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A SEARCH FOR SPECTROSCOPIC BINARIES FROM PUBLISHED RADIAL VELOCITY DATA

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The published radial velocities for a sample of ten suspected spectroscopic binaries were analyzed by means of a computerized period-finding method capable of examining more than 150,000 periods hour^{-1} on modern fast computers. The investigation is intended to provide an indication of the possible usefulness of a similar program on a larger scale, including all those suspected binaries for which seemingly good and sufficient observations have not led to satisfactory periods. A definite answer emerged for four stars. Orbital elements were found for two stars and two showed no periodic variation in velocity. The other six stars require additional observations to reach a definitive conclusion.

Key words: spectroscopic binaries — radial velocities

Introduction

There is a considerable amount of radial velocity data on suspected spectroscopic binaries available in the literature which either has not been thoroughly studied for periodicities or for which such a study was unsuccessful. Some of the published data are unresolved remnants of observational programs that have since been discontinued. This state of affairs brings to mind the question whether, at least for the more complete series of observations, something might be gained by applying relatively new and powerful computerized techniques. In such an effort, results are expected to fall more or less clearly into three different categories. For some stars with sufficiently numerous observations it might be possible to ascertain that no significant part of the radial velocity variation is periodic in nature; these stars could then be deleted from the list of suspected binaries. In many cases, especially when the number of data points is only modest, more than one seemingly satisfactory period will likely be detected. Physical considerations and trial orbit calculations might rule out the majority of these, but as a rule new observations strategically timed with respect to the determined possible periods might still be necessary to obtain definite results. It is further expected that occasionally the data available will by themselves prove sufficient to yield preliminary orbits of acceptable quality, even though the same material previously eluded successful interpretation. The chances for this to occur should be highest for binaries with short and ultrashort periods, since finding these without the aid of efficient computing methods is tedious, particularly if the observations are scattered over large intervals in time.

It is a rather large undertaking to rediscuss all suspected binaries for which a definite status has not yet evolved although, for each of them, a fair amount of data has already been accumulated. Without the results of some pilot investigation conducted on a small but representative sample of such stars it appears uncertain whether the rate of success would warrant the effort. It is the purpose of this paper to provide a pilot study of this kind, by outlining a methodical approach to the problem and by discussing the results for each star selected, regardless of whether our analysis could achieve a definite outcome or not. Aided by the *Bibliography of Stellar Radial Velocities* by Abt and Biggs (1972), we selected ten stars as candidates for which no satisfactory period is known although the number and spacing of the observations as well as their velocity range appears adequate to find such periods, if, indeed, they should exist.

Method

The period-finding technique used in this study is a slight modification of that described by Morbey (1974). By analogy with the manual method, the computer is programmed to assemble the observations on trial periods. The trial periods are made to advance in steps sufficiently small to keep the phase error below 0.1. The resulting radial-velocity/phase diagrams are plotted directly by the line printer, at high speed, whenever the distribution of points approximates a smooth curve with less than a predetermined amount of scatter. The allowable variance about the curve is directly related to the quality of the observations and can easily be adjusted to ensure that all possibly significant diagrams are printed, but that no unnecessary ones are. Trial periods that warrant further investigation are singled out by looking at the computer printout. The simplicity of computations involved allows a search rate of 150,000 periods per hour on a Mod Comp II/25 computer for 40 observations; on an IBM 360/65 the program runs four times faster. With this operational speed there is no need to confine the search to such limited individual period ranges as are suggested by the observations of each star. Rather, the total region of physically possible periods from, say, 0.1 day to 2000 days can be covered quickly.

This capability of the method to extract any conceivable periodicity in a given set of observations has led to a two-step approach in which all possible periods are singled out first, and only then is the question of their individual significance raised. The sampling theorem of information theory has, at times, been misinterpreted to imply that no physical significance can be attached to periodicities shorter than twice the minimum spacing of the measures in time. It is easy to see that this is not true. Within the constraints set by dynamical considerations, any period present in the observational sample is as likely as any other to be the true one, as long as it is not ruled out by additional information. If all potential periods are known, a very efficient reobservation program can be initiated, since new observations can never introduce new periods, although they may change known ones slightly, or eliminate them.

