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Some preliminary statistical results from the eighth catalogue of the orbital elements of spectroscopic binary systems*

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Abstract. The *Eighth catalogue of the orbital elements of spectroscopic binary systems* has recently been published. It contains elements for 1,469 systems of which 814 are of category *c* (reliable) or better. In this paper we investigate the stability of the system of quality assessment, the distribution of orbital periods, the existence of a period-eccentricity relation, the distribution of longitudes of periastra and the distribution of spectroscopic binaries between populations I and II, as shown by their kinematic properties.

Key words : spectroscopic binary—catalogue

1. Introduction

The *Eighth catalogue of the orbital elements of spectroscopic binary systems* (Batten, Fletcher & MacCarthy 1989) is in the press at the time of writing and is the third of the series prepared at the Dominion Astrophysical Observatory during approximately 20 yr (the others were the *sixth catalogue* : Batten 1967; and the *seventh catalogue* : Batten, Fletcher & Mann 1978). During the time, the number of known orbits has almost doubled (indeed we estimate that already about 10% more orbital elements than are in the *eighth catalogue* have been published since our closing date of mid-1987). The rate of growth is illustrated in table 1. The numbers of orbits in the different quality classes *a* to *e* and *i* (indicating that insufficient information is available for a quality assessment) are shown for the three Victoria catalogues, while the last two rows give the totals (*all*) and the sub-totals (*abc*) for those orbital elements considered to be reliable. These sub-totals have remained an almost constant proportion (between 55 and 60%) of the grand total and there are now more *abc* orbits available for study than the grand total of all orbital elements contained in the *sixth catalogue.*

At first sight, this increase in the number of systems for which reliable orbital elements are available offers hope that various statistical properties of the class of spectroscopic binaries can now be much better determined than formerly. We have shown, however, that even the total of 1,469 systems contained in the new catalogue is but a small fraction of the number of binaries that should be observable (Batten & Fletcher 1989). The apparent distributions of orbital elements are probably heavily influenced by selection effects and are not necessarily the true distributions. Nevertheless,

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Table 1. Numbers of entries in successive Victoria catalogues

Quality	VI	VII	VIII
a	36	45	55
b	141	180	303
c	245	324	456
d	187	268	401
e	119	154	243
i	9	7	11
all	737	978	1,469
abc	422	549	814

a study of apparent distributions is the essential first step in any statistical study of this type. In this paper we investigate a number of such apparent distributions, recognizing that they probably are at least partly the results of selection, but without attempting to assess in any great detail just how that selection has operated. The distributions studied are those of the orbital periods, eccentricities, longitudes of periastra and systemic velocities. As a preliminary, however, we first investigate the stability of our system of quality assessment of the orbital elements.

2. The quality ratings

In all three Victoria catalogues, orbital elements have been assigned to one of five quality classes (*a* to *e*) in accordance with the principles explained in the introduction to each catalogue. These assignments have been the sole responsibility of the senior writer of this paper. They are undoubtedly partly subjective and we investigate here how consistent they have been. We make the underlying assumption that the true distribution of quality has remained constant. Some might dispute this; after all techniques of observation and measurement of radial velocity have improved enormously in the 20 years under review. Observers have often applied these techniques to more complex systems, however, and there are always survey programs in which orbital elements are computed from the minimum possible number of observations. We believe that the mixture has remained roughly constant, but the problem only becomes important if intercomparison of the three Victoria catalogues shows that the proportions of elements assigned to the different categories have changed. We would then have to ask whether this was a change in the underlying population or in our perception of it.

The necessary comparison is implicit in table 1. To make it clearer we present table 2, which is derived from table 1 by ignoring the *i* orbital elements (about 1% of the total) and normalizing the remainder to a total of 1,000. The figures given in table 2, therefore, are simple percentages multiplied by 10. In the penultimate column we give the figures for a mean Victoria catalogue. In the last column, σ is the square root of the corresponding entry in the previous column, rounded to the nearest whole number. We believe that this number serves as a rough indication of the significance of deviations from the means: few will dispute that deviations less than σ hardly need to be taken seriously. In fact, only one deviation (that for *a*-quality orbits in the *eighth catalogue*) even equals the corresponding value of σ. Since it is unlikely that the true distribution of quality and our perception of it have changed by equal amounts in opposite senses, we feel justified in concluding that neither has changed significantly over the last 20 years.

