COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4636

Konkoly Observatory
Budapest
25 September 1998

HU ISSN 0374 – 0676

THE HERTZSPRUNG SEQUENCE FROM RADIAL VELOCITIES

N.A. GORYNYA

Institute of Astronomy, Russian Academy of Sciences, 48, Pyatnitskaya Str., Moscow 109017, Russia. E-mail: gorynya@sai.msu.su

In the 1920ies, photometric data accumulated for a large number of Cepheid made it possible to study the shape of Cepheid light curves and to establish an empirical sequence (the so-called Hertzsprung sequence) showing the dependence of the light curve shape upon the value of the period (Hertzsprung, 1926).

Somewhat later, Kukarkin and Parenago (1937), from all light curves of 102 Cepheids published by that time, established the relation between the phase of the secondary maximum (hump) of the light curve upon period: the secondary maximum appears on the descending branch of the light curve for stars with periods around 6 days and then shifts itself towards the maximum, coinciding with the latter at the period of about 10 days. For stars with periods exceeding 10 days, the hump is already observed on the ascending branch.

The secondary details can be also observed on the radial velocity curve. It is believed that the hump on the V_r curve is positioned at the same phase as that on the light curve (Fadeev, 1994). However, this statement should be carefully verified, especially because the shapes of the light curve and the velocity curve are not, generally speaking, a mirror image of each other (Sachkov et al., 1998). The first attempt to present a sequence similar to the Hertzsprung sequence but for the radial velocity curves was made by Joy (1937), but he was unable to succeed because of low accuracy of individual measurements and insufficient number of observations per Cepheid.

In 1987–1998, we acquired about 6000 individual correlation-spectrometer measurements of radial velocities for 128 Cepheids, with typical accuracy about 0.5 km/s (Gorynya et al., 1992, 1996, 1998). For further analysis, we selected radial velocity curves of 36 classical Cepheids best covered by observations. We excluded velocity curves of spectroscopic binaries, double-mode stars, and low-amplitude Cepheids. Thus, our sample contains only DCEP variables according to the classification system of the GCVS (1985), which presumably pulsate in the fundamental mode. These data permitted us, for the first time, to reveal the Hertzsprung sequence quite confidently.

To study the Hertzsprung sequence for the velocity curves, we used the so-called standard curves which fix the shape of the curve for each star. A standard curve is a set of one hundred velocity values for phases from 0 to 0.99 at steps of 0.01, constructed using the method described by Berdnikov (1992). In this process, the observations were fitted, entirely or in pieces, by an appropriate function (a Fourier series, a spline, or a polinomial of the third degree). From the standard curves, the phases of the details under consideration were determined with errors not exceeding 0.05.

Figure 1 shows the dependence of the phase of the secondary minimum (the primary minimum of the radial velocity corresponds to zero phase) upon period; Fig. 2, the dependence of the phase difference between the same detail and the velocity maximum upon period. Figure 3 presents the dependence of the velocity-curve asymmetry upon period. The asymmetry is the duration of the velocity-curve descending branch expressed as a fraction of the period. Obviously each of these plots can be derived from two others.

In these relations, similar to the case of the light-curve analysis, the stars can be readily subdivided into three groups: with periods shorter than 10 days; with periods from 10 to 20 days; and with periods exceeding 20 days. The first and the third groups show the depression on the ascending branch of the radial velocity curve, whereas the second group shows it on the descending branch, the phase of the secondary minimum being essentially constant, about -0.2.

The period grouping of the stars can probably be explained by the different nature of the secondary minimum for different period values, similar to the situation with the secondary maximum of the light curve (Fadeev, 1994).

We are going to extend our sample adding spectroscopic binary Cepheids (pulsational velocity curves). It is planned to study the behavior of the depression in more detail for long-period Cepheids, insufficiently represented in the sample used for this study. Besides that, we are going to study the phase shift between radial velocity curves and light curves; this investigation requires simultaneous sets of spectroscopic and photometric observations (preliminary analysis shows that the phases of the secondary detail are different for light curves and velocity curves; cf., for example, Figure 1 in Sachkov et al., 1996).

