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DISCOVERY OF PERIODIC VARIATIONS IN THE CIRCULAR POLARIZATION OF THE WHITE DWARF G195−19*

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ABSTRACT

The circular polarization observed in the continuum radiation of the DC white dwarf G195−19 has been found to be periodically variable with a period of 1.34 days. In the wavelength band 3800–5400 Å, the mean polarization is −0.224 percent and the amplitude of the variable component is 0.250 percent. The polarization in other bands is not so strongly modulated. In a broad wavelength band the star showed no detectable linear polarization (0.09 ± 0.13 percent) at a time when the circular polarization was close to maximum.

The DC white dwarf G195−19 = GR 250 was recently found to show circular polarization of continuum light (Angel and Landstreet 1971; Kemp, Swedlund, and Wolstoncroft 1971), an effect similar to that discovered earlier in the λ4135 white dwarf Grw+70°8247 (Kemp *et al.* 1970). The mean effect detected in a broad wavelength band from 3800 to 6000 Å was −0.42 percent (Angel and Landstreet 1971). During the period 1971 January 19–February 1, we made further polarization measurements of this star at the 82-inch and 107-inch telescopes of McDonald Observatory, using the polarimeter described earlier (Angel and Landstreet 1970*a*, *b*).

Early in the observing run we found that the polarization in a wavelength band from 3800 to 5400 Å (defined by a Corning 4-96 blue-green filter) was not constant, and from then on we made several measurements in this band each workable night. Thirty-three observations of typically 40 minutes duration each were obtained on eight separate nights. These data and the results of measurements made in other colors are listed in Table 1. The nightsky contribution to these measurements was kept small by using small diaphragms, 4″ on the 107-inch and 7″ on the 82-inch telescopes. All runs were made on moonless nights. The circular-polarization values in Table 1 are corrected for the night-sky contribution and for the diminished sensitivity of the instrument away from the central wavelength, where the Pockels cell does not give exactly $\frac{1}{4}\lambda$ retardation. Neither of the above effects gives a correction of more than a few percent. The standard deviations are calculated from the accumulated totals, on the assumption that counting statistics are the only source of error.

An inspection of the thirty-three blue-green data points indicates a period of about 32 hours, the polarization varying between about zero and −0.5 percent. A good fit of the form

$$P(t) = P_0 + P_1 \sin(\omega t - \phi) \qquad (1)$$

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TABLE 1

MEASURED CIRCULAR POLARIZATION OF G195−19

Mean Wavelength of Passband (Å)	Half-Power Points of Passband (Å)	Filter*	Time of Measurement (J.D. 2440000+)	Phase†	Measured‡ Circular Polarization (percent)
4900..........	3800, 5850	None	971.013	0.9747	−0.49±0.11
			971.022	0.9816	−0.41±0.12
			971.031	0.9886	−0.72±0.15
3550..........	3175, 3925	Corning 7-54	973.963	0.1790	−0.59±0.10
			976.990	0.4398	−0.18±0.12
			978.853	0.8315	−0.83±0.07
			979.772	0.5182	−0.20±0.09
			979.964	0.6613	−0.42±0.10
			980.788	0.2767	−0.19±0.10
			980.921	0.3763	−0.39±0.10
			980.987	0.4254	−0.31±0.11
4300..........	3800, 4775	Corning 5-59	979.829	0.5607	+0.17±0.05
4600..........	3775, 5400	Corning 4-96	970.884	0.8788	−0.44±0.11
			970.913	0.9006	−0.46±0.11
			970.932	0.9145	−0.43±0.09
			976.961	0.4184	−0.14±0.10
			976.969	0.4243	+0.05±0.10
			977.006	0.4520	−0.14±0.10
			977.817	0.0574	−0.57±0.06
			977.891	0.1129	−0.39±0.05
			977.995	0.1904	−0.32±0.05
			978.015	0.2052	−0.33±0.10
			978.747	0.7525	−0.19±0.05
			978.819	0.8065	−0.26±0.05
			978.885	0.8557	−0.39±0.05
			978.913	0.8762	−0.41±0.05
			978.994	0.9370	−0.51±0.04
			979.013	0.9510	−0.50±0.09
			979.744	0.4967	+0.01±0.05
			979.874	0.5940	−0.11±0.05
			980.002	0.6900	−0.05±0.05
			980.746	0.2459	−0.18±0.05
			980.814	0.2966	−0.17±0.06
			980.839	0.3149	−0.06±0.05
			980.864	0.3336	−0.11±0.05
			980.890	0.3528	−0.03±0.05
			980.955	0.4015	+0.01±0.05
			982.907	0.8596	−0.35±0.05
			982.956	0.8961	−0.38±0.05
			982.992	0.9236	−0.44±0.05
			983.799	0.5256	−0.01±0.05
			983.840	0.5569	−0.04±0.05
			983.891	0.5950	−0.02±0.05
			983.936	0.6280	−0.07±0.05
			983.977	0.6586	−0.03±0.05
5850..........	5075, 6450	Corning 3-70	970.968	0.9415	−0.31±0.12
			970.995	0.9620	−0.55±0.14
			979.794	0.5340	−0.57±0.10
			984.011	0.6847	−0.29±0.20
6550..........	6000, 7000	Chance OR-2	974.004	0.2094	−0.53±0.24
			976.917	0.3851	−0.49±0.09
			978.783	0.7790	−0.99±0.10
			978.954	0.9072	−0.83±0.10
			979.923	0.6306	−1.02±0.11
7200..........	6675, 7600	Corning 2-64	977.442	1.1513	−0.86±0.15

