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The Recent Period Evolution of the RRc stars HY Com, RU Psc and AP Ser

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Abstract

The first overtone RR Lyrae stars HY Com, RU Psc and AP Ser have shown frequent sudden period changes in recent years, as calculated from NSVS and ASAS-3 data.

1 Introduction

The RRc stars, RR Lyrae stars pulsating in the radial first overtone mode, have been known to show irregular period changes (see e.g. Jurcsik et al., 2001). Rathbun & Smith (1997) found very few RRc stars with large period changes in globular clusters, in contrast to RRab stars. Some Galactic RRc stars have been found to undergo sudden period changes. Since there is good coverage for some of these in the Northern Sky Variability Survey (NSVS; Woźniak et al., 2004) and the All Sky Automated Survey (ASAS-3; Pojmański et al., 2005), their data can be used to study the recent period history of these stars.

A notable example of an RRc star showing sudden period changes is HY Com (Oja, 1981, 1995). The available ASAS-3 data from 2002 to 2006 are plotted in Fig. 1. The period derived from the 2002–2003 observing season was used for the phase plot in the top left panel. It is clear that this period also reasonably fits the second observing season, but not the later data. To explain the phase diagram the period must have changed at the end of the second observing season. This change must have been quite abrupt as well (significantly less than an observing season) as the period fits two observing seasons, but fails completely for a third. For practical purposes this change in period will be regarded as instantaneous for the remainder of this paper. As will be seen further, the period found for the third season will not fit the data from the final season either, so that another period change must be assumed between these two seasons.

In the following section, a method to model these abrupt period changes is outlined, and then applied to the observations of HY Com. Two other stars, RU Psc and AP Ser, also showing frequent period changes, will be treated as well.

2 Calculation procedure

The procedure used by Wils et al. (2007) to calculate the epoch and magnitude of a sudden period change was extended to allow for multiple changes. Epochs t_1, ..., t_n are chosen at which an instantaneous period change is assumed, as well as parameters q_1, ..., q_n representing the fractional frequency change with respect to the base frequency at those epochs. The times of observation t are then transformed to a time t' which for $t_i < t \leq t_{i+1}$ is given by $T_i(t) = T_{i-1}(t) + q_i(t - t_i)$, for i in 1, ..., n and with $T_0(t) = t$.

The value of t_{n+1} is fixed as the time of the last observation. This procedure essentially stretches or contracts the time between period changes so that a single period can be used that is valid over the entire observation interval. The method further assumes that the shape of the light curve does not change, and that there were no phase shifts. With these modified times t' one can then proceed as before: in order to find the best values for the $2n$ parameters t_i and q_i, the sum of the squared residuals from the best fit Fourier series with two harmonics is minimized by using the downhill simplex minimization method (Nelder & Mead, 1965).

3 HY Com

The results of the procedure outlined in the previous section applied to the ASAS-3 data for HY Com are shown in Fig. 1. The top right panel shows the phase plot with a single period change near the end of the 2003–2004 season (the data for the final season were not used in the calculation for this specific case). The bottom panel shows the phase plot with two period changes using all the ASAS-3 data for the calculations.

