ZEEMAN OBSERVATIONS OF W SGR*

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Footnote *Based on observations obtained at the European Southern Observatory, La Silla, Chile.

Abstract A new precise method for measuring magnetic fields on Zeeman plates of the southern cepheid W Sgr is reviewed. Ten plates over the $7^{d}.6$ period of pulsation show two extrema in the measured values of the effective magnetic field. The method has a precision of ±0.4μ in the Zeeman shift corresponding to ±50 gauss (g). A negative "spike" of -220g occurred at the time of arrival of the compressional wave of pulsation at the stellar surface. A positive field of +270g occurred at the phase of most rapid contraction near the temperature minimum of the pulsation cycle.

I. INTRODUCTION

In his classic compilation of observational results on stellar magnetic fields, H. W. Babcock (1958) includes observations of a number of pulsating variables. Most of the fields measured were small and observationally uncertain. However, RR Lyr (No. 68 in the catalogue) showed stronger fields of as high as H_e = -1580±115g on plate Pc2294 and +1170±112g on plate Ce10149. For FF Aql, plate Ce7035 gave a field of -250±38g and on plate Pb1008ηAql gave H_e = -85±85g. A number of Zeeman plates were obtained by Preston on δ Cep but measurements of those plates have not appeared in the literature. Kraft (1967), however, mentioned that the plates showed a field reaching a maximum as high as -500g at minimum light (and zero field at maximum light).

Line crowding and asymmetric profiles make conventional Zeeman measurements extremely difficult for these stars with F - G spectral types.

II. RESULTS OF A NEW TECHNIQUE

A southern sky survey for magnetic fields was begun in 1970 at the European Southern Observatory by HJW (Wood & Campusano, 1975). The ten plates discussed here have 3.3Å/mm reciprocal dispersion. Details of the observations are given in a recent paper by Wood et al. (1977) and are shown in Figure 1. The curve is Jacobsen's (1974) "1923 standard" radial velocity curve calculated on:

$$JD(vis\ max) = 2434587\overset{d}{.}26 + 7\overset{d}{.}594812E$$

From a discussion of a large body of observations spanning more than 50y, Jacobsen found that the 1923 and 1973 RV curves were nearly identical but that large distortions in the hump near phase 0.36 occur with a period of about 17y.

We have found that a small shift of 0.057 in phase was necessary to fit our RV observations (Wood et al., 1977, op. cit., Fig. 1) onto Jacobsen's curve. This correction has also been applied to the magnetic observations shown in Figure 1 of this paper. Jacobsen found that similar small phase and velocity shifts were necessary to fit all his observations together.

The measurements were obtained from the conventional coudé Zeeman plates in a new way. The spectrograms are first digitized using a computer-controlled digital microdensitometer described by Albrecht et al. (1977). Then, in a separate data handling program, sections of the o- and e-ray are shifted with respect to each other in a manner analagous to that used in the photoelectric radial-velocity spectrometer.

We have found that the correlation curve (sum of the squares of the channel-by-channel differences of the two spectra) reaches a sharp minimum when the best-fit Zeeman shift between the two spectra is achieved. In the case of W Sgr, we use a 116Å band centered on λ4262Å in which we have counted approximately 130 lines. We recall that the z-values are different for each line. However, since the lines are sharp in this supergiant and the measured field is expected to be small, it is gratifying to see how smooth and symmetric are the correlation curves for the 10 plates of W Sgr: they are easily fit by parabolas to aid in the precise determination of the Zeeman shifts.

After removal of the projected slit tilt using the Fe comparison spectra (typically ∿ 1μ), the residual relative shift between the two spectra is a measure of the mean Zeeman shift of all 130 lines in the 116Å region used. The technique is described in detail in Weiss et al. (1978) where an error discussion is also included.

A detailed line-identification study of this spectral region centered on λ4262Å was carried out for the spectrum of Canopus by Rakos et al. (1977). The study showed that the mean z-value for the region is ∿ 1.3. We have applied this value in order to set the ordinate in Figure 1 in gauss. The maximum Zeeman shifts measured are of the order of 2μ (270g) which are five times the precision of the method (±0.4μ).

