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VZ AQUILAE: A STUDY IN THE EVOLUTION OF A BL HERCULIS STAR

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Abstract

VZ Aquilae is presented as a BL Herculis star. An increasing period is determined and used to suggest evolutionary changes.

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The variability of VZ Aquilae was discovered by Oosterhoff (1943), and a period of 1.668239 days was reported by Kwee (1967a).

Tsesevich (1969) lists VZ Aql as a long period RR Lyrae-type star, while the General Catalogue of Variable Stars (Kukarkin *et al.* 1969) classifies it as a Population II Cepheid, or W Vir star. Kraft (1972) divides the W Vir stars into "loop" Cepheids, having higher luminosities with periods greater than 8 days, and "above the horizontal branch" (AHB) Cepheids, having lower luminosities with periods less than 8 days. Schwarzchild and Harm (1970) have shown that for a star on its second trip up the red-giant branch a sharply blueward path into the instability strip is caused by helium shell flashes. This model corresponds to Kraft's loop Cepheids. The designation "W Vir star" is now often reserved for this longer period subgroup of Population II Cepheids. The AHB stars are referred to as BL Her stars (Smith *et al.* 1978). Strom *et al.* (Gingold 1976) have suggested that BL Her stars are post-horizontal branch stars that have exhausted the helium in their cores and are now moving towards the asymptotic giant branch.

The light curve of a BL Her star is characterized by a steep rising branch, a pronounced maximum, a secondary hump or shoulder on the descending branch, and possibly a small hump at the base of the rising branch (Kwee 1967b). Figure 1 is a mean light curve for VZ Aql from JD 2429757 through JD 2434653, June, 1940, through October, 1953. Features that characterize short period Population II Cepheids or BL Her stars are clearly seen. These features, along with its period, suggest that VZ Aql is a BL Her star.

During the summer of 1983, while working as a research assistant at the Maria Mitchell Observatory (MMO), the author investigated VZ Aql. Magnitude estimates were taken from 950 NA photographic patrol plates covering the period JD 2425062 through JD 2445563, June, 1927, through August, 1983. Estimates were made using a comparison sequence with magnitudes based on Marjorie Williams' unpublished sequence obtained at MMO. Phases were calculated using the ephemeris given by Kukarkin *et al.* (1967):

$$\text{JD } 2438231.625 + 1\overset{d}{.}668239 \text{ E.} \qquad (1)$$

One seasonal light curve with a maximum determined from the bisection method (Campbell and Jacchia 1941) was used as a standard to determine times of maximum for other individual light curves. From equation (1) an O-C diagram was constructed for the years 1927 through 1982. Figure 2 shows this O-C diagram. A parabola was best fitted to the data using the method of least squares. The new elements found are:

$$\text{JD}_{max}(\text{hel.}) = 2442967.756 + 1.668270 \text{ E} + 2.67686 \times 10^{-9} \text{ E}^2. \qquad (2)$$

$$\pm 0.008682 \quad \pm 0.000003183 \quad \pm 2.97163 \times 10^{-10}$$

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The equation for the best fitted parabola predicted an O-C value for the year 1983 of 0.032. The observed value of 0.03 is an indication of the accuracy of the parabola in describing the observed data.

From equation (2) a rate of increase in the period was found to be $7.02 \times 10^{-7} \pm 0.78 \times 10^{-7}$ cycles per year. Rates of change in periods found in BL Her stars could be due to evolution and are good indications of their evolutionary stages (Wehlau and Bohlender 1982). It is interesting to note that of the twelve BL Her stars in Wehlau and Bohlender's paper, nine had increasing periods while three had such small increases that they were thought to be constant. With these results in mind, an evolutionary model was sought which would fit both the period and the rate of change in the period of VZ Aql. Rates of change in periods were computed using values given by Gingold (1976) for times spent in the instability strip. Periods were determined from densities using the period/density relationship:

$$P\sqrt{\rho} = Q. \qquad (3)$$

To find the periods for models, the pulsation constant, Q, for BL Her stars was first computed. From Table II of Demers and Harris' paper on the instability strip of Population II Cepheids four BL Her stars with periods close to that of VZ Aql were chosen (Demers and Harris 1974). The effective temperature and the luminosities in solar units were given. From:

$$\frac{L}{L_\odot} = \left(\frac{R}{R_\odot}\right)^2 \left(\frac{T_e}{T_{e\odot}}\right)^4 \qquad (4)$$

a radius for each star was computed. Assuming a mass of 0.6 solar masses, the density for each star was determined from:

$$\frac{\rho}{\rho_\odot} = \frac{M/M_\odot}{R^3/R_\odot^3} \qquad (5)$$

Taking the log of equation (3) gives a linear relationship between density and period:

$$\log P = -1/2 \log\rho + \log Q. \qquad (6)$$

A graph plotting the period against the density of the four BL Her stars was constructed and a line with a slope of -1/2 was forced through the points. A value of the intercept, logQ, was found to be -1.42, or Q = 0.038, for BL Her stars. This value of Q was then used in equation (3) to find periods for the models.