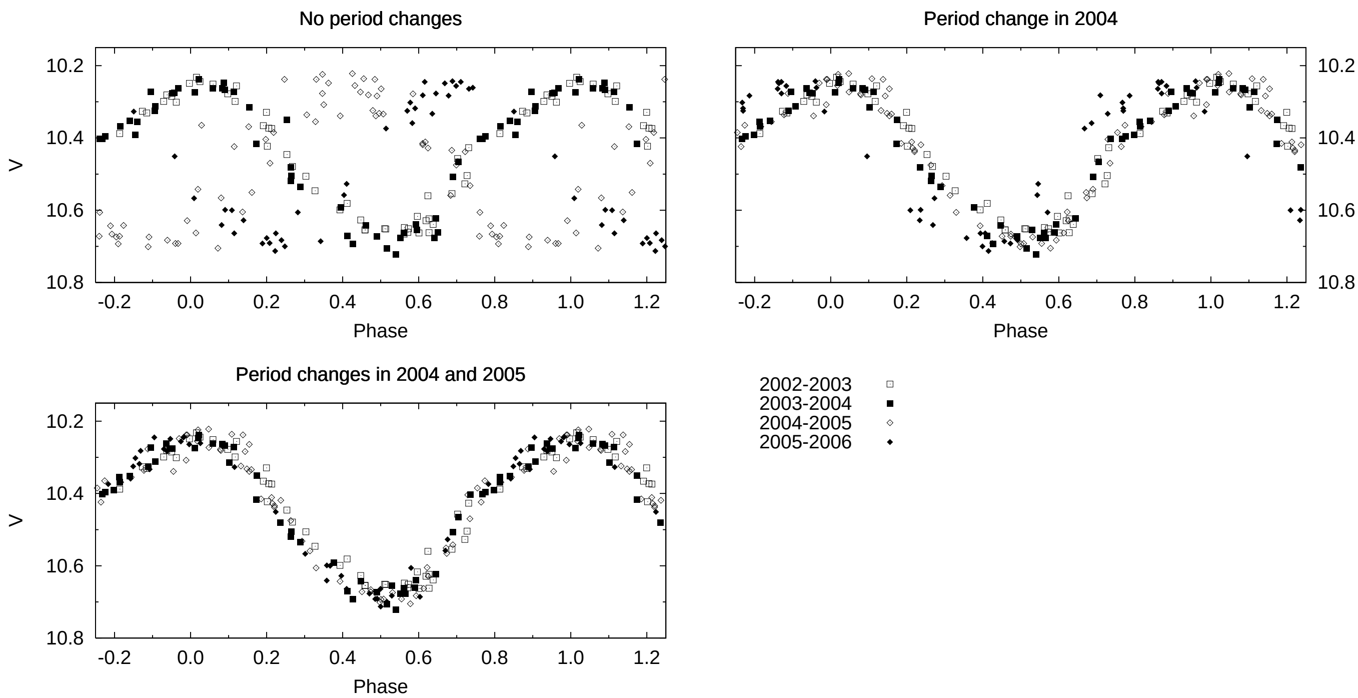

Figure 1. Phase plots of HY Com with ASAS-3 data constructed using the procedure described in the text. The top left panel is a phase plot without period changes, the top right panel has an abrupt period change in 2004, and the bottom panel has an additional period change in 2005. Details for the periods before and after the changes are given in Table 1.

The calculations were then extended to include the data from NSVS. The red sensitive NSVS data were adjusted in time by applying the heliocentric correction and in magnitude by applying a shift to align them with the average ASAS-3 V magnitude. This revealed another abrupt period change between the NSVS and ASAS-3 data sets. Because of the long gap in data between the NSVS data and the data from Oja (1995) and from Hipparcos (ESA, 1997), no attempt was undertaken to extend the calculations further in the past. At least the Oja data for the years 1994 and 1995 do agree with the earliest

Table 1: Calculated abrupt period changes for HY Com

Year	Change (s)	HJD – 2400000	New Period (d)
–	–	48762.653	0.448615
2001.39	–14	52050.550	0.448447
2004.32	+21	53123.685	0.448694
2005.66	–11	53611.415	0.448564

derived period. Koen (2001) suggested the Blazhko effect with a period of 2 years to explain the behaviour of HY Com from the Hipparcos data. This is however not possible with the data available now.

Figure 2 gives the final phase plot including all the data from 1994 to 2006 and taking into account three instantaneous period changes. Table 1 lists their details: the time at which they occurred (given as a year including decimals), the sign and magnitude in seconds, a time of maximum useful in an ephemeris, and the new period in days. The first line in the table gives an initial ephemeris to be used before the first calculated period change.

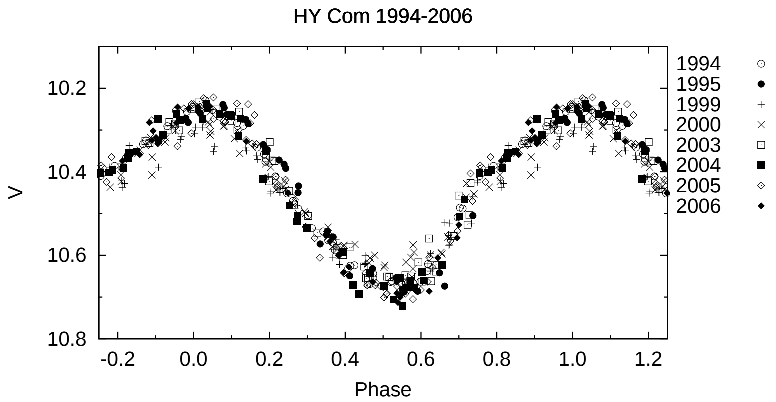

Figure 2. Phase plot of HY Com using all available data and the three period changes from Table 1.

Unfortunately the method used does not allow to easily estimate formal uncertainties on the final results. By changing some of the calculated values and viewing the impact on the phase plot, the precision is likely to be of the order of 10–50 days on the epochs, and a few seconds on the value of the change.

