Long-term Secular Changes in the Period of Mira Stars

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Abstract A possible secular change of the period is investigated for 362 Mira stars. Mean periods and the proportion of stars with increasing and decreasing period were calculated using all available maxima found. The state as it was known in 1938 is compared year by year up until 2013. Analysis of O–C diagrams for the stars shows a rate of change of $+6.8 \times 10^{-6}$ days/day, standard error 3.8×10^{-6}. The mean period over 75 years shows an increase by 0.15 day for the investigated stars, and by 2013 58% of them had an increasing period.

1. Introduction

Mira stars are pulsating red giants with large amplitudes in visual light and periods typically in the range from 100 to over 600 days. In the H-R diagram they are located at the Asymptotic Giant Branch (AGB). There has been a debate about the predominant mode in which Miras pulsate. Recent research now suggests that Miras are fundamental mode pulsators (Willson and Marengo 2012).

Although the pulsation period (P) for a typical Mira is quite regular it features short and long term variations of several kinds. All Miras have small random cycle-to-cycle variations in amplitude, cycle length, and in the shape of their light curves. About 15% also have a meandering behavior where P alters by up to 10% within 50 years (Zijlstra and Bedding 2002), a process not fully understood. Eight stars (R Aql, R Cen, BH Cru, LX Cyg, W Dra, R Hya, Z Tau, and T UMi) are identified as having large period changes (Templeton *et al.* 2005). Those stars either have a continuously increasing or decreasing P over their observed history or have a large sudden change in P after a long time of stability.

The random and meandering behavior has made it difficult to identify long term evolutionary changes in P for individual stars besides the eight stars mentioned above. Sterken *et al.* (1999) found evidence for a linear increase of P for χ Cygni at a rate of $+36 \times 10^{-6}$ days/day over its more than 300-year history. On the other hand, no significant long term change of P for o Ceti seems to have occurred during its over 400 years of recorded history.

The aim of this study is to investigate if a secular change in P can be detected in the available data by averaging a large number of stars with the longest history of observation, and also to see if a longer baseline gives a stronger signal for period changes or if the periods are dominated by random fluctuations at all time scales. The present paper is a follow-up to a similar study made by Percy and Au (1999).

2. Models

Evolutionary models for AGB-stars from Wood and Zarro (1981) and Vassiliadis and Wood (1993) show some interesting features in the supposed evolution of P for AGB-stars.

1) With intervals of ~10^5 years the star goes through a thermal pulse (TP) when accreted helium from hydrogen fusion ignites and for a period of ~10^3 years is the main energy source. The TP causes P to decrease and increase in rapid succession, but after the pulse is over P is reset to a shorter value than before the TP started.

2) Between the TPs hydrogen fusion again takes over as the main energy source. During this phase P slowly increases.

Since the TPs only last for 1–2% of the total time spent in the AGB-phase we would expect a small percentage of the Miras to have a rapidly changing period and the majority to have a period that increases very slowly.

From the models of Vassiliadis and Wood, Percy and Au (1999) estimated the rate of change of P in the intra-TP phase. The average change for a 1 solar mass-star was estimated to be $+29\times10^{-6}$ days/day for a star pulsating in the fundamental mode and $+11\times10^{-6}$ days/day for a star pulsating in the first overtone.

3. Analysis

In their study Percy and Au analyzed O–C diagrams from Kowalsky *et al.* (1986), data that span 75 years (1900–1975) of observations in the AAVSO International Database, and include 391 long period variables (Mira and SR). They calculated the rate of change from parabolic fits to O–C diagrams and found an average change from all stars of $+17\times10^{-6}$ days/day, standard error 10×10^{-6}, and that 55% of the stars had an increasing period.

This analysis is based on a collection of maxima for 489 Mira stars compiled by the author (Karlsson 2013). The collection contains maxima of two types, those computed and fitted by the author to individual observations and those collected from various published sources. For the fitted maxima, data from the organizations AAVSO, AFOEV, VSOLJ, and BAAVSS were used. The published maxima were used to complement these and to extend the baseline backward and fill in gaps among the fitted maxima.

From the original 489 stars those with the longest record were selected. The criterion was that at least twenty maxima before 1938 must exist. Some stars have one or a few very early maxima, sometimes of uncertain or dubious quality, followed by a long gap with no observations. To prevent such outliers from affecting the results, another criterion was that at least five maxima within twenty cycles must be available at the beginning of the series for each star. If not, the earliest maximum was removed until this criterion was fulfilled. The eight stars with known large period changes, mentioned above, were also removed, as they may be in a TP while the aim of this study is to investigate intra-TP behavior.

For each of the thus-selected 362 stars three different tests were made.

- The mean P was calculated from a linear fit to all maxima for the star.

