THE COMPLICATED PERIOD CHANGES OF IV CYGNI

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Abstract

IV Cygni is a short-period RRab star with frequent period changes. Data spanning the years 1948-1990 are analyzed. Two previously known periods are confirmed, and four new periods are presented.

IV Cygni, a fourteenth magnitude RR Lyrae star of the sub-type RRa, has previously been subjected to period analysis by Tsesevich (1969) and Belserene (1978) for the years prior to 1978. Tsesevich presents a constant period of 0.33433895 day for 1950-1960. Belserene's work extends this period to 1969, and she presents a new period of 0.3343322 day for 1969-1978.

IV Cyg was well monitored via the photographic plate collection of the Maria Mitchell Observatory from 1965 to 1990, with an additional set of twenty-one images present on 1948-1959 plates. Magnitude estimates taken from these plates were divided into sections by year, with an average section containing twenty-six points. Folded light curves were produced using Belserene's ephemeris:

$$JD_{max} = 2440338.214 + 0.3343322\ E. \qquad (1)$$

The phase shifts of the maxima of these light curves were found by fitting a smoothed, characteristic curve to each light curve through computerized, non-linear least squares analysis (Belserene 1986). The computer calculated the fraction of a period by which the maxima of these curves were displaced from the zero point predicted with equation (1). Additional (O-C)/P values for 1948-1965 were calculated using the heliocentric dates of maximum listed by Tsesevich (1969) in his Table 3. These dates of maxima were used as O, observed maxima, and (O-C)/P values were calculated directly.

Creating a plot of (O-C)/P values, as a function of the average JD of the data from which they were created, provides a detailed picture of the period changes of a star such as IV Cyg. If the calculated times of maximum agree with the observed times, then the curve will have a slope of zero. But if the star's period is longer than the period in the ephemeris, the observed times of maximum will lag behind the computed times. This would result in an increase in (O-C) values as time goes on and the slope of the curve would be positive. Similarly, a shorter period would result in a negative slope of the curve.

As shown in Figure 1, IV Cyg appears to have undergone at least two major period changes since 1948, and, as this paper suggests, may have undergone as many as five period sudden changes. Table 1 lists six subsets within which the (O-C)/P data appears to be linear. The line segments provide characteristic epochs and periods for each time interval. The revised epochs and periods in Table 1 were calculated from the slopes and intercepts of the six least-squares lines. Although several of these sets might have been combined to produce an average epoch and period for a longer span of years, doing so increases the uncertainty in the elements produced by linear analysis.

The epochs and periods calculated from the six data sets reveal several new things about IV Cyg's period changes. The period obtained from Set 1 confirms Tsesevich's period within error and extends it to 1965.8. Set 2 represents a decrease to provide a new period in 1965.8-1969.7, contrary to Belserene's earlier findings. In 1969-1970, IV Cyg experienced yet another period decrease. The period then remained constant at 0.3343320 day for the next nine years (Set 3), which agrees within error with Belserene's analysis of these years. A positive period change takes place sometime between 1978-1980.

Table 1. IV Cyg Periods From Latest Data Analysis

Interval	*Epoch*	*Period*	*Period Change*
Set 1 1948.6 - 1965.8	2434611.6599 $\pm$0.0015	0.3343387^{d} $\pm$0.0000003	
Set 2 1965.8 - 1969.7	2440169.0377 $\pm$0.0003	0.3343350 $\pm$0.0000002	0.0000037^{d} $\pm$0.0000004
Set 3 1969.7 - 1978.7	2442011.5448 $\pm$0.0011	0.3343320 $\pm$0.0000003	-0.0000030 $\pm$0.0000004
Set 4 1979.6 - 1983.7	2444906.8654 $\pm$0.0004	0.3343356 $\pm$0.0000003	+0.0000036 $\pm$0.0000004
Set 5 1984.7 - 1987.6	2446407.3829 $\pm$0.0008	0.3343398 $\pm$0.0000005	+0.0000042 $\pm$0.0000006
Set 6 1988.4 - 1990.4	2447617.7156 $\pm$0.0014	0.3343372 $\pm$0.0000014	-0.0000026 $\pm$0.0000015

After Set 4 the situation is less clear. The spaces existing between the line segments of Set 4 and Set 5 and again between Set 5 and Set 6 may indicate very sudden changes in the period, each occurring over several months at most. To further investigate this problem, the magnitude estimates from 1987 were divided into smaller subsets. The composite 1987 light curve shows some horizontal scatter, and these smaller subsets might have revealed whether this scatter was due to a sudden period change or just poor magnitude estimates. Unfortunately, these subsets were too small to be used to produce distinct light curves and the evidence was inconclusive.

