AC HER AND U MON: RV TAURI STARS IN THE AAVSO PHOTOELECTRIC PHOTOMETRY PROGRAM

John R. Percy
Akos Bakos
Erindale Campus
University of Toronto
Mississauga, Ontario L5L 1C6
Canada

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Abstract

There are two RV Tauri stars in the AAVSO photoelectric photometry program. AC Herculis is a so-called RVa star: it has no significant long-term variations in mean magnitude. U Monocerotis is an RVb star: it has conspicuous long-term variations in mean magnitude, on a time scale of about 2500 days. The light curves of AC Her and U Mon are used to illustrate the RVa and RVb classification. The cause of the RVb phenomenon is poorly understood; current theories will be reviewed briefly. Times of minimum of AC Her and U Mon have been determined from the light curves, and added to a database compiled by E. Zsoldos (Konkoly Observatory, Hungary). The long-term (O-C) diagrams have been derived. Although these are dominated by the effects of random cycle-to-cycle fluctuations in period, it is possible to begin to see the effects of stellar evolution. The majority of the stars have decreasing periods, as would be expected for stars in the post-asymptotic-giant branch phase of evolution.

1. Introduction

According to the *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985), RV Tauri stars are "pulsating supergiants having spectral types F to G at maximum light, and K to M at minimum light. The light curves are characterized by the presence of double waves with alternating primary (deep) and secondary (shallow) minima, which can vary in depth so that primary minima may become secondary ones, and vice versa; the complete light amplitude may reach 3 to 4 magnitudes in V. The periods between two adjacent primary minima (called the 'double' or formal period) lie in the range 30 to 150 days. Two sub-types may be isolated: RVa—variables which do not vary in mean magnitude; RVb—variables which periodically vary in mean magnitude, with periods of 600 to 1500 days (or more), and with amplitudes up to 2 magnitudes in V."

RV Tauri stars appear to be post-AGB (asymptotic giant branch) stars, evolving from the red giant to the white dwarf phase (Jura 1986). The double wave light curves are believed to be due to a resonance between the period of the fundamental mode of pulsation and that of the first overtone mode (Fokin 1994). The cause of the RVb phenomenon—the slow variation in the mean magnitude—is not known.

There are two RV Tauri stars in the AAVSO photoelectric photometry program (Percy 1984; Percy 1991): AC Her, which is an RVa star, and U Mon, which is an RVb star. In this paper, we analyze the first ten years of AAVSO photoelectric observations of these stars.

Table 1. Comparison and check stars for AAVSO photoelectric photometry program RV Tauri stars.

Program Stars			*V*	*B*	*Spectrum*
AC Her = HD 170756					
	Comparison star	HD 170897	7.39	8.45	K0
	Check star	HD 170561	8.82	10.00	K0
U Mon = HD 059693					
	Comparison star	HD 059730	6.58	8.20	K2
	Check star	HD 059381	5.71	7.32	K5III

2. Observations

The program stars and their comparison and check stars are shown in Table 1. The observations (Mattei and Landis 1997), made by 19 observers, were corrected for differential extinction, and transformed to the standard UBV system using a standard computer program at AAVSO Headquarters. Observations were made in V only; the transformation uses the mean catalogue values of (B-V) for the stars, assuming these to be correct and constant. This assumption introduces a potential error of a few thousandths of a magnitude. The accuracy of the observations ranges from about 0.01 to 0.02 magnitude, as estimated from the scatter in the differential magnitudes of the check stars, and from other studies using data from the AAVSO photoelectric photometry program. The scatter in the observations of the check star for AC Her is somewhat greater, on account of its much fainter magnitude—V = 8.82. The observations have been deposited in the AAVSO archive of photoelectric data, and may be obtained from AAVSO Headquarters (25 Birch Street, Cambridge MA 02138-1205, USA; e-mail: aavso@aavso.org). Contributors to the AAVSO photoelectric photometry database on AC Her and U Mon, along with the number of observations made of each star, are listed in Table 2.

