Mass Profiles and Shapes of Cosmological Structures
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DARK MATTER IN THE CENTRAL REGIONS OF EARLY TYPE GALAXIES

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Abstract. We investigate the well-known correlations between the dynamical mass-to-light ratio M/L and other global observables of elliptical (E) and lenticular (S0) galaxies. We construct two-integral Jeans and three-integral Schwarzschild dynamical models for a sample of 25 E/S0 galaxies with SAURON integral-field stellar kinematics to about one effective (half-light) radius $R_{\rm e}$. The comparison of the dynamical M/L with the $(M/L)_{\rm pop}$ inferred from the analysis of the stellar population, indicates that dark matter in early-type galaxies contributes $\sim 30\%$ of the total mass inside one $R_{\rm e}$, in agreement with previous studies, with significant variations from galaxy to galaxy. Our results suggest a variation in M/L at constant $(M/L)_{\rm pop}$, which seems to be linked to the galaxy dynamics. We speculate that fast rotating galaxies have lower dark matter fractions than the slow rotating and generally more massive ones.

1 Introduction

We measured the M/L in the central regions, for a sample of 25 early-type galaxies with SAURON (Bacon et al. 2001) integral-field kinematics (Emsellem et al. 2004), using both two-integral Jeans models and three-integral Schwarzschild models (Cappellari et al. 2005). The galaxy sample was extracted from the SAURON survey (de Zeeuw et al. 2002) and spans over a factor of a hundred in mass. To

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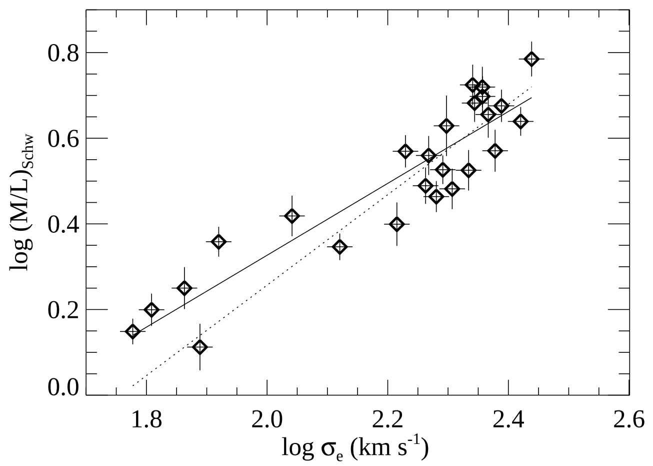

Fig. 1. (M/L)–$\sigma_{\rm e}$ correlation. The solid line is the correlation $(M/L_I) = (3.80 \pm 0.14) \times (\sigma_{\rm e}/200 \text{ km s}^{-1})^{0.84\pm0.07}$ obtained by fitting all galaxies, while the dotted line is the fit obtained by excluding galaxies with $\log \sigma_{\rm e} < 2$. The galaxy with the smallest $\sigma_{\rm e}$ is M32.

this sample we added the galaxy M32 to explore the low-mass range. The models are constrained by `SAURON` kinematics, to about one effective (half-light) radius $R_{\rm e}$ and HST/WFPC2 + MDM ground-based photometry in the I-band. We studied the correlations of the M/L with global observables of the galaxies and we found a sequence of increasing scatter when the M/L is correlated to: (i) the luminosity-weighted second moment of the velocity inside the half-light radius $\sigma_{\rm e}$ (Fig. 1), (ii) the galaxy mass, (iii) the K-band luminosity and (iv) the I-band luminosity. These correlations suggest that the M/L depends primarily on galaxy mass, but at a given mass it is a function of $\sigma_{\rm e}$, which in turn is related to the galaxy concentration. For our galaxy sample the (M/L)–$\sigma_{\rm e}$ relation has an observed scatter of 18% and an inferred intrinsic scatter of $\sim 13\%$.

We compared the M/L derived from the dynamical models, which does not depend on any assumption of spatial or dynamical homology, with the classic predictions for the $(M/L)_{\rm FP}$ derived from the Fundamental Plane, which fully depends on the assumptions of homology and virial equilibrium (e. g. Ciotti, Lanzoni & Renzini 1996). The slope of our observed correlations of M/L with luminosity, mass and $\sigma_{\rm e}$, can account for 80–90% of the tilt of the FP. We also compared directly the M/L from the models with the virial predictions, derived from integral-field kinematics, for our own sample (Fig. 2), and found a relation $(M/L) \propto (M/L)_{\rm vir}^{1.08\pm0.07}$, which confirms, with smaller uncertainties, the results from the FP comparisons. This also shows that, when the effective radii are determined in the classic way using growth curves and $\sigma_{\rm e}$ is measured in an extended aperture as we do, the virial mass is a good estimator of galaxy mass. This has implications for high redshift studies, where the construction of full dynamical models is unfeasible, but the virial mass can still be mesured.

