THE DISTRIBUTION OF FE, CR AND SI OVER THE SURFACE OF Θ AUR

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ABSTRACT. Very accurate spectroscopic line profiles have been obtained at various phases during the $3^d.618$ period of the magnetic variable Ap-star Θ Aur. These profiles were observed using a Reticon detector at the coudé focus of the 3.5 metre Canada-France-Hawaii telescope. The mapping of Si, Cr and Fe over the surface of the star was done by solving the Inverse Problem. Complex spotty structure has been revealed with the number of Fe spots found being as great as six. The distribution of Cr is found to be similar to Fe but with less detailed structure. Si is distributed quite differently from Fe and Cr. Discussion of the relationship of the magnetic field maximum phase and the light curve along with the maps of the distribution of elements suggests that the principal spots of Fe and Cr are in phase with the light variability but they are 90° out of phase with Si and the magnetic field variation. We are surprised by the Si variability seeming to be 90° out of phase with the light variability.

INTRODUCTION

Θ Aur (HD40132 = HR2095) is a magnetic Ap star (B9p) with a very well defined magnetic variability. Borra and Landstreet (1980) have measured an effective magnetic field that varies almost sinusoidally from about + 350 Gauss to − 250 Gauss. Rensbergen et al. (1980 a & b) made a detailed study of Θ Aur including an attempt to map the surface distribution of elements. They obtained the best ephemeris for the variability of Θ Aur by combining results from several papers as well as their own work. They give J. D. = 2442766.55 + $3^d.6190 \pm 0^d.0005$ for magnetic positive extremum and note that the light curve extrema do not coincide with the H_e extrema.

OBSERVATIONS

Observations of Θ Aur were made in 1981 and 1982 at the coudé spectrograph of the CFHT using a Reticon detector. The dispersion is 2.5 A/mm and the total instrumental profile is 90 mA FWHM. Pixel spacing is 35 mA so we smoothed the data from the Reticon over three pixels. The

C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 137–140.

signal-to-noise ratio for the observations is around 500 (see Fig. 1). Three regions of the spectrum were monitored: λλ 4890 - 4955, λλ 5010 - 5075 and λλ 5480 - 5545.

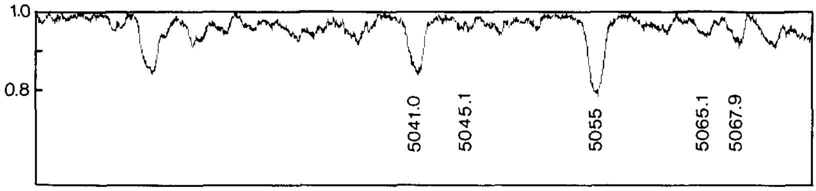

Fig. 1 An example of the spectrum of Θ Aur as observed using a Reticon detector. Wavelengths of some of the analysed lines are noted.

In order to map the star using the techniques of Goncharsky et al. (1982) we need to obtain V_r and V sin i. To eliminate the effects of the variable profiles in obtaining V_r and V sin i, the profiles for all phases were plotted on one diagram and the outer envelope used. From this it was determined that V sin i = 55 km/s and V_r = 31 km/s.

MAPPING THE SURFACE DISTRIBUTION OF LINE STRENGTH

Because of the width of the lines in Θ Aur, only a few lines were free enough of blends to be chosen for mapping using profiles. To use the approach of Goncharsky et al. for mapping, you must estimate i from the period, radius and V sin i of the star. Rensbergen et al. (1984 a & b) discuss the possible values of radius in Θ Aur and estimate it to be between 3.5 and 7.2 R_o. Consequently two intermediate values of radius were tried in this analysis, R = 4.0 R_o (with corresponding i = 80°) and R = 4.9 R_o (with corresponding i = 53°). The difference between the models for these different values of R (and i) was not great. Most of the maps presented here are for i = 53°.

Fig. 2 gives the maps for the Fe distribution. Fig. 2a is the only map that assumes i = 80° and it gives the result for the strong line Fe IIλ4923. We note that the contours are smooth and that one major spot at the longitude of light maximum dominates. Fig. 2b shows the more complex spot structure of the weaker lines; in this case the line is Fe IIλ5045. One might be inclined to dismiss the complex structure as noise except for the fact that the pattern repeats for the other weak Fe lines. Fig. 2c is a composite and shows that for the lines λ5045, λ5065, λ5067 and λ5510 there is remarkable repeatability in the location of the spots. For the purposes of this discussion the spots are labelled from I to VI. Spot IV coincides with the major spot of the map for λ4923. We note here that the longitude for these maps is arbitrary and that on this arbitrary scale the H_e positive extremum occurs when longitude 155° ± 25° is subsolar, light maximum when 83° is subsolar and light minimum when 255° is subsolar.

In Fig. 3 we see comparable maps for Cr and Si. Fig. 3a is for the CrII line λ5508 and Fig. 3b is for the SiII line λ5041. Note that the Cr pattern resembles Fe but the major peak for Si is displaced almost 90° earlier in phase so that it should correspond roughly to the longitude of the magnetic negative extremum.

