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The integral magnetic field of 53 Cam — an effect of ring-like element distribution ? ⋆

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Abstract. Modelling the field structure has to account for the element distribution in the star's atmosphere. The effect of inhomogeneous covering of the radiating stellar atmosphere on the phase curve of luminosity and integral magnetic field strength is examined and demonstrated at the well-investigated CP star 53 Cam. Using a special computer program, which supplies a fourth component to the three magnetic vector components as factor, the best fitting of the known observational data is achieved by a ring-like arrangement of elements around the poles, corresponding well to theoretical predictions.

Key words: Magnetic stars, modelling, element distribution, 53 Cam

1 Introduction

Since all information about the magnetic field of a star is contained in the Zeeman-displaced line profiles originating from its atmosphere, the line-transferring process through it has to be pursued and analyzed during all stages. Keeping in mind the immense complexity of the stellar magnetic field, the pioneers of stellar magnetism stuck only to the global *observable effect* at that time and called the longitudinal component of the integral magnetic field, discernable by the Zeeman-displacement of the line profiles in polarized light (Stokes V), the *effective magnetic field* B_{eff}.

2 The complexity of the stellar magnetic field

The really observed integral radiation emerging from the star is a result of vast processes of mixing, averaging, and convolving with an overwhelming amount of parameters. Further, there is a principal lack of information because of partial invisibility of the star's sphere. Therefore, the so-called "ill-posed" inversion problem (Khokhlova 1986) cannot be solved totally. In contrary to this the straight-forward calculation of a reasonable model of the magnetic star, which needs only a limited set of hypothetical but appropriate parameters, is practicable in any case. These parameters have to be fitted to the real observational results by means of physically based trial calculations.

3 Accounting for the element distribution

A very complication for the analysis of the magnetic field structure is the distribution of the line-bearing chemical elements over the star's surface. Only for hydrogen the distribution is assumed to be nearly equal. The better measurable metallic lines are bound to elements, whose distribution is a matter of analysis itself. The distribution of elements, however, is not random at all. Theoretical considerations suggest, that the atoms are settled by their magnetic and electric properties around the magnetic poles in form of rings —

⋆ Poster representation available by www.ewald-gerth.de/118.pdf.

from outside by accretion and from inside by diffusion. This is, of course, known long ago, but it will be confirmed here.

The analysis of the element distribution was tackled by "Magnetic Doppler Imaging" (Piskunov 2001), using the Doppler-shift of element-determined lines caused by the star's rotation in presence of a magnetic field. Besides the Doppler-shift there is also a Zeeman-shift of the line profiles, coordinated to the topographic surface elements. The Zeeman-shift of a spectral line gives clear evidence of the existence of a magnetic field, which might be concentrated in small areas as spots. Averaging and convolution with other areas, where the line comes from, makes the shift more or less disappearing.

4 Model Integral Magnetic Fields — constructed by a computer program

Modelling stellar magnetic fields outgoing from sources in a straight-forward calculation was outlined by Gerth, Glagolevskij, and Scholz (1997, 1998). Already in the first publications the authors stated definitely: "The magnetic field vector consists of three components with the unity vectors in direction of the radius of the star (normal vector), in direction of the longitude (φ-vector), and in direction of the latitude (δ-vector). A fourth component is added for a scalar magnitude, which can be used for different purposes (brightness, transparency, factor)."

Here we use the fourth component as the factor, which is related to the topographic element density on the surface, represented as a cartographic map. The magnetic field is calculated using the MCD method proposed by Gerth and Glagolevskij (2000, 2001). Nevertheless, this is not the only possible way. Calculations of the magnetic surface field can also be performed, of course, by other methods, such as described by Bagnulo et al. (1996) — using spherical harmonics, which render the three components of the magnetic vector on the star's surface.

The integral magnetic field B_{int} and the effective magnetic field B_{eff} are variable with the aspect to the star body by inclination and rotation. The mathematics of integration over the visible disk and the convolution according to the rotation as well as the influence of the magnetic field on form and asymmetry of the line profile are outlined in foregoing papers of the authors (2004a,b).

5 The effect of a small radiating surface spot on the integral field

At first we show, that the distribution can modify the phase curve. The limitation of the resolution is given by the convolution of every topographic point, which is projected onto the phase curve in a broad cos-like curve covering nearly half the period. Therefore we conclude, that phase curves have to be smooth, and sharp peaks and edges suggested by plots of observations cannot be real.

