The Pulsation Properties of the Double-Mode RR Lyrae Variable V79 in Messier 3

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Abstract The double-mode RR Lyrae variable V79 in M3 was observed on seven nights in April 2006 with a 14-inch Schmidt-Cassegrain telescope. A total of 275 CCD frames were obtained. An analysis of these observations indicates that the first-overtone period P_1 was 0.3590 day, the fundamental period P_0 was 0.4834 day, and the amplitude ratio A_1/A_0 was 1.00 ± 0.22. These results imply that the fundamental period increased and that the strength of the fundamental mode oscillations relative to the first-overtone may have increased since 1998 when the star was previously observed. The data also indicate that the periods may fluctuate from cycle to cycle.

1. Introduction

The variability of V79 in Messier 3 was first discovered on Harvard plates obtained between 1895 and 1900 (Bailey 1913). From the beginning, it exhibited peculiar characteristics. The only way that Bailey could plot a satisfactory light curve that fit all of the observations was to assume that the period changed abruptly from 0.48285 day to 0.48329 day in mid-1897. A subsequent investigation by Szeidl (1965) showed that its light curve varied with an amplitude of 0.5 magnitude at maximum light. This is standard behavior for a star that exhibits the Blazhko effect, a periodic modulation of the light curve shape on a timescale typically of tens of days (Smith 1995).

The variation pattern for V79 changed suddenly in the early 1990s. After pulsating in the fundamental mode for at least a century, the star began to pulsate in the first-overtone mode as well. In fact, the first-overtone became its dominant mode. This was the first time that a mode change had been observed in an RR Lyrae variable and it appeared that it might have occurred as a consequence of the star's blueward evolution. Initially, the first-overtone pulsations were detected in observations made in 1996 by Kaluzny *et al.* (1998) and the discovery was announced by Clement *et al.* (1997, hereafter Cle97). However, Corwin *et al.* (1998, 1999, hereafter Cor98, Cor99) and Clement and Goranskij (1999, hereafter CG) later showed that the switch occurred in April 1992. The CG study was based mainly on photographs in the Sternberg Observatory plate collection, plates obtained over the interval 1949–1992. The final observations of the series were made on the night of March 31/April 1, 1992, and at that time, the star appeared to be pulsating in the fundamental mode. About a month later, on May 12/13, when Corwin *et al.* started their observations, the star was pulsating in two modes with the first-overtone dominating. Observations since that time have indicated that the star continues to pulsate in both modes, but the relative strength of the two modes has not remained constant.

The mode change of V79 captured the interest of *Sky & Telescope* magazine (Roth 1998) and they published a finding chart. They also interviewed RR Lyrae expert Horace Smith who commented that, if the change was evolutionary, this would be a very important discovery. However, he also cautioned that the star migh't be dithering and therefore recommended that astronomers continue to observe it. The motivation for our present investigation was to check the current status of V79's pulsations.

2. The observational data

Our CCD observations were obtained on seven nights in April 2006 with Mike Thompson's 14-inch Schmidt-Cassegrain *f*/10 telescope located at longitude: 120° 59' 32".0 W and latitude: 39° 02' 13".1 N in California. The camera was an SBIG STL-1301E with 1280 × 1024 16μ pixels which gave a scale of 0.966 arcseconds per pixel. The field of view was approximately 20 × 16 minutes of arc. The telescope pointing was controlled by THESKY6 and the frames were obtained through a clear filter at intervals of ten minutes. In each case, the exposure time was three minutes. The journal of observations is outlined in Table 1.

The raw images were dark-subtracted with eight "median combined" darks, and were then flat-fielded with sixteen averaged dome flats. V79 appeared to be sufficiently isolated from the other stars to justify the use of aperture photometry for the reductions, so the MIRA PRO package was used to derive the magnitudes relative to four reference stars. The catalogue numbers and coordinates of these four stars are listed in Table 2. The estimated errors in the photometry were ≤ 0.012 magnitude.

A plot of our derived magnitudes for the seven nights is shown in Figure 1. At the beginning of night #1, the observed magnitude was 15.4. After that, the brightness decreased to minimum light at magnitude = 15.7, increased to maximum light at magnitude = 14.97 and then decreased again to magnitude = 15.1 at the end of the night. Thus on the first night, the span of the observations included both minimum and maximum light. The observations also extended through minimum light on nights #2, #4, #5, and #6, and through maximum on nights #3 and #7. However, one can readily see that the magnitudes of maximum and minimum light changed over the course of the observations. This is the signature of a double-mode RR Lyrae variable.

3. The period search

The magnitudes were period-searched using Stellingwerf's (1978) phase dispersion minimization (PDM) technique with a 5×2 bin structure. In this technique, a series of periods are tested, and for each one, a Θ statistic is evaluated. Θ measures the amount of scatter of the phased light curve, thus the lower the value, the more significant the period. In the upper panel of Figure 2, we have plotted Θ values based on our period search of the observed magnitudes. The best period is the first-overtone, $P_1 = 0.3590$ day. There is also a significant dip at 0.348 day which we attribute to an alias period that appears because the observations were obtained over a twelve-day interval.