Tracks computed by Gingold (1976) for stars having a heavy element abundance of 0.001, a helium envelope abundance of 0.3, and an initial core mass of 0.4664 $M_\odot$ were used to find a model that best described VZ Aql. Of the Gingold models, the best model found was that of a star with total mass of 0.527 $M_\odot$, a period of 2.2 days, and an increase in period of 2.89×10^{-7} cycles per year. The model was moving redward on its third trip through the instability strip.

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1983JAVSO..12...54C

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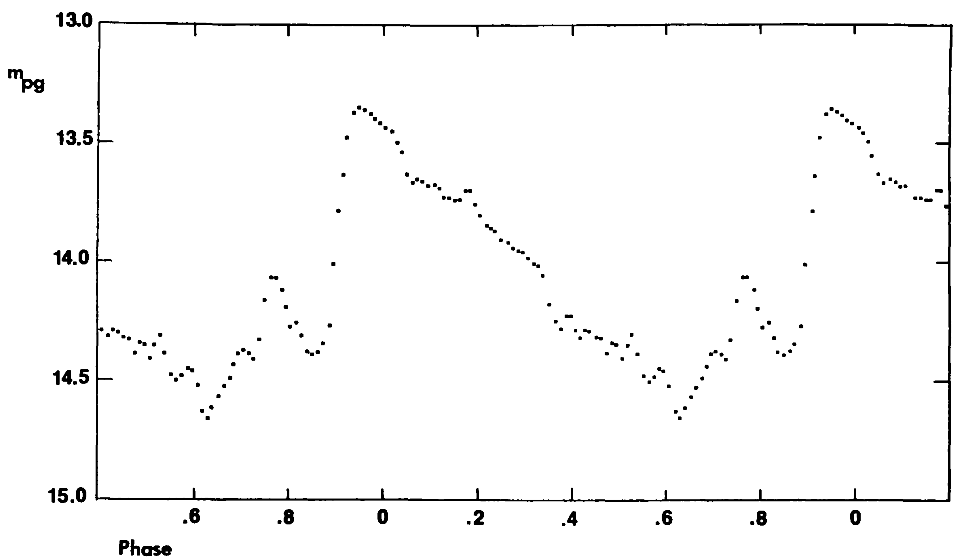

Figure 1. Mean photographic light curve of VZ Aql for years 1940-1953. Phases were computed from the ephemeris JD 2438231.625 + 1.668239 E.

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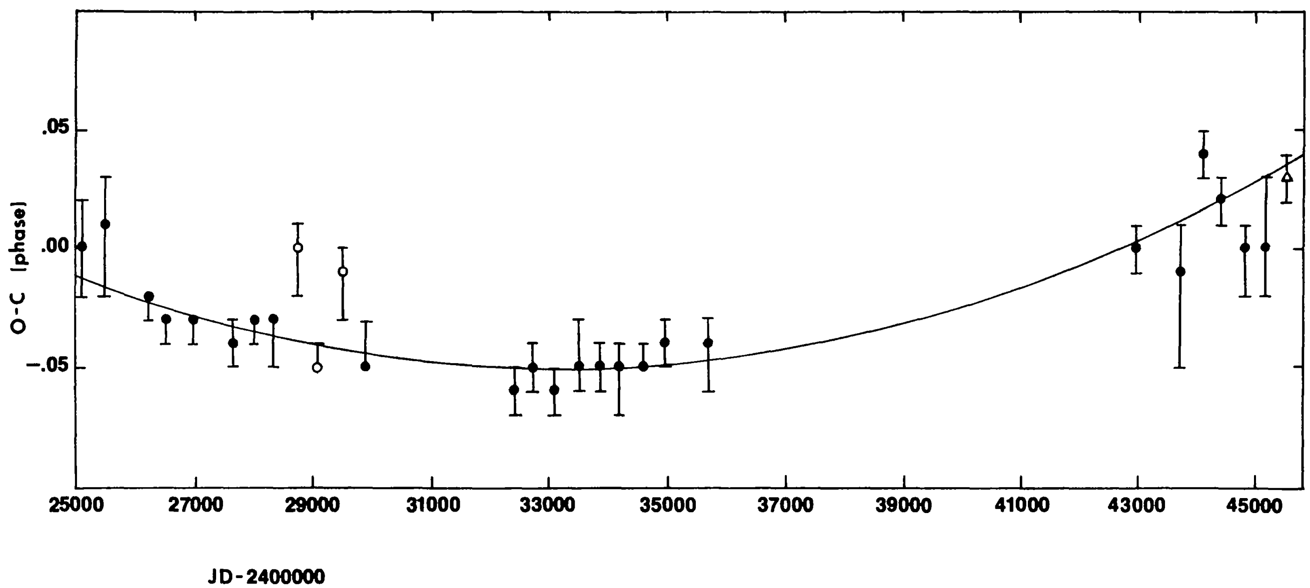

Figure 2. O-C diagram for VZ Aql for years 1927-1983, calculated from JD 2438231.625 + 1.668239 E. The parabola represents the least squares solution. Bars indicate the greatest possible uncertainty in determined times of maximum. Open circles (o) are points computed from Williams' unpublished data; filled circles (●) are the author's data; the open triangle (Δ) is the O-C value for 1983 found after the least squares solution was computed.

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