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Salpeter Mass Functions of Young Populous Clusters in the LMC?

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1. The Magellanic Clouds as Laboratories for Deriving IMFs

Although astronomers are not able to perform experiments with their objects under study, the Magellanic Clouds provide quite well what we may call an "astrophysical laboratory" (see Westerlund, 1990, for a review on Magellanic Cloud research). An important topic which can be tackled by investigating Magellanic Cloud objects is the shape of the Initial Mass Function (IMF) of newly formed stars.

The question whether the mass spectrum of stars that are born in a star-forming region has a universal shape or varies according to some (still unknown) laws, is fundamental for understanding both star formation and galactic evolution. A theory of star formation which is unable to predict the IMF of stars will always be considered as incomplete. The stellar mass spectrum is of relevance for galaxy evolution, since it controls the supernova rate and generally the amount of energy injected into the interstellar medium by massive stars. Moreover, the yield of freshly synthesized elements is a direct function of the stellar mass spectrum.

It has long been acknowledged that the young populous star clusters in the Magellanic Clouds are principally ideal targets for the investigation of the mass spectrum of their stars: They offer a high number of stars and a large mass interval with an upper limit of 10–15 solar masses. Such conditions are not found in the Milky Way. On the other hand, the extreme crowding of the stars complicates severely the derivation of a reliable luminosity function.

The crowding difficulty appears indeed prominently in papers related to this subject. Elson et al. (1989) counted stars on photographic plates in the surroundings of several young populous clusters in the Magellanic Clouds and determined mass functions which were surprisingly flat. If we assume a power law description of the shape $dN = m^{-(1+x)}$ dm (where dN is the number of stars in the mass interval between m–dm and m+dm), then Elson et al. found values for x in the range $-0.8 < x < 0.8$). Remember that the population in the solar environment can be described by $x = 1.3$. A systematic difference between stellar mass functions in the Magellanic Clouds and in the Milky Way would be a very important result.

However, in a paper by Mateo (1989) on the same topic, a quite different conclusion was reached. Mateo performed CCD photometry in Magellanic Cloud clusters of a wide range in age, among

The 2nd ESO/CTIO Workshop on

Mass Loss on the AGB and Beyond

will be held in La Serena, Chile, on 21-24 January 1992.

The aim of this workshop is to bring together observers and theoreticians to discuss the evolutionary stage of low and intermediate mass stars between the AGB and planetary nebulae: the **transition objects**.
Specific topics will include: transition objects, protoplanetary nebulae, mass-loss mechanisms and estimators, PN formation, new techniques: FIR, mm and sub-mm.
Invited speakers are: J. Dyson, Manchester; H. Habing, Leiden; P. Huggins, New York; M. Jura, Los Angeles; M. Morris, Los Angeles; H. Olofsson, Onsala; A. Omont, Grenoble; F. Pijpers, Leiden; D. Rouan, Meudon; R. Waters, Groningen; B. Zuckerman, Los Angeles.

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them also young clusters and he found the clusters to exhibit very steep mass functions with x exceeding 3.

At the time of appearance of the two cited papers, we had started working on the problem of determining stellar mass functions in Magellanic Cloud clusters and those contradictory statements meant an additional motivation for us to study this problem in more detail.

2. The Photometry

We used the Danish 1.5-m and the CCD #5 in December 1988 to observe the young clusters NGC1711, 2004, 2100, 2214, and 2164 in the Johnson B and V bands. We knew from earlier experience (Cayrel et al., 1989) that good seeing is the most important precondition for successful work on luminosity functions of this type of clusters. A seeing of around 1″ can already be considered as satisfactory and we were glad to meet this condition. Another experience was that long exposures, which are necessary to find faint stars, are affected by heavy charge overflow by bright stars in the cluster region. We thus obtained sequences of typically 10 shorter exposures, summed them up and proceeded the work on the summed images which now have a much larger dynamical range.

Stellar photometry on the frames was performed with DAOPHOT and the photometric calibration was achieved by using local photoelectrically measured stars (Alcaíno and Alvarado, 1989). We estimate the absolute error of our zero points to be around 0.03 mag. Figures 1 and 2 display the resulting colour-magnitude diagrams for NGC 2004 and 1711 and the neighbouring field regions. For NGC 1711, this is the first published CMD based on CCD photometry.

Earlier photographic work for our clusters has been done by Robertson (1974), and it is interesting to compare his data with ours. Bencevenni et al. (1990) also published a CMD for NGC2004, which was calibrated with the Robertson photometry and we included their data in our comparison. The residuals are more or less constant but show a magnitude- and colour-dependence at the bright end of the star distribution. We suspect that this effect is caused by a non-linearity in the Robertson magnitude scale since we found no saturation or non-linearity in our data. Clearly, one should be careful in using this photographic photometry for detailed comparison with theoretical colour-magnitude diagrams.

