THE STELLAR IMF OF GALACTIC CLUSTERS AND ITS EVOLUTION

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Abstract

We show that one can obtain a good fit to the measured main sequence mass function (MF) of a large sample of Galactic clusters (young and old) with a tapered Salpeter power law distribution function with an exponential truncation. The average value of the power law index is very close to Salpeter (≈ 2.3), whereas the characteristic mass is in the range 0.1 – 0.5 M⊙ and does not seem to vary in a systematic way with the present cluster parameters such as metal abundance and central concentration. However, a remarkable correlation with age is seen, in that the peak mass of young clusters increases with it. This trend does not extend to globular clusters, whose peak mass is firmly at ≈ 0.35 M⊙. This correlation is due to the onset of mass segregation following early dynamical interactions in the loose cluster cores. Differences between globular and younger clusters may depend on the initial environment of star formation, which in turn affects their total mass.

1. Introduction

Conflicting claims exist as to the universality of the IMF (see e.g. Gilmore 2002) or lack thereof (e.g. Eisenhauer 2002). This unsatisfactory state of affairs has its most likely origin in the lack of uniformity of the experimental data used to infer the stellar IMF. The comparison of different data-sets, obtained by different authors in different environments (see e.g. the reviews of Scalo 1998, Kroupa 2001 and Chabrier 2003) is unfortunately hampered by systematic uncertainties. Therefore, our only hope to assess observationally whether the star formation process and its end result, namely the IMF, are the same everywhere rests on our ability to secure a statistically complete and physically homogeneous sample of stars. This is presently possible for Galactic clusters thanks to the recent advancements in the instrumentation (HST, VLT,
etc.) and in our understanding of the dynamical evolution of stellar systems (Meylan & Heggie 1997).

In Paresce & De Marchi (2000, hereafter PDM00) we studied the luminosity function (LFs) of a homogeneous sample of globular clusters (GCs) and showed that, within the present uncertainties, they can all be traced back to the same global MF and, most likely, the same IMF. That work suggests that the latter has a log-normal form below 1$M_\odot$, with a characteristic mass $m_c = 0.33 \pm 0.03 M_\odot$ and width $\sigma = 0.34 \pm 0.04$, independently of the cluster physical parameters or dynamical history. In a subsequent paper (De Marchi et al. 2004) this analysis has been extended to a homogeneous sample of young Galactic clusters (YCs), with ages ranging from a few Myr to a Gyr, by comparing their MF to one another and to that of GCs. Here follows a summary of the main results.

2. The sample

While the GCs in the sample have all been observed with the same instrument and band, and the data reduced with the same reproducible processing (see PDM00 for details), the YCs data come from several different sources. To enforce the highest degree of uniformity, we have searched the literature on YC LFs with specific guidelines, namely: the availability of recent, high quality photometry to supplement Schmidt plate material; a clear indication of which portion of the cluster has been studied; a solid membership selection; a reliable conversion from magnitude to mass; a detailed explanation of any correction to the MF to account for stellar multiplicity. The list of YCs selected in this way and the respective references are given in Figure 1.

Since the YC data span a wide wavelength range, it is not possible to directly compare to one another their LFs. Instead, we have concentrated on their MFs, which most authors approximate with a segmented power law, as done for instance by Kroupa (2001). The MFs are shown in Figure 1 (thick solid lines). Since most authors converted magnitudes to masses using the relationships of D’Antona & Mazzitelli (1994), the differences in the MFs should reflect those in the LFs.

In order to compare the MFs of the YCs in Figure 1 to one another and to that of GCs, it is useful to define some parameters that describe the MF shape. A log–normal distribution offers a suitable parametric description of the MF of GCs (PDM00). However, when extended to masses above those currently observable in GCs, a log–normal MF would fall off far more rapidly than the MF of YCs. In fact, the latter is in most cases very close to a Salpeter power law above 1$M_\odot$. For this reason,
we have looked for a different functional form which would accurately reproduce the observed MF of GCs and which, once extended above $1 \, M_\odot$, would still be compatible with the MF of YCs. Following the notation of Elmegreen (1999), one can write the MF as:

$$f(m) = \frac{dN}{dm} \propto m^{-\alpha} \left[ 1 - e^{-(m/m_p)^\beta} \right]$$  \hspace{1cm} (1)$$

where $m_p$ is the peak mass, $\alpha$ the index of the power law portion for high masses and $\beta$ the tapering exponent which causes the MF to flatten at low masses. The values of the tapered power law (TPL) parameters providing the best fit (dashed lines) to the observations are shown on the right-hand side of Figure 1, together with the cluster age. The typical uncertainty on $m_p$ is $< 0.1 \, M_\odot$.

