PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC, **111**:94–97, 1999 January

Long-Term Changes in Mira Stars. I. Period Fluctuations in Mira Stars

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Received 1998 August 13; accepted 1998 September 22

ABSTRACT. It has been known since the pioneering work of Eddington & Plakidis that the period changes in Mira stars are dominated by the effects of random cycle-to-cycle fluctuations in period, at least in the limited sample of stars that were studied. We have extended their work, using a portion of the American Association of Variable Star Observers (AAVSO) international database of variable star observations: times and magnitudes of maximum and minimum magnitude of 391 bright Mira stars over 75 yr (Kowalsky et al.). The Eddington & Plakidis model fits the data in almost every case, at least over a time interval of several tens of cycles. There is a weak correlation between the fractional period fluctuation, per cycle, and the period (or color) of the star, but not with the amplitude or chemical type (M, S, or C).

1. INTRODUCTION

Mira stars are pulsating red giants of late spectral type. By definition, they have visual amplitudes greater than 2.5 mag. They have periods of about 100–1000 days. They are evolving through the tip of the asymptotic giant branch (AGB) in the H-R diagram and, as such, are affected by two significant processes: (1) in the interior, helium shell flashes, which cause large excursions in their luminosity and period on a timescale of tens of thousands of years, and (2) in the outer layers, pulsation-enhanced mass loss, which reduces their envelope masses, and drives their evolution to the white dwarf stage.

Models of these evolutionary processes can potentially be tested by observing the period changes in Mira stars. Unfortunately, it has been known since the pioneering work of Eddington & Plakidis (1929) that the period changes—at least in the limited sample of stars that were studied—are dominated by the effects of random cycle-to-cycle fluctuations, of unknown cause. Further systematic studies were carried out by Sterne & Campbell (1936), Isles & Saw (see, e.g., Isles & Saw 1987), and Lloyd (1989). More recently, Koen and Lombard (Koen & Lombard 1993; Lombard & Koen 1993) have carefully reexamined the existing methods of period change analysis and have developed more appropriate new ones. Their most recent work (Lombard & Koen 1997) suggests a technique for identifying real discrete period changes that may occur in Mira stars by working in the frequency domain and looking for a low-frequency signal in the power spectrum. This is a very promising method for studying real, long-term changes in these stars.

The possible cause of these random fluctuations is of some interest, especially as the amplitudes of Mira stars are also somewhat irregular. Since the outer layers of Mira stars contain large convection cells with random distribution, the pulsation of the star cannot be strictly radially symmetric. Tuthill, Haniff, & Baldwin (1997) have recently used interferometry to detect hot spots on M supergiants. In the case of Mira stars, interferometric observations (Karovska, Nisenson, & Standley 1989) indicate that these stars are nonspherical. The outer layers of Mira stars are also affected by shock waves (Hill & Willson 1979) that, because of their inherently nonlinear nature, may add an element of randomness to the pulsation. Furthermore, there is some evidence for multiperiodicity in Mira stars (Barthès & Tuchman 1994). If the multiperiodicity is sufficiently complex, it can produce quasi randomness in the pulsation, also.

The work described here was carried out, using the Eddington & Plakidis method, to determine whether these random, cycle-to-cycle period fluctuations were a general property of Miras and whether their magnitude was correlated with any other properties of the stars; see Percy et al. (1990) for a brief summary). This work has the advantage that it considers a very large sample of Mira stars in a systematic way. We have recently used the same approach, successfully, on a sample of RV Tauri stars (Percy et al. 1997).

2. OBSERVATIONS

This study was carried out using a 75 yr database of times and magnitudes of maximum and minimum brightness of 391 bright Mira stars, determined from visual observations by the American Association of Variable Star Observers (AAVSO) (Kowalsky et al. 1986). The accuracy of the data depends on several factors: the brightness of the star at the particular maximum or minimum and the density of observations, which will be low if the star was near the Sun at the time. Generally, the times are accurate to 3–5 days, and the magnitudes are accurate to 0.1–0.2 mag at maximum; the accuracy is somewhat poorer at minimum. In the case of the magnitudes, this is the internal accuracy; the magnitudes are determined relative to a sequence of comparison stars, and the adopted magnitudes of these may differ significantly from the *UBV* system. The adopted magnitudes, however, have been extremely stable over the 75 yr; this is one of the very important and positive features of the AAVSO data.

