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Surface temperature maps for II Peg during 1999–2002

M. Lindborg[1], M. J. Korpi[1,4], I. Tuominen[1], T. Hackman[1], I. Ilyin[2], and N. Piskunov[3]

[1]Observatory, PO BOX 14, FI-00014 University of Helsinki, Finland
[2]Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany
[3]Department of Astronomy and Space Physics, Uppsala University, SE-751 20, Uppsala, Sweden
[4]NORDITA, Roslagstullsbacken 23, SE-10691 Stockholm, Sweden

Abstract. The active RS CVn star II Peg has been spectroscopically monitored for almost 18 years with the SOFIN spectrograph at NOT, La Palma, Spain. In this paper we present five new surface temperature maps of the object for the years 1999 (two maps), 2001 (one map) and 2002 (two maps).

Keywords. techniques: spectroscopic, stars: late-type, stars: spots

1. Introduction

II Peg is one of the very active RS CVn stars and it is the brightest X-ray star with 50pc of the Sun. RS CVn stars are closely detached binaries where the more massive component is a G-K giant or subgiant and the secondary a subgiant or dwarf of spectral class G to M. Because of the low luminosity of the secondary many RS CVn systems appear as single-line binaries which are suitable for spectral analysis (Berdyugina *et al.* 1998a). In close binaries the rapid rotation is maintained by tidal forces due to the close companion. Large amplitude brightness variation of RS CVn stars imply the presence of enormous star spots on their surfaces covering up to 50% of the visible disk. Also coronal X-ray and microwave emissions, strong flares in the optical, UV, radio and X-ray are seen. Cool spots on the stellar surface will locally alter the photospheric absorption lines and continuum intensities.

Previous investigations on the temperature distribution over the surface of II Peg include the study of Berdyugina *et al.* (1998b), who presented surface temperature maps for 1992-1996, and Bergyugina *et al.* (1999c) with surface maps for 1996–1999, both studies were based on observations with the SOFIN-spectrograph at NOT. Gu *et al.* (2003) presented surface images of II Peg for 1999-2001 based on observations with the Coude echelle spectrograph at the Xinglong station of the National Astronomical Observatories, China, but the spectral lines used for inversions were different to that of SOFIN observations. Photometric light curve variations of the object were analysed by Berdyugina & Tuominen (1998c), and by Rodonò *et al.* (2000). The results of Berdyugina *et al.* (1998a,b, 1999a,b,c) and Berdyugina & Tuominen (1998c) consistently show that there are two active longitudes separated approximately by 180°, migrating in the orbital reference frame, and that a switch of activity level occurs periodically with a period of 4.65 years. In the surface images of Gu *et al.* (2003) the general spot pattern was quite similar, but the drift with respect of the orbital frame was less obvious, and the switch of the activity level appeared to occur earlier than predicted by Berdyugina

Table 1. Summary of the observations.

HJD 2450000+	Phase	S/N	Label	HJD 245000+	Phase	S/N	Label
July-August 1999				September 1999			
1383.7017	0.7998	248	9	1443.4928	0.6915	179	4
1384.7178	0.9509	238	11	1443.6184	0.7102	164	5
1385.7232	0.1004	217	1	1444.4788	0.8382	230	6
1386.7124	0.2475	229	3	1445.5656	0.9998	194	7
1387.7094	0.3958	200	5	1447.6084	0.3036	174	1
1388.7278	0.5472	181	7	1448.6212	0.4542	184	2
1389.7031	0.6923	178	8	1449.5979	0.5994	178	3
1390.7198	0.8435	151	10				
1391.7045	0.9899	243	12				
1392.7108	0.1396	258	2				
1393.7275	0.2908	189	4				
1394.7386	0.4411	206	6				
August 2001				August 2002			
2120.5503	0.3796	192	3	2507.6078	0.9405	139	9
2121.5642	0.5303	225	4	2508.6582	0.0967	208	1
2122.7102	0.7008	185	6	2509.5877	0.2349	200	3
2123.6083	0.8344	196	8	2510.5909	0.3842	216	4
2124.5644	0.9765	193	10	2511.5413	0.5255	195	5
2125.6758	0.1418	177	1	2512.6316	0.6876	212	7
2126.7146	0.2963	189	2	2513.5494	0.8242	179	8
2128.6067	0.5777	166	5	2514.5854	0.9782	206	10
2129.6470	0.7324	190	7	2515.5768	0.1257	207	2
2130.6415	0.8804	208	9	2518.5749	0.5715	129	6
November 2002							
2588.3964	0.9549	207	7				
2589.3764	0.1007	160	1				
2591.3567	0.3951	241	3				
2592.3705	0.5459	219	4				
2597.4333	0.2988	252	2				
2599.4798	0.6031	275	5				
2600.4896	0.7532	259	6				