A program for obtaining the elements of single-lined spectroscopic binaries by the Marquardt technique of damped least squares (Marquardt 1963) was written to determine the best of the possible periods located by the period-finding routine. The program allows any or all of the orbital elements to be simultaneously varied and at the same time constrains the elements within their permitted magnitudes and signs. If the radial velocities satisfy several periods, trial orbit calculations can often rule out most of these by showing that although the velocity/phase diagram is a smooth curve with little scatter, no Keplerian velocity curve that would leave reasonable residuals can be drawn through the given points. The orbit program includes an analysis of the correlation of the phase residuals with hour angle of observation, which immediately indicates whether or not any period is spurious. This makes it easier to decide which of two otherwise equally acceptable orbits is likely to be the correct one. In difficult cases a definite answer cannot be obtained in this way and additional observations are the only means by which the uncertainty can be resolved.

Results

In the following presentation some stars are discussed individually and others in small groups, whenever one way or the other was more convenient or less repetitious. Systematic differences in the velocities published from different observatories have been taken into consideration.

HD 23848 (42 Persei). The 40 published observations of this star were compiled from the following sources: Harper (1920, 1937), Frost, Barrett, and Struve (1929), Palmer et al. (1968), Beardsley (1969), and Abt (1970). The measures are well distributed over the 81.8 km sec^{-1} velocity range and show a good spread in hour angle. A period search between 0.1 and 500 days singled out possible periods at $0^{d}637$, $0^{d}696$, $1^{d}765$, and $2^{d}292$. For each of these periods one individual Allegheny observation was consistently off in the velocity/phase diagram by more than 40 km sec^{-1} and was therefore rejected. Only the orbit based on $P = 1^{d}765$ gave a satisfactory fit to the observations and the other listed periods were all found to be spurious ones associated with $P = 1^{d}765$. Two more of the Allegheny measures have residuals $|V_{(o-c)}| >$ 20 km sec^{-1} of opposite sign. Recalculation of the orbit without them resulted in only insignificant changes of the orbital elements but in a marked decrease of the variance about the curve. The elements listed in Table I and the plot in Figure 1 are based on the remaining 37 points.

TABLE I

THE ELEMENTS

	HD 23848 42 Persei	HD 16246 30 Arietis
V_0 (km sec^{-1})	-11.85 ± 0.37	14.37 ± 0.22
K (km sec^{-1})	34.41 ± 0.50	22.41 ± 0.31
e	0.089 ± 0.015	0.062 ± 0.012
ω (degrees)	260.6 ± 9.6	281.4 ± 12.3
T_0 (JD)	2437640.030 ± 0.047	2421946.382 ± 0.037
P (days)	$1.765346 \pm 2 \times 10^{-6}$	$1.109526 \pm 10 \times 10^{-6}$
$a \sin i$ (km)	8.3193×10^5	3.4122×10^5
$f(\mathfrak{M})$ (solar masses)	0.0074	0.0013

