DARK MATTER AND THE TULLY-FISHER RELATION IN 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 an 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 15% within one effective 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 at K_S-band than spirals 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.

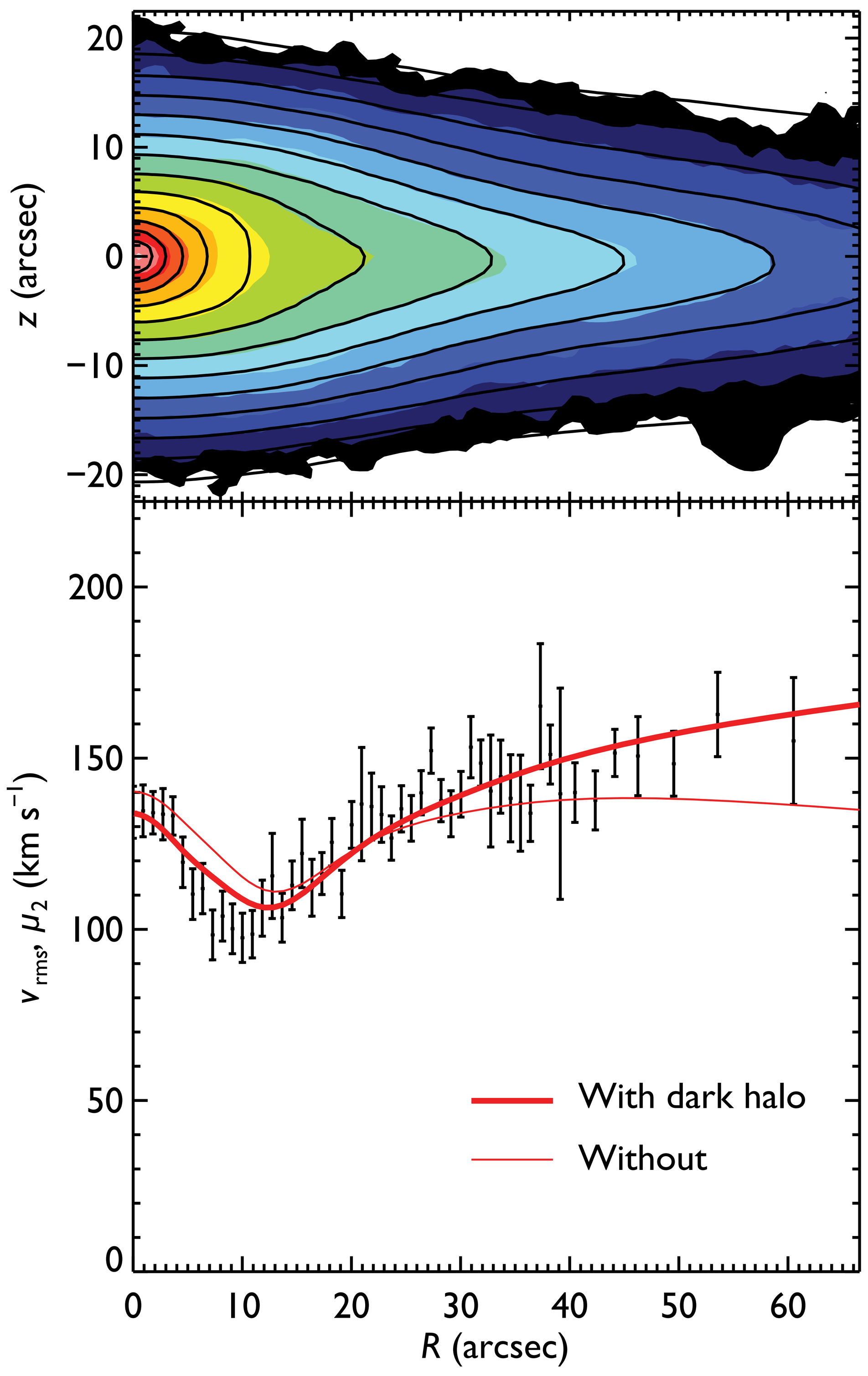


Figure 1
Observed photometry (Bureau et al. 2006) and multi-Gaussian expansion of the luminous component of the galaxy (*top*). Observed stellar kinematics and model second velocity moment with and without dark halo (*bottom*)

