# A SHARED TULLY-FISHER RELATION FOR SPIRAL AND S0 GALAXIES

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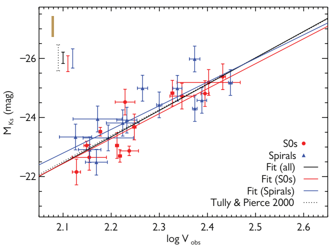
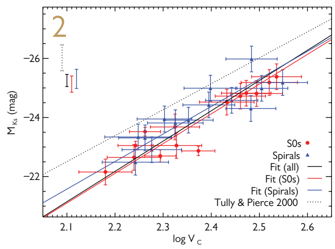
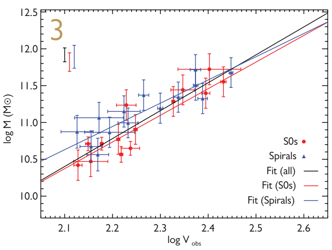
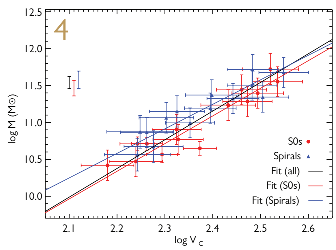



## FIGURES 1–4

Tully-Fisher-like diagrams for a sample of 14 spiral galaxies (blue triangles) and 14 S0s (red circles).

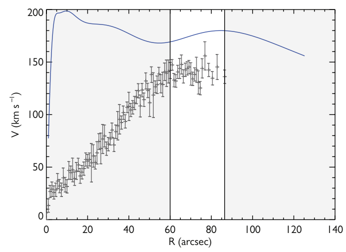
The horizontal axes of Figures 1 and 2 show the observed line-of-sight stellar velocity in the flat region of the rotation curve.

The horizontal axes of Figures 3 and 4 show the circular velocities of mass models of the galaxies evaluated at the same radius as the flat region of the observed rotation curve.

The vertical axes of Figures 1 and 3 show the observed $K_S$-band total absolute magnitude taken from 2MASS. Figures 1 and 3 also show the relation between magnitude and HI line width found by Tully & Pierce (2000) as a dotted line. Following Bedregal et al. (2006), we have calibrated the intercept of this reference relation by assuming $W_{max} = 2v_{max}$ and adopting $H_0 = 70$ km/s/Mpc (where $W_{max}$ is the width of the spatially unresolved HI line profile).

The vertical axes of figures 2 and 4 show the dynamical mass of the galaxy. We calculated this using the dynamical mass-to-light ratio measured in Williams et al. (2008).

The error bars in the top-left of each diagram show the intercept $a$ (and error) in the fit $y = a + b\log(x - 2.5)$ for each sample (all, spirals, S0s, Tully & Pierce 2000).




## FIGURE 5

Sample observed stellar kinematics (points) and model circular velocity (line) for NGC 4469. The velocities plotted in Figures 1–4 are the mean of those within the unshaded radial interval. The circular velocity is that of the axisymmetric mass distribution determined as described in Figure 6.

## 1 INTRODUCTION

The Tully-Fisher relation is a well-known and strong correlation between the total magnitude and maximum rotational velocity of spiral galaxies. It is a natural consequence of the assumption that such galaxies have approximately equal dynamical mass-to-light ratios.

Many authors have argued that S0 galaxies are the faded direct descendents of spiral galaxies (Dressler 1980; Dressler et al. 1997, Moran et al. 2007). Processes such as strangulation (Larson et al. 1980) or ram-pressure stripping (Gunn & Gott 1972) are thought to have stripped these galaxies of their gas and left them unable to form stars. S0s are therefore expected to emit less light for a given dynamical mass than spirals and should have higher mass-to-light ratios on average. They should therefore lie below the Tully-Fisher relation of spiral galaxies. Indeed, this is exactly what Bedregal et al. (2006) found when they compared several samples of cluster S0s to the spiral Tully-Fisher relation of Tully & Pierce (2000).

## 2 DATA & MODELS

In this work we analyse the Tully-Fisher relation of a sample of 28 edge-on disk galaxies, half of which are spirals and half of which are S0s. We do this using stellar kinematics (Chung & Bureau 2004) and $K$-band images (Bureau et al. 2006) that were observed and reduced identically for both spirals and S0s.

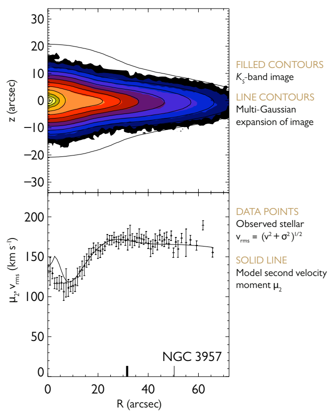
We measure the maximum observed rotation velocity directly from the stellar kinematics by taking the mean of data points in the flat region of the curve. A sample rotation curve is shown in Figure 5.

