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THE PERIODICITIES OF Z URSAE MAJORIS

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Abstract

A Fourier analysis of the AAVSO visual light curve of Z Ursae Majoris shows that the cycle of variation is currently 195.5 days with an unstable superposed period of about 205 days. There is no sign of the reported 1560 day period.

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1. Historical Summary

Z Ursae Majoris was discovered to be variable by King (Miller *et al*. 1918) on Draper Memorial plates taken between 1897 and 1904. Early observations by Enebo (1907) seemed to indicate a periodicity of 102 days, though further work by him and Pracka (1909) approximately doubled the derived period to 205 days. A marked disturbance in the light curve occurred in 1909, during which the minima became irregular and the period decreased from 205 days to 180. (Unfortunately, I have been unable to find the light curve for this disturbed portion.) Loreta (1940) found that later patterns of variation were similar to those existing before the 1909 disturbance, namely, a secondary maximum reminiscent of the Cepheid variable Eta Aquilae, although highly irregular. (See Figure 1.) He derived a primary period of 198.3 days and a secondary period of about 1560 days.

The *General Catalogue of Variable Stars* (Kukarkin *et al*. 1969) lists a primary period of 196 days and a secondary period of 1560 days. The light curve is described as being "like RV Tauri with clear second minima," but the present analysis shows that these statements are somewhat unsatisfactory.

The spectral class of Z Ursae Majoris has been quoted as M5eIII and as M6eIII (Miller 1953; Keenan and McNeil 1976). Assuming that the star is a typical semi-regular red giant of spectral class M6eIII, its absolute magnitude would be $M_V = 0.3$ at maximum, so its apparent magnitude, $m_V = 7.0$, implies a distance of 220 parsecs. The published proper motion of 0.029 arc-sec/year (Wilson 1953) implies a tangential velocity of 30 km/sec at 220 parsecs. Merrill (1923) finds an absorption-line velocity of -53 km/sec with respect to the sun, suggesting a space velocity of about 61 km/sec. (The emission-line velocity was -59 km/sec.)

There is no evidence that this star is a spectroscopic binary.

2. Methods: Fourier Analysis of the Light Curve and Search for the Smallest Standard Deviation

A "Fourier series" representation of a light curve is a sum of sine and cosine curves, each of which has a distinct *frequency* and *amplitude* determined by the nature of the whole light curve. If the sine and cosine curves (which we will call the "wave-like components" in what follows) are then added together, with the appropriate relative amplitudes, the result will be a reconstruction of the original light curve.

The results of such a representation are often displayed as a "power spectrum," which shows the relative importance of the wave-like components of different frequencies (or periods) in the representation of the light curve. (Mathematically, the power spectrum as used in this paper is a plotted curve, in which the x-axis is the period of the sine and cosine curves and the y-axis is the sum of the squares of their amplitudes.) For example, the power spectrum in Figure 2 shows a large amplitude between 175 and 200 days, indicating that the wave-like components with those periods are most important in this data sample.

One method of analysis that we shall employ is the Fourier analysis based on the so-called "Fast Fourier Transform" (FFT) developed during the 1960s. A limitation of this method is that the data of the light curve are arranged in ten-day running means, and we cannot infer anything about the components that have periods less than about four times this value, or 40 days.

We shall also use a method based on searching for the "smallest standard deviation." Its purpose is very similar to that of the Fourier analysis, namely, to determine which periods are the most important in any cyclic light curve. In this method, we first construct an average light curve from a data sample using an assumed value for the unknown period, and we then compare each data point with this average curve. The aim is to obtain a number that quantitatively describes the goodness of the agreement between the actual data and the average curve for each assumed value of period. Usually, the so-called "standard deviation" is used, and the period that gives the smallest standard deviation is assumed to be the "best" period for the data.

(Mathematically, the standard deviation for a given period and mean light curve is derived in several steps. First, we evaluate for each point the difference between the observed data and the computed mean curve, the "O-C", or "Observed minus Computed." This number is squared, and the squares for all the data points are added together. This sum is then divided by the total number of data points, and the square-root of this result is then called the "standard deviation.")