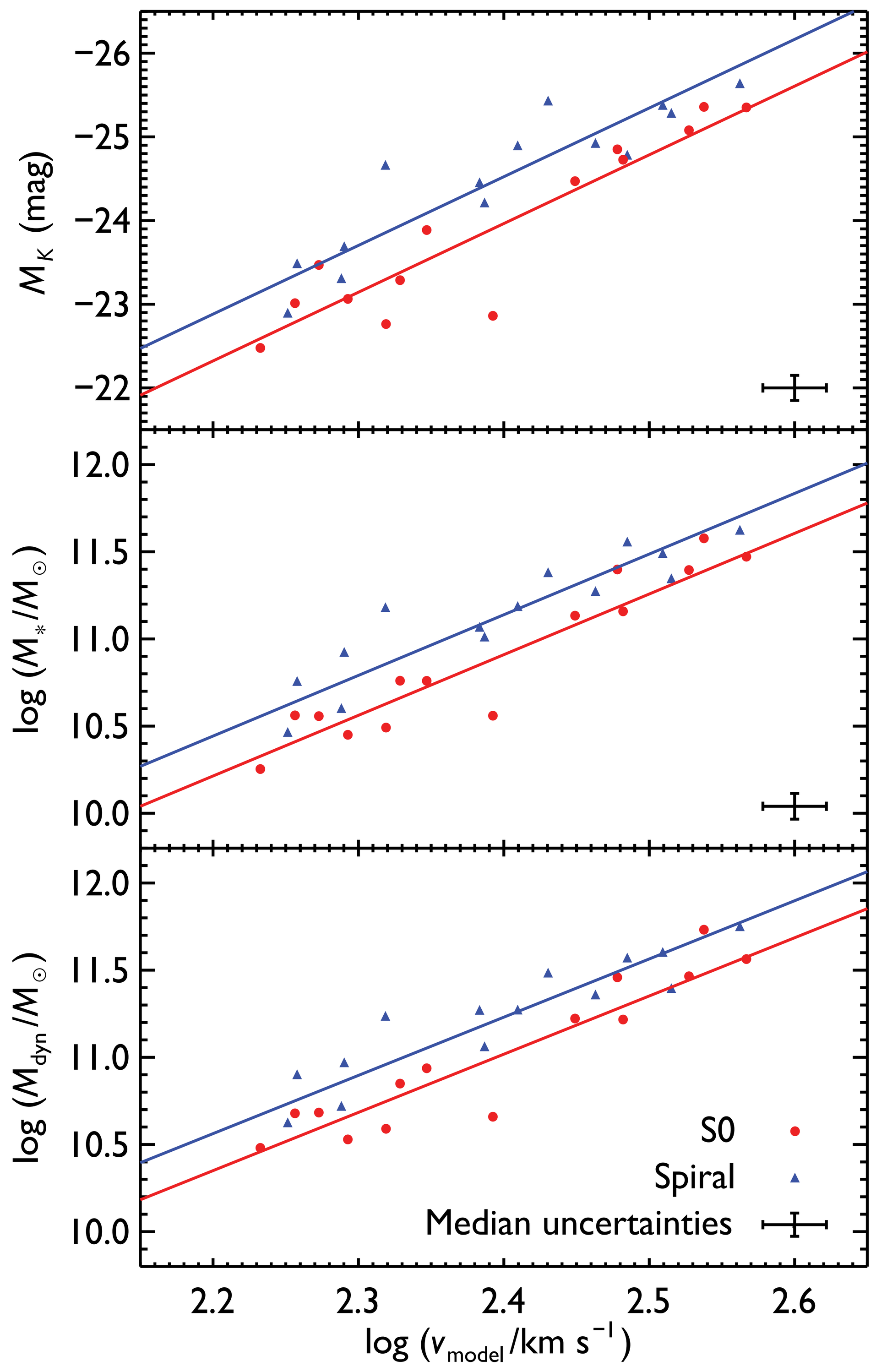
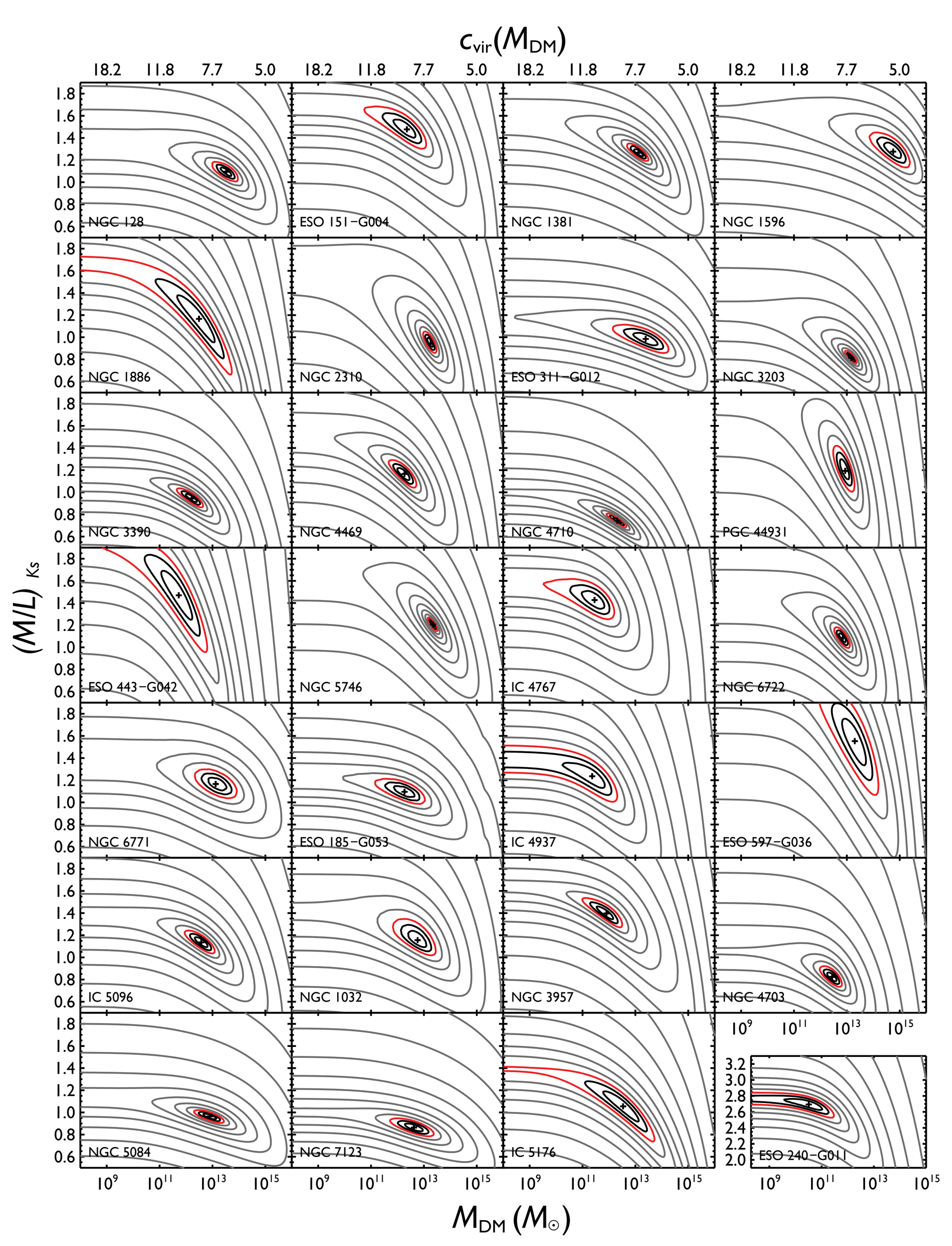


