ON THE POSSIBLE ROLE OF MAGNETIC FIELDS IN THE DYNAMICS OF THE Be PHENOMENON

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A problem that has intrigued me for some years is that of the dynamics of the Be phenomenon. For, although the Be phenomenon has been extensively studied for decades, the problems associated with the dynamics of the circumstellar envelopes about Be stars – the problems associated with their formation, with their maintenance, and with their dissolution – have, until very recently, received little more than qualitative consideration.

In what follows, I shall direct my remarks to those Be stars for which close binary companions – if any – play no major role in the Be phenomenon. (It is my belief – perhaps, hope – that the set so restricted is not an empty set.) For such Be stars, there appears to be no question but that the rapid rotation of the star involved plays a decisive role in the phenomenon. However, it is also clear that rotation, alone, is not enough to either move centrifugally supported matter outward from the star's equator to form a circumstellar envelope or to move the matter within such an envelope, once formed, off to infinity.

This raises the question as to just what physics it is that, in cooperation with these stars' rapid rotations, accounts for the envelope dynamics. Two such possibilities have been at least semi-quantitatively explored within the last few years: (1) radiation pressure and (2) magnetic field lines coupling the rapidly rotating star to the matter in the circumstellar envelope. Some aspects of the first of these possibilities are being presented in the contributed papers by others. It is to certain aspects of the second of these that I should like to direct your attention.

The study of steady-state situations – situations in which the partial derivatives of all macroscopic quantities vanish – is the obvious problem with which to begin such a discussion. Not because most or all of the Be stars are observed to be in situations that appear to be steady-state (or nearly steady-state) ones (because they are not), but because at least certain basic aspects of this situation are mathematically tractable, because at least some Be stars do show little if anything in the way of time variations over decades, and because steady-state solutions provide a natural point of departure for the consideration of all other situations, that is, for the consideration of the non steady-state situations that clearly play such an important part in the phenomenon.

The search for steady-state solutions having the required mathematical properties for the magneto-rotational model has been found to constitute an eigenvalue problem (Limber, 1974). When these mathematical requirements are supplemented by the physical requirement that the magnetic energy per unit volume not significantly exceed that in the form of the mass motions at any point within the circumstellar envelope, the acceptable solutions are still further restricted. Nevertheless, families of steady-state solutions have been found that satisfy these requirements

A. Slettebak (ed.), Be and Shell Stars, 371–373.

and that appear to be generally consistent with the observations for values for the relevant parameters that appear to be reasonable – reasonable, that is, if one considers pre-outburst, photospheric magnetic field strengths in the range from a few gauss to several hundred gauss to be reasonable and if one considers values for the equatorial rotational velocities not much more than 5 or 10% smaller than the critical rotational velocities to be reasonable.

At least as interesting, however, is the finding that for many combinations of the relevant parameters which, at least at first sight, appear not unreasonable, no acceptable steady-state solutions are found to exist. Thus, for example, for one somewhat oversimplified formulation of the problem: given a star and given the rate at which angular momentum is supplied to the equatorial region (presumably through evolutionary effects in the deep interior), the star can achieve acceptable steady-state solutions by adjusting its equatorial angular velocity to an appropriate value if the value of the pre-outburst photospheric magnetic field strength lies within a certain range. For all other values for this field strength, no possible adjustment of the star's equatorial angular velocity will lead to acceptable steady-state solutions. Thus, if at any time the rate at which angular momentum is being supplied to the star's equatorial region is inconsistent with steady-state solutions for the star's given photospheric magnetic field strength, then its subsequent photospheric and envelope evolution will, of necessity, be time-dependent.

Further, if after an interval during which a steady-state solution is possible and has been set up, there is a change in the rate at which angular momentum is supplied to the equatorial regions from the interior, then either the circumstellar envelope will be found to undergo changes in its structure from its initial steady-state situation that will bring it to another steady-state situation appropriate to the new input parameters or, if no such steady-state solution exists for the new parameters, the initial steady-state situation will be followed by a time-dependent situation for which there is no steady-state relief in sight. Since such changes result from changes in the rate at which angular momentum is supplied to the star's equatorial region, such time-variation might be expected to be characterized by time-scales of months, years, decades, or longer, but not to minutes or hours. In this connection it may be worth noting that, although the analogy with the Be phenomenon is not a very close one in a number of ways, interactive effects of differential rotation and magnetic fields appear to be capable of accounting for the observed properties of the sun-spot cycle in a very reasonable, semi-quantitative way (Leighton, 1969); and in the Sun's case, the characteristic time-scale for the phenomenon is one or two decades. It is thus not altogether unreasonable to consider the possibility that similar interactive effects of differential rotation and magnetic fields might give rise to the periods of this same order that are so often observed in the Be phenomenon.

It is of interest in this discussion of the observed time variations in the Be phenomenon to point out that for the steady-state solutions that exist for the cases studied, the matter moving outward through the circumstellar envelopes is not, except very close to the photospheres, even approximately centrifugally supported; that is, the effects of the magnetic fields are not in any major way to increase the angular momentum of the matter as it moves outward from the stars' equators. Consequently, in breakdowns of steady-state solutions, either by reason of decreases in the rate of angular momentum input into the stars' equatorial regions or by reason of hydromagnetic instabilities, sizable portions of these circumstellar envelopes could fall back toward the stars' surfaces.

This brings us to the last point that I should like to make concerning the possible role of magnetic fields in the Be phenomenon: that of the possibility of hydromagnetic instabilities within the envelopes. Whether the envelopes of Be stars are formed through effects of the kind here described, involving magnetic fields, through the effects of radiation pressure, or through still other mechanisms, if there are pre-outburst photospheric magnetic field strengths of the order of tens of gauss or more and if the outward velocities within the inner part of the envelopes are quite small with respect to the circular components of velocity there, then the mass motions within the inner portions of the envelopes, by reason of the combination of differential circular motion and outward motion, will lead to a severe stretching and winding around of the magnetic field lines until conditions would appear to become favorable for the snapping and reconnection of field lines. Although the theory for the reconnection of field lines is not yet very quantitative, solar flares bear solid testimony to the fact that such events not only can take place but actually do so – and under conditions that may be no more extreme than these encountered in Be envelopes. It thus appears quite possible that such snappings and reconnections of field lines will take place from time to time within the envelopes of Be stars, giving rise to flare-like outbursts. And it is very tempting for me to think in terms of such an explanation for the short-term time-variations in the range of minutes to hours that are observed in the profiles and integrated strengths of emission and shell lines. I, personally, feel that it is very important to continue the observational study of the short-term time variations that take place within Be envelopes both for the purpose of learning more about the physical and geometrical properties of the individual 'flares' and also for the purpose of learning more of possible temporal relationships between flare activity and other developments in the history of an envelope. We should learn more of the short-term time-variations in this way; we might learn something of the role of magnetic fields in the Be phenomenon, as well.

References

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