THE ASTROPHYSICAL JOURNAL, 303:766–768, 1986 April 15

ON THE AMPLITUDES OF BUMP CEPHEIDS

J. D. FERNIE AND SIU-KUEN J. CHAN
David Dunlap Observatory, University of Toronto
Received 1985 July 26; accepted 1985 October 7

ABSTRACT

Over 100 Galactic classical Cepheids in the period range 5–15 days having well-determined photoelectric V mag light curves have been examined in terms of the amplitude-period diagram.

We verify the long-known dip at log $P \approx 0.95$ in the upper envelope of the amplitude distribution but find in addition a coincident rise in the lower envelope, so that all Cepheids with periods between ~ 7.2 and 11 days have very similar amplitudes. Furthermore, we tentatively conclude that all classical Galactic Cepheids in this period range show bumps or shoulders in their lightcurves, some uncertainty remaining because of the difficulty of recognizing incipient cases.

The similarity in light amplitude leads us to the conclusion that all Cepheids in our sample having bumps on the descending branch of the light curve have the same relative pulsational amplitude $\Delta R/R = 0.10 \pm 0.01$. This also applies to the shorter period cases with bumps on the ascending branch, but at periods beyond 11 days the pulsational amplitudes rise rapidly. We note the possibility that the two sets (ascending branch bumps/descending branch bumps) form separate sequences in the amplitude-period diagram and perhaps arise from different mechanisms.

Subject heading: stars: Cepheids

I. INTRODUCTION

The presence of bumps in the light curves of some classical Cepheids gives rise in part to the so-called Hertzsprung Progression. This describes how, beginning at periods of ~ 6 days, a bump may appear on the descending branch of a light curve, its phase approaching maximum light with increasing period, until, at periods over 10 days, the bump moves down the ascending branch. (Throughout this paper we take "bump" to include "shoulders," "humps," and any well-defined disturbance on the light curve.)

The origin of such bumps remains to be clarified. Whitney (1956) and Christy (1968) suggested that they arise from a pulse at the driving source traveling into the star, reflecting off its core, and appearing at the surface during the following cycle. Simon and Schmidt (1976) and Simon (1977), on the other hand, have suggested that bumps arise through resonance between the fundamental and second-harmonic modes of the pulsation. Whitney (1983) has had considerable success in reconciling these theories, although the actual reason for the bumps' existence at all remains unclear. We refer the reader to this paper and references therein for further details and a general review.

Since the theory of bumpy light curves (or, of course, velocity curves) is as yet inchoate, and since, furthermore, the subject bears on the curiously wayward Cepheid masses derived from such light curves, it is important that observation provide as many constraints as possible for theorists to base their work on. We believe we have accidentally discovered two such constraints that seem not to have been noticed before. These are that all classical Cepheids having bumps on their descending branches (and some with bumps on the ascending branch) have almost identical relative pulsational amplitudes, and (less certainly) that *all* classical Cepheids with periods between ~ 7.2 and 11 days are bump Cepheids, although not all bump Cepheids lie in this range. These conclusions pertain to Galactic Cepheids; we have not carried the investigation to extragalactic Cepheids, since the data for these are less reliable.

II. THE DATA

Several excellent photoelectric data bases for classical Cepheids have been produced in recent years. We have based this work on the material produced by Pel (1976), Moffett and Barnes (1980, 1984), Feltz and McNamara (1980), and Szabados (1980, 1981), which together give accurate V mag light curves for over 200 Cepheids. (Pel's data are in the *VBLUW* log I system; we have transformed the appropriate portions of these data to V and $B-V$.)

From this collection we have examined the light curves of Cepheids with periods between 5 and 15 days, the range of most interest for bump Cepheids. Only those light curves for which it could be said unequivocally that there is or is not a bump were retained, and of these only the ones for which maximum and minimum light (and hence amplitude) were well defined. This selection yielded 102 Cepheids, of which 40 were bump Cepheids. The V mag amplitudes were determined for all 102 stars, and among the bump cases note was taken as to whether the bump is on the ascending or descending branch of the light curve.

