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DETERMINATION OF THE INITIAL MASS FUNCTION IN OPEN CLUSTERS FROM REALISTIC SIMULATIONS

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RESUMEN

Presentamos simulaciones numéricas detalladas de cúmulos abiertos que incluyen los efectos de la rotación estelar y de la presencia de sistemas binarios no resueltos. Aplicamos por primera vez la estadística no paramétrica D, y utilizamos un analísis bayesiano para estimar la función inicial de masas estelares en varios cúmulos. Concluímos que, si bien la pendiente de la FIM para masas superiores a 1.2 $M_{\odot}$ parece ser la misma, la pendiente para masas menores presenta una mayor variabilidad, posiblemente relacionada con la segregación en masa.

ABSTRACT

We present detailed simulations of open clusters including the effects produced by stellar rotation and by the presence of unresolved binaries. We apply for the first time the non parametric statistic D, and follow a Bayesian approach to derive the initial mass function in several open clusters. We find that even though the slope of the IMF seems rather constant above 1.2 $M_{\odot}$, there is some variability at smaller masses, perhaps linked with mass segregation.

Key words: **METHODS: STATISTICAL — STARS: EVOLUTION — STARS: HR DIAGRAM — STARS: MASS FUNCTION**

1. INTRODUCTION

Measuring the initial mass function (IMF) from a given cluster is a difficult procedure : even assuming no dynamical evolution and mass segregation effects, the number of stars in a given position in a colour-magnitude diagram (CMD) is not only a function of age (and hence of the present-day mass function, PDMF) but can also be affected by the fact that some stars may be rapidly rotating or are members of unresolved binary systems. Hence only a Bayesian technique can handle this type of degeneracy when attempting to infer the mass function from the information contained in a CMD.

2. DERIVING THE IMF WITH BAYESIAN STATISTICS

As introduced elsewhere (Valls-Gabaud & Lastennet, this volume) one can use a non-parametric statistics to decide whether a given model IMF is consistent with the data in a CMD. To do this, we use the following procedure. First we decide on a model IMF, that is, a given set of slopes and lower and upper masses, and a given fraction of unresolved binaries, along with a distribution function $f(q)$ for their mass ratios $q = M_2/M_1$. Second we assume that the distance, age and colour excess are known, and use stellar tracks to evolve a population of stars extracted from Step 1. To assess systematics, we use three different sets of tracks computed independently by the groups at Padova and Geneva, along with those by Claret & Giménez (1992). The systematics are very small, and in any case negligible with respect to the effects of rotation, which are as —if not more— important as unresolved binaries for the upper mass range around the turn off (see Lastennet & Valls-Gabaud 1999, for further details). The simulated CMDs can take into account, in addition to binaries and stellar rotation, a metallicity and age spread (possible intrinsic dispersion). The theoretical diagrams in the HR plane are transformed in the observable CMDs with the semi-empirical calibrations of Lejeune, Cuisinier, & Buser (1997), extended for different metallicities. The simulations are as realistic as possible except for the lack of dynamical evolution, which could be studied coupling this program to N-body simulations. The third step involves extracting a sub-sample from the model CMD of the same size as the observed CMD sample, and adding in the photometric errors corresponding to the observed CCD frame from which the CMD was extracted.

Once a realization of a synthetic CMD is done, it can be compared with the observed CMD, and the difference between the two assessed via, for example, the D statistic (Valls-Gabaud & Lastennet, this volume; see also Peacock 1983; Fasano & Franceschini 1987). For a series of realizations of synthetic CMDs, we compute the D statistic between this set and the observed CMD, resulting in a number of $D_{\rm os}$ values. By construction, the smaller the values of $D_{\rm os}$, the better agreement between model and data (the analogous at one dimension being the absolute value of the difference between the cumulative distributions). Yet this does not guarantee that the model is a good fit to the data, just that it is a best fit, given the model. To assess the goodness of fit, we proceed in Step 5 to construct the distribution of $D_{\rm ss}$ values comparing simulated CMDs extracted from the same model. The extent to which the empirical distribution $D_{\rm os}$ agrees with the calibration one, $D_{\rm ss}$, provides the ground to accept statistically the null hypothesis that the observed CMD and the simulated ones are extracted from the same parent distribution.

