

studies, we compared the location of candidate Be stars in the published finder charts to the location of their proposed matches in our polarimetric images.

The polarimetry of these candidate Be stars was then painstakingly checked for contamination and other unwanted effects with two different techniques. The PC-CDPACK task *graf* plotted the least squares solution of the photometry in the 8 wave-plate positions as well as the expected  $\cos 4\psi_i$  curve (see Figure 2-7). Large deviations from the expected curve indicated: a) the data was of low SNR quality, b) likely contamination events, c) nearby cosmic ray hits, and/or d) nearby uncorrected bad pixels. The images were examined with *imexamine* to determine which of the above scenarios were the cause of large deviations. In the event that scenario b, c, or d were the cause, the problem was sometimes resolved by using a smaller aperture, with the lower limit of an acceptable aperture size being the FWHM of the image. These smaller apertures had higher errors than the most optimal aperture size identified by *macrol*; however, in my opinion, the greater reliability these smaller apertures afforded outweighed the benefit of using apertures with slightly lower errors. On rare occasions, the cause of large deviations was scenario c or d **and** the locations of these bad pixels were inside of the FWHM. In these situations, I explored using fewer wave-plate positions to determine the polarization solution. For example, if a cosmic ray hit occurred nearby a star in the 6th wave-plate position image, the star's polarization was re-calculated using only wave-plate positions 1-5. Note that one technically only needs three wave-plate positions to derive self-consistent polarization measurements and errors, while the use of two wave-plate positions will generate polarization measurements without the generation of accurate errors. Thus our occasional use of fewer than 8 wave-plate positions should not skew any of our results.

The second contamination check involved using the PCCDPACK task *checkcen*, which plotted the radial profile of the ordinary and extra-ordinary image of a specific star in all 8 wave-plate positions. The task allowed one to a) ensure that the same ordinary and extra-ordinary stars were being used to calculate the polarization of a target (in very crowded regions, this requirement was sometimes violated) and b) ensure that no significant contamination from neighboring stars occurred within the optimal aperture size. If this latter type of contamination was found, the polarization measurement from a smaller acceptable aperture was used instead. I adopted this strategy as I believe that using data of higher reliability was more beneficial than using data with lower relative photon noise, which might be somewhat unreliable.

### 2.2.3 Polarimetric Standard Stars

Observations of both unpolarized and polarized standard stars were made on a nightly basis during both our 2001 and 2002 observing runs. A summary of our observations is presented in Table 2.6 and 2.7, while a summary of literature data for these targets is presented in Table 2.8.

Observations of unpolarized standard stars were made to determine the instrumental polarization of the polarimeter. A non-trivial difficulty we encountered was a lack of published data on suitable, faint southern hemisphere unpolarized standard stars;

Table 2.6 2001 Polarization Standards

Target Name	Filter	Ave. %P	Ave. %Err	Ave. PA	N obs
BD 25727	U	4.748	0.041	31.0	1
	B	5.757	0.027	21.5	2
	V	6.321	0.012	15.6	6
	R	6.189	0.038	18.1	1
	I	5.354	0.025	23.7	1
HD 298383	U	3.729	0.025	144.5	2
	B	4.685	0.025	135.8	2
	V	5.329	0.019	130.2	7
	R	5.124	0.017	133.0	2
	I	4.596	0.080	138.8	1
HD 251204	B	4.951	0.027	135.5	1
	R	4.270	0.045	144.5	1
HD 9540	U	0.059	0.031	124.3	2
HIP 21556	B	0.069	0.073	35.3	1
	V	0.048	0.018	12.1	2
	R	0.059	0.039	119.2	1
	I	0.028	0.079	0.5	1

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Note. — Summary of polarization and unpolarized standard stars observed during the 2001 CTIO 1.5m run. Data were combined using a  $1/\sigma^2$  weighting technique.

Table 2.7 2002 Polarization Standards

Target Name	Filter	Ave. %P	Ave. %Err	Ave. PA	N obs
BD 25727	U	4.670	0.048	119.6	1
	B	5.669	0.036	111.3	1
	V	6.283	0.037	105.1	2
	R	6.179	0.033	107.3	1
	I	5.480	0.037	112.8	1
HD 298383	U	3.694	0.031	54.5	2
	B	4.595	0.022	45.8	3
	V	5.255	0.017	40.2	9
	R	5.169	0.025	43.4	3
	I	4.543	0.034	48.6	3
HD 155197	B	4.005	0.025	3.0	2
	V	4.343	0.015	176.1	7
	R	4.247	0.036	178.0	1
	I	3.660	0.056	3.8	1
HD 9540	U	0.102	0.018	168.2	3
	B	0.057	0.020	168.9	3
	V	0.036	0.018	100.1	2
HIP 21556	U	0.261	0.111	172.0	1
	B	0.043	0.052	92.8	1
	V	0.066	0.022	158.1	3
	R	0.044	0.021	15.0	3
	I	0.024	0.020	49.8	2

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Note. — Summary of polarization and unpolarized standard stars observed during 2002 CTIO 1.5m run. Data were combined using a  $1/\sigma^2$  weighting technique.

