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THE SPECTRAL DEPENDENCE OF CIRCULAR POLARIZATION IN Grw+70°8247

J. R. P. ANGEL*
Columbia Astrophysics Laboratory, Columbia University

J. D. LANDSTREET
Department of Astronomy, University of Western Ontario, London 72, Ontario, Canada

AND

J. B. OKE
Hale Observatories, California Institute of Technology, Carnegie Institution of Washington
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ABSTRACT

Sharp changes in circular polarization with wavelength are seen in new observations of Grw+70°8247 made with 80 Å resolution. Some of the structure is associated with the Minkowski bands. Continued broad-band measurements show that while the polarization below 6000 Å appears to remain constant, above this wavelength there have been significant changes in the past year.

I. INTRODUCTION

The white dwarf Grw+70°8247 is remarkable in showing relatively strong circular polarization (of a few percent) across the whole optical spectrum. Since its discovery (Kemp *et al.* 1970), three other dwarfs showing circular polarization have been found (Angel and Landstreet 1971; Landstreet and Angel 1971) but none with so pronounced an effect. The polarization is almost certainly due to an intense, ordered magnetic field at the surface of the star, which could be expected to produce a Zeeman effect large enough to show up even in the broad shallow bands of this star. The measurements of the wavelength dependence made so far (Angel and Landstreet 1970; Gehrels 1970) have spectral resolution of a few hundred angstroms at best, not enough to show possible structure at the absorption bands, although sharp differences between adjacent measurements are apparent, especially between 3500 and 4300 Å. In this paper we report the results of new narrow-band measurements, which show fine-scale spectral structure of the polarization, and also of continued broad-band measurements made to check for variability.

II. OBSERVATIONS

The broad-band measurements have all been made with the polarimeter described by Angel and Landstreet (1970), and the data were reduced in the same way as previously, yielding the results given in Table 1. Where earlier measurements have been made in the same band, these are given in the last column. A comparison of the new and previously reported results shows that there is no evidence of secular change in either linear or circular polarization on the blue side of 6000 Å. Beyond 6000 Å, however, recent measurements of circular polarization are smaller than those measured a year ago by both ourselves and Gehrels by significant amounts. At present, nothing definite can be said about the time scale of this variation. Our earlier limits on the amount of variability on various time scales were in the range below 6000 Å (Angel and Landstreet 1970). One new result which appears in Table 1 is the measurement of circular polarization at

* Alfred P. Sloan Research Fellow.

TABLE 1

NEW BROAD-BAND POLARIZATION MEASUREMENTS OF Grw+70°8247

Mean and Half-Power Points of Passband* (Å)	Filter†	Date of Observation (JD 2440000+)	Measured Polarization (%)	Previously Measured Polarization‡ (%)
		Circular Polarization Measurements		
3200 3100, 3300	5-cm $NiSO_4$+ Corning 7-54	891.60	−1.62±0.22	...
3425 3175, 3600	0.75-cm $NiSO_4$ +Corning 7-54	891.71	−0.82±0.17	−0.75±0.14
3475 3250, 3650	0.75-cm $NiSO_4$ +Corning 7-54 +Corning 7-60	891.70	−1.49±0.33	...
3550 3175, 3925	Corning 7-54	1061.82	−1.87±0.13	−1.54±0.06
4300 3800, 4775	Corning 5-59	882.56 1060.86	−3.58±0.23 −3.73±0.13	−3.68±0.11
4750 4125, 5400	Corning 4-67	855.57	−3.78±0.30	−3.58±0.17
4900 3800, 5850	None	1040.98	−3.52±0.26 −3.34±0.30	−3.29±0.05
5850 5075, 6450	Corning 3-70	1094.67	−3.04±0.11	−3.24±0.19
6550 6000, 7000	Chance OR-2	1041.96 1094.77 Mean	−2.45±0.15 −2.28±0.11 −2.36±0.09	−3.18±0.18
7200 6675, 7600	Corning 2-64	1040.97 1041.98 1042.93 Mean	−2.39±0.78 −1.42±0.42 −0.75±0.26 −1.04±0.21	...
7400 7075, 7800	2-mm Schott RG-10	1041.97 1042.96 1043.96 Mean	−0.90±0.50 −1.27±0.19 −0.75±0.22 −1.04±0.14	−2.42±0.38
		Linear Polarization Measurements		
4300 3800, 4775	Corning 5-59	1153.65	3.05±0.21 21°±2.5°§	2.88±0.13 24°±3°§
4750 4125, 5400	Corning 4-67	855.67	2.02±0.60 28°±8°§	...

* Passbands are for combined filter-photocathode sensitivity curve. The effect of one atmosphere of extinction is included except for ultraviolet measurements with $NiSO_4$, which are corrected for extinction of actual air mass.

