DISTANCES AND RADII OF CLASSICAL CEPHEIDS

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1. INTRODUCTION

Suppose one of the current high angular resolution instruments were capable of measuring the instantaneous angular diameter of a Cepheid throughout its pulsation cycle. By comparing the angular diameter variation to the linear displacement variation, obtained from the integrated radial velocity curve, one could determine both the linear radius and the distance of the variable. This distance would be independent of all other astrophysical distance scales and would be geometric, i.e. independent of the effects of interstellar obscuration.

Although none of the current instruments has this capability, the same result can be accomplished indirectly through use of the stellar surface brightness. Recall that the visual surface brightness can be expressed in terms of the apparent visual magnitude and the stellar angular diameter. At any phase in the Cepheid pulsation, knowledge of the visual surface brightness and the apparent magnitude permits inference of the angular diameter.

From stars with measured angular diameters it is known that the visual surface brightness parameter F_V correlates remarkably well with the Johnson V-R color index (Barnes and Evans 1976; Barnes, Evans and Parsons 1976; Barnes, Evans and Moffett 1978). Johnson VR photometry may thus be used to determine the visual surface brightness and hence the stellar angular diameter. As shown in the referenced works, such angular diameters are essentially independent of the choice of interstellar obscuration corrections. This approach to stellar angular diameters and then to variable star distances is therefore nearly equivalent to direct measurements.

In the present discussion I show how this technique may be applied to the determination of the Cepheid distance scale.

Patrick A. Wayman (ed.), Highlights of Astronomy, Vol. 5, 479–482.

https://doi.org/10.1017/S1539299600004305 Published online by Cambridge University Press

2. CEPHEID SURFACE BRIGHTNESS

Thompson (1975) has devised a method for determining the visual surface brightness of a Cepheid, to within an unknown additive constant, from photometry and radial velocities. His method requires a priori knowledge of the star's linear radius, but not of the distance or luminosity. To obtain the linear radii, we have adopted Balona's (1977) results for the Cepheid period-radius relation. The photometric and radial velocity data were nearly the same as used by Barnes et al. (1977).

To minimize the problem of phase-matching the photometric and radial velocity data, we used only those eleven Cepheids (with BVRI data) for which simultaneous photometry and radial velocities have established the relative phases (Breger 1967, Evans 1976). We simply shifted the radial velocity phases until minimum radial velocity occurred at the appropriate phase relative to the V light curve.

For all eleven Cepheids the data are consistent with a linear relation between F_V and $(V-R)_o$ and with no distinction between rising and falling branches of the light curve. This confirms the observational and theoretical arguments for linearity given by Barnes et al.(1977). Furthermore, the slopes are independent of period and have a scatter about their mean value in accordance with the observational uncertainties. The mean slope is -0.363 ± 0.011 (s.e.m.). This slope is somewhat less negative than the best fit to the A-F-G stars of known angular diameter given by Barnes et al. (1977), in agreement with their, and Evans' (1977), suspicions.

Until a Cepheid angular diameter is actually measured, the zero point to this linear relation must be acquired either by assuming that Cepheids have surface brightnesses similar to non-variable F supergiants or by using model atmosphere results. Happily, both choices give the same result for the short period Cepheids.

Parsons (1969, 1970a, 1971) has demonstrated that his model atmosphere fluxes for F and G supergiants accurately match the observed fluxes in the blackbody six-color system for a large selection of variables and non-variables. One parameter obtained in the fitting procedure is the stellar angular diameter, tabulated by Parsons (1970b) and Parsons and Bouw (1971). Only one star in Parsons' lists has an observed angular diameter, the F8Ia star δ CMa. Parsons (1970b) gives log $\phi = 0.56 \pm 0.04$, whereas Hanbury Brown et al. (1974) measured 0.56 ± 0.06. This gives us considerable confidence that his mean angular diameters are accurate. There are nineteen Cepheids with both theoretical angular diameters and BVRI photometry for which we have computed visual surface brightnesses.

