A MEDIUM-RESOLUTION SEARCH FOR POLARIMETRIC STRUCTURE: MODERATELY REDDENED SIGHTLINES

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ABSTRACT

Characterization of the interstellar polarization curve has made extensive use of broadband polarimetry measurements. Consequently, features or structure in the polarization curve of up to several hundred Angstroms in scale may exist undetected. Previous efforts to search for such structure have generally produced negative results. In an effort to investigate the report of polarimetric structure on a larger scale by Wolstencroft & Smith [MNRAS, 208, 461 (1984)], we present high signal-to-noise, multiepoch spectropolarimetric observations at the University of Wisconsin’s Pine Bluff Observatory (PBO). Our sample, which consists of nine moderately reddened sightlines, is constructed to maximize the polarimetric signal-to-noise for a reasonably sized sample. We find the that there is no structure common to all sightlines down to a level of 1% of \( p_{\text{max}} \). The individual sightlines show no convincing structure over the range 4000–7000 \( \AA \) to a level of 4% of \( p_{\text{max}} \) (to 2% for five of the sightlines). No evidence is seen for a polarimetric signature of very broadband structure (VBS), which implies that its carriers are at least two to four times less well aligned than the grains producing the continuum polarization. In addition, we find no corroboration for the claims of features (at or above the levels reported above) in the polarization curves of HD 36371, HD 149757, and HD 198478 by Wolstencroft and Smith. © 1996 American Astronomical Society.

1. INTRODUCTION

Interstellar linear polarization results from the differential extinction of starlight as it passes through a medium of aligned, nonspherical interstellar dust grains. Its wavelength dependence in the optical and near infrared is empirically characterized by Serkowski’s Law:

\[
\ln \left( \frac{p(\lambda)}{p_{\text{max}}} \right) = -K \ln^2 \left( \frac{\lambda}{\lambda_{\text{max}}} \right),
\]

where \( p_{\text{max}} \) and \( \lambda_{\text{max}} \) are the maximum polarization and the wavelength at which it occurs; and \( K = 0.01 + 1.66\lambda_{\text{max}}(\mu \text{m}) \) (Whittet et al. 1992). This deceptively simple parametrization could mask the actual complexity of the wavelength dependence. Both spacecraft ultraviolet and ground-based infrared polarimetry data clearly illustrate that the applicability of Serkowski’s Law is generally limited to the optical regime (Martin & Whittet 1990; Clayton et al. 1992; Martin et al. 1992; Somerville et al. 1994; Clayton et al. 1995). Furthermore, discrete features or “structures” analogous to those seen in extinction [e.g., diffuse interstellar bands (DIBs), very broadband structure (VBS)] may also be present (cf. Whittet 1995).

Nearly all of the data used by investigators in deriving and modifying Serkowski’s Law involves broadband filters. Consequently, attempts to ascertain the existence of structure in interstellar polarization curves have necessitated specialized observational programs (i.e., higher resolution). The studies which have been attempted to detect changes in polarization across several of the DIB features have produced negative detections (Martin & Angel 1974, 1975; Fahlman & Walker 1975; Adamson & Whittet 1992, 1995). In contrast, two efforts which looked for structure on larger scales (50–100 \( \AA \), as opposed to 1–3 \( \AA \) for the DIB studies) report positive detections (Mavko et al. 1974; Wolstencroft & Smith 1984). The work of Mavko et al. is only preliminary and lacks the details necessary to effectively evaluate its claims. However, because interstellar polarization is a function of the physical attributes of the dust grains (i.e., composition, size, shape, orientation), the existence or the nonexistence of polarimetric structure offers an additional diagnostic of dust properties. Thus, verification of previous results, particularly the reported detections, and examination of additional sightlines is of interest to researchers of interstellar dust.