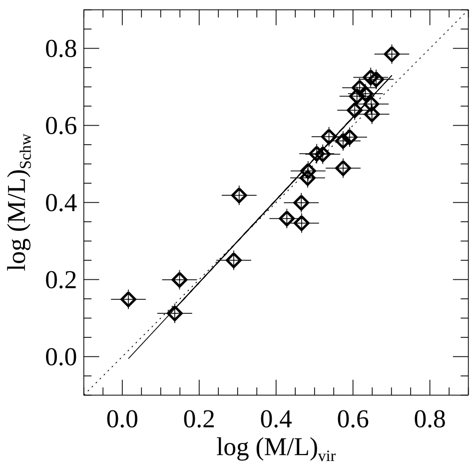

Fig. 2. Comparison between the $(M/L)_{\rm vir} = \beta R_{\rm e}\sigma_{\rm e}^2/(L\,G)$ derived from the virial assumption and the M/L obtained from the Schwarzschild models. The values of $(M/L)_{\rm vir}$ were scaled to match the dynamical M/L, and the best-fitting factor is $\beta = 5.0 \pm 0.1$, in reasonable agreement with simple theoretical predictions. The solid line is a fit between the two quantities, while the dotted line represents a one-to-one correlation.

2 Dark Matter Fraction

These correlations raise the question whether the observed M/L variations are primarily due to differences in the $(M/L)_{\rm pop}$ of the stellar population or differences in the dark-matter fraction. To test this we compared our dynamical M/L with simple estimates of the $(M/L)_{\rm pop}$, derived from the observed line-strengths indices of our galaxies (Fig. 3). We find that the M/L broadly correlates with the $(M/L)_{\rm pop}$, indicating that the variation in the stellar population, mainly due to a variation in the luminosity-weighted age, is an important factor in driving the observed M/L variation. The relatively small scatter in the correlation indicates that the IMF of the stellar population varies little among different galaxies, consistent with results obtained for spiral galaxies by Bell & de Jong (2001).

The accuracy of our M/L determinations allows us to detect significant deviations from a one-to-one correlation, which must be due to either variations of the IMF among galaxies, or to variations in the dark matter fraction within $R_{\rm e}$. In the latter case the dark matter fraction is found to be less than $\sim 30\%$, consistent with earlier findings by e. g. Gerhard et al. (2001). We find some evidence for the variation in M/L to be related to the dynamics of the galaxies. In fact the slow rotating galaxies in our sample, which are more common among the most luminous objects, tend to have a higher M/L at given $(M/L)_{\rm pop}$, than the fast rotating and generally fainter galaxies. Assuming a constant IMF among galaxies, these results would suggest that the slow rotating massive galaxies have a higher ($\sim 30\%$) dark matter fraction than the fast rotating galaxies. We speculate that

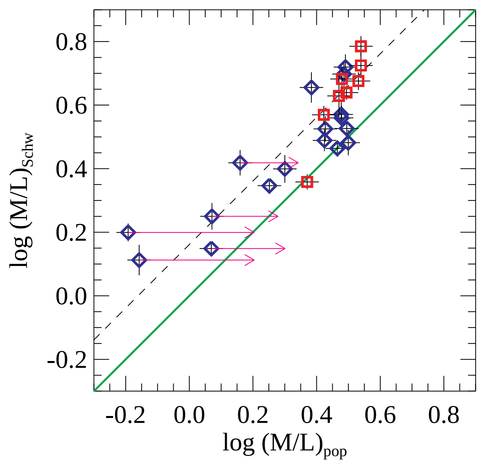

Fig. 3. Dynamical (i. e. total) M/L from the Schwarzschild modeling as a function of $(M/L)_{\rm pop}$ using the Single Stellar Population models of Vazdekis et al. (1999), with a Kroupa (2001) IMF. The red squares and the blue diamonds indicate the slow and fast rotating galaxies respectively. The thick green line indicates the one-to-one relation. All galaxies have $(M/L)_{\rm pop} < (M/L)$ within the errors, but the total and stellar M/L clearly do not follow a one-to-one relation. Dark matter is needed to explain the differences in M/L (if the IMF is not varying). The magenta arrows show the variation in the estimated $(M/L)_{\rm pop}$ for the youngest galaxies (luminosity-weighted age < 7 Gyr), if a two-population model is assumed. The $(M/L)_{\rm pop}$ of the young galaxies would move closer to the one-to-one relation. Adopting the Salpeter (1955) IMF all the values of $(M/L)_{\rm pop}$ would increase by $\Delta\log(M/L) \sim 0.16$. This can be visualized by shifting the one-to-one relation to the position of the dashed line. In this case a number of galaxies would have $(M/L)_{\rm pop} > (M/L)$ and this implies that the Salpeter IMF is unphysical.

this difference in M/L indicates a connection between the galaxy assembly history and the dark halo structure.

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