PART III

STELLAR MAGNETISM

PAPER 18

STELLAR MAGNETIC FIELDS

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ABSTRACT

A report is given of a ten-year observational program directed toward the discovery and investigation of the magnetic fields of stars through the Zeeman effect in their spectra. The emphasis has been on the sharp-line stars of type A, of which ten have been found to show irregular magnetic fluctuations without reversal of polarity, ten others to fluctuate irregularly with occasional reversals of polarity, and six to show essentially periodic variations; of the latter group, four are large-amplitude reversers with periods near one week.

The search for and investigation of stellar magnetic fields, which was begun ten years ago, was based on the idea that strong coherent fields might result from rapid axial rotation. Some sort of dynamo process was envisaged; to bring this up to date, it would depend upon rotation in combination with an outer convective layer in which Coriolis forces play a part (Elsasser [1]). Rapid rotation is characteristic of the hotter stars (types B, A and early F) while convective zones prevail in the cooler stars, becoming thin and finally absent as we proceed from the F's to the hotter B-types. It is for the stars of types A and early F, then, that rapid rotation and convection both prevail, and it happens that among stars of just this group the most prominent magnetic effects have been observed. An alternative is that stellar fields are primeval, having been 'frozen in' when the stars were formed, and that they exist independently of any dynamo process.

The Zeeman effect is rather small, spectroscopically, and conditions must be specialized if it is to be observed at all in stellar spectra. The field must be strong, mainly longitudinal, and one polarity must predominate; further, line broadening from other sources, such as the Doppler effect, must be quite limited, else the lines will be too broad to permit detection of the small Zeeman displacements. Fig. 1 shows how the Doppler effect, for an average A-type star with an equatorial velocity of rotation, v_e of 115 km/sec, and a large axial inclination, results in spectrum line-widths

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of about 3 Å. For magnetic observations, we must select stars having lines little wider than one-tenth of this. Only a small proportion of all the hundreds of A-type stars brighter than the eighth magnitude have lines so sharp; for these, either the rotation is inherently slow or the inclination, *i*, to the line of sight is small. Fig. 2 is a plot of line-width, as ordinate, against spectral type, where each dot represents an observed star. The

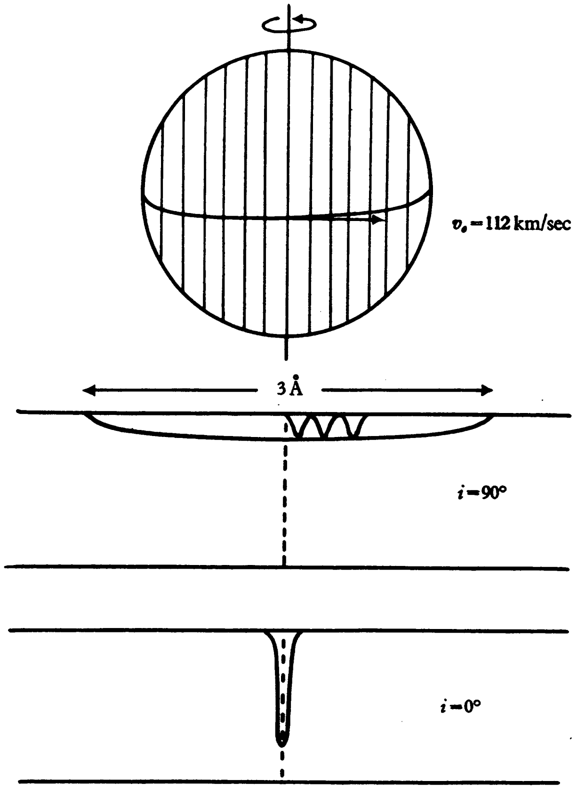

Fig. 1. Diagram illustrating the well-known Doppler broadening of spectrum lines due to axial rotation.

region of ultra-sharp lines in the lower part of the diagram has been rather completely observed, but for increasingly wider lines, additional stars could be found to populate the diagram. It is significant that of the twenty-one sharpest-line stars investigated, nineteen have been found to show a measurable magnetic field, and to display associated spectroscopic features such as abnormal line intensities. Only two of the twenty-one (γ Gem and 95 Leo) have 'normal' spectra without evidence of a coherent magnetic field.

