EVIDENCE OF COMPLEX FIELD STRUCTURE IN THE MAGNETIC WHITE DWARF IN EXO 033319–2554.2

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ABSTRACT

We present detailed theoretical models for polarisation and spectroscopic data from EXO 033319–2554.2 that suggest the presence of two cyclotron emission regions of field strengths $B \sim 5.6 \times 10^7$ G and $B \sim 2.8 \times 10^7$ G, and which are separated by about 90° on the surface of the white dwarf. The large difference in magnetic field strength and the proximity of the two regions imply a more complex field structure than that of a centred dipole field distribution if it is assumed that the regions are connected by closed field lines.

I. INTRODUCTION

EXO 033319–2554.2 was recently reported to be an eclipsing soft X-ray source with a period of 127.7 minutes (Osborne *et al.* 1988). Bailey *et al.* (1987) confirmed its magnetic nature through the detection of circularly polarised light. More interestingly, the spectroscopic data show that EXO 033319–2554.2 is the second AM Her system to exhibit cyclotron harmonics in its optical spectrum similar to those first discovered in VV Puppis.

II. THE CYCLOTRON SPECTRUM

Spectroscopy of EXO 033319 – 2554.2 was obtained by Ferrario *et al.* (1988). The data corresponding to $\phi = 0.9$ and $\phi = 0.1$ are shown in Figures 1 and 2 respectively.

Since $\phi = 0.9$ corresponds to the centre of the bright phase, we assume that the angle θ between the line of sight and the field direction for the main emission region is at a minimum at this phase. The absence of large (≥ 200 Å) shifts in

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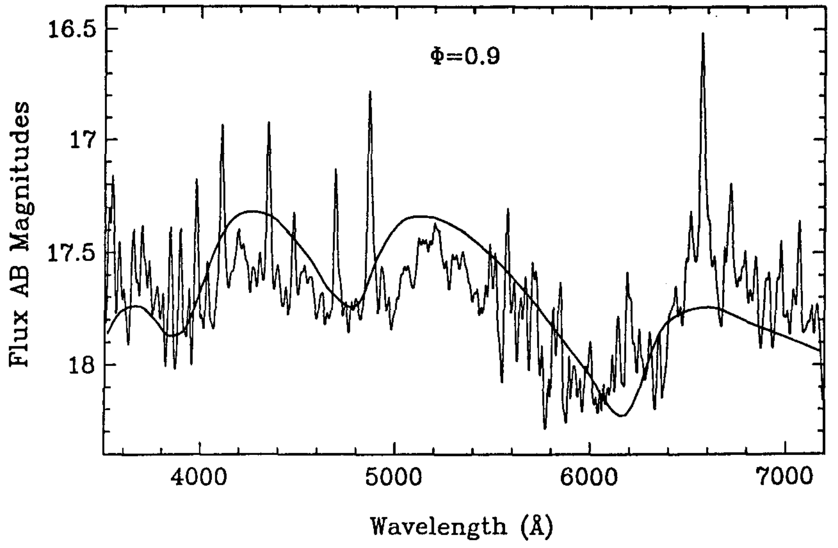

Figure 1. A broad band spectrum of EXO 033319 − 2554.2 acquired by Ferrario *et al.* (1988). The solid line represents our best fit for a magnetic field $B = 5.6 \times 10^7$ G and viewing angle $\theta = 75°$.

the positions of the harmonics with phase indicates that $\theta \geq 75°$ during the bright phase. We have constructed models following Wickramasinghe and Meggitt (1985) assuming point source cyclotron emission regions. We include in Figure 1 the best fit spectrum calculated for the data at $\phi = 0.9$ assuming $\theta = 75°$. The model has $B = 5.6 \times 10^7$ G and an optical depth parameter $\Lambda = 1.1 \times 10^3$ for an electron temperature $T_e = 20$ keV. The features at 4200Å, 5200Å and 6550Å are identified with harmonic numbers 5, 4 and 3. This result is in close agreement with that reported by Beuermann, Thomas and Schwope (1988) who also detected the presence of cyclotron harmonics.

