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The Spectral-type Limits of the Barr Effect

Helmut A. Abt

Kitt Peak National Observatory, Tucson, AZ 85726-732; abt@noao.edu

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ABSTRACT. The Barr Effect is a nonrandom distribution of longitudes of periastron, ω, in spectroscopic binary orbits. Physically one would not expect elliptical binary orbits to show any preferred orientations. Aitken and Struve have shown a preference for $0 < \omega < 90°$ among 275 elliptical binary orbits of all primary types. Some eclipsing binaries show inconsistencies between their light and velocity curves. Struve showed that the velocity curves of some spectroscopic binaries are distorted by absorption in gaseous streams flowing between the components. I wondered about the occurrence of this effect for stars of various spectral types and found that the effect occurs primarily for B0–B3 V-lll primaries but may be present in a few of the remaining BA stars. The B0–B3 region is also where the mean radial velocities of stars (single plus binaries) in open clusters are systematically larger than for other stars.

1. THE PROBLEM

The longitude of periastron, ω, in the orbit of a spectroscopic binary is the angle, in the direction of motion, from the ascending node (where the star moves into the plane of the sky) to periastron (where the star is closest to the focus) for an elliptical orbit. When periastron is furthermost from the observer, $\omega = 90°$; when periastron is closest to the observer, $\omega = 270°$. One would expect that the elliptical orbits of spectroscopic binaries would be distributed randomly because there is no known galactic force that tends to align the ellipses. Therefore the distribution of values of ω should be flat. Nevertheless, there is evidence that that is not always true.

J. Miller Barr, a Canadian amateur, first noticed in 1908 (Barr 1908), after the orbital elements of the first 30 binaries had been published in the literature, that there was a preference for values of ω between 0° and 90°. The reason for that preference was soon learned because one-quarter of his orbits were for Cepheid variables, which are not binaries. However, with the discovery of many more binary orbital elements, that preference in values of ω remained and the nonrandom distribution of ω is still called the Barr Effect.

By 1935 when 275 elliptical orbital elements were known (Aitken 1935), the distribution of ωs in the four quadrants (0°–90°, 90°–180°, 180°–270°, 270°–360°) was 93:60:60:62, where the statistical errors of those numbers ranged from ± 14 to ± 11.

Struve (1948) discussed this problem in his Bruce Gold Medal lecture. In particular he emphasized the case of U Cep, an eclipsing binary with a period of 2.492 days. Its secondary eclipses occurred exactly halfway between primary eclipses, so the orbits of the two components must either be circular, or $\omega = 0°$ or 180° (i.e., symmetrical about the line of apsides). However, Carpenter's (1930) orbital elements showed that $e = 0.474 \pm 0.022$ (i.e., very elliptical) and $\omega = 25.0° \pm 3.3°$ for the primary (i.e., not symmetrical about the line of apsides). What was wrong: the photometric light curve or the spectroscopic orbital elements?

It seemed unlikely to Struve that the light curve could be drastically in error, so he looked at his spectra taken at the McDonald Observatory. He saw that the hydrogen absorption lines were often asymmetrical. Evidently the system has streams of gas moving between the components that are contributing to the atmospheric absorption lines. Working under him, Robert Hardie did a Ph.D. thesis (Hardie 1950) in which instead of measuring the positions of the line cores, he measured the midpoints of the line wings, taken at one-quarter of the line depths. Those measures were approximate ones made on moderate-dispersion spectra. The resulting radial velocity curve gave $e = 0.15 \pm 0.05$ and $\omega = 10° \pm 15°$; i.e., the corrected velocity curve was closer to the results from the light curve, suggesting that correcting for absorption in the gaseous streams may give results closer to those of the light curve. Using better spectra, Batten (1974) proved that that interpretation is true.

Using the larger Batten et al. (1989) catalog of spectroscopic binary orbits (SB8), Howarth (1993) showed statistically that the Barr Effect is real for short-period binaries with a preferred $\omega \sim 40°$ for all the binaries and $\omega \sim 100°$ for short-period binaries.

There is one more complication. Lucy & Sweeney (1971) found that if the eccentricity is small, ω is poorly determined. In fact, when observers derive values of $e < 0.05$, the orbits are often circular within their errors. Therefore we should treat with suspicion any orbital elements with $e < 0.05$.

