ARE THE s-CEPHEIDS CROSSING THE INSTABILITY STRIP FOR THE FIRST TIME?

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ABSTRACT. Using the literature data on secular period changes reported for the small-amplitude Cepheids (s-Cepheids) it is shown that these stars are not crossing the instability strip for the first time. After correction of the observed pulsational chracteristics of s-Cepheids, in the diagram "$\log\left(\frac{dP}{P}\right)_{100} - \log P$" they become indistinguishable from usual classic Cepheids, which are supposed to have already crossed the instability strip more than (or at least) once.

Key words: Stars: Cepheids.

1. Introduction

More than forty years ago Efremov (Efremov, 1968) supposed that the small- amplitude Cepheids (or so-called s-Cepheids) having the sinusoidal curves of the light and radial velocity may be the stars which are crossing the instability strip for the first time. Since that time this hypothesis was not doubted. Efremov's argumentation was the following. The large-amplitude pulsators (usual Cepheids) should likely have an increased atmospheric helium abundance (but this could not be checked observationally because of the lack of photospheric helium lines in the yellow supergiant spectra), which can appear just after the star becomes the red giant and experiences the large-scale mixing which may bring an additional helium from the central parts of the star into the upper layers. If so, then the weak pulsational activity of s-Cepheids (i.e. small amplitudes of the light and radial velocity) can be explained by the relatively "low" (i.e. primordial) atmospheric helium content.

Kovtyukh et al. (Kovtyukh et al., 1996) performed the detailed spectroscopic analysis of some s-Cepheids and also summarized the results of previous investigations. The authors showed that carbon abundance is decreased in these stars. This is an obvious sign that s-Cepheids with decreased carbon abundance have already passed the evolutionary stage of the red supergiant (where the large-scale mixing event and the subsequent alteration of the atmospheric abundances of carbon and nitrogen should appear), and thus they are crossing the instability strip not for the first time. One can speculate that CN-anomalies may appear even earlier, i.e. at the main-sequence phase. It is very likely that a large fraction of Cepheids were rapid rotators on the main-sequence, with meridional mixing bringing CNO-processed material to the stellar surface. This theoretical prediction is made, e.g., by (Przybilla et al., 2010; see also references therein for the earlier papers about rotationally-induced mixing). Nevertheless, we have to note that some observational data contradict this theoretical conclusion. Fast rotation of B star could be the favouring factor for the turbulent mixing, but not necessarily. For instance, (Mathys et al., 2002, their Table 3) derived the NLTE CNO abundance for O-B I-V type stars in several open clusters. The CNO abundances in those stars show quite large differences from star to star. The mean values for C and O are slightly lower than the corresponding solar values, but the mean nitrogen abundance is the same as the solar one, while incomplete CNO cycle together with dredge-up episode require that carbon should be deficient and nitrogen remarkably abundant.

Another illustrative example can be found in (Luck et al., 2000), where IC 4725 open cluster was investigated. It contains, in particular, several B stars and one Cepheid U Sgr. What we can learn from the Table 6 and 7 of that paper? B stars show a variety of the abundance values for each investigated elements, and this is different from what we see in Cepheid, although all of these stars are from the same cloud. For instance, carbon in B stars is lower than in U Sgr. The main reason for this strange situation could be the following. B stars show their suprficial abundance anomalies, they are not yet mixed stars. These supeficial anomalies can arise, e.g. due to an atomic diffusion process in their rather dynamically stable atmospheres (despite they could be even fast rotators with meridional circu-

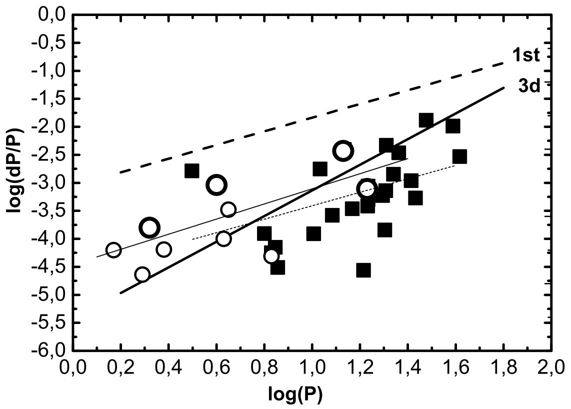

Figure 1: Secular period change $\log\left(\frac{dP}{P}\right)_{100}$ vs. observed pulsational period $\log(P)$. The shown are: a) position of the s-Cepheids as determined by Berdnikov et al. (Berdnikov et al., 1997): *large circles* - the stars with reliably determined evolutionary period change (assigned weight is 2), *small circles* - those having the less reliable determination (assigned weight is 1), b) *filled squares* - ordinary Cepheids from Saitou (Saitou, 1989), c) *thick long−dashed line* represents the theoretical relation for the first crossing, d) *thick solid line* - the same for the third crossing), e) *thin short−dashed line* gives the fit for ordinary Cpeheids, f) *thin solid line* is the best fit for s-Cepheids.

lation).