Figure 3
Tully-Fisher relations for the spirals and S0s in the sample as functions of K_S-band luminosity (*top*), stellar mass (*middle*) and dynamical mass (*bottom*).

1 Mass models

In Williams et al. (2009), we present mass models of 28 edge-on early-type disk galaxies (S0–Sb). These were found by solving the Jeans equations for an axisymmetric stellar component of constant mass-to-light ratio, $(M/L)_{K_S}$, and an NFW halo (Navarro et al. 1997) assuming constant anisotropy in the meridional plane, β_z (Cappellari 2008). This gives a prediction of the second velocity moment, which we compare to the observed stellar kinematics (Chung & Bureau 2004) to constrain the three parameters of the model, $(M/L)_{K_S}$, halo mass M_{DM} and β_z. An example model for one of the 28 galaxies is shown in FIGURE 1.

These simple models are able to reproduce the wide range of observed stellar kinematics, which extend to 2-3 effective radii. In FIGURE 2 we show contours of χ^2 for the sample. This demonstrates the constraints we are able to place on $(M/L)_{K_S}$ and M_{DM} for each galaxy.



2 Model halo properties

The median $(M/L)_{K_S}$ for the sample is 1.09 (solar units) with an rms scatter of 0.33.

The median M_{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 15% within one effective radius and 50% within R_{25}. All but two are maximal.

Models without a dark halo are also able to reproduce the observed kinematics satisfactorily in most cases. The improvement when a halo is added is statistically significant, however, and the stellar mass-to-light ratios of mass models with dark haloes match the independent expectations of stellar population models better.