We estimate the precision of the amplitudes to be typically 0.02 or 0.03 mag, depending on the observational coverage around maximum and minimum.

A more serious systematic effect arises from binarity among the Cepheids. In this restricted period range, $M_v \approx -4$, so that a late-B companion could easily reduce the observed amplitude by about 0.04 mag and yet have so small an effect on the colors as to go unsuspected. We note, for example, that among the bump Cepheids, the four having the lowest amplitudes are all known to be or suspected of being binaries. No attempt has been made to eliminate these, however, since not all stars in the sample have been examined for binarity, and in any case photometric methods for detecting binarity are notorious for their inconsistency. Rather than confuse the statistics, we have not attempted to eliminate binary cases, but emphasize that some stars in the amplitude-period plot (Fig. 1) will be scattered downward because of this.

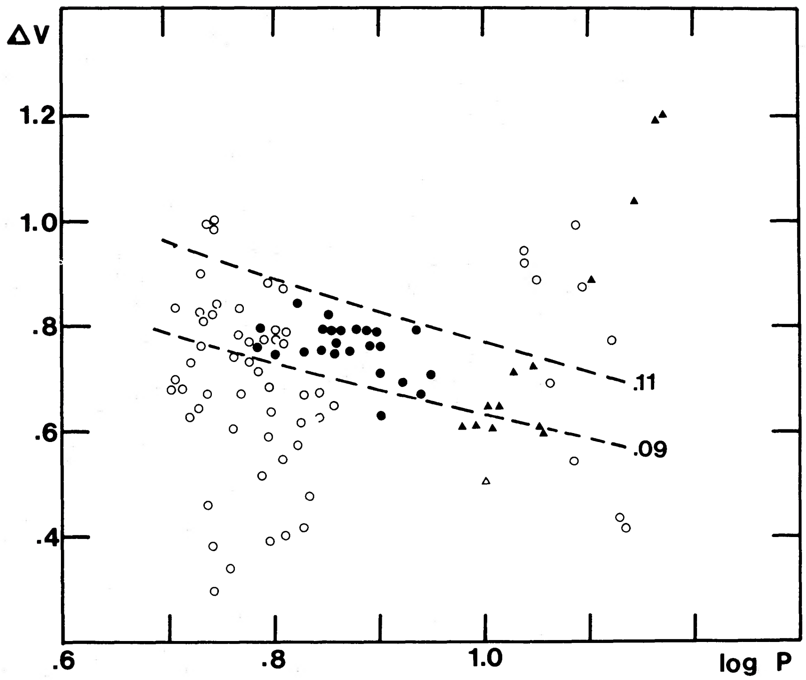

FIG. 1.—Visual light amplitude as a function of period. *Open circles*, nonbump Cepheids; *filled circles*, Cepheids with bumps on the descending branch; *filled triangles*, Cepheids with bumps on the ascending branch; *open trianale*, BZ Cyg, which has a double maximum. The dashed lines are lines of constant relative pulsational amplitude, $\Delta R/R = 0.09$ and 0.11 respectively.

III. DISCUSSION

Figure 1 is the amplitude-period diagram for our data. Open circles represent non-bump Cepheids, filled circles are Cepheids with bumps on the descending branch of the light curve, filled triangles are cases of bumps on the ascending branch, and the open triangle represents BZ Cyg, a star whose bump effectively produces a double maximum, so that one cannot choose reliably between ascending and descending branch cases. It is suspected of binarity, but whether that is the reason for its low amplitude remains unknown.

There are several striking features of Figure 1. It has a "butterfly" appearance, with the shorter and longer period stars showing wide ranges in amplitude, but the intermediate-period ones showing a restricted range. A dip in the upper envelope of amplitudes at $\log P \approx 0.95$ has long been known; it is explicitly shown in Figure 1 of Schaltenbrand and Tammann (1970), for example, where the diagram is constructed for a much wider range of periods than shown here. van Genderen (1970) has also noted its existence, and it may be seen in Figure 5 of Kraft (1961). It appears in terms of velocity amplitudes in Figure 2 of Carsons and Stothers (1984). What does not seem to have been noticed before is the general lack of very low amplitude stars at this point also.

