A Unique Mass Function from Galaxies to Clusters ?

G. Giuricin[1,2], *F. Mardirossian*[1,2], *M. Mezzetti*[1,2]
M. Persic[2,3], *& P. Salucci*[2]

(1) Dipartimento di Astronomia, Università degli Studi di Trieste, Trieste, Italy
(2) SISSA, Strada Costiera 11, I–34014 Trieste, Italy
(3) Osservatorio Astronomico, via G.B. Tiepolo 11, I–34131 Trieste, Italy

Abstract

We present an observational mass function ranging from galaxies to massive galaxy clusters, derived from direct dynamical mass estimates. Our mass function shows, in the low-mass range of galaxies and groups, a behaviour in agreement with that of standard CDM ($n = -2$), while in the high-mass range (clusters) our mass function is shallower (and thus contains more power) than standard CDM; it also results shallower than the recent mass function by Bahcall & Cen (1993).

Subject headings: galaxies: clustering

1 Introduction

The observational mass functions of bound systems can provide tight constraints to theories which describe the Universe density field at different scales, and, in general, can produce important diagnostics for cosmological models (see, e.g., Edge et al. 1990; Henry & Arnaud 1992; Lilje 1992).

Galaxies, groups and clusters of galaxies trace the observed large scale structure of the Universe, and contribute to map the distribution of the total (luminous and dark) mass, M. In this paper we consider the mass function (MF, hereafter), $n(M)$, of galaxies, groups and clusters of galaxies; $n(M)$ is the number of systems per unit volume and per unit mass. These MFs are obtained straight from the dynamics of galaxies, groups and clusters (see, e.g., Ashman, Persic, & Salucci 1993, Pisani et al. 1992, Biviano et al. 1993), rather than from indirect methods (see, e.g., Bahcall & Cen 1992; Bahcall & Cen 1993). In this way it is possible, in the estimate of the MFs, to avoid using cluster mass-to-luminosity ratios, which usually translate luminosity functions (LF, hereafter) into MF, or to avoid being forced to chose some X-ray-sources models coupled with X-ray-temperature functions (see, e.g., Henry & Arnaud 1991). In fact, often indirect techniques are more model-dependent than the direct analysis is, and may induce biases which are not easily detectable.

In the present paper we use $H_0 = 100\,h$ km s^{-1} Mpc^{-1}, and the masses are expressed in solar units.

2 The Mass Functions

We assemble the MF of galaxies, of groups, and of clusters of galaxies, which have been obtained from direct determinations. The MF, so obtained, is defined over three available observational windows, corresponding to the mass intervals of galaxies, groups, and of massive clusters, and it ranges between $\sim 2 \times 10^{11} h^{-1} M_\odot$ and $\sim 5 \times 10^{15} h^{-1} M_\odot$. The galaxy MF is derived from Ashman, Persic, & Salucci (1993); the group MF from Pisani et al (1992); and the cluster MF from Biviano et al. (1993).

2.1 Galaxy MF

Ashman, Persic, & Salucci (1993) (see also Persic & Salucci 1988, 1990) have shown that, in spiral galaxies, $M \propto L^p$ with $p = 0.5 \pm 0.1$, where M and L are the halo mass and the luminosity, respectively. They have shown that, as a consequence of this, at low masses $n(M) \propto M^{-\alpha_{gal}}$, with $1.6 \lesssim \alpha_{gal} \lesssim 2$.

In the present paper we assume that the halo MF does not depend on the morphological type of the embedded optical galaxy, and that the halo mass well describes the total mass of the galaxy.

In order to normalize the galaxy MF, we use the result (from the dynamics of galaxy pairs, i.e. independent of optical morphology) that the halo of an L_B^* galaxy has a mass of $M \sim 1.5 \times 10^{12} h^{-1} M_\odot$ (Charlton & Salpeter 1991). Using the mixed-morphology B-band luminosity function of Efstathiou, Ellis, & Peterson (1988) (for $0.03\, L_B^* \lesssim L \lesssim 0.5\, L_B^*$, i.e. in the luminosity range where the luminosity function is power law), our galaxy MF is the power law

$$n(M) \;\simeq\; 7^{+3.5}_{-2.5} \times 10^7 h^{2.2}\ M^{-1.8\pm0.2} \qquad \mathrm{Mpc}^{-3}\ \mathrm{M}_\odot{}^{-1} \tag{1}$$

in the mass range between $2.5 \times 10^{11} h^{-1} M_\odot$ and $1.1 \times 10^{12} h^{-1} M_\odot$ (corresponding to the above luminosity range).

