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THE HUBBLE SPACE TELESCOPE NORTHERN-HEMISPHERE GRID OF STELLAR POLARIMETRIC STANDARDS

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ABSTRACT

Results are presented from a comprehensive program of optical polarimetry of strongly polarized and null-polarization standard stars. Potential sources of systematic error either instrumental in origin or due to absolute calibration are critically discussed. Although the project emphasized the requirements of a spaceborne optical-UV observatory (*HST*), the resulting grid of standards represents a distinct improvement over previous such tabulations and offers an opportunity to reference future multiwavelength polarimetry to a common system.

1. INTRODUCTION

In the years prior to launch of the Hubble Space Telescope (*HST*), the Space Telescope Science Institute (STScI) sponsored several programs aimed at obtaining uniformly complete and accurate photometry, spectrophotometry, and polarimetry of a variety of celestial targets for in-flight calibration of the science instruments. Bohlin *et al.* (1990; see also internal STScI publications referenced therein) describe the goals of the project, present an atlas of targets, and summarize preliminary results. The capabilities and calibration methodology for the polarimetric modes of the observatory are discussed in particular by Lupie & Stockman (1988). In this paper we present the complete calibration results for the stellar targets of the northern-hemisphere portion of the polarimetric program.

2. OBSERVATIONS

The fundamental objectives of the project were (1) to establish a grid of strongly polarized, nonvariable standards to serve as calibrators for the degree and position angle of polarization, and (2) to identify a sample of null targets for verification of polarimetric purity (i.e., the absence of instrumental polarization). Because UV polarization standards have not yet been established, the target list emphasized hot stars with polarization histories and reasonably well-understood polarizing mechanisms. When possible, objects were incorporated from other HST calibration lists. The fact that several bright targets are also common to the standard list of the Wisconsin Ultraviolet Photo-Polarimeter Experiment will permit cross-calibration with another UV-sensitive orbiting observatory.

The database consists of ground-based linear polarimetry in standard photometric bandpasses. Northern-hemisphere observations were made with the Two-Holer polarimeter/photometer constructed by G.D.S. at the University of Minnesota (the southern-hemisphere program, to be reported elsewhere, was carried out by S. Tapia using the similar Minipol polarimeter). Two-Holer is an aperture polarimeter with rapid modulation (~ 80 Hz) provided by a rotating achromatic half-wave retarder and Wollaston prism polarizing beamsplitter. The complementary polarized beams are detected with RCA GaAs photomultipliers operating in pulse-counting mode and recorded at 1 ms intervals by the instrument computer. Acquisition and guiding are accomplished with an intensified TV viewing the sky surrounding the circular entrance aperture.

The observations were obtained in eight observing runs scattered throughout the period 30 Oct. 1985–16 Nov. 1987. The majority of the work utilized the Mt. Lemmon 1.5 m telescope of the University of Minnesota/University of California, San Diego, however the 2.3 m reflector of Steward Observatory was required to gain access to sources above $\delta = +60°$. Measurements were obtained in standard Johnson UBV filter bandpasses plus a near-UV "*N*" band which served as a final ground-based point of reference for extrapolation into the space-UV. The latter, defined by a Hoya U-340 plus crystalline $CuSO_4$ blocking filter, yields a bandpass of full width at half maximum (FWHM) ≈ 650 Å and $\lambda_{\rm eff} \approx 3450$. Strongly polarized stellar targets were also observed in Kron–Cousins *R* and *I* bandpasses to provide adequate spectral baselines for fits of the observed $P(\lambda)$ to analytic interstellar relations.

2.1 Absolute Calibration

Rapid polarimetric modulation ensures that the statistical quality of the data approaches that due to the photon counts alone. For Two-Holer, this has been verified on numerous occasions during our long experience with the

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instrument (e.g., Moore *et al.* 1987). The uncertainty in the degree of polarization is then

$$\sigma_P(\%) \approx 100\sqrt{2/N}, \tag{1}$$

where N is the total number of detected photons. In addition, when $P \gg \sigma_P$,

$$\sigma_\theta(^\circ) \approx 28.65\sigma_P/P. \tag{2}$$

Of particular importance for a calibration program are systematic sources of error. The wavelength-dependent polarimetric efficiency of the instrument was measured each run by means of observations of stars through a Glan–Thompson prism placed ahead of the entrance aperture. Such a prism is an effective linear polarizer to ~ 1 part in 10^4 over the entire range of sensitivity of the instrument, and for moderately polarized objects a simple division by the appropriate efficiency factor is a suitable calibration to a precision of better than 0.05% absolute.

