Spectropolarimetric Observations of the Accreting Binary System V356 Sagittarii

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Abstract

I present the analysis of five years of spectropolarimetric data of the binary star system V356 Sagittarii (Sgr) and its accretion disk surrounding one, and possibly both, of the stellar components. These data were obtained with the Half-Wave Spectropolarimeter (HPOL) during its time at both the Pine Bluff Observatory at the University of Wisconsin-Madison and the Ritter Observatory at the University of Toledo across a total of 41 observation nights. In order to analyze characteristics of the disk itself, we use polarimetry to detect the vector orientation of the light passing through the disk to determine how the light is being polarized. The interstellar medium contains dust particles that can also polarize, or change the orientation of, the light coming from V356 Sgr. This interstellar polarization must be removed in order to analyze the intrinsic polarization coming strictly from V356 Sgr. Removing the interstellar polarization will include analyzing surrounding field stars that are close to V356 Sgr in order to determine an average local interstellar polarization, producing a fitted Serkowski Law curve to the Q and U Stokes' polarization parameters to provide the true interstellar polarization from the interstellar medium, and finally, subtracting this interstellar polarization from the total polarization to give the intrinsic polarization of V356 Sgr. The intrinsic polarization and position angle can be analyzed as a function of phase to investigate the distribution of circumstellar material within the accretion disk and determine whether the disk surrounds one or both stars. I will provide personal insight on the system's evolutionary track, its current placement on said track, and if and when it will explode as a supernova.

1 Introduction

A progenitor Type Ia supernova, a system which will eventually produce a Type Ia supernova, is composed of a set of binary stars. After the primary star turns off the main sequence and onto the asymptotic giant branch, it will become a red giant and spill much of its matter onto the secondary star in the form of an accretion disk. The two stars will eventually be engulfed in a common envelope as the primary star becomes a white dwarf. The supernova explosion is caused after the secondary star becomes a red giant, spills its matter onto the white dwarf, and causes it to reach a critical mass and explode. The uniform mass of the white dwarf prior to the explosion ensures consistent luminosity of the explosion. Type Ia supernovae are valuable to astronomers because they serve as standard candles for their respective host galaxies. These standard candles allow for a distance to the galaxy to be calculated, which can reveal other characteristics of the galaxy. Because this process takes millions of years, astronomers cannot observe one system evolving from beginning to end; rather, systems at each step along the process may be analyzed to help piece together the evolution of progenitor Type Ia supernovae. To confirm steps of this evolution, we have chosen to observe V356 Sgr, which currently resides at the initial mass transfer step.

V356 Sgr consists of a binary set of stars; the primary component is a B3 V star of 12.1 $M_{\odot}$, 6 $R_{\odot}$, 2640 $L_{\odot}$, and 0.1 $D_{\odot}$, whereas the secondary component is an A2 II star of 4.7 $M_{\odot}$, 14 $R_{\odot}$, 1350 $L_{\odot}$, and 0.0023 $D_{\odot}$ (Popper 1955; Popper 1980). These primary and secondary components will be the opposite of the conventional definition described above, due to the differing scientific focus throughout this research project. A thick disk of transferred matter from the secondary star surrounds the primary star, and the disk is edge-on (orbital inclination $\approx 90°$) when viewed from Earth, providing well-defined, total eclipses, making this system a favorable target to study (Wilson & Caldwell 1978; Popper 1955). The current evolutionary stage of the secondary star has been updated frequently. It has been known for years that the secondary component is a red supergiant; Wilson & Caldwell (1978) proposed that it has recently begun helium ignition in the core, and Ziółkowski (1985) proposed that it is currently burning hydrogen in its shell. V356 Sgr has a period of 8.896106 days, with an eclipse lasting 11 hours. During eclipse, roughly 1% of the system's total light is scattered in our line of sight, allowing analysis of the system's polarization and polarized flux.

The purpose of this study is to determine where V356 Sgr lies on the progenitor Type Ia supernova evolutionary track by confirming the proposal in Mike Malatesta's senior thesis (Malatesta 2012) that the system is engulfed in a common envelope. I will address the distribution of the circumstellar material (CSM) by analyzing the mass transfer and accretion disk. Finally, I will discuss possibilities of a link between distribution of the CSM and characteristics of the eventual supernova.

2 Observations

The data analyzed in this study were obtained by the Half-Wave Spectropolarimeter (HPOL) during its time at both the Pine Bluff Observatory (PBO) at the University of

Wisconsin-Madison and the Ritter Observatory at the University of Toledo. Data obtained during 1994-1995 were collected on the 36-inch telescope at PBO by a Reticon detector with a spectral range of 3200−7600Å at a spectral resolution of 25Å. Data obtained during 1996-1998 were also collected at PBO, but instead with a 400 x 1200 pixel CCD camera. Because observations with the CCD camera provided data across such a wide spectrum, two gratings were required; a blue grating with a spectral range of 3200−6020Å at a spectral resolution of 7Å, and a red grating with a spectral range of 5980−10500Å at a spectral resolution of 10Å (Nordsieck & Harris 1996; Draper 2014). HPOL became inactive in 2004, and began collecting data again in 2012 at the Ritter Observatory. Data obtained during 2012 were collected on the 1-meter telescope at Ritter Observatory by the same CCD camera. Most of the observation dates have both red and blue grating data; however, due to weather conditions or time restraints, several dates have only red or only blue grating data.

3 Data Analysis

3.1 Raw Data

Data were collected on 41 nights throughout 1994-1998 and 2012. After initial data reduction, I was provided with two types of files for each grating observation; ASCDMP files contained flux values at each wavelength, whereas HDMP files contained Q, U, and error values at each wavelength. Data were collected in intervals of 3Å for both ASCDMP and HDMP files. In addition to wavelength and flux values, the ASCDMP files also contained a time stamp of the Reduced Julian Date (RJD) marking the beginning of the exposure, as well as a value for the duration of the exposure time, allowing for the calculation of the median Julian Date, or the middle of the observation. While the data files indicate that the time stamps are provided in Modified Julian Date, it was discovered later in this study that HPOL actually provides what is commonly considered the Reduced Julian Date, and so the following equation was used to calculate median Julian Dates:

$$JD_{Median} = RJD_{Median} + 2400000.$$

Phase calculation was also affected by this misunderstanding. The phase of the system, or the fraction of the orbit since primary eclipse, was calculated for each observation night. Phase was calculated with the standard equation for calculating the Reduced Julian Date (Polidan 1989; Hall, Henry, & Murray 1981):

$$RJD_{Median} = 2433900.266 + (Period \times Phase) + [(3.5 \times 10^{-8}) Phase^2],$$

where Period = 8.896106, and rearranging to solve for the Phase produces:

$$Phase = 1.52833 \times 10^{-8} \sqrt{(1.2232 \times 10^{23}) JD_{Median} + 6.88484 \times 10^{31}} - 1.27087 \times 10^{8}.$$

Median Julian Dates, their corresponding Gregorian date of observation, and their corresponding calculated Phase are displayed in TABLE 1.

Table 1

Gregorian Date	Median Julian Date	Phase
1994 Sep 29	2449625.09	0.4828
1994 Sep 30	2449626.08	0.5941
1995 May 19	2449857.39	0.5950
1995 Jun 21	2449890.30	0.2943
1995 Jul 02	2449901.30	0.5308
1995 Jul 08	2449907.23	0.1974
1995 Jul 24	2449923.22	0.9948
1995 Jul 31	2449930.20	0.7794
1995 Aug 21	2449951.22	0.1422
[r]1995 Aug 24	2449954.18	0.4749
1995 Aug 26	2449956.19	0.7008
[r]1995 Sep 10	2449971.11	0.3780
[b]1995 Sep 11	2449972.13	0.4926
1996 Jul 05	2450270.29	0.0079
[b]1996 Jul 14	2450279.31	0.0218
1996 Sep 14	2450341.17	0.9753
1997 Sep 05	2450697.18	0.9934
1997 Sep 13	2450705.13	0.8870
1998 Jul 31	2451026.20	0.9776
1998 Aug 01	2451027.21	0.0911
1998 Aug 09	2451035.23	0.9926
1998 Aug 12	2451038.25	0.3321
1998 Aug 17	2451043.21	0.8896
1998 Aug 18	2451044.13	0.9930
[b]1998 Aug 19	2451045.12	0.1043
[b]1998 Aug 29	2451055.21	0.2385
1998 Aug 30	2451056.10	0.3385
1998 Sep 05	2451062.15	0.0186
1998 Sep 06	2451063.14	0.1299
2012 May 14	2456062.38	0.0783
2012 May 15	2456063.38	0.1907
[r]2012 May 16	2456064.38	0.3031
2012 May 17	2456065.37	0.4144
2012 May 18	2456066.37	0.5268
[r]2012 Jul 10	2456119.25	0.4709
2012 Jul 11	2456120.23	0.5810
[r]2012 Jul 12	2456121.20	0.6901
2012 Jul 13	2456122.24	0.8070
2012 Jul 14	2456123.23	0.9183
2012 Jul 16	2456125.24	0.1442
2012 Jul 17	2456126.24	0.2566

Table 1.— Gregorian dates of observation and their corresponding median Julian dates and phases. [r]Only red grating observations taken. [b]Only blue grating observations taken. Median Julian dates for all other observations are calculated using blue grating exposure time.

3.2 Data Combination and Familiarization

In order to more efficiently work with the data, I combined the data from the two file types (ASCDMP and HDMP) by matching wavelengths between each set of files. This produced one file (for each date, for each blue or red grating) that contained values of flux, Q, U, and error for each wavelength. Then, in order to familiarize myself with the study, I ran the data through the PFIL routine, an IDL program that combines blue and red grating data, runs the data through *UBVRI* (Ultraviolet [3200-4000Å], Blue [4000-5000Å], Visible [5000-7000Å], Red [5500-8000Å], Infrared [7000-9000Å]) artificial filter bands, and calculates an average position angle (PA) and flux-weighted polarization (P) for each observation date, by utilizing the following equations:

$$P = \sqrt{Q^2 + U^2} \qquad \text{and} \qquad PA = 0.5 \arctan\left(\frac{U}{Q}\right).$$

In addition, flux was plotted against wavelength for each night to highlight the spectroscopy of the project and to confirm the presence of strong absorption Balmer lines (Hα [6563Å], Hβ [4861Å], Hγ [4341Å], Hδ [4102Å]) in the atmospheres of A- and B-type stars. FIGURE 1 displays the wavelength dependence of flux for observation night 2012 Jul 11.

FIGURE 1

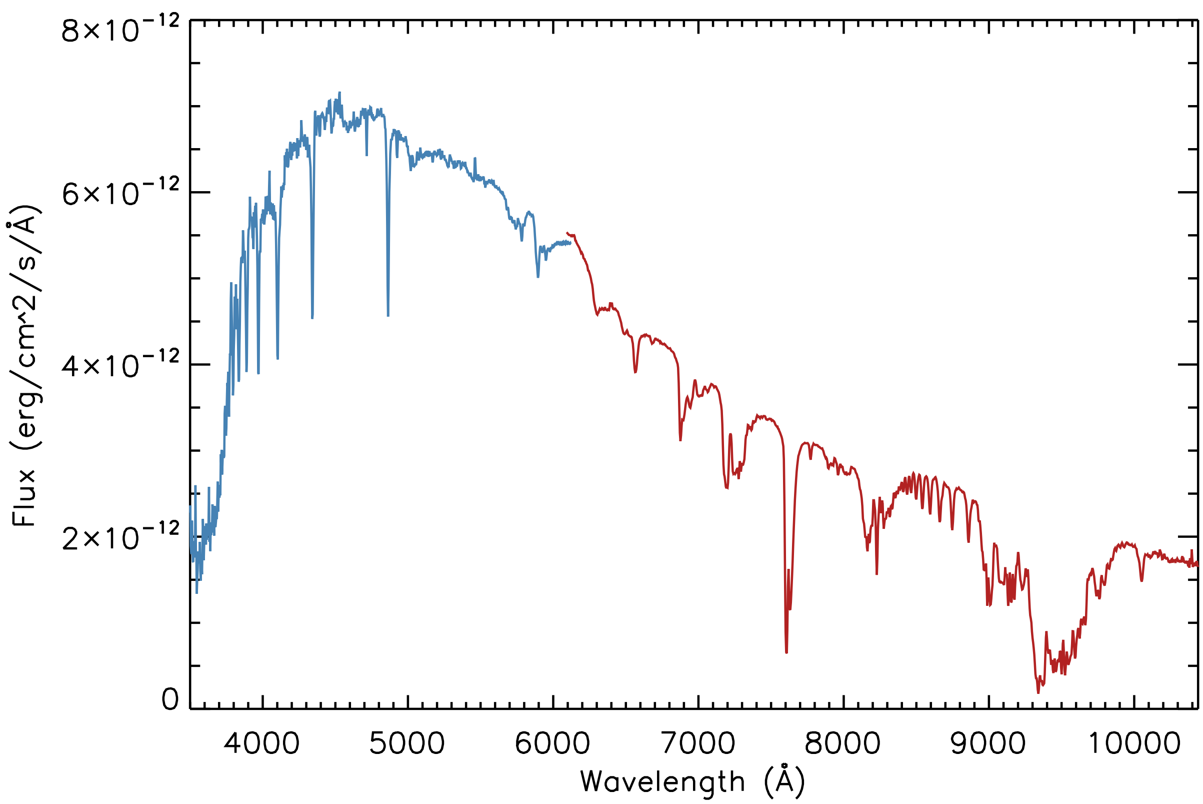

FIGURE 1.— Wavelength dependence of the flux for observation night 2012 Jul 11. Data from the blue and red gratings are displayed in blue and red color, respectively.

Because the data contains both intrinsic polarization from the system and interstellar polarization (ISP) from the interstellar medium (ISM), a majority of this project will consist of subtracting the interstellar polarization for the purpose of analyzing only the intrinsic polarization coming from the system. To confirm that the subtraction method works properly, a comparison of the pre-subtracted and post-subtracted data must be made. Table 2 displays results from pfil of unsubtracted data.

Table 2

Date	Filter	Q (%)	U (%)	Pol (%)	Pol error (%)	PA (°)	PA error (°)
1994 Sep 29	UX	-0.014741	0.421117	0.421375	0.117262	46.002366	7.972252
	B	-0.071135	0.785438	0.788652	0.027383	47.587518	0.994704
	V	-0.209883	0.878256	0.902987	0.024912	51.720157	0.790342
	R	-0.158571	0.866079	0.880476	0.032095	50.187706	1.044262
	I	-0.008386	0.37239	0.372484	0.05456	45.645015	4.19626
1994 Sep 30	UX	-0.537425	0.673886	0.861945	0.106296	64.286205	3.532879
	B	-0.307532	0.712189	0.77575	0.021705	56.677637	0.801559
	V	-0.299714	0.842181	0.893922	0.017574	54.794763	0.563185
	R	-0.353158	0.938953	1.003171	0.021591	55.306118	0.616576
	I	-0.259763	0.588286	0.643084	0.035329	56.912154	1.573811
1995 May 19	UX	-4.657282	-0.047449	4.657524	0.113345	—	0.697169
	B	-0.243701	0.8937	0.926331	0.015791	52.626487	0.488343
	V	-0.2951	0.758949	0.814302	0.007192	55.623713	0.253005
	R	-0.267695	0.584711	0.643076	0.003836	57.29973	0.170904
	I	-0.399968	0.759623	0.858488	0.005395	58.884203	0.180035
1995 Jun 21	UX	9.18213	-1.847224	9.366095	0.045335	-5.687353	0.138665
	B	-0.105313	0.83398	0.840604	0.055715	48.598547	1.898762
	V	-0.422381	0.799269	0.904012	0.01385	58.927297	0.438911
	R	-0.337244	0.635062	0.719053	0.005794	58.985051	0.23084
	I	-0.426016	0.775512	0.884821	0.006232	59.390762	0.201758
1995 Jul 02	UX	-0.33513	2.436628	2.459619	0.452067	48.920037	5.265353
	B	-0.376608	0.918352	0.992574	0.029567	56.149042	0.853379
	V	-0.37651	0.864758	0.943168	0.009527	56.764002	0.289363
	R	-0.269913	0.659426	0.712528	0.004942	56.129992	0.198717
	I	-0.383553	0.796306	0.883865	0.00677	57.859252	0.219435
1995 Jul 08	UX	-0.09143	1.530052	1.532782	0.155907	46.709859	2.913916
	B	-0.278408	0.781463	0.829575	0.011136	54.804614	0.384553
	V	-0.361241	0.878445	0.949822	0.006351	56.176915	0.191548
	R	-0.303002	0.695066	0.758239	0.003946	56.776986	0.149089
	I	-0.368789	0.791043	0.872786	0.007322	57.497589	0.240348
1995 Jul 24	UX	0.032142	0.166473	0.169547	0.044564	39.535988	7.529872
	B	-0.021668	0.855101	0.855376	0.054541	45.725779	1.82667
	V	-0.339371	1.021294	1.076204	0.021746	54.190703	0.578873
	R	-0.30361	0.67198	0.737385	0.009463	57.157077	0.367656
	I	-0.457788	0.878018	0.990195	0.007943	58.768488	0.229809
1995 Jul 31	UX	0.179084	2.067789	2.075529	0.288293	42.525083	3.979224
	B	-0.354214	0.822516	0.895545	0.021983	56.649482	0.703206
	V	-0.341665	0.865588	0.930579	0.008489	55.770065	0.261347
	R	-0.292955	0.682881	0.743068	0.00448	56.609639	0.172736
	I	-0.392285	0.807954	0.898152	0.007032	57.948962	0.22428
1995 Aug 21	UX	-0.35265	0.580197	0.678963	0.172191	60.64585	7.265367
	B	-0.225294	0.846405	0.875876	0.015834	52.452626	0.517908
	V	-0.322005	0.89225	0.948576	0.005402	54.922035	0.16315
	R	-0.271683	0.674388	0.727056	0.003229	55.971237	0.127235
	I	-0.394282	0.788563	0.881641	0.006165	58.282546	0.200317
[r]1995 Aug 24	V	-0.312422	0.846146	0.901981	0.010752	55.132812	0.341493
	R	-0.360392	0.808245	0.884953	0.005993	57.015905	0.194007
	I	-0.383629	0.690276	0.789717	0.007587	59.531793	0.27521