et al. (1999c). Rodonò *et al.* (2000) found a much more complicated spot pattern from their analysis of photometry: they report on the existence of a longitudinally uniformly distributed component together with three active longitudes, with complicated cyclic behavior. Carroll *et al.* (2009) have also applied a Zeeman Doppler imaging technique to derive the magnetic field configuration on the surface of II Peg during 2007 using spectropolarimetric (Stokes I and V) observations with SOFIN. Their maps show a very similar spot pattern as found by Berdyugina *et al.* (1998b, 1999c); moreover, the radial field direction is opposite on different active longitudes.

2. Observations

When a star rotates rapidly star spots modify the observed spectral line profiles. As the star rotates, these bumps will move across the absorption line profiles (Hackman *et al.* 2001; Kurster, M. 1993). The surface imaging techique is basically to trace these distortions and create a surface map of the star. We use the surface imaging technique developed by Piskunov (the code INVERS7, Piskunov *et al.* 1990; Piskunov 1991).

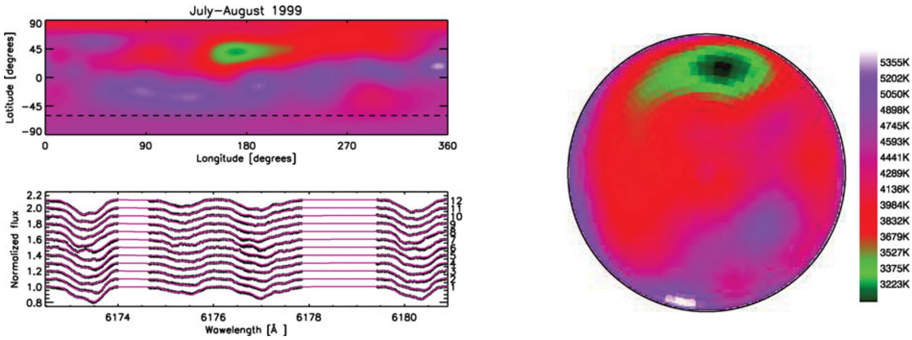

Figure 1. Observing run during July - August 1999. Upper left panel: Mercator projection of the obtained surface temperature distribution. Lower left panel: observed (crosses) and calculated line profiles (solid lines). Panel on the right: Pole-on projection of the surface temperature distribution.

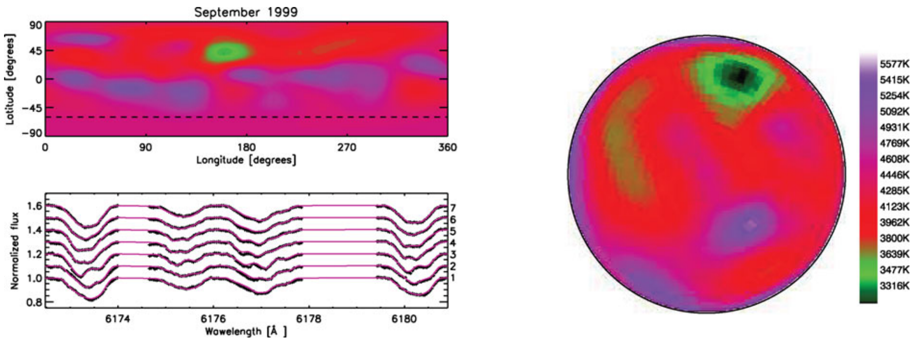

Figure 2. Observing run during September 1999.

