SOME SPECTROSCOPIC OBSERVATIONS OF VISUAL BINARIES

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Abstract. The use of a coudé spectrograph for securing the high-resolution spectrograms necessary to follow the slow variations of radial velocity exhibited by visual binaries is discussed. Recent observations, using the spectrograph at the coudé focus of the Dominion Astrophysical Observatory's 48-in. reflector, are then presented for the systems of α UMa, ε Hya, β LMi and γ Leo.

Observation of the slow changes in radial velocity exhibited by visual binaries has been for some years one of the programs carried on at the Dominion Astrophysical Observatory. Much of the work prior to 1965 was done by A. B. Underhill, though R. M. Petrie also had an interest in certain systems. They used perforce the 72-in. telescope with its two-prism Cassegrain spectrograph to obtain for example the velocities published by Underhill (1963). The low resolution of this instrument, however, resulted in observations of rather low accuracy, whereas to detect small variations in radial velocity the observations must be of very high precision, and this requires spectrograms of high resolution. Since the completion of the 48-in. telescope with its coudé spectrograph in 1962, its high resolving power has been used to advantage by Petrie, A. H. Batten, J. M. Fletcher and myself for the observation of visual binaries.

For the purpose of spectroscopic observation we may divide the visual binaries into four groups. The first includes those stars which are unresolved on the spectrograph slit-head and for which the difference in magnitude is so large that only one spectrum is visible. To the spectroscopic observer these stars are simply single-line spectroscopic binaries with periods of a few decades. We are observing several such systems, for example α Ursae Majoris, which I discussed before the American Astronomical Society a year ago (Scarfe, 1968).

The second group is a small one, and consists of stars which though single on the slit-head, show two spectra near nodal passage. Such systems must be composed of stars nearly equal in magnitude, and have periods short enough that the difference in radial velocity is sufficient to resolve the lines. An example is δ Equulei, which is expected to pass through a node later this year, and which is being observed by Popper and Dworetsky at Lick as well as by ourselves.

The third group includes those stars which are resolved on the slit-head, and which must therefore be observed separately. Such systems are usually of such long period that changes in the radial velocities are not significant over one's working lifetime, except for a few very nearby stars, such as 70 Ophiuchi. However a determination of the difference in velocity between the components provides a check on the elements and the parallax.

The fourth group is that of stars which appear single on the slit-head, but produce

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two spectra which are not resolved. Unless the components are of very different spectral type, there is little that can be done with them, since the blending of the spectra makes radial velocity measures unreliable.

Triple or multiple systems may be grouped in the same way, except that since often they include a binary of short period and consequent large range of velocity, the number of such systems which must be consigned to the fourth group is not large. On the other hand, for such a system it is necessary to obtain a large number of spectra in order to eliminate the effects of short-period motions. Triple systems may show one, two, or three spectra. Examples of each case are, respectively, μ Orionis, for which I discussed some of Petrie's observations two years ago (Scarfe, 1967), 1 Geminorum, studied by Abt and Kallarakal (1963), and HD 100018, recently discussed by Petrie and Batten (1970). For systems of more than three stars it becomes very complicated to sort out the spectra; a useful discussion of this problem has recently been made by Evans (1968).

A further restriction on the list of stars of which useful radial velocity observations may be made arises from the necessity that the radial velocities be very accurate in order to obtain reliable measurements of small changes, or of small differences between the components of resolved binaries. To do this, high-dispersion, high-resolution spectrograms must be obtained and one is therefore restricted to rather bright stars. Moreover one cannot hope to detect small velocity variations for stars with diffuse lines, and one is therefore limited, with rare exceptions, to stars later than spectral type F5.

The spectra used for this paper were obtained using the Dominion Astrophysical Observatory's 48-in. telescope and coudé spectrograph, with the camera combinations listed in Table I. The first two digits in a number representing a camera are the focal length of that camera in inches. The next digit (or two in the case of 32121) gives the approximate grating ruling in units of 100 lines per millimetre and the final one is the order in which the grating is used. The 9663 and 3263 combinations are now seldom used, and have not been since 1965, when the 830 lines per millimetre grating came into use. Finally the letter *M* indicates a mosaic of four gratings aligned to act as a single large one.

