COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5851

Konkoly Observatory
Budapest
26 September 2008

HU ISSN 0374 – 0676

THE LONGITUDINAL MAGNETIC FIELD OF THE ROAP STAR HD 99563

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The chemically peculiar star HD 99563 is an important member of the class of rapidly oscillating Ap (roAp) stars and its monoperiodic rapid oscillation shows the highest known radial velocity amplitude among these (Elkin et al. 2005). The rapid pulsation was discovered photometrically by Dorokhova & Dorokhov (1998) and was comprehensively studied by Handler et al. (2006) in a multisite photometric campaign. The longitudinal magnetic field in HD 99563 was first detected by Hubrig et al. (2004) and later confirmed by Hubrig et al. (2006).

The roAp stars as a class are in general well-described by the oblique pulsator model, which assumes a dipole magnetic field axis that is aligned with the stellar pulsation axis. It is important to observe the longitudinal magnetic field over the stellar rotation period for HD 99563 to provide a geometrical model of the magnetic field structure.

We obtained observations of the magnetic field with the 6-m telescope BTA (Big Telescope Alt-azimuthal) of the Special Astrophysical Observatory in Russia. The observations and the data reduction were performed similarly to the procedures described by Kudryavtsev et al. (2006). The results of our magnetic field measurements together with those obtained by Hubrig et al. (2004, 2006) are given in Table 1.

Table 1: The longitudinal magnetic field measurements for HD 99563. The columns give: HJD of the middle of the exposure, rotational phase using the ephemeris of Handler et al. (2006), the longitudinal magnetic field B_l, the standard deviation of B_l and the observing place. The first three measurements were taken from Hubrig et al. (2004, 2006) who used ESO VLT and the other six are our observations with 6-m BTA.

HJD (2450000+)	Phase	B_l [G]	σ [G]	Telescope
2494.483	0.0728	-688	145	VLT
3012.749	0.0617	-235	73	VLT
3015.727	0.0845	-670	84	VLT
3395.550	0.5273	+580	100	BTA
3718.580	0.4660	+680	100	BTA
3719.553	0.8002	-320	280	BTA
3784.569	0.1289	-110	120	BTA
3786.526	0.8010	-750	160	BTA
3812.523	0.7290	+270	120	BTA