In light of these new data, the substantial, sudden period changes discussed by Tsesevich (1969) and Belserene (1978) can be reconsidered. Although the data above can be satisfied by five sudden period changes occurring in 1948-1990, those period changes are smaller than previously noted. Figure 1 also shows that a set of six line segments is not the only way to investigate these period changes. Whereas the use of line segments provided characteristic periods for chosen sections of the data, other subsets demonstrate parabolic change. Two sections of data, one ranging from 1965.8 to 1971.6 (Figure 2) and the other from 1977.6 to 1983.6 (Figure 3), were analyzed using least-squares fitted parabolas. The rate of change of the period in 1965.8 - 1971.6 in days per year was -0.0000004 $\pm$ 0.0000002. In 1977.6-1983.6, the rate of change in days per year was +0.0000012 $\mp$ 0.0000005. Therefore, although IV Cyg's period changes at first do appear to be small and sudden, the possibility of larger spans of more complicated, continuous change cannot be ruled out without considering a larger sample of data.

An underlying pattern in IV Cyg's complicated period changes may be present in the results of this O-C analysis. The sizes of the period changes between successive sets of years are virtually identical, with all but one agreeing with an average period change of 0.0000034 day, within the uncertainty. The period first decreases by approximately this fraction of a day and then decreases again as demonstrated by the slopes of Set 2 and Set 3. Next, in 1979 (the beginning of Set 4), IV Cyg demonstrated a sudden increase in the period by this same fraction of a day, within the uncertainty. The period of Set 4 is slightly longer than the period for Set 2. The period for Set 5 is slightly longer than the period for Set 1. Set 6 shows that the star's period decreases again to a value which corresponds to the period for Set 4. The slopes of the line segments in Figure 1 visually reveal this pattern. The apparently large, sudden changes in the gaps before and after Set 5 are the only features of the diagram which contradict this preference for certain periods.

This series of increases and decreases in IV Cyg's period might be the result of some long-term, repetitive variation of the star, in addition to the readily observed 0.3343 day pulsations. Belserene (1978) relates the process of semi-convection to IV Cyg's sudden period changes. If the pattern revealed by this recent analysis is not simply a coincidence, this analysis suggests a pattern in the semi-convective events or in whatever causes these sudden period changes. Subsequent values of (O-C)/P for the years following 1990 would be of interest in investigating this effect.

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References

Belserene, E. P. 1978, *J. Amer. Assoc. Var. Star Obs.,* 7, 76.
Belserene, E. P. 1986, *J. Amer. Assoc. Var. Star Obs.,* **15**, 243.
Tsesevich, V. P. 1969, *RR Lyrae Stars,* trans. from Russian.

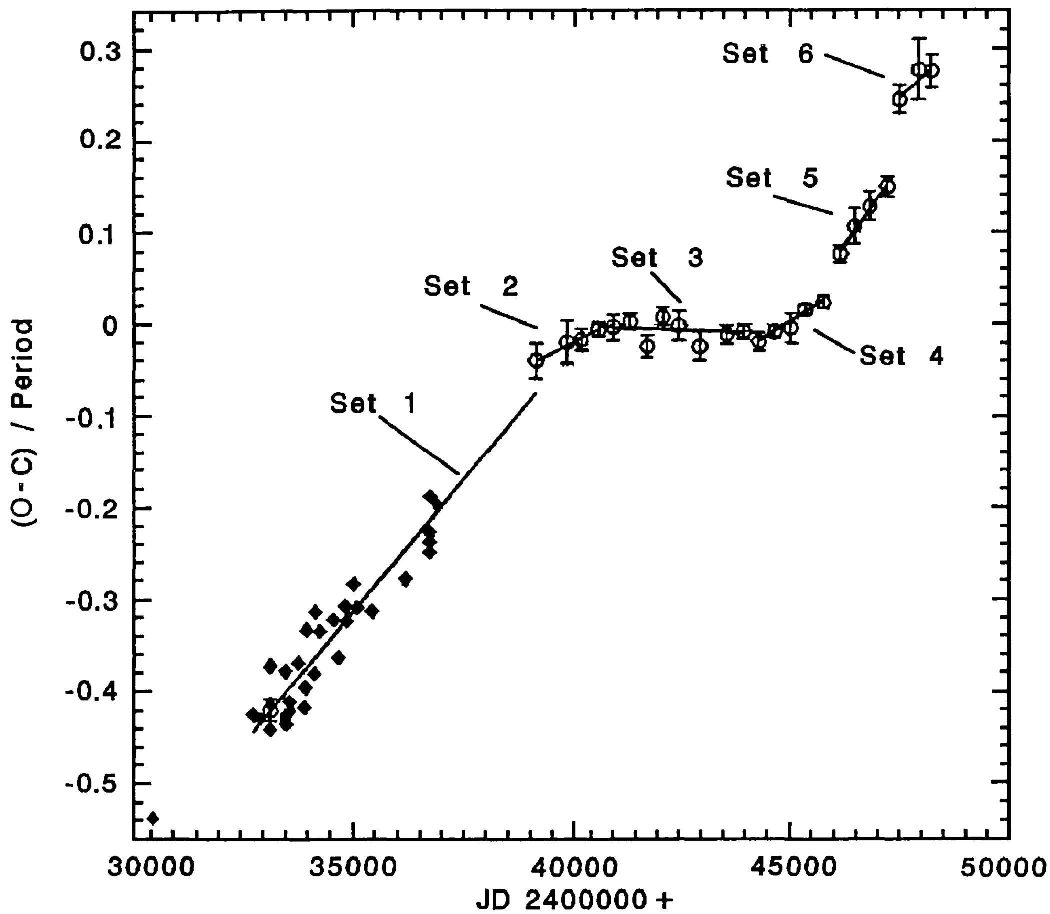

Figure 1. (O-C)/P diagram for IV Cyg for the years 1928-1990. The open circles are the Maria Mitchell Observatory data. Error bars came from non-linear least squares analysis. No error information was available for Tsesevich's (1969) observed maxima (diamonds). Least-squares line segments are shown. Changes in the slopes represent changes in the period.