The spectrum at $\phi = 0.1$ exhibits a further emission peak at 4720Å and a broad depression centred near 5650Å. We have interpreted these features to be also of cyclotron origin arising from a second emission region. The best fit model is included in Figure 2. This region has $B = 2.8 \times 10^7$ G, $\Lambda = 3.2 \times 10^5$, $T_e = 10$ keV, and is assumed to be viewed at $\theta = 90°$. The peaks at 4720Å and 5400Å correspond to harmonic numbers 9 and 8 while the dip at 5650Å occurs at the blue edge of harmonic number 7 which is optically thick and almost completely undetectable. The peak at 6650Å is attributed to the main emission region which

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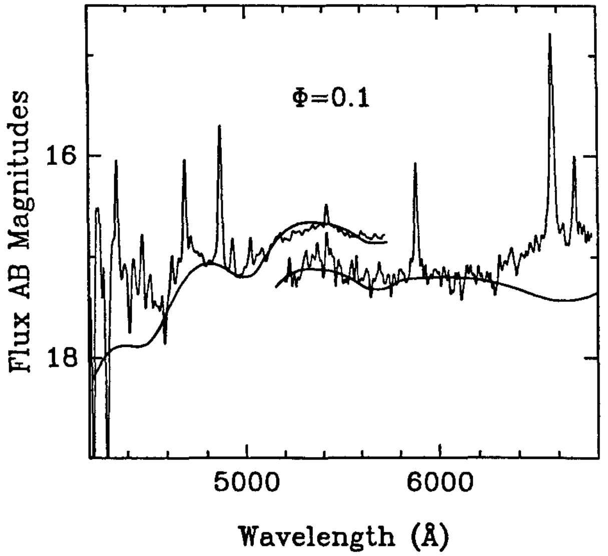

Figure 2. Spectra of EXO 033319−2554.2 at $\phi = 0.1$ obtained by Ferrario *et al.* (1988). The solid line represents our best fit for a magnetic field $B = 2.8 \times 10^7$ G and viewing angle $\theta = 90°$.

is assumed to be also visible at $\phi = 0.1$. We note that there is some evidence that the feature at 4720Å is also seen at $\phi = 0.3$ (Figure 4 of Ferrario *et al.* 1988), indicating that the second cyclotron emission region may still be making some contribution to the total light at this phase. This is in agreement with the length of the bright phase in the circular polarisation data obtained by Berriman and Smith (1988, see their Figure 1a) only one night after our AAT spectroscopy.

It has recently been argued by Ferrario, Wickramasinghe and Tuohy (1988) that, except for special orientations of the magnetic axis, the emission regions on the white dwarf surface are likely to occur near the foot points of closed field lines. If this hypothesis is correct, the observed ratio of field strengths for the emission regions in EXO 033319–2554.2 rules out a centred dipole field distribution. However, the observed ratio of 2:1 is consistent with that expected for the field strengths at the foot points of closed field lines which connect the polar and equatorial regions in a centred quadrupole field distribution. Such a field distribution has recently been proposed by Meggitt and Wickramasinghe (1988) for the AM Herculis variable 2A0311–227. However, it should be emphasised that the physics of the coupling region is not yet fully understood so that other possibilities cannot be excluded.

II. POLARISATION BEHAVIOUR

Circular polarimetry of EXO 033319–2554.2 was obtained by Ferrario *et al.* (1988) (Figure 3). The data show circular polarisation reaching $\sim 10\%$ in the blue and lasting from about $\phi = 0.65$ to $\phi = 0.2$. Furthermore, a reversal in the sign of the circular polarisation is evident from $\phi = 0.1$ to $\phi = 0.2$.

We have constructed theoretical polarisation curves by adding the contributions from two point source cyclotron emission regions contributing polarisation of opposite sign and characterised by the same parameters used to interpret the cyclotron spectra. The emission regions are 90° apart on the white dwarf surface at colatitudes of 15° (5.6×10^7 G region) and 105° (2.8×10^7 G region). The orbital inclination is 88°. The location of the higher field cyclotron emission re-