The next step on the way to mass functions is the determination of luminosity functions for our clusters which, with the help of theoretical mass-luminosity relations, can be afterwards transformed into mass functions.

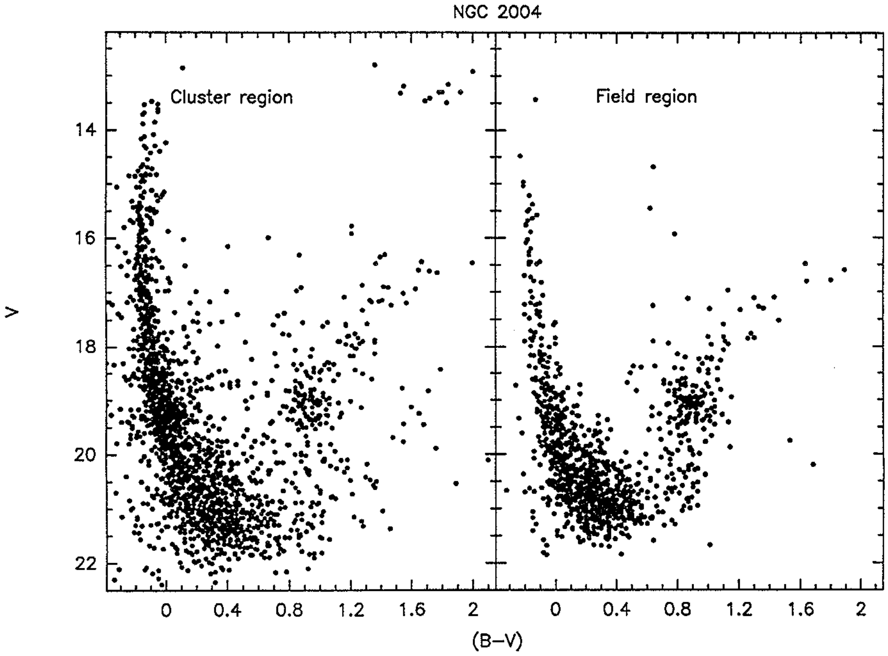

Figure 1: *The colour-magnitude diagram of NGC2004 and a neighbouring field region. One can distinguish also red giants belonging to older populations and the clump of intermediate-age He-core burning giants. The red supergiants are missing in the field region, indicating that a population as young as the cluster is not present in the field.*

3. Luminosity Functions and Data Incompleteness

Within the procedure of deriving LFs for our clusters, the most severe problem is the quantitative evaluation of the data incompleteness. It is very easy to find all bright stars in the frame but very difficult to find the faint ones! A widely used approach to this problem is to perform experiments with artificial stars, which are inserted in the original image with known coordinates and magnitudes. Recovering them in a normal

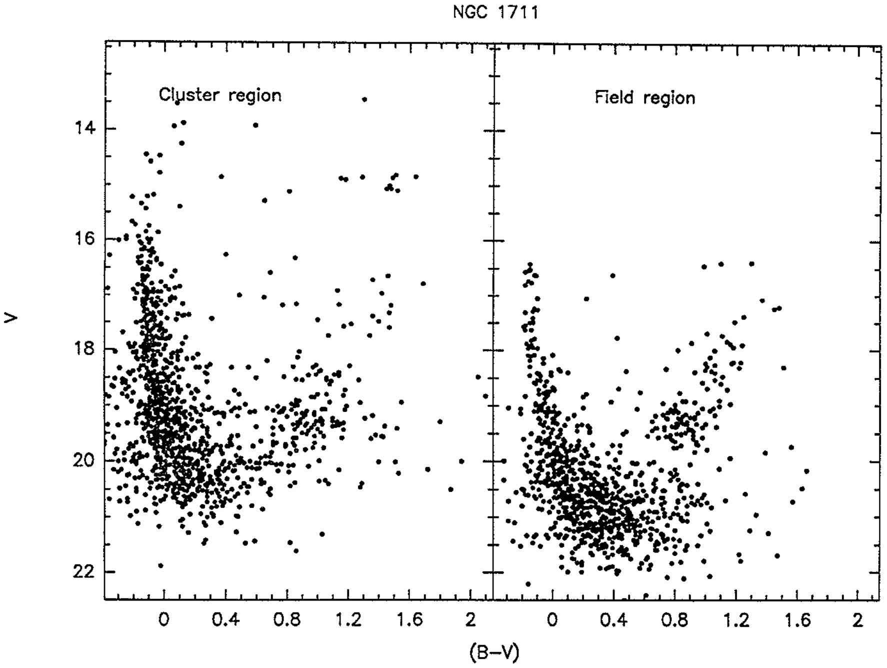

Figure 2: *The colour-magnitude diagram of NGC1711 and a neighbouring field region. Note that the photometry is deeper in the field, since the crowding is moderate with respect to the cluster region. Although NGC1711 is located far from the main body of the LMC, the number density of He-core burning field stars is not much lower than in the region of NGC2004. This shows that the distribution of faint stars in the LMC is much more extended than the distribution of the bright ones.*