How frequent are such systems? Savedoff (1951) considered the eclipsing binaries in Pierce's list (1947) and computed $e \cos$

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ω from the light curves and from the radial velocity curves. Among 73 binaries with data from both sources, 11 have values of $e \cos \omega$ that differed by more than 0.05 between the two sources. If we eliminate the four systems with contemporary orbital elements showing zero eccentricity (for which ω is not defined), their periods are all <10 days. Their spectral types are B or A. However, this may not be a fair sample of binaries with gaseous streams because the discovered eclipsing binaries almost always are closely-spaced systems with short periods.

More generally, what are the limits in spectral types for the binaries that show the Barr Effect or that have gaseous streams that distort the velocity curves?

2. THE SEARCH

At the time of writing there were 2801 binaries with known spectroscopic orbital elements in the online SB9 catalog (Pourbaix et al. 2004). I selected from them the binaries whose primaries have types of O3-F9 V-lll, yielding about 1270 binaries. I eliminated those with grade 1 (out of 5 grades or "e" in Batten et al. 1989 catalog), if the grades were known. I also eliminated all orbits with $e < 0.05$. That left 570 binaries.

Those binaries were grouped by spectral type as shown in Figures 1 and 2. In the figures the binaries are grouped by values of ω as $0 \leq \omega < 90°$, $0 \leq \omega < 180°$, $180 \leq \omega < 270°$, and $270 \leq \omega < 360°$. The vertical scales of all six panels are the same. The dashed lines at 25% are drawn to show the expected probabilities with no Barr Effect. We see that for five of the panels (O3–O9.5 and B4–F9) the data points fit a fraction of 25%, with a mean deviation from the 25% lines of 0.0% and a scatter

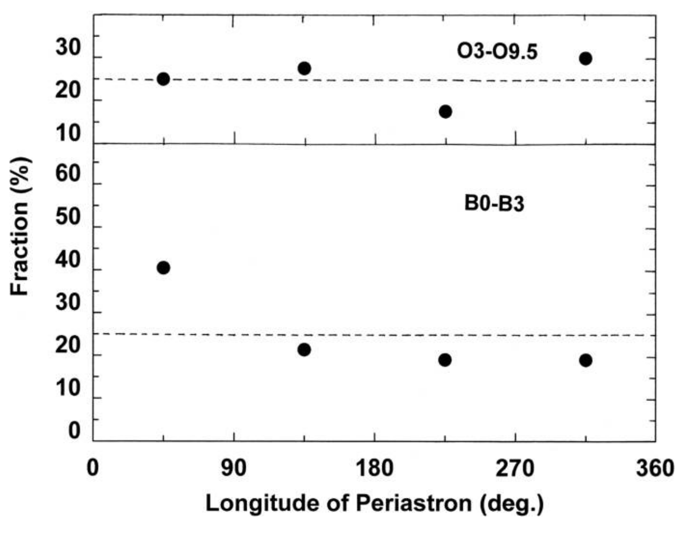

FIG. 1.—For the 84 binaries with B0–B3 V-lll primaries (lower panel) the data point for $0 \leq \omega < 90°$ is 7.4 σ above the mean for the other three data points, showing a nonrandom distribution of values of ω. The 40 binaries (*upper panel*) with O3–O9.5 V-lll primaries have a flat distribution within the accuracies of the counts. The *dashed lines* in both panels are at a fraction of 25%.