In this paper, we present high signal-to-noise spectropolarimetry for nine moderately reddened sightlines, including the three studied by Wolstencroft & Smith (1984), in attempt to quantify the presence or absence of medium-resolution (25 \( \AA \)) structure in the interstellar polarization curve. [Our

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2. DESCRIPTION OF SPECTROPOLARIMETER

Since 1989 January, the University of Wisconsin spectropolarimeter has operated as a dedicated instrument on the 0.9 m telescope of the Pine Bluff Observatory (PBO). A schematic diagram of the instrument, a modified Boller and Chivens small telescope spectograph, is shown in Fig. 1. This system provides simultaneous spectrophotometry and spectropolarimetry over the range 3150–7750 Å with a spectral resolution of 25 Å in normal operating mode. The dedicated nature of the instrumentation and a continuous calibration program have allowed precise determination of the instrument performance. The instrumental polarization zero-point stability is 0.004% (rms). The stability of the polarimetric efficiency is p(%)/100. These two factors combine to determine the minimum (systematic) error for a given pixel: max(p/100, 0.004%). The following passages are intended to provide a brief description of the instrument, its performance, and the data reduction procedures. A more complete and detailed exposition may be found in Nook (1990).

Fig. 1. A schematic of the Wisconsin spectropolarimeter.

Fig. 2. The top panel shows the “ripple” structure due to misalignments between the individual components of the half-wave plate. The unbinned data is an average of several observations of different spectral types taken through the Glaze-Thompson prism. The next three panels illustrate the residuals after calibration with an error in the wavelength calibration of 0, 1, and 2 pixels (6 Å per pixel).

2.1 Instrumentation

The f/13.5 beam of the telescope is focused on the slit and decker apparatus, which consists of two etched Dow Fotoform glass plates that have been first surface aluminized. While many slit and decker configurations are available, all observations presented here use a 12 arcsec slit and a 12 arcsec long decker. This aperture is large enough to allow for the poor photometric quality of a “typical” night. The photometric colors associated with this aperture are found to be reproducible night-to-night within 0.05 mag (Nook 1990).

The half-wave plate, manufactured by Karl Lambrecht, is an achromatic half-wave retarder which consists of four elements which are alternating plates of magnesium fluoride and crystal quartz. The net linear polarization efficiency of this half-wave retarder is better than 85% from 3250 to 8500 Å. The wave plate is rotated by a stepper motor and rack-and-pinion drive, with stops every 11.25°. The drive is left on and the gear is preloaded to achieve good reproducibility in the orientation of the wave plate. Accurate positioning of the wave plate is enforced through software monitoring of a potentiometer, which is connected to the stepper motor drive gear.

The calcite Wollaston prism, also manufactured by Karl Lambrecht, has a clear aperture of 52 mm by 62 mm and is 10 mm thick. The prism angle is 3.7° and is held together
using optical grease. This prism produces two orthogonally polarized beams (ordinary and extraordinary) separated perpendicular to the dispersion of the grating by 1.52° at 3000 Å and 1.22° at 9000 Å.

The typical dispersion element is a 300 lines/mm reflection grating used in first order and blazed at 4500 Å. The current grating tilt configuration allows the inclusion of the 3125 and 7723 Å lines of the Hg-Ar Penray wavelength calibration lamp. Thus, the detector array elements are able to be accurately transformed to wavelength space over the entire polarimetrically usable region without the use of extrapolation techniques.

The ultraviolet achromatic camera is specifically designed for this instrument. The all-refractive nature of the camera eliminates vignetting and thus enhances polarimetric stability. A field flattener with an order separation filter is placed directly in front of the detector system.

The camera focuses the spectra on a proximity-focus microchannel-plate image intensifier supplied by ITT. The S-20 intensifier cathode is deposited on a 25 mm diameter fused silica window. The image tube is coupled by a fiber optic bundle to the dual 10245 Reticon photodiode arrays. With the 300 lines/mm grating, each pixel is approximately 4.7 Å wide. The detector is cooled to −45 °C by a four-stage thermoelectric cooler and a compressed air cooler. The detector is operated in analog mode for a dynamic range of 0–14 mag.

