NEW RESULTS ON THE PERIOD-LUMINOSITY DIAGRAM OF LONG PERIOD VARIABLES

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Abstract

Recently, at least four parallel period-luminosity sequences have been found for AGB variables in the LMC and other stellar systems (e.g. Wood 2000). We compare these findings with period and luminosity data for stars in the Globular Cluster 47 Tuc and in the Galactic field, and investigate the pulsational behaviour at different points throughout the P-L-diagram.

Key words: Stars: variables – Stars: AGB and post-AGB

1. The log P-K-diagram in the LMC/SMC

Surveys in search for Massive Compact Halo Objects (MACHO, EROS, OGLE, ...) produced large databases of lightcurves of variable stars in the Magellanic Clouds and other stellar systems. Wood (2000) identified four parallel logP-K-sequences among the long period variables (LPVs) of the red giant branch in the LMC. Three of these sequences could be attributed to radial pulsation modes, namely second / third overtone mode (in the following called sequence A), first overtone mode (B) and fundamental mode (C). Sequence C corresponds to the P-L-relation for Miras in the LMC. Sequence D, found at even longer periods, could not be explained yet (see Wood et al. 2004). In even larger samples of LPVs, several authors (e.g. Kiss & Bedding 2003, 2004) found additional, slightly shifted sequences below the RGB tip (sequences R1 to R3). Studies in the Galactic Bulge (Glass & Schultheis 2003) and Cen A (Rejkuba et al. 2003) detected similar sequences. These studies produced a new view on the pulsational behaviour of red giants.

2. The log P-K-diagram of 47 Tuc

Systematic searches for long period variables in Globular Clusters are still missing. In light of the new results on P-L-relations in stellar systems we therefore started a photometric monitoring program to find new variables in Globular Clusters and to better characterize the known ones. Globular Clusters provide the advantage of a very narrow mass and age range on the AGB compared to systems like the LMC making a comparison with models easier.

As an example we present here our findings for 47 Tuc (NGC 104). The cluster has a metallicity of [Fe/H]$= -0.66$ (Caretta & Gratton 1997). Hesser et al. (1987) derived a turnoff mass of $0.9\,M_\odot$ (see also Lebzelter et al. 2004a). About a dozen red variables have been previously identified in this cluster, including at least three miras. Photometric time series of the cluster spanning several months were obtained at Mount Stromlo and at Cerro Tololo. At Mount Stromlo we used the MACHO camera (blue filter), at Cerro Tololo monitoring was done in V and I. To explore also the crowded cluster center, an image subtraction method (Alard 2000) was used for our search. In Fig. 1 we give the logP-K-diagram of the LPVs of this cluster. New period determinations (new variables) are marked with open symbols, literature data are shown as filled boxes.

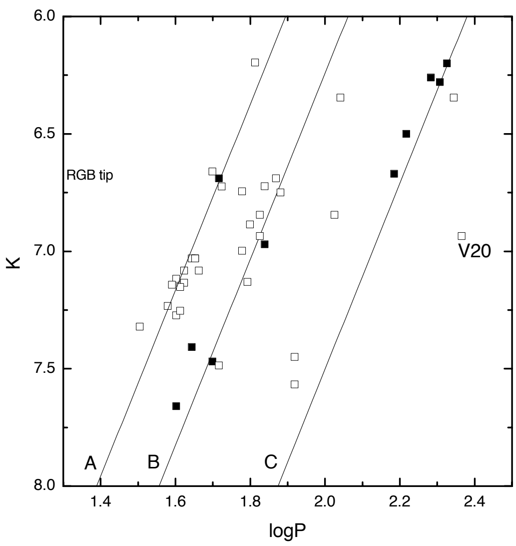

Figure 1. logP-K-diagram of long period variables in 47 Tuc. Open symbols denote new period determinations, filled boxes literature data. Solid lines mark the approximate location of the three logP-K-sequences A, B and C from the LMC. The tip of the RGB is indicated. Stars with two periods are plotted twice.

Our project lead to the discovery and/or characterization of about 30 additional red variables in 47 Tuc. Sequences A, B and C are well defined. Above the RGB tip

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most stars are fundamental mode pulsators, while below the RGB tip almost all stars pulsate in the first or second overtone. A few stars are found in between sequence B and C. These stars may be located on the intermediate sequence detected by Kiss & Bedding (2003). We found that all stars on the upper giant branch are variable. The location of V20 in the logP-K-diagram is not understood yet.

There are two data points above the RGB tip on sequence A and B. The one on sequence B is actually the second period of a star on sequence C. The star on sequence A is more puzzling. In the colour-magnitude diagram this object is found on the upper AGB. Therefore it is very likely that the star is a cluster member. A period twice as long cannot be excluded which would shift the star onto sequence B. Further investigation of this object is needed to understand its nature.

The LPVs of 47 Tuc obviously follow the same P-L-relations as the stars in the Magellanic Clouds. For the cluster stars the scatter around the sequences is less than for LMC variables thus allowing a better definition of the location of the logP-K-relations. For more details we refer to Lebzelter et al. (2004a).

