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Measurements of linear polarization of some Herbig Ae/Be stars

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Abstract. — We have measured the linear polarization of 8 bright Herbig Ae/Be stars in *UBVRI* bands. No unique wavelength dependence of polarization magnitude as well as direction is found in these measurements. Comparison with the earlier measurements shows significant time-variability in some cases.

Key words : polarization — Herbig Ae/Be stars.

1. Introduction.

Herbig Ae/Be stars are the early-type objects with masses lying between those of the low-mass T Tauri stars and the massive OB stars and are characterized by the signs of early stages of star formation. Most of these objects show photometric variability and infrared excesses.

It has been suggested (cf. Strom *et al.*, 1971 ; Strom *et al.*, 1972) that Herbig Ae/Be stars are surrounded by circumstellar material consisting of gas and dust. This has been substantiated, in general, by polarimetric observations (cf. Breger, 1974 ; Vrba, 1978 ; Garrison and Anderson, 1978 ; Vrba *et al.*, 1979 ; Bergener *et al.*, 1987). Although, only a few, far spaced polarimetric observations are available in the literature, they do indicate significant variability in the degree and direction of polarization in about half of the total cases studied.

We were motivated to measure the polarization of this group of objects (i) as a part of a program of studying star forming regions, and (ii) to systematically monitor their photometric as well as polarimetric behaviour. The observations were made in March 1989, and from the list of Herbig (1960) 8 relatively brighter objects, namely AB Aur, T Ori, V 380 Ori, HD 250550 (MWC 789), Lk Hα 215, HD 259431 (MWC 147), Z CMa (MWC 165), and HD 53367 (MWC 166) were selected for observations.

2. Observations.

The observations were done with the 104 cm telescope of U.P. State Observatory, Nainital. A fast star-and-sky chopping polarimeter, similar to that described by Viswanathan (1972), was used for the study. Briefly, the star and the neighbouring sky are chopped alternately every 20 msec with a chopper just before the focal plane of the instrument. The chopper is a stiff metallic plate with two semi-circular eccentric slots separated by 8 mm (equivalent to about 2 arcmin on the sky). A high grade plastic polaroid acts as the analyzer. This is mounted on a spur-gear assembly which is coupled to a stepper motor. One step of the stepper motor corresponds to 1.8°. Thus, the polaroid completes one rotation in 200 steps, and the signals due to star and sky are recorded in separate memory locations at each step. An LED – photo-transistor pair defines an initial position of the polaroid. Subsequent steps and revolutions are defined with reference to this index. Two LED – photo-transistor pairs provide indexes for the star and the sky locations in the computer memory. A thermoelectrically cooled EMI 9658R photomultiplier tube was used for the observations. The filters are the Fernie (1974) combinations of Schott colour glass filters. Each object was observed twice, and all the observations were done with an aperture of 15 arc sec diameter.

The degree of polarization, position angle, and their errors were determined by the least-squares method. Several standard stars – both polarized as well as unpolarized – were observed to assess the performance of the instrument. The instrumental polarization is well below 0.1% , and was subtracted from the observations.

3. Results and discussion.

The results of our measurements are given in table I and shown in figure 1. In some cases no measurements were done in the *U* band because of very long integration times involved. In other cases where such measurements have been done, the errors are generally large owing to very low photon flux. Since only one aperture (15 arc sec diameter) was used, no efforts were made to estimate the contribution of nebulosity alone surrounding the stars.

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Before discussing the individual objects, following points can be made from these observations :

i) AB Aur and T Ori have negligible degree of polarization.

ii) Out of the objects with significant polarization, Lk Hα 215, HD 259431, and HD 250550, show weak-to-insignificant wavelength dependence of polarization.

iii) Five stars (Lk Hα 215, HD 259431, Z CMa, V380 Ori, and HD 250550) show no wavelength dependence of position angle.

iv) In the other three stars, either the wavelength dependence of position angle is weak (HD 53367 and AB Aur) or peculiar (T Ori).

