EVIDENCE FOR APSIDAL MOTION IN BM MONOCEROTIS

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Abstract

BM Monocerotis has a rotation of the line of apsides with a period of 168 years, and an orbital eccentricity of 0.18. The evidence for this rotation and eccentricity is (1) the position of the secondary minimum (relative to the primary) has changed 0.062 period in phase over 23 years and; (2) the O-C curve (back to 1890) is not straight, and appears to be part of a sinusoid. This paper also reports on five minima timings, the light curve of BM Mon, and its spectrum.

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The variability of BM Monocerotis was discovered by Morgenroth (1933), who gave a range of magnitude 12.5 to 13.5 and classified it as an Algol-type eclipsing binary. Piotrowski (1934) gave a period of 1.24499 days, which later (Piotrowski 1947) was corrected to 1.244942 days. All of Piotrowski's observations were reported by Szafraniec (1962), along with a list of comparison stars. Wachmann (1968) presented thirteen minima timings, a detailed light curve, a good finder chart, and a period of 1.2449410 ± 0.0000009 days. Wachmann's photographic light curve shows a maximum at magnitude 12.18, with a primary minimum at magnitude 13.77. A secondary minimum at half phase is as faint as magnitude 12.29.

At the suggestion of Marvin Baldwin, I undertook a study of BM Mon during 1977 and 1978. I made 171 visual magnitude estimates using a variety of telescopes, including the 20-inch at Wellesley College. I used the sequence of comparison stars given by Szafraniec (1962). The light curve obtained from my observations is shown in Figure 1. Figure 2 shows the observations near minimum (folded around the time of minimum) in greater detail. Five minima were observed in enough detail for an accurate timing of minimum to be made. These deduced times of minima, along with their estimated errors, are included in Table I. The secondary minimum occurs at 0.562 ± 0.030 of a period in phase, and is near maximum light at half phase.

A secondary minimum which is offset from half phase means that the orbit of BM Mon must have appreciable eccentricity. Wachmann's (1968) light curve taken during the 1950's shows the secondary to occur at half phase. A shift in the phase of the secondary minimum (relative to the primary) implies that the orientation of the orbit is slowly rotating. This rotation of the line of apsides is caused by the oblateness of the two stars in the system. The rate of rotation of the lines of apsides provides information on the mass distribution inside the stars in conjunction with a radial velocity curve. Other than solar neutrino experiments, this is the only way to obtain direct information on stellar interiors, as checks on models of stars. Wood (1963) lists only sixteen stars which are known to have rotation of their lines of apsides.

An eclipsing binary whose line of apsides is rotating will exhibit a sinusoidal O-C curve for both primary and secondary minima, 180° out of phase with each other. The "true" - i.e., time-averaged - period may be found by use of the fact that the average time of a primary minimum and the successive secondary minimum will have a

straight O-C curve. A representative time halfway between primary and secondary minima, for Wachmann's data, is a quarter of a period after his 2434779.380 minimum. The corresponding time for my data is 0.281 of a period after 2443192.7179. With these values, a "true" period of 1.244951 ± 0.000004 days is found.

Information about the orbital eccentricity and rate of periastron advance can be found from an O-C curve for the star. I checked the magnitude of BM Mon on over 500 plates in the Harvard College Observatory's plate collection from the year 1890 on. The O-C curve based on these observations is shown in Figure 3. BM Mon does not have a straight O-C curve. This is best seen in the pre-1900 data, where the phase of mid-eclipse (around 0.05) is inconsistent with any reasonable linear extrapolation from published minima timings. I have drawn onto Figure 3 my judgment of the best fit curve. Using the method of de Kort (1956) I find an eccentricity of 0.18 and an apsidal motion period of 168 years. The argument of periastron, ω, equals zero in the mid 1950s. Due to the nature of the data, formal error estimates are hard to derive. An error of over 30 years in the apsidal motion period or 0.04 in eccentricity would, however, be hard to reconcile with the data.

During 1979, I took a spectrum of BM Mon using the Mark II spectrophotometer on the 1.3m McGraw-Hill telescope at Kitt Peak. The spectrum was single-lined, and typical of an early B-type star. Detailed analysis suggests that BM Mon is type B1, and is probably on the main sequence. With the absolute visual magnitude (M_V = 3.5) and color index (B-V = 0.28) typical for a B1-type star, and the apparent magnitude at secondary minimum (m_{pg} = 12.29), which should be approximately the apparent magnitude of the bright star alone, the apparent distance modulus is seen to be 16.1. For interstellar absorption of 1.9/kpc, a scale height of 140 pc, and a galactic latitude of 5°, this value corresponds to a distance of 4.1 kpc.

Further study of BM Mon would be worthwhile. A high dispersion spectrogram might reveal the presence of the fainter star. A radial velocity curve would yield information about the masses. A photoelectric light curve could be solved for the geometrical elements. And, additional times of primary and secondary minimum, especially photoelectric, would strengthen the interpretation of the O-C curve and the case for apsidal motion.

