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

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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

\footnote{Hubble fellow}
Figure 1.  a) $M/L_B$ and $M/L_K$ versus $B-R$ for our mass dependent formation epoch model with star bursts.  b) maximum-disk $M/L_K$ versus $B-R$ of the Verheijen (1997) sample. Solid line is a fit to our best Salpeter IMF model, dotted line modified Salpeter IMF.  c) Baryonic TF-relations derived from $B$ ($\circ$), $I$ (+) and $K$ (•) observations.

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 $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$ or $D_{\text{UrsaMajor}} = 20$ 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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References

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