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The Determination of the Age of Globular Clusters: A Statistical Approach

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Abstract.
We present a statistical approach for determining the age of Globular Clusters (GCs) that allows estimating the age derived from CMDs more accurately than the conventional method of isochrone fitting. We measure how closely a set of synthetic CMDs constructed from different evolutionary models resemble the observed ones by determining the likelihood using Saha and χ^2 statistics. The model which best matches the observational data, of a set of plausible ones, is the one with the highest value of the estimator. We apply this method to a set of three different evolutionary models presented by three different authors. Each of these sets consists again of many different models of various chemical abundances, ages, input physics and the like. We subsequently derive the age of GCs NGC 6397, M92 and M3. With a confidence level of 99%, we find that the best estimate of the age is 14.0 Gyrs within the range of 13.8 to 14.4 Gyrs for NGC 6397, 14.75 Gyrs within the range of 14.50 to 15.40 Gyrs for M92, and 16.0 Gyrs within the range of 15.9 to 16.3 Gyrs for M3.

1. Introduction

The age of Globular Clusters (GCs) has been recognized as being of key importance for deriving the age of the Universe. However, up to now, determining the reliable age of GCs has proven rather difficult. This is not only because of errors introduced by the observations, but also because of the rather subjective way in which the stellar evolutionary models have been selected in some conventional procedures like the isochrone fitting and the way in which observational data has been fit. In this work, we present a statistical approach for determining the age of GCs that overcomes some of theses difficulties. Our method avoids the difficulty in selecting the stellar evolutionary model which best matches the

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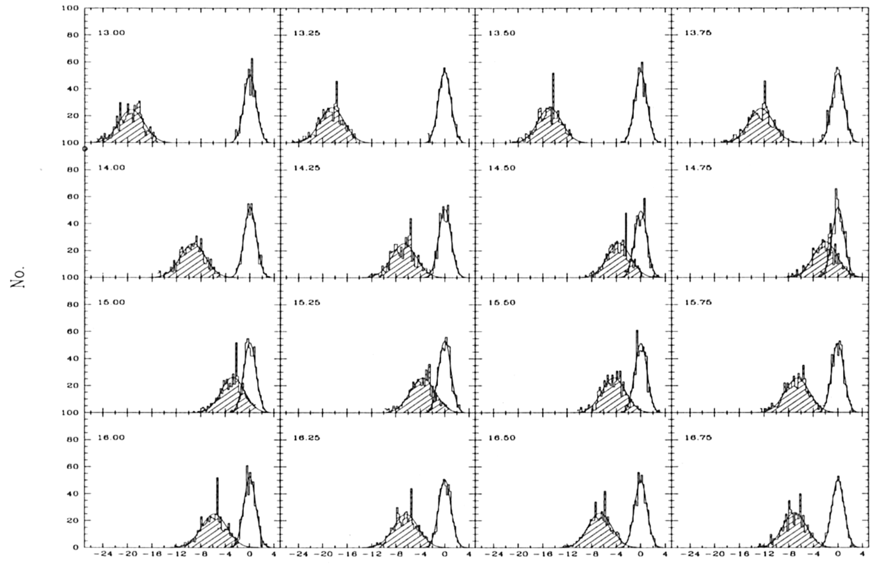

Figure 1. Distribution of values of log W for different ages of the Padova isochrones for stars in NGC 6397 (see text for details).

observational data of the CMD. This is done by determining the likelihood using the Saha statistics or W (Saha 1998). The goodness of the fit of our method is estimated from the χ^2 statistics by Press et al. 1986. As an example, we apply the method to NGC 6397, M92 and M3, and give an estimate for their age with a confidence level of 99%.

2. Observational data and stellar evolutionary models

The observational data consist of V and I photometry of three GCs of the Galaxy: NGC 6397 (D'Antona 1999 & King 1999), M92 and M3 (JKT data by Rosenberg 1999). We removed all stars with excessive photometric errors (3 σ in the colour) and we selected only stars out to a radius of r<140′ for M92 and r<170′ for M3. The number of stars in each sample is given in Tab. 1. We selected the models computed by Bertelli et al. 1994 and Girardi et al 1996 (Padova isochrones), tracks developed by Demarque et al (Yale isochrones) and a set of models by Cassini et al. (1998, 1999; Pisa isochrones). We chose them as they were published in the theoretical plane and we use the transformations computed by Bruzual & Charlot 2000 to convert them to the observational plane.

3. Results

The full details of the approach are presented in Rengel 2000. As an example, Fig. 1 shows the distribution of values of log W for a sample of 1187 stars in NGC 6397. The non-shaded regions represent the distribution of frequencies of log W obtained from 500 model-model comparisons, the shaded regions for

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Table 1. Summary of the results of the best estimation of the age of the samples considered in this work, for every evolutionary model

Evolutionary Model	Z of the Isochrone	χ^2_{min}	χ^2_{red}	Best estimation of t [Gyrs]	Interval of 99% of confidence
NGC 6397	1187 stars	B=14400			
Padua	0.0004	1352.81	2.82	14.50	[14.3 - 15.1]
Yale	0.0004	1089.04	2.34	14.00	[13.8 - 14.3]
NGC 6397	373 stars	B=8400			
Padua	0.0004	232.84	1.41	14.25	[13.7 - 15.6]
Yale	0.0004	206.80	1.25	14.00	[13.3 - 15.1]
Pisa	0.0002	249,95	1.41	13.00	[11.9 - 14.2]
M92	4846 stars	B=12000			
Padua	0.0001	2221.63	1.31	14.75	[14.5 - 15.4]
Yale	0.0002	2455.26	1.42	15.00	[14.6 - 15.7]
M92	1482 stars	B=12000			
Padua	0.0001	678.79	1.73	15.00	[14.8 - 15.5]
Yale	0.0002	769.67	1.91	15.00	[14.7 - 15.5]
Pisa	0.0002	832.86	2.06	12.00	[11.8 - 12.1]
M3	10333 stars	B=14400			
Padua	0.0004	3558.38	1.59	15.75	[15.7 - 15.9]
Yale	0.0004	3037.01	1.37	16.00	[15.9 - 16.3]
M3	4929 stars	B=14400			
Padua	0.0004	1038.53	2.14	16.25	[16.2 - 16.6]
Yale	0.0004	757.20	1.68	16.00	[15.9 - 16.3]
Pisa	0.0002	1120.65	2.45	14.00	[13.9 - 14.2]

500 data-model comparisons. The estimation of the age is given for the age of the isochrone that corresponds to the minimal distance obtained between the Gaussian median fits to the model-model and data-model distributions (14.75 Gyrs). A summary of the results obtained for the best estimation of the age of the GCs for each of the models is given in Tab. 1.

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