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On the polarization of ϕ Persei

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Abstract. Polarimetric data of ϕ Per from recent observations with the HPOL spectropolarimeter and from an earlier study in the literature have been compared. It is shown that for measurements with accuracies $\Delta p \sim 0.003\%$, temporal changes are readily detected, these seemingly being unrelated to periodic changes in scattering geometry associated with the binary nature of the star. From studies of the $p(\lambda)$ measurements, the global intrinsic polarization has been separated from the superimposed interstellar component. The wavelength dependence of the sporadic polarization changes suggests that the disks surrounding the component stars may be inclined to the orbital plane of the binary system.

Key words: polarization – binaries: spectroscopic – stars: individual: ϕ Per

1. Introduction

An observational feature of Be stars is intrinsic linear polarization produced by free electron scattering of photospheric radiation within an extended atmosphere. The basic geometry of the situation has been modelled by Brown & McLean (1977) in terms of

- (1) an optically thin, axisymmetric electron distribution,
- (2) the inclination of the axis of this dissociated atmosphere and
- (3) a mean value of its optical depth.

The fact that this intrinsic polarized radiation emanates from the dissociated atmosphere is usually made evident from either temporal variability or from the wavelength dependence of the polarization, the latter being very different from that produced by interstellar dust. Reviews covering Be star polarimetry are by Coyne (1976) and Coyne & McLean (1982), and a review of spectropolarimetric variability in OB (including Be) stars can be found in Bjorkman (1994). Recently, a series of papers (Wood et al. 1996a, 1996b; Wood, Bjorkman, & Bjorkman 1997) has investigated the linear polarization of Be stars as a function of wavelength using spectropolarimetry and Monte Carlo modelling techniques.

The star ϕ Per (HD10516) is found in Bidelman's (1976) list of early-type shell stars and is commonly referenced as a Be star. A spectroscopic study made by Poeckert (1981) reveals a system comprising a $21 M_{\odot}$ star with V$\sin i$ = 450 km s^{-1} and a $3.4 M_{\odot}$ secondary, both stars possessing circumstellar disks. Brown (1992) cites the spectroscopic binary period as $P = 126.699 \pm 0.003$ days (see Harmenec, 1985) with $T = JD$ 2424473.5 being the epoch of phase zero – near or shortly after the time of conjunction with the primary in front (see Dustheimer, 1939). Recently, Thaller et al. (1995) and Gies et al. (1996) have provided convincing evidence from Doppler tomography and from IUE and HST ultraviolet observations that the binary companion to ϕ Per is a hot subdwarf, essentially confirming the results of Poeckert (1981).

Polarimetry of ϕ Per has been undertaken by several workers. Combined with its intrinsic polarization, it displays a substantial interstellar component. As a result of the very different wavelength dependences of the two polarigenic mechanisms and distinct differences between their associated directions of vibration, vectorial separation techniques can readily be applied to this star. From such a study, Coyne & McLean (1975) (later referred to as CMcL) demonstrated that ϕ Per exhibits an intrinsic polarization, $p_* \sim 1\%$ with a position angle of 25.°9; the interstellar polarization is also $\sim 1\%$ but with a position angle of 104°, being consistent with other stars in that galactic location. The data clearly show small temporal variations but little was made of this in their analysis. Similar results for these parameters, but carrying less weight, have also been obtained by Poeckert et al. (1979). McDavid (1994) has also reported the variable nature of the polarization in ϕ Per from filter polarimetry over a period of several years. Quirrenbach et al. (1997), using a subset of the data included in this paper, reported BVR values for the intrinsic polarization of ϕ Per of 1.89%, 1.66%, and 1.45%, respectively, at an intrinsic position angle of 24.°5, and an interstellar value of 0.82% maximum, assuming the interstellar position angle of 99° from McLean & Brown (1978).

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For the study here, it was decided to investigate the $p(\lambda)$ of ϕ Per in broad outline using the equivalent of filter measurements by consolidating data obtained at high spectral resolution. The constructed passbands were selected to match those of earlier work of CMcL so that an additional study might be made of the temporal behaviour of the star using an extended time base.