Fig. 1 shows the translation of one radiating bright point (1a) in comparison with a magnetic field point (1b) on the surface of a star to the corresponding phase curve. The point is extended to a spot with the diameter 10° and located on the positive pole by $\varphi = 180°$, $\delta = 45°$. Topographic and phase coordinates are adequate. The parameter of the phase curves is the inclination angle i.

In both cases the positive spot produces a positive part of the phase curve. The broad phase curves will be convoluted with other parts of the map rendering smoothed curves — without sharp details.

In Fig. 2 we demonstrate the effect of the element distribution as phase curves of B_{eff} — applying especially to the hitherto already well-investigated star 53 Cam (Gerth, Glagolevskij, Scholz 1997, 2000), which is used as an example for the element distribution.

The photoelectric observations of Borra and Landstreet (1977) are related only to H lines. Since hydrogen is distributed equally, we can model the magnetic field completely on the base of magnetic sources with a decentered dipole. But this alone does not hold for the observations of Babcock (1960) based on metal lines, despite we use the same constellation of magnetic sources as we did in fitting the H-line data.

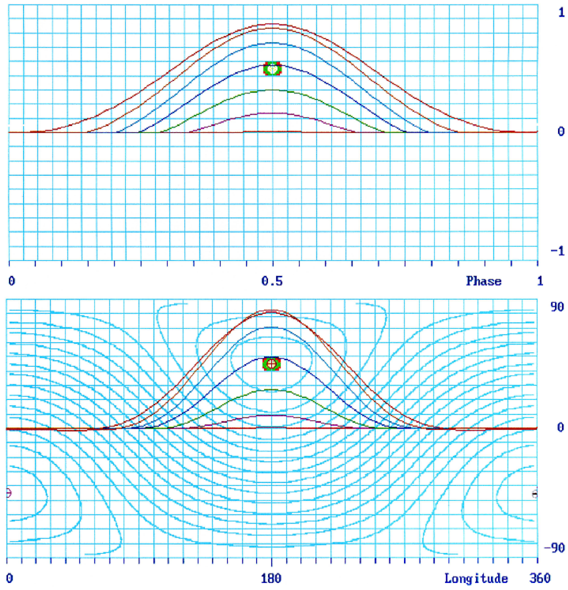

Figure 1: Series of phase curves produced by a spot-like radiating point on the surface. Parameter of the series is the inclination angle i. From below to above: $i = 135°$, $105°$, $90°$, $75°$, $60°$, $45°$, $30°$. Top: Brightness phase curves of a single bright spot (emission). Bottom: Magnetic phase curves of a spot on the pole. The total field is indicated by magnetic iso-lines.

6 Modelling of the magnetic field of 53 Cam — using observational data (Borra & Landstreet, Babcock)

6.1 The covering effect of the surface on the phase curve

The covering area is a circle with a right-angled profile. The program allows also other profiles as triangle, parabola, semicircle, sinus, Gaussian, rings. On account of the smoothing effect the choice of the profile form makes no significant difference in forming the phase curve.

The series of panels in Fig. 2 from top to bottom is self-explaining. In every case the coordinate net marks the covered area, where the transferring factor is zero.

The magnetic field structure is calculated by the MCD method using the parameters found for the star 53 Cam in a former paper of the authors (2000):

No	Magnetic charge	radius fraction	Longitude	Latitude [relative units]
1.	60	0.1	110°	6°
2.	-60	0.1	270°	-6°

The modelling is reduced to a dipole, so that no more than two sources are needed. The dipole is slightly decentered in order to get a better fit to the observational data of Borra and Landstreet (1977), but does no matter here. The fitting has been totally achieved by a dip in the center, where only the degree of the diameter and the factor fits the Borra/Landstreet data as well as the Babcock data (1960). The dip in the center is surrounded by a ring.

The instruments of decentering and covering guarantee full fitting.

6.2 Observed effective magnetic field strength B_{eff} of 53 Cam

In Fig. 3 we show once more the diagrams of the phase curves taking the figures from our earlier paper (Gerth, Glagolevskij, Scholz 2000), using observational data of other authors.

By courtesy of Dr. G. Scholz we had at our disposal a copy of the original (handwritten) list of measurements from H. W. Babcock himself. The lines were measured all together averaging the Zeeman shifts, so that we cannot discern single elements and their surface arrangement.

