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Secular Evolution in Mira and Semiregular Variable Pulsations

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Abstract

The Mira and semiregular variables are pulsating stars in very advanced stages of evolution, and they exhibit a wide variety of pulsation behavior. It is suspected that a small fraction of these variables (including R Aql, R Hya, T UMi, and LX Cyg) exhibit large secular period changes because of structural readjustments from recent thermal pulses. Analysis of secular period changes and other changes in pulsation behavior may therefore be useful in studies of the evolution of these stars. The American Association of Variable Star Observers (AAVSO) International Database (ID) contains data on over 1500 Mira and semiregular variables. Data for these stars span nearly a century in some cases, making it possible to study the evolution of the pulsation behavior over time. We present preliminary results of a study of period change in these stars using data from the AAVSO ID, and discuss the consequences of our results on models of Mira and semiregular variable star evolution.

AAVSO Data

The AAVSO archives contain over 10 million data points for several thousand different variable stars, a large percentage of which are observations of Mira, semiregular, and other long period variables. Many variables have nearly a century of recorded observations (see Fig. 1), making studies of long-term evolution possible.

AAVSO data consist primarily of:
- **visual magnitude estimates**
- **instrumental filtered and unfiltered photometry**

Visual magnitude estimates were made using charts with known comparison stars. Though visual estimates from different observers have significant scatter, validation of the data (*see Waagen & Mattei, poster 9.02*) provides a further means to ensure the data are reliable.

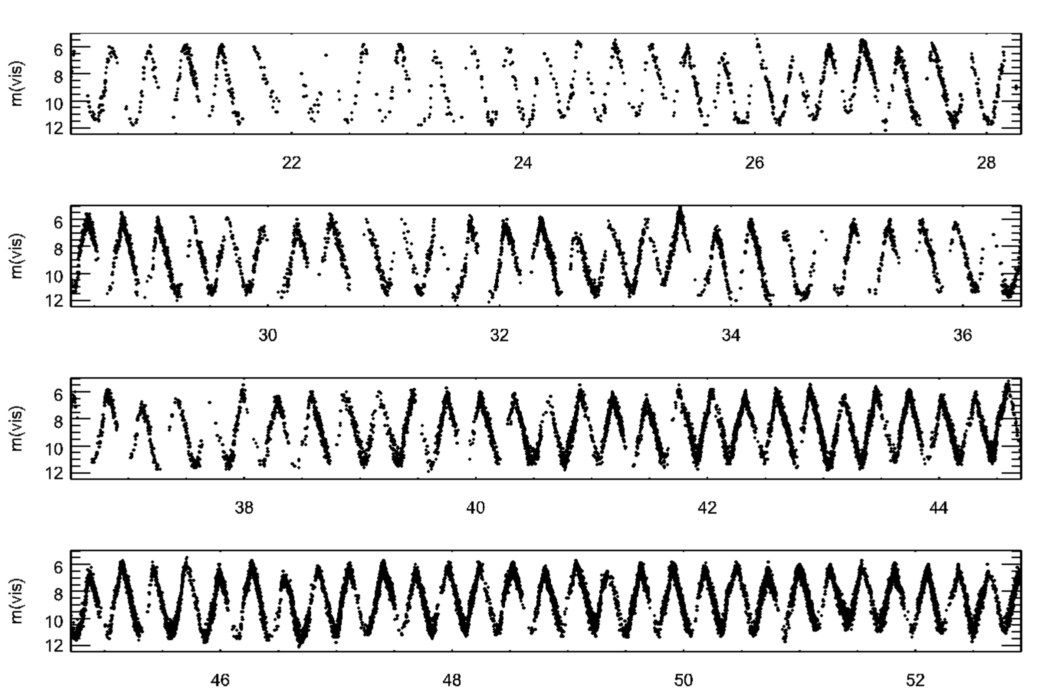

Figure 1: AAVSO visual light curve for the star R Aquilae, a Mira variable which has exhibited a montonically decreasing period throughout the 20th century. The period has declined from about 310 days in 1910 to about 270 days today.

Time-series analysis: Wavelet transform

We use several different time-series analysis programs developed by the AAVSO both to obtain average periods and to investigate whether the periods, amplitudes, Fourier harmonic components, and/or mean magnitudes are changing. We use the CLEANest algorithm (Foster 1996) and variants to obtain periods and Fourier components, and wavelet analysis (Foster 1995) to search for secular changes.

