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A SEARCH FOR BINARIES AMONG SHORT-PERIOD SOUTHERN CEPHEIDS

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RESUMEN

Observaciones fotométricas en el sistema $UBV(RI)_{KC}$ y observaciones fotoeléctricas de velocidades radiales de 15 cefeidas del hemisferio sur con períodos entre 3 y 7 días se han obtenido simultáneamente. La comparación de las curvas de velocidad radial resultantes con observaciones anteriores revela la naturaleza binaria de tres nuevas cefeidas, R TrA, AP Sgr y V496 Aql. Se confirma además la naturaleza binaria de V350 Sgr que había sido anunciada previamente por Evans (1971). En el diagrama *U-B* versus *B-V*, todas las cefeidas muestran lazos abiertos de forma muy similar y pequeña abertura. Las binarias reconocidas espectroscópicamente no se distinguen en forma significativa de las demás cefeidas supuestamente no binarias. Esto probablemente implica que las estrellas compañeras de las cefeidas binarias no son muy luminosas y no cambian en forma significativa las propiedades fotométricas de las cefeidas. La confiabilidad de los resultados del "open loop method" en el caso de pequeñas aperturas se pone en duda. El método de la velocidad γ variable es el más confiable en la actualidad para la búsqueda de binarias con componente cefeida.

ABSTRACT

Simultaneous photoelectric radial velocity and $UBV(RI)_{KC}$ photometric observations of 15 southern cepheids with periods between 3 and 7 days have been carried out. Comparison of the resulting radial velocity curves with earlier data reveals the binary nature of three new cepheids, RTrA, AP Sgr and V496 Aql. The binary nature of V350 Sgr, previously announced by Evans (1971), is confirmed.

In the *U-B* versus *B-V* diagram, all of the cepheids show open loops of very similar shape and (small) opening. The spectroscopically recognized binaries are not distinguished significantly from the other, (presumably) non-binary cepheids. This probably implies that the companion stars to the binary cepheids are not very luminous and do not alter the photometric properties of the cepheids significantly. Doubts are casted on the reliability of the open loop method results in the case of small loop openings. The variable γ velocity method is found to be more reliable at present when dealing with the search for cepheid binaries.

Key words: STARS-CEPHEIDS – STARS-BINARIES

I. INTRODUCTION

It has long been believed that there is a deficiency of epheids occurring in binary systems. Abt (1959) found hat only about 2% of the cepheids were spectroscopic inaries, comparing the only four hitherto known epheid binaries with the number of 195 cepheids for which velocity curves were available at that time, mainly rom the work of Joy (1937) and Stibbs (1955).

Since then, there has been a lot of work aiming to letect more binaries among cepheids, and new techiques and methods have been developed in order to ttack the problem. Among the new approaches which ollowed the traditional search for variable γ velocities in the cepheid radial velocity curves, we find photometric tests, direct spectroscopic identification of blue companions from satellite ultraviolet spectra, and speckle interferometry. Consequently, the number of known or suspected cepheid binaries has grown continuously during the last 20 years; for example, the thorough study of Evans (1968) revealed several new cases of cepheid binaries, and the then available material, mainly radial velocity data from two or more epochs, led this author to postulate a 15% figure as the frequency of cepheids in binary systems.

In recent years, the number given by different authors for the frequency of cepheid binaries has grown further. Madore (1977) finds a 20-27% figure, based on open loops shown by cepheid binaries in the *U-B* versus *B-V* two color plot, and Fernie (1980), using another photometric test, obtains even a 35% figure. The disturbing fact about existing photometric binary detec-

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tion methods is that if positive results, with regard to the binary nature of a given cepheid, are required from different photometric tests, the incidence of duplicity among cepheids drops to perhaps less than 15%, implying that neither of the actually existing photometric detection methods is infallible. The principal reason for this relatively poor agreement between the results of different photometric tests, all of which require *U* observations, is probably the fact that for most cepheids existing photometry, especially in the *U* band, is only poor, limiting severely the reliability of the results of these methods.

With regard to the classical γ velocity method, detection of cepheid binaries is complicated by the intrinsic variation of the cepheid's radial velocity. In all known cases of cepheid binaries, the period of the orbital motion is in excess of 500 days and the amplitude of the γ velocity variation is less than about 20 km s^{-1} being nearly always considerably smaller than the amplitude of the cepheid's intrinsic velocity variation and therefore difficult to detect. High-quality velocity curves from at least two different epochs are required to establish the binary character of a cepheid in this way.