Figure 3 shows the recent period evolution of HY Com on an $O-C$ plot using a single constant period. The available times of maximum in this plot from Hübscher (2007) and the TAROT instrument (Bringer et al., 1999; maxima extracted from the GEOS RR Lyrae database at http://dbRR.ast.obs-mip.fr, Le Borgne et al., 2006) were supplemented, for those years with enough data, with normal maxima determined from the data sources also used above. This was done by fitting a model curve based on the ASAS-3 data from 2003 to the observations. Uncertainties on the maxima timings were plotted when available. For the normal maxima an uncertainty of $0\overset{d}{.}01$ was assumed. In view of the two most recent maxima (from TAROT and Hübscher, 2007) in Fig. 3, which date from after the

Table 2: Calculated abrupt period changes for RU Psc

Year	Change (s)	HJD – 2400000	New Period (d)
–	–	51486.610	0.390251
2003.58	+23	52853.659	0.390513
2004.02	–20	53011.816	0.390279

currently available ASAS-3 data, it is likely that the period has increased again, less than a year after the last abrupt change.

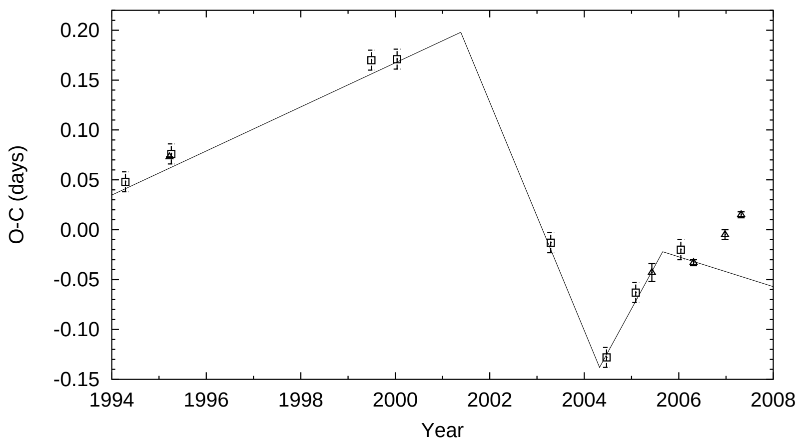

Figure 3. $O-C$ plot of HY Com showing the evolution of the period as given in Table 1. Maxima timings from the literature are given as triangles, normal maxima as squares.

4 RU Psc

RU Psc is another RRc star that has been known to undergo abrupt period changes (Mendes de Oliveira & Nemec, 1988). The recent data on RU Psc from the NSVS and ASAS-3 surveys show two abrupt period changes, separated by only half a year, detailed in Table 2. Both occurred during the time of the ASAS-3 observations. Unfortunately not as many observations are available so that the calculated data are less reliable. For instance, only three data points were available for 2006, and these do not agree with the phase plot in Fig. 4 assuming the two period changes. Therefore a third period change cannot be excluded. This is further confirmed by recent maxima timings from the GEOS RR Lyrae database, as can be seen in the $O-C$ plot in Fig. 5. Although the NSVS data from 1999 seem to fit the period from the earliest ASAS-3 period (until mid 2003), two maxima reported by Agerer & Hübscher (2002) likely indicate two more period changes between 1999 and 2002.