### 2.2 Polarimetric Efficiency

The polarimetric efficiency is used as a pixel-weighting function during data reduction. Its effective characterization involves corrections for the wavelength dependence of the waveplate retardance, beam convergence, and scattered light (Nordsieck et al. 1993). One is able to quantify the efficiency by observing bright stars through a Glan–Thompson prism, which produces light that is effectively 100% polarized over the useful range of the polarimeter. Below, we discuss briefly two issues not considered in Nordsieck et al.

The scattered light has two primary sources. One originates with the light which does not follow the normal beam path. This produces a uniform illumination of the detector and thus, a wavelength-independent depolarization. A second source arises from the scattered light of the zeroth-order beam overlapping with the first order. This can generate a significant depolarization below 4000 Å depending on the “color” of the object. For spectral types earlier than K5 (as are all the stars in our program sample), this effect does not vary significantly with wavelength or spectral type. However, for later spectral types, the depolarization is a strong function of wavelength. An infrared blocking filter may be used to eliminate much of the order contamination. The remaining scattered light is removed during data reduction. The efficacy of the removal algorithms can be checked by again using the Glan–Thompson prism. The prism may be positioned such that the beam should fall entirely on a single Reticon array, allowing the other array to sample the scattered light.

### Table 3. Polarized standard star data from the literature.

<table>
<thead>
<tr>
<th>HD</th>
<th>$p_v$ (%)</th>
<th>$\sigma_p$</th>
<th>$\theta_v$ (°)</th>
<th>$\sigma_\theta$</th>
<th>$p_v$ (%)</th>
<th>$\sigma_p$</th>
<th>$\theta_v$ (°)</th>
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</thead>
<tbody>
<tr>
<td>7927</td>
<td>3.30</td>
<td>0.03</td>
<td>91.1</td>
<td>0.2</td>
<td>3.34</td>
<td>0.02</td>
<td>92.3</td>
<td>0.1</td>
</tr>
<tr>
<td>19820</td>
<td>4.79</td>
<td>0.03</td>
<td>114.9</td>
<td>0.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>25443</td>
<td>5.13</td>
<td>0.06</td>
<td>134.2</td>
<td>0.3</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>154445</td>
<td>3.78</td>
<td>0.06</td>
<td>88.8</td>
<td>0.1</td>
<td>3.74</td>
<td>0.01</td>
<td>90.1</td>
<td>0.1</td>
</tr>
<tr>
<td>161056</td>
<td>4.03</td>
<td>0.03</td>
<td>66.9</td>
<td>0.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>204827</td>
<td>5.32</td>
<td>0.01</td>
<td>58.7</td>
<td>0.1</td>
<td>5.49</td>
<td>0.02</td>
<td>59.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>
An additional consideration is due to misalignments among the individual components of the half-wave plate. The effect manifests itself as a small amplitude oscillation or "ripple" in the position angle spectrum. Using the Glan-Thompson prism, which itself does not produce any such structure, one obtains the deviations from a constant position angle. A corrective pixel map, the average of many observations, may then be applied during data reduction. However, as was discovered during the course of our observational program, the ripple can be removed to a high degree if, and only if, an accurate wavelength calibration is made. The top panel in Fig. 2 illustrates the wavelength dependence of the ripple. The remaining panels show the effects of removal with a 0, 1, and 2 pixel error. For sufficiently high signal-to-noise observations, the unique characteristics of the ripple signature allow one to indentify problems due to wavelength mismatches. Corrections may then be made by shifting the calibration by the number of pixels which minimizes the ripple. We have found this to be a reasonably effective remedy and manually performed this operation for each observation in our sample.

### 2.3 Data Reduction

During spectropolarimetric observations, the half-wave plate is rotated through all eight positions, which are grouped into four pairs. The difference in the position between the two settings that form a pair is 45°, which corresponds to a 90° rotation of the plane of linear polarization. In order to remove systematic effects during data reduction, the wave plate moves between the two positions in a pair many times per integration. Two buffers exist in hardware in order to accumulate simultaneously the data for each wave plate position in the pair. At the end of an integration, each buffer is saved into an individual unit called a "scan." Four sets of the "double" scans are taken for each position pair: a sky, an object, an object, and a sky integration (8 scans). Thus, each pair of object integrations is bracketed by sky integrations. The completion of all four position pairs constitutes an observational cycle (32 scans). The data are reduced using a package developed at the University of Wisconsin specifically for the reduction of data obtained with a reticon detector (Percival 1979; Tobin 1979; Lupie 1983; Nook 1990). The reduction is a two step process, where the polarimetry is reduced first, followed by the spectrophotometry. In this paper, we consider only the polarimetric reduction.

