Multicolor CCD Photometry and Period Analysis of Three Pulsating Variable Stars

Kevin B. Alton
UnderOak Observatory, 70 Summit Avenue, Cedar Knolls, NJ 07927; mail@underoakobservatory.com

Received November 21, 2013; revised January 14, 2014; accepted January 28, 2014

Abstract Multicolor CCD photometry of three pulsating variable stars, RR Leo, TYC 790-1124-1, and V337 Ori has lead to period solutions using Fourier methods on light curves acquired at UnderOak Observatory (UO). New photometric data from RR Leo largely corroborate findings previously reported for this well-studied RRab variable. An O–C diagram period analysis using a rich historical record of time-of-maximum light data produced an updated quadratic ephemeris for RR Leo. Although not compelling, underlying sinusoidal variability in the quadratic residuals suggest that this intrinsic variable may also have a gravitationally bound cohort. Light curves from the poorly studied HADS variable TYC 790-1124-1 were remarkably symmetrical; this behavior was observed during a single campaign in 2011 which lasted only one month. Fortunately, starting nearly a decade ago photometric data were also captured by the ASAS survey between 2002 and 2009; the combined results reveal that the fundamental period and light curve shape for TYC 790-1124-1 has substantively remained unchanged. V337 Ori has only been studied by two other investigative groups within the past three years; their results and the two most prominent pulsation frequencies at 4.96877 and 6.72 c/d detected in the UO light curves are in good agreement. Notably, this HADS exhibits significant cycle-to-cycle amplitude variability which may be related to these and other pulsation modes not detected in the present study.

1. Introduction

CCD images in three passbands (B, V, and I_c) were used to produce new light curves for the intrinsically variable stars RR Leo, V337 Ori, and TYC 790-1124-1. Light curves for RR Leo, an RR Lyrae pulsator, have been available in the literature for over eighty years using data derived from photographic plates (Allen and Marsh 1932). Thereafter multi-color CCD-based light curves of this RRab variable have been published by Liu and Janes (1989) and Ekmekçi *et al.* (2012). By contrast, light curves and period analyses for V337 Ori (Khruslov 2011; Wils *et al.* 2012) and TYC 790-1124-1 (Pojmański *et al.* 2005), both high-amplitude δ Scuti (HADS) variables, were only published within the last decade from data collected during the ASAS (Pojmański 2002), NSVS (Woźniak *et al.* 2004), and/or SuperWASP surveys (Butters *et al.* 2010).

2. Image acquisition and data reduction

All images were acquired at UnderOak Observatory (UO) in Morris County, New Jersey, using a 20-cm catadioptric telescope outfitted with an SBIG ST-402ME CCD camera. Automated multi-bandwidth imaging was performed with SBIG photometric B, V, and I_c filters manufactured to match the Bessell prescription. The computer clock was updated automatically via the U.S. Naval Observatory Time Server immediately prior to each session and all observations recorded as UTC. Image acquisition (object frames, darks, and flats) was performed using CCDSOFT 5 (Software Bisque 2011) while calibration and registration were accomplished with AIP4WIN v2.3.1 (Berry and Burnell 2008). Exposure time for B-filtered images was 90 seconds, whereas V- and I-filtered data were collected within 60 seconds with a thermoelectrically cooled camera. Darks ($n>10$) were time- and temperature-matched with object frames; the median of all darks collected nightly was subtracted from each object frame. As necessary, new twilight sky-flats (bias- and dark-corrected) in each band-pass were collected ($n>15$) after any change in the optical train orientation; final object images were corrected by standard flats division. Further photometric reduction was performed with MPO CANOPUS v10.3.0.2 (Minor Planet Observer 2010) to ultimately calculate ephemerides (HJD from UTC) and the fundamental period of variability (Henden and Kaitchuck 1990). To minimize the need for air mass corrections due to differential refraction and color extinction, 1) comparison stars were always within the same field-of-view (~7.9 × 11.8 arcmin) for each target image, 2) every effort was made to select comparison stars which were as close to the color index (B–V) of each target as possible, and 3) only data from stars positioned above 30° altitude (airmass <2.0) were included in light curves.

The mean derived magnitude for each comparison star varied between ± 0.025 (V and I_c) and ± 0.04 (B) mag. Over each session, Comp/Cavg values remained essentially constant, indicating comparison stars did not exhibit any variable behavior beyond that which would be expected from experimental error. As an example, this is illustrated (Figure 1) where the nearly parallel fit of the four comparison stars (B-bandpass) used to derive magnitudes for TYC 790-1124-1 also suggests that did they did not need to be color-corrected (air mass = 1.134 to 1.996). This finding is particularly relevant since, compared to V- and I-passbands, the B-filtered data are the most affected by air mass differences. Similar results were also obtained with the comparison stars used for V337 Ori and RR Leo (Table 1). Instrumental readings were reduced to catalog-based magnitudes using the "Derivedmags" feature and the MPOSC3 reference catalog built into MPO CANOPUS. When using more than one comparison star, a separate derived magnitude is computed for each target-comparison pair and the mean becomes the derived magnitude for the target. Almost all stars in the MPOSC3 reference catalog have $BVRI_c$ magnitudes derived from

Table 1. Astrometric coordinates (J2000) and MPOSC3 catalog magnitudes (B, V, and I_c) for RR Leo, TYC 790 1124 01, V337 Ori, and the corresponding comparison stars (C1–C4) used in this study.

Star Identification	*R.A.* h m s	*Dec.* ° ′ ″	*MPOSC3*[a] *B mag.*	*MPOSC3*[a] *V mag.*	*MPOSC3*[a] *I_c mag.*	*MPOSC3*[a] *(B–V)*
RR Leo	10 07 43.47	23 59 30.4	9.78–11.56[b]	9.69–11.12[b]	9.61–10.59[b]	0.01–0.43[b]
C1	10 07 41.56	24 04 50.1	12.47	11.84	11.13	0.63
C2	10 07 33.83	24 03 13.4	13.77	13.25	12.64	0.52
C3	10 07 51.06	24 05 26.9	14.12	13.55	12.89	0.57
TYC 790–1124–01	07 44 51.02	13 15 03.6	10.44–10.80[b]	10.05–10.32[b]	9.63–9.80[b]	0.35–0.51[b]
C1	07 44 42.71	13 17 39.8	12.00	11.31	10.54	0.69
C2	07 44 31.16	13 16 53.0	13.46	12.52	11.54	0.93
C3	07 44 30.35	13 12 18.8	14.00	13.34	12.60	0.66
C4	07 45 12.14	13 17 07.1	11.42	10.42	9.38	1.00
V337 Ori	05 59 20.58	20 02 07.5	10.93–11.78[b]	10.56–11.23[b]	10.20–10.64[b]	0.22–0.71[b]
C1	05 59 01.98	19 56 17.1	12.36	11.76	11.08	0.60
C2	05 59 28.07	19 57 34.8	12.75	12.36	11.88	0.39
C3	05 59 24.43	19 57 40.7	13.42	12.16	10.88	1.25
C4	05 59 08.10	20 02 10.7	13.21	12.18	11.12	1.03

Notes: a. MPOSC3 is a hybrid catalog which includes a large subset of the Carlsberg Meridian Catalog (CMC-14) as well as data from the Sloan Digital Sky Survey (SDSS). b. Range of values determined at UO for each variable.

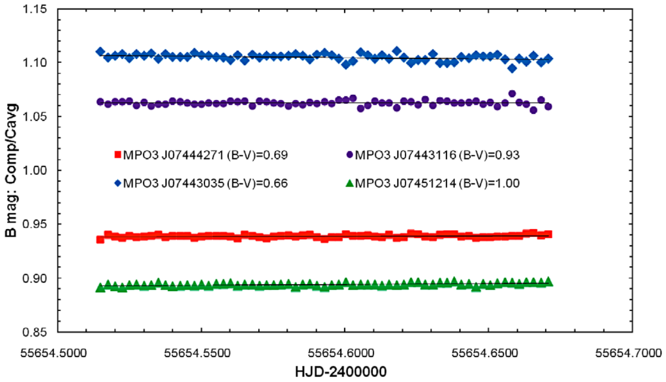

Figure 1. Representative plot showing behavior of comparison stars (B mag.: Comp/Cavg) used for TYC 790-1124-1 during a session when the air mass ranged from 1.134 to 1.996.

2MASS J–K magnitudes; these have an internal consistency of ±0.05 mag. for V, ±0.08 mag. for B, ±0.03 mag. for I_c, and ±0.05 mag. for B–V (Warner 2007). Thereafter, all light curve data (HJD vs magnitude) from each target were further analyzed by discrete Fourier transform (PERIOD04, Lenz and Breger 2005) and/or by the Lomb-Scargle method (PERANSO v2.5, Vanmunster 2013). During the 2009 campaign photometric sessions (V and I_c) for RR Leo occurred between 10 April 2009 and 02 May 2009; two years later imaging of this target in three colors (B, V, and I_c) was completed between 21 April 2011 and 02 June 2011. Photometric data for V337 Ori were collected between 14 Jan 2011 and 24 Feb 2011, while imaging of TYC 790-1124-1 was conducted during a one-month period starting on 03 March 2011.

3. Results and discussion

Photometric data (JD vs magnitude) from this study have been uploaded to the AAVSO International Database (AID; AAVSO 2013) and are also available electronically by request (mail@underoakobservatory.com). Times of maximum acquired at UO were estimated using the polynomial extremum fit feature in PERANSO; mean values (B, V, and I_c) are summarized in Table 2. Discrete Fourier transform analysis (spectral window = 50 c/d) was used to determine the fundamental pulsating frequency for each variable star followed by successive pre-whitening to tease out other potential oscillations. Only independent oscillations with $S/N > 4$ and above the passband error detection limits are presented; those derived from harmonics or combination frequencies are not tabulated (Table 3). In all cases, uncertainties in frequency, amplitude, and phase were estimated by the Monte Carlo simulation ($n \geq 400$) routine built into PERIOD04.

Table 2. Mean times of maximum (HJD from UTC) for the pulsating variables RR Leo, TYC 790-1124-1, and V337 Ori as determined at UnderOak Observatory using B, V, and I_c passbands.