We now discuss the individual stars in detail and compare our measurements with earlier results. However, it should be noted that our measurements were done with a 15 arcsec aperture.

AB Aur

Our measurements show insignificant polarization which is in agreement with the findings of Hall (1958). Vrba (1975) and Garrison and Anderson (1978), however, reported much higher values.

We find somewhat different values of position angles than those of Vrba (1975). The two measurements, however, agree in the *B*-band.

Vrba *et al.* (1979) have classified this object as non-variable (Tab. VI). If our measurements are also taken into consideration then this classification may need revalidation.

T Ori

Within the error bars, the present measurements generally agree with earlier results. An important exception is Vrba's (1975) finding of a high value of polarization in *R*-band. Similarly, except in *I*-band where we find different value of position angle, other measurements of position angle are in good agreeement with each other. Breger (1974) has, however, reported a very different value based on his unfiltered measurements.

Vrba *et al.* (1979, Tab. VI) have classified T Ori as a polarimetric variable. We feel that degree of variability is much less pronounced in this case.

V 380 Ori

This object shows fairly high degree of polarization in all the filters. Although a possible contribution of the interstellar polarization may not be ruled out, the two important contributors are (i) circumstellar dust, and (i) extremely bright circular reflection nebula NGC 1999 (diameter ~ 1'.5) surrounding the star. Multiaperture polarimetry by Vrba *et al.* (1979) and Breger (1974) confirm the significant contribution of the latter.

We find a different wavelength dependence of polarization than that of Vrba *et al.* (1979). Since our measurements were done with only one aperture, this difference could possibly be due to the aperture effect.

Our measurements of position angle are in agreement with the February 1977 measurements of Vrba *et al.* (1979) and the 1974 measurements of Breger (1974). Vrba (1975), however, found significantly different values in October 1973. This may be explained as due to large variations in the circumstellar material.

MWC 789 (HD 250550)

The degree of polarization for this object is high. Except in the *U*-band where the measurement errors are large, the position angle is remarkably constant in all the bands. These findings are in good agreement with those of Vrba (1975) but very different from the ones reported by Garrison and Anderson (1978).

Other stars

The agreement between the various measurements of the remaining stars, namely Lk Hα 215, MWC 147 (HD 259431), Z CMa (MWC 165), and MWC 166 (HD 53367), is quite good, indicating that time variability is perhaps not very significant in these cases.

We tend to agree with Vrba *et al.* (1979) that a large portion of the observed polarization originates in the circumstellar material.

Time variability :

In order to see the sime variability of polarization of Herbig Ae/Be stars, we have tabulated the available data for a sample of 6 stars in table II. It is seen from table II that although the degree of polarization shows considerable variation, the position angle is reasonably constant. This seems to be in order when one assumes that bulk of the polarization originates in the circumstellar material which is likely to undergo rapid variations in its optical thickness but not in the morphology.

4. Conclusions.

We have presented *UBVRI* polarimetric measurements of 8 Herbig Ae/Be stars. The following conclusions can be drawn from these observations about the polarimetric behaviour of Herbig Ae/Be stars :

The degree of polarization ranges from negligible (AB Aur and T Ori) to ~ 1% (Lk Hα 215, HD 259431, and HD 250550). In the latter cases, the wavelength dependence of polarization is weak-to-insignificant. Similarly, there is no uniformity in the behaviour of position angle. Five stars (Lk Hα 215, HD 259431, Z CMa, V380 Ori, and HD 250550) show no wavelength dependence of position angle. In the other three cases, the wavelength dependence of position angle is either weak (HD 53367 and AB Aur) or peculiar (T Ori).

Further, although time variability seems to be a common feature, no unique pattern is seen. Data over longer periods are required before any definite conclusions can be drawn. A part of polarization may be contributed to by nebulosity in some cases. Multi-aperture observations of individual objects are needed to sift the contribution of nebulosity and

the circumstellar dust.