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1995 Aug 26	UX	0.153053	1.028589	1.039914	0.106175	40.768264	2.924944
	B	-0.265856	0.827309	0.868976	0.018831	53.907421	0.620825
	V	-0.329487	0.766931	0.834713	0.008059	56.624586	0.276583
	R	-0.275006	0.618861	0.677213	0.00405	56.97956	0.171338
	I	-0.39968	0.774933	0.871932	0.005896	58.641453	0.193721
[r]1995 Sep 10	V	-0.359137	0.707027	0.793011	0.012878	58.464215	0.465241
	R	-0.331017	0.758012	0.827136	0.007377	56.795208	0.255502
	I	-0.311585	0.712886	0.778005	0.010155	56.804466	0.373913
[b]1995 Sep 11	UX	-0.554295	0.115089	0.566117	0.114826	84.135128	5.810679
	B	-0.143365	0.659143	0.674553	0.013651	51.13541	0.579758
1996 Jul 05	UX	-0.128469	0.2737	0.30235	0.068672	57.572163	6.506666
	B	-0.335336	0.728397	0.801881	0.01293	57.360089	0.461925
	V	-0.406252	0.852431	0.944287	0.005355	57.740774	0.162448
	R	-0.344386	0.688661	0.769971	0.003234	58.284358	0.120341
	I	-0.449702	0.845536	0.957687	0.005741	59.003223	0.171733
[b]1996 Jul 14	UX	-0.975145	1.473355	1.766829	0.115491	61.749358	1.872605
	B	-0.608792	0.767855	0.979912	0.018771	64.204524	0.548787
1996 Sep 14	UX	0.045977	0.707594	0.709086	0.227515	43.14118	9.19862
	B	-0.391455	0.771634	0.865249	0.01533	58.44948	0.507562
	V	-0.439279	0.837008	0.945277	0.006729	58.845697	0.203937
	R	-0.345446	0.68477	0.76697	0.00374	58.384776	0.139691
	I	-0.4433	0.846106	0.955202	0.005715	58.825684	0.171412
1997 Sep 05	UX	-2.667459	0.753458	2.771829	0.073051	82.113491	0.755007
	B	-0.401811	0.849813	0.940018	0.032518	57.652926	0.991026
	V	-0.371503	0.992703	1.05994	0.009474	55.258778	0.256052
	R	-0.312265	0.786569	0.846286	0.005832	55.82646	0.197412
	I	-0.369655	0.895477	0.968775	0.010628	56.215459	0.314277
1997 Sep 13	UX	3.739809	0.955437	3.859926	0.196583	7.165621	1.459014
	B	-0.224096	0.748959	0.781766	0.014811	53.32884	0.542744
	V	-0.257048	0.896434	0.932559	0.007135	52.999979	0.21917
	R	-0.239181	0.761937	0.798596	0.004543	53.713831	0.162953
	I	-0.222361	0.785915	0.816766	0.007211	52.898971	0.252923
1998 Jul 31	UX	-0.126407	0.587665	0.601106	0.277513	51.06969	13.225867
	B	-0.233745	0.997081	1.024113	0.036209	51.596778	1.0129
	V	-0.281395	0.971579	1.011508	0.010917	53.076204	0.309191
	R	-0.3334	0.905369	0.964784	0.00613	55.106375	0.182017
	I	-0.395601	0.804304	0.896329	0.00681	58.095236	0.217669
1998 Aug 01	UX	1.032648	-0.292959	1.0734	0.304456	-7.919234	8.125614
	B	-0.318541	0.73556	0.801572	0.016748	56.70773	0.598578
	V	-0.32934	0.914457	0.970137	0.007592	54.753002	0.224197
	R	-0.311025	0.914457	0.963749	0.004954	54.413884	0.147247
	I	-0.318939	0.80302	0.864039	0.006194	55.830856	0.205374
1998 Aug 09	UX	0.863275	0.332656	0.925151	0.551996	10.536877	17.092899
	B	-0.116206	0.669274	0.679288	0.062906	49.925045	2.652977
	V	-0.111267	0.917355	0.924078	0.015083	48.457826	0.467596
	R	-0.099247	0.898428	0.903893	0.009307	48.151887	0.294973
	I	-0.066846	0.745106	0.748098	0.012193	47.563236	0.466928
1998 Aug 12	UX	1.151672	1.951527	2.266011	0.603254	29.726739	7.626591
	B	0.046098	0.653938	0.655561	0.09503	42.983849	4.152776
	V	-0.167088	0.967247	0.981573	0.016781	49.900451	0.489777
	R	-0.285606	0.886312	0.931193	0.008023	53.93054	0.246816
	I	-0.277945	0.779603	0.827668	0.007829	54.811122	0.270985
1998 Aug 17	UX	-0.825196	-0.297	0.877016	0.394025	——	12.870889
	B	-0.222247	0.645495	0.682684	0.036135	54.499418	1.516347
	V	-0.379086	0.82935	0.911881	0.010521	57.282295	0.330521
	R	-0.37232	0.855174	0.932709	0.005789	56.76351	0.177808
	I	-0.36846	0.749068	0.834785	0.00664	58.096081	0.22786
1998 Aug 18	UX	-0.664101	0.687719	0.956027	0.364965	66.999524	10.936389
	B	-0.119138	0.854862	0.863124	0.032347	48.966954	1.073617
	V	-0.32843	0.928039	0.98444	0.01141	54.744363	0.332051
	R	-0.400779	0.902664	0.987637	0.006373	56.970515	0.184872
	I	-0.341963	0.788924	0.859848	0.007061	56.717271	0.23525
[b]1998 Aug 19	UX	2.47516	-0.313555	2.494942	0.443797	-3.609909	5.095849
	B	-0.377021	0.5777249	0.689465	0.043414	61.574976	1.803876

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[b]1998 Aug 29	UX	0.147153	0.914379	0.926144	0.583218	40.428827	18.040327
	B	-0.035655	0.945368	0.94604	0.057944	46.079944	1.754641
1998 Aug 30	UX	-2.097298	0.444724	2.143931	0.241917	84.013989	3.232572
	B	-0.104536	0.68561	0.693534	0.019517	49.334583	0.806175
	V	-0.348476	0.842802	0.912004	0.008494	56.231902	0.266815
	R	-0.354658	0.859483	0.929781	0.005205	56.211529	0.160388
	I	-0.368032	0.748983	0.834519	0.00627	58.084185	0.215247
1998 Sep 05	UX	-0.699356	1.527147	1.679665	0.408704	57.30268	6.970729
	B	-0.359498	0.697522	0.784714	0.038221	58.633118	1.395346
	V	-0.280107	0.799664	0.847303	0.011174	54.652201	0.377785
	R	-0.207211	0.820815	0.846566	0.006522	52.084011	0.220719
	I	-0.187933	0.743191	0.766585	0.007928	52.095515	0.296264
1998 Sep 06	UX	5.257391	1.816937	5.562501	0.756863	9.532488	3.897984
	B	0.468832	0.737654	0.874035	0.067871	28.780558	2.224576
	V	0.145582	0.753585	0.767519	0.015006	39.532961	0.560086
	R	0.01038	0.839981	0.840045	0.007407	44.646008	0.252586
	I	0.083585	0.765002	0.769555	0.007732	41.882254	0.287847
2012 May 14	UX	—	—	38.031629	3.908593	—	2.944206
	B	-0.345215	1.075697	1.129733	0.033793	53.896294	0.856915
	V	-0.33348	0.968426	1.024235	0.008823	54.500646	0.246787
	R	-0.371589	0.925993	0.997768	0.005188	55.932466	0.148967
	I	-0.377341	0.82153	0.904045	0.006006	57.334992	0.190261
2012 May 15	UX	14.571175	-4.701738	15.31096	1.555026	-8.941768	2.909564
	B	-0.173748	0.780508	0.799613	0.015216	51.27495	0.545134
	V	-0.312069	0.909451	0.961504	0.005999	54.469568	0.178748
	R	-0.380038	0.890406	0.968118	0.004282	56.556729	0.126702
	I	-0.398486	0.804578	0.897851	0.005808	58.173989	0.185302
[r]2012 May 16	V	-0.388942	0.950761	1.027241	0.007303	56.124359	0.203673
	R	-0.386931	0.900586	0.980189	0.003981	56.625231	0.116352
	I	-0.388475	0.766739	0.859536	0.005398	58.434713	0.179929
2012 May 17	UX	-8.009886	-2.681651	8.446865	3.346631	—	11.350234
	B	-0.180694	0.753153	0.774526	0.020043	51.745608	0.741341
	V	-0.252625	0.907064	0.941526	0.007282	52.781465	0.221547
	R	-0.346327	0.915178	0.978516	0.004622	55.363967	0.13532
	I	-0.346913	0.81264	0.883591	0.006031	56.55871	0.195552
2012 May 18	UX	12.674681	-2.263708	12.875244	1.509913	-5.06315	3.359612
	B	-0.192816	0.732311	0.75727	0.020378	52.375523	0.770921
	V	-0.292424	0.873892	0.92152	0.007037	54.250697	0.218778
	R	-0.345709	0.880423	0.945864	0.00448	55.719025	0.13569
	I	-0.352188	0.793575	0.868215	0.005643	56.965821	0.186204
[r]2012 Jul 10	V	-0.24835	0.52622	0.581881	0.01004	57.632503	0.494296
	R	-0.231749	0.559542	0.605636	0.005145	56.249088	0.243367
	I	-0.226282	0.570182	0.613442	0.006061	55.82305	0.283045
2012 Jul 11	UX	-4.683318	8.527507	9.728918	1.511112	—	4.449638
	B	-0.212784	0.756511	0.785867	0.019502	52.854866	0.710914
	V	-0.300588	0.862647	0.913517	0.006554	54.605393	0.205526
	R	-0.337294	0.831363	0.89718	0.003747	56.041487	0.11966
	I	-0.354846	0.728857	0.810647	0.00466	57.979644	0.164699
[r]2012 Jul 12	V	-0.347826	0.826721	0.896912	0.00635	56.40897	0.202807
	R	-0.364157	0.802451	0.881214	0.003434	57.204424	0.111641
	I	-0.375418	0.714171	0.806832	0.004378	58.864775	0.155457
2012 Jul 13	UX	23.215126	—	—	8.164137	39.173726	2.034848
	B	0.08484	0.496155	0.503357	0.031076	40.148303	1.768627
	V	-0.299347	0.829758	0.882104	0.008237	54.918813	0.267504
	R	-0.326109	0.816139	0.87888	0.00446	55.89023	0.145371
	I	-0.354494	0.738192	0.818898	0.005074	57.825594	0.177497
2012 Jul 14	UX	—	-0.7631	11.069489	1.144495	—	2.961959
	B	-0.193696	0.933372	0.953258	0.015135	50.861889	0.454848
	V	-0.35121	0.952045	1.01476	0.006128	55.124517	0.172994
	R	-0.387299	0.912404	0.991202	0.003881	56.500185	0.112165
	I	-0.399292	0.785558	0.881212	0.004914	58.471917	0.159754
2012 Jul 16	UX	17.094261	8.734982	19.19671	1.433514	13.533269	2.139281
	B	-0.242092	0.660601	0.703564	0.019286	55.06325	0.785297
	V	-0.287271	0.826716	0.875205	0.007008	54.580783	0.229407

Table continued on next page....

	R	-0.352001	0.831966	0.903367	0.004101	56.466492	0.130049
	I	-0.367901	0.750251	0.8356	0.00474	58.060979	0.162519
2012 Jul 17	UX	19.522455	-6.060703	20.441584	2.475944	-8.623419	3.469915
	B	-0.277848	0.677797	0.732535	0.033508	56.145052	1.31044
	V	-0.360022	0.811143	0.887451	0.008657	56.966912	0.279455
	R	-0.3684	0.798094	0.879018	0.005257	57.389004	0.171332
	I	-0.350925	0.731474	0.811297	0.006311	57.814696	0.222832

TABLE 2.— Results from PFIL routine for unsubtracted data. [r]Only red grating observations taken. [b]Only blue grating observations taken.

To confirm that the system was not changing drastically over time, I compared polarization across all observation nights. From the 1990's observations to the 2012 observations, no significant change in polarization occured; *i.e.*, for the V filter band data, polarization remained between 0.8% and 1.1% over time (FIGURE 2).

FIGURE 2

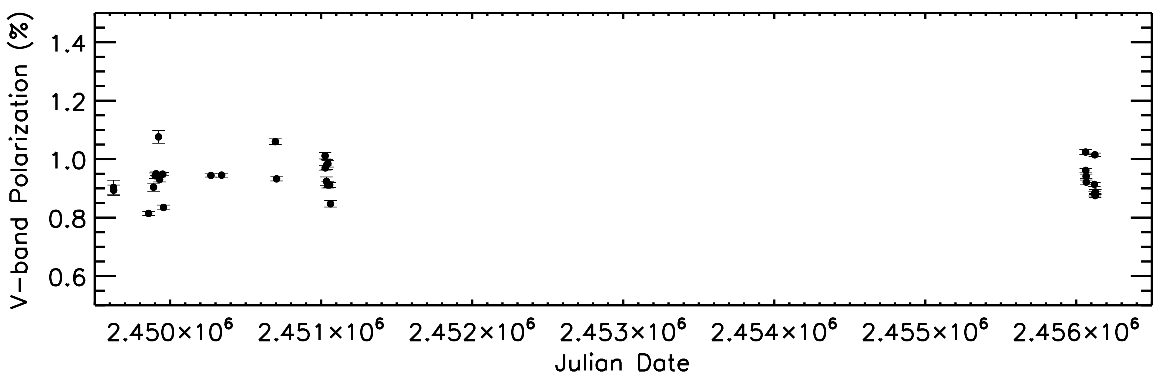

FIGURE 2.— V-band polarization variation over all observation nights; includes the 1990's and 2012 data.

The last step I took before starting work on the ISP part of this project was to create plots of the unsubtracted data to highlight the changes in polarization and position angle across the phase of the system. This allowed for a comparison of unsubtracted and subtracted data in order to identify if the subtraction method worked, and if so, how the ISP affected the data received from HPOL. I compared the phase to polarization and position angle of the data that resulted from the $BVRI$ filters; U was left out of this comparison due to its high noise level. FIGURES 3 and 4 display polarization and position angle, respectively. In order to better visualize the changes with respect to phase, the phase has been extended in both directions by 0.2 phase.

FIGURE 3

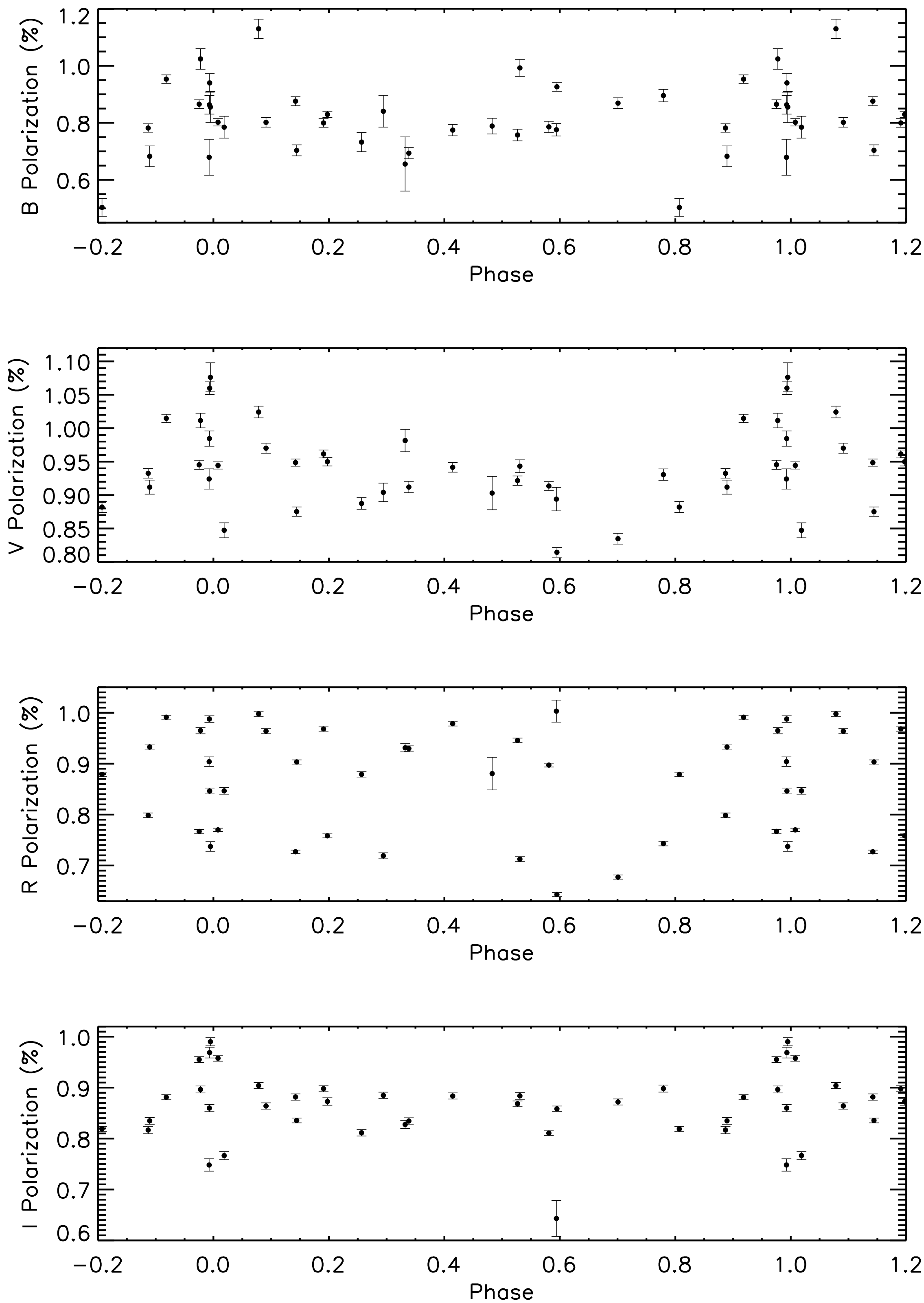

FIGURE 3.— *BVRI* polarization variation over more than one phase of the system.

