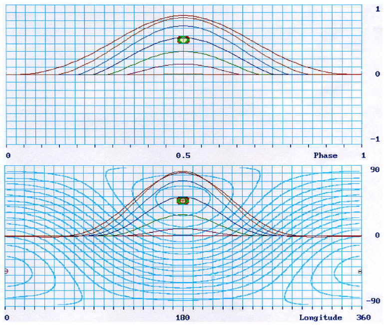
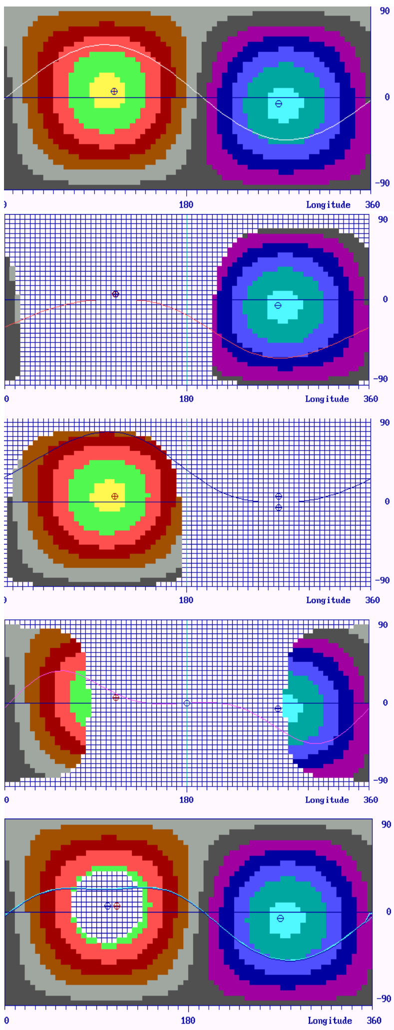
The integral magnetic field of 53 Cam – an effect of ring-like element distribution ?

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



Translation of one radiating point on the surface of a star to the phase curve. The point is extended to a spot with diameter 10° and located on the positive pole by φ = 180°, δ = 45°. Topographic and phase coordinates are adequate. Parameter of the phase curves is the inclination angle *i* marked by colours.
Top: Brightness phase curves of a single bright spot (emission) – demonstrating the multivalent fourth component in the program, used here as factor for the distribution of elements, from which the effective field is measured.
Bottom: Magnetic phase curves of a spot on the pole. The total field is indicated by magnetic iso-lines.
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.



Demonstration of the effect of covering parts of the surface of a magnetic star. 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 figures 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.

Ewald Gerth and Yurij V. Glagolevskij

Abstract. The magnetic field of a star is the result of integration over its visible hemisphere, related to the information transferring medium: the spectral line profile. Modelling the field structure has to account also for the element distribution in the star's atmosphere. The effect is demonstrated at the well-investigated CP star 53 Cam by fitting the known observational data using a special computer program, which supplies a fourth component to the three magnetic vector components as factor. The theoretically predicted ring-like arrangement of elements around the poles affords the best fitting.

All **information** about the **magnetic field** of a star is contained in the Zeeman-displaced line profiles originating from its atmosphere.
For full comprehension of the physics there has to be taken into account:
1. the atomic processes of absorption and emission,
2. the radiation transfer through the stellar atmosphere
3. the geometric conditions –
   a. the projection at the spherical surface to the line of sight,
   b. the stratification of the atmospheric layers,
   c. the topographic arrangement of the observable field, –
4. the mathematical problem of integration over the star's visible disk,
5. the reconstruction of the intrinsic 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 (the "ill-posed" inversion problem – Khokhlova, 1986).

Keeping in mind the immense **complexity of the stellar magnetic field**, the pioneers of stellar magnetism stuck only to the observable *effect* and called the longitudinal component (Stokes V), discernable by the Zeeman-displacement of the line profiles in polarized light, the ***effective magnetic field*** B_{eff}.

A very complication for the analysis 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** – 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), 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.

The important **statement** on existing and observed stellar magnetic fields is:
The observed magnetic field is an **integrated** one, called the ***integral magnetic field*** B_{int}, which exists independently of visibility and detection.
The integration is not related to the magnetic field itself but to the information transferring medium: the **spectral line profile**.
The element distribution acts like a transparency filter for the field. Accounting for all integration, projection, polarization, and measuring effects, we measure the ***effective magnetic field*** B_{eff}.

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 (l-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 (2000a,b).
However, 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.

The integral magnetic field $\boldsymbol{B}_{int}$ as well as the effective magnetic field $\boldsymbol{B}_{eff}$ 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 of the star 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).

