Period Evolution in Mira Variables

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Abstract We investigate a number of Mira variables which show evolution in their periods. Three different types of period changes are found: continuous changes, sudden changes, and meandering periods. On the order of 1% of Miras show evidence for period changes, but unstable periods may be common among the longest period Miras. The case of R Hya is studied in more detail, using archived data from AAVSO, AFOEV, BAAVSS, RASNZ, and VSOLJ, and historical records: we find that its period evolved from almost 500 days around its discovery (AD 1662) to about 385 days since AD 1950. The period change was accompanied by a dramatic change in its mass-loss rate. Such changes in mass-loss rates, especially for the Miras with meandering periods, could be one of the causes of the rings seen around many descendents of Mira variables, the planetary nebulae.

1. Introduction

Mira variables are pulsating red giant stars. They have periods longer than about 100 days (most are around 200–400 days) and visual amplitudes larger than 2.5 magnitudes. A closely related group of variables, the semiregulars (SRa and SRb), have smaller amplitudes and shorter, less regular periods. Both Miras and SR variables are found near the end point of the evolution of solar-like stars, immediately before the formation of a planetary nebula.

Many Mira variables are bright. Several are naked-eye variables, and over 200 are brighter than 9th magnitude at maximum. Miras are popular with many amateur astronomers, being easy to observe and having conveniently long periods. Archives of these amateur observations, such as those maintained by the American Association of Variable Star Observers (AAVSO), British Astronomical Association, Variable Star Section (BAAVSS), Association Française d'Étoiles Variables (AFOEV), Variable Star Observers League of Japan (VSOLJ), and Royal Astronomical Society of New Zealand, Variable Star Section (RASNZ), have become a valuable tool in scientific studies of these stars.

The archives have shown that the amplitudes of Miras can vary over time, but the periods tend to be very stable. The big exception has always been R Hya, which already in AD 1841 was found to show a changing period. We have analyzed archival data for a number of Miras for which claims of changing periods have been made.

2. Data analysis

The detailed analysis is illustrated in Figure 1, for the case of R Aql. We took all available data from all organizations listed in the abstract, and added historical data. There is some overlap between the databases, and not all stars may have occurred in all databases. The top panel in Figure 1 shows the light curve, from AD 1856 when the star was discovered. Individual magnitude estimates are available from about AD 1900. Prior to this, only the dates of maximum and/or minimum were normally published. This is fine for "O–C" type methods, but is more of a problem for full analysis of the light curves. We assigned the dates arbitrary magnitudes, as is obvious in the figure. Our analysis method requires both maxima and minima, but the latter were less often observed. Therefore, where two consecutive maxima were observed, we assumed a minimum midway between: these are also included in the panel. The full data were analyzed using wavelet transforms. The result is shown in the second panel where the frequency is plotted as function of the Julian date. The third panel shows the semi-amplitude of the pulsation (this is not known for the pre-1900 data). Finally, the bottom panel shows the period.

When analyzed in this way, most Miras will show small period fluctuations of typically a few per cent, around a constant mean period. A few Miras show larger variations, and these are the stars studied in this paper. In the particular case or R Aql, Figure 1 shows that the period has been declining steadily.

3. Three types of variable periods

3.1. Continuously changing periods

We confirm four cases where the period of a Mira has decreased or increased continuously over a time of a century or more. R Aql, shown in Figure 1, is a well-known case, where the period has evolved from 365 days around AD 1850, to 275 days at present. The decline has been continuous, with no indications for epochs of stable periods. The case of R Hya, evolving from 495 to 385 days, is discussed in more detail below. We also find a decreasing period in RU Vul, from 160 to 110 days over 50 years. This star is a small amplitude SRa variable, rather than a Mira. Finally, W Dra shows a period *increase* from 155 to 180 days over 90 years of observations.

The change in period is in all four cases large: even for the least unstable star in this group (W Dra) it varied by more than 15%. The period of Mira variables depends on their mass and radius. Miras have strong stellar winds, which can remove much of the star within 10^5 yr. However, over a few centuries the mass is nearly constant. The strong period evolution must mean that the radius is changing.

