Phase curves and line profiles of stellar magnetic fields

related to the Stokes-parameters I, Q, U, V

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Modeling of the magnetic field structure of stars for fitting the **derived magnitudes** of the field strength to the observation requires a physically founded theory for the construction of the field by the **generating magnitudes.**

Relating to the potential theory, the magnetic field – like every vector field – is generated by its **sources and vortices**, which combine superposing the fields linearly.

The Magnetic Charge Distribution (MCD) allows the calculation of the fields of point-like sources with ***virtual magnetic charges***, despite those do not really exist.

The combination of two oppositely charged sources, however, is a magnetic dipole with a **magnetic moment**, which is a real generating magnitude of the magnetic field.

The field generating magnitudes (sources, vortices, multipoles) define the **vector field** in the whole surrounding space, especially also on the surface of a sphere of a stellar body.

The MCD-method offers the possibility of analyzing the magnetic field in respect to its generating sources, separating even **combinations** of sources like magnetic dipoles.

The observation of the integral magnetic field from the star's surface is given as phase curves and line profiles of the polarized light according to the four **Stokes parameters I, Q, U, V**.

With the help of the model, typical phase curves and line profiles can be constructed, compared with the observed ones, and fitted to them by **variation of parameters**.

Here are raised only two typical cases:

1. magnetic **monopole**
2. magnetic **dipole,**

both seen equator-on with the poles in the equatorial plane.

The magnetic dipole in the plane of the equator is realized approximately at the CP star 53 Cam (Bagnulo et al. 2000, Gerth et al. 2000).
The deviation of the phase curve from the sinusoidal form is caused, presumably, by the arrangements of **rings** with accretion or depletion of chemical elements **around the poles**.

We demonstrate here only the very simple cases. The **algorithm** for the calculation of phase curves and line profiles from the magnetic field distribution an the star's surface is, of course, much more general and allows arbitrary angles if sight and the overlay of an opacity layer on the surface by a factor.

The **theory** for the algorithms of the computer program is described by Gerth et al. (1997, 2001). The program allows the calculation and the graphical representation of maps, globes and line profiles in connection with the phase relation.
The line profiles with gravity center are shown on the screen, moving in the course of the rotation.

The line profile is formed only by the weighted **integration** over the visible hemisphere of the field components on the surface elements in direction to the observer accounting for the limb darkening. The spectral Zeeman displacement from every surface element is spread over the classes of a frequency distribution. The physical line forming due to radiative transfer (and others) is not accounted for. Such "physical profiles" would be included by convolution for each surface element.

The model calculations are very instructive, because by this way the clean and undisturbed situation is investigated, under which the magnetic field is generated out of its sources.

Results:

1. The phase curves represent the course of integral magnetic field, which is the gravity center of the profile.
2. The line profiles are usually asymmetric and deviate heavily from the (Gauss-) normal distribution.
3. Maximum and gravity center do not coincide.
4. A maximum is not given by the sight pole-on, but by the integral over the disk of all field components in sight.
5. The profiles vary in form and width with the phase.
6. The Stokes components **Q** and **U** produce double waves of the phase curves and an inversion of the profile form.
7. The **I** and **V** Stokes components show the best correlation of the profile to the phase curve.

References:

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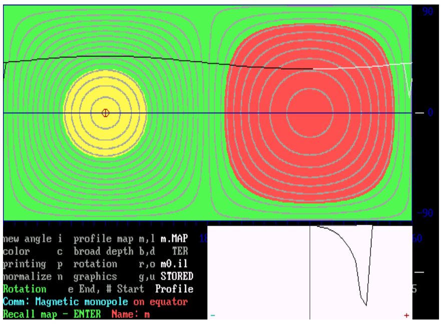
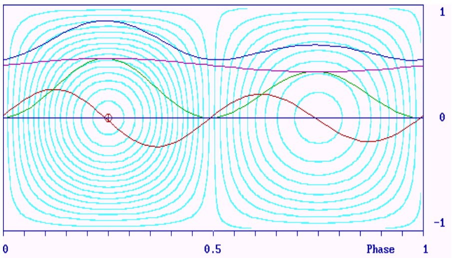
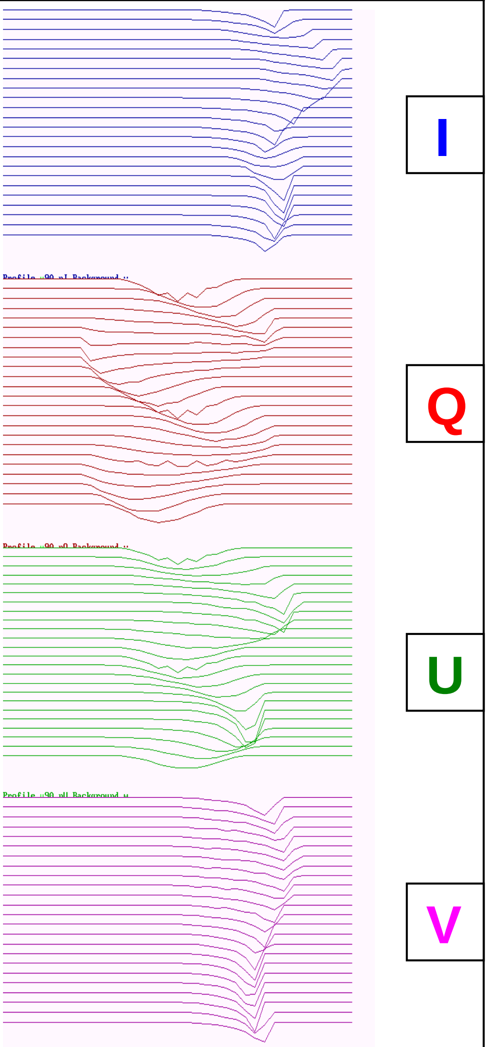


