Day 3:

Things That Tick

New Horizons in Time-Domain Astronomy
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Spectroscopic Binaries: Towards the 100-Year Time Domain

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Invited Talk

Abstract. Good measurements of visual binary stars (position angle and angular separation) have been made for nearly 200 years. Radial-velocity observers have exhibited less patience; when the orbital periods of late-type stars in the catalogue published in 1978 are sorted into bins half a logarithmic unit wide, the modal bin is the one with periods between 3 and 10 days. The same treatment of the writer's orbits shows the modal bin to be the one between 1000 and 3000 days. Of course the spectroscopists cannot quickly catch up the 200 years that the visual observers have been going, but many spectroscopic orbits with periods of decades, and a few of the order of a century, have been published. Technical developments have also been made in 'visual' orbit determination, and orbits with periods of only a few days have been determined for certain 'visual' binaries. In principle, therefore, the time domains of visual and spectroscopic binaries now largely overlap. Overlap is essential, as it is only by combining both techniques that orbits can be determined in three dimensions, as is necessary for the important objective of determining stellar masses accurately. Nevertheless the actual overlap—objects with accurate measurements by both techniques—remains disappointingly small. There have, however, been unforeseen benefits from the observation of spectroscopic binaries that have unconventionally long orbital periods, not a few of which have proved to be interesting and significant objects in their own right. It has also been shown that binary membership is more common than was once thought (orbits have even been determined for some of the IAU standard radial-velocity stars!); a recent study of the radial velocities of K giants that had been monitored for 45 years found a binary incidence of 30%, whereas a figure of 13.7% was given as recently as 2005 for a similar group.

Keywords. stars:binaries:spectroscopic

After all that we have been hearing about big, and in many cases futuristic, projects, involving huge expense and large numbers of people, I am afraid that this talk will seem rather low-key. The truth is that, as far as spectroscopic binaries are concerned, it is inevitable that for a long time to come the 100-year time domain must be largely *retrospective*, because, no matter how frequent and sensitive future observations may be, they can not retrieve time that is already past. Plenty of good visual orbits with periods of 100 years or more have been determined, so it might be argued that even if spectroscopic orbits with 100-year periods could be derived, that would not be much of an achievement, because binary systems are just binary systems and it is only a question of what observational technique you use to observe them that decides whether you call them visual binaries or spectroscopic ones. But that is not quite so. In order to obtain stellar masses, which I suppose are the most critical data of all about stars, binaries need to be observed both 'visually'—by which I mean in angular measure on the sky, whether literally by eye or by interferometric or other such procedures—*and* spectroscopically. The visual orbit has a scale only in angular measure and not in kilometres, while the scale of a spectroscopic orbit by itself includes the undetermined factor sin i, i being the orbital inclination; the factor even enters *cubed* in the expression for the mass. Unfortunately for the progress of astrophysics, there has been remarkably little overlap between the period distributions of visual and spectroscopic binaries, although I have been doing my best to remedy that from the spectroscopic side.

Visual binaries have been carefully measured for position angle and angular separation since the time of Wilhelm Struve nearly 200 years ago. The observers have clearly realised that in most cases they could not hope to obtain orbits within their own lifetimes, but they nevertheless selflessly accumulated good measurements for posterity and we are certainly reaping the benefits from them now. Spectroscopists have not been so altruistic. They have seized on the short-period systems and tended to ignore the others. There is, perhaps, an extenuating circumstance, inasmuch as among the visual binaries it is the wide—and therefore usually slow—ones that are the easiest to resolve and measure. Among spectroscopic binaries it is the ones with the largest amplitudes—and therefore usually the shortest periods—that are the easiest. The fierce observational selection that arises in that way has even been exacerbated in recent years by the parcelling out of observing time by time-allocation committees which lack patience and require to see results published before they will grant any further time.