Figure 1 compares the visual surface brightnesses of the Cepheids to those for similar color stars of known angular diameter. For Cepheids bluer than $(V-R)_o = 0.6$ the agreement is excellent. In particular note the agreement with δ CMa at $(V-R)_o = 0.47$. Because of the paucity of observed angular diameters in this color range, the mean curve from Barnes et al. (1978) is very poorly determined. It could easily be altered to fit simultaneously the short period Cepheids and the few observed angular diameter stars. The long period Cepheids are clearly different. After examining the uncertainties involved, we are convinced that the long period Cepheids cannot lie on the same relation as the non-variable stars of measured angular diameter.

Ignoring the Cepheids to the red of $(V-R)_0 = 0.6$, we find the model atmosphere values of F_V to be represented by a linear relation with the same slope as found in the previous, completely independent analysis. Hence, we have adopted the previous value of the slope and used the model results only to establish the zero point, 3.956 ± 0.006 (s.e.m.). This linear relation is shown in Figure 1.

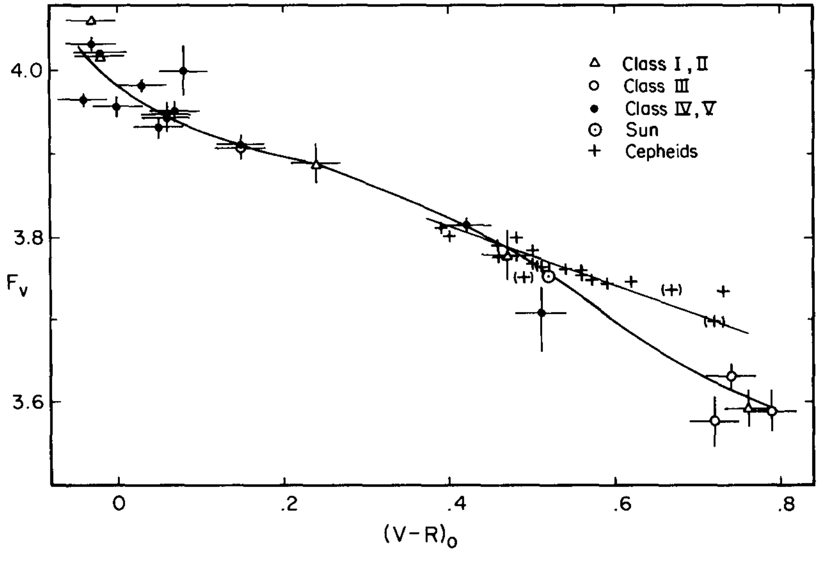

Figure 1: The relation between visual surface brightness parameter and $(V-R)_0$ for Cepheids (plus signs) and for stars of measured angular diameter (all other symbols). Uncertain values are enclosed in parentheses.

3. RADII AND DISTANCES FOR CEPHEIDS

With the relation between F_V and $(V-R)_0$ established for Cepheids, we have used the technique described earlier to determine radii and distances for the seven short-period Cepheids for which the requisite data exist and for which Evans (1976) has established phase matching (η Aql, RT Aur, δ Cep, W Gem, ζ Gem, S Sge, and T Vul). The radii are essentially in agreement with the Baade-Wesselink results of Balona (1977). The present results average 0.03 ± 0.04 larger in log $R/R_\odot$ than Balona's.

A weighted mean of the distances yields a distance scale 0.30 mag ± 0.24 mag larger in the distance modulus than the Fernie and Hube (1968) and Sandage and Tammann (1969) scales. The quoted uncertainties encompass both the random and systematic uncertainties.

In conclusion, we have shown that the surface brightnesses of Cepheid variables may be determined from the Cepheids themselves, that for short-period Cepheids the resultant values are in good agreement with non-variables of the same color, and that the preliminary distance scale to which these values lead supports other recent suggestions for an enlarged Cepheid distance scale.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the many contributions of my collaborators B. J. Beardsley, D. S. Evans, T. J. Moffett, and S. B. Parsons, without whom this work would not have been accomplished. Discussions with J. D. Fernie were also most valuable. Financial support from NSF through grant AST76-21316 is gratefully acknowledged.

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