THE CHANGING PERIOD OF Z TAURI

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Abstract

A preliminary examination of the observed dates of Z Tauri's maxima showed a decreasing period. Careful examination revealed three distinct discontinuities, showing the graph to be a joining of three approximately straight lines. A graph of the corresponding maximum and minimum magnitudes seems to be related to the O-C curve, suggesting irregularities of the pulsation mechanism. An ephemeris is plotted for the next five cycles.

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1. Introduction

Z Tauri conforms well to the definition of a Mira-type variable star, as given in the **General Catalogue of Variable Stars** (GCVS) (Kukarkin et al. 1969). Because of its long period, Z Tau, like other Miras, is rather difficult to observe. Even though the data for this star span about 65 years, there are still at least sixty more years of data to be collected before the study of this star will be anywhere near completion. One of the most important reasons for studying Mira variables includes answering the questions surrounding their pulsation mechanism. Expanding our knowledge on this subject would also help the study of stellar structure (What happens to the star's atmosphere when it pulses?) and evolution (Is this a normal stage in a star's lifetime?).

2. Analysis

The maxima of Z Tau were observed to occur as much as 480 days after the predicted dates in the period between 1974 and 1977. Several sources of data were used to construct Tables I and II. The AAVSO's published tables listing maximum and minimum magnitudes and estimated dates of maxima were used to collect the early data on Z Tau. Z Tau's light curves were retrieved from the AAVSO's archival files in order to extend the sample available to 1983. From Table II, the observed intervals from the maximum of one cycle to the next were averaged, giving a mean period equal to 475.6 days. The observed date of maximum of cycle N = 11, JD 2420602, was taken as the zero point. The calculated dates of maxima were computed, using

$$t_n = t_o + P_m n \qquad (1)$$

from the GCVS, where t_n equals the date of maximum (C) for the cycle being calculated, P_m equals the mean period, 475.6 days, and n equals the cycle number being calculated, minus 11. Next, the calculated dates were subtracted from the observed dates (O); these values were then tabulated and plotted against their respective cycle numbers. See Figure 1.

Upon preliminary examination, the O-C graph appeared to be parabolic. Consequently, even though there are only a few scattered points previous to cycle N = 11, dates of maxima were calculated for them, as well as in order to extend the baseline. Their values are marked with asterisks in Table I. A careful examination of the curve reveals three fairly distinct discontinuities: the O-C curve approximates a straight line from cycle N = 3 up to N = 19, then switches abruptly to another line of shallower slope from cycle N = 20 to N = 48 (the maximum), then "turns over" to another line of fairly steep negative slope. However, these discontinuities could be exaggerated as a result of switching from one observer (and his instrument) to another. The uncertainty error in the estimated dates of maxima was given by the AAVSO to be ± 1 day, which would not have a significant effect on the O-C graph because, with a period of 475.6 days, one day makes little difference. The periods for each straight line segment were calculated from the slopes of the three lines, using equation (2):

$$P_s = S + P_m, \qquad (2)$$

where P_m equals the mean period, S equals the slope of that line segment, and P_s equals the period of that line segment. The period that was associated with the line extending from cycle N = 3 to N = 19 was 499.6 days, which matches fairly well the period that was published for Z Tau at that time (500 days). The periods for lines two (cycle N = 20 to N = 48) and three (cycle N = 49 to N = 63) were found to be 486.6 days and 465.6 days, respectively.

Because of these abrupt changes in slope, it is impossible to predict when there will be enough data to confirm whether or not the O-C curve is parabolic. The dates corresponding to the slope changes and the new values for the slope are just too unpredictable as yet.

Assuming that the slope of the O-C curve will remain constant for a while longer, an ephemeris for the next five cycles was calculated. See Table III. The predicted O values were calculated by finding a C value from equation (1) and adding an O-C "deviation" value to it. This "deviation" was computed using equation (3):

$$\Delta y/\Delta x = [(O-C)_2 - (O-C)_1]/ \Delta \text{cycle } N, \qquad (3)$$

where $\Delta y/\Delta x$ equals the slope of the O-C curve from cycle N = 48 to N = 63 (-10.3), $(O-C)_2$ equals cycle N = 63's O-C value (409.8), cycle N equals 63 minus the cycle N being calculated, and $(O-C)_1$ is the deviation being found. Now the future predicted dates of maximum will also have an error of ± 1 day.

For comparison with the O-C graph, Z Tau's maximum and minimum magnitudes were plotted against their associated cycle numbers. See Figure 2. The changes in the maximum and minimum magnitudes (9.2 to 11.9 for maximum and 13.2 to 14.5 for minimum) were rather erratic while the O-C curve was climbing (which might be a sign of not-well-observed data). Then, at cycle N = 40 (the beginning of the "turn-over" of the curve), the changes in the magnitudes settled down into a "yo-yo" effect (from 9.2 to 9.8 for maximum and 13.9 to 14.1 for minimum). This apparent behavior may be the result of measurement errors; on the other hand, if Z Tau is in fact oscillating between two distinct magnitudes, then the star may be pulsing in two modes, and the O-C curve's behavior is just the beat behavior of the two modes. Again, carefully observed data will reveal whether or not this is true. The error in the maximum magnitude estimates was given as ± 0.2, which would explain the yo-yo effect in the minimum magnitudes (they have a spread of 0.2 magnitude), but not the same affect in the maximum magnitudes, which have a spread of 0.6 magnitude.

