The Baryonic Mass Function of Spiral Galaxies: Clues to Galaxy Formation

Paolo Salucci\textsuperscript{1} and Massimo Persic\textsuperscript{2}

\textsuperscript{1} SISSA – International School for Advanced Studies, via Beirut 2-4, I–34013 Trieste, Italy
\textsuperscript{2} Osservatorio Astronomico, via G.B. Tiepolo 11, I-34131 Trieste, Italy

\texttt{salucci@galileo.sissa.it, persic@ts.astro.it}

21 March 2022

ABSTRACT

We compute the baryonic mass function, $\psi_S(M_b)d\log M_b$, of disc galaxies using the luminosity functions and baryonic mass-to-light ratios reliable for this goal. On scales from $10^8 M_\odot$ to $10^{11} M_\odot$ this function is featureless, $\psi_S \propto M_b^{-1/2}$. Outside this mass range $\psi_S$ is a strong inverse function of $M_b$. The contributions to the baryon density $\Omega_{SB}$ from objects of different mass indicate that spirals have a characteristic mass scale at $M_b^* \simeq 2 \times 10^{11} M_\odot$, around which more than 50\% of the total baryonic mass is concentrated. The integral value, $\Omega_{SB} = (1.4 \pm 0.2) \times 10^{-3}$, confirms, to a higher accuracy, previous evidence (Persic & Salucci 1992) that the fraction of BBN baryons locked in disc galaxies is negligible and matches that of high-$z$ Damped Ly-$\alpha$ systems (DLAs). We investigate the scenario where DLAs are the progenitors of present-day spirals, and find a simple relationship between their masses and HI column densities by which the DLA mass function closely matches that of spiral discs.

1 INTRODUCTION

The visible mass of a galaxy is intimately related to the process of its formation, indicating how, during its cosmological history, the primordial baryon-to-total density ratio $\Omega_{BBN}/\Omega$ has been modified. Furthermore, the inventory of stars and gas in galaxies sheds light on where the BBN baryons reside at the present time, and helps to investigate the nature of the baryonic structures observed at high $z$.

In this connection, a step forward was made by Persic & Salucci (1992; hereafter PS92) who estimated the cosmological density of the baryonic matter in spirals $\Omega_{SB}$ (and in other bound systems) by averaging the spirals’ disc masses $M_\star(L_B)$ over their luminosity function (LF), $\phi^\star(L_B)dL_B$:

$$\Omega_{SB} = \frac{1}{\rho_c} \int_{L_B^{\min}}^{L_B^{\max}} M_\star(L_B) \phi^\star(L_B) dL_B$$

where $\rho_c$ is the critical mass density of the Universe and $L_B^{\max}, L_B^{\min}$ have their obvious meanings. By means of the disc mass vs. luminosity relationship [derived by applying the Persic & Salucci (1990a) method of mass decomposition to $\sim 60$ rotation curves] and adopting the Schechter LF (derived from the AARS survey, $\sim 200$ objects; Efstathiou et al. 1988), PS92 found $\Omega_{SB} = 7.4 \times 10^{-3}$ implying that only few percent of the cosmologically synthesized baryons are detected today in spirals (or in other bound structures, PS92).

Our knowledge of the properties of spirals has improved enormously in the past few years. In fact, with respect to PS92, we can now rely on: (a) LFs deeper by about 5 magnitudes and resolved by Hubble Type; (b) HI mass estimates for objects spanning the whole luminosity range of disc systems; (c) determinations of disc masses for Sa and dwarf spirals; (d) refined derivations of disc and bulge masses in normal spirals.

Based on this new knowledge, we investigate two crucial (and timely) cosmological issues: the baryonic mass function of disc systems, and the connection between the population of local spirals and that of high-$z$ Damped Ly-$\alpha$ clouds (DLAs).

As the halo mass function carries direct information on the spectrum of primordial cosmological perturbations and the

---

\* $\rho_c = \frac{3 H_0^2}{8 \pi G}$. We use $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$ throughout. No result in this paper depends crucially on the value of $H_0$. 

© 0000 RAS
luminosity function reflects the evolution of the stellar populations of galaxies, the baryonic mass function of disc systems (DMF) is a unique probe into the late stages of their formation, including the dark-to-luminous coupling that has formed spirals as we see them today.

The plan of this paper is as follows. In section 2 we introduce the spiral LF and (disc mass)-vs.-luminosity relation. In sections 3 and 4 we estimate the DMF and the amount of baryons locked in spirals. In section 5 we investigate the connection between spirals and DLAs. Finally, in section 6 we briefly discuss some cosmological implications.

