Erfahrungsbericht: Massenfunktion südlicher Sternhaufen

Jörg Sanner
Sternwarte der Universität Bonn
Auf dem Hügel 71
D-53121 Bonn
Tel.: +2 28/73-93 99
E-mail: jsanner@astro.uni-bonn.de

Bonn, 1998

Dieser Bericht wurde in englischer Sprache abgefaßt, um ihn auch meinen Betreuern Dr Alan Vaughan (Macquarie University, Sydney) und Dr James Biggs (Perth Observatory) sowie dem Leiter der IAU-Arbeitsgruppe "Carte du Ciel", Alain Fresneau (Observatoire de Strasbourg), zugänglich zu machen.

Abstract

This report describes my activities to determine the mass function of selected open star clusters of the southern hemisphere. Although the tasks could not yet be completed due to poor or missing second epoch material, good results can be expected after adding new photographic material to be obtained at Perth Observatory in early 1998.

Contents

cluster	field	CdC zone	α (2000)			δ (2000)			number of
			h	m	s	$^\circ$	$'$	$''$	PPM stars
NGC 4103	1096	Sydney	12	13	03	–61	31	50	55
NGC 4755	904	Sydney	12	47	36	–59	30	57	49
	905	Sydney	12	59	47	–59	30	43	50
NGC 5281	1282	Sydney	13	51	17	–63	27	45	41
IC 2602	1270	Sydney	10	35	12	–63	29	46	55
	1271	Sydney	10	51	58	–63	27	45	41
	28414	Melbourne	10	42	29	–65	31	26	32

Table 1: List of the clusters with their corresponding Carte du Ciel field numbers. The number of PPM stars shows how many objects were available on the plates for transformation of the plate coordinates of the stars in the cluster region to their celestial positions.

1 Introduction

The research stay at Macquarie University in Sydney and Perth Observatory was done to gather the data used for proper motion studies of open star clusters of the southern hemisphere. The results of this work shall be combined with deep CCD exposures of these clusters to distinguish between members and non-members of the objects. This information will be used to obtain the initial mass function of the clusters [Sanner 1997].

For proper motion studies, old photographic plates covering the selected objects are required. Suitable material can be found in the archives of the Carte du Ciel project. In 1887, an international conference took place in Paris during which both the “Astrographic Catalog” and “Carte du Ciel” projects were initiated [Wood 1971]. The sky was divided into “declination zones” each of which was dedicated to one observatory.

While the data of the stars of the Astrographic Catalog, which covers stars down to 11.5 mag, were extracted from the plates and published, the Carte du Ciel plates (down to between 14.0 and 15.5 mag) were never completely processed [Brosche 1996].

Of particular interest for this work are the Carte du Ciel declination zones of Sydney (-52° to -64°) and Melbourne Observatories (-65° to -90°).

2 Selection of the plates

In the archive of Macquarie University, where the plate archives of both Sydney and Melbourne Observatories are located, I was able to find a total of seven fields covering the areas of the selected clusters. Table 1 shows details about these fields. The fields are numbered according to a traditional, internal reference system used when the plates were taken.

The information about the plates taken of these fields was extracted from the original observing log books. They cover the records of both the Astrographic Catalogue and the

plate	field	date	plate	field	date
215	28414	19.3.1892	3386_s	1270	6.5.1897
712	28414	23.3.1893	3391_s	1282	6.5.1897
2860_s	905	13.3.1896	725_{RH}	1282	14.5.1901
2875_s	1096	18.3.1896	733_{RH}	1271	17.5.1901
2893_s	904	14.4.1896	3275	28414	18.3.1910
2930_s	1270	6.5.1896	$7735Sa$	1096	27.4.1978
2931_s	1271	6.5.1896	$7736Sa$	1096	1.5.1978
3324_s	904	29.4.1897	$7992Sa$	904	18.3.1980
3333_s	905	30.4.1897	$7993Sa$	904	18.3.1980
3360_s	1096	3.5.1897	$7998Sa$	905	20.3.1980

Table 2: List of the plates selected to be measured at Perth Observatory. Besides the plate numbers, the field numbers and the date of observation are given. Plates with indices s, RH, and Sa were taken at Sydney Observatory, non-indexed plates at Melbourne Observatory.

Carte du Ciel plates. However, only the latter were selected, because they reach down to fainter magnitudes.