2. The data

The new data are from the spectropolarimetric survey program at the University of Wisconsin's Pine Bluff Observatory (PBO) and were obtained between August 1989 and January 1996 using the 0.9m telescope and attached polarimeter (HPOL) comprising a rotatable superachromatic half-wave plate prior to a fixed polarizer, a spectrometer and a Reticon detector system (see Wolff et al., 1996). The final five PBO observations were made with a new CCD detector system that replaced the Reticon at the beginning of 1995 (see Nordsieck & Harris 1996). This latter configuration has not yet been completely calibrated in terms of instrumental polarization but the potential error in offset is no more than $\pm 0.05\%$ and, if present, would have little or no affect on the discussion of the presented measurements. A typical record of data for ϕ Per is presented in Fig. 1.

In order to compare and combine the new measurements with those of CMcL, made between November 1966 and January 1975, the spectrally resolved multichannel results from PBO were consolidated using Gaussian envelopes over the spectral intervals corresponding to the central wavelengths and passbands of the filters employed by CMcL, so providing comensurate filter-equivalent results. The characteristics of the selected filters are noted in Table 1 and the reduced PBO measurements, expressed in terms of the degree of polarization, p, and the position angle, θ, are collected in Table 2. Conversion to normalised Stokes parameters (NSPs) is readily achieved by the usual formulae:

$$q = p\cos 2\theta \quad \text{and} \quad u = p\sin 2\theta \quad .$$

As an example of the behaviour of the combined data, Fig. 2 displays the NSPs of the measurements of CMcL and from the PBO for filter #3 (5180/800). It can be seen immediately that the two data sources provide NSP values which are distinctly different both in regard of their position in the qu-plane and in their distribution; the polarization values of CMcL are smaller and their scatter greater. The differences in general location may arise through long term variability of the star itself (the long term monitoring of McDavid (1994) does show evidence for such polarimetric variabilty), or they may be caused by filter passband mismatch, or by offsets produced by other instrumental factors. The differences in the scatter of the two data sets reflect the accuracy of the measurements; according to CMcL, their polarization values have uncertainties $\Delta p \sim \pm 0 \cdot 04\%$ while the PBO measurements, combined from some several hundred detector elements, carry uncertainties which are typically 10 times smaller (see Table 2).

Although CMcL noted that their measurements displayed temporal variability, it can be seen from Fig. 2 that its form is not readily apparent, whereas the PBO data immediately indicate a dispersion which is maximum along a direction $\sim 50°$ in the qu-plane ($\equiv 25°$ in equatorial co-ordinates). As it turned out, subsequent investigation of the data showed that the results and conclusions were less defined when both the CMcL and PBO data sets were utilised in combination and it was decided, therefore, to concentrate solely on the new measurements from the latter source.

Table 1. Descriptions of the characteristics of the filters selected from the list of CMcL. Columns 2 and 3 provide the central wavelengths and FWHM of the filters for which the Reticon or CCD measurements of PBO have been consolidated. It may be noted for filters #5 and #6 that the passbands generated by the Reticon system are severely distorted from being Gaussian by the fall off in sensitivity in the red. Any difference in pass band between the Reticon and CCD detectors does not, however, influence the outcome of the discussion in this paper.

Filter No :	Central Wavelength (Å)	Passband (FWHM) (Å)
#1	3600	500
#2	4250	1000
#3	5180	800
#4	6500	400
#5	8400	2100
#6	9400	1700

3. Analysis of PBO data

3.1. The basic geometry

To explore the quantitative behaviour of the PBO data, the investigation and reduction techniques of Clarke & McGale (1987) (later referred to as CMcG) have been applied. These are appropriate to systems with localised condensations of scattering material in orbit around either a single illuminating star or as part of mass transfer between close binary stars. According to the prescription, individual polarization measurements may be represented by the summation of three contributors *viz*: a constant intrinsic contribution, a variable intrinsic part, the value depending on orbital position of the condensations, and an interstellar off-set; each measurement also carries experimental noise.

In previous analyses, it has been assumed that the first two contributors to the recorded stellar polarization, i.e. any global component and any variable source, are essentially reflecting the same basic geometry in terms of an intrinsic line for the system. This scenario has been summarised in Equation (2) of CMcG in which the two intrinsic contributions are resolved into their q, u values by the same angle. For such cases, the intrinsic line obtained from a wavelength dependence study should be identical to or orthogonal to the major principal axis (MPA) determined from any temporal variations. An example of such a system is the star γ Cas (see Clarke, 1990). With knowledge of the intrinsic line and/or with some partial knowledge of the in-