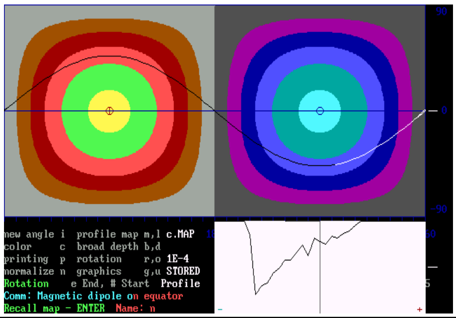
Magnetic monopole with coordinates $\varphi = 90°$ $\delta = 0°$ r = 0.3.
The field is always positive with a minimum at $\varphi = 270°$ $\delta = 0°$, corresponding to the phase curve of the integral longitudinal field.
The line profile is asymmetric and has its deepest point a the field minimum by phase 0.75, which deviates from the gravity center.
The profile is moving on the screen in phase of the rotation.



Phase curves of the Stokes parameters for a magnetic monopole:
I blue **Q** red **U** green **V** violet
The curves of the parameters I and V show a similar behavior because of the overall positive field strength in radial direction.
The Q-curve has positive and negative parts because of the gradient of the field in direction of the longitude with maxima and minima and zero at the pole and counter pole. The U-curve is always positive.



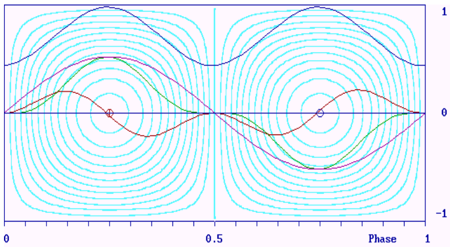
Series of line profiles by phase step 0.05 for Stokes **I**, **Q**, **U**, **V** .
A virtual magnetic monupole is investigated for its Stokes profiles.
The parameters I and V reflect best the expected course of the field;
Q shows a double wave with a change of polarity and asymmetry;
U is only positive; I, U an V have the steep edge at the positive side.



Central magnetic **dipole** with separated magnetic charges :

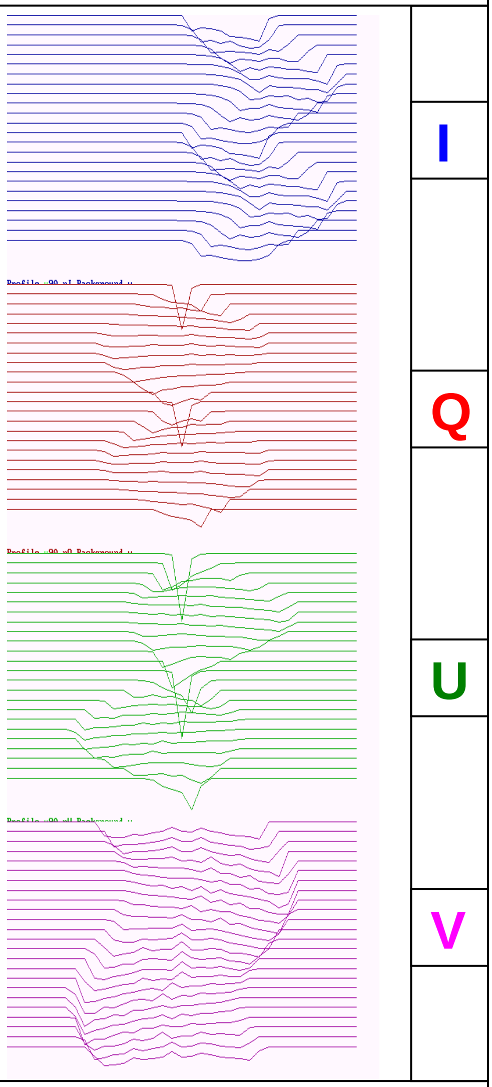
Parameters:	Radius-fraction	Longitude	Latitude	Charge
	$r_1 = 0.5$	$\varphi_1 = 90°$	$\delta_1 = +45°$	$Q_1 = +1$
	$r_2 = 0.5$	$\varphi_2 = 270°$	$\delta_2 = -45°$	$Q_2 = -1$

The line profile changes the polarity at phases 0 and 0.5 with a nearly rectangular form and shows at the poles an extreme asymmetry with a steep edge at the side turned away from the middle line. M – m



Phase curves of the Stokes parameters for a magnetic dipole I Q U V

The first part of the phase curves up to phase 0.5 shows principle agreement with the curves of the magnetic monopole. In the second part the polarity is changing. Nevertheless, extrema and zero points are similarly arranged. The **U**-curve is has its extrema at the poles, which coincide there with the **V**-curve.



Series of line profiles by phase step 0.05 for Stokes **I**, **Q**, **U**, **V** .
Stokes profiles of a magnetic dipole consisting of two magnetic charges in the equatorial plane. The parameters I and V reflect also for a dipole best the expected course of the field. Besides the double wave, at Q and U the variability of the wave length is conspicuous.

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