The archive was found to be incomplete. While all the first epoch plates were found, most of the second epoch plates from the 1970s and 1980s were missing. According to Richard Lomb from Sydney Observatory [Lomb 1997], a series of plates was borrowed in the early 1980s, even before the plates were brought to Macquarie University in 1984, and were never returned to the archive. Therefore, only a maximum of two second epoch plates per field were found. Second epoch plates of the fields containing NGC 5281 and IC 2602 were found to have never been taken at all. Fortunately, Dr James Biggs, Director of Perth Observatory, offered me the opportunity to observe the fields with the Perth Astrograph. Because the clusters could only be poorly (if at all) observed during the time I visited Perth, these observations will be done by the staff of Perth Observatory in April, 1998.

A complete list of the plates extracted from the archive is shown in table 2.

Most plates of the Carte du Ciel project were exposed three times with a little shift of the telescope between the exposures. This led to three images of each star, located in the corners of a small triangle, see e.g. [Brosche 1996]. Triple images of this type can cause severe problems because the three images of bright stars (especially the stars used for coordinate transformation) merge to one large black area on the plate which cannot be used to transform the positions of the much fainter and therefore clearly separated target objects. However, only plate 3275 of the Melbourne archive showed this typical pattern.

Plate 725_{RH} and 733_{RH} had three images in one straight line (see appendix A.1) which were so distant that merging of different images of the same star did not occur. It was even easily possible to see which images belong to the same star so that double measurements could be avoided in most cases. If erroneously one of the stars of a different exposure was measured, its position will be rejected automatically later because of its missing counterpart on the second epoch plates.

3 The measurements

To obtain proper motions, it is not sufficient to determine the positions of the candidate stars for cluster membership on the plates. In addition, several stars with known positions and proper motions have to be measured, from which one can obtain a transformation from the rectangular plate positions (x, y) to the spherical celestial coordinates (α, δ). Usually, the PPM star catalogue [Röser & Bastian 1993] is used for this purpose. Approximately 40 to 60 PPM stars are found on each of the plates, as seen in table 1.

So it was necessary to obtain the (x, y) coordinates of both all the PPM stars and of *all* stars in a certain region of the plates which can be assumed to contain all members of the star cluster.

The measurements were performed with Perth Observatory's Carl Zeiss measuring machine. With this instrument, one can determine the position of the sled carrying the plate with an accuracy of 1μm for both coordinates x and y. However, this is not the precision of the stellar positions themselves, because the uncertainty of visually centering the stars with respect to the eyepiece's cross hair is of the order of several μm. In addition, the positional accuracy may be influenced by systematic errors caused by the stars' parameters, e.g. their magnitudes and colours. Another systematic error is induced by a massive distortion of the lens of Sydney's astrograph: Towards the corners of the plates the stellar images show secure radial elongation. The real accuracy of the positions measured therefore is a function of various parameters.

Initial measurements indicated that one single measurement per star was not sufficient to achieve a precision good enough for proper motion studies. Therefore I decided to measure each plate twice, which, of course, meant that I would not be able to measure all the plates in time. I decided to cancel the measurements of IC 2602 for several reasons:

- The only Carte du Ciel first epoch plate of the Melbourne field 28414 was plate no. 3275. (See also the remark in appendix A.2.) I had taken two Astrographic Catalogue plates (215, 712) of that region with me, too, but because of their short exposure times of only 5 minutes they did not cover many stars. A minimum of two good plates of the same epoch is necessary for an acceptable proper motion study.

- As already described in section 2, it would have been very difficult to measure the triple images of plate 3275 with the equipment provided at Perth Observatory. The only chance would have been to digitize the plate and determine the positions with special software developed to solve the triple image problem [Geffert et al. 1996]. However, this would have led to taking the plate with me to Europe because there is no operational plate scanner which provides a sufficient accuracy in Australia.

Then, the problem of how to return the plates back to the archive would have raised: Because of the value of the plates it would not have been possible to send them back by post.

- There was no second epoch material available for IC 2602 yet.

The second measurement of each plate was performed with the plate attached to its plate holder in reverse position (i.e. with an orientation changed by 180°) to reduce systematic errors caused by the subjective determination of the centre of the stellar image by the measuring person [Wood 1971]. For further testing of the facility one of the plates (2875_s) was measured for four times: In addition to the usual two settings it was also installed on the plate holder rotated by 90 and 270° with respect to the normal position. All the measurements are listed in table 3.

