2000BASI...28..243H

Bull. Astr. Soc. India (2000) **28**, 243-245

Internal rotation and toroidal part of the magnetic field of AB Doradus

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Abstract. We solve analytically Chandrasekhar's (1956) MHD equations for the steady parts of internal rotation and toroidal component of the magnetic field of the AB Doradus. By taking observed (Donati and Cameron 1997) surface rotation as the boundary condition and assuming that the base of the convection zone rotates rigidly, we estimate the size of the convective envelope to be 40% of the radius and the rotation velocity at the base to be not less than 1.42 x 10^{-4} rad/sec. We deduce that the toroidal magnetic field is distributed throughout the convective envelope. By taking the average density of $1.78 gm\ cm^{-3}$ and radius 5.95 x 10^{10} cms (Allen 1972), we obtain a Mega gauss field near base of the convective envelope. We present rotational and toroidal magnetic field profiles in the interior, and conjecture on the time dependent part of the magnetic field.

Key words : toroidal magnetic field, rotation

1. Introduction

The K0 dwarf AB Doradus is studied extensively by different authors (Donati and Cameron 1997, references therein) for different purposes. The observations show that it is a low mass rapidly rotating (~ 50 times the equatorial rotation of the sun) star which possesses a complex spot distribution over it's surface. It is also found that the magnetic field of this star is time dependent, and the time scales of variations are found to be ~ 1 day. Recently, Donati and Cameron (1997) found that the magnetic field of the star is time dependent and it's surface rotation is differential.

Assuming that the dominant part of the sun's rotation is steady, recently we (Hiremath and Gokhale 1995, Hiremath and Gokhale 1996) solved Chandrasekhar's MHD equations for the internal rotation part of the magnetic field. The solution yields isorotation contours similar to those inferred by helioseismology. Inspired by this similarity and with the appropriate boundary conditions, we solve Chandrasekhar's MHD equations for the steady parts of internal rotation Ω and toroidal magnetic field T in the region of the convective envelope of AB Doradus.

2. Results and discussion

In Fig 1 (a), we present radial variation of rotation for the three latitude zones (equator, 40.5^o and 71.8^o). For the sake of comparison, the rotation is normalized to the sun's surface equatorial rotation. It is interesting to note that the radial variation is similar to the radial variation of the sun's rotation in the region of convective envelope. This solution also yields lower limit on the core rotation of 1.42×10^{-4} *rad sec* $^{-1}$. Using the limit on the core rotation as the boundary condition at the base of the convection zone, we obtain the rotation in the convective envelope. For a consistent solution and for star's radius of 5.95×10^{10}*cms* (Allen 1972), we estimate size of the convective envelope to be 40% of the radius.

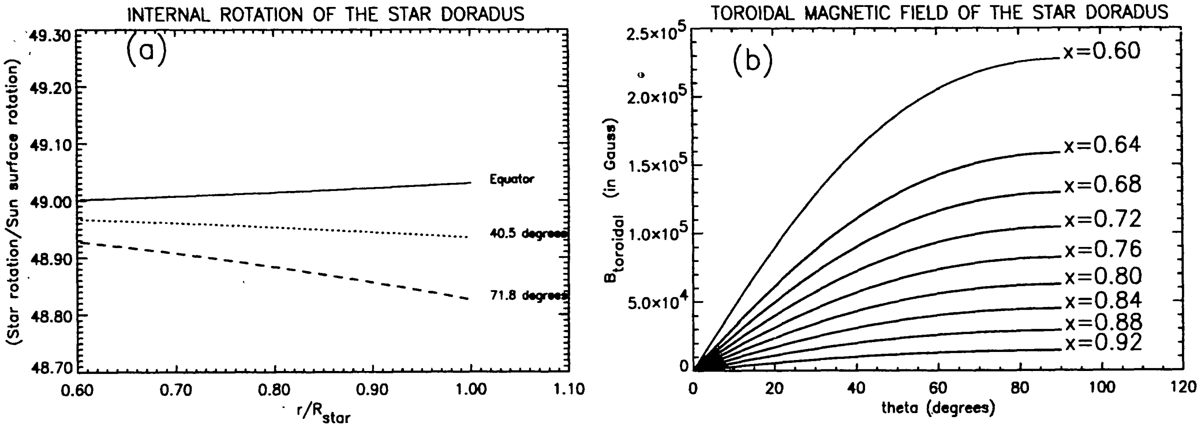

Fig. 1. Fig 1 (a) represents the radial and the latitudinal variation of 'steady' part of rotation in the convective envelope of the AB Doradus star. Fig 1 (b) represents the radial and latitudinal variation of 'steady' component of toroidal magnetic field. In Fig 1 (b), star's pole is at $\theta = 0^0$ and equator is at $\theta = 90^0$.

By taking the mean density 1.78 *gm* cm^{-3}, correspondingly, we compute the toroidal component of the magnetic field whose latitudinal variation for different radii is presented in Fig 1 (b). It may be noted that the field structure thus obtained is steady and we can not compare with the observed magnetic field. However, in the following, we can make some conjectures on the time dependent part of the toroidal magnetic field.

If we follow solar dynamo theories, adopted to explain the solar time dependent part of the magnetic field, toroidal field is determined (Levy 1992) as follows. Toroidal field is ~ $(L\Omega B_p/\eta)$, where L is the characteristic size of the convective envelope, B_p is the strength of poloidal magnetic field and η is the magnetic eddy diffusivity. By taking typical values, related to AB Doradus, as : $L \sim 10^{10}$cms, $\Omega = 1.4 \times 10^{-4}$ rad/sec (~ 10^6 cm/sec) and $\eta \sim 10^{12} cm^2$ sec^{-1}, we get the strength of the toroidal field to be ~ 10^7 gauss. However, this result contradicts the observation (Donati and Cameron 1997) which gives the inferred field to be ~ 10^3 gauss. This raises doubts about applicability of so called dynamo theories to this star.

Alternative way is to think that the toroidal field (which may be of primordial origin) is distributed throughout the convective envelope. In fact, present study indicates that toroidal field may be distributed everywhere in the convective envelope as shown in Fig 1 (b). The active regions are formed from the toroidal perturbations of the underlying field leading to instabilities and bringing the toroidal field to the surface. For example, if the resulting Alfven type perturbations have strengths similar to those of the ambient study magnetic field, then the observed fields of 800 gauss might have formed just beneath the surface. However, validity and details of such a mechanism remains to be worked out.

Acknowledgements

Author is grateful to Prof. M.H. Gokhale for useful comments and discussions.

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