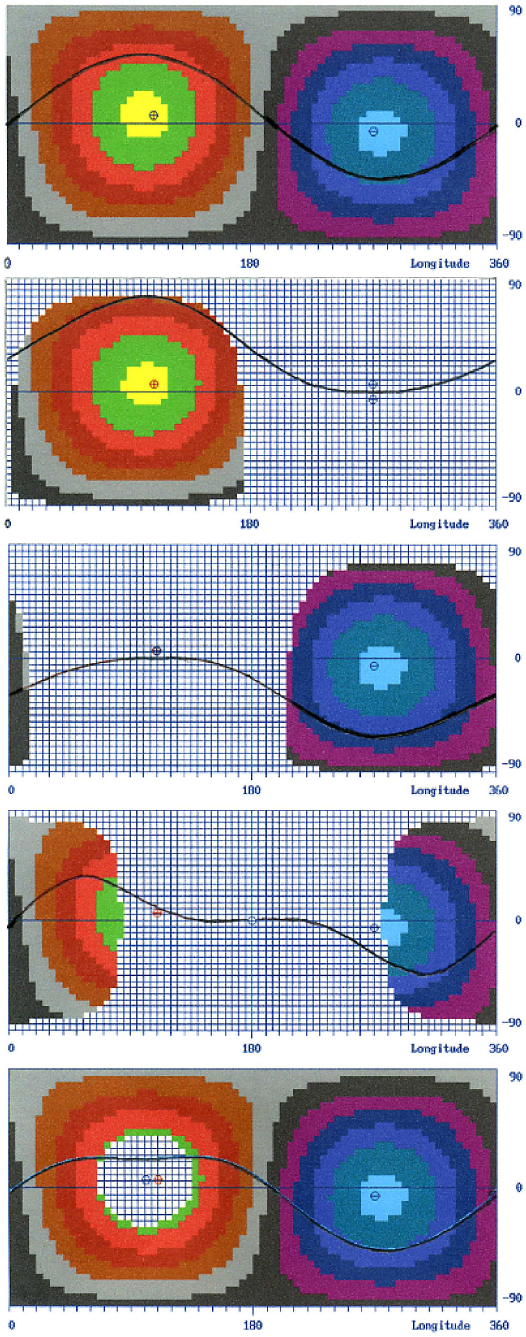

Figure 2: *Demonstration of the effect of covering parts of the surface of a magnetic star onto the phase curve.*

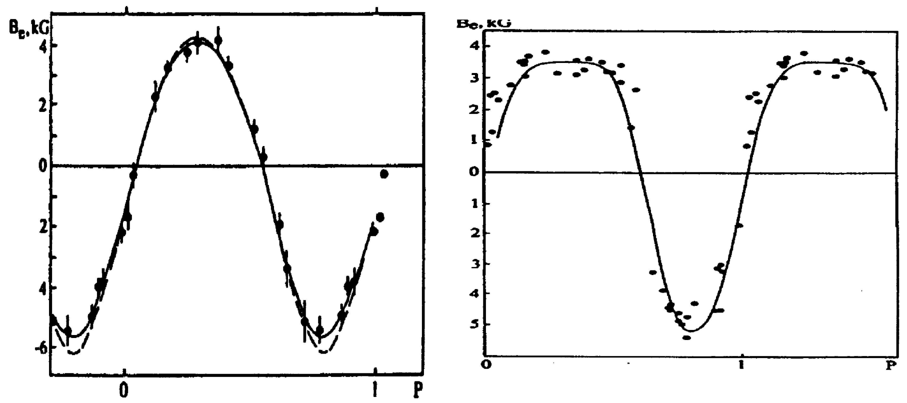

Figure 3: *Observed effective magnetic field strength* B_{eff} *of 53 Cam*
1) from Borra and Landstreet (1977), by hydrogen lines photoelectrically (left panel),
2) from Babcock (1960), by metal lines of the prominent elements Fe, Cr, Ti, Si, Eu — taken on photographic plates (right panel).

6.3 Modelling by fitting

The modelling of 53 Cam by fitting to the data of Borra and Landstreet is performed by a decentered dipole, whose magnetic moment is shifted off the center by 0.2 r in radial direction. The equal surface covering by hydrogen renders additional assumptions on the element distribution superfluous.

In Fig. 4 the parameters of the construction of the magnetic field by a dipole are:

No	Magnetic charge	radius fraction	Longitude	Latitude [relative units]
1.	60	-0.15	95°	-6°
2.	-60	0.25	275°	6°

If we further stick to the model found by the photometric data, then fitting can only be achieved by application of a covering, e.g. a transmission map, which corresponds to the distribution of elements.