The reduction process groups the raw polarization scans into sets of 16 scans: a sky and an object integration for each wave plate orientation. Each scan contains two spectra, the ordinary and extraordinary: one for each detector array. We refer to the two arrays as $A$ and $B$. Then, the sky scans are subtracted from the corresponding object scans. Next, the scattered light correction is applied (the Reticon thermal background requires the sky-subtraction to be done before the scattered light correction). The measured counts are then combined into "diffsums," using the following equation (Nordsieck et al. 1993):

$$d(\alpha) = \frac{N_A(\alpha) - N_A(\beta)}{N_A(\alpha) + N_A(\beta)} \frac{N_B(\alpha) - N_B(\beta)}{N_B(\alpha) + N_B(\beta)}$$

where $\alpha$ and $\beta = (\alpha + 45)°$ are the wave plate orientations for a given position pair, and $N_A$ and $N_B$ refer to the raw counts observed in the $A$ and $B$ reticon arrays. A diffsum produces polarimetric signal while cancelling both the gain differences.

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**Table 4. Observational sample.**

<table>
<thead>
<tr>
<th>HD</th>
<th>V</th>
<th>Sp Typeb</th>
<th>$E_{R-V}$</th>
<th>IR Pol. ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7927</td>
<td>5.0</td>
<td>F0 Ia</td>
<td>0.51</td>
<td>1,2</td>
</tr>
<tr>
<td>21291</td>
<td>4.2</td>
<td>B9 Ia</td>
<td>0.42</td>
<td>1,2</td>
</tr>
<tr>
<td>21389</td>
<td>4.5</td>
<td>A0 Iae</td>
<td>0.56</td>
<td>...</td>
</tr>
<tr>
<td>31964</td>
<td>3.0</td>
<td>F0 Ia</td>
<td>0.37</td>
<td>...</td>
</tr>
<tr>
<td>36371</td>
<td>4.2</td>
<td>B5 Iab</td>
<td>0.45</td>
<td>...</td>
</tr>
<tr>
<td>14957</td>
<td>2.6</td>
<td>O9.5 V</td>
<td>0.33</td>
<td>1,2</td>
</tr>
<tr>
<td>154445</td>
<td>5.6</td>
<td>B1 V</td>
<td>0.42</td>
<td>1,2</td>
</tr>
<tr>
<td>187929</td>
<td>3.8</td>
<td>F6-G2</td>
<td>0.18</td>
<td>1</td>
</tr>
<tr>
<td>198478</td>
<td>4.8</td>
<td>B3 Iae</td>
<td>0.53</td>
<td>1,2</td>
</tr>
</tbody>
</table>

**Table 5. Serkowski fits for the observed sample.**

<table>
<thead>
<tr>
<th>HD</th>
<th>$p_{max}(%)$</th>
<th>$\lambda_{max}(\AA)$</th>
<th>$\theta_{max}(\degree)$</th>
<th>$d(\alpha)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>7927</td>
<td>3.31</td>
<td>5070</td>
<td>92.4</td>
<td>2.0</td>
</tr>
<tr>
<td>21291</td>
<td>3.47</td>
<td>5220</td>
<td>115.3</td>
<td>0.0</td>
</tr>
<tr>
<td>21389</td>
<td>3.54</td>
<td>5300</td>
<td>119.6</td>
<td>0.2</td>
</tr>
<tr>
<td>31964</td>
<td>2.01</td>
<td>5230</td>
<td>143.7</td>
<td>-0.8</td>
</tr>
<tr>
<td>36371</td>
<td>2.07</td>
<td>5700</td>
<td>176.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>14957</td>
<td>1.45</td>
<td>6020</td>
<td>124.4</td>
<td>1.2</td>
</tr>
<tr>
<td>154445</td>
<td>3.66</td>
<td>5690</td>
<td>88.3</td>
<td>0.0</td>
</tr>
<tr>
<td>187929</td>
<td>1.73</td>
<td>5530</td>
<td>92.5</td>
<td>1.5</td>
</tr>
<tr>
<td>198478</td>
<td>2.75</td>
<td>5150</td>
<td>2.5</td>
<td>-0.6</td>
</tr>
</tbody>
</table>