Soon after the methods of measuring accurate radial velocities were developed at Lick and Bonn in the 1890s, Lick Observatory started the great project of measuring repeatedly the velocities of all stars brighter than magnitude $5\frac{1}{2}$. After that project was concluded in 1925, however, the bright stars were almost entirely ignored by radial-velocity observers. Although one might hope that now, after more than 100 years, 100-year orbits could be derived, in actuality that is not so, because there is a gap of 50 years in the data. I can illustrate the situation that pertained not much more than 30 years ago by this quotation from the sixth edition of Smart's book, published in 1977: "The orbital periods of spectroscopic binaries are generally several days only . . . ", and by a histogram (Fig. 1) showing the distribution in half-dex period bins of the 204 late-type orbits that were listed with quality *c* or better in the 1978 Catalogue of Spectroscopic Binary Orbits. [The modal bin is the 3–10-day one.]

When I was a comparatively young man I was somewhat of an instrument-building enthusiast, and in that capacity I developed the method of measuring radial velocities by cross-correlation of spectra, first on the Cambridge 36-inch telescope and then, in collaboration with Jim Gunn, on the 200-inch at Palomar. I felt obliged to obtain a good lot of astronomical results at Cambridge, just to show that the method worked—a conclusion that was strongly resisted by the great majority of those who saw themselves as experts at the time. But then I got interested in binary stars, and the absence of any demand other than my own for observing time on the 36-inch reflector led me to see that, despite the disadvantages of site and climate, the constant access to the telescope provided freedoms not enjoyed by many other astronomers to pursue a project on spectroscopic binaries.

Partly with a view to providing a regular input of binary orbits into the literature, but also partly to advertise the seemingly despised method of cross-correlation that I had developed, in 1975 I started in *The Observatory* Magazine a series of orbit papers, featuring the words *PHOTOELECTRIC RADIAL VELOCITIES* conspicuously in the series title. Of course that expression appears tautological now that radial velocities are all measured photoelectrically, but at the time it was very distinctive. At the start of the series I had already been observing for nine years and felt that I had enough data 'in the bank' to put a paper of that series in every issue of *Observatory* (it is published every two months) indefinitely, as long as my own interest held up and the Editors were willing

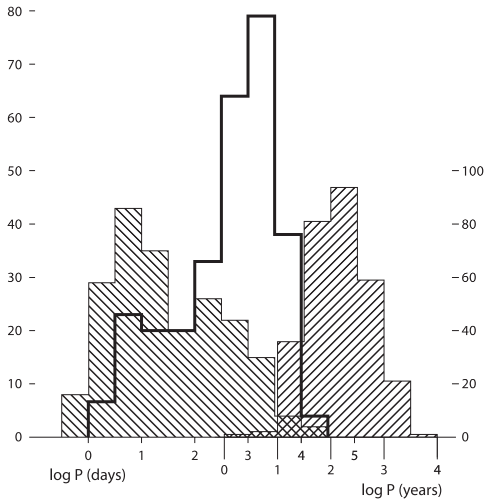

Figure 1. Period distribution of three sets of binary orbits. The ordinates on the left refer to the left-hand (diagonally shaded) distribution and the central one (no hatching), while the right-hand scale refers to the right-hand shaded distribution. From left to right: *a*) The 204 spectroscopic orbits of tolerable quality (qualities $a - c$) for stars with at least one component of type F5 or later, listed in the *Seventh Catalogue of the Orbital Elements of Spectroscopic Binary Systems* (*Publ. Dominion Astr. Obs.*, vol.17, 1978); that was the total number of such orbits known at that time, soon after my series of papers giving photoelectrically determined spectroscopic orbits started. (*b*)The 291 spectroscopic orbits published in Papers 1–200 in my series of papers in *The Observatory* in 1975–2009. (*c*) The 294 'visual' orbits published in IAU Commission 26 *Circulars* 165–174 (2008 June–2011 June), which could be expected in principle to include *all* such orbits published in the three-year interval shortly before those dates. The point of this diagram is to illustrate the disappointingly small overlap between the distributions of the spectroscopic orbits and the published visual ones, notwithstanding that it has been demonstrated that modern interferometers can produce orbits for binary systems with periods little longer than log P (days) = 0.

to accept the papers. In fact the series is still going!—the current issue of the Magazine carries the paper with the serial number 219.

