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Surface Imaging of HD 199178: High Latitude Spot and Differential Rotation

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Abstract. We present surface (Doppler) imaging temperature maps of the FK Comae-type star HD 199178 (V1794 Cyg). The maps have been calculated from high resolution spectra and simultaneous Johnson V-photometry obtained between 1994 and 1997. All maps reveal a high latitude spot, which is 1200-1600 K cooler than the mean surface temperature. The observed slightly flat bottomed absorption lines can be explained by antisolar surface differential rotation. The presence of differential rotation is supported by the variations in the photometric rotation period.

1. Introduction

HD 199178 (V1794 Cygni) is a rapidly rotating single G5 III-IV subgiant (Herbig 1958), which was classified as a FK Comae-type star by Bopp & Rucinski (1981). In an extensive analysis of photometry between 1975 and 1995, Jetsu et al. (1999b) showed that the photometric period of HD 199178 is variable and interpreted this variability as a signature of differential rotation.

We use the surface (Doppler) imaging technique developed by Piskunov (1991) to derive surface temperature maps for HD 199178. Our modified version of this technique includes Johnson V-photometry in the inversion. We also model the effect of surface differential rotation on the absorption line profiles.

2. Observations

High resolution spectra were obtained with the SOFIN échelle spectrograph at the 2.5 m Nordic Optical telescope (NOT), La Palma and the 2 m Ritchey-Chretien telescope Coudé-spectrograph of the National Astronomical Observatory (Rozhen), Bulgaria. The observations are summarized in Table 1. The V-photometry was obtained with the 60 cm telescope at the Mount Maidanak Observatory and the APT Phoenix 10" telescope at Mt. Hopkins, Arizona (Jetsu et al. 1999a; Hackman et al. 2001).

3. Surface Temperature Maps of HD 199178

The following three spectral regions are used for the surface imaging solution: 6409.0 – 6413.5 Å (strongest line Fe I λ6411.649 Å), 6427.5 – 6441.0 Å (Fe I

Table 1. The spectral observations of HD 199178: Dates, mean signal-to-noise (S/N), spectral regions, resolution element (W_λ), number of spectra ($n_{\rm sp}$) and number of photometric observations ($n_{\rm ph}$). The July 1994 spectral observations were obtained at Rozhen (Bulgaria), the rest are from the Nordic Optical Telescope (Spain).

Dates	S/N	spectral regions			W_λ (Å)	$n_{\rm sp}$	$n_{\rm ph}$
		6411 Å	6435 Å	7511 Å			
July 18-31, 1994	239		x		0.20	19	21
August 14-24, 1994	264	x	x	x	0.10	11	17
November 12-21, 1994	205		x	x	0.05	9	-
July 12-23, 1995	332	x	x	x	0.10	11	18
October 24-31, 1996	326	x	x	x	0.10	8	20
June 18-28, 1997	278	x	x	x	0.10	12	25

λ6430.846 Å; FeII λ6432.680 Å; CaI λ6439.075 Å) and 7509.0 – 7513.5 Å (FeI λ7511.020 Å). Temperature maps are calculated for *July 1994*, *August 1994*, *November 1994*, *July 1995*, *October 1996* and *June 1997*. (The images from July 1994 to November 1994 have previously been published in Hackman et al. 2001.)

Table 2. Stellar parameters used for the surface images in Fig. 3.

Parameter	Adopted value
Gravity lg(g)	3.5
Inclination i	60°
Rotation velocity v sin i	70 km s^{-1}
Differential rotation α	-0.17
Rotation period $P_{\rm rot}$	3.3250
Micro turbulence $v_{\rm micro}$	1.4 km s^{-1}
Macro turbulence $v_{\rm macro}$	4.0 km s^{-1}
Element abundances	solar

Although the period of HD 199178 is variable, we choose to use a constant period, because this helps in comparing the different surface images. Because each image is derived from spectra within a time interval of about 10 nights, the main error caused by the variable period will be longitudinal shifts of the spots between the images. We use the ephemeris derived for the years 1994 and 1995

$$\mathrm{HJD_{min}} = (2449511.150 \pm 0.070) + (3.3250 \pm 0.0012)E, \qquad (1)$$

where the HJD$_{\rm min}$ is the epoch of the light curve minimum and $P = 3^{\rm d}\!.3250$ is the rotation period (Jetsu et al. 1999b).