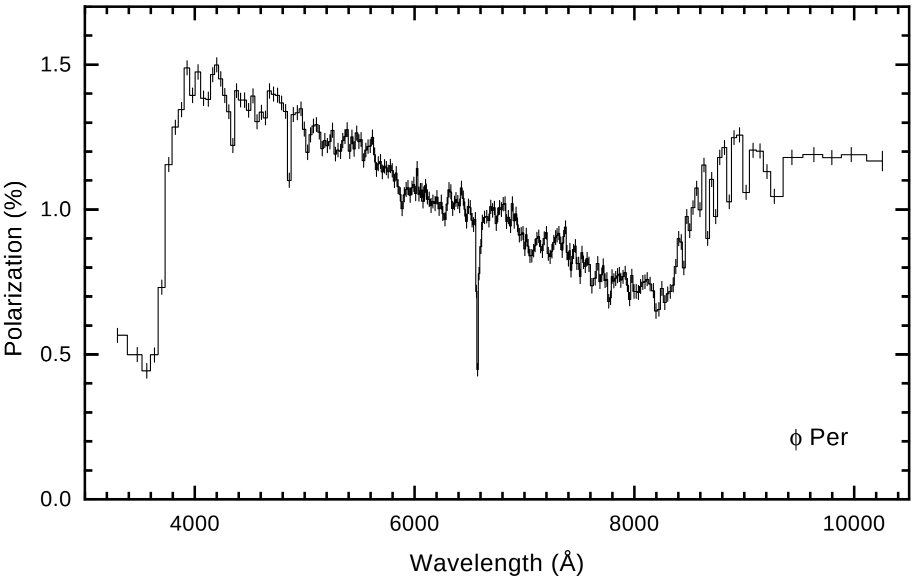

Fig. 1. A representative sample of spectropolarimetric data for ϕ Per taken at PBO on 4 Sep 1995.

Table 2. Measured polarization values corresponding to the filter passbands of CMcL (see Table 1). The values are corrected for any instrumental polarization which is assessed regularly in the PBO observing program. Each observation comprises the Julian Date and, for each filter, the measured degree of polarization, p, in per cent, its 1σ uncertainty, based on an internal assessment of the contributions of the detector elements of the Reticon or CCD within the passband, and the position angle, θ, of the direction of vibration relative to the equatorial frame.