2 BASIC PROPERTIES OF SPIRALS

2.1 Luminosity function

Recent large surveys have obtained the LF of galaxies down to $M_B \sim -12.5$. The standard Schechter (1976) function,

$$\phi(L_B) \, dL_B = \phi_0 \left( \frac{L_B}{L_B^*} \right)^{-\alpha} \, e^{-\frac{L_B}{L_B^*}} \, dL_B,$$

is generally found to give an excellent fit to the data (Efstathiou et al. 1988; Loveday et al. 1992; Marzke et al. 1994; Lin et al. 1996; Radcliffe et al. 1998). However, for $M_B \gtrsim -15$, there is a significant excess of objects above the Schechter prediction (e.g., Loveday 1998). We consider the two cases separately.

(i): $M_B < -15$.

With respect to the earlier AARS survey, the Autofib Redshift Survey (1700 objects; Ellis et al. 1996) has filled the gap $B = 17 - 21$ in the coverage of apparent magnitudes, and has significantly increased the size of the sample down to $B = 22$. This has made it possible to determine the LF for each spiral Hubble Type, down to $M_B \simeq -15.5$, with an accurate estimate of the faint-end slope and the overall normalization (Heyl et al. 1997). In detail, we take the Heyl et al. (1997) Sa LF and we combine the remaining three Sb-Sdm LFs into a single late-type LF (see Fig.1). The parameters of these two Schechter functions are reported in Table 1. The values of $\alpha$, $\phi_0$, and $L_B^*$ vary, field by field and survey by survey. The typical uncertainties involved in the determination of $\alpha$, $\phi_0$ and $M_B$ (Lin et al. 1996; Radcliffe et al. 1998) are : 0.05, 20%, and 0.1 mag, respectively.

The observational input is further increased by considering also the spiral LF of Marzke et al. (1998), built from the morphology of the objects rather than from their spectral features: the relative Schechter parameters are given in Table 1. For later considerations let us notice that, from the above LFs, the value of the parameter $L_B^*$ relative to the entire spiral population is: $L_B^* \simeq 2 \times 10^{10}L_B^*$. Finally, for $M_B < -15$, both LFs neglect low-surface-brightness (LSB) galaxies, which constitute a very small (and

$\dagger$ In this paper the magnitudes are in the $B_{ESO}$ system. When transformed from the $B_J$ system, the adopted conversion is $B_{ESO} = B_J + 0.2$. 
The stellar $M_\star(L_B)$ and baryonic $M_b(L_B)$ relations (solid and dot-dashed lines). Filled circles and empty squares represent the data for late spirals and dwarf irregulars. The short-dashed line and the dot-short-dashed line denote $M_\star(L_B)$ for, respectively, maximum-disc and photometric masses. We also show $M_b(L_B)$ corresponding to a (baryonic mass)-to-light ratio assumed to be constant with luminosity (dotted line).

(ii) $M_B > -15$.

The 2.4-million-galaxy APM survey has provided the first direct information on the very faint end of the LF, reaching $M_B \approx -12.5$. It has found, faintwards of $M_B \sim -15$, an increasing excess of galaxies with respect to the Schechter profile, mostly of late-type morphology and low surface brightness (Loveday 1998; see also Marzke et al. 1994, Lin et al. 1996, Zucca et al. 1997). This rapid increase can be taken into account by adding to the standard LF an additional power-law term that switches on at $M_B \sim -15$ and becomes comparable to the Schechter term at $M_B \sim -14$ (see Loveday 1998).

Thus, the luminosity function of disc systems can be written as:

$$\phi^\delta(L_B) = \phi(L_B) + \phi(L_B') \left(\frac{L_B}{L_B'}\right)^{-2.7},$$

with $\phi(L_B)$ given by eq.(2a) and $L_B' \simeq 8 \times 10^7 L_\odot$ (Loveday 1998).