Table 2.8 Literature Polarization Standards

Target Name	Filter	Ave. %P	Ave. %Err	Ave. PA	N obs	Ref.
BD 25727	V	6.434	0.026	29.7	1	HC
	R	6.124	0.011	29.7	1	HC
	I	5.454	0.009	29.7	1	HC
HD 298383	U	4.027	0.028	147.96	12	T
	B	4.846	0.013	147.94	8	T
	V	5.233	0.009	148.61	12	T
	R	5.163	0.011	148.67	9	T
	I	4.700	0.056	148.61	2	T
HD 155197	B	4.112	0.047	103.06	3	S
	V	4.320	0.023	102.84	3	S
	R	4.274	0.027	102.88	3	S
	I	3.906	0.041	103.18	3	S
HD 251204	B	4.464	0.046	154.8	1	HR,W
	R	4.784	0.026	152.9	2	HR,W,HC

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Note. — Summary of literature polarization data for polarized and unpolarized standards observed in this study. T denotes Tapia (1988) , S denotes Schulte-Ladbeck et al. (1992) , W denotes Weitenbeck (1999), HR denotes HPOL Reticon data, and HC denotes HPOL CCD data.

Table 2.9 Instrumental Polarization Corrections

Target Name	Filter	2001		2002	
		Rotation	Pol. Eff.	Rotation	Pol. Eff.
HD 298383	U	3.5	0.93	3.5	0.92
	B	12.1	0.97	12.1	0.95
	V	18.4	1.02	18.4	1.0
	R	15.7	0.99	15.3	1.0
	I	9.8	0.98	10.0	0.97
HD 155197	B	...	...	10.1	0.97
	V	...	...	16.7	1.0
	R	...	...	14.9	0.99
	I	...	...	9.4	0.94
BD 25727	U	1.3**		0.1**	
	B	8.2**		8.4**	
	V	14.1	0.98	14.6	0.98
	R	11.6	1.01	12.4	1.0
	I	6.0	0.98	6.9	1.0
HD 251204	B	19.3	1.11	...	...
	R	8.4	0.89	...	...
Final Cal.	U	3.5	0.93	3.5	0.92
Final Cal.	B	12.1	0.97	11.1	0.96
Final Cal.	V	18.4	1.0	17.6	1.0
Final Cal.	R	15.7	0.99	15.1	1.0
Final Cal.	I	9.8	0.98	9.7	0.96

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Note. — Using the given literature polarization information for polarization standard stars, we calculate the instrumental PA rotation and polarimetric efficiency for each filter of each standard. The calcite block was installed in a different orientation in the filter wheel for the 2002 run, compared to the 2001 run, resulting in a systematic PA shift of  $90^\circ$  present in all 2002 data. We have subtracted this effect from the 2002 data presented above, in order to better demonstrate the consistency of the 2001 and 2002 data. \*\* denotes an extrapolated result, from nearby filters, under the assumption that the polarization standard has no PA rotation with wavelength. The final calibration for 2001 is based only on observations of HD 298383. The final calibration for 2002 is an average of HD 298383 and HD 155197 data.

many of the published standards were too bright to observe with the CTIO 1.5m or had rather large polarizations. In addition to observing the unpolarized standard HD 9540, we also observed a nearby M1.5 star, HIP 21556, in both 2001 and 2002. One generally doesn't expect M-type main sequence stars to exhibit significant intrinsic polarization, and the target's nearby location implies a lack of significant interstellar dust along its line of sight, hence a lack of significant interstellar polarization. With the exception of the U filter, which showed a hint of non-zero polarization, all observations we obtained of this object from 2001 and 2002 were consistent with zero polarization. HIP 21556 has also been observed once with the HPOL polarimeter using its "faint mode" configuration, on 9 October 2004. The I band polarization measured was  $0.21\% \pm 0.1\%$  at  $143^\circ$  and the R band polarization was  $0.40\% \pm 0.03\%$  at  $162^\circ$ . This observation was extremely noisy, as HIP 21556 is at HPOL's "faint mode" detection limit; however, it does not appear to be inconsistent with being unpolarized. Note that in its "faint mode", HPOL's true errors are underestimated by a factor of 5-10 (B. Babler 2004, private communication), depending upon the polarization of the object. Thus our unpolarized standard data indicate that the polarimeter had an instrumental polarization consistent with zero for both 2001 and 2002 in the B, V, R, and I filters. The U filter observations in 2001 are consistent with zero polarization, while the U filter observations in 2002 are consistent with an instrumental polarization of  $\sim 0.1\%$ , which was removed from the data.

Observations of polarized standard stars serve two purposes: they allow one to calibrate the polarimetric efficiency of each filter and determine the zero-point of the polarization position angle in each filter. Each filter slightly attenuates the polarization signal from stellar sources and one can quantify this effect by comparing the magnitude of the observed polarization of polarized standard stars to the literature values of these targets. We summarize the literature values of the polarization standard stars used in this study in Table 2.8 and tabulate the final polarimetric efficiencies for each filter in both our 2001 and 2002 data in Table 2.9. The instrumental setup also induced a constant position angle rotation into our data: this rotation was determined by comparing the observed position angle of polarized standard stars to the literature position angle of these targets. The position angle rotation correction we applied to our data is summarized in Table 2.9. The consistency of both the polarimetric efficiency and the position angle rotation in each filter from 2001 to 2002 illustrates the robust stability of this polarimeter.

## 2.3 Infrared Spectroscopy

The near-infrared (IR) observations presented in this thesis were obtained at the 3m NASA Infrared Telescope Facility (IRTF), using the SpeX spectrograph, whose design is described in detail by Rayner et al. (2003). We used SpeX in its short cross-dispersed mode using a  $0.3 \times 15$  arc-second slit, providing spectral coverage from 8000 - 24,000Å at a resolution, R, of 2000. Data were recorded on a Raytheon 1024 x 1024 InSb array.

We followed the standard observing techniques described in Cushing et al. (2004)