Figure 4

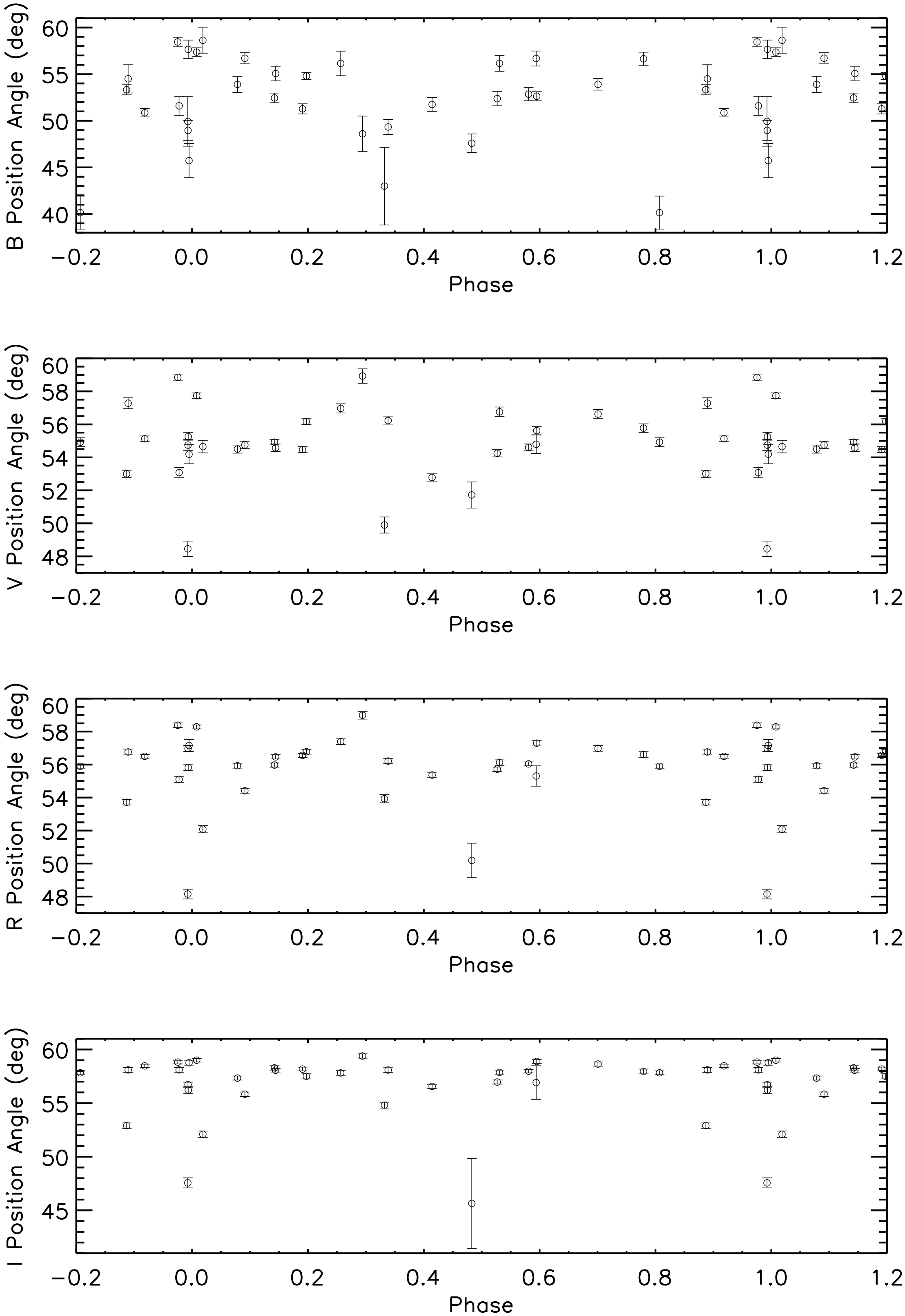

Figure 4.— *BVRI* position angle variation over more than one phase of the system.

4 Interstellar Polarization

Because the data from HPOL includes both intrinsic polarization from V356 Sgr and interstellar polarization from the interstellar medium between Earth and V356 Sgr, the interstellar polarization must be removed in order to analyze the polarization coming strictly from the disk. By following the process layed out in Draper et al. (2014) and Quirrenbach et al. (1997), I calculated field star ISP and PA estimates, which were used in conglomeration with a Serkowski Law curve (Serkowski, Mathewson, & Ford 1975; Wilking, Lebofsky, & Rieke 1982) to determine the ISP contribution at each wavelength. These wavelength-dependent ISP values could then be subtracted from the original total polarization to get intrinsic polarization values at each wavelength.

4.1 Field Star ISP Estimates

In order to calculate an accurate estimate for the ISP, it was necessary to find field stars that were close to V356 Sgr in the sky (both visually and spatially), then assume that the ISP affecting those field stars was identical to that affecting V356 Sgr. V356 Sgr is located at $RA = 18h\ 47m\ 52.33151s$ and $Dec = -20°\ 16m\ 28.2467s$, so I chose to find stars within a 5° proximity (or $20m$ in RA), *i.e.*:

$$18h\ 27m\ 52.33151s < RA < 19h\ 07m\ 52.33151s$$
$$\text{and}$$
$$-25°\ 16m\ 28.2467s < Dec < -15°\ 16m\ 28.2467s.$$

I found 40 field stars in online astronomical databases such as WUPPOL, Heiles (2000), and SIMBAD that matched this criteria and recorded their distance from Earth, polarization, position angle, and star type. Those that were variable, emission-line, or Be stars were ruled out as likely field star candidates due to their unreliability in constant polarization over time. After these were removed, 26 candidates remained. The distance to V356 Sgr was calculated with distance parallax as 454.5 parsecs ± 212.8, so I wanted to limit candidates to this error range between 241.7 and 667.3 parsecs; for convenience, I rounded the values and chose 250 and 650 parsecs as the limits. To visualize the field stars, I created an RA vs. Dec plot (Figure 5) of the 26 candidates (plus V356 Sgr) and calculated their polarization vectors from their position angle and polarization values. In addition, the stars were grouped by distance (<250 parsecs, 250-650 parsecs, >650 parsecs) according to whether or not they fit in the error range of V356 Sgr's distance. All 26 candidates were plotted on a Q-U plot in order to determine their vector polarization similarity to V356 Sgr (Figure 6) using the following equations:

$$U = Pol\, sin(2\, PA) \qquad \text{and} \qquad Q = Pol\, cos(2\, PA)\ ,$$

where PA is converted from degrees to radians. 7 candidates were chosen as exhibiting a close resemblance to V356 Sgr's polarization, both in magnitude and direction, as well as fitting within the distance error range. The resulting RA vs. Dec plot with the 7 selected stars bearing filled symbols is shown in Figure 5.

FIGURE 5

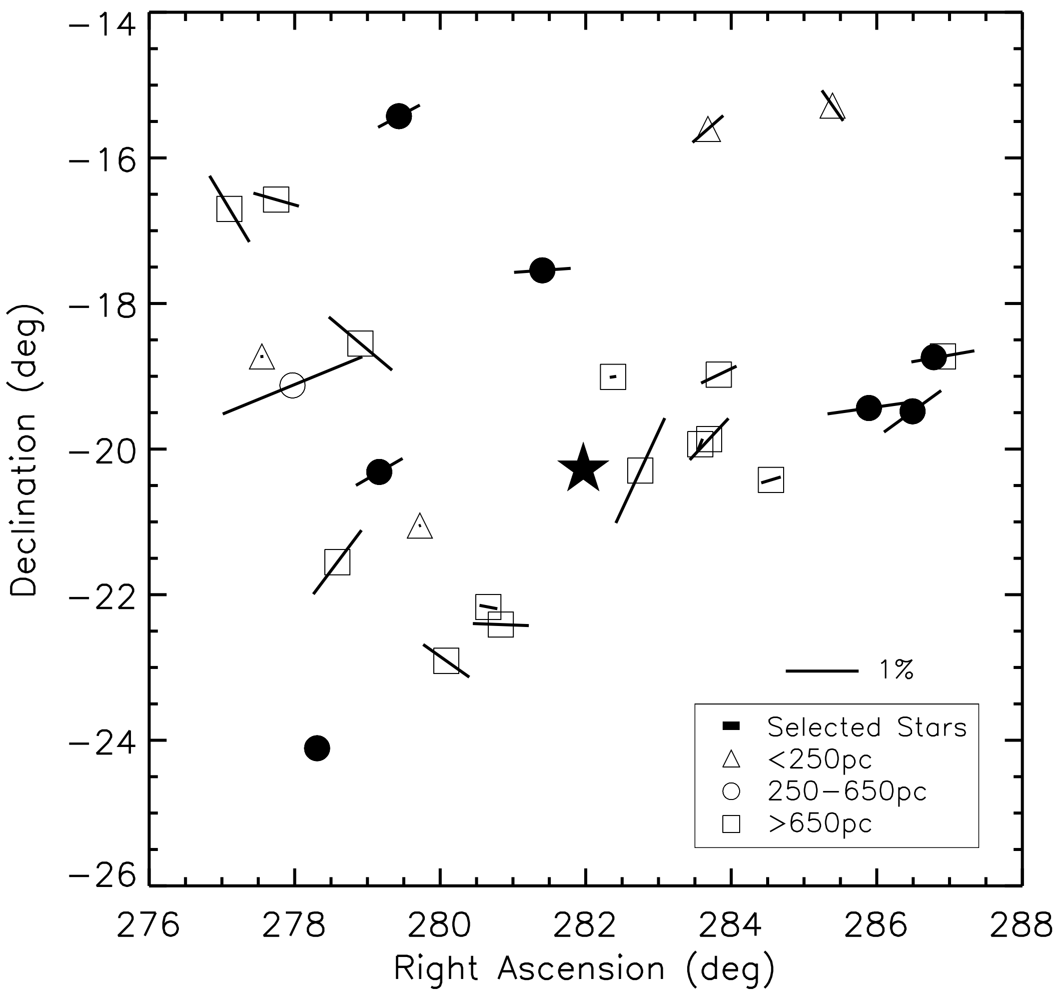

FIGURE 5.— Visual map of the 26 field star candidates. Symbol groups have been selected based on distance from Earth, with the 7 selected stars bearing filled symbols. Vector lines provide magnitude and direction of polarization coming from the star, which is assumed to be ISP. V356 Sgr is in the center of the plot, indicated by a filled, five-pointed star.

FIGURE 6

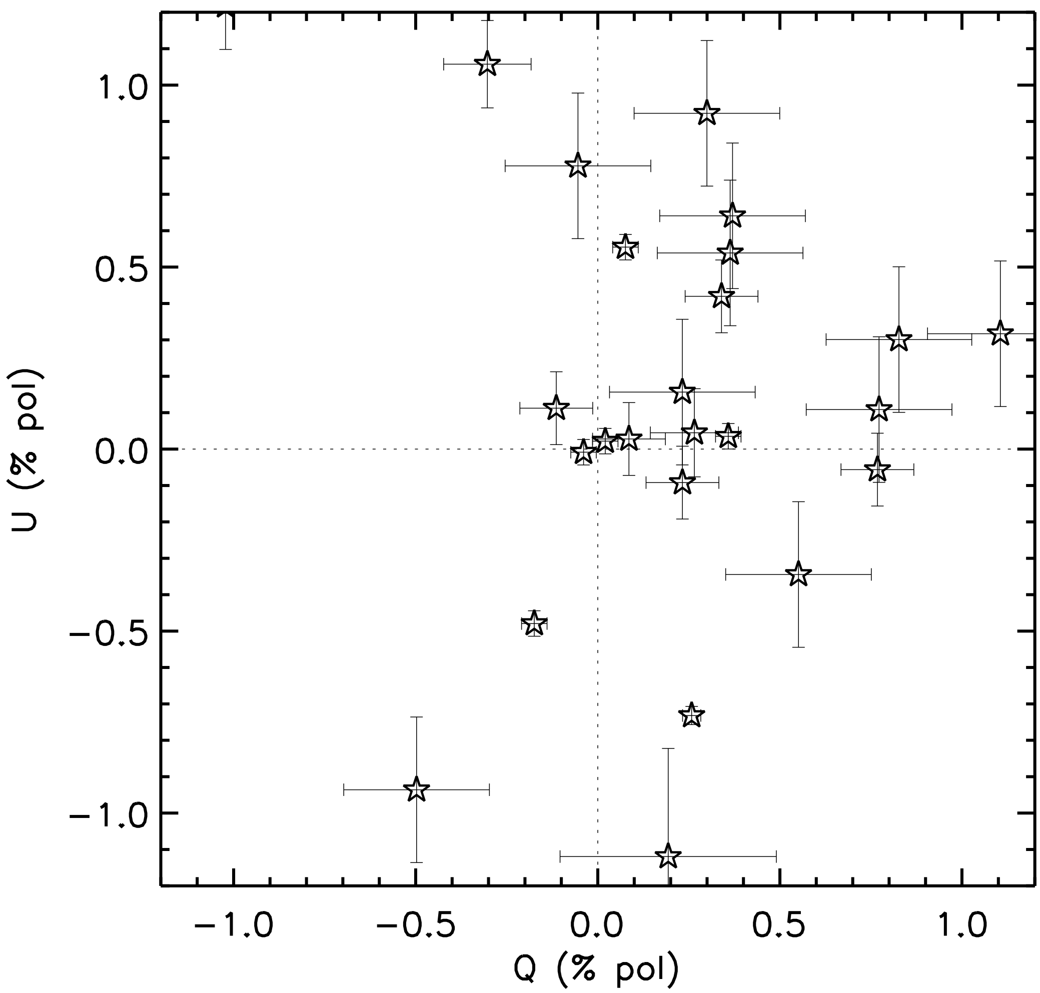

FIGURE 6.— Q and U values calculated from the polarization and position angle of each of the original 26 candidates. Placement on the Q-U plot provides insight on star's polarization similarity to V356 Sgr.

In order to calculate a range of ISP estimates, I used four different methods to not only determine whether they outputted similar results, but also to determine which, if any, provided the best approximation for the ISP affecting V356 Sgr. These four methods were Distance Weighted Average of all 7 field stars, Error Weighted Average of all 7 field stars, Error Weighted Average of the 4 spatially closest field stars to V356 Sgr, and Error Weighted Average of the 2 spatially closest field stars to V356 Sgr. Each method will be described in greater detail below.

Distance Weighted Average The Distance Weighted Average is an average polarization calculated with a weight of the distance from a specific field star to V356 Sgr; this required that I first find the true distances between each star and V356 Sgr. This was done by combining the results from GCIRC, a routine that computes great circle arc distances, with the following Law of Cosines:

$$D_{Star\rightarrow V356} = \sqrt{D^2_{Earth\rightarrow V356} + D^2_{Earth\rightarrow Star} - \left[2\, D_{Earth\rightarrow V356}\, D_{Earth\rightarrow Star}\, cos\left(\frac{Angle_{gcirc}}{3600}\right)\right]} \,,$$

where $D_{Star\rightarrow V356}$ is the distance between the field star and V356 Sgr, $D_{Earth\rightarrow V356}$ is the distance between Earth and V356 Sgr (calculated with distance parallax), $D_{Earth\rightarrow Star}$ is the distance between Earth and the field star (retrieved from online databases), and $Angle_{gcirc}$ is the great circle arc distance outputted by the GCIRC routine. Weights for all 7 field stars were calculated from these distance values, Q and U values for each star were averaged together with these weights, and an average polarization and position angle value was computed from the resulting average Q and U values.

Error Weighted Average The Error Weighted Average is an average polarization calculated with a weight of the polarization error from each field star. A similar method for calculating distance weights was used for polarization error weights; these error weights were then applied to the Q and U values for each star, which were then used to calculate an average polarization and position angle weighted by polarization error. This method was used with three sets of field star data: all 7 field stars, and the closest four and closest two field stars, where spatial proximity was determined by a star's $D_{Star\rightarrow V356}$ value.

TABLE 3 displays the results from these four weighted average methods, and FIGURE 7 shows all four ISP vectors plotted on top of the 7 field star candidates.

TABLE 3

Method	Q_{fs} (%)	U_{fs} (%)	Pol_{fs} (%)	PA_{fs} (°)
Distance (7)	0.39453397	0.57871004	0.70040157	27.857947
Error (7)	0.54225727	0.44309421	0.70026811	19.626629
Error (2)	0.28673669	0.59169198	0.65750843	32.072476
Error (4)	0.53512861	0.50083855	0.73294057	21.552112

TABLE 3.— Results from the four weighted average methods. Each set serves as a different ISP estimate, providing four possible ISP estimates.