The all-sky nature of the program precluded the use of a single primary standard for position angle reference; moreover, errors would be introduced into the database that were star polarimetrically variable. Thus, throughout the project, all data were recorded as instrumental position angles. During the final analysis, the relative offsets between various epochs were determined by subjecting the large number of multiple V-band observations of the polarized targets to a least-squares analysis which minimized the position angle variance summed over all of the stars. This procedure resulted in a self-consistent calibration of the entire list, and at the same time avoided the accumulation of errors which ensues from a simple "bootstrap" technique. Moreover, the variability of a given star relative to the ensemble was evident in the χ^2_ν indices of its multiple measurements, enabling the process to be iterated with suspected variables discarded. In fact, only one star, HD236633, was sufficiently discrepant that it was omitted from the final analysis.

The fundamental link between measured position angles and the equatorial coordinate system was established by observations of scattered moonlight during one run. Since the polarization produced by Rayleigh scattering is accurately orthogonal to the scattering plane, the true position angle of polarization was known to a precision determined primarily by the uncertainty of centroiding on the gibbous moon (in this case, $\sigma_\theta = 0\overset{\circ}{.}2$). Offsets were made both toward and away from zenith to gauge the effect of contamination by scattered city lights.

2.2 Instrumental Polarization

The use of complementary detector channels effectively cancels instrumental components introduced at or behind the rotating waveplate. Stokes parameter (Q vs U) plots of our many observations of the unpolarized targets revealed no systematic clustering of the data points at the level of 0.03% (1σ), though a few individual stars are clearly polarized at the 0.1%–0.2% level. This essentially rules out significant components arising in either the telescope or instrument, and is the only test for the polarimetric purity of a telescope with a nonrotatable tube. Nevertheless, as further insurance against instrumental sources, each of the null-polarization targets was measured *twice* in each waveband, the two observations being made in orthogonal orientations of the polarimeter on the tailpiece of the telescope. A component of polarization which arises within the instrument itself is canceled when the data are appropriately combined.

Considering all possible sources of instrumental polarization and calibration error, we are confident that the results presented here for the polarized targets achieve the program goal of $\sigma_P = 0.05\%$–0.10% absolute and that systematic errors in the quoted position angles amount to no more than $0\overset{\circ}{.}7$ ($\sim 3\sigma$ confidence). The special precautions noted above for the unpolarized targets serve to reduce any systematic components in polarization for these stars to $\lesssim 0.03\%$ absolute, comparable to the statistical uncertainties of the measurements.

Note that in the following tabulations all values are quoted *as measured*, i.e., without correction for the statistical bias which affects polarimetry at small values of polarimetric signal-to-noise ratio, P/σ_P (e.g., Wardle & Kronberg 1974; Simmons & Stewart 1985). This convention permits straightforward Q–U analysis of the data, if desired. A bias correction is completely insignificant for the strongly polarized targets, whose entries individually have P/σ_P of $\sim$100:1. Uncertainties in position angle are not well-defined for the unpolarized targets, and thus are not quoted.

3. RESULTS

Polarimetry of the *HST* stellar targets accessible from the northern hemisphere is presented in Tables 1 through 3. Table 1 contains for the polarized stars: name, V magnitude and spectral type in the first column, followed by the coordinates (epoch 2000, as tabulated by Bohlin *et al.* or precessed from SAO catalog coordinates), waveband, mean degree of polarization and 1σ statistical uncertainty, and mean position angle of polarization and 1σ uncertainty. The final column denotes the number of epochs each star was observed and evidence for variability, if appropriate. We include as Table 2 an assortment of measurements of other commonly-used "standard" stars which were observed during the same runs and are referenced to the *HST* system. Each of the latter objects was observed at most once in a given waveband. Results for the *HST* unpolarized target list are presented in a similar format in Table 3.

3.1 Polarized Targets

Where possible, multiple V-band measurements of each of the polarized targets were obtained to assess any variability which may be present. Such variability could result from intrinsic polarization in the stellar photosphere or the motion of intervening interstellar clouds across our line of sight. As shown in the final column of Table 1, objects were generally observed on three or four occasions, however stars above the $\delta = +60^\circ$ limit of the Mt. Lemmon tele-

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TABLE 1. *HST* polarized standard targets.

