3.11 MAGNETISM IN WHITE DWARFS

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Abstract. Searches have been made for the normal and quadratic Zeeman effect and broad-band circular polarization in white dwarf stars. A positive effect has been found in Grw + 70°8247 whose continuum shows both linear and circular polarization.

It has been realized for some time that in gravitational collapse the magnetic flux passing through the star may be conserved, resulting in very high fields in the collapsed object (Woltjer, 1964). The discovery of pulsars, which are generally thought to be neutron stars with fields of order 10^{12} G, shows that magnetic flux must be largely conserved in collapse to a neutron star. If no flux is lost, the field strength is increased as $1/R^2$, requiring initial fields before collapse of order 100 G. Such a value is not inconsistent with the fields observed in normal stars, ranging from about 1 G in the sun to 10^4 G in magnetic A stars.

In collapse to a white dwarf, the reduction in radius is typically a factor of 100, giving the possibility of field amplification of up to 10000. Thus fields of between 10^4 and 10^8 G could be expected, depending on the initial field. Various techniques exist to detect fields in this range. In the range from 10^4 to 10^6 G, the normal Zeeman effect is strong enough to be detectable, even though the spectral lines are very broad in dwarfs. We have searched for the Zeeman effect in the Hγ absorption line of a dozen DA dwarfs, and have been able to set an upper limit of between 10^4 and 10^5 G on their fields (Angel and Landstreet, 1970a). Above a few times 10^5 G, the quadratic Zeeman effect would cause a detectable shift of spectral lines, as pointed out by Preston (1970). He concludes from the lack of such shifts that few if any white dwarfs with hydrogen absorption lines can have surface fields in excess of 5×10^5 G. Above a few times 10^6 G the quadratic Zeeman effect is so strong that spectral lines can be smeared out in a non-uniform field, or be so shifted as not to be identified. In this domain magnetic fields can be detected through the circular polarization of continuum radiation (Kemp *et al.*, 1970a). It is this effect which has led to the recent discovery of a very strong field ($\sim 10^7$ G) in one white dwarf, Grw + 70°8247. So far this dwarf appears to be unique. A survey of other dwarfs without spectral lines has revealed no continuum circular polarization down to a level about two orders of magnitude less than that seen for Grw + 70°8247 (Angel and Landstreet, 1970b).

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The initial observations of circular polarization of the continuum light of this star were made by Kemp at Oregon and confirmed by us at Kitt Peak, and are reported in the paper by Kemp *et al.* (1970b). Immediately after the discovery, we made extensive observations at the 107-in. telescope of McDonald Observatory to obtain the wavelength and time dependence of the effect, and discovered linear polarization. (Angel and Landstreet, 1970b) In brief, we find that the polarization is quite constant in time scale between a few seconds and a few days. The wavelength dependence is very striking: the component of circular polarization, which changes only slightly over the range of visible light, drops off very sharply in the ultraviolet, being less than 1 % at 3300 Å. The linear polarization peaks in violet light and drops to zero in the red. Our detailed spectral measurements of both the linear and circular polarization below 7000 Å agree to within a few percent with the later measurements in broader spectral bands by Gehrels. This agreement is very gratifying as the two techniques are quite different. The polarization measurements have been extended to the near infrared (9200 Å) by Gehrels, where the linear polarization reappears with position angle
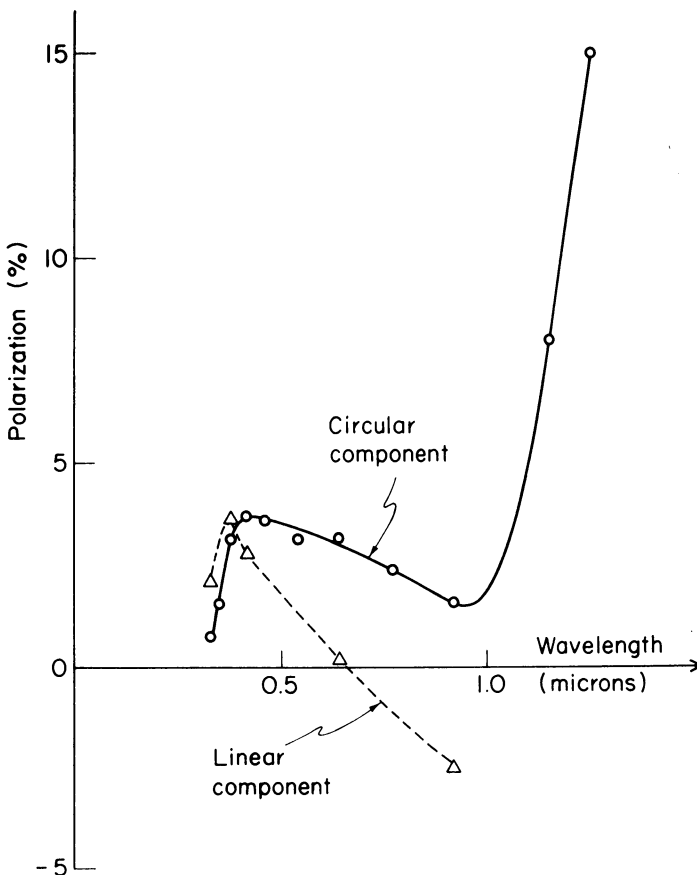

