APPLICATION OF DEUTSCH'S METHOD FOR 53 CAM

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ABSTRACT. 53 Cam is a well-known magnetic, spectroscopic and photometric variable star of Ap-type. The line intensities of 53 Cam show a variation, which has a period of 8^h. The oblique-rotator model, developed mathematically by Deutsch /1970/, has been applied for the spectral and magnetic variations. In this paper, using Deutsch's method, the distribution of CrII, EuII, TiII, SrII on the stellar surface is analysed and the relation between the abundance of elements and the magnetic structure is studied. The Laplace and Fourier coefficients for each elements have been computed and also the distribution of the elements at the stellar surface has been drawn by a Sinclair ZX Spectrum personal computer.

1. INTRODUCTION

53 Cam is classified as an A2p star. Probably, this star has a red companion /V=12.06/. The magnetic field of the star is strong and variable. Borra and Landstreet /1976/ observed $-5400 \pm 350 < H_e < +4300 \pm 460$ gauss, with a period of $8^h.0267$. The star is a spectroscopic binary as well.
The photoelectric magnetic curves of Borra and Landstreet are explained very satisfactorily by oblique-rotator models the observed variation in field strength it is possible to infer the distribution of magnetic flux over the stellar surface, although not always uniquely. Borra and Landstreet found, that one of the magnetic poles is stronger than the other. A field which has this property and easy to model can be obtained by displacing a dipole along its axis with a fraction of the stellar radius. Borra and Landstreet found that the observed magnetic curves of 53 Cam could be modelled this way, although an extremely large displacement /a=0.67/ was necessary to reproduce the $H_e(\Phi)$ curve of 53 Cam. They fitted a

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decentred dipole model for the observed extremes of H_e and H_s to determine the values of i, β, H_p and a, where i is less than 90^o, β is the angle between the observable stellar rotational pole and the positive magnetic pole, H_p is the field value at the stronger magnetic pole, and **a** is the fractional displacement in the direction of the positive pole. Preston /1970/ calculated the parameters $(i, \beta, H_p, a) = (65^o, 100^o, -28{,}000$ gauss$, -0.15)$ or $(80^o, 115^o, -28{,}000$ gauss$, -0.15)$. According to Huchra /1972/ $(i, \beta, H_p, a) = (50^o, 100^o, -28{,}400$ gauss$, -0.145)$. All of the model parameters vary about 10%.

2. APPLICATION OF THE OBLIQUE-ROTATOR MODEL

This paper applies Deutsch's /1970/ method and uses his notations. The variation in abundance is represented by the variation of the distribution function $\xi(\Psi, \nu)$ for a given spectral line. On the stellar surface the polar distance is Ψ , and the azimuth is ν. $\xi(\Psi, \nu)$ may be represented as the real part of a Laplace-series:

$$\Xi(\Psi, \nu) = \langle W\rangle \sum_{n=0}^{\infty} \sum_{m=-n}^{n} A_n^m \exp(im\varphi) P_n^{|m|}(\cos\Theta)$$

where $\langle W\rangle$ is the observed equivalent width, averaged over the cycle of the variation.

The Ψ, ν spherical coordinate system is related to the star, the θ, φ system is related to the observer.

$$\Xi(\Psi, \nu) = \langle W\rangle \sum_{n=0}^{\infty} \sum_{m=-n}^{n} B_n^m \exp(im\varphi) P_n^{|m|}(\cos\Theta)$$

The variations of observable quantities such as $W/\langle W\rangle$ and V as functions of the phase can be expressed by Fourier series. The Fourier coefficients are functions of A_n^m.

$$W/\langle W\rangle = \sum_{n=m}^{\infty} D_{-m} \exp(-im\Phi)$$

$$(W/\langle W\rangle) \cdot V = (V_e \sin\chi) \sum_{m=0}^{\infty} E_{-m} \exp(-im\Phi)$$

$$D_{-m} = \sum_{n=m}^{\infty} P_n^m A_n^m \qquad E_{-m} = \sum_{n=m}^{\infty} Q_n^m A_n^m$$

We assume the classical limb darkening and line weakening laws:

$$\Lambda = 1 - \mu + \mu\cos\Theta \qquad J = 1 - \kappa + \kappa\cos\Theta$$

For further details of mathematics see Deutsch /1970/.