In total, a number of 4818 objects were measured. The table shows a large difference between the highest (plate 3324_s) and lowest (plate $7992Sa$) number of stars. This cannot only be explained by a varying "real" density of stars from field to field, but by the different exposure times. Especially all the second epoch plates proved to be exposed too short. Therefore, after including the 1998 Perth plates into the calculation, I expect a massive improvement of the results concerning both the number of stars for which proper motions can be obtained and the accuracy of the proper motions themselves.

Therefore, of course, I cannot yet present final results of my studies of the selected open star clusters.

4 Data reduction

For data reduction, standard software of the Sternwarte Bonn [Geffert et al. 1997] is used. The main steps during this procedure are:

- Cross-identification of the stars on the different plates.

- Determination of average positions of the stars using the 0° and 180° measurements.

- Transformation from plate coordinates (x, y) to celestial coordinates (α, δ) using polynomials of first, second or (as in this case) third order. The 3, 6, or 10 plate coordinates, respectively, are computed with respect to the PPM stars.

- Determination of the proper motions of the stars in the cluster area.

The accuracy of the measurements can be checked by applying the obtained transformation on the plate positions of the PPM stars and comparing the computed with the catalogue values ("observed – calculated", "$O - C$"). Table 4 shows the mean $O - C$ values of the PPM stars on each of the plates.

The slightly higher values for the old plates are a result of partially irregularly shaped stellar images. For those, the determination of a precise position on the plate is very difficult. With the measurements of the new plates completed, an improvement of these deviations will be attempted by removing probably poorly measured PPM stars from the sample.

plate	field	plate orientation	number of stars (total)	number of stars (cluster)
2860_s	905	0°	251	202
		180°	258	209
2875_s	1096	0°	172	116
		0°	149	93
		90°	168	113
		180°	166	111
		270°	166	111
2893_s	904	0°	216	167
		180°	209	161
3324_s	904	0°	356	307
		180°	312	263
3333_s	905	0°	329	279
		180°	335	286
3360_s	1096	0°	157	101
		180°	150	95
3391_s	1282	0°	131	90
		180°	130	89
725_{RH}	1282	0°	148	107
		180°	153	112
$7735Sa$	1096	0°	143	88
		180°	140	86
$7736Sa$	1096	0°	119	55
		180°	108	53
$7992Sa$	904	0°	99	51
		180°	95	47
$7993Sa$	904	0°	104	52
		180°	97	50
$7998Sa$	905	0°	132	82
		180°	137	87

Table 3: List of the measurements. For each plate, the total number of stars is indicated as well as the number of stars measured in the region of the cluster. The figures for normal and reverse measurements are given separately.

plate	Epoch	$\sigma(\alpha)$	$\sigma(\delta)$
2860_s	1896	0.28	0.30
2875_s	1896	0.27	0.30
2893_s	1896	0.37	0.31
3324_s	1897	0.32	0.31
3333_s	1897	0.27	0.36
3360_s	1897	0.27	0.36
3391_s	1897	0.22	0.32
725_{RH}	1901	0.43	0.45
$7735Sa$	1978	0.15	0.14
$7736Sa$	1978	0.16	0.16
$7992Sa$	1980	0.23	0.22
$7993Sa$	1980	0.19	0.19
$7998Sa$	1980	0.13	0.15

Table 4: List of the root mean square (rms) σ of the positions of the PPM stars on the plates measured at Perth Observatory for both celestial coordinates α and δ after merging the normal and reverse measurements. The values are given in arc seconds.

5 The first test: Proper motions of NGC 4755

Only for the cluster NGC 4755 a proper motion study could be attempted so far because it is covered by two fields which doubles the number of measurements available.

Fig. 1 shows the (x, y) positions of the stars measured on the plate 2893_s in $0°$ orientation. Including this and all the other measurements of plates of the fields 904 and 905 available so far, the preliminary vector point plot diagram shown in fig. 2 was computed.

As the recent epoch plates were exposed for twelve minutes only, the study is limited by their poor sensitivity. Major improvements concerning the errors of the studies and the limiting magnitude are expected after including the new Perth data.

The diagram shows a circular clustering of objects around –15 mas/yr in the direction of right ascension and 0 mas/yr in declination. This represents the cluster members whereas the stars with highly differing proper motions very likely do not belong to the cluster. After including the new data a much more pronounced peak of the cluster stars can be expected.