3. ANALYSIS

We have used the method of Eddington & Plakidis (1929) to test the hypothesis of random, cycle-to-cycle fluctuations in period. Let ϵ be the average random fluctuation per period and a be the average random error in the measured times of maximum brightness. These quantities are assumed to be *accidental* and *uncorrelated*. Note that ϵ is a property of the star, whereas a is primarily a property of the process of observation; in principle, it could be determined with perfect accuracy. We define $z(r)$ as the $O-C$ of the rth maximum, compared with the ephemeris, and $u(x, r) = z(r + x) - z(r)$ is the accumulated delay in x periods that, according to the hypothesis, is the sum of x uncorrelated random fluctuations. Allowing also for the random errors in the measured times of maximum, we find that the average value $\langle u(x)\rangle$ over all values of r is given by $\langle u(x)\rangle^2 = 2a^2 + x\epsilon^2$, so a plot of $\langle u(x)\rangle^2$ against x should be a straight line with slope ϵ^2 and intercept $2a^2$. The values of $\langle u(x)\rangle^2$ become less reliable as x becomes large, as pointed out by Eddington & Plakidis (1929). Note that x is measured in cycles, not days.

The values of $z(r)$ were determined from the best ephemerides of the stars (Kowalsky et al. 1986) and then used to determine $\langle u(x)\rangle^2$ for all possible pairs of maxima x cycles apart. The $\langle u(x)\rangle^2$ values were plotted against x. From the linear region of the graph, the slope was determined by least squares. One example of such a plot is shown in Figure 1.

Since the intercept is close to zero, and there is some scatter in the graph, and there may be some curvature near $x = 0$, the intercept is best determined by visually extrapolating the graph to $x = 0$ or by using the value of $u(1)$.

Using the "contingency table" method of Sterne & Campbell (1936) and the "span test" method of Isles & Saw (1987), we had determined (Percy et al. 1990) that the following stars show real changes in the mean period, which *may* be significant at the $P = 0.99$ level; the ones marked * are marginal, and the ones marked ** failed to pass one of the four tests for significant period change: W Tau*, S Ori, Z Tau, Z Aur, V CMi*, T CMi*, R Hya, U UMi**, Z Sco**, RT Sco*, W Dra**, R Aql, RU Lyr*, S Lac**, and V Cas*. Note that the method of Lombard & Koen (1997) is better suited to this purpose than the methods which we used.

4. RESULTS

A typical example of a $\langle u(x)\rangle$ diagram is shown in Figure 1, for Mira itself. The diagram is linear out to $x = 19$. A table of all of the a and ϵ values can be obtained from J. R. P.

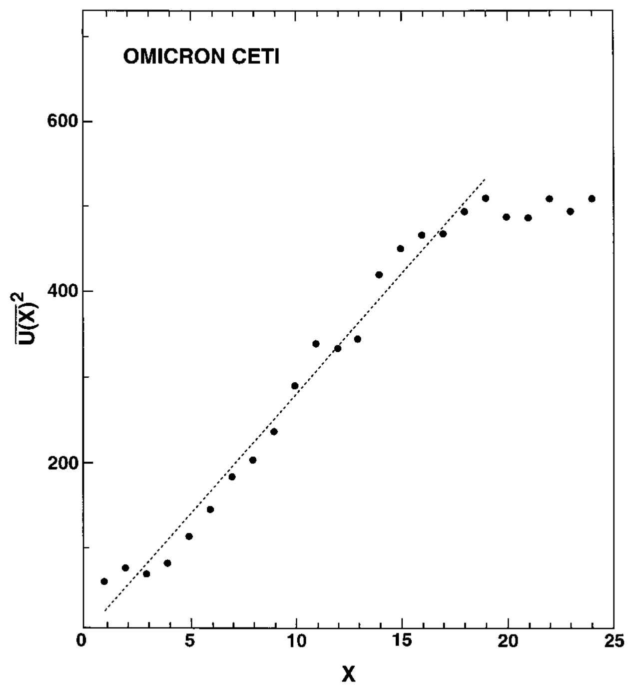

FIG. 1.—Example of a typical $u\langle(x)\rangle$ diagram, for Mira itself; x is expressed in cycles. The diagram is linear out to $x = 20$.

