No. 106 WAVELENGTH DEPENDENCE OF POLARIZATION X. INTERSTELLAR POLARIZATION*

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ABSTRACT

A survey of O and B stars was started with the new 154-cm Catalina reflector. The equipment is described and results are given for 33 stars. Of these, seven stars show variable polarization. Striking discrepencies from the mean interstellar polarization-wavelength dependence are found near Orion. The brighter component of θ^2 Orionis, a spectroscopic binary with a 21-day period, shows variations of $\pm 0.5\%$ in the ultraviolet. The spectroscopic binary φ Per shows variations of about $\pm 0.2\%$. Both stars have a strong wavelength dependence of the polarization position angles. A time dependence of the position angle is found for the spectroscopic binary and shell star ζ Tau.

1. Introduction

As a continuation of a program of study of the wavelength dependence of interstellar and stellar polarization, a survey of the polarization of O and B stars as faint as $V=8.0$ near the galactic plane and well distributed in galactic longitudes was undertaken. The first results of this survey are presented in Sec. III. A subsequent paper will give further observations and a more thorough discussion of the results. In Papers II and VIII (see references) we found a mean interstellar polarization curve, with a maximum at about 5200 Å decreasing rapidly towards longer wavelengths and less rapidly towards shorter wavelengths. On the other hand, several stars show large deviations from such a mean curve (Paper VIII), indicating a large dispersion in the wavelength dependence of interstellar polarization. With the additional observations contained in the present paper, we rediscuss this mean interstellar polarization curve and the degree of dispersion in the polarization-wavelength dependence for various stars (Sec. IV).

In the course of the survey several stars were found to have variable polarization. Available observations on these stars are limited. In anticipation of further observations a preliminary discussion of these variations is presented (Sec. V).

2. The Equipment

In November 1965 the 154-cm reflector of the Lunar and Planetary Laboratory, situated at an elevation of 2510 m in the Santa Catalina Mountains north of Tucson, was first used for polarization measurements. The observations in this paper represent the first group of polarization measurements made with this telescope. The telescope has Cassegrain arrangements only, and both the $f/13$ and $f/45$ secondary mirrors are used in this program.

For a determination of instrumental effects we observed 20 stars within 51 pc and with less than 0.04% polarization over a wide range of galactic coordinates (Behr 1956). The instrumental polarizations for the seven filters from *I*nfrared to *N*ickel sulfate, described below, are respectively 0.03, 0.07, 0.11, 0.11, 0.13, 0.17, and 0.14%, and their equatorial position angles respectively 146, 144, 152, 148, 147, 150 and 153°. These amounts are known with a probable error of ±0.01%. No difference between $f/13$ and $f/45$ was found. We are indebted to J. H. Richardson of the Kitt Peak National Observatory for the care with which he aluminized the three mirrors.

Figure 1 shows the polarimetric equipment at the Catalina 154-cm telescope. The polarimeter is the same as that used previously (Gehrels and Teska 1960); the paper referred to also has a description of the calibration of polarization position angles. The polarimeter has, successively, a slide for the Lyot depolarizer, a field-viewing eyepiece, a slide for diaphragms (0.25 to 10 mm in diameter), an eyepiece for centering, a filterslide, a Wollaston prism, a Fabry field lens, and two photomultiplier tubes. Seen in Fig. 1 is the Wollaston neck and the dry-ice box for S-1 phototubes; there is a separate Wollaston neck and ice box for blue-sensitive tubes. For photometry with these boxes, the Wollaston neck is clamped in a fixed orientation, or a separate 1P21 ice-box is put on instead of the Wollaston arrangements.

The output of the phototubes is simultaneously received by two Weitbrecht integrators and recorded on the strip chart on top of the console. The recorder is currently used only for visual display and as a diary for the observer, since all data is punched on paper tape. The outputs are digitized by the voltmeter seen under the recorder. Below the digital voltmeter is a high-voltage power supply for the phototubes, and below it are the programmer, and the clock/timer. The time is displayed in binary code ($1^h35^m.4$ is shown). To the right is the paper-tape punch with the integrator power supply on top.

Since Paper VIII, the following improvements have been made. D. L. Brumbaugh designed the clock/timer and he and V. J. Borg improved the digitization equipment, especially its speed. The integration time for objects brighter than eighth visual magnitude is ordinarily 7 sec, during which occur the readout and the punching of the Wollaston angle, object identification, time, depolarizer state, filter and star/sky identification,

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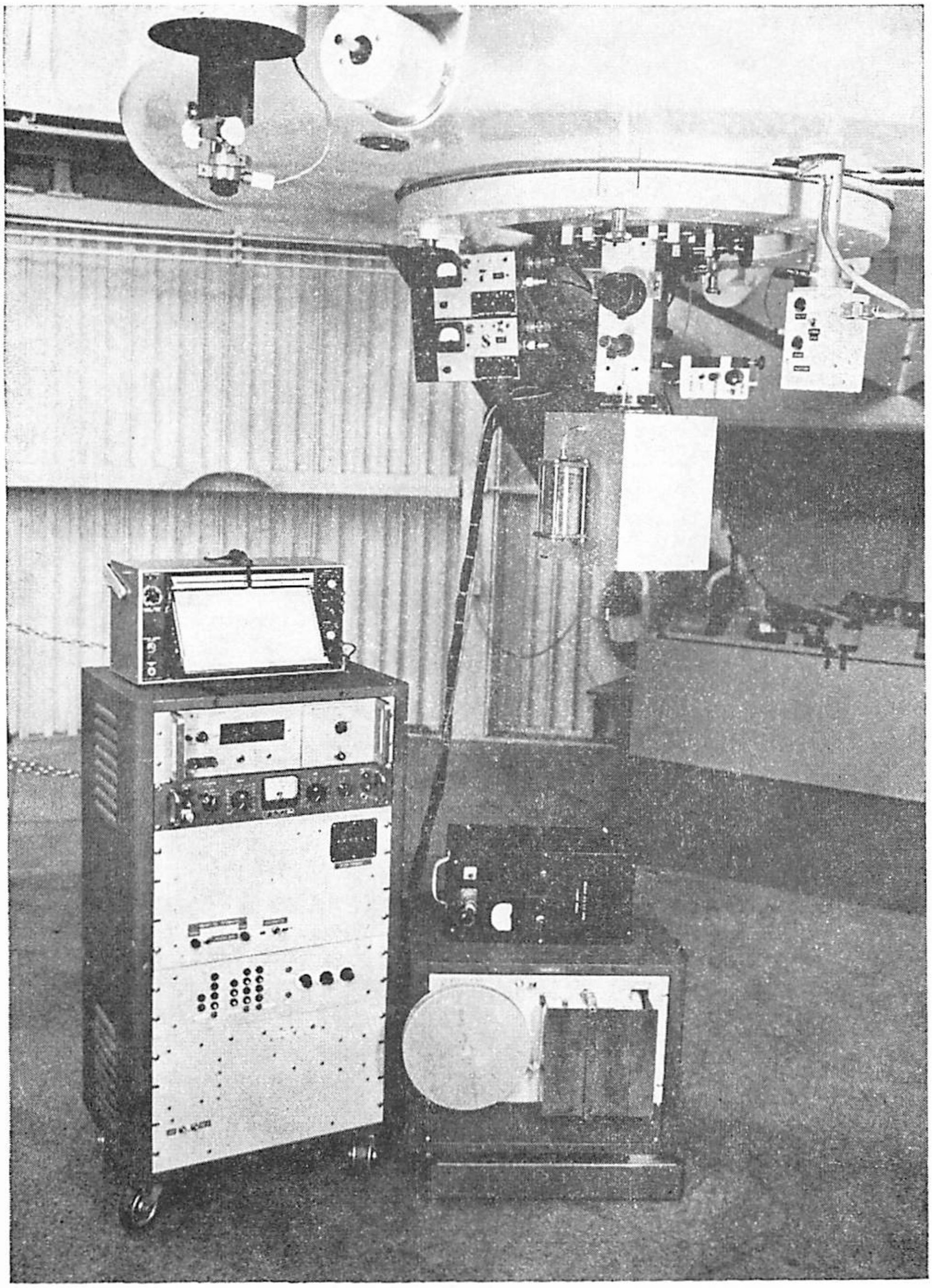

FIG. 1. Photopolarimeter with dry-ice box and Weitbrecht integrators mounted on the Catalina 61-in. (154-cm) telescope. Strip-chart recorder, digital console, paper punch, and integrator power supply are also shown.

After the integration, the readout and punching of the measured intensities takes 5 sec. During this latter 5 sec of readout an experienced observer has just enough time to change the Wollaston angle or the depolarizer state, and to check the centering, in order to start the next integration. E. H. Roland made the new dry-ice box for the S-1 phototubes (RCA 7102) so that the refrigeration is considerably improved. T. M. Teska selected the best blue-sensitive tubes; the EMI 6255S were replaced by 6255B, and those in turn by EMI D205R (super S-11 with quartz window).

