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The Chemical Composition of S-Cepheids and Double-Mode Cepheids

I.A. Usenko[1], V.V. Kovtjukh[1], S.M. Andrievsky[1], V.G. Klochkova[2], and G.A. Galazutdinov[2]

[1] *Department of Astronomy, Odessa State University, Shevchenko Park, Odessa, 270014, Ukraine*

[2] *Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhyz, Stavropol' Territory, 357147, Russia*

The main aim of this work is to consider the evolutionary status of s-Cepheids (SC), - small-amplitude Cepheids with smooth sinusoidal light, colour and radial velocity curves. The unusual character of these objects could be explained in two ways: (1) SCs are crossing the Cepheid instability strip for the first time and they are first (or high) overtone pulsators (Efremov 1970); (2) SCs have close early-type companions, which affect gravitationally the Cepheid He II zone. Such an effect can decrease the Cepheid pulsational activity (Lloyd Evans, 1968).

According to theoretical calculations, low helium abundance in Cepheid atmospheres, which are crossing the instability strip for the first time, could produce small-amplitude oscillations. On the other hand, double-mode Cepheids (DMC) show oscillations with two (or three) periods: fundamental with large-amplitude asymmetrical light, colour and radial velocity curves, and first overtone with smooth sinusoidal small-amplitude ones. Nevertheless, detailed spectral and photometric investigations permit the detection of companions for the brightest SCs, and support the second hypothesis.

In order to solve these problems we obtained during 1990-1995 high-resolution photographic and CCD spectra of some SCs and DMCs for further abundance analysis of these stars. Our observational programme included 14 SCs (V473 Lyr, SU Cas, EU Tau, DT Cyg, V526 Mon, SZ Tau, V1334 Cyg, α UMi, FF Aql, V1162 Aql, V924 Cyg, V440 Per, V636 Cas, Y Oph) and 4 DMCs (TU Cas, EW Sct, BQ Ser, VX Pup).

Spectral observations of SCs and DMCs were made with: (1) The Main Stellar Spectrograph fed by the 6-m telescope SAO RAS at the reciprocal dispersion 9 Å/mm and 14 Å/mm. (2) The CCD-echelle spectrograph LYNX fed by the 6-m telescope SAO RAS (Panchuk et al. 1993) with resolution power about 25000. (3) The CCD-spectrograph AURELLIE fed by the the 1.52-m telescope Haute Provence Observatory with resolution power about 11000.

All spectra were reduced on the automatic computing system of the Crimean Astrophysical Observatory. For reducing CCD-echelle LYNX and AURELLE spectra we used DECH 20 code (Galazutdinov, 1992). We have carried out the LTE analysis and the atmosphere models for the programme stars were interpolated from Kurucz (1979) (for SC) and Kurucz (1992) (for DMC) grids.

The comparative results of spectroscopic investigations have shown: (1) Carbon is under-abundant for most SCs. This can be explained by the reduction of carbon's abundance after dredge-up (Luck & Lambert, 1985). It is accompanied by nitrogen overabundance with normal oxygen content. This agrees with Luck & Lambert (1985) about unaltered oxygen content in the supergiants after the first dredge-up. (2) The majority of SCs shows abundances for α- and Fe- group elements, close to solar ones (with small deficiency for EU Tau, V526 Mon and V924 Cyg). DMCs indicate a greater deficiency for these elements. (3) The majority of s-process elements show some overabundance or close to solar for SCs, except EU Tau, V526 Mon and V924 Cyg, mentioned above. It is noticeable especially for SU Cas, DT Cyg and FF Aql. Probably, all these stars have passed through red-giant stage and they could not be crossing the instability strip for the first time. (4) Iron abundance data for DMC strongly support the existence of P_1/P_0 - [Fe/H] relation, which was discussed in Andrievsky et al. 1993). From theoretical models of DMC pulsation (e.g., Moskalik et al. 1992; Christensen-Dalsgaard 1993) the period ratio P_1/P_0 can depend both on the detailed chemical composition and on the pulsation period P_0. Theoretical analyses based on the 'old' Los Alamos opacities focussed on the dependence on period, whereas models using the 'new' Livermore opacities show a small systematic change of P_1/P_0 ratio with period in the period interval relevant for the DMC. Since the revised models show a strong dependence of P_1/P_0 ratio on the composition parameters (mainly through the opacity) it is necessary to know the detailed chemical composition in order to perform precise comparisons of observed and theoretical period ratios. (5) Carbon deficiency, nitrogen overabundance and some overabundance of s-process elements in SC atmospheres indicate that these objects are not crossing the Cepheid instability strip for the first time, and therefore they are not overtone pulsators. (6) Two SC objects, V1162 Aql and V636 Cas, showed the agreeable surprise: their CNO abundances are solar-like. Consequently, we have detected Cepheids, crossing the Cepheid instability strip for the first time. These stars have the lower T_{eff} value (5500 K) and later spectral type (G0-G5) compared with other SC. It should be noted that, according to Berdnikov (1994), V1162 Aql has a very asymmetrical light curve and, probably it is a normal classical Cepheid. (7) The peculiarity of s-Cepheid light, colour and radial velocity curves could be explained by the presence of the companion.

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