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Long period variables in globular clusters

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Abstract. We present results from our survey of long period variables (LPVs) in globular clusters of the Milky Way and the LMC. Based on a large sample of previously known and newly discoverd LPVs in 47 Tuc we produce a P-L-diagram for the LPVs in this cluster and compare it with pulsation models. For the first time measurement of masses of AGB stars have shown that mass loss of the order of 0.3 $M_{\odot}$ occurs on the RGB and AGB. We discuss the pulsation mode along the evolutionary path up the giant branch. Results from two further clusters are briefly summarized.

Key words. Stars: late type – Stars: AGB and post-AGB – Stars: oscillations – Stars: mass loss

1. Introduction

It is now well established that pulsating red giants lie on a series of up to six parallel period-luminosity (PL) sequences (e.g. Wood 2000, contributions by Wood and Kiss in this volume). The stars known to populate these sequences are generally field variables so that their metallicities, masses and ages are not known individually. The dispersion in the PL relations is almost certainly mainly a consequence of the dispersion in mass and metallicity at a given pulsation period. This hampers the comparison of observed PL relations with pulsation models.

LPVs in globular clusters are well suited for carrying out such a comparison, and for studying the relation between pulsation, mass loss and stellar evolution along the giant branch, since fundamental parameters like initial mass, luminosity and metallicity are well known. However, only small numbers of these variables are known in globular clusters. To rectify this situation, we undertook a search program for long period variables in globular clusters. Here we present first results on three of these clusters.

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2. 47 Tuc

The relatively large number of known or proposed LPVs in 47 Tuc made this cluster a good starting point. Basic parameters of 47 Tuc can be found in the literature: $(m - M) = 13.5 \pm 0.08$ (Gratton et al. 2003), [Fe/H]= −0.66 (Caretta & Gratton 1997), an age of 11.2±1.1 Gyr (Gratton et al. 2003). The corresponding turnoff mass lies between 0.86 and 0.9 $M_{\odot}$. Our search program led to the discovery of 22 new variables in this cluster and the first period determination for 8 previously suspected LPVs. Details of the observations and data reduction can be found in Lebzelter & Wood (2005).

All variables of our sample, with the possible exception of V19, are on the upper giant branch of 47 Tuc and almost certainly members of the cluster. Our colour magnitude diagram of 47 Tuc clearly shows that all stars on the giant branch redder than $V - I_C \approx 1.8$ are variable. We also found that all stars with a high infrared excess detected in this cluster (Origlia et al. 2002; Ramdani & Jorissen 2001) are variable.

2.1. The *K*-log*P*-diagram

We constructed a *K*-log*P*-diagram for the LPVs in 47 Tuc using *K* magnitudes from the literature or from 2MASS (Fig. 1). In the figure we also show the *K*-log*P*-relations derived by Ita et al. (2004) for the LPVs in the LMC. Obviously, the 47 Tuc variables do not fall exactly on these sequences although they also seem to form two to three sequences in the *K*-log*P*-plane. We note that about half the variables are more luminous than the RGB tip and are thus AGB stars. The other stars are either on the AGB or the RGB.

2.2. Comparison with pulsation models

Using the global parameters of 47 Tuc we calculated linear pulsation models for red giants using an updated version of the code described in Fox & Wood (1982). Details of the additions to this code can be found in Lebzelter & Wood (2005). We construced models without and with mass loss, respectively. The models with mass loss use a Reimers' mass loss law adjusted so that the stars leave the AGB at the maximum luminosity observed for the 47 Tuc red giants. Figure 2 shows a comparison of the observed *K*-log*P*-diagram with pulsation models without and with mass loss.

