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ON THE INTERPRETATION OF THE MAGNETIC CURVES OF THE Ap STARS AS DETERMINED BY THE PHOTOGRAPHIC TECHNIQUE

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ABSTRACT

Theoretical Zeeman-analyzed line profiles in magnetic stars have been computed for decentered dipole configurations of the magnetic field. It is found, on the basis of these profiles, that if the core of the lines are emphasized during the reduction of Zeeman-analyzed photographic plates, the longitudinal field obtained deviates from its true value. The deviations predicted are successful in producing the anharmonic variations observed in several Ap stars.

Subject headings: line profiles — magnetic stars — peculiar A stars — Zeeman effect

I. INTRODUCTION

One of the failures of the oblique rotator model listed by Preston (1967) is that it does not predict the anharmonic variations of the longitudinal component of the magnetic field that are observed in many Ap stars. Landstreet (1970) has proposed a decentered dipole configuration of the magnetic-field geometry to explain those curves. This model is attractive because of its simplicity and its explanation of many other observed features of the Ap stars (Preston 1971). Landstreet's fit to the magnetic curve of 53 Camelopardalis is excellent. However, Huchra (1972) finds that the parameters of this model of 53 Cam are incompatible with the observed amplitude of the surface field (H_s). The parameters of the decentered model determined by Huchra, to agree with longitudinal and surface field extrema, fit poorly the longitudinal field curve.

In this work, theoretical Zeeman-analyzed line profiles are computed for decentered dipole configurations of the magnetic-field geometry. These line profiles are then analyzed, attempting to simulate actual photographic measurements.

II. THE MODELS

The computer program used has been briefly described by Borra (1973*a*) and in greater detail by Borra (1972). The visible disk of the star is subdivided into slices of approximately equal area. Given a configuration of the geometry of the magnetic field, the wavelength dependence of the Stokes parameters across a spectral line formed in the presence of the magnetic field is computed for each slice, under the Milne-Eddington approximation. Rotation is taken into account and the wavelength dependence of the Stokes parameters is synthesized for the whole visible disk. The line profiles in circularly polarized light formed by a Babcock-type Zeeman analyzer are computed from the Stokes parameters. The spectral line used has the same characteristic as in Borra and Dworetsky (1973*a*, Paper I) and Borra (1973*b*, Paper II). The wavelength dependence of the absorption coefficients is taken to be Gaussian. The saturated line is assumed to have a simple triplet splitting, a g-value of 1.2 and a wavelength of 4260 Å. The magnetic-field geometry considered is a decentered dipole one (Landstreet 1970), and we are dealing with the oblique rotator only. The various parameters of the models have been defined in Paper II. Several values of the longitudinal component of the magnetic field are obtained for each model (see Paper II for more complete definitions): H_e represents the true longitudinal fields; $H_e{}^c$ the longitudinal field obtained from the Zeeman-analyzed line profiles; H_{e3} and H_{e7} are values of the longitudinal field obtained from the Zeeman-analyzed line profiles (after convolution with an instrumental profile and application of a photographic curve) taking only, respectively, 30 percent and 70 percent of the profiles (from the deepest part of the line) into account.

We will not attempt to reproduce the magnetic curves of specific Ap stars. Rather, we will consider a very general case and show how the H_{e3} and H_{e7} curves can reproduce the general features of the magnetic curves of some Ap stars.

The models considered have in common the following parameters: $H_p = 10{,}000$ gauss; $v_e = 15.0$ km s^{-1}; $i = 90°$; $\beta = 90°$. The decentering parameter a ranges from 0.0 to 0.4. Note that it is H_p, the value of the magnetic field at the strongest pole on the surface of the star, that is kept the same for all values of a and not the dipole strength. In figures 1 through 5 we have plotted the H_e, $H_e{}^c$, H_{e3}, H_{e7} curves during half of the cycle for this family of models. Ideally one would like to reproduce exactly the weighting that the human eye gives to different parts of the profiles during the reductions, but this is a rather difficult thing to accomplish numerically. There is probably a tendency to emphasize the core of the lines. H_{e3} and H_{e7} are useful in that they give us an indication of the changes in the measured longitudinal field when different parts of the profiles are emphasized.

