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PERIOD REVISION AND REFINEMENT FOR V960 AQUILAE

DAVID WILNER
Maria Mitchell Observatory
Nantucket, MA 02554

Abstract

The RR Lyrae variable V960 Aquilae was examined for period changes in the interval 1931 through 1985 on plates of the Maria Mitchell Observatory collection. Previously published linear elements have been revised; the new elements are:

$$JD_{(max)} = 2445965.575 + 0.6271527\ E. \qquad (1)$$

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1. Introduction

V960 Aquilae, an RR Lyrae variable, was discovered in 1939 at the Maria Mitchell Observatory (MMO) by John Heath. Elements were determined by Bakos using data gathered from the Leiden plate collection (Harwood 1962). In the present study, the star was examined for deviations from the published elements using observations from all of the available MMO plates from 1931 through 1985.

2. Observations

More than 1100 plates with centers in the Scutum field have been taken at MMO since 1931 and a large fraction contain images of V960 Aql. The star's photographic magnitude, which varies from 14.1 to 15.7, was estimated using the same sequence of comparison stars employed by Bakos. Examination of the plates resulted in 667 data points considered useful for further analysis. Data from plates taken prior to 1931 and approximately 170 magnitude estimates deemed to be of inferior quality were rejected.

Intervals containing few or no plates occur between 1941 and 1946 and also between 1957 and 1974. These gaps, however, did not present difficulties in the determination of revised elements.

3. Analysis

From a least squares solution using 29 observations on the rising branch of the light curve, Bakos derived the heliocentric elements

$$\begin{array}{llll} JD\ 2428729.463 & +\ 0.627162\ E & -\ 0.009\ (s-3.0). & (2) \\ \pm 0.004 & \pm 0.000004 & \pm 0.002 & \end{array}$$

The parameter "s" in equation (2) refers to the step value Bakos assigned to the brightness of the sequence stars. Equation (2), then, finds the times when the star is expected to be at s = 3.0 (photographic magnitude 15.05) on the rising branch. The JD of maximum was taken to be 2428729.489 (Harwood 1962).

A standard O-C analysis (see Tsesevich 1969, e.g.) was performed based on this epoch of maximum and the period in equation (2). An IBM PC was used to compute the heliocentric phase for each of the Nantucket observations and the data were partitioned into groups of one or two observing seasons. The resulting composite light curves were then compared with each other to detect phase shifts over time. The procedure involved MMO library software that performs a non-linear least squares fit of each data set to a standard light curve.

(Belserene 1986). The program determines the best fit for the entire curve rather than just rising branches or extrema and hence provides more accurate O-C data. Bakos' mean light curve of 29 points reduced from 279 observations served as the standard. The phase shifts for 25 sub-intervals containing from 13 to 59 points were then plotted in an O-C vs. JD diagram (Figure 1) to verify Bakos' elements and to determine if any substantial period changes had occurred. The error bars in the figure indicate plus and minus one standard deviation as calculated by the non-linear least squares program.

The most striking feature of this O-C diagram is the constancy of the period over the entire range of 55 years. A line fitted to the points by least squares results in the elements

$$JD_{(max)} = \underset{\pm 0.005}{2445965.581} + \underset{\pm 0.0000003}{0.6271529}\ E. \qquad (3)$$

The discrepancy with Bakos' period in the fifth decimal place is probably due to the shorter interval (1935 - 1939) and smaller data set with which he worked, and the strong dependence he placed on the slope of the rising branch. See Belserene (1983) for a description of the method used to derive mean errors from the variation of the sum of the squares of residuals in the vicinity of their minimum.

In addition to the period revision, equation (3) presents a significant change in the time of maximum as predicted by equation (2). This can be traced to the fact that the JD of maximum as published by Harwood is not consistent with Bakos' mean light curve. According to unpublished material at MMO, it represents a linear extrapolation along the rising branch to the brightest step value of the mean light curve; the actual point of maximum brightness occurs 0.028 day later than such a linear extrapolation suggests. The open circle in Figure 1 illustrates Bakos' epoch after this correction has been applied. This point was not used in the above analysis, but it is clearly consistent with the new epoch and period.