The adopted stellar parameters (Table 2) are the same as in Hackman et al. (2001). The differential rotation is implemented by adjusting the angular rotational velocity for each latitude (b) with the relation

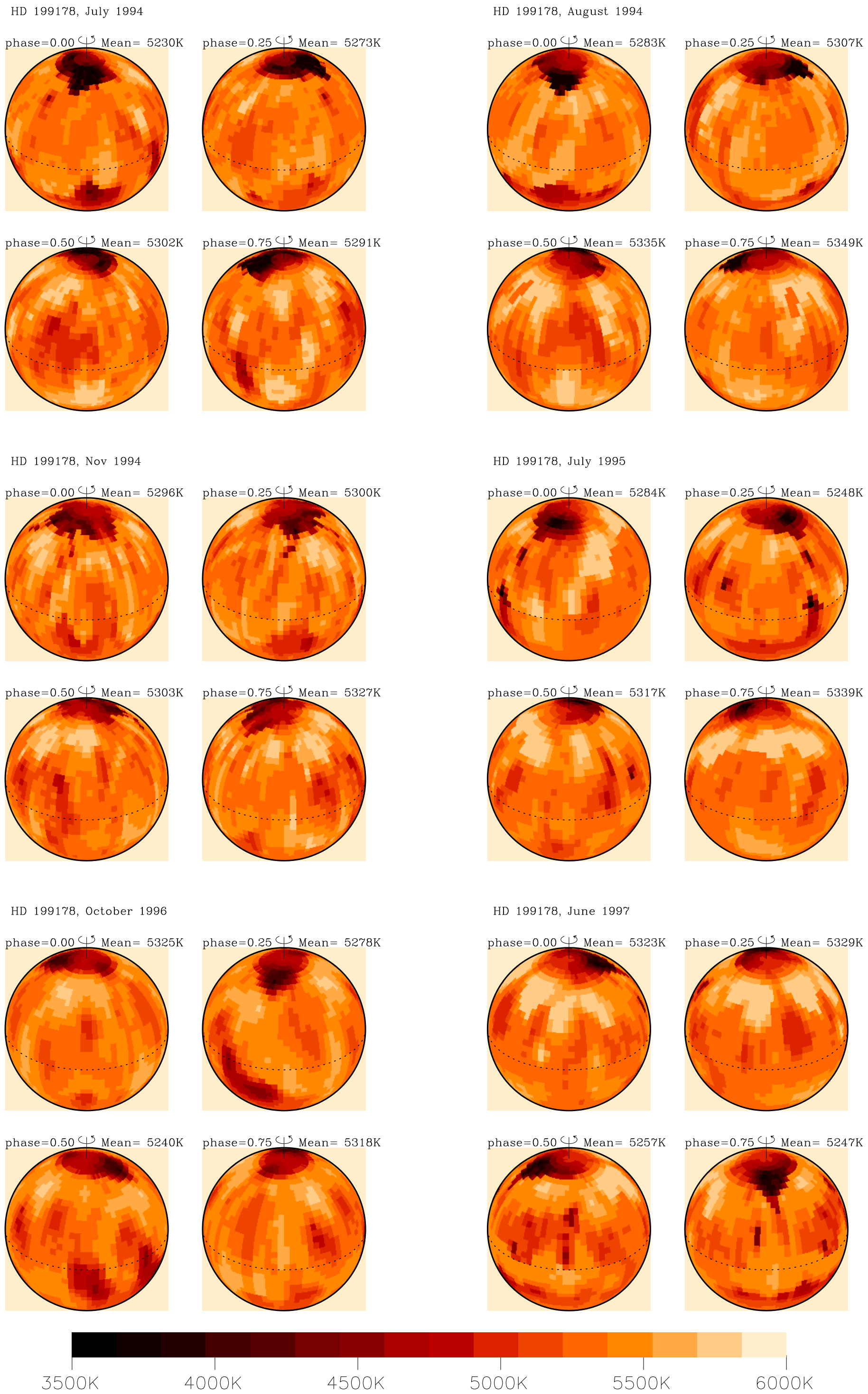

Figure 1. Surface (Doppler) images of HD 199178.