Star Identification	*Mean ToMx* (HJD)*	*(±SD)*
RR Leo	2454949.6032	0.0023
	2454973.5807	0.0021
	2455714.6146	0.0021
TYC 790-1124-1	2455623.6431	0.0054
	2455628.6812	0.0050
	2455645.5858	0.0056
	2455648.6441	0.0057
	2455649.5408	0.0049
	2455654.5778	0.0055
V337 Ori	2455575.6836	0.0011
	2455576.6959	0.0036
	2455584.5327	0.0030
	2455585.5403	0.0013
	2455585.7473	0.0018
	2455592.5906	0.0034
	2455596.6171	0.0042
	2455601.6435	0.0021
	2455603.6569	0.0025
	2455605.6703	0.0045
	2455608.6902	0.0020
	2455616.5385	0.0029

* *Times of maximum and associated error estimated using best fit polynomial (PERANSO, Vanmunster 2013).*

3.1. RR Leo

Folded light curves from 2009 and 2011 (Figure 2) exhibited a fundamental period of 0.452405 ± 0.000001 d which is similar to that reported by Le Borgne *et al.* (2007c). A well-fit ($r^2 > 0.994$) quadratic relationship between observed-minus-calculated residuals and time which spans over 110 years of observation was observed in the so-called "O–C diagram" for RR Leo (Figure 3). As was similarly shown by Olah and Szeidl (1978) and Le Borgne *et al.* (2007c), the plot describes an upwardly-turned parabola, thereby suggesting that the period of this system is slowly increasing with time. Along with new values reported herein, data (Table 4) in Figures 3 and 4 include those reported by Olah and Szeidl (1978), Le Borgne *et al.* (2007c), and time-of-maximum light values published since 2007. When using the GCVS linear elements (Samus *et al.* 2012) a discontinuous curve resulted which could be easily remedied by period-

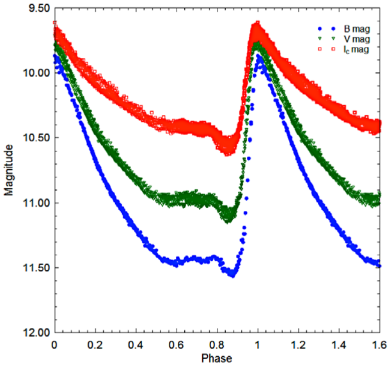

Figure 2. Folded multi-color light curves (P = 0.452405 d) from RR Leo acquired at UO in 2009 and 2011.

shifting data collected prior to 1936. Non-linear regression analysis using a scaled Levenberg-Marquardt algorithm (Press *et al.* 1992) as implemented in QTIPLOT (v0.9.8.9; Vasilief 2013) revealed that the time-to-maximum residual data from the initial timing in 1898 until 2012 could be fit ($r^2 > 0.997$) by a quadratic expression as follows:

$$C = c + a_1E + a_2E^2 \tag{1}$$

Accordingly, the coefficients (± error) for each solved term in Equation 1 are as follows:

$$C = –6.480 (\pm 0.490) \times 10^{-3} – 9.052 (\pm 0.154) \times 10^{-7} E + 1.881 (\pm 0.006) \times 10^{-10} E^2, \tag{2}$$

and lead to the updated quadratic ephemeris for RR Leo:

$$\text{Max HJD} = 2456285.5459 (\pm 0.0005) + 0.4524032 (\pm 0.0000002) E \\ + 1.881 (\pm 0.006) \times 10^{-10} E^2. \tag{3}$$

In this case, the period rate of increase ($\Delta p/p = 2a_2 = 3.763 (\pm 0.012) \times 10^{-10}$) for RR Leo has lasted for at least 114 years. The period increase rate ($dP/dt = 8.32 (\pm 0.03) \times 10^{-10} dd^{-1}$) compares favorably to the same value ($8.26 (\pm 0.04) \times 10^{-10} dd^{-1}$) calculated by Le Borgne *et al.* (2007c). As first suggested by Olah and Szeidl (1978), the residuals (Figure 4) after fitting the quadratic model appear to exhibit behavior consistent with cyclic variation and could be fit by a quadratic expression modulated with a sinusoidal term as follows:

$$C = c + a_1E + a_2E^2 + a_3\sin(a_4E + a_5) \tag{4}$$

Accordingly, the coefficients (±error) for each solved term in Equation 4 are:

Table 3. Independent frequencies detected in RR Leo, TYC 790-1124-1, and V337 Ori light curves by discrete Fourier transform analysis.

Star Identification	*Frequency c/d*	*Semi-Amplitude Magnitude*	*S/N*[b]	*Phase*
RR Leo (B mag)	f_1 2.2102 (2)[a]	0.593 (8)	285	0.391 (2)
RR Leo (V mag)	f_1 2.213087 (2)	0.429 (2)	153	0.718 (1)
	f_2 3.31987 (3)	0.049 (2)	17.3	0.095 (9)
	f_3 3.09 (2)	0.040 (3)	13.7	0.94 (7)
RR Leo (I_c mag)	f_1 2.2131 (3)	0.295 (7)	297	0.18 (4)
	f_4 2.396 (7)	0.037 (6)	36.9	0.76 (28)
	f_5 4.25 (1)	0.028 (6)	24	0.13 (27)
TYC 790-1124-1 (B mag)	f_1 5.5584 (6)	0.145 (1)	68.9	0.292 (1)
TYC 790-1124-1 (V mag)	f_1 5.5598 (5)	0.109 (9)	102	0.510 (2)
TYC 790-1124-1 (I_c mag)	f_1 5.5586 (6)	0.066 (6)	110	0.61 (1)
V337 Ori (B mag)	f_1 4.96877 (9)	0.287 (6)	138	0.529 (2)
	f_2 6.72 (7)	0.043 (6)	19.5	0.79 (3)
V337 Ori (V mag)	f_1 4.9691 (1)	0.205 (2)	104	0.225 (3)
	f_2 6.72 (7)	0.023 (2)	13.2	0.429 (3)
V337 Ori (I_c mag)	f_1 4.97 (3)	0.121 (4)	136	0.08 (2)

Notes: a. Uncertainty (Monte Carlo simulation) of least significant figure(s) is indicated within parentheses. b. Signal-to-noise (S/N) estimated with box size adjusted to ~1/5 of the measured frequency (PERIOD04, Lenz and Breger 2005).

$$C = -4.49\,(\pm 4.73) \times 10^{-4} + 6.547\,(\pm 2.387) \times 10^{-8}\,E + 1.513\,(\pm 0.774) \times 10^{-12}\,E^2 + 3.751\,(\pm 0.590) \times 10^{-3} \sin[1.400\,(\pm 0.058) \times 10^{-4}\,E + 2.242\,(\pm 0.147)]. \quad (5)$$

The amplitude (0.003751 ± 0.000590 d) of the periodic oscillation is defined by a_3, the coefficient of the sine term. Assuming for the moment that this behavior is associated with another gravitationally bound body, then according to the relationship:

$$P_3 = 2\pi P/\omega, \text{ where the angular frequency, } \omega = a_4 = 1.400\,(\pm 0.058) \times 10^{-4}, \quad (6)$$

its Keplerian orbital period would be 55.6 (±2.3) years.

Further assessment of light curves from RR Leo using PERIOD04 (Table 3) revealed that in addition to its dominant frequency (~2.213 c/d) Fourier analysis

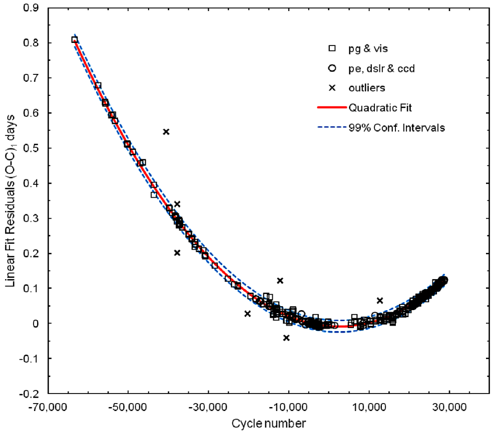

Figure 3. Plot of RR Leo published time-of-maximum data vs epoch using linear elements from Samus *et al.* (2012). Parabolic relation of O–C residuals is well fit by quadratic expression.

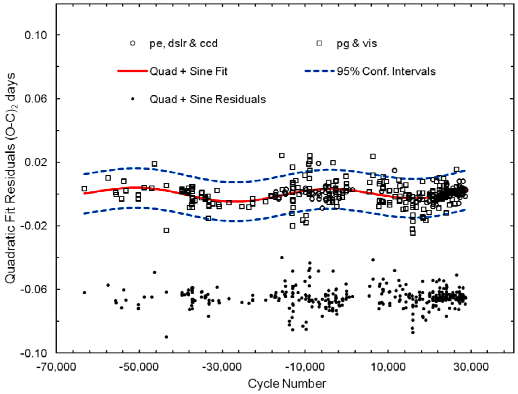

Figure 4. Plot of RR Leo (O–C)$_2$ residuals from quadratic fit of published time-of-maximum data vs epoch data. Apparent cyclic relationship can be fit by quadratic expression modulated with a sinusoidal term. Residuals are offset by a constant amount to keep all data on scale.

uncovered oscillations corresponding to the 1st through 6th harmonics of the fundamental (not shown). Successively pre-whitening spectra with newly detected pulsations also exposed four other potential independent oscillations (Figure 5). None of these values are common to another passband so it is still difficult to judge whether these signals are real without additional data. Curiously, Ekmekçi *et al.* (2012) published a very different set of pulsation frequencies from multicolor (B, V, and R) light curves collected in 2007, none of which agree with the primary pulsation mode observed herein or similarly reported elsewhere (Samus *et al.* 2012; Watson *et al.* 2006–2013). It is not obvious why these differences exist, particularly since this and their investigation used PERIOD04 to analyze light curve data from RR Leo.

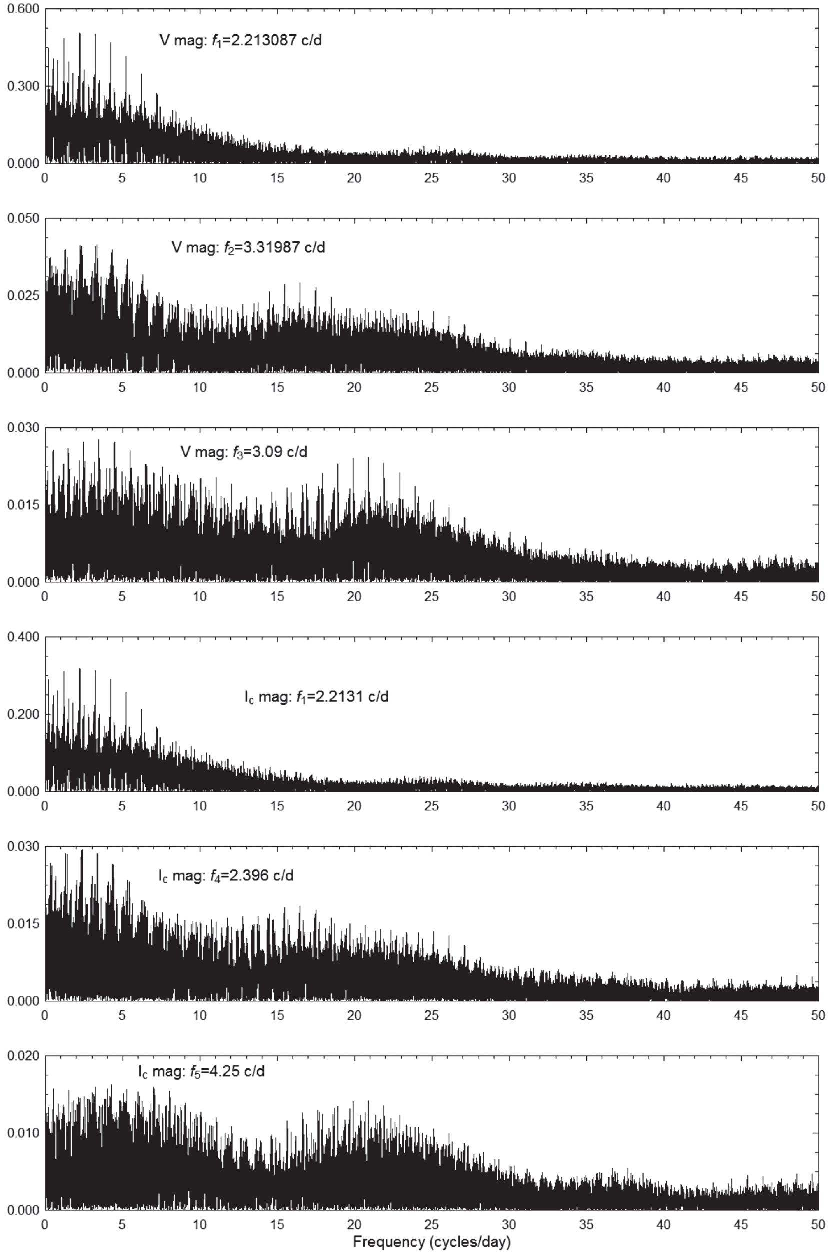

Figure 5. Periodograms showing primary oscillation (f_1 = 2.2131 c/d) of RR Leo and four potential independent pulsations (f_2–f_5) uncovered by successively pre-whitening Fourier spectra from V- and I$_c$-passband light curves.