III. DISCUSSION

We can see from figures 2 through 5 that although the H_e and $H_e{}^c$ curves are very nearly symmetric, the

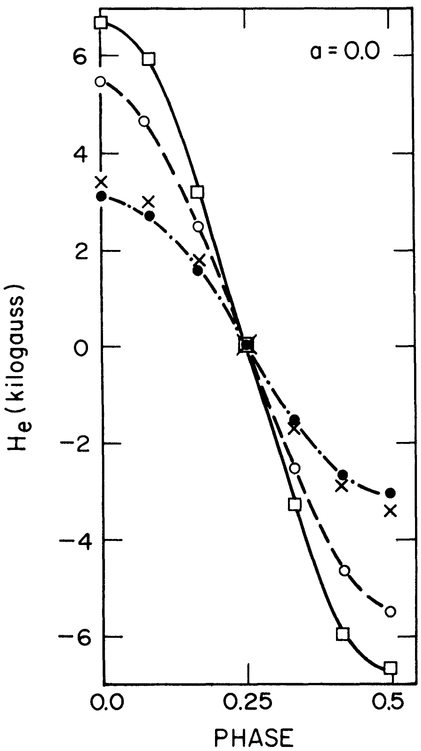

FIG. 1

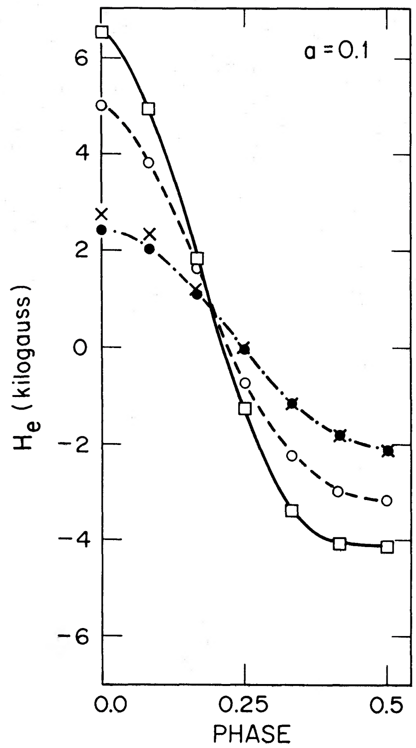

FIG. 2

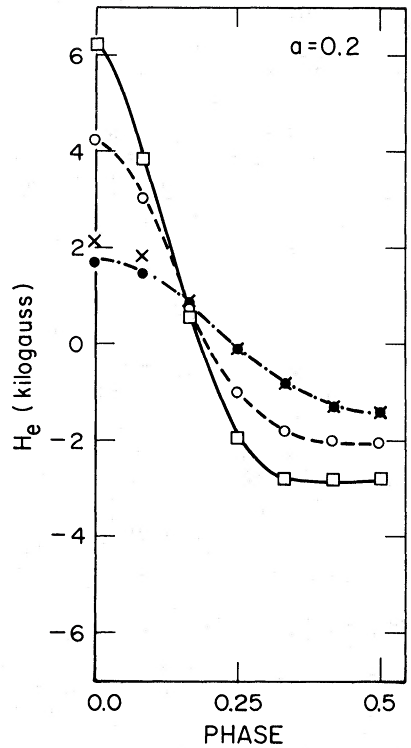

FIG. 3

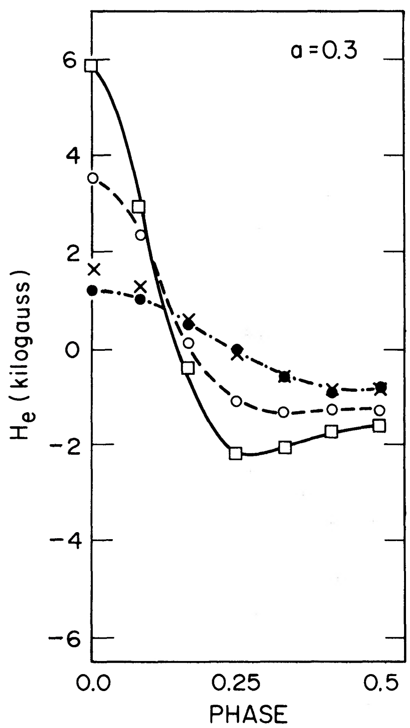

FIG. 4

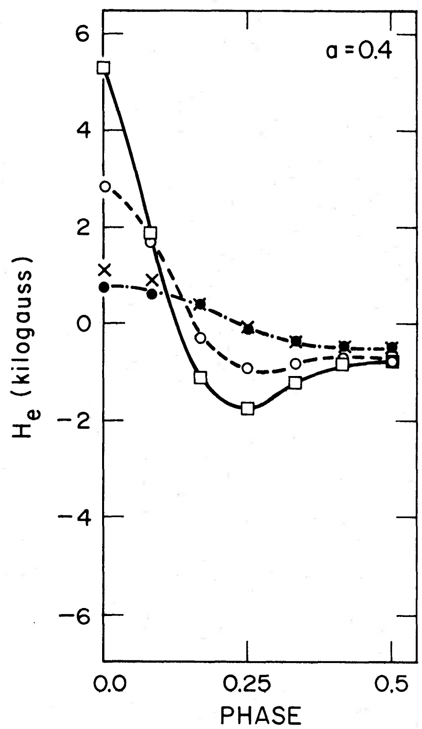

FIG. 5

FIGS. 1–5.—Values of the longitudinal field obtained in different conditions are plotted as a function of phase for decentered dipole models of magnetic stars. The figures are identified with the decentering parameter a. The symbols are: $H_e(\cdot)$; $H_e^c(\times)$; $H_{e7}(\bigcirc)$; $H_{e3}(\square)$.

H_{e3} and H_{e7} curves are not. For $a = 0.0$ the H_{e3} and H_{e7} curves are symmetric. As a is increased, one of the extrema becomes sharper while the other broadens. As a increases, H_{e3} and H_{e7} near $\phi = 0.5$ decrease with respect to H_{e3} and H_{e7} near $\phi = 0.0$. Phase 0.0 is taken to be when the line of sight lies in the plane defined by the axis of rotation and dipole axis, the observer viewing the strongest pole on the surface of the star. For the models with $a = 0.3$ and 0.4 the negative extrema of H_{e3} and H_{e7} do not occur at phase 0.5 as might be expected. There is a dip in the H_{e3} and H_{e7} curves, centered on phase 0.5. These features are remarkably similar to the ones observed in some Ap stars, such as 53 Cam (Huchra 1972) and α^2 CVn (Babcock 1958*b*). Notice that Huchra finds that the H_e curve derived from his model does not reproduce well the photographically determined longitudinal magnetic field. He invokes a more complicated geometry to account for this deficiency. It appears that if H_{e3} or H_{e7} mimics the actual reduction procedure, this deficiency is explained with a simple decentered dipole. In α^2 