The *weighted wavelet Z-transform (*WWZ*)* uses a sliding window function to compute the Fourier transform of a set of data over definable spans of time. For our analysis, we use a wide window which provides good period resolution at the expense of some time resolution. The time spans of the data are long enough in most cases to allow reliable detection of secular changes (Fig. 2).

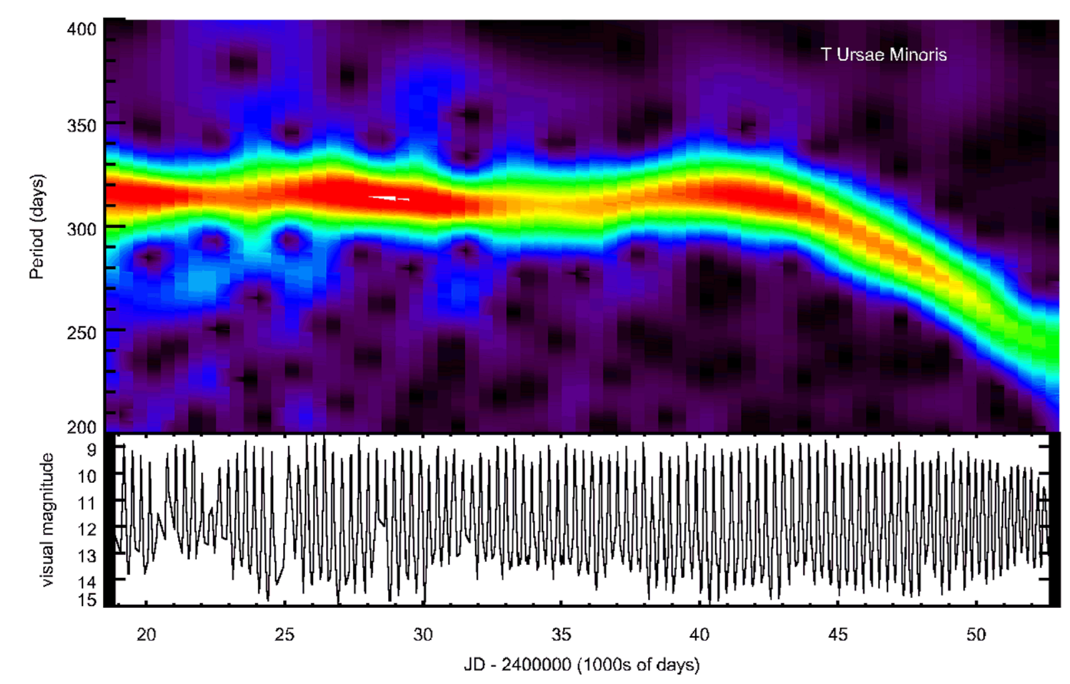

Figure 2: Weighted wavelet Z-transform (Foster 1995) of the Mira variable T UMi. This star began a rapid phase of period decline around 1970, from its original period of about 320 days, to its current (but still declining) value of about 240 days. T UMi is the best candidate for secular changes driven by evolutionary behavior – likely a thermal pulse (Mattei & Foster 1995; Szatmary, Kiss, & Bebesi 2003).

Wavelet analysis results

We analyzed 546 Mira variables for which the AAVSO has at least 500 visual data points.

- **Nearly all stars exhibit period variability at the level of a few percent (average period variability is 2.8% -- see Fig. 3)**
- **Period variability of 5% or greater is rare, limited to less than 6% of the stars in the sample**
- **Longer period variables show *slightly* larger period variability, though this may be due to relative scarcity of variables with periods longer than 400 days (Fig. 4)**
- **There is no trend of extreme period changes with period**