The characteristics of the filters used in this program have been given in Paper VII. The filter at $1/\lambda = 1.39$ was replaced by an orange interference filter (Baird Atomic B-5; "Peak: 6450A+50A−25A. Total width at half peak: 1032A–1290A. Peak transmission: 50–60%"). The effective wave numbers for all filter/tube combinations used in the current study were estimated anew. For white light (which approximates the reddened B stars of this paper) at 1.3 air masses they are 1.06, 1.21, 1.56, 1.93, 2.33, 2.78, 3.03 μ^{-1}, and for a reddened K star 1.05, 1.19, 1.54, 1.91, 2.29, 2.75, and 3.00 μ^{-1}. These wave numbers are uncertain by ±0.02 since the

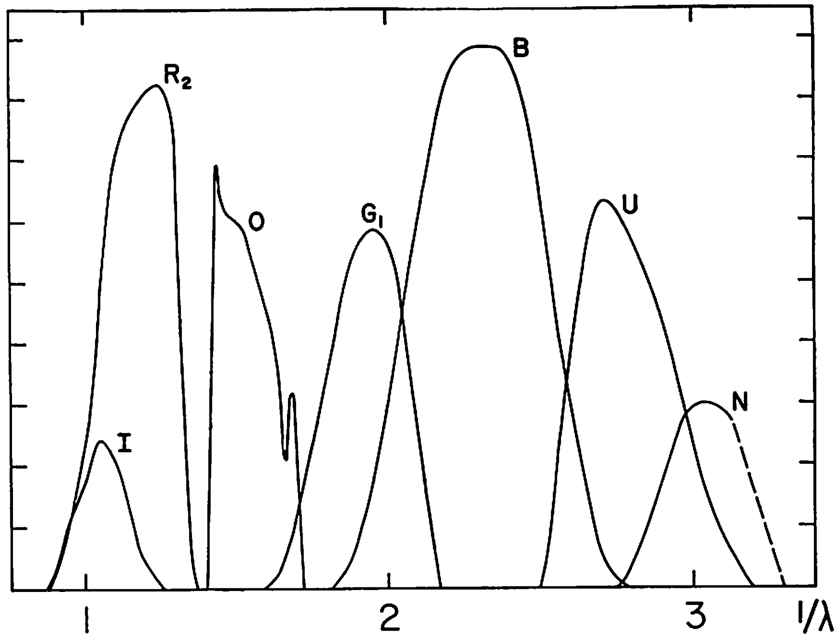

FIG. 2. Response curves to white light through 1.3 air masses at 2200 m altitude for the various filter/tube combinations. For filter designations, characteristics and effective wave numbers see Sec. II. The response of the red system (I,R,O) has been multiplied by a factor of 40 to normalize it to the blue system (N,U,B,G).

tube responses are not measured but adopted from the manufacturer's mean curve.

Figure 2 shows the response curves for the various filter/tube combinations. The letter used to designate each filter is as in Paper VII. The new interference filter described above is the O filter. In the tables to follow, these filters are designated by the effective wave numbers given above for white light and an extinction of 1.3 air masses. Only three stars with spectral type later than B occur in the tables, and these are indicated. The nearly complete absence of red leakage for the U $(1/\lambda=2.78)$ and N $(1/\lambda=3.03)$ filters is periodically checked, on the reddest objects. We are grateful to S. F. Pellicori for the determination of the filter and tube characteristics.

3. The Observations

Most of the observations were made between June 1966 and February 1967; a few were made earlier in 1966 or later in 1967.

The observations at each filter are made by taking measurements with and without depolarizer at each of six orientations of the Wollaston prism, the orientations being separated by intervals of 30°. On the average this routine is repeated three times giving a total of 18 pairs of measurements. For faint stars, for stars with small polarization, and especially for the filters at $1/\lambda=1.06$ and $1/\lambda=3.03$ a total of 24 to 30 pairs of measurements is usually made, in order to obtain the desired accuracy. Such a set, of about 18 pairs of measurements at a given filter, is defined as a single observation. A least-squares solution for the percentage polarization and position angle is run at the Numerical Analysis Laboratory of the University of Arizona. We are indebted to D. L. Coffeen and Mrs. L. C. Hess for certain improvements in the data processing. The instrumental polarization appropriate to each orientation of the Wollaston prism is subtracted from the measured value of the polarization at that orientation. Each final value of the percentage polarization is multiplied by a factor of 1.004, the measured value for the depolarizer deficiency.

Tables I and II are a journal of observations for stars which, in the course of this program, show no variable polarization and for stars with indications of variable polarization, respectively. The polarization position angle, θ, is in the equatorial coordinate frame. The dates are given in Universal Time.

Table III gives the weighted mean percentage of polarization during the present observing period. Five stars (HD 37041, 36371, 37202, 134320, 134335) in Table III and in subsequent tables have been previously observed (Paper VIII). Only in the case of HD 36371 have we combined the previous observations with the new ones. In the cases of HD 37041 and HD 37202 there are indications of variability (discussed in Sec. V); the Paper VIII results for HD 134320 and 134335 are considered too poor to be combined with the new values. A few entries marked with a semicolon represent single observations. All other entries represent the weighted mean value of two (in some cases three) independent observations made on separate nights. In previous papers we used the inverse of the probable error as the weighting factor rather than the inverse of the probable error squared. The statistics were poor, with only six measurements per least-squares solution. This is no longer true. Hence the weights assigned here are the inverse of the squares of the probable errors obtained from each separate least-squares solution. The average probable error of the weighted mean values is ±0.04%. This probable error is largest (±0.06%) for $1/\lambda=1.06$ and $1/\lambda=3.03$ and smallest (±0.02%) for $1/\lambda=1.93$. Colons in Table III indicate probable errors greater than ±0.10%.

Table IV lists the equatorial position angles. Again we have the weighted mean values from two (in a few cases three) independent observations, with weights equal to the reciprocal of the square of the individual probable errors. These errors in position angle are proportional to the error in percentage polarization divided by the polarization (Hall and Serkowski 1963); and weights have been assigned on this basis. The average probable error for the position angle is ±1°.1. This average probable error is largest (±1°.6) at $1/\lambda=1.06$ and smallest (±0°.8) at $1/\lambda=1.93$. Single observations in Table IV are indicated by a semicolon; colons indicate probable errors greater than ±3°.

Table V presents some of the fundamental data for the stars observed in this program. This table has been constructed in the same way as Table VI of Paper VIII (see references there), with the addition of a column

Table I. Journal of observations. Nonvariable polarization.

HD	1/λ	Yr.Mo.Day	P% ± pe		θ
4180	1.06	66.12.09	0.858	.032	85.33
4180	1.06	67.01.12	0.937	.043	84.82
4180	1.21	66.12.09	0.825	.020	81.69
4180	1.21	67.01.12	0.821	.022	82.06
4180	1.56	66.12.09	1.106	.032	80.88
4180	1.56	67.01.12	1.053	.023	82.64
4180	1.93	67.01.02	1.042	.019	83.79
4180	1.93	67.01.03	1.044	.016	83.45
4180	2.33	67.01.02	1.044	.018	85.87
4180	2.33	67.01.03	1.080	.019	84.81
4180	2.78	67.01.02	1.028	.019	84.38
4180	2.78	67.01.03	1.006	.018	84.31
4180	3.03	67.01.02	0.967	.037	90.73
4180	3.03	67.01.03	1.019	.044	84.56
4768	1.06	66.08.15	1.637	.061	83.81
4768	1.06	66.08.26	1.801	.107	97.01
4768	1.21	66.08.15	1.767	.104	82.48
4768	1.21	66.08.26	1.942	.077	71.89
4768	1.56	66.08.15	2.365	.077	79.14
4768	1.56	66.08.26	2.325	.090	82.87
4768	1.93	66.10.10	2.369	.034	82.69
4768	1.93	66.10.13	2.502	.075	81.47
4768	2.33	66.10.10	2.355	.028	81.72
4768	2.33	66.10.13	2.387	.023	80.61
4768	2.78	66.10.10	2.304	.047	81.15
4768	2.78	66.10.13	2.151	.036	79.86
4768	3.03	66.10.10	2.407	.140	78.00
4768	3.03	66.10.13	2.164	.096	78.15
7252	1.06	66.08.13	2.986	.162	107.11
7252	1.06	67.01.12	2.411	.142	97.35
7252	1.21	66.08.13	2.527	.055	101.11
7252	1.21	67.01.12	2.649	.068	96.08
7252	1.56	66.08.13	3.802	.033	96.16
7252	1.56	67.01.12	3.426	.089	96.55
7252	1.93	67.01.13	3.619	.023	97.35
7252	1.93	67.01.28	3.793	.079	98.29
7252	2.33	67.01.13	3.498	.026	98.11
7252	2.33	67.01.28	3.719	.030	98.08
7252	2.78	67.01.13	3.370	.060	97.58
7252	2.78	67.01.28	3.398	.028	97.92
7252	3.03	67.01.13	3.144	.109	98.42
7252	3.03	67.01.28	2.886	.110	101.08
7902	1.06	66.10.11	2.231	.124	94.85
7902	1.06	66.10.12	1.887	.092	96.48
7902	1.06	67.01.12	1.805	.099	95.28
7902	1.21	66.10.11	2.642	.084	98.19
7902	1.21	66.10.12	2.444	.060	95.91
7902	1.56	66.10.11	3.160.	.061	94.91
7902	1.56	66.10.12	3.228	.056	95.05
7902	1.93	66.10.11	3.349	.017	96.02
7902	1.93	66.12.08	3.296	.017	95.55
7902	2.33	66.10.11	3.307	.017	96.58
7902	2.33	66.12.08	3.208	.017	95.12
7902	2.78	66.10.11	3.268	.099	93.26
7902	2.78	66.12.08	2.946	.029	96.96
7902	3.03	66.10.11	2.647	.076	93.93
7902	3.03	66.12.08	3.009	.082	97.28
8965	1.06	66.08.13	1.955	.155	99.71
8965	1.06	66.08.15	2.031	.110	100.71
8965	1.21	66.08.13	2.360	.061	105.46
8965	1.21	66.08.15	2.081	.050	106.21
8965	1.56	66.08.13	2.970	.071	107.31
8965	1.56	66.08.15	2.980	.051	101.51
8965	1.93	67.01.13	3.123	.033	105.17
8965	1.93	67.02.07	2.919	.029	105.10
8965	2.33	67.01.13	2.897	.027	103.49
8965	2.33	67.02.07	2.902	.020	104.54
8965	2.78	67.01.13	2.704	.035	102.44
8965	2.78	67.02.07	2.657	.023	104.14
8965	3.03	67.01.13	2.570	.062	103.77
8965	3.03	67.02.07	2.442	.086	106.90
10898	1.06	66.10.12	2.643	.181	94.63
10898	1.21	66.08.26	3.007	.079	95.59
10898	1.21	66.10.11	3.382	.059	93.79
10898	1.21	66.10.12	3.369	.047	92.45
10898	1.56	66.08.26	4.073	.083	94.21
10898	1.56	66.10.11	4.042	.113	94.72
10898	1.56	66.10.12	4.009	.075	93.21
10898	1.93	66.09.21	4.615	.051	93.93
10898	1.93	66.09.22	4.597	.038	94.20
10898	2.33	66.09.21	4.227	.022	95.10
10898	2.33	66.09.22	4.384	.021	93.79
10898	2.78	66.09.21	3.882	.102	94.85
10898	2.78	66.09.22	3.959	.062	94.43
10898	3.03	66.09.21	4.027	.103	95.29
10898	3.03	66.09.22	3.783	.107	93.33
10898	3.03	66.09.22	3.792	.107	93.41
15558	1.06	66.10.12	3.661	.149	121.91
15558	1.06	66.11.16	3.748	.119	121.73
15558	1.21	66.10.12	4.264	.063	121.43
15558	1.21	66.11.16	4.294	.062	121.01
15558	1.56	66.10.12	5.390	.082	119.39
15558	1.56	66.11.16	5.264	.082	119.20
15558	1.93	66.10.11	5.311	.023	120.57
15558	1.93	66.10.13	5.279	.030	119.57
15558	2.33	66.10.11	5.139	.018	121.11
15558	2.33	66.10.13	5.458	.036	118.57
15558	2.78	66.10.11	4.529	.042	119.18
15558	2.78	66.10.13	4.764	.035	118.78
15558	3.03	66.10.10	4.362	.233	121.67
15558	3.03	66.10.13	4.481	.107	114.37
17506	1.05	66.08.29	0.722	.030	118.31
17506	1.05	66.12.09	0.751	.013	118.65
17506	1.19	66.08.29	0.815	.010	119.35
17506	1.19	66.12.09	0.797	.016	115.52
17506	1.54	66.08.29	0.991	.015	113.91
17506	1.54	66.12.09	0.923	.017	110.59
17506	1.91	66.12.09	1.127	.035	112.97
17506	1.91	67.01.02	1.138	.023	115.36
17506	2.29	66.12.09	1.105	.030	111.75
17506	2.29	67.01.02	1.043	.024	111.36
17506	2.75	66.12.09	0.885	.033	112.78
17506	2.75	67.01.02	1.112	.044	119.61
17506	2.75	67.02.08	0.920	.047	111.85
17506	3.00	66.12.09	0.994	.072	116.17
17506	3.00	67.01.02	1.112	.135	119.90
17506	3.00	67.02.08	0.764	.154	111.07