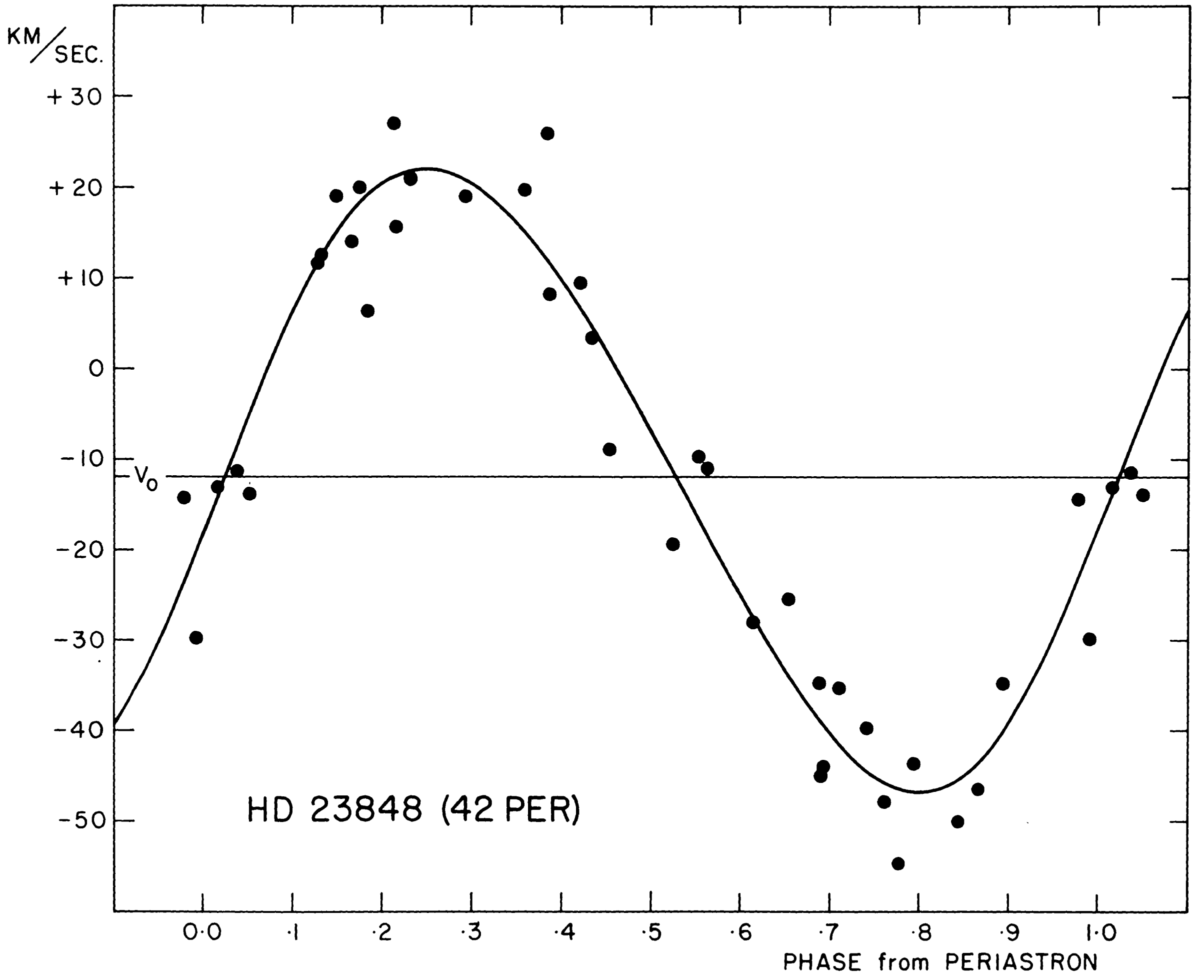

FIG. 1 —Radial velocities and computed curve for HD 23848.

HD 16246 (ADS1982 A). This star is the brighter component of the double 30 Arietis. In 1916 it was found to be a spectroscopic binary and an orbit with period 9ᵈ85 was published by Adams and Joy (1919). Since in the *Bibliography of Stellar Radial Velocities* by Abt and Biggs (1972) the paper by Adams and Joy is erroneously listed for the fainter component HD 16232, 30 Ari A was included in our sample under the impression that no orbit was known. An analysis of the 29 data points published by Abt (1970) revealed possible periods at 0ᵈ153, 0ᵈ526, 0ᵈ908, 1ᵈ109, and 9ᵈ851. In the velocity/phase diagrams for all these periods one observation showed consistently large deviations from a smooth curve and was consequently discarded. Orbits with acceptable residuals were obtained only for the periods $P_1 = 1^{d}109526$ and $P_2 = 9^{d}852551$. The solution converging on P_2 reproduced the other elements of the published orbit quite closely. Further analysis showed that the phase residuals of the observations assembled on P_2 are significantly correlated with hour angle while no such correlation exists for P_1. Since, in addition, the new orbit fits the data points better than the original one there is little doubt that P_1 is the correct period. The new elements are given in Table I and the observations are plotted in Figure 2.

HD 23325. This is a Pleiades star, possibly of spectral type Am (Abt et al. 1965). The radial velocities have a range of 37 km sec^{-1} and were taken from Smith and Struve (1944), Abt et al. (loc. cit.), Abt (1970), and Pearce and Hill (1974).