2.2 Disc masses

2.2.1 Sb–Im galaxies

Using a very large dataset of 1100 high-quality rotation curves (RCs) and a newly devised method of mass modelling, Persic et al. (1996) have determined the stellar disc and bulge masses of Sb-Sdm normal spirals ($-18 > M_B > -22.5$) as a function of blue luminosity (see also Salucci & Persic 1997). In addition, recent RC analyses have provided the stellar disc masses for a number of dwarf galaxies, $-15.5 > M_B > -18$ [see Salucci & Persic (1997) and references therein]. Combining these results we find ($L_{10} \equiv 10^{10} L_B$):

$$M_\star(L_B) = 3.7 \times 10^{10} \left[\left(\frac{L_B}{L_{10}}\right)^{1.23} g(L_B) + 9.5 \times 10^{-2} \left(\frac{L_B}{L_{10}}\right)^{0.98}\right] M_\odot$$

and

$$g(L_B) = \exp\left[-0.87 \times \left(\log \frac{L_B}{L_{10}} - 0.64\right)^2\right],$$

that links the stellar mass and the luminosity of disc systems in a way quite different from the simple $M_b \propto L_B$ law (see Fig.2).

The uncertainty $\delta M_\star/M_\star|_{th}$ ranges from 5% at the highest luminosities to 30% at the lowest luminosities. However, the actual disc mass variance for galaxies of a given luminosity, $\delta M_b/M_b$, is larger in that it also includes a variance due to observational errors plus an intrinsic component $\delta M_b/M_b|_{cosm}$. This latter uncertainty, which must be taken into account when convolving the
mass-to-light ratios with the luminosity function, can be estimated from the values of the disc masses derived for individual galaxies. Using ~ 100 objects in Persic & Salucci (1990a), Salucci et al. (1991), and Persic et al. (1996), we conservatively estimate: $\delta \log M^*_{\cosm} < 2.3 \frac{M_*}{M_\odot} \simeq 0.2$ dex.

The quantity $\delta \log M^*_{\cosm}$ is often related to the mean scatter of the Tully-Fisher (TF) relation, $\sigma_{\log V} \simeq 0.10$ dex (e.g., Willick 1998). We stress that there is no direct link between these two quantities. In fact, at a fixed luminosity: $2 \sigma_{\log V} \simeq \Sigma(M_*) + \Sigma(\beta) + \Sigma(L/R_{\text{opt}})$ (Salucci et al. 1993), where $R_{\text{opt}}$ is the disc size, $\beta$ is the disc-to-total mass fraction inside $R_{\text{opt}}$, and $\Sigma(x)$ is the cosmic log-variance of the quantity $\log x$ convolved with its measurement errors. Nevertheless, since $\Sigma(L/R_{\text{opt}}) = 0.05 - 0.1$ and $\Sigma(\beta) \sim 0.05$ (e.g., Persic et al. 1996), we can state that the variance of the TF relation and that of eq.(3) are mutually consistent.

Note that the mass vs. luminosity relation assumed here is robust with respect to the particular method employed in deriving the disc masses. In Fig.2, we plot the $M_* - L_B$ relationship corresponding to $M_*(L_B)$ obtained (1) as maximum-disc solutions (Persic & Salucci 1990b), and (2) via stellar population synthesis models (Salucci et al. 1991). In both cases, the differences with the RC-slope-best-fit values used to derive eq.(3) are irrelevant to the main results of this paper.

2.2.2 Sa galaxies

The bulge and disc masses of Sa galaxies are obtained from: (a) dynamical modelling of the line-of-sight dispersion velocity profiles (of either the stars and/or the gas) and/or of the extended HI and optical RCs; and (b) comparing the observed galaxy spectra with stellar population synthesis templates (e.g.: Corsini et al. 1999; Bertola et al. 1993, 1998; Silva et al. 1998; Honma & Sofue 1997; Quillen & Frogel 1997; Jablonka & Arimoto 1992). Given that Sa galaxies contribute significantly to the spiral LF only in the very small range of magnitudes $-22 < M_B < -21$, the ~20 objects available in the literature turn out to be sufficient to determine an average mass-to-light ratio in this region and to establish its trend with luminosity. We find that the stellar masses increase with luminosity slightly more steeply than linear, in good agreement with eq.(3). However, the mass-to-light ratios of Sa galaxies are a factor of order two larger than the corresponding values for late spirals. We therefore assume: $M^{*\text{Sa}}_*(L_B) = 1.5 \times M^{*\text{Sb-Sdm}}_*(L_B)$. [The main results of this paper do not depend on the (suitable) actual value assumed for this proportionality constant.]