6 Outlook and summary

As mentioned above, the proper motion studies – and therefore the determination of the mass functions – of the three clusters cannot be completed yet.

Once I receive the new exposures from Perth Observatory, the following steps will be performed:

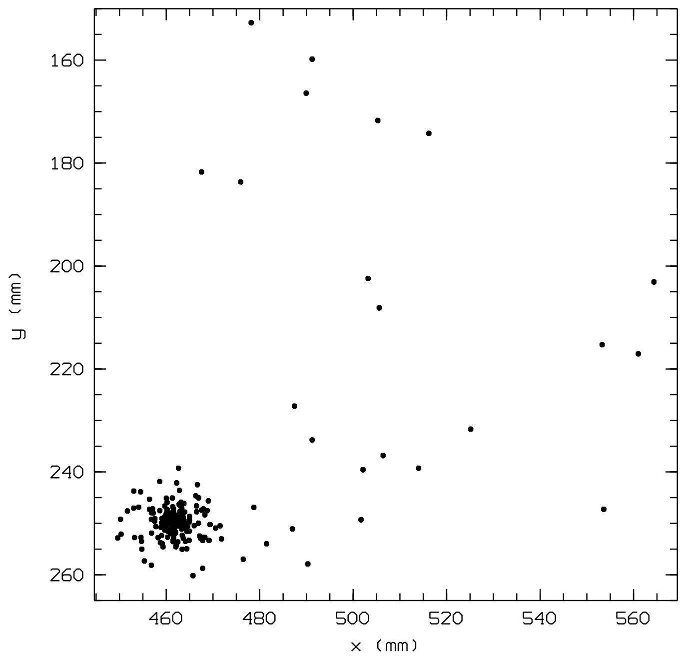

Figure 1: Diagram of the x, y positions measured on plate 2893_s in 0° orientation. The cluster is located in the lower left corner, whereas the points spread over the plate represent the PPM stars.

- Completion of the proper motion studies.
- Improving/Comparing the PPM proper motions with data of the HIPPARCOS and Tycho catalogues. [ESA 1997]
- Membership determination by the received proper motions.
- Combination of these results with the photometric data.
- Determination of the mass functions of the three open star clusters.

After adding the new Perth plates, I expect the following improvements of the proper motion studies:

- Because more measurements will be available, a higher accuracy will be achieved.

  This means that the cluster member stars will show a higher concentration in the vector point plot diagram and therefore can be better distinguished from the non-members.

- Because the new plates will cover stars with fainter magnitudes than the available Sydney second epoch plates, proper motions will be determined for many more stars. So far, the limiting factor of the proper motion study is the poor quality of the second epoch plates.

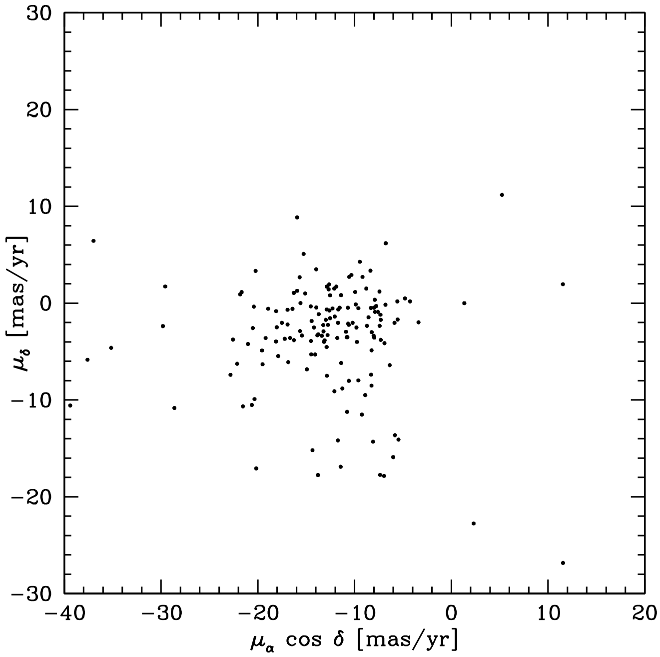

Figure 2: Preliminary vector point plot diagram of NGC 4755. A concentration of points is visible around $(-15, 0)$. This indicates the cluster members, whereas the data points outside this region correspond to the field stars. The diagram is to be improved with new recent photographic material which will be taken in early 1998.

