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Modelling of solar-like starspots by magnetic charges

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Abstract. For the investigation of solar-like spots in stars we propose a method of the "Magnetic Charge Distribution" (MCD), which has been applied up to now only to stars with global extension of strong magnetic fields. A model of a solar-like spot can be constructed as an arrangement of magnetic dipoles under the surface of the star/sun. After this model the typical phase curves produced by such a magnetic spot and the line profiles according to all 4 Stokes-parameters I, Q, U, V in polarised integral light are calculated using a special computer program[1].

The sun is the only star, which exhibits by observation from the earth a detailed topographic structure. The origin of the conspicuous spots has been attributed to magneto-hydrodynamic processes in the plasma, which are described well by the dynamo theory. Supposing, the generation of sun-spots by the action of a dynamo is bound to the spectral class, then also in other G-stars solar-like starspots accompanied by magnetic phenomena should be revealed. Since we receive from all other stars only the integral radiation, we have to disentangle the information by an inversion procedure. Modelling methods, however, can help to asses the effect of such spots onto the integral magnetic field.

1. Modelling of starspots

For the investigation of solar-like spots in stars we propose a modelling method of the "Magnetic Charge Distribution" (MCD), which has been applied up to now only to stars with global extension of strong magnetic fields. The location of the magnetic sources is not bound to the center of the star. Thus, a "decentered dipole" as proposed by Landstreet (1980) might be considered as real. In the case of sunspots we have even the extreme case of decentration with the magnetic sources anywhere under the surface. Each single source is surrounded by a spherical magnetic field, which offers decisive advantages for the numerical computation. Magnetic sources can combine to dipoles and multipoles (Gerth & Glagolevskij 1997, 1998, 2001).

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2. The sunspot as a magnetic dipole

A real sunspot usually shows a complicate microstructure, which can be described only with a high number of parameters. Modelling and fitting, however, becomes effective using as few parameters as possible for a first approximation. So we reduce the bipolar groups of a sunspot to a magnetic dipole with two sources of opposite magnetic charges. Therefore we need only a set of 7 parameters. It should be emphasized that the dipole may be located and directed anywhere, inside and even outside the star (e.g., in a companion). Thus, the MCD-method offers a high flexibility for fitting to the global observational facts.

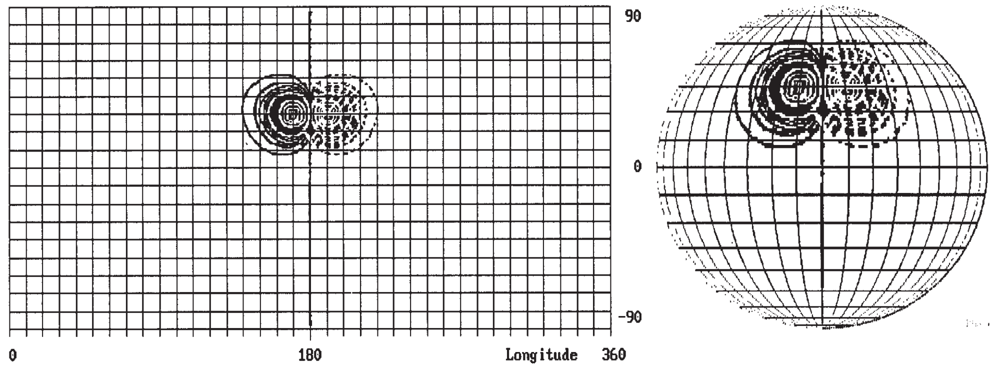

Figure 1. Mercator-map and globe of the magnetic surface field of a spot. Magnetic sources:
$\varphi_1 = 170^o$ $\delta_1 = 30^o$ $r_1 = 0.9$ $Q_1 = +1$
$\varphi_2 = 190^o$ $\delta_2 = 30^o$ $r_2 = 0.9$ $Q_2 = -1$
Region of positive magnetic field - solid iso-lines; negative magnetic field - dashed iso-lines

In the case of a solar-like starspot the dipole is located shallowly under the surface with the direction of the magnetic moment crosswise to the radial vector, thus simulating the arrangement of the proceeding and following spots of opposite polarity. This is an extremely decentered dipole, which rises no problem using the MCD-method. A more complicated structure with better approach to a real sunspot would be achieved using a set of numerous magnetic dipoles.

Fig. 1 shows the Mercator-map and the spherical projection of the magnetic field distribution over the surface for a magnetic dipole. The distance between the proceeding and the following spot is assumed to 20^o, and the line of connection of the spots is set parallel to the equator for sifting out the typical features. Real sunspots are usually inclined. This can easily be achieved by choice of parameters. The lines with iso-magnetic field strength mark characteristic circles on the surface, that we attribute roughly to the magnetic structure of a spot.

3. The phase curves of the integral magnetic field strength

The map of the star with its conspicuous magnetic poles can be revealed only by the stellar rotation. Therefore, longitude and phase are corresponding magnitudes and can be put together in one and the same diagram, coordinating the extrema of the curves of the integral magnetic field to the magnetic poles on the surface of the star.

The integration of the surface magnetic field over the visible disk of the star is carried out by a computer program developed by GERTH et al. (1997, 1998). The computer performs the integration by averaging all line profiles of the radiation from all surface elements and weighting by the projection and vignetting conditions. Varying the angle i of the line of sight as the parameter, one gets a group of phase curves, which allows the determination of i by fitting to the observational measurements (Fig. 2a).