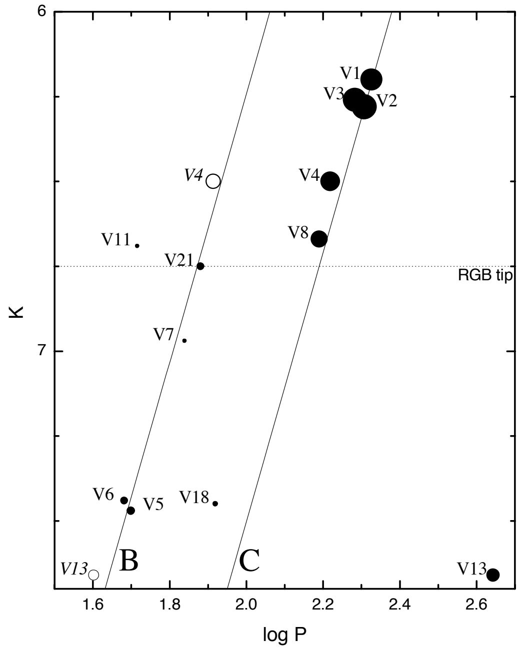

Figure 2. logP-K-diagram of 47 Tuc variables with velocity monitoring. Symbol size corresponds to the velocity amplitude of 1.6 μm CO lines. Open symbols mark second periods of the star obviously not determining the velocity amplitude. Taken from Lebzelter et al. (2004a).

3. Velocity variations along the P-K-sequences

To better understand the stellar variability along the different pulsation sequences we monitored velocity variations of a number of long period variables in 47 Tuc. We used near IR lines of CO at 1.6μm which are well suited for monitoring the pulsation (e.g. Hinkle et al. 1982). These previous studies, exclusively done for field stars (see below), gave very similar velocity curves for all miras investigated, and clearly different velocity variations for semiregular variables (SRVs).

Among the 47 Tuc variables we found the same kind of velocity curves as for the field stars. Fig. 2 shows the location of the monitored variables in the logP-K-diagram. The symbol size indicates the velocity amplitude of each variable. Large velocity amplitudes (similar to field miras) are exclusively found among the most luminous stars. They are all pulsating in fundamental mode (sequence C). Pulsation amplitudes are significantly smaller along sequence A and B (overtone pulsation). V18, located between sequence B and C (possibly on the R1 relation identified by e.g. Kiss & Bedding 2003), has a velocity amplitude similar to stars on sequence B. V13 has a long secondary period (corresponding to sequence D) that dominates the star's velocity change. Along sequence C the velocity amplitude obviously increases with luminosity (period). This corresponds to the path of stellar evolution. There is no such trend visible along sequence B. For V4 a short period (sequence B) is reported in the literature, but this could not be confirmed by our own photometric monitoring.

Mass loss properties of the 47 Tuc variables are unfortunately only poorly known. Mass loss seems to increase with luminosity along sequence C just as the pulsation amplitude does. However, the star with the largest infrared excess is V18 (Ramdani & Jorissen 2001), located far below the RGB tip in between sequence B and C. The star has a rather small velocity amplitude. Thus we cannot derive a general relation between pulsation amplitude and mass loss. Better characterization of the mass loss for a larger fraction of the 47 Tuc LPVs is required to investigate this question.

Velocity curves for a large sample of nearby LPVs, both miras and semiregular variables, have been observed in the past (see Lebzelter & Hinkle 2002 for a summary). Recently, this sample was extended by additional velocity curves for southern miras and some SRVs showing mira characteristics like large light amplitude or long pulsation period. (Lebzelter et al. 2004b). Using Hipparcos distances we constructed a logP-K-diagram for these field LPVs (Fig. 3, left panel). The 47 Tuc variables shown in Fig. 2 were included as well. In the right panel of Fig. 3 we show the velocity amplitude of each star.

Despite the rather large uncertainties of the Hipparcos distances most field LPVs in Fig. 3 can be clearly attributed to one of the logP-K-sequences. All large amplitude LPVs are found on sequence C (fundamental mode).