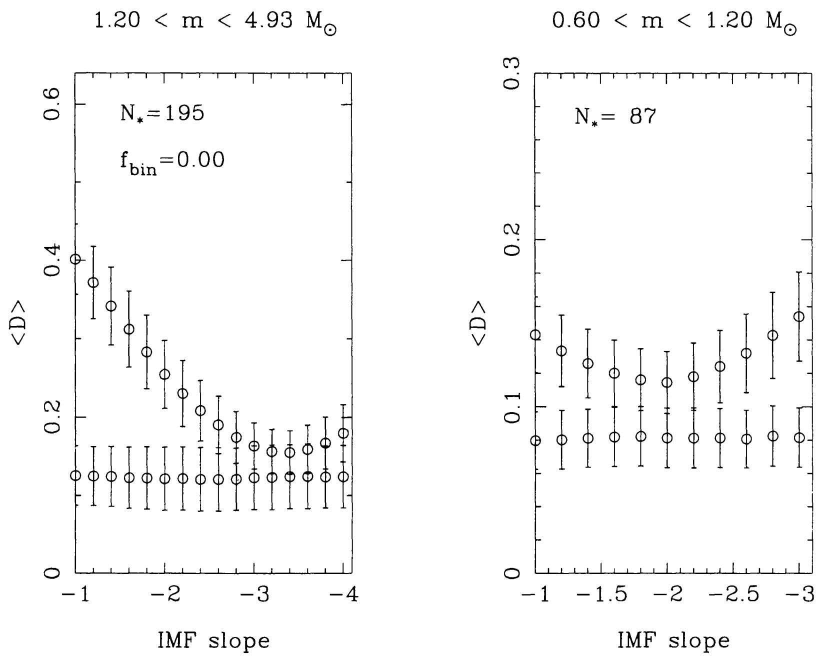

Fig. 1. Test using an IMF with two possibly different slopes, above and below 1.20 $M_\odot$. The left panel shows that under the assumption of no binary systems, the $N_* = 195$ stars of the Pleiades above this mass are consistent with a slope of -3.5 (Salpeter's index is -2.35): the parabolic-shaped figure of $< D_{\rm os} >$ crosses the distribution of $< D_{\rm ss} >$ around that value. Values between -3.0 and -3.8 are consistent at the 1σ level. The right panel shows the distributions for the $N_* = 87$ stars of lower masses. In this case, even though a slope of -2.0 is preferred by the $< D_{\rm os} >$, the calibration $< D_{\rm ss} >$ shows that it is a poor fit at the 1σ level, possibly because of the lack of binaries.

The procedure is illustrated in Figure 1 in Valls-Gabaud & Lastennet (this volume), and here we will only present a further extension for the case of an IMF with two slopes. Taking the observed CMD of the Pleiades (extracted from the BDA database compiled by Mermilliod [1994]) we could ask whether the slopes above and below 1.20 $M_\odot$ are statistically different. There are $N_* = 195$ stars above 1.20 $M_\odot$ in the compilation we use, and $N_* = 87$ below that mass, down to 0.60 $M_\odot$, the smallest mass available in our stellar tracks. We then apply our procedure to the two subsets of the CMD independently. Figure 1 shows the results for series of assumptions regarding the slope of the IMF (note that Salpeter's value is -2.35 in this notation), but keeping a fraction of binaries equal to zero (i.e., all stars are single in this example). The minimum value of $< D_{\rm os} >$ favors a slope of about -3.5, and that is the best fit to the data in the upper mass range. Whether this best fit is a good fit is indicated by the distribution of $< D_{\rm ss} >$ which is roughly constant with slope. It is because the best fit value of $< D_{\rm os} >$ is within 1σ of $< D_{\rm ss} >$ in the range -3.0 to -3.8, that the hypothesis that the IMF slope above 1.20 $M_\odot$ in the Pleiades is in this range can be accepted at this statistical level. This also implies that we can reject Salpeter's at more than 2σ, again assuming no binaries. In contrast, the lower masses, between 0.6 and 1.20 $M_\odot$, present a best fit around −2.0, but the fit is not good, as can be seen by comparing $< D_{\rm os} >$ with $< D_{\rm ss} >$ in the right panel of Figure 1. There is clearly a degeneracy between the slope of the IMF and the fraction of binaries, and this illustrates the power of the D statistic used here: we are able to discriminate very quickly among different models and assumptions, but the parameter space allowed, given the data that we have used and the stellar tracks, is very wide.

