

Two decades of optical photometry of short-period eclipsing RS CVn systems and other active chromosphere systems

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Abstract

I present *BVRI* photometry of short-period ($P < 1$ d) eclipsing RS CVn binary star systems collected between 1988 and 2009 at Mount Laguna Observatory. Most of the data are for ER Vul and WY Cnc, with light curves nearly every year during that time period. I also present light curves for at least several years for XY UMa, BH Vir, CG Cyg, RT And, and UV Psc. I have fewer light curves for SV Cam, UV Leo, 1E1919+0427, and GSC 2038-0293. In addition to the eclipsing short-period systems, I also include *UBVRI* data for two longer period noneclipsing RS CVn binary systems: UZ Lib and DM UMa, as well as two active chromosphere single stars: FK Com and HD 199178.

Keywords: technique: photometric – stars: variable – stars: eclipsing – stars: RS CVn

1 Introduction

In 1986, I initiated a program of optical photometry of RS CVn systems using the 24'' (0.6 m) telescope at Mt. Laguna Observatory operated by San Diego State University. In 1988 I started concentrating on the short-period eclipsing group of RS CVn systems (Hall, 1976) with the goal of collecting annual light curves of as many members of the short-period eclipsing group as possible in order to better understand the starspot evolution in these systems.

There are three primary advantages of observing the short-period eclipsing systems. First, the presence of the eclipse provides a marker to help determine the spot longitude, even if the orbital period is slightly inaccurate. Secondly, if spot evolution is driven by

stellar rotation, then the faster rotation of the short-period systems will drive the spot evolution more rapidly, thereby reducing the time needed to study spot evolution or possible spot cycles. Finally, as a visiting observer needing to travel long distances to the observatory, it is, weather permitting, possible to collect complete light curves of short period systems in a single observing run. That would not be possible with long-period systems.

As a lower priority observing project, I used the times after the primary targets had set or before they had risen to observe a small sample of long-period systems. I chose noneclipsing systems in this case because I would typically get on the order of 10 data points for these stars in an observing run. Such sparse light curves would not be scientifically useful for eclipsing binary systems, but would allow characterizing the cyclic wave present in non-eclipsing RS CVn systems.

Short period eclipsing systems in my sample include WY Cnc, ER Vul, XY UMa, BH Vir, CG Cyg, RT And, UV Psc, SV Cam, UV Leo, GSC 2038-0293, and 1E1919+0427. I observed the long-period ($P > 1$ day) non-eclipsing RS CVn systems and FK Com type stars: BD 61°1211, UZ Lib, FK Com, and HD 199178.

2 Observations

I used the 0.6-m (24") telescope at Mount Laguna Observatory operated by San Diego State University for all the observations reported in this paper. The observatory is at an altitude of 1859 meters above sea level and is located at 116°43 west longitude and 32°84 north latitude. The telescope was equipped with a single-channel photoelectric photometer. Initially the photometer used an EMI 6256 photomultiplier tube operated at -1300V and cooled to -10°F . The blue sensitive EMI tube had filters designed to closely match the standard Johnson *UBV* system.

Beginning in May 1990, the photometer, retaining the same electronics, used a Hamamatsu R943-02 GaAs photomultiplier tube cooled to the same temperature and operated at -1450V . The red sensitivity of the newer Hamamatsu tube allowed the addition of *R* and *I* filters, so that the filter system closely matched the standard Johnson–Cousins *UBVRI* system. During the summer of 1992, the first Hamamatsu tube failed and was replaced with the older EMI tube until a new Hamamatsu tube was purchased.

Because RS CVn stars are relatively cool they are faint in the ultraviolet. Hence *U* band observations either have higher errors or require longer integrations. Because the short-period systems ($P < 1\text{day}$) require fairly high time resolution, especially during eclipses, I only observed these systems in the *BVRI* bands (*BV* bands with the EMI tube). The long period systems do not have such stringent time resolution requirements, so I also observed these systems in the *U* band.

Each observation usually consisted of two integrations. The integration times depended on the brightness of the star, but were usually 10 or 20 seconds with the Hamamatsu tube. The less sensitive EMI tube required longer integration times of up to 40 seconds. I used either a 19", 26", or rarely a 36" aperture for the observations. Each night I selected the aperture to use based on the seeing conditions, recent telescope tracking behavior, and the amount of moonlight. For each observation I cycled through the filters in order and then

cycled back in the reverse order to get two integrations per observation. I always checked the telescope tracking before starting and after finishing the filter sequence. If the telescope had drifted enough to affect the count rate, I repeated the observation. If the counts from the two integrations in each filter did not agree to within about 1%, I did an extra integration. If the data consistently did not agree to within 1%, I stopped working until sky conditions improved. Hence nearly all of these differential data are accurate to at least 1%. Data collected on nights having excellent sky conditions are often more accurate.

I regularly observed the comparison stars and sky background by using the observing sequence: sky, comparison star, variable, variable, variable, comparison star, sky. When using a check star, I occasionally observed the check star in place of the middle variable star. The long period stars had no time resolution constraints, so I regularly observed the check star. The short-period stars need high time resolution. Hence after I established that there was no evidence for variability in the comparison star or if previous workers found no such evidence, I did not observe the check star.

The reported data are differential magnitudes in the sense of variable *minus* comparison. I used standards from Landolt (1983) to calibrate the comparison stars and to find the coefficients needed to transform the magnitudes into the standard Johnson-Cousins *UBVRI* photometric system. Unless explicitly stated otherwise, all data are in the standard photometric system.