During the past four years, several changes, in particular the introduction of image slicers, have so increased the speed of the spectrograph that it has recently become

TABLE I

Camera combinations

Camera	Dispersion (Å/mm)	R.V. accuracy (internal s.e.m. for a sharp-lined star)	Magnitude for a one-hour exposure (blue)
9663, 9682, 9682M	2.2–2.4	0.07 km/sec	5.5 (9682M)
3263, 3282	5.5–6.0	0.15 km/sec	6.5
32121	10.0	0.21 km/sec	7.2

possible to observe many stars at dispersions higher than previously. The magnitudes in the last column of Table I, in fact, represent the present state of affairs, and assume the use of image slicers. Work on these changes has however meant that at intervals certain combinations became unavailable temporarily. Moreover the iron arc was replaced by an iron-argon hollow cathode lamp in 1964, and this made several changes in the choice of comparison lines necessary. For these reasons the observational material is less homogeneous than one might wish. But since the choice of lines for radial velocity measurements has been made using sky spectra as well as several IAU standard velocity stars, and since observations of such stars are made on nearly all nights, very little systematic error is expected from this source.

The requirement of high resolution becomes more stringent for the stars of group two, in which one may observe two spectra from a single stellar image. Using the long camera a velocity difference of 15 km/sec between sharp-lined components can be detected reliably. For smaller separations the effects of line-blending must be taken into account. This problem has been discussed for early-type stars on spectrograms of lower dispersion by Petrie *et al.* (1967) and a further contribution, for the case of sharp-lined stars has been presented at this colloquium by Batten and Fletcher (1971). The problem has also been discussed theoretically by Tatum (1968).

I compiled an observing list in 1965 using the catalogue of orbits published by Worley (1963), and revised it using Dommanget's (1967) catalogue of ephemerides. It probably needs further revision and for this purpose I should be happy to have your suggestions.

The remainder of what I have to say is essentially a progress report on observations of some of the stars on my observing list. The first star that I wish to discuss is α Ursae

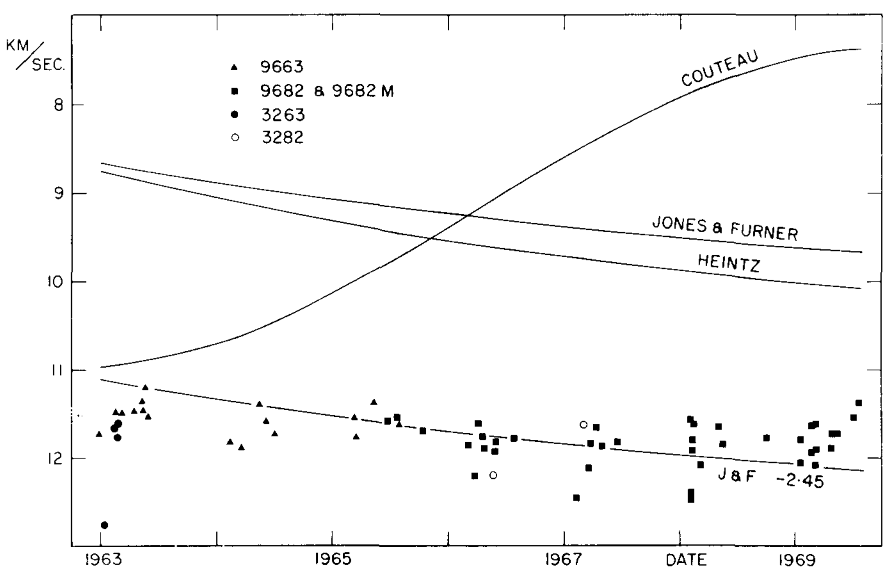

Fig. 1. Coudé radial velocities of α Ursae Majoris.