Name/V/SpT	α	δ (2000)	λ	P (%)	σ_P	θ (°)	σ_θ	N,Var?[a]
BD+64°106	00 57	36.71	N	—	—	—	—	
10.34	+64 51	26.5	U	5.110	± .104	97.04	± .58	
B1V			B	5.506	± .090	97.15	± .47	
			V	5.687	± .037	96.63	± .18	2
			R	5.150	± .098	96.74	± .54	
			I	4.696	± .052	96.89	± .32	
HD236633	01 09	12.27	N	5.150	± .046	91.98	± .26	
9.2	+60 37	41.5	U	5.236	± .050	92.52	± .27	
B0III			B	5.532	± .040	92.53	± .21	
			V	5.485	± .016	93.76	± .08	4,VAR
			R	5.376	± .028	93.04	± .15	
			I	4.805	± .036	93.14	± .21	
HD7927	01 20	04.88	N	2.914	± .035	92.70	± .35	
4.95	+58 13	54.1	U	2.962	± .078	93.65	± .76	
F0Ia			B	3.234	± .049	91.43	± .43	
			V	3.298	± .025	91.08	± .22	4,var
			R	3.026	± .037	90.84	± .35	
			I	2.777	± .029	90.10	± .31	
BD+59°389	02 02	42.06	N	5.525	± .098	98.78	± .51	
9.07	+60 15	26.5	U	5.772	± .051	98.22	± .26	
F0Ib			B	6.345	± .035	98.14	± .16	
			V	6.701	± .015	98.09	± .07	4
			R	6.430	± .022	98.14	± .10	
			I	5.797	± .023	98.26	± .11	
HD19820	03 14	05.35	N	4.085	± .021	115.39	± .15	
7.11	+59 33	47.7	U	4.218	± .022	115.57	± .15	
O9IV			B	4.699	± .036	115.70	± .22	
			V	4.787	± .028	114.93	± .17	3
			R	4.526	± .025	114.46	± .16	
			I	4.081	± .024	114.48	± .17	
HD25443	04 06	08.07	N	—	—	—	—	
6.78	+62 06	07.0	U	4.930	± .062	134.55	± .36	
B0III			B	5.232	± .092	134.28	± .51	
			V	5.127	± .061	134.23	± .34	1
			R	4.734	± .045	133.65	± .28	
			I	4.249	± .041	134.21	± .28	
HD154445	17 05	32.24	N	2.899	± .090	87.34	± .89	
5.61	−00 53	31.7	U	3.144	± .102	87.91	± .92	
B1V			B	3.445	± .047	88.88	± .39	
			V	3.780	± .062	88.79	± .47	2
			R	3.683	± .072	88.91	± .56	
			I	3.246	± .078	89.91	± .69	
HD155197	17 10	15.69	N	3.317	± .091	103.88	± .78	
9.2	−04 50	03.1	U	3.559	± .114	102.94	± .91	
A0			B	4.112	± .047	103.06	± .33	
			V	4.320	± .023	102.84	± .15	3,VAR
			R	4.274	± .027	102.88	± .18	
			I	3.906	± .041	103.18	± .30	
HD161056	17 43	47.03	N	2.909	± .041	66.59	± .41	
6.32	−07 04	46.2	U	3.191	± .040	66.50	± .51	
B1.5V			B	3.799	± .055	66.56	± .42	
			V	4.030	± .025	66.93	± .18	3
			R	4.012	± .032	67.33	± .23	
			I	3.575	± .030	67.78	± .24	
Hiltner 960	20 23	28.44	N	5.207	± .095	56.85	± .52	
10.6	+39 20	56.1	U	5.459	± .078	56.13	± .41	
B0V			B	5.720	± .061	55.06	± .31	
			V	5.663	± .021	54.79	± .11	5,var
			R	5.210	± .029	54.54	± .16	
			I	4.455	± .030	53.96	± .19	
HD204827	21 28	57.70	N	5.473	± .035	57.62	± .18	
7.93	+58 44	24.0	U	5.548	± .037	57.57	± .20	
B0V			B	5.648	± .022	58.20	± .11	
			V	5.322	± .014	58.73	± .08	4
			R	4.893	± .029	59.10	± .17	
			I	4.186	± .030	59.94	± .20	

[a] Number of observations and evidence for variability, if any. var = $\delta P \lesssim 0.05\%$, $\delta\theta \lesssim 0.5°$; VAR = $\delta P \gtrsim 0.05\%$, $\delta\theta \gtrsim 0.5°$.