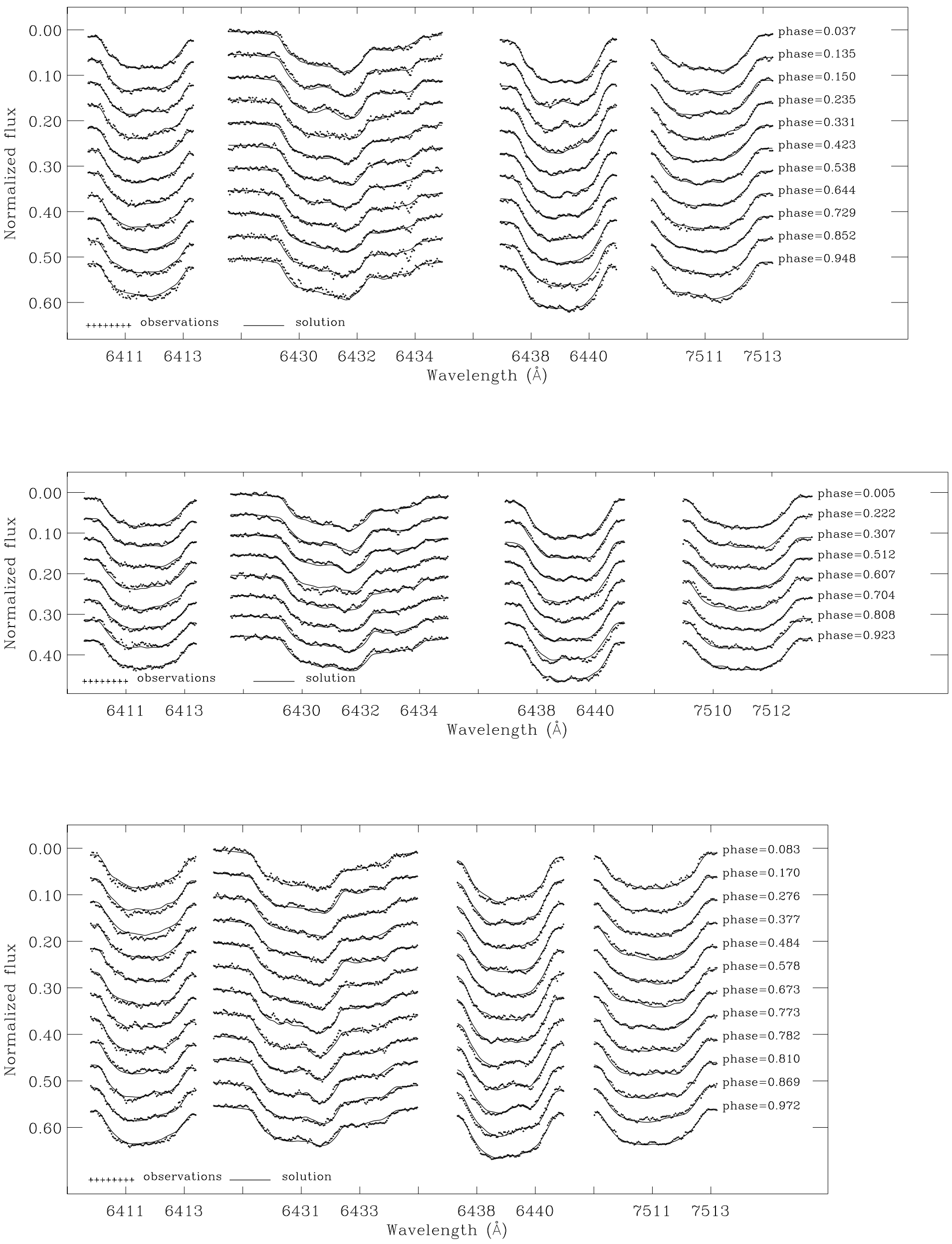

Figure 2. The observations and calculated spectra based on the surface imaging solutions in Fig. 1 for July 1995, October 1996 and June 1997. The mean deviation of the observations from the model is 0.38 %, 0.42 % and 0.42% respectively. The spectra for the July, August and November 1994 images can be found in Hackman et al. (2001).