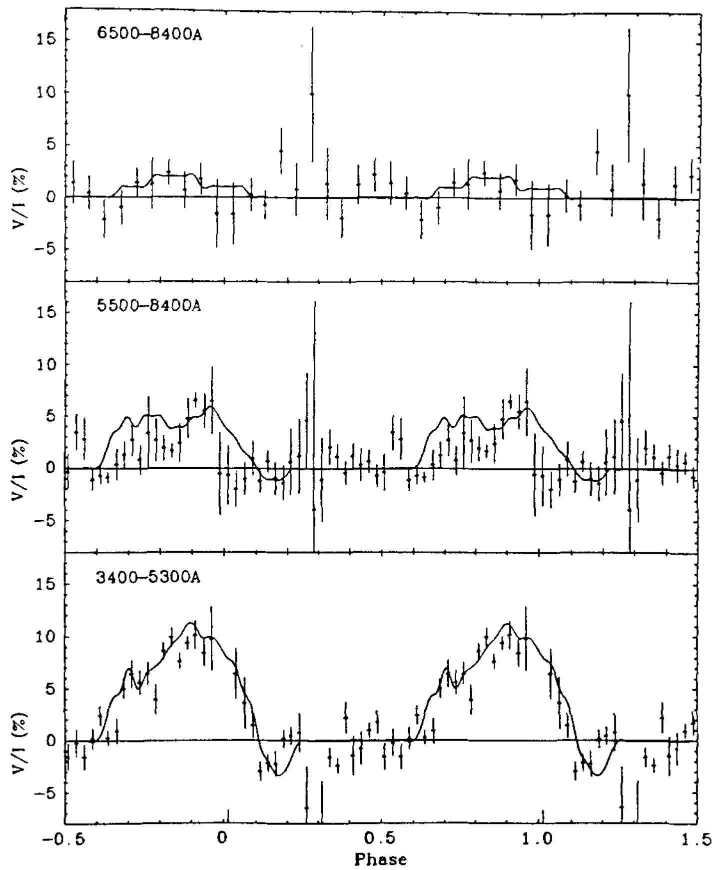

Figure 3. Circular polarisation data for EXO 033319 – 2554.2 obtained by Ferrario *et al.* (1988) and theoretical polarisation curves obtained by adding the contributions of two cyclotron emission regions (see text).

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gion and the orbital inclination are chosen to be consistent with the values determined by Ferrario *et al.* (1988). We assume that the contribution to the circularly polarised light from the lower field region is half of the contribution from the higher field region and that the unpolarised background is about four times less important for the bluest of the presented bands. The latter assumption may be justified by noting that the red star is only likely to make an important contribution to the total light for $\lambda \geq 7000$ Å.

In our model the main emission region ($B = 5.6 \times 10^7$ G) is visible from $\phi = 0.65$ to $\phi = 0.1$ and the secondary emission region from $\phi = 0.65$ to $\phi = 0.25$, and they are viewed most directly at $\phi = 0.85$ and $\phi = 0.95$ respectively. We point out that the lengths of the bright phases corresponding to the two regions are in complete agreement with our spectroscopic observations. Namely, the main emission region is eclipsed by the body of the white dwarf at $\phi = 0.1$ which coincides with the phase of last detection of cyclotron harmonics originating from the 5.6×10^7 G region. The eclipse of the secondary region is also in excellent agreement with the spectroscopic data, which show the presence of cyclotron harmonics from the 2.8×10^7 G region until $\phi = 0.3$. Berriman and Smith (1988) also suggest the presence of two cyclotron emission regions by comparing the circular polarisation data that they obtained on two consecutive nights. In one night they detected a reversal in the sign of the circular polarisation data, similar to that detected by us, but this reversal was not present in the next night. A temporal variation in the zero crossing of the circular polarisation curve and a change in the percentage of the polarised light can be explained as a change in the balance between the two poles in response to a change in the accretion rate.

REFERENCES

Bailey, J. A., Ferrario, L., Tuohy, I. R., Wickramasinghe, D. T., and Hough, J. H. 1987, *IAU Circ*, # 4517.

Berriman, G., and Smith, P. S. 1988, *Ap. J.*, **329**, L97.

Beuermann, K., Thomas, H. C., and Schwope, A. 1988, *Astr. Ap.*, **195**, L15.

Ferrario, L., Wickramasinghe, D. T., and Tuohy, I. R. 1988, *Ap. J.*, submitted.

Ferrario, L., Wickramasinghe, D. T., Bailey, J. A., Tuohy, I. R., and Hough, J. H. 1988, *Ap. J.*, in press.

Meggitt, S.M.A., and Wickramasinghe, D.T. 1988, *M. N. R. A. S.*, in press.

Osborne, J. P., Giommi, P., Angelini, L., Tagliaferri, G., and Stella, L. 1988, *Ap. J.*, **328**, L45.

Wickramasinghe, D. T., and Meggitt, S. M. A. 1985, *M. N. R. A. S.*, **216**, 857.