In Williams et al. (2008) we modelled the mass distribution by assuming a constant dynamical mass-to-light ratio and axisymmetry. This allowed us to compute a model of the circular velocity, which is of course free from the effects of projection and asymmetric drift. The way this was done is summarized in Figure 6. We show the measured dynamical mass-to-light ratios of the sample in Figure 7. In this work we characterize the circular velocity curve by taking its average at the same radii that we used to measure the observed velocity (see Figure 5).

We plot the observed and model velocities against the total magnitude (see Figures 1 and 2), which we find by adopting the total apparent magnitude in the 2MASS Extended Source Catalog the distance in HyperLEDA.

We also plot the velocities against the dynamical mass of the system (Figures 3 and 4), which is derived from its total magnitude and the dynamical mass-to-light ratio we measured in Williams et al. (2008).

It is important to note that at no point in the analysis do we do anything that might systematically affect the S0s in the sample differently to the spirals.




## FIGURE 6

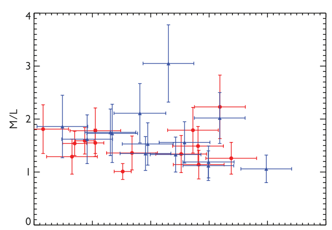
A sample stellar dynamical model used in Williams et al. (2008) to determine the dynamical mass-to-light ratio. Mass models are first generated with multi-Gaussian expansions of $K$-band images. The stellar kinematics are then computed by solving the Jeans equations while assuming a constant mass-to-light ratio and anisotropy, and neglecting non-axisymmetries. The models contain only one free parameter: the mass-to-light ratio. The striking accuracy of the fits suggests that dark matter is not a significant component by mass within 0.5–1 $R_{25}$ or 2–4 $R_e$. The thick notche on the $R$-axis is at 1 $R_e$ and the thin notch is at 0.5 $R_{25}$.

## 3 DISCUSSION

We do not see a significant difference between spirals and S0s in any of the figures showing measures of velocity against measures of magnitude (Figures 1 and 3). Note in particular the error bars in the top-left of each plot. These show the intercept a (and error) in the relation $M_{K_S} = a + b\log(v - 2.5)$. The intercepts for the spirals and S0s in our sample lie within each other's error bars.

If velocity is plotted against dynamical mass rather than magnitude then any systematic difference between the stellar populations of spirals and S0s should change (or introduce) an offset between the two classes. There is no significant change in the offset (or tightening of the fit) when this is done (Figures 2 and 4). Given the absence of a systematic difference between the dynamical mass-to-light ratios of spirals and S0s (Figure 7), this is not surprising.

The entire sample is significantly offset from the Tully-Fisher relation found by Tully & Pierce (2000) in Figure 3 (model circular velocity). This offset is in the same sense and of approximately the same size (+1 mag) as that found in Bedregal et al. (2006), who plot an observed velocity corrected for asymmetric drift. We speculate that most likely reason for this offset is their assumption that the width (or separation of the horns) of a spatially unresolved HI line is exactly twice the maximum rotational velocity of the stellar component. By comparing our data (or indeed those of Bedregal et al. 2006) to Tully & Pierce's (2000) relation, you are not comparing apples with apples. The good agreement between our sample and Tully & Pierce (2000) in Figure 1 may be a coincidence. Further work is needed to explain this offset, but we can find no explanation that would affect S0s differently to spirals.




## FIGURE 7

Dynamical mass-to-light ratio as a function of 2MASS $K_S$-band magnitude. Dynamical mass-to-light ratio was measured in Williams et al. (2008) by scaling a model of the second velocity moment to the observed stellar kinematic quantity $v_{rms} = (v^2 + \sigma^2)^{1/2}$ Spiral galaxies are shown as blue triangles and S0s are red circles.

## 4 CONCLUSIONS

- There is no significant difference between the Tully-Fisher relations of a sample of 14 spirals and one of 14 lenticulars (Figure 1). The implications of this for theories of the evolutionary links between S0s and spirals are as yet unclear.

- There is also no difference when a model circular velocity (effectively an asymmetric drift correction) is plotted against magnitude (Figure 3). We believe our circular velocity models are accurate but even if they are not then problems should not affect spirals and S0s differently at large radii.

- The intercepts and scatters of the relations are not significantly altered when observed and model velocities are plotted against dynamical mass (Figures 2 and 4).

- We speculate that the offset found by Bedregal et al. (2006) was due to comparing two samples whose rotation velocities had been measured in different ways. We argue that when trying to distinguish between the Tully-Fisher relations of spirals and S0s, you must measure the rotation velocity of the two classes in the same way. We find no offset when we do this.

**NOTE:** these numbers (and particularly the errors) are preliminary and this work is unpublished. We are, however, confident that there is no systematic difference between the analysis of spirals and S0s that would affect our conclusions.

## REFERENCES

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