Note. — These values were computed from a nonlinear least-squares fit of the Stokes $Q$ and $U$ parameters for the PBO and available IR polarimetry data to the empirical Serkowski curve (see equation 1). The estimated uncertainties associated with the fit parameters are 0.01%, 10 $\AA$, 0.1 $\degree$, and 0.1 $\degree/\mu m^{-1}$

*Units are $\degree/\mu m^{-1}$, $x = 1/\lambda$
2.4 Standard Star Observations

Observations of both polarized and unpolarized "standard" stars are made at PBO on a regular basis. In addition, observations are always made immediately before and after any telescope/instrument modifications. Table 1 summarizes the PBO unpolarized standard observations from the fall of 1989 until the spring of 1993. We list the wide-band (3200–7700 Å), normalized Stokes parameters, $Q(\%)$ and $U(\%)$, of calibrated data, (i.e., instrumental polarization removed). The formal errors [err(%)], derived from the least-squares fit described in Sec. 2.3 and the root-mean-square (rms) deviations are also given. Table 2 presents the polarized standard star observations, integrated over a synthetic $V$ filter response. This facilitates comparison with other published polarimetry, such as that given in Table 3. It should be noted that we compute polarization and position angle values from the spectropolarimetry data in the following way:

$$\langle X(\lambda) \rangle = \frac{\int X(\lambda) F(\lambda) S(\lambda) d\lambda}{\int F(\lambda) S(\lambda) d\lambda},$$

where $X(\lambda)$ is a normalized Stokes parameter, $F(\lambda)$ is the stellar monochromatic flux in units of ergs/s/cm²/A, and $S(\lambda)$ is the desired instrumental response. We use the $V$-band response curves tabulated in Bessell (1990).

3. DATA

An observational program was designed to search for structure in the interstellar polarization curve along several lines of sight. Our selection criterion was that of "polarimetric magnitude": $m_p = m - 5 \log p$, where $m$ and $p$ are the apparent magnitude and the linear polarization, respectively. This quantity, derived under the assumption of photon-limited errors, is fundamentally an indicator of polarimetric signal-to-noise. For a fixed integration time, the object with the lowest polarimetric magnitude provides the most favorable value of $\sigma_p / p$. The selection bias of the criterion is towards moderately reddened, bright objects. Objects with large polarization variations ($\geq 0.1\%$) were discarded. Our final sample is listed in Table 4.
The observations were made at PBO during the interval from 1990 March to 1993 March and reduced in the manner described above. Each object was observed an average of seven times. The multiepoch nature of our data allows us to both sample and effectively average over the low level of polarimetric variability which may be present. Individual observations are coadded using either an error- or exposure-weighted scheme. The latter is used for sightlines where the polarimetric variation is greater than the minimum systematic error, $p(\%)/100$. In all cases, the errors (residuals) from the least-squares fit to the coadded Stokes parameters are well below $p(\%)/100$.

An analysis procedure was constructed to clearly identify deviations from the Serkowski Law. We exploit the mathematical definitions of the Stokes’ parameters $Q$ and $U$,