In total, there are 137 observations of AC Her covering the interval JD 2445795 to 2450005, and 183 observations of U Mon covering the interval JD 2445413 to 2449837. Although the observations were made by 19 different observers, the majority used SSP-3 photometers with solid-state detectors and standard V filters. Transformation coefficients were determined for each observer separately, generally using observations of red-blue star pairs. Systematic differences among the data from different observers were therefore very small. Figure 5, for instance, is based on data from five different

Table 2. Observers of AAVSO RV Tauri program stars AC Her and U Mon.

Name	*n (AC Her)*	*n (U Mon)*	*Name*	*n (AC Her)*	*n (U Mon)*
Barksdale, W.	0	5	Powell, H.	2	0
Gorski, L.	0	8	Pray, D.	0	50
Hakes, B.	14	0	Ripley, G.	3	0
Isles, J.	2	0	Smith, M.	0	23
Johnsson, R.	1	0	Snyder, L.	1	0
Kneipp, P.	14	0	Soder, J.	1	0
Koster, A.	31	9	Stoikidis, N.	4	4
Langhans, T.	17	0	Thompson, R.	19	13
Luedeke, K.	24	30	Wood, J.	0	20
Manker, P.	4	21			

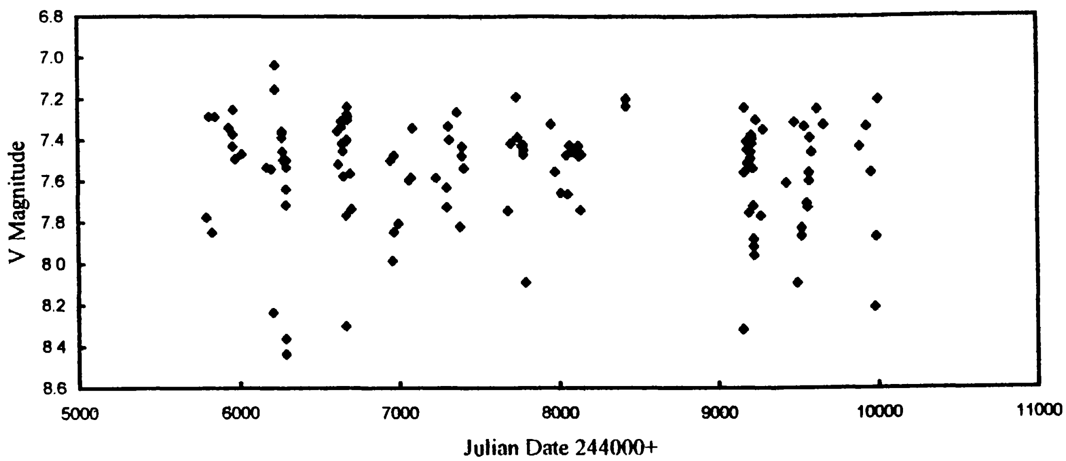

Figure 1. The AAVSO differential V light curve of AC Herculis, relative to HD 170897, over about 4000 days.