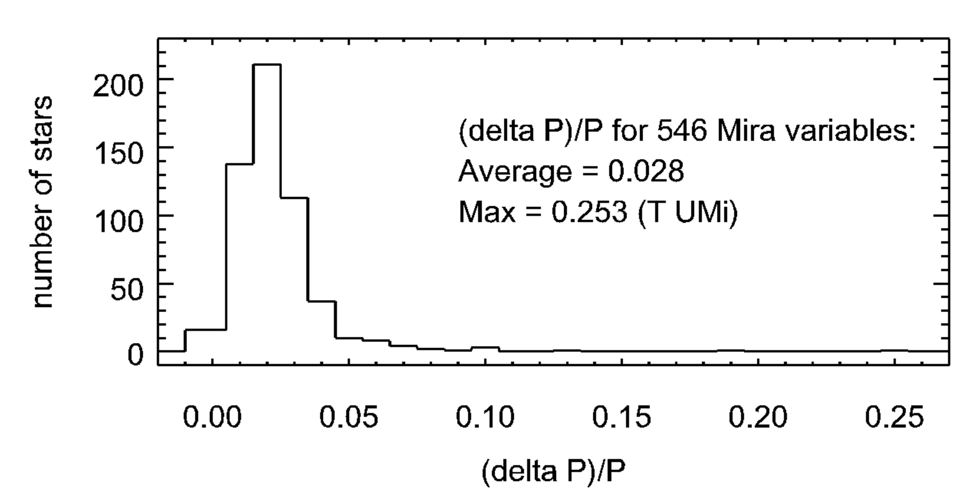

Figure 3: Histogram showing the distribution of fractional period change for the sample of 546 Mira variables in our test sample. The distribution average is 2.8%, meaning that the periods of Miras vary by this amount on average. Fewer than 6% of Miras have fractional period variations larger than 5%, and large period changes (> 10%) are very rare.

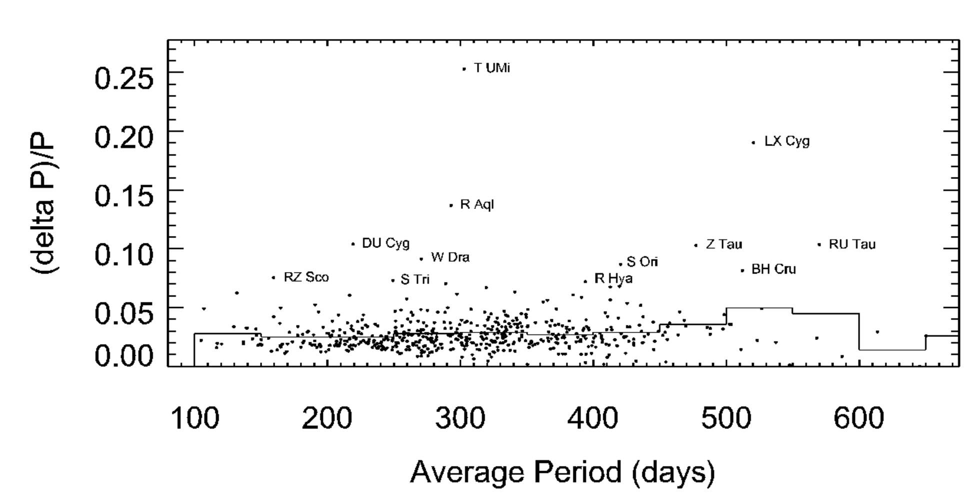

Figure 4: Fractional period change versus period for the Miras in our sample. The period changes of the Miras shown in Figure 5 are labeled. The solid line represents the average fractional period change for stars lying within 50-day bins of period. There is a modest trend towards larger fractional changes at larger periods, but the trend may be spurious because of the small numbers of stars contained within the larger period bins. In particular, the average period change for stars in the 500-550 day period bin is heavily skewed by LX Cyg (19%) and BH Cru (8%).

Wavelet analysis results (contd.)

Wavelet analysis revealed that essentially all Mira variables exhibit some random period changes, most likely the cycle-to-cycle variations that have been noted since the earliest studies of these stars (Eddington & Plakidis 1929; Sterne 1934). Such period changes are not likely due to evolutionary events, but rather to nonlinear behavior in the pulsating stellar envelope.

A small fraction of Mira stars exhibit period changes greater than five percent over the span of available data (Fig. 5). In the most drastic cases (T UMi, LX Cyg) such changes are believed to be caused by evolutionary events such as thermal pulses, and the accompanying thermal readjustment of the stellar interior. The magnitude and rate of period changes observed are consistent with previously published theoretical models (Vassiliadis & Wood 1993). Other stars exhibit long-term "meandering periods" (Zijlstra & Bedding 2003). The reason for this behavior is not yet known.

