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LETTER

Letter to the Editor

Permanent active longitudes and activity cycles on RS CVn stars

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Abstract. A new analysis of the published long-term photometric observations has revealed permanent active-longitude structures in four RS CVn stars: EI Eri, II Peg, σ Gem, and HR 7275. Two active longitudes separated by half of the period are found to dominate on the surface during all available seasons. The positions of the longitudes on three stars (EI Eri, II Peg, HR 7275) are migrating in the orbital reference frame, and there is no preferred orientation with respect to the line of centres in the binaries. The rate of migration is approximately constant. In case of σ Gem the active longitude migration is synchronized with the orbital motion in the direction of the line of centres in the binary. The active region lifetimes can be longer than the time span of the observations ($\geq$15 yr). The periods of the active longitude rotation are determined: for EI Eri $1\overset{d}{.}9510$, for II Peg $6\overset{d}{.}7066$, for σ Gem $19\overset{d}{.}604$, for HR 7275 $28\overset{d}{.}263$. Long-term activity cycles of the stars are discovered from the analysis of the relative contribution of the two longitudes to the photometric variability. One longitude is found to be usually more active than the other at a given moment, and the change of the activity level between the longitudes is cyclic with periods of years. The switch of the activity takes a much shorter time, about a few months, similar to the "flip-flop" phenomenon found for FK Com stars. Moments of switching are regarded as new tracers of the activity, and total cycles, which return activity to the same longitude, are found to be for EI Eri 9.0 yr, for II Peg 9.3 yr, for σ Gem 14.9 yr, for HR 7275 17.5 yr.

Key words: stars: activity – starspots – stars: late-type – stars: individual: II Peg, EI Eri, σ Gem, HR 7275

1. Introduction

Since the late sixties, when large cool spots were found on late-type active stars, and the seventies, when the reality of these spots was established, many questions still remain concerning the nature and evolution of these spots, as well as their lifetimes, activity cycles, latitude extent and correlation with other signatures of activity. Questions regarding active binaries with spotted components of the RS CVn type have been widely reviewed e.g. by Hall (1996). Analysis of long-term photometric observations of RS CVn stars using the few-spot approximation has established the following facts: (1) lifetimes of relatively small spots are proportional to their sizes, while lifetimes of relatively large spots are probably determined by the surface differential rotation; (2) the magnitude of the differential rotation is proportional to the period of the stellar rotation, and it decreases for shorter rotation periods; (3) there should exist long-term activity cycles similar to the solar 11-year sunspot or 22-year magnetic cycles, though cycle tracers are still under discussion. Active-longitude structures have been reported on some RS CVn stars (e.g. Henry et al. 1995, Jetsu 1996). However, the discussion is not completed yet because of some contradictory results and a few non-consistent assumptions (see the discussion by Hall 1996).

Obviously, the long time span of photometric observations makes them attractive for searching long-lived active-longitude structures on spotted stars. Extensive photometric data have been used for spot modelling by Strassmeier (1990), Strassmeier et al. (1994) and Henry et al. (1995). In the present paper we used these observations for searching active longitudes on four RS CVn stars. However, we prefer to use the original light curves published in these papers. It is natural to suggest that the deepest minimum in the light curve is caused by the largest active region on the stellar surface consisting probably of a group of spots. The secondary minimum, if present, should correspond to another, smaller active region. Then, tracing the minima in time could provide information on migration of the active regions with no assumptions on their structures, shapes, areas, temperatures, and latitudes. Such an approach has been applied e.g. to data of FK Com by Jetsu et al. (1991) and revealed two active longitudes on its surface. One must note, that the technique of surface (Doppler) imaging, which has been applied to many RS CVn stars for the last decade, can be used for the same purpose, but the available time base of surface images for a particular star is short.

Recently, we obtained new surface images of one of the most active RS CVn star II Peg (Berdyugina et al. 1998b). We found that two high-latitude active regions were dominant on the stellar surface in 1992-1996, which were interpreted as two long-lived migrating active longitudes. The period of the longitude rotation deduced from the images well coincides with the

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Table 1. Orbital parameters and active longitudes

Star	Orbital parameters		Active longitudes		
	Epoch (JD)	$P_{\rm orb}$ (days)	$P_{\rm spot}$ (days)	Separation (phase)	Cycle (years)
EI Eri	2446091.5388[a]	1.947227[a]	1.9510±0.0005	0.51±0.05	9.0
II Peg	2449582.9268[b]	6.724333[b]	6.7066±0.0004	0.52±0.07	9.3
σ Gem	2447237.02[c]	19.604471[c]	19.604±0.003	0.52±0.08	14.9
HR 7275	2442493.509[d]	28.5895[d]	28.263±0.012	0.53±0.11	17.5