which lists our observed mean value of the polarization position angle. An exclamation mark (!) in this column indicates wavelength dependence of the position angle. The P_{vis} column now gives the weighted mean of the polarizations at $1/\lambda=1.56$, 1.93 and 2.33 (colons and semicolons are given half weight). The photometric data for HD 37061 are from Lee (1966).

4. *Interstellar Polarization*

Table VI gives the normalized polarizations. The normalization is performed by setting the straight average of the polarizations at $1/\lambda=1.93$ and $1/\lambda=2.33$ equal to 100%. In this way we can both compare stars which are variously polarized to one another, and also combine the observations for various stars in order to study the more general features of interstellar polarization. Colons are used in Table VI to indicate that the probable error for the normalized polarization is ±8% or greater. Semicolons are for single observations.

Figures 3(a) to 3(e) give the normalized polarization curves both for the stars observed in the present study (solid curves) and for the stars of Paper VIII (dashed

TABLE I (*continued*)

HD	1/λ	Yr.Mo.Day	P%	± pe	θ
25914	1.06	66.09.25	3.437	.138	138.33
25914	1.06	66.10.12	2.954	.089	137.48
25914	1.06	67.01.01	3.161	.094	137.61
25914	1.21	66.09.25	3.950	.056	137.91
25914	1.21	66.10.12	3.714	.074	137.98
25914	1.56	66.09.25	4.338	.077	139.46
25914	1.56	66.10.12	4.451	.089	137.39
25914	1.93	66.09.24	4.647	.025	141.17
25914	1.93	66.10.18	4.578	.038	139.89
25914	2.33	66.09.24	4.562	.020	141.21
25914	2.33	66.10.18	4.266	.032	139.27
25914	2.78	66.09.24	4.078	.056	139.36
25914	2.78	66.10.18	4.082	.074	140.46
25914	3.03	66.09.24	3.571	.166	138.66
25914	3.03	66.10.18	3.774	.108	138.21
25940	1.06	66.09.23	0.767	.038	176.23
25940	1.06	66.09.25	0.717	.046	171.14
25940	1.06	67.01.01	0.714	.029	168.65
25940	1.06	67.01.27	0.621	.024	168.20
25940	1.21	66.09.23	0.688	.028	174.83
25940	1.21	66.09.25	0.794	.019	170.46
25940	1.21	67.01.01	0.755	.018	167.89
25940	1.21	67.01.27	0.700	.017	173.14
25940	1.56	66.09.23	0.759	.013	169.68
25940	1.56	66.09.25	0.879	.024	173.39
25940	1.56	67.01.01	0.928	.021	172.34
25940	1.56	67.01.27	0.783	.023	171.41
25940	1.93	67.01.02	0.797	.027	169.38
25940	2.33	66.09.22	0.651	.016	176.50
25940	2.33	67.01.02	0.737	.021	170.42
25940	2.78	66.09.22	0.409	.018	176.48
25940	2.78	67.01.02	0.471	.028	171.38
25940	3.03	66.09.21	0.494	.062	171.69
25940	3.03	67.01.02	0.232	.064	178.82
29866	1.06	66.10.12	1.528	.076	16.39
29866	1.06	67.01.12	1.616	.091	7.84
29866	1.21	66.10.12	1.482	.047	12.01
29866	1.21	67.01.12	1.544	.047	8.19
29866	1.21	67.01.26	1.522	.052	10.68
29866	1.56	66.10.12	1.687	.036	11.00
29866	1.56	67.01.12	1.823	.056	9.00
29866	1.56	67.01.26	1.738	.051	11.08
29866	1.93	67.01.13	1.724	.012	10.26
29866	1.93	67.02.08	1.806	.013	9.09
29866	2.33	67.01.13	1.605	.011	11.12
29866	2.33	67.02.08	1.721	.082	16.51
29866	2.78	67.01.13	1.438	.032	13.68
29866	2.78	67.02.08	1.426	.023	12.29
29866	3.03	67.01.13	1.193	.051	15.75
29866	3.03	67.02.08	1.211	.067	10.84
32481	1.06	67.02.06	1.473	.128	91.33
32481	1.21	67.02.06	1.706	.057	78.39
32481	1.56	67.02.06	2.061	.081	80.01
32481	1.93	66.12.14	1.725	.040	77.05
32481	1.93	67.01.13	1.989	.043	81.01
32481	2.33	66.12.14	1.810	.026	77.37
32481	2.33	67.01.13	1.958	.021	81.88
32481	2.78	66.12.14	1.762	.046	72.90
32481	2.78	67.01.13	1.699	.082	82.11
32481	3.03	66.12.14	1.444	.131	83.34

HD	1/λ	Yr.Mo.Day	P%	± pe	θ
32990	1.06	67.01.01	1.026	.044	85.97
32990	1.06	67.01.12	1.058	.058	88.48
32990	1.21	67.01.01	1.240	.030	86.16
32990	1.21	67.01.12	1.327	.041	86.34
32990	1.56	67.01.01	1.506	.039	83.88
32990	1.56	67.01.12	1.572	.076	85.69
32990	1.93	66.12.09	1.697	.033	78.66
32990	1.93	67.01.03	1.665	.013	85.23
32990	2.33	66.12.09	1.672	.023	84.61
32990	2.33	67.01.03	1.607	.021	85.59
32990	2.78	66.12.09	1.547	.026	83.71
32990	2.78	67.01.03	1.489	.019	86.07
32990	3.03	66.12.09	1.435	.039	83.91
32990	3.03	67.01.03	1.287	.050	85.42
36371	1.06	63.12.02	1.520	.031	177.64
36371	1.21	63.12.02	1.700	.058	176.47
36371	1.21	66.10.12	1.641	.023	179.92
36371	1.39	63.12.02	2.040	.040	178.59
36371	1.39	65.09.21	1.561	.072	176.39
36371	1.56	66.10.12	1.801	.038	181.22
36371	1.93	63.12.01	2.230	.049	173.51
36371	1.93	65.08.27	2.221	.072	179.34
36371	2.33	63.12.01	2.090	.040	172.21
36371	2.33	65.08.27	2.197	.049	178.82
36371	2.78	63.12.01	1.830	.036	170.60
36371	2.78	65.08.13	1.690	.399	173.79
36371	3.03	63.12.01	1.780	.081	168.90
37061	1.06	67.02.08	1.369	.075	62.57
37061	1.21	67.02.08	1.687	.054	57.25
37061	1.56	67.02.08	1.508	.046	63.83
37061	1.93	67.01.03	1.523	.022	66.12
37061	1.93	67.02.04	1.549	.057	65.23
37061	2.33	67.01.03	1.367	.029	70.24
37061	2.33	67.02.04	1.454	.014	67.43
37061	2.78	67.01.03	1.201	.044	73.08
37061	2.78	67.02.04	1.293	.030	67.71
37061	3.03	67.01.03	1.096	.073	75.25
37061	3.03	67.02.04	1.478	.107	69.20
37367	1.06	67.01.12	0.596	.108	23.69
37367	1.06	67.02.06	0.457	.071	21.17
37367	1.21	67.01.12	0.638	.030	16.00
37367	1.21	67.02.06	0.803	.045	29.22
37367	1.56	67.01.12	0.686	.075	21.61
37367	1.56	67.02.06	0.989	.060	24.74
37367	1.93	67.01.03	0.751	.065	24.34
37367	1.93	67.01.13	0.817	.011	24.60
37367	2.33	67.01.03	0.626	.019	22.22
37367	2.33	67.01.13	0.727	.061	21.68
37367	2.78	67.01.03	0.511	.020	28.64
37367	2.78	67.01.13	0.736	.039	21.44
37367	3.03	67.01.03	0.635	.078	40.05
37367	3.03	67.01.13	0.447	.063	21.65
40111	1.06	66.12.13	0.685	.044	177.92
40111	1.06	67.01.01	0.719	.044	161.20
40111	1.21	66.12.13	0.602	.024	180.58
40111	1.21	67.01.01	0.809	.024	161.38
40111	1.56	66.12.13	0.853	.039	180.63
40111	1.56	67.01.01	1.048	.031	163.86
40111	1.93	66.12.09	0.686	.014	170.60

