RS CVN STARS IN THE AAVSO PHOTOELECTRIC PHOTOMETRY PROGRAM

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Received January 30, 2001

Abstract

We report V photometry of three RS CVn stars—HK Lac, SZ Psc, and λ And—from the AAVSO photoelectric photometry program, and from transformed Hipparcos photometry, over 3500 days. Eighteen photoelectric photometry observers contributed to this project. The stars vary on periods of days to weeks, due to rotation of a spotted photosphere. The rotational light curves vary on time scales of months to years, due to changes in the area and/or distribution of the spots.

1. Introduction

The RS CVn stars have been defined by Hall (1976) as "binaries with orbital periods between 1 and 14 days, with the hotter component F–G IV–V and with strong H and K emission seen in the spectrum outside eclipse." There are also similar stars with orbital periods less than a day ("the short-period group") and greater than 14 days ("the long-period group"). It is probably appropriate to lump all these stars together and call them "stars showing the RS CVn phenomenon."

Some of these stars are eclipsing variable stars, but they all show additional out-of-eclipse variability which is due to large starspots (or starspot regions) which rotate into and out of the field of view. The period of variability is approximately the period of rotation of the spotted star. If the starspot region changes in longitude on the star, then the period of variability is not exactly the period of rotation; in fact, the latter cannot be determined from the former, in that case. In fact, the period of the variability may seem to change, depending on the distribution of spots during the time interval over which the period is determined. The amplitude of the rotational variability is also variable, as the size and possibly the temperature of the starspot region changes, and the relative phase of the rotational variability may vary as the starspot region migrates around the star.

These stars began to attract wide interest in the 1970's, not just because of their photometric variability, but also because of exotic properties which are reminiscent of solar activity but on a much grander scale—radio emission and flaring, thermal X-ray emission indicating temperatures of 10,000,000 K, and strong and variable emission lines. This extreme stellar "activity" is caused by the relatively rapid rotation of the active star which results (in most cases) from tidal interaction between the star and its companion; in some cases, these tidal interactions have "spun up" the rotation of the star and synchronized the rotation and the revolution (orbital) periods.

RS CVn stars are bright and interesting, and can be observed with a simple photoelectric photometer on a small telescope by amateur astronomers. This was one of the driving forces behind the growth of photoelectric photometry among amateur astronomers in the 1980's. Because of these developments, three RS CVn stars were placed in the AAVSO Photoelectric Photometry Program in the early 1980's. These stars are relatively easy to observe: they are bright; the colors are moderate, so it is easier to find comparison stars for them than for the extremely red stars in the program; and the stars are a subject of scientific interest. The AAVSO photoelectric photometry observations of these three stars are presented here for the first time. They are not sufficiently extensive to allow detailed studies of the stars, but they will supplement the data of other researchers, and they do illuminate the properties of RS CVn stars in general, and these three stars in particular. The data are available from: AAVSO, 25 Birch Street, Cambridge MA 02138-1205, USA; e-mail: aavso@aavso.org.

2. Observations

Observations, corrected for extinction, and transformed to the standard V system, were made and provided through the AAVSO photoelectric photometry program (Landis *et al.* 1992; Landis 1998). The comparison stars and their assumed magnitudes are given in the sections below. The standard deviation of the measurements was typically 0.008 magnitude, as judged from the constancy of the check stars. The following observers contributed the following numbers of measurements: Frank Dempsey (9), Brian Hakes (17), John Isles (11), Robert Johnsson (7), Paul Kneipp (1), George Kohl (13), Kenneth Luedeke (47), Phil Manker (3), Russell Milton (45), Harry Powell (1), Donald Pray (106), Mike Smith (1), Lee Snyder (6), Hans Sorensen (70), Nick Stoikidis (15), Raymond Thompson (24), Thomas Walker (4), Jim Wood (22).

Additional observations were obtained from the Epoch Photometry Database of the Hipparcos satellite (Perryman *et al.* 1997; see also the recent paper by Percy and Marinova (1999) in this Journal, which describes the special properties of the Hipparcos photometry when applied to studies such as this one). They were transformed to the standard V system using the equations given by Harmanec (1998) and the Hipparcos catalogue UBV colors, assumed to be constant. Any errors introduced by color uncertainties or variations are much smaller than the standard deviation.

