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FURTHER POLARIZATION STUDIES OF Grw+70°8247 AND OTHER WHITE DWARFS*

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ABSTRACT

Further observations of polarization in the white dwarf Grw+70°8247 have been made. The circular polarization in a broad band from 4000 to 6000 Å is found not to fluctuate by more than 3 percent on a time scale from 24 seconds to a few days. The circular polarization rises steeply from less than 1 percent at 3300 Å to 3.5 percent at 4000 Å, and then drops slowly to 2.5 percent at 7600 Å. In ultraviolet and blue light the star shows a component of linear polarization of between 2 and 3.5 percent at a position angle of about 20°.

Six other DC white dwarfs, one DA and one DBp, examined for circular polarization, gave null results generally to an accuracy of about 0.1 percent.

I. INTRODUCTION

It has recently been reported (Kemp *et al.* 1970) that the continuum radiation from the λ4135 white dwarf Grw+70°8247 is circularly polarized. This unique effect is taken as evidence that the star has a magnetic field of the order of 10^7 gauss. This paper presents the results of further, more detailed observations of the polarization of that star and also the results of a search for other circularly polarized white dwarfs.

II. INSTRUMENTATION

All of the measurements to be described were made with the photoelectric polarimeter described by Angel and Landstreet (1970). Observations were made by using the Kitt Peak No. 2 36-inch telescope (1970 June 30–July 3) and the 107-inch telescope of the McDonald Observatory (1970 July 3–July 7).

The basic instrument consists of a Pockels cell, operated as a reversible quarter-wave plate, followed by a Wollaston prism, color filters, and two Channeltron photomultipliers. It is used to measure linear polarization by inserting a quarter-wave plate between the collimating lens and the Pockels cell. The wave plate is rotated through four steps of 45° to permit measurement of both components of linear polarization and to eliminate residual effects of circular polarization.

Several checks are made during observations to make sure that the system is properly calibrated. Nearby white dwarfs which are usually neither circularly nor linearly polarized are used to check the overall system for spurious circular and linear polarization. This is found to be less than 0.5 percent. Response to true circular polarization is checked by introducing a Polaroid and wave plate before the circular analyzer. We use one of three wave plates which give a retardation of $\frac{1}{4}$ wavelength at 3500, 5000, or 6500 Å.

A further check on the accuracy of the instrument was made by measuring the linear

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polarization of HR 6601, a star whose polarization as a function of wavelength is already accurately known (Coyne and Gehrels 1966). The measurement was made with a blue Corning 5-59 filter and a quarter-wave plate for 5000 Å and with a neutral density filter to reduce the intensity by a factor of 160, bringing the count rate to about that of Grw+70°8247. We obtain $P = 3.64$ percent $\pm$ 0.10 percent and $\theta = 72° \pm 3°$, compared with a value of $P = 3.75$ percent $\pm$ 0.1 percent and $\theta = 65° \pm 3°$ found by interpolating the data of Coyne and Gehrels to our effective wavelength. This measurement shows that the method of analysis for linear polarization is valid, and also indicates that

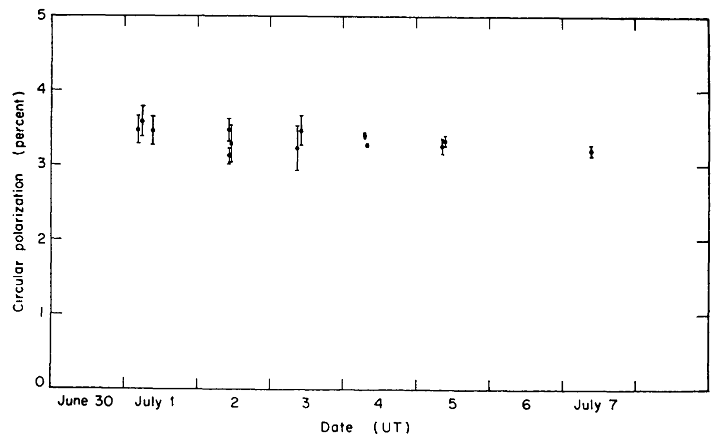

FIG. 1.—Measurements of the circular polarization of Grw+70°8247 made on six different nights without filters.