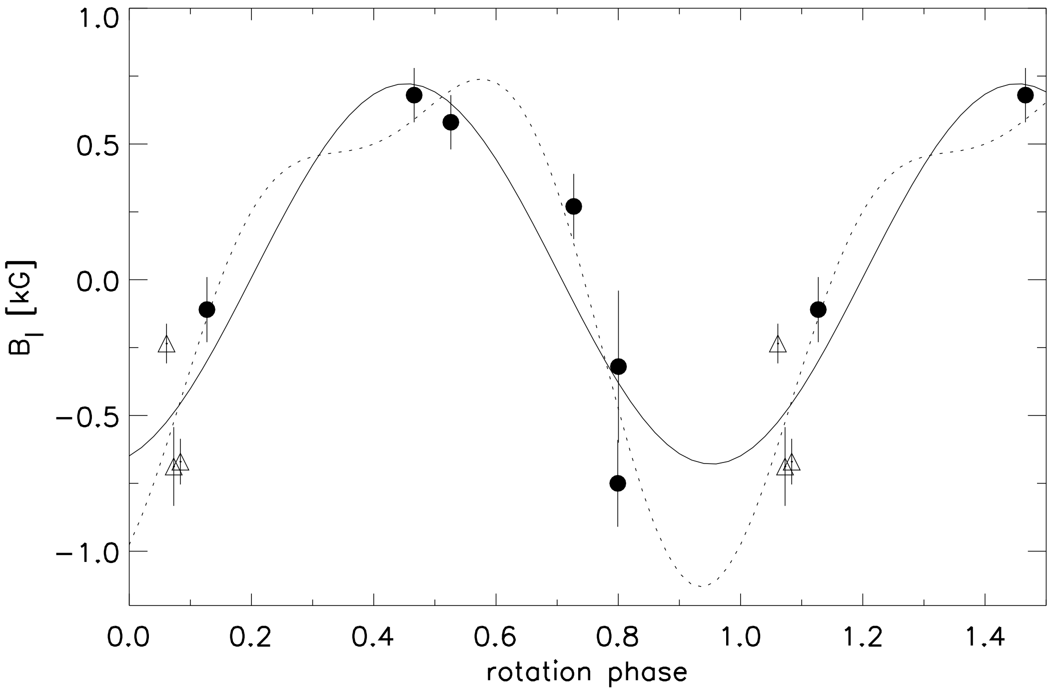

Figure 1. Variation of the longitudinal magnetic field in HD 99563 (filled circles - new observations from the 6-m telescope, triangles - results by Hubrig et al. 2004, 2006). A best-fit sine curve is shown with the full line, while the dotted line is for a sine curve including the first harmonic. Both curves fit the observations well, but several measurements with similar phases do show a scatter. The differences in the two points at the phase near 0.8 may be explained by relatively large errors. Although the differences in the measurements from VLT, obtained at nearly equal rotational phases, are still not clear.

We have a total of nine points spread over the rotation period. Fig. 1 shows the variation of the longitudinal field with the stellar rotation period according to the ephemeris given by Handler et al. (2006):

$$\mathrm{HJD} = 2452031.29627 + 2.91179E.$$

This rotation period is quite reliable and additionally supported by Doppler imaging and line profile variations (Freyhammer et al 2008). The number of magnetic field measurements is not sufficient to determine the rotation period independently. Least-squares sine fitting was performed with the program Period04 (Lenz & Breger 2004), which for a pure sine curve uses:

$$B_l = B_0 + B_1 \sin(2\pi(\omega_1 t + \phi_1)).$$

The observations are illustrated in Fig. 1 with the fitted curve shown as a solid line for the determined parameters: mean magnetic field $B_0 = 21 \pm 58$ G and amplitude $B_1 = 701 \pm 114$ G. Alternatively, for a least-squares sine fit that also includes the first harmonic, i.e.,

$$B_l = B_0 + B_1 \sin(2\pi(\omega_1 t + \phi_1)) + B_2 \sin(2\pi(2\omega_1 t + \phi_2)),$$

we get the curve shown with a dotted line in the figure. This fit has the magnetic field parameters: $B_0 = 6 \pm 77$ G, $\mathrm{B}_1 = 846 \pm 149$ G, $\mathrm{B}_2 = 311 \pm 186$ G. The harmonic amplitude is significant only at the 1.7σ level, indicating that a purely sinusoidal fit is sufficient for the present observations.

The photometry by Handler et al. (2006) shows a double wave light variation with the rotation period, and maximum brightness in the U and B filters at phases 0.25 and 0.75 and minimum brightness at phases 0.0 and 0.50. The variations in the V, R, I filters are in antiphase to U and B and have lower amplitudes. This behaviour is typical for a dipole rotator where two opposing spots come into view over the rotation period.

The minima of the U and B filters thus coincide with the times when one of the magnetic poles is closest to the line-of-sight, i.e., the times of magnetic maxima and minima in Fig. 1. The fit to the magnetic measurements possibly suggests a minor phase offset of $\Delta\varphi_{\mathrm{rot}} = -0.046 \pm 0.027$ (units of fractional phase) as the magnetic minimum in Fig. 1 occurs near phase 0.95, while the positive extremum coincides with phase 0.45. This phase difference has, however, only a 1.7σ significance, and considering the uncertainties in the magnetic curve, more observations are needed at a higher precision.

Handler et al. (2006) calculated the radius of HD 99563 to be $2.38\,\mathrm{R}_{\odot}$. Taking into account the longitudinal field variations and the projected rotation velocity of $v \sin i = 28.5 \pm 1.1\,\mathrm{km\,s^{-1}}$ (Elkin et al. 2005), the geometrical parameters for an oblique rotator model are: inclination angle between rotation axis and line of sight $i = 43.^{\circ}5$ and magnetic obliquity (angle between rotation axis and the magnetic dipole axis) $\beta = 88.^{\circ}4$. These are similar to those determined by Handler et al. (2006).

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