A few early light curves of CG Cyg, taken with the less sensitive EMI tube, are in *V* band only to allow better time resolution. Without *B – V* data, these light curves are in the instrumental *v* system. The photometer electronics were starting to fail from age near the end of this project. In January of 2009, the filter wheel motor failed. I therefore set the photometer in the *V* filter and left it there. Hence the January 2009 data on WY Cnc are also in the instrumental *v*-band only. January 2009 was the last observing run for this project.

As mentioned above, I usually did not work if the two integrations in an observation did not typically agree to within 1%. I only occasionally made exceptions to this rule when I needed to work at higher than optimal air mass or less than optimal sky conditions in order to complete a light curve. Data collected under these less than optimal conditions represent a very small portion of the data reported here. Hence the differential photometric data collected for this project are accurate to better than 1% or 0.01 magnitude. Many of the data collected under good sky conditions are differentially more precise. Many nights at Mt. Laguna allow differential photometry accurate to $\frac{1}{2}\%$ or occasionally even $\frac{1}{4}\%$.

All-sky photometry is of course less accurate. I calibrated some of the comparison stars more than once. Independent calibrations using Landolt (1983) standards typically agree to 0.02 or 0.03 magnitudes in the *B* and *V* bands and to 0.01 or occasionally 0.02 magnitudes in the *R* and *I* bands.

The photometer clock was not directly connected to a time standard. I set it manually using an accurately calibrated clock or time signal at the start of each night. The photometer clock was therefore accurate to about 1 second. The real limitation to the time resolution was, however, the time required to cycle through the filters for an observation. Depending on the integration time, the time required to complete an observation was typically a few minutes. Hence the time resolution for the observations is typically on the order of a few minutes, or a little over 0.001 days. For stars with periods of less than a day the time

resolution of the light curves is therefore typically better than 1%.

3 Stars observed

As part of this program I have observed to some degree most of the stars in the short-period eclipsing group of RS CVn systems. Having started observing them in 1988, I have the most complete sets of light curves for WY Cnc and ER Vul. I also have many light curves for XY UMa, BH Vir, CG Cyg, RT And, and UV Psc. I have relatively few light curves for SV Cam, 1E1919+0427, GSC 2038-0293, and UV Leo. I also observed the long-period ($P > 1$ day) stars: BD 61°1211, FK Com, UZ Lib, and HD 199178. Table 1 lists the observing log.

I started observing RS CVn stars in order to study the evolution of starspots on these systems, so it is important to analyze each year's light curves separately. Hence the data tables are in a format that clearly separates the light curves for each year. I tried to collect each year's light curves in as short a time as possible because the star spots in these systems may change fairly rapidly. For consistency, I used the same ephemeris to calculate all the phases for each star, even if a new ephemeris became available. For workers wishing to use a more recent ephemeris, the data tables include both the heliocentric Julian day and the phase.

Table 1: Observing Log.

Star	Years Observed
WY Cancr	Annually 1988 to 2009; 1993 incomplete
ER Vulpeculae	Annually 1988 to 2008; 1996 incomplete
XY Ursae Majoris	1987, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2003, 2004, 2006, 2007, 2008
BH Virginis	Annually 1993 to 2008
CG Cygni	1988, 1991, 1994, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2006, 2007, 2008
RT Andromedae	1995(Feb.), 1996(Jan.), 1997(Jan.), 1997(Dec.), 1999(Jan.), 1999(Aug.), 2000(Jan.), 2001(Jan.), 2001(July), 2003(Jan.), 2004(Jan.), 2004(Aug.), 2006(Jan.), 2006(Aug.), 2008(Jan.)
UV Piscium	1998, 1999, 2002, 2003, 2004, 2005, 2006
SV Camelopardis	1995, 2001, 2003
UV Leonis	2007
GSC 2038-0293	2007, 2008
1E1919+0427	1992, 1993, 1994
BD 61°1211	Annually 1986 to 2008
UZ Librae	1988, 1989, 1990, 1992, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2006,
FK Comae	1988, 1989, 1990, 1991, 1992, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2003, 2004
HD 199178 = V1794 Cyg	Annually 1990 to 2002

Table 2: Average Comparison Star Magnitudes.

Star	Comparison Star	<i>U</i>	<i>B</i>	<i>V</i>	<i>R</i>	<i>I</i>	<i>n</i>
WY Cancri	SAO 80583		8.62	8.33	8.15	7.99	3
ER Vulpeculae	HD 200425		8.35	7.79	7.45	7.15	2
XY Ursae Majoris	SAO 27139		10.03	9.57	9.29	9.05	3
BH Virginis	GSC 4968 0476		11.01	10.39	10.03	9.69	1
CG Cygni	BD 34°4216		9.71	8.96	8.46	7.97	2
RT Andromedae	SAO 35208		10.26	10.13	10.05	9.99	2
UV Piscium	SAO 109761		9.22	7.67	6.82	6.02	2
SV Camelopardalis	SAO 1020		9.22	8.70	8.39	8.12	1
UV Leonis	SAO 99225		9.26	8.20	7.61	7.11	1
	SAO 99223		8.77	8.33	8.04	7.77	1
GSC 2038-0293	SAO 84175		10.74	10.09	9.64	9.28	1
	SAO 84179		7.87	7.09	6.64	6.23	1
BD 61°1211	SAO 15365	11.41	10.32	9.10	8.49	7.94	3
UZ Librae	BD−7°4044	11.42	10.53	9.43	8.83	8.33	2
FK Comae	HD 117567	8.03	8.07	7.64	7.36	7.13	2
HD 199178	SAO 50313	8.64	7.70	6.63	6.08	5.59	1

3.1 WY Cancri

I have obtained at least partial light curves of WY Cancri during the winter or spring of every year from 1988 to 2009. In 1993 I was only able to obtain partial light curves. In 2009 I was only able to obtain instrumental *v* band data.

