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Chemical abundances of β Cephei stars from low- and high-resolution UV spectra

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Abstract. We determined the stellar parameters ($T_{\rm eff}$, [m/H], θ) and $E(B-V)$ for all β Cephei stars observed during the IUE satellite mission. All parameters were derived using an algorithmic procedure of fitting theoretical flux distributions (Kurucz 1996) to the IUE observations.

1. Introduction

In early type stars the ultraviolet spectral region is important for several reasons. Firstly, since the majority of the total flux is emitted here, it provides a rather sensitive indicator of a photospheric temperature and luminosity. Secondly, the UV spectra are dominated by lines of the iron-group elements, which are the origin of the opacity bump at temperature 2×10^5 K, where the classical κ-mechanism drives pulsations of β Cep stars. Consequently, the position of the instability domain in the HR diagram strongly depends on the metal abundance (Pamyatnykh 1999).

We derive stellar parameters (metallicity, [m/H], effective temperature, $T_{\rm eff}$, stellar diameter, θ), and interstellar extinction, $E(B-V)$, for all β Cep stars observed by *International Ultraviolet Explorer* satellite. The parameters are derived by means of an algorithmic procedure of fitting theoretical flux distributions to the low-resolution IUE spectra and optical spectrophotometric observations. The errors are estimated by using the bootstrap method (Press et al. 1992). We also show some examples of high-resolution HST/GHRS spectra for one β Cep star: γ Peg.

2. Analysis of low resolution IUE spectra

2.1. Observations and method

The observational material consists of the IUE spectra with the absolute calibration and reduction done by NEWSIPS package. The spectra were co-added if more than one spectrum was available for a star. The ultraviolet observations expressed in the absolute units were supplemented by optical spectrophotometric measurements taken from the literature. We used Johnson and Strömgren photometry if no optical spectrophotometric data were available.

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We applied the least-squares (LS) optimization algorithm of fitting theoretical flux distributions to observations. This method enables us to obtain various parameters involved in stellar spectra ($T_{\rm eff}$, [m/H], $E(B-V)$, θ). We used theoretical models of Kurucz (1996) with the value of the microturbulent velocity, $v_t = 2\,{\rm km\,s^{-1}}$, for all stars. In addition, the mean interstellar reddening curve of Fitzpatrick (1999) was adopted for the majority of the analysed objects. Because of the spatial variability of the extinction law, for the field stars with $E(B-V) > 0.10$, five additional parameters, specifying the shape of the UV extinction curve were estimated. For β Cep stars in open clusters we adopted the extinction curves from Massa & Fitzpatrick (1986). The surface gravity was determined as a mean value from four methods. Three of them use Strömgren and Geneva photometry. In the last method, we estimated the gravities using the formula obtained from stellar evolutionary models computed by A. Pamyatnykh (private communication) for OPAL opacities with $Z = 0.02$. We found the following relation: $\log g = -12.5894 + 4.4810 \log T_{\rm eff} - 0.7870 \log L/{\rm L}_{\odot}$, with a standard deviation of 0.01 in $\log g$. We used Hipparcos parallaxes in order to calculate $\log L/{\rm L}_{\odot}$. During the best-fit procedure the luminosity was corrected for the Lutz-Kelker bias (Lutz & Kelker 1973). The distances to the clusters were taken from the literature. The errors were estimated by using the technique of bootstrap resampling (Press et al. 1992, Niemczura 2003). This technique allows to get reliable uncertainties of the parameters and correlations between them.

2.2. Results

In Fig. 1, we show the $\log g$ vs. $\log T_{\rm eff}$ diagrams with observational points and theoretical instability strips for three values of Z. The mean value of the metal abundance parameter [m/H] for the field stars is equal to -0.14 ± 0.03, and ranges from -0.47 (27 CMa) to 0.21 (HN Aqr). The mean values of [m/H] for the stars in clusters are equal to 0.05 ± 0.06 for NGC 3293, -0.43 ± 0.05 for NGC 4755 and -0.01 ± 0.06 for NGC 6231. The clusters NGC 3293 and NGC 4755 have similar ages, but the β Cep instability strip in the second one is shifted to the lower temperatures. This can be explained by the lower value of [m/H] obtained for the NGC 4755 stars. The mean [m/H] for all stars we analysed is -0.13 ± 0.03. These determinations are consistent with our previous results (Daszyńska et al. 2002), obtained with the less accurate method. Metal abundances of hot stars in the solar vicinity are lower by about 0.20 than the solar value and were reported by many authors (see Niemczura 2003 and references therein). The values from the low-resolution IUE observations are in agreement with these results. In the next step we checked whether the obtained metallicities are correlated with any stellar parameter. We found small correlations between [m/H] and all parameters (from 0.17 for $E(B-V)$ to 0.26 for $T_{\rm eff}$), which mean that [m/H] can be reliably derived from the best-fit procedure. Then we tried to find quantities which can be determined by metallicity in β Cep stars. The value of the dominant period, its amplitudes of the light and radial velocity variations, as well as the projected rotational velocity are not correlated with the value of [m/H], as has been already shown by Daszyńska et al. (2002). For more details we refer reader to Niemczura & Daszyńska-Daszkiewicz (2003).