† All filters are standard thickness unless noted; $NiSO_4$ is 410 g liter^{-1} solution.

‡ From Angel and Landstreet (1970), measured on JD 2440768–74.

§ Equatorial position angle.

3200 Å, which appears to be increasing again after a sharp minimum around 3400 Å.

In order to make circular polarization observations with finer spectral resolution than can be obtained with glass filters and a single channel, polarimeter optics were constructed for use with the Cassegrain multichannel spectrophotometer of the 200-inch (508-cm) Hale telescope (Oke 1969). The method is very similar to that used for the broad-band measurements described above. A Lasermetrics KD*P Pockels cell is mounted above the entrance diaphragm of the spectrophotometer. The converging f/16 beam is collimated by a negative quartz lens immediately above the cell and reconverged by a second lens directly below. A small Glan-Thomson polarizing prism is mounted directly above the entrance diaphragm with its axis set at 45° to the principal axes of the Pockels cell. Only one entrance aperture is used. The two scalers A and B for each photomultiplier channel (normally used for star and sky) measure the intensity in left and right circular polarization by accepting alternately photomultiplier pulses as the polarity of the Pockels cell is reversed every 10 ms. The system was calibrated for each of the cell-operating voltages used by measuring the response in each spectral band to both unpolarized and pure circularly polarized light. The polarized light was made by mounting a HNP'B or HR Polaroid followed by a Fresnel rhomb or a quartz quarter-wave plate in the incoming beam. The measurements reported below are corrected for the nightsky contribution, which was found to be not significantly polarized, and for the efficiency of the polarimeter at each wavelength. The errors quoted are standard deviations calculated from photon counting statistics and include the effect of 1 percent uncertainty in the polarization of the night sky.

Circular polarization measurements were made on 1971 June 16/17 (JD 2441119.9) in which channels 160 Å wide between 3000 and 5600 Å and 360 Å wide between 5600 and 11,360 Å were used. Most of the runs were made with optimum setting for the infrared—that is, 3.35 kV applied to the KD*P crystal giving quarter-wave retardation at about 7000 Å—but some data were taken with 1.85 kV ($\lambda/4$ at 4500 Å). Measurements were made on 1971 June 17/18 (JD 2441120.9) in the wavelength region 3000–7500 Å using 80 Å passbands and 1.85 kV on the Pockels cell. The results are shown in Figure 1. Vertical lines denote data taken with 80 Å passbands and extend to $\pm 1\ \sigma$ from the measured value. Horizontal error bars on the points plotted as open circles indicate the bandpass of bands with 160 Å or 360 Å width; vertical bars also extend to $\pm 1\ \sigma$ on these points.

The absolute spectral energy distribution for Grw+70°8247 has been measured on numerous occasions using the multichannel spectrometer mentioned above. The results obtained on 1969 August 12/13 are shown below the polarization data in the figure, where $AB = -2.5 \log f_\nu - 48.60$ is plotted against wavelength. The flux f_ν is in units of ergs $s^{-1}\ cm^{-2}\ Hz^{-1}$ and is based on the absolute calibration of α Lyr given by Oke and Schild (1970). The bandpass was 40 Å for $\lambda < 5800$ Å and 80 Å for $\lambda > 5800$ Å. Standard deviations are less than 0.02 mag for $\lambda < 8300$ and vary from 0.05 to 0.10 mag from λ8400 to λ10,600. A few representative error bars are shown in the figure.

III. DISCUSSION

The shape of the spectral dependence is generally in good agreement with the broadband results. The reality of the local minimum in the polarization around 3500 Å found from $NiSO_4$-filter measurements is confirmed, as is the low value of polarization recently measured with glass filters above 7000 Å. The polarization measured in the infrared near 1.1 μ does not appear to agree with values around 10 percent found by Kemp and Swedlund (1970) near 1.2 μ, but this may be due to secular change in the polarization in red light discussed above or to strong polarization in the red end of Kemp and Swedlund's rather broad bands.

The most striking feature of these observations is the spectral structure in the polarization, some of which is associated with known bands in the absorption spectrum of the star (Greenstein and Matthews 1957; Greenstein 1970). Sharp steps in the polarization are found in association with the bands at $\lambda\lambda$4135 and 4470, and a weaker feature seems to be associated with the band at λ3910. All of these bands are clearly seen in the absolute spectral energy distribution shown in the figure. The clear step at λ5375 appears to correspond to an absorption feature in the energy distribution which goes from λ5380 to λ5460. The rather large fractional changes in polarization that occur at the Minkowski bands lead one to believe that these bands are not incidental but are in some way intimately associated with the whole phenomenon of circular polarization.