SAO 80583 was used as the comparison star and SAO 80598 as the check. On 7 January 1994 the calibrated magnitudes of SAO 80583 were: $B = 8.60$, $V = 8.31$, $R = 8.14$, and $I = 7.99$. On 28 May 1998 the calibrated magnitudes were: $B = 8.65$, $V = 8.35$, $R = 8.15$, and $I = 7.99$. On 1 May 2003 I found calibrated magnitudes of $B = 8.62$, $V = 8.33$, $R = 8.15$, and $I = 7.99$. The phases were using the ephemeris given by Hall and Kreiner (1980): $\phi_0 = 2426352.3895 + 0.82937122E$.

The WY Cnc data have been more extensively analyzed than the data on other stars in this sample. Heckert and Zeilik (1990) published a brief analysis of the 1988 and 1989 data, which are also incorporated into the more extensive analysis of Zeilik et al. (1990). Heckert et al. (1998) completed an analysis of the star spots using the first decade of data on this star. The data through 1997 are archived in the IAU Commission 27 data archives (file 322E), but for convenience they are also included in Table 3 along with the more recent data. Heckert (2001) and Heckert (2003) followed up with analysis of the light curves collected through 2003. Kozhevnikova et al. (2006, 2007) analyze these data as well as data collected at the Crimean Astrophysical Observatory and the Kourouka Astronomical Observatory.

The WY Cnc data are in Table 3. A small portion of Table 3 is reproduced below to illustrate the format of the tables.

Table 3: WY Cancri.

Date:	May	1988	Date:	May	1988
Filter: <i>B</i>			Filter: <i>V</i>		
PHASE	MAG	HJD	PHASE	MAG	HJD
			0.219	1.136	2447291.7061
			0.227	1.124	2447291.7128
0.245	1.523	2447291.7280	0.245	1.129	2447291.7280
0.250	1.524	2447291.7317	0.250	1.125	2447291.7317
0.254	1.524	2447291.7353	0.254	1.114	2447291.7353
0.270	1.507	2447291.7485	0.270	1.104	2447291.7485
0.280	1.516	2447291.7566	0.280	1.100	2447291.7566
0.400	1.523	2447292.6860	0.400	1.110	2447292.6860
0.407	1.534	2447292.6920	0.407	1.113	2447292.6920
0.419	1.529	2447292.7012	0.419	1.109	2447292.7013
0.422	1.522	2447292.7044	0.422	1.105	2447292.7043
0.426	1.531	2447292.7070	0.426	1.107	2447292.7070
0.436	1.522	2447292.7159	0.436	1.109	2447292.7159
0.440	1.526	2447292.7188	0.440	1.108	2447292.7187
0.443	1.538	2447292.7214	0.443	1.120	2447292.7214
0.454	1.545	2447292.7309	0.454	1.137	2447292.7309

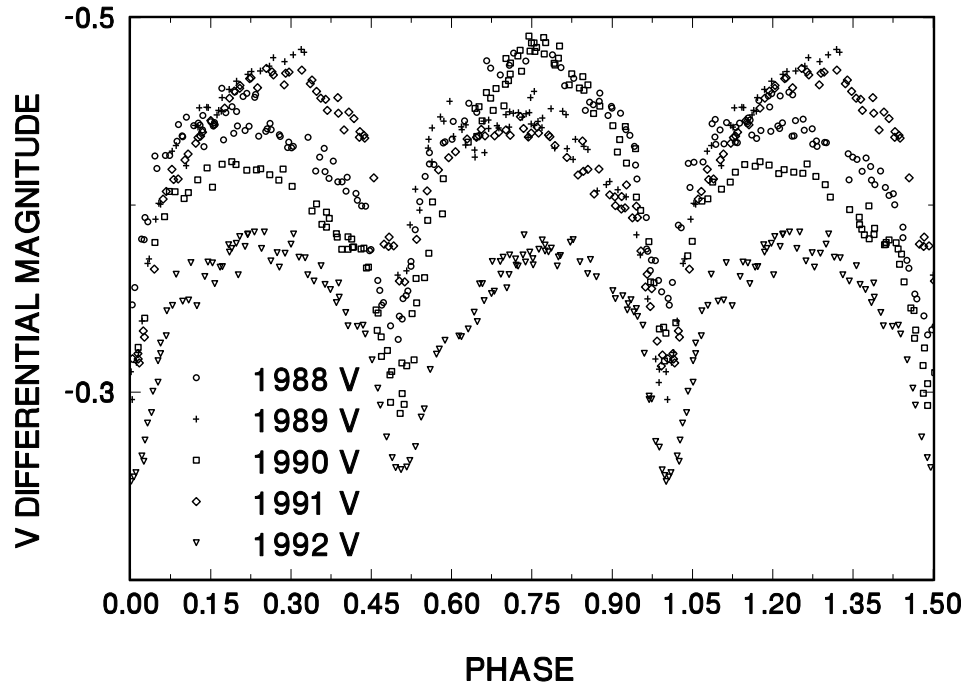
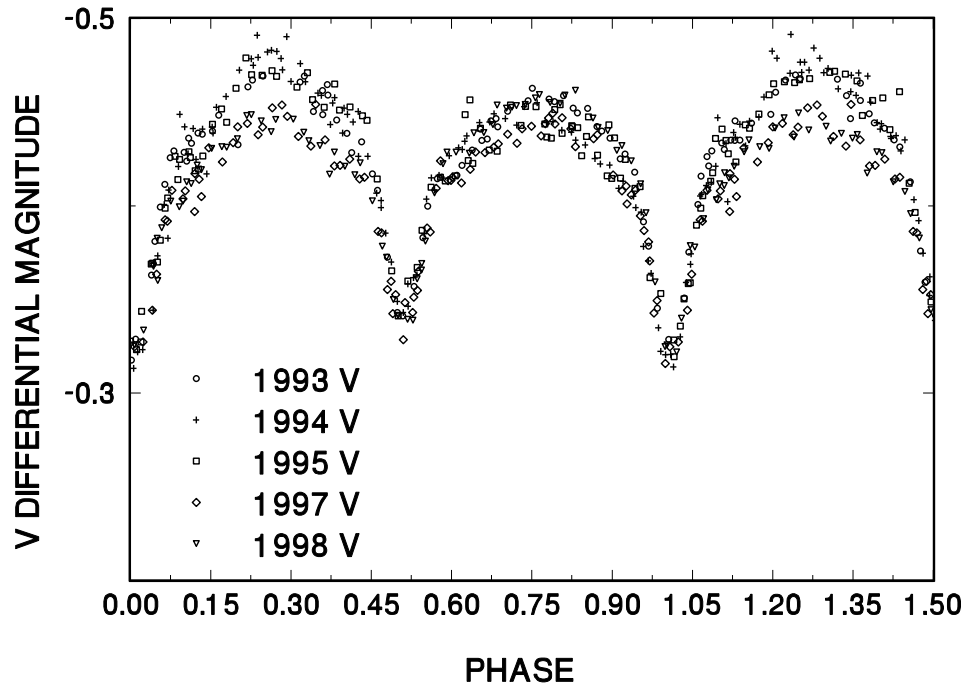
3.2 ER Vulpeculae