To search for the secondary period, we derived a mean light curve by fitting a cubic spline interpolation function through the mean magnitudes of the ten phase bins. The residuals to this curve were measured and the PDM technique was used again to derive a period. The Θ-period plot for this search is shown in the second panel of Figure 2. The minimum value of Θ occurs at 0.4834 day, the fundamental mode period P_0.

The next step in our analysis was to revise the magnitudes by subtracting the mean curve for the secondary period from the observed magnitudes and repeat the PDM period search. The Θ-period plot for these revised magnitudes is shown in the central panel of Figure 2. In this plot, the minimum near P = 0.359 day is more pronounced than the one at 0.348 day.

Further period searches showed that there were two additional periods, 0.21 day and 1.40 day, that were present because of interaction between the fundamental and first-overtone oscillations: [$1/0.21 = 1/P_1 + 1/P_0$] and [$1/1.40 = 1/P_1 - 1/P_0$]. We derived the corrected residuals and the corrected magnitudes by subtracting the light curves for these two "interactive" periods from the residuals and from the revised magnitudes, respectively. The two lower plots in Figure 2 show the results of the new PDM period searches. The best periods, 0.4834 and 0.3590 day, remain the same, but the Θ values are lower. The corresponding light curves are plotted in Figure 3.

Our adopted periods are listed in Table 3. Also listed are the periods derived in other investigations of V79 since 1992 when it became a double-mode pulsator. From 1992 to 1998, the P_1 values were all in the range 0.358 to 0.359 day and the P_0 values in the range 0.479 to 0.480 day. Our 2006 observations show no substantial change in P_1, but P_0 increased to 0.483 day. If V79 is evolving blueward, its period should not be increasing. Prior to 1988, the period was approximately 0.483 day, but CG found that the period decreased to 0.480 day between 1988 and 1990. Generally, with a ten-minute spacing of observations made over an interval of twelve days, it should be possible to derive these periods to a precision of approximately 0.0003 day. However, a close examination of Figure 3 indicates that the observations made on night #1 are displaced relative to the others by a phase of ~0.1. It was not possible to derive a period that fitted all of the observations simultaneously. This shift could be caused by a sudden increase in the period between night #1 and the rest of the observations. In other words, the star may be "dithering."

4. The amplitude ratio

The amplitude ratio is another parameter that can provide information about the evolution of a double-mode variable. If the star is evolving blueward, one would expect the amplitude of the first-overtone oscillations to increase relative to those of the fundamental mode, i.e., the value of A_1/A_0 should increase. We derived the amplitudes for the light curves of Figure 3 by fitting a four-order Fourier series to the corrected magnitudes and to the corrected residuals: The amplitudes of the two modes turned out to be the same: first-overtone $A_1 = 0.255 \pm 0.038$ and fundamental $A_0 = 0.255 \pm 0.040$. Thus $A_1/A_0 = 1.00 \pm 0.22$. The errors in amplitude were determined by adding in quadrature the standard deviation of the light curve fits at maximum and minimum light. The error in the amplitude ratio was determined by adding in quadrature the percentage errors we derived for A_1 and A_0. The amplitude ratios for the observations since 1992 are listed in Table 3 and there is no indication that A_1/A_0 has been steadily increasing since the star began pulsating in two modes. In fact, it appears that the ratio in 2006 was significantly lower than in 1996. Unfortunately, the filters and magnitude systems for the various studies are not all the same and it is hard to know how that affects the results. There is not much published information concerning the dependence of amplitude ratios on color because most investigations of double-mode variables have focussed on the period ratios. However, Clementini *et al.* (2004) presented light curves in both *B* and *V* for the double-mode RR Lyrae variable V13 in M3, and it appears that the ratio is not affected by the wavelength band. As expected, the *B* amplitudes, $A_0 = 0.693$ and $A_1 = 0.308$, are larger than the corresponding *V* amplitudes, $A_0 = 0.534$ and $A_1 = 0.246$, but the ratios are 0.44 for *B* and 0.46 for *V*. In other words, it appears that the amplitude ratio does not depend on color. We therefore assume that the amplitude ratios we have derived for our 2006 observations can be compared directly with the ones derived in the previous studies.

5. Conclusion

Our analysis of observations of V79 in April 2006 has shown that the period of fundamental mode pulsation was higher and that the amplitude ratio A_1/A_0 was lower than a decade earlier. This result calls into question the hypothesis that the star's pulsation mode change in 1992 was due to blueward evolution. It also illustrates that it is worthwhile to continue to study this star which can be readily observed with a 14-inch telescope.

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Table 1. Journal of observations of V79.

Night #	*Date (2006)*	*Julian Date 2453000+*	*No. of Frames*
1	Apr 17	843.6817–.9803	42
2	Apr 18	844.6886–.9733	41
3	Apr 19	845.6817–.9733	42
4	Apr 26	852.6963–.9733	37
5	Apr 27	853.7025–.9733	39
6	Apr 28	854.7412–.9733	34
7	Apr 29	855.6955–.9733	40

Table 2. The reference stars.