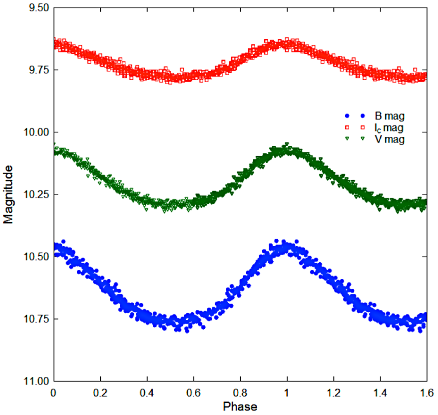

Figure 6. Folded multi-color light curves (P = 0.179846 d) from TYC 790-1124-1 data acquired at UO in 2011.

The observed B–V (~0.42) around phase 0.6 where the color index for RRab variables tend to be fairly constant compares favorably to values reported by Preston (1964) and consistent with a late A or early F spectral class star. In this case, the low interstellar reddening (E(B–V) = 0.0346 ± 0.0035) observed within a 5-arcmin radius of RR Leo (Schlafly and Finkbeiner 2011; Schlegel *et al.* 1998) would not dramatically alter conclusions based upon the observed color index.

3.2 TYC 790-1124-1 (ASAS J074451+1315.0)

Collectively, folded light curves in all passbands from the 2011 campaign at UO (Figure 6) exhibited a primary period of 0.179846 day which is essentially identical to that estimated (0.179846 day) from the ASAS survey (Pojmański *et al.* 2005). Based on these findings, the following linear ephemeris is proposed for this system:

$$\text{Max HJD} = 2455654.5778\,(\pm 0.0055) + 0.179846\,(\pm 0.000006)\,\text{E} \qquad (7)$$

The shape of each (B, V, and I_c) light curve is symmetrical with little variation at minimum or maximum light over the month-long observation period. Discrete Fourier analysis of the UO data revealed (Table 3) a principal pulsation mode at ~5.559 c/d along with a much less intense first harmonic at ~11.12 c/d. All other observations derived from Fourier analysis were below the limits of reliable detection. Pojmański *et al.* (2005) reported the only other light curve (V mag.) for this star (ASAS J074451+1315.0) based upon data collected from the ASAS survey. Combined Fourier analyses of the ASAS (2002–2009) and UO (2011) data using PERANSO 2.5 (Lomb-Scargle method) produced a good fit of the folded V-mag light curves despite greater scatter in the ASAS

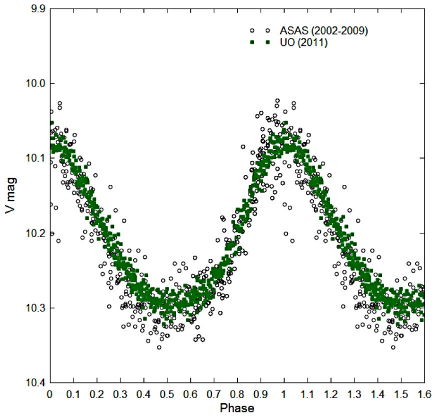

Figure 7. Folded V-mag light curves (P = 0.179846 d) from TYC 790-1124-1 data acquired by the ASAS survey between 2002 and 2009 and at UO in 2011.

data (Figure 7). Individual and combined analyses yielded the same result, suggesting that the fundamental pulsation period (0.179846 ± 0.000006 d) had not appreciably changed during this nine year observation interval (2002–2011). It should be noted that light curves from the RRc subclass of RR Lyrae type pulsating variables are also symmetrical and have been reported with fundamental periods as low as 0.2 day. Arguably, a case could be made to potentially classify TYC 790-1124-1 as an RRc variable rather than a HADS. Poretti (2001a, 2001b) describes three methods to separate monoperiodic RRc and HADs variables according to their fundamental period ($1/f_1$), the semi-amplitudes of the fundamental (A_1) and first harmonic (A_2), and the ratio ($R_{21} = A_2/A_1$) of the semi-amplitudes. A subset of the OGLE (Udalski *et al.* 1992) database used in Poretti's (2001b) paper is conveniently maintained at the CDS website (http://cdsweb.u-strasbg.fr/) so that findings from the present study could be analyzed along with data from stars known to be RRc or HADs variables. Accordingly, three tests were successfully applied using results from the Fourier decomposition and frequency analysis of pulsating ($P < 1$ d) stars in the OGLE database. In the first relationship, when the amplitude ratio (R_{21}) from I_c-band is plotted against the period (d) of known HADS and RRc variables, clear separation of each population can be seen (Figure 8). Two other examples in which R_{21} and A_1 (Figure 9) or A_1^2 and A_2 (Figure 10) are similarly plotted convincingly show that TYC 790-1124-1 appears in the cluster with other known HADS stars. Based on the B–V color index range (0.35–0.51) observed herein, this pulsator would appear to vary from spectral class F3 to F6, which is not unexpected for a δ Scuti variable star (Lee *et al.* 2008). Interstellar reddening (E(B–V) = 0.0386 ± 0.0022) within a 5-arcmin radius (Schlafly and Finkbeiner 2011; Schlegel *et al.* 1998) would not significantly alter spectral classification of this system based upon the observed color index.

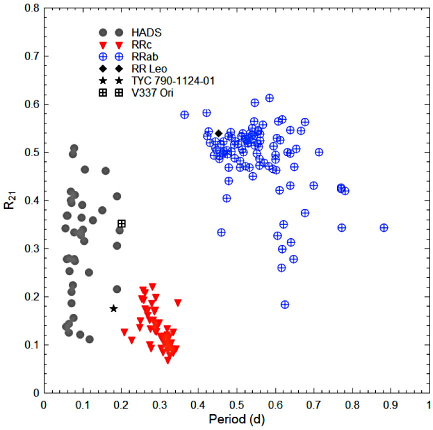

Figure 8. Diagram showing clustering of known HADS, RRc, and RRab pulsators as a function of period (d) and the fundamental to first harmonic amplitude ratio (R_{21}). Data from RR Leo, TYC 790-1124-1, and V337 Ori are superimposed to illustrate class separation achieved using the approach from Poretti (2001a).

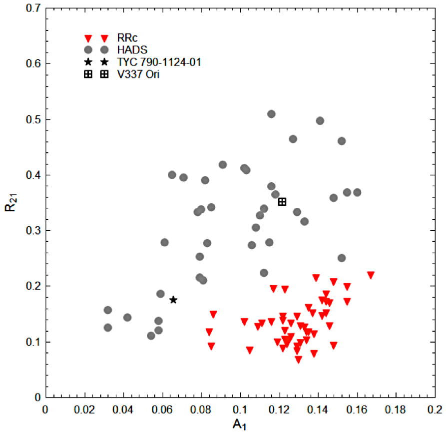

Figure 9. Diagram showing clustering of known HADS and RRc pulsators as a function of the fundamental pulsation mode, semi-amplitude (A_1), and amplitude ratio (R_{21}). Corresponding data from TYC 790-1124-1 and V337 Ori are superimposed to illustrate class separation achieved using the approach from Poretti (2001a).

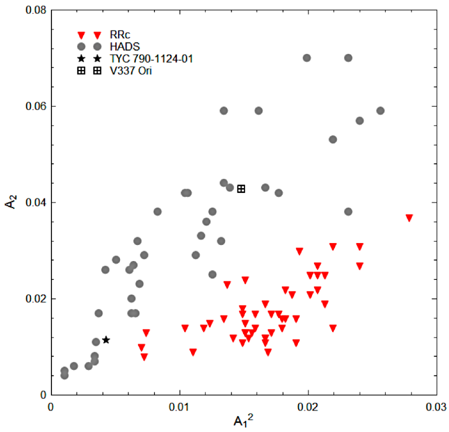

Figure 10. Diagram showing clustering of known HADS and RRc pulsators as a function of the fundamental pulsation, mode semi-amplitude (A_1^2), and the first harmonic semi-amplitude (A_2). Corresponding data from TYC 790-1124-1 and V337 Ori are superimposed to illustrate class separation achieved using the approach from Poretti (2001b).

3.3. V337 Ori (ASAS J055921+2002.1)

Samus and Antipin (2005) corrected the record on this HADS which had previously been misidentified as a nearby irregular red variable (Ahnert 1950; Neckel 1958). Folded light curves from the 2011 campaign at UO (Figure 11) exhibited a primary period of 0.201259 day (4.968722 c/d) which compares favorably with those estimated by other investigators (Samus and Antipin 2005; Khruslov 2011; Wils *et al.* 2012). Linear elements from the latest epoch collected at UO were determined as follows:

$$\text{Max HJD} = 2455616.5385\,(\pm 0.0029) + 0.201259\,(\pm 0.000001)\,\text{E} \qquad (8)$$

Khruslov (2011) and more recently Wils *et al.* (2012) conducted an in-depth analysis on the light curve (V mag.) variation of V337 Ori using Fourier techniques. The time span for observations analyzed by both investigators extended over a longer time period (years) and culled data from three diverse photometric surveys (ASAS, Pojmański 2002; NSVS, Woźniak *et al.* 2004; SuperWASP, Butters *et al.* 2010). Nonetheless, similar to the findings reported herein (Table 3), the fundamental (f_1) pulsation frequency was observed at 4.96877 c/d. This along with other related harmonics (1st–4th) and combinations were also detected during the present four-week campaign in all three passbands. Khruslov (2011) and Wils *et al.* (2012) measured a second oscillation at 6.724 c/d as well as combination frequencies at 11.693 (f_1+f_2) and 1.75509 ($f_2–f_1$) c/d. Similarly, an independent pulsation at 6.72 c/d was detected in the B- and V-magnitude light curves acquired at UO, but not in the I_c passband (Figure 12). Many other potential oscillations were observed, but none rose above the limits of reliable detection.

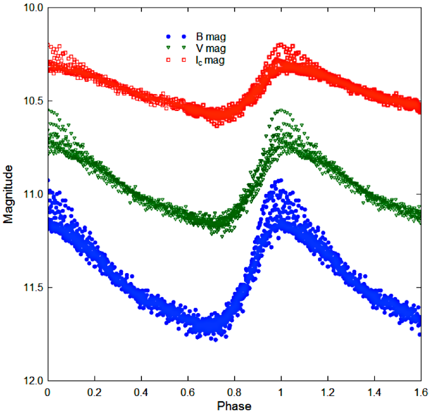

Figure 11. Folded multi-color light curves (P = 0.201259 d) from V337 Ori acquired at UO in 2011.

