VISUAL AND PHOTOELECTRIC OBSERVATIONS OF BETA LYRAE, 1983-87

DAVID B. WILLIAMS
9270-A Racquetball Way
Indianapolis, IN 46260

Received 24 June 1988

Abstract

Visual observations of beta Lyrae from 1983 to 1987 and photoelectric observations from 1986 to 1987 have been used to determine nine normal times of primary minima. Current linear light elements derived from these observations are

$$\text{Min. I} = \text{HJD } 2445562.487 + 12.93465\ E.$$

* * * * *

Beta Lyrae is an interactive binary star system of extraordinary interest. Light variation is continuous, with two maxima at magnitude +3.4 and two unequal minima at +4.3 (primary) and +3.8 (secondary) during each 12.9-day orbital cycle.

The English amateur John Goodricke not only discovered its variability in 1784 (see Gilman 1978) but also noted the unequal minima and determined the period to the hour. Considering beta Lyrae's brightness and prominent location in a very recognizable constellation, it is amazing that beta wasn't the first non-eruptive variable star to be discovered. Goodricke himself pointed out that D. Cassini used beta and gamma Lyr as comparison stars for Nova Vulpeculae 1670 on many nights for more than a month. Cassini's non-discovery of beta Lyr has been examined by Herczeg (1987).

F. W. A. Argelander (1844; 1859) published the first detailed light curve of beta Lyr and discovered that the period was changing. Klimek and Kreiner (1973) analyzed almost 200 years of observations and found that eclipses can be predicted by the second-power light elements:

$$\text{Min. I} = \text{HJD } 2408247.953 + 12.913800\ E + 3.882 \times 10^{-6}\ E^2, \quad (1)$$

which represent a steady lengthening of the period by 19 seconds per year. The current understanding of beta Lyr has been lucidly presented by Tomkin and Lambert (1987).

I began making nightly visual estimates of beta Lyr in 1983. Estimates were made by decimal interpolation, using gamma and zeta Lyr as the comparison stars. Gamma, the nearest visible star to beta, is slightly brighter than beta at maximum. Zeta, marking the other adjacent corner of the Lyra parallelogram, is nearly equal to beta at primary minimum. On the scale of gamma = 0, zeta = 10, my estimates of beta ranged from 1 to 11. The unit interval is very close to 0.1 magnitude.

At mid-northern latitudes, beta Lyr can be observed visually from February to November. One observation per night is generally adequate. With a 12.9-day period, beta's brightness normally changes by less than 0.1 magnitude during the few hours before dawn in the spring, during short summer nights, or before setting in the autumn. However, within $\pm$24 hours of primary minimum, beta dims and brightens by more than 0.5 magnitude. During this steepest portion of the light curve, a second observation after several hours could be useful.

To form seasonal light curves and obtain times of minima, each estimate was reduced to orbital phase using the light elements:

$$\text{Min. I} = \text{HJD } 2436379.532 + 12.93016 \text{ E.} \qquad (2)$$

The phase of minimum light was determined from each seasonal light curve by the tracing paper method. Normal times of minima were then derived by calculating the predicted time of the minimum nearest to the mid-point of each season's observations and adding the difference, converted to days, between the observed phase of minimum and the predicted 0.0 phase.

Equation (2) was used for light curves of beta Lyr in three previous papers in this Journal (Landis et al. 1973; 1975; 1976), so I could compare the phase of minimum from my observations with photoelectric light curves from a decade earlier. The three annual light curves published by Landis et al. for 1972, 1973, and 1974 show the phase of primary minimum occurring progressively later than phase 0.0, at about phases 0.07, 0.08, and 0.09. Figure 1 is my light curve for 1983, which shows the phase of minimum later still, near phase 0.2. These observations indicate that the period in equation (2) is too short, as expected for a binary star whose period is lengthening with each orbital cycle.