* All filters are standard thickness; mean and half-power wavelengths of passband refer to combined filter-photocathode sensitivity curve with one atmosphere of extinction.

† Phases calculated with $P = 1.339$ days, zero phase at J.D. 2440975.062.

‡ Sign of polarization is positve if the E-vector in a stationary plane rotates counterclockwise as seen by observer facing star.

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was obtained by the method of least squares by varying the parameters P_0, P_1, ω, and ϕ to minimize the function

$$\chi^2 = \sum_{i=1}^{33} \frac{1}{\sigma_i^2} [P(t_i) - P(i)]^2 , \tag{2}$$

where $P(i)$ and σ_i are the values of polarization and standard deviation given in Table 1. This procedure yields a best-fit period of 1.339 days, with $P_0 = -0.224$ percent and $P_1 = 0.250$ percent, and the phase such that the polarization is at a maximum strength on J.D. 2440975.062. With this best fit χ^2 has a value 25.28, which is very satisfactory for thirty-three data points fitted with a function with four variables. Figure 1*a* shows all the data points in blue-green light superposed; the period taken is 1.339 days. We have checked to see if other periods give a good fit by minimizing χ^2 with respect to P_0, P_1, and ϕ for a range of periods from $\frac{1}{2}$ to 5 days. Figure 2 shows the result of this

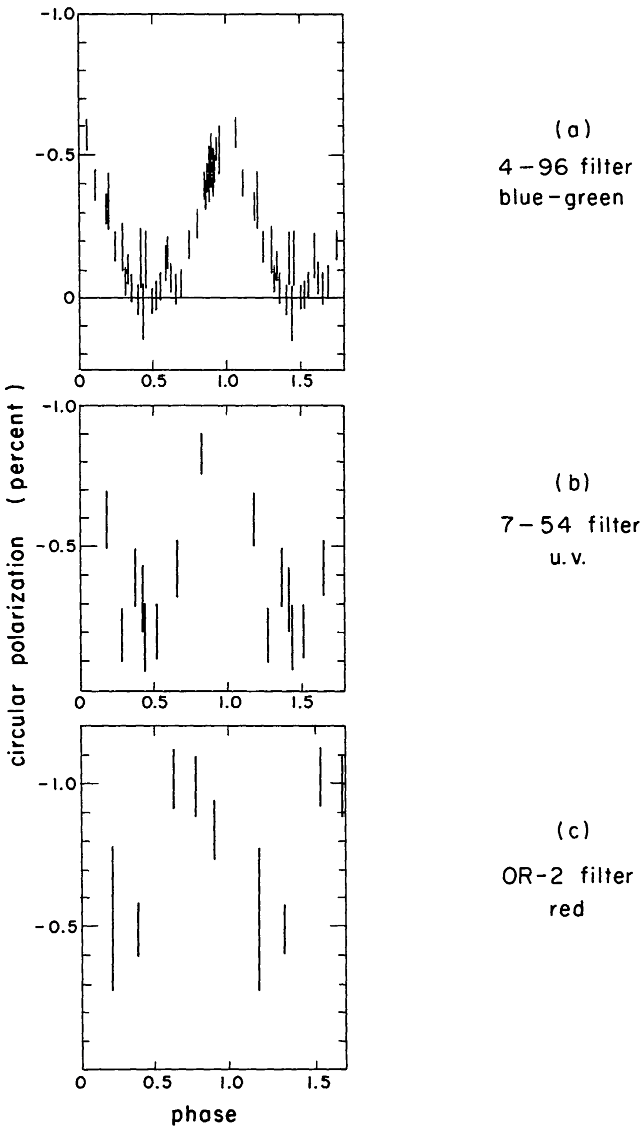

FIG. 1.—Polarization data superposed with period 1.339 and phase = 0 at J.D. 2440979.0786. The vertical lines join the points 1 standard deviation above and below the measured values.