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TABLE I. — *Polarization of the observed Herbig Ae/Be stars.*

Object	Filter	P ± ε (%)	θ (deg.)
AB Aur	U	0.05 ± 0.08	90 ± 15
	B	0.08 ± 0.04	49 ± 14
	V	0.08 ± 0.04	91 ± 6
	R	0.10 ± 0.04	87 ± 6
	I	0.12 ± 0.06	92 ± 7
T Ori	U	-	-
	B	0.23 ± 0.17	30 ± 24
	V	0.21 ± 0.06	68 ± 9
	R	0.12 ± 0.05	75 ± 10
	I	0.26 ± 0.09	25 ± 10
V 380 Ori	U	2.65 ± 1.53	139 ± 16
	B	1.05 ± 0.32	112 ± 6
	V	0.70 ± 0.10	110 ± 4
	R	0.55 ± 0.06	111 ± 3
	I	0.43 ± 0.12	110 ± 7
HD 250550 (MWC 789)	U	1.00 ± 0.48	110 ± 12
	B	1.20 ± 0.11	171 ± 3
	V	1.08 ± 0.06	168 ± 1
	R	1.00 ± 0.05	169 ± 1
	I	0.81 ± 0.10	175 ± 4
LK Hα 215	U	-	-
	B	1.14 ± 0.27	81 ± 7
	V	1.10 ± 0.08	73 ± 2
	R	1.00 ± 0.06	80 ± 2
	I	0.99 ± 0.10	72 ± 3
HD 259431 (MWC 147)	U	-	-
	B	0.86 ± 0.08	106 ± 3
	V	0.87 ± 0.05	106 ± 2
	R	0.91 ± 0.04	106 ± 1
	I	0.70 ± 0.06	105 ± 2
Z CMa (MWC 165)	U	-	-
	B	1.51 ± 0.34	155 ± 6
	V	0.84 ± 0.08	156 ± 6
	R	0.79 ± 0.04	155 ± 2
	I	0.53 ± 0.06	155 ± 3
HD 53367 (MWC 166)	U	0.61 ± 0.09	94 ± 4
	B	0.63 ± 0.11	55 ± 5
	V	0.30 ± 0.05	40 ± 5
	R	0.23 ± 0.04	67 ± 7
	I	0.16 ± 0.06	67 ± 10

TABLE II. — *Polarization measurements of 6 Herbig Ae/Be stars at different epochs.*