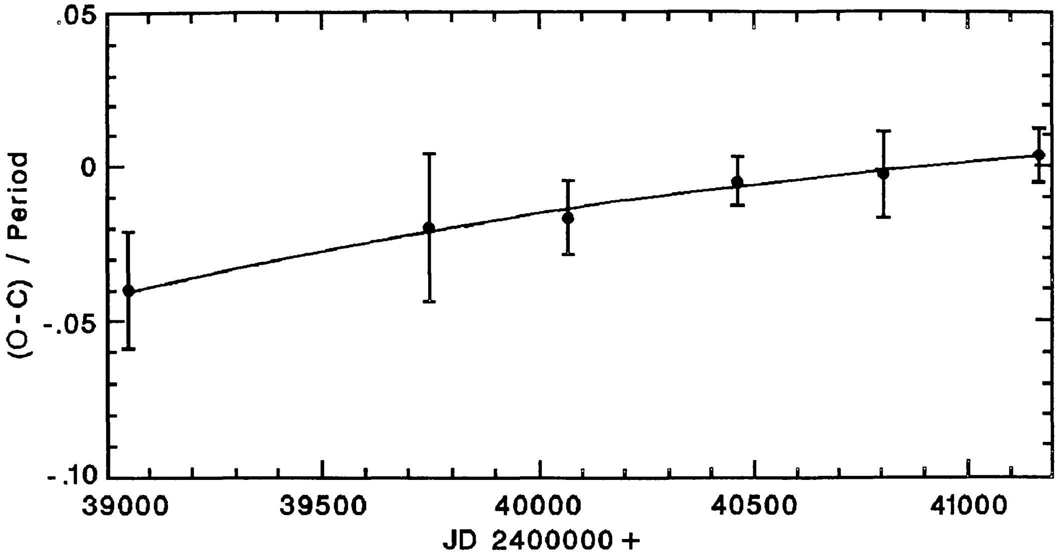

Figure 2. (O-C)/P diagram for IV Cyg for the years 1965-1971. A least squares fitted parabola is indicated. The rate of change in the period indicated by this parabola in days per year is -0.0000004 ± 0.0000002.

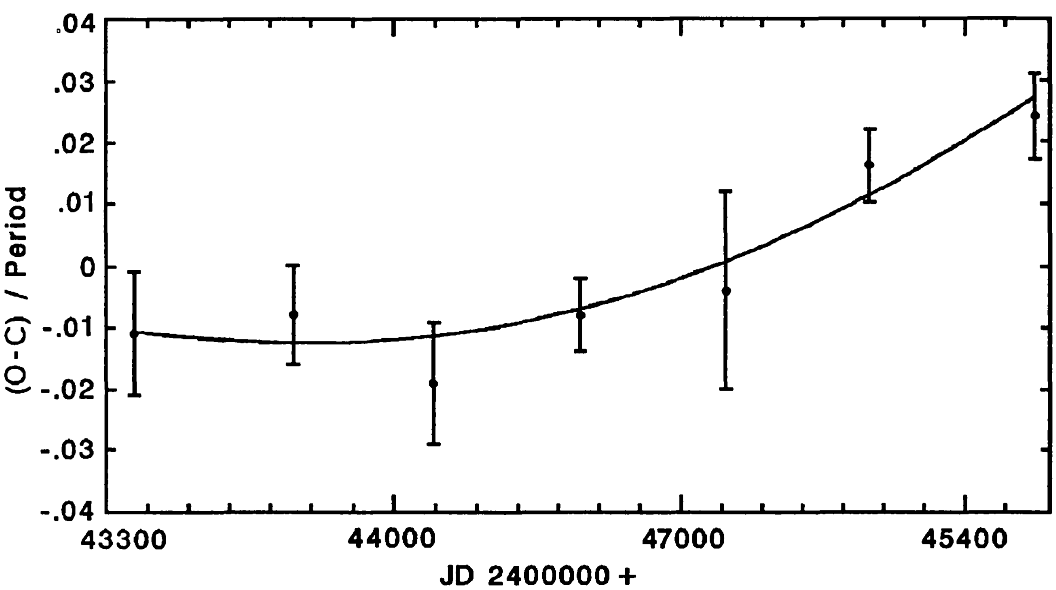

Figure 3. (O-C)/P diagram for IV Cyg for the years 1977-1983. A least squares fitted parabola is indicated. The rate of change in the period indicated by this parabola in days per year is +0.0000012 ± 0.0000005.