2.2 Group MF

Pisani et al. (1992) have studied the problem of evaluating the distribution of the masses of galaxy groups by considering some sets of groups mainly belonging to the Local Supercluster. Out of these sets of groups we have chosen the groups identified by Tully (1987) in the Nearby Galaxy Catalogue (Tully 1988), because this catalogue represents a good sample of the nearby Universe, including also faint (but only gas-rich) galaxies. However, some completeness problems in the catalogue and the presence of the Local Supercluster in the sampled volume have suggested us to give only upper- and lower-limit estimates for the group MF. Following Pisani et al. (1992), we have conservatively chosen the high-mass groups between $1.1 \times 10^{13} h^{-1} M_\odot$ and $1 \times 10^{14} h^{-1} M_\odot$. In this mass range the group MF can be well described by the power law:

$$n(M) \;=\; A_{gr}\ h^2\ M^{-2}\ \mathrm{Mpc}^{-3}\ \mathrm{M}_\odot{}^{-1}, \tag{2}$$

where A_{gr} assumes the values 3.9×10^{10} and 1.4×10^{10} for the upper and the lower limit MF, respectively.

In order to estimate A_{gr}, we have taken into account the obscuration produced by our Galaxy (within $|b| \leq 15^o$) and the fraction ($\sim 40\%$) of groups comprised in the above-mentioned mass range. The value of A_{gr} corresponding to the MF upper limit has been deduced from the number of groups contained in the volume where the Nearby Galaxy Catalogue is complete (corresponding to systemic velocities smaller than 1500 km s^{-1}). We consider this estimate as an upper limit because the volume considered contains the richest region of Virgo Supercluster. On the other hand, the incompletion correction factor given by Tully (1987) allows us to estimate the total number of groups within 3000 km s^{-1} (including also faraway binary galaxies) which, therefore, leads to a value of A_{gr} corresponding to the MF lower limit. In fact, a volume corresponding to a radius of 3000 km s^{-1} samples the Universe better than a volume of radius $1500 kms^{-1}$ and, moreover, faint and gas-poor galaxies belonging to faraway groups are probably lost thus reducing the number of identified systems.

2.3 Cluster MF

Biviano et al. (1993) have studied the distribution function of the masses of 75 clusters, each having at least 20 galaxy members with measured redshifts within $1.5\,h^{-1}$ Mpc, and with mean redshift $z \leq 0.15$ (in order to reasonably reduce evolutionary effects). Possible subclustering problems have suggested to consider only the masses evaluated, via the Virial Theorem, within an aperture of half the Abell radius ($0.75\,h^{-1}$ Mpc) in 69 clusters. Subsequently, problems of incompleteness in the medium/low-mass regime have suggested to conservatively define only the MF of massive clusters. This can be represented by the power law:

$$n(M) \simeq 1.0 \times 10^{14} h^{1.7}\ M^{-2.3}\ \mathrm{Mpc}^{-3}\ \mathrm{M}_{\odot}{}^{-1} \tag{3}$$

in the mass range $4 \times 10^{14} h^{-1} M_{\odot} \lesssim M \lesssim 1.6 \times 10^{15} h^{-1} M_{\odot}$. The numerical coefficient of Eq.3 (see Biviano et al. 1993) corresponds to Peacock & West (1992) estimate of the number density of clusters (this value is ~ 1.5 times smaller than those reported by Scaramella et al. 1992 and Zucca et al. 1993). The associated uncertainty band has been estimated by means of the error propagation method.

Girardi et al. (1993) have shown that most of the clusters considered are quite well described by King density profiles. The median and mean cluster core radii are $\sim 0.15\,h^{-1}$ Mpc and $\sim 0.17\,h^{-1}$ Mpc, respectively. We adopted a multiplicative coefficient 3 (in the masses) to translate Biviano et al.'s (1993) original MF (obtained with masses evaluated within half the

Abell radius, i.e. typically $\sim 4-5$ core radii) into an asymptotic MF. So, Eq.(3) (with Peacock & West's density) can be considered as a lower limit to the cluster MF; vice-versa, the MF with masses 3 times as large can be considered as an upper limit.

3 A Unique Mass Function ?

Eqs.(1), (2), and (3) describe the MF of galaxies, of massive groups of galaxies, and of massive clusters of galaxies, respectively. It is possible to use these functions and their uncertainty bands to constrain a unique MF of bound systems which could give the mass distribution from galaxies up to massive clusters. Fig.1 shows these MFs together with the respective uncertainty bands (for groups, only the upper and lower limits are drawn).

The presence of MF-uncertainty-bands suggests to consider for the putative unique MF both an upper limit and a lower limit, if an analytic function is used to fit the logarithmic data. On the other hand, if a linear fit is preferred, it may be useful to obtain the steepest and the shallowest lines allowed within the uncertainty bands, and to consider these two lines as limits for the MF.