- An O–C diagram was constructed by using the determined P, and a parabola was fitted to the diagram and the rate of change (β) in days/day was calculated as the coefficient of $E^2 \times 2 / P$, where E is the cycle number.

- The maxima were divided in two halves of equal time and P was calculated for the first and second half by linear fits on both groups.

These calculations were first done with all maxima up to 2013-01-01. Then all maxima for one year, first 2012, then 2011, and so on, were removed and the calculations were repeated until only maxima older than 1938-01-01 remained. This process makes it possible to analyze how P and β develops over time as more data becomes available.

The average time span between the first and last maxima for the 362 stars was 52 years for 1938, and 127 years for 2013.

4. Results

Figure 1 shows, up to each year, the mean and standard error of β from the O–C diagrams. After fluctuating at a much higher level, after 1975 β stabilizes between $+7 \times 10^{-6}$ and $+9 \times 10^{-6}$ days/day. With all maxima, the result for 2013 is the average rate of change $+6.8 \times 10^{-6}$ days/day, standard error 3.8×10^{-6}, a significance level of 1.8σ. The standard deviation for the individual stars is 73×10^{-6}.

Figure 2 shows the frequency distribution of β for 2013 and a comparison with the distribution from Percy and Au (1999). The distribution is more compressed towards the center compared to Percy and Au, probably an effect of the longer timeline used in this study.

Figure 3 shows the relation between β and P. The three stars with the largest rate of change are V Del -520×10^{-6}, Z Sco -390×10^{-6}, and R Nor $+330 \times 10^{-6}$ days/day.

The mean period year by year for the 362 stars is shown in Figure 4. During the 75 years the mean period increases by 0.15 day. For 1938 it was 306.17 days and for 2013 it was 306.32 days.

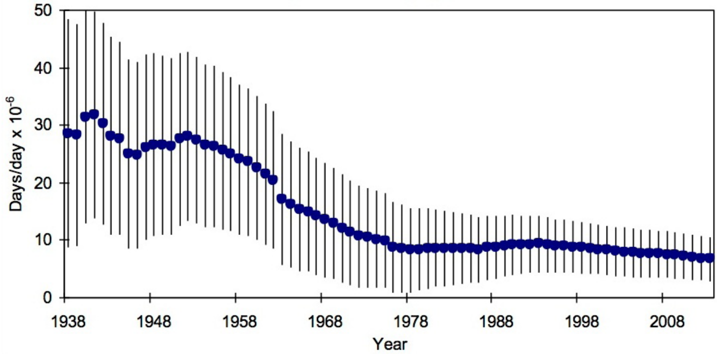

Figure 1. Average rate of change (β) when including maxima up to specified year. The error bars show the standard error.

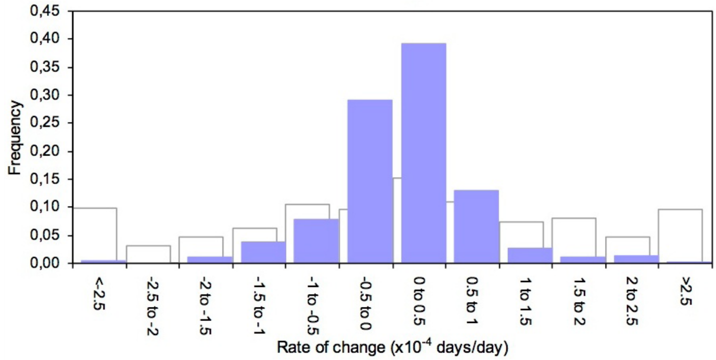

Figure 2. The distribution of β in this study (blue) and the distribution from Percy and Au (1999) (white).

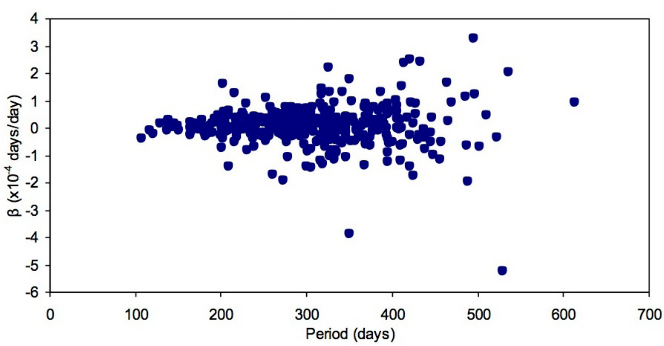

Figure 3. The relation between β and period for the 362 stars.