I have obtained light curves for ER Vulpeculae during July or August of each year from 1988 to 2008. An instrument malfunction prevented collecting complete light curves in 1996. Otherwise the light curves contain at most small gaps. HD 200425 was used as the comparison star and in the early light curves I used HD 200270 as the check star. The standard magnitudes of HD 200425 were calibrated on two different occasions using Landolt (1983) standards. On 16 August 1998 I found: $B = 8.36$, $V = 7.79$, $R = 7.44$, and $I = 7.14$. On 10 August 2003 I found $B = 8.34$, $V = 7.78$, $R = 7.45$, and $I = 7.15$. The calibrated magnitudes on these two dates agree to within 1%. The phases were calculated using the ephemeris given by Akan et al. (1987): $\phi_0 = 2440182.2621 + 0.69809409E$.

Heckert and Zeilik (1991) published an analysis of the 1988 and 1989 data. Otherwise the ER Vul data are unpublished. The ER Vul data are in Table 4. Figures 1 to 4 show the V light curves from 1988 to 2008 with 5 light curves in each graph. The light curves clearly show very large year to year variations in the overall light levels both during and out of eclipses. ER Vul is clearly – as once described to me by M. Zeilik (private communication) – “wild and woolly.”

3.3 XY Ursae Majoris

I have fairly complete $BVRI$ light curves for XY UMa for most years from 1994 to 2008. The years for which I do not have data are 1997, 2002, and 2005. An analysis of these data through 2000 combined with data from other workers has been published by Pribulla et al. (2001). Otherwise the data are unpublished.

Figure 1: Differential V magnitudes of ER Vul from 1988 to 1992.Figure 2: Differential V magnitudes of ER Vul from 1993 to 1998.

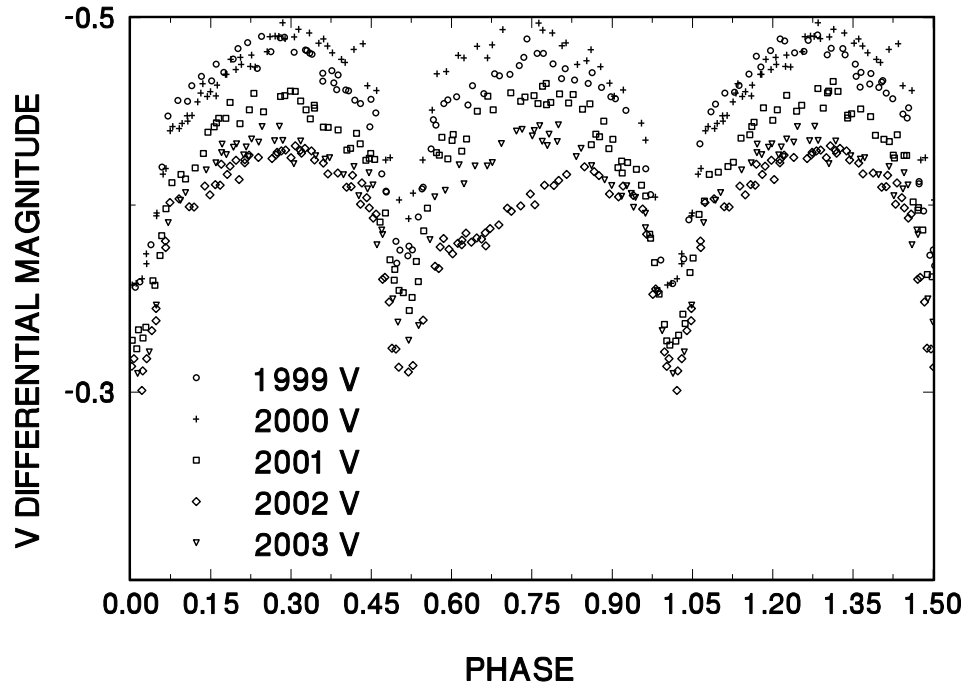


Figure 3: Differential V magnitudes of ER Vul from 1999 to 2003.