Star	Filter	P ± ε (%)	θ (deg)	Aperture (arcsec)	Epoch	Reference
T Ori	None	0.11 ± 0.10	150	4	Feb. 72	Breger (1974)
	U	-	-	-	-	
	B	0.62 ± 0.14	61.1 ± 6.5	10	Oct. 73	Vrba et al (1979)
		0.38 ± 0.21	34 ± 21	-	Jan. 76	Garrison & Anderson (1978)
		0.23 ± 0.17	30 ± 24	15	Mar. 89	Present
	V	0.55 ± 0.28	51 ± 14	10	Oct. 73	Vrba et al (1979)
		0.34 ± 0.16	77 ± 16	-	Jan. 76	Garrison & Anderson (1978)
		0.21 ± 0.06	68 ± 9	15	Mar. 89	Present
	R	1.58 ± 0.40	75.9 ± 7.5	10	Oct. 73	Vrba et al (1979)
		0.15 ± 0.20	77 ± 31	-	Jan. 76	Garrison & Anderson (1978)
		0.12 ± 0.05	75 ± 10	15	Mar. 89	Present
	I	0.66 ± 0.20	76.9 ± 8.8	10	Oct. 73	Vrba et al (1979)
		0.26 ± 0.09	25 ± 10	15	Mar. 89	Present
V 380 Ori	None	1.23 ± 0.17	81	4	Feb. 74	Breger (1974)
		0.83 ± 0.17	85	13	Feb. 74	Breger (1974)
	U	0.08 ± 0.16	151 ± 57	10	Oct. 73	Vrba et al (1979)
		1.23 ± 0.37	122 ± 8	-	Jan. 76	Garrison & Anderson (1978)
		0.06 ± 0.09	147 ± 43	10	Feb. 77	Vrba et al (1979)
		2.65 ± 1.53	139 ± 16	15	Mar. 89	Present
	B	0.80 ± 0.06	88.8 ± 2.1	10	Oct. 73	Vrba et al (1979)
		0.96 ± 0.13	95 ± 3	-	Jan. 76	Garrison & Anderson (1978)
		0.47 ± 0.06	116 ± 4	10	Feb. 77	Vrba et al (1979)
		1.05 ± 0.32	112 ± 6	15	Mar. 89	Present
	V	0.98 ± 0.06	86.2 ± 1.8	10	Oct. 73	Vrba et al (1979)
		1.13 ± 0.10	94 ± 3	-	Jan. 76	Garrison & Anderson (1978)
		0.47 ± 0.06	106 ± 3	10	Feb. 77	Vrba et al (1979)
		0.70 ± 0.10	110 ± 4	15	Mar. 89	Present
	R	1.31 ± 0.14	74.4 ± 3.2	10	Oct. 73	Vrba et al (1979)
		1.08 ± 0.15	104 ± 5	-	Jan. 76	Garrison & Anderson (1978)
		0.55 ± 0.06	111 ± 3	15	Mar. 89	Present
	I	1.25 ± 0.18	84.9 ± 4.2	10	Oct. 73	Vrba et al (1979)
		0.43 ± 0.12	110 ± 7	15	Mar. 89	Present
	Hα	1.38 ± 0.43	115 ± 9	-	Jan. 76	Garrison & Anderson (1978)
HD 250550 (MWC 789)	None	0.71 ± 0.13	6	4	Feb.72	Breger (1974)
	U	0.85 ± 0.01	176 ± 1	10	1972-73	Vrba (1974)
		1.23 ± 0.33	163 ± 8	-	Jan.76	Garrison & Anderson (1978)
		1.00 ± 0.48	110 ± 12	15	Mar.89	Present
	B	0.71 ± 0.06	167 ± 2	10	1972-73	Vrba (1974)
		0.83 ± 0.04	3 ± 1	-	Jan.76	Garrison & Anderson (1978)
		1.20 ± 0.11	171 ± 3	15	Mar.89	Present
	V	0.97 ± 0.08	172 ± 2	10	1972-73	Vrba (1974)
		1.40 ± 0.05	19 ± 1	-	Jan.76	Garrison & Anderson (1978)
		1.08 ± 0.06	168 ± 1	15	Mar.89	Present
	R	0.43 ± 0.05	177 ± 3	10	1972-73	Vrba (1974)
		1.48 ± 0.90	4 ± 4	-	Jan.76	Garrison & Anderson (1978)
		1.00 ± 0.05	169 ± 1	15	Mar. 89	Present
	I	0.97 ± 0.03	174 ± 1	10	1972-73	Vrba (1974)
		0.81 ± 0.10	175 ± 4	15	Mar.89	Present

