## Secular Evolution in Z Tauri

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*Received December 10, 2004; revised April 19, 2005; accepted April 22, 2005*

**Abstract** Z Tauri is a Mira variable with observations in the AAVSO International Database dating back 85 years. Wavelet analysis of the observations reveals a period decline of around 13% from 500 days to 442 days per cycle. In addition, flat minima suggest the possible presence of an undetected companion.

### 1. Introduction

Z Tau—R.A. $05^h 52^m 24.90^s$, Dec. +15° 47' 44.5" (J2000 FK5)—is a Mira variable with a visual magnitude range of 9.2–14.2 and a period of 466.2 days, according to the fourth edition of the *General Catalogue of Variable Stars* (GCVS, Kholopov *et al.* 1985). It has been classified as an S-star (Stephensen 1984), placing it in an intermediate evolutionary stage between Miras and Carbon stars, and it has been suggested to be undergoing a thermal pulse (Whitelock 1999; Templeton, Mattei, and Willson 2005).

### 2. Period change

An analysis of 3,210 visual and CCD*V* observations from the AAVSO International Database (Figure 1) suggests a decrease in period of 13% in the last 85 years from 499.5 ± 1.5 days to 442.4 ± 3.7 days, indicating a decrease in radius. Periods were determined using the CLEANEST Fourier transform (Foster 1995) of the first and last five cycles, respectively. Uncertainty is calculated by the CLEANEST algorithm, but experience has shown it should be doubled. This agrees with data published in the first four issues of the GCVS, which give Z Tau a period of 494.13d in the third (Kukarkin *et al.* 1971) and second (Kukarkin *et al.* 1958) editions of the GCVS and 500.09d in the first edition (Kukarkin *et al.* 1948). This decrease is higher than expected for normal cycle-to-cycle variations of Mira stars (Wood and Zarro 1981).

### 3. Cycle-to-cycle variations

A weighted wavelet analysis (Foster 1996) of all the data reveals that the apparent period change was not monotonic (Figure 2). During two episodes the period detected by the analysis actually increased (Figure 3). Beginning around JD

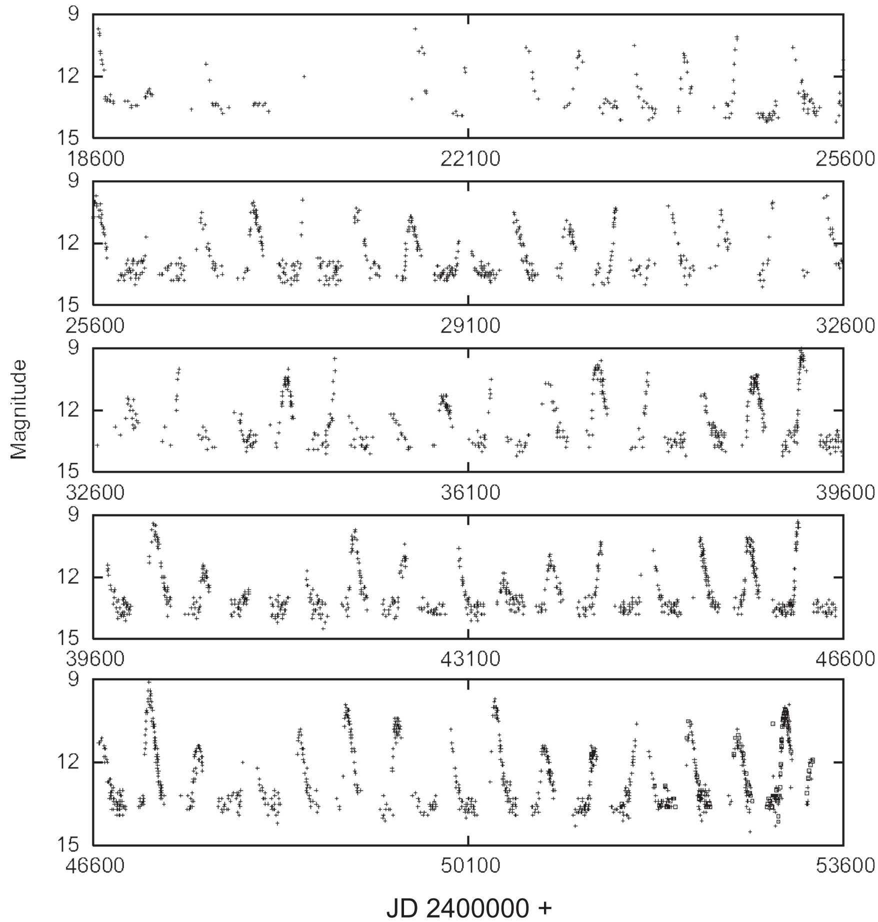


Figure 1. Visual and CCD*V* observations of Z Tau, 1909–2005, from the AAVSO International Database. Squares denote CCD observations; plus signs denote visual observations.

