Models for GD90 and G99-47

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Theoretical continuum and line spectra have been computed for magnetic DA white dwarfs GD90 and G99-47 by assuming centred and offcentred dipole field geometries. The results are used to investigate the dependence of broad band circular polarisation, computed on the basis of standard magnetoabsorption theory, on effective temperature and on magnetic field. A comparison is made between theory and observations of the two magnetic DA white dwarfs.

INTRODUCTION

Angel *et al.* (1974) reported the discovery of GD90, the first magnetic DA white dwarf to exhibit resolvable Zeeman structure in the Balmer lines. Since then two other magnetic DA white dwarfs have been discovered: G99-47 (Liebert *et al.* 1975) and BPM25114 (Wickramasinghe & Bessell 1976). Zeeman structure in Balmer lines has also been observed in the magnetic DAB white dwarfs Feige 7 (Liebert *et al.* 1977) and G35-26 (Greenstein 1978). These objects provide a unique opportunity for the verification of the Zeeman theory of hydrogen at high magnetic fields by astronomical observations, and for investigating the field structure in magnetic white dwarfs.

In this paper we summarise the results of detailed analyses of the magnetic DA white dwarfs GD90 and G99-47 using models constructed on the assumption of centred and offcentred dipole field distributions. We show that within this class, models can be found which are in agreement with the observed continuum polarisation, spectrum and line polarisation. A detailed account of this work will be published elsewhere.

MODELS AND DISCUSSION

The models were constructed under the basic assumption that the magnetic field does not influence the pressure and temperature structure of the atmosphere. The main features of the models are as follows.

(1) The field distribution is assumed to be that of a centred or offcentred dipole. The free parameters in the models are effective temperature T_e, gravity g, dipole field strength B_d, the ratio d/R of the displacement of the dipole from the centre of the star to the radius of the star, and the angle i between the line of sight and the magnetic axis. When the dipole is decentred its direction is assumed to be along the line through the centre of the star and the dipole itself. In our notation, a positive value of d/R corresponds to a field geometry in which the stronger pole has positive polarity with the field lines going out of the star.

(2) The radiative transfer equations are formulated in terms of Stokes parameters and solved numerically by the method described by Martin & Wickramasinghe (1979).

Polarisation in the continuum has been included by using the theories of Kemp (1977) and Lamb & Sutherland (1974). The Balmer lines were computed also allowing for polarisation by using Kemic's (1974) calculations of the Zeeman effect.

GD90

Models were constructed for various dipole field strengths assuming d/R = 0, 0.1, and 0.2 and adopting an effective temperature of 12000K consistent with the observed colours of GD90. The zero field model atmospheres were taken from Wickramasinghe (1972). Models which are in general agreement with the spectrum (Angel *et al.* 1974) and the observed mean broad band circular polarisation (Brown *et al.* 1977) are listed in Table 1. A more sensitive indicator of the field geometry is the wavelength dependence of circular polarisation in the lines. The centred dipole model predicts broad circular polarisation features for both the σ^+ and σ^- components which are not in accordance with observations. On the other hand, the offcentred dipole model with i = 90° has a polarisation spectrum similar to that observed (Fig.1). For this model the observed sign of

Table 1 Data for GD90.

B_d (gauss)	d/R	i(°)	Theoretical $\overline{V}$(λλ3500-5500 Å) (%)	Observed $\overline{V}$(λλ3500-5500 Å) (%)
9×10^6	0	105	0.07	-0.12 ± 0.08 (Brown *et al.* 1977)
9×10^6	-0.1	90	0.02	