reduction procedure leads to the derivation of "completeness factors" (ratio recovered stars/inserted stars), so one can correct the "observed" LF into a "real" LF.

What is the "completeness correction" to be applied to the stars figuring in a colour-magnitude diagram? After all, both the V and the B data have their individual completeness factors. The essential point is that the completeness is only dependent on the exposure level of the frame. The reduction, i.e. the reaction of the photometry software to the charge distribution on the CCD, is almost exactly the same for a V- and a B-frame, as long as the same star field is considered. As can be seen from Figure 1, there is almost no change in colour along our main sequences, so the relative magnitudes of the same stars are the same on B- and V-frames. Thus, given equal exposure levels, the photometry software finds the same stars in both wavelength bands and the completeness in the colour-magnitude diagram is the same as in the individual frames. In case of different exposure levels, the completeness in the colour-magnitude diagram is controlled by the smaller of the two completeness factors of the contributing frames.

4. Mass Functions

Transforming the luminosity function of a stellar cluster into a mass function requires knowledge of the cluster properties, distance, metallicity and age to select the proper isochrone. It is clear that the choice of the stellar models and their corresponding isochrones will have some influence on the end result. Thus a straightforward determination of a cluster MF is not possible if one does not know e.g. cluster metallicities, while one also has the freedom to select between different published theoretical models. What we can do instead is to assume several metallicities, derive the corresponding ages and show the effect of metallicity variation on the MF slopes. This is done in Table 1. Three sets of stellar models are employed, namely those by Maeder (1990), Bertelli et al. (1990) and Castellani et al. (1990).

It can be seen that the Bertelli et al. isochrones give the steepest slopes in the mass function which is due to their incorporation of strong convective overshooting. A high metallicity also tends to steepen the slopes. Only for NGC 2004 is a preliminary spectroscopic metallicity determination available (Jüttner et al., 1991) that points to −0.6 dex. In view of the low metallicity of another young LMC cluster (NGC 1818), for which Richtler et al. (1989) obtained −0.9 dex, it is probable that assuming a solar metallicity overestimates the metal content of young LMC clusters. In spite of the fact that we are forced to make the comparison between different stellar models with the assumption of solar metallicity (since neither Maeder nor Castellani et al. compute metal-poor tracks in the appropriate mass range), the MF slopes are (within the given uncertainties) not really distinguishable from the Salpeter value x = 1.35 (see Table 1).

Table 1: *Cluster properties and IMF slopes*

Object	Ages [Myr]			Z	MF slopes (x)		
	B	M	C		B	M	C
NGC 1711	60	32	25	0.02 0.001	1.9 1.2	1.3 –	1.3 –
NGC 2004	–	16	12	0.02	–	1.0	1.1
NGC 2164	100	63	36	0.02 0.004 0.001	1.5 1.4 1.1	1.1 – –	1.3 – –
NGC 2214	100	63	36	0.02 0.004 0.001	1.4 1.3 1.0	1.1 – –	1.3 – –

Z: Metallicity; B: Bertelli et al., 1990; M: Maeder, 1990; C: Castellani et al., 1990.

5. Comparison with Previous Work

How large the effects of isochrone uncertainty and completeness treatment can be becomes clear if we look at an earlier preliminary analysis of our data. Richtler and de Boer (1989) quoted IMF slopes for NGC2214 and 2164 with only crude assumptions for the completeness and the mass-luminosity relation and thus arrived at much steeper values than the present ones. Richtler et al. (1991) demonstrated the details of the effects of data incompleteness and model dependence.

What are the reasons for the differences between our results and those of Mateo and Elson et al.? One may suspect that star counts on photographic plates are an inadequate technique for those very crowded stellar fields and indeed, a comparison of our star counts with those of Elson et al. reveal that we have found more stars by a factor 2. Moreover, quantifying the completeness in photographic star counts is very difficult, but altogether there are no obvious reasons for the differing results.