TABLE II *(continued)*

Star	Filter	P ± ε (%)	θ (deg.)	Aperture (arcsec)	Epoch	Reference
	Hα	1.56 ± 0. 47	23 ± 8	-	Jan.76	Garrison & Anderson (1978)
Lk Hα 215	None	1.04 ± 0.17	73	4	Feb.72	Breger (1974)
	U	0.97 ± 0.13	62.3 ± 3.8	10	Oct.73	Vrba et al (1979)
		0.85 ± 0.22	56 ± 7	-	Jan.76	Garrison & Anderson (1978)
	B	1.04 ± 0.03	68.1 ± 0.8	10	Oct.73	Vrba et al (1979)
		0.78 ± 0.12	73 ± 3	-	Jan.76	Garrison & Anderson (1978)
		1.14 ± 0.27	81 ± 7	15	Mar.89	Present
	V	1.43 ± 0.07	76.5 ± 1.4	10	Oct.73	Vrba et al (1979)
		0.80 ± 0.10	88 ± 2	-	Jan. 76	Garrison & Anderson (1978)
		1.10 ± 0.08	73 ± 2	15	Mar.89	Present
	R	0.88 ± 0.37	37 ± 14	10	Oct.73	Vrba et al (1979)
		1.01 ± 0.13	77 ± 3	-	Jan.76	Garrison & Anderson (1978)
		1.00 ± 0.06	80 ± 2	15	Mar.89	Present
	I	1.19 ± 0.13	80.1 ± 3.1	10	Oct.73	Vrba et al (1979)
		0.99 ± 10	72 ± 3	15	Mar.89	Present
HD 259431 (MWC 147)	None	1.05 ± 0.13	91	4	Feb.72	Breger (1974)
	U	0.48 ± 0.06	101 ± 4	10	1972-73	Vrba (1974)
		0.61 ± 0.25	146 ± 19	-	Jan.76	Garrison & Anderson (1978)
	B	0.79 ± 0.24	100 ± 9	10	1972-73	Vrba (1974)
		1.08 ± 0.03	106 ± 1	-	Jan.76	Garrison & Anderson (1978)
		0.86 ± 0.08	106 ± 3	15	Mar.89	Present
	V	1.05 ± 0.14	99 ± 4	10	1972-73	Vrba (1974)
		0.92 ± 0.05	115 ± 1	-	Jan.76	Garrison & Anderson (1978)
		0.87 ± 0.05	106 ± 2	15	Mar.89	Present
	R	1.37 ± 0.18	90 ± 4	10	1972-73	Vrba (1974)
		0.97 ± 0.21	108 ± 6	10	Mar.74	Vrba et al (1979)
		0.78 ± 0.06	104 ± 2	-	Jan.76	Garrison & Anderson (1978)
		0.91 ± 0.04	104 ± 1	15	Mar.89	Present
	I	1.17 ± 0.06	103 ± 2	10	1972-73	Vrba (1974)
		0.94 ± 0.12	105 ± 3.7	10	Mar.74	Vrba et al (1979)
		0.70 ± 0.06	105 ± 2	15	Mar.89	Present
Z CMa	None	0.82 ± 0.13	148	4	Dec.71	Breger (1974)
	U	1.09 ± 0.22	150 ± 6	-	Jan.76	Garrison & Anderson (1978)
	B	0.87 ± 0.07	156 ± 2	10	Nov.72	Vrba (1974)
		0.18 ± 0.12	137 ± 19	-	Jan.76	Garrison & Anderson (1978)
		1.51 ± 0.34	155 ± 6	15	Mar.89	Present
	V	0.90 ± 0.08	160 ± 3	10	Nov.72	Vrba(1974)
		0.14 ± 0.16	9 ± 30	-	Jan.76	Garrison & Anderson (1978)
		0.84 ± 0.08	156 ± 4	15	Mar.89	Present
	R	0.86 ± 0.06	166 ± 2	10	Nov.72	Vrba (1974)
		0.70 ± 0.16	164 ± 5	-	Jan.76	Garrison & Anderson (1978)
		0.79 ± 0.04	155 ± 2	15	Mar.89	Present
	I	1.29 ± 0.03	160 ± 1	10	Nov.72	Vrba (1974)
		0.53 ± 0.06	155 ± 3	15	Mar.89	Present