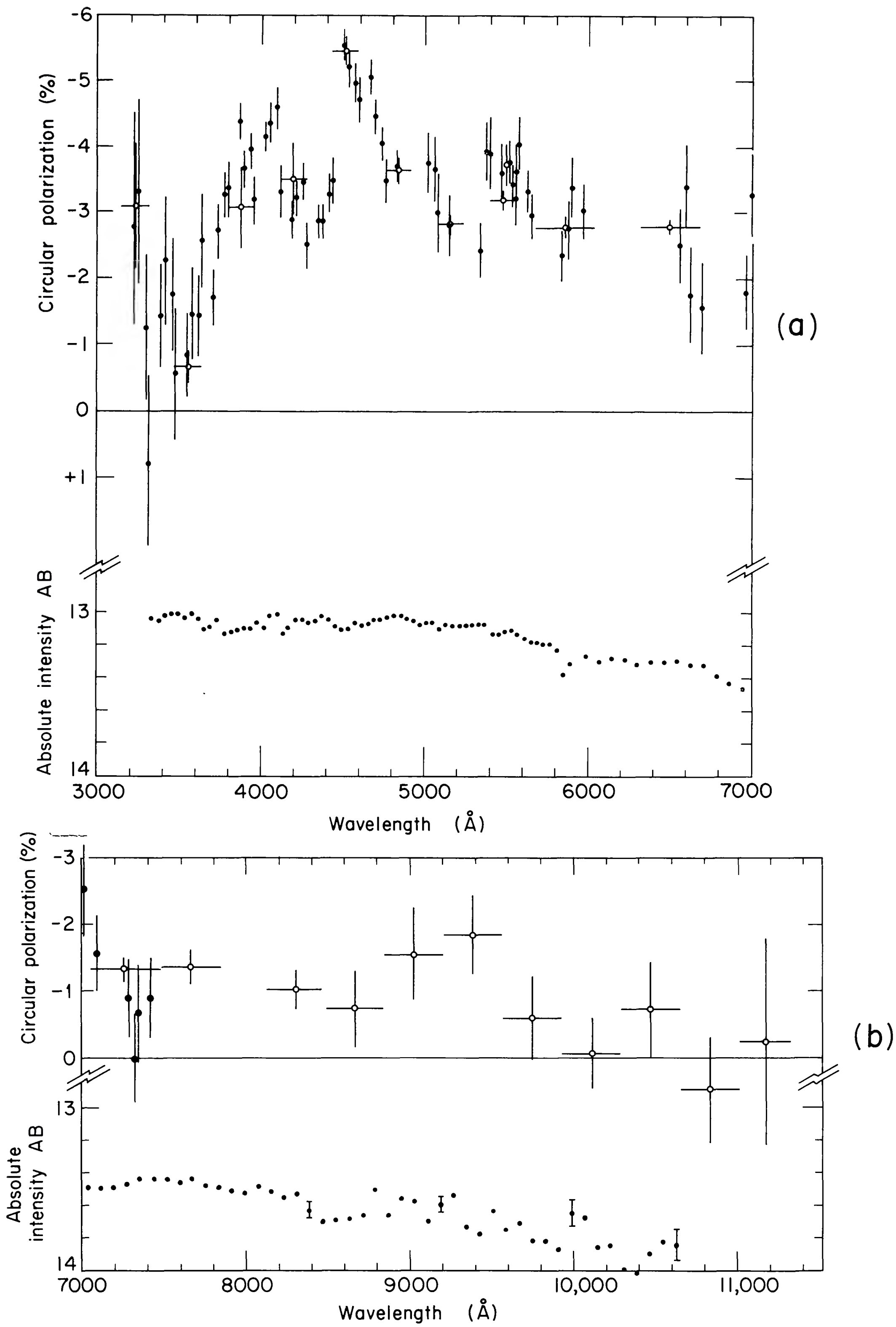

FIG. 1.—Circular polarization and absolute spectral energy distribution over the range (*a*) 3000–7000 Å and (*b*) 7000–11,500 Å. Significance of the error bars is explained in text.

A normal Zeeman splitting of the bands cannot explain in detail the observed effects; for example, the polarization step at λ4470 is stronger than that at λ5875, although the absorption at λ5875 is stronger. If we leave these difficulties for the moment, it is possible to make an estimate, along the lines used for normal magnetic stars, of the field strength involved. Such an estimate, based on the Zeeman effect, does not require any assumption about the continuous circular polarization. The absorption profile of the band at 4470 Å is roughly 7 percent deep and 100 Å wide. A field along the line of sight of 10^6 gauss, assuming a normal Lorentz triplet expected in the Paschen-Back limit, would separate the left- and right-handed components by 20 Å and cause a difference in circular polarization in the line wings of 2 percent, close to the observed value. While this must be only a rough estimate, it is difficult to see how a field much less than 10^6 gauss could cause such pronounced polarization structure in the weak absorption features. In the following paper, we consider in more detail the possible origins of the polarization and band structure.

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