curves). The average probable error for the normalized polarizations plotted in Figs. 3(a) to 3(c) is ±3.0%. Where the probable error is greater than ±8%, an open square is used; open circles represent single observations. Omitted from the figures because of unusually large uncertainties are HD 83953 of this paper and the following stars of Paper VIII: HD 24431, 134320, 134335, 193443. The irregular red variable μ Cephei (HD 206936) has also been omitted since its large amplitude variation in percentage polarization (approx 2%) will be discussed in a subsequent paper in this series. The observation at $1/\lambda=3.03$ for HD 134320 has not been plotted, since the probable error is ±22%. For ζ Tau (HD 37202) the combined values from Table X of Paper VIII and the present Table VI (colons and semicolons half weight) are plotted. Since θ^2 Orionis (HD 37041) has variable polarization only the 1964 observations are plotted.

The marked similarity of a majority of the curves is a noteworthy feature of Figs. 3(a) to 3(e), as are the departures from this "characteristic" curve. We have combined the observations for 52 of the stars in order

TABLE I (*continued*)

HD	1/λ	Yr.Mo.Day	P%	± pe	θ
40111	1.93	67.01.03	0.741	.010	170.05
40111	2.33	66.12.09	0.704	.034	168.11
40111	2.33	67.01.03	0.680	.014	169.69
40111	2.78	66.12.09	0.512	.026	175.88
40111	2.78	67.01.03	0.273	.052	168.45
40111	3.03	66.12.09	0.253	.055	166.74
40111	3.03	67.01.03	0.533	.086	161.35
41398	1.06	67.01.12	1.698	.110	162.79
41398	1.21	67.01.12	1.851	.068	159.42
41398	1.56	67.01.12	2.245	.071	162.80
41398	1.93	66.12.14	2.081	.025	168.46
41398	2.33	66.12.14	2.098	.020	167.71
41398	2.78	66.12.14	1.566	.029	169.89
41398	3.03	66.12.14	1.697	.079	163.79
46484	1.06	66.12.13	0.825	.096	162.17
46484	1.21	66.12.13	0.977	.046	174.18
46484	1.56	66.12.13	1.492	.087	181.43
46484	1.93	66.12.14	1.290	.029	175.28
46484	2.33	66.12.14	1.206	.017	177.35
46484	2.78	66.12.14	0.990	.054	178.99
47240	1.06	66.12.13	1.000	.072	178.24
47240	1.06	67.01.01	0.657	.050	167.19
47240	1.06	67.02.08	0.607	.050	171.90
47240	1.21	66.12.13	0.945	.036	173.63
47240	1.21	67.01.01	0.841	.068	170.82
47240	1.21	67.02.08	0.753	.034	172.10
47240	1.56	66.12.13	1.078	.039	180.95
47240	1.56	67.01.01	0.993	.040	172.90
47240	1.56	67.02.08	1.021	.068	176.22
47240	1.93	67.02.07	0.996	.013	172.45
47240	2.33	67.02.07	1.076	.051	172.68
47240	2.78	67.02.07	0.691	.033	180.80
47240	2.78	67.02.07	0.752	.074	180.16
47240	3.03	67.02.07	0.631	.067	176.06
83953	1.06	67.01.03	0.539	.078	175.14
83953	1.06	67.01.12	0.337	.035	174.70
83953	1.21	67.01.03	0.381	.021	172.76
83953	1.21	67.01.12	0.364	.025	172.64
83953	1.56	67.01.03	0.411	.035	177.61
83953	1.56	67.01.12	0.297	.018	177.78
83953	1.93	67.01.13	0.323	.014	183.13
83953	2.33	67.01.13	0.580	.074	167.16
83953	2.78	67.01.13	0.114	.022	
83953	3.03	67.01.13	0.105	.037	
134320	1.05	66.03.16	0.404	.035	89.75
134320	1.05	66.06.13	0.447	.031	90.56
134320	1.19	66.03.16	0.432	.019	83.51
134320	1.19	66.06.13	0.456	.029	84.19
134320	1.37	66.03.16	0.529	.029	86.80
134320	1.54	66.03.16	0.621	.027	86.28
134320	1.54	66.06.13	0.600	.024	85.94
134320	1.91	66.03.13	0.604	.011	82.84
134320	2.29	66.03.14	0.617	.016	88.20
134320	2.29	66.03.15	0.635	.023	93.14
134320	2.75	66.03.14	0.533	.055	90.20
134320	2.75	66.03.15	0.655	.036	86.88
134320	3.00	66.03.14	0.584	.143	78.87
134320	3.00	66.03.15	0.994	.141	86.39
134335	1.05	66.03.16	0.362	.027	83.95
134335	1.05	66.06.13	0.313	.039	95.69
134335	1.19	66.03.16	0.508	.017	85.42
134335	1.19	66.06.13	0.578	.013	82.69
134335	1.37	66.03.16	0.489	.046	80.97
134335	1.54	66.03.16	0.590	.030	88.02
134335	1.54	66.06.13	0.624	.041	82.40
134335	1.91	66.02.28	0.639	.079	82.28
134335	1.91	66.03.13	0.661	.014	81.10
134335	2.29	66.02.28	0.701	.073	83.23
134335	2.29	66.03.13	0.644	.072	84.18
134335	2.75	66.02.14	0.603	.082	80.70
134335	2.75	66.02.28	0.535	.044	78.97
134335	2.75	66.03.13	0.501	.058	98.32
134335	3.00	66.02.28	0.610	.075	79.61
134335	3.00	66.03.13	0.453	.089	76.69
179406	1.06	66.06.11	0.994	.056	177.20
179406	1.21	66.06.11	1.006	.037	181.18
179406	1.56	66.06.11	1.211	.045	178.92
179406	1.56	66.07.06	1.111	.035	184.74
179406	1.93	66.06.15	1.385	.011	183.71
179406	1.93	66.07.06	1.315	.057	182.46
179406	1.93	66.07.22	1.078	.057	
179406	2.33	66.06.15	1.327	.010	184.62
179406	2.33	66.07.22	1.239	.036	
179406	2.78	66.06.15	1.155	.018	183.65
179406	2.78	66.07.22	0.820	.078	
179406	3.03	66.06.15	1.147	.037	186.99
179406	3.03	66.07.22	1.065	.067	
193237	1.06	66.08.27	0.761	.035	40.73
193237	1.06	66.10.14	0.953	.032	39.46
193237	1.21	66.08.27	0.918	.020	38.85
193237	1.21	66.10.14	1.062	.015	40.74
193237	1.56	66.08.27	1.201	.025	38.84
193237	1.56	66.10.14	1.383	.023	40.22
193237	1.93	66.07.26	1.372	.007	38.17
193237	1.93	66.08.27	1.432	.010	35.08
193237	2.33	66.07.26	1.365	.030	38.58
193237	2.33	66.08.27	1.501	.005	35.15
193237	2.78	66.07.26	1.381	.012	38.42
193237	2.78	66.08.27	1.412	.013	37.22
193237	3.03	66.07.26	1.372	.019	40.04
193237	3.03	66.08.27	1.368	.022	39.28
216411	1.06	66.08.15	1.588	.068	45.69
216411	1.06	66.08.22	1.389	.084	44.10
216411	1.21	66.08.15	2.082	.046	50.89
216411	1.21	66.08.22	2.131	.031	46.52
216411	1.56	66.08.15	2.627	.053	45.19
216411	1.56	66.08.22	2.427	.068	49.16
216411	1.93	66.07.22	2.659	.046	50.96
216411	1.93	66.07.26	2.653	.026	48.39
216411	1.93	66.10.10	2.784	.063	48.66
216411	2.33	66.07.22	3.010	.044	51.27
216411	2.33	66.07.26	2.529	.016	49.28
216411	2.33	66.10.10	2.967	.059	49.21
216411	2.78	66.07.26	2.263	.052	49.01
216411	2.78	66.08.12	2.391	.040	47.95
216411	3.03	66.07.26	2.107	.067	51.20
216411	3.03	66.08.12	2.245	.087	51.84

TABLE II. Journal of observations. Variable polarization.