$$Q = p \cos 2\theta,$$

$$U = p \sin 2\theta$$

in order to separate the deviations in polarization ($p$) and those in position angle ($\theta$). For each object, we perform a nonlinear least-squares fit of the coadded PBO data (and any available infrared polarimetry) to Serkowski’s Law [Eq. (1)]. The fitting routine iterates on four parameters: $Q_{\max}$, $U_{\max}$, $\lambda_{\max}$, and $d\theta/d\lambda$, where $x = 1/\lambda$ and $d\theta/d\lambda$ is the position angle rotation about $\theta_{\max}$. The next step entails the subtraction of the resulting Serkowski’s Law (see Table 5 for the compilation of parameters for our sample), including the position angle rotation. Then, we normalize the data by $p_{\max}$ and rotate by $-\theta_{\max}$. Figures 3–6 display the unweighted, coadded, and transformed Stokes parameters ($Q^*$ and $U^*$) for each object. Figure 7 presents a exposure-weighted addition of all the transformed data. Our analysis technique effectively places any polarization structure associated with the grains producing the continuum polarization (i.e., with the same position angle) into the $Q^*$ spectrum. The resulting $U^*$ spectrum is diagnostic of position angle structure. Now, in the transformed (dimensionless) spectra, the minimum systematic error has the value of 0.01 (i.e., $p_{\max}/100$).

4. DISCUSSION

An examination of Figs. 3–6 reveals no convincing examples of interstellar polarization features down to a level of $0.04p_{\max}$ in all sightlines, and to $0.02p_{\max}$ in 5 of them. The other four sightlines suffer from a lack of signal-to-noise over part of the displayed wavelength range and likely an incomplete ripple correction (e.g., notice the oscillatory structure in the $U^*$ spectrum for HD 187929). The degree to which the polarization follows Serkowski’s Law is made more vivid in Fig. 7. The coaddition of all sightlines dramatically reduces the noise level. Now, the threshold of nondetection becomes $0.01p_{\max}$. Figure 7 also highlights what may be the only “real” structure—a slight depression in the amount of polarization (in the transformed $Q$) redward of 6500 Å. The amplitude of the effect and the presence of a slight blue depression (most likely a residual from the scattering correction, see Sec. 2) make any definitive statement problematic. However, an investigation is currently under-
way at PBO using an “updated” CCD-based instrument, which extends the wavelength coverage to 10 500 Å and the dynamic range by 2 mag. This system will also be available periodically on the WIYN (3.5 m) telescope.

4.1 Very Broad Structure

A shallow, very broadband structure (VBS) is known to be present in the extinction curves of many stars (van Breda & Whittet 1981, and references contained within; Reimann & Friedemann 1991). The band ranges from about 5000 to 6700 Å, with an “average” maximum depth of approximately 0.02 mag per magnitude $A_V$ (at 5700 Å, cf. van Breda & Whittet 1981). Like the DIB features, the exact nature of VBS carriers is currently unknown. Dust grains are generally viewed as the likely source, although current theories range from “big” grains to a separate population of very small grains (cf. van Breda & Whittet 1981; Jenniskens 1994). The unique characteristics of our data set allow us to examine the possibility that VBS arises from the same grains (or a subset thereof) which produce the continuum polarization and extinction (i.e., the aligned grains). This can be accomplished through the use of the model of Martin & Angel (1974). They developed a theory for aligned interstellar grains which relates the changes in polarization ($\Delta p$) and extinction ($\Delta \tau$) across a spectral feature: $\Delta p/p = f \Delta \tau/\tau$, where $p$ and $\tau$ are the continuum polarization and extinction optical depth values, and $f$ is a parameter which ranges from 1.0 to 1.8 (see also Martin & Angel 1975).

Transparency variations on the timescale of hours prohibit one from using the PBO data to derive extinction curves of sufficient accuracy to measure VBS parameters. In addition, there is virtually no overlap of our dataset with published VBS measurements. Consequently, we restrict our consideration to the results of van Breda & Whittet, which give $\Delta \tau = 0.02$. This leads to a prediction for $\Delta p/p = Q^*$ of 0.02–0.04, depending upon the value of $f$. While the lack of actual VBS profiles prevents a quantitative analysis (i.e., $\chi^2$ fitting), we see no evidence for a polarimetric signature for VBS at the predicted level. If we take VBS to be a “universal” phenomenon (i.e., present in all of our sightlines), we can place a conservative upper limit of $\Delta p/p \leq 0.01$. This implies that the dust grain carriers of VBS are much more poorly aligned than those grains producing the continuum polarization. Using the Martin & Angel model, one finds that the alignment efficiency ($\eta = \Delta p/\Delta \tau$) for the VBS carriers is at least two to four times less efficient than for the “continuum” grains.