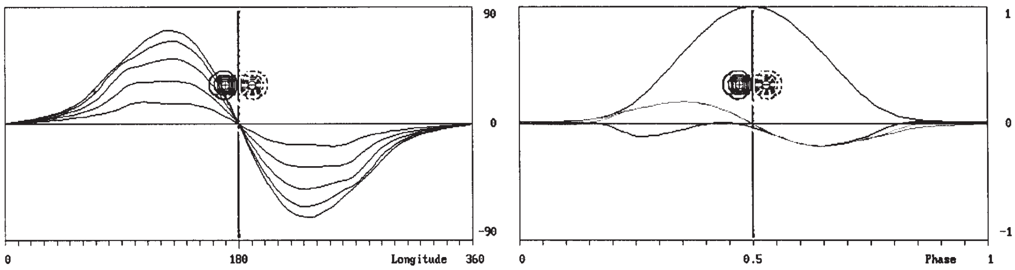

Figure 2. Spot feature and corresponding phase curves of the integral magnetic field

a) longitudinal magnetic field - STOKES V. Group of phase curves for the inclination angles $i = 70^o$ to 110^o by step 10^o (from top to bottom). All polarization types are vignetted by limb darkening separately.

b) in polarized light (ZEEMAN-effect) from top to bottom at phase 0.5:
1. - STOKES I - absolute surface field
2. - STOKES U - cross-linearly polarized
3. - STOKES Q - long-linearly polarized
4. - STOKES V - circularly polarized light

The algorithms of the STOKES-components are derived by GERTH & GLAGOLEVSKIJ (2001).

We can see at Fig. 2a, that all phase curves have a turning point near the phase of the spot center P=0.5. The difference between the maxima and the minima is much larger than this could be expected regarding only the distance between the proceeding and the following spots. This phenomenon can easily be explained by the large areas covered by the fields of unique polarity, which contribute to the integral field strength - shifting the extrema apart. On the other hand, it can not be concluded from the difference between maximum and minimum in the phase curve on the distance and location of the pair of spots with opposite magnetic polarity.

4. The polarised integral magnetic field and the Stokes parameters

Since the measurement of the magnetic field is practicable only as the result of the ZEEMAN-splitting of the absorption lines, we have to regard the polarization conditions of the atmosphere on each surface element of the star in direction to the observer. Traditionally we measure the longitudinal field by the σ-components of the circularly polarized light with the ZEEMAN-displacement of the line profile to the left and to the right in the spectrum, which is not disturbed by the linearly polarized π-components. This is the STOKES-parameter V, which gives by integration over the visible disk the effective magnetic field B_{eff}. The non-polarized light is the STOKES-parameter I, which is unaffected by the magnetic field. This is the absolute surface magnetic field B_s, which results only in a line broadening. In Fig. 2b the phase curves for the integral Q, U, V, and I components are shown. In order to represent all 4 curves in one diagram, the curve of the I-component is reduced by the ordinate to 1/3.

5. The line profiles of the integral magnetic field

The line profile is an important indicator for the surface structure of the magnetic field. The radiation from all surface elements is spread over the classes of a frequency distribution, rendering the line profile for the momentary aspect of the star. As the aspect changes with the rotation, the profile varies its form. The profile is also influenced by the chemical distribution of elements and the movements of and on the star, resulting in line broadening. Here we consider only the action of the distribution of the magnetic field on the line profile.

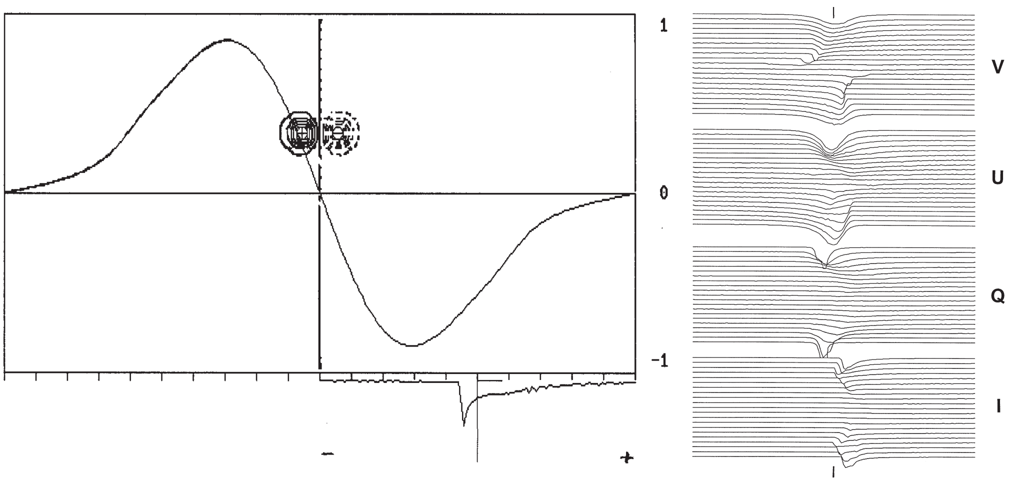

Figure 3. Phase curve of the integral magnetic field with spot feature and b) line profiles.
a) The line profile at the phase 0.4 is extremely asymmetric with the peek at the negative side and the gravity center at the positive one - both oscillating in antiphase.
Course of the line profile over the period by 20 steps

V - circularly polarized light
U - long-linearly polarized light
Q - cross-linearly polarized light
I - natural unpolarized light

Figure 3a shows the profile in connection with the phase curve and the position of the spot. The profile (Stokes V at phase P=0.4) is extremely asymmetric, the gravity center being at the positive side and the minimum at the negative one with different extension of the wings. The variation of the profile in the course of the phase can be reviewed in a series of profiles (Fig. 3b). The gravity center and the minimum oscillate in antiphase for Stokes V and U with a phase jump at the transition of the (double-)spot. The line profiles of all four Stokes-parameters show a characteristic behavior in the phase course.

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