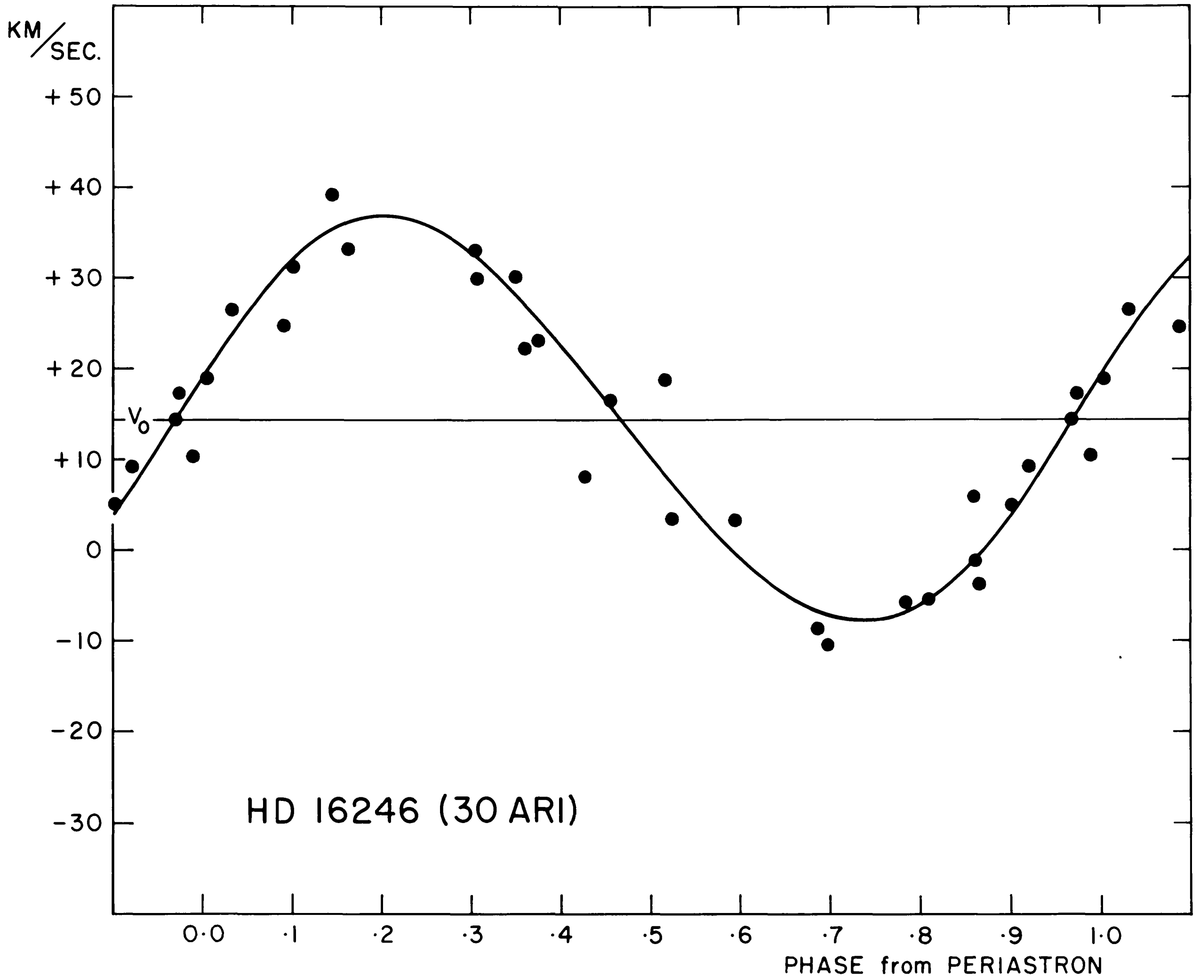

FIG. 2 — Radial velocities and computed curve for HD 16246.

