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BVRI polarimetry of carbon stars

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Abstract. *BVRI* polarimetry of carbon stars belonging to different variability types – VX And, UU Aur, T Cae, Y CVn, U Hya, Y Hya, RY Mon, W Ori, Y Per, RT Pup, and X Vel – is presented. Though there is significant scatter, on the average, carbon stars show a flatter wavelength dependence than oxygen-rich objects. Circumstellar grain scattering appears to be the main mechanism responsible for the continuum polarization in these objects.

Key words: polarization – carbon stars – variable stars – circumstellar matter

1. Introduction

Many late-type variables are found to exhibit intrinsic linear polarization which often varies quasi-periodically (Dyck 1968; Kruszewski et al. 1968; Dyck & Jennings 1971; Dyck & Sanford 1971; Serkowski 1971; Shawl 1975a). Multiwavelength polarimetric studies are important in determining the specific mechanism which produces the polarization. If dust scattering is the main mechanism operative, multiwavelength observations would provide important information not only on the nature and sizes of the grains responsible but also on their distribution in the envelope, and a study of the variation of polarization and its wavelength dependence would throw light on the process of formation and evolution of circumstellar dust clouds.

In general, carbon stars have received comparatively less attention polarimetrically. In this paper we present the results of *BVRI* polarimetry of a sample of carbon stars.

2. Programme stars and observations

Some of the basic data on the programme stars, taken from Kukarkin et al. (1969), are listed in Table 1. Representative objects belonging to different variability types were included in the observational programme. A few of the objects for which polarization measurements are reported earlier in the literature were included because for these objects, in addition to the wavelength dependence, information on the time dependence can also be obtained. All the objects except Y Hya have been detected in the 12, 25, and 60 μm passbands in the far IR by the InfraRed Astronomy Satellite (IRAS) and most of them even at 100 μm, indicating the presence of extended cool dust envelopes around them.

Linear polarization measurements of the programme stars in the *BVRI* bands were obtained with the 102-cm telescope of the Vainu Bappu Observatory, Kavalur, during the period 1984–87. The polarimeter used consists of a superachromatic half-wave plate rotated at 10.41 Hz acting as the polarizer and a Wollaston prism acting as the analyzer. A microcomputer system built around a Z-80 microprocessor was employed for the acquisition and on-line processing of the data. A detailed description of the instrument and the method of calibration are given in Deshpande et al. (1985). Table 2, which contains the linear polarization measurements of unpolarized stars obtained on two occasions, shows that the instrumental polarization in the *BVRI* bands is negligible and did not significantly vary with time.

3. Observational results

The linear polarization (P%), position angle ($\theta°$) and the errors of their measurements, and the corresponding Julian days of observation are given in Table 3. The values of P% and $\theta°$ are plotted in Figs. 1–4. The polarization measurements in the *B* band, in general, have large errors because of the low photon flux in this band.

The salient results of polarization measurements of each object are described in the following sections, and comparisons with the previously published results are made wherever possible. Information on the light curve around the times of polarimetric observations is derived from the AAVSO visual data (Mattei 1986, private communication).

3.1. Y Persei

The Mira variable Y Per was observed on two occasions, and the results are plotted in Fig. 1 which also contains the mean light curve drawn through the AAVSO data obtained during the corresponding period. The epochs of polarimetric observations are indicated in the figure. The uncertainties in measurements are higher in the *B* band because of the low photon flux. The results obtained in each band on both occasions agree within the observational errors; but the values in the *VRI* bands obtained close to the light minimum lie systematically below those obtained on the descending branch of the light curve. The star was fainter by ~0.2 mag on the former occasion. The measurements in *V* and *B* obtained by Dyck & Sanford (1971) during 1969 Dec. 1 – 1970 Jan. 2 are also plotted and the corresponding photometric phases are approximately indicated in Fig. 1 (The epoch of maximum light was taken from Kukarkin et al. 1969). The agreement in both the amount and position angle of polarization, especially in the *V* band, is remarkable. The polarization is nearly constant in the *VR* spectral region, but decreases towards the *I* band.