scope are more poorly characterized. Evidence for variability was quantified by a χ^2 analysis of the calibrated results (strictly, the test should be applied to the normal variables Q and U, but with values of P/σ_P as large as they are here, P and θ are equivalent). Stars are characterized as probable variables ("var": $\delta P \lesssim 0.05\%$, $\delta\theta \lesssim 0.5°$), or definite variables ("VAR": $\delta P \gtrsim 0.05\%$, $\delta\theta \gtrsim 0.5°$). The two certain cases are HD236633 and HD155197; the former exhibits $\delta P \approx 0.15\%$ and both show fluctuations in position angle of $\delta\theta \approx 1°$. Two additional targets, Hiltner 960 and HD7927 (Φ Cas), fall in the "probable" classification. Variability of the latter star was also found by Bastien *et al.* (1987) and Dolan & Tapia (1986). Strong variability of another of our standard targets, HD25443, was noted by Bastien *et al.*; our coverage was restricted to just one epoch due to its large declination.

Meaningful extrapolation of the ground-based polarimetry into the space-UV demands special care in characterizing the spectral dependence of polarization. Accordingly, the effective wavelength of each filter band was determined on a star-by-star basis by convolving the photon spectrum of the appropriate spectral type (Gunn & Stryker 1983) with a mean atmospheric transmission function and with measured curves for the filter transmission and photomultiplier response. The resulting spectrum of broad-band $P(\lambda)$ was then fit by least-squares to the empirical relation

TABLE 2. Additional commonly-used polarized standards referenced to the *HST* system.

Name/V/SpT	α	δ (2000)	λ	P (%)	σ_P	θ (°)	σ_θ
HD236954	02 13	37.30	U	5.790	± .099	111.20	± .49
9.4	+59 10	15.2	B	—	—	—	—
B3			V	—	—	—	—
			R	—	—	—	—
HD245310	05 36	22.91	U	3.495	± .056	147.61	± .46
9.10	+21 11	10.9	B	4.550	± .064	145.97	± .40
B0			V	—	—	—	—
			R	—	—	—	—
HD155528	17 12	19.87	U	—	—	—	—
8.7	−04 24	08.9	B	4.612	± .038	91.24	± .24
B8			V	4.986	± .064	92.61	± .37
			R	—	—	—	—
HD183143	19 27	26.47	U	4.951	± .068	178.51	± .39
6.9	+18 17	45.5	B	—	—	—	—
B7Ia			V	—	—	—	—
			R	—	—	—	—
VI Cyg #12	20 32	40.94	U	—	—	—	—
11.5	+41 14	26.2	B	—	—	—	—
B5Ia			V	8.947	± .088	115.03	± .28
			R	7.893	± .037	116.23	± .14

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TABLE 3. *HST* unpolarized standard targets.