Research aiming to detect the binary nature of individual cepheids and to determine the frequency of cepheids with companions is important for several reasons. Since stellar evolution theory suggests that the vast majority of cepheid companions will be B stars, cepheid binaries will have colours being too blue and apparent magnitudes being too bright. Use of such "contaminated" cepheids will lead to systematic errors in the determination of the correct period-luminosity-colour relation, as well as in the determination of the location of the cepheid instability strip in the Hertzsprung-Russell diagram. Furthermore, eclipsing binaries with a cepheid component might be detected, providing perhaps the possibility to obtain a few cepheid masses independent of stellar evolution or pulsation theory and to shed more light on the cepheid mass discrepancy problem. Finally, important tests for stellar evolution theory might be provided by a comparison of.the frequency of cepheid binaries with main sequence binaries.

II. OBSERVATIONS

In the present binary search programme, fifteen cepheids with periods between 3 and 7 days were observed photometrically and spectroscopically at the Sutherland station of the South African Astronomical Observatory. The stars are listed in Table 1.

The photometric observations were obtained with the two channel People's photometer attached to the SAAO 50-cm reflector, in the $UBV(RI)_{KC}$ system, during two runs in June and July, 1980. A standard cooled S13 blue tube was used for the *UBV* observations, whereas an extended S20 tube was used to obtain the *VRI* observations in the Kron-Cousins system. A Nova computer served to control the photometer, and pulse counting was employed. The data were punched on paper tapes which were later analyzed in the SAAO computer center in Cape Town. For every cepheid, a principal nearby comparison star was selected.

TABLE 1

THE OBSERVED CEPHEIDS, THEIR MEAN *V* MAGNITUDES, PERIODS (IN DAYS) AND EPOCHS OF MAXIMUM LIGHT. PERIODS AND EPOCHS WERE TAKEN FROM PEL (1976) EXCEPT FOR SS Sct AND V350 Sgr*

Star	*V*	Period	HJD of maximum light
AZ Cen	8.64	3.21068	2441053.38
R TrA	6.66	3.389287	40838.21
SS Sct	8.20	3.671253	35315.625
AG Cru	8.18	3.83728	41117.38
BF Oph	7.34	4.06784	40680.61
V482 Sco	7.96	4.52786	40754.45
S Cru	6.58	4.68997	40301.19
AP Sgr	7.00	5.05793	40390.31
V350 Sgr	7.45	5.15419	35317.227
V Cen	6.82	5.49392	40665.60
RV Sco	7.05	6.06133	34925.38
S TrA	6.41	6.32344	40734.45
BB Sgr	6.99	6.63699	35303.49
U Sgr	6.71	6.744925	41146.41
V496 Aql	7.79	6.80703	40850.14

* Values from Schaltenbrand and Tammann 1971.

Frequent nightly observations of E regions photometric standard stars permitted to tie the comparison stars into the standard $UBV(RI)_{KC}$ system. About 40 observations per cepheid and per colour could be obtained. The data will be published in detail elsewhere.

The radial velocity observations were obtained during June 24 and July 7, 1980 with the photoelectric radial velocity spectrophotometer operated at the Coudé focus of the Radcliffe 1.9-m reflector. A mask of δ TrA (G0 II) centered at 5400 A was used for all observations, the dispersion at this wavelength being 13.6 A mm^{-1}. Radial velocity standard stars from the General Catalogue of Wilson (1953) were frequently observed to provide the transformation of the cepheid velocities to the standard system. The data were reduced at the SAAO computing center in Cape Town. Details of the observations and the data have been published (Gieren 1981). For all of the cepheids, complete light-, color- and radial velocity, curves of very good quality could be obtained, providing a sound base for a search of new cepheid binaries.

III. RESULTS OF THE VARIABLE γ VELOCITY METHOD

In order to investigate for variable γ velocities, the present radial velocity curves were compared to earlier data. The main sources for first-epoch velocity measurements are the work of Stibbs (1955) and Joy (1937). The work of Stibbs is more useful in this respect because his observations are of better quality than those of Joy, due to the higher dispersion (49 A mm^{-1}) of his spectrograms. Nevertheless, due to the fact that, with the exception of U Sgr, for none of the cepheids of the present list high-dispersion radial velocity curves have been published before, the possibility to recognize small γ velocity variations is limited to a γ velocity amplitude of at least about 5 km s^{-1}.

The comparison leads to the following result: for 4 cepheids, R TrA, AP Sgr, V350 Sgr and V496 Aql the deviation of their present velocity curves from earlier ones is clearly more than 5 km s^{-1} permitting the fairly safe conclusion that these cepheids have companions. One of the stars, V350 Sgr, had been claimed to be a binary before (Evans 1971), but detailed observations have not been published. In the case of V496 Aql, there are two series of observations of Stibbs (1955) which were made in different years; while the first series fits very well into the present curve, the later series falls clearly below it by about 7 km s^{-1} in average. The case of AP Sgr seems quite clear as well. Joy's measurements fall in average clearly below the present curve, and so do the six observations obtained by Evans (1968). In the case of R TrA the observations of Evans (1968) coincide well with the present curve, but the radial velocities of Stibbs (1955) are clearly more positive, in average by about 6 km s^{-1}, than the present 1980 velocities.