CVn the sharp extremum occurs at positive polarity while the sharp extremum occurs at negative polarity in 53 Cam. Following our interpretation, this would indicate that the dipole is displaced in the direction of the positive pole in α^2 CVn and of the negative pole in 53 Cam.

Both in 53 Cam and β CrB the sharp extremum occurs at maximum H_s (however, the sharpness of the negative extremum is not well established in β CrB). Preston (1967) remarks that in the periodic variables the lines are usually broadest during the sharp extremum. Both these features are in agreement with the models which have larger H_s during this extremum.

As an additional note in favor of the decentered dipole model, let us consider a remark made by Babcock (1958*a*) on the appearance of the Zeeman-analyzed line components of 53 Cam on a plate taken near positive extremum (the broad extremum in this star). Babcock comments on the sharp and symmetric line components, indicating that at this time the field was nearly purely longitudinal. Babcock's description fields very well the appearance of the theoretical Zeeman-analyzed line profiles near $\phi = 0.5$ of the models. The observer then views the weakest pole of the star and the magnetic field is nearly purely longitudinal.

Both H_{e3} and H_{e7} tend to overestimate H_e near $\phi = 0.0$ and $\phi = 0.5$. This is caused by the complicated effect on the line profiles of a combination of field geometry and rotational Doppler shifts. Rotation is necessary to produce the sharp and broad extrema. For models with parameters equal to those of the models of figures 2 and 3, but $v_e = 0.0$, the H_{e3} and H_{e7} curves reproduce fairly closely the H_e and H_{e7} curves at all phases. If a is further increased (with $v_e = 0.0$) the H_{e3} and H_{e7} curves reproduce poorly the H_e curve (see Paper II).