2443100 the period increased 1% over a 4,000 day period and beginning around JD 2446500 the period increased 0.5% over 1,500 days before resuming its decline both times. We subtracted a linear fit from the strongest period in 500-day windows and then fit a sinusoid to the residuals. The result was a separation of the episodes of nonmonotonic decline of 43 ± 4 years. These are likely the result of cycle-to-cycle period fluctuations of a non-evolutionary nature (Eddington and Plakidis 1929; Percy and Colivas 1999). These fluctuations can dominate O–C diagrams of Mira stars and emulate short period changes, especially over intervals over 20 cycles. In this case the interval between the detected period increases is around 32 cycles. Our wavelet analysis also detected 1 cycle/year aliases.

More observations will be needed over the coming century.

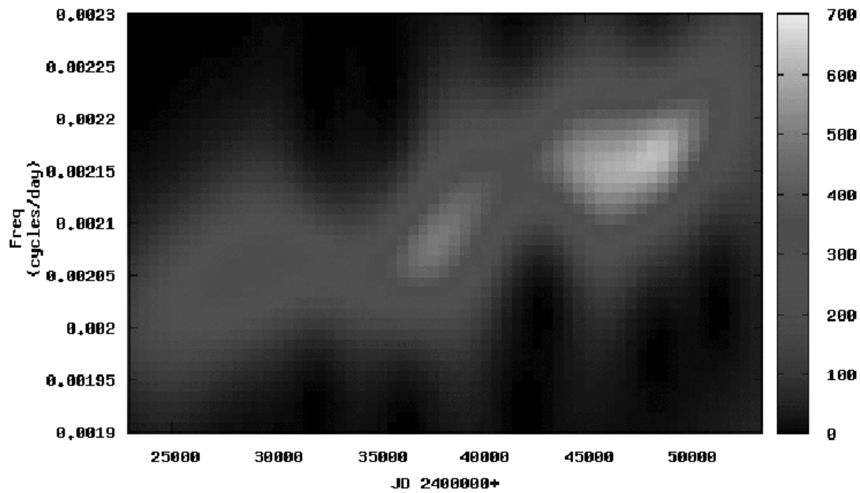


Figure 2. Z Tau period changes detected through wavelet analysis. Lighter colors are higher power.

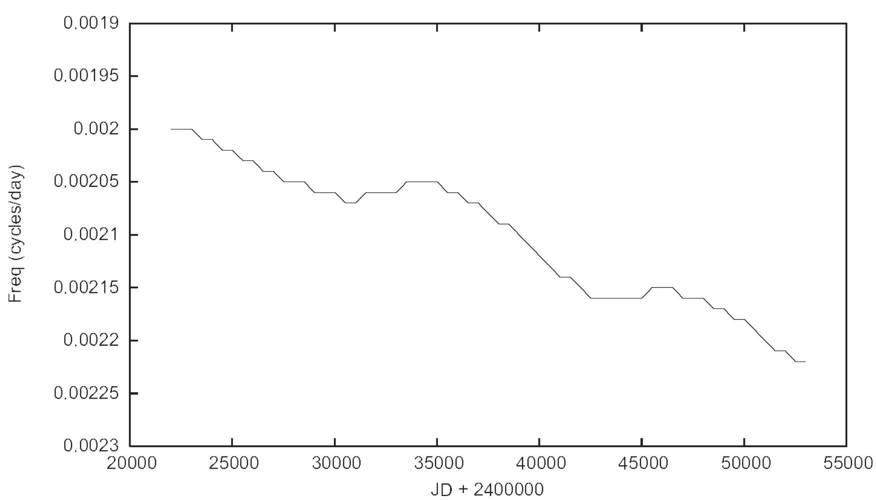


Figure 3. Z Tau period evolution. Note temporary increases in period around JD 2443100 and JD 2446500.

## 4. Amplitude change

The amplitude also changed significantly during this period (Figure 4) but this seems to be caused by variations in maxima only. Gaps in the data caused by annual solar obscuration prevent a careful statistical analysis of the amplitude variations. Flat minima in long period variables could be caused by the presence of a companion such as in o Cet (Merrill 1956). No observations in UV or X-Ray have been made of Z Tau at this date. Observing campaigns in the Johnson *B*-band looking for flare activity would be useful.