Four more cepheids fall in the category of possible binaries: BF Oph, V482 Sco, BB Sgr and U Sgr. Earlier data are not sufficiently precise or abundant, or the indicated systematic velocity difference is too small (< 5 km s^{-1}) to permit safe conclusions. In the case of the interesting cluster-member U Sgr, there are five earlier sets of data, among them a high-dispersion study of Jacobsen (1974). His curve coincides remarkably well with the curve of Breger (1967), and both curves are shifted by about 5 km s^{-1} to more positive velocities, with respect to the present curve. U Sgr might well be another cepheid binary. In view of the importance of U Sgr as one of the few cluster cepheids used in the calibration of the PLC relation, it should definitively be re-observed in order to decide the question. For the other 7 cepheids of the sample comparison with older data gives no evidence for a variable γ velocity.

IV. RESULTS FROM PHOTOMETRIC TESTS

Madore (1977) found that cepheids describe an open loop in the *U-B* versus *B-V* diagram when the light of a main sequence B star is added to the cepheid. The degreee of opening, as well as the shape of the loop depend in a sensitive way of the magnitude difference between cepheid and B star.

In order to apply this test, smooth curves were drawn through the (*U-B*) and (*B-V*) measurements of the cepheids, and from them the *U-B* versus *B-V* two colour plots were constructed. Inspection of these plots reveals the following:

a) All cepheids, without any exception, show open loops, in a counterclockwise sense as colours go from blue to red.

b) The degree of opening seems to increase slightly with period, being about 0.02 mag for cepheids with periods between 3 and 4 days and about 0.05 mag for P = 6-7 days. The shape of the loops is very similar for all cepheids.

c) None of the four cepheids identified as binaries from the variable γ velocity method shows notable differences from the other cepheids of similar period.

According to the present results, it is obvious that the vast majority of cepheids, if not all, do show slightly open loops in the *U-B* versus *B-V* diagram. Past photometry has normally not been good enough to reveal this fact; for instance, the data of Mitchell *et al.* (1964) suggest straight lines for AG Cru and V Cen (see Fig. 1 of Madore 1977), although in reality these cepheids do show open loops, as is demonstrated by the present photometry. The fact that none of the four cepheids which have companions, according to the γ velocity results, shows an enhanced opening of its loop or a markedly different shape than the other, (presumably) non-binary cepheids, is preoccupying and casts doubts over the applicability of the open loop method. It is probable that the companions of the present binary cepheids are just not luminous enough to influence the cepheid's photometric properties significanlty. This would imply, however, that from the open loop method clear and reliable results can only be expected for those cepheids which have very bright companions, and that the test cannot be trusted if the loop opening becomes small, in the case of moderate luminosity companions. It is certainly not possible to recognize companions which are up to 4 mag. fainter in visual magnitude than the cepheid, as was suggested by Madore (1977).

Another indicator of the presence of a blue companion to a cepheid is the ratio of the (*U-B*) amplitude to the (*B-V*) amplitude. A plot of this ratio for the present sample of cepheids against period shows that it is increasing linearly, in the period range studied, but for none of the cepheids the amplitude ratio is remarkably small, deviating strongly from the mean. This leads to the same conclusion as the *U-B* versus *B-V* plots, namely that none of the blue companion stars is sufficiently bright to reduce the (*U-B*) amplitude of the corresponding cepheid significantly.

V. CONCLUSIONS

Comparing the results of both methods employed in this study to search for new cepheid binaries, it must be emphasized that the spectroscopic method still produces the more reliable results. Doubts are casted on the reliability of the results of the *U-B* versus *B-V* loop method in the case of small loop openings, and it seems possible that only high luminosity cepheid companions can be recognized beyond any doubt with this method. High quality photometry of many more cepheids, especially of those known to have companions from non-photometric methods, extending as far as possible to the UV, will be necessary to establish more clearly the limits of the open loop method.

With respect to the establishment of the frequency of cepheids occurring in binary systems, progress can be expected in future years mainly from new high quality radial velocity observations which should be carried out using the fast radial velocity spectrophotometers. The photometric binary detection methods still seem to be questionable at the present time, but in view of their possible importance mainly due to their speed, efforts should be made to improve their reliability.

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DISCUSSION

Pişmiş: Some of the light curves of the Cepheids you showed had bumps. The bump reminds one of a cepheid of Population II. The position of the bump on the light curve varies with phase. Does this affect in any way the *b* velocity of the system?

Gieren: I am not sure to what extent the bump phase of a given cepheid varies in time. I do not think that this is a common effect. What I have done is simply to compare the overall shift of different epochs. I have not observed that for the cepheids of the present sample the bump occurs at a different phase than in previous observations (within the errors).

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