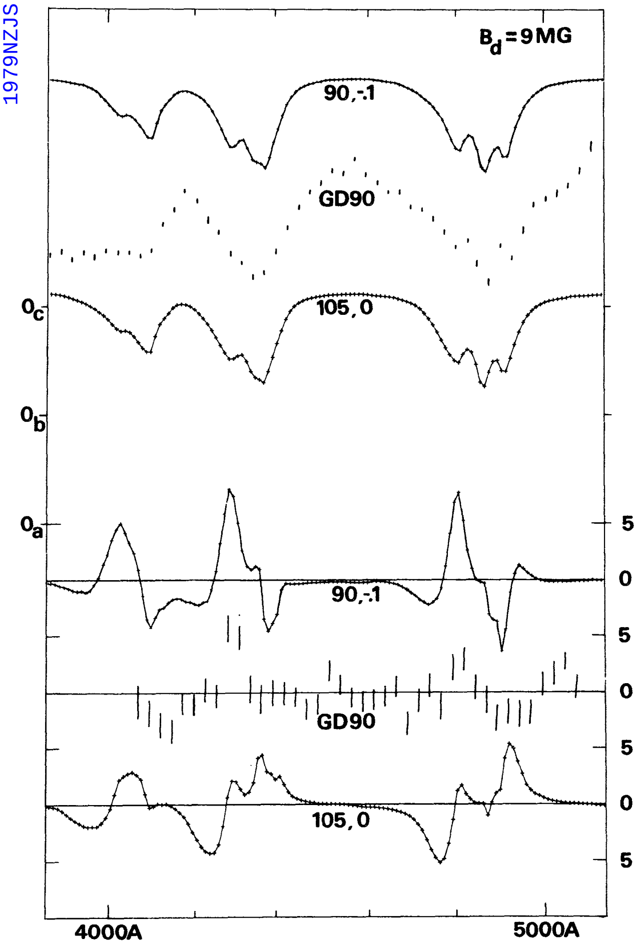

Fig.1 Observed and theoretical fluxes and circular polarisation for GD90. There are three sets of values presented: (a) a model 12000K magnetic white dwarf, dipole strength $B_d = 9 \times 10^6$ gauss (9MG), viewing angle $i = 105°$, centred dipole ($d/R = 0$); (b) observations of magnetic DA white dwarf GD90 from Angel *et al.* (1974); (c) a model 12000K magnetic white dwarf, dipole strength $B_d = $ 9MG, viewing angle $i = 90°$, dipole offset by -10% ($d/R = -0.1$).

The bottom three curves represent circular polarisation for (a), (b), and (c), from the bottom up respectively; the scales on the right have percentage units, with *negative* polarisation values upwards. The top three curves represent flux multiplied by frequency, in arbitrary units; the zeros of these three curves are indicated on the left (0_a, 0_b, 0_c). The values of the parameters i and d/R are indicated next to the theoretical curves, whose flux values in the continuum are normalised to those of the observed spectrum (b).

polarisation of the σ^- components of Hβ and Hγ requires the stronger pole to have negative polarity with the field lines going into the star. The sharp circular polarisation features arise from the central (equatorial) weak field regions of the visible stellar disc which have a net longitudinal field component towards the observer for $i = 90°$ in the offcentred case.

G99-47

Liebert *et al.* (1975) proposed two centred dipole models with $B_d = 2 \times 10^7$G, $i = 150°$, and $B_d = 2.5 \times 10^7$G, $i = 120°$ which were in general agreement with the observed quadratic Zeeman shift at Hα and with the circular polarisation of Hα. However, they also noted that there was a discrepancy of a factor of 4 between the mean field strengths deduced from continuum circular polarisation and from the Zeeman effect. We have constructed models with the same field parameters by assuming $T_e = 6000$K, consistent with the photometric data for this star. The zero field models were obtained from Wickramasinghe *et al.* (1977). We find remarkable agreement between theory and observations for the model with $B_d = 2.5 \times 10^7$G, $i = 120°$ as is shown in Table 2. The observed and theoretical spectra are compared in Fig.2.

Table 2 Data for G99-47.

Wavelength region	Theoretical $\overline{V}$ (%) $d/r = 0$, $B_d = 2.5 \times 10^7$G, $i = 120°$	Observed $\overline{V}$ (%)
λλ3500–5500 Å	0.49	0.45 (Angel & Landstreet 1972)
λλ6020–6380 Å	0.96	0.95±0.15 (Liebert *et al.* 1975)
λλ6740–7120 Å	−0.42	−0.28±0.15 (Liebert *et al.* 1975)

SUMMARY

The method of analysis used in this paper is an improvement on previous methods which were based on approximate atmospheres and approximate solutions to the radiative transfer equations. In the case of GD90, we have found good agreement between observations and theory. In this star there is strong evidence from the circular polarisation data in the lines to suggest an offcentred dipole field distribution. The agreement between the field strength deduced from the Zeeman effect and from broad band polarisation supports the magnetic dichroism theory of Lamb & Sutherland (1974) for the bound-free absorption in the Paschen continuum of hydrogen.