The values of a are less well determined than the values of ϵ, for reasons given above. They are, however, consistent with the expected errors in measuring the times of maximum, namely 3–5 days.

For the 17 stars in common between our study and that of Eddington & Plakidis (1929), the values of ϵ generally agree within a factor of 2, despite the different and much longer time base of our study. There are three exceptions: R Hya and R Aql, which both show significant period changes, and T Cep.

The $\langle u(x)\rangle^2$ diagrams were linear out to values of x ranging from 10 to 50 (typically 15 to 25). The stars that were not linear to $x = 10$ included a few stars for which the data were very sparse (T Cnc, V Hya, RS Dra, RU Cap, and SZ And) and several for which the $O-C$ diagrams showed a great deal of point-to-point scatter (R Hor, V Tau, S Aur, R Col, V Cam, R Lyn, RR Mon, RX Sgr, R Sgr, TY Sgr, and S Aqr). Of these, V Tau, V Cam, and RR Mon showed apparent abrupt changes in period. RU Cyg has too small an amplitude to be a Mira star. V Cnc is very unusual; the period and other properties are normal, but the $O-C$ diagram oscillates by about 10 days on a timescale of a few periods, giving the $O-C$ diagram a very scattered look.

There is a linear correlation between ϵ and the period of the star, as might be expected. Therefore, in Figure 2, we plot the fractional fluctuation ϵ/P against period. Note that (within the statistics of small numbers) there are relatively more large values of ϵ among the longer period stars. These are the largest stars and those with the most extreme properties—convection

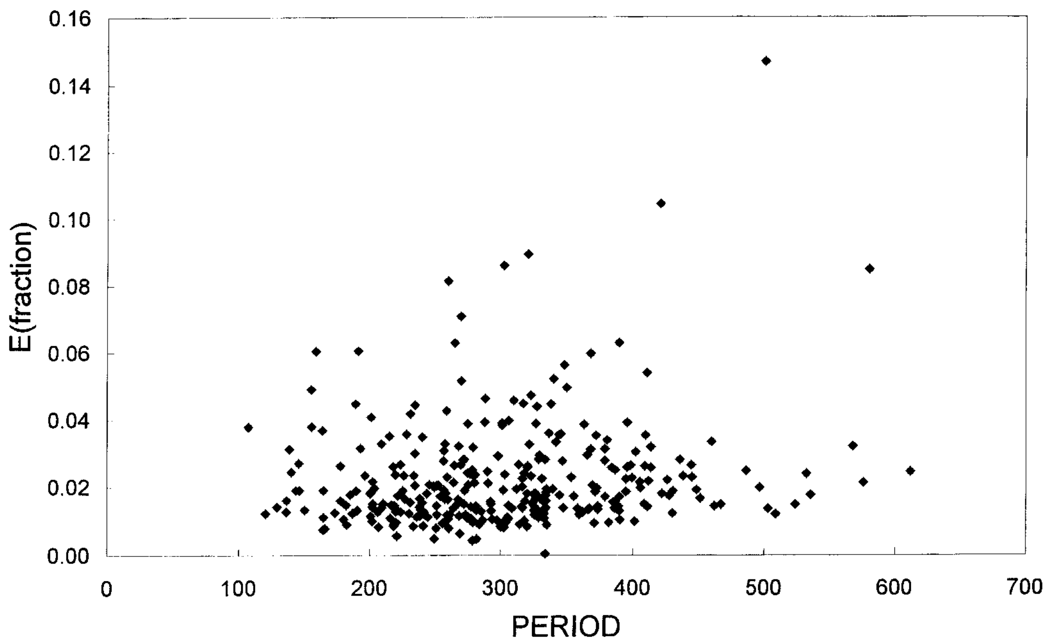

FIG. 2.—Relation between the average relative fluctuation in period ϵ/P and the period P

cells and shock waves, for instance. There is little or no correlation between the fractional fluctuation and the chemical type (M, S, or C), the amplitude, the period, or the color, though a few long-period Miras show a particularly large fractional fluctuation.

Figure 3 shows the correlation between ϵ/P and the color of the star. Here, there is also a correlation. This is not unexpected, since cooler stars tend to have longer periods. Here, however, there is a significant number of small-ϵ stars, even among the coolest ones.