Name/V/SpT	$\frac{\alpha}{\delta}$ (2000)	λ	P (%)		σ_P	$\theta(°)$
β Cas	00 09 10.72	N	.049	±	.023	98.84
2.27	+59 08 59.1	U	.049	±	.026	92.91
F2III		B	.015	±	.027	113.86
		V	.037	±	.024	72.51
HD12021	01 57 56.11	N	.054	±	.029	24.01
8.86	−02 05 58.2	U	.128	±	.028	5.88
B7		B	.112	±	.025	169.24
		V	.078	±	.018	160.10
HD14069	02 16 45.16	N	.088	±	.037	22.27
9.00	+07 41 11.1	U	.083	±	.041	172.31
A0		B	.111	±	.036	93.62
		V	.022	±	.019	156.57
ξ^2 Cet	02 28 09.53	N	.086	±	.043	27.70
4.29	+08 27 36.3	U	.092	±	.033	49.07
B9III		B	.092	±	.024	41.56
		V	.085	±	.024	114.40
HD21447	03 30 00.21	N	.070	±	.035	92.85
5.10	+55 27 07.0	U	.042	±	.039	122.94
A1IV		B	.017	±	.030	28.63
		V	.051	±	.020	171.49
G191B2B	05 05 30.62	N	—		—	—
11.78	+52 49 54.0	U	.065	±	.038	91.75
DA1		B	.090	±	.048	156.82
		V	.061	±	.038	147.65
β Tau	05 26 17.52	N	.058	±	.024	35.94
1.62	+28 36 26.7	U	.227	±	.024	159.11
B7III		B	.073	±	.025	109.14
		V	.051	±	.024	52.98
γ Gem	06 37 42.73	N	.039	±	.026	37.63
1.92	+16 23 57.3	U	.062	±	.015	152.23
A0V		B	.076	±	.020	4.92
		V	.039	±	.017	65.94
θ UMa	09 32 51.41	N	.050	±	.020	105.57
3.18	+51 40 38.4	U	.032	±	.027	71.93
F6IV		B	.072	±	.015	118.48
		V	.037	±	.014	30.32
β UMa	11 01 50.47	N	.046	±	.018	97.62
2.37	+56 22 56.6	U	.052	±	.013	91.64
A1V		B	.023	±	.017	53.83
		V	.009	±	.019	107.76
GD319	12 50 04.49	N	—		—	—
12.32	+55 06 02.5	U	.065	±	.033	131.92
DA		B	.045	±	.047	142.79
		V	.089	±	.093	140.15
γ Boo	14 32 04.68	N	.047	±	.021	112.92
3.02	+38 18 29.7	U	.016	±	.016	71.22
A7III		B	.002	±	.018	45.00
		V	.065	±	.019	21.26
BD+33°2642	15 51 59.86	N	.208	±	.031	176.69
10.84	+32 56 54.8	U	.162	±	.030	21.38
B2IV		B	.145	±	.029	29.69
		V	.231	±	.031	12.67
BD+32°3739	20 12 02.11	N	.048	±	.028	37.11
9.31	+32 47 43.5	U	.073	±	.032	162.50
A6V		B	.039	±	.021	79.38
		V	.025	±	.017	35.79
BD+28°4211	21 51 11.07	N	.041	±	.031	38.66
10.53	+28 51 51.8	U	.067	±	.023	135.00
Op		B	.063	±	.023	30.30
		V	.054	±	.027	54.22
HD212311	22 21 58.55	N	.065	±	.025	170.08
8.10	+56 31 52.8	U	.033	±	.026	121.32
A0V		B	.028	±	.025	86.95
		V	.034	±	.021	50.99
ζ Peg	22 41 27.74	N	.037	±	.040	141.26
3.40	+10 49 52.9	U	.033	±	.031	13.68
B8III		B	.028	±	.019	116.15
		V	.045	±	.019	39.85

for interstellar polarization derived by Wilking *et al.* (1982):

$$P(\lambda)/P(\lambda_{\max})=\exp\{-[-0.010 +1.86\times 10^{-4}\lambda_{\max}]\ln^2(\lambda_{\max}/\lambda)\}, \quad (3)$$

TABLE 4. Fits of the polarized targets to interstellar relations.

Name	$P_{\max}$[a] (%)	$\lambda_{\max}$[a] (Å)	$\chi^2_{\nu,P}$	θ_{5500}[b] (°)	$\delta\theta/\delta\lambda$[b] (°/Å)	$\chi^2_{\nu,\theta}$
BD +64°106	5.67	5009	3.7	96.76	-1.12×10^{-5}	0.5
HD236633	5.62	4950	11.3	93.31	2.06×10^{-4}	17.6
HD7927	3.29	5109	2.3	91.34	-5.64×10^{-4}	1.5
BD +59°389	6.67	5451	3.6	98.13	2.58×10^{-5}	0.8
HD19820	4.76	5235	3.4	114.98	-2.69×10^{-4}	2.1
HD25443	5.20	4718	1.9	134.17	-9.10×10^{-5}	1.2
HD154445	3.72	5669	0.8	88.88	3.38×10^{-4}	0.6
HD155197	4.34	5746	1.5	102.93	5.11×10^{-6}	0.7
HD161056	4.01	5877	6.3	66.99	3.01×10^{-4}	6.3
Hiltner 960	5.77	4535	9.1	54.92	-4.30×10^{-4}	1.9
HD204827	5.64	4138	2.0	58.69	5.02×10^{-4}	0.5

[a] Coefficients of fits of $P(\lambda)$ to the interstellar relation of Wilking, Lebofsky, & Rieke (1982).

