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THE ROLE OF MASS IN THE EVOLUTION OF GALAXIES: THE DOWNSIZING EFFECT

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Abstract. The multifrequency analysis of a large and complete sample of nearby, normal late-type galaxies shows that all their physical, structural and kinematical properties are strongly related to the total dynamical mass as traced by the H band luminosity. Mass, more than angular momentum, is thus the most important parameter governing galaxy evolution. By combining our multifrequency observational dataset with multizone chemo-spectrophotometric models of galaxy evolution we show that most of the properties of nearby galaxies can be well reproduced by assuming that they evolved smoothly without need for interactions or mergers. Massive galaxies formed most of their stars late in the past, while low luminosity objects are still forming stars at a rate comparable to that they had in the past. The properties of nearby galaxies are thus consistent with a secular evolution.

1 Introduction

The morphological classification, first introduced by Hubble in the 30s, has been often used as a clear proof of a different evolutionary pattern of galaxies. Different models have been proposed in the literature to explain the origin of the Hubble sequence, as extensively discussed in the recent reviews of Sandage (2005) and van den Bergh (1998). It has been shown, for instance, that early type galaxies are generally dominated by evolved stellar populations, have $r^{1/4}$ light profiles, are hot systems poor of gas and not active in star formation. On the other hand, late-type galaxies are rotating systems, rich in gas, still forming stars, and characterized by exponential radial profiles.

The multifrequency datasets now available for large samples of galaxies allowed us to see whether these general properties typical of late-type galaxies changes along the Hubble sequence, from Sa to Sm-Im-BCD, as later shown by Roberts & Haynes (1994) and Kennicutt (1998). Early spirals are generally bulge dominated, poor of gas, containing evolved stellar populations and less active in star formation than Sc-Sm galaxies. Given this mild and regular variation of most of the galaxies properties along the Hubble sequence, it has been claimed that the angular momentum, probably linked to the morphological type, is an important parameter driving the evolution of late-type galaxies. The large scatter in statistical properties of galaxies within each morphological class, however, let us think that angular momentum is probably not the principal driver of galaxy evolution.

To observationally constrain models of galaxy formation and evolution, we constructed a large ($\sim$ 3500 objects) optically selected, complete sample of nearby (vel < 10000 km/s) galaxies spanning the whole range in morphological type (ellipticals, spirals, dwarf ellipticals, irregulars and blue compact) and luminosity (-22< M_B < -13). By combining our own observations with data available in the literature, we covered the whole electromagnetic spectrum, from the UV to radio centimetric wavelengths, including both imaging and spectroscopic data. This dataset, now made available to the community through the GOLDMINE database (http://goldmine.mib.infn.it/; Gavazzi et al. 2003), allowed us to make a complete statistical analysis of galaxy properties including at the same time the atomic and molecular gas component, the structural parameters (concentration index, effective surface brightness and radii), the present and past star formation activity and kinematical properties (Tully-Fisher and fundamental plane relations).

The analysis done so far mostly by our team since 1993 has clearly shown that the total dynamical mass, as

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traced by the H band luminosity (Gavazzi et al. 1996), more than the morphological type, is the parameter better characterizing the properties of galaxies. These results, combined with those found by Cowie and collaborators (1996) using deep K band imaging and spectroscopy obtained at the Keck for galaxies up to $z \sim 1.7$, have deep cosmological implications, leading both teams to criticize hierarchical models of galaxy formation. Massive galaxies formed most of their stars in the past, while low-luminosity objects are still producing stars at a rate comparable to that they had when formed, thus apparently in contradiction with a hierarchical formation, where the most massive galaxies formed the last (see however De Lucia et al. 2006).
Recent analysis based on large scale optical spectrophotometric surveys such as the SDSS confirmed these early results (see Heavens et al. 2004), now making the downsizing effect a generally accepted result. In this paper we show how the downsizing effect is not limited to the optical spectral domain (stellar populations) but extends to other variables being quite universal, in case modulated by the environment (Boselli & Gavazzi 2006). We then compare our observational results to the multizone chemo-spectrophotometric models of galaxy evolution of Boissier & Prantzos (2000) and discuss these new evidences in the framework of galaxy formation and evolution.