J D 244+	Filter #1	Filter #2	Filter #3	Filter #4	Filter #5	Filter #6
7758	0.649 $\pm$ 0.004 45.8	1.016 $\pm$ 0.002 36.7	1.067 $\pm$ 0.002 35.9	0.869 $\pm$ 0.005 37.5	0.817 $\pm$ 0.005 38.3	0.755 $\pm$ 0.010 39.8
7795	0.603 $\pm$ 0.003 44.7	1.029 $\pm$ 0.001 35.1	1.093 $\pm$ 0.001 34.3	0.868 $\pm$ 0.004 35.6	0.827 $\pm$ 0.006 34.5	0.783 $\pm$ 0.012 33.4
7844	0.701 $\pm$ 0.005 43.6	1.114 $\pm$ 0.002 35.3	1.132 $\pm$ 0.002 34.3	0.834 $\pm$ 0.006 37.0	0.814 $\pm$ 0.009 36.0	0.741 $\pm$ 0.017 34.9
8091	0.722 $\pm$ 0.008 39.6	1.173 $\pm$ 0.003 34.1	1.215 $\pm$ 0.002 33.6	0.885 $\pm$ 0.006 35.0	0.940 $\pm$ 0.008 36.1	0.915 $\pm$ 0.014 36.9
8111	0.782 $\pm$ 0.003 39.4	1.231 $\pm$ 0.001 33.6	1.264 $\pm$ 0.001 33.2	0.937 $\pm$ 0.003 36.1	0.929 $\pm$ 0.004 35.3	0.885 $\pm$ 0.008 35.3
8139	0.655 $\pm$ 0.003 41.9	1.048 $\pm$ 0.001 34.2	1.097 $\pm$ 0.001 33.1	0.836 $\pm$ 0.003 35.6	0.822 $\pm$ 0.004 35.6	0.783 $\pm$ 0.007 35.9
8177	0.632 $\pm$ 0.002 41.8	1.056 $\pm$ 0.001 34.6	1.094 $\pm$ 0.001 34.3	0.803 $\pm$ 0.002 36.6	0.800 $\pm$ 0.003 36.7	0.752 $\pm$ 0.005 37.1
8227	0.671 $\pm$ 0.003 43.7	1.065 $\pm$ 0.001 35.9	1.111 $\pm$ 0.001 35.4	0.809 $\pm$ 0.003 38.6	0.801 $\pm$ 0.004 38.5	0.752 $\pm$ 0.007 39.6
8240	0.755 $\pm$ 0.003 42.1	1.172 $\pm$ 0.001 35.0	1.203 $\pm$ 0.001 34.3	0.883 $\pm$ 0.003 36.3	0.840 $\pm$ 0.004 34.9	0.778 $\pm$ 0.007 34.5
8531	0.702 $\pm$ 0.010 45.7	1.140 $\pm$ 0.004 36.0	1.194 $\pm$ 0.003 34.9	0.839 $\pm$ 0.011 38.0	0.787 $\pm$ 0.012 37.4	0.698 $\pm$ 0.023 37.0
8695	0.749 $\pm$ 0.010 40.8	1.197 $\pm$ 0.004 34.9	1.254 $\pm$ 0.003 34.2	0.910 $\pm$ 0.007 36.8	0.907 $\pm$ 0.009 36.9	0.865 $\pm$ 0.017 37.5
8891	0.598 $\pm$ 0.004 44.8	1.015 $\pm$ 0.002 35.5	1.072 $\pm$ 0.001 34.8	0.810 $\pm$ 0.004 37.6	0.817 $\pm$ 0.005 36.8	0.788 $\pm$ 0.009 36.7
8919	0.691 $\pm$ 0.005 42.7	1.119 $\pm$ 0.002 35.9	1.131 $\pm$ 0.002 35.5	0.869 $\pm$ 0.008 37.3	0.845 $\pm$ 0.006 38.2	0.818 $\pm$ 0.010 39.7
8995	0.663 $\pm$ 0.003 42.4	1.056 $\pm$ 0.001 35.4	1.091 $\pm$ 0.001 34.7	0.808 $\pm$ 0.003 38.1	0.787 $\pm$ 0.003 37.2	0.745 $\pm$ 0.005 37.6
9761	0.751 $\pm$ 0.007 39.9	1.297 $\pm$ 0.003 32.9	1.361 $\pm$ 0.002 32.7	0.946 $\pm$ 0.002 36.9	0.946 $\pm$ 0.001 36.3	0.891 $\pm$ 0.002 36.6
9779	0.595 $\pm$ 0.008 45.7	1.088 $\pm$ 0.003 36.5	1.146 $\pm$ 0.002 36.2	0.847 $\pm$ 0.002 39.3	0.840 $\pm$ 0.001 38.5	0.782 $\pm$ 0.002 38.6
9948	No Values	No Values	No Values	0.869 $\pm$ 0.006 39.8	0.832 $\pm$ 0.006 39.5	0.782 $\pm$ 0.005 39.5
9952	0.736 $\pm$ 0.005 44.8	1.255 $\pm$ 0.002 36.1	1.334 $\pm$ 0.002 35.4	0.953 $\pm$ 0.002 38.3	0.945 $\pm$ 0.001 38.3	0.886 $\pm$ 0.002 38.8
9965	0.710 $\pm$ 0.005 43.9	1.190 $\pm$ 0.002 35.1	1.265 $\pm$ 0.002 34.6	0.953 $\pm$ 0.002 37.4	0.927 $\pm$ 0.001 37.3	0.869 $\pm$ 0.002 37.6

terstellar polarization, it is then possible to explore decoupling the two components. The interstellar component also carries a well defined wavelength dependence and this additional dimension may also be used. This is expressed by the Serkowski law (1973), *viz:* $p(\lambda) = p_{\max} \exp(-K \ln^2(\lambda_{\max}/\lambda))$ where $p_{\max}$ is the maximum value of the polarization occurring at a wavelength of $\lambda_{\max}$ and K is a coefficient normally taken as a constant = 1.15.

As the analysis of the data for ϕ Per shows below, the above description is not strictly applicable as there is a wavelength dispersion of the MPA with the suggestion also of a small difference in orientation between the two intrinsic contributions. No matter the astrophysical reason for this, the situation may be described by further generalising Equation (2) of CMcG so that the jth measurement of the NSPs, q_{*j}, u_{*j}, is represented by

$$q_{*j} = q_I + p_G \cos 2\alpha + \tau_0(q_0 + q_1 \cos\phi_j + q_2 \cos 2\phi_j) \cos 2\beta$$

