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Environmental properties of Galaxy Populations in the Halo model

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Abstract. We study the relationship between *mass* and *luminosity* in a given photometric band using data coming from large surveys (2dF and SDSS), and results from high resolution N-body simulations. We have undertaken a critical reappraisal of the derivation of this M-L relationship, using additional constraints coming from Tully-Fisher relations and a restricted mass range. This formalism can be regarded as a *recipe* to derive M-L relationships for any given photometric band for which a Luminosity Function (LF) can be assigned. We apply it to two *independent* problems: the derivation of the Mass Function (MF) of Sab galaxies and the dependence of the LF on local density. Both these tests give very encouraging results. This fact implies then the validity of the two implicit assumptions of this model: the existence of a *universal ML relation* for galaxies and the circumstance that environmental properties can be entirely described by *local* variations of the MF.

Key words. Galaxies: luminosity function, mass function – Cosmology: theory – Large-scale structure of Universe

1. Introduction

With the advent of large photometric and redshift surveys like the 2dF and the SDSS, some authors (Vale & Ostriker 2004; Tasitsiomi et al. 2004; van den Bosch et al. 2003) have used the very accurate LF derived from these surveys in models in which they tried to derive a statistical relationship between galaxy mass and luminosities. Here we present a model to derive the M-L relation which rests on very few hypotheses. We have constrained the scope of our investigation by setting two constraints. First we consider the ML relationship in a mass range in which we can reliably assume that the multiplicity function is unity, i.e. each halo hosts (on average) a single luminous galaxy. This allows us to avoid specifying a multiplicity function, thus diminishing the uncertainties connected to its modelling. The second constraint is that we take explicitly into account an observational relationship between mass and luminosity, i.e. the Tully-Fisher relation, to restrict the domain of validity of the ML relationship. Because the TF relationship applies only to disk galaxies, we consistently impose this constraint within a magnitude interval for each

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photometric band where disk galaxies dominate in number density over elliptical, at least in the nearby Universe.

2. Statistical Mass-Luminosity relation

To determine a (statistical) relationship between Mass and Luminosity in a given band we closely follow the method introduced by Vale & Ostriker (2004), although we will arrive at a differential equation rather than an integral one for the relationship $M_{halo}(M_J)$ between *halo mass* M_{halo} and *galaxy magnitude* M_J. If we equate the LF in a given band J: $\Phi(< M_J)dM_J$, to the Mass Function (hereafter MF) derived from N-body simulations, : $\Psi(M_{halo})dM_{halo}$, we obtain an equation for the dependence of the magnitude on the mass:

$$\frac{dM_J}{dM_{halo}} = c_b \frac{\Phi\,(< M_J\,[M_{halo}])}{\Psi(M_{halo})} \tag{1}$$

The factor c_b can be regarded as a bias factor between the halos' and galaxies number densities. Due to the finite mass resolution and dynamical range of N-body simulations, and the limits of the group finder, the number density of halos could not reflect the actual number density of collapsed halos in the Universe. Although c_b could probably depend on M_{halo} and on other parameters, we will for simplicity assume it to be constant. Moreover, we will assume that the LF is described by a *Schechter* function, while for the MF we will simply assume a power law:

$$d\Psi(m) = m^{\beta} dm \tag{2}$$

The latter is found to be a very good approximation to the 2dF and SDSS LF's (....) over the range of galactic masses ($M_{halo} \leq 2 \times 10^{12} M_{\odot}$ considered in this work.
Finally, we choose the initial value pair from which the numerical integration of eq. 1 is started to be consistent with the Tully-Fisher relation.

3. Two consistency checks

3.1. Mass distributions of Sab

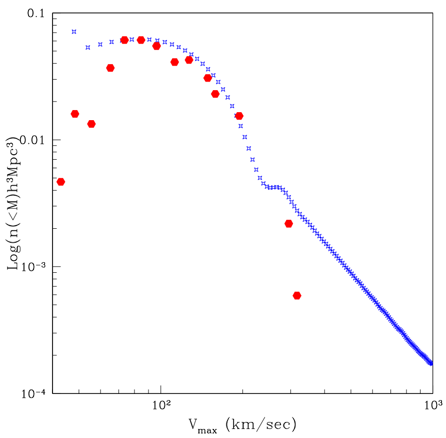

Fig. 1. The mass function for $S_a - S_{ab}$ galaxies (blue dots) compared with the measurements by Shimasaku (1993) (red dots). The normalization factor was chosen such that the total number of galaxies and halos coincide in the relevant ranges.

Cuesta-Bolao & Serna (2003) have deduced LFs' for different types of relatively nearby galaxies ($z < 0.1$). If we adopt the LF for, say, the $S_a - S_{ab}$ galaxies, and, with the help of the *universal* M-L relation found in the previous section we transform it to a MF, we obtain the result shown in figure 1, where the resulting MF is compared with the rather outdated data from Shimasaku (1993). The observed MF was derived by measuring optical rotation curves. The agreement between the predicted and the observed MF is quite good. Deviations at low and high masses can be understood in terms of resolution effects in the N-body simulations and of selection effects in the data, respectively.

3.2. Environmental dependence of the Luminosity Function

A second independent test consists in using the M-L relation in conjunction with different MFs' to derive the relative LFs'. The halo MF depends on the environment: underdense environment typically lack of very massive halos (Lemson & Kauffmann 1999; Antonuccio-

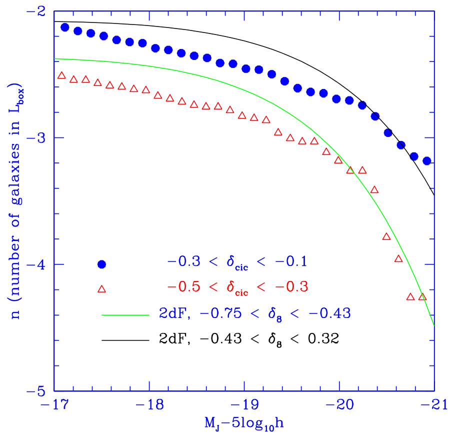

Fig. 2. Luminosity functions for different environments. The continuous curves are Schechter fits to data from Croton et al. (2005), while filled points and triangles are predictions from our model for field (points) and "void" (open triangles) environments, respectively. δ_8 is the average overdensity in spheres of $8h^{-1}$ Mpc, δ_{cic} is the overdensity estimated in N-body simulations using a CIC estimator with 64 neighbours. The inputs MFs were derived for two different simulations with comparable mass resolution (see text).

Delogu et al. 2002), so their MF falls of more steeply at increasing halo mass.
In Figure 2 we show the LFs for different environments, deduced from MFs measured from two different simulations: the GIF2 run from the VIRGO Consortium and a run recently performed by Heitmann et al. (2004). Also in this independent test the LFs for different environments thus deduced seem to explain well the observed data, reproducing both the sharp decline for large masses and the offset between underdense and field regions.

4. Conclusions

The main novelty of our model lies in the minimal set of underlying hypotheses we set. More specifically, our model is characterised by 3 fundamental features:

- The *mass range* is restricted to the maximum interval over which the halo multiplicity function is unitary;
- The M-L relation deduced using the observed LF and the MF deduced from simulations is regarded as *universal*, i.e. we assume that it holds for all different environments;
- Local variations in the LF are assumed to be produced by local variations in the MF.

Despite its simplicity, this model seem to correctly reproduce two *independent* sets of observed data, thus confirming the ability of the model to explain environmental and morphological properties. We are now applying this model to more recent data from the SDSS.

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