3.2. Sudden changes

A few Miras show sudden and fast period changes after a long phase of stable periods. The best case is T UMi (Gál and Szátmary 1995; Mattei and Foster 1995), shown in Figure 2. For 60 years it behaved as a perfect Mira with a constant period of 320 days. Around AD 1980 its period suddenly, for no apparent reason, started

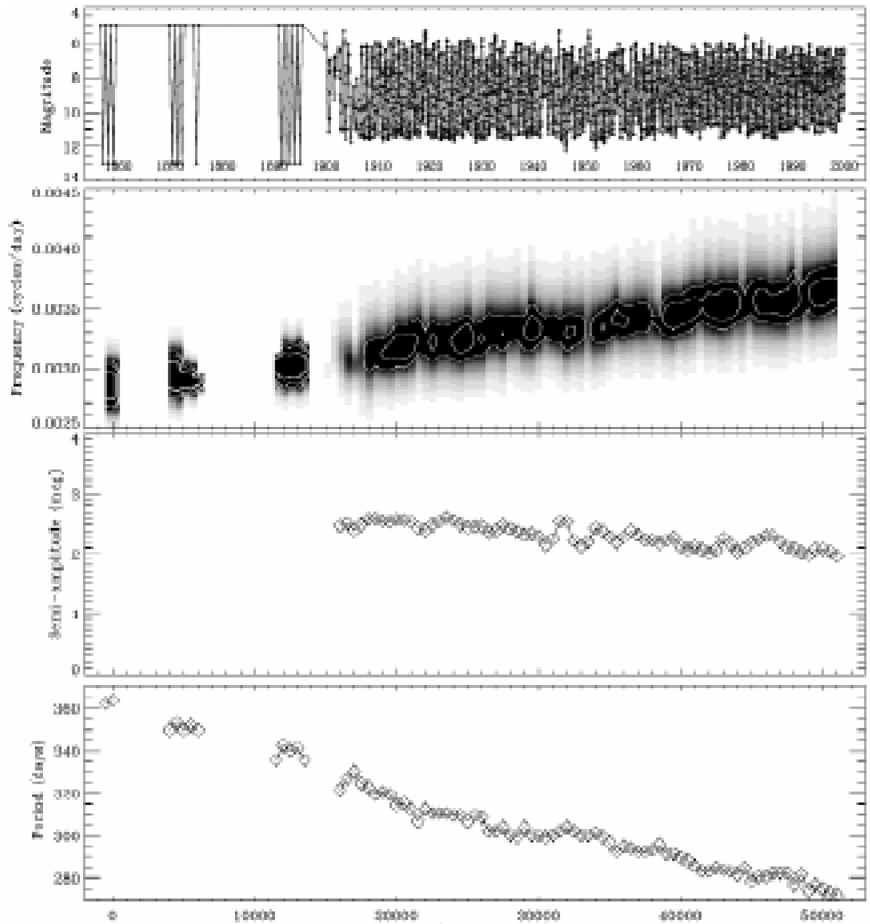

Figure 1. The light curve, period, and amplitude of the Mira variable R Aql.

to decline. The figure shows that the period has reached 240 days and the decrease is still continuing. Compared to the continuously changing Miras, the total change in the period is very similar (20%) but the rate of change is ten times faster.

BH Cru may be a similar case (Bedding *et al.* 2000). It was discovered as a variable in 1965, and its period has increased since 1975 from 420 to 530 days. It is not known whether its period was stable before, but we include it with T UMi because of its similar extreme rate of change.