The next step was to create a composite light curve of all 667 Nantucket observations using the elements of equation (3). A mean light curve was then formed by averaging the composite curve in 40 overlapping phase bins using a 3-bin triangular smoothing filter. This mean light curve is closely comparable to Bakos'. It spans the same range of magnitudes and contains a similar dip before the rising branch and a similar bump on the descending branch. The entire O-C procedure was repeated with the new elements and with the new mean light curve serving as the standard, in the hope of improving the accuracy of the revised elements. The resulting O-C diagram (Figure 2) is nearly a horizontal line at zero as expected. Least squares analysis of the O-C data results in the final linear elements

$$JD_{(max)} = \underset{\pm 0.004}{2445965.575} + \underset{\pm 0.00000014}{0.62715271}\ E. \qquad (4)$$

Note the small improvement in the quoted error in comparison to equation (3).

A least-squares parabola was also fitted to the O-C data. The elements corresponding to the parabola are

$$JD_{(max)} = \underset{\pm 0.005}{2445965.572} + \underset{\pm 0.0000007}{0.6271520}\ E - \underset{\pm 2 \times 10^{-11}}{2 \times 10^{-11}}\ E^2. \qquad (5)$$

The functional form of a second degree polynomial implies a constant rate of change of the star's period. The F-test (Pringle 1975) gives a probability of 67% for the coefficient of the parabolic term being non-zero. Thus, the curvature should not be considered statistacally significant.

Figures 4 and 5 are final composite and phase-averaged light curves created with the 667 Nantucket observations and equation (4). The skew of the light curve confirms that V960 Aquilae is an RR Lyrae star of type **ab**.

4. Acknowledgements

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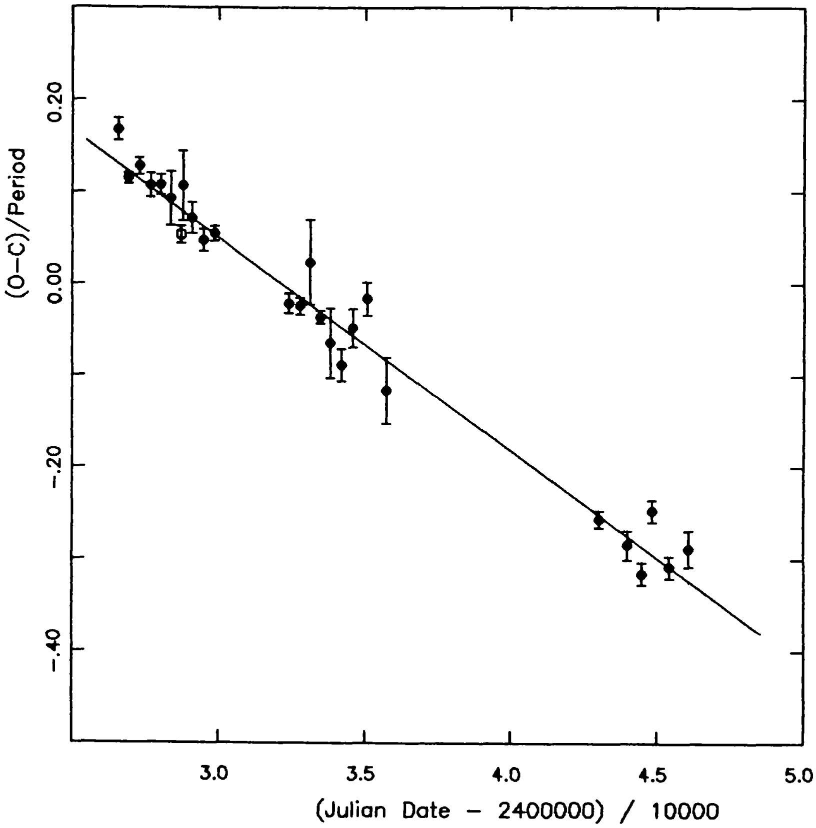

Figure 1. O-C vs. Julian Day for V960 Aql, based on the elements in equation (2). Filled circles are Nantucket data; the line corresponds to the elements in equation (3). The open circle, which was not used in the analysis, represents the previously published elements corrected for a new definition of the light curve's maximum (see text). O-C is given in fractions of the period.