It is clear that the models without mass loss fail to reproduce the observed periods for the smaller amplitude pulsators (overtone pulsators). In fact the model sequences avoid the observed sequences. In contrast, the overtone

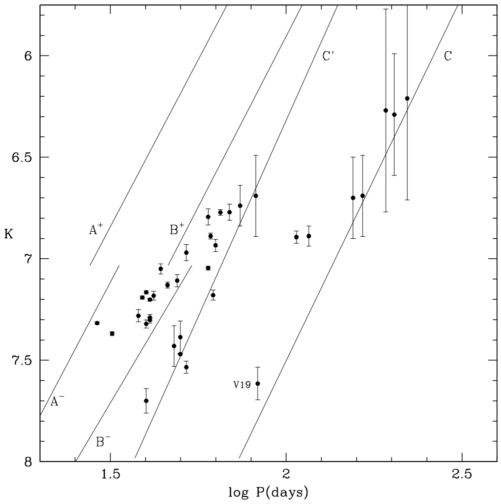

Fig. 1. The *K*-log*P*-diagram for the LPVs in 47 Tuc. Error bars indicate measured or estimated light amplitudes. The lines show the sequences of LPVs in the LMC as given by (Ita et al. 2004). Figure taken from (Lebzelter & Wood 2005).

pulsation periods for stars that have undergone mass loss agree well with the observations. The periods of the mass loss models are longer than those of the models without mass loss due to the lower stellar mass, and the slope of the *K*-log*P* relations is smaller due to the decrease in mass with luminosity.

The large ampliude variables, i.e. the miras, seem to be consistent with the models without mass loss, while the models with mass loss do not fit the observed *K*-log*P*-sequence (ignoring V19, see Lebzelter & Wood 2005). We believe this contradiction can be explained by the nonlinear effects in the pulsation of red giants with large amplitudes. Linear models are probably not appropriate for these stars. Preliminary nonlinear pulsation calculations made for these models show that the full-amplitude pulsation periods are considerably shorter than the linear periods (see also the paper by Wood in this volume). Thus the periods of *nonlinear* fundamental mode models may be able to explain the periods of the miras in 47 Tuc.

It seems that stars start pulsating at $K \approx 7.7$ in the 1st to 3rd overtone mode, then evolve up

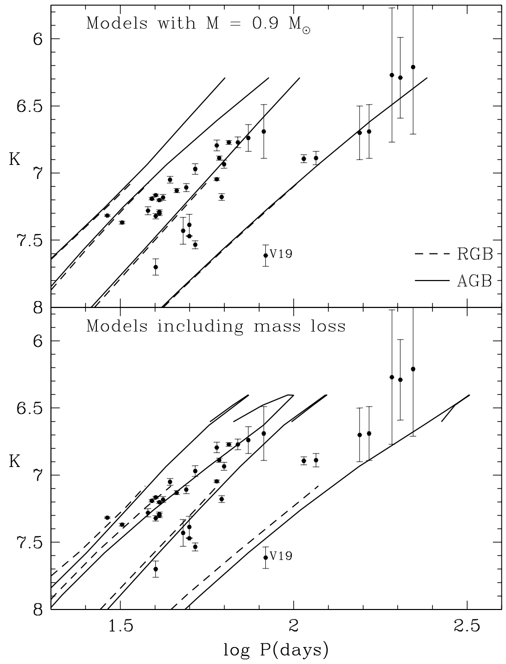

Fig. 2. The K-log$P$-diagram for the LPVs in 47 Tuc compared with models without (upper panel) and with (lower panel) mass loss. The fundamental mode and the first three overtone modes are shown for the models (from right to left). Only variables with reasonably well-determined periods are shown. Figure taken from (Lebzelter & Wood 2005).

to higher luminosities transiting to fundamental mode pulsation at $K \approx 6.2$. This is broadly consistent with what is expected from the linear non-adiabatic growth rates of the models. In total the stars loose about 0.3 $M_\odot$ during their evolution along the giant branch.