Modelling of 53 Cam – using observational data (Borra & Landstreet, Babcock)

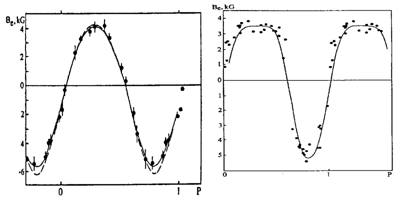
In this poster we demonstrate the effect of the element distribution as phase curves of $\boldsymbol{B}_{eff}$ – applying especially to the star 53 Cam (Gerth, Glagolevskij 1997, 2000).
On the left side of the poster we show, that the distribution can modify the phase curve. The limitation of the resolution 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. 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 metallic lines, despite we use the same constellation of magnetic sources as we did in fitting the H-line-data.
Obviously the field-relevant metallic elements are **distributed in rings around the poles** – for this gives the best fit of the observational data to the proposed **sources-rings-model**.

References

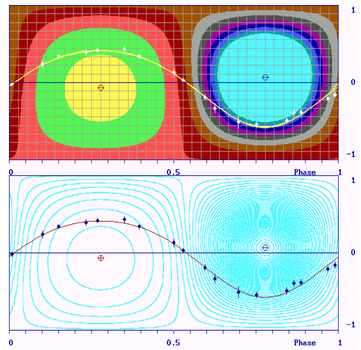
Babcock H.W.: 1960, in: *Stellar atmospheres*, ed. J. Greenstein, Chicago Press
Bagnulo S. et al.: 1996, Astron. Astrophys., **303**, 115
Borra E., Landstreet J.D.: 1977, Astrophys. J.,212, 141
Khokhlova V.I. et al.: 1986, Astrophys. J., **307**, 768
Piskunov N.: 2001 ASP Conf. Ser., **248**, 293
Gerth E., Glagolevskij Yu.V., Scholz G.: 1997, Proc. Int. Conf. SAO, 67
Gerth E., Glagolevskij Yu.V., Scholz G.: 1998, Contrib. Obs. Skalnaté Pleso, **27**, 461
Gerth E., Glagolevskij Yu.V. : 2000a, Proc. Int. Conf. SAO, 151
Gerth E., Glagolevskij Yu.V. : 2000b, ASP Conf. Ser., **248**, 333
Gerth E., Glagolevskij Yu.V. : 2004a, Proc. Int. Conf. SAO, 152
Gerth E., Glagolevskij Yu.V. : 2004b, Proc. Int. Conf. SAO, 166
Gerth E., Glagolevskij Yu.V., Scholz G.: 2000, Proc. Int. Conf. SAO, 158

Papers and posters of the authors are available from the homepage: www.ewald-gerth.de

Fitting and modelling of observations by magnetic charges and rings



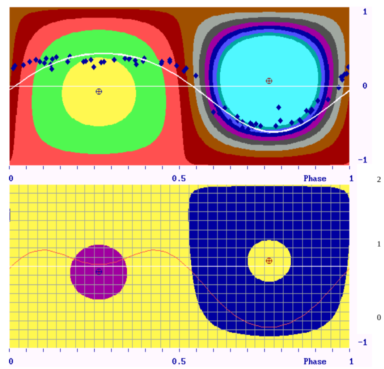
Observed effective magnetic field strength B_{eff} of the CP star 53 Cam
1. from Borra and Landstreet (1977), measured at hydrogen-lines photoelectrically (left penal),
2. from Babcock (1960), measured at metal-lines of the prominent elements Fe, Cr, Ti, Si, Eu - taken on photographic plates (right penal).
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. [Figures taken from Gerth/Glagolevskij (2000a)].



Modelling of 53 Cam by fitting to the data of Borra and Landstreet by a decentralized 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.

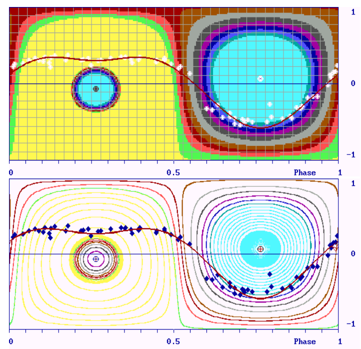
Parameters:	Magnetic charge	radius fraction	Longitude	Latitude [relative units]
1.	60	-0.15	95°	-6°
2.	-60	0.25	275°	6°

Top: Magnetic map with iso-areas and coordinated phase curve
Bottom: Phase curve fitted to the observational data, coordinated to the magnetic field.



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. 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.
Bottom: The covering map of the transmission factor, which 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 red 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°.

The "magneto-effective map" together with Babcock's data and the resulting phase curve are put together in the following representations on the background of the magnetic map by iso-areas and iso-lines.
The second figure gives an impression on field structure and polarity.



The phase curve corresponds to a covering like rings around the poles, suggesting a ring-like settling of chemical elements on the surface.

Poster representation at the Conference on MAGNETIC STARS, Special Astrophysical Observatory, Nizhnij Arkhyz, Russia, 28 August – 1 September 2006