## 5. Historical analysis

The decreasing period of Z Tau has been addressed previously. First, a period of 480 days was proposed in a paper presented at the 78th meeting of the AAVSO. (Lynch 1979). Nothing more than the proposed period was published by Lynch. Nagel (1986) proposed a period of 475.6 days based on O–C analysis of data from 1974 to 1983. However, O–C calculations can be affected by the large gaps in the data. Percy *et al.* (1990) analyzed AAVSO times of maxima spanning 75 years and found a statistically significant period decline.

Our analysis shows the period of Z Tau has continued to decline since the last published study. Continued monitoring of this star for period change is essential for a complete analysis of this behavior.

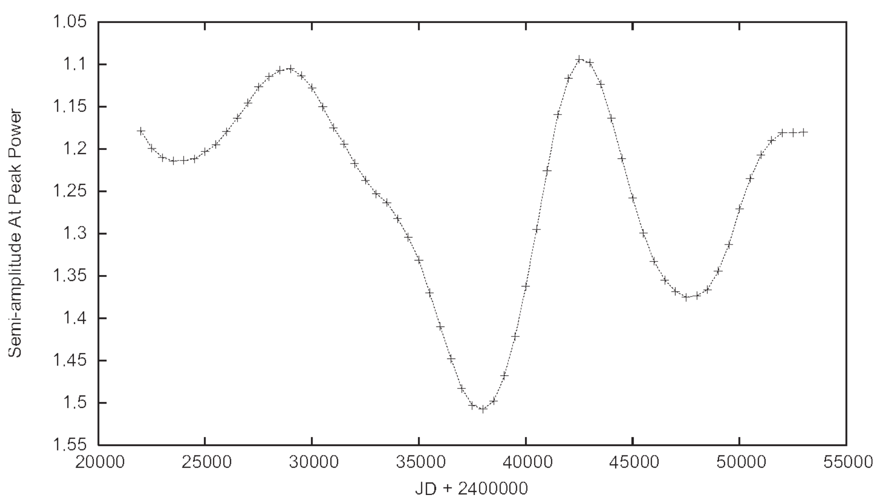


Figure 4. Z Tau amplitude evolution. Gaps in the data caused by annual solar interference prevent a rigorous statistical analysis.

## 6. Acknowledgements

We would like to acknowledge the hundreds of tireless AAVSO observers who contributed data to this database, and also Matthew Templeton and Sarah T. Sechelski for help with the data. Wavelet analysis was done using WINWWZ, a program developed by Klingenberg to implement Foster's WWZ routines on Windows computers. It is available for download via the AAVSO web site: http://www.aavso.org.

This research was supported in part by the American Astronomical Society's Small Research Grant Program.

## References

Eddington, A. S., and Plakidis, S. 1929, *Mon. Not. Roy. Astron. Soc.*, **90**, 65.
Foster, G. 1995, *Astron. J.*, **109**, 1889.
Foster, G. 1996, *Astron. J.*, **112**, 1709.
Kukarkin, B. V., *et al.* 1948, *General Catalogue of Variable Stars*, First Ed., Moscow.
Kukarkin, B. V., *et al.* 1958, *General Catalogue of Variable Stars*, Second Ed., Moscow.
Kukarkin, B. V., *et al.* 1971, *General Catalogue of Variable Stars*, Third Ed., Moscow.
Kholopov, P. N., *et al.* 1985, *General Catalogue of Variable Stars*, Fourth Ed., Moscow.
Lynch, R. F. 1979, *J. Amer. Assoc. Var. Star Obs.*, **8**, 25.
Merrill, P. W. 1956, *Publ. Astron. Soc. Pacific*, **68**, 162.
Nagel, L. M. 1986, *J. Amer. Assoc. Var. Star Obs.*, **15**, 48.
Percy, J. R., and Colivas, T. 1999, *Publ. Astron. Soc. Pacific*, **111**, 94.
Percy, J. R., Colivas, T., Sloan, W. B., and Mattei, J. A. 1990, in *Confrontation Between Stellar Pulsation and Evolution*, eds. C. Cacciari and G. Clementini, *Astronomical Society of the Pacific Conference Series*, **11**, 446.
Stephenson, C. B. 1984, *Publ. Warner and Swasey Obs.*, **3**, 1.
Templeton, M. R., Mattei, J. A., and Willson, L. A. 2005, *Astron. J.*, **130**, 776.
Whitelock, P. A. 1999, *New Astron. Rev.*, **43**, 437.
Wood, P. R., and Zarro, D. M. 1981, *Astrophys. J.*, **247**, 247.