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β Cephei and SPB stars in the Large Magellanic Cloud

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Abstract. This is a progress report of the study of pulsating main-sequence stars in the LMC. Using the OGLE-II photometry supplemented by the MACHO photometry, we find 64 β Cephei stars in the LMC. Their periods are generally much longer than observed in stars of this type in the Galaxy (the median value is 0.27 d compared with 0.17 d in the Galaxy). In 20 stars with short periods attributable to the β Cephei-type instability, we also find modes with periods longer than $\sim$0.4 d. They are likely low-order g modes, which means that in these stars both kinds of variability, β Cephei and SPB, are observed. We also show examples of the multiperiodic SPB stars in the LMC, the first beyond our Galaxy.

1. Metallicity and pulsations of stars in the upper part of the main sequence

Presently we know of about 90 β Cephei and 100 SPB stars in the Galaxy. Their pulsational instability is caused by the κ-mechanism working at temperature of about 2×10^5 K (see, e.g., Dziembowski & Pamyatnykh 1993). Since the opacity bump driving pulsations in these stars originates as a result of a large number of bound-bound transitions in the iron-group ions, the metallicity dependence of the instability strips is an obvious consequence. Pamyatnykh (1999) showed this in detail, finding that the β Cephei instability strip practically vanishes at $Z < 0.01$. A similar shrinking of the instability strip is predicted for SPB stars, although the dependence is not so strong and even at $Z = 0.01$ the instability strip is still quite large.

Observationally, this dependence was confirmed by Pigulski et al. (2002) who found a striking difference between the incidence of β Cephei stars in northern and southern open clusters. This fact could be explained as a result of the metallicity gradient in the Galaxy. It is therefore very important to know whether, and how many β Cephei and SPB stars could be found in objects of even lower metallicities. With their low metallicities, the Large (LMC, $Z_{\rm LMC} \simeq 0.008$)

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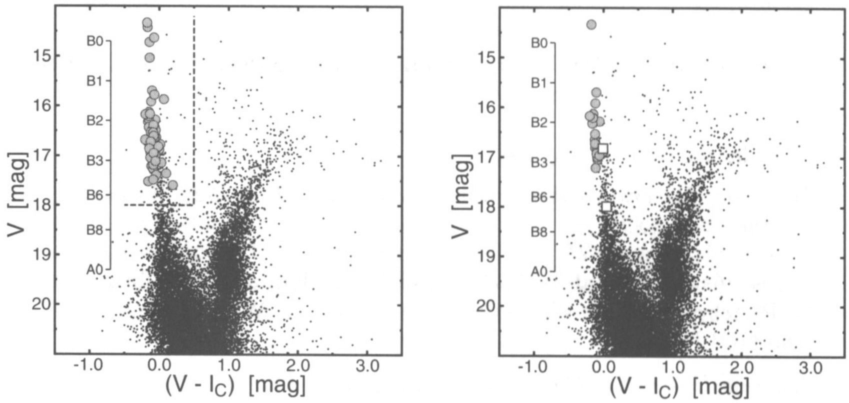

Figure 1. *Left:* Colour-magnitude diagram for the LMC showing the positions of the 64 β Cephei stars (grey dots) we found. The dashed line shows the limits of magnitudes and colours of the analyzed stars. Main-sequence spectral types are also given as a guide. *Right:* The same as in the left diagram, but only stars with long periods are plotted as grey dots. Two examples of SPB stars mentioned in the text are shown as open squares.

and Small (SMC, $Z_{\rm SMC} \simeq 0.004$) Magellanic Clouds are among the best objects for such a study.

2. Data selection and analysis

The Magellanic Clouds were the targets of many observational surveys, including the microlensing ones, OGLE and MACHO, that provided photometric data for millions of stars. Recently, the OGLE-II observations of Magellanic Clouds have been reprocessed and the photometry of all stars in the reference frames has been obtained by means of the modified DIA software of Woźniak (2000). We used this photometry to search for periodic variations of stars located in the upper main-sequence of the LMC. For over 75 000 stars with $V < 18$ and $(V - I) < 0.5$ we calculated Fourier periodograms in the range 0 to 20 d^{-1}. Light curves of stars showing dominant periods shorter than 0.35 d were checked in detail.

3. β Cephei stars in the Large Magellanic Cloud

The first three β Cephei stars in the LMC were found by Pigulski & Kołaczkowski (2002) in the OGLE-II catalogue of variable candidates (Żebruń et al. 2000). The new analysis of the OGLE-II data led us to the discovery of 64 β Cephei stars including the three we found earlier. We also used the MACHO data (Allsman & Axelrod 2001). Detected frequencies were confirmed in all stars with the available MACHO photometry (~80% of the sample). In the final analysis we combined data from both surveys.

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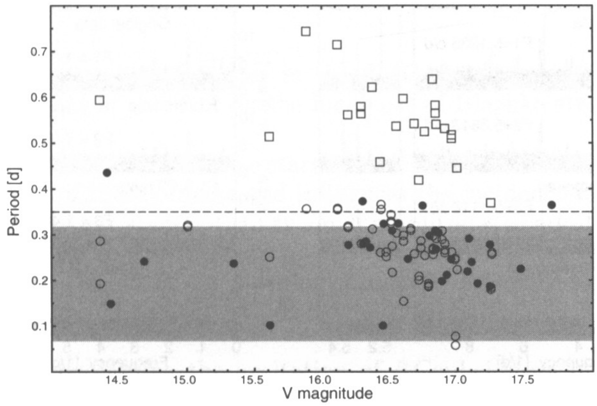

Figure 2. Periods detected in 64 β Cephei stars plotted against the V magnitude. Periods in monoperiodic stars are shown as filled circles, those found in multiperiodic stars as open circles (short periods) and open squares (long periods). The grey strip shows the range of periods observed in the Galactic β Cephei stars.