After the main-sequence phase, all superficial anomalies will be erased due to a global convective mixing, and we may observe yellow supergiant star with a normal chemical composition of all the elements, with an exception for C, N and Na.

However, Berdnikov et al. (Berdnikov et al., 1997) provided some observational argumentation in favour of the hypothesis that s-Cepheids are crossing the instability strip for the first time. Those authors determined the secular changes in the pulsational periods among the s-Cepheids and compared obtained values with theoretically predicted period changes. The latter ones come from Saitou (Saitou, 1989). In Fig. 1 we reproduced the original Fig. 6 from Berdnikov et al. (Berdnikov et al., 1997), but with more detailed representation of the data for ordinary galactic Cepheids, as listed by Saitou (Saitou, 1989). Shown in Fig. 1 is the fractional pulsational period change during 100 yrs (i.e., $\log\left(\frac{dP}{P}\right)_{100}$) vs. observed pulsational period $\log(P)$. Observed period changes for studied s-Cepheids and for ordinary Cepheids are compared with theoretically expected values for the stars performing their first and third passages across the instability strip (from all ordinary Cepheids listed by Saitou (Saitou, 1989) only the stars showing the positive increments of period were selected, which are appropriate for the 1st or 3d crossing). It should be noted that Saitou (Saitou, 1989) gives the derived period change also as a function of the helium content and overall metallicity. Taking into account that 1) the helium content cannot be directly estimated for yellow supergiants, and 2) the metallicity of the classical Cepheids within the errors of spectroscopic analysis is close to the solar one, we adopted for *theoretical* dependencies shown in Fig. 1 the normal mass fractions of helium and other metals (i.e., Y=0.28 and Z=0.02).

Although, as it might be concluded from Fig. 1, the secular changes for s-Cepheids are quite similar to what is theoretically expected for the third crossing, Berdnikov et al. (Berdnikov et al., 1997) argued that a) there is an offset between the theoretical relation for the third crossing and the fitting line for ordinary Cepheids (supposedly crossing the instability strip not for the first time, for example, more likely for the third time, if only positive increments are selected), b) some offset also takes place between the locus of s-Cepheids and theoretical relation for the third crossing. As one can guess from above mentioned assumption, this should mean that by a formal shift of the theoretical dependencies "period change-period" to a best agreement between the fitting line for ordinary Cepheids and theoretical relation for the third crossing, one can also reach a marginal agreement between the observed position of the s-Cepheids and the theoretical line for the first crossing. Thus, those authors make a conclusion that within the "$\log\left(\frac{dP}{P}\right)_{100} - \log(P)$" diagram the small-amplitude s-Cepheids deviate from the ordinary Cepheids, and that these stars therefore are crossing the instability strip for the first time (while ordinary Cepheids with positive increments do cross for the third time). This conclusion appears to be in some contradiction with our previous results based on spectroscopic investigation of the s-Cepheids, and it deserves a special consideration.

2. Solution of the problem

During the last years it became clear that many properties of the s-Cepheids can be understood and explained by supposing that they are not fundamental pulsators, but instead are the first overtone ones (see, e.g. Antonello et al., 1990). Thus, their observed pulsational periods should be considered as overtone ones P_1, and they have to be converted into periods of the fundamental mode $P_0 \approx P_1/0.71$ (Christensen-Dalsgaard & Petersen, 1995), if we are particularly interested in the further comparison with the fundamental pulsators.

With recalculated periods ($\log(P)$), the position of s-Cepheids within the discussed diagram has been revisited. For unique galactic s-Cepheid V473 Lyr the

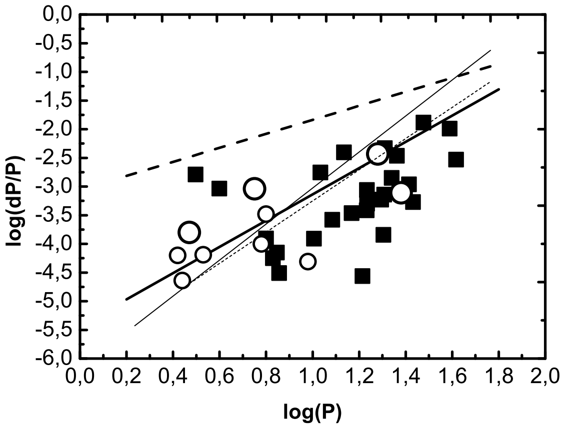

Figure 2: Same as Fig.1, but with corrected periods for s-Cepheids (case A).