Figure 7

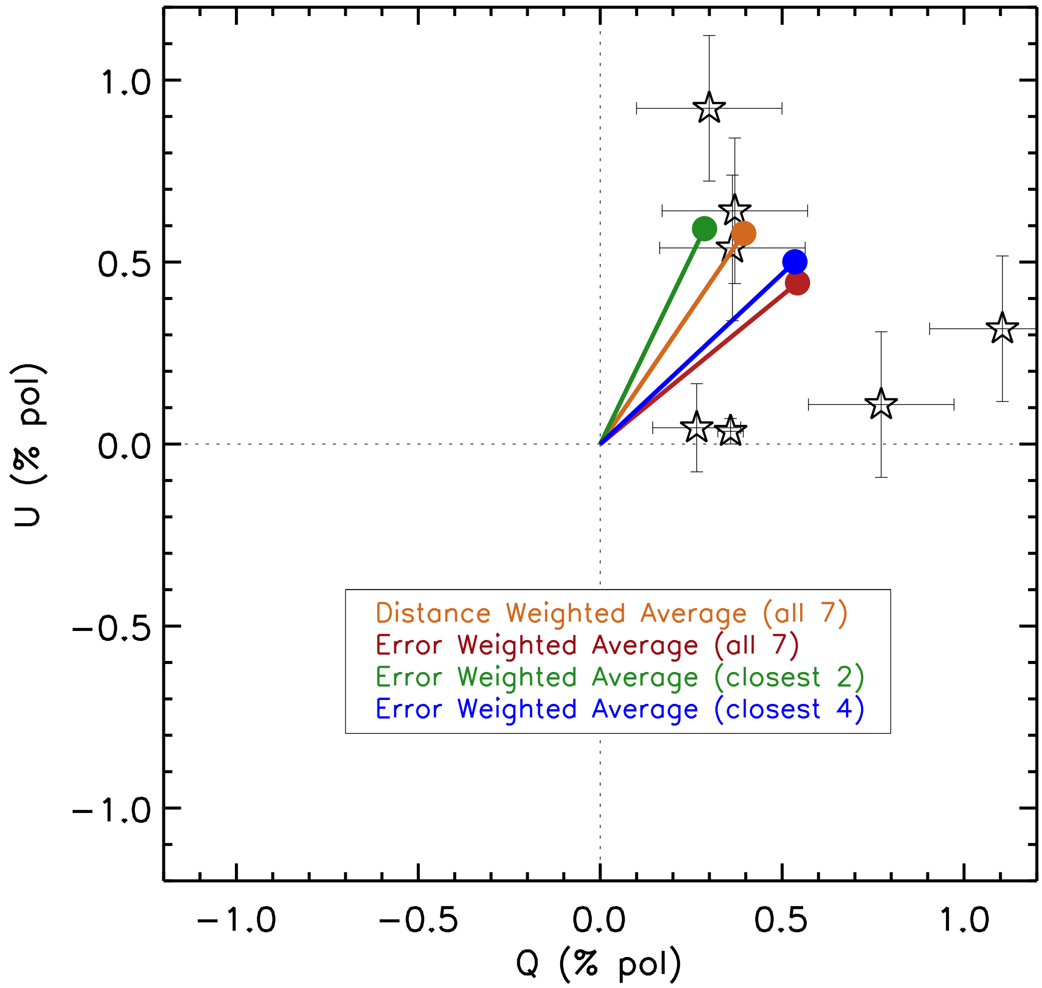

Figure 7.— The four ISP estimates portrayed as vectors on top of a Q-U plot of the 7 field stars used in the ISP estimation process.

4.2 Serkowski Law Curve

The Serkowski Law Curve method has been described in detail in Draper et al. (2014) as a technique for separating ISP into parallel and perpendicular components based on the wavelength dependence of the U polarization parameter, then using these separated components to determine an ISP value at each wavelength, which can ultimately be subtracted from the total polarization obtained by HPOL to get the intrinsic polarization of V356 Sgr. This method is briefly summarized below.

In order to separate the ISP into perpendicular and parallel components, I needed the system to be horizontal with U considered constant and all variation in Q; this ensured that Q contained the parallel component of the ISP ($ISP_{\|}$) and the parallel component of the intrinsic polarization, while the U contained only the perpendicular component of the ISP

($ISP_\perp$), and the perpendicular component of the intrinsic polarization was eliminated with the rotation. A Q-U plot was created with each point representing the V-band polarization for each observation night, where the four blue-grating-only dates were excluded due to their lack of V-band data, the five red-grating-only dates were excluded due to their noisy and untrustworthy V-band data, and one date was excluded due to its unusually large Q value, leaving 31 data points. A line was fitted to the data to establish an average position angle at which the data points were tilted, which represented the angle at which the system itself was tilted. The 31 points were rotated across the Q-U plot by this average position angle (51.6492° in Q-U space; 25.8246° in real space) so that the best fit line would be horizontal and all variation would be in the Q' ("Q-prime": rotated Q values). This rotation is presented in FIGURES 8 and 9.

FIGURE 8

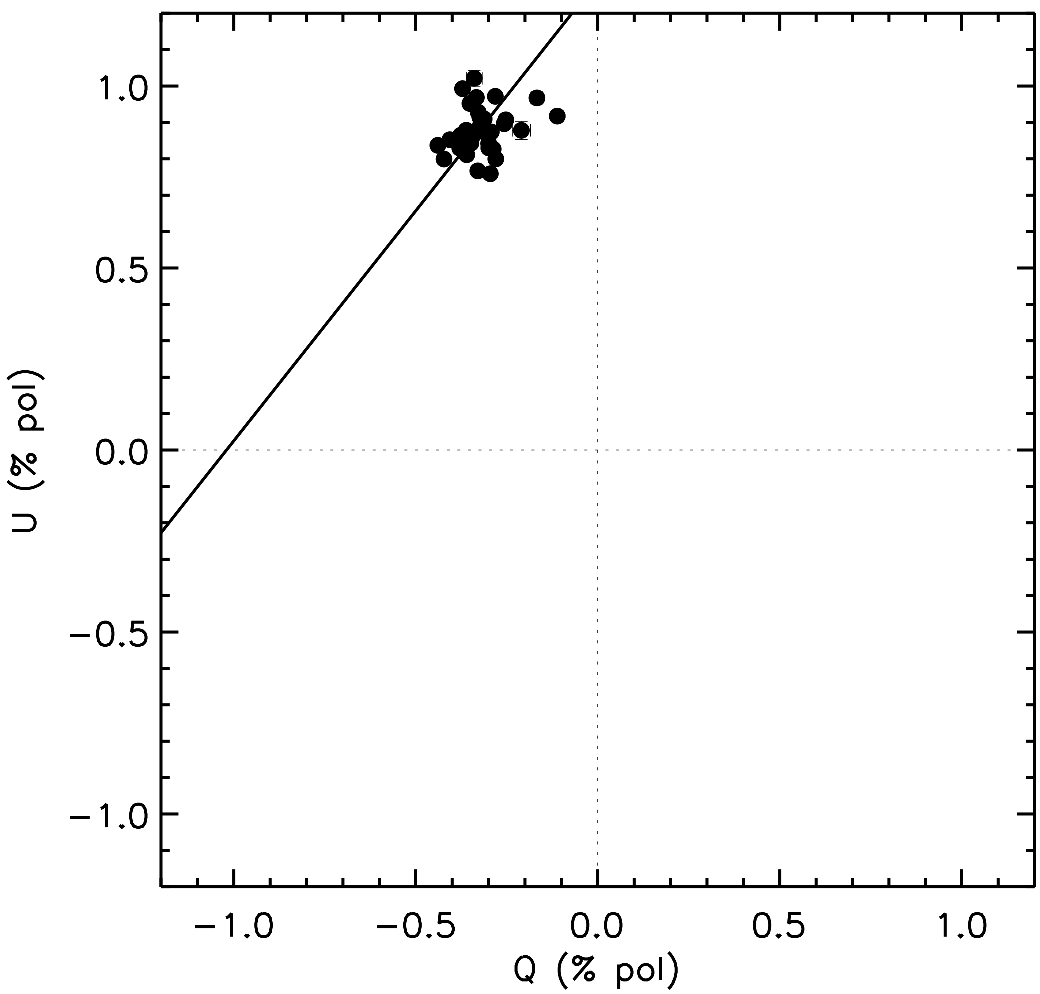

FIGURE 8.— Q-U polarization in V-band for the 31 dates that did not exhibit noisy data. A line has been fit to the points by which the data will be rotated.

FIGURE 9

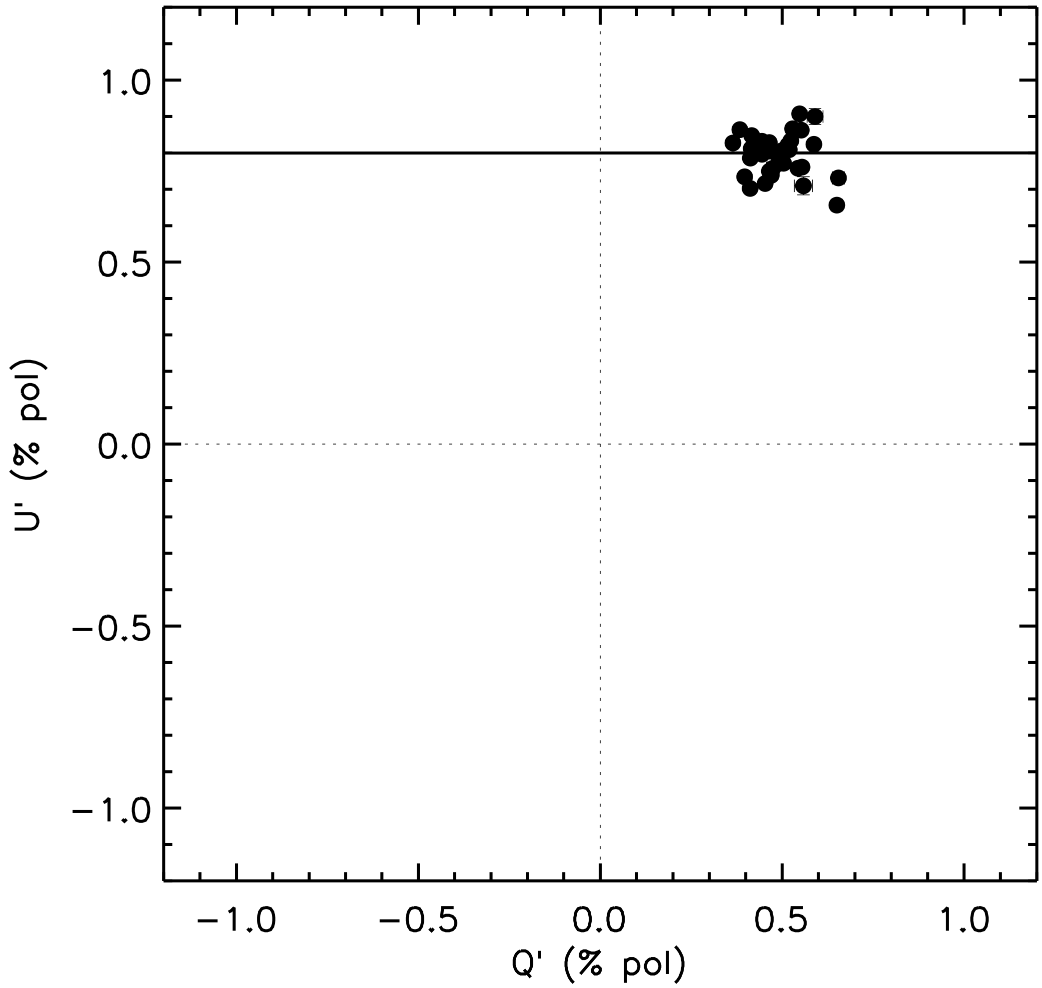

FIGURE 9.— Result of the Q-U rotation: Q'-U'. Best fit line is horizontal, with all variation in Q', and U' considered constant.

An averaging routine was applied to all Q and U data across the 31 nights in order to determine an average Q' and U' value for each wavelength. All average Q and U values were rotated by the previously determined average position angle (25.8246°) to ensure that Q' contained $ISP_{\parallel}$ and the parallel intrinsic polarization, while U' contained $ISP_{\perp}$. The Q' and U' data were then binned into a binsize of 50Å for aesthetic purposes and to establish better statistical averages. Because ISP is wavelength dependent (due to the range in sizes of molecules in the ISM), the binned U' was plotted against wavelength and fitted with the empirical Serkowski Law,

$$P(\lambda) = ISP_{\perp} \exp\left[-K \ln^2\left(\frac{\lambda_{max}}{\lambda}\right)\right],$$

where

$$K = (1.68 \times 10^{-4})\lambda_{max} - 0.002.$$

This fit provided a maximum wavelength of $\lambda_{max} = 6059.5946$Å at which the curve peaked, which corresponded to a maximum U' value synonymous with the $ISP_{\perp}$, or $U'_{max}(= ISP_{\perp}) = 0.79346555\%$. This wavelength-dependent U' data and its fitted Serkowski Law curve are shown in FIGURE 10.

FIGURE 10

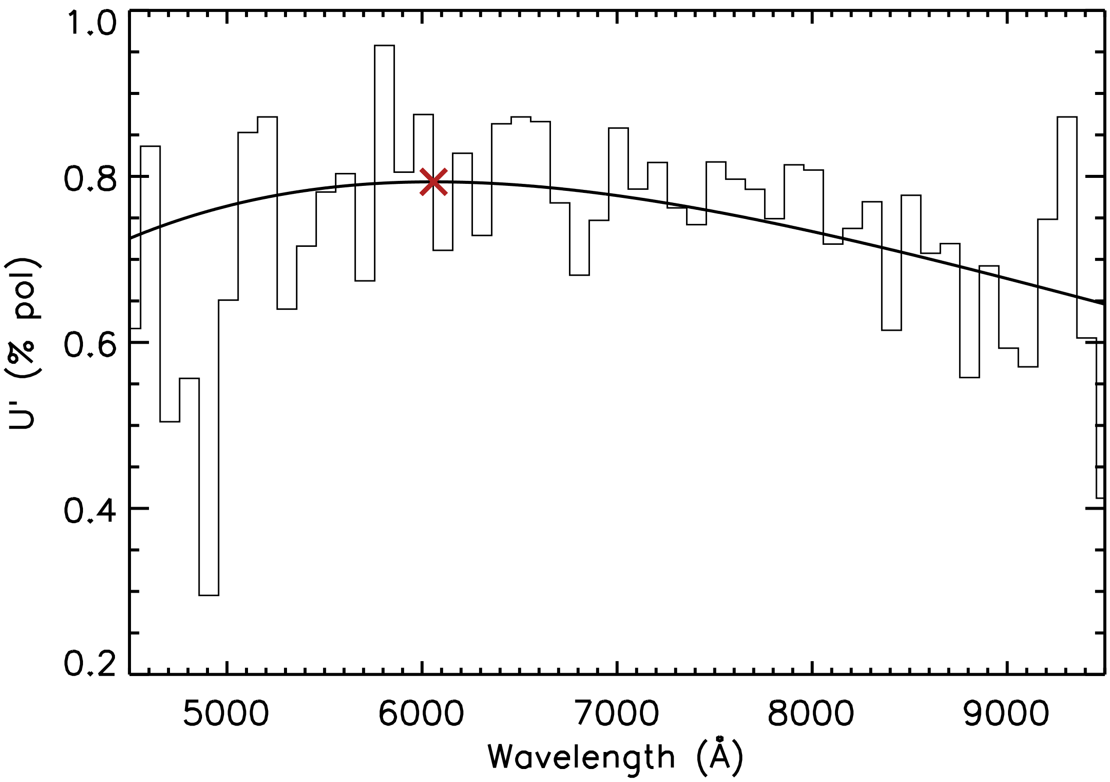

FIGURE 10.— Binned, wavelength-dependent, U' data with its fitted Serkowski Law curve. The red 'X' denotes the peak of the curve, *i.e.*, U'_{max} ($= ISP_{\perp}$) and λ_{max}.

4.3 ISP Subtraction

Once λ_{max} and $ISP_{\perp}$ values were determined, the ISP contribution at each wavelength could be found and ultimately subtracted from Pol_{Tot} to leave only Pol_{Intr}. The PA-dependent equations for Q and U that were used for the field star ISP estimates were rearranged to solve for $ISP_{\parallel}$:

$$ISP_{\parallel} = \frac{ISP_{\perp}}{\tan(2\,PA_{fs})} ,$$

using each of the four PA_{fs} values in TABLE 3. The average total ISP was then computed simply as the vector of the perpendicular and parallel ISP's:

$$ISP_{Tot} = \sqrt{ISP_{\perp}^2 + ISP_{\parallel}^2} .$$

TABLE 4 displays the calculated values for each of the four PA_{fs} estimates.

TABLE 4

Method	PA_{fs} (°)	$ISP_{\parallel}$ (%)	ISP_{Tot} (%)
Distance (7)	27.857947	0.540943	0.960316
Error (7)	19.626629	0.971041	1.253997
Error (2)	32.072476	0.384517	0.881726
Error (4)	21.552112	0.847790	1.161180

TABLE 4.— $ISP_{\parallel}$ and ISP_{Tot} values for each of the four field star PA_{fs} estimates.

The wavelength dependence of the ISP could then be calculated by using each ISP_{Tot} value in place of $ISP_{\perp}$ in the original Serkowski Law equation, as:

$$ISP(\lambda) = ISP_{Tot}\ \exp\left[-K \ln^2\left(\frac{\lambda_{max}}{\lambda}\right)\right] .$$

The wavelength-dependent $ISP(\lambda)$ can be separated into $Q_{ISP}(\lambda)$ and $U_{ISP}(\lambda)$ with:

$$Q_{ISP}(\lambda) = ISP(\lambda)\, cos(2\,PA) \qquad \text{and} \qquad U_{ISP}(\lambda) = ISP(\lambda)\, sin(2\,PA) \ .$$

Finally, intrinsic Q and U values can be calculated with a simple subtraction:

$$Q_{Intr}(\lambda) = Q(\lambda) - Q_{ISP}(\lambda) \qquad \text{and} \qquad U_{Intr}(\lambda) = U(\lambda) - U_{ISP}(\lambda) \ ,$$

where $Q(\lambda)$ and $U(\lambda)$ are the original data from which the ISP needed to be subtracted. This method was applied to each set of blue and red grating data separately, for each observation night, and for each of the four PA_{fs} values. The resulting $Q(\lambda)$ and $U(\lambda)$ will henceforth be considered ISP-subtracted, and were ready to be run through the PFIL routine as representing intrinsic Q and U data coming strictly from the disk. As a comparison to the original data, TABLE 5 displays results from PFIL of subtracted (intrinsic) data using the PA_{fs} value from the Distance Weighted Average Method ($PA_{fs} = 27.857947°$).