TABLE 1

MEASURED CIRCULAR POLARIZATION AS A FUNCTION OF TIME

Date (1970)	Time (UT)	Measured Polarization (%)	Deviation from Weighted Mean (%)
July 3/4.....	07:18:30	3.40±0.04	+0.11
	07:50:10	3.27±0.02	−0.02
July 4/5.....	08:57:40	3.26±0.10	−0.03
	09:00:25	3.32±0.07	+0.03
July 6/7.....	09:41:10	3.20±0.07	−0.09

the calibration of the polarimeter is probably not in error by more than 10 percent when it is used to measure circular polarization.

III. OBSERVATIONS OF Grw+70°8247

a) *Time Variation of Circular Polarization*

To study possible time variation of the circular polarization, the light from Grw +70°8247 was measured in a broad band from 4000 to 7000 Å. The measured values are shown in Figure 1. These values are corrected for the nightsky background, and the indicated standard deviations include the uncertainties due to both counting statistics and the variability of the night sky. The comparatively large errors shown for the first three nights result from the poor counting statistics of the smaller aperture telescope. The data obtained with the 107-inch telescope over a period of 4 days, listed in Table 1, were all taken under identical settings of the instrument. The mean polarizations from these five runs do not show statistically significant variations from the mean value of 3.29 percent. The data from the 36-inch telescope were obtained with a slightly different geometry, which resulted in a different wavelength response, so they cannot be compared accurately with the later points.

A Fourier analysis for short-term variability was performed on the data from the longest (1 hour) 107-inch run, which was printed out every 12 seconds. No statistically significant peaks appear in the power spectrum.

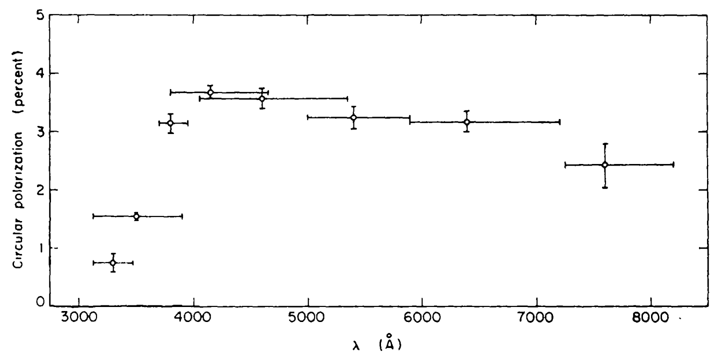

FIG. 2.—Measured circular polarization of Grw+70°8247 as a function of wavelength. Significance of the error bars is explained in text.

TABLE 2

CIRCULAR POLARIZATION OF Grw+70°8247 AS A FUNCTION OF WAVELENGTH

Wavelength of Maximum Transmission (Å)	Width at Half-Power Points (Å)	Measured Circular Polarization (%)	Number of Measurements	Filter*
3300	350	0.75±0.14	2	2.5 mm Corning 7-54 plus 6.3 mm $NiSO_4$, 600 g l^{-1}
3500	800	1.54±0.06	4	St. th. Corning 7-54
3800	250	3.14±0.16	1	St. th. Corning 7-54 plus st. th. Corning 4-96
4150	850	3.68±0.11	1	St. th. Corning 5-59
4600	1300	3.58±0.17	1	St. th. Corning 4-67
5400	900	3.13±0.19	1	St. th. Corning 3-70 minus st. th. Chance OR-2
6400	1200	3.18±0.18	3	St. th. Chance OR-2
7600	950	2.42±0.38	1	4-mm Schott RG-10

* St. th.=standard thickness.