The value of the standard deviation is then plotted on the y-axis and the assumed period is plotted on the x-axis, as in the example shown in Figure 3. Note, in this figure, the best fit is obtained in the neighborhood of 193 days, where the y-coordinate (the standard deviation) has its smallest value.

3. Results of Analysis for Dominant Periods in the Light Curve of Z Ursae Majoris

Our first application of the FFT program to the light curve displayed in Figure 1 led to a complicated power spectrum that was difficult to interpret. Closer examination of the light curve shows why this occurred: there is a definite disruption in the curve around JD 2,431,000 (1944), and the average cycle seems to be different before and after this disruption.

In view of the earlier reports of period-changes associated with the earlier (1909) disturbance, I decided to split the data into three sections:

a)	Pre-disruption	JD 2425450-2432950,	first 5000 days;
b)	Disruption	JD 2430950-2432950,	next 2000 days;
c)	Post-disruption	JD 2432950-2443850,	last 10900 days.

We discuss these portions of data separately.

a) Pre-disruption.

Figure 2 shows the power spectrum of the first portion of the data, and we see a fairly broad peak with nearly equal power at periods of 191 and 193 days, which are adjacent points on the graph. Figure 3 shows the variation of standard deviation with assumed period using the same data. There is a rather broad minimum indicating a best fit at about 192.5 days, so these data together suggest a somewhat poorly defined period of 192.5 days.

The mean light curve for these data, Figure 4, reveals no trace of a secondary maximum, although the error bars would allow it to appear. This would seem to indicate that the secondary peak has a different period, although neither the power spectrum nor the curve of standard deviations shows it. My conclusion from examining the data is that a peak does appear a little more often than once per primary cycle, but that its periodicity is so badly defined that it is lost in the noise.

b) Disruption.

The FFT program gave a power spectrum with a very low, very broad peak, indicating only a vague periodicity. This was verified by the mean light curve, in that the light appeared to vary more or less at random during this interval.

c) Post-disruption.

The power spectrum for this section of the light curve is shown in Figure 5, and the splitting of the peak near 200 days is noticeable.

I further subdivided these data into three portions: the first half, the second half, and a middle section using the latter part of the first half and the first part of the second half. The power spectrum for each of these sections is shown in Figure 6, and the three peaks definitely indicate two distinct periods. The first half has a period of 192.0 days while the middle section and the second half show a period of 195.5 days.

Figures 7 and 8 show the variation of standard deviation with period and the mean light curve for these data, confirming the results of the power spectrum analysis.

4. Long-Period Behavior

In addition to a change of period, the light curve, itself, reveals that the last few cycles are different from the previous several cycles, in that they seem to have a smaller amplitude and a fainter mean light. We note that, should the disturbances of 1909 and 1944 be regular, these data would place the next occurance around 1979, when our current data end. Continued observations of this star could prove interesting.

The power spectra show no trace of a 1560-day period, even during the interval in which the AAVSO data overlap the data of Loreta. There is, however, some power in the wave-like components with periods between 5000 and 6000 days. The power is small, and we are dealing with a period which is a sizeable fraction of the available span of time, so the spectrum is not reliable. Most likely, this power represents a beat phenomenon resulting from the superposition of two separate periodicities. For example, a variable secondary period of 205 days and a primary period of 195.5 days would produce a beat period of 4200 days (and a beat between 195.5 and 203 days would have a period of 5300 days). It is suggestive that the power spectra show a weak indication of a secondary period in this range.

We conclude that the secondary maxima and minima in the visual light curve of Z Ursae Majoris are the result of a separate, poorly defined period of about 205 days. This seems to be true except during intervals of disturbance.