Table 2. Normalized numbers of entries in the various quality classes

Quality	VI	VII	VIII	Mean	σ
a	49	46	38	45	7
b	194	185	208	196	14
c	337	334	313	328	18
d	257	276	275	269	16
e	164	159	166	163	13
all	1,001*	1,000	1,000	1,001*	
abc	580	565	559	568	24

*round-off error

This is the more interesting because Batten believed, while he was classifying the orbits, that he was judging more harshly than he had done in the past. The only evidence to show for that belief, however, is a barely significant decline in the proportion of *a*-quality orbits and an even smaller, but interestingly consistent decline in the proportion of *abc* orbits taken together.

3. Distribution of periods

Figure 1 displays the distribution of the logarithms of periods listed in the *eighth catalogue*. The shaded portions of each bin represent the distribution for systems in the quality classes *a*, *b* and *c*, while the full extents represent the totals for the *catalogue*. Both distributions have a marked peak for periods in the interval 1 day to 10 days, although the peak is less prominent for the better observed systems. Those systems

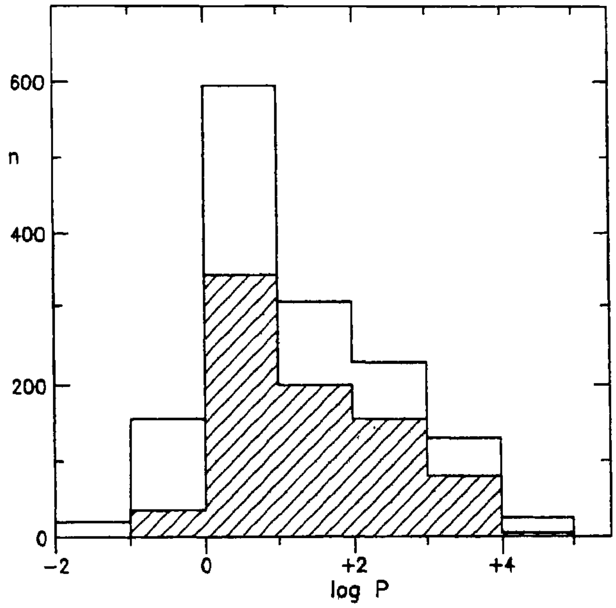


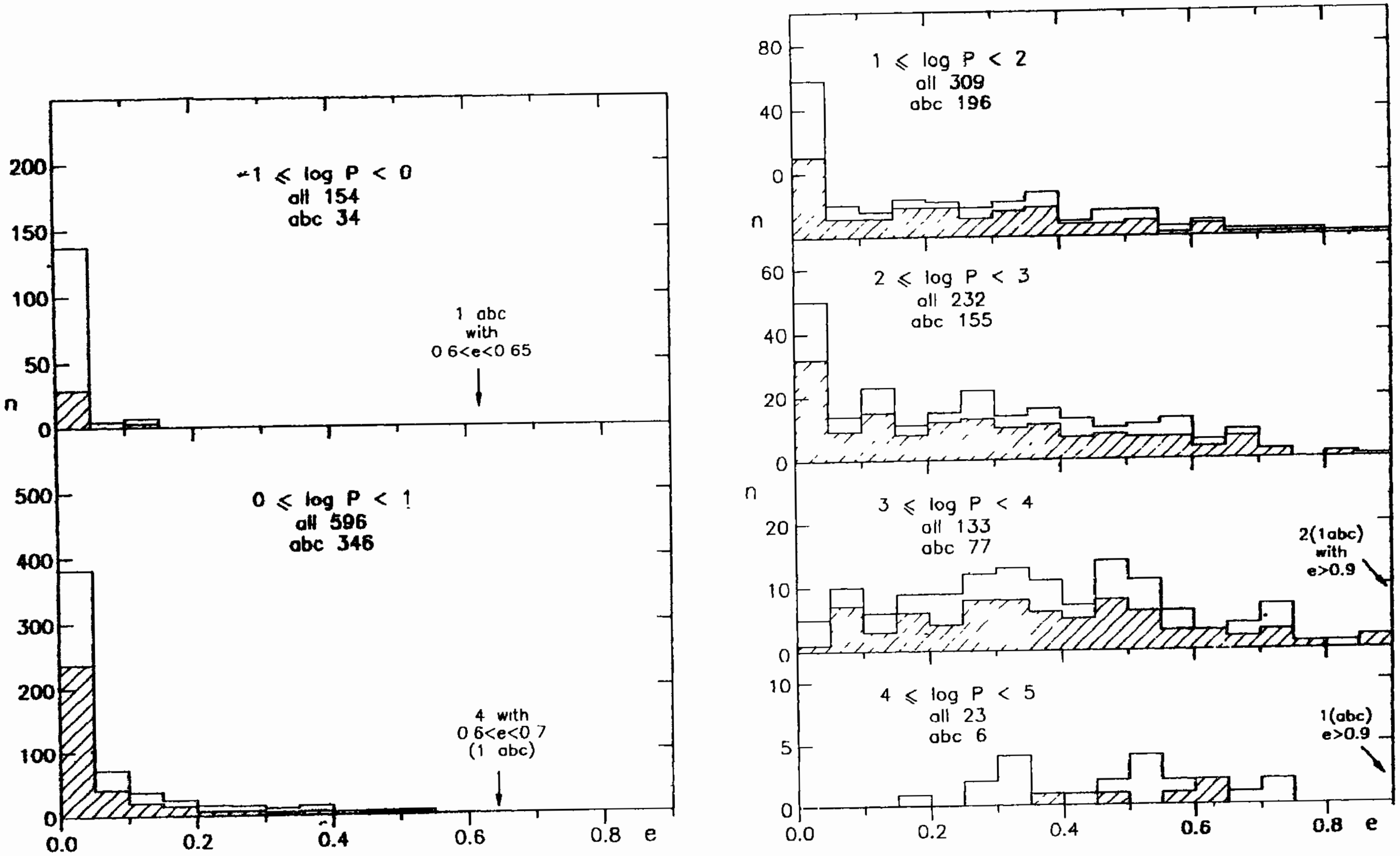
Figure 1. Frequency distribution of log P(P in days). Open blocks: all systems in the Catalogue; shaded blocks: systems with orbits rated *a*, *b* or *c*.