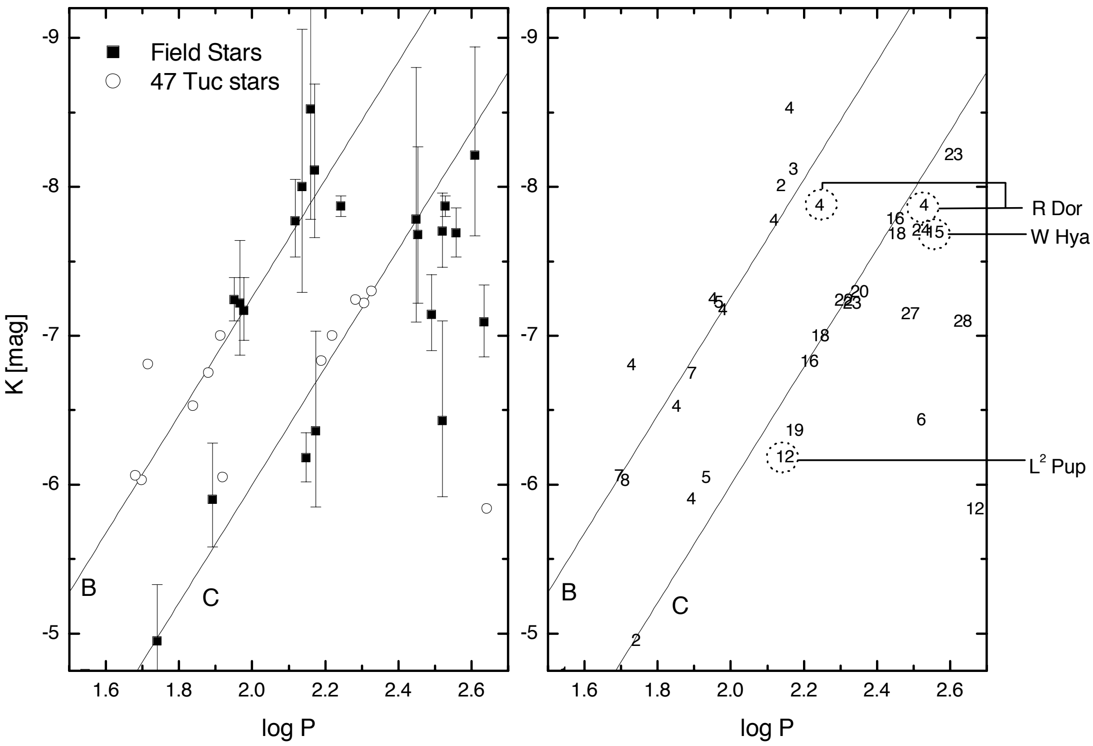

Figure 3. Period-luminosity diagram for 47 Tuc and field LPVs with known velocity variations. Solid lines indicate the approximate location of the logP-K-sequences B and C from the LMC. In the left panel, stars are divided by symbol into field and globular cluster LPVs. Error bars have been calculated from $\sigma(\pi)$ as given in the Hipparcos catalogue. The right panel gives the velocity amplitude measured for each object.

Velocity amplitude throughout sequence B is typically 4 kms^{-1}. Most stars on sequence C are miras, but there are a few semiregular variables as well. With an amplitude of only 4 kms^{-1} R Dor should be on sequence B. The star pulsates with two periods (one on sequence B and one on sequence C), however, the longer period seems to dominate. The other two SRVs on sequence C are W Hya and L^2 Pup. Both stars are exceptional among SRVs as they have an untypically large light amplitude.

Large amplitude SRVs seem to form a distinct group among the LPVs. Beside W Hya and L^2 Pup we also studied T Cen (Hinkle et al. 1984, Lebzelter et al. 2004b). All three show velocity amplitudes of 12 to 14 kms^{-1}, i.e. three times more than typical SRVs. Fig. 4 shows the distribution of velocity amplitudes of all stars of our sample. Three peaks can be seen corresponding to SRVs, large amplitude SRVs and miras, respectively.

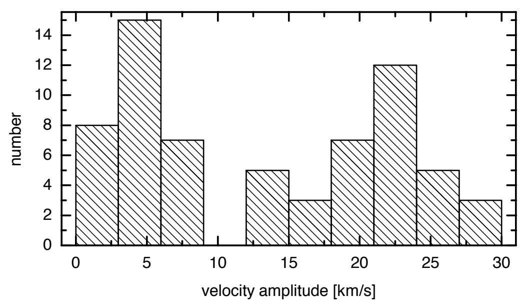

Figure 4. Number of LPVs versus near-infrared velocity amplitude.

4. Summary

The logP-K sequences found for LPVs in the LMC are also clearly visible in the Globular Cluster 47 Tuc. Stars below and above the RGB tip pulsate in different modes. Large velocity amplitudes are exclusively found among fundamental mode pulsators. Stars pulsating in first or second overtone show a velocity amplitude of about 4 kms^{-1}. The same behaviour seems to be true for LPVs in the Galactic field, but major uncertainties in the distance (and thus luminosity) prohibit a similarly clear picture. Among the fundamental mode pulsators we find a few SRVs with velocity amplitudes smaller than those of the miras, but larger than typical SRVs. These stars seem to form a distinct group among the LPVs. We suggest that the reason for these stars showing smaller velocity amplitudes than miras is their higher mass.

The logP-K-diagram of 47 Tuc (Fig. 2) indicates that stars switch from first overtone to fundamental mode pulsation during their evolution along the AGB. However, as there are few examples of field stars known to switch from fundamental to first overtone mode (e.g. Kiss et al. 2000, Lebzelter et al. 2004b) exceptions to this general trend obviously exist. A possible explanation for this behaviour may be a period change due to an ongoing Thermal Pulse.

Our search program for LPVs in Globular clusters will continue. The results for 47 Tuc may promise a further possibility for an independent distance determination of stellar systems.

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