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Majoris. The velocities presented to the American Astronomical Society last year are brought up-to-date in Figure 1. The mean velocity this year is significantly more positive than it has been for some time now. As a result, the velocity curve derived from the elements of Jones and Furner (1937), displaced by the mean O–C value, fits the observations rather poorly, passing above all the observations made in 1963 and below all those of 1969. And the elements of Heintz (1963) and Couteau (1959) fare even worse. If the present trend continues, however, the observations may eventually favour a longitude of periastron closer to that of Couteau than seemed likely a year ago.

The system ε Hydrae AB has also been followed with the coudé spectrograph since 1963, though fewer plates have been secured of it than of α Ursae Majoris. The data, presented in Figure 2, follow the velocity curve of Adams (1939) reasonably well,

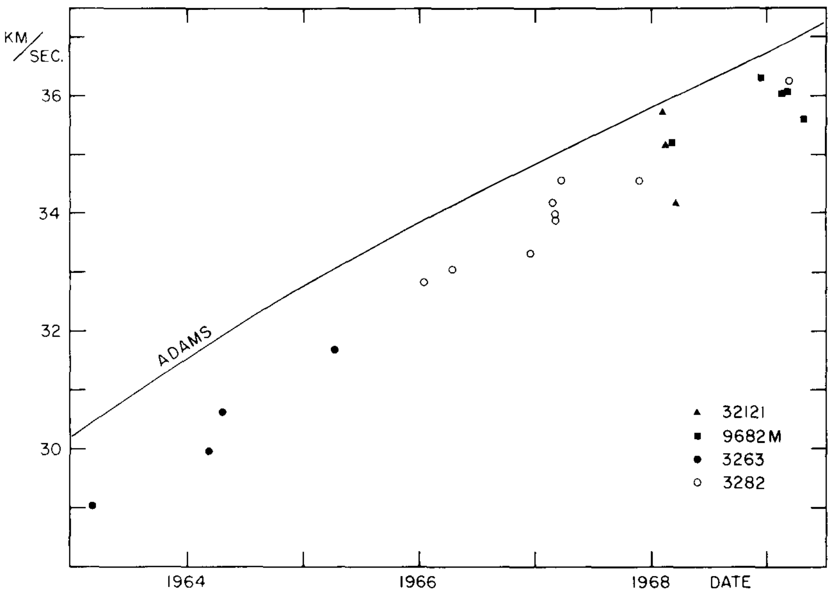

Fig. 2. Coudé radial velocities of ε Hydrae.

though shifted by either about 1 km/sec or one year. The scatter is smaller than that obtained by Adams (1939), who used Lick three-prism plates to establish her curve. Moreover the slope of the variation is slightly steeper, indicating perhaps a slightly larger value of K than she found. No evidence for the secondary variation suggested by Underhill (1963) has been found; the observations are however hardly numerous enough to reveal such an effect.

The lines in the spectrum of ε Hydrae are rather shallow but not broadened by stellar rotation. A small portion of the spectra of ε Hydrae (G0III) and of ζ Herculis (G0IV) is shown in Figure 3. The original dispersion of these tracings is 2.4 Å/mm. The lines of ε Hya are obviously shallower but no less sharp than those of ζ Her. Two explanations for this phenomenon seem possible. The first is that ε Hya is really a weak-line star of Population II while ζ Her is of Population I. However, the systemic radial velocity of ε Hya, while large, is smaller than that of ζ Her. The second explanation is that ε Hya B is brighter than previously thought, as was suggested by Zeller (1965), but that it is of fairly early spectral type and therefore contributes some continuum light but few lines to the spectrum. Such a continuum would tend to fill in and weaken the lines in the spectrum of the primary. The secondary of ζ Herculis, on the