include many with long periods whose radial velocity variations have been determined photoelectrically. As Griffin (1985) has shown, such systems tend to fill the gap that previously existed between spectroscopic and visual binaries. We believe that the peak in the period distribution is largely a result of observational selection. The sharp cut-off for periods less than a day is probably more apparent than real. Binaries of the W UMa type are very numerous, but still only relatively few have been observed spectroscopically. A similar histogram constructed for known eclipsing binaries might show a peak for $-1 \leqslant \log P < 0$. There cannot, however, be infinitesimally short periods. King (1988) summarized reasons for believing that the minimum observed period of about $0^d.05$ is an absolute minimum. Ritter (1987), however, who now lists 39 cataclysmic variables with periods less than $0^d.1$, includes two with periods even shorter than $0^d.05$. Most of these very short periods have become known only in the last decade or so, an exception being VV Pup ($0^d.07$), the period of which was first determined by Oosterhoff (1936). The steep decline in the number of systems found in this interval of the period distribution is probably real. The gradual decline to long periods, however, is almost certainly largely a selection effect: the longer the period, the harder a binary is to detect. Common-proper-motion pairs could be regarded as binaries of infinitely long period, so there is no obvious upper limit to the distribution. We would expect the distribution of major axes to show similar characteristics, but it would be complicated by the $\sin i$ factor that we cannot eliminate for most spectroscopic binaries. For that reason, we have not considered it here.

