Effects of [Fe/H] on the properties of Galactic classical Cepheids

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Abstract. Correlations have been searched for between the atmospheric [Fe/H] value and the observed amplitudes of classical Cepheids. Model calculations show that fundamental mode pulsation is unstable for solar like chemical composition between 8 and 10 days, but observations contradict the models. The ratio of the radial velocity and photometric amplitudes, $A_{V_{RAD}}/A_{B}$, shows a mild metallicity dependence.

1. Introduction

Classical Cepheids are radially pulsating supergiant stars. Their pulsation is a free radial oscillation of the outer layers of the star. The pulsation is maintained by the $\kappa$-mechanism and is stable in a narrow zone, in the so-called instability strip in the Hertzsprung-Russell diagram. The radial oscillation and the instability strip result in many relationships between the properties of Cepheids. The most important is the period-luminosity (P-L) relationship.

Motivated by the fact that the dependence of the pulsation amplitude on log $P$ is neither linear, nor unique, we revised the period-amplitude (P-A) relationship of Galactic classical Cepheids for the $U$, $B$, $V$, $R_C$, $I_C$ photometric bands and the pulsational radial velocity variations (Klagyivik & Szabados 2009).

The different patterns of the P-A diagrams based on Galactic and Magellanic Clouds Cepheids show that the metallicity is a non-negligible factor of the pulsation amplitudes, first mentioned by van Genderen (1978). The role played by the metallicity in adjusting the P-L relationship has been frequently discussed from both observational and theoretical points of view (see the recent summary by Romaniello et al. 2008), though the results are controversial. Using the homogeneous OGLE data base, Paczyński & Pindor (2000) found that the higher the metal content of the host galaxy, the larger the photometric amplitude.

Here we present the results on the period dependence of [Fe/H] and the metallicity dependence of the amplitude ratio $A_{V_{RAD}}/A_{B}$, i.e., the ratio of the peak-to-peak amplitudes of the radial velocity variations over the brightness variations in the Johnson $B$ band.

We used a data base of observational data of 369 Galactic classical Cepheids. This catalogue contains the photometric and radial velocity amplitudes, some parameters derived from the amplitudes and the spectroscopically determined [Fe/H] ratio for 179 stars. For details see Klagyivik & Szabados (2009) where it is also shown that there exists a dichotomy separating short- and long-period Cepheids and the limiting period value is 10.47 days.
2. Discussion

2.1. Period dependence of [Fe/H]

Figure 1. Period dependence of [Fe/H]. Circles represent fundamental mode Cepheids with short pulsation period (P < 10.47 days), squares mean long period stars (P > 10.47 days), while triangles correspond to first overtone Cepheids. Filled symbols represent solitary stars, while Cepheids denoted with open symbols have known companions.

According to the P-L relationship, long-period Cepheids are more luminous than their shorter period counterparts, and being more massive, they evolve rapidly. As a consequence, longer period Cepheids are also younger, and owing to the gradual enrichment of the heavy elements in the interstellar matter, the metallicity of the younger stellar population is larger. This trend is clearly seen in Fig. 1.

Buchler et al. (1997) found that the fundamental mode limit cycles are unstable in the period range 8-10 days for Cepheids with metallicity between $Z = 0.014$ and 0.035. This metallicity range corresponds to the $-0.154 - 0.244$ interval of [Fe/H] using the conversion relation $\log Z = [\text{Fe/H}] - 1.7$ (Caputo et al. 2001). The corresponding stars pulsate in the first overtone with a period of $P_1 \approx 0.7 P_0$, causing a relative excess of first overtone Cepheids in the period interval of 5.6-7.0 days. Magellanic Clouds are metal deficient as compared with our Galaxy, therefore fundamental mode pulsation is allowed there in the 8-10 days period range. In spite of the model calculations the box that corresponds to the models in Fig. 2 is not empty: observations show that fundamental mode pulsators do exist in our Galaxy in this period range. The error of the individual [Fe/H] values is about 0.05-0.10 dex, but this fact may not fully explain the discrepancy between models and observations.

2.2. Metallicity dependence of the amplitude ratio $q$

Importance of the specific amplitude ratio $A_{V_{\text{RAD}}} / A_B$ – referred to as the $q$ parameter – was discussed by Klagyivik & Szabados (2009). This ratio is sensitive to the binarity, because companions reduce the observable photometric amplitudes, and an unrecognized orbital motion superimposed on pulsational changes results in an increased $A_{V_{\text{RAD}}}$. Therefore in the case of testing the metallicity dependence of $q$ we have to exclude binary Cepheids.

The relationship between $q$ and metallicity is presented in Fig. 3. The symbols are the same as in Fig. 1. Linear least squares fits have been applied to each group of Cepheids separately and
to all fundamental mode pulsators as well. The results are summarized in Table 1. Coefficients $a$ and $b$ correspond to the following formula:

$$q = a + b \times [\text{Fe/H}]$$

(1)

Table 1. Coefficients of the linear fit to the $q$ vs. [Fe/H] relationship (Eq.1)

| Sample                     | $a$   | $\sigma_a$ | $b$   | $\sigma_b$ | $N$ |
|----------------------------|-------|------------|-------|------------|-----|
| $\log P < 1.02$           | 34.68 | 0.83       | -14.09| 7.34       | 23  |
| $\log P > 1.02$           | 31.65 | 0.96       | -3.53 | 5.54       | 23  |
| All fundamental mode Cepheids | 33.36 | 0.65       | -9.45 | 4.49       | 46  |
| First overtone Cepheids    | 35.28 | 1.01       | -16.80| 8.91       | 15  |

All types of Cepheids follow the same trend, the higher the metallicity, the lower the $A_{\text{rad}}/A_B$ ratio. These correlations are not very strong ($2\sigma$).

3. Conclusion
We searched for metallicity dependences of several parameters related to the pulsation of Cepheids. The correlations we have found are not very strong, but clearly demonstrate that the effect of the chemical composition on the pulsation is non-negligible. The individual [Fe/H] values have an error of 0.05-0.10, so a more precise formulation of these relations is mainly hindered by uncertainties of the abundance determination.

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Figure 3. Metallicity dependence of the amplitude ratio $q$. The solid line corresponds to the fit based on all fundamental mode Cepheids, while dotted, dashed and dash-dotted lines represent the fit to short period, long period and first overtone Cepheids, respectively.

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