Although V337 Ori and TYC 790-1124-1 ostensibly share the same HADS classification, the general shape of their light curves is quite different. The overall light curve profile for V337 Ori is not unlike that observed for many RRab pulsators, however, the shorter period (0.201259 d) clearly separates this HADS from its RRab brethren (Figure 8) like RR Leo. As noted earlier, the brightness changes for TYC 790-1124-1 are symmetrical while maximum light is fairly constant over time in each of the three passbands evaluated (Figure 6). By contrast, the light curves for V337 Ori are asymmetrical with significant cycle-to-cycle variability at maximum light. The most extreme change for V337 Ori occurred within a single six-hour session on 24 Jan 2011 where maximum light was captured twice (Figure 13) and varied by 0.185 B-mag. Similarly large brightness changes over a short period of time (hours) have been observed for many other HADS, including GSC 0376-0596 (Buchheim 2006), VX Hya (Templeton *et al.* 2009), and GP And (Zhou and Jiang 2011) where the peak-to-peak variability approached 0.1 V-mag. The evidence thus far from this study and other investigators (Khruslov 2011; Wils *et al.* 2012) demonstrates that a single dominant pulsation frequency occurs at 4.9687 c/d. The weight of evidence from all Fourier analyses suggests that V337 Ori is a multiperiodic HADS with at least one additional independent pulsation mode (6.72 c/d). This, along with potentially two other low-amplitude (~0.017) close-frequency pulsations at 6.48 and 6.61 c/d which nearly met the limits of reliable detection, may account for the observed cycle-to-cycle variability in maximum light. It is unknown which, if any, of the pulsations vary in amplitude with time. Additional high precision light curve data from multiple sites would be helpful in fully characterizing the variable nature of V337 Ori.

V337 Ori is located in the Winter Milky Way where the observed color within a 5-arcmin radius of this variable is significantly reddened (E(B–V) = 1.34 ± 0.06) due to interstellar dust (Schlafly and Finkbeiner 2011;

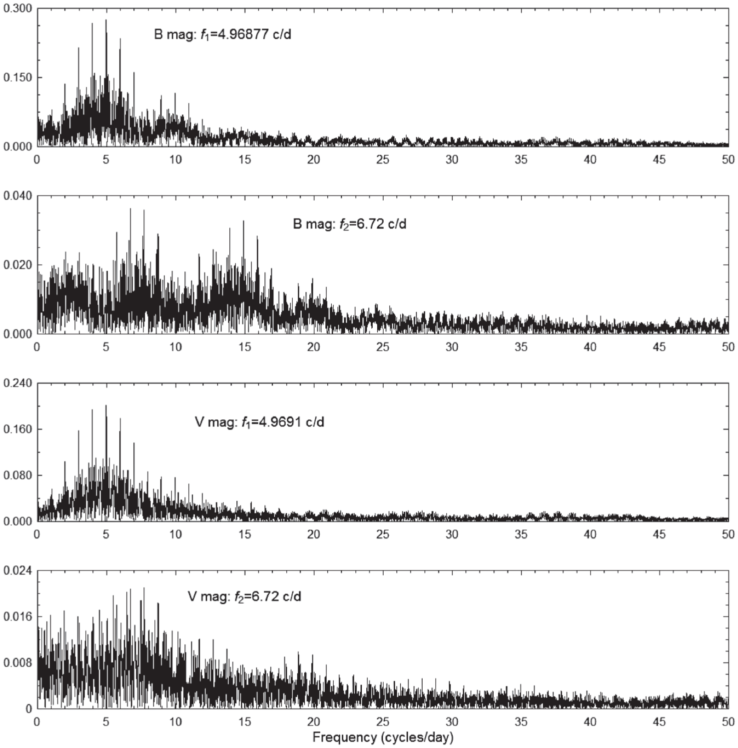

Figure 12. Periodograms showing fundamental mode of oscillation (f_1) for V337 Ori and second independent pulsation (f_2=6.72 c/d) exposed after successively pre-whitening the initial Fourier spectra from B- and V-mag light curves.

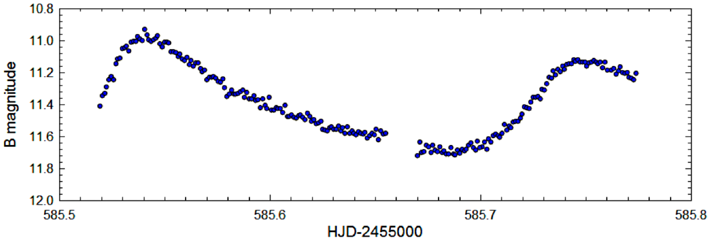

Figure 13. Unfolded light curve data (HJD vs B magnitude) from V337Ori collected during a single night on 24 Jan 2011 showing large cycle-to-cycle amplitude changes (ΔB mag. = 0.185) observed with this HADS pulsator.

Schlegel *et al.* 1998). Estimating the total extinction for V337 Ori is unreliable because of its low Galactic latitude (b = –1.85°) and determining the true intrinsic color is complicated by the fact that its distance is unknown. The observed B–V color index predicts a cooler star (G6) than would be expected for a HADS variable. However, based on the V–I_c (0.12–0.52) color index observed herein which is less susceptible to reddening effects, V337 Ori would appear no cooler than spectral class A3 to F6 and well within the normal range for a HADS variable (Lee *et al.* 2008). Evidence from the 2MASS infrared survey (Skrutskie *et al.* 2006) using the published values in J, K, and H passbands (J–H and J–K color indices) suggests an effective temperature at least as hot as an F6-class star.

4. Summary

New light curve data from RR Leo largely corroborate findings previously reported for this RRab variable. In addition to its dominant frequency (2.21309 c/d), Fourier decomposition potentially uncovered as many as four other independent pulsations. A period analysis using over 110 years of time-of-maximum light data produced a revised quadratic ephemeris for RR Leo. Further evidence from the quadratic residuals suggests an underlying sinusoidal-like variability (~56 y) in the O–C diagram, possibly corresponding to the gravitational influence of a binary partner. Light curves from the HADS pulsator TYC 790-1124-1 remained symmetrical between the first time data for this system were collected (2002) and the 2011 campaign at UO. In addition, the fundamental period of oscillation (0.179846 d) appeared to be constant over this time. V337 Ori exhibits significant cycle-to-cycle amplitude variability; in addition to the fundamental pulsation (~4.969 c/d) strong evidence exists for another independent oscillation at 6.72 c/d. At this time it is unknown whether the rapid light curve changes can be attributed to potential close-frequency pairs which beat or amplitude variability of individual oscillations. Further studies of this system may be necessary to fully characterize all oscillations which lead to these rapid changes in maximum light.

5. Acknowledgements

This research has made use of the SIMBAD database, operated at Centre de Données astronomiques de Strasbourg, France. Times-of-maximum data from the B.R.N.O., *Inf. Bull. Var. Stars*, AAVSO, GEOS, and VSOLJ websites proved invaluable to the period assessment of RR Leo. The diligence and dedication shown by all associated with these organizations is very much appreciated. This research has made use of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts. Many thanks to Patrick Wils, Lubos Brat, and an anonymous referee for their helpful discussion and comments on this paper.

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
14639.8100	–63344	0.80920	0.00341	Gaposchkin 1934
17257.6800	–57557	0.67917	0.01026	Gaposchkin 1934
18062.4390	–55778	0.63049	0.00112	Luizet 1911
18120.3412	–55650	0.62635	–0.00022	Kukarkin 1928
18756.3730	–54244	0.59317	–0.00306	Luizet 1911
18966.2850	–53780	0.59467	0.00830	Robinson 1930
19202.4170	–53258	0.57737	0.00198	Luizet 1911
20547.7740	–50284	0.51670	0.00194	Jordan 1929
20567.6760	–50240	0.51339	–0.00049	Jordan 1929
20577.6260	–50218	0.51074	–0.00271	Jordan 1929
21220.4560	–48797	0.48986	0.00417	Kukarkin 1933
22023.4200	–47022	0.45575	0.00367	Martin and Plummer 1921
22313.8600	–46380	0.45925	0.01903	Gaposchkin 1934
23588.6125	–43562	0.36743	–0.02255	Kukarkin and Parenago 1931
23588.6404	–43562	0.39533	0.00535	Soloviev 1936b
24922.9000**	–40613	0.54709	0.00535	Gaposchkin 1934
25299.5270	–39780	0.33047	0.00322	Oosterhoff 1930
25304.5020	–39769	0.32915	0.00206	Oosterhoff 1930
25318.5250	–39738	0.32796	0.00136	Oosterhoff 1930
25323.5020	–39727	0.32863	0.00221	Oosterhoff 1930
25335.7160	–39700	0.32801	0.00202	Nielsen 1929
25645.5940	–39015	0.31660	0.00137	Oosterhoff 1930
25920.1880	–38408	0.30787	0.00203	Allen and Marsh 1932
26016.5440	–38195	0.30409	0.00152	Oosterhoff 1930
26030.5700	–38164	0.30590	0.00380	Oosterhoff 1930
26031.4730	–38162	0.30411	0.00205	Oosterhoff 1930
26060.4240	–38098	0.30194	0.00085	Oosterhoff 1930
26143.2000	–37915	0.28997	–0.00834	Zakharov 1953
26146.2800**	–37908	0.20322	–0.09499	Zakharov 1953
26148.2270**	–37904	0.34064	0.0425	Zakharov 1953
26382.5197	–37386	0.29361	0.00328	Zakharov 1953
26387.4973	–37375	0.29489	0.00472	Lause 1931
26397.4484	–37353	0.29333	0.00349	Lause 1931
26406.4862	–37333	0.28327	–0.00627	Lause 1931
26415.5357	–37313	0.28490	–0.00434	Lause 1931
26416.4417	–37311	0.28612	–0.00310	Lause 1931
26417.3513	–37309	0.29093	0.00175	Lause 1931
26420.5077	–37302	0.28058	–0.00850	Lause 1931

Table continued on following pages

Table 4. Recalculated quadratic residuals (O–C)$_2$ for RR Leo times-of-maximum following linear least squares fit of (O–C)$_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*(O–C)$_1^*$*	*(O–C)$_2$*	*Reference*
26421.4239	–37300	0.29199	0.00294	Lause 1931
26430.4662	–37280	0.28642	–0.00233	Lause 1931
26440.4186	–37258	0.28617	–0.00225	Lause 1931
26474.3538	–37183	0.29187	0.00457	Lause 1931
26487.4637	–37154	0.28237	–0.00450	Lause 1931
26497.4180	–37132	0.28402	–0.00253	Lause 1931
26764.3200	–36542	0.27397	–0.00386	Detre 1936
27458.2710	–35008	0.25365	–0.00215	Tsesevich 1934
27472.7500	–34976	0.25606	0.00072	Gaposchkin 1934
27498.5360	–34919	0.25564	0.00110	Kanishcheva and Lange 1971
27834.6510	–34176	0.24242	–0.00179	Soloviev 1936a, 1936b
27840.5310	–34163	0.24131	–0.00272	Kooreman 1935
27864.5070	–34110	0.24046	–0.00284	Kooreman 1935
27869.4830	–34099	0.24014	–0.00301	Kooreman 1935
27874.4590	–34088	0.23981	–0.00319	Kooreman 1935
27875.3640	–34086	0.24002	–0.00295	Kooreman 1935
27889.3880	–34055	0.23983	–0.00272	Kooreman 1935
27903.4120	–34024	0.23964	–0.00248	Kooreman 1935
28178.4600	–33416	0.23251	–0.00134	Soloviev and Shakhovskoj 1958
28190.2080	–33390	0.21829	–0.01522	Guriev 1937
28245.4067	–33268	0.22500	–0.00686	Balázs and Detre 1949
28249.4800	–33259	0.22676	–0.00498	Balázs and Detre 1949
28250.3822	–33257	0.22418	–0.00754	Balázs and Detre 1949
28668.3830	–32333	0.21357	–0.00591	Balázs and Detre 1949
29136.6050	–31298	0.20850	0.00235	Soloviev and Shakhovskoj 1958
29312.5725	–30909	0.19501	–0.00624	Balázs and Detre 1949
29371.3806	–30779	0.19198	–0.00764	Balázs and Detre 1949
30440.3598	–28416	0.16581	–0.00535	Balázs and Detre 1949
31888.4332	–25215	0.12826	–0.00771	Balázs and Detre 1949
32615.4126	–23608	0.11163	–0.00812	Balázs and Detre 1949
33010.3456	–22735	0.10528	–0.00607	Balázs and Detre 1949
33011.7061	–22732	0.10860	–0.00272	Ashbrook 1949
33024.3700	–22704	0.10548	–0.00557	Balázs and Detre 1949
34097.3710**	–20332	0.02958	–0.06013	Balázs and Detre 1949
34443.5010	–19567	0.07870	–0.00457	Olah and Szeidl 1978