TABLE 5

Date	Filter	Q_{Intr}(%)	U_{Intr}(%)	Pol_{Intr}(%)	Pol_{Intr} error (%)	PA_{Intr}(°)	PA_{Intr} error (°)
1995 May 19	UX	-5.0689384	-0.65127452	5.1106062	0.11334454	-86.339272	0.63536134
	B	-0.72722688	0.18445455	0.7502549	0.01579062	82.883787	0.60295229
	V	-0.82786298	-0.022518265	0.82816918	0.0071915399	-89.220951	0.24876853
	R	-0.80661447	-0.2057865	0.83245119	0.003836375	-82.843891	0.13202461
	I	-0.91745086	5.6963222E-4	0.91745104	0.0053950901	89.982208	0.16846451
1995 Jun 21	UX	8.7729226	-2.4474571	9.1079206	0.045334798	-7.7939802	0.14259525
	B	-0.59005853	0.12294707	0.60273132	0.055714627	84.115003	2.6481225
	V	-0.95546474	0.017332044	0.95562192	0.013850268	89.480382	0.41520702
	R	-0.87603359	-0.1552455	0.8896831	0.0057940188	-84.975351	0.18656801
	I	-0.94330823	0.016737931	0.94345672	0.0062315007	89.491724	0.18921836

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1995 Jul 02	UX	-0.74738235	1.8324903	1.9790404	0.45206681	56.094059	6.5439591
	B	-0.86142813	0.20720816	0.88599867	0.02956735	83.237496	0.95603093
	V	-0.90944682	0.083036543	0.91322976	0.0095266255	87.391548	0.29884889
	R	-0.80871244	-0.13089575	0.81923715	0.0049424726	-85.403001	0.17283323
	I	-0.90035084	0.038257687	0.90116329	0.0067701748	88.783422	0.21522316
1995 Jul 08	UX	-0.50739648	0.91990534	1.0505603	0.15590665	59.440005	4.2514419
	B	-0.76051771	0.07429547	0.76413808	0.011135753	87.210216	0.41748449
	V	-0.89378905	0.097294147	0.89906897	0.0063507911	86.893736	0.20236128
	R	-0.84208976	-0.095677786	0.84750776	0.0039460288	-86.758936	0.13338567
	I	-0.88610948	0.032227411	0.88669534	0.0073224342	88.958543	0.23657762
1995 Jul 24	UX	-0.37974699	-0.43769391	0.57946849	0.044564155	-65.472591	2.2031723
	B	-0.50540811	0.14554261	0.52594678	0.05454118	81.967577	2.9708132
	V	-0.8721647	0.23978241	0.90452577	0.021746282	82.31379	0.68874217
	R	-0.84253241	-0.11852131	0.85082792	0.0094632984	-85.996291	0.31863495
	I	-0.97520109	0.11906713	0.98244295	0.0079431923	86.519459	0.23162229
1995 Jul 31	UX	-0.23407183	1.4617643	1.4803866	0.28829331	49.548758	5.5789442
	B	-0.83785445	0.11310285	0.84545393	0.021982505	86.156023	0.74486891
	V	-0.87442095	0.084130743	0.87845887	0.0084894167	87.252151	0.27685287
	R	-0.83199459	-0.1077917	0.83894818	0.0044804075	-86.308987	0.15299421
	I	-0.90984378	0.048789859	0.91115101	0.0070315051	88.465238	0.22108056
1995 Aug 21	UX	-0.76382758	-0.022926095	0.76417156	0.17219116	-89.140394	6.4552432
	B	-0.71034928	0.13491692	0.72304819	0.015834442	84.622936	0.62737636
	V	-0.85486548	0.11063998	0.86199547	0.0054021406	86.312771	0.17953681
	R	-0.81077792	-0.11636679	0.81908612	0.0032291028	-85.9162	0.11293926
	I	-0.91209813	0.029021514	0.91255972	0.0061647568	89.088772	0.19352954
1995 Aug 26	UX	-0.25853798	0.42485924	0.49734019	0.10617498	60.660801	6.1159124
	B	-0.74755632	0.12074225	0.75724444	0.018831495	85.412523	0.71242855
	V	-0.86210216	-0.014319046	0.86222107	0.008058804	-89.524213	0.26775931
	R	-0.81385768	-0.17153673	0.83173865	0.004050285	-84.048984	0.1395055
	I	-0.91726376	0.01573189	0.91739866	0.0058961126	89.508706	0.18411971
1996 Jul 05	UX	-0.54199986	-0.3328754	0.63605808	0.068671506	-74.221675	3.0929465
	B	-0.81986913	0.017675365	0.82005964	0.012929707	89.382478	0.45168518
	V	-0.93915713	0.070754965	0.94181866	0.0053545886	87.845767	0.16287388
	R	-0.88325234	-0.10175897	0.88909481	0.0032344064	-86.713977	0.10421713
	I	-0.96704206	0.086692131	0.97092012	0.0057409528	87.438653	0.16939207
1996 Sep 14	UX	-0.36623587	0.10295255	0.38043126	0.22751485	82.149395	17.132714
	B	-0.87578942	0.061202054	0.87792528	0.015329845	88.001268	0.50023355
	V	-0.9720288	0.055560571	0.97361541	0.0067291845	88.364279	0.1980011
	R	-0.88428712	-0.10561316	0.89057164	0.0037398512	-86.594619	0.12030345
	I	-0.9606747	0.087211513	0.96462518	0.0057153547	87.406405	0.16973727
1997 Sep 05	UX	-3.0626646	0.17376171	3.0675899	0.073050715	88.376384	0.68221268
	B	-0.88612078	0.13941832	0.89702146	0.032518356	85.529312	1.0385283
	V	-0.90439472	0.21104767	0.92869313	0.0094736249	83.432316	0.29223792
	R	-0.8508641	-0.0034578431	0.85087113	0.0058317354	-89.883573	0.19634807
	I	-0.88533913	0.13906188	0.89619395	0.01062777	85.536685	0.33972911
1997 Sep 13	UX	3.3265948	0.34932727	3.344886	0.19658298	2.9973428	1.6836709
	B	-0.70646923	0.041404674	0.70768151	0.014810833	88.322921	0.5995622
	V	-0.78961169	0.11525872	0.79797944	0.0071345185	85.847621	0.25613302
	R	-0.77804209	-0.028474803	0.77856298	0.0045425307	-88.952007	0.16714629
	I	-0.73887629	0.028281171	0.73941734	0.0072109625	88.904006	0.27938058
1998 Jul 31	UX	-0.56534551	-0.056178198	0.56812986	0.27751271	-87.162579	13.993549
	B	-0.71767535	0.28724345	0.77302438	0.036209459	79.093328	1.341904
	V	-0.81437174	0.18979809	0.83619653	0.010917016	83.44039	0.37401428
	R	-0.86898693	0.11967199	0.87718851	0.0061298543	86.07943	0.20019344
	I	-0.89678051	0.069164162	0.8994437	0.006810368	87.794893	0.21691481
1998 Aug 01	UX	0.61127732	-0.91103312	1.0971059	0.3044563	-28.069754	7.9500349
	B	-0.80041644	0.028736371	0.80093211	0.016748283	88.971927	0.59905569
	V	-0.85655744	0.13319585	0.86685165	0.0075922428	85.580604	0.25090997
	R	-0.84673567	0.12639146	0.85611687	0.0049535747	85.755093	0.16575944
	I	-0.81987645	0.06823593	0.82271109	0.0061941999	87.621197	0.21569023
1998 Aug 09	UX	0.42287182	-0.3133364	0.52630816	0.5519958	-18.268714	30.046112
	B	-0.59942227	-0.039515932	0.60072337	0.062906374	-88.114159	2.9999411
	V	-0.64417652	0.13567273	0.6583088	0.015082968	84.053255	0.65637157
	R	-0.63409441	0.11390459	0.64424372	0.0093069259	84.908179	0.41385544
	I	-0.56714336	0.01126024	0.56725513	0.012193162	89.431286	0.61578703

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1998 Aug 12	UX	0.7083716	1.3012849	1.4815981	0.60325354	30.718876	11.664392
	B	-0.43667146	-0.054197628	0.44002198	0.095029593	-86.462443	6.1869572
	V	-0.70013925	0.18535772	0.72425994	0.016781409	82.585733	0.6637837
	R	-0.82075502	0.10134628	0.82698843	0.0080227051	86.480389	0.27791629
	I	-0.77855371	0.045301242	0.77987055	0.0078290549	88.334955	0.28759374
1998 Aug 17	UX	-1.258782	-0.93299165	1.5668457	0.39402475	-71.727333	7.2042683
	B	-0.70539735	-0.06319899	0.7082228	0.036134804	-87.440166	1.4616669
	V	-0.91195973	0.047720472	0.91320742	0.010520686	88.502292	0.33004049
	R	-0.90803785	0.069373405	0.91068403	0.0057890021	87.815562	0.18210782
	I	-0.86952693	0.014094176	0.86964115	0.0066397212	89.535682	0.21872699
1998 Aug 18	UX	-1.0988763	0.049982748	1.1000125	0.36496534	88.697834	9.5048797
	B	-0.6017044	0.14702398	0.61940636	0.032346695	83.134527	1.4960526
	V	-0.86131103	0.14639927	0.87366437	0.01141041	85.176736	0.37415301
	R	-0.93654398	0.11679455	0.94379849	0.0063734685	86.445723	0.19345911
	I	-0.84304677	0.053924221	0.8447696	0.0070608693	88.170069	0.23944871
1998 Aug 30	UX	-2.5202055	-0.17560463	2.526316	0.24191701	-88.007069	2.7432875
	B	-0.58689115	-0.02191799	0.58730028	0.019516614	-88.93061	0.95199987
	V	-0.88132571	0.061208204	0.88344861	0.0084940439	88.013584	0.27543925
	R	-0.89060481	0.073345842	0.89361991	0.0052054785	87.646008	0.16687852
	I	-0.8692547	0.013779261	0.8693639	0.0062701996	89.545912	0.20662001
1998 Sep 05	UX	-1.1357088	0.88709567	1.4411014	0.40870351	71.0034	8.1246832
	B	-0.84349191	-0.012409379	0.84358319	0.038220893	-89.57856	1.2979726
	V	-0.81305324	0.017928402	0.81325089	0.011173533	89.368391	0.39360318
	R	-0.74283335	0.035153861	0.7436647	0.0065224118	88.645273	0.25126018
	I	-0.68896611	0.0082660944	0.6890157	0.0079276831	89.656299	0.32961713
2012 May 14	UX	-37.02791	-10.825322	38.577891	3.9085932	-81.851704	2.9025159
	B	-0.83128003	0.36272743	0.9069717	0.03379254	78.213017	1.0673816
	V	-0.86684875	0.18607076	0.88659409	0.0088232825	83.942587	0.28510049
	R	-0.90670881	0.14106898	0.9176172	0.0051883289	85.578305	0.16197895
	I	-0.87695125	0.088692011	0.88142485	0.0060040778	87.112459	0.1951433
2012 May 15	UX	14.168004	-5.2931177	15.124465	1.5550264	-10.242757	2.9454412
	B	-0.65834564	0.069690458	0.66202397	0.015215654	86.978669	0.65842985
	V	-0.84496982	0.12778263	0.85457732	0.0059992679	85.700229	0.2011127
	R	-0.91487244	0.10590063	0.92098128	0.0042817335	86.698565	0.13318688
	I	-0.89751823	0.072587872	0.90044876	0.005807537	87.688094	0.1847675
2012 May 17	UX	-8.4117455	-3.2711056	9.0253861	3.3466306	-79.375124	10.622692
	B	-0.66408661	0.044103889	0.66554954	0.020042929	88.100197	0.86272705
	V	-0.78552866	0.1253906	0.79547349	0.0072817233	85.465311	0.26224129
	R	-0.8819318	0.1295427	0.89139498	0.0046220859	85.821922	0.14854582
	I	-0.84696002	0.079161173	0.85065138	0.0060314459	87.330175	0.20312456
2012 May 18	UX	12.266793	-2.862004	12.596241	1.5099133	-6.5664619	3.4340267
	B	-0.67776819	0.020973909	0.67809264	0.020378291	89.113753	0.86093695
	V	-0.82545516	0.092032217	0.83056977	0.0070374605	86.819102	0.24273503
	R	-0.88120012	0.094954384	0.8863013	0.0044800729	86.924886	0.14480925
	I	-0.85221614	0.060124347	0.85433441	0.0056431829	87.982213	0.1892295
2012 Jul 11	UX	-5.0871553	-9.1198627	10.442751	1.5111117	-59.576616	4.1454747
	B	-0.69943615	0.042681496	0.70073721	0.019501738	88.253988	0.79727979
	V	-0.83374686	0.080599057	0.83763359	0.0065537769	87.239157	0.22414558
	R	-0.87239708	0.046464114	0.87363355	0.0037474602	88.475641	0.12288541
	I	-0.85448142	-0.0040170581	0.85449086	0.0046604735	-89.865318	0.15624827
2012 Jul 13	UX	22.825044	111.9989	114.30107	8.1641367	39.240515	2.0462212
	B	-0.40330784	-0.21986857	0.45934671	0.031075587	-75.701201	1.9380784
	V	-0.83258878	0.047589146	0.83394772	0.0082367673	88.364318	0.28295058
	R	-0.86116959	0.031302284	0.86173829	0.0044597869	88.959144	0.1482625
	I	-0.85417336	0.0052528402	0.85418951	0.0050737435	89.823824	0.17016368
2012 Jul 14	UX	-11.431431	-1.3326321	11.508846	1.1444954	-86.675341	2.8488849
	B	-0.67943798	0.22087645	0.7144385	0.015135065	80.995661	0.60689287
	V	-0.88421168	0.1702276	0.90044862	0.0061277713	84.551393	0.19495583
	R	-0.92276091	0.12697869	0.93145654	0.0038808665	86.082439	0.11935998
	I	-0.89920671	0.052273735	0.90072485	0.0049140612	88.336475	0.15629354
2012 Jul 16	UX	16.697535	8.153059	18.581713	1.4335141	13.012647	2.2100843
	B	-0.7276765	-0.051662915	0.72950815	0.019286121	-87.969485	0.75736871
	V	-0.82037174	0.044754691	0.82159161	0.0070084826	88.438681	0.24437716
	R	-0.88725062	0.04685098	0.88848673	0.0041008821	88.488656	0.13222664
	I	-0.86757493	0.017319387	0.86774779	0.0047403478	89.428174	0.15649819

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2012 Jul 17	UX	19.141542	-6.6194334	20.253779	2.4759436	-9.5380772	3.50209
	B	-0.76294138	-0.033747737	0.76368741	0.033508335	-88.733618	1.2569842
	V	-0.89316978	0.029112302	0.8936441	0.0086569265	89.066566	0.27751838
	R	-0.90348712	0.013218341	0.90358381	0.0052570698	89.580896	0.16667402
	I	-0.85037145	-0.0011235922	0.85037219	0.0063105203	-89.962143	0.21259289

TABLE 5.— Results from PFIL routine for subtracted (intrinsic) data. Data calculated with PA_{fs} = 27.857947° (Distance Weighted Average (7) Method).

In addition, a comparison may be made between the intrinsic data from the Distance Weighted Average Method and the Error Weighted Average Method to demonstrate how little the final data sets varied as a result of the different ISP estimate calculations. The intrinsic data from the Error Weighted Average Method ($PA_{fs} = 19.626629°$) is displayed in TABLE 6.