5. Acknowledgements

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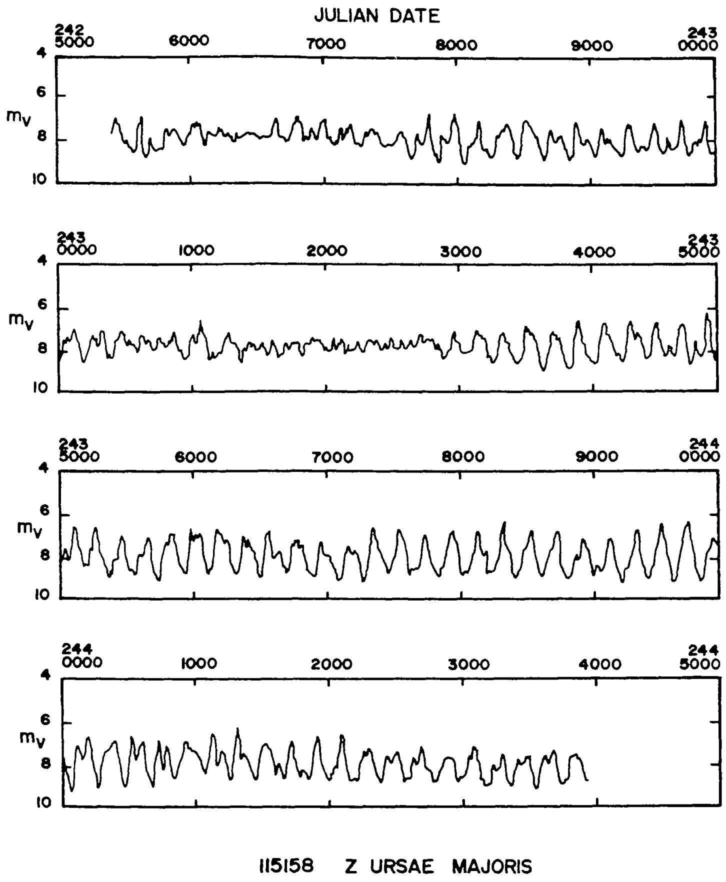

Figure 1. Light curve of Z Ursae Majoris based on AAVSO visual observations.

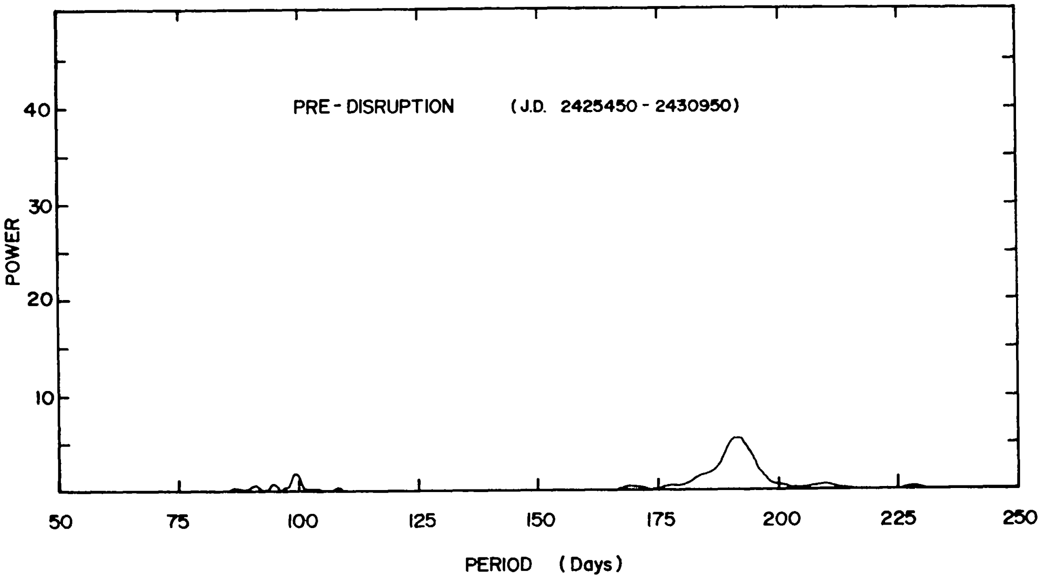

Figure 2. FFT Diagram of Pre-Disruption data.