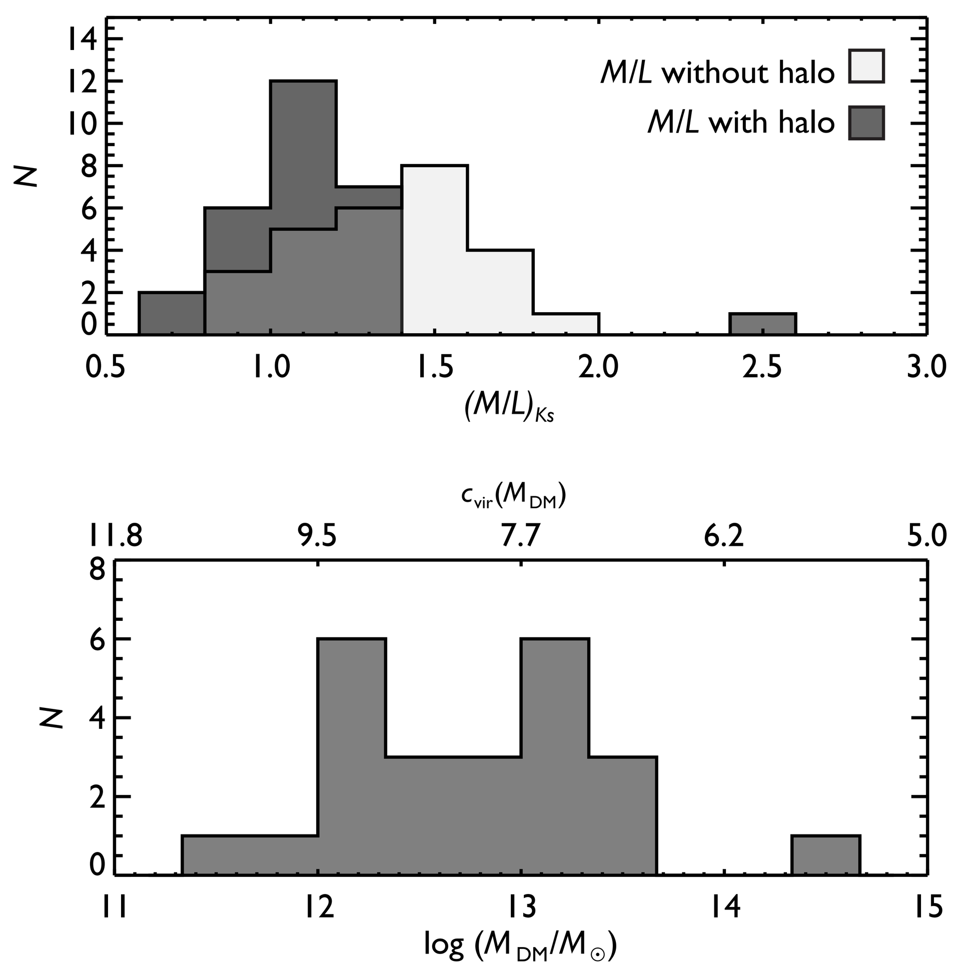


Figure 2
Left: Contours of χ^2 (observed kinematics – model) as a function of $(M/L)_{K_S}$ and M_{DM} for the complete sample. The red contours are the 3σ confidence intervals. For clarity the figure has been marginalized over the third parameter, β_z. *Above*: histograms of the parameters of the best-fitting mass models.

3 The Tully-Fisher relation and the origin of S0s

Using the circular velocity of the models, we constructed Tully-Fisher Relations (TFRs) as functions of luminosity, stellar mass, and dynamical mass for the S0s and spirals separately (see FIGURE 3, Williams et al. in preparation. Preprints available).

We find that S0s are 0.5 mag fainter at K_S-band than spirals for a given rotational velocity. For truncated star formation stellar population synthesis models, this fading would take ~1 Gyr, but we know that the processes which form S0s began at earlier times (Dressler et al. 1997, Fasano et al. 2000). 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 stellar and dynamical mass. This is consistent with a small (10–20%) but systematic contraction of spirals as they transform to S0s, consistent with the morphological dependence of the local size—luminosity relation (Courteau et al. 2007).

References

Bureau et al., 2006, MNRAS, 370, 753 • Cappellari, 2008, MNRAS, 390, 71 • Chung & Bureau, 2004, AJ, 127, 3192 • Courteau et al., 2007, ApJ, 671, 203 • Dressler et al., 1997, ApJ, 490, 577 • Fasano et al., 2000, ApJ, 542, 673 • Navarro et al., 1997, ApJ, 490, 493 • Williams et al., 2009, MNRAS, in press