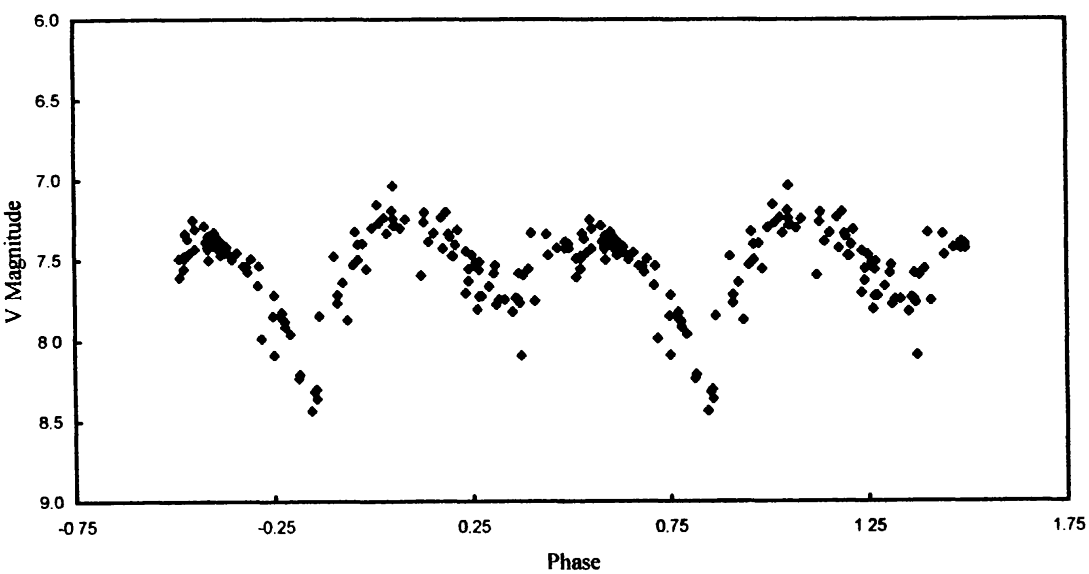

Figure 2. The differential V phase curve of AC Herculis, based on a period of 75.41 days and an epoch of JD 2445772.53. Note the relatively low scatter, indicating that this star is regular over both short and long time scales.

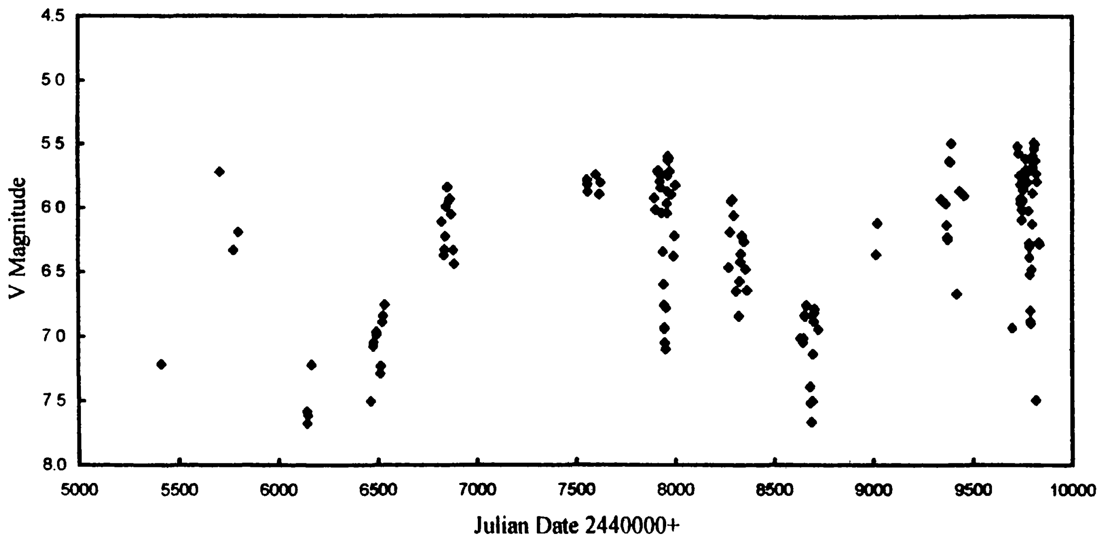

Figure 3. The AAVSO differential V light curve of U Monocerotis, relative to HD 59730, over about 4000 days. Note the pronounced long-term variations, on a time scale of about 2500 days.