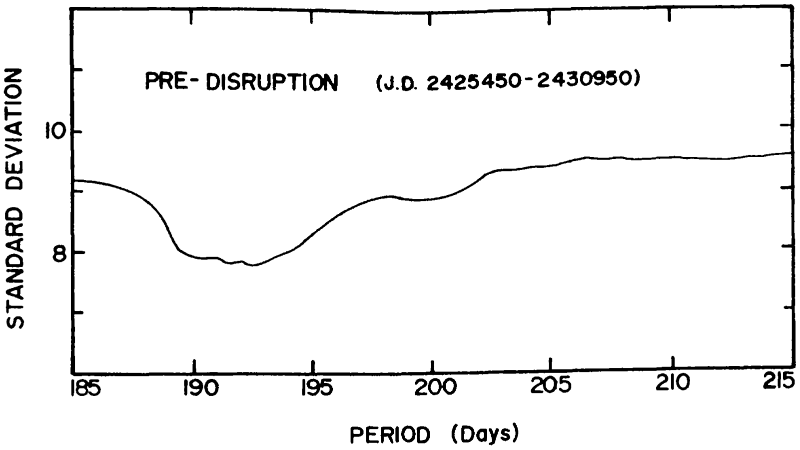

Figure 3. Sums of Standard Deviation for various model light curves of Pre-Disruption data.

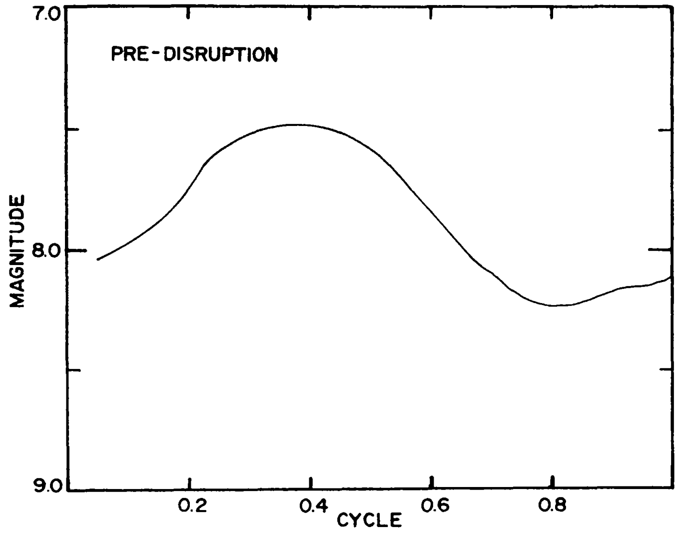

Figure 4. Mean light curve of Pre-Disruption data.

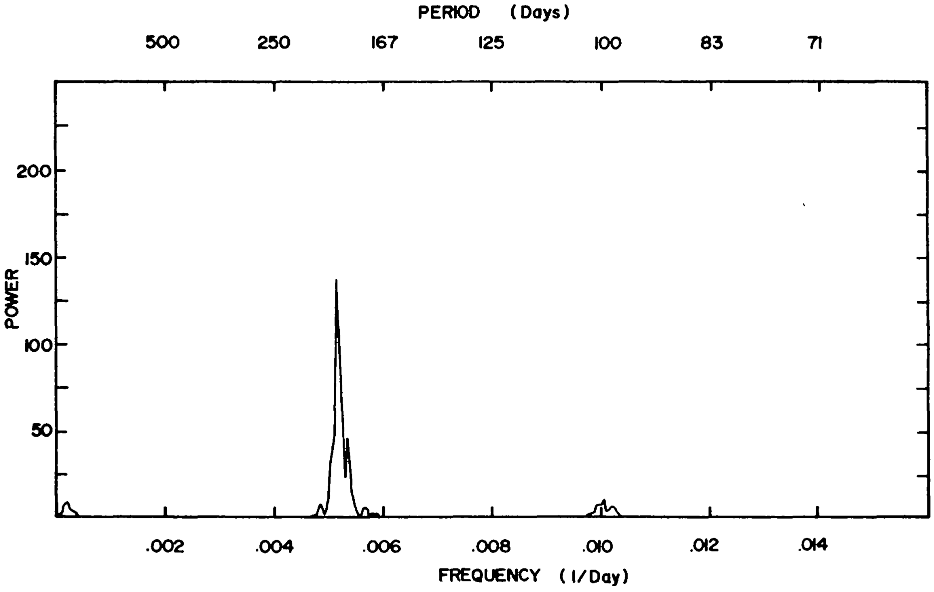

Figure 5. FFT Diagram of Post-Disruption data (JD 2432950 - 2443850).