Fig. 1. Circular and linear components of polarization of Grw + 70°8247.

rotated by about 90°, and to 1.2 μ by Kemp, where the circular polarization increases very steeply. All the data so far are compiled on Figure 1.

The complex wavelength dependence of the polarization is not yet understood, but there seems little doubt that a strong magnetic field is responsible for the effect. The phenomenon of elliptical polarization by preferential absorption in a magnetic field is well known, and has been investigated in laboratory measurements of solids (the Faraday and Kerr magneto-optic effects) and in a thin plasma (propagation through the ionosphere). Elliptical polarization of emitted thermal radiation is the inverse process required by detailed balance and has been demonstrated in the laboratory for emission from hot solids and flames (Kemp *et al.*, 1970a).

In the presence of a field, the opacity of the stellar atmosphere becomes polarization dependent, and in general will result in elliptical polarization. For the special case of propagation parallel to the magnetic field in an ionized medium, the absorption coefficients for the two senses of circular polarization are in the ratio $\{(\omega+\omega_B)/(\omega-\omega_B)\}^2$, where ω is the angular frequency of the propagated wave and ω_B is the cyclotron frequency eB/m (Ratcliffe, 1959). This difference in opacity will lead to a net circular polarization q of order ω_B/ω in the continuum emission.

Acknowledgements

References

Angel, J. R. P. and Landstreet, J.: 1970a, *Astrophys. J. Letters* **160**, L147.
Angel, J. R. P. and Landstreet, J.: 1970b, *Astrophys. J. Letters* **162**, L61.
Kemp, J. C., Swedlund, J. B., and Evans, B. D.: 1970a, *Phys. Rev. Letters* **24**, 1211.
Kemp, J. C., Swedlund, J. B., Landstreet, J., and Angel, J. R. P.: 1970b, *Astrophys. J. Letters* **161**, L77.
Preston, G. W.: 1970, *Astrophys. J. Letters* **160**, L143.
Ratcliffe, J. A.: 1959, *The Magneto-Ionic Theory*, Cambridge, England.
Woltjer, L.: 1964, *Astrophys. J.* **140**, 1309.

Discussion

J. Kristian: Doesn't the observed wavelength dependence of the polarisation drastically disagree with Kemp's theory?

R. Angel: Yes, but it should not be taken to give accurately the effect in a white dwarf, where there is radiative transfer. There are many arguments, however, which lead one to believe that V will be of order ω_c/ω, where ω_c is the cyclotron frequency.