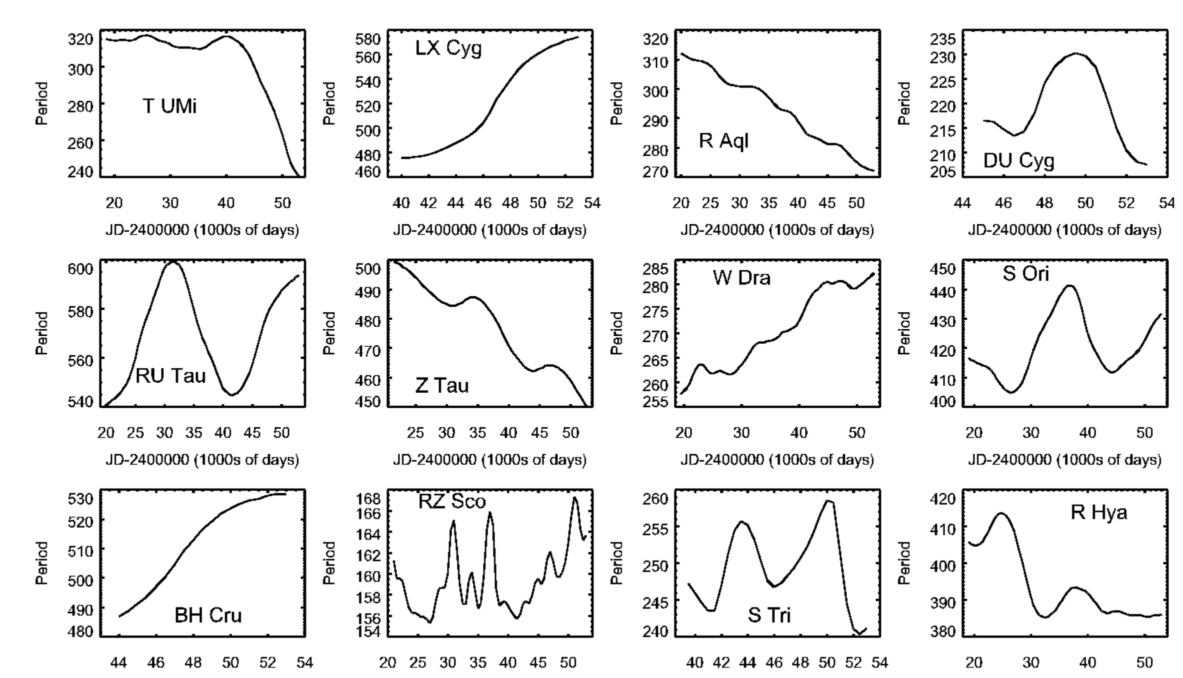

Figure 5: Period versus time for the twelve Mira-type variables having the largest fractional period changes, as noted in Figure 4. Six of these (T UMi, LX Cyg, R Aql, Z Tau, W Dra, and BH Cru) may be undergoing thermal pulses or other long-term evolutionary changes. Several others (e.g. RU Tau, S Ori, and S Tri) may be "meandering Miras" (Zijlstra & Bedding 2003). Such stars appear to undergo long-term, orderly period changes which last for many cycles but are not monotonic.

Wavelet analysis of semiregular variables

A preliminary wavelet analysis of 189 semiregular variables (types SRa and SRb) has been completed. Detection of period change is more difficult in these stars, given the smaller amplitudes and increased photometric scatter among very red (C-type) stars.

Among SRa variables, RS Aur, RS Cyg, and SS Vir show some evidence of meandering periods, while W Hya has shown a steadier period change (from 410 days in 1949 to 380 days today) and may be undergoing an evolutionary event.

Future work

Work continues on all of the Miras and Semiregular variables for which sufficient data are available in the AAVSO ID. We plan to perform more detailed studies of these stars than the initial automated data processing allowed, and this has already been completed for several stars (for example, see Templeton 2003, IBVS 5483). We also plan to include analyses of secular changes in mean magnitude, amplitude, and Fourier harmonic components in the final analysis.

We are also working to expand the current tables of maxima and minima times and magnitudes published by the AAVSO, currently available through 1975. Analysis of these data (as in Percy & Colivas 1999) complement the time-series analysis of the photometry.

References

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