[a] Strassmeier (1990);
[b] Berdyugina et al. (1998a);
[c] Duemmler et al. (1997);
[d] Eker (1989).

mean photometric period determined from the two-spot photometric curve modelling by Henry et al. (1995) for 1976-1992. Then, we found that spots in the earliest images well follow the latest photometric spots, and active regions can exist more than 6 years. Taking into account the results on II Peg, we decided to reanalyse all available long-term photometric observations for some RS CVn stars. Here, we report our first results for four stars of different periods of rotation: EI Eri ($1^{\rm d}.95$), II Peg ($6^{\rm d}.71$), σ Gem ($19^{\rm d}.6$), and HR 7275 ($28^{\rm d}.3$).

2. Data and results

The photometric data used for each star are referred to below in the individual paragraphs. Light curve minima are considered as caused by the presence of active regions on the stellar surfaces. Phases of light curve minima were calculated in the orbital reference frame and plotted versus time of observations in Julian dates (Fig. 1). The uncertainties of phase determination were less than ±0.1 for primary minima and within ±0.15 for secondary minima. The orbital parameters of the stars used are given in Table 1. The zero epoch (phase=0) always corresponds to the conjunction when the primary component is behind the secondary. The observed minimum phases of all studied stars are well arranged in two *permanent* strips with approximately the same slope, which can be naturally interpreted as two long-lived active longitudes. Recently, a similar permanent structure was found on the FK Com star HD 199178 (Jetsu et al. 1998). The slope of the strips in Fig. 1 is determined by the difference between the orbital and spot rotation periods. Small variations from the linear slope are probably caused by either errors in phase or real internal spot migration within active regions. Note that active regions exist during the whole time spans, and, therefore, their lifetimes can be more than fifteen years. As the deepest minima (largest active regions) are marked by filled symbols in Fig. 1, one of the longitudes is seen to be usually more active than the other, and its domination continues for several years. The switch of the activity between the longitudes happens within much shorter time scale, namely within a few months. A similar phenomenon, called “flip-flop”, has been found for FK Com (Jetsu et al. 1991), which is an extremely rapidly rotating single late-type giant. The switch of the activity between the longitudes on II Peg and EI Eri (Fig. 1) is repeated after the same time interval and, therefore, seems to be periodic. The other two stars are suggested to show a similar behaviour. Thus, the spot area and/or temperature within one active longitude appears to be changing periodically. The total cycle of the activity, when the domination returns to the same longitude, is determined by the moments of switching, and these can be regarded as new tracers of the activity cycles of spotted stars. The periods determined are given in Table 1, and the results for each star are considered in the following short discussion.

EI Eri. Photometric observations for 1980-1988 and 1989-1996, which we used for the new analysis, are from Strassmeier (1990) and Strassmeier et al. (1997), respectively. The light-curve shape of the star is known to be rapidly changing, even within a few consecutive stellar rotations. Seasonal photometric periods were found to be variable within $1^{\rm d}.93$–$1^{\rm d}.95$, while the average value for 1980-1996 is $1^{\rm d}.952717 \pm 0^{\rm d}.000031$ (Strassmeier et al. 1997). The star has been studied with different surface imaging techniques by Strassmeier et al. (1991) and Hatzes & Vogt (1992), which revealed either a cool polar spot with appendages or high-latitude spots as causes of the light-curve variability. The positions of the polar appendages well fit the two-longitude structure on the star (Fig. 1). The determined period of the spot rotation (Table 1) is slightly longer than the orbital period and well coincides with the average photometric period. Switching of the activity between the active longitude was observed three times during about 16 years. Thus, the total cycle length of 9.0 yr is determined.

II Peg. Photometric observations for 1974-1992 are from Henry et al. (1995). They made two-spot modelling of the light curves and identified twelve spots on the stellar surface with lifetimes ranging from a few months to 6 years. Periods of their rotation have been found in the range of $6^{\rm d}.6890$–$6^{\rm d}.7446$. The average value of the period is $6^{\rm d}.7158$. They found also (i) two active longitudes with fixed orbital location and separation of 0.43 and widths of about 0.2 in phase and (ii) possible cyclic variations of the mean and maximum magnitudes in V-band with periods of 4.4±0.2 and 11±2 years. Jetsu (1996) used the results of the modeling and found one active longitude with a period of $6^{\rm d}.7194$. In our analysis, in addition to the data of Henry et al., we used our new results of surface imaging of the star for 1992-