We conclude from these observations that for periods P with 24 sec $< P <$ 2 hours, there is no evidence for variation of the circular polarization with an amplitude of more than 0.07 percent (2 percent of the mean value), while over a period of four days there is no evidence for variation by more than 0.1 percent (3 percent of the mean value).

b) Wavelength Dependence of Circular Polarization

Preliminary measurements of the dependence of circular polarization on wavelength were reported by Kemp *et al.* (1970). We have improved these preliminary results by measuring the circular polarization in eight different wavelength regions covering the range from 3100 to 8000 Å. The results are shown in Figure 2 and are listed in Table 2 along with the filter combinations used. The points in Figure 2 are plotted at the maximum transmission point of the filter-photocathode sensitivity curve, and the horizontal error bars extend to the half-power points of the sensitivity curve. The vertical error bars include the effects of counting statistics and variability of the night sky. The circular polarization in a band from 0.8 and 1.6 μ has been measured by Kemp and Swedlund (Kemp 1970*b*). At an effective wavelength between 1.1 and 1.2 μ, they find a value of 10 percent $\pm$ 3 percent, which indicates that the polarization rises again toward longer wavelengths.

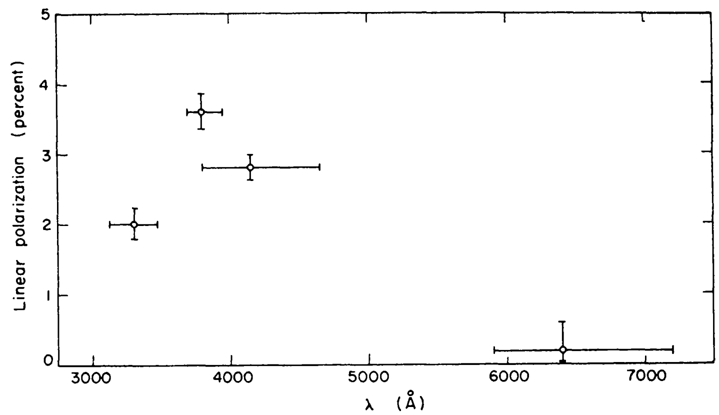

FIG. 3.—Measured magnitude of the linear polarization of Grw+70°8247 as a function of wavelength. Significance of the error bars is explained in text.

TABLE 3

LINEAR POLARIZATION OF Grw+70°8247 AS A FUNCTION OF WAVELENGTH

Wavelength of Maximum Transmission (Å)*	Width at Half-Power Points (Å)*	Measured Linear Polarization (%)	Measured Direction Angle (°)
3300	350	2.1 ±0.22	20.5±3
3800	250	3.7 ±0.24	16.5±3
4150	850	2.8 ±0.17	24 ±3
6400	1200	0.18±0.40	. . .

* See Table 2 for description of filters used.

c) Linear Polarization

Linear polarization was found to be present in the continuum radiation below 5000 Å. Four wavelength regions were measured by the method given above, and the results are shown in Figure 3 and listed in Table 3. The error bars in Figure 3 have the same significance as those in Figure 2. The uncertainty in the position angle of the polarization is due mainly to small errors in alignment of the polarimeter.

IV. SEARCH FOR OTHER CIRCULARLY POLARIZED WHITE DWARFS

We have made a preliminary search in broad-band light for circular polarization in other white dwarfs. We have concentrated mostly on observing a number of DC white dwarfs. If the absence of spectral features is the result of a large magnetic field which has smeared any absorption lines to the point of invisibility, then these dwarfs might also show large circular polarization. We have also observed one DA star and the peculiar DB star HZ 29 which Ostriker and Hesser (1968) have suggested may be magnetic. None of the stars observed showed a mean polarization significantly different from zero, with a standard deviation of 0.1 percent or less. As was done for Grw+70°8247, the data were later Fourier-analyzed for all periods from twice the scaling period (12 sec) to twice the length of the observation (typically 15–30 min). In no case was the power spectrum significantly different from a noise spectrum.