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
35069.6055	–18183	0.07087	–0.00131	Olah and Szeidl 1978
35069.6060	–18183	0.07137	–0.00081	Olah and Szeidl 1978
35127.5109	–18055	0.06993	–0.00126	Olah and Szeidl 1978
35479.4664	–17277	0.06344	–0.00188	Olah and Szeidl 1978
35489.4204	–17255	0.06479	–0.00037	Olah and Szeidl 1978
35542.3512	–17138	0.06558	0.00128	Olah and Szeidl 1978
35561.3490	–17096	0.06286	–0.00113	Olah and Szeidl 1978
35874.3982	–16404	0.05589	–0.00310	Geyer 1961
35925.5190	–16291	0.05625	–0.00195	Olah and Szeidl 1978
36229.5490	–15619	0.07795	0.02440	Huth 1964
36287.4330	–15491	0.05561	0.00292	Huth 1964
36513.6249	–14991	0.05086	0.00149	Olah and Szeidl 1978
36586.4585	–14830	0.04914	0.00082	Olah and Szeidl 1978
36599.5870	–14801	0.05823	0.01010	Huth 1964
36604.5533	–14790	0.04821	0.00014	Olah and Szeidl 1978
36610.4410	–14777	0.05479	0.00681	Ahnert 1959a,b
36614.5064	–14768	0.04865	0.00073	Olah and Szeidl 1978
36667.4640	–14651	0.07624	0.02907	Huth 1964
36672.4142	–14640	0.05011	0.00301	Geyer 1961
37024.3510	–13862	0.02492	–0.01730	Wenske 1980
37028.4250	–13853	0.02738	–0.01478	Wenske 1980
37042.4570	–13822	0.03519	–0.00678	Wenske 1980
37316.6118	–13216	0.03965	0.00131	Olah and Szeidl 1978
37366.3610	–13106	0.02559	–0.01211	Wenske 1980
37375.4010	–13086	0.01772	–0.01986	Wenske 1980
37375.4270	–13086	0.04372	0.00614	Ahnert 1961a,b
37375.4380	–13086	0.05472	0.01714	Huth 1964
37376.3220	–13084	0.03394	–0.00364	Ahnert 1961a,b
37376.3290	–13084	0.04094	0.00336	Ahnert 1961a,b
37399.4010	–13033	0.04088	0.00360	Huth 1964
37399.4050	–13033	0.04488	0.00760	Ahnert 1961b
37403.4700	–13024	0.03834	0.00112	Ahnert 1961b
37432.4290	–12960	0.04417	0.00732	Karetnikov 1961, 1962
37447.3468	–12927	0.03299	–0.00367	Karetnikov 1961, 1962
37454.5845	–12911	0.03240	–0.00417	Karetnikov 1961, 1962
37466.3425	–12885	0.02817	–0.00825	Karetnikov 1961, 1962
37476.3066	–12863	0.03962	0.00332	Karetnikov 1961, 1962
37768.1020	–12218	0.04134	0.00867	Demjanovski 1975

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	$(O–C)_1^*$	$(O–C)_2$	*Reference*
37780.3990**	–12191	0.12372	0.09120	Demjanovski 1975
38000.6250	–11704	0.03418	0.00430	Demjanovski 1975
38107.3840	–11468	0.02836	–0.00028	Demjanovski 1975
38414.5572	–10789	0.02651	0.00133	Olah and Szeidl 1978
38496.4220	–10608	0.00813	–0.01617	Wenske 1980
38497.7320**	–10605	–0.03905	–0.06333	Demjanovski 1975
38732.5970	–10086	0.03382	0.01203	Demjanovski 1975
38824.8760	–9882	0.02459	0.00375	Fitch *et al.* 1966
38825.7780	–9880	0.02180	0.00097	Fitch *et al.* 1966
38848.3830	–9830	0.00714	–0.01346	Wenske 1980
38852.4500	–9821	0.00260	–0.01796	Wenske 1980
38881.4237	–9757	0.02313	0.00286	Olah and Szeidl 1978
39146.5225	–9171	0.01945	0.00181	Olah and Szeidl 1978
39150.5922	–9162	0.01761	0.00001	Olah and Szeidl 1978
39172.3260	–9114	0.03654	0.01914	Braune *et al.* 1970
39205.3310	–9041	0.01683	–0.00026	Wenske 1980
39228.4130	–8990	0.02677	0.00990	Braune *et al.* 1970
39233.3800	–8979	0.01744	0.00062	Braune *et al.* 1970
39238.3590	–8968	0.02011	0.00334	Braune *et al.* 1970
39257.3710	–8926	0.03160	0.01501	Braune *et al.* 1970
39257.3800	–8926	0.04060	0.02401	Braune *et al.* 1970
39305.3300	–8820	0.03691	0.02077	Braune *et al.* 1970
39503.4564	–8382	0.01504	0.00071	Olah and Szeidl 1978
39507.5280	–8373	0.01510	0.00081	Olah and Szeidl 1978
39536.4770	–8309	0.01093	–0.00310	Wenske 1980
39608.4100	–8150	0.01340	0.00000	Wenske 1980
39906.5364	–7491	0.01261	0.00175	Olah and Szeidl 1978
40220.0600	–6798	0.02765	0.01928	Epstein 1969
40232.7079	–6770	0.00854	0.00027	Olah and Szeidl 1978
40301.4680	–6618	0.00486	–0.00289	Wenske 1980
40321.3750	–6574	0.00655	–0.00105	Wenske 1980
40654.3372	–5838	0.00729	0.00207	Olah and Szeidl 1978
40657.4930	–5831	–0.00367	–0.00886	Wenske 1980
40980.5097	–5117	0.00422	0.00114	Olah and Szeidl 1978
40984.5770	–5108	–0.00002	–0.00308	Wenske 1980
41003.5855	–5066	0.00796	0.00502	Olah and Szeidl 1978
41008.5610	–5055	0.00713	0.00423	Wenske 1980
41028.4580	–5011	–0.00117	–0.00395	Wenske 1980

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
41033.4430	–5000	0.00750	0.00475	Wenske 1980
41071.4360	–4916	–0.00054	–0.00305	Wenske 1980
41311.6607	–4385	0.00332	0.00221	Olah and Szeidl 1978
41312.5677	–4383	0.00553	0.00443	Olah and Szeidl 1978
41332.4760	–4339	0.00853	0.00754	Braune and Mundry 1973
41389.4700	–4213	0.00097	0.00030	Wenske 1980
41390.3720	–4211	–0.00181	–0.00248	Wenske 1980
41394.4410	–4202	–0.00435	–0.00500	Braune and Mundry 1973
41394.4450	–4202	–0.00035	–0.00100	Braune and Mundry 1973
41405.3030	–4178	0.00021	–0.00038	Berdnikov 1977
41682.6190	–3565	–0.00089	–0.00002	Olah and Szeidl 1978
41736.4500	–3446	–0.00469	–0.00356	Tsesevich 1974
41751.3770	–3413	–0.00667	–0.00547	Wenske 1980
41771.2830	–3369	–0.00597	–0.00468	Berdnikov 1977
41794.3650	–3318	0.00397	0.00537	Braune *et al.* 1977
41812.4750	–3278	0.01824	0.01973	Braune *et al.* 1977
42019.6515	–2820	–0.00139	0.00104	Olah and Szeidl 1978
42089.3220	–2666	0.00054	0.00327	Braune *et al.* 1977
42095.6600	–2652	0.00503	0.00779	Braune *et al.* 1977
42102.4420	–2637	0.00113	0.00392	Braune *et al.* 1977
42106.5120	–2628	–0.00041	0.00239	Wenske 1980
42145.4180	–2542	–0.00023	0.00273	Wenske 1980
42150.4000	–2531	0.00544	0.00843	Braune *et al.* 1977
42154.4630	–2522	–0.00310	–0.00010	Wenske 1980
42183.4110	–2458	–0.00827	–0.00515	Braune *et al.* 1977
42202.4090	–2416	–0.01079	–0.00759	Braune *et al.* 1977
42443.5415	–1883	–0.00392	0.00019	Olah and Szeidl 1978
42469.3260	–1826	–0.00583	–0.00163	Braune *et al.* 1977
42492.3970	–1775	–0.00689	–0.00261	Wenske 1980
42829.4335	–1030	–0.00340	0.00195	Olah and Szeidl 1978
42840.2870	–1006	–0.00734	–0.00196	Braune *et al.* 1979
42857.4820	–968	–0.00329	0.00214	Wenske 1980
42891.4100	–893	–0.00478	0.00074	Wenske 1980
43213.5140	–181	–0.00481	0.00150	Olah and Szeidl 1978
43224.3810	–157	0.00475	0.01108	Braune *et al.* 1979
43281.3760	–31	–0.00181	0.00464	Braune *et al.* 1979
43295.3980	0	–0.00400	0.00248	Braune *et al.* 1979
43295.4020	0	0.00000	0.00648	Samus *et al.* 2012

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
43560.5004	586	–0.00407	0.00287	Szeidl and Pocs 2002
43911.5572	1362	–0.00447	0.00289	Szeidl and Pocs 2002
45757.3220	5442	–0.00434	0.00149	Firmanyuk *et al.* 1985
45812.5203	5564	0.00198	0.00767	Le Borgne 2004
46174.4401	6364	0.00714	0.01176	Le Borgne 2004
46175.3568	6366	0.01905	0.02367	Le Borgne 2004
46826.3220	7805	–0.00971	–0.00762	Braune and Hübscher 1987
46864.3270	7889	–0.00574	–0.00383	Braune and Hübscher 1987
46869.3030	7900	–0.00607	–0.00418	Braune and Hübscher 1987
46877.4460	7918	–0.00615	–0.00430	Braune and Hübscher 1987
46883.3380	7931	0.00474	0.00656	Braune and Hübscher 1987
46910.4830	7991	0.00614	0.00784	Hübscher *et al.* 1990
47121.7456	8458	0.00107	0.00174	Liu and Janes 1989
47124.0020	8463	–0.00450	–0.00383	Liu and Janes 1989
47172.4080	8570	–0.00458	–0.00416	Hübscher and Lichtenknecker 1988
47239.3710	8718	0.00421	0.00428	Hübscher and Lichtenknecker 1988
47262.4340	8769	–0.00485	–0.00490	Hübscher and Lichtenknecker 1988
47263.3470	8771	0.00337	0.00331	Hübscher and Lichtenknecker 1988
47263.3480	8771	0.00437	0.00431	Hübscher and Lichtenknecker 1988
47267.4260	8780	0.01083	0.01075	Hübscher *et al.* 1989
47652.4120	9631	0.01013	0.00787	Aubaud 1990
47966.3690	10325	0.00618	0.00195	Hübscher *et al.* 1990
47970.4410	10334	0.00664	0.00238	Hübscher *et al.* 1990
47989.4340	10376	–0.00088	–0.00527	Hübscher *et al.* 1990
48018.3860	10440	–0.00205	–0.00663	Hübscher *et al.* 1991
48500.2100	11505	0.02308	0.01507	Perryman *et al.* 1997
48604.6970	11736	0.00723	–0.00158	Aubaud 1992
48683.4180	11910	0.01180	0.00237	Hübscher *et al.* 1992
49021.3650	12657	0.02100	0.00880	Hübscher *et al.* 1994
49030.4580**	12677	0.06614	0.05385	Vandenbroere 1997
49044.4240	12708	0.00794	–0.00446	Vandenbroere 1997
49087.4050	12803	0.01158	–0.00119	Hübscher *et al.* 1993
49097.3640	12825	0.01793	0.00507	Vandenbroere 1997