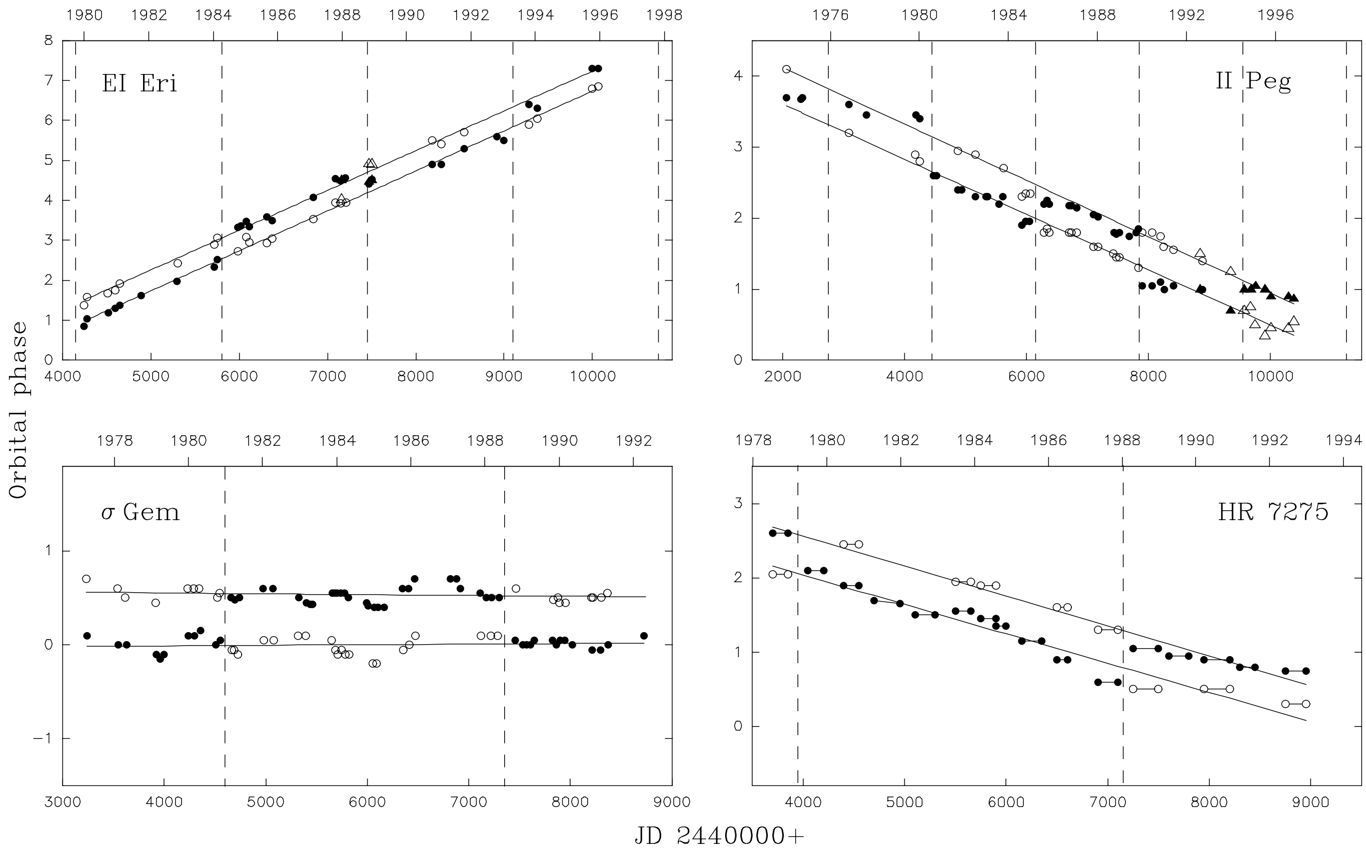

Fig. 1. Phases of light curve minima of EI Eri, II Peg, σ Gem, and HR 7275 in the orbital reference frame plotted versus mean epoch of the observing run (Julian dates). Primary minima (larger active regions) are marked by filled symbols, while secondary minima (smaller active regions) are shown by open symbols. Circles are the photometric observations, and triangles are the results of surface imaging of EI Eri and II Peg. For HR 7275 phases of minima are given vs. first and last observation dates in a given light curve (connected by short lines). The continuous lines are linear fits to the active longitudes, and the dashed lines denote the switching moments of the active longitudes with half of the cycle lengths from Table 1.