$$-\tau_0(u_1 \sin\phi_j + u_2 \sin 2\phi_j) \sin 2\beta + n_{qj} \qquad (1)$$

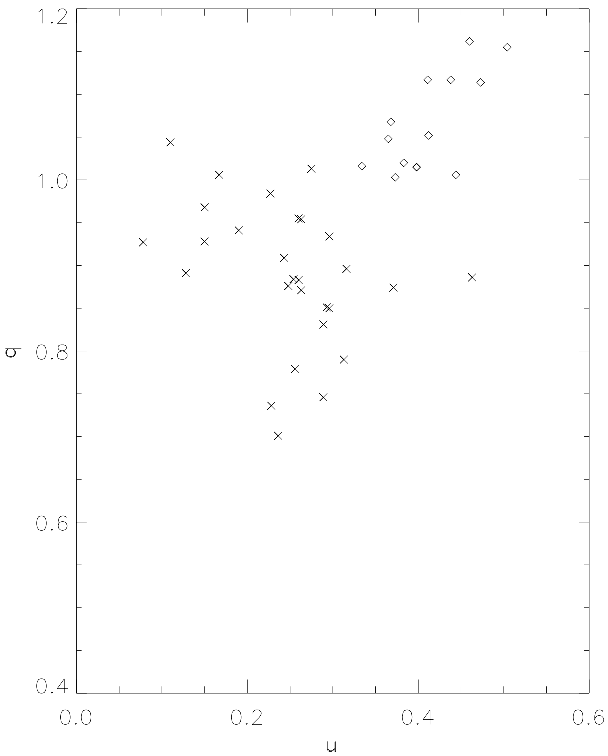

Fig. 2. Recorded normalised Stokes parameter values for filter #3 (5180/800); the points marked $\times$ correspond to measurements made by CMcL and those marked $\diamond$ are from PBO.

and

$$u_{*j} = u_I + p_G \sin 2\alpha + \tau_0(q_0 + q_1 \cos\phi_j + q_2 \cos 2\phi_j) \sin 2\beta$$

$$-\tau_0(u_1 \sin\phi_j + u_2 \sin 2\phi_j)\cos 2\beta + n_{uj} \qquad (2)$$

the distinction being that $\alpha \neq \beta$.

In Equations (1) and (2), q_I, u_I correspond to the interstellar component, with position angle θ_I, given by $\tan 2\theta_I = u_I/q_I$; p_G is the the off-set produced by an intrinsic global contribution with its intrinsic frame set at an angle α to equatorial coordinates; τ_0 is the optical depth of the localised condensation of scattering material, q_0, q_1, q_2, u_1 and u_2 are the coefficients of the polarization produced by it and β is the angle of the MPA associated with it. These values of the polarigenic coefficients depend on the geometry of the system (see CMcG, Equation (1)) and ϕ is an azimuthal angle describing the location of the scattering condensation; it is related to its orbital phase and hence depends on the time at which the measurement are made. The terms n_{qj}, n_{uj} are the noise contributions associated with each individual measurement, with + and $-$ values being equally likely.

According to the recipe of CMcG, the data for each filter were transformed to a co-ordinate frame with origin at their centre of gravity. In this frame, it is assumed that the summations of each of the terms $q_1 \cos\phi_j$, $q_2 \cos 2\phi_j$, $u_1 \sin\phi_j$, $u_2 \sin 2\phi_j$ and the noise contribution average to zero over the data set.

Table 3. Results from the data analysis for ϕ Per. Columns 2 and 3 give NSP values for the centre of gravity of the PBO data for each filter and column 4 lists the orientation of the MPA corresponding to the maximum variance of the data. Column 5 is the calculated intrinsic polarization following subtraction of the interstellar component and the effect of localised scattering condensations. The second moments of the data in the MPA frame, equivalent to the sample variances of the temporal fluctuations are given in columns 6 and 7.

Filter No :	$\overline{q_*}$	$\overline{u_*}$	Position Angle (β)	p_G	m_q	m_u
#1	0.05094	0.68325	22.56	1.3379	0.0047	0.0012
#2	0.38057	1.05861	27.24	1.8842	0.0078	0.0012
#3	0.42089	1.09481	28.74	1.9271	0.0086	0.0013
#4	0.23229	0.83747	30.58	1.5095	0.0026	0.0014
#5	0.23641	0.81950	31.71	1.3168	0.0034	0.0016
#6	0.21523	0.76874	34.94	1.1770	0.0039	0.0027

Thus, in the limit, the mean values of $\overline{q_*}$, $\overline{u_*}$ are given by

$$\overline{q_*} = q_I + q_G \cos 2\alpha + \tau_0 q_0 \cos 2\beta$$

$$\overline{u_*} = u_I + u_G \sin 2\alpha + \tau_0 q_0 \sin 2\beta \quad .$$

Again, according to CMcG (see Equation 6), the sums of the second moments of q and u were calculated as the co-ordinate frame was rotated until a maximum for the q parameter was obtained, so determining the orientation of the MPA and providing a value for β.