6.4 Some remarks on the fitting method

The fitting method is related to the program used by the authors. In the present case we simply used the graphic algorithms of the program and calculated the cartographical map by varying the parameters of the magnetic dipole and looking for the best correspondence to the phase curve of the dots of the real observations by eye. This is, indeed, a good method, which comprises knowledge and experience. False and flawed measurements are easily recognized. The program, however, contains also an algorithm for the mathematically correct *least squares optimization,* by means of which the best fitting parameters of the magnetic dipole (or multipole) are determined in an iterative progression. All tests showed that the eye-guided method gives already a good approximation, which might serve as the starting condition for a following refining iteration.

6.5 Graphical representation of the map comprised with the phase diagram of the observational data

The magneto-effective map together with Babcock's data and the resulting phase curve are put together in Fig. 6. The phase curve corresponds to a covering like rings around the poles, suggesting a ring-like settling of chemical elements on the surface.

7 Conclusion

The covering of the surface of a star by an inhomogeneous distribution of elements, from which the line-bearing radiation comes, is important for forming the phase curve of the observed integral magnetic field strength. In the case of an equal covering as established for hydrogen it does not play any role. For metallic lines, however, the element distribution should not be neglected as this usually has been done hitherto. At the example of the magnetic CP star 53 Cam we show that the dip in the positive part of the phase curve

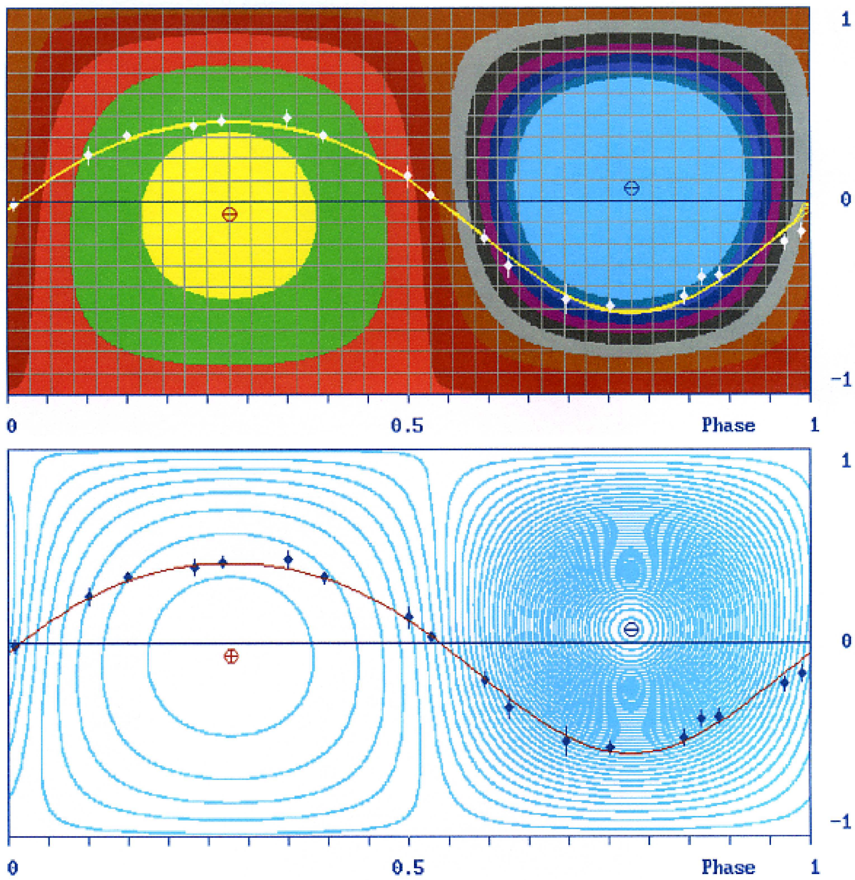

Figure 4: *Fitting of the photoelectrical observations of Borra and Landstreet.*
Top: Magnetic map with iso-areas and coordinated phase curve.
Bottom: Phase curve fitted to the observational data, coordinated to the magnetic field.