HD	1/λ	Yr.Mo.Day	P% ± pe	θ
10516	1.06	66.08.22	0.822 .031	34.93
10516	1.06	66.08.29	0.812 .031	35.13
10516	1.06	66.12.09	0.902 .026	33.90
10516	1.06	67.01.02	0.843 .021	30.65
10516	1.21	66.08.15	0.676 .074	34.51
10516	1.21	66.08.22	0.744 .025	36.52
10516	1.21	66.08.29	0.686 .019	38.23
10516	1.21	66.12.09	0.895 .021	39.11
10516	1.21	67.01.02	0.693 .016	34.47
10516	1.56	66.08.15	0.790 .093	41.85
10516	1.56	66.08.29	0.726 .019	45.46
10516	1.56	66.12.09	0.920 .017	45.02
10516	1.56	67.01.02	0.686 .018	39.94
10516	1.93	66.11.17	1.054 .011	41.98
10516	1.93	67.01.02	0.929 .019	42.59
10516	2.33	66.11.17	1.147 .007	41.33
10516	2.33	66.12.08	1.102 .019	40.79
10516	2.33	67.01.02	0.945 .015	42.11
10516	2.78	66.11.17	0.823 .012	50.13
10516	2.78	66.12.08	0.683 .018	53.67
10516	2.78	67.01.02	0.606 .021	59.54
10516	3.03	66.11.17	0.718 .017	59.81
10516	3.03	66.12.08	0.767 .044	65.75
10516	3.03	67.01.02	0.488 .035	70.36
35468	1.06	67.01.26	0.070 .012	74.21
35468	1.06	67.01.27	0.149 .068	82.89
35468	1.21	67.01.26	0.132 .006	79.49
35468	1.21	67.01.27	0.159 .014	81.30
35468	1.56	67.01.26	0.195 .008	74.58
35468	1.56	67.01.27	0.159 .010	75.74
35468	1.93	67.01.03	0.196 .025	85.23
35468	1.93	67.01.27	0.209 .011	79.10
35468	2.33	67.01.03	0.232 .022	82.69
35468	2.33	67.01.27	0.209 .009	76.36
35468	2.78	67.01.03	0.307 .022	73.07
35468	2.78	67.01.27	0.282 .014	68.80
35468	3.03	67.01.03	0.338 .033	68.41
35468	3.03	67.01.27	0.282 .014	70.39
37041	1.06	64.01.27	0.808 .067	94.01
37041	1.06	64.01.29	1.010 .081	103.98
37041	1.06	64.01.29	0.923 .049	94.17
37041	1.06	67.02.08	1.132 .043	104.22
37041	1.21	64.01.27	0.925 .067	108.47
37041	1.21	64.01.29	0.966 .058	101.41
37041	1.21	67.02.08	1.012 .025	100.11
37041	1.39	64.01.27	0.969 .054	85.39
37041	1.39	64.01.29	0.833 .063	94.41
37041	1.56	67.02.08	1.071 .043	100.84
37041	1.93	64.01.24	0.955 .067	106.10
37041	1.93	64.01.28	0.829 .031	105.42
37041	1.93	67.02.05	1.040 .010	91.30
37041	1.93	67.04.23	0.946 .027	98.06
37041	2.33	64.01.24	0.565 .018	98.69
37041	2.33	64.01.28	0.624 .040	104.38
37041	2.33	67.02.05	0.981 .006	86.78
37041	2.33	67.04.23	0.855 .019	91.91
37041	2.78	64.01.24	0.357 .045	79.11
37041	2.78	64.01.28	0.474 .094	102.26
37041	2.78	67.02.05	0.872 .015	81.90
37041	2.78	67.04.23	0.450 .064	84.58
37041	3.03	64.01.24	0.260 .030	
37041	3.03	64.01.28	0.447 .040	
37041	3.03	67.02.05	0.800 .034	79.44
37041	3.03	67.04.23	0.207 .134	78.67
37202	1.06	64.01.25	1.400 .054	30.43
37202	1.06	65.08.13	1.355 .027	
37202	1.21	64.01.25	1.260 .022	30.95
37202	1.21	65.09.21	1.056 .139	28.19
37202	1.21	67.04.22	1.276 .020	33.09
37202	1.39	64.01.25	1.210 .036	33.71
37202	1.39	65.09.21	1.213 .206	34.01
37202	1.56	67.04.22	1.368 .063	32.93
37202	1.93	64.01.26	1.437 .031	25.53
37202	1.93	64.01.28	1.512 .054	26.72
37202	1.93	66.12.09	1.517 .018	35.36
37202	2.33	64.01.26	1.522 .045	27.40
37202	2.33	64.01.28	1.542 .040	27.50
37202	2.33	66.12.09	1.684 .023	36.47
37202	2.33	67.04.22	1.536 .024	35.24
37202	2.78	64.01.26	0.952 .058	23.39
37202	2.78	64.01.28	0.997 .045	23.20
37202	2.78	65.08.13	1.080 .112	
37202	2.78	66.12.09	1.111 .015	40.62
37202	2.78	67.04.22	1.089 .050	29.36
37202	3.03	64.01.26	0.688 .081	18.16
37202	3.03	64.01.28	0.669 .063	17.24
37202	3.03	66.12.09	0.908 .052	41.63
37202	3.03	67.04.22	0.558 .025	35.00
169454	1.06	66.06.08	1.239 .032	9.23
169454	1.06	66.10.14	1.498 .045	13.92
169454	1.21	66.06.08	1.431 .025	10.34
169454	1.21	66.10.14	1.593 .028	14.05
169454	1.56	66.06.08	1.888 .025	16.33
169454	1.56	66.10.14	1.982 .047	18.13
169454	1.93	66.06.14	2.022 .029	17.04
169454	1.93	66.07.12	1.714 .021	13.58
169454	2.33	66.06.14	1.879 .015	16.90
169454	2.33	66.07.12	1.611 .020	16.41
169454	2.78	66.06.14	1.724 .040	14.45
169454	2.78	66.07.12	1.255 .104	20.30
169454	3.03	66.06.14	1.968 .087	21.92
181615	1.06	66.06.07	0.594 .033	163.19
181615	1.06	67.04.22	0.437 .023	173.85
181615	1.21	66.06.07	0.696 .010	163.06
181615	1.21	67.04.22	0.596 .014	174.84
181615	1.56	66.06.07	0.939 .021	164.82
181615	1.56	67.04.22	0.664 .020	171.17
181615	1.93	66.06.14	1.004 .026	168.20
181615	1.93	66.11.17	0.780 .015	170.70
181615	2.33	66.11.17	0.667 .038	173.63
181615	2.78	66.06.14	0.920 .015	171.79
181615	2.78	66.11.17	0.514 .019	179.15
181615	3.03	66.06.14	0.859 .034	171.00
181615	3.03	66.11.17	0.580 .040	188.56
197770	1.06	66.08.13	2.845 .109	131.35
197770	1.21	66.08.13	3.175 .038	130.65
197770	1.56	66.08.13	3.475 .039	129.71
197770	1.85	66.08.13	4.077 .044	131.04
197770	1.93	66.07.26	4.005 .011	130.17
197770	1.93	66.10.10	3.772 .016	130.02
197770	2.33	66.10.10	3.770 .013	129.18
197770	2.78	66.07.26	3.571 .027	131.80
197770	2.78	66.10.10	3.367 .019	128.55
197770	3.03	66.07.26	3.380 .035	130.02
197770	3.03	66.10.10	2.860 .089	128.36

to obtain a mean interstellar polarization curve. All stars in Figs. 3(a) to 3(e) except HD 6675, 35468, 37041, and 37202 have been used for this purpose.

In Table VII we list the results obtained by taking the weighted mean of the normalized polarizations for all stars at a given wavelength and the curve is plotted at the bottom of Fig. 3(e). The error bars there give the average probable error, which is a measure of the precision of determining polarization for a single star at the respective wavelength. It does not indicate the dispersion in interstellar polarization for various stars.

The mean curve shows the characteristic broad maximum centered at about 5200 Å with a sharper decrease at larger than at shorter wavelengths. We have also determined a separate mean interstellar polarization curve for stars with $P \geq 2\%$ and $P < 2\%$, respectively, at $1/\lambda = 1.93$. There is no significant difference between the two groups. It is to be noted, however, that all of the stars in Figs. 3(a) to 3(d) which show marked peculiarities have polarizations less than 2%. We include among such stars the following: HD 6675, 25291, 25940, 35468, 37041, 37202, 37367, 40111.

Table VIII lists the residuals of the observed position angles from the weighted mean position angle (see Table V). In determining this mean, colons and semicolons in Table IV are given half weight. Colons in Table VIII indicate probable errors greater than $\pm 3°$; semicolons indicate single observations. Exclamation marks (!) behind the HD number note stars for which there is an appreciable rotation of the plane of polarization with wavelength. The judgment that a star shows rotation is based both upon the probable errors and the smoothness of the variation of the residuals with wavelength.

5. *Variable Polarizations*

There is a growing problem in polarization studies as to whether the interstellar polarization is varying or whether all the variations which we observe are intrinsic to a star, stellar system, or circumstellar clouds. Intrinsic variations are now well established for various types of stars including the spectroscopic binary β Lyrae (Shakhovskoi 1964; Appenzeller 1965;

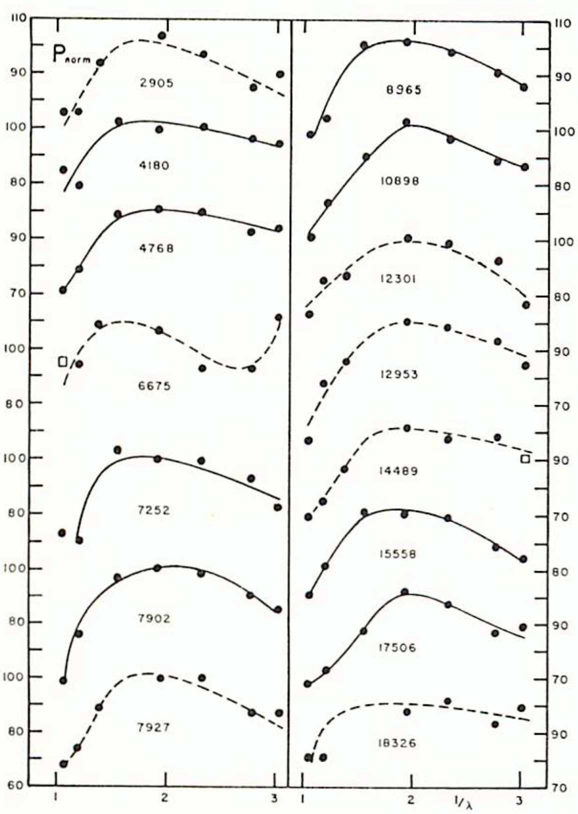

FIG. 3 (a). Normalized polarizations (see Sec. IV). Open circles are single observations; squares indicate that the probable error is greater than $\pm 8\%$. Dotted curves are for previous and solid curves for present observations.