2.2.3 Gas content

HI masses have recently been derived, through HI-flux observations, for two large samples of spirals that include also irregular dwarfs (Hoffman et al. 1996; Rhee 1996). The data for the combined sample ($10^7 L_\odot \lesssim L_B \lesssim 10^{11} L_\odot$) imply a strong $M_{HI}(L_B)$ relation (see Fig.3), especially so if it is reckoned that this is steeper at lower masses than at higher masses (Hoffman et al. 1996; Salpeter & Hoffman 1996). In detail, we have:

$$\frac{M_{HI}}{M_\odot} = 1.6 \times 10^6 \left( \frac{L_B}{10^9 L_\odot} \right)^{0.81} \left[ 1 - 0.18 \left( \frac{L_B}{10^9 L_\odot} \right)^{-0.4} \right]$$

(see Salpeter & Hoffman 1996 for further details). To take the helium contribution into account, we multiply the r.h.s. of eq.(4) by 1.33.

(see Salpeter & Hoffman 1996 for further details). To take the helium contribution into account, we multiply the r.h.s. of eq.(4) by 1.33.

© 0000 RAS, MNRAS 000, 000-000
Two other disc-like gaseous components are present in spirals: (i) molecular gas ($H_2$, CO) which, however, being distributed as the exponential stellar disc, is already taken into account by $M_*$; and (ii) ionized hydrogen (found by pioneering Hα-emission measurements, see Bland-Hawthorn et al. 1997), the mass of which is, however, difficult to estimate, also because the HI/HII transition has a sharp edge (Corbelli & Schneider 1997). For the time being we consider the HII component as provisionally unidentified baryonic dark matter.

The baryonic masses of disc systems are then obtained from eqs.(3) and (4):

$$M_b = 1.33 M_{HI} + M_*$$

We emphasize that these determinations are more accurate than those in PS92 in the following respects: (i) they hold down to $\sim 4$ magnitudes fainter; (ii) they include the gaseous disc mass; (iii) they bear smaller theoretical and observational uncertainties; and (iv) they allow us to take into account the population of LSB galaxies whose HI masses, much larger than their corresponding stellar masses (e.g., de Blok et al. 1996), are well represented by eq.(4). It is worth noticing that these improvements, while absolutely needed to derive the spiral baryonic mass function, imply refinements on $\Omega_{SB}$ (as estimated by PS92) that are too small to affect the PS92 claim $\Omega_{SB} \ll \Omega_{BBN}$.

3 THE DISC MASS FUNCTION

We investigate disc systems in the luminosity range between $\simeq 10^7 L_\odot$ and $L_B^{max} \simeq 8 \times 10^{10} L_\odot$, corresponding to the mass range between $M_b(10^7 L_B) \simeq 10^7 M_\odot$ and $M_{b}^{max} \equiv M_b(L_{B}^{max}) \simeq 4 \times 10^{11} M_\odot$. Massive ($M_b \gtrsim 10^{11} M_\odot$) discs are rare objects, while light discs ($10^7 M_\odot \lesssim M_b \lesssim 10^9 M_\odot$) constitute the most numerous population of galaxies in the Universe: the lowest masses considered here reflect the lack of suitable data, not the lack of objects. Stellar disc masses are known only for $L_B \gtrsim 5 \times 10^7 L_\odot$: however, at these luminosities the gas mass given by eq.(4) is, by far, the main baryonic component.

By using eqs.(2)-(5) we derive the disc (systems) mass function (DMF), $\psi^S(M_b)$, defined as:

$$\psi^S(M_b) \, d \log M_b = \phi^S(L_B(M_b)) \frac{dL_B}{dM_b} \, d \log M_b.$$  

We take into account the scatter of the $M_b(L_B)$ relation by convolving the r.h.s of eq.(6) with a Gaussian of half-width $\delta \log M_b = 0.2$ corresponding to the maximum cosmic variance in relationship (3).

Fig.4 shows that the DMF can be well described by a power law $\psi^S \propto M_b^{-1/2}$ over three decades in mass, different from the LF that can hardly be reproduced by a power law over more than a decade in luminosity. A good fit for the DMF is:

$$\psi^S = 1.2 \times 10^{-3} \left[ 1 + \left( \frac{M_b}{M_\odot} \right)^{-1.46} \right] \left( \frac{M_b}{2.7 \times 10^{11} M_\odot} \right)^{-0.46} e^{-\left( \frac{M_b}{M_t} \right)},$$

where $M_\odot = 2.7 \times 10^{11} M_\odot$ and $M_t = 6.7 \times 10^7 M_\odot$.