The determined centres of gravity of the $\overline{q_*}$, $\overline{u_*}$ values for each simulated filter are listed in Table 3 (columns 2 and 3) and the determined values of the MPA are listed in column 4.

In order to explore the contribution of the interstellar component, the chosen strategy was first to assume that $\alpha = \beta$ and to use estimates for q_I, u_I for each passband by the application of Serkowski's law. The exercise was undertaken using a grid of values for $p_{\max}$, $\lambda_{\max}$ and θ_I with the aim of minimising the dispersion of the position angles of the intrinsic polarization as determined for each filter. Values for θ_I were centered on 104° in accordance with the measurements of field stars and the study of CMcL. It was assumed that θ_I was constant without displaying wavelength dispersion. The exercise revealed that as either $\lambda_{\max}$ or θ_I were allowed to increase, critical values occurred beyond which no value of $p_{\max}$ produced the required minimum. These first order solutions were then fine tuned by adding contributions for the term $\tau_0 q_0$ with the appropriate value of β for each filter, providing acceptable values for $p_{\max} = 0.948\%$, $\lambda_{\max} = 0.457\mu$m and $\theta_I = 102°$ with $\tau_0 q_0 = 0.03\%$. Using these values, the intrinsic polarization corresponding to each filter has been calculated and these values are listed in column 5 of Table 3. Its wavelength dependent behaviour is depicted in Fig. 3, displaying a form similar to that deduced by CMcL, but with larger values.

3.2. The time dependent variations

The recorded measurements of ϕ Per reveal obvious temporal changes with the direction of the MPA lying close to the intrinsic

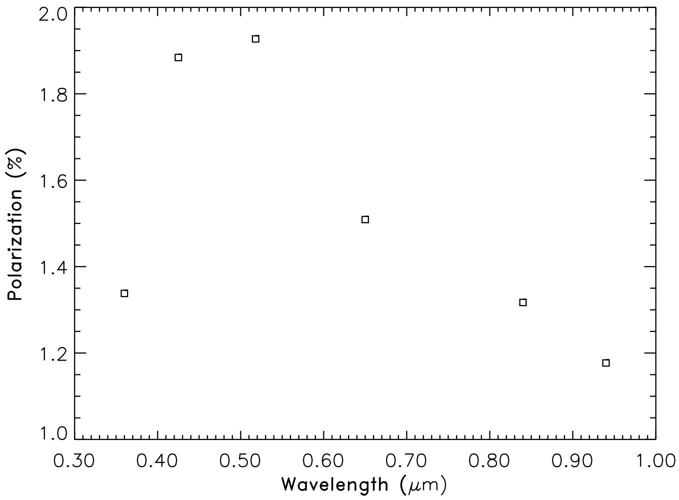

Fig. 3. The evaluated wavelength dependence of the intrinsic polarization of ϕ Per.

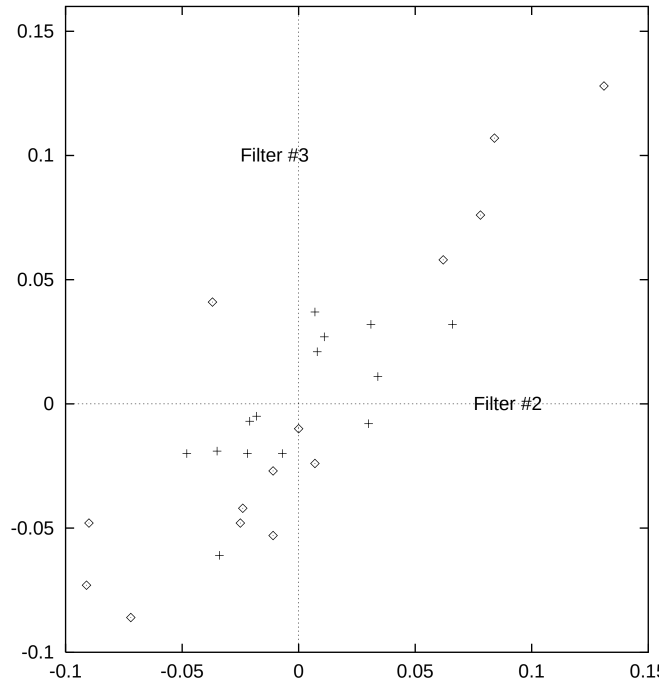

Fig. 4. The $q(\diamond)$ and $u(+)$ values rotated to the MPA and related to the centre of gravity of the data distribution for each of the two filters #2 and #3 are plotted illustrating the coherence of the temporal variability of these normalised Stokes parameters in these passbands.