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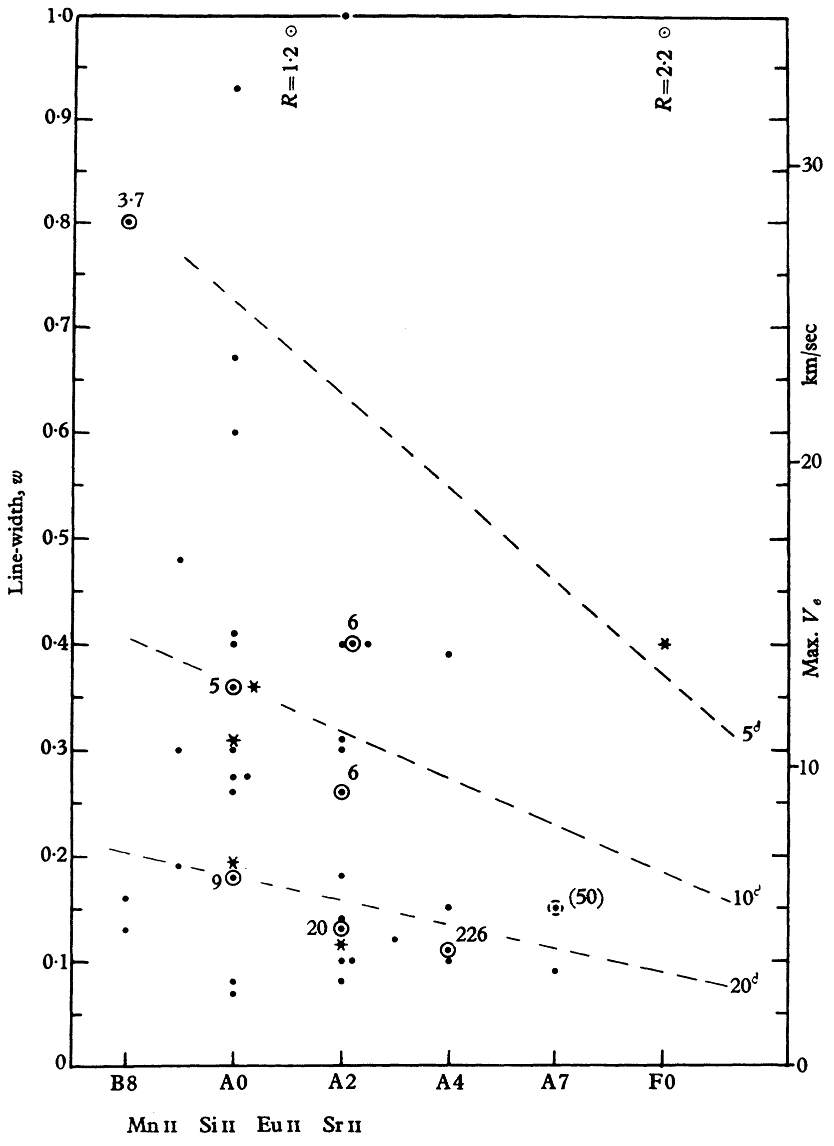

Fig. 2. The sharpest-line A-type stars plotted on a diagram of line-width, w, v. spectral type. Dots represent peculiar stars with magnetic fields; those encircled are periodic variables. Asterisks represent 'ordinary' stars. Of twenty-one stars having lines less than 0·2 Å wide, all but two have magnetic fields. The dashed lines indicate the minimum Doppler broadening corresponding to the rotational period in days.

If we regard these ultra-sharp-line stars as a statistical sample of normal, rapidly rotating A-type stars, selected for small axial inclination, then it would be a fair conclusion that a majority of the rapid rotators of whatever inclination also possess strong magnetic fields. The alternative is that the nineteen ultra-sharp-line magnetic stars are inherently slow rotators. This suggests the theory that they have lost angular momentum because of their strong magnetic field; this loss might have occurred through magnetic coupling between the star and a circumstellar gas cloud. But if this second alternative is correct, we have difficulty in answering this question: Statistically speaking, a small percentage of the hundreds of observable rapidly rotating A-type stars must have a small inclination and, therefore, sharp lines; if they are not included in our hard-found group of twenty-one ultra-sharp-line stars, then where are they?

In order to obtain as much information as possible from the observational work, a balance has been sought between the search for new magnetic stars and repeated observations for the study of variations. Table 1 gives a condensation of the results.

Table 1. *Number of magnetic stars with various characteristics*

Peculiar A-type stars (B 8, A 0, A 2, A 4, A 7, F 0)	
Irregular magnetic fluctuations without reversal of polarity	10
Irregular magnetic fluctuations with reversal of polarity	10
Probably irregular, insufficiently observed	21
Periodic, large amplitude 'one week' reversers (early A-type)	4
Periodic, non-reversing, slower reversers (late A-type)	2
Metallic-line F-type stars. Fields relatively weak	
HD 3883, 51 Sag, 63 Tau, 68 Tau, 16 Ori	5
Red Giants (Irregular fluctuations)	
Type Mp: HD 4174, VV Cep, WY Gem	2
Type S: R Gem, HR 1105	2
RR Lyr (Cluster type variable, pulsating; rapid variations)	1
Others: AG Peg, HD 98088	2

Since several of the strongest magnetic fields and some of the most interesting associated phenomena have been found among the sharp-line A-type stars, a large share of the effort has been devoted to them; however, several other types, such as RR Lyrae, are receiving attention. Tests of classical cepheids have revealed no strong fields, although FF Aquilae deserves further investigation. There is no evidence that any star shows a constant magnetic field; for all that have been adequately observed, the fields appear to be variable. The peculiar stars of type A have been discussed by W. W. Morgan [2], the spectrum variables by A. J.

Deutsch[3, 4], and stellar magnetic fields by H. W. Babcock and T. G. Cowling[5]. It is hoped that a more complete report and discussion of the observations of stellar magnetic fields can be published shortly in the *Astrophysical Journal*[6].

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Discussion

Biermann: Do we have to understand that the contribution, say, of the relatively large following parts of a spot to the magnetic splitting of the lines, in the diagram we saw last, will effectively be dominant?

Babcock: The spots will not be dominant because they are dark and the field is concentrated in a very small area. The flux comes out from the spot and goes back to the photosphere over a very large area which is optically effective.

Schatzman: What is the limiting amplitude you can reach?

Babcock: Well, we can reach about seventh–eighth magnitude and perhaps the ninth if the dispersion is reduced.

Alfvén: In your picture showing the surface of a magnetic variable star you have some regions where the magnetic flux is directed outwards, and some regions where the flux goes inwards through the surface. The true average flux, integrated over the whole surface is, of course, zero. What comes out of your measurements? Do you measure the true average field (which should be zero) or do you measure a mean which differs from zero?

Babcock: We measure the mean longitudinal component of the magnetic field in the line of sight, weighted according to the surface brightness, and integrated over the visible hemisphere.