Table 1. Basic data on the programme stars

Star	Galactic latitude ($b°$)	Variability type	Period (d)	Spectral type
VX And	−18	SRa	369	N7(C4, 3)
UU Aur	+14	SRb	235	N3(C5, 4)
T Cae	−40	SR	156	N4(C6, 4)
Y CVn	+72	SRb	158	N3(C5, 4)
U Hya	+38	SRb	450	N2(C7, 3)
Y Hya	+24	SRb	303	N3p(C5, 0)
RY Mon	0	SRa	466	R(C4, 8)
W Ori	−23	SRb	212	N5(C5, 3)
Y Per	−10	M	252	C4, 3e
RT Pup	−4	SRb	100	C6, 2
X Vel	+10	SR	140	Nb

3.2. *W Orionis*

Dyck (1968) has reported polarization measurements of W Ori in V and B obtained on five nights spread over about 100 d. The average values obtained by him are: $P_B = 0.24 \pm 0.11\%$ and $P_V = 0.34 \pm 0.09\%$ against $P_B = 0.03 \pm 0.11$ and $P_V = 0.15 \pm 0.04$, presently obtained. The differences in the two sets are significant when we consider the low instrumental polarization (Table 2), indicating a possible long-term variation in the polarization. The low values obtained by us in all wavelength bands (Fig. 3) suggest the interstellar polarization to be negligible in the direction of W Ori (b = −23°).

3.3. *Y Canum Venaticorum*

The polarimetric observations of Y CVn were obtained close to a light maximum, and the values are found to be close to zero at all wavelength bands. The plot of polarization in the blue spectral region of late type stars against their spectral types given by Serkowski (1971) indicates a value ~0.25% for Y CVn. Dyck et al. (1971) have reported a polarization of 2.2% at 1.05 μm, and 0.0 at 1.6 μm (date of observation, 1971 March 6). If the value at 1.05 μm reported by them is correct, it shows that Y CVn exhibits a large variation in polarization. The galactic latitude of the object is $b = +72°$. The very low polarization values listed in Table 3 indicate that the interstellar component of polarization is almost zero. More polarimetric observations are needed.

3.4. *Y Hydrae*

Again, Fig. 1 of Serkowski (1971) indicates a value ~0.07% in the blue spectral region for Y Hya, and the present observations (Fig. 2) agree with this. Probably, the polarization peaks in the $V-R$ spectral region. As already mentioned, Y Hya is not detected at longer IR wavelengths by IRAS.

3.5. *Other objects*

The remaining seven objects given in Table 3 – RY Mon, UU Aur, T Cae, U Hya, VX And, RT Pup, and X Vel – do not have previously reported polarization measurements in any spectral region. Only the first two were observed more than once. The observations of RY Mon (Fig. 4) span over more than 750 d and do not show any appreciable change in the amount of polarization; however, position angles in the R band show a large scatter, significantly in excess of the errors of measurement.

On the second night of observation of UU Aur (JD 2 446 118.31), the instrument was used in the single channel mode since one photomultiplier tube set up did not behave properly. However, the internal consistency in the integrations of UU Aur, and the observations of a polarimetric standard obtained on that night indicate that the measurements given in Table 3 are reliable.