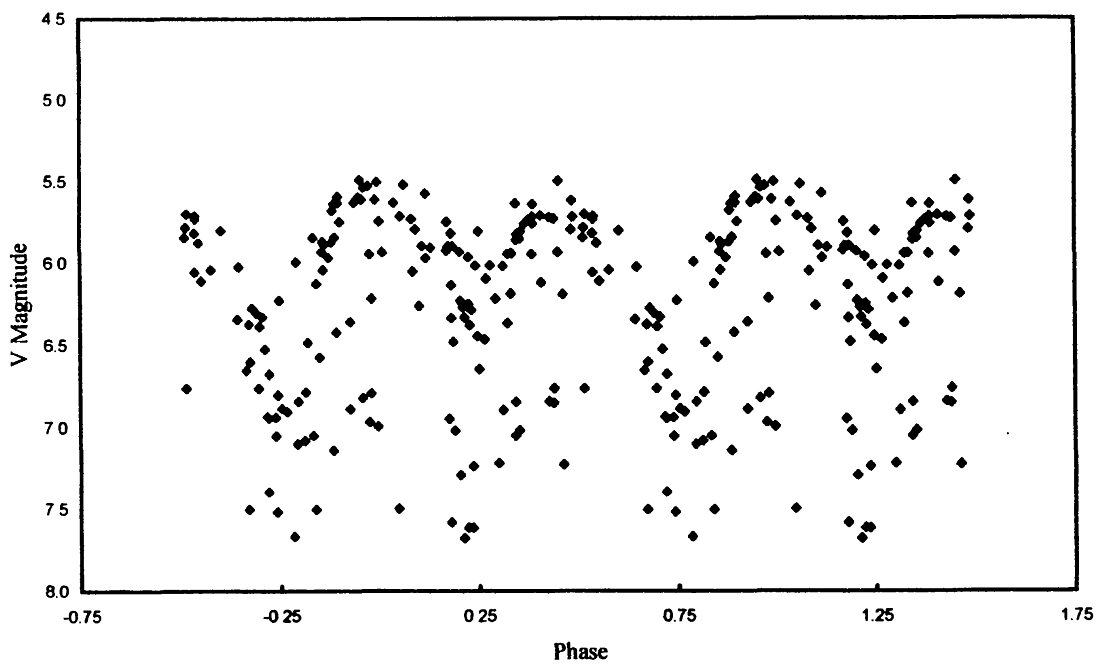

Figure 4. The differential V phase curve of U Monocerotis, based on a period of 92.23 days and an epoch of JD 2449721.03. Note the scatter, caused by the long-term variations (and also the variation of the amplitude of the pulsation with the phase of the long-term variations).

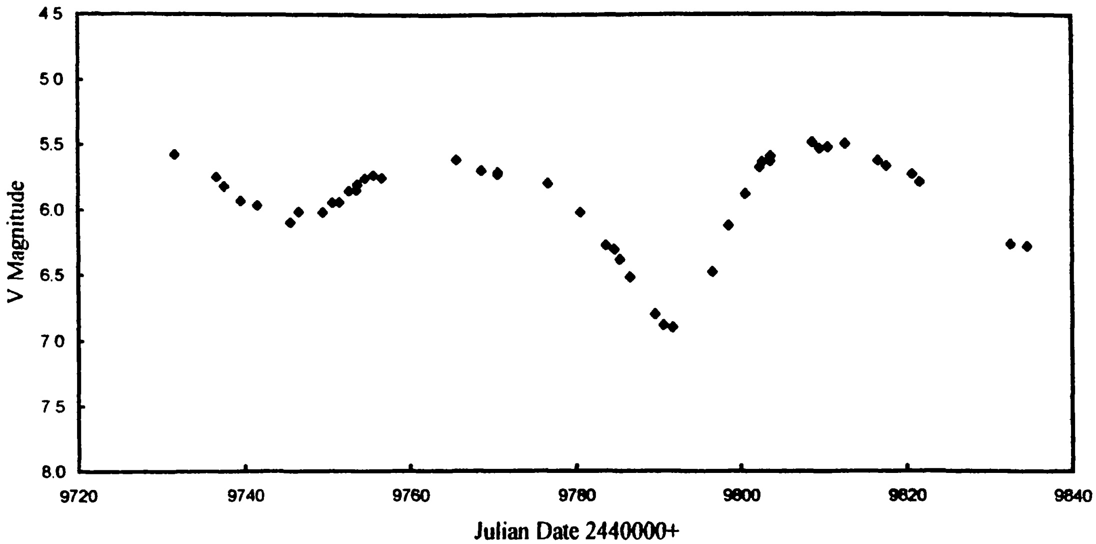

Figure 5. The AAVSO differential V light curve of U Monocerotis, relative to HD 59730, over one cycle. Note the typical double-wave shape of the light curve.

observers, yet the scatter is acceptably small.