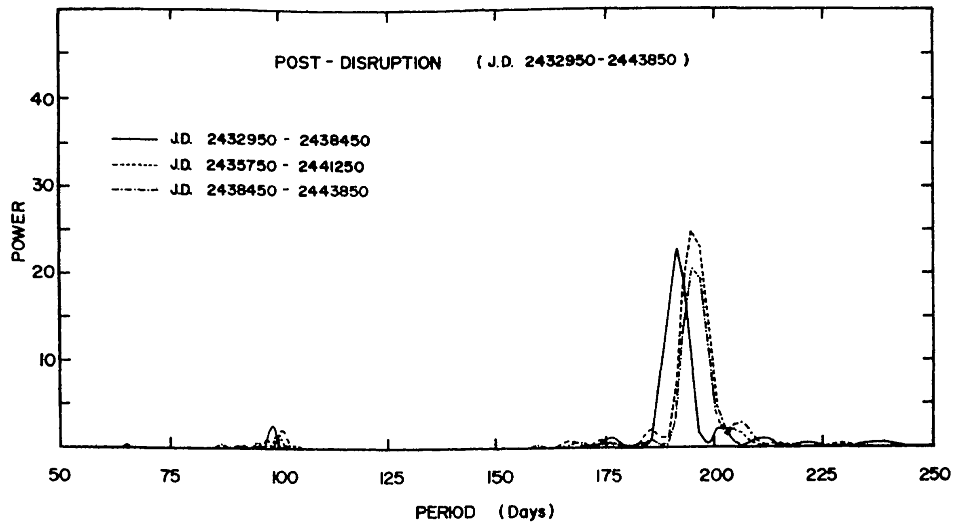

Figure 6. FFT Diagram of Post-Disruption data split into three sections (see text).

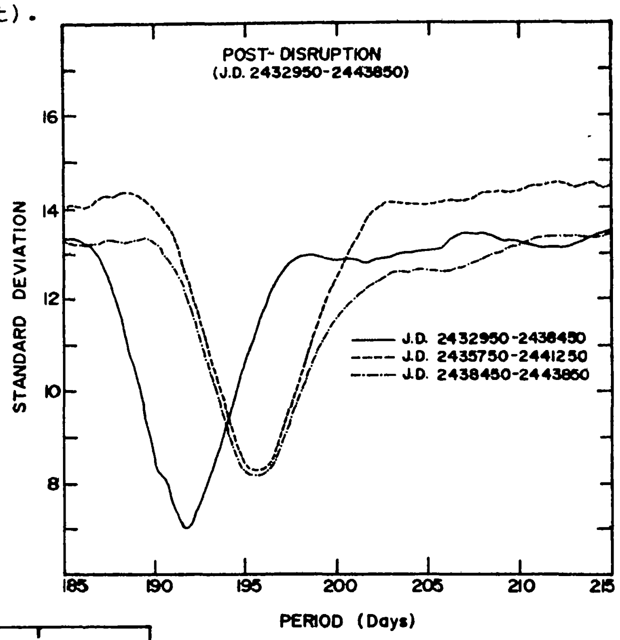

Figure 7. Sums of Standard Deviations for various model light curves of Post-Disruption data split into three sections.

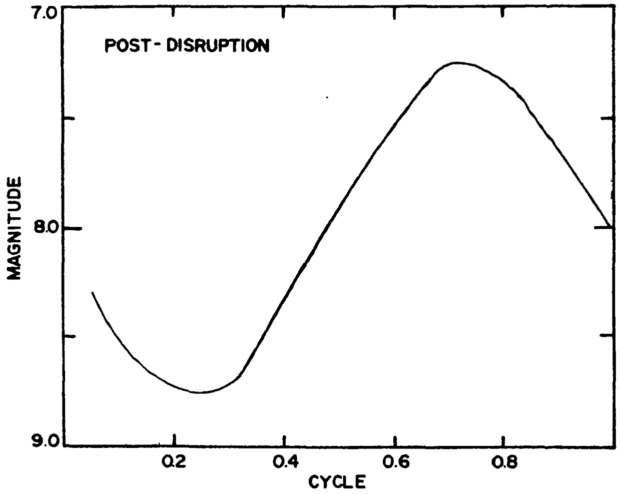

Figure 8. Mean light curve of Post-Disruption data.