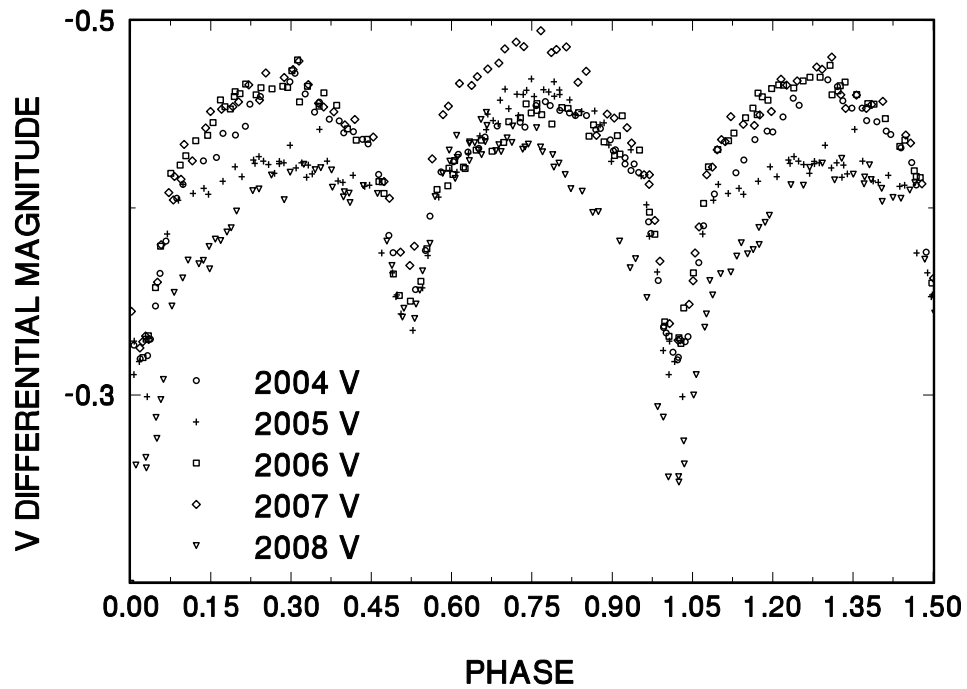


Figure 4: Differential V magnitudes of ER Vul from 2004 to 2008.

I also have instrumental v band data for 1987. The 1987 data were collected and reduced with older now obsolete computers, so they were no longer in an electronically readable form. I therefore typed the 1987 data into the end of Table 5 from a paper printout of the reduced data. The printout unfortunately had no HJD data, so the 1987 data include only the phases and differential magnitudes. Heckert and Zeilik (1988) published a brief analysis of the 1987 data.

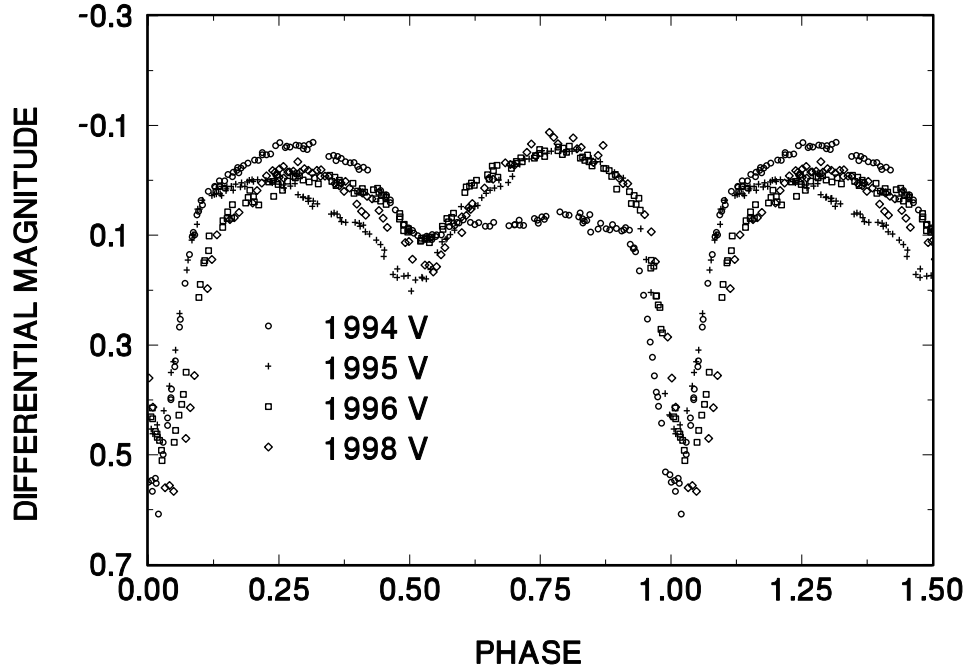


Figure 5: Differential V magnitudes of XY UMa from 1994 to 1998.

SAO 27139 was used as the comparison star, and the calibration was done with Landolt (1983) standards. For 28 May 1998, I obtained $B = 10.02$, $V = 9.59$, $R = 9.29$, and $I = 9.05$. On 27 May 1999 I repeated the calibration and found $B = 10.04$, $V = 9.57$, $R = 9.28$, and $I = 9.05$, and on 1 May 2003 I found $B = 10.02$, $V = 9.56$, $R = 9.29$, and $I = 9.05$. These three independent calibrations agree with each other well. The phases were calculated using the ephemeris $\phi_0 = 2435216.4991 + 0.478994587E$ from Hall and Kreiner (1980).