4. Discussion

4.1. *Wavelength dependence of polarization*

Of the ten objects with significant polarization, we find that the polarization increases systematically towards the red only in RT Pup. UU Aur shows a dip in the polarization curve around the V band. In X Vel, the polarization is larger in the R band than in V. Only three other carbon stars – R Lep, V CrB, and SS Vir, all Miras – have published multi-wavelength observations. R Lep shows a secular change in the wavelength dependence of polarization; the observations obtained in 1987 show an increase of polarization towards the red, while those obtained earlier show a decrease (Raveendran & Rao 1989). The polarization in V CrB is found to decrease towards red, whereas in SS Vir it shows a dip in the yellow spectral region (Kruszewski et al. 1968; Shawl 1975a). At low levels, the distortion of the wavelength dependence of intrinsic polarization by the interstellar component would be significant. Extensive multiband polarimetric observations by Serkowski et al. (1975) show that the interstellar polarization has a peak occurring at a median wavelength $\lambda = 0.545$ μm. Hence, the maximum effect of interstellar polarization will be felt in the yellow spectral region. The wavelength dependence of polarization in SS Vir was determined when the polarization was very low (~0.10% in the V band) and the interstellar polarization was presumed to be negligible because of its high galactic latitude ($b = +63°$) (Dyck 1968). Using the equation $E(B-V) = 0.058$ cosec b given by Arp (1962) and the empirical relation $P_{max} \leq 9.0\, E(B-V)$ obtained by Serkowski et al. (1975), we find that the interstellar component towards SS Vir can have a value of $P \leq 0.58\%$. Since UU Aur and X Vel are at lower galactic

Table 2. Instrumental polarization (%)

Star	Date	B	R	R	I
HR 2047	1984 Dec. 19	0.07 ± 0.07	0.05 ± 0.05	0.04 ± 0.05	0.04 ± 0.04
HR 4751	1987 Mar. 6	0.02 ± 0.03	0.04 ± 0.03	—	—

Table 3. *BVRI* polarimetry of carbon stars

Star	JD 2 446 000 +	*B* P%	*B* θ°	*V* P%	*V* θ°	*R* P%	*R* θ°	*I* P%	*I* θ°
VX And	056.14	0.57 ± 0.37	37 ± 18	0.58 ± 0.04	70 ± 2	0.44 ± 0.04	62 ± 3	0.34 ± 0.02	71 ± 2
UU Aur	056.21	0.55 ± 0.07	176 ± 4	0.41 ± 0.02	172 ± 1	0.56 ± 0.08	2 ± 4	0.44 ± 0.03	178 ± 2
UU Aur	118.31	0.52 ± 0.08	138 ± 4	0.70 ± 0.03	166 ± 1	0.54 ± 0.02	160 ± 1	0.15 ± 0.02	177 ± 3
T Cae	055.21	0.25 ± 0.18	179 ± 20	0.15 ± 0.06	7 ± 11	0.19 ± 0.06	171 ± 8	0.13 ± 0.03	168 ± 6
Y CVn	117.48	0.05 ± 0.04	—	0.01 ± 0.01	—	0.01 ± 0.02	—	0.00 ± 0.01	—
U Hya	471.38	0.89 ± 0.12	69 ± 4	0.44 ± 0.01	67 ± 1	0.36 ± 0.02	69 ± 1	—	—
Y Hya	115.25	0.10 ± 0.11	—	0.10 ± 0.04	26 ± 11	0.19 ± 0.02	10 ± 3	0.07 ± 0.01	9 ± 4
RY Mon	054.35	0.35 ± 0.28	—	0.24 ± 0.07	165 ± 8	0.22 ± 0.06	156 ± 7	0.12 ± 0.04	160 ± 8
RY mon	116.30	0.60 ± 0.34	59 ± 16	0.25 ± 0.05	146 ± 6	0.14 ± 0.04	6 ± 7	0.11 ± 0.02	171 ± 5
RY Mon	827.23	0.55 ± 0.14	153 ± 7	0.28 ± 0.03	154 ± 3	0.22 ± 0.04	138 ± 5	0.21 ± 0.05	152 ± 7
W Ori	054.33	0.03 ± 0.11	—	0.15 ± 0.04	129 ± 7	0.08 ± 0.03	125 ± 11	0.03 ± 0.02	122 ± 12
Y Per	055.09	0.64 ± 0.46	10 ± 21	0.97 ± 0.13	120 ± 4	0.94 ± 0.09	108 ± 3	0.81 ± 0.05	126 ± 2
Y Per	117.13	1.86 ± 0.61	101 ± 9	0.85 ± 0.09	117 ± 3	0.76 ± 0.09	121 ± 2	0.68 ± 0.04	116 ± 2
RT Pup	505.20	0.68 ± 0.06	62 ± 3	0.86 ± 0.04	51 ± 1	0.95 ± 0.05	57 ± 2	—	—
X Vel	115.28	0.24 ± 0.21	—	0.29 ± 0.03	1 ± 3	0.51 ± 0.04	178 ± 2	0.36 ± 0.02	4 ± 1