TABLE 6

Date	Filter	Q_{Intr}(%)	U_{Intr}(%)	Pol_{Intr}(%)	Pol_{Intr} error (%)	PA_{Intr}(°)	PA_{Intr} error (°)
1995 May 19	UX	-5.3962417	-0.65127453	5.4354009	0.11334454	-86.559113	0.59739505
	B	-1.111673	0.18445454	1.1268719	0.01579062	85.289505	0.40143684
	V	-1.2514567	-0.02251828	1.2516593	0.0071915399	-89.48457	0.16459945
	R	-1.2351031	-0.20578651	1.2521293	0.003836375	-85.270279	0.087773719
	I	-1.328895	0.00056962	1.3288952	0.0053950901	89.987715	0.11630559
1995 Jun 21	UX	8.4475666	-2.4474571	8.7949661	0.045334798	-8.0787673	0.14766927
	B	-0.97547375	0.12294706	0.98319124	0.055714627	86.408203	1.6233936
	V	-1.3793134	0.017332029	1.3794223	0.013850268	89.640033	0.28764282
	R	-1.3044192	-0.15524551	1.313625	0.0057940188	-86.606428	0.12635752
	I	-1.3546013	0.016737917	1.3547047	0.0062315007	89.64603	0.13177731
1995 Jul 02	UX	-1.0748548	1.8324902	2.1244607	0.45206681	60.196962	6.0960222
	B	-1.2469031	0.20720815	1.2640026	0.02956735	85.28245	0.67012689
	V	-1.3331784	0.08303653	1.3357619	0.0095266255	88.217974	0.20431613
	R	-1.2371059	-0.13089577	1.2440115	0.0049424726	-86.980054	0.1138184
	I	-1.3112506	0.038257673	1.3118086	0.0067701748	89.164388	0.14785024
1995 Jul 08	UX	-0.83812625	0.91990533	1.2444603	0.15590665	66.168331	3.5890227
	B	-1.1438373	0.074295457	1.1462476	0.011135753	88.141844	0.27831317
	V	-1.3172115	0.097294132	1.3207999	0.0063507911	87.887791	0.1377474
	R	-1.270712	-0.095677801	1.2743089	0.0039460288	-87.847025	0.088711139
	I	-1.2974252	0.032227397	1.2978254	0.0073224342	89.288542	0.16163366
1995 Jul 24	UX	-0.70723512	-0.43769392	0.83171959	0.044564155	-74.123721	1.5349752
	B	-0.89002401	0.14554259	0.90184554	0.05454118	85.356404	1.7325468
	V	-1.2957825	0.2397824	1.3177814	0.021746282	84.758047	0.47275294
	R	-1.271023	-0.11852132	1.276537	0.0094632984	-87.336318	0.2123742
	I	-1.3865902	0.11906712	1.3916929	0.0079431923	87.546008	0.16350998
1995 Jul 31	UX	-0.562567	1.4617643	1.5662811	0.28829331	55.524727	5.2729962
	B	-1.2223914	0.11310284	1.2276127	0.021982505	87.35685	0.51298941
	V	-1.2980092	0.084130729	1.3007328	0.0084894167	88.14577	0.18697449
	R	-1.2605784	-0.10779171	1.2651786	0.0044804075	-87.556267	0.10145146
	I	-1.3213484	0.048789845	1.3222488	0.0070315051	88.942673	0.15234483
1995 Aug 21	UX	-1.0907499	-0.022926102	1.0909909	0.17219116	-89.397943	4.5214982
	B	-1.096011	0.1349169	1.1042837	0.015834442	86.491146	0.41078513
	V	-1.2785365	0.11063997	1.2833147	0.0054021406	87.52707	0.12059389
	R	-1.2394059	-0.1163668	1.2448567	0.0032291028	-87.31813	0.074311344
	I	-1.3238073	0.0290215	1.3241254	0.0061647568	89.372055	0.13337654
1995 Aug 26	UX	-0.58578932	0.42485923	0.72363975	0.10617498	72.023749	4.2033194
	B	-1.1305503	0.12074223	1.1369797	0.018831495	86.951968	0.47448743
	V	-1.2855785	-0.01431906	1.2856582	0.008058804	-89.680922	0.17957161
	R	-1.2422924	-0.17153674	1.2540794	0.004050285	-86.069128	0.092523733
	I	-1.3287884	0.015731876	1.3288815	0.0058961126	89.660841	0.12710778

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1996 Jul 05	UX	-0.87079361	-0.33287541	0.93224865	0.068671506	-79.5399	2.1102671
	B	-1.2051155	0.017675352	1.2052451	0.012929707	89.579848	0.30733066
	V	-1.362864	0.070754951	1.3646994	0.0053545886	88.514035	0.11240399
	R	-1.3116989	-0.10175898	1.3156402	0.0032344064	-87.781992	0.070428766
	I	-1.3783732	0.086692117	1.3810967	0.0057409528	88.20057	0.11908375
1996 Sep 14	UX	-0.69398129	0.10295254	0.70157626	0.22751485	85.780836	9.2902517
	B	-1.2608784	0.061202042	1.2623629	0.015329845	88.61054	0.34789338
	V	-1.395612	0.055560557	1.3967175	0.0067291845	88.860099	0.13802141
	R	-1.3127137	-0.10561317	1.3169554	0.0037398512	-87.700109	0.081353433
	I	-1.3720332	0.087211499	1.3748021	0.0057153547	88.181476	0.11909557
1997 Sep 05	UX	-3.3768887	0.17376171	3.3813563	0.073050715	88.527184	0.61890807
	B	-1.2711898	0.13941831	1.2788123	0.032518356	86.870533	0.72847455
	V	-1.3280905	0.21104766	1.3447548	0.0094736249	85.485292	0.2018207
	R	-1.2790976	-0.0034578568	1.2791023	0.0058317354	-89.92255	0.13061262
	I	-1.2953538	0.13906187	1.3027968	0.01062777	86.936253	0.23369966
1997 Sep 13	UX	2.9980531	0.34932726	3.018336	0.19658298	3.3230115	1.8658252
	B	-1.0899987	0.041404661	1.0907848	0.014810833	88.9123	0.38898513
	V	-1.2130471	0.1152587	1.2185105	0.0071345185	87.286139	0.16773666
	R	-1.2064844	-0.028474818	1.2068204	0.0045425307	-89.323988	0.10783205
	I	-1.1495514	0.028281156	1.1498992	0.0072109625	89.295345	0.17964952
1998 Jul 31	UX	-0.91434032	-0.056178211	0.91606452	0.27751271	-88.242043	8.6785951
	B	-1.1024426	0.28724344	1.1392491	0.036209459	82.698082	0.91053358
	V	-1.2381354	0.18979807	1.2525983	0.010917016	85.642383	0.24968056
	R	-1.2948736	0.11967198	1.3003919	0.0061298543	87.359862	0.13504189
	I	-1.2952627	0.069164148	1.297108	0.006810368	88.471713	0.15041358
1998 Aug 01	UX	0.27625064	-0.91103313	0.95199568	0.3044563	-36.565615	9.1618378
	B	-1.1835499	0.028736358	1.1838987	0.016748283	89.304567	0.40527365
	V	-1.2800398	0.13319584	1.2869511	0.0075922428	87.0297	0.16900543
	R	-1.2726726	0.12639144	1.2789333	0.0049535747	87.164219	0.11095923
	I	-1.2181658	0.068235917	1.2200754	0.0061941999	88.39695	0.14544244
1998 Aug 09	UX	0.072712015	-0.31333641	0.32166247	0.5519958	-38.467663	49.161825
	B	-0.98362151	-0.039515945	0.98441495	0.062906374	-88.849715	1.8306658
	V	-1.067887	0.13567272	1.076471	0.015082968	86.379738	0.40139975
	R	-1.059345	0.11390457	1.0654511	0.0093069259	86.931461	0.25024496
	I	-0.96492392	0.011260227	0.96498962	0.012193162	89.665702	0.36198146
1998 Aug 12	UX	0.35590842	1.3012849	1.3490787	0.60325354	37.351695	12.81018
	B	-0.82051598	-0.054197644	0.822304	0.095029593	-88.110457	3.3106943
	V	-1.1239618	0.18535771	1.1391434	0.016781409	85.317685	0.42202936
	R	-1.2462454	0.10134627	1.2503594	0.0080227051	87.675427	0.183814
	I	-1.1765816	0.045301228	1.1774533	0.0078290549	88.897527	0.19048389
1998 Aug 17	UX	-1.6035211	-0.93299166	1.8551963	0.39402475	-74.903732	6.0845187
	B	-1.0895444	-0.063199003	1.0913758	0.036134804	-88.340135	0.94851454
	V	-1.3356413	0.047720458	1.3364935	0.010520686	88.976884	0.22551208
	R	-1.3339808	0.069373391	1.3357834	0.0057890021	88.511509	0.12415387
	I	-1.2679192	0.014094163	1.2679976	0.0066397212	89.681559	0.15001132
1998 Aug 18	UX	-1.4445611	0.049982735	1.4454256	0.36496534	89.009155	7.2335002
	B	-0.98538754	0.14702396	0.99629546	0.032346695	85.756911	0.93011014
	V	-1.2849982	0.14639926	1.2933109	0.01141041	86.750167	0.25274986
	R	-1.3625241	0.11679454	1.3675207	0.0063734685	87.550308	0.13351638
	I	-1.2414528	0.053924208	1.2426234	0.0070608693	88.756416	0.16278383
1998 Aug 30	UX	-2.8564542	-0.17560464	2.8618468	0.24191701	-88.241039	2.421657
	B	-0.97040639	-0.021918005	0.97065388	0.019516614	-89.353052	0.57601355
	V	-1.304988	0.061208189	1.3064226	0.0084940439	88.6573	0.18626164
	R	-1.3167298	0.073345828	1.318771	0.0052054785	88.405869	0.1130795
	I	-1.2677712	0.013779247	1.2678461	0.0062701996	89.688637	0.14167964
1998 Sep 05	UX	-1.4826483	0.88709566	1.7277687	0.40870351	74.553567	6.7766552
	B	-1.2283099	-0.012409394	1.2283726	0.038220893	-89.71058	0.89138089
	V	-1.2367923	0.017928389	1.2369223	0.011173533	89.584748	0.25878597
	R	-1.1687005	0.035153847	1.1692291	0.0065224118	89.138543	0.15980899
	I	-1.087332	0.0082660807	1.0873634	0.0079276831	89.782213	0.20886429
2012 May 14	UX	-37.34616	-10.825322	38.883458	3.9085932	-81.9175	2.8797064
	B	-1.2177446	0.36272741	1.2706192	0.03379254	81.706435	0.76190011
	V	-1.2909238	0.18607075	1.3042647	0.0088232825	85.899	0.19380146

Table continued on next page....

	R	-1.3321765	0.14106897	1.3396248	0.0051883289	86.97763	0.11095246
	I	-1.2741859	0.088691997	1.2772689	0.0060040778	88.009118	0.13466557
2012 May 15	UX	13.847448	-5.2931177	14.824605	1.5550264	-10.459552	3.0050192
	B	-1.0436437	0.069690445	1.045968	0.015215654	88.089837	0.41673967
	V	-1.2686729	0.12778262	1.2750919	0.0059992679	87.124236	0.13478743
	R	-1.3401132	0.10590062	1.344291	0.0042817335	87.74083	0.091247074
	I	-1.294293	0.072587859	1.2963268	0.005807537	88.395016	0.12834238
2012 May 17	UX	-8.7312589	-3.2711056	9.3238948	3.3466306	-79.730939	10.282602
	B	-1.0484264	0.044103878	1.0493536	0.020042929	88.795582	0.54718217
	V	-1.2092345	0.12539058	1.2157182	0.0072817233	87.039955	0.17159074
	R	-1.3077849	0.12954269	1.3141852	0.0046220859	87.171504	0.10075673
	I	-1.2445419	0.07916116	1.2470569	0.0060314459	88.18025	0.13855678
2012 May 18	UX	11.942487	-2.862004	12.280638	1.5099133	-6.7383551	3.5222786
	B	-1.0633481	0.020973896	1.063555	0.020378291	89.435006	0.54890911
	V	-1.249262	0.092032202	1.2526474	0.0070374605	87.893332	0.16094584
	R	-1.306963	0.094954369	1.3104078	0.0044800729	87.9223	0.097942509
	I	-1.2497824	0.060124333	1.2512278	0.0056431829	88.622869	0.12920531
2012 Jul 11	UX	-5.4082417	-9.1198627	10.602876	1.5111117	-60.334346	4.0828697
	B	-1.0863672	0.042681482	1.0872053	0.019501738	88.875048	0.51387132
	V	-1.2576555	0.080599043	1.2602355	0.0065537769	88.166553	0.14898158
	R	-1.2978512	0.046464099	1.2986827	0.0037474602	88.974816	0.082665936
	I	-1.2517353	-0.0040170715	1.2517418	0.0046604735	-89.908059	0.10666156
2012 Jul 13	UX	22.514899	111.9989	114.23954	8.1641367	39.316724	2.0473232
	B	-0.79142814	-0.21986858	0.82140167	0.031075587	-82.237018	1.083818
	V	-1.256563	0.047589132	1.2574638	0.0082367673	88.915547	0.18765231
	R	-1.2865896	0.031302269	1.2869704	0.0044597869	89.30314	0.099274605
	I	-1.2514627	0.0052528272	1.2514737	0.0050737435	89.879751	0.11614469
2012 Jul 14	UX	-11.740145	-1.3326321	11.815537	1.1444954	-86.762013	2.7749374
	B	-1.0656456	0.22087644	1.0882955	0.015135065	84.145051	0.39840985
	V	-1.3079952	0.17022758	1.3190258	0.0061277713	86.292486	0.13308891
	R	-1.3485001	0.12697867	1.3544652	0.0038808665	87.310358	0.082083046
	I	-1.2966828	0.052273721	1.2977361	0.0049140612	88.845726	0.10847928
2012 Jul 16	UX	16.382104	8.153059	18.29879	1.4335141	13.229324	2.244255
	B	-1.1137588	-0.051662929	1.1149564	0.019286121	-88.672083	0.49554104
	V	-1.2442335	0.044754676	1.2450381	0.0070084826	88.969984	0.16126271
	R	-1.3128215	0.046850966	1.3136573	0.0041008821	88.978065	0.089430947
	I	-1.26486	0.017319374	1.2649785	0.0047403478	89.607752	0.10735435
2012 Jul 17	UX	18.838684	-6.6194334	19.967797	2.4759436	-9.6800873	3.5522475
	B	-1.1486335	-0.03374775	1.1491292	0.033508335	-89.15854	0.83536566
	V	-1.3170691	0.029112287	1.3173908	0.0086569265	89.36687	0.18825292
	R	-1.3289287	0.013218327	1.3289945	0.0052570698	89.715055	0.11332173
	I	-1.2474754	-0.0011236058	1.2474759	0.0063105203	-89.974192	0.1449191

TABLE 6.— Results from PFIL routine for subtracted (intrinsic) data. Data calculated with PA_{fs} = 19.626629° (Error Weighted Average (7) Method).

5 Phase Analysis

Once the intrinsic polarization data was separated from the ISP, the polarization and position angle of the disk could be analyzed throughout the phase of V356 Sgr's orbit in order to discover properties of the stellar-disk system. Because four methods were used to determine the field star ISP estimates, and four sets of ISP were subtracted from the original data, there were four resulting sets of intrinsic data. The field star position angle estimates ranged from $\sim 19° - 32°$, causing different intrinsic data sets that each represent a possibly real data set. Because a true field star position angle is unknown, all four sets of data will be displayed below.

The Polarization vs. Phase and Position Angle vs. Phase plots that follow assist in revealing information about the disk of V356 Sgr, including possible clumps that reside within, how far the disk stretches around one or both stars, and other physical characteristics. Figures 11-18 show Polarization vs. Phase and Position Angle vs. Phase plots for each of the four intrinsic data sets that resulted from the four ISP estimation methods.

FIGURE 11

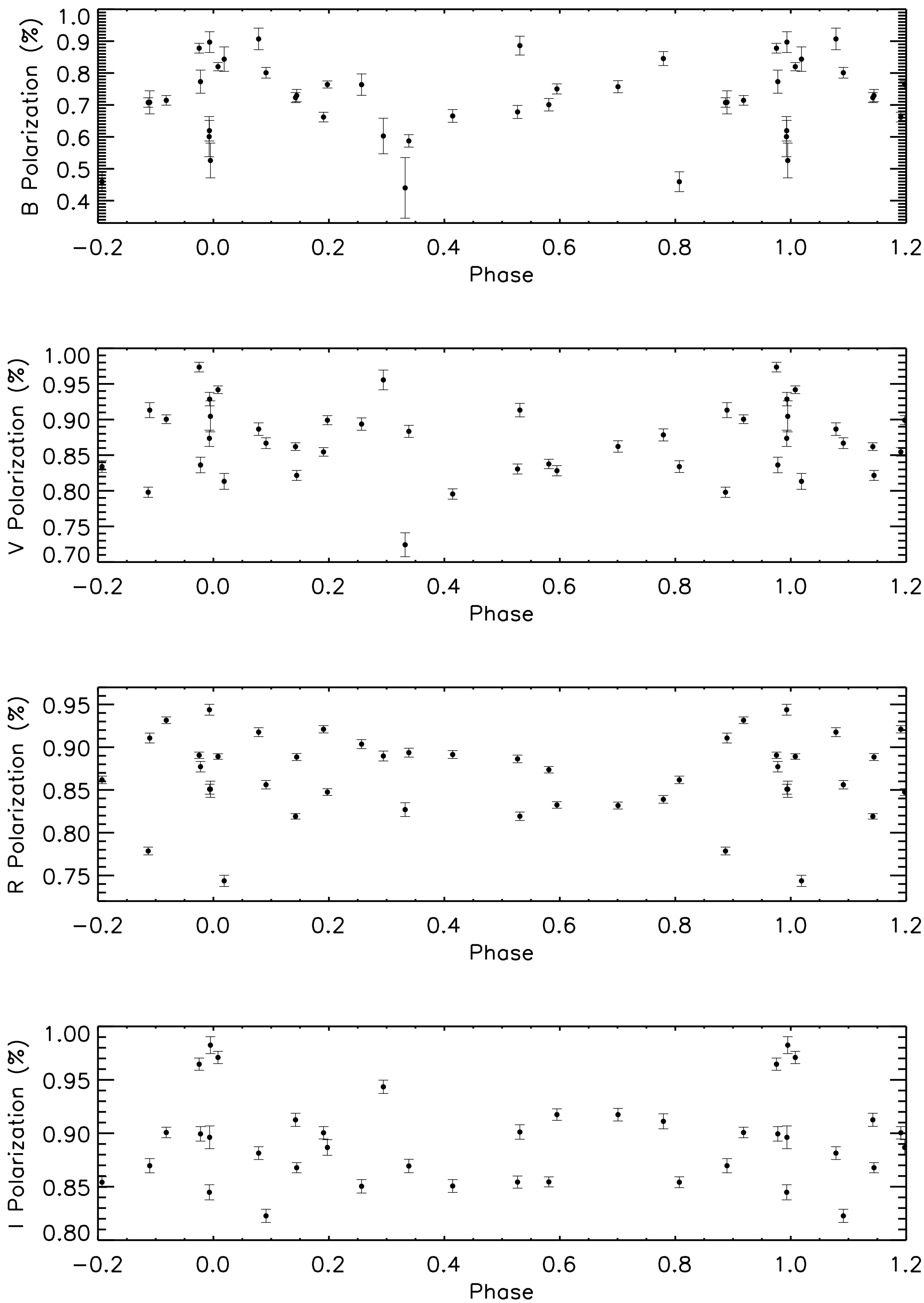

FIGURE 11.— *BVRI* intrinsic polarization variation over more than one phase of the system. Data calculated with $PA_{fs} = 27.857947°$.