line as determined from $p(\lambda)$ studies. Confirmation of the reality of the time dependent behaviour is obtained from inspection of Fig. 4 in which the variations as recorded with filters #2 and #3 are compared; excellent correlations of the variations for both the q and u are self-evident. The fact that u displays changes as well as q is of significance as most other Be stars exhibit polarimetric variations limited to following the direction of the intrinsic line ($\equiv q$).

From the distribution of the data points in the qu-plane, the suggested geometry is for the inclination, i, of the spectroscopic binary system and the co-latitude of the localised scattering condensation both to be close to 90° (see Clarke & McGale, 1986).

Possible periodicity in the polarimetric variations was searched for, with and without the inclusion of the CMcL data, using a simple algorithm to calculate the Fourier components of both the q and u parameters in the frame of the MPA with origin at the data centre of gravity. No significant frequencies were found in the range up to $0.02\,\mathrm{d}^{-1}$ covering both the basic spectroscopic period, 126.7 d ($\equiv 0.0079\,\mathrm{d}^{-1}$), and its harmonic, 63.3 d ($\equiv 0.0158\,\mathrm{d}^{-1}$). The periodograms for each filter, however, did display similar characteristics, possibly reflecting the windowing and sampling effects of the timings of the observations.

From plots in the qu-plane (see, for example, Fig. 2) visual inspection of the time progression movements in the data was made but no recognisable pattern emerged. The phase of the binary system was checked against specific features such as the time of the maximum $\pm q$ values but, as might have been expected from the period search, no significant correlations were evident. It seems, therefore, that the polarimetric variations are caused by small sporadic changes in the shell system surrounding the stars and that they bear no relation to the spectroscopic binary orbital characteristics. It is of interest to note that the photometric exercise of Brown (1992) came to the same conclusion in that he found minimum light in one cycle was at a time of near normal light in another. He concluded, from several orbital cycles, that photometry shows short-term, long-term and abrupt variations, the latter likely to result by variations in opacity of the circumstellar material and not by eclipses or intrinsic stellar variations.

A remarkable feature apparent in the reduced data is the recorded dispersion of the MPA (see Table 3 – column 4). Each filter provides an MPA close to the intrinsic line as calculated from the $p(\lambda)$ studies above, but there is a smooth wavelength progression of its value with small discontinuities at the Balmer and Paschen jumps (see Fig. 5). This suggests that the scattering condensations causing the polarimetric variations appear within the system at locations outside the plane of symmetry associated with the more constant global polarization, the latter probably being linked to the geometry of the binary system. The initial generation of a new disturbance may be at the edge of the disk of the primary star at a point in the region where the secondary star has its maximum gravitational effect. The polarimetric variations that are subsequently seen may then be related to motion of the localised disturbance following the orbital plane of the disk. The fact that the determined MPA's are at angles to the intrinsic line suggests that the disk material is set at a small angle relative to the plane of symmetry of the whole system. Thus the primary star's rotational equator may be set at an angle of some 15° to 20° to the binary star's orbital plane, this value coming from the overall spread of β (see Fig.5). What is seen of the equatorial material depends on the opacity of the orbital plane