While analyzing the first season's observations, I noticed that the phase of each estimate of beta fainter than zeta (beta = 11) was very close to the phase of minimum found from the composite light curve. When I took the mean of the phases of all these faintest observations, it proved to be virtually identical to the phase of minimum found from the full light curve. To my eye, beta never appeared fainter than zeta on two consecutive nights. Here, it seemed, was a method of determining times of minima for beta Lyr without recording, reducing, and plotting 75-100 observations.

I tested this method again in 1984 and obtained equally good results. But I also discovered that, due to the inevitable errors of visual observation, almost all the estimates of beta equal to zeta (beta = 10) fell in the same narrow phase range as the fainter-than-zeta estimates. The reduced observations showed that I could not consistently distinguish the 0.1 magnitude difference between equal-to and fainter-than zeta, so the mean phase of all observations of beta = 10 or 11 was used to derive a normal time of minimum for each season. (The difficulty in consistently noting when beta is fainter than zeta is almost certainly due to angle error as the orientation of beta and its two comparison stars change with advancing hour angle; see Williams 1987.)

During the next three years, I limited visual observations to recording the times when beta appeared equal to or fainter than zeta. In 1986, I also began photoelectric observations in the **V** passband with a 20-cm Newtonian reflector and Optec SSP-3 solid-state photometer. The photoelectric observations were reduced to phase and plotted as seasonal light curves to derive normal times of minima in the same manner as the visual light curves.

Figure 2 shows the photoelectric observations for 1986 and 1987. The two sets of data agree well except near primary minimum. Mass flux from the primary (brighter) component to the secondary produces variable absorption of the primary's light within about 0.03 phase of primary minimum (Wilson 1974). Near phase 0.0, the observations in 1987 are 0.15 magnitude fainter than the observations in 1986.

The photoelectric differential **V** measures for the two seasons are listed in Table II. Gamma Lyr was used as the comparison star, and each measure is fully corrected for extinction and transformation to the Johnson **V** system. The light of the close companion star beta-2 Lyr, +7.22 **V**, was included in the photometer diaphragm and has been removed from the listed observations by calculation. Almost all the observations represent the mean of three or four measures, and the standard deviation from the mean is given. In four instances, only two measures could be made, and the difference from the mean is indicated by an asterisk (*).

The times of minima determined by each method are listed in Table I. These nine times were used, with equal weight, to derive revised light elements for beta Lyr by least-squares linear regression:

$$\text{Min. I} = \text{HJD } \underset{\pm 0.130}{2445562.487} + \underset{\pm 0.00115}{12.93465}\ E. \qquad (3)$$

During the 25.1 years that elapsed between the initial epochs of equations (2) and (3), the period lengthened by 0.0045 day.

Figure 3 is an O-C diagram plotted according to equation (3). The second-power light elements of Klimek and Kreiner (equation 1) are represented by the dashed line. The diagram shows that the first three years of visual data and the photoelectric minima in 1986-87 agree well with equation (1). But the visual times of minima derived from the mean phase of the faintest estimates in 1986 and 1987 are significantly earlier than the photoelectric results. This suggests that determining the phase of minimum from the mean phase of faintest estimates is not always as reliable as determining the phase of minimum from a seasonal light curve, in which observations on the descending and ascending branches also contribute to the result.

The photometric disturbance of beta Lyr's light curve at primary minimum may cause faintest light to occur somewhat sooner or later than the actual time of mid-eclipse during a particular observing season. Also, observations of faintest light may not be distributed randomly around the time of mid-eclipse due to cloudy or missed nights. Nonetheless, noting when beta is equal to or fainter than zeta during the course of each observing season, and performing some simple calculations, is an easy way for casual observers to monitor the changing period of this important binary star system.

REFERENCES

Argelander, F. W. A. 1844, **De stella Beta Lyrae variabili disquisito,** Bonn.

______________________ 1859, **De stella Beta Lyrae variabili,** Bonn.

Gilman, C. 1978, **Sky & Telescope 56,** 400.

Herczeg, T. J. 1987, **Publ. Astron. Soc. Pacific 99,** 186.