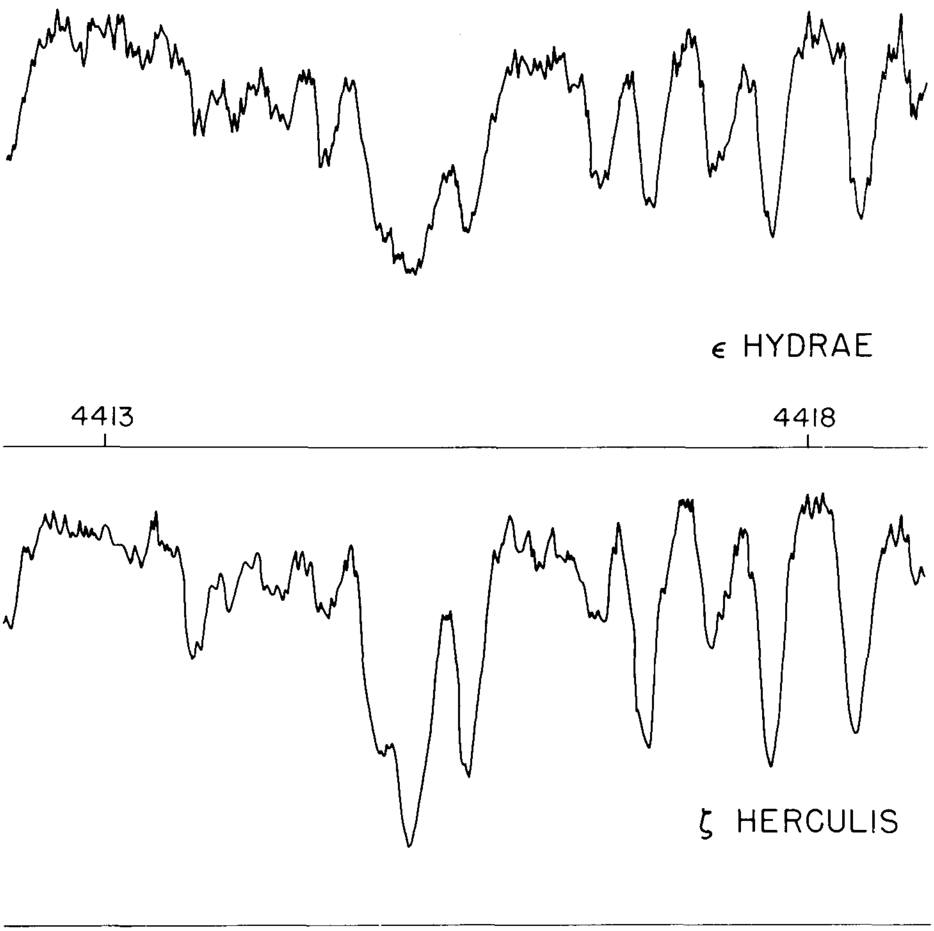

Fig. 3. Intensity tracings of the spectra of ε Hya G0 III and ζ Her G0 IV – original dispersion 2.4 Å/mm.

other hand, is of type K0 and over two magnitudes fainter than its primary visually. I plan to test this hypothesis by finding the amount of weakening as a function of wavelength, but have not done so yet.

The star β Leonis Minoris has been followed since 1965 and the observations so far secured are presented in Figure 4. There has been little variation over the past four years. The curves represent the elements of Baize (1950) and of Van Biesbroeck (1962),

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as quoted by Underhill (1963) and Dommanget (1967), with V_0 and K_1 determined from the observations by the method of least squares. It is however still much too early to expect this procedure to produce reliable results. This is clearly indicated by the fact that both sets of elements and the parallax listed in the Yale Catalogue give K_1+K_2 about ten times larger than the K_1 so determined. The secondary would thus be of very small mass and therefore probably so faint as to escape detection by visual observers. It is obvious, moreover, that the coudé velocities so far obtained are fitted equally well by either set of elements.