It is found that the observations of $W/\langle W\rangle$ and $(W/\langle W\rangle) \cdot V$ can well be represented by Fourier series of second degree. The period can be observed. The parameters $\mu, \kappa, \Lambda_o, \chi, V_e$ of the star have to be determined and substituted into the following equations:

$$d_o = p_o a_o^o + p_1 a_1^o \cos\chi + \tfrac{1}{2} p_2 a_2^o (1 + 3\cos 2\chi) = 1$$

$$d_{-1} = p_1 a_1^1 \sin\chi + \tfrac{3}{2} p_2 a_2^1 \sin 2\chi$$

$$\delta_{-1} = p_1 \alpha_1^1 \sin\chi + \tfrac{3}{2} p_2 \alpha_2^1 \sin 2\chi$$

$d_{-2}=3p_2a_2^2\sin^2\chi$

$\delta_{-2}=3p_2\alpha_2^2\sin^2\chi$

$e_o=0$

$e_{-1}(V_e\sin\chi)=V_e(-q_1\alpha_1^1\sin\chi-\frac{1}{2}q_2\alpha_2^1\sin2\chi)$

$\varepsilon_{-1}(V_e\sin\chi)=V_e(q_1a_1^1\sin\chi-\frac{1}{2}q_2a_2^1\sin2\chi)$

$e_{-2}(V_e\sin\chi)=V_e(-2q_2\ {}_2^2\sin^2\chi)$

$\varepsilon_{-2}(V_e\sin\chi)=V_e(-2q_2a_2^2\sin^2\chi)$

This system of equations can be solved for a_n^m, α_n^m and we obtain the distribution function:

$$\xi=a_o^o+a_1^o\cos\Psi+\frac{1}{2}a_2^o(3\cos^2\Psi-1)+(a_1^1\cos\nu-\alpha_1^1\sin\nu)\sin\Psi+$$
$$+3(a_2^1\cos\nu-\alpha_2^1\sin\nu)\cos\Psi\sin\Psi+3(a_2^2\cos2\nu-\alpha_2^2\sin2\nu)\sin^2\Psi$$

This method was applied in many cases:

Pyper/1969/.................................α^2 CVn
Deutsch/1970/.............................HD 125248
Rice/1970/................................HD 173650
Megessier/1975/...........................108 Aqr
Molnar, Mallama, Sorkey, Holm/1975/.......ι Cas
Floquet/1978/.............................HD 216533
Jasinski, Muciek, Woszczyk/1981/..........ι Cas

3. DETERMINATION OF STELLAR PARAMETERS

53 Cam /HR 3109=HD 65339/ is a spectroscopic and magnetic variable. Preston and Stepien /1968/ determined a period of $8^d.0278$ from photometric and magnetic observations of 53 Cam. A slightly shorter period, based on magnetic measurements, was determined by Borra and Landstreet/1977/:

JD/Positive crossover/=2435855.652+8.0267E

This paper uses the value $P=8^d.0267$.

The parameters μ and K could be determined from the model of the atmosphere of Ap star. For a given star, Θ_e, T_e and log g are to investigated. Selecting the $H\beta$, $H\gamma$ lines from the spectra of 53 Cam, and comparing these observed profiles with Mihalas' theoretical profiles the best fit has been obtained for log g=4 and $\Theta_{eff}=0.6$. An independent way of determining Θ_{eff} is given by the photometric indices from the Stömgren b-y through the Geneva B2-V1. Oke and Conti /1966/ found $0.606<\Theta_e<0.618$ from B-V. Hauck /1967/ obtained $\Theta_e=0.598$ from b-y and 0.608 from B2-V1. In this paper $\Theta_e=0.6$ is used, then $T_e=8400^oK$.