We use the stellar model atmospheres of Kurucz (1993) for local line profile calculations for a set of temperatures and limb angles. This table is then used for the disk integration of a given surface temperature distribution. The surface imaging problem can be solved by searching for a such surface temperature distribution that minimizes the discrepancy function between the observations and the calculated line profiles (Hackman *et al.* 2001).

High resolution spectra of II Peg were measured in July-August 1999, September 1999, August 2001, August 2002 and November 2002. All the observations were made using the SOFIN high resolution echelle spectrograph at the 2.6 m Nordic Optical Telescope (NOT), La Palma, Spain. The data were acquired with the 2nd camera equipped with a CCD detector of 1152×298 pixels, and the spectral region $6160-6210$Å was chosen for surface imaging. The observations are summarized in Table 1.

The spectral observations were reduced with the 4A software system (Ilyin 2000). Bias, cosmic ray, flat field and scattered light corrections, wavelength calibration and normalization were included in the reduction process.

The stellar parameters used in the inversions were chosen according to Berdyugina *et al.* (1998a), and read T_{eff}=4600 K, $\xi_t = 2.4$ kms^{-1}, ζ_t=3.5 kms^{-1}, $P_{\rm orb}$=6.724333 d, $v\sin i$=22.6 kms^{-1}, $i = 60°$.

3. Results and conclusions

The following spectral lines were used in the surface temperature inversions: Fe I 6173 Å, Ni I 6175 Å, Ni I 6177 Å, and Fe I 6180 Å.

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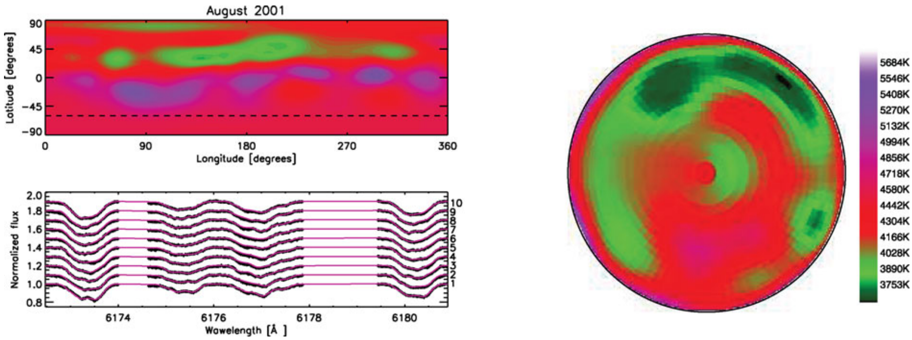

Figure 3. Observing run during August 2001.

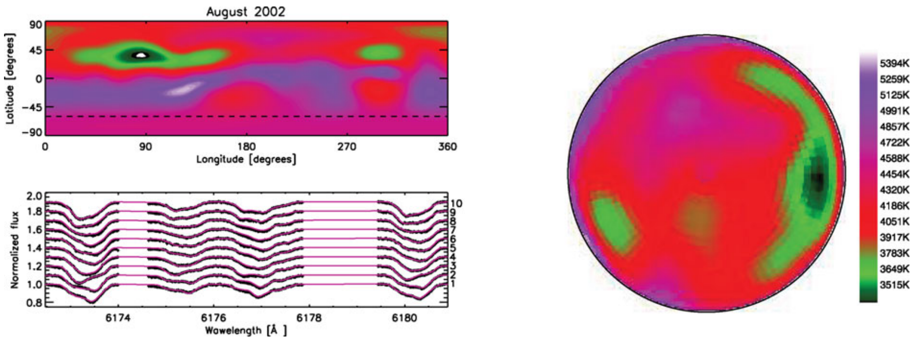

Figure 4. Observing run during August 2002.