Klimek, Z., and Kreiner, J. M. 1973, **Acta Astron. 23,** 331.

Landis, H. J., Lovell, L. P., Frazier, T. H., and Hall, D. S. 1973, **Journ. Amer. Assoc. Var. Star Obs. 2,** 67.

Landis, H. J., Lovell, L. P., and Hall, D. S. 1975, **Journ. Amer. Assoc. Var. Star Obs. 4,** 18.

____ 1976, **Journ. Amer. Assoc. Var. Star Obs. 4,** 80.

Tomkin, J., and Lambert, D. L. 1987, **Sky & Telescope 74,** 354.

Williams, D. B. 1987, **Journ. Amer. Assoc. Var. Star Obs. 16,** 118.

Wilson, R. E. 1974, **Astrophys. Journ. 189,** 319.

TABLE I

Normal Epochs of Primary Minimum for Beta Lyrae

Year	Min. I (JD)	O-C (Eq. 1)	O-C (Eq. 3)	Method *
1983	2445562.51	+0ᵈ06	+0ᵈ02	Visual, FE
	5562.57	+0.12	+0.08	Visual, LC
1984	5898.71	-0.08	-0.08	Visual, LC
	5911.66	-0.07	-0.06	Visual, FE
1985	6235.18	+0.03	+0.09	Visual, FE
1986	6635.88	-0.31	-0.19	Visual, FE
	6649.03	-0.09	+0.03	PEP, LC
1987	7011.41	+0.05	+0.24	PEP, LC
	7023.97	-0.32	-0.13	Visual, FE

*FE = mean phase of faintest estimates; LC = composite light curve

TABLE II

Differential V Magnitudes for Beta - Gamma Lyrae

HJD	ΔV	σ_1	HJD	ΔV	σ_1
2446589.774	+0.352	±0.013*	2446723.578	+0.156	±0.004
597.718	0.825	0.053	724.529	0.234	0.006
610.756	0.793	0.019	725.524	0.485	0.004
611.689	0.274	0.010	932.828	0.690	0.006
615.660	0.355	0.006	939.792	0.495	0.017
616.726	0.590	0.009*	942.722	0.089	0.011
617.659	0.342	0.008	948.698	0.181	0.012
618.646	0.189	0.006	950.703	0.186	0.003
619.637	0.129	0.011	951.782	0.315	0.001
628.692	0.369	0.019	952.699	0.526	0.002
629.700	0.548	0.015	960.720	0.403	0.006
630.823	0.277	0.011	961.680	0.165	0.007
633.663	0.123	0.006	971.690	0.674	0.009
634.653	0.328	0.021	974.826	0.157	0.002
635.650	0.884	0.003	975.665	0.152	0.002
639.680	0.154	0.004	993.697	0.221	0.007
641.627	0.392	0.002	994.691	0.118	0.009
642.639	0.557	0.006	997.701	0.792	0.005
643.653	0.290	0.003*	47023.665	0.923	0.004
646.763	0.136	0.004	024.679	0.982	0.029
647.761	0.355	0.006	025.667	0.356	0.006
661.642	0.945	0.006*	026.640	0.189	0.011
662.616	0.787	0.007	037.660	0.931	0.005
663.636	0.243	0.004	039.640	0.197	0.004
671.585	0.129	0.004	052.637	0.185	0.001
687.594	0.964	0.006	062.616	1.133	0.003
701.541	0.714	0.006	064.632	0.323	0.001
711.536	0.211	0.002	070.592	0.335	0.002
712.551	0.431	0.004	072.643	0.154	0.007
714.524	0.725	0.004	081.592	0.429	0.005
719.547	0.519	0.002	082.554	0.539	0.030
722.529	0.201	0.002	087.589	0.430	0.006