III. DISCUSSION

On the assumption that these observations, taken over 190 cycles (1445d) form a pattern which repeats in the $7^{d}.6$ pulsation period, let us consider the physical behavior of the stellar atmosphere and the related magnetic field changes. At phase 0, we have maximum light, but maximum radius occurs much later, in the variable hump area of the RV curve at phase ∿ 0.5. Thus maximum light is caused by a considerable temperature increase of the photosphere as the compressional wave hits these layers. Just before phase zero, the field reaches -220g at RV minimum where the photosphere is expanding most rapidly.

It is at the time when the compressional wave of pulsation encounters the atmospheric layers observed that we might expect lines of force "frozen" into the material to be compressed yielding a momentarily higher-valued field. This negative-field spike at RV minimum is followed immediately by an overshoot to positive field values of ∿ 100g. These two positive field points (phases between 0.0 and 0.1) come from two plates taken in quick succession on the same night during maximum light.

Maximum radius (∿ phase 0.5) shows a measured value of ∿ -120g at phase 0.4. However, near minimum light when the photosphere is at its greatest velocity of contraction (phase 0.75) the opposite positive field extreme has occurred (+270g at phase 0.63). Why, when the photosphere is contracting fastest and cooling, should we see an increase in the effective field? Perhaps, if the temperature is as large as in _β Dor_: 1550°K (Estes & Wood, 1970), a change in the continuous opacity might be sufficient to move line-formation regions into layers which have higher-valued (positive) fields.

IV. CONCLUSION

Observations of the $7\overset{d}{.}6$ cepheid _W Sgr_ have been described on the assumption that the phase plot of Figure 1 holds true for every cycle. A negative-field spike of -220g at the phase of maximum light may be related to the sudden compression of the photosphere at the time of arrival of the pulsational wave from the interior. Another less strong negative-field minimum occurs at the phase of the hump. Christy (1966) suggests that the hump represents the arrival of a pulse reflected off the stellar core ∿ 1.4 cycles later. Thus one would expect a negative spike at the hump phase for the same reasons that one finds the negative spike at the phase of arrival of the main pulse.

The positive field maximum, on the other hand, is observed at the time of contraction and cooling. The surface reaches its highest velocity at this time. The cooling may be sufficient for a significant continuum opacity change so that layers with stronger fields are seen.

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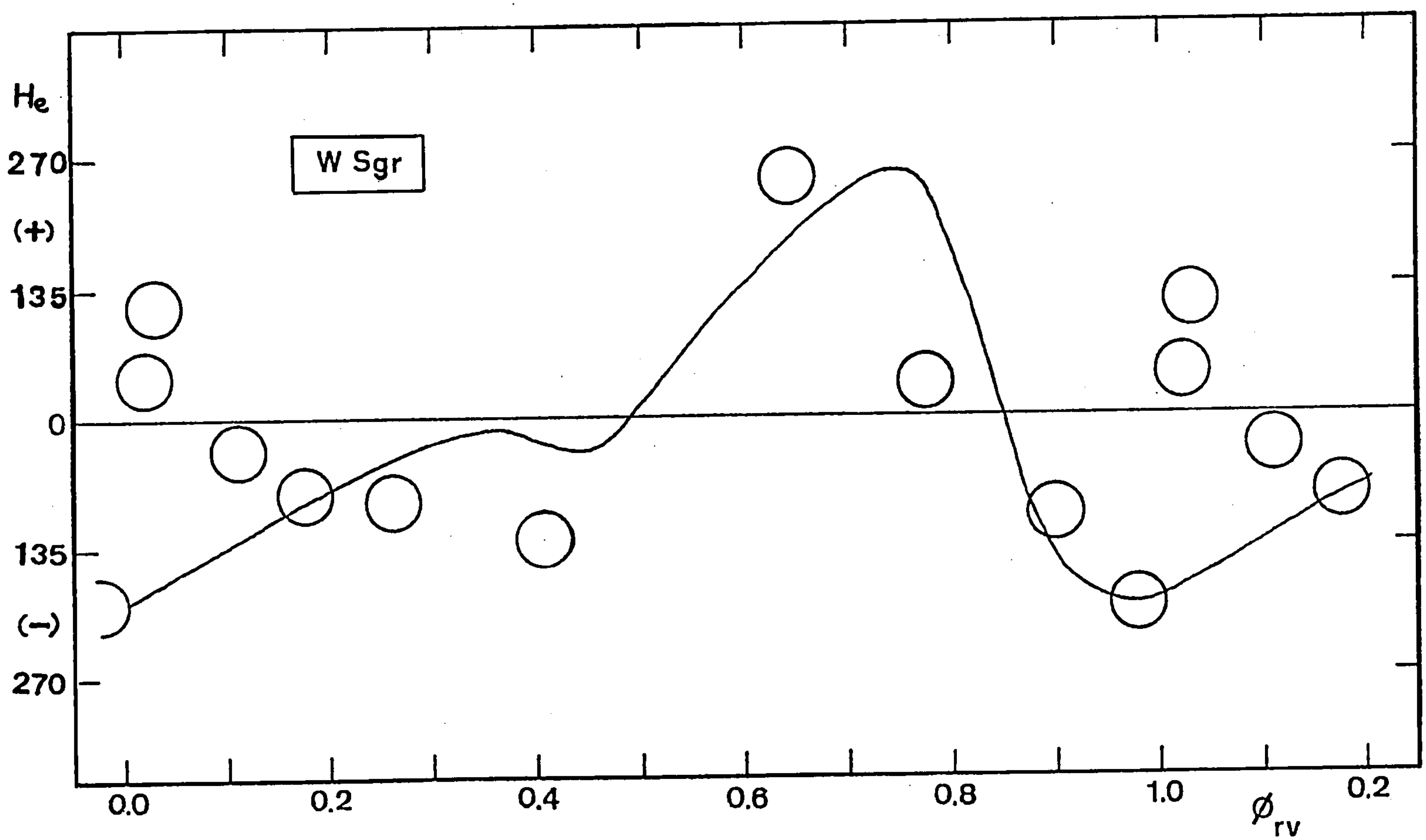