4. Period eccentricity relation

The question of whether or not there is a period-eccentricity relation for all binaries has been long discussed. We investigate it here for the spectroscopic binaries with known orbits by displaying the distributions of the orbital eccentricities in different period ranges (figures 2a-f). The distribution for $-2 \leqslant \log P < -1$ is trivial and is not shown: 19 systems in that interval are listed in the *catalogue*, and all but one have circular orbits, that one possibly having a small orbital eccentricity. The remaining figures show that up to $P = 10$d, and possibly even up to $P = 100$d, circular orbits predominate. Eccentricites greater than 0.2 are rare, and those greater than 0.7 are as yet unknown, up to $P = 10$d. Eccentricities greater than 0.9 are associated with periods greater than 1,000d. Once again, observational selection plays a part. It is easier to observe a small velocity variation in a long period if a high eccentricity is combined with certain values of the longitude of periastron (0° or 180°). Those of us who observe visual binaries spectroscopically select such systems deliberately. The absence of circular orbits from figure 2f and their relative scarcity in figure 2e is entirely explicable in this way. If there were large numbers of short-period eccentric orbits, however, we should expect to have discovered more of them than we have. The eccentricity distribution in figure 2b (periods between 1 and 10d) resembles half a Gaussian centred on $e = 0$, with perhaps a somewhat extended tail.

We believe that observational selection cannot account for all the features presented in figure 2. Tentatively, we suggest that there is evidence for two populations of spectroscopic binaries. In one, most members of which have periods of less than 100d, all orbits are circular or nearly so. In the other, most members of which have periods in



Figures 2a-f. **Frequency distributions of orbital eccentricities** in different period ranges (P in days) Open and shaded blocks **as in figure 1. Notice that the vertical scale is different for each section. There are** a few systems in the *Catalogue* for which no information at all is given **about the eccentricity. Therefore the totals given do not add up to 1,469**

excess of 100d, all eccentricities appear to be equally probable, except perhaps the very largest and the very smallest. One would suppose that in the short-period systems tidal action, magnetic braking and possibly even mass-transfer act to circularize orbits relatively quickly. The long-period systems provide evidence for the primeval distribution of eccentricities which, when allowance is made for observational selection, was probably random. It is of interest that the two populations overlap. There is an appreciable number of eccentric orbits with $P < 100$d, while, even in the interval $100\text{d} \leqslant P < 1{,}000$d, there are more orbits that are circular or nearly circular than are found in any other equal interval of eccentricity. More detailed study of the systems in this overlapping area might confirm the existence of two populations and throw some light on the mechanisms producing them.

5. Longitudes of periastra

It has been known since the time of Barr (1908) that more spectroscopic binaries are observed with longitudes of periastra, ω, in the interval 0° to 180° than in the complementary interval. Struve drew attention to this fact in several papers, emphasizing more particularly the concentration in the first quadrant. He inspired statistical analyses (Blanco & Williams 1948; Scott 1949) of the data in the last of the Lick catalogues (Moore & Neubauer 1948) and since then it has become something of a tradition to examine the data of each new catalogue (Batten & Ovenden 1968; Fracastoro 1979). It is well established that the effect is more marked for eclipsing binaries than non-eclipsing ones and is also dependent on spectral type of the primary and ranges of period and eccentricity considered. In this paper, we are content to demonstrate only that the effect is present in the larger body of data now available. The observed distributions of ω are illustrated in figure 3, once again for all elliptical orbits known (929), and for those considered reliable (601). The non-uniformity of both distributions is obvious on inspection. We will return later to the question of whether or not the deviations from uniformity are significant.

Presumably every one would agree that a real non-uniformity in the orientation of the major axes of binary orbits is the least likely of all the possible explanations of the observed distribution. Most people will accept the explanation advanced by Struve (1948) that measures of radial velocity are affected by streams of matter between the binary components so that a false eccentricity is ascribed to a circular orbit and a value of ω in the first quadrant is deduced. Batten & Ovenden pointed out other possible causes, in particular selection effects favouring the discovery of orbits with particular values of e of ω, and artifacts of the measurement and analysis of the data. Selection effects of the kind envisaged do exist but are small. They will be dependent on the spectral type and the semi-amplitude K, and act differently for one-spectrum and two-spectra binaries. They would be symmetrical about either the 0°-180° line or the 90°-270° line. We believe that they play only a minor role in producing the observed distribution. Artifacts of measurement and analysis have been little studied, but they could play a role when observations are poor in quality or few in number. They would, therefore, be more likely to affect the orbits of d and e quality.