\[\] with $\int_{range} L_B \phi(L_B) dL_B = \int_{range} M_b \psi(M_b) dM_b$ from the conservation of the number of galaxies.
At the highest masses, the DMF shows a sharp cutoff that noticeably occurs at a mass \( \sim M_b^\oplus > 3 \ M_b(L_B^*) \) (with \( M_b(L_B) \approx 8 \times 10^{10} \ M_\odot \)), quite different from the baryonic mass corresponding to \( L_B^* \approx 2 \times 10^{10} \), the "knee" of the spiral LF (e.g.: Heyl et al. 1997; Marzke, 1998). This supports the scenario in which spirals were formed under an upper mass limit, \( \sim M_b^{max} \), due to the inability of a larger baryonic mass to cool fast enough to settle into a disc within a Hubble time (Rees & Ostriker 1977; see also Thoul & Weinberg 1996). This sharp cutoff gets broadened in the LF (Figs. 4 and 5) because the radiating efficiencies of stellar discs of a given mass have a significant scatter, due to differences in the discs’ stellar populations (see Oliva et al. 1995).

At \( L_B < 10^8 L_\odot \), there is a steepening of the DMF, parallel to that of the LF, that might hint to a bimodal distribution. In any case, also in the DMF there is no sign that downwards of the smallest observed masses, \( M_b \sim 10^7 \ M_\odot \), the objects are disappearing.

Let us notice that the intrinsic variance of the \( M_b(L_B) \) relationship has negligible effect on the DMF, both because the latter is essentially a power law and because \( \delta \log M_b \) is much smaller than the range of \( \log M_b \).

Finally, the main features of the DMF do not depend on which (suitable) LF is assumed: the Marzke et al. (1998) LF yields a DMF very similar to eq. (7) (see Fig.7 in the Appendix.)

Despite the baryonic mass function being essentially featureless, spirals do have a characteristic mass scale: \( M_b^\oplus \). In Fig.(5) we show \( \Delta \Omega_b^S(M_b) \), the differential contribution to \( \Omega_b^S \) from spirals belonging to intervals of width 0.3 centered on \( \log M_b \): in spite of the wide range of baryonic mass (5 decades: 24 intervals), the major contribution to \( \Omega_b^S \) (\( \gtrsim 60\% \)) comes from objects within a factor 3 of \( M_b^\oplus \). Thus, spirals do form with masses in the range \( 10^7 \ M_\odot - 10^{12} \ M_\odot \): but most of the galactic baryons are actually locked at one specific mass scale, \( M_b^\oplus \), higher than the mass of an \( L_B^* \) galaxy and much higher than the mass of the great majority of the objects. Actually, more than 75\% of the total baryonic mass is segregated in less than 0.5\% of the objects! Conversely, the light is much more evenly distributed among galaxies of different luminosities: e.g., objects with \( M_b < 10^{-5} \ M_b^\oplus \) still contain more than 20\% of the total light.

As a consequence, the "typical" scale \( L_B^* \) does not have a cosmological significance, neither as the most relevant mass scale nor as the mass at which the mass function cuts off. At \( L_B^* \) the mass function is still increasing, with most of the cosmological baryon mass density located at \( L_B > L_B^* \).

### 4 THE BARYON CONTENT OF SPIRALS

Let us refine the PS92 estimate of the cosmological density of the stellar component in disc systems with the improved LF and mass-vs.-light relation of the previous sections. From eqs.(2)-(5) we have:

\[
\Omega_b^S = 1.44^{+0.15}_{-0.20} \times 10^{-3},
\]

marginally larger and substantially more accurate than the PS92 estimate. The Marzke et al. (1998) LF yields: \( \Omega_b^S = (1.3 \pm 0.25) \times 10^{-3} \). Let us notice that if we neglect the (relevant) presence of dark matter inside \( R_{opt} \) and/or the luminosity dependence of the (stellar + gas) mass-to-light ratio, we are led to overestimate \( \Omega_b^S \) by up to a factor of 4 and to fictitiously reduce the observed discrepancy between \( \Omega_b^S \) and \( \Omega_{BBN} \).

As a finer detail in eq.(8), the amount of HI+HeI in spirals is

\[
\Omega_b(S) = (1.7 \pm 0.8) \times 10^{-4}.
\]
This is in good agreement with the cosmological HI content, $\Omega_{\text{gas}} = (3.3 \pm 1) \times 10^{-4}$, estimated by integrating the HI mass function of Zwaan et al. (1997), especially considering that the latter may include the S0 discs, neglected in our present estimate.