The systematic application of this technique to a sub-sample of open clusters (see Figure 2) suggests that the slope of the IMF above about 1.20 $M_\odot$ is fairly constant, while below this critical mass there seems to be a wider variation. Different assumptions regarding the fraction of binaries do not seem to affect the conclusion, which perhaps suggests that there is some dynamical effect such as mass segregation playing an important role.

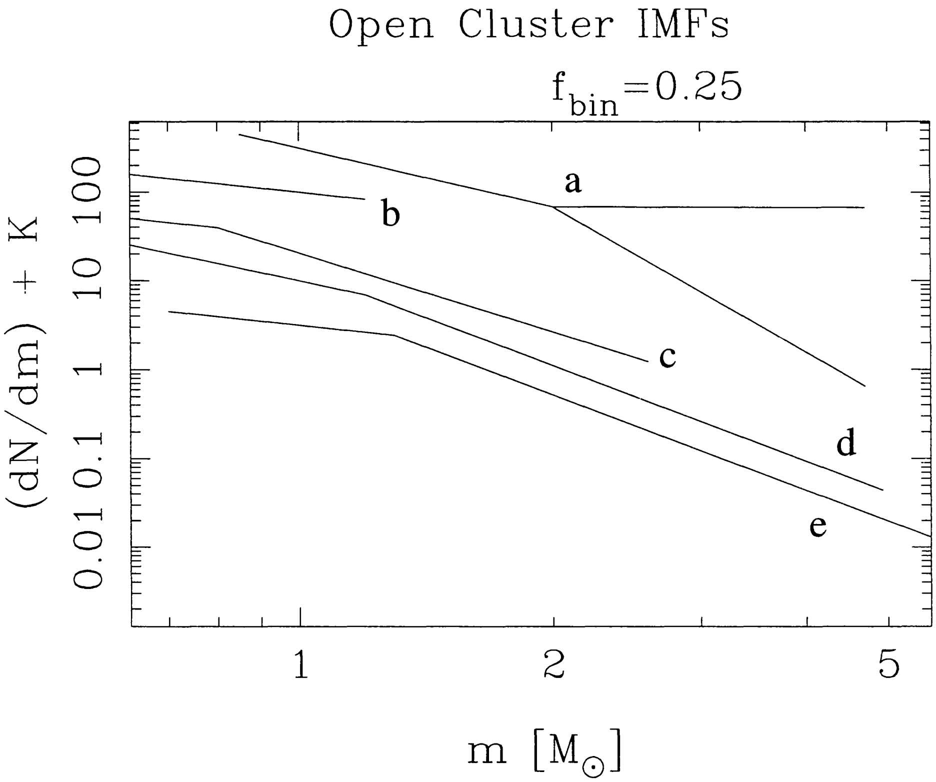

Fig. 2. Summary of the preliminary results obtained so far. Whilst the slope of the IMF seems to be roughly the same above about 1.2 $M_\odot$, there seems to be a wide range below that mass. The IMFs in this panel were derived under the assumption $f_{\rm bin} = 0.25$. Curve labels correspond to: a) NGC 2516, b) NGC 188, c) Hyades, d) Pleiades, and e) α Persei.

3. CONCLUSIONS

We have presented the first attempts at deriving the initial mass function of open clusters using Bayesian techniques. These require very realistic simulations of CMDs that incorporate the effect of unresolved binaries, stellar rotation, photometric errors and spread in intrinsic quantities like age and metallicity. The technique is limited by the small number of stars available, but allows us to reject statistically different IMFs. A preliminary result that requires further analysis seems to be that the IMF appears to be universal in open clusters for masses larger than about 1.20 $M_\odot$, and quite variable below this mass. Whether this may be due to mass segregation effects remains to be seen.

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