53 Cam is classified as an A2p star and from the model of

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Mihalas /Crygar 1965/ μ=0.6.
Since

$$\kappa = 1 - \frac{1}{2-\mu}\left[\frac{2(3-\mu)}{1.05} - (4-\mu)\right],$$

from this equation κ=0.16. The corresponding value of is $1-\frac{1}{3}\mu$ /Chandrasekhar 1946/. We may now proceed to find the values for p_n, q_n. For 53 Cam:

p_o=0.9523809	q_o=0
p_1=0.6824829	q_1=0.2093537
p_2=0.3243197	q_2=0.3656341

To solve the system of equations we must know the angle x and the equatorial velocity V_e. There exist different procedures to obtain them.
One of them is:

$$V_e = \frac{50.613\ R}{P}$$

where V_e : equatorial rotation velocity in km/s
R : the stellar radius in solar units
P : the rotation period in days

Stift/1974/ studied the radii of Ap stars. The radii of 35 magnetic and other peculiar A and B-type stars were calculated with the help of luminosities and effective temperatures derived for the individual stars. The results indicate a range of the radii of Ap stars from 1.7$R_\odot$ to 4.4$R_\odot$. The radius of 53 Cam is 2.1$R_\odot$ according to Glagolevskij/1971/ and 2.0$R_\odot$ according to Stift/1974/. The corresponding equatorial velocity is V_e=12.61 km/s.
An alternative determination of V_e is

$$V_e = -\frac{3p_2(e_{-2}V_e \sin x)}{2q_2\ _{-2}} = \frac{3p_2(\varepsilon_{-2}V_e \sin x)}{2q_2 d_{-2}}$$

From this V_e=$\approx$10 km/s
The parameter x was taken from the model of Borra and Landstreet/1976/.

4. RESULTS

53 Cam is a peculiar Sr-Cr-Eu star. For CrII, EuII, TiII and SrII I have computed the Laplace coefficients from the observations of Faraggiana /1973/. She measured the radial velocity and equivalent widths at different phases. From the measurements we deduce that TiII and EuII vary in anti-phase, that is the minimum of EuII= the maximum of TiII at phase 0.35 and the maximum of EuII= the minimum of TiII at phase 0.7. TiII varies in phase with the magnetic field and EuII varies in antiphase with it. The Laplace coefficients for the elements are:

	CrII	EuII	TiII	SrII
a_0^0	2	1.5	0.4024709	1.1280839
a_1^0	-3	-1	-5	10.1
a_2^0	1	2	10	-10
a_1^1	-17.752941	-0.2160624	3.4075218	-23.927259
α_1^1	29.755943	0.500322	-5.3442993	39.728049
a_2^1	8.0887676	16.213051	-9.0918818	-0.9081441
α_2^1	-13.913373	-28.087616	14.635785	0.4707353
a_2^2	-0.0082621	0.0649432	0.7875502	0.8740808
α_2^2	-0.0110430	-0.0780557	0.4299339	1.2217495

5. DISCUSSION

In the photos of Fig 1, the distribution of the elements CrII, TiII, EuII, SrII on the stellar surface can be seen. From the point of view of the distribution of the elements, two groups can be distinguished: the first group consist of EuII and TiII, the second is of CrII and SrII. There are two patches of overabundance in the distribution of EuII and TiII. In the cases of CrII and SrII we have found one patch of overabundance on the stellar surface. From the observations we know, that EuII is in antiphase with TiII. The photos shows that, where EuII has patches of overabundance, there TiII has patches of underabundance. In the cases of SrII and CrII there is overabundance on one hemisphere and underabundance on the other hemisphere. In either cases the overabundance is in the same hemisphere. In the photos there is overabundance of TiII, CrII and SrII at the positive magnetic pole and overabundance of TiII at the negative magnetic pole. Thus overabundance of TiII at the magnetic pole and underabundance of TiII at the magnetic equator can be seen. The case of EuII is the opposite of TiII. Thus overabundance of EuII is at the magnetic equator, and underabundance is at the magnetic pole. Overabundance of CrII and SrII is found only at the positive magnetic pole, and underabundance at the negative magnetic pole. In the photos the light patches correspond to overabundance, the dark patches to underabundance of the elements. All photos show half of the stellar surface.