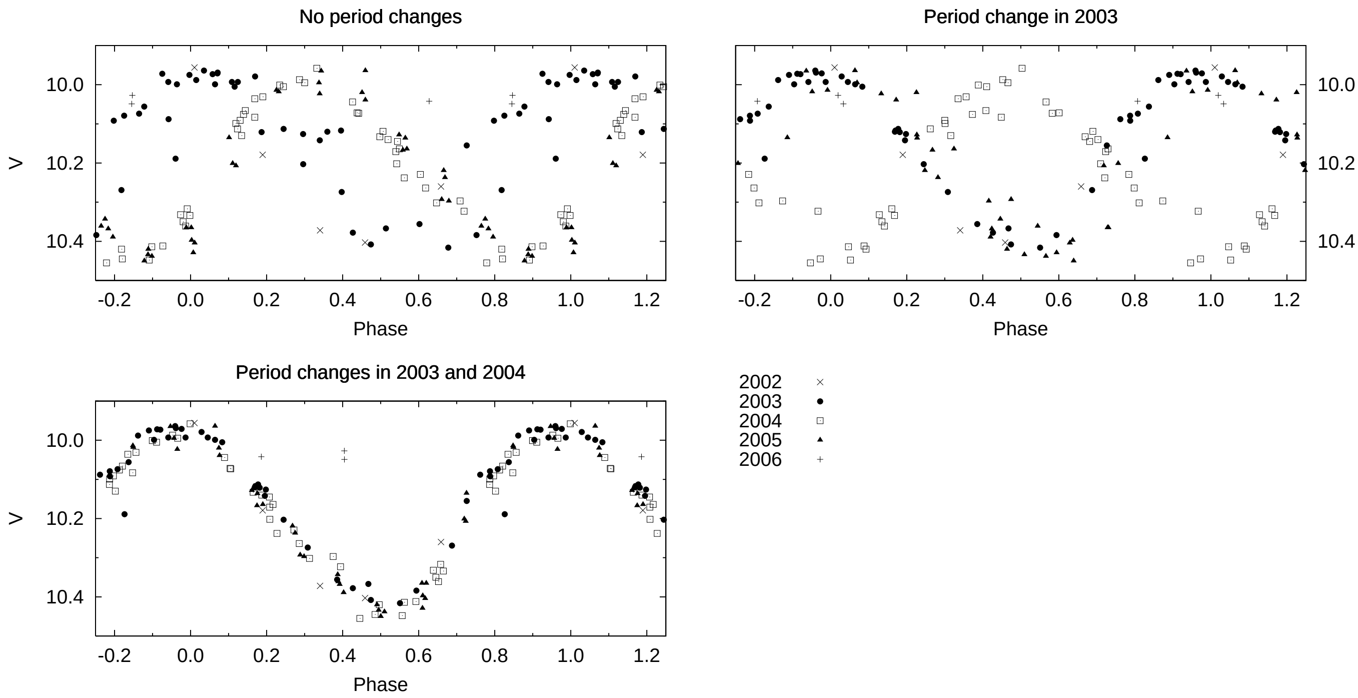

Figure 4. Phase plot of RU Psc using data from ASAS-3. The upper left panel plots all data with a single period of 0.^{d}390251. The upper right panel assumes a period change in 2003. The lower panel takes into account the two period changes given in Table 2.

Table 3: Calculated abrupt period changes for AP Ser

Year	Change (s)	HJD – 2400000	New Period (d)
–	–	51322.722	0.340805
2000.17	+3	51606.607	0.340838
2004.26	+8	53099.479	0.340926
2005.75	–15	53645.643	0.340758

5 AP Ser

The RRc star AP Ser has a known history of period changes as well (Peña et al., 1990 and Blättler, 2000). Because of the large gaps with earlier data sets, only the NSVS and ASAS-3 data will be considered here. Using the method of section 2, three sudden period changes can be found, with one period change during the NSVS observation era and two during that of ASAS-3. These are listed in Table 3. Phase plots are provided in Fig. 6. Since very few recent maxima timings of AP Ser are available, an $O-C$ plot is not given.

6 Discussion

It would be very difficult to obtain the above results with the traditional $O-C$ method of investigating period changes. Deviations from a straight line might be attributed to period noise (Sterne, 1934). This is due in part to the fact that maxima for an RRc variable are broad. The uncertainty in determining their exact time, which is often underestimated,

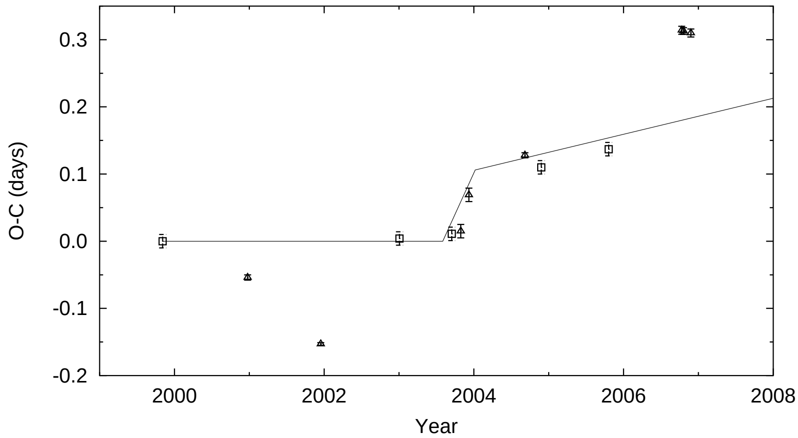

Figure 5. $O-C$ plot of RU Psc showing the evolution of the period as given in Table 2. Maxima timings from the GEOS RR Lyrae database are given as triangles, normal maxima derived from survey data as squares.

may thus hide small changes in the period. The main reason is however that the period changes in HY Com, RU Psc and AP Ser are frequent and with a limited number of maxima timings in between changes it would be hard to obtain a reliable period. This is especially so if these maxima times are determined from survey data such as from NSVS and ASAS-3, because there will not be enough data available to accurately calculate two times of maximum between period changes. Essentially, good coverage of the star in phase as well as in time is needed.