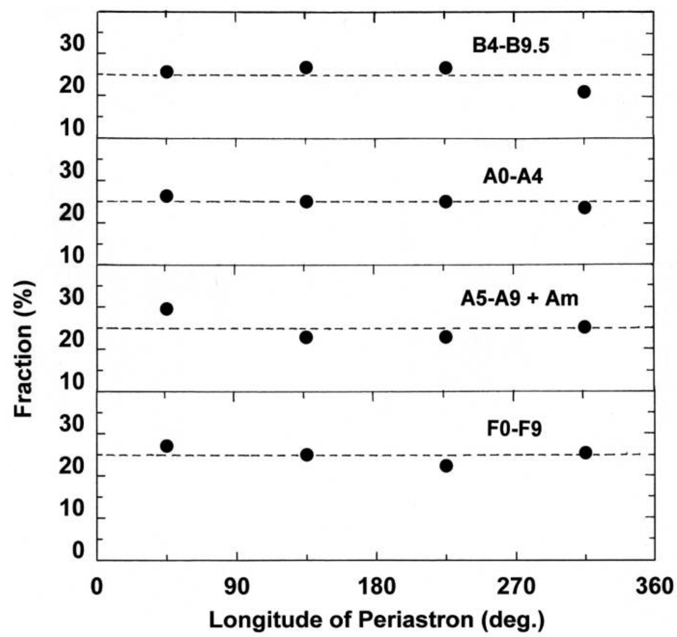

FIG. 2.—For 90 binaries with B4–B9.5 V-lll primaries (*top panel*), the four data points show a random distribution about fraction = 25% (*dashed line*). Similarly, for 76 A0–A4 V-lll binaries (*second panel*), 88 A5–A9 + Am binaries (*third panel*), and 192 F0–F9 binaries (*bottom panel*), the data points fit 25% frequency within the average standard deviation of 2.8%.

of ±2.8%. Therefore for those spectral types, the occurrence of the Barr Effect must be less than about 2.8%. However, for B0–B3 primaries, the distribution shows a strong preference for $0 \leq \omega < 90°$, just as Aitken and Struve found for all binaries. Therefore approximately 20% of all of the B0–B3 V-lll stars have gaseous streams that have strong enough absorption lines to contribute substantially to the primary's atmospheric lines and distort the velocity curves. If we count only the 47 binaries with periods <10 days, the fractions in the four quadrants are 40:26:13:21, not significantly different than for the 84 stars of all periods (40:21:19:19). However, this is a statistical study, not an astrophysical one that shows evidence of streams, so we have no new information about the distribution of periods for binaries showing the Barr Effect.

For the five bins outside of B0–B3 there is a mean scatter about the 25% line of 2.8%, while the data point for first quadrant for the B0–B3 primaries deviates from the remaining three points by 20.7% or 7.4 σ. For a distribution with a scatter of 2.8%, the statistical probability of a point at 20.7% is vanishingly small. Therefore the B0–B3 binaries seem to show a pronounced Barr Effect.

The binaries were binned by spectral type in bins of roughly 75 binaries per bin for statistical reasons. However, could the second bin be O9–B3 or B0–B5? At the risk of using too small samples, I found that the 16 O9–O9.5 binaries had a distribution for the four ranges in ω of 4:6:2:4, indicating no preference for

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$0 \leq \omega < 90°$. Therefore, O9–O9.5 binaries should not be included. For 14 B0 binaries the distribution is 8:2:3:1, indicating that B0 should be included. For the 23 B3 binaries the distribution is 9:2:6:6, indicating that B3 should be included. Finally, for 21 B4–B5 binaries the distribution is 4:6:3:8, indicating that B4–B5 should not be included. Therefore the spectral range showing the largest Barr Effect is B0–B3V-III.

I did not consider binaries with primaries later than F9 because their radial velocities would be based primarily on narrow metallic lines, not on the broad hydrogen lines that showed contributions from gaseous streams. Also Griffin (1991) showed that late-type binaries do not show a pronounced Barr Effect.

The average of the standard deviations of the data points for O3–O9.5 and B4–F9 primaries is 2.8%, so roughly that fraction of the remaining stars (outside B0–B3) may also have distorting streams. After all, of the seven eccentric systems for which Savedoff found substantial discrepancies between the light and velocity curves, two binaries (TX UMa, RU Mon) have B4–B9 primaries and three binaries (W UMi, AQ Peg, XX Cep) have A-type primaries.

3. CONCLUSIONS

We conclude that most of the binaries showing the Barr Effect are B0–B3 V-lll stars, but a few may have other B- or A-type primaries.

Recently it was found (Abt 2008) that many B0–B3 stars (singles and binaries) in open clusters have larger radial velocities than for the remaining stars. The current study showing that many binaries in the same spectral-type range have distorted radial velocity curves due to gaseous streams confirms the finding that their mean (gamma) velocities may also be abnormal.

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