Dark matter and the Tully-Fisher relations of spiral and S0 galaxies

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Abstract. We construct mass models of 28 S0–Sb galaxies. The models have an axisymmetric stellar component and a NFW dark halo and are constrained by observed K_S-band photometry and stellar kinematics. The median dark halo virial mass is $10^{12.8}\,M_\odot$, and the median dark/total mass fraction is 20% within a sphere of radius $r_{1/2}$, the intrinsic half-light radius, and 50% within R_{25}. We compare the Tully-Fisher relations of the spirals and S0s in the sample and find that S0s are 0.5 mag fainter than spirals at K_S-band and 0.2 dex less massive for a given rotational velocity. We use this result to rule out scenarios in which spirals are transformed into S0s by processes which truncate star formation without affecting galaxy dynamics or structure, and raise the possibility of a break in homology between spirals and S0s.

Keywords: galaxies: elliptical and lenticular, cD – galaxies: kinematics and dynamics – galaxies: spiral – galaxies: stellar content

MASS MODELS

In [1] we presented mass models for a sample of 28 edge-on early-type disk galaxies (S0–Sb). The models are composed of an axisymmetric stellar component, based on observed K_S-band photometry [2] assuming a constant stellar mass-to-light ratio $(M/L)_{K_S}$, and a spherical NFW dark halo [3] of mass $M_{\rm DM}$. The model parameters are constrained by solving the Jeans equations assuming a constant anisotropy in the meridional plane $\beta_z \equiv 1-\sigma_z^2/\sigma_R^2$, which yields a prediction of the second velocity moment, and comparing to observed stellar kinematics [5]. These simple models are able to reproduce the wide range of observed stellar kinematics, which extend to 2–3 effective radii.

The median $(M/L)_{K_S}$ for the sample is 1.09 (solar units) with an rms scatter of 0.33. The median $M_{\rm DM}$ for the sample is $10^{12.8}\,M_\odot$ with an rms scatter of 0.7 dex. This is equivalent to halo concentrations between 7 and 9. The mass models have a median dark/total mass fraction of 20% within a sphere of radius $r_{1/2}$, the intrinsic half-light radius (approximately equal to $1.33\,R_{\rm e}$, where $R_{\rm e}$ is the projected half-light (or effective) radius and 50% within R_{25}. All but two models are consistent with being maximal [6], although they were not constructed under this assumption. Models without a dark halo are also able to reproduce the observed kinematics satisfactorily in most cases, but the improvements when halos are added are statistically significant. Moreover, a preliminary comparison shows that the stellar mass-to-light ratios of mass models without dark matter very significantly exceed the predictions of stellar population models for plausible initial mass functions, but this effect is significantly reduced for our preferred mass models with dark haloes. We will use these results to measure the normalization and universality of the IMF in more detail in the future.

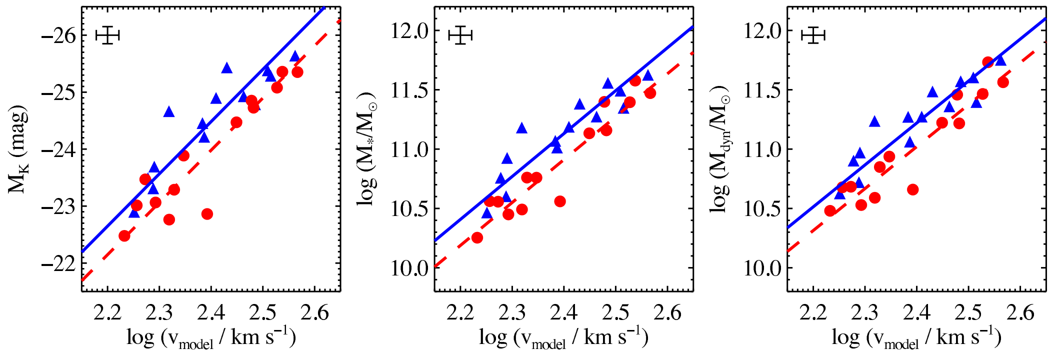

FIGURE 1. Tully-Fisher relations of the sample of 28 disk galaxies, shown as functions of K_S-band luminosity, stellar mass and dynamical mass. Spirals are shown as blue triangles with a solid line of best fit, S0s as red circles with a dashed line. Median error bars are shown in the top left of each plot.

THE TULLY-FISHER RELATION

Using the circular velocities of the models, we constructed Tully-Fisher relations (TFRs) as functions of luminosity, stellar mass, and dynamical mass for the S0s and spirals separately (Fig. 1). We find that S0s are 0.5 mag fainter than spirals at K_S-band for a given rotational velocity. In stellar population synthesis models in which star formation is truncated, this fading would take $\sim$ 1 Gyr, but we know that the processes which form S0s began at earlier times [7, 8]. We therefore rule out scenarios in which spirals are transformed into S0s by an environmental or secular process which simply truncates star formation, without affecting the dynamics or structure of the galaxies.

The offset of the S0 TFR could be explained by recent star formation in S0s, but we find that the offset of the S0 TFR persists as a function of both stellar and dynamical mass (S0s are 0.2 dex less massive for a given model circular velocity). The offset could therefore be explained by a small (10–20%) but systematic contraction or compactification of spirals as they transform to S0s, an effect consistent with the morphological dependence of the local size–luminosity relation [9]. This possibility is discussed in more detail in our paper on the TFR [10].

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