Batten & Ovenden also pointed out that no rigorous test of the significance of any departure from uniformity can be devised in isolation from a hypothesis of the origin of

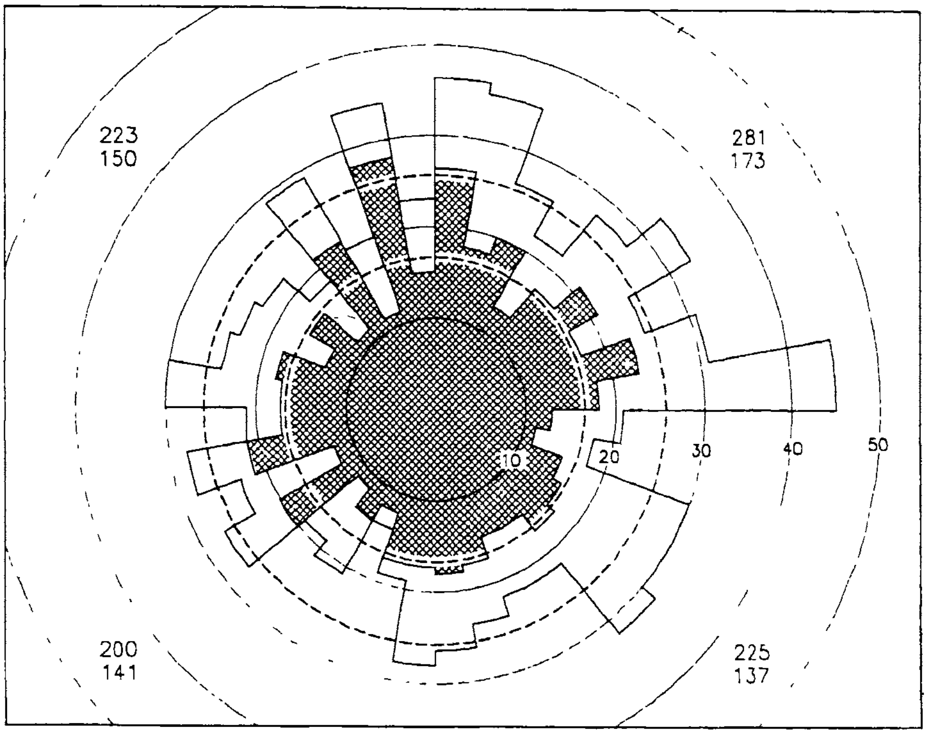


Figure 3. Frequency distributions of longitudes of periastra for all elliptical orbits in the *Catalogue* (929 open blocks) and those rated *a*, *b* or *c* (601 shaded blocks) The means for 10° sectors are indicated and the total found in each quadrant are shown

such deviations. Various approximate assessments can be devised. The mean numbers for each 10° sector are 25.8 (*all* systems) and 16.7 (*abc* systems). The standard deviations of a single sector are, respectively, 6.25 and 4.05. It will again probably be acknowledged that any departures less than those figures can be ignored as statistical fluctuations, while departures in excess of twice those figures (*i.e.* since whole numbers must be used, equal to or greater than 13 and 9) should be investigated. Only one sector does depart by more than two standard deviations (as it happens, by more than three) and that is the prominent spur betweeen 0° and 10° in the outer distribution (*all* systems). It disappears completely when only reliable orbits are considered, as does the nearly symmetrically placed spur between 170° and 180°. We believe that the spurs *are* the results of artifacts of analysis; although a contributory factor to their disappearance in the inner distribution may be that now we have observed the secondary components of some Algols, we force the observations of the primaries to fit circular orbits and have removed the systems from those to be included in figure 3. Undoubtedly this spur contributed to previous estimates of the Barr effect which, however, still remains in the inner distribution. To illustrate this, the total numbers for each quadrant are given in figure 3. If the distribution were completely uniform the expected number in each quadrant (to the nearest integer) would be 232 and 150.