3. HK Lac

HK Lac (HD 209813, K0III, V = 6.5) has a photometric period of about 24.4 days; see Oláh *et al.* (1997) for a recent review that presents a comprehensive spot-modelling analysis for "thirty years in the life of HK Lac." The star is also a spectroscopic binary with approximately the same period (Batten *et al.* 1989), so the orbital and rotation periods are the same—the rotation is tidally-locked to the orbit. According to Gorza and Heard (1971), the orbital ephemeris is:

$$\begin{array}{cc} 2440017.170 + & 24.4284\,E, \\ \pm 0.054 & \pm 0.0005 \end{array}$$

where the epoch is the time of periastron passage (the customary element used in spectroscopic binary studies). The star was observed relative to HD 208728 (K0, V = 6.78, comp) and HD 210731 (F8V, V = 7.39, check). There is slight evidence that the check star (relative to the comparison star) may have faded by 0.02 in V over the past 3000 days.

Figure 1 shows a V light curve of HK Lac, including both AAVSO photometry and transformed Hipparcos photometry. The two sources of data agree satisfactorily, showing that the transformation of the Hipparcos data was successful. The light curve shows changes in both mean magnitude and amplitude of the 24-day rotational variability. A naive approach would be to say that, when there are fewer spot regions (beginning and end of the dataset), the mean magnitude is brighter, and the amplitude of the rotational variability is smaller, but see Henry *et al.* (1995) for a more sophisticated discussion. The V amplitude varies, from about 0.20 in the first three years, to 0.25 in the second three years, to 0.10 in the third three years.

It is possible to construct phase curves of portions of the data, to determine the amplitude and phase of the rotational variability at various epochs. Unfortunately the data are rather sparse. To get enough data points to plot a curve, we need to use a long time interval, but then there is "phase smearing" because the area and distribution of spots may change during the interval. For HK Lac and λ And, we were able to divide the data into the segments indicated in Tables 1 and 2, respectively, as a compromise. In Figure 2, we plot a phase curve of HK Lac for the most recent data: after JD 2449200. The period used is 25.80 days, and the epoch is that of the first observation: JD 2446683.5603. For all three stars, the phases can easily be transformed to a different epoch, using the assumed period. The variability at earlier times has been studied by others—Oláh *et al.* (1997) for instance. Note that the amplitude is small—perhaps 0.06 magnitude—and the mean V magnitude is about 6.82. The scatter of about 0.01 is mostly instrumental, but some of it may be due to changes in the area and distribution of spots during the interval. Table 1 gives a detailed summary of the magnitudes and phases of maximum and minimum; the phases are determined in each case from the period (25.80 days) and epoch (JD 2446683.5603) given above. These properties of the light curve change substantially with time, as Oláh *et al.* (1997) have described in detail. The changes in phase would produce significant changes in the apparent period of the variability of the star.

4. SZ Psc

SZ Psc (HD 219113, F8 + K1, V = 7.24) has a photometric period of about 3.966 days; see Kalimeris *et al.* (1995) for a recent article. It is an eclipsing spectroscopic system (Batten *et al.* 1989) with an orbital period of 3.9653 days. It was observed relative to HD 219018 (G1V, V = 7.72, comp) and HD 219114 (F0V, V = 7.3, check).

Figure 3 shows a phase curve for SZ Psc, using the AAVSO photoelectric photometry and the transformed Hipparcos data. The agreement between the two datasets is satisfactory. The period (adopted from the *General Catalogue of Variable Stars* (Kholopov *et al.* 1985)) is 3.96579 days, and the epoch is that of the first observation: JD2446687.5585. Since the measurements were made randomly in phase, only a few occur at (eclipse) minimum, but those tend to occur at the same phase (0.83 for primary minimum, 0.32 for secondary minimum), which indicates that there has been no large change in the orbital period during the interval of the data. There is significant scatter outside of eclipse, indicating that there are changes in the area and distribution of the spots, but our sparse data are not well suited for studying these changes.