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
49101.4270	12834	0.00939	–0.00351	Hübscher *et al.* 1993
49439.3740	13581	0.01859	0.00266	Hübscher *et al.* 1994
49472.3870	13654	0.00688	–0.00936	Hübscher *et al.* 1994
49776.4070	14326	0.01858	–0.00058	Hübscher *et al.* 1995
49781.3750	14337	0.01026	–0.00896	Hübscher *et al.* 1995
49786.3550	14348	0.01393	–0.00533	Hübscher *et al.* 1995
49786.3660	14348	0.02493	0.00567	Hübscher *et al.* 1995
50049.6540	14930	0.02003	–0.00191	Vandenbroere 1998
50097.6090	15036	0.02134	–0.00111	Vandenbroere 1998
50170.4459	15197	0.02292	–0.00030	Agerer and Hübscher 1997
50194.4204	15250	0.02058	–0.00290	Agerer and Hübscher 1997
50489.3650	15902	0.00474	–0.02196	Hübscher *et al.* 1997
50499.3380	15924	0.02509	–0.00172	Vandenbroere 2001
50518.3160	15966	0.00257	–0.02446	Hübscher *et al.* 1997
50518.3320	15966	0.01857	–0.00846	Vandenbroere 2001
50541.3960	16017	0.01051	–0.01678	Vandenbroere1999
50542.3140	16019	0.02373	–0.00357	Vandenbroere 2001
50546.3760	16028	0.01419	–0.01316	Hübscher *et al.* 1997
50546.3820	16028	0.02019	–0.00716	Dahm and Kleikamp 1998
50865.3220	16733	0.02291	–0.00814	Hübscher *et al.* 1998
50896.5410	16802	0.02677	–0.00465	Agerer *et al.* 1999
50897.4450	16804	0.02599	–0.00545	Hübscher *et al.* 1998
50898.3530	16806	0.02920	–0.00225	Agerer *et al.* 1999
51234.4838	17549	0.03178	–0.00380	Agerer and Hübscher 2000
51245.3460	17573	0.03654	0.00082	Hübscher *et al.* 1999
51272.4863	17633	0.03324	–0.00282	Agerer and Hübscher 2000
51278.3690	17646	0.03483	–0.00130	Agerer and Hübscher 2000
51568.3660	18287	0.04772	0.00784	Hübscher *et al.* 2000
51610.4170	18380	0.02615	–0.01430	Hübscher *et al.* 2000
51610.4320	18380	0.04115	0.00070	Hübscher *et al.* 2000
51612.6900	18385	0.03718	–0.00329	Wils *et al.* 2006
51625.3460	18413	0.02617	–0.01447	Hübscher *et al.* 2000
51672.3950	18517	0.02626	–0.01501	Hübscher *et al.* 2000
51677.3770	18528	0.03194	–0.00940	Hübscher *et al.* 2000
51924.3800	19074	0.02820	–0.01651	Hübscher 2001
52052.4202	19357	0.04109	–0.00540	Agerer and Hübscher 2002
52279.5190	19859	0.03846	–0.01129	Hübscher *et al.* 2002
52322.5040	19954	0.04609	–0.00428	Agerer and Hübscher 2003

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
52347.3900	20009	0.05046	–0.00027	Agerer and Hübscher 2003
52361.4155	20040	0.05177	0.00083	Agerer and Hübscher 2003
52365.4856	20049	0.05033	–0.00067	Agerer and Hübscher 2003
52366.3899	20051	0.04984	–0.00117	Agerer and Hübscher 2003
52664.5201	20710	0.05286	–0.00261	Agerer and Hübscher 2003
52683.5208	20752	0.05304	–0.00272	Agerer and Hübscher 2003
52694.3772	20776	0.05200	–0.00393	Agerer and Hübscher 2003
52697.5500	20783	0.05805	0.00207	Hübscher *et al.* 2003
52717.4458	20827	0.04854	–0.00774	Agerer and Hübscher 2003
52717.4548	20827	0.05754	0.00126	Hübscher 2005a
52722.4268	20838	0.05321	–0.00314	Agerer and Hübscher 2003
52722.4390	20838	0.06541	0.00906	Hübscher *et al.* 2003
52746.4007	20891	0.05027	–0.00645	Agerer and Hübscher 2003
52751.3823	20902	0.05554	–0.00126	Agerer and Hübscher 2003
52787.5720	20982	0.05378	–0.00358	Le Borgne *et al.* 2008b
53046.3460	21554	0.05881	–0.00261	Le Borgne *et al.* 2004
53047.6990	21557	0.05463	–0.00681	Le Borgne *et al.* 2004
53048.6040	21559	0.05485	–0.00661	Le Borgne *et al.* 2004
53049.5150	21561	0.06106	–0.00041	Le Borgne *et al.* 2004
53050.4200	21563	0.06127	–0.00021	Le Borgne *et al.* 2004
53051.3220	21565	0.05849	–0.00301	Le Borgne *et al.* 2004
53068.5139	21603	0.05944	–0.00233	Hübscher 2005a
53071.6791	21610	0.05789	–0.00393	Samolyk 2010
53092.9420	21657	0.05830	–0.00386	Le Borgne *et al.* 2008b
53101.5400	21676	0.06083	–0.00147	Le Borgne *et al.* 2004
53107.4310	21689	0.07072	0.00832	Hübscher 2005b
53145.4225	21773	0.06118	–0.00183	Hübscher 2005a
53152.6592	21789	0.05959	–0.00354	Samolyk 2010
53332.2570	22186	0.05725	–0.00880	Hirosawa 2012
53357.5980	22242	0.06422	–0.00224	Le Borgne *et al.* 2005a
53362.5750	22253	0.06490	–0.00165	Le Borgne *et al.* 2005a
53386.5640	22306	0.07705	0.01011	Vandenbroere 2005
53405.5534	22348	0.06593	–0.00133	Samolyk 2010
53407.3670	22352	0.06996	0.00267	Hübscher *et al.* 2005a
53438.5810	22421	0.06882	0.00101	Le Borgne *et al.* 2005b
53443.5550	22432	0.06649	–0.00139	Le Borgne *et al.* 2005b
53463.0070	22475	0.06558	–0.00263	Le Borgne *et al.* 2008b
53463.4600	22476	0.06619	–0.00203	Le Borgne *et al.* 2005b

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
53463.4613	22476	0.06749	–0.00073	Hübscher *et al.* 2005b
53464.3720	22478	0.06698	–0.00134	Vandenbroere and Denoux 2007
53469.7943	22490	0.06539	–0.00306	Samolyk 2010
53477.0310	22506	0.06781	–0.00066	Hirosawa 2012
53478.3906	22509	0.07091	–0.00087	Hübscher *et al.* 2005b
53674.2800	22942	0.06905	–0.00289	Hirosawa 2012
53683.3260	22962	0.07502	0.00265	Hirosawa 2012
53708.6660	23018	0.07037	–0.00217	Le Borgne *et al.* 2006a
53718.6140	23040	0.07142	–0.00141	Le Borgne *et al.* 2006a
53735.8060	23078	0.06998	–0.00304	Le Borgne *et al.* 2008b
53746.6620	23102	0.07384	0.00075	Le Borgne *et al.* 2006b
53750.2850	23110	0.07179	–0.00147	Hirosawa 2012
53760.6880	23133	0.07396	0.00050	Le Borgne *et al.* 2006b
53772.0000	23158	0.07588	0.00170	Hirosawa 2012
53813.6221	23250	0.07414	–0.00047	Samolyk 2010
53838.5020	23305	0.07282	–0.00188	Le Borgne *et al.* 2006b
53843.4770	23316	0.08484	0.00988	Le Borgne *et al.* 2006b
53876.0570	23388	0.08050	0.00523	Hirosawa 2012
53886.0040	23410	0.07485	–0.00059	Hirosawa 2012
54084.6070	23849	0.07719	–0.00176	Le Borgne *et al.* 2007a
54093.6560	23869	0.07832	–0.00078	Le Borgne *et al.* 2007a
54098.6310	23880	0.07700	–0.00220	Le Borgne *et al.* 2007a
54103.6080	23891	0.07767	–0.00161	Le Borgne *et al.* 2007b
54119.4450	23926	0.08090	0.00134	Le Borgne *et al.* 2007b
54124.4190	23937	0.07858	–0.00108	Le Borgne *et al.* 2007b
54129.3950	23948	0.07825	–0.00149	Le Borgne *et al.* 2007b
54172.3756	24043	0.08149	0.00097	Martignoni 2011
54172.3800	24043	0.08589	0.00537	Vandenbroere and Denoux 2007
54173.7308	24046	0.07951	–0.00103	Samolyk 2010
54175.5410	24050	0.08013	–0.00044	Le Borgne *et al.* 2007b
54181.4301	24063	0.08812	0.00744	Yilmaz *et al.* 2009
54185.9470	24073	0.08109	0.00033	Hirosawa 2012
54195.4457	24094	0.07953	–0.00140	Hübscher 2007
54195.4472	24094	0.08103	0.00010	Hübscher 2007
54200.4271	24105	0.08460	0.00358	Yilmaz *et al.* 2009
54205.3991	24116	0.06918	–0.01194	Hübscher 2007