3.3. Meandering Miras

A number of long-period Miras show evidence for meandering or fluctuating periods. The example of S Ori is shown in Figure 3; other cases include W Hya, T Cep, and R Nor. Their periods change by about 10% over 50 years, followed by

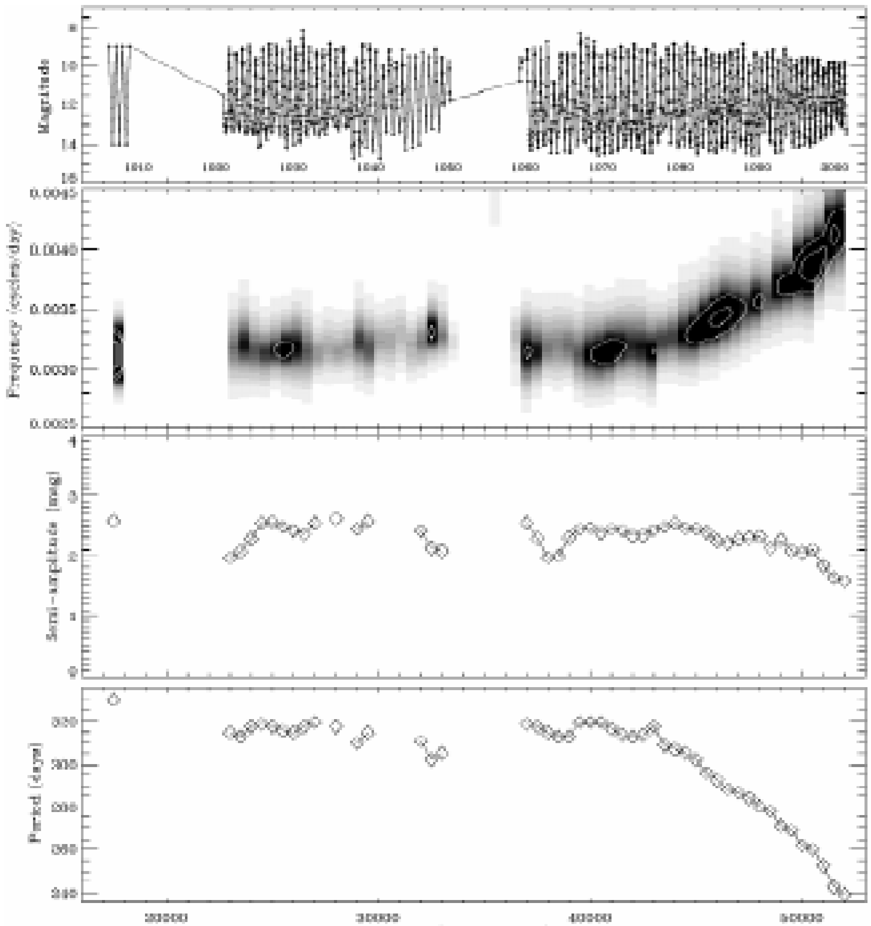

Figure 2. The light curve, period, and amplitude of the Mira variable T UMi.

a return to the previous period. Compared to the other two types, the period change in the meandering Miras is smaller and the rate of change similar to the continuously changing stars like R Aql. All meandering Miras have periods of 400 days or longer.

3.4. How common?

The large majority of Miras show no evidence for changing periods. We estimate that no more than 1–2% of Miras show continuous changes. (But two of the four are among the brightest ($V < 6$) Miras known.) Sudden changes are found in fewer than 1% of Miras. In contrast, meandering periods are found in ~15% of Miras with periods longer than 400 days. And most (or all) Miras with periods longer than 500 days have unstable periods. There is a clear indication that the Miras with the longest periods are the ones most prone to period fluctuations.