Probably the data are still too few for it to be profitable to discuss in detail the deviations of individual 10° sectors from the mean. Yet it is noticeable that, apart from the 0°-180° spur, most features of the outer distribution are present also in the inner. Notice in particular the preponderance of values of ω between 80° and 90° and 100° and 110° Systematic trends over several consecutive sectors are perhaps more significant. There are three of these in each distribution; one in each quadrant except the first, all of them being deviations below the mean. The one in the third quadrant corresponds to a feature identified by Batten & Ovenden as statistically the most significant deviation in the data then available. It is still present, though reduced, in the augmented data, even when only the most reliably determined orbits are considered. Perhaps it will be reduced further as more data are gathered, but at the moment it seems to be a real deviation We have no explanation to offer for it.

It is ironic that Barr discovered his effect 80 years ago from an analysis of thirty elliptical orbits some of which were wrongly interpreted Cepheid variables. Today, with a thirty-fold increase in the data, we can say little more than he did· there are more orbits with ω between 0° and 180° than between 180° and 360°. We are not certain that the explanation proposed by Struve, and now generally accepted, is the complete one

6. Kinematic properties of spectroscopic binaries

Since the question of whether or not the frequencies of close binaries are the same in populations I and II continues to attract attention, it is of interest to investigate the distribution of $|V_0|$ to see if there are any high-velocity systems included in the catalogue This distribution is shown in figure 4. Since there are a number of triple system, with two orbits but only one V_0, in the *eighth catalogue*, and some systems (*e.g.* x-ray pulsars) for which no information about V_0 is available, only 1419 systems (and 794 reliable ones) are included in the plot. The expected overwhelming predominance of low-velocity systems is obvious. There are, however, 112 systems with $V_0 > 50$ km s^{-1}, 56 with $V_0 > 70$ km s^{-1} and 30 with $V_0 > 100$ km s^{-1}. Not all of these are genuine high-velocity stars. Some are Wolf-Rayet binaries for which values of V_0 are badly affected by atmospheric motions and uncertain wavelengths; a few are objects in the Magellanic Clouds. Several are cataclysmic variables, usually regarded as belonging to the intermediate-to-old disc population. Nevertheless, there is a residuum of objects (some 30 to 40) that do have high space velocities with respect to the Sun, some of which, at least, would be assigned to population II (or an intermediate population) on other grounds. Since most population II stars are faint, they have until recently been difficult to observe. Latham *et al.* (1988), however, have published orbital elements for 40 spectroscopic binaries, 16 of which are metal-poor and therefore, presumably, old stars. Their paper reached us too late to include the elements in the *eighth catalogue* and only four of their systems were already known. This makes the sample in their paper virtually independent from that in the *catalogue*, so it is instructive to compare the two. Figure 5 shows the velocity distribution for the new sample. Although the largest number of systems in a single bin is still found for $|V_0| < 10$ km s^{-1}, it is clear that a deliberate search for population II binaries by modern means has been successful. We believe that the small percentage of such binaries in the *eighth catalogue* is, to an appreciable extent, the result of observational selection and the question of the relative frequency of binaries in the different stellar populations is still open.