The results of our observations are presented in Table 4. The mean polarization for the whole run is given in column (7), along with the standard deviation due to counting statistics. The amplitude of a sinusoidal polarization wave which would give a power spectrum peak of the same height as the largest observed peak is given in column (8);

TABLE 4

MEASURED CIRCULAR POLARIZATION OF OTHER WHITE DWARFS

Star Name (1)	Eggen and Greenstein* No. (2)	V (3)	Date of Observation (1970) (4)	Length of Observation (min) (5)	Number of Photons Recorded (thousands) (6)	Measured Mean Circular Polarization (%) (7)	Circular-Polarization Equivalent of Largest Power-Spectrum Peak (%) (8)
Wolf 1516	9	13.82	July 3/4	3.2	1074	-0.12 ± 0.10	0.32
L1261−24 =G57−29	85	15.54	July 3/4	28.0	999	-0.02 ± 0.10	0.50
HZ 29 (DBp)	91	14.18	July 4/5	14.5	3999	-0.03 ± 0.05	0.19
Wolf 457=660−54	95	15.90	July 3/4	29.4	861	$+0.07\pm0.11$	0.59
Wolf 485A (DA)	99	12.30	June 30/ July 1	14.6	1023	$+0.21\pm0.10$	...
L845−70	122	14.30	July 3/4	25.6	2168	-0.03 ± 0.07	0.32
G24−9	138	15.67	July 3/4	15.8	1133	$+0.12\pm0.09$	0.56
L1363−3 =G126−27	148	13.23	July 3/4	13.0	6406	$+0.01\pm0.04$	0.16

* Eggen and Greenstein (1965).

this may be taken as an upper limit on the amplitude of any variable component of stellar circular polarization with a period between 24 sec and twice the length of the run.

V. CONCLUSION

From the foregoing data we may draw several conclusions. First, there is no evidence as yet that the circular polarization of Grw+70°8247 is variable. If the polarization is caused by a magnetic field, then either the axis of the magnetic field coincides with the rotation axis or the star is a very slow rotator with a period of many days. The evidence from other stars known to be magnetic is that the magnetic field does not align with the spin axis. This is true for the magnetic Ap stars (Preston 1967; Landstreet 1970) and the weak fields observed by Severny in giants (Severny 1970), and is presumed to be the case in magnetic neutron-star models of pulsars (Pacini 1968). On the other hand, Grw +70°8247 may well rotate extremely slowly. The mass loss which presumably occurred in the final stages of pre–white-dwarf evolution could have carried off most of the angular momentum of the star, through magnetic coupling between the star and distant escaping material.

Second, it is apparent that the wavelength dependence of the polarization is complex and as yet not fully understood. In particular, the presence of a linear-polarization component in the blue and the sharp drop in circular polarization shortward of 4000 Å need explanation. The simple theory of magnetoemission (Kemp 1970*a*) predicts a circular polarization which is proportional to wavelength and predicts no linear polarization to first order in the magnetic field. Clearly the normal absorption and scattering processes taking place in the stellar atmosphere will be modified by a very strong magnetic field, and may give rise to some of the observed effects.

Finally, it appears that circular polarization is not a common property of white dwarfs. One explanation for this might be that stars like Grw+70°8247 are formed (by evolutionary contraction and consequent magnetic field amplification) only from the main-sequence stars with large ($\gtrsim 10^3$ gauss) magnetic fields. If the peculiar A stars are the only such class of stars, the fraction of white dwarfs which should be formed with very large magnetic fields would be of the order of a few percent.

We should like to thank the Director of McDonald Observatory for making the 107-inch telescope available to us, and the Director of Kitt Peak National Observatory for the use of a 36-inch telescope. We are grateful to Miss Jamie Deckoff for her help in readying the polarimeter and reducing the data.

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