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TABLE I Timings of Minima of BM Monocerotis

EPOCH (JD)	PHASE	SOURCE
2413490.835	-0.012	HCO
15481.519	+0.018	HCO
15701.775	-0.010	HCO
15827.599	+0.004	HCO
16584.532	+0.011	HCO
21190.841	+0.025	HCO
22073.515	+0.034	HCO
25209.535	+0.039	HCO
26297.547	-0.030	Schwach
26332.411	-0.024	Schwach
27450.417	+0.021	Piotrowski
27455.395	+0.019	Schwach
27455.396	+0.0207	Piotrowski
27460.376	+0.0209	Piotrowski
27541.299	+0.0225	Piotrowski
28192.407	+0.0246	Piotrowski
29300.418	+0.015	HCO
29691.315	+0.019	Wachmann
29696.290	+0.015	Wachmann
29937.875	+0.080	HCO
30072.260	+0.011	Wachmann
30077.251	+0.023	HCO
31846.305	+0.0109	Piotrowski
31907.309	+0.0126	Piotrowski
31912.288	+0.0119	Piotrowski
32233.500	+0.028	Wachmann
32447.892	+0.291	HCO
32939.360	+0.004	Wachmann
2433677.593	-0.014	HCO
34769.380	-0.143	Wachmann
34779.380	-0.003	Wachmann
34794.325	+0.002	Wachmann
35044.570	+0.014	Wachmann
35160.332	-0.004	Wachmann
35165.317	+0.001	Wachmann
35486.510	-0.001	Wachmann
36253.388	-0.009	Wachmann
42475.630	+0.001	HCO
42745.777	-0.005	HCO
43181.5183 ± 0.0014	+0.0058	Schaefer
43182.7601 ± 0.0014	+0.0027	Schaefer
43192.7179 ± 0.0014	+0.0010	Schaefer
43482.798 ± 0.002	+0.009	Schaefer
43573.6688 ± 0.0010	-0.0011	Schaefer

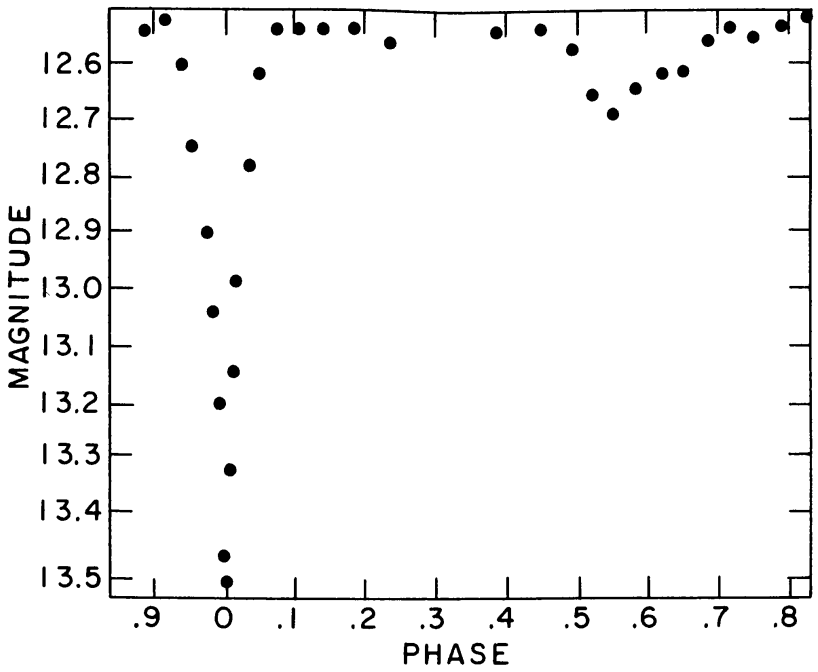

Figure 1. Visual Light Curve of BM Mon. Each point indicates the average of four or more visually estimated magnitudes. For this diagram, 171 points in all were used, of which 66 were in the primary minimum and 32 were in the secondary minimum.