Such a large period (475.6 days) implies that Z Tau has a very large mean radius. To determine its size, Z Tau's spectral type, M8, as obtained by Barnes (1973), and its absolute magnitude at mean light intensity, 1.1, as obtained by Clayton and Feast (1969), were combined with a Hertzsprung-Russell diagram (Getts 1983), giving an effective temperature of 2000o K (corresponding to type M8) and a luminosity of about 10 solar luminosities. Plugging these values into equation (4) led to a radius for Z Tau equal to 1.85 x 10^{12} centimeters, or about 270 solar radii.

$$L = 4\pi R^2(\Sigma T)^4 \qquad (4)$$

3. Conclusion

The sharp changes in the O-C curve seem to indicate that perhaps Z Tau lost some of its mass at these points, causing the star to find a new equilibrium, which would affect its course of evolution. However, before a study exploring the proposed mass-loss/period-change relationship (which would be indicated by a parabolic O-C curve) can be undertaken, more data must be collected. This is also true for whether or not the period changes are a reflection of the beat frequency, in which case the O-C curve will appear cyclic.

4. Acknowledgements

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TABLE I

Dates of Maxima of Z Tauri

Cycle	Max(Obs.) JD2400000+	Max(Calc.) JD2400000+	O-C
3			
4	17110	17272.8*	-162.80
5	17612	17748.4*	-136.40
6			
7	18618	18699.6*	-81.60
8			
9	19602	19650.8*	-48.80
10			
11	20602		
12	21160	21077.60	82.40
13	21618	21553.20	64.80
14	22103	22028.70	74.30
15	22604	22504.30	99.70
16	23114	22979.90	134.10
17	23612	23455.50	158.50
18	24113	23931.10	181.90
19	24614	24406.60	207.40
20	25111	24882.20	228.80
21	25632	25357.80	274.20
22	26130	25833.40	296.60
23	26609	26308.96	300.04
24	27100	26784.50	315.50
25	27580	27260.10	319.88
26	28064	27735.70	328.30
27	28560	28211.30	348.70
28	29050	28686.90	363.10
29	29531	29162.40	368.60
30	30020	29638.00	381.98
31	30500	30113.60	386.40
32	30975	30589.20	385.80
33	31472	31064.80	407.20
34	31950	31540.30	409.66
35	32394	32015.90	378.10
36	32934	32491.50	442.50
37	33415	32967.10	447.90
38	33920	33442.70	477.30
39	34398	33918.20	479.80
40	34879	34393.80	485.20
41	35379	34869.40	509.60
42	35870	35344.98	525.00
43	36340	35820.60	519.40
44	36830	36296.10	533.90
45	37300	36771.70	528.30
46	37790	37247.30	542.70
47	38270	37722.90	547.10
48	38758	38198.50	559.50
49	39209	38674.10	534.96
50	39690	39149.60	540.40
51	40180	39625.20	554.80
52	40630	40100.80	529.20
53	41102	40576.40	525.60
54	41540	41051.90	488.10
55	42030	41527.50	502.50
56	42500	42003.10	496.90
57	42970	42478.70	491.30
58	43440	42954.30	485.70
59	43862	43429.80	432.20
60	44340	43905.40	434.60
61	44820	44381.00	439.00
62	45262	44856.60	405.40
63	45742	45332.20	409.80

TABLE II

Maximum and Miminum Magnitudes of Z Tauri

Cycle	Maximum	Minimum
3		$13^m.5$
4		
5		
6		13.6
7	$9^m.2$	13.5
8		14.1
9		13.8
10		
11		
12		14.0
13		14.5
14		14.0
15	9.5	
16	10.9	14.1
17		13.8
18	10.9	14.0
19	10.1	14.2
20		14.2
21	9.7	13.8
22		13.8
23	10.7	13.6
24	10.1	13.8
25		13.8
26	10.3	13.8
27	10.6	13.7
28		13.7
29	10.7	13.7
30	10.9	14.0
31	10.4	14.0
32	10.6	14.0
33	10.5	14.0
34	$10^m.0$	$13^m.6$
35	9.2	13.2
36	10.7	13.6
37	9.2	14.5
38	10.4	13.6
39	10.4	13.6
40	10.0	13.6
41	10.4	13.6
42	10.5	13.9
43	9.2	14.1
44	9.8	13.9
45	9.8	14.1
46	9.2	13.9
47	9.8	14.1
48	9.2	13.9
49	9.8	14.1
50	9.2	13.9
51	9.8	13.9
52	9.2	14.1
53	9.8	13.9
54	9.2	14.1
55	9.8	13.9
56	9.2	14.1
57	9.8	14.1
58	9.2	13.9
59	9.8	13.9
60	9.2	13.9
61	9.8	14.1
62	9.2	13.9
63	9.2	