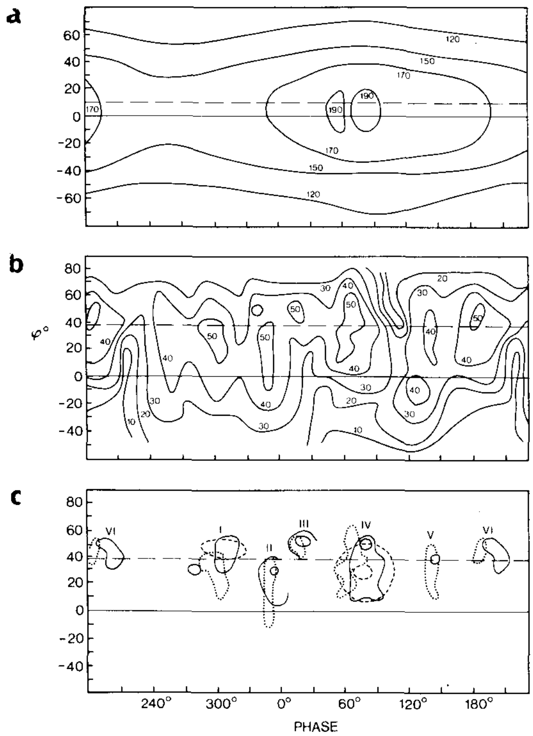

Fig. 2 Maps of the iron line strength distribution. a) Map of the strong line FeII λ4923.9 assuming i = 80°. Contours are marked in mA. b) Map for the weak line FeII λ5045.1 assuming i = 53°. c) Map showing peak values of local line strength for λλ5045, 4065, 5067 and 5510 of FeII assuming i = 53°.

Fig. 4 illustrates the closeness of fit between the observed profiles for three of the lines used for mapping and the profiles predicted by their corresponding maps. In all of the maps discussed above we suggest that the contours are only reliable in a belt within about 45° of the subsolar line. The subsolar line is indicated by a dashed line on the maps.

CONCLUSIONS

The first and simplest conclusion is that for θ Aur we have the Cr and Fe maximum in phase with the light variability but 90° out-of-phase with the Si variability and the variation in H_e. It is not unusual for Cr and Fe to be 90° out-of-phase with the magnetic field, that is what one expects if the Fe and Cr maxima are near the magnetic equator of Ap stars but it does seem unusual to have the light variation and Si variation 90° out-of-phase. The second point is that the maps for weak Fe lines show a fine structure of multiple separate spots that is fairly convincing and that seems to suggest we might not be dealing with a geometry that can be reduced to simple polar spots or a simple magnetic equatorial belt. We note also that Si seems to be associated with the magnetic poles in Θ Aur and with the negative pole especially.

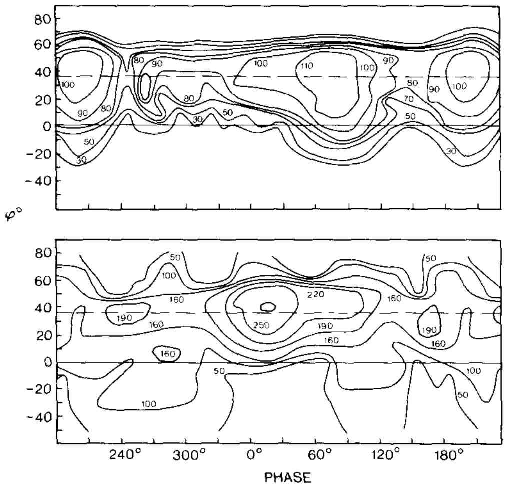

Fig. 3 Maps of the chromium and silicon distribution. a) Map of the CrII λ5508.6 line assuming i = 53°. b) Map for the SiII λ5041.026 line assuming i = 53°. Contours in mA.

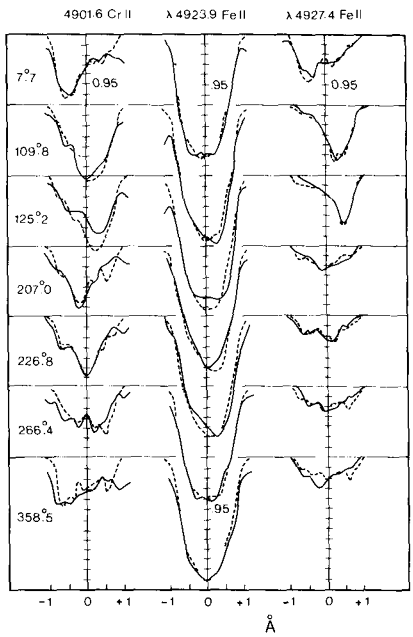

Fig. 4 Comparison of observed profiles (solid line) and profiles computed from maps (dashed lines). Phases are given at the left.

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