With the caveat that the masses of ellipticals and spheroidals are still uncertain by 40% (Salucci & Persic 1997), let us estimate $\Omega_{E_b}$, the cosmological baryonic mass density in ellipticals and S0. By means of the E/S0 Autofib LF and the PS92 mass–luminosity relation (see also Salucci & Persic 1997), we find $\Omega_{E_b} \sim (2 \pm 1) \times 10^{-3}$, in agreement with PS92 and with Salucci et al. (1999). Spheroids then store about twice as much baryonic matter as discs, differently from the common belief of an equipartition of the baryonic matter between discs and spheroids (e.g., Schechter & Dressler 1987). Instead, we point out that with respect to spirals, ellipticals have about 1/10 of the number density, 1/2 of the luminosity density and 2 times the baryonic mass density.

The total amount of baryons in galaxies is then $(3 \pm 1) \times 10^{-3} \rho_c$. It is remarkable that the star formation rate density, derived from the [OII] luminosity function (Hogg et al. 1998), when integrated over the lifetime of the universe, implies [caveat a set of (well justified) assumptions on the IMF, metallicity and extinction] a very similar density of formed stars, $\sim 3 \times 10^{-3} \rho_c$.

5 DAMPED LYMAN-α CLOUDS AS PROTOSPIRALS

At high redshifts ($z \sim 2 - 3$), the Damped Lyα clouds, i.e. neutral-hydrogen absorbers with column densities $N_{HI} > 2 \times 10^{20}$ atoms cm$^{-2}$, dominate the cosmological mass density of the gas in cosmic structures. The column density distribution function, $f(N_{HI}) dN_{HI}$ (i.e., the number of absorbers per absorption distance interval $dx$ and column density interval $dN_{HI}$, see Storrie-Lombardi et al. 1996a), can be represented by:

$$f(N_{HI}) = A \left( \frac{N_{HI}}{N_{\ast}} \right)^{-1.5} e^{-\frac{N_{HI}}{N_{\ast}}},$$

with $N_{\ast} = 10^{21.5}$ cm$^{-2}$ and $A = 10^{23.8 \pm 0.4}$. The corresponding mean cosmological mass density is (e.g., Tytler 1987):

$$\Omega_{DLA} = \frac{H_0 \mu m_p}{c \rho_c} \int_{N_{HI}^{\text{min}}}^{N_{HI}^{\text{max}}} N_{HI} f(N_{HI}, z) dN_{HI}$$

(with $\log N_{HI}^{\text{min}} = 20.3$, $\log N_{HI}^{\text{max}} = 21.8$, $\mu = 0.6$ the mean molecular weight, $m_p$ the proton mass, and $c$ the speed of light), and amounts to (Lanzetta et al. 1995; Storrie-Lombardi et al. 1996b):

$$\Omega_{DLA} \sim (1 \pm 0.35) \times 10^{-3} (\Omega_0 + 1).$$

Comparing eqs.(8) and (12) provides more precise evidence that the baryon content of spirals equals that of DLAs, $\Omega_S \simeq (0.9 - 1.4) \Omega_{DLA}$. [The earlier PS92 estimate was $\Omega_b \simeq (0.4 - 1.2) \Omega_{DLA}$] Indeed, the baryonic content of spirals just reaches that of DLAs [the opposite claim (e.g., Storrie-Lombardi et al. 1996b) is induced by overestimates of the spiral $M_b/L_B$ ratios]: this coincidence is straightforwardly explained if DLAs are the progenitors of present-day spirals (Wolfe et al. 1986; Tytler 1987; Maloney 1992; Lanzetta et al. 1995; Kauffmann 1996). Furthermore, the existence of a narrow mass range at

\[ \text{Figure 6. Differential baryonic-mass number density of Lyα clouds (dotted line) and spirals (solid line). Also shown is the estimated 2σ uncertainty on the DMF.} \]
Table 1. LF parameters for different spiral morphologies(a).

| Type   | $\phi_0^{(c)}$ | $M_B^{(c,d)}$ | $\alpha$ |
|--------|----------------|---------------|----------|
| Sa(a)  | 0.92 x 10^{-3} | -20.43        | 0.99     |
| Sb-Im(a) | 2.60 x 10^{-3} | -19.74        | 1.34     |
| Sa-Im(b) | 3.38 x 10^{-3} | -20.05        | 1.11     |

Notes: (a) from Heyl et al. 1997; (b) from Marzke et al. 1998; (c) adopting $H_0 = 75$ km s^{-1} Mpc^{-1}; (d) in the $B_{ESO}$ system: the adopted conversion from the $B_J$ system is $B_{ESO} = B_J + 0.2$.