The XY UMa data are in Table 5. Figures 5 through 7 show plots of the V band photometry of XY UMa from 1994 to 2008. Between 1999 and 2003 the light curves show minimal year to year variation. The other light curves show significant year to year variation both during and outside of the eclipses. Evidently XY UMa alternates between very active periods and relatively quiescent periods.

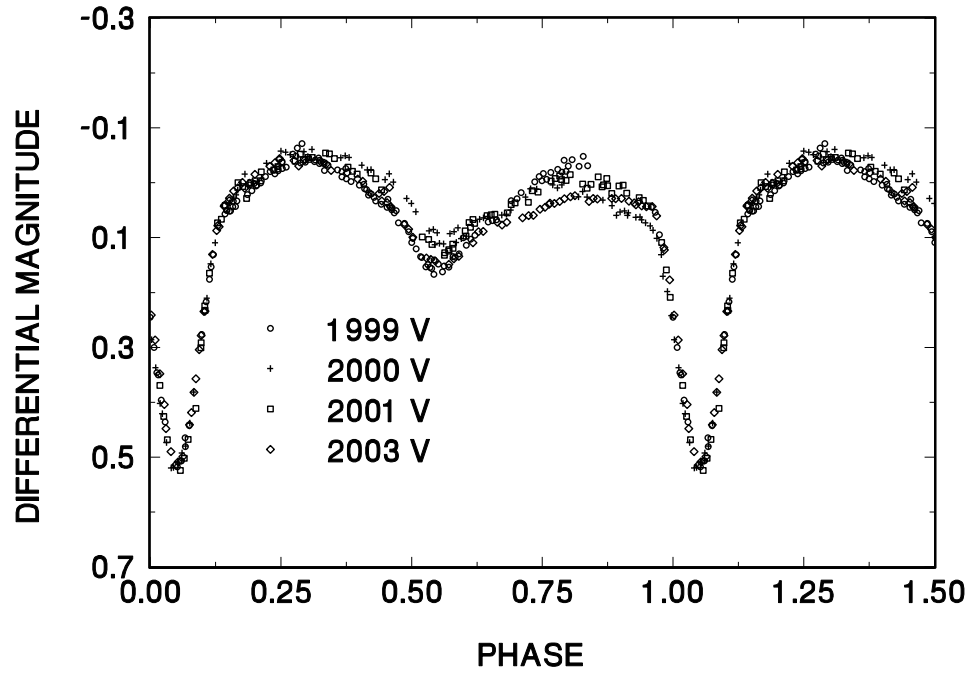


Figure 6: Differential V magnitudes of XY UMa from 1999 to 2003.

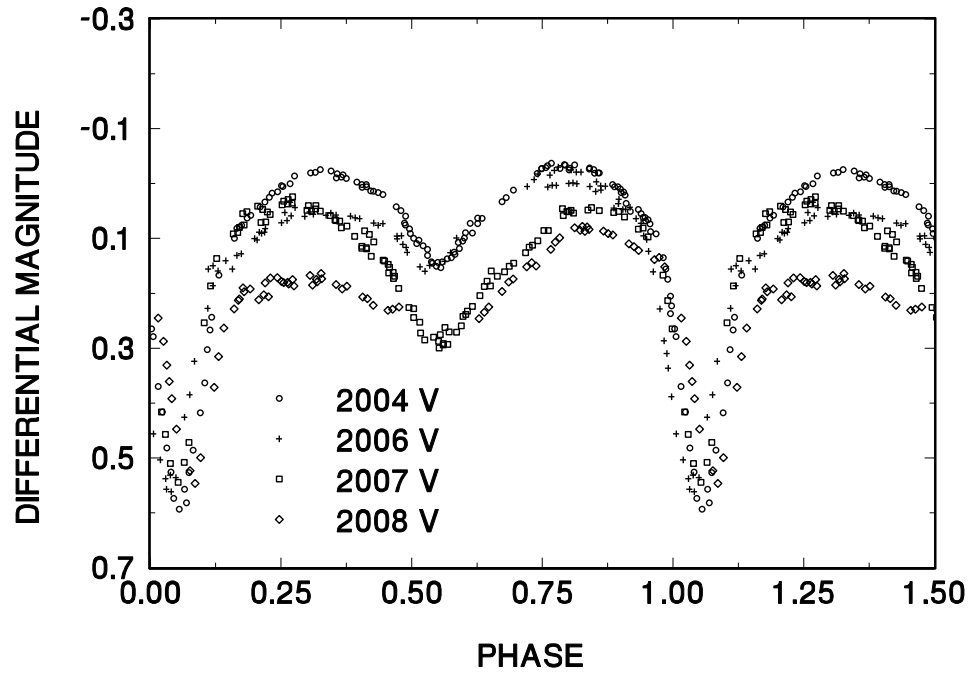


Figure 7: Differential V magnitudes of XY UMa from 2004 to 2008.

3.4 BH Virginis

I started observing BH Vir in 1993 and obtained annual light curves every spring or summer from 1993 until 2008. In the years 1993 and 1997, I observed BH Vir during July or August, which is very late in the observing season, hence I had to observe at large hour angles in order to obtain light curves. During the data analysis stages, I removed any spurious data resulting from these large hour angles. GSC 4968 0476 was used as the comparison star. Using Landolt standards, I calibrated the magnitude of GSC 4968 0476 on 1 May 2003. I found $B = 11.01$, $V = 10.39$, $R = 10.03$, and $I = 9.69$. To compute the phases I used the ephemeris of Koch (1967): $\phi_0 = 2438107.19047 + 0.81687099E$.