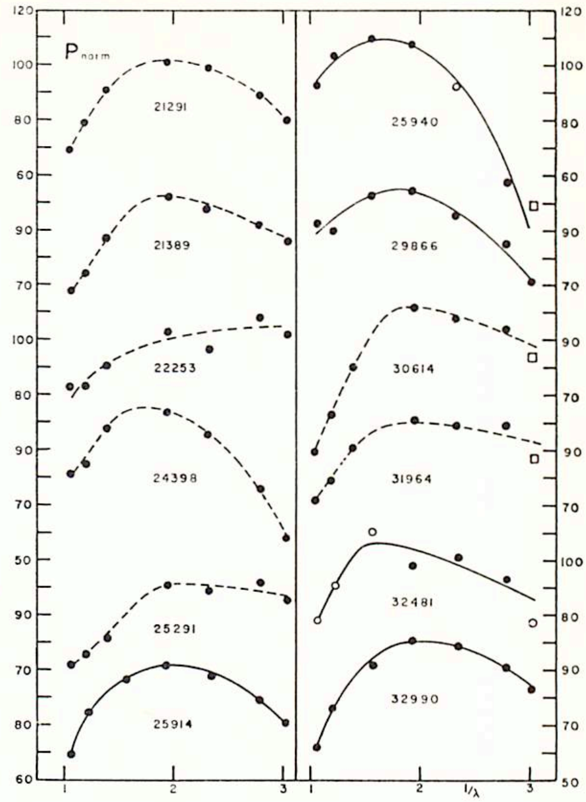

FIG. 3 (b). Same as for Fig. 3(a).

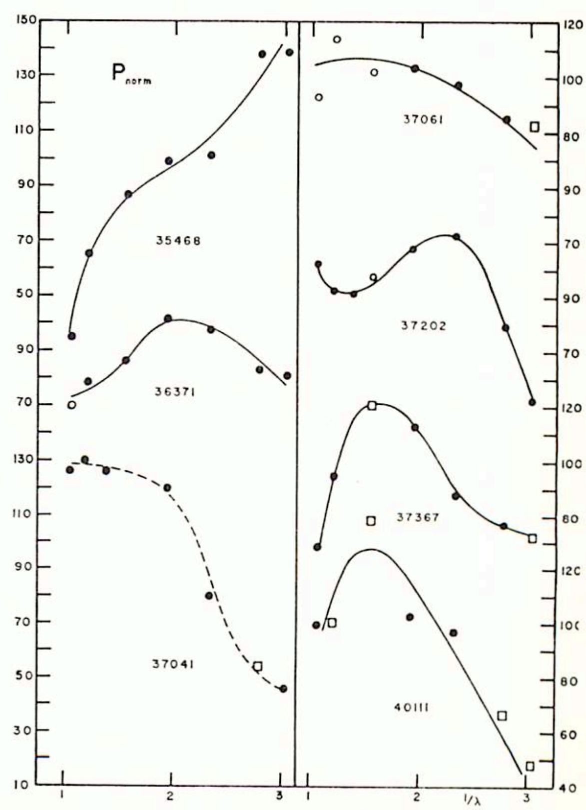

FIG. 3 (c). Same as for Fig. 3(a).

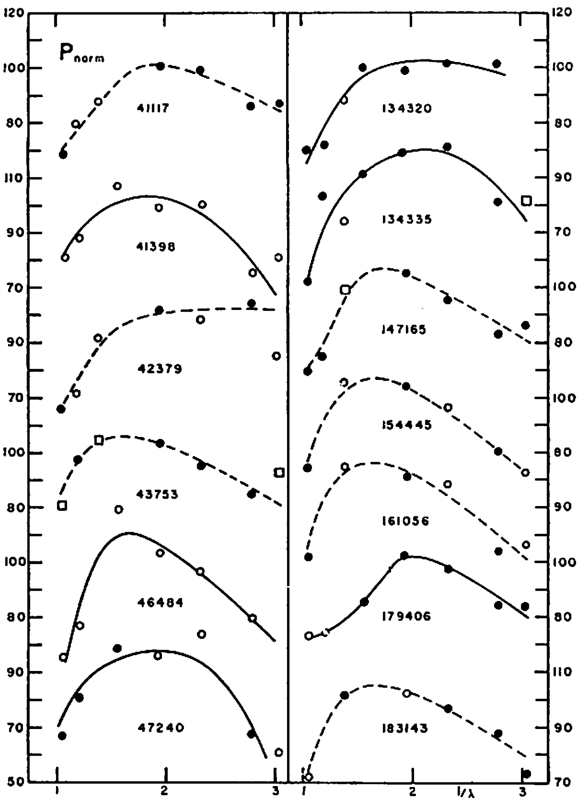

FIG. 3 (d). Same as for Fig. 3(a).

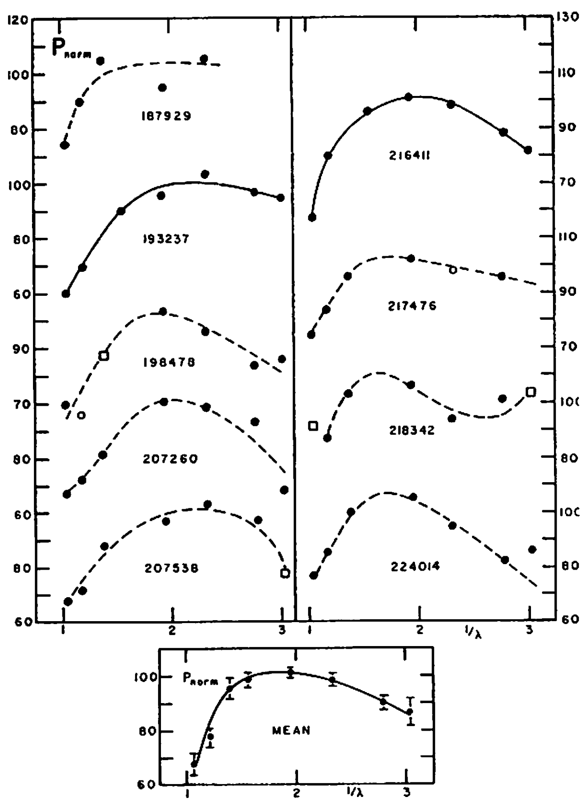

FIG. 3 (e). Same as for Fig. 3(a). Error bars on mean curve give the average probable errors.

TABLE III. Observed percentages of interstellar polarization. Weighted mean values.

HD	Percentage polarization observed at $1/\lambda=$ 1.06	1.21	1.56	1.93	2.33	2.78	3.03
179406	0.99;	1.01;	1.15	1.38	1.32	1.14	1.13
134335[a]	0.35	0.55	0.60	0.66	0.67	0.54	0.55
134320[a]	0.43	0.44	0.61	0.60;	0.62	0.62	0.79:
193237	0.87	1.01	1.30	1.39	1.50	1.40	1.37
216411	1.51	2.12	2.55	2.67	2.61	2.34	2.16
4180	0.89	0.82	1.07	1.04	1.05	1.02	0.99
4768	1.68	1.88	2.35	2.39	2.37	2.21	2.24
7252	2.66:	2.58	3.76	3.64	3.63	3.39	3.02
7902	1.94	2.51	3.20	3.32	3.26	2.97	2.81:
8965	2.01	2.19	2.98	3.01	2.90	2.67	2.53
10898	2.72	3.27	4.04	4.60	4.31	3.94	3.87
15558	3.71	4.28	5.33	5.30	5.20	4.67	4.46
17506[a]	0.75	0.81	0.96	1.13	1.07	0.96	0.98
25914	3.15	3.86	4.39	4.63	4.48:	4.08	3.71
25940	0.68	0.77	0.81	0.80;	0.68	0.43	0.37
29866	1.56	1.52	1.73	1.76	1.61	1.43	1.20
36371	1.52;	1.65	1.80	2.23	2.14	1.81	1.78
37367	0.50	0.69	0.87:	0.82	0.64	0.56	0.52
32990	1.04	1.27	1.52	1.67	1.64	1.51	1.38
32481	1.47;	1.71;	2.06;	1.85	1.90	1.75	1.44;
41398	1.70;	1.85;	2.25;	2.08;	2.10;	1.57;	1.70;
40111	0.70	0.71	0.97	0.72	0.68	0.46	0.33
37202	···	1.28;	1.37;	1.52;	1.61	1.11	0.62
35468	0.07	0.14	0.18	0.21	0.21	0.29	0.29
46484	0.83;	0.98;	1.49;	1.29;	1.21;	0.99;	···
47240	0.70	0.84	1.03	1.00;	1.08;	0.70	0.63;
37061	1.37;	1.69;	1.51;	1.53	1.44	1.26	1.22:
37041	1.13;	1.01;	1.07;	1.03	0.97	···	···
83953	0.37	0.37	0.32	0.32;	0.58;	0.11;	0.11;

[a] These stars are K-type stars and the corresponding effective wave numbers are 1.05, 1.19, 1.54, 1.91, 2.29, 2.75, and 3.00 μ^{-1}.

TABLE IV. Observed position angles of interstellar polarization. Weighted mean values.