TABLE III

Ephemeris for Maxima of Z Tauri

Cycle	C JD2400000+	O-C	O JD2400000+
64	45278.8	399.8	45678.6
65	45744.4	389.8	46134.2
66	46210.0	379.8	46589.8
67	46675.6	369.8	47045.4
68	47141.2	359.8	47501.0

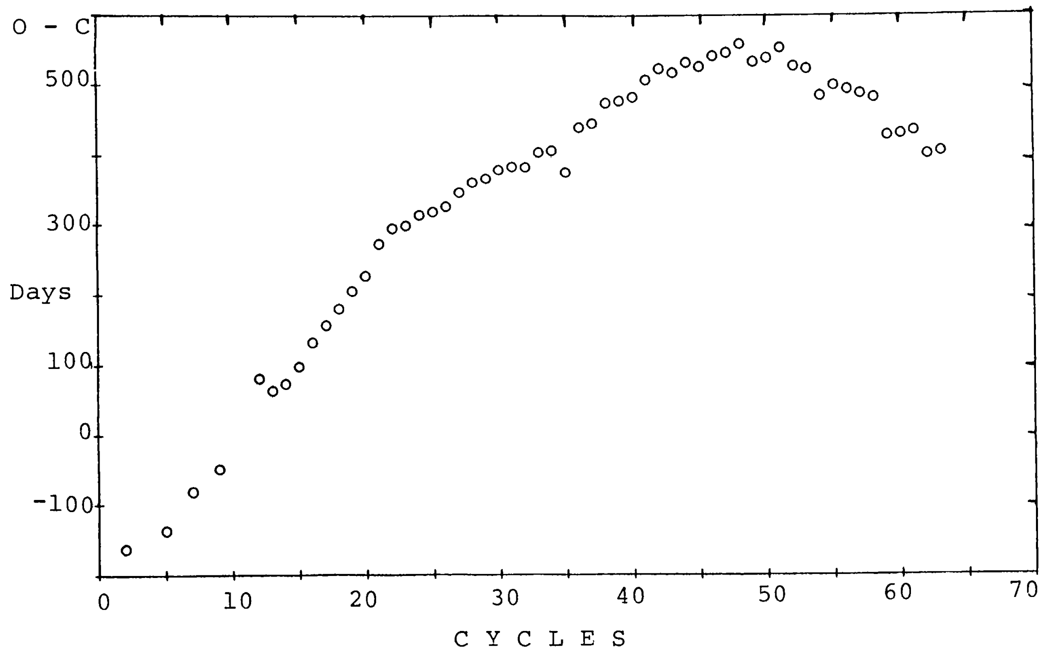

Figure 1. O-C Diagram for Z Tauri where C is defined by JD_{max} = 2,420,602 + 475.6 E

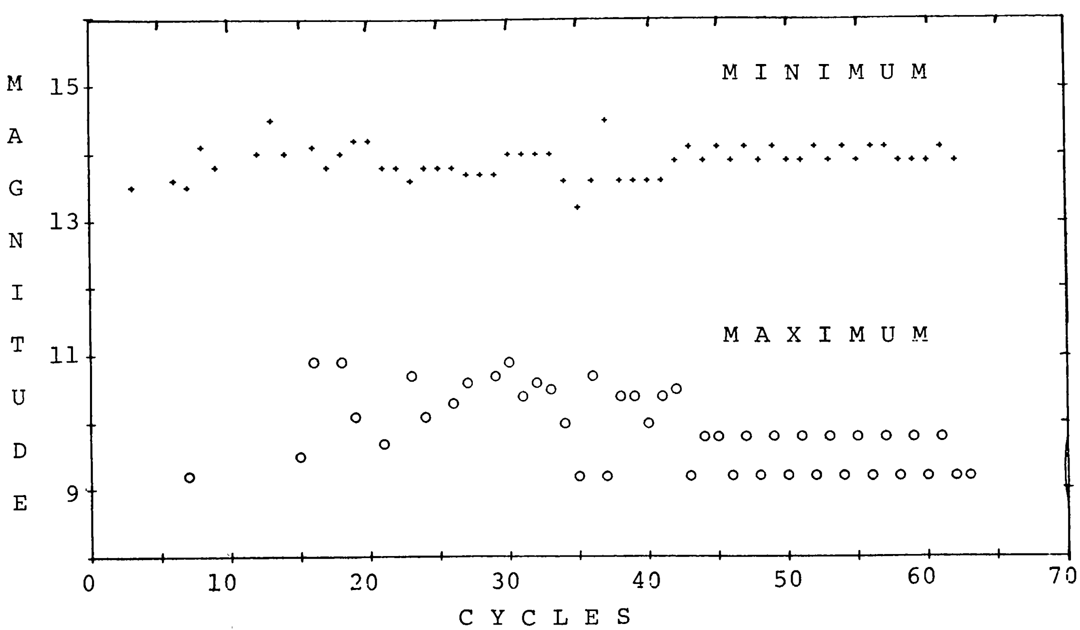

Figure 2. Graph of the observed Maximum and Minimum magnitudes versus cycle numbers for Z Tauri