DUPLICITY, MASS LOSS AND THE CEPHEID MASS ANOMALY

G. Burki
Geneva Observatory
CH 1290 Sauverny
Switzerland

The rate of binaries among cepheid stars is 25 - 35% (Burki, 1984a), a value which is in agreement with the rate among F-M supergiants (31-38%) obtained by Burki and Mayor (1983) from a radial velocity survey.

For binary cepheids, the Wesselink radius R_W is affected by the light of the companion. Balona (1977) found that R_W is too small if the companion is a blue main sequence star and too large if it is a red giant star. This effect has been quantitatively examined by Burki (1984a). For example, it was found that, in the case of a cepheid of period P = 32d with a companion fainter by 2 mag., R_W is 70% of its correct value if we are dealing with a main sequence companion and 130% in the case of a companion redder by 0.6 in B-V. The bias on R_W becomes negligible when the companion is fainter than the cepheid by more than 4 mag.

Following Cox (1979), four basic equations can be used: The definition of Te: log L = f(R,Te); the mass-luminosity law: log L = g (M,Y,Z); the period-density relation: log Q = h(P,M.R); the variation of Q: log Q = k(Te,R,M,L). The relations g and k result from model calculations. The theoretical mass M_{Th} and radius R_{Th} are obtained by resolving equations f,g,h,k for given values of P and T_e. The Wesselink mass M_W is deduced from equations f,h,k, the quantities P,T_e and the Wesselink radius R_W being known.

Table 1: Mean values of the ratio R_W/R_{Th} for the cepheids in Table 6 of Cox (1979)

	P < 10d	P > 10d
Single cepheids	1.01 ± 0.10 (22*)	0.83 ± 0.09 (9*)
Binary cepheids	0.92 ± 0.16 (17*)	0.86 ± 0.09 (4*)
All	0.97 ± 0.13 (39*)	0.84 ± 0.08 (13*)

https://doi.org/10.1017/S025292110001091IX Published online by Cambridge University Press

Table 1 gives the mean values of the ratio R_W/R_{Th} for the cepheids listed by Cox (1979). We see that:

1) R_W and R_{Th} are in agreement (ratio equal to 1) in the case of single cepheids with P < 10 d.

2) In the case of binary cepheids with P < 10d the ratio is not too far from unity but the dispersion is large (0.16): R_W is larger or smaller than R_{Th}, depending on the type of companion.

3) In long period cepheids, R_W is smaller than R_{Th} by about 15%, for both single or binary cepheids. For these stars, it is suggested that the discrepancy is due to the mass loss process, which must be taken into consideration for the calculations of evolutionary models of massive stars.

Indeed, it is now an established fact that the evolution of massive stars is modified by the mass loss process (Maeder, 1980). Burki (1984a) has used the evolutionary log M vs. log L diagram in order to show that preliminary calibrations, derived from the stellar models with mass loss by Maeder, can resolve the inconsistency between M_{Th} and M_W (or R_{Th} and R_W). This result can also be shown in the following way:

Lovy et al. (1984) have determined the pulsation periods of the supergiant models by Maeder, applying the classical linear adiabatic theory. They found the following relation for the fundamental radial mode:

$$\log P = 0.688 \log L - 3.918 \log Te + 13.237 \quad (1)$$

By using further the definition of T_e ($L \sim R^2 Te^4$) and the location of the instability strip (Cogan, 1978), a theoretical period-radius relation can be derived for the long period cepheids:

$$\log R = 0.68 \log P + 1.14 \quad (2)$$

Figure 1 shows the period-radius relation for all single Pop I cepheids that have a Wesselink radius determination. The theoretical relations, based on the models with $\dot{M}$ for the long period cepheids (equation 2) and without $\dot{M}$ for the cepheids with P < 10d (Cogan, 1978; Fernie, 1984) are also shown, as well as the observational log P-log R relations for cepheids with P < 10d and P > 10d, obtained by linear regressions. The vertical width of these relations correspond to twice the residual standard deviation in log R.

We see that:

1) In the case of cepheids with P < 10d, the agreement between observations and theory is quite remarkable (see Burki, 1984b).

2) In the case of cepheids with P > 10d, the theoretical relation based on models with $\dot{M}$ is in satisfactory agreement with the

observations. Note that the theoretical relation deduced from models without $\dot{M}$ would be in poorer agreement with these long period cepheids.

Of course, this comparison between observations and recent stellar models is only preliminary and the following remarks are to be made: i) A different parametrization for the mass loss rate in the models would modify the theoretical relations (1) and (2) ; ii) the observational log P - log R relation for cepheids with P > 10d is based merely on 9 stars ; iii) dividing the cepheids into two groups, with a limit of P ≃10d, does not have a strong physical significance.

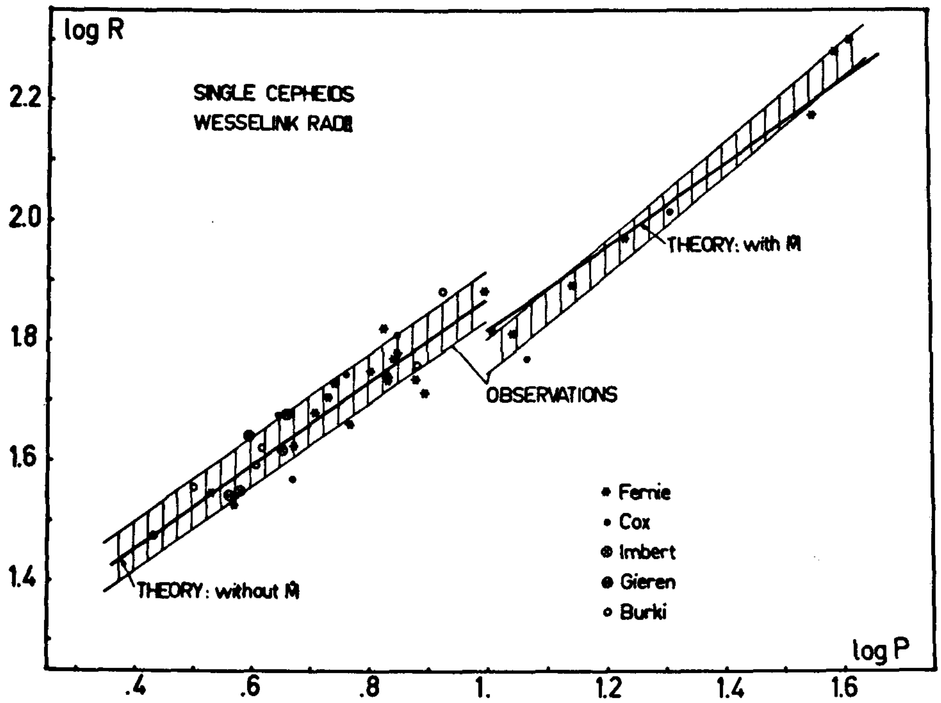

Figure 1: Period-radius relation for the single classical cepheids having a Wesselink determination of the radius. The radii come from Fernie (1984), Cox (1979), Imbert (1981, 1983, 1984), Gieren (1982), Burki (1984b), Burki and Benz (1982). The theoretical relations are from Cogan (1978) and Fernie (1984) for the cepheids with P < 10d and from equation (2) for the long period cepheids.

https://doi.org/10.1017/S0252921100010911X Published online by Cambridge University Press

However, this preliminary result is encouraging, as it backs up a number of other tests made previously. It further brings out the importance of the mass loss process for the evolution of massive stars. The study of long period cepheids must take into account the effect of mass loss.

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https://doi.org/10.1017/S025292110010911X Published online by Cambridge University Press