Since the index $\alpha$ has an almost negligible effect on the shape of the MF around $m_p$, its value cannot be constrained for GCs. We have simply assumed in this case $\alpha = 2.3$ (the Salpeter value). Space limitations do not allow us to show here the TPL fit to the MF of each individual GC, so in Figure 1 we show the average MF (for more details, see De Marchi et al. 2004). Nevertheless, both $m_p$ and $\beta$ span a very narrow range around their average values, with $m_p = 0.35 \pm 0.04 \, M_\odot$ and $\beta = 2.6 \pm 0.3$ for the whole GC sample.
3. The evolution of the mass function

Figure 1 reveals that the shape of the MF can change considerably from cluster to cluster, with the peak varying widely in mass (although $\alpha$ and $\beta$ span a range of values fully consistent with that of GCs). The cluster MFs in Figure 1 are arranged with age increasing from top to bottom and even a casual inspection reveals immediately a strong trend, with the MF peak shifting to higher masses.

The most likely origin of this trend is the combined effect of mass segregation and the limited cluster area covered by the observations. In the absence of tidal interactions with the Galaxy, one expects the global MF of a cluster to vary slowly with time due to evaporation. For massive GCs this process can take several tens or hundreds of Gyr (Gnedin & Ostriker 1997) but, in YCs, mass segregation and the resulting evaporation proceed more rapidly (Raboud & Mermilliod 1998). Portegies Zwart et al. (2001) have shown that the global MF of a 600 Myr old cluster with a mass of 1600 $M_{\odot}$ differs only marginally from its IMF, even when the enhanced erosion induced by the Galactic potential is included in the calculations. However, the same simulations show that the local MF changes dramatically in the inner cluster regions, inside the half-mass radius. This is perfectly in line with the YC data of Figure 1, since all the MFs shown there were obtained in the inner cluster regions.

Without addressing here the details of a complete quantitative analysis (see Portegies Zwart et al. 2001; De Marchi et al. 2004), Figure 2 shows the temporal evolution of the stellar MF inside the half-mass radius of a 1600 $M_{\odot}$ model cluster. The IMF is assumed to be that of Scalo (1986) with an initial peak at $\sim 0.4 M_{\odot}$. The peak mass clearly grows with time, much in the same way as we observe in Figure 1. Since the average stellar mass increases towards the cluster centre, due to mass
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segregation, the location of the MF peak depends steeply on the fraction of cluster area sampled by the data: the wider the latter, the lower the peak mass. Thus, although not specific to any one of the clusters in our sample, the simulation shown in Figure 2 proves rather convincingly that mass segregation, combined with limited sampling of the cluster population, can explain much of the variation noticed in Figure 1.

4. Conclusions

It is, thus, likely that the YCs in Figure 1 share a rather similar IMF, since the progressive difference among their shapes grows with age in the same sense expected from dynamical evolution. Such an IMF would have to be very similar to the MF of the youngest clusters (∼1 Myr old) with a peak mass \( m_p \simeq 0.2 \text{M}_\odot \) or, more likely, \( m_p \simeq 0.15 \text{M}_\odot \) when account is taken of binaries (see Kroupa 2001). The latter is very similar to the IMF of the disc (Chabrier 2003). As discussed by PDM00, the similarity among the MF of GCs suggests that they as well could all share the same IMF.

An obvious question is whether the IMF is the same for both GCs and YCs. More precisely, one could ask whether dynamical evolution in GCs might have proceeded in such a way that the peak of their MF has moved from an initial value of \( m_p \simeq 0.15 \text{M}_\odot \) to the presently observed ∼0.35 \text{M}_\odot. The lack of correlation between the past dynamical history of GCs and their current global MF argues against this hypothesis (PDM00). If, however, GCs are indeed the naked cores of disrupted dwarf galaxies, as suggested e.g. by Martini & Ho (2004), one cannot exclude that their mass structure has been considerably altered and the properties of their IMF homogenised by the stripping process. Evidence of on-going GC disruption has been recently found in NGC 6712 (De Marchi et al. 1999) and NGC 6218 (Pulone et al. 2004). Since any low-mass stars lost by GCs should populate the halo, if the IMF of GCs was originally similar to that of YCs, the halo MF should also be peaked at ∼0.15 \text{M}_\odot. If, however, the MF of the halo turns out to be similar to that currently observed in GCs, it will indicate that their present day MF does not substantially differ from the IMF. Unfortunately, the current uncertainties on the actual properties of the halo MF (Graft & Freese 1996; Gould et al. 1998) do not presently allow us to test this hypothesis.

Regardless as to whether the IMF has a peak at ∼0.15 \text{M}_\odot or ∼0.35 \text{M}_\odot, it appears that its functional form is well matched by a TPL, at least for a large sample of clusters with widely different properties. This lends support to the theoretical predictions of Adams & Fatuzzo
who suggest high- and low-mass stars form through different processes and/or in different environments. Thus, it is probably not premature to suggest that the difference between the peak mass of globular and younger clusters also results from their initial star formation environment, which in turn affects the total mass of these systems. In spite of the many uncertainties still affecting this investigation, the very fact that the IMF seems to have a characteristic scale mass will hopefully soon allow us to characterise the star formation process from the properties of the IMF itself.

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