Integral representation of the stellar surface structure of the magnetic field

E. Gerth[1], **Yu.V. Glagolevskij**[2] **and G. Scholz**[1]

[1] *Astrophysikalisches Institut Potsdam, Telegrafenberg A31, D-14473 Potsdam, Germany*

[2] *Special Astrophysical Observatory of Russian AS, Nizhnij Arkhyz 357147, Russia*

Abstract. The surface structure of the magnetic field in stars is one part of the information about the surface inhomogeneities like brightness, movement or chemical composition, which is contained in the integral radiation flux but distorted beyond recognition by losses of information on the topographical arrangement over the surface because of convolution processes and partial invisibility.

Therefore, the complicated processes, beginning with the representation of the map of the surface field distribution and ending with the resulting phase-curves of the integral magnetic field, are simulated by a computer program. We use this program as a tool for the analysis of the magnetic field structure out of the really observed data in phase diagrams by variation of the parameters and by fitting the calculated curves to the observed ones.

Key words: stars: chemically peculiar - magnetic field - rotation - mapping

1. Programming of the map

Mapping of individual features on the surface of a star out of the integral radiation can be carried out only in the case where the linear convolution integral transform leading to the integral flux is complete and can be inverted. However, we have to cope with the so-called ill-posed inverse problem, which cannot be solved correctly. The method proposed here relates only to a limited number of parameters for the straightforward calculation, thus offering a way to overcome this problem.

The map of the **topographical arrangement** of the surface magnetic field with its vectorial character is therefore constructed by matrices. The matrix elements are defined by the spherical coordinates of the longitude and the latitude.

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).

Contrib. Astron. Obs. Skalnaté Pleso **27**, (1998), 455– 457.

The calculation of the magnetic field components makes use of the fact that the linear aggregates of the potentials of **point-like field sources** are superposed linearly. Thus, the potential of a single source will be calculated by the transform of rectangular to spherical coordinates. Then the field vector is easily derived by the spherical gradient of the potential.

The advantage of the **linear superposition of potentials and vector fields** is obvious: the calculation is not limited to special source configurations. The individual treatment of *monopoles* allows an arbitrary composition of configurations up to higher multipoles. In principle, any field you like can be represented by a row of "monopole" fields, the sum of charges being zero.

The **arrangement of the sources** may be anywhere in the interior of the stellar body. However, there could be magnetic sources placed even at the surface, representing stellar spots like sun spots. Sources outside the star could be positioned in companions, which influence the surface of the main star with their fields.

2. Aspect window and convolution

The **aspect window** is determined by the visible hemisphere of the star. The program computes, for any inclination angle with respect to the rotation axis, the projection of the elements and the limb darkening, reducing it to a rectangular matrix of the same rank as the map.

The matrices of the map and of the aspect window are subjected to a **matrix convolution**, which corresponds to the rotation of the star inclined to the line of sight to the observer. There are a series of geometrical aspects with a number of steps, determined by the rank of the matrix. In the present version of the program the highest rank is 104.

The **convolution algorithm** is the core of the program. It is multivalent and can be used also for other surface quantities.

3. Physical problems of the integral magnetic field

Usually we interpret the effective stellar magnetic field by the **Zeeman displacement** of the gravity centers of the line profiles of oppositely polarized light. Since the light comes from the visible hemisphere of the star, all parts of the surface contribute differently to the whole profile and its resulting spectral position.

The **effective magnetic field** B_{eff} is not simply a mean value but already the result of weighting and convolution of the radiation flux containing the magnetic field information in the form and position of the profiles of all surface elements.

We relate to the fact, that the **center of gravity** of the profiles is given by the mean of the centres weighted by the profile integrals. Thus, we weigh the magnetic field vector of all surface elements with their spherical projection onto the line of sight including the limb darkening and integrate them over the visible hemisphere. The magnetic field is treated by the same procedure as the brightness, regarding only the vectorial character of the magnetic field.

The magnetic field is also influenced by the inhomogeneous distribution of **chemical elements** over the star's surface. This acts like a transmission factor for every surface element and undergoes likewise the weighting of profiles. The fourth component of a scalar magnitude takes the map of the chemical distribution into account.

4. Graphical representation and storage of maps and results

The usefulness of the graphical representation of the calculation is beyond any discussion. In the case of the present program, computer graphics have already served at the first stages of development for controlling and testing purposes.

The **map** of the magnetic field structure is represented by colored isolines.

The **rotation curves** are computed and drawn on to the map, so that it is easy to see how the topographical features act onto the curves.

The calculated maps and phase **curves are stored** as files on disk and may be recalled repeatedly for different calculations and graphical representations in connection with the phase-arranged observational data of real stellar objects, which are plotted in the phase diagrams corresponding to the maps of the magnetic field and/or the chemical distribution.

The program coordinates the magnetic field structure to the **chemical map** (derived by other authors and methods) but does not analyze its distribution structure.

5. The use of the program

The program is used for the investigation of the characteristic **shapes of curves**, as have been observed in magnetic stars. Examples can be seen in the papers about the stars CU Vir and α^2 CVn.

A **catalogue** of maps and resulting curves with systematic variation of parameters will be included in a data bank for comparison with observed curves.

The program will be applied to real early type magnetic stars in order to determine the topographical positions of the poles and to discover their magnetic structure as the basis for the explanation of the connection between **stellar magnetism and chemical composition**.