In figure 6 we have reproduced the H_e, $H_e{}^c$, H_{e3}, and H_{e7} curves obtained from a model having the parameters determined by Huchra (1972) for 53 Cam. Here the phase convention has been changed to match the extrema of H_s in 53 Cam. H_{e3} and H_{e7} do not reproduce exactly the observed longitudinal-field extrema of this star, presumably because H_{e3} and H_{e7} do not reproduce exactly the weight given by the eye or because the parameters of the model are not exact (or a combination of the two). However, the H_{e3} and H_{e7} curves do show a broad and a narrow extremum. If the measured longitudinal magnetic field deviates from its true value in the sense predicted by the models at the extrema, then we can expect the parameters of Huchra model to be in error, as the observed extrema will be larger than the true ones. These extrema are used to determine the parameters of the model. The H_{e3} and H_{e7} extrema from this hypothetical "true" new model will deviate less from the observed ones. I have not attempted to "correct" Huchra's model because these corrections will depend on how well H_{e3} and H_{e7} reproduce the weight given by the eye at the extrema.

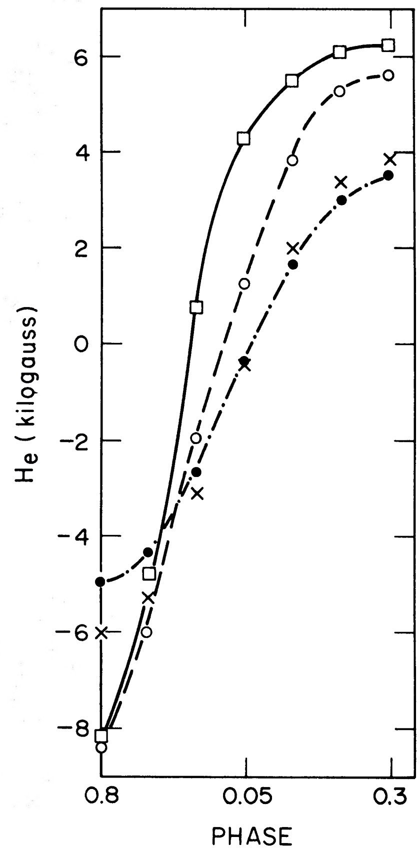

FIG. 6.—Values of the longitudinal field of a model of 53 Cam. The symbols are the same as in the previous figures. The phase convention has been changed.

IV. CONCLUSION

One must use caution in the interpretation of H_{e3} and H_{e7}. They probably do not reproduce exactly what the eye actually measures during the reductions. It is also probable that the eye will tend to emphasize more the core of the lines when they have complicated profiles (during crossover) and less so when the profiles are simple (as near $\phi = 0.5$). However, H_{e3} and H_{e7} are useful as an indication of the direction in which the photographically determined longitudinal field will deviate from its true value when the core of the lines is emphasized during the reductions. These deviations are successful in producing sharp and broad extrema correctly correlated with the phase of maximum and minimum surface field for some Ap stars. Using decentered dipole models, the H_{e3} and H_{e7} curves can reproduce the magnetic curves of all periodic Ap stars with reasonable input parameters (see also Paper II).

To ascertain whether the arguments presented in this work are correct, and thus determine the actual shape of the longitudinal-field variations in magnetic stars, we can use photoelectric observations. One could use either measurements of the circular polarization in the wings of a Balmer line with a passband of a few Å, or obtain photoelectrically the Zeeman analyzed line profiles and compute H_e^c, which appears (for small a), to give a fairly reliable measure of the longitudinal field.

There are a few broadband photoelectric observations of 53 Cam in the literature. Angel and Landstreet (1970) observing with a 5 Å bandpass in the wings of Hγ find a longitudinal field of $\sim 2000 \pm 500$ gauss near positive extremum, instead of ~ 4000 gauss (they attribute the discrepancy to a possible broadening of the bandpass in the converging beam). Kemp and Wolstencroft (1973), using a 15 Å bandpass in Hβ find $\sim 3300 \pm 1000$ gauss at $\phi = 0.23$ (instead of ~ 4000 gauss) and $\sim 800 \pm 500$ gauss at $\phi = 0.45$ (instead of ~ 2500 gauss). It is perhaps premature to speculate on so few measurements, however these observations (especially the one near crossover) are in good agreement with the effects proposed in the present work.

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