4.2 Comparison with Wolstencroft & Smith

Wolstencroft & Smith (1984, hereafter referred to as WS) report the presence of polarimetric structure in three sightlines: HD 36371, HD 149757, and HD 198478. Figures 8–10 display their data (circles) along with the PBO data (solid line), which is binned to a constant error of $p_{\text{max}}/100$. The best-fit Serkowski curve (dashed line) is also displayed. It is important to note that for HD 149757 and HD 198478, the WS data were normalized by values of $p_{\text{max}}$ which differ from those listed in Table 5. The PBO error bar for the position angle spectrum is exact at $\lambda_{\text{max}}$. For other wave-
lengths, it overestimates the 1σ error by up to 20% at the blue and red ends of the spectrum. We examine the claims of WS for each sightline below.

4.2.1 HD 36371

The claim for structure in the HD 36371 observations consists of a possible enhancement of polarization at 5250 and 6050 Å, as well as a position angle rotation in the blue and in the red (in opposite directions). The PBO data show no convincing features over the range spanned by the WS data. Given the magnitude of the errors, the WS data are not inconsistent with the significantly higher signal-to-noise PBO data. The PBO data are in general agreement with those reported by Coyne (1974) and Serkowski et al. (1975). Additionally, Tables 2 and 3 link the PBO calibration to published polarimetry for several standard stars.

4.2.2 HD 149757

WS list the structure for HD 149757 as a feature in both polarization and position angle near 4100 Å, an oscillation in the polarization beyond \( \lambda_{\text{max}} \), and a positive rotation of the position angle in the blue. While discernable in the displayed WS data, only the rotation in blueward position angle rotation is statistically significant. In any case, none of the features have corresponding structure in the PBO data. In fact, there are disagreements in the overall amplitude of polarization, as well as with the sign of the position angle rotation. \( \lambda_{\text{max}} \) and \( p_{\text{max}} \) for the WS data are 6310±20 Å and 1.67%±0.01%, respectively. In contrast, Serkowski et al. (1975) values, which are consistent with the PBO data, are 6000 Å and 1.45%. Furthermore, the Serkowski et al. data also support the position angle rotation observed at PBO.

4.2.3 HD 198478

The HD 198478 data again provide no corroborative evidence of the WS structure claims. Neither a feature near 4400 Å, nor a nonmonotonic position angle rotation are apparent in the PBO data. Large discrepancies are again seen in the amplitude and shape of the WS polarization values. These data provide \( \lambda_{\text{max}} \) and \( p_{\text{max}} \) values of 5790±30 Å and 3.02±0.02. Serkowski et al. (1975) agree with the PBO values. The rotation of the position angle in the PBO data is substantiated both in sign and magnitude by Hsu & Breger (1982), and in sign by Dolan & Tapia (1986).

5. SUMMARY

1. There is no structure common to all sightlines down to a level of 0.01 of \( p_{\text{max}} \). None of the individual sightlines show convincing structure over the range 4000–7000 Å to a level of 0.04 of \( p_{\text{max}} \) (to 0.02 of five of the objects).

2. Using the model of Martin & Angel and the VBS data of van Breda & Whittet, one would predict that, on average, VBS would possess a polarization signature with a peak of \( \Delta p = 0.02–0.04 \) (depending upon the specific parameter values). Adopting an upper limit of \( \Delta p/p = 0.01 \) implies that the VBS carriers possess an alignment efficiency which is at least two to four times lower than that of the grains producing the continuum polarization.
(3) Comparison of our data to that of Wolstencroft & Smith for HD 36371, HD 149757, and HD 198478 reveals no corroboration for their claims of structure in the polarization data of these three objects.

(4) There appear to be several significant discrepancies in the data of Wolstencroft & Smith, when compared with the PBO data, as well as with published polarimetry. The PBO data are linked to the published values in Tables 2 and 3.

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