5. λ And

λ And (HR 8961, HD 222107, G8III-IV, V = 3.82) has a photometric period of about 54 days, so it belongs to the "long-period group"; see Donati *et al.* (1995) for a recent article. It is also a spectroscopic binary with an orbital period of 20.5212 days (Batten *et al.* 1989), so the rotation and revolution are not synchronous. It was observed relative to HR 8964 (HD 222143, G5IV, V = 6.58, comp) and HD 222516 (F5V, V = 6.97, check).

Figure 4 shows a V light curve for λ And, using both AAVSO photoelectric photometry and transformed Hipparcos photometry. The agreement between the two sets of data is satisfactory. There are obvious changes in the amplitude of the 54-day rotational variability, represented by the vertical scatter in the light curve; it is about 0.15 magnitude between JD 2446600 and 2447600, about 0.22 between JD 2447600 and 2449000, about 0.18 between JD 2449000 and 2449500, and possibly a bit larger thereafter (the data are sparse). The changes in mean magnitude tend to be smaller than this, and there is no strong correlation between the mean magnitude and the amplitude of the rotational variability.

Figure 5 shows a phase curve for the most recent data—after JD 2449250. The period used is 54.33 days (the period depends on the latitude of the spot regions (Donati *et al.* 1995)), and the epoch is that of the first observation: JD 2446674.7624. The behavior of the star before that date has been studied by others. There is some phase smearing in Figure 5, especially at minimum. This is to be expected if the area and/or distribution of the spots changes during this time. Table 2 gives a detailed summary of the magnitudes and phases of maximum and minimum, determined in each case using the period (54.33 days) and epoch (JD 2446674.7624) given above. The fact that these properties of the light curve do not change greatly with time suggests that the period of 54.33 days represents the light curve quite well.

6. Discussion

These three stars have now been removed from the AAVSO photoelectric program. They require frequent and extensive monitoring, and we believe that others are doing this work. The AAVSO observations are interesting in their own right, and are now available for others to use. The possibility of combining normal V photometry with transformed Hipparcos photometry has been demonstrated in this paper. The recent behavior of these three RS CVn stars has been noted. From time to time, photometric observations of selected RS CVn stars may be required. These will be solicited by AAVSO Headquarters in the usual way.

7. Acknowledgements

Devi Soondarsingh and Vince Velocci were participants in the University of Toronto Mentorship Program, which enables outstanding senior high school students to work on research projects at the university. We thank the observers who have gathered the data for these stars over the years, and we thank the AAVSO HQ staff for their support. We especially thank Howard J. Landis, the Archivist for the AAVSO photoelectric photometry program, for his help and support.

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Table 1. Magnitudes and Phases of Maximum and Minimum for HK Lac.

JD	V(max)	V(min)	V(mean)	Phase(max)	Phase(min)
2446683–2447424	6.75	7.06	6.91	0.69	0.72
2447448–2447952	6.84	7.09	6.97	0.93	0.62
2447953–2448068	6.87	6.97	6.92	0.18	0.55
2448069–2448170	6.85	7.11	6.98	0.63	0.01
2448171–2448290	6.84	7.14	6.99	0.26	0.87
2448310–2448443	6.87	7.07	6.97	0.04	0.61
2448464–2448605	6.87	7.07	6.97	0.54	0.08
2448629–2448755	6.88	7.02	6.95	0.42	0.65
2448782–2449020	6.77	6.95	6.86	0.68	0.37
2449021–2449857	6.77	6.90	6.84	0.23	0.36

Table 2. Magnitudes and Phases of Maximum and Minimum for λ And.

JD	V(max)	V(min)	V(mean)	Phase(max)	Phase(min)
2446675–2447085	3.75	3.93	3.84	0.83, 0.07	0.78
2447086–2447458	3.78	3.90	3.84	0.48, 0.43	0.75
2447464–2447962	3.74	3.95	3.85	0.32	0.70
2447963–2448285	3.76	3.97	3.87	0.30	0.75
2448286–2448561	3.75	3.98	3.86	0.23	0.72
2448562–2448581	3.80	3.92	3.86	0.06	0.77
2448585–2448698	3.73	3.94	3.83	0.25	0.78
2448699–2448701	3.74	3.77	3.76	0.25	0.29
2448702–2449249	3.76	3.95	3.86	0.30	0.64
2449250–2449980	3.78	4.01	3.90	0.17	0.50