FIGURE 12

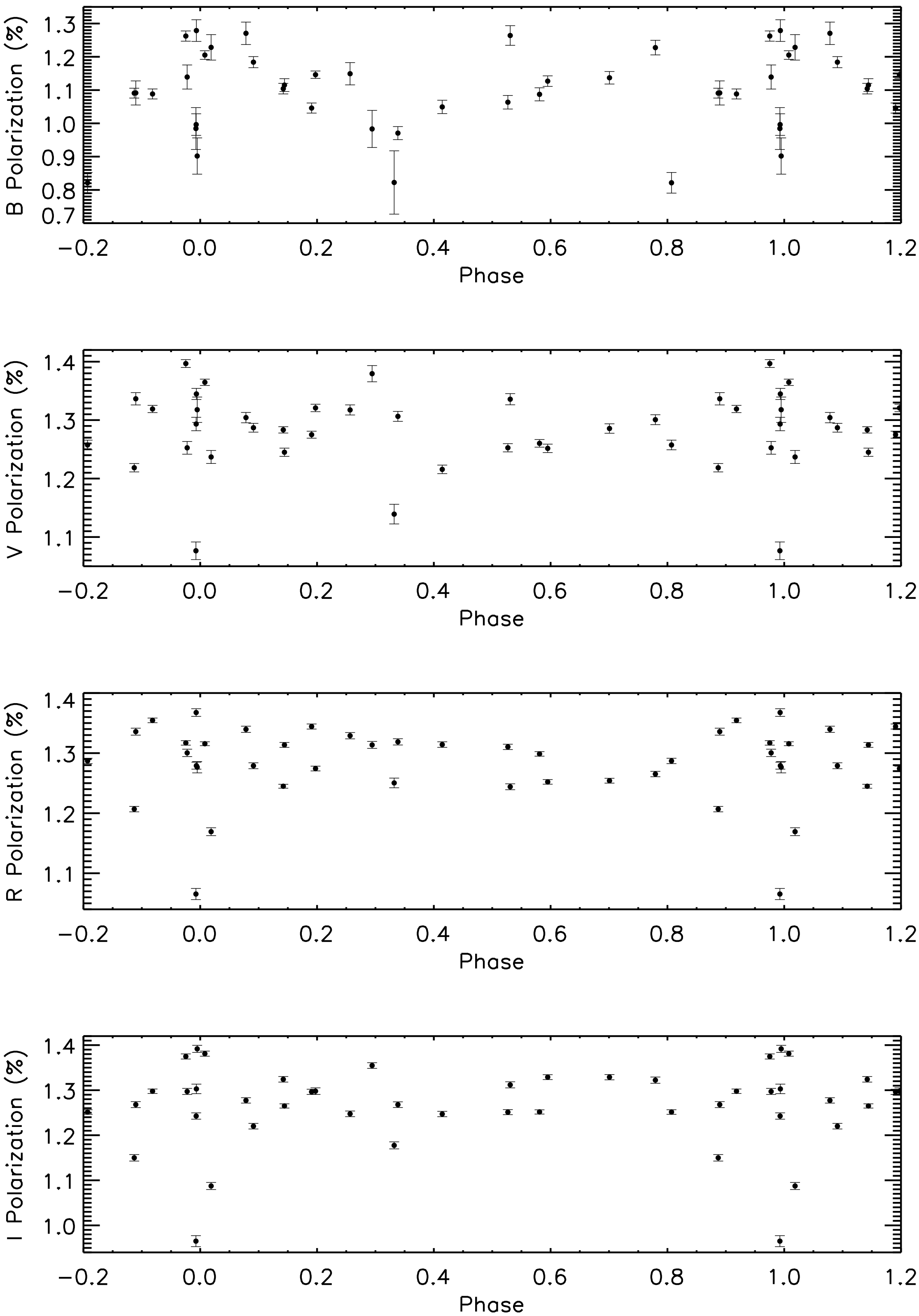

FIGURE 12.— *BVRI* intrinsic polarization variation over more than one phase of the system. Data calculated with $PA_{fs} = 19.626629°$.

Figure 13

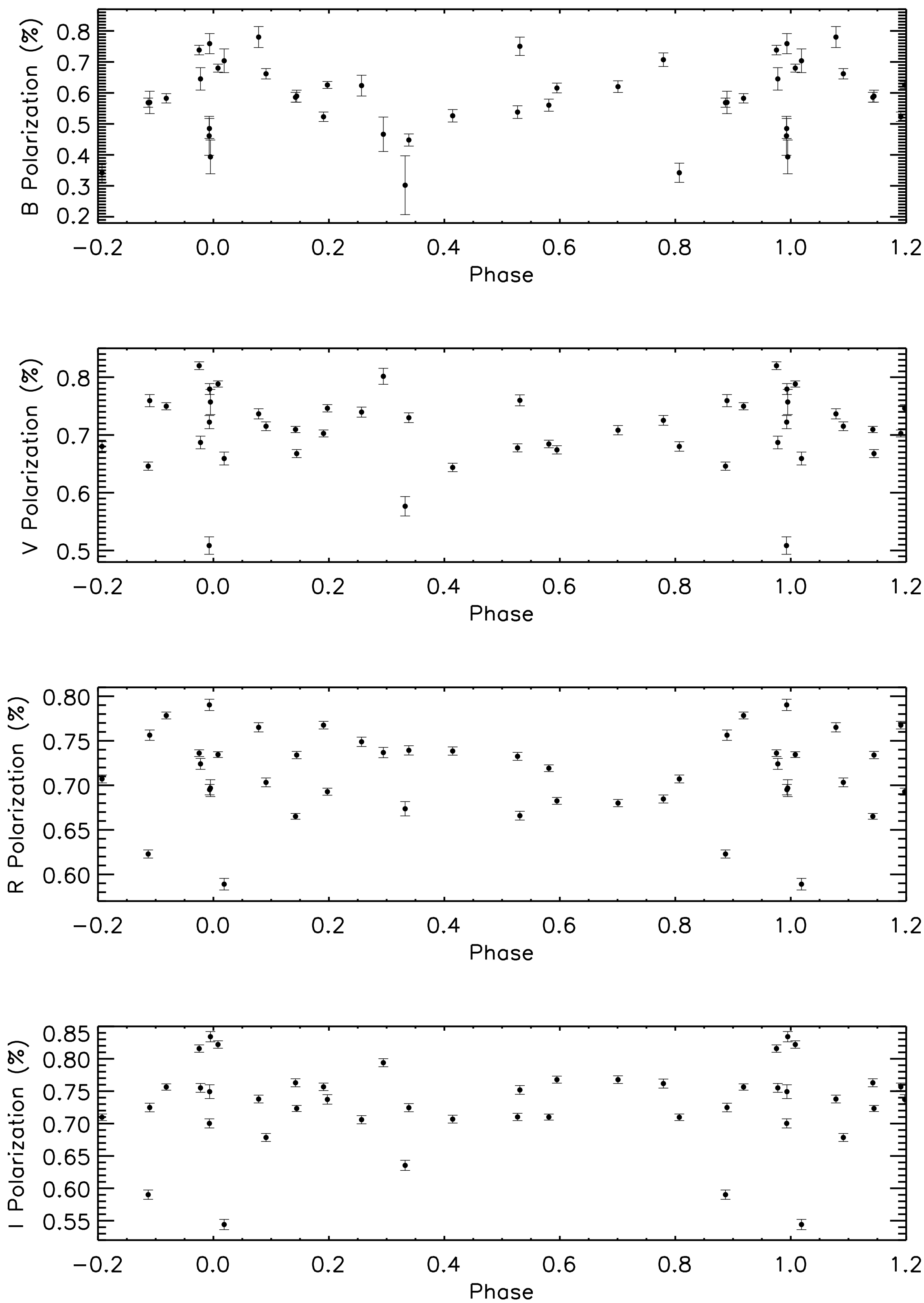

Figure 13.— *BVRI* intrinsic polarization variation over more than one phase of the system. Data calculated with $PA_{fs} = 32.072476°$.

Figure 14

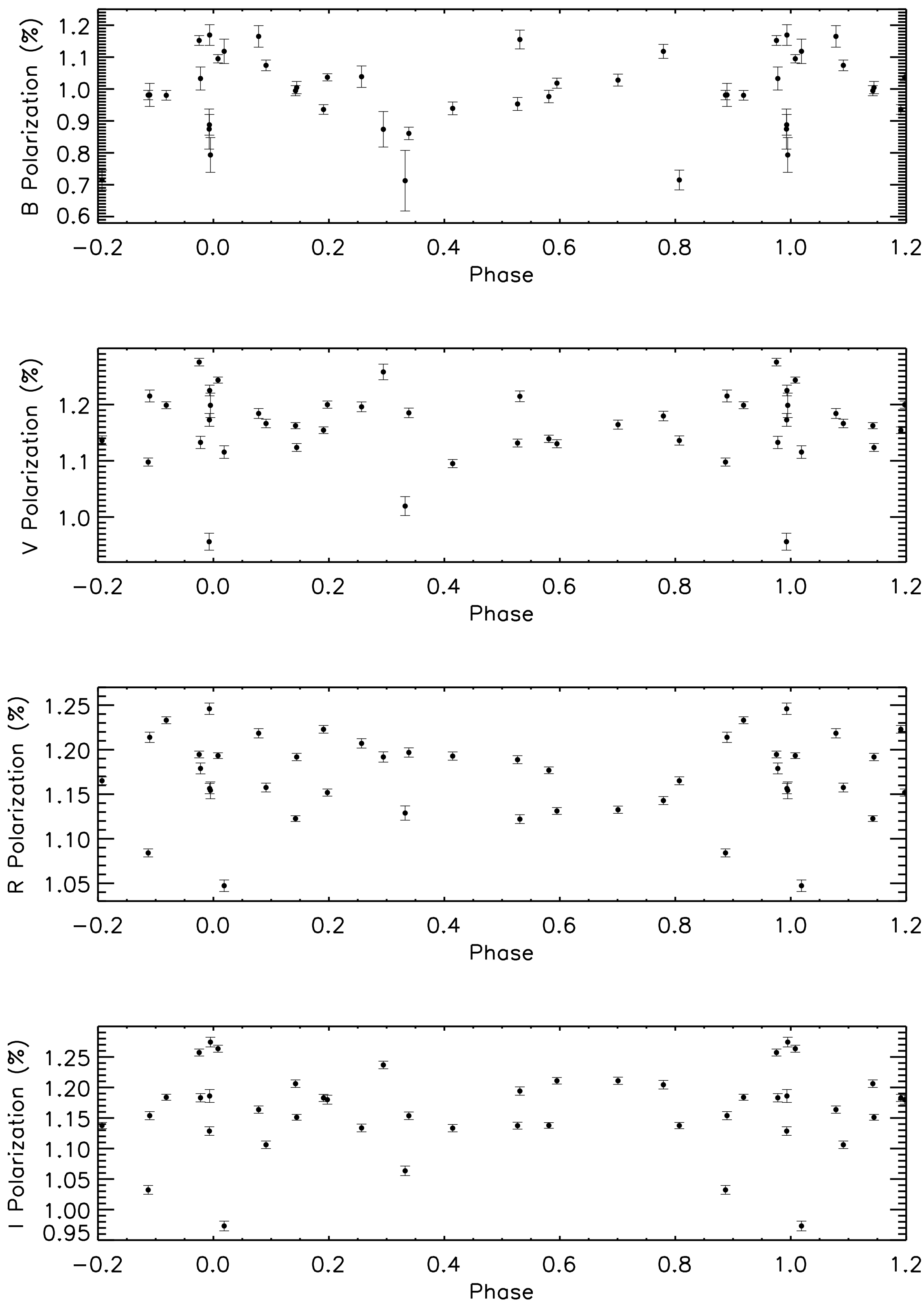

Figure 14.— *BVRI* intrinsic polarization variation over more than one phase of the system. Data calculated with $PA_{fs} = 21.552112°$.

FIGURE 15

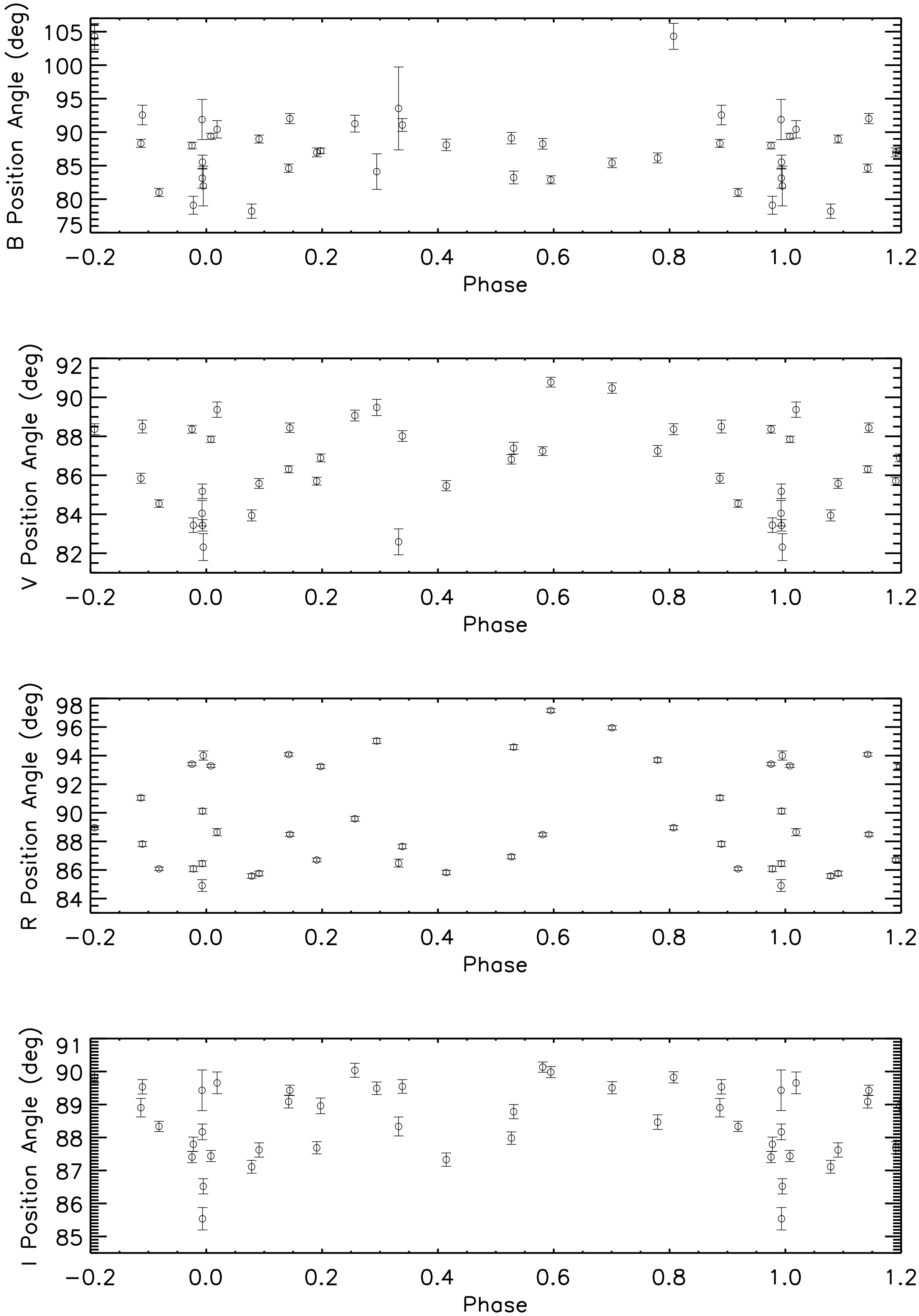

FIGURE 15.— *BVRI* intrinsic position angle variation over more than one phase of the system. Data calculated with $PA_{fs} = 27.857947°$.

FIGURE 16

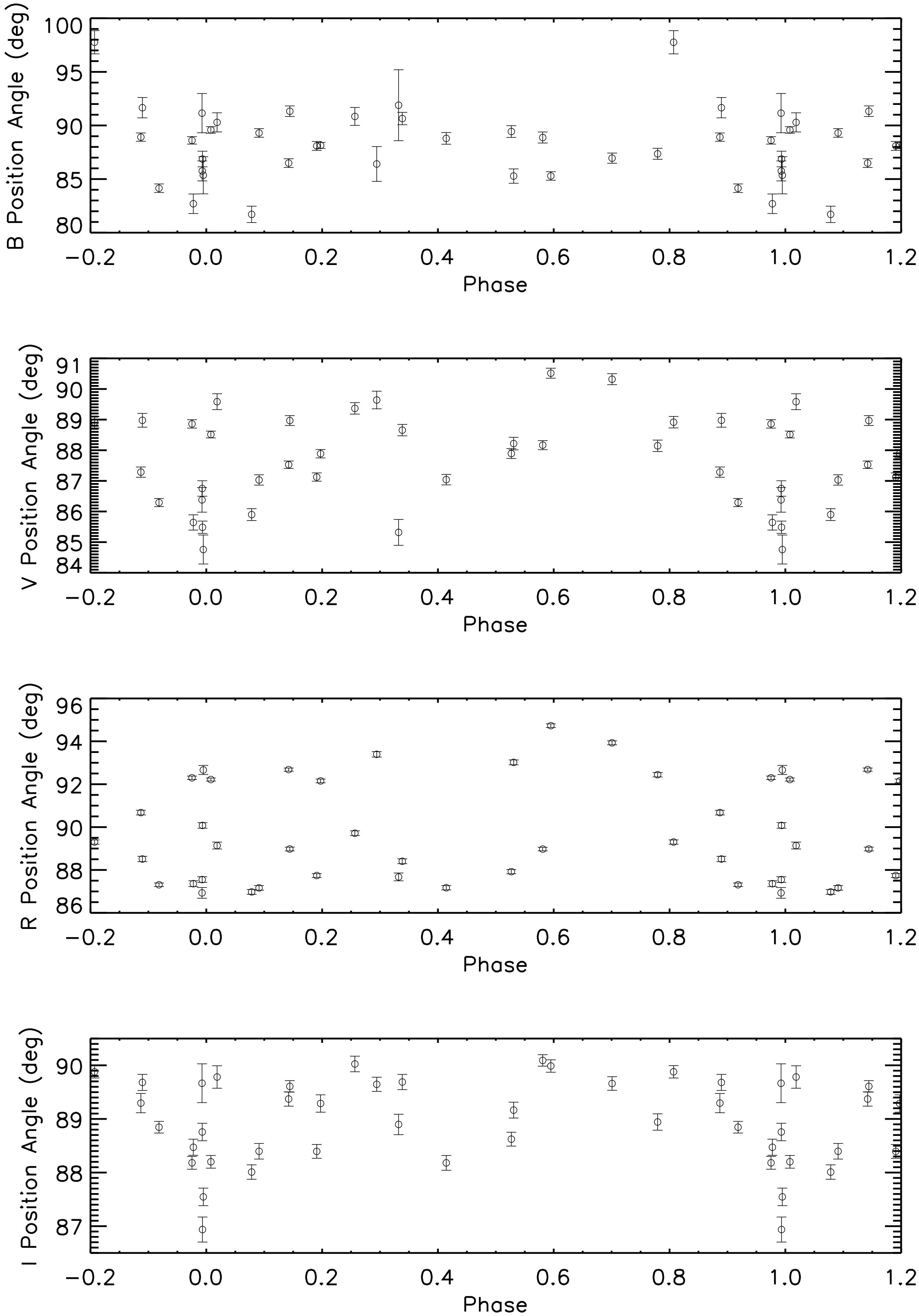

FIGURE 16.— *BVRI* intrinsic position angle variation over more than one phase of the system. Data calculated with $PA_{fs} = 19.626629°$.

