A ROTATING, MAGNETIC, RADIATION-DRIVEN WIND MODEL APPLIED TO BE STARS

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INTRODUCTION

With their rotating, magnetic, radiation-driven wind model, Friend & MacGregor (1984) found that rapid rotation and an open magnetic field could enhance the mass loss rate ($\dot{M}$) and terminal velocity (v_∞) in an O star wind. The purpose of this paper is to see if this model could help explain the winds from Be stars. The following features of Be star winds need to be explained: 1) Be stars exhibit linear polarization (Coyne & McLean 1982), indicating an enhanced equatorial density. 2) There appears to be enhanced mass loss (at low velocity) in the equatorial plane, from IRAS observations of Waters (1986). 3) The width of the broad Balmer emission lines remains unexplained.

WIND MODEL AND RESULTS

Our wind model is based on the Friend & MacGregor (1984) model, which combines the Weber & Davis (1967) description of a rotating, magnetic, solar wind, with the Castor et al. (1975) theory for a line radiation driven wind. The assumptions of the model and the method of solution are described in Poe and Friend (1986). One improvement we have made over the Friend & MacGregor (1984) model is that the star is not treated as a point source of radiation, but instead as a uniform disk. This improvement quantitatively changes the model predictions as follows: the mass loss rates are reduced by a factor of about 2, and the terminal velocities are increased by a factor of about 3. These changes bring the model predictions into much closer agreement with observations of O star winds.

We modeled the wind of a B1.5Ve star ($M = 13\ M_\odot$, $L = 7500\ L_\odot$, $R = 6\ R_\odot$), varying the surface magnetic field strength (B_0) from 0 to 400 G, and the equatorial rotational velocity (v_{rot}) from 0 to 540 km s^{-1}. The results of the wind model are the mass loss rate, the terminal velocity, the radial velocity, and the azimuthal velocity (and magnetic field). Figure 1 shows that the mass loss rate increases rapidly with increasing rotation rate, especially for the higher rotation rates. The magnetic field has very little effect. It is the centrifugal force which drives the higher mass loss. Figure 2 shows that the terminal velocity decreases with increasing rotation rate for small magnetic fields, but increases with increasing rotation rate for the larger magnetic fields. For small fields the centrifugal force reduces the effective escape speed, which lowers the terminal velocity. For larger fields, however,

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the magnetic force increases the azimuthal velocity to such an extent that the increased centrifugal force raises the terminal velocity.

A model with a large rotation rate and a small magnetic field strength will have a greatly enhanced mass loss rate and a reduced velocity, which means the equatorial wind is much denser than the polar wind (the wind from the pole is not affected by rotation). This is qualitatively consistent with IRAS observations and linear polarization measurements, though the radial velocity on the equator still appears to be too large. However, a larger magnetic field may be required to enhance the azimuthal velocity enough to broaden the Balmer emission lines.

Castor, J. I., Abbott, D. C. & Klein, R. I. (1975). Radiation-driven winds in Of stars. Ap. J., 195, 157-74.

Coyne, G. V. & McLean, I. S. (1982). Polarimetry and physics of Be star envelopes. In IAU Symposium 98, Be Stars, ed. M. Jaschek & H.-G. Groth, pp. 77-93. Dordrecht: Reidel.

Friend, D. B. & MacGregor, K. B. (1984). Winds from rotating, magnetic, hot stars. I. general model results. Ap. J., 282, 591-602.

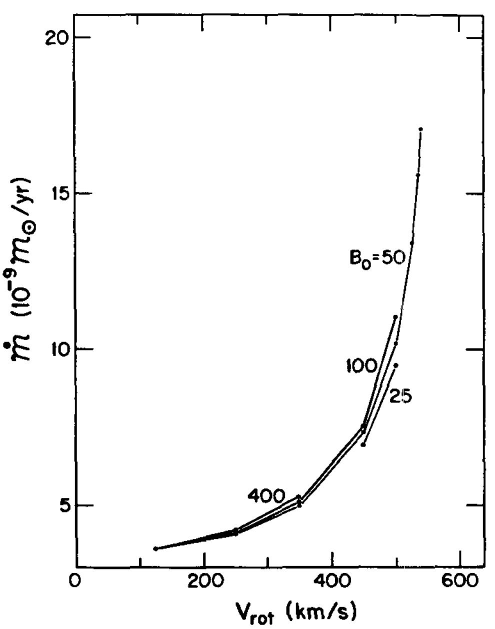
Poe, C. H. & Friend, D. B. (1986). A rotating, magnetic, radiation-driven wind model applied to Be stars. Ap. J., 311, in press.

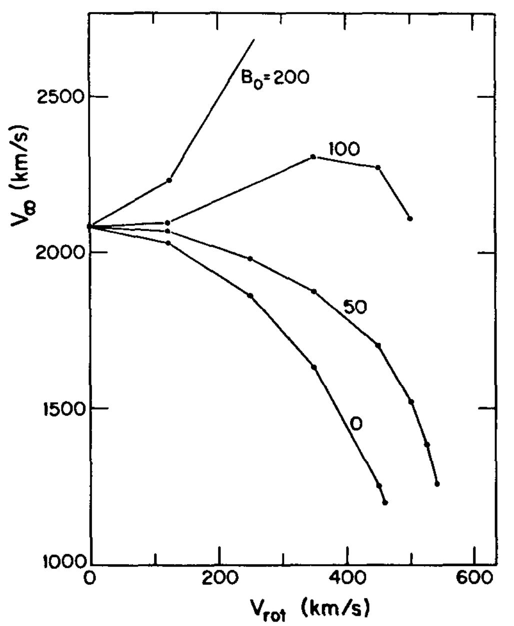
Waters, L. B. F. M. (1986). The density structure of discs around Be stars derived from IRAS observations. Astr. Ap., in press.

Weber, E. J. & Davis, L., Jr. (1967). The angular momentum of the solar wind. Ap. J., 148, 217-27.

Figure 1. Mass loss rates vs. rotational velocity

Figure 2. Terminal velocities vs. rotational velocity





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DISCUSSION FOLLOWING POE

Lamers:

The problem which you have in explaining the very low outflow velocities in the equators of Be stars might be solved if you find some other mechanism to increase the equatorial mass flux. Can you comment on this?

Poe:

Of course, increasing rotation rate will increase the mass- loss rate and thus decrease the velocity law. However, in this steady state model, we cannot calculate other mechanisms that might increase the mass flux.

Cassinelli:

Could you comment on spin-down times?

Poe:

Assuming a mass-loss rate of 10^{-9} solar masses per year and a typical Alfven radius of 10 R_*, then the spin-down time is about 10^8 years. This mass-loss rate is much lower than for the Wolf-Rayet stars so the problem is not as bad.