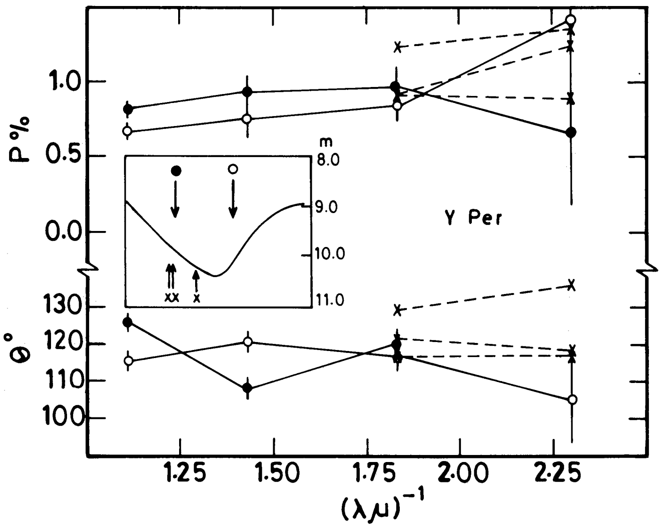

Fig. 1. Polarimetric observations of Y Per. Open and filled circles represent the observations obtained on JD 2 446 055.09 and 117.13, and the crosses that obtained by Dyck & Sanford (1971). The inset shows the mean light curve obtained from the AAVSO data. The arrows indicate the epochs of polarimetric observations

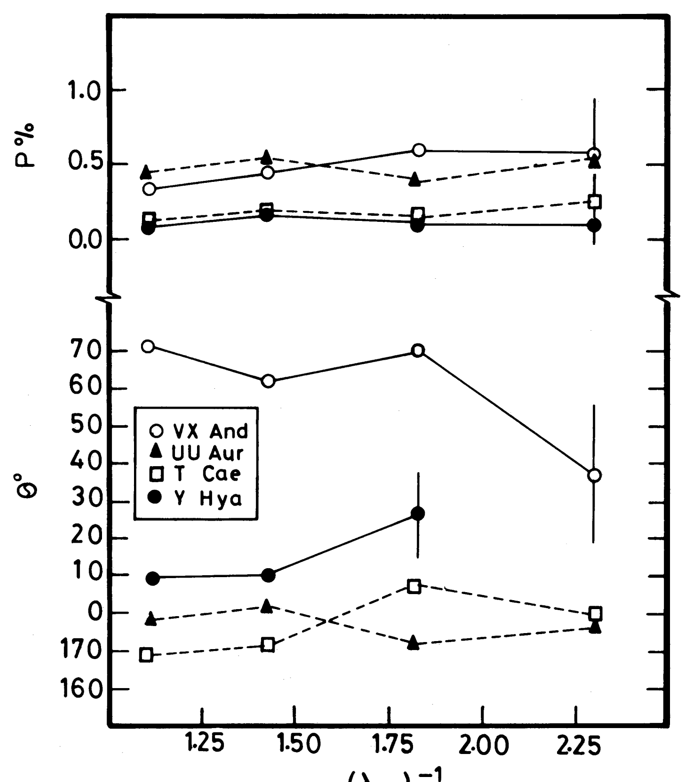

Fig. 2. Polarimetric observations of VX And, UU Aur, T Cae, and Y Hya. To avoid confusion, error bars are indicated only for the observations which show large deviations from the mean behaviour