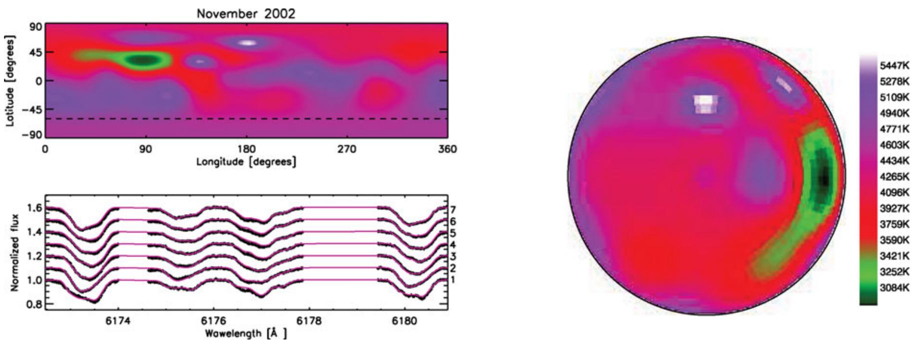

Figure 5. Observing run during November 2002.

Spectral line parameters were obtained from the Vienna Atomic Line Database (Kupka *et al.* 1999); the $log(gf)$ values of the two included Ni I lines were modified from the standard value of -0.53 to -0.2 as the standard values were found to produce much weaker absorption lines than the actually observed ones. This is equivalent to an increase in the Ni abundancy, which is probably the real reason for the observed strong Ni lines.

Figures 1–5 show the results of the inversions. During July-August 1999 (Fig. 1) only one spot is seen approximately at latitude 40°. The minimum temperature inside the spot was measured to occur at the approximate longitude of 170° or phase 0.47. Our image is quite different from the one obtained by Gu *et al.* (2003) for almost a simultaneous observing period, but a different spectral region. Their inversions gave much larger, longitudinally extended, spot structures around 170–290° at roughly 60° of latitude.

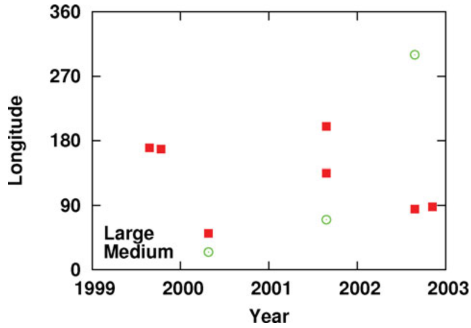

Figure 6. The spot longitudes of II Peg versus time. Square symbols represent larger active regions and circles mark weak structures.

In September 1999 our inversions also show only one strong spot that has barely moved in the orbital reference frame (latitude 44° and longitude 160° or phase 0.44). There is a weaker, longitudinally extended feature visible between 220–270° or phase 0.61–0.75.

Almost two years later, in August 2001 (Fig. 3), the star exhibits much more surface structures: three spots are visible in our image (longitudes 70°, 140°, and 200° or phases 0.19, 0.39 and 0.56) at an approximate latitude of 40°. The inversions of Gu *et al.* (2003) for an observing run 5 months later show much less structure, and the maximal activity seems to have moved roughly to the other side of the star than what was seen in their images during 1999 and 2000.

One year later, in August 2002 (Fig. 4) our maps show one strong spot at the latitude 40° and longitude 80° or phase 0.22, and a weaker one at 300° or phase 0.83. In November 2002 (Fig. 5) only the stronger spot is seen approximately at the same location. Comparing the surface temperature distribution during the observing seasons 1999 and 2002, the maximal spot activity seems to have moved by roughly 100° in the orbital reference frame, while very little drift of the spots can be seen during the consecutive observing runs during 1999 and 2002. In between these two 'states' of only one strong spot at different location on the surface, a much more complex distribution could be seen during August 2001. Our images give some support to the conclusion of Gu *et al.* (2003) of a significant change of the longitudinal spot distribution having occurred sometime during 2001 (Fig. 6).

We plan to continue to study the spot evolution on II Peg by analysing photometric and spectropolarimetric observations of the object, both to invert the surface temperature distribution, but also the magnetic field configuration of the object.

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