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Pinpointing isochrones in clusters ⋆ ⋆⋆

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Abstract. We present measurements of masses and radii for detached eclipsing binaries in the old open clusters NGC 2243 and NGC 6791 with a precision of ~ 1%. In NGC 2243 the detached system NV CMa is found to consist of two almost identical components located near the cluster turn-off. Our masses and radii agree well with the independent results obtained by Kaluzny et al. (2006a), but we find a significantly lower age for the cluster. Using a mass-radius diagram and the isochrones from VandenBerg et al. (2006) we determine an age of 3.1 Gyr for a cluster metallicity of [Fe/H]= −0.52. The system V20 in the metal-rich cluster NGC 6791 is found to consist of a turn-off star and a lower mass main-sequence star. Using the mass and radius of the turn-off star we find an age for the cluster of 7.8±0.3 Gyr, assuming [Fe/H]= +0.37 and scaled solar abundances. The main–sequence component is well matched by model isochrones in the mass-radius plane.

Key words. Stars: binaries, eclipsing – Stars: fundamental parameters – Galaxy: open clusters – Galaxy: open clusters: individual: NGC 6791, NGC 2243

1. Introduction

The precision in the determination of ages for open and globular clusters is usually limited by the lack of accurate knowledge of cluster parameters such as distance and chemical composition, and the amount of interstellar absorption. It is well known that detached eclipsing binaries offer the possibility to determine accurate masses and radii for their individual components and thus, if such systems can be found in star clusters, in particular near their turn-offs, this could add valuable information on the cluster age by constraining the turn-off mass.

Among field stars it has been found that many stars in detached eclipsing binaries with masses in the range 0.6–0.9 $M_\odot$ have radii, which are smaller than predicted by models for their mass (Clausen et al. 1999; Ribas 2006; Torres et al. 2006). This effect may be due to high rotation rates or activity in the component stars. To shed light on this issue, we have

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⋆ Based on observations made with the Nordic Optical Telescope, operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

⋆⋆ Based on observations made with ESO Telescopes at the Paranal Observatory under programme ID 072.D-0187, 076.D-0683, 075.D-0206 and 077.D-0827.

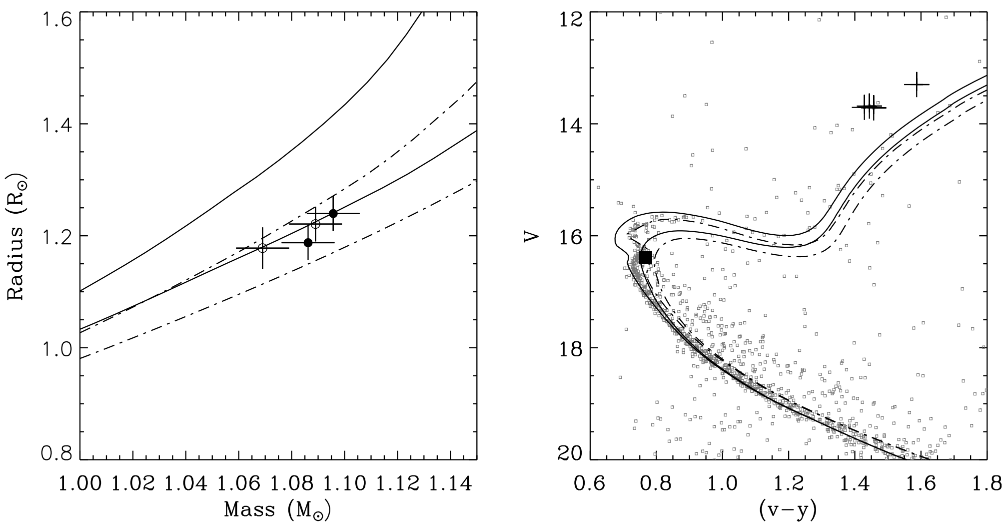

Fig. 1. The mass-radius diagram for NV CMa in NGC 2243 (left panel) with isochrones for ages of 3.1 and 4.3 Gyr for a metallicity of [Fe/H]= −0.52. The full drawn isochrones have [α/Fe]= 0.0 and the dashed have [α/Fe]= 0.3 for the two ages. The filled circles are our mass and radius determinations, and the open circles are the results of Kaluzny et al. (2006a); the horizontal and vertical lines over each symbol indicate the error bars. In the right panel the cluster color-magnitude diagram is shown with the same isochrones, and the location of NV CMa (total light) indicated by the black square near the turn-off. For the adopted cluster parameters, the 4.3 Gyr isochrones clearly provide a poor match to the turn-off morphology of the cluster. Note also the marked dependence on the α-element abundance of the isochrone turn-off morphology.

observed systems which are members of open clusters, since in these cases fundamental parameters like metallicity and age are well determined.

We have started a programme to determine masses and radii for detached eclipsing binaries in old (age > 1 Gyr) open clusters. Since many of the old open clusters are fairly distant, this implies that the turn-off stars will be relatively faint. So far we have studied systems in NGC 188, NGC 2243, NGC 2506 and NGC 6791, and here we present results for NGC 2243 and NGC 6791.

