THE MAGNETIC FIELD GEOMETRY AND ABUNDANCE DISTRIBUTIONS OF IRON-PEAK ELEMENTS IN THE AP STAR 53 CAMELOPARDALIS

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ABSTRACT. Spectra and magnetic measurements of the strongly magnetic Ap spectrum variable 53 Cam have been modelled using a line synthesis programme that calculates LTE line profiles, including magnetic and polarization effects and non-uniform distribution of elements over the star. The magnetic field is found to be reasonably well modelled with colinear dipole, quadrupole and octupole components of strengths (at the strong negative magnetic pole) of -16.3, -7.3, and +4.9 kG respectively. Chromium and iron are almost uniformly distributed with abundances of about 10^2 and 10 times solar. Ti and Ca, in contrast, are quite non-uniformly distributed; Ti is more than 10 times overabundant near the negative pole and probably underabundant elsewhere, while Ca is overabundant around the positive pole and slightly underabundant elsewhere.

1. INTRODUCTION

Magnetic Ap stars often exhibit variations in observed magnetic field and in the strengths of spectral lines. The magnetic variations are usually interpreted as being produced by rotation of the star, which has a strong, roughly dipolar magnetic field inclined at some angle to the rotation axis; the observed variations are simply due to changing aspect. Similarly, the spectrum variations are believed to be due to non-uniform abundance distributions over the stellar surface, with the observed changes again due to changing aspect as the star rotates.

The surface abundance variations are widely suspected to be produced in some way by diffusion of trace elements under the competing influences of gravity and radiation pressure, with some additional effect due to the magnetic field that leads to variations over the

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surface. To test theories of how diffusion may be modified by a strong magnetic field, it is important to have good maps of both the magnetic field structure and of the distribution of chemical abundances with respect to this field structure for a few stars. At present there are no stars for which good maps of both abundances and of the field structure are available.

The star 53 Cam is a well-known Ap star with a large magnetic field ($+4$ kG $\gtrsim B_e \gtrsim -5$ kG, 17 kG $\gtrsim B_s \gtrsim$ 10 kG) and strong variations of lines of Ca, Eu, and Ti (Babcock 1958; Preston 1969; Huchra 1972; Faraggiana 1973; Borra and Landstreet 1977). Both the inclination i of the rotation axis to the line of sight and the obliquity β of the magnetic axis to the rotation axis are large, so the observer sees nearly the whole star in one rotation period. 53 Cam is thus well suited to the kind of mapping that is required, and so a series of high resolution (0.1Å), high signal-to-noise (~300) spectra of the star, spaced at about $\Delta\phi = 0.12$ in phase through the 8.03 day rotation period, were obtained using the coudé Reticon system at the Canada-France-Hawaii telescope. These data, together with Balmer line Zeeman analyzer measurements of the longitudinal field previously obtained, have been modelled to obtain information about the magnetic field geometry and abundance distribution of Ca, Cr, Fe, Sr, and Ti over the surface of the star, using a new line synthesis programme. This programme calculates accurate LTE intensity (and polarization) profiles of spectral lines, taking into account the magnetic splitting and radiative transfer effects for the full Stokes vector, as well as allowing a non-uniform abundance distribution over the stellar surface. This programme is used to model in the "forward" direction; an initial magnetic field geometry and simple abundance distribution is assumed, profiles of various spectral lines are calculated and compared with observations, and the assumed models are modified until reasonable agreement is obtained. In practice, this method seems to converge to satisfactory models.

2. RESULTS FOR 53 CAM

For 53 Cam, this modelling has been carried out using visual inspection of results, and guesses to improve the models. Such a procedure can only cope with a small number of parameters, and so the magnetic field has been limited to colinear dipole, quadrupole, and octupole components of adjustable polar strength and obliquity. The inclination and obliquity (which are interchangeable) have values of about 64° and 82°; the polar strengths of the field components are -16300, -7500, and +4900G at the strong negative pole. The dipole component provides the large observed effective field; the quadrupole introduces an asymmetry such that the field strength around the negative pole is considerably larger than around the positive pole; and the octupole increases the magnitude of the field strength around the magnetic equator relative to that at the poles.

Similarly, a simple few-parameter model of the abundance distribution has been adopted. After considerable experimentation, it was found that all line profile variations could be approximately reproduced assuming three zones, each of constant abundance: a cap extending 60° from each magnetic pole, and a belt, also 60° wide, around the magnetic equator. For each element, the abundance of each of the three zones is adjusted to obtain best agreement with observation.

This simple abundance distribution geometry gives a good model of Cr and Fe lines. Both of these elements are found to be slightly more abundant (about +0.4 dex) in the polar caps than in the equatorial belt; the polar abundance of Cr is about 2.0 dex above solar, while Fe is about 1.0 dex overabundant.

Sr is represented in my spectra by only one, somewhat blended, line, but seems to have an overabundance of about +3.4 dex around the negative pole, and an overabundance of about +2.8 dex elsewhere.

Ca and Ti are still more non-uniform in abundance. Ti seems to be overabundant by about 1.4 dex in the cap around the negative pole, but underabundant by an uncertain factor elsewhere. Ca is apparently rather overabundant around the positive magnetic pole and somewhat underabundant elsewhere. (Models of Ti and Ca are less well-determined than those for Cr, Fe, and Sr because at some phases the observed lines are weak enough to be dominated by rare earth blends or to vanish.)

A paper describing these results in more detail has been submitted to the Astrophysical Journal.

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DISCUSSION

MEGESSIER What are the constraints on the determination of the geometry of the elements overabundances according to your procedure ? How is it correlated to the field geometry ?

LANDSTREET The abundance distribution is assumed to be symmetric around the magnetic axis. The star is simply divided into a small number of zones of constant abundance (caps or rings); the abundance in each zone is adjusted to give the best agreement with observed spectral line profiles. This simple model gives a reasonably good description of Cr and Fe, which are roughly uniform in abundance with slightly (x2) higher abundances at both magnetic poles than around the equator. Ti is not as well modelled, but appears to be strongly concentrated around the negative magnetic pole and depleted elsewhere on the star.