Heckert and Summers (1994, 1995) published the results of modeling the 1993 and 1994 data. Kjurkchieva et al. (2004) published an analysis of the photometric data collected through 2003 along with complementary spectroscopic data. Kozhevnikova et al. (2007) analyze these data combined with data collected at the Crimean Astrophysical Observatory. The BH Vir data are in Table 6.

3.5 CG Cygni

I have fairly complete *BVRI* light curves of CG Cyg collected during most summers from 1994 to 2008. The years 1996 and 2005 are missing. I also have instrumental *v* band data from 1988 and 1991.

BD 34°4216 was used as the comparison star. I calibrated its magnitudes independently on two different dates: $B = 9.71$, $V = 8.96$, $R = 8.44$, $I = 7.95$ on 16 August 1998, and $B = 9.71$, $V = 8.96$, $R = 8.47$, and $I = 7.98$ on 10 August 2003. To calculate the phases, I used the ephemeris of Hall and Kreiner (1980): $\phi_0 = 2444528.5351 + 0.63114347E$.

Heckert (1994, 1996a, 1998a) modeled the light curves for the single years: 1994, 1995, and 1997. Afsar et al. (2004) did a more complete analysis including both the data collected through 2002 and other photometric data. The CG Cyg data are in Table 7.

3.6 RT Andromedae

I started observing RT And during the winter of 1995. I collected approximately annual light curves most years until 2008. During a few years, I collected data during the late summer and did not observe RT And the following winter. While observing RT And during the winter it was often necessary to observe at rather large hour angles to obtain complete light curves. RT And is however at a fairly high declination and on clear winter nights the sky at Mt. Laguna can be very stable. Hence the data, even at large hour angles, were usually consistent to within 1%.

I used SAO 35208 as the comparison star. The calibrated magnitudes are: $B = 10.25$, $V = 10.12$, $R = 10.05$, and $I = 9.99$ on 7 January 1994 and $B = 10.26$, $V = 10.13$, $R = 10.05$, and $I = 9.99$ on 11 January 2000. The phases were calculated with the ephemeris of Hall and Kreiner (1980): $\phi_0 = 2441141.8888 + 0.62892984E$.

The analysis of the light curves from 1995, 1996, and 1997 are published in Heckert (1995, 1998b) and Heckert et al. (1996). The data are not otherwise published. The RT And data are in Table 8.

3.7 UV Piscium

I observed UV Psc in the summers of 1998, 1999, 2002, 2003, 2004, 2005, and 2006. Heckert (1999) and Kjurkchieva et al. (2005) have published analyses of the light curves collected through 2003.

I used SAO 109761 as the comparison star. On 16 August 1998, its calibrated magnitudes were: $B = 9.24$, $V = 7.68$, $R = 6.82$, and $I = 6.05$. On 10 August 2003, the calibrated magnitudes were: $B = 9.20$, $V = 7.65$, $R = 6.81$, and $I = 6.04$. To calculate the phases, I used the ephemeris of Ibanoglu (1987): $\phi_0 = 2444932.2985 + 0.86104771E$. The UV Psc data are in Table 9.

3.8 SV Camelopardalis

I observed SV Cam during the winters of 1995 and 2003 as well as during the spring of 2001. Heckert (1996b) published a brief analysis of the 1995 data. The other data are unpublished. Following Patkós (1982), I used SAO 1020 as the comparison star. I calibrated the comparison star using Landolt standards while observing SV Cam in 2003. The calibrated magnitudes of SAO 1020 in the standard Johnson-Cousins system are: $B = 9.22$, $V = 8.70$, $R = 8.39$, and $I = 8.12$. I calculated the phases using the ephemeris of Hall and Kreiner (1980): $\phi_0 = 2434988.483 + 0.593071E$. The SV Cam data are in Table 10.

3.9 UV Leonis

I observed UV Leonis in 2007 and published a brief analysis of the light curves in Heckert (2009). Using Landolt standards, I calibrated the comparison star, SAO 99225, magnitudes: $B = 9.26$, $V = 8.20$, $R = 7.61$, and $I = 7.11$. The check star, SAO 99223, calibrated magnitudes are: $B = 8.77$, $V = 8.33$, $R = 8.04$, and $I = 7.77$. I calculated the phases using the ephemeris of McCluskey (1966): $\phi_0 = 2438440.7275 + 0.6000855E$. The UV Leo data are in Table 11.

3.10 GSC 2038-0293

GSC 2038-0293 is a recently discovered member of the short-period eclipsing group of RS CVn systems (Bernhard and Frank 2006). I observed GSC 2038-0293 in May and June of 2007 and 2008. The period is so close to a half of a day that it takes longer than the length of my observing runs for the entire light curve to be observable. Hence there are small gaps in each set of light curves.

I used SAO 84175 and SAO 84179 as the comparison and check stars. Using Landolt standards, I obtained calibrated magnitudes for SAO 84175 of: $B = 10.74$, $V = 10.09$, $R = 9.64$, and $I = 9.28$. The calibrated magnitudes for SAO 84179 are: $B = 7.87$, $V = 7.09$, $R = 6.64$, and $I = 6.23$. I find no evidence for variability of the comparison star. The phases were calculated using the ephemeris of Bernhard and Frank (2006): $\phi_0 = 2453560.491 + 0.495410E$.

The GSC 2038-0293 data are in Table 12 and the V data are plotted in Figure 8. These light curves show clear differences between 2007 and 2008, especially near the secondary

eclipse. I have not modeled the data, but it seems that during 2008 there was a large spot near the position of the secondary eclipse.