This will improve not only the evidence of the proper motion study itself, but also the mass function, as the proper motion membership criterion can be extended over a larger mass interval.

A The archives of the Carte du Ciel and Astrographic Catalogue in Australia

A.1 Sydney

The plates of the Sydney zone ($\delta = -52°$ to $-64°$) have been stored in the air conditioned "Rare books room" of the Library of Macquarie University since 1984. They were kept under very poor conditions at Sydney Observatory before, so that some of the plates show some sort of decay. The archive is now maintained by Dr Alan Vaughan from the School of Mathematics, Physics and Computer Engineering (MPCE) of Macquarie University, Sydney, NSW 2109, phone +61/2/9850 8904, e-mail: alanv@macastro.mpce.mq.edu.au.

The plates of the Astrographic Catalogue are stored in black $16 \times 16\text{cm}^2$ cardboard boxes holding 10 to 12 plates each. Typical exposure times are 4 min, 2 min, and 13 sec on each plate. One plate of each field was available, I did not find any backup or rejected plates in those boxes. The plates are sorted by the (internal) number of the guide star used – not by their exposure numbers.

The Carte du Ciel plates are stored in equivalent, mostly blue boxes. I could find various numbers (approx. 2 to 5) of plates of each field.

Most of the Sydney plates – all of them observed by James Short during the last decade of the 19th century – show only one image per star, with typical exposure times of 30 to 60 minutes; only later plates with index "RH" were exposed three times (1 hour, 20 minutes, and 20 seconds), with the three images in one straight, vertical line at a distance of approx. 1 mm each.

Recently, Alan Vaughan was offered the broken plate scanner of the Anglo Australian Observatory (AAO). Discussions about the transport to Macquarie University and the repair of the instrument are under way.

A.2 Melbourne

The Melbourne plates ($\delta = -65°$ to $-90°$) were also stored at Sydney Observatory until they came to Macquarie University in 1984. Now they are located in a room of the so-called "Brunner Collection", also in the library of Macquarie University. They were brought there several years ago because of repair work in the rare books room.

The plates of the Astrographic Catalogue and the Carte du Ciel are stored in big wooden boxes containing 50 plates each. They are sorted by exposure number, and the "accepted" and "rejected" plates are stored in different boxes.

The Melbourne plates must have been checked for suitability immediately after the plate processing: They were classified as "accepted" or "rejected" in the observing log book, and the fields of the "accepted" plates were never observed again.

The Carte du Ciel plates show the typical triple images structure with exposures of 30 minutes each while the Astrographic Catalogue plates were exposed for 5 min, 2.5 min, and 20 sec.

The plates were put into the boxes without any envelopes so that access to the observing log books is essential for finding out the details of the observations.

As the access to the boxes is not very simple at the moment (they are located under a staircase in three piles one after the other) there are plans to move them to another place. They are stacked mixed up so that I cannot state whether the archive is complete or not. However, some of plates were still on display at Sydney Observatory.

A.3 Perth

The plates of the Perth zone ($\delta = -4°$ to $-32°$) are stored in an air conditioned room at Perth Observatory, Walnut Road, Bickley, WA 6076. They are in charge of Dr James Biggs, director of the observatory and Government Astronomer, phone +61/8/9293 8255, e-mail: jamieb@calm.wa.gov.au.

According to Dr Biggs, all plates of the Astrographic Catalogue are there, exposed for three times (6 min, 3 min, 20sec, later only 4 min, 2 min, 13 sec).

The Carte du Ciel plates of the Perth zone were never taken.

References

[Brosche 1996] Brosche P., 1996, Proceedings of the 4th International Workshop of Positional Astronomy and Celestial Mechanics (submitted).

[ESA 1997] ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP–1200.

[Geffert et al. 1996] Geffert M., Bonnefond P., Maintz G., Guibert J., 1996, A&AS 118, 277.

[Geffert et al. 1997] Geffert M., Klemola A.R., Hiesgen M., Schmoll J., 1997, A&AS 124, 157.

[Lomb 1997] Lomb R., private communication, 1997.

[Röser & Bastian 1993] Röser S., Bastian U., 1993, PPM Star Catalogue South, Akademischer Verlag.

[Sanner 1997] Sanner J., 1997, Arbeitsvorhaben: Massenfunktion offener Sternhaufen, submitted to DAAD.

[Wood 1971] Wood H., 1971, Astrographic Catalogue 1900.0, Sydney Section, Vol. LIII, 5.