For the system of γ Leonis, consisting of two normal giants, Worley (1963) gives two sets of elements, by Guntzel-Lingner (1956) and by Rabe (1958). Both have a period of several centuries and predict very little velocity variation at present. Indeed according to Guntzel-Lingner's orbit, the system should pass through a node with velocity dif-

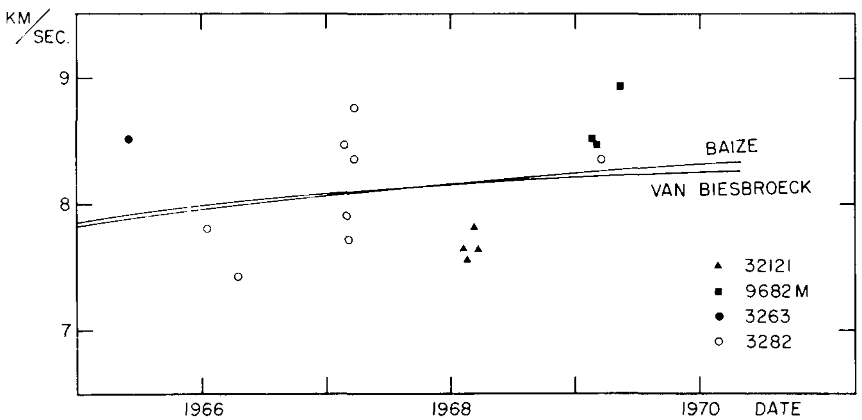

Fig. 4. Coudé radial velocities of β Leonis Minoris.

ference 0.283 (K_1+K_2) in 1970. Obviously no significant improvements in the orbital elements can be expected for a century or more. However a determination of the velocity difference would serve as a check on the parallax and on the masses, assuming the published elements to be correct.

For this determination the material consisted of four plates of each star taken two in 1966 and two in 1969 using the 9682 and 9682M cameras respectively, together with three 3282 plates of each, taken in 1967. Dr H. W. Babcock, director of the Mt. Wilson and Palomar Observatories, also kindly lent me three coudé plates of each star taken in 1952-3 at a dispersion of 2.8 Å/mm. In addition Dr G. Wallerstein of the University of Washington was kind enough to provide me with several measures obtained by himself and W. Westbrooke from Lick plates taken in 1960–1. These three groups of plates each yielded a value of the velocity difference, and using the elements, of K_1+K_2. The difference in each case is very small, only a few tenths of a kilometre per second, and is determined accurately (to ± 0.14 km/sec) only by the

Victoria observations. The values of $K_1 + K_2$ were combined, weighted by the reciprocals of their variances.

The value of $K_1 + K_2$ so obtained using the elements of Guntzel-Lingner, 1.4 km/sec, gives masses so small ($m_1 + m_2 \simeq 0.05\ m_\odot$) that it makes the elements themselves open to serious doubt. On the other hand, Rabe's elements give $K_1 + K_2 = 3.9 \pm 1.4$ km/sec from the observed velocity differences. Hence $m_1 + m_2 = 1.1\ m_\odot$ to within a factor of two and a half. The parallax so obtained is $0\farcs034 \pm 0\farcs012$, giving absolute magnitudes $M_1 = 0\overset{m}{.}2$, $M_2 = 1\overset{m}{.}4$. Thus the present results are no more accurate than those given by the visual observations and the trigonometrical parallax alone. The agreement between the two approaches is however within the error of each, provided one uses the elements of Rabe, but not if one uses those of Guntzel-Lingner.

I plan to continue to follow these and the other stars on my observing list. I would be grateful for any suggestions for additional systems, however.

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Discussion

Rakos: Does not β LMi show some indication of a two years' period in the radial velocities?

Scarfe: I cannot say. The scatter of the observations is too great.

Heintz: α UMa is a case where the spectroscopic and the visual data contradict each other. The meridian results, by the way, support the radial velocities. As to ε Hya, Zeller's results can be shown to be mistaken. My 1963 orbit makes the amplitude K larger than given by the old elements of Adams, and the components appear to be overluminous subgiants, so they may well be population II stars.

Scarfe: Then perhaps this is the explanation of the weak lines.