It is interesting to note that the values of the period changes in Tables 1 to 3 are of the same order (although they are not exactly the same) and that subsequent period changes have opposite signs in almost all cases. Such a behaviour can be explained by discrete mixing events in the semiconvective zone inside the star, as proposed by Sweigart and Renzini (1979). The magnitude of the observed changes, $|\Delta P|/P$ of the order of $6 \cdot 10^{-4}$ on average, is consistent with their theoretical models. However the observed time scale between changes is not. Sweigart and Renzini found an average time scale of a few centuries overall, and specifically of about a century when the star is near the end of its core helium burning phase, whilst the RRc stars discussed in this paper appear to show abrupt period changes once every few years. Belserene (1978) already noted that the observed time scale between these events for the RRab star IV Cyg is much shorter as well. Sweigart and Renzini indicated however that the observed quantities likely depend significantly on the model parameters, while they only studied a limited number of models in detail.

Clearly further theoretical investigation is necessary to fully explain the observed behaviour of the three RRc stars above, and possible other stars of the type. Also in order to be sure of the real timescale in which these period changes take place, regular, almost continuous monitoring of the full light curve of these stars is necessary.

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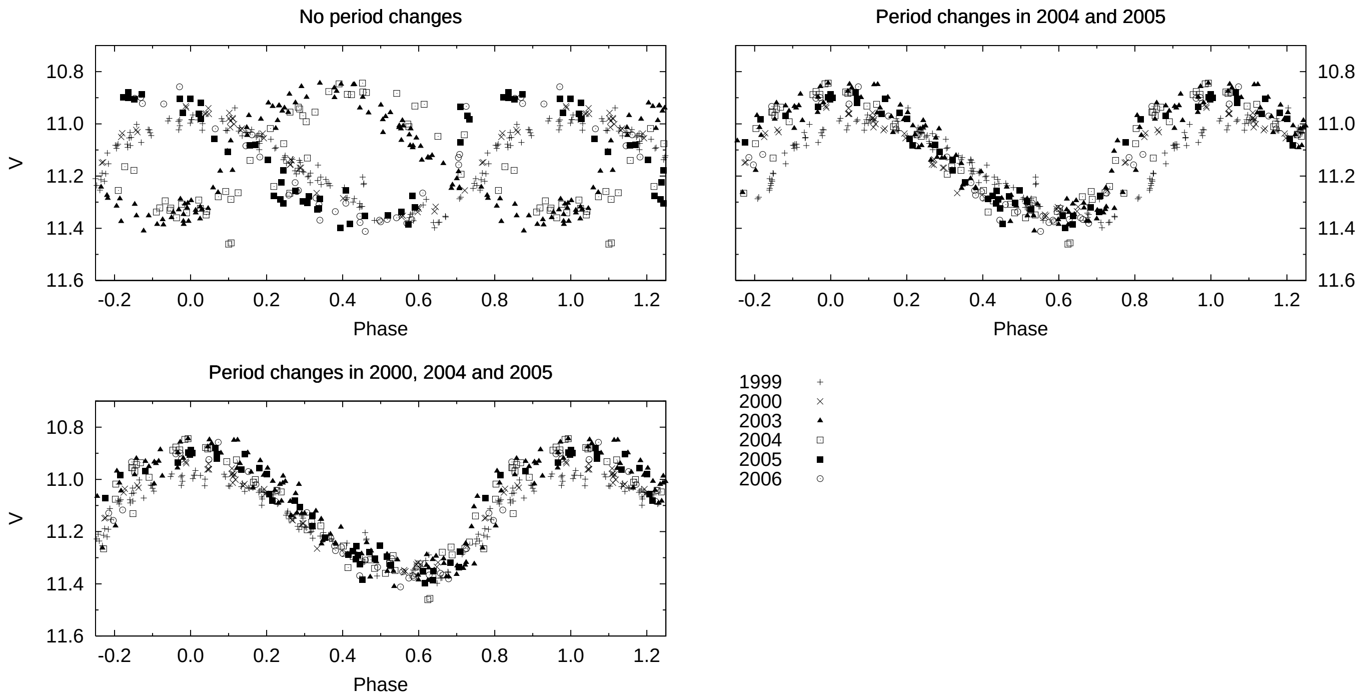

Figure 6. Phase plot of AP Ser using data from NSVS (unadjusted red magnitudes) and ASAS-3. The top left panel plots all data with a single period of $0\overset{\mathrm{d}}{.}340805$. The top right panel assumes period changes in 2004 and 2005. The bottom panel takes into account the three period changes given in Table 3.

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