2 The observational results and model predictions

We limit our analysis to the late-type galaxy population, although most of the result valid for spirals extend also to early-types (see Scodeggio et al. 2002; Pierini et al. 2002; Zibetti et al. 2002).
The near-IR to optical colour magnitude relation is the first strong evidence that massive galaxies are dominated by old stellar populations (Gavazzi 1993; Gavazzi & Scodeggio 1996; Gavazzi et al. 1996). Gavazzi et al. (1996) have also shown that while the surface brightness of the old stellar population, as determined from near-IR imaging, is strongly correlated to the total dynamical mass of galaxies, that of the young stellar populations, obtained from UV imaging, is anticorrelated. By fitting UV to near-IR spectral energy distributions with stellar population synthesis models, Gavazzi et al. (2002) have shown that the star formation history of galaxies can be well reproduced assuming that galaxies are coeval objects (13 Gyr old), and that they evolved as a closed box following a delayed exponential star formation low. At the same time the present day star formation activity, as traced by the Hα and UV emission, as well as the total gas content of galaxies (where the molecular component is determined from CO observations) are also strongly anticorrelated to the total H band luminosity of galaxies (Boselli et al. 2001). On the contrary, metallicity is higher in more massive objects (Zaritsky 1994; Gavazzi et al. 2004).
Structural properties of late-type galaxies, such as the presence of a bulge or the near-IR effective surface brightness, are also strongly correlated to the total dynamical mass (Boselli et al. 1997; Gavazzi et al 2000): while massive spirals can have both bulge dominated and purely exponential disc light profiles, dwarfs are all characterized by exponential discs. Catinella et al. (2006), by analysing long slit spectra of several thousands galaxies, have shown that the amplitude, the exponential scale of the inner region and the slope of the outer part of the rotation curve are related with the total galaxy luminosity.
Using the multizone chemo-spectrophotometric models of galaxy evolution of Boissier & Prantzos (2000) calibrated on the Milky Way, updated with an empirically-determined star formation law (Boissier et al. 2003), we can well reproduce most of the above described relationships. These models use a fixed star formation law and mass accretion history (infall), leaving as a free parameter only the rotational velocity V_C and the spin parameter λ. While the rotational velocity is directly related to the total dynamical mass of galaxies through the virial theorem (and thus to the H band luminosity), the spin parameter is a dimensionless measure of the angular momentum (Mo et al. 1998). Its value in spiral ranges typically between ~ 0.02 for relatively compact galaxies to ~ 0.09 for low surface brightness galaxies (Boissier & Prantzos 2000). The models of Boissier & Prantzos (2000) contains scaling relationships (the total mass varies as V_C^3, the scale-length as $\lambda \times V_C$). Star formation histories depend on the infall timescales, which are a function of V_C in these models, so that roughly speaking, V_C controls the stellar mass accumulated during the history of the galaxy, and λ its radial distribution.

Figure 1 shows the comparison of several observed relationships with the total dynamical mass of galaxies (as traced by the H band luminosity) with multizone chemo-spectrophotometric model predictions. We can first notice that all the plotted entities related to different properties of galaxies such as stellar populations ($B-H$, tracing the star formation history), the normalized total gas content ($\log M_{gas}/M_{dyn}$), the metallicity (12+log(O/H)) as well as the structural parameter $\mu(H)_e$ (the H band effective surface brightness), are strongly