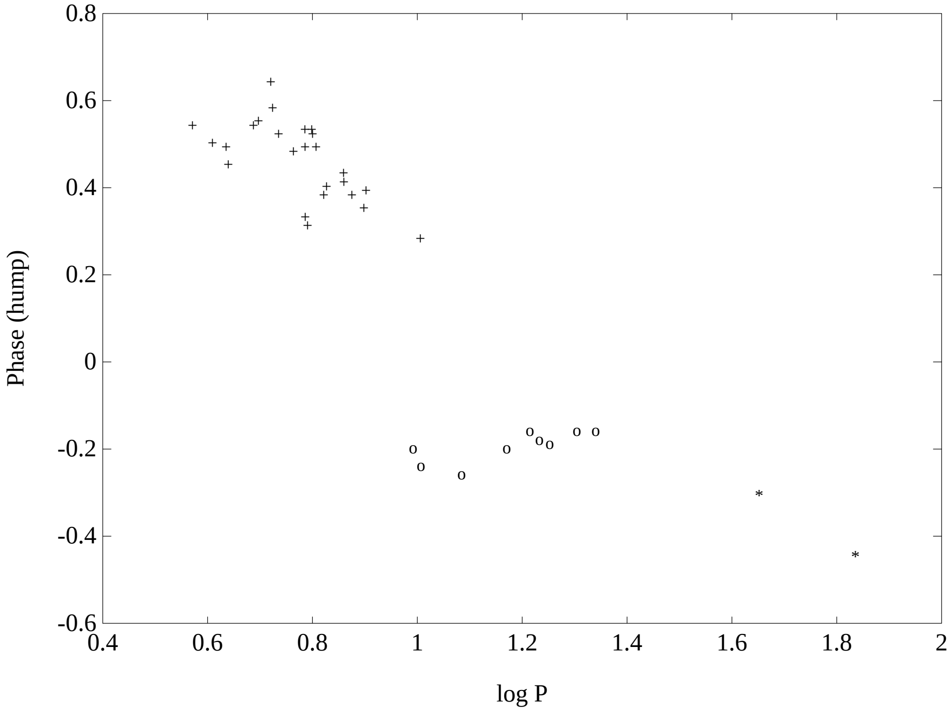

Figure 1. The (period – phase of the secondary minimum) relation. Phases are relative to the minimum of V_r (zero phase) and are expressed as fractions of the period. Crosses, Cepheids with P<10 days; open circles, Cepheids with $10< P <20$ days; asterisks, Cepheids with P>20 days

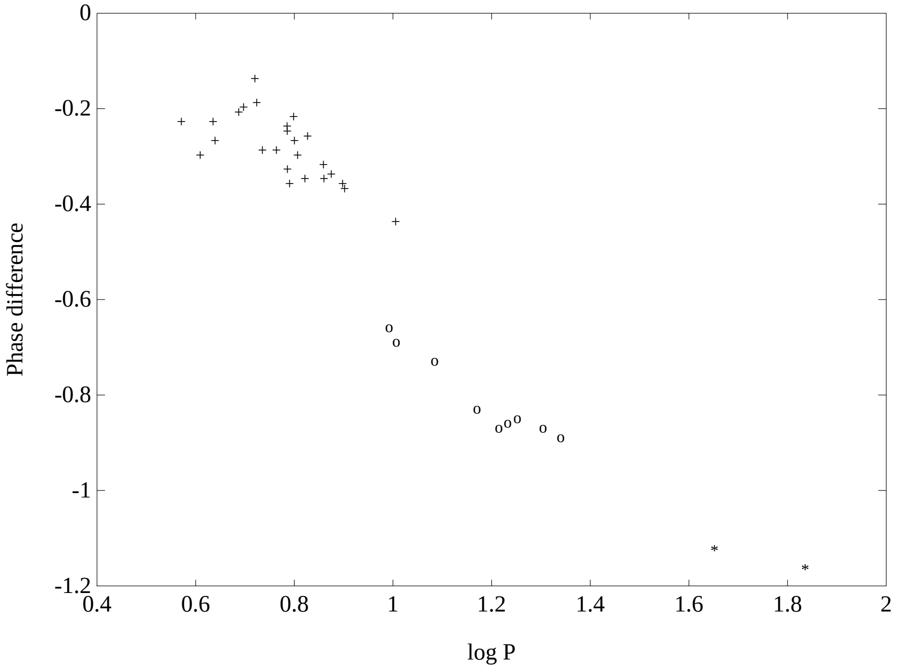

Figure 2. The (period – phase difference between the hump and the radial velocity maximum) relation. Zero phase, maximum V_r. Same notation as in Figure 1

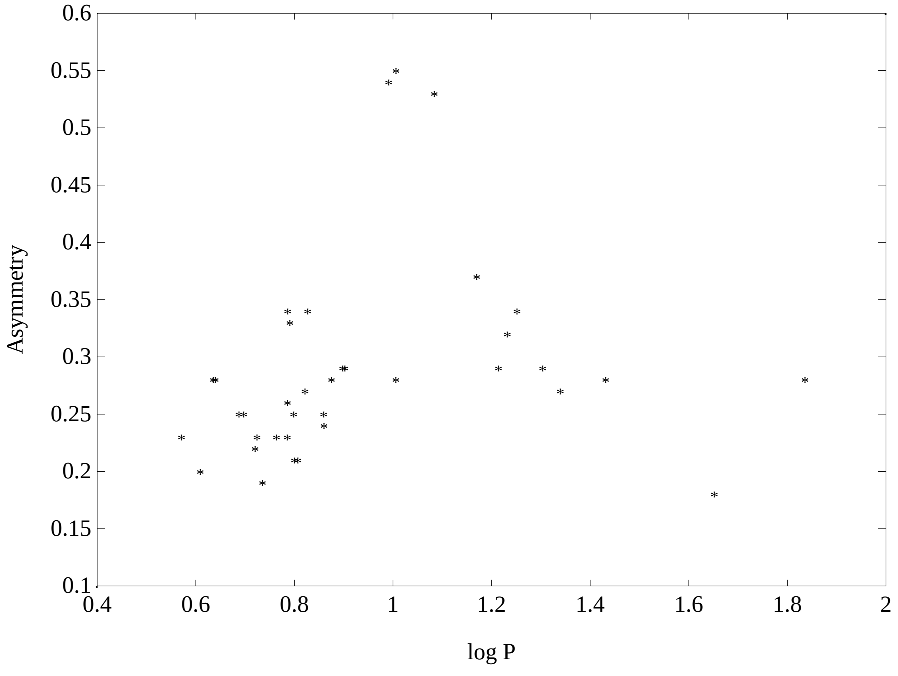

Figure 3. The (period — asymmetry) relation from standard curves. See the definition of the asymmetry in the text

The author wishes to thank M.E. Sachkov for assistance, N.N. Samus, A.S. Rastorgouev, L.N. Berdnikov, and Yu.A. Fadeev for valuable discussion. This study was supported, in part, by the Russian Foundation for Basic Research (grants 96-02-18491, 96-02-18239, 97-02-16739) and by the State Programme "Astronomy". Thanks are due also to the Council of the Programme of Support for Scientific Schools (grant 96-15-96656).

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