We use a Press-Schechter function:

$$n(M) \ = \ A\ h^4\ (M/M^*)^{\alpha-2} exp[-(M/M^*)^{2\alpha}]\ \mathrm{Mpc}^{-3}\ \mathrm{M}_{\odot}{}^{-1}, \qquad (4)$$

as the analytic function to fit our logarithmic data. The upper and the lower limits are defined by the parameter sets ($A = 1.0 \times 10^{-19}, M^* = 1.0 \times 10^{15} h^{-1} M_{\odot}, \alpha = 0.2$) and ($A = 1.3 \times 10^{17}, M^* = 5.0 \times 10^{13} h^{-1} M_{\odot}, \alpha = 0.2$), respectively.

On the other hand, if we try a linear fit to our logarithmic data, the two lines giving the upper limit and the lower limit virtually coincide, with slopes ranging between -1.9 and -2.1. Therefore we give a single power law:

$$n(M) \ = \ 1.5 \times 10^{10}\ h^2\ M^{-2}\ \mathrm{Mpc}^{-3}\ \mathrm{M}_{\odot}{}^{-1}. \qquad (5)$$

In Fig.2 we plot the upper and the lower limit to the unique MF according to Eq.(4), as well as its linear representation given in Eq.(5).

Our observational MF shows, in the low-mass range of galaxies and groups, a behaviour in agreement with that of standard CDM ($n = -2$) while at high masses (clusters) our MF is shallower (and thus contains more power) than standard CDM. It also results shallower than the cluster MF recently derived by Bahcall & Cen (1993).

In the hypothesis that the fraction f of galaxies contained in systems (groups and clusters) is equal to the ratio between the total mass-densities due to systems and due to galaxies, we can obtain the range of values within which the mean mass density in bound objects, Ω_{bound}, is expected to be. The values of Ω_{bound}, estimated for the range of masses between $1 \times 10^{11} h^{-1} M_{\odot}$ and $1 \times 10^{16} h^{-1} M_{\odot}$, are $0.37(1+f)^{-1}$, $1.34(1+f)^{-1}$, $0.65(1+f)^{-1}$, for the lower and the upper MF limits, and for the power-law MF fit, respectively. This implies $\Omega_{bound} \sim 0.5$ for $f = 0.7$, which is thought to be the value tipical for the nearby Universe (see, e.g., Tully 1987).

This work has been partially supported by the *Ministero per l'Università e per la Ricerca Scientifica e Tecnologica*, and by the *Consiglio Nazionale delle Ricerche (CNR-GNA)*.

References

??shman, K.M. 1992, PASP, 104, 1109.

??shman, K.M., Salucci, P., & Persic, M., 1993, MNRAS, 260, 610.

??ahcall, N.A., & Cen, R. 1992, ApJ, 398, L81.

??ahcall, N.A., & Cen, R. 1993, ApJ, 407, L49.

??iviano, A., Girardi, M., Giuricin, G., Mardirossian, F., & Mezzetti, M. 1993, ApJ L, in press.

??organi, S., Bonometto, S., Persic, M., & Salucci, P. 1991, ApJ, 374, 20.

??harlton, J.C., & Salpeter, E.E. 1991, ApJ, 375, 517.

??dge, A.C., Stewart, G.C., Fabian, A.C., & Arnaud, K.A. 1990, MNRAS, 245, 559.

??fstatiou, G., Ellis, R.S., & Peterson, B.A. 1988, MNRAS, 232, 431.

??irardi, M., Biviano, A., Giuricin, G., Mardirossian, F., & Mezzetti, M., 1993, in preparation.

??enry, J.P., & Arnaud, K.A. 1991, ApJ, 372, 410.

??ilje, P.B. 1992, ApJ, 386, L33.

??eacock, J.A., & West, M.J. 1992, MNRAS, 259, 494.

??ersic, M., & Salucci, P. 1988, MNRAS, 234, 131.

??ersic, M., & Salucci, P. 1990, MNRAS, 245, 577.

??isani, A., Giuricin, G., Mardirossian, F., & Mezzetti, M. 1992, ApJ, 389, 68.

??caramella, R., Zamorani, G., Vettolani, G., & Chincarini, G. 1991, AJ, 101, 342.

??ully, B. 1987, ApJ, 321, 280.

??ully, B. 1988, *Nearby Galaxy Catalog*, Cambridge University Press, Cambridge, U.K.

??ucca, E., Zamorani, G., Scaramella, R., & Vettolani, G. 1993, ApJ, in press.

Captions to Figures

Fig.1: The MFs together with the respective uncertainty bands.
Fig.2: The upper and the lower limits for the unique MF, and the power law description of the unique MF.