HD	Position angle observed at $1/\lambda=$ 1.06	1.21	1.56	1.93	2.33	2.78	3.03
179406	177°2;	181°2;	182°3	183°7	184°6;	183°7;	187°0;
134335	90.1:	83.3	84.5	81.1	83.8	84.6:	78.2
134320	90.4	83.9	86.1	82.8;	91.2	87.4	85.3
193237	39.9	40.2	39.7	37.1	35.2	37.9	39.7
216411	45.2	47.8	46.6	49.0	49.6	48.3	51.5
4180	85.1	81.9	82.0	83.6	85.4	84.3	88.0
4768	87.5:	75.2:	80.7	82.5	81.1	80.4	78.1
7252	102.6:	99.0	96.2	97.4	98.1	97.9	99.6
7902	95.6	96.8	95.0	95.0	95.9	96.6	95.2
8965	100.4	105.9	103.5	105.1	104.2	103.6	104.8
10898	93.5	93.4	93.9	94.1	94.4	94.5	94.1
15558	121.8	121.2	119.3	120.2	120.6	118.9	115.6:
17506	118.6	118.3	112.6	114.6	111.5	115.0	116.6
25914	137.8	137.9	138.6	140.8	140.7	139.8	138.3
25940	171.2	170.9	170.4	169.4;	173.9	174.7	172.9
29866	12.6	10.2	10.5	9.7	11.2	12.8	13.9
36371	177.6;	179.6	181.1	175.9	175.2	171.0	168.9
37367	22.2	21.5:	24.0	24.6	22.2	26.1	21.7;
32990	86.9	86.2	84.3	84.3:	85.1	85.2	84.4
32481	91.3;	78.4;	80.0;	79.2	80.3	75.0:	83.3;
41398	162.8;	159.4;	162.8)	168.5;	167.7;	169.9;	163.8;
40111	169.2:	168.2:	168.8:	170.2	169.5	175.4	163.3
37202	···	33.1;	32.9;	35.4;	35.9	39.7	37.8
35468	75.2	79.9	74.9	80.0	77.4	70.2	70.0
46484	162.2;	174.2;	181.4;	175.3;	177.4;	179.0;	···
47240	173.1	177.2	172.7	172.5;	172.7;	180.7	176.1;
37061	62.6;	57.3;	63.8;	66.0	67.9	69.3	72.5
37041	104.2;	100.1;	100.8;	92.0	85.6:	82.4	79.2
83953	174.8	172.7	177.7	183.0;	167.2:	···	···

TABLE V. Various data on the stars observed in this program.

HD	Name	Galactic long	Galactic lat	Sp	V	$B-V$	E_{B-V}	Distance (kpc) R	Phot.	Par.	Rel.[a]	P_{vis}	$\bar{\theta}$	Remarks[b]
169454	−14°5039	18°	0°	B1Ia+	6^{m}61	+0^{m}94	1^{m}16	3.6	0.7:	···		···	15°5	
181615	υ Sgr	22	−14	A pep	4.61	+0.10	···	3.6	···	···		···	169.0	Sp. bin. Var.
179406	20 Aql	28	− 8	B3IV	5.4	···	···	3.6		···		1%28	182.9!	Var.?
134335	BS 5640	38	+59	gK1	5.83	+1.21	0.11	3.6	0.3:	···		0.64	83.0	
134320	46 Boo	39	+60	gK2	5.68	+1.24	0.08	3.6	0.3:	···		0.61	87.0	
193237	P Cyg	76	+ 1	Bp	4.80	+0.41	···	3.6	···	1.0	*f*	1.40	38.5	Shell, Nova 1600
197770	BS 7940	94	+ 9	B2IV	6.32	+0.33	0.57	4.2	0.3	···	*n*	···	130.1	
216411	+58°2492	108	− 2	B1Ia	7.20	+0.60	0.82	4.9	0.9	···	*f*	2.61	48.3!	
4180	o Cas	122	−15	B2V	4.50	−0.06	0.18	5.4	0.2	···	*n*	1.05	84.0	
4768	+58°119	123	− 3	B5Ib	7.57	+0.38	0.48	5.4	1.4	···	*f*	2.37	80.7	
7252	+60°188	126	− 3	B1V	7.12	+0.09	0.35	5.5	0.6	···	*f*	3.68	98.4	
7902	+57°257	127	− 5	B6Ib	6.93	+0.40	0.48	5.5	1.0	···	*f*	3.26	95.7	
8965	+59°260	128	− 2	B0.5V	7.28	+0.02	0.30	5.6	1.0	···	*f*	2.96	104.0	
10898	+57°399	131	− 4	B2Ib	7.40	+0.35	0.53	5.6	1.1	···	*f*	4.32	94.0	
10516	φ Per	131	−11	B1III? pe	4.06	−0.04	···	5.6	···	0.06	*n*	···	44.4!	Sp. bin. Var.
15558	+60°502	135	+ 2	O6	7.81	+0.52	0.84	5.8	0.5	···		5.28	120.0!	
17506	η Per	139	− 3	K3Ib	3.79	+1.69	0.31	5.8	0.2	0.25	*n*	1.05	115.3	
25914	+56°884	147	+ 3	B6Ia	7.99	+0.60	0.68	6.0	1.5	···	*f*	4.50	139.1	
25940	48 Per	153	− 3	B3V pe	4.04	−0.06	0.14:	6.0	0.1:	0.07	*n*	0.76	172.1!	Var.?
29866	BS 1500	163	− 3	B7? e	6.06	+0.10	···	6.1	···	···		1.70	11.5	
36371	χAur	176	+ 1	B5Iab	4.77	+0.35	0.45	6.1	0.5	···		2.06	175.5!	Sp. bin.
37367	BS 1924	179	− 1	B2V	5.95	···	···	6.0	···	···		0.76	23.2	Sp. bin.
32990	103 Tau	179	−10	B2V	5.41	···	···	6.0	···	···		1.61	85.3	Sp. bin.
32481	+21°754	181	−13		8.10	···	···	6.0	···	···		1.91	80.8	
41398	+28°1008	182	+ 3	B2Ib	7.46	+0.32	0.50	6.0	1.1	···	*f*	2.14	165.0	
40111	139 Tau	184	+ 1	B1Ib	4.83	−0.07	0.15	6.0	0.9	···		0.79	169.3	
37202	ζ Tau	186	− 6	B2IV p	3.03	−0.18	0.06:	5.9	0.2:	neg		1.53	35.8!	Sp. bin. Var? Shell
35468	γ Ori	197	−16	B2III	1.63	−0.21	0.03	5.6	0.1	0.04	*n*	0.20	75.4!	Var.?
46484	+04°1319	207	− 4	B1V	7.74	+0.36	0.62	5.2	0.4	···		1.33	174.9	
47240	BS 2432	207	+ 1	B1Ib	6.15	+0.14	0.36	5.2	1.0	···		1.04	175.6	
37061	−05°1325	209	−15	B1V	6.80	+0.27	0.53	5.2	0.3	···		1.49	66.8!	
37041	θ^2 Ori	209	−19	O9.5V p	5.07	−0.08	0.22:	5.2	0.6	neg		1.01	89.8!	Var.? Sp. bin.
83953	BS 3858	256	+22	B2 pe	4.78	−0.12	···	···	···	···		0.39	175.1	

[a] In the relative distance column, *near* stands for 0.1–0.3 kpc and *far* for 0.6–1.5 kpc.
[b] In the position angle column, an exclamation mark (!) indicates wavelength dependence of position angle.

TABLE VI. Normalized polarizations.

HD	1.06	1.21	1.56	1.93	2.33	2.78	3.03
	Normalized percentage polarization at $1/\lambda=$						
179406	73.5;	74.4;	85.0	102.3	97.7	84.2	83.4
134335	52.0	82.9	90.4	99.1	100.9	80.3	81.8:
134320	69.8	71.6	99.3	98.5	101.5	100.7	129.1:
193237	60.0	69.9	90.0	96.4	103.6	96.6	94.8
216411	57.2	80.2	96.6	101.1	98.9	88.8	81.8
4180	84.5	78.5	102.2	99.5	100.5	96.9	94.4
4768	70.4	78.9	98.5	100.4	99.6	92.7	94.1
7252	73.3	70.9	103.4	100.1	99.9	93.4	83.1
7902	58.8	76.3	97.2	101.0	99.0	90.6	85.5
8965	67.9	74.2	100.8	101.8	98.2	90.4	85.5
10898	61.1	73.4	90.6	103.3	96.7	88.4	86.9
15558	70.7	81.5	101.4	100.9	99.1	88.9	84.9
17506	68.0	73.8	87.7	102.8	97.2	87.0	89.6
25914	69.2	84.9	96.3	101.6	98.4	89.6	81.6
25940	92.4	103.5	109.9	107.7	92.3;	57.7	49.6:
29866	92.8	90.0	102.8	104.6	95.4	84.9	71.2
36371	69.6;	75.4	82.5	102.1	97.9	82.8	81.5
37367	68.8	95.0	120.1:	112.4	87.6	77.0:	71.9:
32990	62.6	76.8	92.0	101.0	99.0	91.3	83.4
32481	78.6;	91.1;	110.0;	98.6	101.4	93.2	77.1;
41398	81.3;	88.6;	107.4;	99.6;	100.4;	74.9;	81.2;
40111	99.9	100.5:	138.4:	102.8	97.2	66.0:	47.5:
37202	···	82.8;	87.5;	97.1;	102.9	70.9	39.6
35468	34.4	64.9	86.4	98.8	101.2	137.9	138.4
46484	66.1;	78.3;	119.6;	103.4;	96.6;	79.3;	···
47240	67.9	81.4	99.8	96.1;	103.9;	67.7;	60.9;
37061	92.4;	113.8;	101.8;	103.0	97.0	85.3	82.1:
37041	113.0;	101.0;	107.0;	103.0	97.0	···	···
83953	82.2:	82.8	71.1	71.5;	128.5:	25.2;	23.3:

TABLE VII. Mean interstellar polarization.[a]

$1/\lambda$	No. of Stars	Mean Norm. Pol.	Average Prob. Error
1.06	52	68%	3%
1.21	49	78	3
1.39	27	96	3
1.56	25	99	2
1.93	52	101	2
2.33	52	98	2
2.78	51	90	3
3.03	50	87	5

[a] All stars of Table X in Paper VIII and of the present Table VI except HD 6675, 24431, 35468, 37041, 37202, 83953, 193443, and 206936.