Another programme that I started in the very first observing season, 1966, was on the 'Redman K stars'. There was a stage in the development of the cross-correlation method when the faintest stars that were readily observed with the 36-inch telescope were of the seventh magnitude. Redman, then Director of The Observatories at Cambridge, pointed out the existence of hundreds of seventh-magnitude K stars whose radial velocities he himself had measured from 90-Å/mm spectrograms taken with the 72-inch reflector at the Dominion Astrophysical Observatory, with which the new photoelectric velocities could be compared. I did indeed observe 80-odd of those stars in 1966 and again in 1969, and published the results. Whereas Redman had needed to give two-hour exposures on the 72-inch reflector, my observations took only a few minutes on the 36-inch and were several times more accurate! Nine of the stars appeared, with varying degrees of certainty, to change their velocities between 1966 and 1969. In 1973 I obtained another round of measurements of the Redman stars, because it was beginning to become apparent that stars were liable to change their velocities on longer time-scales than those with which most spectroscopists have usually concerned themselves; since then the same set of stars has been re-observed in most seasons, with just one observation per season except for stars that have proved to vary in velocity. The systematic coverage of one observation in each of 30 seasons over a total interval of 45 years has just been completed and a paper giving the results hs been submitted. The proportion of binaries among that sample of K giants amounts to 30%, more than double the 13.7% that was asserted (to a precision of 0.1%!) from a much larger but much less careful observing programme in 2005.

A third project that has recently been published refers to spectroscopic binaries in the field of the Hyades star cluster. Inasmuch as there was no history of interest in stellar radial velocities at Palomar Observatory, there was no entrenched opposition to the powerful new method, and as early as 1971 Jim Gunn and I were allowed to make a (much improved) version of the Cambridge spectrometer for the 200-inch telescope. Initially it was to investigate the dynamics of certain globular star clusters—it had never previously been possible to measure the velocities of the individual red giants in such clusters with an accuracy below the velocity dispersion that the virial theorem might lead one to expect, but that was easily done with the new spectrometer. The instrument was also used on certain open clusters, and discovered many binaries in the Hyades. Many of them were written up in several papers published long ago, but I have been following others ever since, and a paper giving 54 new orbits is now in press.

It is of no small interest to compare the distribution of orbital periods of the binaries in the three programmes I have described—field stars in the *Observatory* series Fig. 1, the Redman K giants (Fig. 2), and the Hyades (Fig. 3)—with the histogram I showed from the 1978 orbit catalogue. My choice of stars is still affected by observational selection but not nearly as seriously as the *Catalogue* distribution. You will see that the modal 'bin' for the *Observatory* and Redman stars is the 1000–3000-day one, while in the Hyades it is the 3000–10000-day one—fully three orders of magnitude longer than the one in the *Catalogue*! I would point out that periods above 10^4 days are still heavily discriminated against by observational selection even in my own work; 10^4 days is some 27 years, and $10^{4.5}$ days is 86 years and so is far beyond a working lifetime. Within that limitation, the distribution of orbital periods (on a logarithmic scale) may be considered to be monotonically rising even to the longest periods currently accessible.