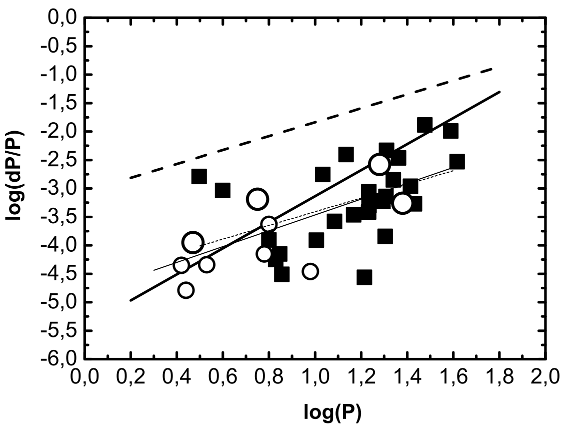

Figure 3: Same as Fig.2, but for the case B.

Table 1: Initial and redetermined characteristics for s-Cepheids

Star	1	2	3	4	5
V473 Lyr	0.17	0.42	−4.20	−4.35	+
SU Cas	0.29	0.44	−4.64	−4.79	+
EU Tau	0.32	0.47	−3.80	−3.95	++
UY Mon	0.38	0.53	−4.19	−4.34	+
αUMi	0.60	0.75	−3.04	−3.19	++
V1726 Gyg	0.63	0.78	−4.00	−4.15	+
GI Car	0.65	0.80	−3.48	−3.63	+
V496 Aql	0.83	0.98	−4.31	−4.46	+
SZ Cas	1.13	1.28	−2.43	−2.58	++
Y Oph	1.23	1.38	−3.11	−3.26	++

1 – $\log(P)$, where P is observed period,

2 – $\log(P_0)$, where P_0 is fundamental period,

3 – $\log\left(\frac{dP}{P}\right)_{100}$ – original value of the secular period change determined by Berdnikov et al. (Berdnikov et al., 1997),

4 – $\log\left(\frac{dP}{P_0}\right)_{100}$ – with corrected period (case B, see text),

5 – Remarks: stars denoted by "++" have the reliably determined value of the secular period change, while for the stars denoted by "+" these values are less reliable.

We use an usual classification for SU Cas as s-Cepheid (General Catalogue of Variable Stars).

pulsations in the second overtone were supposed (see, Burki et al. Burki et al., 1986; Andrievsky et al., 1998), and its true fundamental period was found as $P_0 \approx P_2/0.57$. The term $\log\left(\frac{dP}{P}\right)_{100}$ (the ratio between the experimentally determined period change dP and observed period) may also require some correction. Let us consider two cases.

Case A. Period changes dP for s-Cepheids are smaller than those observed in ususal Cepheids of the comparable periods P_0 of a fundamental mode (i.e., $dP \equiv dP_1 = const \times dP_0$, where $const = 0.71$). In this case one gets $\frac{dP}{P} = \frac{dP_1}{P_1} = \frac{dP_0}{P_0}$, therefore we have to leave observed ratio $\frac{dP}{P}$ unchanged. This means that comparably to Fig. 1, the corrected positions of the s-Cepeids are conditioned by the horizontal rightward shift due to transformation of the observed period P_1 into P_0. The corrected positions are shown in Fig. 2.

Case B. Although s-Cepheids are overtone pulsators, their actual (observed) period changes may correspond to the unexcited fundamental pulsations. In other words, the period change in a given s-Cepheid may be larger than that in the fundamental pulsator of a similar observed period. This assumption implies that the evolutionary period change (which should, of course, depend upon the stellar radius and luminosity, and their variation with a time) $dP \equiv dP_0$, and thus observed ratio $\frac{dP}{P}$ should be substituted with $\frac{dP_0}{P_1/0.71} = \frac{dP_0}{P_0}$. In this case, an additional vertical downward shift ($\approx$ 0.15 dex) should be taken into account. The corrected positions of the s-Cepheids are shown in Fig. 3 (the necessary numerical values for s-Cepheids are also presented in Table 1).

3. Discussion and conclusion

Figs. 2-3 (and even Fig. 1) leave practically no doubt that observed period changes in s-Cepheids are close to those in classical Cepheids, and being taken together, the observed changes in both stellar groups are close to those which are expected for the 3d crossing Cepheids, It is interesting to note that (Neilson et al., 2012) have shown that mass loss during the Cepheid stage can result in a positive period changes if large enough. Thus one can imagine that it is not necessary to advocate overtone pulsation (first or second) to explain the displacement of points in the "period - period change" diagram away from that expected for a third crossing using overtone pulsation.

Nevertheless, we cannot rely only on this hypothesis simoly because Neilson et al. considering the case of Cepheid Polaris were forced to tune their model using a quite large mass loss rate for this star (10^{-6} solar masses per year). We think that there is no reason to believe in a such large ratio taking into account that Polaris has a quite high gravity value and a very small pulsational activity - two factors that can hardly enlarge the mass loss.

Summarizing, one can conclude that there is no firm ground to consider all the small-amplitude s-Cepheids as the stars which are performing their crossing the instability strip only for the first time. It is, of course, not completely excepted that some of them can really be the first crossers (for example, Luck, Kovtyukh & Andrievsky (Luck et al., 2001) detected and described Cepheids with solar-like carbon abundance: SV Vul).

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