$$\Omega(b) = \Omega_{\text{equator}}(1 - \alpha \sin^2 b). \tag{2}$$

The best solution is obtained with $\alpha = -0.17$. This indicates that the pole rotates faster than the equator, contrary to the solar case. The negative α value arises from the slightly flat bottomed absorption line profiles (Fig. 2). Although the flat bottomed profile could also be explained by a large polar spot, differential rotation offers a better solution (Hackman et al. 2001).

All images (Fig. 1) show a large cool spot at a high latitude, $60° \lesssim b \lesssim 70°$. Apparently we see the same active region in the images from *July 1994* to *July 1995*, although some evolution occurs. As for the *October 1996* image, the apparent change in the spot longitude could be just a consequence of the varying photometric rotation period. In this image there is, however, also a smaller high latitude spot on the opposite side of the star. It is therefore not certain, whether the main spot in the *June 1997* image is the same as in the previous images. In all images there are artifacts typical for Doppler imaging, such as low latitude "shadows" of the high latitude spot, stripes and high contrast features.

Table 3. Temperatures T_{spot}, longitudes ℓ and latitudes b of the main spot in each image, and seasonal photometric periods P. The P values were derived using the TSPA method (Jetsu & Pelt 1999).

Image	T_{spot} (K)	ℓ (°)	b (°)	P (d)
July 1994	3700	-5	67	3.352 ± 0.019
August 1994	3700	-15	61	3.384 ± 0.012
November 1994	4100	-70	65	-
July 1995	3700	-30	70	3.2829 ± 0.0054
October 1996	3900	-104	67	3.310 ± 0.011
June 1997	3700	94	65	3.3440 ± 0.0085

If the the star really is rotating differentially, we should see a relation between the latitude of the main spot and the photometric rotation period. In fact, there are indications that the photometric rotation period depends on the spot latitude (Fig. 3). However, more observations are needed to quantify the differential rotation of HD 199178.

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References

Bopp B.W., Rucinski S.M., 1981, in: Fundamental Problems in the Theory of Stellar Evolution, IAU Symp. 93, ed. Sugimoto D., Lamb D.Q., Schramm D.N. (Reidel, Dordrecht), 177

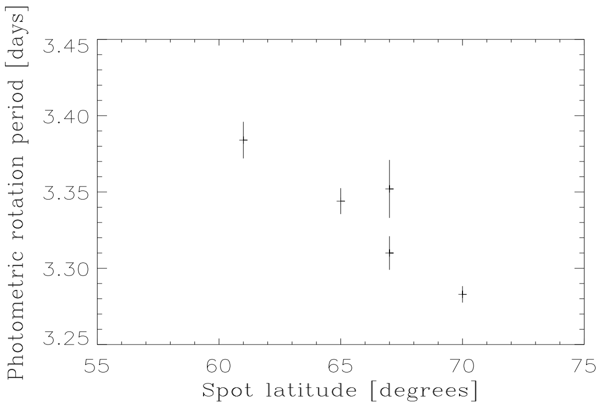

Figure 3. The spot latitudes vs. photometric rotation periods from Table 3 indicate antisolar differential rotation.

Hackman T., Jetsu L., Tuominen I., 2001, A&A374, 171

Herbig G.H., 1958, ApJ 128, 259

Jetsu L., Pelt J., 1999, A&AS139, 629

Jetsu L., Tuominen I., Bopp B.W., et al., 1999a, A&AS139, 513

Jetsu L., Pelt J., Tuominen I., 1999b, A&A351, 212

Piskunov N.E., 1991, in: The Sun and Cool Stars: activity, magnetism, dynamos, IAU Coll. 130, ed. Tuominen I., Moss D., Rüdiger G. (Springer-Verlag, Heidelberg), 309