1996 (Berdyugina et al. 1998b). From the images we found two migrating active longitudes with a separation of about 0.5 in phase. The period of the spot rotation of $6^{\rm d}.7095\pm0^{\rm d}.0013$ has been determined from the images. The present result confirms the active longitudes and period but with higher accuracy (Table 1). Five events of switching of the activity between the active longitudes were observed during 23 years. The cycle of 9.3 yr is found from the switching moments, and it is close to one of the value found by Henry et al. from the magnitude variations.

σ **Gem.** Photometric observations for 1977-1992 were compiled by Henry et al. (1995). With two-spot modeling they have identified 16 spots on the surface with lifetimes ranging from a few months to 4.6 years. Periods of their rotation have been found to be both longer and shorter than $P_{\rm orb}$, in the range of $19^{\rm d}.21$–$19^{\rm d}.94$. They noticed also that major long-lived spots spent most of their lives near the two conjunctions. The separation of 0.47 and widths of 0.2 in phase have been determined for active longitudes. Jetsu (1996) confirmed this result using the same data. Switches of the activity are seen very clearly near 1981 and 1988.4 in Fig. 1. The total activity cycle can be estimated to 14.9 years, which is almost twice the cycle found by Henry et al. from the V-magnitude variations.

HR 7275. Photometric observations for 1978-1993 are from Strassmeier et al. (1994). For light curve modelling they used up to five circular spots including a polar cap. Using the mean rotational period of the star of $28^{\rm d}.3$, they identified twenty spots with lifetimes from 1 to 4.5 years. They did not reveal any homogeneous long-term trend, or periodicity, in the spot behaviour. In the available data the total activity cycle is not observed, but its length can be estimated to 17.5 years from two switching times.

3. Discussion and conclusions

From the results obtained for four RS CVn stars the following common conclusions can be drawn.

Spot lifetimes. Active regions determining active longitudes exist permanently, though their areas and/or temperature are periodically changing. Then, the relations for spot lifetimes should be revised. Lifetimes of active regions of many years should give new constraints for the global magnetic field models for this type of stars.

Active longitude orientation. In three cases out of four, active longitudes have no preferable orientation with respect to the line of centres in the binary. In other words, they are not synchronized with the orbital motion. However, in the case of σ Gem they are synchronized, and located in the line of centres of the binary. Nevertheless, this problem should be studied with other stars from the point of view of the present results.

Activity cycles. All stars show similar behaviour: one longitude is usually more active than the other, and the changing of the activity between the longitudes is cyclic with periods of years. Switch of the activity happens on a much shorter time scale, during a few months. Periodical repetition of the switches allows to consider them as new tracers of the activity cycles of the spotted stars. The cyclic activity discovered seems to be basically different from that in the Sun, since the structure is strongly nonaxisymmetric. Also, the almost linear phase migration of the active regions suggests a very small, if at all, latitude motion of the spots. Although photometry gives no information about magnetic polarity, one can suppose that switching moments correspond to changing polarity of the magnetic field in the active regions and, probably, special symmetric redistribution of the spots on the stellar surface.

Magnetic dynamo models. By analogy with sunspots, active regions on the surfaces of RS CVn stars may be accociated with magnetic field structures, generated by a dynamo operating in the convective envelopes. Simplified theoretical calculations by Moss & Tuominen (1997) showed that synchronized close late-type binaries can be expected to exhibit large-scale nonaxisymmetric magnetic fields with maxima at the longitudes corresponding to the two conjunctions. Such a case is observed for σ Gem, while the other three stars show noticeable non-synchronization of the active longitudes and, therefore, no preferred orientation. The above calculations showed also that the field maxima are symmetrically located in both hemispheres relative to the orbital plane. All stars discussed here seem to have inclinations of their rotational axes of $\leq 60°$ (Stawikovski&Głębocki 1994; Głębocki&Stawikovski 1994; Berdyugina et al. 1998a). Thus, the discovered two permanent active regions on the surfaces of four RS CVn stars seem to be one half of the total magnetic structure of the stars. The other two appear to be located in the invisible parts of the stellar surfaces, near the invisible poles of the stars, since surface imaging of rapidly rotating late-type stars shows in general mainly high-latitude spots. Proximity of the spots to the polar regions has also been found with flux tube calculations for single active stars by Schüssler et al. (1996). They showed that the mean latitude of the magnetic flux emergence shifts towards the poles for increasingly rapid rotation and deep convective zones. Obviously, the presence of the secondary component and the orbital motion induce additional forces which should affect the flux tube trajectories. They could also somehow provoke the observed migration of the active longitudes and their periodic switching, especially with the presence of some non-synchronized rotation. The latter can be caused e.g. by differential rotation of the outer layers or a different rotation rate of the stellar core. Evidently, new dynamo and flux-tube simulations for binaries with magnetic activity are necessary.

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