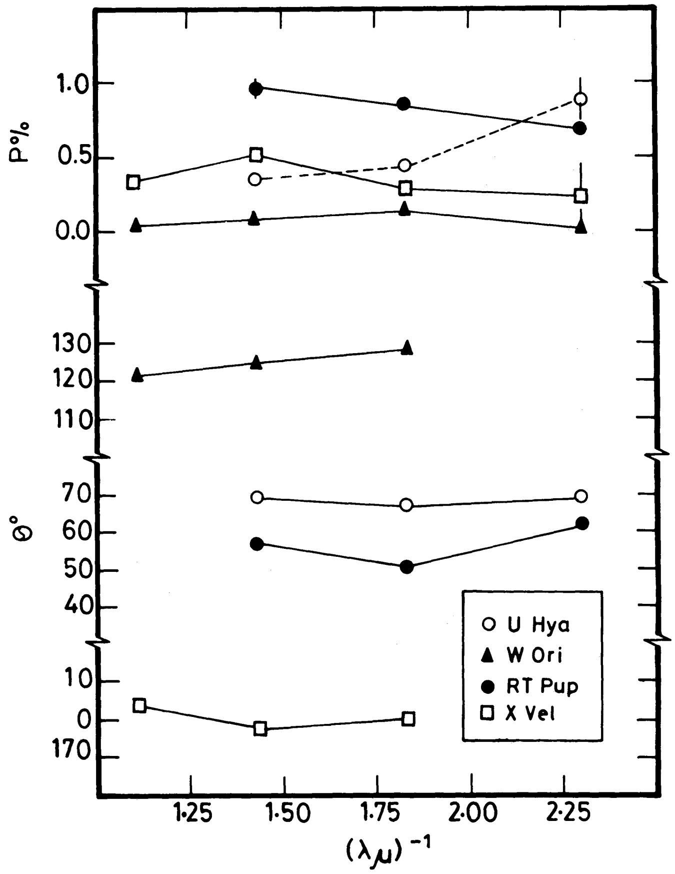

Fig. 3. Polarimetric observations of U Hya, W Ori, RT Pup, and X Vel. To avoid confusion, error bars are indicated only for the observations which show large deviations from the mean behaviour

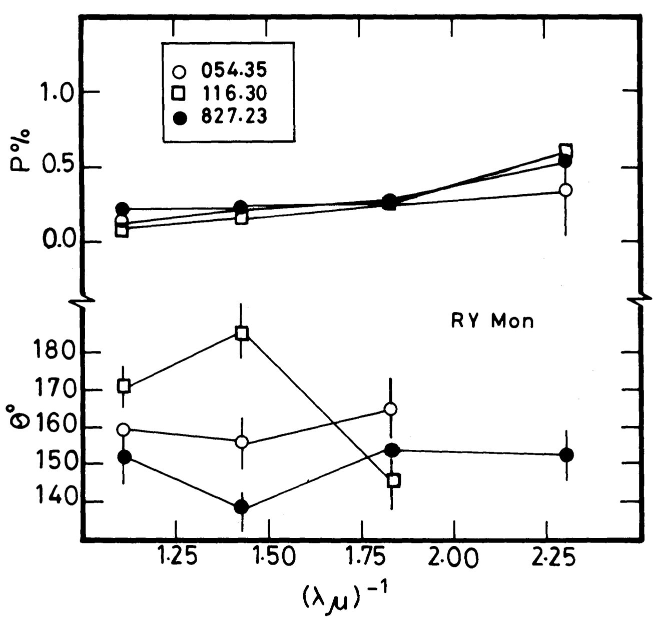

Fig. 4. Polarimetric observations of RY Mon. Note the large scatter in position angles in the *R* band

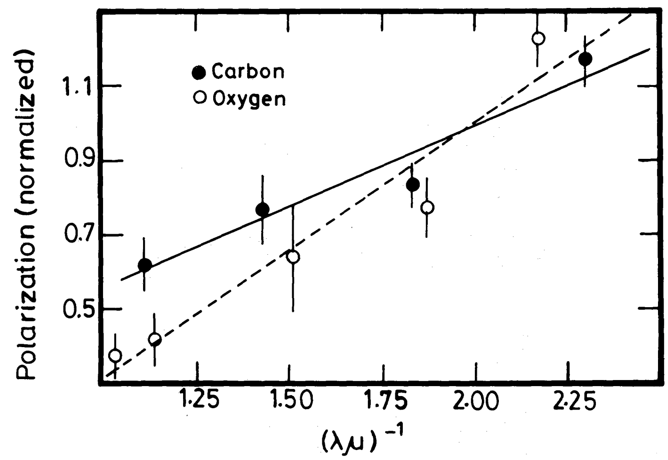

Fig. 5. Plots of average normalized polarization of six carbon stars and that of five oxygen-rich stars which show similar low levels of polarization (see text). The vertical bars represent standard deviations of the mean values. The straight lines are the respective least square solutions