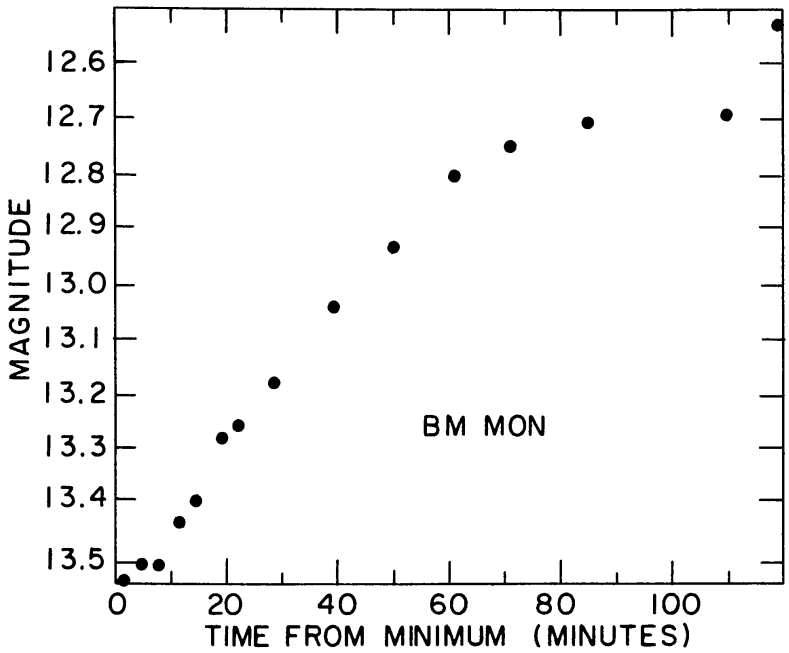

Figure 2. Primary Minimum of BM Mon, folded about mid-eclipse. Each dot indicates the average magnitude for the mean time plotted. Five or more magnitude estimates were averaged to form each dot.

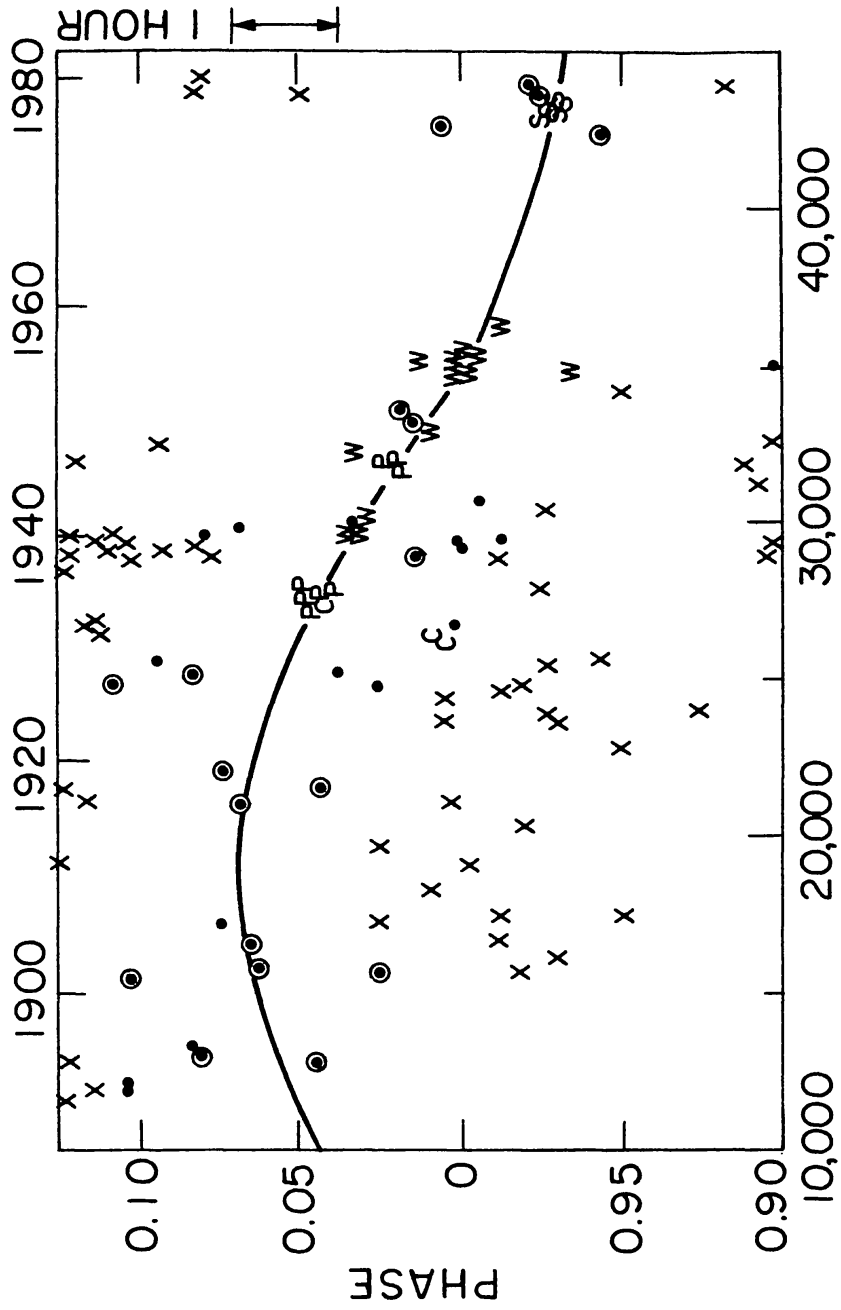

Figure 3. Modified O-C Curve for BM Mon. An "x" indicates a plate from Harvard College Observatory on which BM Mon was seen to be at maximum light. "⊙" or a "." is used to indicate whether BM Mon was brighter or fainter, respectively, than magnitude 13.0, a brightness level intermediate between maximum and minimum. One hour is a typical exposure time for these plates. "C", "P", "W", or "S" indicates times of minima observed by Schwach (Morgenroth 1933), Piotrowski (Szafraniec 1962), Wachmann (1968), or Schaefer (this paper), respectively. A period of 1.244951 days and epoch JD 2434799.380 were used in constructing this plot.