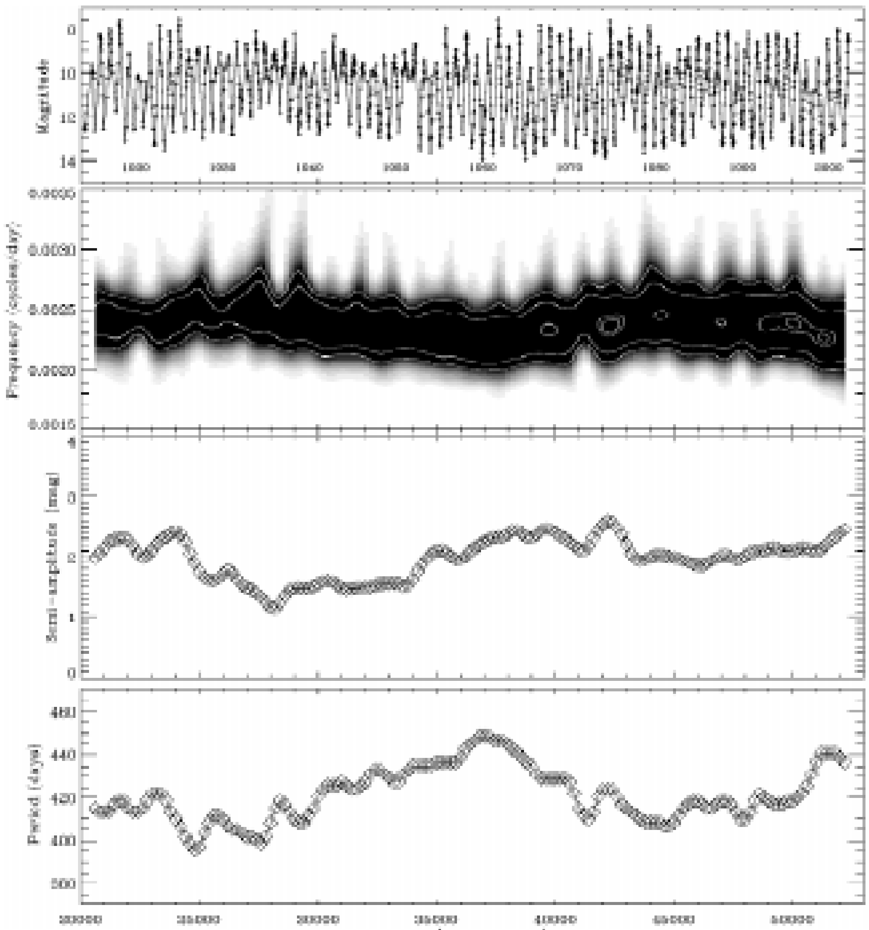

Figure 3. The light curve, period, and amplitude of the Mira variable S Ori.

4. A case study: R Hya

R Hya is the third-brightest Mira variable in the sky. Olbers (1841) first discovered that the period was changing. Wood and Zarro (1981) attributed its changing period to a thermal pulse, in which the helium around the core ignites, leading to rapid changes in luminosity and radius. The thermal pulse should have occurred around the time of the discovery of R Hya.

R Hya was discovered by Johannes Hevelius in AD 1662, and independently by Geminiaro Montanari in AD 1670. Giacomo Filippo Maraldi (Cassini's nephew) first identified the star as a variable in 1704, and observed it for about 10 years. Subsequently the star was not observed for over 70 years (this gap coincides with the depth of the Little Ice Age, when the cloud cover—and famines—in Northern

Europe may have hampered observations at the low declination of R Hya.) Table 1 gives a list of all pre-1850 observations of which we are aware : the early observations are described in Müller and Hartwig (1918) and Argelander (1869). Since about 1900 R Hya has been extensively monitored by, for example, VSOLJ, BAAVSS, and AAVSO observers.

We have determined the period using wavelet analysis, and for the old observations (listed in Table 1) from closely spaced maxima. The resulting period evolution, described in Zijlstra *et al.* 2002, is shown in Figure 4. The earliest time at which the period is well determined is AD 1705. Before this, the two observations close to maximum are in phase with the same period. Figure 4 shows that the main decline occurred between c. 1770 and 1950. After 1950, the period remained stable at 385 days. Before 1770 the period was 495 days, with no evidence for rapid change. Wood and Zarro (1981) discuss a possible period increase during the oldest observations, but we do not confirm this.

Table 1. Pre-1850 observations of R Hya.