A second striking feature of Figure 1 is that all the stars in this intermediate-period, restricted amplitude range are bump Cepheids. In particular, the shorter period, descending branch cases have a quite remarkable similarity in amplitude. The ascending branch cases share this similarity until periods exceed ~11 days, after which the amplitudes rise very rapidly.

One might question the effect of having omitted those stars for which the existence of a bump is uncertain. These are cases where although there is adequate phase coverage by the observations, the existence of a weak bump really cannot be distinguished from slight photometric errors. Only about 12% of the stars fall into this category, however, and if they were plotted in Figure 1 as either bump or nonbump cases they would not alter any of our conclusions.

The descending branch bump Cepheids in Figure 1, while showing very similar amplitudes, do have a tendency towards lower amplitudes at longer periods, a tendency continued by the ascending branch cases up to periods around 11 days, after which the amplitudes rise rapidly. Disregarding these longest period cases for the moment, we note that it has been shown elsewhere (Fernie 1965) that the physical amplitude (change in radius) of a Cepheid in the pulsational cycle is very nearly proportional to the product of the period and the (visual) light amplitude, i.e., $\Delta R \propto P\Delta V$. Thus the tendency in Figure 1 for ΔV to decrease as P increases suggests that perhaps ΔR is the same for these stars. Probably, however, it is the quantity $\Delta R/R$ that is more meaningful physically, so we have computed this quantity. A more recent calibration of ΔR as a function of $P\Delta V$ is given in Fernie (1977), while R was found from $\log R = 1.177 + 0.694 \log P$, as derived in Fernie (1984). (This is the relation derived from theoretical models; in this particular and small period range, use of other P-R relations discussed in that paper would make little difference.)

From these relations we have computed the lines of constant $\Delta R/R$, as shown in Figure 1 for $\Delta R/R = 0.09$ and 0.11. If some small allowance is made for binary cases, one may conclude that up to periods of ~11 days, all bump Cepheids have relative pulsational amplitudes of $10\% \pm 1\%$. At longer periods, however, there is a sharp departure from this condition, our two longest period cases showing $\Delta R/R > 0.20$. An alternative possibility is that the ascending branch cases arise from a different mechanism and so form their own sequence in Figure 1, which just happens to cross the first sequence at its lower end.

This work was supported in part through an operating grant (to J. D. F.) from the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

Carson, T. R., and Stothers, R. B. 1984, *Ap. J.*, **276**, 593
Christy, R. F. 1968, *Quart. J.R.A.S.*, **9**, 13.
Feltz, K. A., and McNamara, D. H., 1980. *Pub. A.S.P.*, **92**, 609.
Fernie, J. D. 1965, *Observatory*, **85**, 185.
———. 1977, *M.N.R.A.S.*, **180**, 339.
———. 1984, *Ap. J.*, **282**, 641.
Kraft, R. P. 1961, *Ap. J.*, **134**, 616.
Moffett, T. J., and Barnes. T. G. 1980, *Ap. J. Suppl.*, **44**, 427.
———. 1984, *Ap. J. Suppl.*, **55**, 389.
Pel, J. W. 1976, *Astr. Ap. Suppl.*, **24**, 413.
Schaltenbrand R., and Tammann, G. A. 1970, *Astr. Ap.*, **7**, 289.
Simon, N. R. 1977, *Ap. J.*, **217**, 160.
Simon, N. R., and Schmidt, E. G. 1976, *Ap. J.*, **205**, 162.
Szabados, L. 1980, *Mitt. Sternw. Ungarischen Akad. Wiss*, No. 76, p. 1.
———. 1981, *Mitt. Sternw. Ungarischen Akad. Wiss.*, No. 77, p. 1.
van Genderen, A. M. 1970, *Astr. Ap.*, **7**, 244.
Whitney, C. A. 1956, *A.J.*, **61**, 192.
———. 1983, *Ap. J.*, **274**, 830.

SIU-KUEN J. CHAN and J. D. FERNIE: David Dunlap Observatory, P.O. Box 360, Richmond Hill, Ont. L4C 4Y6, Canada