In the colour-magnitude diagram of the LMC (Fig. 1) β Cephei stars are located in the range $14 < V < 17.5$. The most interesting discovery, however, are the periods detected in these stars (Fig. 2). In 31 out of 64 stars, we detected only a single mode. The remaining stars are multiperiodic with up to five modes detected. An example of a multiperiodic β Cephei star is shown in the amplitude spectra in Fig. 3.

Fig. 2 shows several interesting features: (i) Short periods in the LMC β Cephei stars are generally longer than in the Galactic ones. The median value is 0.17 d for the Galaxy and 0.27 d for the LMC. (ii) There is a correlation between periods and magnitudes among stars with $16.0 < V < 17.5$. We expect this type of behaviour, because for a given mode the period generally lengthens with increasing radius. (iii) In 20 stars we detected periods which are $1.7 - 2.2$ times longer than the short period(s). They are shown in Fig. 2 as open squares and seem to follow some period-magnitude relation too. Such long periods have not been observed in the Galactic β Cephei stars. They can probably be explained in terms of the low-order g modes, so the stars can be regarded both as β Cephei and SPB stars.

4. The first extragalactic SPB stars

In addition to the above-mentioned β Cephei stars showing SPB-type behaviour, we found some 'classical' SPB stars in the LMC, that is multiperiodic stars showing only periods longer than ~0.5 d. An example of an early B-type SPB star is shown in Fig. 3, but we also found such stars among late B-type stars (see Fig. 1). The complete search for SPB stars in the LMC is not yet finished because it requires the analysis of thousands of fainter stars and also bright

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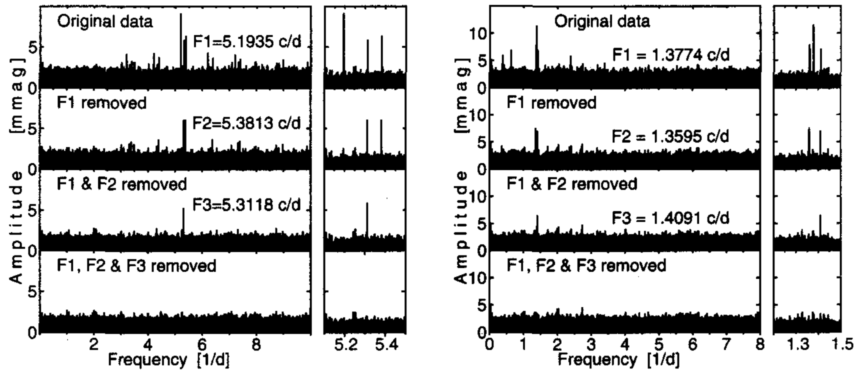

Figure 3. Fourier periodograms of the multiperiodic β Cephei star SC1-108285 (left) and SPB star SC1-223227 (right) in the LMC. The consecutive steps of prewhitening are shown from top to bottom.

stars with periods longer than 0.35 d. This work is in progress now and will be published separately.

5. Conclusions

Despite the large number of variable stars we found, the incidence of β Cephei stars in the LMC is clearly lower than in the Galaxy. This confirms the strong dependence of the driving mechanism on metallicity. A detailed modelling of the observed periods, especially the long periods found in β Cephei stars, will probably allow constraints to be put on the metallicities and evolutionary status of these variables in the LMC. Furthermore, we will extend our analysis both to longer periods and fainter stars. This will surely lead to the discovery of a large number of SPB stars, but will also increase the number of stars showing simultaneously β Cephei and SPB-type pulsations.

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Discussion

Mizerski: RR Lyrae stars are fainter in the SMC than in the Galactic bulge. What is the influence of this fact on the incidence of Blazhko stars?

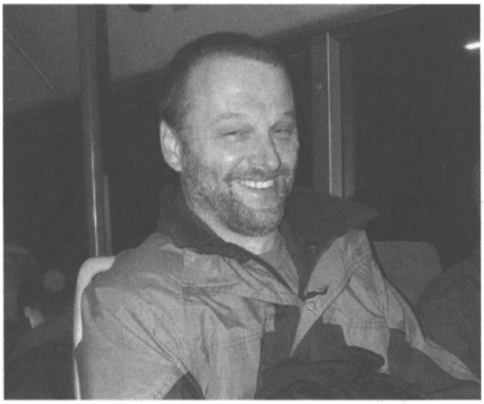
Pigulski: The fact that the RR Lyrae stars in the SMC are fainter results in a bit worse photometry of these objects and influences the incidence rate of Blazhko stars in such a way that stars with very small amplitudes of additional frequencies cannot be detected in the SMC. But the number of low amplitude Blazhko stars is low and so this effect can't explain the large difference in the incidence rates of Blazhko stars in the Galactic Bulge and the SMC.

Aerts: Instead of explaining the excitation of β Cephei stars in clusters with higher than average Z, couldn't it be that we do not understand well enough the excitation of modes at low Z?

Pigulski: This question should be addressed to theoreticians, but I think there is a little chance to get driving for really low Z. The incidence of β Cephei stars in the LMC is in fact very low.

Handler: The radial fundamental mode period of a TAMS β Cephei star is about 6 hr. Assuming that your L or C stars do not pulsate in different modes than galactic β Cep stars do, you seem to have a quite large proportion of post-main sequence objects in your sample!

Pigulski: With such a large sample of stars observed we can indeed have some stars beyond the main sequence, e.g. in the second contraction phase or at the beginning of the shell hydrogen burning phase. In fact, we found no evidence for large period changes in some stars. However, what we really need is a careful comparison with the theoretical models. That's what we are going to do soon.



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