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Pinpointing isochrones in clusters

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Abstract. Detached eclipsing binaries allow the determination of accurate stellar masses and radii. Here we present the first results of a programme which aims at using such systems for the determination of accurate stellar parameters in open star clusters and discuss this in relation to the study of pulsating stars. As an example we show results for a detached eclipsing system in the old open cluster NGC 188 and briefly discuss the two intermediate age open clusters NGC 1817 and NGC 2506 which both contains pulsating stars and detached eclipsing binaries.

Key words. Stars: fundamental parameters – Stars: pulsating – Galaxy: open clusters

1. Introduction

One of the problems for the study of stellar pulsation and its confrontation with theoretical models is the generally poor knowledge of the basic stellar parameters, such as mass and radius. Detached eclipsing binaries offer the possibility to determine these with high accuracy. But it is rare to find such systems which also contains a pulsating star. One possible way of combining the information from detached eclipsing binaries and pulsating stars is to study both in open clusters. Here one can determine masses and radii from the binary system(s). Given that the location in the color–magnitude diagram (CMD) is known for both the binary components and the pulsating stars it is possible to obtain good mass and radius estimates for the pulsating stars. The cluster also provide good constraints on the age, distance and chemical composition for the pulsating stars. In addition to this, models which describe the behaviour of pulsating stars in a cluster must also be capable of properly describe the other cluster stars and the morphology of the CMD. We have started a programme to study detached eclipsing binaries in open

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Table 1. Parameters for V12

	Primary	Secondary
$M/M_{\odot}$	1.105 ± 0.008	1.425 ± 0.014
$R/R_{\odot}$	1.084 ± 0.008	1.386 ± 0.016

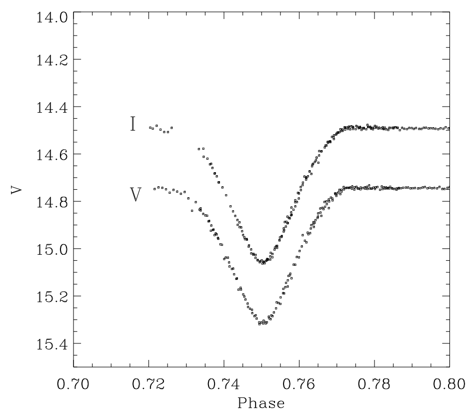

Fig. 1. The lightcurve for one of the eclipses in the detached system V12 in NGC 188. The orbital period is close to 6.5 days. The *I* band data has been artificially offset from the *V* data.

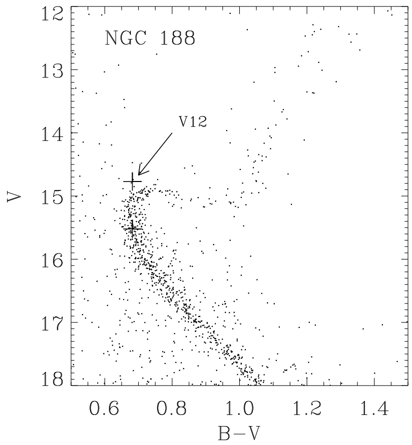

Fig. 2. The color-magnitude diagram for NGC 188 (based on data from Platais et al. 2003) with the observed location of V12 indicated by the arrow. We have also marked a point $0\overset{m}{.}75$ fainter than this corresponding to the location of two identical stars each with half the luminosity of V12. As can be seen from Table 1 this is consistent with both components of V12 being very near the cluster turnoff and having nearly identical temperatures.

clusters, preferably clusters which also contains pulsating stars. This paper describes some preliminary results from this programme and discuss some future possibilities.

2. Detached eclipsing binaries in clusters – an example

Since there are only relatively few known detached eclipsing binaries known in open clusters our programme has started by collecting data for known systems without much regard to the population of pulsating stars. This includes such clusters as NGC 188 and NGC 6791 which both are among the oldest known open clusters. Below we shall present our results for NGC 188 for which our dataset is now complete with radial velocities and eclipse photometry – this will serve as and example of the high accuracy of parameters which can be obtained from these systems.

Zhang et al. (2002) discovered a detached eclipsing binary, V12, in NGC 188 as part of a photometric study of the cluster. Radial velocities for this object were obtained from WIYN by Meibom et al. (2006, in preparation). In Fig. 1 the lightcurve for one of the eclipses in V12 is shown and in Fig. 2 the location of V12 is shown in the CMD of Platais et al. (2003). For the determination of the radii and inclinination of the binary orbit we obtained photometry from the Nordic Optical Telescope, the Flemish Mercator Telescope and the 1m telescope at Bialkow Observatory in Poland.