Year	*month*	*date of maximum*	*observer*
1662	04	18	Hevelius[(a)]
1670/2[(b)]	04	15	Montanari[(a)]
1704	03	20	Maraldi
1705	09	01:	Maraldi
1708	05	20	Maraldi
1709	11	01:	Maraldi
1712	05	15:	Maraldi
1784	01	26	Pigott
1785	05	25	Pigott[(c)]
1805	05	05	Piazzi
1809	04	04	Piazzi
1818	03	31:	Olbers[(d)]
1823	04	18	Olbers
1827	01	30	Schwerd
1843	05	30	Argelander
1848	04	23	Argelander

a. These are dates of observations rather than dates of maxima. However, given the magnitude range these observations could only have been made close to maximum.

b. There are two possible dates for this observation: AD 1670 or AD 1672 are both mentioned in the original publications by Maraldi and Cassini. But in his calculations Maraldi uses 1670, and we find that in April 1672 the star should have been near minimum.

c. Pigott mentions simultaneous observations by Goodricke which have not been published.

d. Olbers also reports observations between 14 March and 4 May 1817, post-maximum, and between 13 Feb and 15 May 1822, also with an earlier maximum.

The evolution of the pulsation amplitude (only available from 1900 onwards) mirrors the period change, declining until 1950 and remaining constant since. This mirroring between amplitude and period is also seen for R Aql and T UMi, and appears to be a common feature.

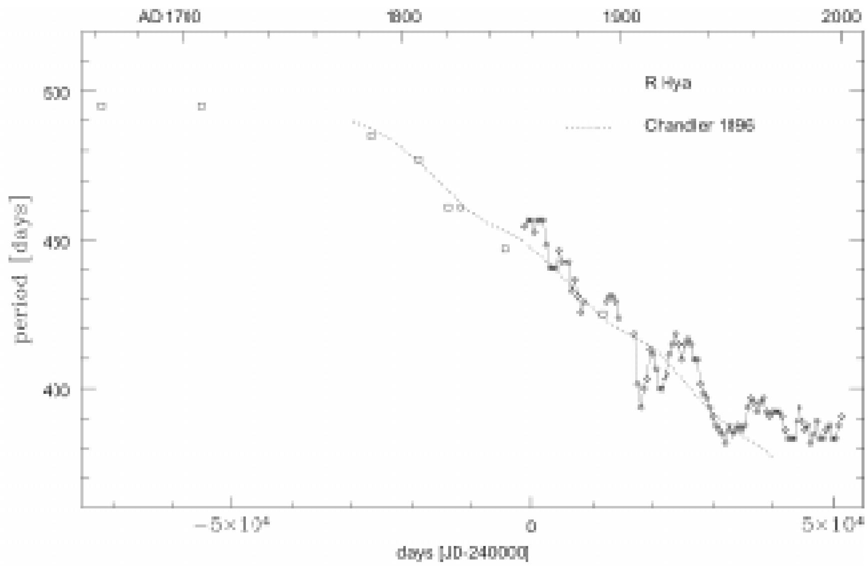

Figure 4. The period evolution of R Hya between 1662 and 2001. The first point is uncertain; the period is well determined from 1704 onwards. Extrapolation of the linear decline suggests the decline began around 1770. The dashed line is the fit proposed by Chandler (1896) in the *3rd Catalogue of Variable Stars.*

5. Mass loss variability

Mira stars experience stellar winds which are ~10^8 times stronger than the solar wind. Vassiliadis and Wood (1993) found an empirical correlation of mass loss rate with period for Miras of the form log $M = A + BP$, where A and B are constants and P is the period. Their relation suggests that even relatively minor fluctuations in the period can yield large changes in the stellar wind. Blöcker (1995) proposed an alternative relation for the mass loss rate, which does not depend on the period but rather on the luminosity of the star.

The main cause of evolution in Mira variables is believed to be the thermal pulse cycle. Roughly every 10^4 yr, the helium in the star ignites explosively: the so-called thermal pulse. For about 10^2 yr following this event, the star will be a few times more luminous than before the explosion. Over 10^3 yr, the helium slowly extinguishes again: during this phase the star is *less* luminous than before the explosion. Finally normal hydrogen burning resumes and the star recovers its pre-pulse luminosity.