Figure 1. Effective magnetic fields for W Sgr plotted on the $7^{d}.6$ period of pulsation. The curve is Jacobsen's "1923 standard" radial velocity curve. The γ-velocity and zero-field axes coincide.

Discussion

Mullan: Sometimes during the oscillation of a Cepheid there is emission in the K line. Do you find any correlation between your measurements of the field, and emission in the K line core?

J. Wood: My plates were not exposed well enough to see the K line core, since I was looking at the continuum around 4300 and exposing for those metallic lines. So I really can't say anything about that.

Mullan: I think that would be an extremely crucial observation.

J. Wood: Yes. I might mention that we found a magnetic field for Canopus, which has a K2 width that doesn't fit on the Wilson-Bappu relation. And Bappu himself has said that he finds this to be the case on the Sun: whenever there are strong magnetic regions, the K2 width does not correspond to the average K2 width for the Sun.

Michalitsianos: Have there been attempts to measure the circular polarization?

J. Wood: This is circular. That is, we have two spectrograms which are analyzed for right-hand and left-hand circular polarization. Do you mean, in the integrated light?

Michalitsianos: I thought you said the transverse component.

J. Wood: No, these are only longitudinal Zeeman effect, which means circular polarization.

Stellingwerf: You mentioned a 17-year cycle of the radial velocity curve. That sounds suspiciously like some kind of a star spot cycle. I wonder if you could comment on whether we might be able to pick up magnetic field effects on that.

J. Wood: That's an interesting question. The only people I know who have looked into this are Sidney Wolff, Preston, and others who have looked at 73 Dra and other stars that are spectrum variables. They have been observed over long periods of time, and there was really no evidence of long-term changes in the magnetic field. But this, of course, was not a Cepheid. You might expect spots if there are magnetic fields, although these fields are weak compared to those in the Ap stars.

Stellingwerf: I believe it was suggested by Detre and Szeidl that the Blazhko long-term variations of RR Lyrae (two-year period) might be due to a stellar cycle effect. He explains the discrepancy between Babcock's measurements on RR Lyrae and Preston's lack of positive detection of a field in this way.

J. Wood: I've played around a lot with Detre and Szeidl's observations, trying to get some sense out of Babcock's many magnetic observations of RR Lyrae. But there is no way to fit those observations into any of the periods that Detre and Szeidl found. I could not find any "solar cycle".