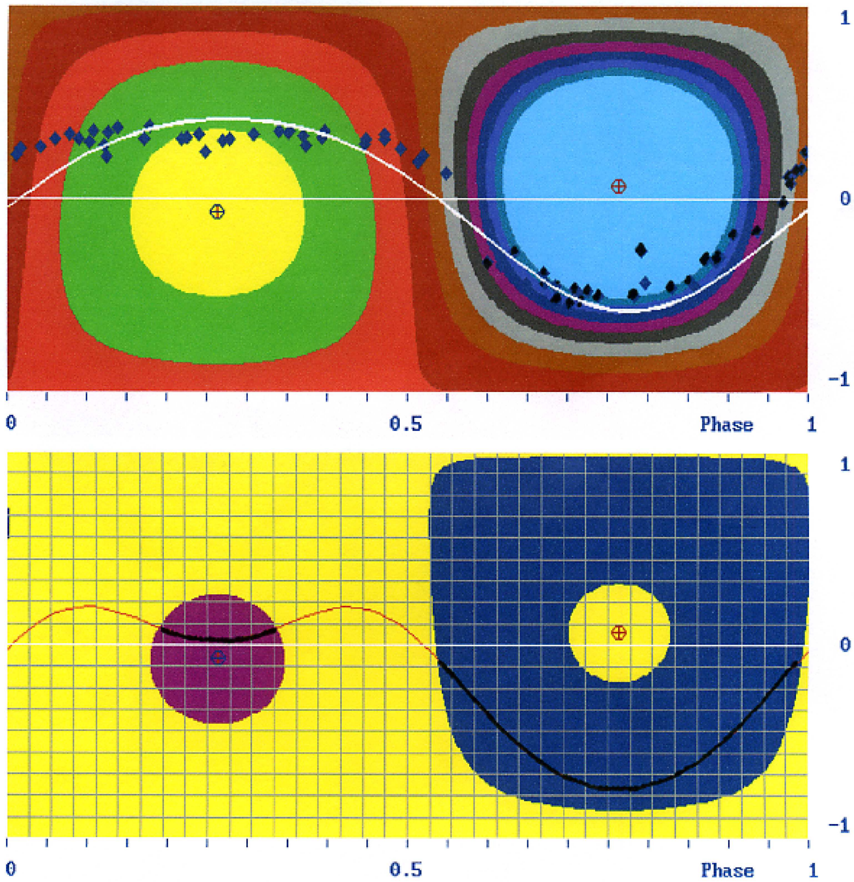

Figure 5: *Insertion of Babcock's observational data in the map/phase diagram obtained by means of Borra's and Landstreet's photometric data.*
Top: The principal agreement is quite obvious. Nevertheless, there is a deviation in the region of the positive pole, where the maximum is broadened and has a dip in the center.
Bottom: The covering map of the transmission factor modifies the measurable magnetic field strength on the surface and fits the data by a depression at the positive pole and a negative depression at the negative pole. This means, that the caps at both poles are flattened up to dented. The profiles are chosen rectangular for computation only, however, all will be smoothed, anyhow. The phase curve shows the curse of the factor-map as it would be a brightness curve. The diameters of the spots on the poles are 180°, 60°, 45°.

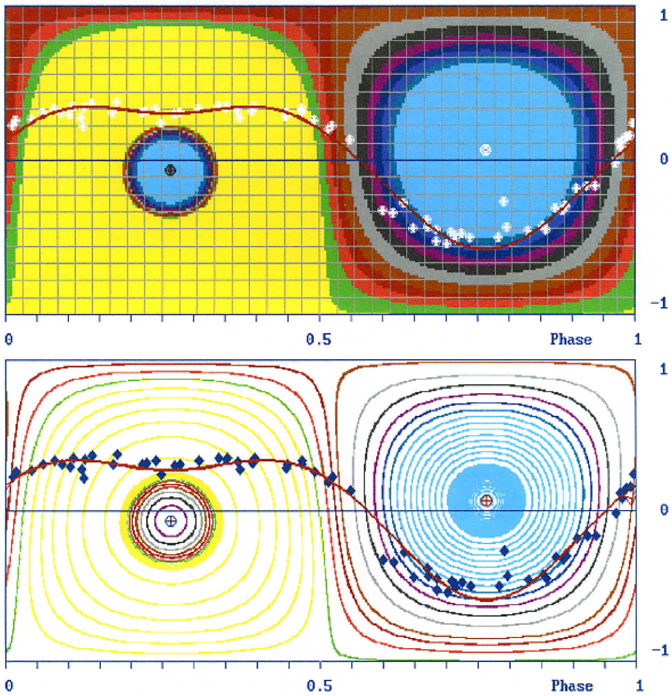

Figure 6: *Magnetic map with phase curve of the observations.*
Top: Map-phase-diagram with shadowed (colored) magnetic isolines differently arranged to Fig. 5 because of the ring-like covering.
Bottom: Representation of the map in form of isolines, which gives an impression on field structure and polarity related to the phase curve with the dots of the observations.

in Babcock's historic measuring data can be explained well by the assumption of a ring-like arrangement of metal elements around the poles.

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