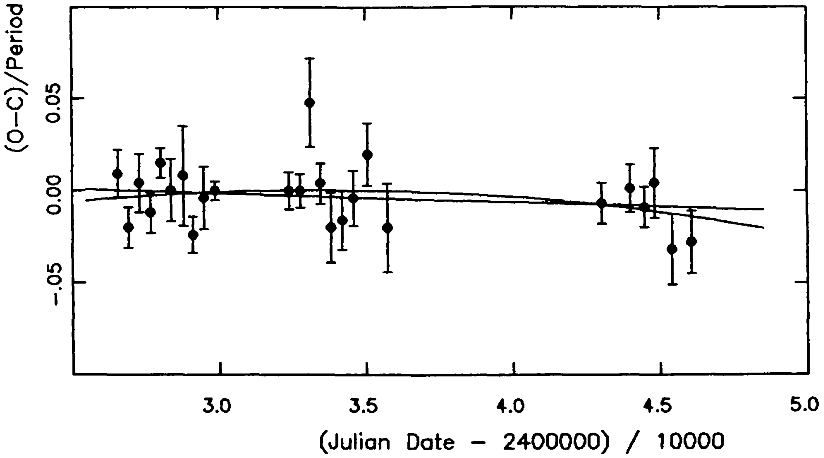

Figure 2. Final O-C diagram for V960 Aql, based on the elements in equation (3). All points are from the Maria Mitchell Observatory. Elements derived from the line and the parabola are given in equations (4) and (5).

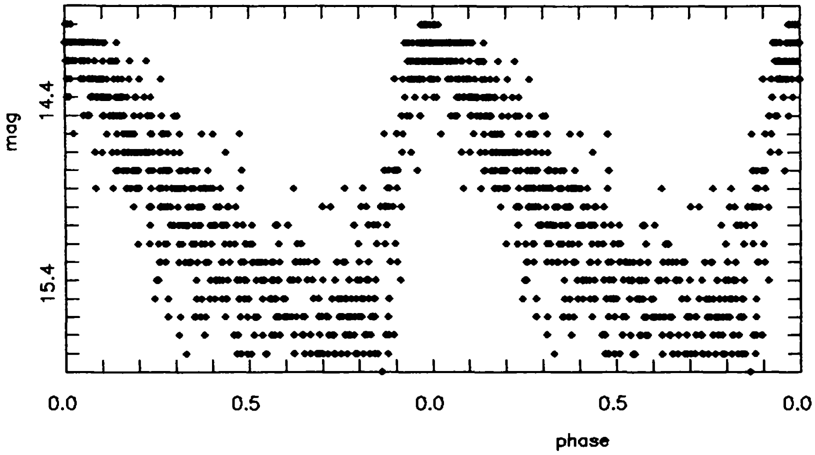

Figure 3. Photographic magnitudes of V960 Aql from 1931 through 1985 plotted against phase.

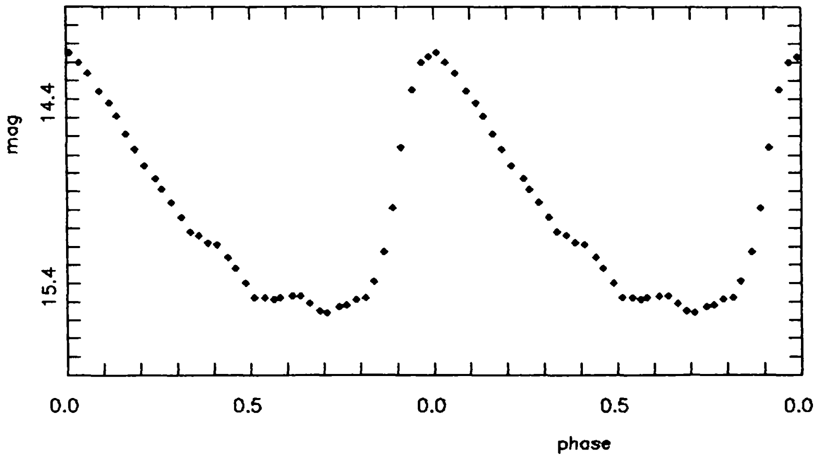

Figure 4. Phase averaged light curve from the observations in Figure 3.