2. NGC 2243

This cluster has been extensively studied by several authors (Anthony-Twarog et al. 2005; Kaluzny et al. 2006a) and is known to host several detached eclipsing systems (Kaluzny et al. 2006b). We have obtained spectra of the detached eclipsing system NV CMa with UVES/FLAMES (Dekker et al. 2000; Pasquini et al. 2002) on the ESO VLT and used them in combination with photometry from the Danish 1.54m telescope on La Silla to determine the masses and radii of the individual components.

As part of our observations we obtained spectra for four red horizontal branch stars with UVES/FLAMES in order to determine the cluster abundance (details will be published elsewhere) and find [Fe/H]= -0.52 ± 0.08 and enhancements of the α-elements of ~ 0.1 dex.

In the left panel in Fig. 1 we show our determined masses and radii (filled circles) with isochrones from VandenBerg et al. (2006). The results of Kaluzny et al. (2006a) are shown as open circles. As can be seen the results agree very well.

In Kaluzny et al. (2006a) the age was determined by comparing the observations

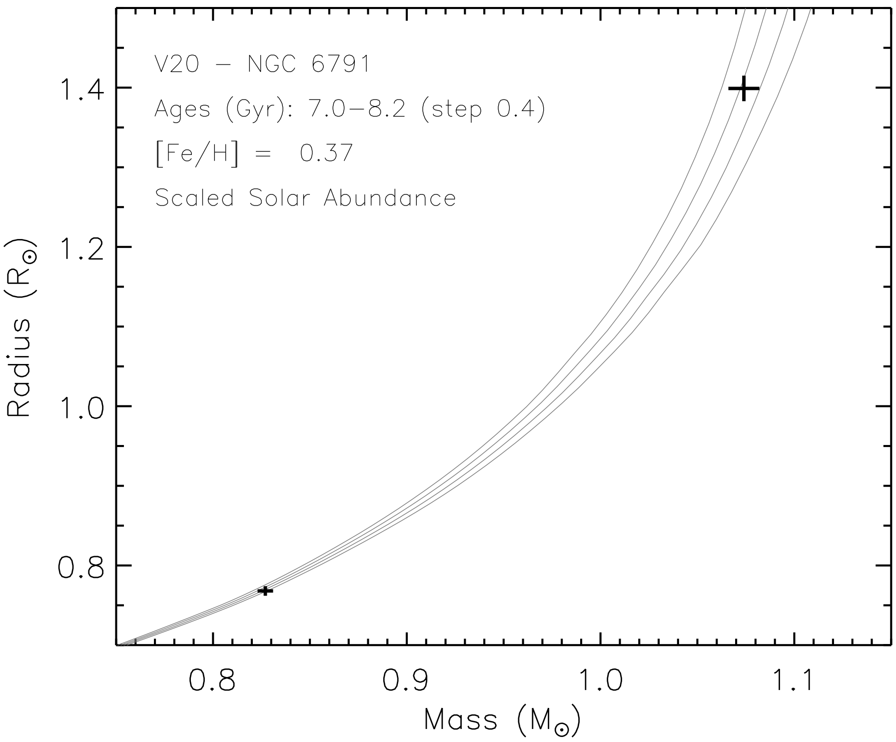

Fig. 2. The mass and radius for the two components in the V20 binary system in NGC 6791. Isochrones for ages 8.2, 7.8, 7.4 and 7.2 Gyr are plotted. It can be seen that the 1 σ error on the age (for fixed metallicity) is only 0.3 Gyr. The isochrones are for a scaled solar abundance of [Fe/H]= +0.37, see VandenBerg et al. (2006).

to isochrones in the age-radius and age-luminosity plane and they found a cluster age of 4.35±0.25 Gyr.

In the right panel in Fig. 1 we show the *uvby* color-magnitude diagram (CMD) with the isochrones from the mass–radius plot for a cluster distance and reddening of $(m-M)_V = 13.14$ and $E(b-y) = 0.039$. As can be seen the lower age provides a significantly better match to the observed CMD – we suspect that the different result obtained by Kaluzny et al. (2006a) is due to an erroneous temperature estimate. It is however also clear, that the detailed morphology is quite dependent on the adopted α-enhancement. Our spectroscopy yields an α-enhancement of 0.1 dex. Since the detailed turn-off morphology is quite sensitive to this parameter, we will study this in greater detail for our final analysis.