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	$(O–C)_1^*$	$(O–C)_2$	*Reference*
54209.4710	24125	0.08028	–0.00084	Le Borgne *et al.* 2007b
54211.2878	24129	0.08064	–0.00055	Yilmaz *et al.* 2009
54213.9950	24135	0.08786	0.00665	Hirosawa 2012
54215.3591	24138	0.08070	–0.00056	Yilmaz *et al.* 2009
54234.3555	24180	0.08762	0.00633	Yilmaz *et al.* 2009
54244.3088	24202	0.08351	0.00187	Yilmaz *et al.* 2009
54486.7925	24738	0.08415	0.00234	Samolyk 2010
54512.5796	24795	0.08504	–0.00122	Hübscher *et al.* 2009b
54514.3920	24799	0.08573	–0.00102	Hübscher *et al.* 2009a
54529.3190	24832	0.08855	0.00177	Hübscher *et al.* 2009a
54532.9320	24840	0.08657	–0.00048	Hirosawa 2012
54535.6518	24846	0.08043	–0.00670	Samolyk 2010
54539.7270	24855	0.08587	–0.00131	Samolyk 2010
54563.7025	24908	0.08953	0.00228	Samolyk 2010
54576.3700	24936	0.08818	0.00048	Le Borgne *et al.* 2008a
54589.4878	24965	0.08867	0.00073	Hübscher *et al.* 2009c
54594.4667	24976	0.08707	–0.00112	Hübscher *et al.* 2009b
54796.6900	25423	0.08964	0.00136	Le Borgne *et al.* 2009a
54800.3050	25431	0.09313	0.00102	Hirosawa 2012
54821.5730	25478	0.08899	–0.00319	Le Borgne *et al.* 2009a
54860.4790	25564	0.09450	0.00191	Le Borgne *et al.* 2009b
54875.8608	25598	0.09468	0.00134	Samolyk 2010
54877.6700	25602	0.09511	0.00147	Le Borgne *et al.* 2009b
54878.5750	25604	0.09495	0.00126	Le Borgne *et al.* 2009b
54885.3610	25619	0.09505	0.00123	Le Borgne *et al.* 2009b
54890.3380	25630	0.09572	0.00181	Le Borgne *et al.* 2010b
54903.4570	25659	0.09532	0.00115	Le Borgne *et al.* 2010b
54905.7194	25664	0.09575	0.00154	Samolyk 2010
54908.4344	25670	0.09639	0.00213	Hübscher *et al.* 2010
54908.4360	25670	0.09799	0.00373	Le Borgne *et al.* 2010b
54913.4100	25681	0.09566	0.00130	Le Borgne *et al.* 2009b
54917.4810	25690	0.09512	0.00069	Le Borgne *et al.* 2009b
54923.8143	25704	0.09492	0.00036	Samolyk 2010
54932.4117	25723	0.09684	0.00212	Hübscher *et al.* 2010
54949.6032	25761	0.09735	0.00229	This study
54973.5807	25814	0.09805	0.00253	This study
55142.3180	26187	0.09265	–0.00619	Hirosawa 2012
55167.6610	26243	0.10163	0.00229	Le Borgne *et al.* 2010a

Table continued on following pages

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
55217.8755	26354	0.10047	0.00013	Samolyk 2011
55220.5900	26360	0.10061	0.00022	Le Borgne *et al.* 2010b
55261.7583	26451	0.10112	–0.00009	Samolyk 2011
55276.6882	26484	0.10204	0.00053	Samolyk 2011
55281.6644	26495	0.10192	0.00030	Samolyk 2011
55293.4310	26521	0.10629	0.00444	Vandenbroere and Salmon 2010
55294.3323	26523	0.10280	0.00094	Hübscher and Monninger 2011
55297.4990	26530	0.10275	0.00082	Le Borgne *et al.* 2011
55303.3950	26543	0.11764	0.01559	Vandenbroere and Salmon 2010
55519.6270	27021	0.10564	–0.00079	Le Borgne *et al.* 2011
55521.8901	27026	0.10677	0.00029	Samolyk 2011
55524.6060	27032	0.10831	0.00178	Le Borgne *et al.* 2011
55527.3128	27038	0.10075	–0.00584	Hirosawa 2012
55533.6540	27052	0.10845	0.00173	Le Borgne *et al.* 2011
55576.6330	27147	0.11008	0.00248	Le Borgne *et al.* 2012
55600.6160	27200	0.11624	0.00814	Vandenbroere and Hambsch 2011
55601.5171	27202	0.11255	0.00444	Vandenbroere and Hambsch 2011
55602.4230	27204	0.11367	0.00553	Vandenbroere and Hambsch 2011
55604.6817	27209	0.11040	0.00222	Samolyk 2012
55614.6340	27231	0.11005	0.00166	Le Borgne *et al.* 2012
55631.3740	27268	0.11150	0.00276	Vandenbroere and Hambsch 2011
55643.5860	27295	0.10888	–0.00011	Le Borgne *et al.* 2012
55666.6594	27346	0.11022	0.00076	Samolyk 2012
55668.0140	27349	0.10764	–0.00185	Hirosawa 2012
55669.3740	27352	0.11046	0.00094	Vandenbroere and Hambsch 2011
55714.6146	27452	0.11170	0.00124	This study
55890.6020	27841	0.11813	0.00398	Le Borgne *et al.* 2012
55904.6250	27872	0.11694	0.00249	Le Borgne *et al.* 2012
55905.9802	27875	0.11496	0.00048	Samolyk 2012

Table continued on next page

Table 4. Recalculated quadratic residuals $(O–C)_2$ for RR Leo times-of-maximum following linear least squares fit of $(O–C)_1$ and cycle number between 1898 Dec 17 and 2012 Dec 24, cont.

Time of Maximum (HJD–2400000)	*Cycle Number*	*$(O–C)_1^*$*	*$(O–C)_2$*	*Reference*
55942.6240	27956	0.11491	–0.00035	Vandenbroere and Le Borgne 2012
55946.6990	27965	0.11837	0.00302	Le Borgne *et al.* 2013
55951.6742	27976	0.11724	0.00179	Le Borgne *et al.* 2013
55961.6271	27998	0.11749	0.00182	Le Borgne *et al.* 2013
55963.8890	28003	0.11742	0.00171	Samolyk 2013
55969.7716	28016	0.11891	0.00307	Samolyk 2013
55976.1036	28030	0.11740	0.00143	Hirosawa 2013
55980.6283	28040	0.11817	0.00210	Le Borgne *et al.* 2013
55987.4147	28055	0.11867	0.00246	Le Borgne *et al.* 2013
55988.3185	28057	0.11768	0.00145	Le Borgne *et al.* 2013
55997.3670	28077	0.11832	0.00189	Vandenbroere and Le Borgne 2012
56000.5320	28084	0.11656	0.00007	Le Borgne *et al.* 2013
56000.9883	28085	0.12047	0.00397	Hirosawa 2013
56002.3450	28088	0.11999	0.00346	Vandenbroere and Le Borgne 2012
56006.4214	28097	0.12485	0.00823	Hübscher *et al.* 2013
56011.3920	28108	0.11912	0.00240	Vandenbroere and Le Borgne 2012
56035.3686	28161	0.11888	0.00164	Le Borgne *et al.* 2013
56250.2570	28636	0.12046	–0.00142	Hirosawa 2013
56251.6186	28639	0.12488	0.00297	Le Borgne *et al.* 2013
56259.3091	28656	0.12470	0.00262	Hirosawa 2013
56285.5483	28714	0.12508	0.00243	Le Borgne *et al.* 2013

*Notes: *$(O–C)_1$ residuals from linear elements reported (GCVS, Samus et al. 2012) for RR Leo. **Value rejected as outlier.*

References

AAVSO. 2013, observations from the AAVSO International Database (http://www.aavso.org).

Agerer, F., Dahm, M., and Hübscher, J. 1999, *Inf. Bull. Var. Stars*, No. 4712, 1.

Agerer, F., and Hübscher, J. 1997, *Inf. Bull. Var. Stars*, No. 4472, 1.

Agerer, F., and Hübscher, J. 2000, *Inf. Bull. Var. Stars*, No. 4912, 1.

Agerer, F., and Hübscher, J. 2002, *Inf. Bull. Var. Stars*, No. 5296, 1.

Agerer, F., and Hübscher, J. 2003, *Inf. Bull. Var. Stars*, No. 5485, 1.

Ahnert, P. 1950, *Mitt. Veränderliche Sterne*, No. 118, 1.

Ahnert, P. 1959a, *Mitt. Veränderliche Sterne*, No. 399, 1.

Ahnert, P. 1959b, *Mitt. Veränderliche Sterne*, No. 419, 1.

Ahnert, P. 1961a, *Mitt. Veränderliche Sterne*, No. 579, 1.

Ahnert, P. 1961b, *Mitt. Veränderliche Sterne*, No. 567, 1.

Allen, L. B., and Marsh, F. E. 1932, *Bull. Harvard Coll. Obs.*, No. 888, 19.

Ashbrook, J. 1949, *Astron. J.*, **54**, 198.

Aubaud, J. 1990, *AFOEV Bull.*, **51**, 1.

Aubaud, J. 1992, *AFOEV Bull.*, **59**, 3.

Balázs, J., and Detre, L. 1949, *Commun. Konkoly Obs.*, No. 21, 1.

Berdnikov, L. N. 1977, *Perem. Zvezdy Prilozh.*, **3**, 329.

Berry, R., and Burnell, J. 2005, *Handbook of Astronomical Image Processing*, Willmann-Bell, Richmond.

Braune, W., and Hübscher, J. 1987, *BAV Mitt.*, No. 46, 1.

Braune, W., Hübscher, J., and Mundry, E. 1970, *Astron. Nachr.*, **292**, 185.

Braune, W., Hübscher, J., and Mundry, E. 1977, *Astron. Nachr.*, **298**, 121.

Braune, W., Hübscher, J., and Mundry, E. 1979, *Astron. Nachr.*, **300**, 165.

Braune, W., and Mundry, E. 1973, *Astron. Nachr.*, **294**, 225.

Buchheim, B. 2006, in *The Society for Astronomical Sciences 25th Annual Symposium on Telescope Science. Held May 23-25, 2006, at Big Bear, CA*, Society for Astronomical Sciences, Rancho Cucamonga, CA, 183.

Butters, O. W., *et al.* 2010, *Astron. Astrophys.*, **520**, L10.

Dahm, M., and Kleikamp, W. 1998, *BAV Rundbrief*, **47**, 67.

Demjanovsky, V. 1975, *Perem. Zvezdy Prilozh.*, **2**, 301.

Detre, L. 1936, *Astron. Nachr.*, **259**, 305.

Ekmekçi, F., Çelik, L., and Şenavci, H. V. 2012, paper presented at the 20th Stellar Pulsation Conference Series on impact of new instrumentation and new insights in stellar pulsations, Granada, 5–9 September 2011.

Epstein, I. 1969, *Astron. J.*, **74**, 1131.

Firmanyuk, B. N., Derevyagin, V. G., and Lysova, L. E. 1985, *Astron. Circ.,* No. 1374, 7.

Fitch, W. S., Wisniewski, W. Z., and Johnson, H. L. 1966, *Commun. Lunar Planet. Lab.*, **5**, 71.

Gaposchkin, S. 1934, *Circ. Harvard Coll. Obs.*, No. 392, 1.

Geyer, E. H. 1961, *Z. Astrofiz.*, **52**, 229.

Guriev, N. 1937, *Tadjik Obs. Circ.*, No. 26, 1.

Henden, A. A., and Kaitchuck, R. H. 1990, *Astronomical Photometry: A Text and Handbook for the Advanced Amateur and Professional Astronomer*, Willmann-Bell, Richmond.

Hirosawa, K. 2012, *Var. Star Bull.* (VSOLJ), No. 52, 6.

Hirosawa, K. 2013, *Var. Star Bull.* (VSOLJ), No. 54, 2.

Hübscher, J. 2001, *BAV Mitt.*, No. 143, 1.

Hübscher, J. 2005a, *Inf. Bull. Var. Stars*, No. 5643, 1.

Hübscher, J. 2005b, *BAV Mitt.*, No. 171, 1.

Hübscher, J. 2007, *Inf. Bull. Var. Stars*, No. 5802, 1.

Hübscher, J., Agerer, F., Busch, H., Goldhahn, H., Hassforther, B., and Dahm, M. 1999, *BAV Mitt.*, No. 122, 1.

Hübscher, J., Agerer, F., Busch, H., Goldhahn, H., Hassforther, B., and Dahm, M. 2000, *BAV Mitt.*, No. 131, 1.

Hübscher, J., Agerer, F., Busch, H., Goldhahn, H., Hassforther, B., Lange, T., and Paschke, A. 2002, *BAV Mitt.*, No. 154, 1.

Hübscher, J., Agerer, F., Frank, P., and Wunder, E. 1994, *BAV Mitt.*, No. 68, 1.