FIGURE 17

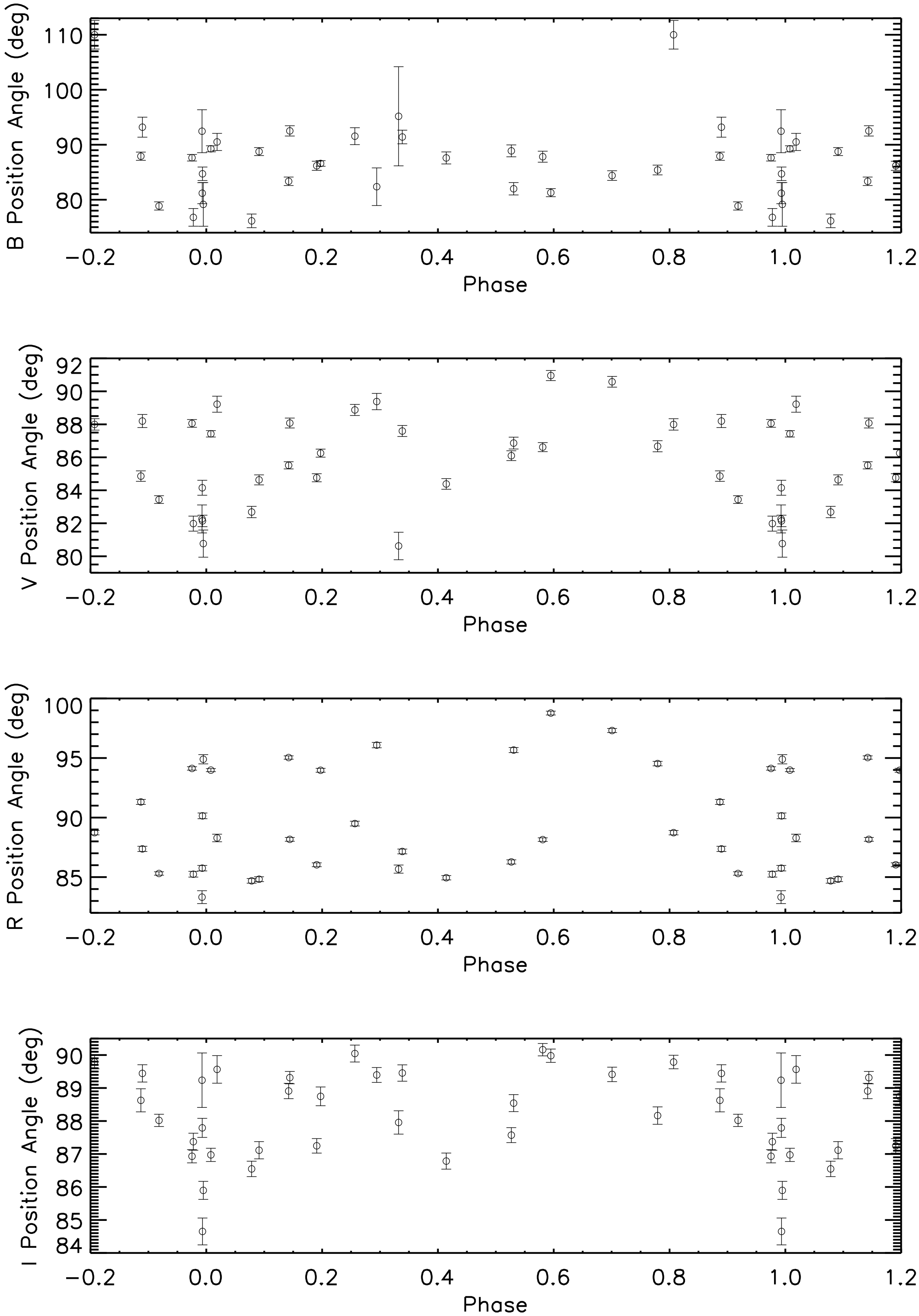

FIGURE 17.— *BVRI* intrinsic position angle variation over more than one phase of the system. Data calculated with $PA_{fs} = 32.072476°$.

Figure 18

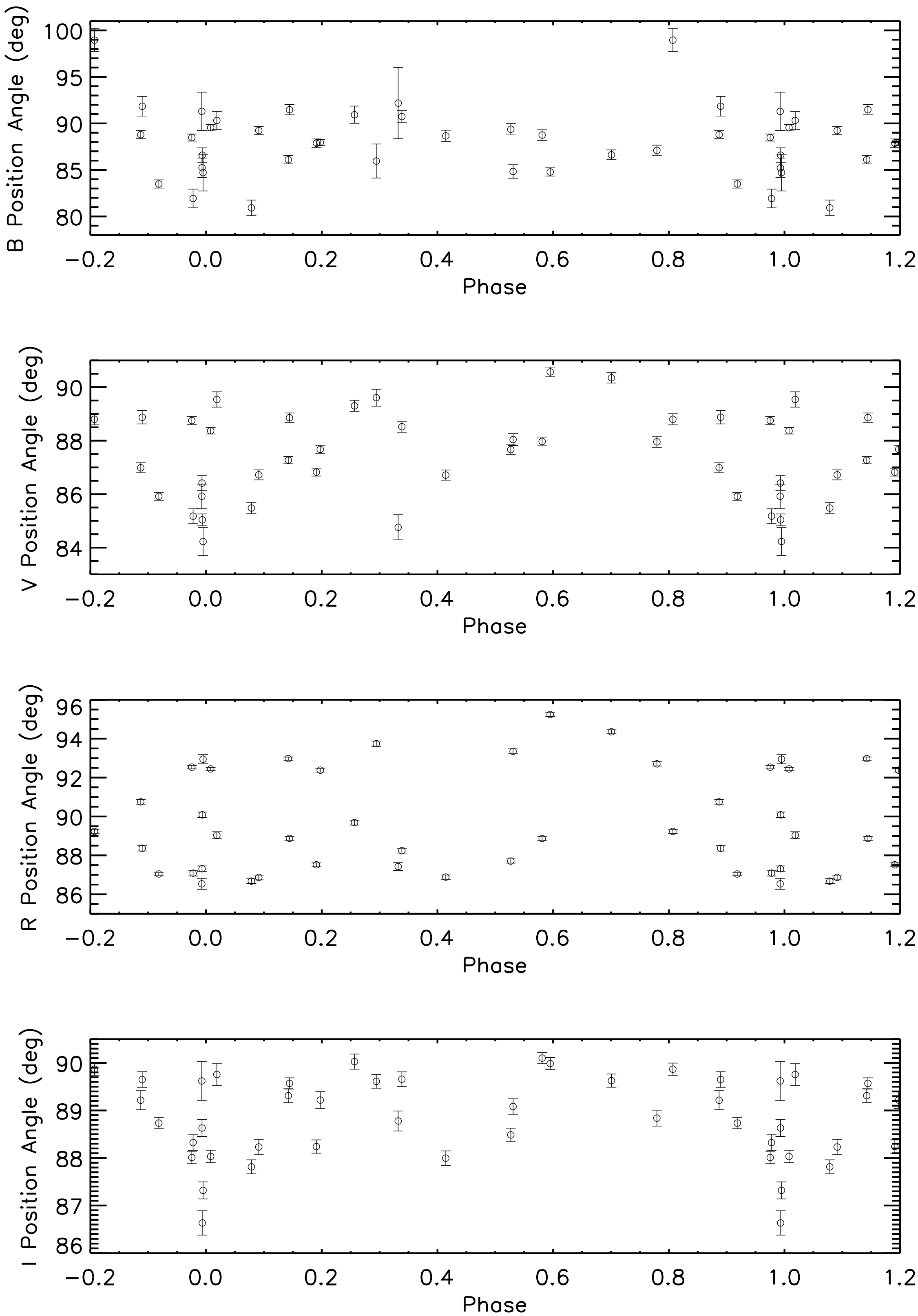

Figure 18.— *BVRI* intrinsic position angle variation over more than one phase of the system. Data calculated with $PA_{fs} = 21.552112°$.

6 Flux Polarization

Polarized flux, or the flux of the scattered light only, can provide more insight on the characteristics of the disk around V356 Sgr as well as evidence to confirm that some of the disk most likely surrounds both stars rather than just the primary star. I used light curve data from Popper (1955) for absolute flux measurements and calibrated them to V356 Sgr's phases, then multiplied the light curve flux by the intrinsic *V*-band polarization. FIGURE 19 displays normalized flux from the light curve, the *V*-band intrinsic polarization of V356 Sgr, and the polarized flux, a product of the normalized flux and the intrinsic polarization.

FIGURE 19

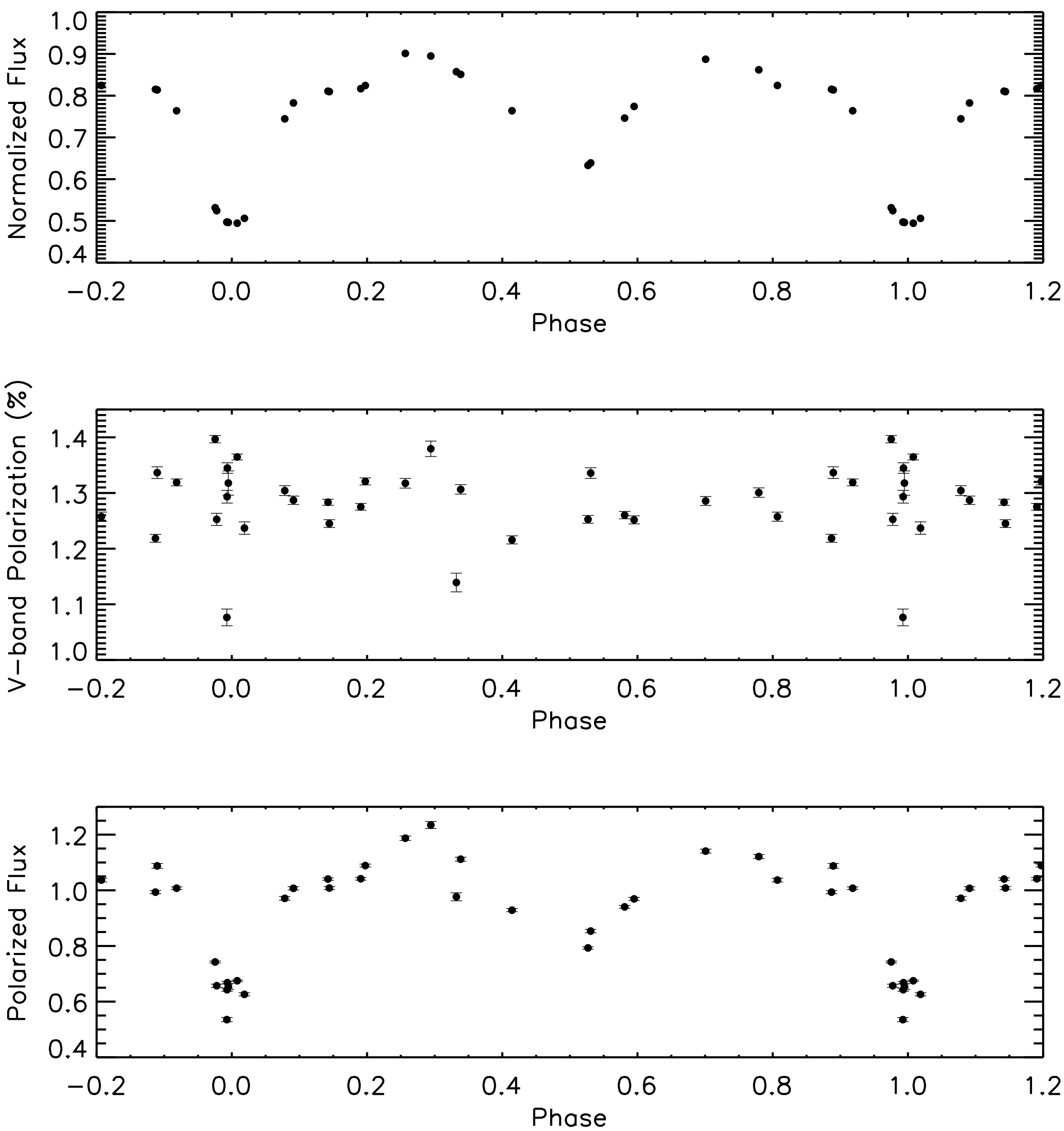

FIGURE 19.— Normalized flux, *V*-band polarization, and polarized flux variation over more than one phase of the system. Data calculated with $PA_{fs} = 19.626629°$.

The polarized flux dips, or the decreases in scattered light, at primary eclipse ($Phase = 0.0$, $Phase = 1.0$) are expected. When the primary star and disk are behind the secondary star during primary eclipse, much of the scattered light from the disk should be blocked, thus creating a dip in polarized flux. However, there is also a slight dip at secondary eclipse when the secondary star is behind the primary star. This indicates that some of the disk must also be surrounding the secondary star if the primary star blocks some of the disk during its transit. This may reveal a new step in V356 Sgr's evolutionary track.

7 Discussion & Conclusion

While Wilson & Caldwell (1978) provided an accurate and current description of the V356 Sgr system, its specific placement along the progenitor supernova evolutionary track has only been suggested. As mentioned previously, Wilson & Caldwell (1978) proposed that the secondary star has recently begun burning helium in its core, while Ziółkowski (1985) furthered this model by suggesting that it has also started burning hydrogen in its shell. The prominent hydrogen Balmer absorption lines in FIGURE 1 supports Ziółkowski's proposition.

The intrinsic polarization and position angle data have revealed new information about the disk itself. The Polarization vs. Phase plots (FIGURES 11-14) show that polarization varies periodically with phase, and different parts of the disk may be polarizing more or less light than other parts of the disk. Not only does this suggest that the disk is not uniform, but also, because of the periodicity, there could be significant clumps in the disk causing peaks of polarization. This could indicate that the disk is unstable and has not reached any form of equilibrium. In addition, FIGURES 11-14 show that the polarization of the system never actually reaches 0%, suggesting that the disk is always somewhat visible; this contributes to my proposition that the disk may also surround the secondary star in a common envelope.

While the Position Angle vs. Phase plots (FIGURES 15-18) do not show patterns nearly as periodic as the Polarization vs. Phase plots, there are slight dips at primary eclipse. The position angle variation across all the plots shows a range of at least 10° within a phase, possibly indicating that there are inconsistencies in the disk that are causing it to appear to wobble. The slight dips at primary eclipse could be a result of a particularly large clump in the disk that distorts how we see the system's axial tilt.

A detailed explanation of the standard Type Ia supernova evolutionary track is provided in Hachisu et al. (1999). Included is a diagram of the four steps that precede helium mass transfer from the primary star to the secondary star, after which the secondary star (at this stage, a white dwarf) will be overflowed, resulting in a supernova. V356 Sgr is considered to be working through the original four steps, specifically step two, the unstable mass transfer from the secondary star to the primary star. I propose that V356 Sgr is currently transitioning into the next step of its evolutionary track: Common Envelope Evolution, during which the disk around the primary star that has resulted from mass transfer from the secondary star has begun to spread around the secondary star as well.

In order to determine more about the disk and its relationship with the secondary star, further observations must be made at secondary eclipse ($Phase = 0.5$). Most observations thus far have focused on primary eclipse, which have been helpful in determining the disk's relationship with the primary star. In order to fill more gaps in our knowledge concerning the characteristics of the V356 Sgr disk, future observations should focus on $Phase = 0.5$, or secondary eclipse.

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9 References

Draper, Z. H. et al. 2014, ApJ, 786, 120

Hachisu, I. et al. 1999, ApJ, 519, 314

Hall, D. S., Henry, G. W., & Murray, W. H. 1981, AcA, 31, 383

Heiles, C. 2000, AJ, 119, 923

Malatesta, M., 2012, Senior Thesis, University of Denver

Nordsieck, K. H. & Harris, W. 1996, ASPC, 97, 100

Polidan, R. S. 1989, SSRv, 50, 85

Popper, D. M. 1955, ApJ, 121, 56

Popper, D. M. 1980, ARA&A, 18, 115

Quirrenbach, A. et al. 1997, ApJ, 479, 477

Serkowski, K., Mathewson, D. S., & Ford, V. L. 1975, ApJ, 196, 261

Wilking, B. A., Lebofsky, M. J., & Rieke, G. H. 1982, AJ, 87, 695

Wilson, R. E. & Caldwell, C. N. 1978, ApJ, 221, 917

Ziółkowski, J. 1985, AcA, 35, 199