I should perhaps point out that there is nobody to identify for you, on Day 1 of your professional lifetime, all of the stars whose periods are of the maximum length that you can hope to document, so that you can get started on them straight away. Inevitably you learn about many of the long-period stars only when it is really too late! For myself, before I could start observing it was necessary to develop the procedure without which

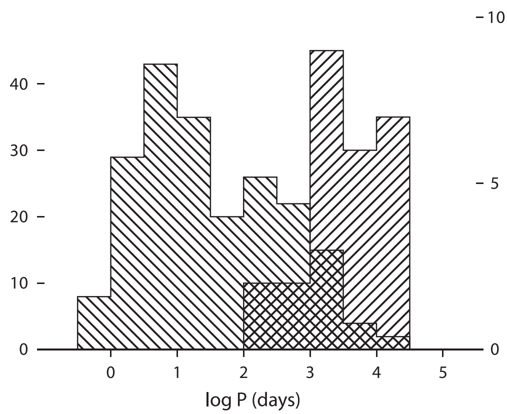

Figure 2. The *Seventh Catalogue* distribution of spectroscopic binary periods (Fig. 1(a)) is contrasted here with the distribution of periods for the binaries found among the 'Redman K stars' (R.F. Griffin, JA&A, in press, 2012). Since the selection criteria for those stars discriminated against dwarfs there are no very short periods in the Redman sample.

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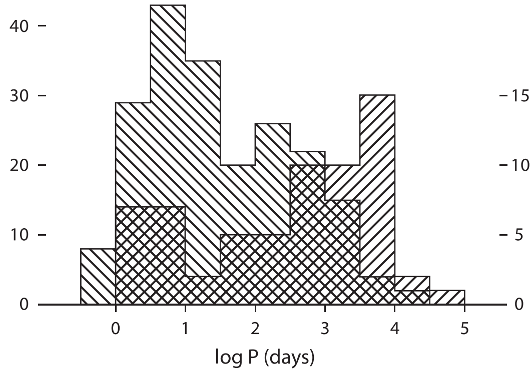

Figure 3. The *Seventh Catalogue* distribution of spectroscopic binary periods (Fig. 1(a)) is contrasted here with the distribution of periods for Hyades spectroscopic binaries with known orbits (mostly from R.F. Griffin, JA&A, in press, 2012).

it would have been impossible to follow a large number of low-amplitude binaries year after year and decade after decade. My successors can start observations on Day 1, on instrumentation (better, actually, than any that I have ever had) that is already provided for their use by others.

It is obvious not only that I personally am not in a position to extend the period distribution of spectroscopic binaries much further towards longer periods, but also that progress in that direction is in any case going to be extremely slow, a task for generations yet to come. A more practical possibility for increasing the much-to-be-desired overlap between the periods of spectroscopic and visual binaries would seem to be from the 'visual' side—and indeed the instrumental enthusiasts among the visual-binary people have by no means been idle. They have developed first of all the speckle method and then interferometry with widely separated apertures, that have given resolutions down to a single millisecond of arc and allowed good 'visual' orbits to be produced for 'spectroscopic' binaries with periods down to a few days, such as that of β Aurigae. In principle, therefore, there is now a huge overlap between the domains of visual and spectroscopic binaries, which ought to allow stellar masses to be derived on a wholesale scale for stars of all different types and luminosities. Unfortunately that does not seem to be happening. I have looked at the distribution of orbital periods whose publication has been documented in the last ten issues of the IAU Commission 26 Circulars, which in principle record all the newly determined 'visual' orbits, and I have added that distribution to Fig. 1 for comparison with two of the distributions I have already given for spectroscopic orbits. The modal bin of the visual orbits is the 100–300-year bin, and there are more than 20 orbits with altogether ludicrous periods of more than a thousand years, no more than a sixth of whose periods can possibly be covered by observation! Only three of the 300 orbits have periods as 'short' as 10 years. We really need someone to light a fire under the visual people and explain to them what they ought to be doing!

The observation of spectroscopic binaries has not proved to be such an arid and boring exercise as you might imagine, partly because many of the stars concerned prove to be interesting objects in their own right. That is particularly the case with the whole class of composite-spectrum binaries, in which the late-type star whose radial velocity I can measure has a companion of early type. The spectra of many such pairs have been skilfully disentangled by my colleague and co-author, and the systems have been revealed as having remarkable diversity.

