.1 L_* was well described by a non-evolving galaxy population with metric-size – luminosity correlations consistent with local galaxies. For these galaxies, more sensitive tests of evolution must be made using observables that are independent of cosmology.

4 References

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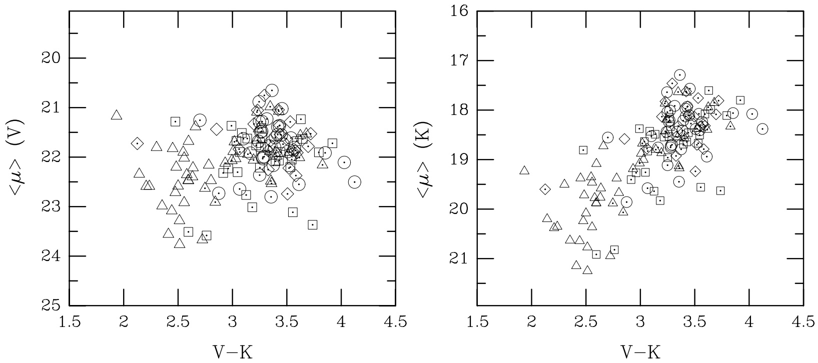

Figure 3: Rest-frame V and K surface-brightness averaged within twice the first radial moment of the light distribution vs. rest-frame V-K color.

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