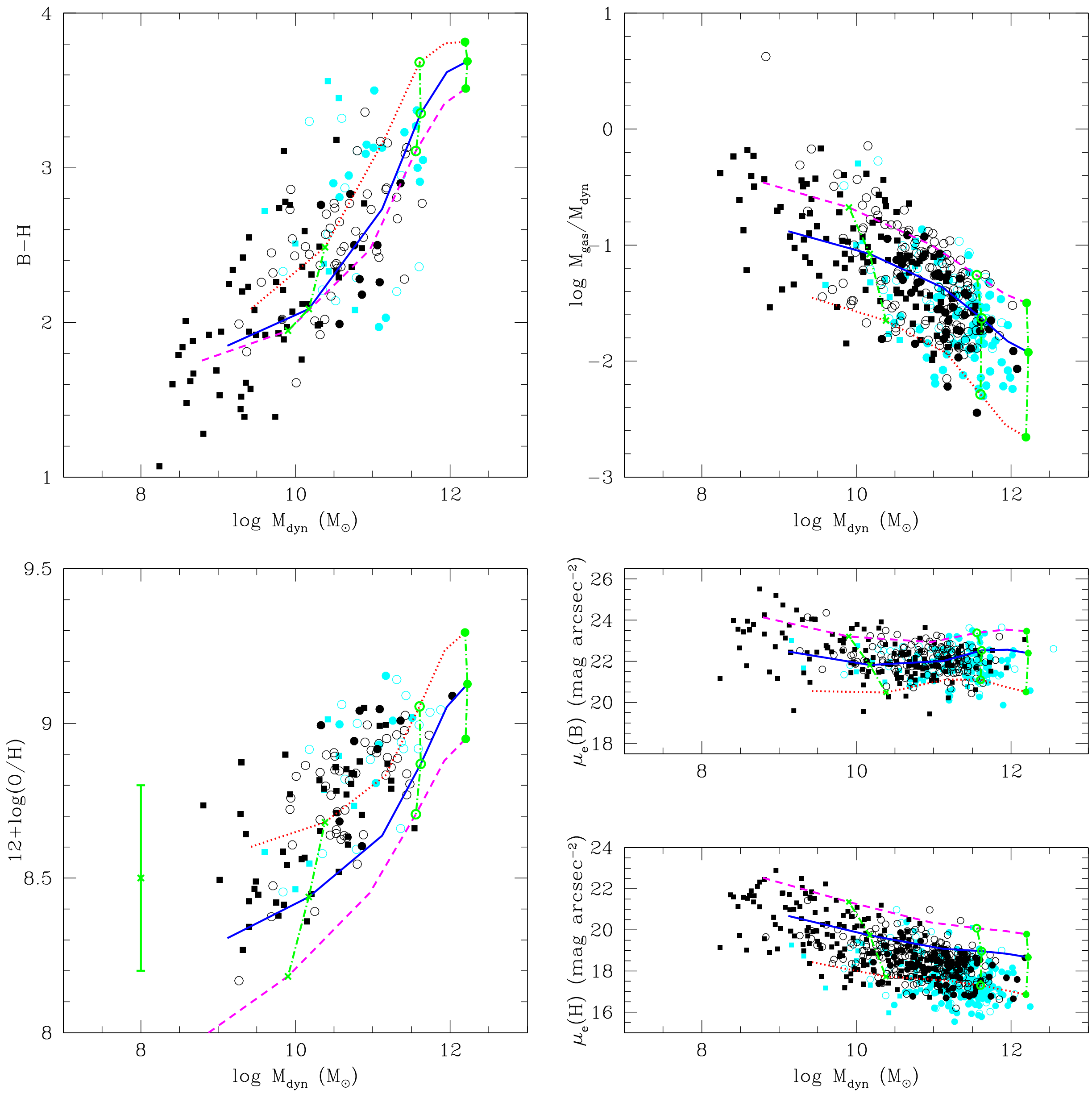

Fig. 1. The comparison of the color (upper left), gas (upper right), metallicity (lower left) and effective surface brightness (lower right, in B and H bands) mass relations for late-type galaxies compared to multizone models predictions grids. The red dotted line indicates the model predictions for λ=0.02 (spin value for compact galaxies), the blue continuum line for λ=0.05 (mean spin value for normal galaxies) and the magenta dashed line for λ=0.09 (spin value for low surface brightness galaxies). The velocity parameter V_C varies between 40 (log $M_{dyn} \sim 9$ M⊙) and 360 (log $M_{dyn} \sim 12.2$ M⊙) km/s. The dotted-dashed green lines indicates model predictions for fixed velocities at 80, 220 and 360 km/s. Blue symbols are for bulge dominated galaxies ($C_{31} > 4$), filled dots for Sa-Sb, empty circles for Sbc-Sc and filled squares for Scd-Sm-Im-BCD. The error bar given in 12+log(O/H) of 0.3 dex corresponds to the uncertainty generally accepted on the yield of oxigen.

related to the total dynamical mass of galaxies. Models reproduce qualitatively well all the plotted relationships, and confirm then that most of the properties of the nearby galaxies can be reproduced by a passive, secular evolution principally governed by the total mass. The dispersion inside each relation could be partly due to a different spin parameter (angular momentum), although other sources of scatter might exist (observational uncertainties, micro star formation history, extinction..). This result is consistent with the variation of the star formation and gas density per comoving volume of the universe with look-back time (Boselli et al. 2001), and are thus a further strong constraint for hierarchical models of galaxy formation.

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