$\sim 10^{11} M_\odot$ for the $\Omega_c$-dominating objects may give support to the single-population model which identifies DLAs as discs rotating at one same high rotation speed, $V_{rot} \sim 250$ km s$^{-1}$ (Prochaska & Wolfe 1997, 1998).

Let us investigate further the putative link between DLAs and spirals by comparing the cosmological distribution of their masses. The scenario in which DLAs are progenitors of $z = 0$ discs yields a one-to-one link between a present-day spiral of mass $M_b$ and a high-$z$ DLA of mass $M_{Ly\alpha}$. With the assumption that spirals have retained most of the baryon content of their DLA progenitors (assumption supported by the similar cosmological densities of the two populations), we postulate: $\psi^{Ly\alpha}(M_{Ly\alpha}) = \psi^B(M_b)$. It is, then, remarkable that the latter is fully consistent with the column density distribution of eq.(10) if a suitable relationship exists between the central face-on column densities and the DLA masses. In fact, discs of the same mass having exponential surface density profiles with same lengthscale will produce a range of observed column densities, both because of having different inclinations and because of having a range of impact parameters for different lines of sight. So, if we model DLAs as exponential discs truncated at 5 lengthscales with vertical-to-radial lengthscale ratio of 0.1 - 0.3, by averaging over all lines of sight and inclination angles we get: $N_{Ly\alpha}^0 = N_{HI}f$^{-1}, with $f \approx 0.7 - 0.5$ (being $f \approx \frac{z_D}{z}[1 - (1 + n)e^{-n}] \ln(\frac{z_D}{z_D})^{-2}$ with $z_D$ the disc vertical lengthscale). Then, let us assume $N_{Ly\alpha}/N_b = [M_{Ly\alpha}/(aM_b^\beta)]^\gamma$: when $a = 0.3$ and $\beta = 0.45$, the DMF and the DLA mass function essentially coincide (see Fig.6).

6 CONCLUDING REMARKS

The baryonic mass function of disc systems is essentially a power law, $\psi^B(M_b)d\log M_b \propto M_b^{-1/2}d\log M_b$, from $10^8 M_\odot$ to $M_b^{\odot} \sim 2 \times 10^{11} M_\odot$, where a sudden cutoff occurs because of the lack of objects. In terms of their baryonic content, spirals have a preferred mass scale $M_b^{\odot}$, around which most of the baryons with angular momentum are locked.

The main feature of the luminosity function, an exponential decline at $L_B^*$, does not show up in the DMF. The (astrophysical) features of the luminosity function do not relate with the (cosmological) ones emerging from the baryonic mass function.

The cosmological density of the luminous matter in spirals is a negligible fraction, $\sim 1/50$, of all the baryons synthesized in the Big Bang, and it is in good agreement with the cosmological density of high-$z$ DLA clouds.

In addition, we propose a continuity between the DLA clouds and spiral galaxies: their (baryon) mass functions implying that, at $z = 3$, $\sim 10^{-4}$ objects Mpc$^{-3}$ with baryonic masses of $\sim 2 \times 10^{11} M_\odot$, total masses of $\sim 4 \times 10^{12} M_\odot$, and dynamical times of $\sim 1$ Gyr, are the protagonists of structure in the Universe.

APPENDIX

In Table 1 we report the Schechter parameters of the LFs used in the paper.

In Fig.7 we show the DMF constructed using the $M_b(L_B)$ relation described by eqs.(3)-(5) and the spiral LF of Marzke et al. (1998).
Figure 7. The spiral galaxy luminosity function of Marzke et al. 1998 (dotted line) and the corresponding baryonic mass function, from the $M_b(L_B)$ relation in eqs.(3)-(5) (solid line).