A search for periodicities in the 21 observations yielded seven possible periods ranging from $0\overset{\mathrm{d}}{.}105$ to $24\overset{\mathrm{d}}{.}78$. Amazingly, orbit calculations based on all of these detected periods produced almost acceptable results, with two of them fitting the observations significantly better than the other five. The most probable period is $3\overset{\mathrm{d}}{.}151802$ days, but the lack of data points close to minimum velocity does not permit any conclusions without further observations. The binary nature of HD 23325 must be considered as uncertain.

HD 176818. The 24 observations of this B3 star, published by Plaskett and Pearce (1931), are well distributed over a total velocity range of 98.9 km sec^{-1}. Five possible periods were found, ranging from 0.349 to 57.153 days. All trial orbits in the neighborhood of these periodicities are poorly defined and result in large observational residuals. The best orbital solution converged on a period of 48.808314 days with a standard deviation of 10.4 km sec^{-1} for one observation of average weight. While a scatter of this magnitude may be acceptable for a B star, some of the other periods are not ruled out by the observations. In particular, the trial orbit based on $P = 0\overset{\mathrm{d}}{.}980$ is only slightly inferior and its standard deviation decreases to 8.2 km sec^{-1} if a single measure with large residual is rejected.. We conclude that HD 176818 is probably a spectroscopic binary but that the available data are insufficient to establish this.

HD 23387, HD 23489, HD 23763, HD 23863. These four Pleiades stars have velocity ranges between 46 and 52 km sec^{-1}. There are 20 observations for HD 23863 and between 25 and 27 for the other three stars. The measures were obtained from Harper (1937), Smith and Struve (1944), Abt et al. (1965), Abt (1970), and Pearce and Hill (1974). The four stars are discussed together because, according to our results, none of them is likely to be a spectroscopic binary. The evidence against their binary nature is particularly strong for HD 23763 and HD 23387. For the first of these only three extremely short periods are possible and orbits based on these trial periods do not represent the data with acceptable scatter. The situation for HD 23387 is very similar, except that the two possible periods for this star have the more probable values of 0.5 and 1.0 day. Additional observations are required to obtain definite answers for HD 23489 and HD 23863. In the first case many periodicities between $0\overset{\mathrm{d}}{.}12$ and $5\overset{\mathrm{d}}{.}0$ are contained in the data because the velocity distribution is rather poor. Two short-period orbits have considerably less scatter than all others but do not really represent the observations well. For HD 23863 only short periods are found of which one, $0\overset{\mathrm{d}}{.}310091$, yields reasonably well-determined orbital elements.

HD 1404, HD 100889. For each of these stars our investigation reached the definite result that no significant part of the observed velocity variation is periodic on a time scale relevant to spectroscopic binaries. HD 1404 was announced as a binary by Frost and Lee in 1910. Lee (1910) measured double lines on two occasions and Beardsley (1969) regards the star as ". . . evidently a spectroscopic binary of very short period." The 37 observations contained in Beardsley's catalog were searched for periodicities in the range 0.01 to 2000 days. The modest change in velocity of 34.4 km sec^{-1} suggests that most of the recorded variation is caused by observational scatter. For the 61 measures of HD 100889 published by Beardsley (loc. cit.) a period of the order of 150 days has been proposed, but this was not substantiated by the period search, again over the region 0.01 to 2000 days. With an observed velocity range of 98.4 km sec^{-1}, measured at 40 Å mm^{-1} dispersion, the variability of the star should be real. The velocity extremes, however, are represented only by one high and low point each. Discarding these brings the range down to 68.5 km sec^{-1} which is still rather large. We conclude that the radial velocity variations in HD 100889 are probably real but are caused by some process other than binary motion.

Summary

At the beginning of this paper the question was raised whether a thorough analysis of existing data for dubious binary candidates might be useful in the sense that the rate of success in obtaining definite results would warrant the effort. We tried to answer this question by working through a sample of ten stars whose available radial velocity data looked encouraging. We found two acceptable new orbits and could further establish that two other stars previously assumed to be binaries, cannot be considered as such from the existing data. For the remainder of the sample additional observations are required to either rule out all possible periods or to isolate the correct ones. In either case the procedure for these stars is now straightforward since all potential periods are sufficiently short for a definite answer to be obtained from a few nights' observations.

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