GSC #	R.A. (2000) h m s	Dec. (2000) ° ' ''
0200401606	13 42 44.36	+28 29 08.5
0200400250	13 42 21.99	+28 28 41.1
0200400513	13 42 38.85	+28 23 30.6
0200401083	13 42 12.38	+28 25 57.2

Note: These data were obtained from the Hubble Guide Star Catalog*, version 1.2, the catalogue used by* THESKY*6 software.*

Table 3. The pulsation properties of V79.

Year	P_1	P_0	filter	A_1/A_0	Source
1992	0.3575	0.4797	B	1.6*	Cor99
1993	0.3575	0.4797	B	1.6*	Cor99
1996	0.358	0.480	V	1.73±0.13	Cle97
1998	0.359	0.479	V	1.33±0.10	CG
2006	0.3590	0.4834	clear	1.00±0.22	This paper

* *In their 1998 investigation, Corwin et al. derived* A_1/A_0 *ratios of 1.28 and 1.48 for 1992 and 1993, respectively. Their 1999 values are different because the light curves they used for estimating the amplitude ratios in 1999 had the interaction frequency* ($1/P_1 + 1/P_0$) *subtracted, but in 1998 they did not.*

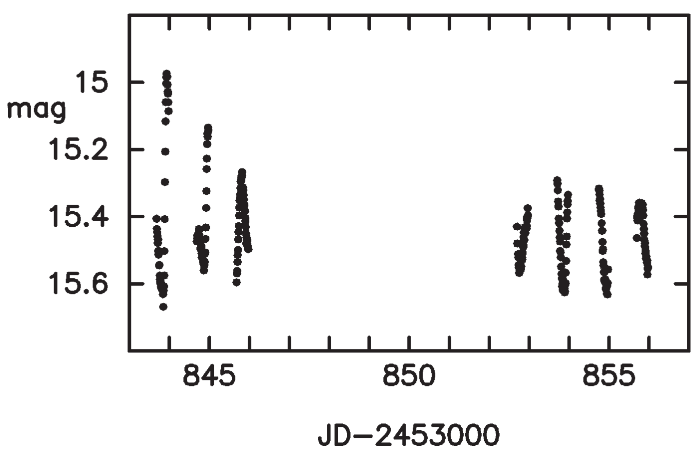

Figure 1. Plot of our observations: magnitudes versus Julian date. These magnitudes are not on a standard system because the observations were made through a clear filter.

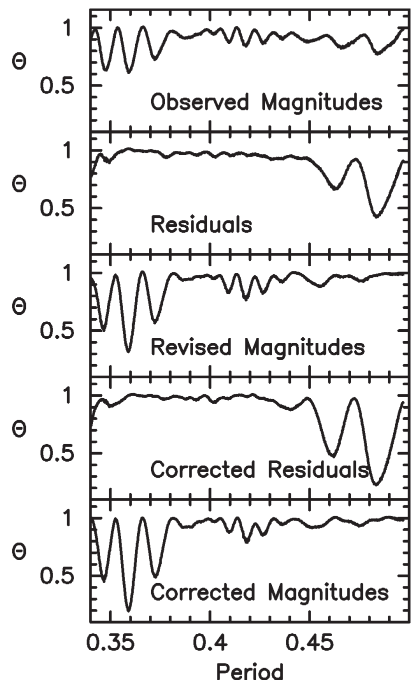

Figure 2. Θ transforms (plots of Stellingwerf's Θ statistic versus period) for V79 based on observations made in April 2006. In each plot, the period for which Θ is a minimum is considered to be the best period. Our procedure for deriving the residuals, revised magnitudes, corrected residuals, and corrected magnitudes is described in Section 3.

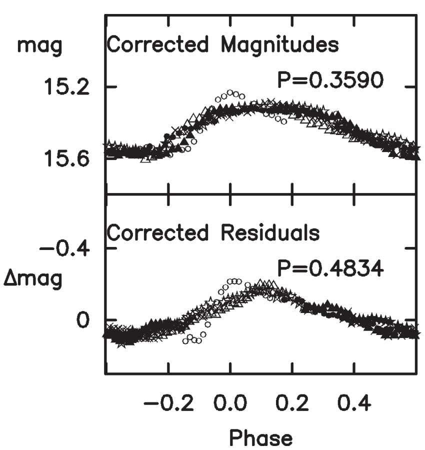

Figure 3. Prewhitened light curves based on the April 2006 observations. In the upper panel, the corrected (prewhitened) magnitudes have been plotted with the first-overtone period, and in the lower panel, the (prewhitened) residuals have been plotted with the fundamental period. The different symbols denote observations made on different nights. Nights #1 to #7 are plotted as open circles, open triangles, open stars, solid circles, solid triangles, solid stars and crosses, respectively. The scatter on these curves demonstrates that it was not possible to find periods that fit all of the observations simultaneously. The points for the first night are displaced relative to the others. We interpret this as irregularity that can occur from one cycle to the next.