3. NGC 6791

NGC 6791 has received much attention during the past decade with extensive searches for variables, exoplanets, and white dwarfs, detailed abundance studies and age determinations. The cluster is special due to its richness in stars, high age and high metallicity. Age estimates have ranged between 7 and 12 Gyr, with typical values around 9 Gyr – however the determination of the age for the cluster is hampered by a relatively high and uncertain red-

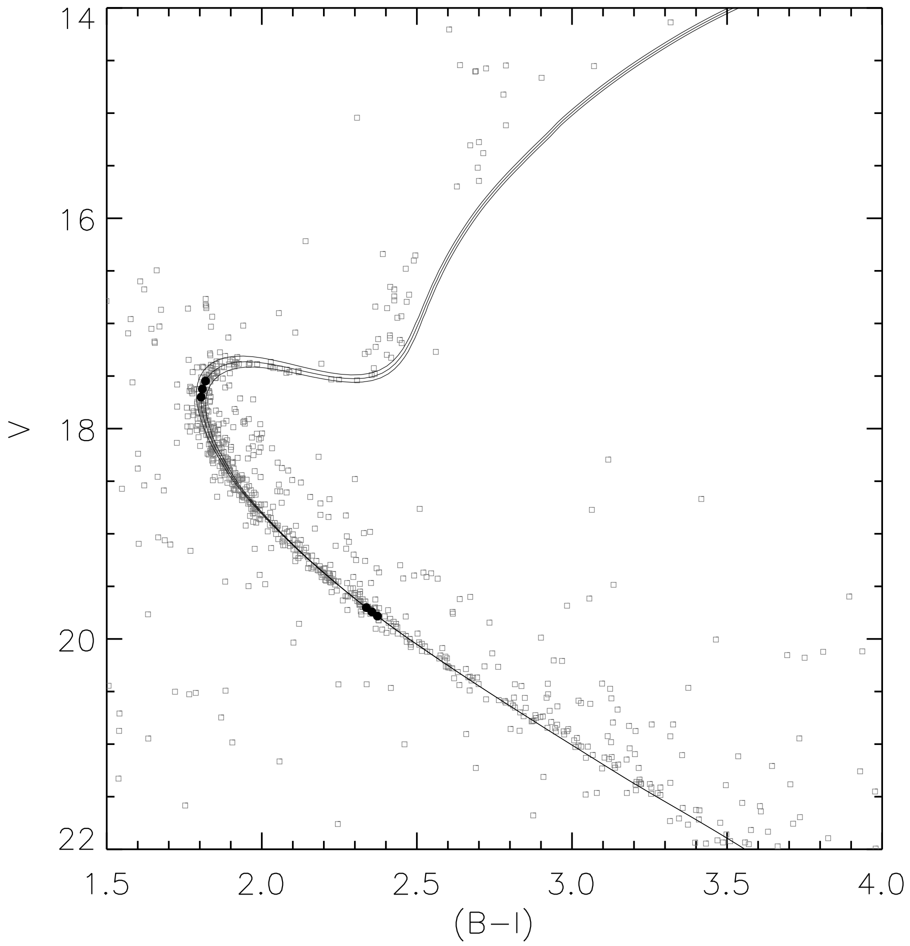

Fig. 3. The CMD for NGC 6791 based on the photometry from Stetson et al. (2003) with isochrones from VandenBerg et al. (2006) for a scaled solar abundance of +0.37, reddening of E($B-V$)=0.15 and distancemodulus of $(m-M)_V = 13.50$. The ages of the isochrones are 7.4, 7.8 and 8.2 Gyr. We note that for these values of the cluster reddening and distance, the agreement with the results in the mass-radius plane is very good – see Fig. 2. For the 7.8 Gyr isochrone we have marked the location of the components of V20 according to their masses and their 1 σ errors as small filled circles. The $(B-I, V)$ locations correspond very well to those obtained from the light–curve solutions.

dening, high metallicity and poorly known distance.

We have studied the detached eclipsing system V20 using the Nordic Optical Telescope (time-series photometry of eclipses) and UVES (radial velocities) in order to determine the parameters of this system. The details of the results reported here will be given in Grundahl et al. (2008; in preparation). In short, we obtained 15 useful epochs of spectroscopy with a typical precision of 0.5 km/s per measurement. This results in masses and radii for the two components with a precision better than 1%. In Fig. 2 we show the mass-radius diagram. From the figure we see that the age can be determined with a precision of 0.3 Gyr from the primary component. The period of the system is about 14.5 days, which implies a slow rotation period for the components, when assuming the velocities are synchronized. Slow rotation implies low activity, and therefore should not affect the inferred radii. Indeed, we note that the V20 secondary component seems to be well represented by the isochrones.

Figure 3 shows the color–magnitude diagram for NGC 6791 with isochrones for ages 8.2, 7.8 and 7.4 Gyr. Our light-curve solution shows that the primary component is located roughly at $V = 17.64$ and the secondary at $V = 19.86$. The isochrones from VandenBerg et al. (2006) appears to reproduce the lower main–sequence, turn-off and subgiant regions very well – for the red giant branch the models appear to be too cool. With the adopted isochrone set and cluster metallicity we find the age to be 7.8±0.3 Gyr for NGC 6791.

4. Conclusions

We have presented preliminary results for two detached eclipsing systems in NGC 2243 and NGC 6791. We have demonstrated that the masses and radii can be measured with high accuracy (1%). In the case of NGC 6791 we showed that the internal precision (for an adopted metallicity and isochrone library) is 0.3 Gyr. This uncertainty can be reduced if more spectroscopic observations are collected, since it is the uncertainty on the mass which dominates the precision in age.

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