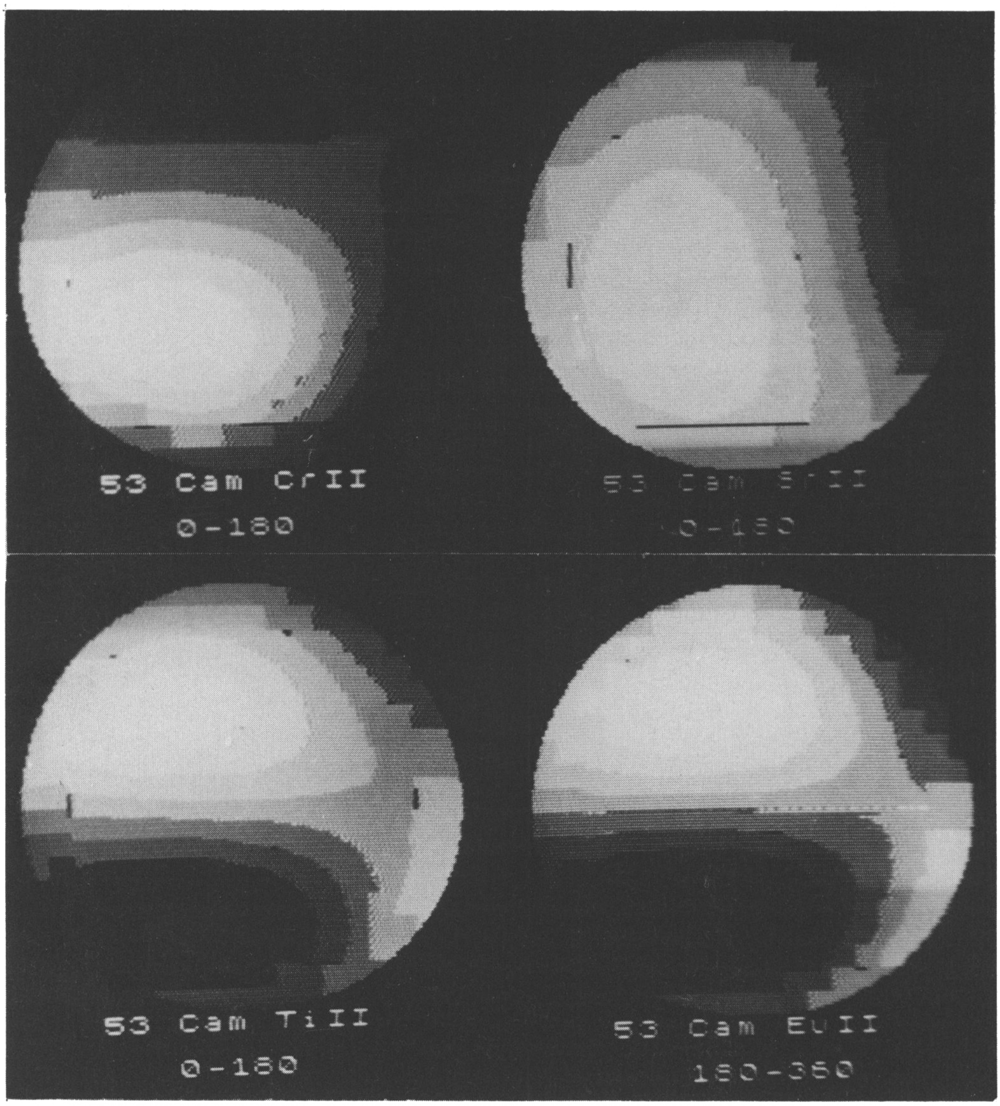

Fig. 1. The distribution of the elements CrII, SrII, TiII EuII on the surface of 53 Cam is shown in the photos.

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