Only one star—Z Aur—showed a ratio of ϵ/P greater than 0.10. This star showed a large, abrupt change in period in

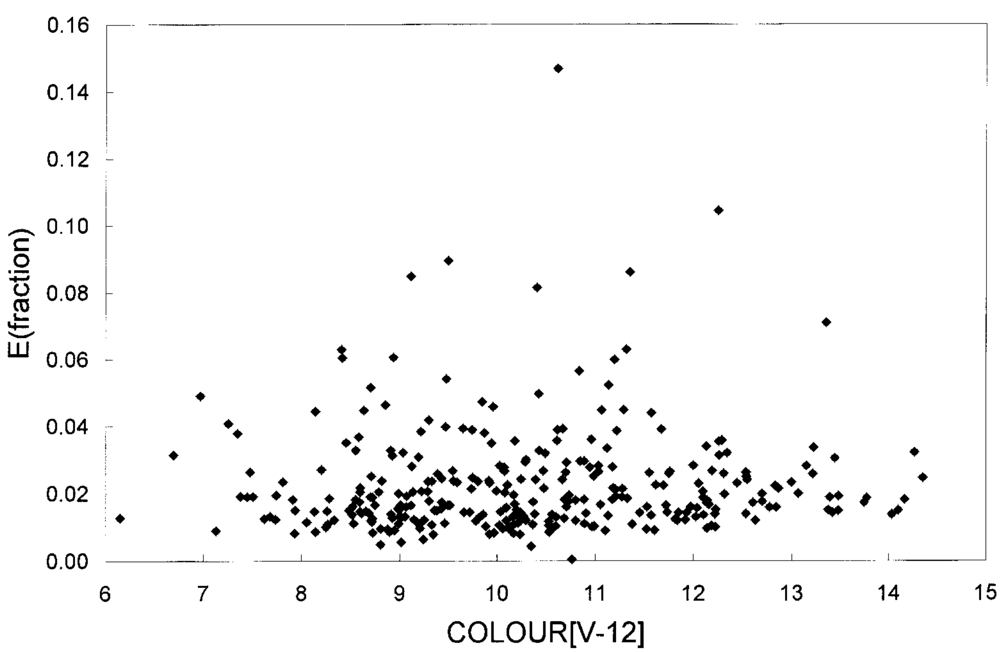

FIG. 3.—Relation between the average relative fluctuation in period ϵ/P and the $V-12$ μm color

JD 2,425,575. According to the General Catalogue of Variable Stars, it is not a Mira star but, rather, an SRd variable.

5. DISCUSSION AND CONCLUSIONS

Our results confirm that, for almost all of the Miras in our large sample, the $O-C$ diagrams of Mira stars are dominated by random cycle-to-cycle fluctuations in period, at least over intervals of about 20 cycles. This has two important implications: (1) It will be very difficult to detect evolutionary period changes from the $O-C$ diagrams, and (2) there are one or more random physical processes, within the star, which result in the pulsation being less regular than for Cepheids, for instance.

Lombard & Koen (1997) have published an excellent discussion of the problem of distinguishing between real, long-term changes in period and apparent changes due to cycle-to-cycle fluctuations. As they point out, it is important to know whether the fluctuations are random or serially correlated. In our case, it appears that they are random, at least over 10–20 cycles.

A few Miras are known to show large linear or abrupt changes in period. Helium shell flashes should result in most Miras having small positive period changes and some having larger negative period changes. These changes should be linear; the cause of abrupt changes is not known. The evolutionary changes will be difficult to observe because they are so small (and dominated by the random fluctuations), but it may be possible to observe them by averaging the period changes over many dozens of stars (Percy, Au, & Bagby 1997a).

We thank the AAVSO observers and Headquarters staff; without their skill and dedication, this research would not have been possible. J. R. P. especially thanks the Director of the AAVSO, Janet A. Mattei, for her long-term collaboration. We also acknowledge the help of Winnie Au and Barry Sloan in this project. J. R. P. thanks NSERC Canada, Erindale College, University of Toronto, and the Section 25 Program of Employment Canada, for research support. The compilation of the database on which this research is based was supported by a grant from the J. P. Bickell Foundation.

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