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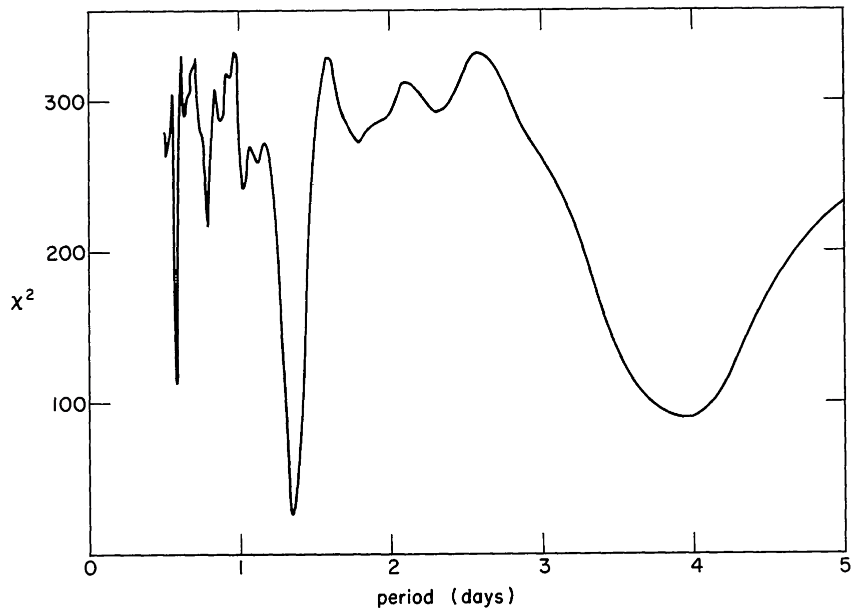

FIG. 2.—χ^2 as a function of frequency for the 33 data points taken with the 4-96 filter

analysis; it is apparent that the period 1.34 days gives much the best fit. The two other periods, 0.57 and 4.0 days, which give weaker minima in χ^2, are to be expected because the data are sampled each day for only a small fraction of a day. For the stellar frequency of 0.748 cycles/day the sum and difference frequencies produced by sampling once a day are 1.748 and 0.252 cycles/day, corresponding exactly to the above two secondary minima. From the values of χ^2 obtained near the minimum the error in the determined period can be estimated. For 30 degrees of freedom the value of χ^2, which has 10 percent probability of being exceeded, is 40.3 (Fisher 1958). The range of trial periods giving χ^2 less than this is 1.345 ± 0.030 days. (The χ^2 curve is asymmetric about the minimum value at 1.339.)

Figures 1*b* and 1*c* show the data in ultraviolet (Corning 7-54 filter) and red light (Chance OR-2 filter), superposed with the same period and phase as Figure 1*a*. A striking result is that the polarization in red light, which is quite strong, does not follow the same variation as the blue-green data. There is no pronounced minimum at phase 0.5. On the minimum of January 28 (J.D. 2440979.8), for example, the mean blue-green polarization was -0.05 percent, while the effect in red light was -1.02 ± 0.11 percent. On the same night, a definite effect of opposite sign, $+0.17 \pm 0.05$ percent, was measured in blue light (Table 1). The variation of polarization in the ultraviolet is similar to that of the blue-green, although the minimum is not so low, and the maximum appears to be higher. It should be noted that the apparent wavelength dependence of polarization obtained in November (Angel and Landstreet 1971) is not valid because the points were obtained at different phases.

The polarization data from the 37-minute blue-green run on J.D. 2440980.95 was printed out every 11 seconds and was subsequently Fourier-analyzed for all periods from 22 seconds to 75 minutes. No significant periods were found in this range. The amplitude of a polarization wave which would have produced a peak in the power spectrum as large as the largest peak observed is 0.19 percent; periodic variation with an amplitude 50 percent larger than this and a period in the range in question would almost certainly have been detected.

The star was observed in the band 3800–6000 Å for linear polarization on J.D. 2440977.85, when the circular polarization in the 4-96 filter band was near maximum

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and had a value of about 0.45 percent. The measured value is $p_x = p \cos \theta = +0.09 \pm 0.09$ percent and $p_y = p \sin \theta = +0.02 \pm 0.09$ percent. It therefore appears that linear polarization, if present, is substantially smaller than the circular polarization.

An unwidened S-20 image-tube spectrum of the star at 200 Å mm^{-1} exposed over the range 4000–6000 Å obtained on January 24 shows a smooth continuum with no features apparent on visual inspection.

The most obvious interpretation of the periodic variation of the polarization is as a rotational period, if the effect is assumed to be caused by a magnetic field which is not symmetrical about the spin axis. Such an interpretation requires that the polarization at a given wavelength cannot be simply a linear function of the magnetic field as predicted by the theory of Kemp (1970). If the circular polarization at a point on the surface were a function of the form $V(\lambda, B) = B_l F(\lambda)$, where B_l is the line-of-sight component of the field, then the polarization averaged over the star's disk would be

$$\langle V(\lambda) \rangle = F(\lambda) \int_{\text{disk}} B_l(A) dA \, ,$$

and the ratio of polarizations in two colors

$$\frac{\langle V(\lambda_1) \rangle}{\langle V(\lambda_2) \rangle} = \frac{F(\lambda_1)}{F(\lambda_2)}$$

would be independent of phase, which is contrary to observations. Our data could be explained if the polarization over the surface of the star depends on another variable besides the field, or if $V(\lambda, B)$ is not separable.

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