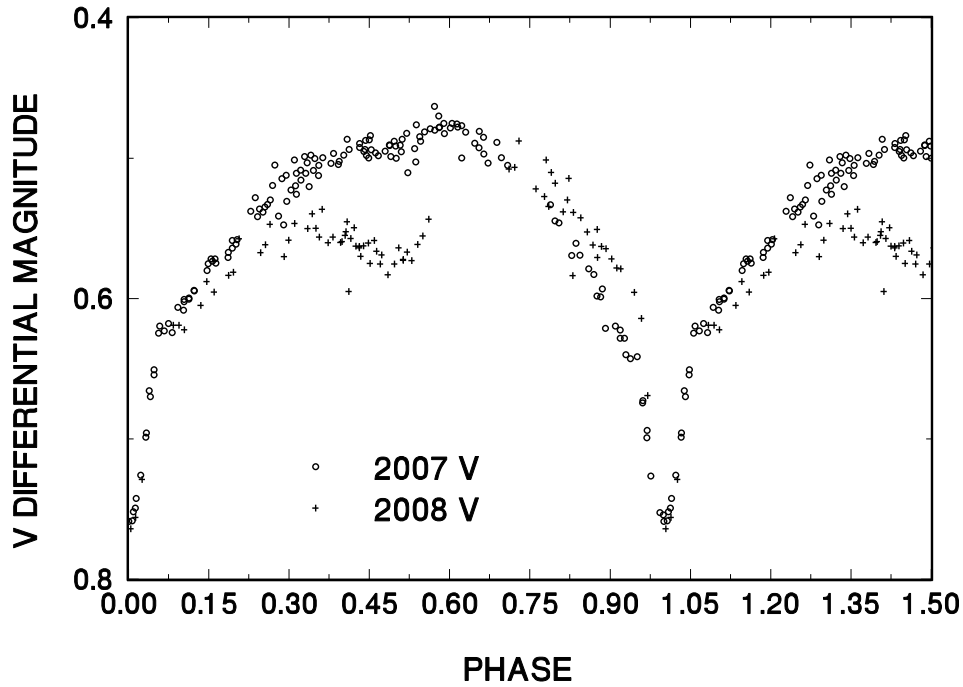


Figure 8: Differential V magnitudes of GSC 2038-0293 for 2007 and 2008.

3.11 1E1919+0427

I observed 1E1919+0427 in 1992, 1993, and 1994. Because this star is faint and required longer integration times, it was only observed in the B and V bands. I used the comparison star A in the finding chart given by Summers and Heckert (1997) and did not calibrate the comparison star magnitudes. Summers and Heckert (1997) published an analysis of these data along with data collected at Capilla Peak Observatory. All of those data are available from the IAU Commission 27 Archives file number 317E. I include the Mount Laguna Observatory data only in Table 13.

3.12 Long Period Stars

3.12.1 BD 61°1211

I observed BD 61°1211 = DM UMa from 1986 to 2008. The data through 2007 along with other data were analyzed by Rosario et al. (2009) and are available electronically in Table 2 of that publication. They are also included here. The earliest data from 1986 and 1987 are in the instrumental system because I did not observe any calibration standards those years. The data collected since 1988 are in the standard $UBVRI$ system.

I used SAO 15365 as the comparison star and SAO 15388 as the check star. On 22 and 23 May 1994 I calibrated the magnitudes of SAO 15365 and got: $U = 11.47, B = 10.33, V = 9.13, R = 8.50$, and $I = 7.94$. On 28 May 1998 I got: $U = 11.36, B = 10.33, V = 9.05, R = 8.49$, and $I = 7.94$. On 27 May 1999 I got: $U = 11.39, B = 10.29, V = 9.11, R = 8.47$, and $I = 7.93$. I calculated the phases using the ephemeris of Mohin et al. (1985): $\phi_0 = 2443881.4 + 7.492E$.

3.12.2 UZ Librae

I observed UZ Librae most years from 1988 to 2006 except for 1993, 1997, and 2005. I used BD $-7^\circ 4044$ as the comparison star and BD $-8^\circ 3998$ as the check. I calibrated the comparison star magnitudes on 16 August 1998 and got: $U = 11.37, B = 10.54, V = 9.42, R = 8.82$, and $I = 8.31$. On 27 May 1999 I got: $U = 11.47, B = 10.51, V = 9.43, R = 8.83$, and $I = 8.35$. The phases were calculated using the ephemeris of Grewing et al. (1989): $\phi_0 = 2445428.88.4 + 4.767885E$.

3.12.3 FK Comae

I observed FK Comae most years from 1988 to 2004 except for 1993 and 1997. I used HD 117567 as the comparison star and HD 117876 as the check. I calibrated the comparison star magnitudes on 28 May 1998. I got: $U = 8.03, B = 8.08, V = 7.64, R = 7.36$, and $I = 7.12$. On 1 May 2003 I measured the calibrated magnitudes as: $U = 8.02, B = 8.06, V = 7.63, R = 7.36$, and $I = 7.13$. I calculated the phases using the ephemeris of Chugainov (1976): $\phi_0 = 2442192.345 + 2.400E$.

3.12.4 HD 199178=V1794 Cyg

I observed HD 199178 each year from 1990 to 2002. I used SAO 50313 as the comparison star and SAO 50326 as the check star. On 22 May 1994 I measured the comparison star magnitudes as: $U = 8.64, B = 7.70, V = 6.63, R = 6.08$, and $I = 5.59$. I calculated the phases using the ephemeris of Bopp et al. (1983): $\phi_0 = 2444395.7 + 3.337E$. The data for all these long period stars are in Table 14.

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