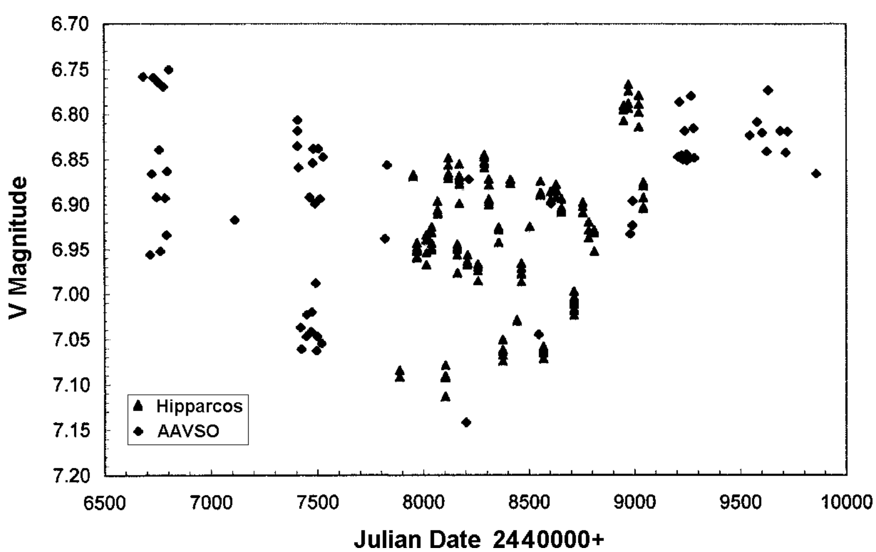

Figure 1. V light curve of HK Lac, including AAVSO photoelectric photometry (diamonds) and transformed Hipparcos photometry (triangles).

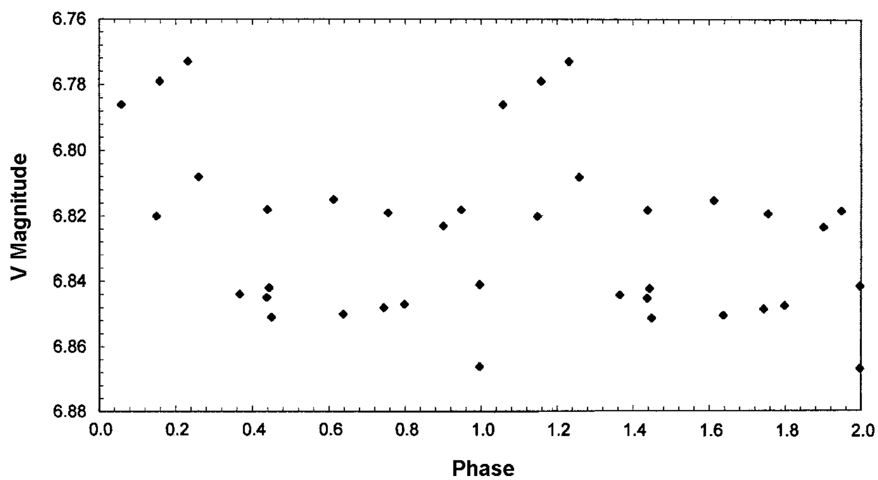

Figure 2. V phase curve of HK Lac, using the data in Figure 1 after JD 2449200, a period of 25.80 days, and an epoch of JD 2446683.5603.