* only two measurements made

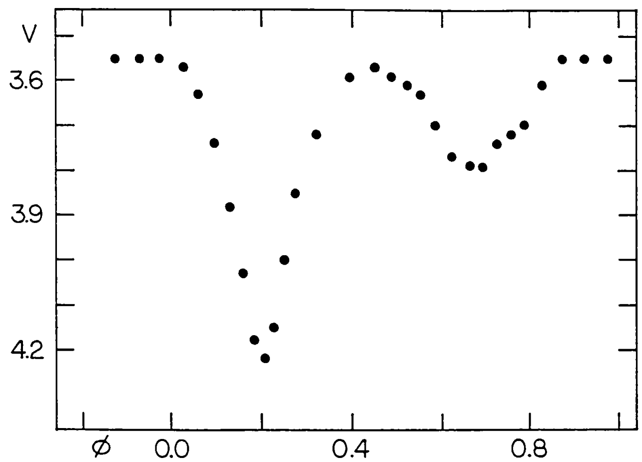

Figure 1. Visual light curve of beta Lyrae, 1983. Phases are calculated according to equation (2). Each point is a running mean of 6 estimates. The true heights of the maximum are supressed by about 0.15 magnitude due to the observer's systematic tendency to overestimate the brightness difference between two stars when that difference is small.

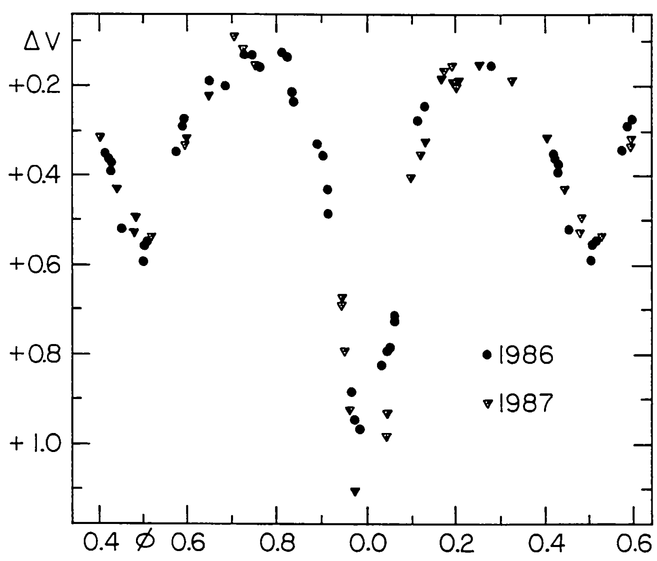

Figure 2. Photoelectric observations of beta Lyrae, 1986-87. Phases are calculated according to equation (3).

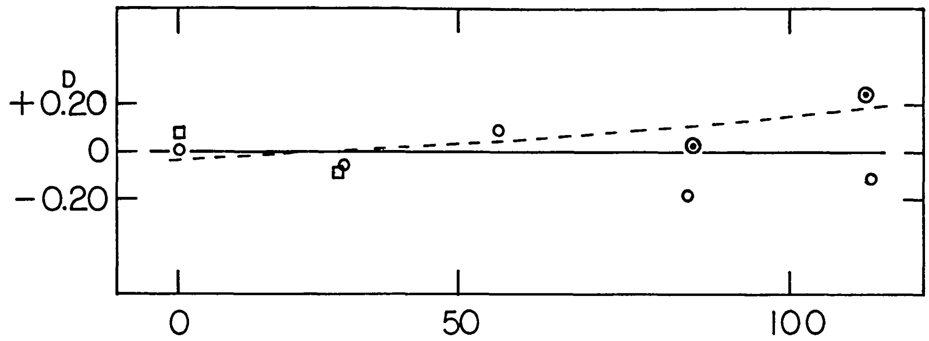

Figure 3. Beta Lyrae, observed minus calculated residuals according to equation (3), plotted against orbital cycles. Squares are minima from visual seasonal light curves; open circles are minima from the mean phase of faintest visual estimates; dotted circles are minima from photoelectric seasonal light curves. The second-power light elements of Klimek and Kreiner (1973) (equation 1) are indicated by the dashed line.