Hübscher, J., Agerer, F., Hassforther, B., and Dahm, M. 1998, *BAV Mitt.*, No. 113, 1.

Hübscher, J., Agerer, F., Hassforther, B., Lange, T., and Paschke, A. 2003, *BAV Mitt.*, No. 157, 1.

Hübscher, J., Agerer, F., and Wunder, E. 1991, *BAV Mitt.*, No. 59, 1.

Hübscher, J., Agerer, F., and Wunder, E. 1992, *BAV Mitt.*, No. 60, 1.

Hübscher, J., Agerer, F., and Wunder, E. 1993, *BAV Mitt.*, No. 62, 1.

Hübscher, J., Agerer, F., and Wunder, E. 1995, *BAV Mitt.*, No. 79, 1.

Hübscher, J., Agerer, F., and Wunder, E. 1997, *BAV Mitt.*, No. 101, 1.

Hübscher, J., Braune, W., and Lehmann, P. B. 2013, *Inf. Bull. Var. Stars*, No. 6048, 1.

Hübscher, J., Lange, T., Paschke, A., Vohla, F., and Walter, F. 2005a, *BAV Mitt.*, No. 174, 1.

Hübscher, J., Lehmann, P. B., Monninger, G., Steinbach, H.-M., and Walter, F. 2010, *Inf. Bull. Var. Stars*, No. 5918, 1.

Hübscher, J., and Lichtenknecker, D. 1988, *BAV Mitt.*, No. 50, 1.

Hübscher, J., Lichtenknecker, D., and Wunder, E. 1989, *BAV Mitt.*, No. 52, 1.

Hübscher, J., Lichtenknecker, D., and Wunder, E. 1990, *BAV Mitt.*, No. 56, 1.

Hübscher, J., and Monninger, G. 2011, *Inf. Bull. Var. Stars*, No. 5959, 1.

Hübscher, J., Paschke, A., and Walter, F. 2005b, *Inf. Bull. Var. Stars*, No. 5657, 1.

Hübscher, J., Steinbach, H.-M., Vohla, F., and Walter, F. 2009a, *BAV Mitt.*, No. 202, 1.

Hübscher, J., Steinbach, H.-M., and Walter, F. 2009b, *Inf. Bull. Var. Stars*, No. 5874, 1.

Hübscher, J., Steinbach, H.-M., and Walter, F. 2009c, *Inf. Bull. Var. Stars*, No. 5889, 1.

Huth, H. 1964, *Mitt. Veränderliche Sterne*, **2**, 112.

Jordan, F. C. 1929, *Publ. Allegheny Obs.*, **7**, 1.

Kanishcheva, R. K., and Lange G. A. 1971, *Perem. Zvedzy Prilozh.*, **1**, 107.

Karetnikov, V. G. 1961, *Astron. Circ.*, No. 225, 13.

Karetnikov, V. G. 1962, *Perem. Zvezdy*, **14**, 238.

Khruslov, A. V. 2011, *Perem. Zvezdy Prilozh.*, **11**, 24.

Kooreman, C. J. 1935, *Bull. Astron. Inst. Netherlands*, **7**, 301.

Kukarkin, B. V. 1928, *Perem. Zvezdy*, **1**, No. 5, 3.

Kukarkin, B. V. 1933, *Perem. Zvezdy*, **4**, 93.

Kukarkin, B. V., and Parenago, P. P. 1931, *Perem. Zvezdy*, **3**, 34.

Lause, P. 1931, *Astron. Nachr.*, **244**, 417.

Le Borgne, J.-F. 2004, *GEOS Circular on RR Type Variables*, No. RR22, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2004, *Inf. Bull. Var. Stars*, No. 5568, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2005a, *Inf. Bull. Var. Stars*, No. 5622, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2005b, *Inf. Bull. Var. Stars*, No. 5650, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2006a, *Inf. Bull. Var. Stars*, No. 5686, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2006b, *Inf. Bull. Var. Stars*, No. 5717, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2007a, *Inf. Bull. Var. Stars*, No. 5767, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2007b, *Inf. Bull. Var. Stars*, No. 5790, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2008a, *Inf. Bull. Var. Stars*, No. 5853, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2009a, *Inf. Bull. Var. Stars*, No. 5877, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2009b, *Inf. Bull. Var. Stars*, No. 5895, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2010a, *Inf. Bull. Var. Stars*, No. 5934, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2011, *Inf. Bull. Var. Stars*, No. 5986, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2012, *Inf. Bull. Var. Stars*, No. 6009, 1.

Le Borgne, J.-F., Klotz, A., and Boër, M. 2013, *Inf. Bull. Var. Stars*, No. 6043, 1.

Le Borgne, J.-F., Klotz, A., and Kugel, F. 2010b, *GEOS Circular on RR Type Variables*, No. RR44, 1.

Le Borgne, J.-F., Vandenbroere, J., Henden, A. A., Butterworth, N., and Dvorak, S. 2008b, *Inf. Bull. Var. Stars*, No. 5854, 1.

Le Borgne, J. F., *et al.* 2007c, *Astron. Astrophys.*, **476**, 307.

Lee, Y.-H., Kim, S.S., Shin, J., and Lee, J. 2008, *Publ. Astron. Soc. Japan*, **60**, 551.

Lenz, P., and Breger, M. 2005, *Commun. Asteroseismology*, **146**, 53.

Liu, T., and Janes, K. A. 1989, *Astron. J., Suppl. Ser.*, **69**, 593.

Luizet, M. 1911, *Bull. Astron.*, **28**, 452.

Martignoni, M. 2011, *Inf. Bull. Var. Stars*, No. 6006, 1.

Martin, C., and Plummer, H. C. 1921, *Mon. Not. Roy. Astron. Soc.*, **81**, 458.

Minor Planet Observer. 2010, MPO Software Suite (http://www.minorplanetobserver.com), BDW Publishing, Colorado Springs.

Neckel, H. 1958, *Astrophys. J.*, **128**, 510.

Nielsen, A.V. 1929, *Astron. Nachr.*, **235**, 177.

Olah, K., and Szeidl, B. 1978, *Commun. Konkoly Obs.*, No. 71, 1.

Oosterhoff, P. T. 1930, *Bull. Astron. Inst. Netherlands*, **6**, 39.
Perryman, M. A. C, *et al.* 1997, *Astron. Astrophys.*, **323**, L49.
Pojmański, G. 2002, *Acta. Astron.*, **52**, 397.
Pojmański, G., Pilecki, B., and Szczygiel, D. 2005, *Acta. Astron.*, **55**, 275.
Poretti, E. 2001a, *Commun. Asteroseismology*, **140**, 40.
Poretti, E. 2001b, *Astron. Astrophys.*, **371**, 986.
Press, W., Teukolsky, S. A., Vetterling, W. T., and Flannery, B. P. 1992, *Numerical Recipes in FORTRAN*, Cambridge Univ. Press, Cambridge.
Preston, G. W. 1964, *Ann. Rev. Astron. Astrophys.*, **2**, 23.
Robinson, L.V. 1930, *Bull. Harvard Coll. Obs.*, No. 876, 23.
Samolyk, G. 2010, *J. Amer. Assoc. Var. Star Obs.*, **38**, 12.
Samolyk, G. 2011, *J. Amer. Assoc. Var. Star Obs.*, **39**, 23.
Samolyk, G. 2012, *J. Amer. Assoc. Var. Star Obs.*, **40**, 923.
Samolyk, G. 2013, *J. Amer. Assoc. Var. Star Obs.*, **41**, 85.
Samus, N. N., and Antipin, S. V. 2005, *Inf. Bull. Var. Stars*, No. 5699, 3.
Samus, N. N., *et al.* 2012, *General Catalogue of Variable Stars* (GCVS; http://www.sai.msu.su/gcvs/gcvs/).
Schlafly, E. F., and Finkbeiner, D. P. 2011, *Astrophys. J.*, **737**, 103.
Schlegel, D. J., Finkbeiner, D. P., and Davis, M. 1998, *Astrophys. J.*, **500**, 525.
Skrutskie, M. F., *et al.* 2006, *Astron. J.*, **131**, 1163.
Software Bisque. 2011, CCDSOFT CCD control software (http://www.bisque.com), Santa Barbara Instrument Group, Santa Barbara, CA.
Soloviev, A. V. 1936a, *Perem. Zvezdy*, **5**, 77.
Soloviev, A. V. 1936b, *Tadjik Obs. Circ.*, No. 15, 1.
Soloviev, A. V., and Shakhovskoj, N. M. 1958, *Tadjik Tr.*, **7**, 45.
Szeidl, B., and Pocs, M. D. 2002, *Inf. Bull. Var. Stars*, No. 5349, 1.
Templeton, M. R., Samolyk, G., Dvorak, S., Poklar, R., Butterworth, N., and Gerner, H. 2009, *Publ. Astron. Soc. Pacific*, **121**, 1076.
Tsesevich, V. P. 1934, *Leningrad Bull.*, No. 4, 1.
Tsesevich, V. P. 1974, *Astron. Tsirk.*, No. 811, 1.
Udalski, A., Szymański, M., Kałużny, J., Kubiak, M., and Mateo, M. 1992, *Acta Astron.*, **42**, 253.
Vandenbroere, J. 1997, *GEOS Circular on RR Type Variables*, No. RR14, 1.
Vandenbroere, J. 1998, *GEOS Circular on RR Type Variables*, No. RR15, 1.
Vandenbroere, J. 1999, *GEOS Circular on RR Type Variables*, No. RR16, 1.
Vandenbroere, J. 2001, *GEOS Circular on RR Type Variables*, No. RR17, 1.
Vandenbroere, J. 2005, *GEOS Circular on RR Type Variables*, No. RR23, 1.
Vandenbroere, J., and Denoux, E. 2007, *GEOS Circular on RR Type Variables*, No. RR30, 1.
Vandenbroere, J., and Hambsch, F.-J. 2011, *GEOS Circular on RR Type Variables*, No. RR47, 1.
Vandenbroere, J., and Le Borgne, J.-F. 2012, *GEOS Circular on RR Type Variables*, No. RR49, 1.

Vandenbroere, J., and Salmon, G. 2010, *GEOS Circular on RR Type Variables*, No. RR45, 1.

Vanmunster, T. 2013, PERANSO (v.2.50) Light Curve and Period Analysis Software (http://www.peranso.com/).

Vasilief, I. 2013, QTIPLOT (v. 0.9.8.9) Data Analysis and Scientific Visualization (http://soft.proindependent.com/qtiplot.html).

Warner, B. 2007, *Minor Planet Bull.*, **34**, 113.

Watson, C., Henden, A. A., and Price, A. 2013, AAVSO International Variable Star Index VSX (Watson+, 2006–2013; http://www.aavso.org/vsx).

Wenske, W. 1980, *BAV Rundbrief*, **29**, 45.

Wils, P., Lloyd, C., and Bernhard, K. 2006, *Mon. Not. Roy. Astron. Soc.*, **368**, 1757.

Wils, P., *et al.* 2012, *Inf. Bull. Var. Stars*, No. 6015, 1.

Woźniak, P. R., *et al.* 2004, *Astron. J.*, **127**, 2436.

Yilmaz, M., *et al.* 2009, *Inf. Bull. Var. Stars*, No. 5887, 1.

Zakharov, G.P. 1953, *Perem. Zvezdy*, **9**, 271.

Zhou, A.-Y., and Jiang, S.-Y. 2011, *Astron. J.*, **142**, 100.