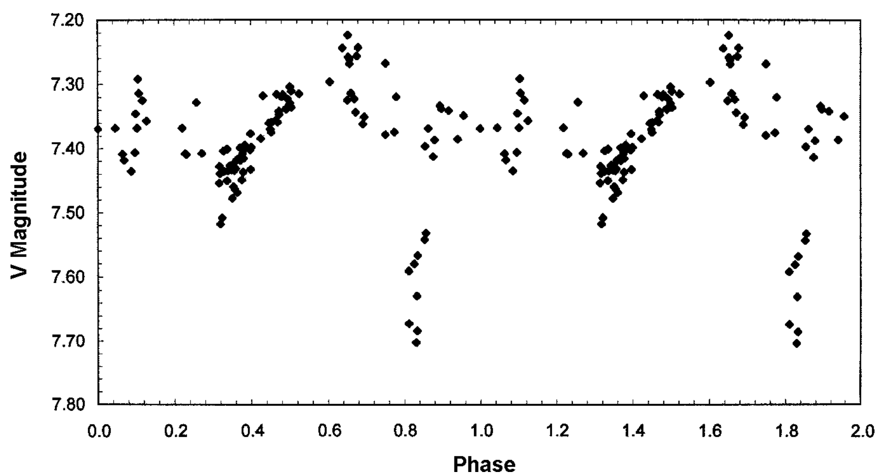

Figure 3. V phase curve of SZ Psc, including AAVSO photoelectric photometry and transformed Hipparcos photometry, a period of 3.96579 days, and an epoch of JD 2446687.5585.

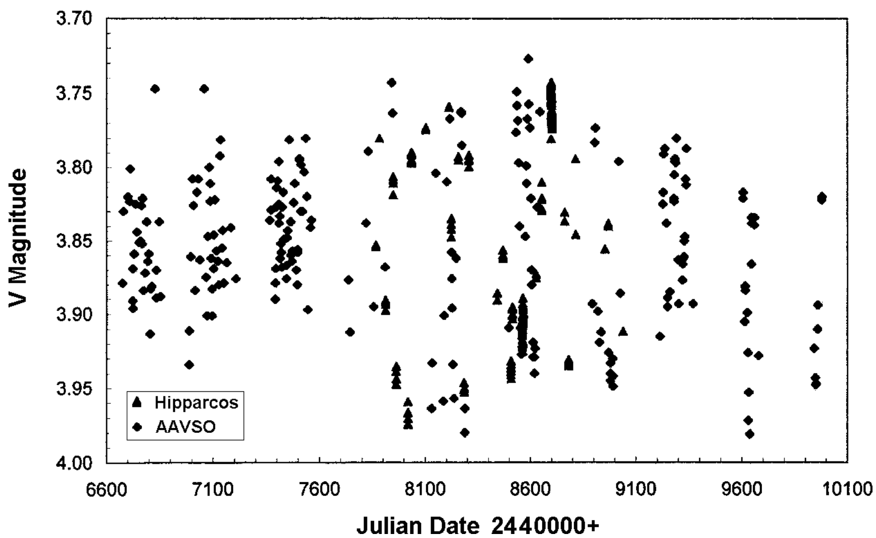

Figure 4. V light curve of λ And, including AAVSO photoelectric photometry (diamonds) and transformed Hipparcos photometry (triangles).

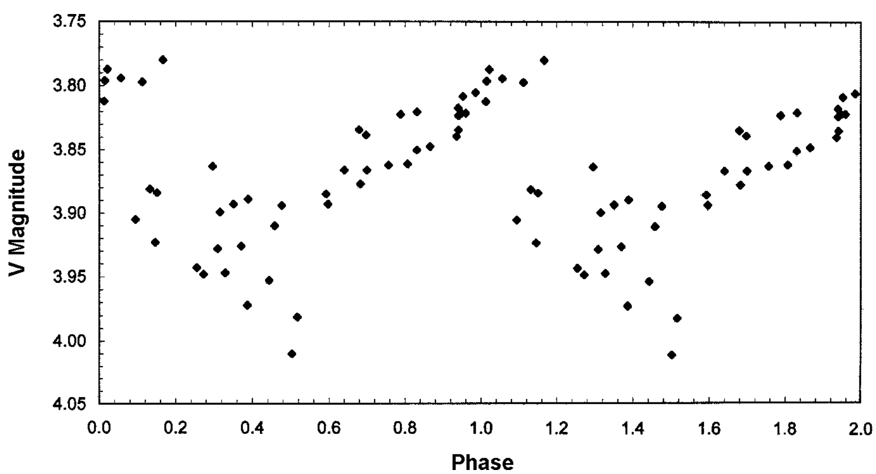

Figure 5. V phase curve of λ And, using the data in Figure 4 after JD 2449250, a period of 54.33 days, and an epoch of JD 2446674.7624.