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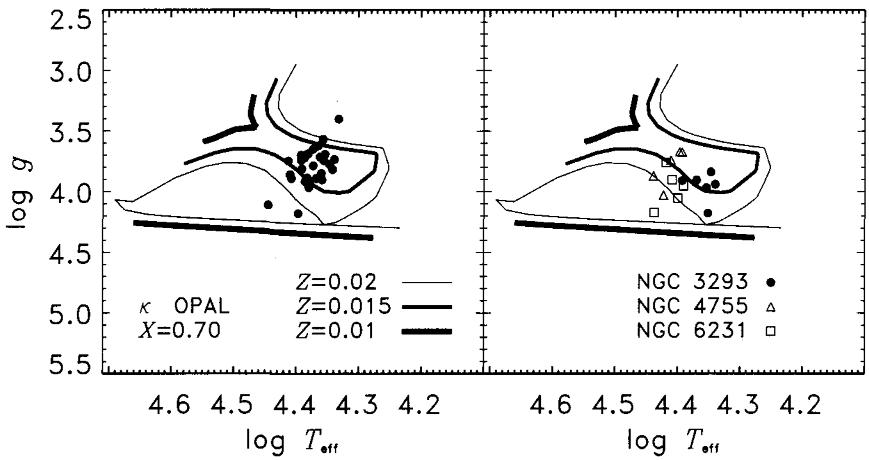

Figure 1. Theoretical instability domains of β Cep stars and observational data in the $\log g$ – $\log T_{\rm eff}$ diagram. The instability domains and lines of ZAMS were taken from Pamyatnykh (1999).

3. High resolution HST/GHRS spectra of the β Cephei star γ Peg

High-quality UV spectra of γ Peg have become available with Goddard High Resolution Spectrograph (GHRS) aboard HST. Observations were made with two gratings, G160M (1340 – 1380 Å) and ECH-B (2060 – 2071 Å), with the spectral resolving power of about 20 000 and 80 000, respectively. Both spectral ranges are dominated by iron peak elements such as Fe, Cr, Mn, Ni, Si, Zn, V and Ti. In Fig. 2 we show a comparison of the ECH-B spectrum of γ Peg with the theoretical one computed with Kurucz LTE line-blanketed models for [m/H]= -0.2 and stellar parameters obtained from the above analysis of IUE spectra. The overall fit is quite good, but for more detail analysis the abundances of elements should be determined individually.

4. Conclusions and future prospects

The abundance of the metals, especially of Fe, in β Cephei pulsating variables is one of the fundamental parameters. In the case of main sequence B stars, values obtained from the UV spectra mainly give the estimation of [Fe/H]. Because the Kurucz models are overestimated in Fe we have to include a correction for [m/H] of about 0.12. The metallicities of the β Cep stars predicted by the pulsation theory are not in contradiction with most values determined by us. Pamyatnykh (1999) showed that the β Cephei instability strip vanishes for $Z \approx 0.01$, corresponding to [m/H] ≈ -0.30, and to [m/H] ≈ -0.42 from the Kurucz's fluxes. There are a few stars with the metallicity parameter lower than this limit. But we have to remember that our values give information mainly about photospheric metal abundances. Some other effects, which we did not take into

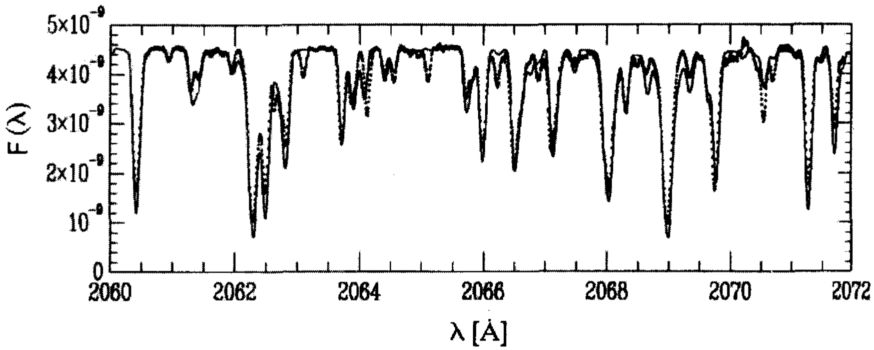

Figure 2. Comparison of HST/GHRS spectrum of γ Peg with the theoretical one computed with Kurucz LTE models for [m/H]= −0.2.

account, such as diffusion or element mixing may also play a significant role. We did not change the mixture of elements either.

In spite of this, our results provide very important information about the metallicity range for these pulsating stars. However, for asteroseismological purposes, there is a need for a detailed analysis of chemical composition, because oscillation frequencies are very sensitive to the adopted mixture. This is the aim of our future work and here we show an example of high-resolution HST/GHRS spectrum of γ Peg with the best-fit of theoretical models.

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