latitudes, $+14^\circ$ and $+10^\circ$, it is likely that the modulations by the respective interstellar components are appreciable and the observed wavelength dependences in these objects do not represent the intrinsic polarizations.

The similarity in the wavelength dependences observed in the majority of objects indicates that in carbon stars, in general, polarization increases towards the blue. A major source of scatter in the wavelength dependences observed is probably the uncertainty in the effective wavelengths of observation due to the large differences in the spectra of the objects.

4.2. Comparison with oxygen-rich stars

Figure 5 shows a plot of the average of the normalized wavelength dependence (unity at $\lambda^{-1} \approx 2.06\ \mu m^{-1}$) of six objects – Y Per, RY Mon, VX And, T Cae, U Hya, and R Lep (excluding the last set of observations given in Raveendran & Rao 1989) – which show qualitatively similar wavelength dependences. Shawl (1975a) has published extensive multiband polarimetry of several oxygen-rich stars; some of the objects like V CVn and VY CMa show very large amounts of polarization. The observed polarizations in the *B* band in all the above mentioned carbon-rich objects do not exceed 1.0%. It would be more appropriate to compare these objects with the oxygen-rich stars which show similar amounts of polarization. The paper of Shawl (1975a) contains good data on five such oxygen-rich objects – R Hya, R Boo, X Her, Z UMa, and g Her – in which the observed polarizations in the *B* band are always less than 1.5%. The first two are Miras and the rest are variables of semi-regular type. The average of the normalized polarization of these objects are also plotted in Fig. 5. There is a considerable scatter in the behaviour of each object at different times. The largest scatter in the normalized polarization of oxygen-rich objects occurs in the UV (Dyck & Sanford 1971; Dyck & Jennings 1971; Shawl 1975a). It is interesting to see from Fig. 5 that, on average, the carbon stars show a flatter wavelength dependence than the oxygen-rich objects. If only oxygen-rich Miras are considered, then the average normalized wavelength dependence of polarization is found to be still steeper towards the blue (Dyck & Sanford 1971).

4.3. Polarization mechanism

There are two main mechanisms usually invoked to explain the intrinsic polarization of late-type stars in general. Harrington (1969) has shown that the light emerging from the limb of a star would be highly polarized due to Raleigh scattering by molecules or atoms if the Planck function has a steep gradient in the atmosphere. However, for a net observable polarization, photospheric asymmetry should be present and the proposed sources of asymmetry are non-radial pulsation of the star, variation of temperature over the surface and the presence of giant convection cells (Harrington 1969; Schwarzschild 1975). The other suggested mechanism is the scattering by molecules or dust grains in an extended asymmetric circumstellar envelope (Kruszewski et al. 1968; Shawl 1975b; Daniel 1978).

The rather weak wavelength dependence of polarization indicates that circumstellar grain scattering is the main mechanism responsible for the continuum polarization in carbon stars. The close resemblance in the normalized wavelength dependences indicates that the dust particles involved are of similar nature. The identification of grains in the envelope presents a major difficulty because of the inverse nature of the problem involved. Polarization models of circumstellar grain scattering by Raveendran (1991) show that graphites do not adequately explain the mean polarimetric behaviour of carbon stars. Here it may be mentioned that neither do they adequately explain the IR spectra of circumstellar dust envelopes around carbon-rich objects (Rowan-Robinson & Harris 1983). It has been pointed out by Czyzak et al. (1982) that graphite formation in circumstellar envelopes is not a very likely process and carbon grains exist, most likely, in some other form, such as amorphous carbon.

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