Stellar Mass-to-Light Ratios and the Tully-Fisher relation

Roelof S. de Jong\(^1\) and Eric F. Bell

Steward Observatory, 933 N. Cherry Ave., Tucson, AZ 85721, U.S.A.

Abstract. We use spiral galaxy evolution models to argue that there are substantial variations in stellar mass-to-light ratio \((M/L)\) within and among galaxies. Our models show a strong correlation between stellar \(M/L\) and galaxy color. We compare the colors and maximum-disk \(M/L\) values of a sample of galaxies to the model color-\(M/L\) relation, finding that a Salpeter IMF is too massive but that an IMF with fewer low mass stars fits the observations well. Applying our color-\(M/L\) relation to the Tully-Fisher (TF) relation, we find a stellar mass TF-relation that is independent of originating passband. Adding the HI gas mass, we find that the maximum slope of the baryonic TF-relation is 3.5.

1. Galaxy Evolution Models and Mass-to-Light Ratios

We have used the galaxy evolution models described by Bell & Bower (2000) to investigate stellar \(M/L\) ratios of galaxies. These models were tuned to fit the observed trends between the colors and the structural parameters of spiral galaxies (Bell & de Jong 2000). Using a local gas density dependent star formation law, the photometric evolution is calculated, taking chemical evolution into account. As well as a closed box model we have models with gas infall and outflow, mass dependent formation epochs and star bursts. All models show large variations in \(M/L\), amounting from a factor 8 in \(B\) to 2 in \(K\), but in all models we find a strong correlation between \(M/L\) and optical color (e.g. Fig. 1a). The slope of the color-\(M/L\) relation is very robust against the particular stellar population synthesis model and against the exact details of the galaxy evolution model. The main uncertainty in the correlation is the zero-point, which is determined by the assumed IMF; most notably by the relative amount of low mass stars, which contribute to the mass but not to the luminosity and color.

A constraint on the color-\(M/L\) correlation zero-point can be obtained from galaxy rotation curves. The stellar disk in a galaxy cannot be more massive than allowed by its rotation curve, resulting in a maximum-disk \(M/L\). In Fig. 1b we show the maximum-disk \(M/L\) values versus the extinction corrected \(B-R\) color for the Verheijen (1998) galaxy sample. These \(M/L\) values are truly upper limits: any mass not accounted for in the rotation curve decompositions will push the stellar \(M/L\) even lower. The solid line in Fig. 1b shows the fit to the color-\(M/L\) relation for our best model using a standard Salpeter IMF. Clearly

\(^1\)Hubble fellow
this model over-predicts the maximum allowed mass for many galaxies, as many galaxies lie below the line. Using a Salpeter IMF with a flat slope below 0.6 $M_\odot$ as suggested by recent observations results in the dotted line which is consistent with the observations (for $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$ or $D_{\text{Ursa Major}} = 20 \text{ Mpc}$).

2. Tully-Fisher Relations

Observed TF-relations are known to have a passband dependence, both in slope and in zero-point. Applying Tully et al. (1998) extinction corrections and our color-$M/L$ correlations, we can calculate stellar mass TF-relations from the observed TF-relations. We find that the stellar mass TF-relations derived from the different passbands are equal to within the uncertainties. By adding in the HI gas mass we can calculate the baryonic TF-relations (Fig. 1c). We find that the slope of the baryonic TF-relation must be less than $3.5 \pm 0.2$, significantly lower than found by McGaugh et al. (2000), mainly due to our use of stellar M/Ls consistent with maximum disk constraints and our exclusion of low luminosity dwarfs with poorly determined inclinations and rotation velocities.

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