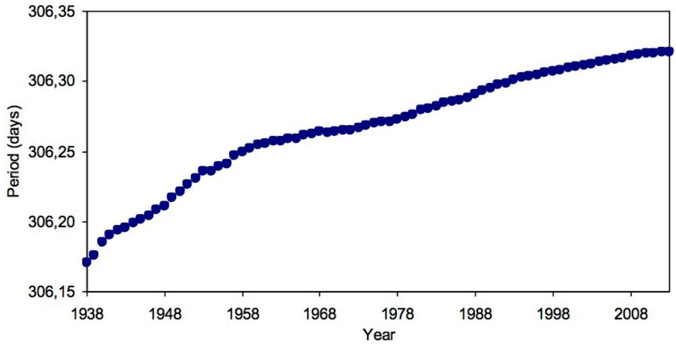

Figure 4. The mean period for the 362 stars when including maxima up to the specified year.

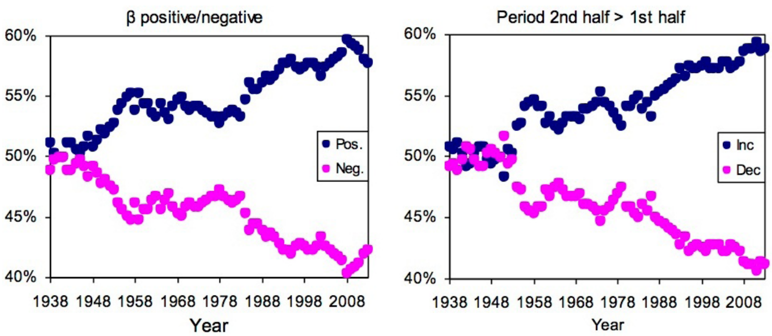

Figure 5. Percentage of stars with increasing/decreasing P up to the specified year. To the left, positive or negative sign of β from the O–C diagrams; to the right, mean P for the second half compared to the first half of each star's series of maxima.

The results from two countings of the number of stars that had an increasing or decreasing P at each year are shown in Figure 5. Figure 5, left panel, shows the proportion with a positive or negative value of β when including all maxima up to the specified year. Figure 5, right panel, shows the proportion with longer or shorter P for the second half compared to the first when dividing the maxima of the stars in two parts of equal length. Both tests shows about the same result. For the early years the proportions are about 50% each. As more maxima are added the proportion of stars with increasing P goes up. For 2013 58% of the stars from the first and 59% from the second test have an increasing P.

5. Discussion

The means and totals from all four tests support the theoretical models that Mira stars in their intra-TP phase can have a slowly increasing period, as well as that the P on shorter time scales, as the 127 years in this study, is dominated by random and meandering features.

The two tests that count the number of stars with increasing or decreasing P show that as more data are added the tendency for increasing P gets stronger. The two tests show for the 1938 case a near-equal distribution of stars having a increasing or decreasing period. 75 years later, 209 of 362 stars have a positive value for β and 213 of 362 have a longer mean period for the second half compared to the first half over their observed history. If the probability would be 0.5 each for the cases of increasing and decreasing period, a pure random distribution of 209 (or more) of 362 would have a probability of 0.13%, which corresponds to a significance level of 3.0σ.

The investigation of β from the O–C diagrams has a lower significance level of 1.8σ (for 2013) for the case of an increasing P, but the rate of change is quite stable, $+7 \times 10^{-6}$ to $+9 \times 10^{-6}$ days/day, over the last 37 of the 75 investigated years. The mean P computed with data up to each year is increasing throughout the whole 75-year interval, although with different paces. The alternate method to compute the rate of change, from a linear fit to the mean periods, gives a change of about $+10 \times 10^{-6}$ days/day.

The spread of the rate of change for the individual stars varies from -520×10^{-6} days/day to $+330 \times 10^{-6}$ days/day, with a standard deviation of 73×10^{-6}. The spread seems to have a normally distributed shape around the mean. There is a weak, but not significant, correlation for stars with longer P to have a larger rate of change, from $+4 \times 10^{-6}$ days/day for a star with a P of 100 days to $+11 \times 10^{-6}$ days/day for a star with a P of 600 days.

Percy and Au determined the mean value for β to be twice as large as the value in this analysis. The significance levels are about the same in both studies. For the percentage of stars with a positive value of β Percy and Au got 55%. This is lower than the 58% in this analysis, but it is from only 75 years of data compared to 127 years. At 75 years of data in this analysis (at 1962) the percentage of stars with positive β was 54%. The difference in value of β between the two studies may to some extent depend on the fact that Percy and Au in their study also included SR stars and did not exclude the stars with known large period changes.

The rate of change of P in this analysis is on the order of the value estimated by Percy and Au (1999) from the models of Vassiliadis and Wood (1993) for a one solar mass AGB-star pulsating in the first overtone, but it is four times lower than the estimated value for a star pulsating in the fundamental mode from the same models. It is, however, unknown how the 362 analyzed stars' masses and evolutionary phases compare to the star used in the models or how accurate the models themselves are. Consequently it is hard to say to what degree the results contradict the information, reviewed by Willson and Marengo (2012), that Mira stars are predominantly fundamental mode pulsators.

6. Acknowledgements

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