3. NGC 2808

NGC 2808 is a cluster of probably similar age as 47 Tuc, but a lower metallicity ([Fe/H]= −1.5). The cluster is well known for its outstanding horizontal branch extending far to the blue (e.g. Bedin et al. 2000). To explain the horizontal branch it was speculated that the cluster consists of more than one population (D'Antona & Caloi 2004). Only two long period variables were known in this cluster before the start of our monitoring program. We detected more than a dozen further LPVs in this cluster allowing us to again construct a K-log$P$ diagram (Fig. 3).

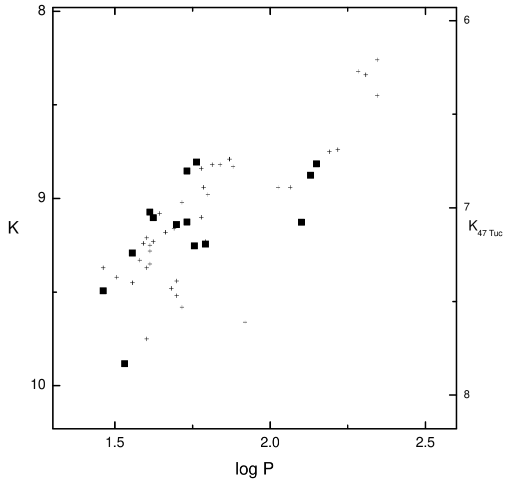

Fig. 3. The K-log$P$-diagram for the LPVs in NGC 2808 (filled boxes). For comparison the LPVs found in 47 Tuc (crosses) have been overplotted shifted to the distance of NGC 2808 (right y-axis).

The LPVs in NGC 2808 show roughly the same pattern in the K-log$P$-plane as the corresponding stars in 47 Tuc. However, fewer LPVs have been detected in NGC 2808 than in 47 Tuc, which is probably only to a minor part due to the larger distance of the cluster. It can also be seen that the maximum luminosity reached by the LPVs is less in NGC 2808 than in 47 Tuc, as expected if the former is slightly older.

4. NGC1783

The third cluster we want to briefly discuss here is NGC 1783, a cluster belonging to the LMC. This cluster is much younger than the two galactic clusters discussed before, the red giants observed have a typical mass of about 2.1 $M_\odot$. The metallicity of the cluster is [Fe/H]= −0.45 (Frogel et al. 1990). Mould et al. (1989) list about 15 AGB stars in the cluster, among them two carbon stars.

Two LPVs in this cluster were known before, one variable infrared source and one semiregular variable detected by the MACHO survey. We did photometric monitoring in the *J* and *K* band with SOFI at the NTT. Our measurements confirmed the two known variables and detected four further stars, for two of which we could determine also a period. For the variable infrared source Nishida et al. (1999) give a period of 460 d, while our own measurements suggest a period of about 320 d. Although our light curve coverage is not complete, the reason for this discrepancy is not clear.

In a *K*-log*P*-diagram all detected variables are more luminous than the variables in the two galactic clusters, but again fall onto two parallel sequences roughly in agreement with the ones from the LMC and the two galactic clusters. The absence of variables at lower luminosity is probably caused by observing in the near infared where the amplitudes of the short period variables fall below our detection limit. We note that there is only one mira (large amplitude variable) in the cluster and this star is highly dust enshrouded. This indicates that for these mass and metallicity values the mira phase is rather short and terminated by high mass loss.

5. Conclusions

From our monitoring program of long period variables in globular clusters we can draw the following conclusions.

- The reddest giants in all investigated clusters are all variable.
- LPVs first pulsate in an overtone mode and switch to fundamental mode pulsation when crossing some luminosity limit.
- Linear pulsation models including mass loss reproduce the P-L-relations of overtone pulsators while models without mass loss do not. This is the first time that measurements of the masses of stars on the AGB have shown that mass loss of the order of $0.3\,M_\odot$ occurs along the RGB and AGB.
- Observed fundamental mode P-L-relations cannot be reproduced by linear pulsation models with mass loss. This is probably due to nonlinear effects becoming important in these stars (see also the contribution by Wood in this volume).

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