7 REFERENCES

Bertola, F., Pizzella, A., Persic, M., & Salucci, P. 1993, ApJ, 416, L45
Bertola, F., et al. 1998, ApJ, 509, L93
Bland-Hawthorn, J., Freeman, K.C., & Quinn, P.J. 1997, ApJ, 490, 143
Corbelli, E., & Schneider, S.E. 1997, ApJ, 479, 244
Corsini, E.M., et al. 1999, A&A, 342, 671
de Blok, W.J.G., McGaugh, S.S., & van der Hulst, J.M. 1996, MNRAS, 283, 18
Efstathiou, G., Ellis, R.S., & Peterson, B.A. 1988, MNRAS, 232, 431
Ellis, R.S., Colless, M., Broadhurst, T., Heyl, J., & Glazebrook, K. 1996, MNRAS, 280, 235
Heyl, J., Colless, M., Ellis, R.S., & Broadhurst, T. 1997, MNRAS, 285, 613
Hoffman, G.L., Salpeter, E.E., Farhat, B., Roos, T., Williams, H., & Helou, G. 1996, ApJS, 105, 269
Hogg, D.W., Cohen, J.G., Blandford, R., & Pahre, M.A. 1998, ApJ, 504, 622
Honma, M., & Sofue, Y. 1997, PASJ, 49, 453
Jablonka, P., & Arimoto, N. 1992, A&A, 255, 63
Kauffmann, G. 1996, MNRAS, 281, 475
Lanzetta, K.M., Wolfe, A.M., & Turnshek, D.A. 1995, ApJ, 440, 445
Lin, H., et al. 1996, ApJ, 464, 60
Loveday, J. 1998, in Proc. XVIII Moriond Astrophysics Meetings "Dwarf Galaxies and Cosmology", ed. Thuan et al. (Editions Frontières), in press [astro-ph/9805255]
Loveday, J., Peterson, B.A., Efstathiou, G., & Maddox, S.J. 1992, ApJ, 390, 338
Maloney, P. 1992, ApJ, 398, L89
Marzke, R.O., Huchra, J.P., & Geller, M.J. 1994, ApJ, 428, 43
Marzke, R.O., et al. 1998, ApJ, 503, 617
Oliva, E., Origlia, L., Kotilainen, J.K, and Moorwood, A.F.M. 1995, A&A, 301, 55
Persic, M., & Salucci, P. 1990a, MNRAS, 245, 577
Persic, M., & Salucci, P. 1990b, MNRAS, 247, 349
Persic, M., & Salucci, P. 1992, MNRAS, 258, 14P (PS92)
Persic, M., Salucci, P., & Stel, F. 1996, MNRAS, 281, 27
Prochaska, J.X., & Wolfe, A.M. 1997, ApJ, 487, 73
Prochaska, J.X., & Wolfe, A.M. 1998, ApJ, 507, 113
Quillen, A.C., & Frogel, J.A. 1997, ApJ, 487, 603
Radcliffe, A., Shanks, T., Parker, Q.A., & Fong, R. 1998, MNRAS, 293, 197
Rhee, M.-H. 1996, PhD thesis, University of Groningen
Rees, M.J., & Ostriker, J.P. 1977, MNRAS, 179, 541
Salpeter, E.E., & Hoffman, G.L. 1996, ApJ, 465, 595
Salucci, P., Ashman, K.M., & Persic, M. 1991, ApJ, 379, 89

© 0000 RAS, MNRAS 000, 000–000
Salucci, P., Frenk, C.S., & Persic, M. 1993, MNRAS, 262, 392
Salucci, P., & Persic, M. 1997, in "Dark and Visible Matter in Galaxies", ed. M.Persic & P.Salucci, ASP Conference Series (San Francisco: Astronomical Society of the Pacific), 117, 1
Salucci, P., et al. 1999, in preparation
Schechter, P.L. 1976, ApJ, 203, 297
Schechter, P.L., & Dressler, A. 1987, AJ, 94, 563
Silva, L., Granato, G.L., Bressan, A., & Danese, L. 1998, ApJ, 509, 103
Sprayberry, D., Impey, C.D., Irwin, M.J., & Bothun, G.D. 1997, ApJ, 482, 104
Storrie-Lombardi, L.J., Irwin, M.J., & McMahon, R.G. 1996a, MNRAS, 282, 1330
Storrie-Lombardi, L.J., McMahon, R.G., & Irwin, M.J. 1996b, MNRAS, 283, L79
Thoul, A.A. & Weinberg, D.H. 1996, ApJ, 465, 608
Tytler, D. 1987, ApJ, 321, 69
Willick, J.A. 1998. astro-ph/9809160
Wolfe, A.M., Turnshek, D.A., & Smith, H.E., & Cohen, R.D. 1986, ApJS, 61, 249
Zucca, E., et al. 1997, A&A, 326, 477
Zwaan, M.A., Briggs, F.H., Sprayberry, D., & Sorar, E. 1997, ApJ, 490, 173