Concerning the work of Mateo, we have one cluster in common, NGC1711. When we follow as close as possible the procedure described by Mateo (including his mass-luminosity relation) but using our own data, we get a reasonable agreement. The main difference, however, is in the treatment of completeness. Mateo considers the completeness on B and V frames as being independent, so that the resulting completeness factor would be the product of the individual B- and V completeness factors, whereas we found that they are fully dependent, as we explained already in section 2.

An example: Given 0.8 as the completeness factor for both B and V frames, Mateo would use 0.64 as the "resulting completeness" in the colour-magnitude diagram, while we would still use 0.8. This, of course, makes a large difference for the luminosity function to emerge, particularly if the completeness is low. Mateo does not list his completeness factors, but since he used a 1-m telescope for most of his data, we expect them to be lower than ours.

6. Conclusion and Prospects

What can we conclude? We can neither prove nor disprove the hypothesis that the shape of the IMF is universal, but we can show that at least the very steep IMFs found by Mateo (1989) are not real but result most likely from a special aspect of his data reduction. The IMFs which we derive from our photometry are, however, still uncertain. We require a better knowledge of the cluster metallicities before we can draw firm conclusions. Moreover, theoretical mass-luminosity relations for metal-poor and massive stars are missing. We also derived our IMFs with the assumption that all stars making up our luminosity function are single and not binaries. Nevertheless, our IMFs are indistinguishable from the IMF determined in the solar neighbourhood and thus the idea of a universal shape of the IMF gains additional support.

We think that photometry of Magellanic Cloud clusters with the NTT in excellent seeing would mean the most important step forward. Firstly, the number statistics could be improved by a significant factor thus allowing to decide whether the description of the IMF by a single power law is really adequate over a large mass interval or not. Secondly, the danger of contamination by merged stellar images is expected to decrease considerably. Thirdly, also older clusters with narrower mass intervals could be investigated in order to uncover the influence of cluster dynamics on the IMF.

The potential of the Magellanic Clouds as "astrophysical laboratories" is still very much alive!

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A "Happy Hour" at ESO Headquarters

On April 30, 1991, on the occasion of the 25th anniversary of Mrs. Christa Euler's services with ESO, the Section Visiting Astronomers had the pleasure to invite all ESO staff, on behalf of the Director General, to a "Happy Hour". The event was celebrated in a friendly and informal atmosphere. A beautiful book on the paintings in the Musée d'Orsay was presented to her by Prof. H. van der Laan, and J. Breysacher gave her a nice bouqet of spring flowers.

Mrs. Christa Euler joined ESO Chile on April 1st, 1966, at the time when Prof. O. Heckmann was the Director General of the Organization. At first she was installed in the office at the Santiago guesthouse and later in the Vitacura building, where she was responsible for all secretarial work in Santiago. Three years later, on the arrival of Prof. B.E. Westerlund, she took over the post of secretary to the ESO Director in Chile. With the exception of a ten-month period spent in the Personnel Department in Hamburg, she held this position until mid-1976. Her definitive move to Europe took place in September 1976. At the newly installed Headquarters in Garching, she took up duty in the Section Visiting Astronomers then headed by Dr. A.B. Muller. During the 15 years that Mrs. Christa Euler has now been working in this Section, she has – among many other things – remarkably handled about ten thousand proposals for observing time and perfectly organized several hundreds of travel arrangements to La Silla. Today her name is familiar to most European astronomers as well as to many others overseas.

J. BREYSACHER, ESO

Whatever Happened to Comet Halley?

As reported in the last issue of the *Messenger* (No. **63,** p. 22), Comet Halley was found to have undergone a major outburst, seen as a 19-mag cloud surrounding the nucleus in mid-February 1991 on CCD frames, obtained with the Danish 1.5-m telescope at La Silla. At that time, the comet was more than 14 A.U. from the Sun; this was the first time such an event had ever been observed, so far from the Sun. Observations at Hawaii (K. Meech) and Pic du Midi (C. Buil and collaborators) have confirmed the outburst. The French observers used a 61-cm telescope with a CCD, illustrating that Halley had become so bright that it was almost within reach of well-equipped amateur astronomers!

Very deep CCD observations were made at La Silla during March and April 1991, and it is now possible to say more about the nature of this outburst, although the cause has still not been unambiguously identified.

In late February, it was possible to obtain a low-dispersion, low-S/N spectrum of the coma with the 3.5-m NTT. It showed a solar reflection spectrum, which together with the measured colour strongly indicates that the coma mainly consists of dust particles. Still it cannot be excluded that there is a little gas present.

Comparing the many ESO images which were obtained during a 60-day interval, starting on February 12, it is clear that the surface brightness of the cloud progressively becomes fainter while its size increases. At the same time the brightness of the central condensation decreases and it becomes