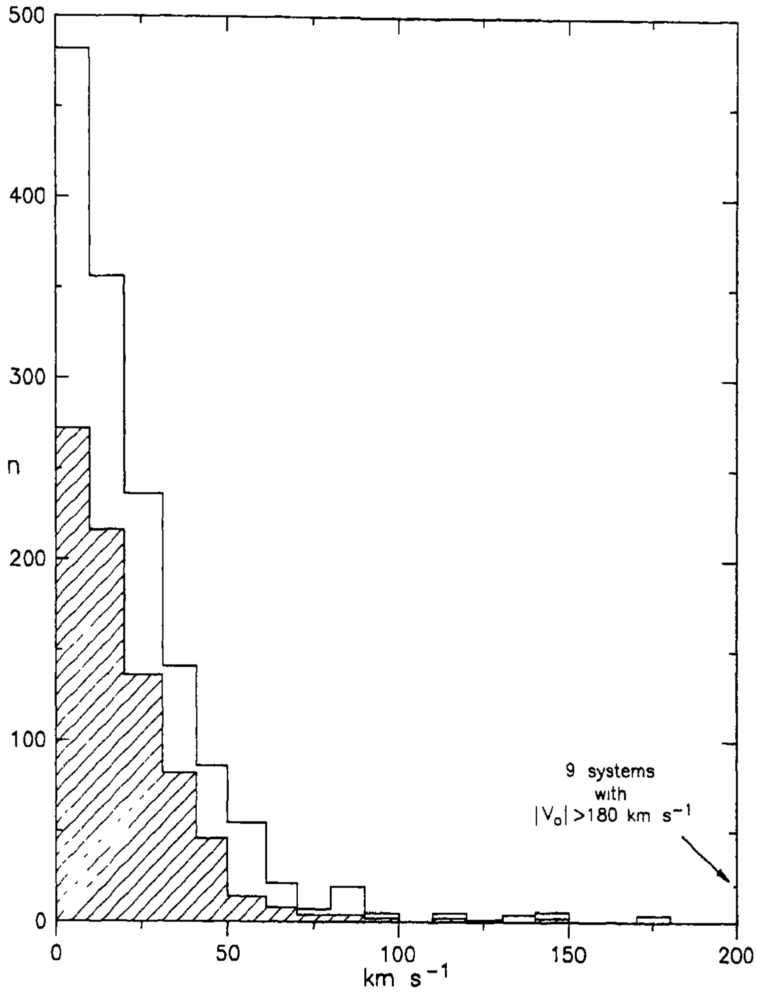


Figure 4. Distribution of $|V_0|$ for all systems for which V_0 is known (open) and for all *a*, *b* or *c* systems (shaded) for which V_0 is known.

7. Concluding remarks

We have shown that the assignment of orbital qualities in the three successive Victoria catalogues has remained remarkably consistent over two decades, even though it is partly subjective. We find that the observed distribution of periods peaks strongly between 1 and 10d, but we believe this to be an effect of observational selection. From a study of the distribution of orbital eccentricites in different period ranges, we suggest that there are two overlapping populations of spectroscopic binaries, the orbits of one of which, with periods less than 1,000d, have been circularized, while those of the other, with periods greater than 10d, have not. The distribution of observed longitudes of periastra is shown to be still non-uniform. The Barr effect is the predominant departure from uniformity and is probably primarily the result of gas-streaming in interacting binaries,

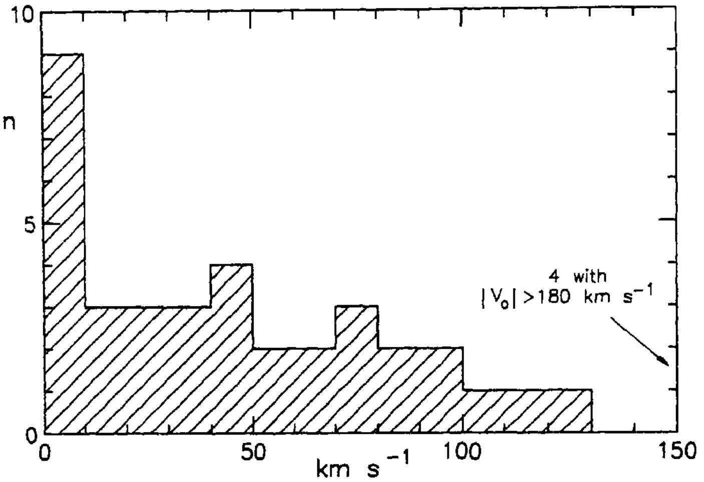


Figure 5. Distribution of $|V_0|$ for the sample of binaries observed by Latham *et al* Note that the vertical scale is different from that of figure 4

but other unexplained effects may be present. High-velocity stars are seriously under-represented in the *eighth catalogue*, but this is believed to be largely a selection effect.

Finally, we draw attention to the fact that very few of the conclusions just summarized are affected by whether we include all systems in the analysis or just those whose orbits are considered reliably determined. Our chief purpose in giving both distributions wherever appropriate was to check this point. The only matter on which we might have been seriously misled by the distributions derived from all systems is the 0°-180° spur in the ω-distribution. We believe that the general characteristics of frequency distributions can nearly always be reliably inferred from the totality of systems in the *catalogue*. Those wanting to make quantitative estimates, however, should probably confine themselves to the 814 reliable systems.

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