Belton and Woolf 1965; Serkowski 1965; Rucinski 1966), the irregular red variable μ Cephei (Grigoryan 1959; Coyne and Gehrels 1966; Serkowski 1966), and various Mira type variables (Serkowski 1966).

Tables IX and X list the difference of our observations made during 1966–1967, with those of other observers extending from 1949 to 1965. The second column in each of these tables lists the difference between our observations at $1/\lambda=2.33$ and those of Hall (1958); the third column lists the difference between our observations at $1/\lambda=1.93$ and Hiltner (1956); the

TABLE VIII. Residuals of position angles.

HD[a]	Observed minus mean for each star at $1/\lambda=$ 1.06	1.21	1.56	1.93	2.33	2.78	3.03
179406!	− 6°;	− 2°;	0°	+1°	+2°;	+1;°	+ 4°;
134335	+ 7:	0	+ 1	−2	+1	+2:	− 5
134320	+ 3	− 3	− 1	−4;	+4	0	− 2
193237	+ 1	+ 2	+ 1	−1	−3	−1	+ 1
216411!	− 3	0	− 2	+1	+1	0	+ 3
4180	+ 1	− 2	− 2	0	+1	0	+ 4
4768	+ 7:	− 5:	0	+2	0	0	− 3
7252	+ 4:	+ 1	− 2	−1	0	0	+ 1
7902	0	+ 1	− 1	−1	0	+1	0
8965	− 4	+ 2	0	+1	0	0	+ 1
10898	0	− 1	0	0	0	+1	0
15558!	+ 2	+ 1	− 1	0	+1	−1	− 4:
17506	+ 3	+ 3	− 3	−1	−4	0	+ 1
25914	− 1	− 1	− 1	+2	+2	+1	− 1
25940!	− 1	− 1	− 2	−3;	+1	+3	+ 1
29866	+ 1	− 1	− 1	−2	0	+1	+ 2
36371!	+ 2;	+ 4	+ 6	0	0	−4	− 7
37367	− 1	− 2:	+ 1	+1	−1	+3	− 2;
32990	+ 2	+ 1	− 1	−1:	0	0	− 1
32481	+11;	− 2;	− 1;	−2	0	−6:	+ 3;
41398	− 2;	− 6;	− 2;	+4;	+3;	+5;	− 1;
40111	0:	− 1:	− 1:	+1	0	+6	− 6
37202!	···	− 3;	− 3;	0;	0	+4	+ 2
35468!	0	+ 5	0	+5	+2	−5	− 5
46484	−13;	− 1;	+ 6;	0;	+2;	+4;	···
47240	− 2	+ 2	− 3	−3;	−3;	+5	+ 1;
37061!	− 4;	−10;	− 3;	−1	+1	+2	+ 6
37041!	+14;	+10;	+11;	+2	−4:	−7	−11
83953	0	− 2	+ 2	+8;	−8:	···	···

[a] Stars with exclamation marks (!) show appreciable wavelength dependence of position angles.

TABLE IX. Our percentage polarization minus that of other observers.

HD	Hall 1949–54	Hiltner 1949–54	Behr 1956–58	Serkowski 1960–65
179406	−0.38%	···	···	···
134335	···	···	+0.05%	···
134320	···	···	−0.03	···
193237	+0.26	+0.33%	···	···
216411	−0.06	−0.05	···	+0.02%
4180	−0.01	···	+0.29	···
4768	+0.30	+0.14	···	···
7252	+0.50	+0.05	···	+0.10
7902	(−0.93)	+0.33	···	+0.30
8965	−0.14	+0.16	···	+0.10
10898	(+0.63)	(+0.69)	···	···
15558	−0.10	+0.23	···	+0.02
17506	+0.15	···	···	···
25914	(−0.95)	−0.07	···	−0.16
25940	−0.47	···	−0.21	···
29866	−0.37	···	···	···
36371	−0.44	···	+0.20	+0.06
37367	−0.33	···	···	···
32990	+0.30	···	···	···
32481	+0.01	···	···	···
41398	−0.57	−0.14	···	···
37202	+0.27	···	···	···
40111	−0.47	−0.34	···	···
35468	−0.43	···	+0.03	···
46484	−0.17	−0.09	···	···
47240	−0.44	−0.06	···	···
37061	+0.01	···	···	···
37041	+0.28	···	···	···
83953	−0.20	···	···	···
Syst. Diff.	−0.10	+0.04	+0.06	+0.09
Mean Res.	0.28	0.17	0.14	0.11

fourth column gives the difference between the weighted means of our observations at $1/\lambda=1.93$ and $1/\lambda=2.33$ with those of Behr (1956); and the last column gives the average of the differences between our observations at $1/\lambda=1.93$, 2.33, and 2.78 with Serkowski's green, blue, and ultraviolet filters, respectively. The Serkowski observations were supplied to us directly by the author, corrections being applied in the same way as described in Sec. III of Paper VIII (see references there). At the bottom of each table the systematic difference is the straight average, and the mean residual the average of the absolute value, of the residuals exclusive of those in parentheses.

In Table X, with the exception of HD 35468 there are no significant residuals. Large residuals in Table IX for HD 7902, 10898, and 25914 may indicate variations in percentage of polarization. All three of these stars have large polarizations (greater than 3%) and they are relatively distant.

We now discuss the polarimetric observations of the B2III star, γ Orionis (HD 35468). In Table X, the residuals of the position angle in both the Hall and Behr columns are remarkably large (of the order of 50°) and similar. Our determination of θ is the result of measurements at seven independent wavelengths made on three different nights (see Table II). The largest probable error for the combined value at a single wavelength is ±1.9°. For a total of ten other stars observed on three different nights on which we observed γ Orionis the mean absolute residual in position angle, Coyne-Hall, is ±4°. It appears that either the plane of polarization of γ Orionis has rotated or that we or Hall and Behr are in error by some 50° for γ Orionis. There also appears to be a dependence of θ on wavelength (see Table VIII) and a monotonically increasing polarization with decreasing wavelength [see Tables III and VI, and Fig. 3(c)]. Although the percentage of polarization is small with a maximum of 0.3% at $1/\lambda=3.03$, the average probable error of the combined observations from two different nights is also small, ±0.01%. The remarkable wavelength dependence of the percentage of polarization depicted in Fig. 3(c), which suggests a small mean particle size for the scatterer, as well as the indications of a rotation of the plane of polarization with wavelength and time, suggest γ Orionis as a candidate for more detailed observations, especially in the far ultraviolet.

For the spectroscopic binary and shell star, ζ Tau (HD 37202) we find no change in the percentage

TABLE X. Our position angle minus that of other observers.

HD	Hall 1949–54	Hiltner 1949–54	Behr 1956–58	Serkowski 1960–65
179406	− 1°	…	…	…
134335	…	…	+ 4°	…
134320	…	…	+ 6	…
193237	+ 9	+ 2°	…	…
216411	+ 2	+ 4	…	+ 3°
4180	0	…	+ 1	…
4768	− 2	− 4	…	…
7252	− 1	− 1	…	0
7902	− 1	0	…	0
8965	+ 1	+ 2	…	− 1
10898	− 3	− 1	…	…
15558	− 1	0	…	…
17506	− 4	…	…	…
25914	+ 1	− 3	…	…
25940	− 2	…	− 1	…
29866	+ 5	…	…	…
36371	0	…	+ 2	0
37367	+10	…	…	…
32990	− 3	…	…	…
32481	+ 6	…	…	…
41398	− 1	+ 2	…	…
40111	− 8	+ 6	…	…
37202	+13	…	…	…
35468	(+56)	…	(+46)	…
46484	+11	+11	…	…
47240	+ 1	+ 2	…	…
37061	+ 2	…	…	…
37041	−16	…	…	…
83953	− 1	…	…	…
Syst. Diff.	+ 0.7	+ 1.5	+ 2.4	+ 0.4
Mean Res.	4.0	2.9	2.8	+ 0.8

polarization between 1964 and 1967. There is, however, a change in the position angle. The mean angle for the 1964–65 observation is 26°.8; for the 1967 observations it is 35°.8. For both epochs there appears to be a rotation of position angle with wavelength of the order of 5° to 10°. The rotation, however, is in the opposite sense for the two epochs, such that the difference in the position angle at $1/\lambda=3.03$ between the two epochs is 20°.

We have checked the internal consistency of the position angles for both the 1964–65 and the 1967 observations by intercomparisons of observations on other stars and planets observed on the different nights during each of the two observing runs when HD 37202 was observed. There appear to be no systematic effects.

In Table II, in addition to HD 35468 and HD 37202 for five other stars suspected of variability in polarization the individual observations are given. Four of these stars are spectroscopic binaries. HD 10516 (φ Persei) is of particular interest since its period is 127 days and the variations in the percentage polarization are of the order of 0.2%±0.02 occurring over a period of about 4 months. Furthermore, there is a rotation of the plane of polarization with wavelength of the order of 30°. Likewise HD 37041 (θ^2 Orionis), a spectroscopic binary with a period of 21 days, has a variation in the ultraviolet polarization of 0.5%±0.04 and a rotation of the plane of polarization with wavelength of the order of 20°.

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