I would like to finish by referring to some of the results, and challenges, of orbit deter-

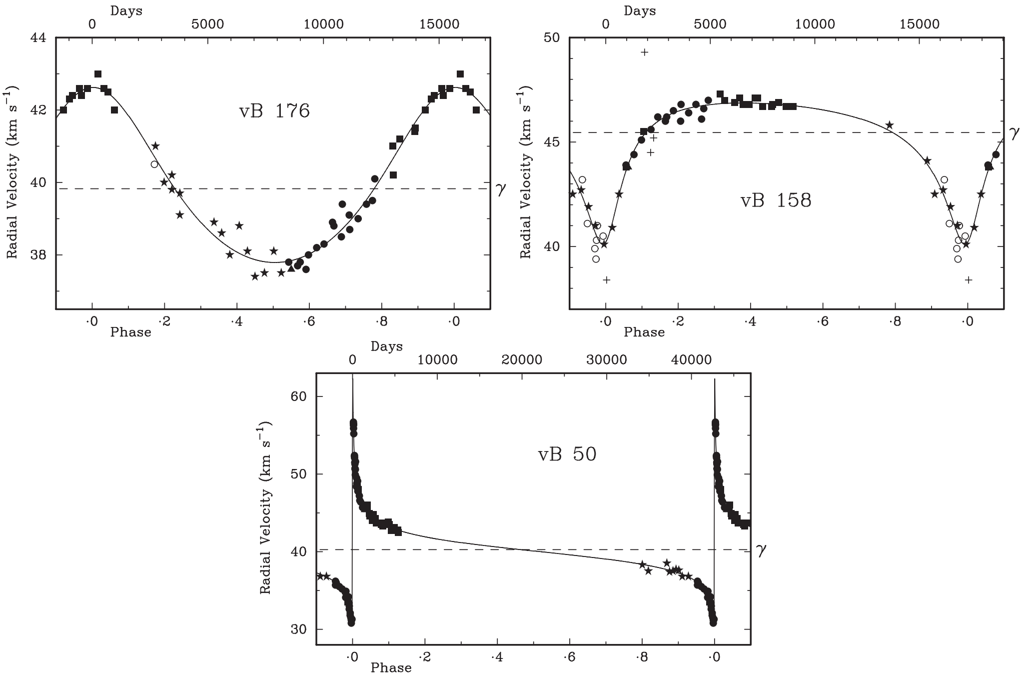

Figure 4. Orbits of Hyades binaries van Bueren 176, 158, and 50. The different symbols represent observations obtained with different instruments.

mination of long-period spectroscopic binaries. First, δ Andromedae was quite definitely shown by both Lick and Bonn measurements to have had a maximum of velocity in the early years of the last century. So in due course it was bound to have another one. For about 25 years after I put it on my observing programme in 1969 it went absolutely nowhere, but then it started to move, and now it appears to be right on the crest of a fresh maximum. Another bright star with a similar period, that I shall be able to write up if I can keep going just a few more years, is τ Piscium. The late-type primary star in the beautiful visual pair Albireo (β Cygni) remains a conundrum. It definitely showed a small rise in velocity during the early part of the last century, and it has equally definitely shown a small decline in the forty years that I have been observing it. Its case well illustrates the difficulties that are caused by the half-century of neglect that I mentioned previously. The two intervals of observation may be linked directly, giving an orbital period of a little over 100 years, but there could equally well be an intervening cycle, in which case the period would be about 56 years. The visual orbit by Hartkopf is not well determined and has a period of 97 years, but the radial velocities cannot be made to fit it well. Fig. 4 shows the orbits of three Hyades binaries: van Bueren 176, which has been seen almost round its 43-year orbit, van Bueren 158, whose orbit of about 48 years still has some way to go and meanwhile is less well determined, and finally van Bueren 50, the *pièce de résistance*, whose period of 115 years is determined within about 10% because although there is an enormous gap in phase coverage we have seen both nodes of its extremely eccentric orbit. It also has an interferometric orbit which has very similar elements and a period of 112 years.