After some 10^4 yr, the hydrogen burning has replenished the helium layer (as helium is the product of hydrogen burning), the helium re-ignites and the cycle repeats. Both the luminosity and the period vary during this cycle, especially following the flash, and both Vassiliadis and Wood, and Blöcker relations predict that the mass loss rate will also strongly fluctuate.

R Hya has commonly been explained as a thermal pulse event, and should now be in a phase of decreasing mass loss. The star is surrounded by a circumstellar envelope, as shown by data from the IRAS satellite. But there is little gas and dust close to the star: the envelope is detached from the star (Hashimoto *et al.* 1998). Detached shells have commonly been interpreted as due to a decline in the mass-loss rate following a thermal pulse (Zijlstra *et al.* 1992). The radius of the shell, combined with the known expansion velocity, shows that the mass loss ceased or declined strongly around 250 years ago, coincident with the onset of the decline in period. The decrease in mass loss rate has been at least a factor of 10. This large decrease agrees with predictions of Vassiliadis and Wood based on its change in period, while Blöcker predicts a much smaller change. The Vassiliadis and Wood relation does not include the physical parameters of the star (such as mass, metallicity) and may therefore not give the correct mass loss rate for a particular star (Willson 2000). But because these parameters are constant over the short time scales studied here, the relation may still correctly predict the *change* in mass loss rate during a period fluctuation. R Hya suggests that there is indeed a direct relation between the period and the mass-loss rate.

This raises the question whether the meandering Miras, in which the period fluctuates over a century or so, may also show related mass-loss fluctuations. Evidence for such an effect is found in images of planetary nebulae, which are the fossil shells of Mira stars. A number of young planetary nebulae show concentric rings in the shell. A well-published example is CRL 2688; the HST image is reproduced in Figure 5. The precise origin of the rings is not known, but they are likely due to epochs of enhanced mass loss during the preceding Mira phase. The separation between the rings shows that the interval between such epochs must be of the order of a few centuries. The time scales are close to those of the meandering Miras: *Mass loss variations induced by period changes may be one of the causes of the rings seen around planetary nebulae.*

The meandering periods cannot be caused by the thermal pulse cycle. There is one other model in the literature (Ya'ari and Tuchman 1999), based on the non-linear or even chaotic nature of the Mira pulsations, which predicts period instabilities. This model also predicts variations of the R Hya-type, so that a thermal pulse is not the only possible explanation even for R Hya itself. This difference may be tested with future observations: The thermal-pulse model predicts that the period of R Hya will continue to decline, although the rate of change will slow down. In the non-linear model, the period will become constant and the decline may even reverse again.

The extensive archives on Mira variables (AAVSO, BAAVSS, AFOEV, VSOLJ, RASNZ) contain the *only* data sets which span a sufficiently long time range to be

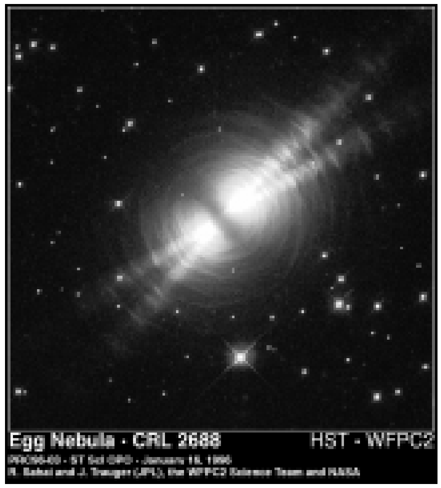

Figure 5. The rings seen around the post-Mira star CRL 2688.

sensitive to slow instabilities. The different predictions for the future evolution of R Hya can only be tested by continuing the observations. Further Mira variables with sudden large period changes are likely to be found through the next century of observations.

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