3. Light curves

Figure 1 shows the AAVSO photoelectric V light curve of AC Her over the 10+ years of observation. There are no obvious long-term variations. Figure 2 shows the phase curve of AC Her using the period of 75.41 days. The curve is relatively smooth at all phases, indicating that this star is relatively periodic.

Figure 3 shows the AAVSO photoelectric V light curve of U Mon over the 10+ years of observation. The long-term variations are very pronounced. Figure 4 shows the phase curve of U Mon using the period of 92.23 days. The scatter is very pronounced at all phases, reflecting the long-term variability shown in Figure 3. Figure 5 shows the light curve of U Mon over one cycle of about 100 days. The star shows a smooth, classic double-wave light curve.

4. Times of minimum brightness

Since the minima of RV Tauri stars are much better defined than the maxima, they are usually used for studies of the period and of period changes in these stars (Percy *et al.* 1997). For AC Her, the phase diagram is smooth, and well-suited for determining a time of minimum from the large body of data. The time of minimum so determined is JD 2445835.79, with an estimated uncertainty of 0.1 day.

In the case of U Mon, the phase curve is not suitable for determining a time of minimum. Most of the cycles are somewhat sparse, with the exception of the one shown in Figure 5, and one other. These have therefore been used to derive individual times of minimum, namely JD 2447946.53 (deep) and JD 2447990.58 (shallow) in the cycle JD 2447910–2448000, and JD 2449745.73 (shallow) and JD 2449791.76 (deep) in the cycle JD 2449730–2449810. The estimated uncertainty is 0.1 day for the deep minima, and 1.0 day for the shallow ones.

The times of minimum of the long-term variations of U Mon are JD 2446250 and 2448750, with an uncertainty of 50 days. These times were determined by (i) visual inspection of the long-term light curve and (ii) fitting the light curve to a time-reversed light curve on acetate (the "tracing-paper method").

5. The period of U Mon

Although the period of U Mon clearly decreased abruptly in 1957 (Percy *et al.* 1991, Figure 1), the more recent behavior of the period is less clear. Several times of minimum around JD 2442000 show no particular trend (Percy 1997). The two deep minima determined in section 4 give a period of 92.26 days, and the two shallow minima give 92.38 days. It is therefore not unreasonable to use the period of 92.23 days in Figure 4.

6. Discussion

6.1. The (O-C) diagram

The (O-C) diagrams of RV Tauri stars are known to be dominated by the effects of random cycle-to-cycle fluctuations in the period (Percy *et al.* 1997), as is the case in Mira stars (Eddington and Plakidis 1929). It may be possible, however, by averaging over a large number of stars, to detect the slow decrease in period which is predicted by evolutionary models of post-AGB stars (see Percy *et al.* 1991, for instance). A preliminary study (Percy 1997) indicates that 13 of 16 RV Tauri stars with well-defined (O-C) diagrams have decreasing periods. This is the case for both AC Her and U Mon.

6.2. The nature of the RVb phenomenon

The long-term changes in the mean magnitude of some RV Tauri stars have not been adequately explained, though some sort of binary model seems to be indicated on the basis of the long-term radial velocity variations and the eclipse-like light curve. Based on the phasing, the eclipse must involve a disc or torus of dust, perhaps ejected from the RV Tauri star during its AGB phase. Another possibility is that the RV Tauri star is in an eccentric orbit about another star, and mass loss occurs when the stars are at periastron. This may also explain the puzzling fact that, in U Mon and one or two other RVb stars, the amplitude of pulsation seems to be greater at the maximum of the long-term variation. This effect is very difficult to explain if the long-term brightness variations are strictly geometrical.

7. Closing remarks

Sections 6.1 and 6.2 indicate that long-term monitoring of RV Tauri stars can be useful in detecting period changes due to evolution and long-term changes in mean magnitude and amplitude. AAVSO observations of RV Tauri stars can contribute in both of these areas.

8. Acknowledgements

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