[b] Coefficients of linear fits to $\theta(\lambda)$. Values of $\delta\theta/\delta\lambda \gtrsim 10^{-4}$ represent significant rotations of position angle with wavelength.

with λ in Ångstrom units. Coefficients of these fits are contained in Table 4. Also tabulated are the coefficients of a first-order fit to $\theta(\lambda)$, parametrized as

$$\theta(\lambda)=\theta_{5500}+\delta\theta/\delta\lambda(\lambda-5500). \quad (4)$$

Uncertainties in the fits described by Eq. (3) are typically $\sim$0.02% and $\sim$50 Å for $P_{\max}$ and $\lambda_{\max}$, respectively, while values of $\delta\theta/\delta\lambda \gtrsim 10^{-4}$ (°/Å) in Eq. (4) represent significant rotations with wavelength. Some feeling for the simplicity of the polarizing mechanism(s), and thus the reliability of a particular extrapolation, can be gained from the χ^2_ν indices for each fit. For example, the multiplicity of polarizing sources suggested by the variability of HD236633 and Hiltner 960 is supported by unusually large $\chi^2_{\nu,P}$, $\chi^2_{\nu,\theta}$.

Finally, we summarize in the first column of Table 5 those targets which, on the basis of this program, are best suited to serve as strongly-polarized standards. Each of the objects listed showed no evidence of polarimetric variability to a limit of $\delta P \approx 0.05\%$; $\delta\theta \approx 0.05°$ in data obtained at a minimum of three epochs during the two year period of the program.

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TABLE 5. Recommended polarized and unpolarized standards from the *HST* target list.

Polarized Stars	Unpolarized Stars
BD+59°389	β Cas
HD19820	HD21447
HD161056	β UMa
HD204827	γ Boo
	BD+32°3739
	HD212311
	ζ Peg

3.2 Unpolarized Targets

The *HST* unpolarized target list includes an assortment of very nearby giants and main-sequence stars of intermediate to early spectral type, hot white dwarfs not known to be magnetic, and a few stars from the list of spectrophotometric standard targets. In the broad spectral bands of the polarimeter, objects brighter than $V \approx 6$ produced sufficiently high photon rates that attenuation was required to prevent damage to the photomultipliers. A variety of techniques of reducing the photon flux without producing polarization were investigated; the method finally adopted was to attach a mask containing ~50 small drilled holes to the top of the Cassegrain baffle tube in the converging beam from the secondary. The mask had the effects of introducing ~5 mags of attenuation and of substantially increasing the image size due to diffraction at the small holes. Observations of moderately bright stars both with and without the mask as well as in various orientations on the baffle tube confirmed that the procedure was polarimetrically clean to a level of ~0.03%.

A few of the null-polarization targets were, in fact, found to be significantly polarized. These are generally the fainter (more distant) objects: HD12021 with $P \approx 0.08\%$; $\theta \approx 170°$, GD319 with $P \approx 0.06\%$; $\theta \approx 135°$, and especially BD+33°2642 with $P \approx 0.17\%$; $\theta \approx 15°$. β Tau and ξ^2 Cet each exhibit a single discrepant filter band with polarization at the 0.1%–0.2% level. Although such behavior does not have a ready astrophysical explanation, the values persist even after combining data from the two orthogonal orientations of the polarimeter, and thus appear not be be instrumental in origin.

The prime null polarization calibrators to emerge from the program are tabulated in the second column of Table 5. These stars range in apparent magnitude from $V = 2.3–11.8$ and show no evidence for significant polarization above the 0.05% level. Of course, additional stars from Table 3 could be used as null standards if it is assumed that their significant polarizations are stable, and appropriate corrections are made.

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REFERENCES

Bastien, P., Drissen, L., Menard, F., Moffat, A. F. J., Robert, C., & St-Louis, N. 1988, AJ, 95, 900
Bohlin, R. C., Turnshek, D. A., Williamson, R. L., Lupie, O. L., Koornneef, J., & Morgan, D. H. 1990, AJ, 99, 1243
Dolan, J. F., & Tapia, S. 1986, PASP, 98, 792
Gunn, J. E., & Stryker, L. L. 1983, ApJS, 52, 121
Lupie, O. L., & Stockman, H. S. 1988, in Polarized Radiation of Circumstellar Origin, edited by C. V. Coyne *et al.* (Vatican Observatory, Vatican City State), pp. 705–723
Moore, R. L., Schmidt, G. D., & West, S. C. 1987, ApJ, 314, 176
Simmons, J. F. L., & Stewart, B. G. 1985, A&A, 142, 100
Wardle, J. F. C., & Kronberg, P. P. 1974, ApJ, 194, 249
Wilking, B. A., Lebofsky, M. J., & Rieke, G. H. 1982 AJ, 87, 695

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