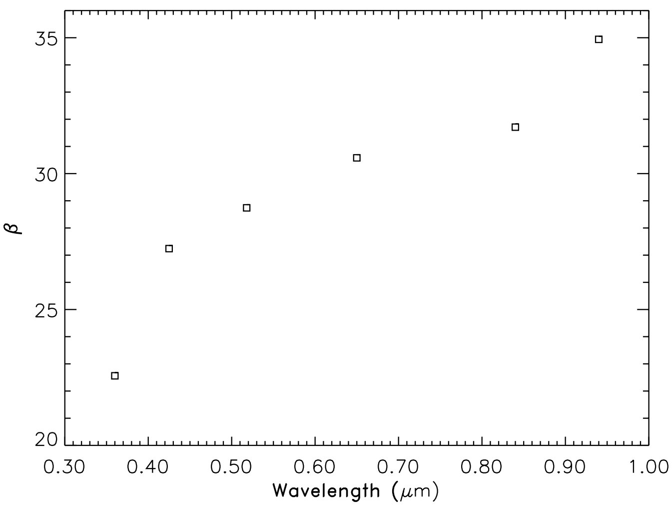

Fig. 5. The variation with wavelength of the MPA (β) [see Table 3] associated with the temporal changes of the intrinsic polarization of ϕ Per. The internal uncertainties in β are of the order of a few hundredths of a degree, an accuracy which is commensurate with the error estimate based on the signal-to-noise ratio (σ/p) of the measurements (see Naghizadeh-Khouei and Clarke, 1993).

cloud. Because of the wavelength dependence of the bound-free absorption, changes in optical depth along the line of sight alter the apparent range of orbital planes contributing to the polarimetric variation. The data reveal changes on time scales of the order of ten days but in order to investigate the proposed scenario further, it would be useful to obtain data over observational runs concentrated over a succession of nights rather than the seasonal synoptic scheme that has been undertaken so far. This would allow the investigation of periodicity on time scales more in keeping with the rotational times expected of the primary star. It may also be mentioned that Faraday rotation can be ruled out for an explanation of the behaviour of the MPAs as the dispersion does not follow a λ^2 curve.

Table 3 also lists the second moments, m_q, m_u, for each filter following rotation of the data to the frame of the MPA. The values correspond to the sample variances of the NSP displacements from their centre of gravity. Because of the extreme high accuracy of the data, measurement noise has negligible effect on the moment values and no attempt has been made to allow for it. It is very striking that the temporal fluctuations are most strongly apparent for filters #2 and #3 with passbands which do not encompass the strong hydrogen features; filter #1 includes the Balmer discontinuity, filter #4 includes Hα and filters #5 and #6 both include the Paschen discontinuity. It would therefore appear that it is the opacity of the disk of the primary star, strongly controlled by the state of the contained hydrogen, which dictates the amount of radiation intercepted by the localised scattering concentrations on the disk's periphery. Obviously more could be done in the way of analysis by reconfiguring the wavelength passbands and concentrating more on particular spectrum features but this is left to a later paper.

4. Conclusion

An attempt has been made to collate polarimetric data from two sources with the aim of extending the time base for the possible detection of variations caused by the binary nature of ϕ Per, perhaps leading to some geometric insight on the system. Differences in instrumental off-sets and/or long term changes in the stellar scattering cloud and the relatively poor accuracies of the early data set prevented any meaningful outcome. However, with the increase in accuracy provided by the new PBO data by a factor just greater than ten over the usual reported stellar polarimetry (e.g. see CMcL), new phenomena related to the geometry of the ϕ Per system have been revealed. The exercise promotes the notion of the usefulness of striving to achieve polarimetric accuracies of $\Delta p \sim \pm 0.001\%$.

In summary, the wavelength behaviour of the polarimetric fluctuations can be ascribed to events deep inside the ϕ Per binary system. The opacity of the primary star's disk, particularly in wavelength regions associated with hydrogen features, controls the amount of radiation intercepted by the scattering condensations, whatever their location in orbit about the primary star. Thus the degree of polarization generated, being dependent on the amount of scattered radiation relative to the total amount of light from the system, is controlled by the opacity of the primary star's disk. The orientation of the observed MPA is governed by what is seen of the geometry of the disk system and this is influenced by the opacity of the dissociated material in the binary orbital plane.

In addition to the need to make repeated polarization measurements of ϕ Per over shorter time scales of say a few per night, extending over several nights, a further suggestion might be made. It is well known that some stars exhibit circular polarization when their light passes through complex interstellar clouds with orientational changes in the mean alignment of the dust grains. The light which is initially polarized in the early part of its path may have a different direction of vibration from the dust alignment in the later part of the cloud. As the grains are birefringent, the early linear polarization will be converted to contain a circular component. For ϕ Per the situation is different in that the interstellar cloud is being probed by light already polarized intrinsically by the stellar environment and whose wavelength and orientational characteristics are known. It would be of great interest to measure the resultant circular polarization imposed by the interstellar dust. As well as making broadband observations, measurements of the hydrogen emission lines would be particularly useful as they display substantial intrinsic linear polarization variations across their profiles (see CMcL and McLean et al., 1979). All such studies would provide excellent new information on the optical properties of the interstellar dust grains along the line of sight.

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