Since the two components of V12 are located close to the cluster turnoff we can determine an age for the cluster which is independent of reddening estimates, distance and temperature scale by using isochrones in the (M, R)-plane. See Fig. 3 for an example of this. We are currently working on this analysis, and have determined an age close to 6.2Gyr (Meibom et al. 2006, in preparation). Please

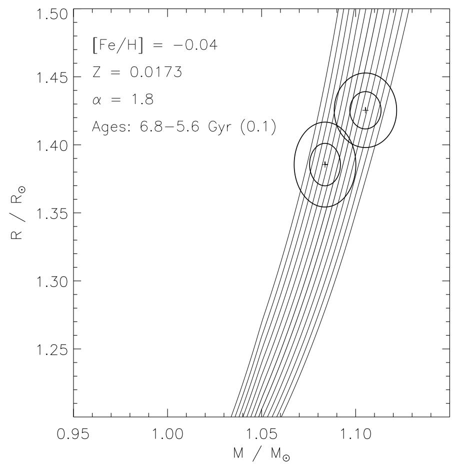

Fig. 3. The (M, R) diagram for the two components of V12. Isochrones for ages between 5.6 and 6.8 Gyr are plotted in steps of 0.1 Gyr. We assign an age of 6.2 Gyr as the most probable.

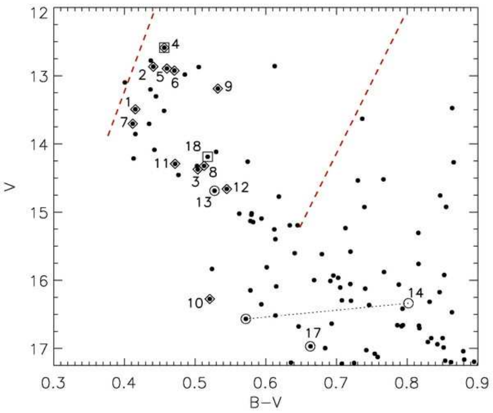

Fig. 4. Color-magnitude diagram for NGC 1817. The two detached eclipsing binaries have numbers 4 and 18. The δ Scuti stars are marked with diamonds.

note, that this result is not final and that a full analysis has not been carried out yet.

It should be possible to improve even further on the determination of properties of V12 presented here. V12 is well isolated and bright enough that a 2-4m class telescope can obtain velocities with a precision better than 1km/s per epoch of observation (as is the case for our observations) and photometry can reach a precision of a few mmag for relatively short exposures. Our photometric data were collected using 4 different instruments. With a more homogeneous instrumentation it will be possible to more acurately determine the depth of the eclipses – this should reduce the errorbar for the radii.

3. Pulsating stars and eclipsing binaries

During several observing campaigns to search for variable stars in the clusters NGC 1817 (Arentoft et al. 2005) and NGC 2506 we have discovered several promising detached eclipsing systems. A discussion of our photometric data for NGC 2506 can be found in Arentoft et al. (these proceedings).

In NGC 2506 we have found 6 δ Scuti variables and at least two detached eclipsing systems, one in the turnoff region and the other somewhat fainter at $V = 17.44$. Such a combination is very well suited to determine the cluster age since the lower luminosity system provides a check on main-sequence models (the components are un-evolved) whereas the brightest system has its two components slightly evolved being near the turnoff, thereby providing the age sensitivity. We have obtained spectra for both detached systems and are currently analyzing these. The δ Scuti stars are located in the blue straggler region of the CMD, this may be "bad news" for their applicability to asteroseismology.

The cluster NGC 1817 is younger than NGC 2506 and here the 12 δ Scuti stars found by Arentoft et al. (2005) are located at the cluster turnoff. In January 2005 we obtained additional photometry for this cluster over a larger field and discovered 6 new δ Scuti stars making this cluster one of the richest with this type of stars. One of the δ Scuti stars found by Arentoft et al. is located in a detached eclipsing system with components near the turnoff. A second detached system, suspected by Arentoft et al., was confirmed by the new observations. This appears to consist of two main–sequence stars, thus the detached systems offer the possibility of obtain very strong handles on the masses for the δ Scuti stars in this cluster. We are currently working on aquiring additional photometry of the eclipses for the systems and spectroscopic velocities for the systems. In Fig. 4 we show the CMD for NGC 1817.

4. Future possibilities

The study of pulsating stars in clusters is not new, and several observing campaigns has been carried out particularly for δ Scuti stars in fairly young clusters such as the Pleiades and Praesepe (Li et al. (2004); Frandsen et al. (2001)). To our knowledge thare has not yet been any succesful attempt to measure solar-like oscillations in open clusters. With the advance in the techniques for measureing accurate radial velocities seen during the past ~5 years (Butler et al. 2004) it now appears resonable to speculate that the brightest turnoff or subgiant stars in the nearest open clusters could now be studied with asteroseismic methods. As an example consider the Hyades. In this cluster several stars are brighter than $V = 7.4$ and have $V sini < 10$km/s. Simple estimates with the HARPS and UVES exposure time calculaters available through the ESO `www` pages indicate that for a $V \sim 7.2$ star it is possible to obtain a sufficient signal to achieve better than 3m/s measurement precision with exposure times close to one minute in typical weather conditions. This would be sufficient for a determination of the large frequency separation, and (depending on the stellar type) the small separation.

The Hyades has a detached eclipsing system with masses and radii determined by (Torres & Ribas 2002) – this provides accurate constraints on the mass and radius for the other cluster stars. In addition the cluster distance and heavy element abundance is very well determined. Coupling these constraints with asteroseismic information could the cluster distance could potentially lead to significant progress.

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