We have also seen that it is possible to find a model for G99-47 which is in agreement with all available data. In particular, there is no discrepancy between the field strength deduced from the observed continuum polarisation and that deduced from the Zeeman effect. This suggests that the rigid wavefunction method used to compute the magnetoabsorption by H^- is applicable up to field strengths of at least about 2×10^7G.

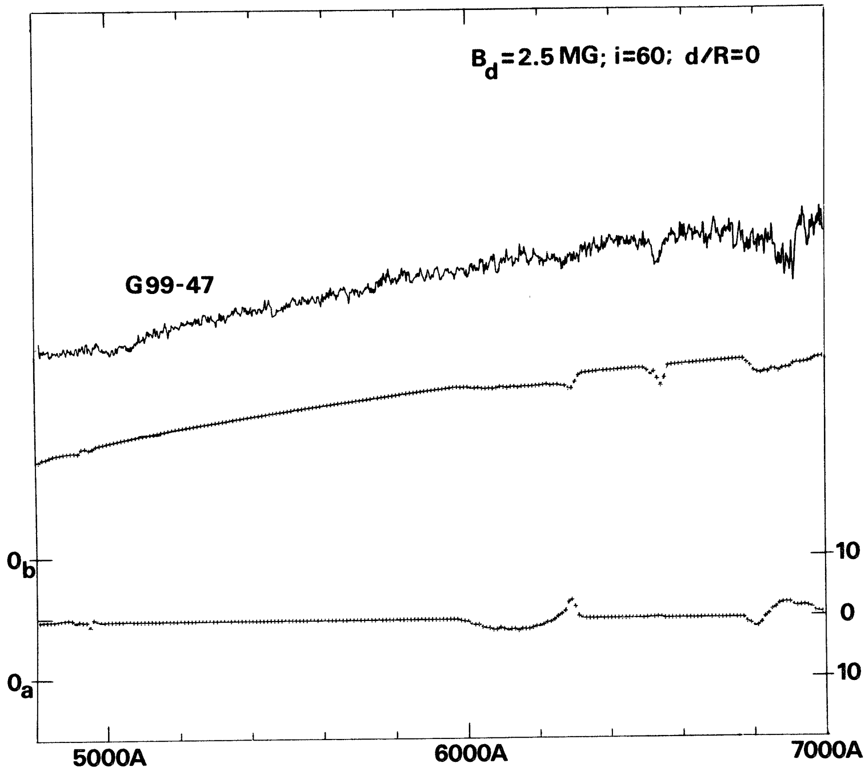

Fig.2 Observed and theoretical fluxes for G99-47. There are two sets of values presented: (a) observations of magnetic DA white dwarf G99-47 from Liebert *et al.* (1975); (b) a model 6000 K magnetic white dwarf, dipole strength B_d = 2.5MG, viewing angle i = 60°, centred dipole (d/R = 0).

The top two curves represent flux for (a) and (b), from the bottom up respectively; the zeros of these are indicated on the left (0_a, 0_b). The flux of (b) is normalised in the continuum to that of (a). Circular polarisation for (b) is represented by the bottom curve; the scale on the right has percentage units, with positive polarisation upwards. If the viewing angle is i = 120° (as indicated by observations of circular polarisation and discussed in the text) instead of i = 60°, the flux is unchanged, and the sign of the circular polarisation is reversed.

In conclusion, the present work shows that it is adequate to use zero field model atmospheres for the analysis of magnetic DA white dwarfs provided the radiative transfer equations are solved accurately. The effect of the magnetic field on the structure of the atmosphere will have to be considered if more detailed agreement with observations, particularly in the lines, is required.

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