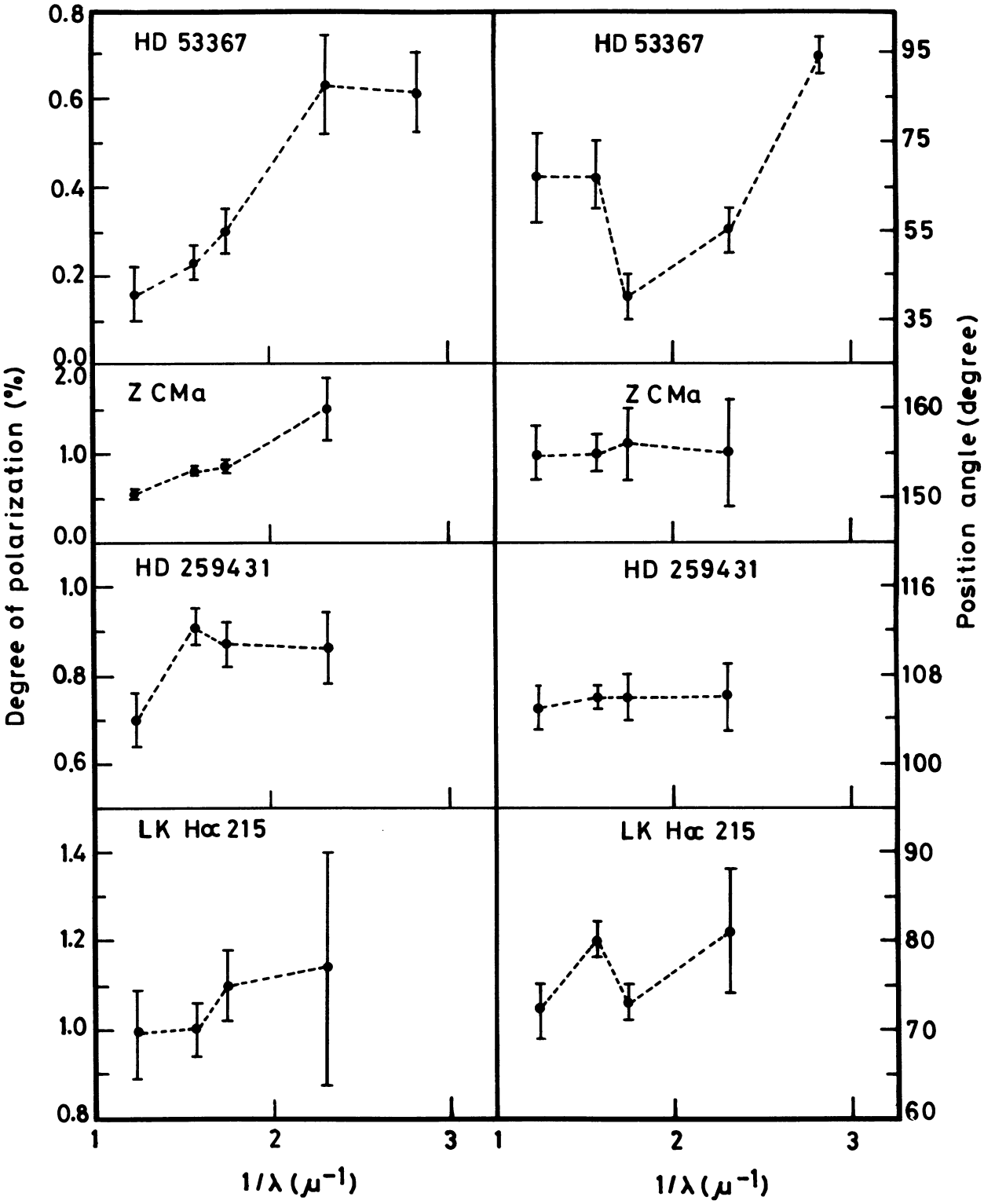

FIGURE 1. — Degree of polarization $P(\%)$ and position angle (degrees) as a function of $1/\lambda$ (μm^{-1}) for the stars observed by us. The error bars represent uncertainties in the measured quantities at 1 σ level.

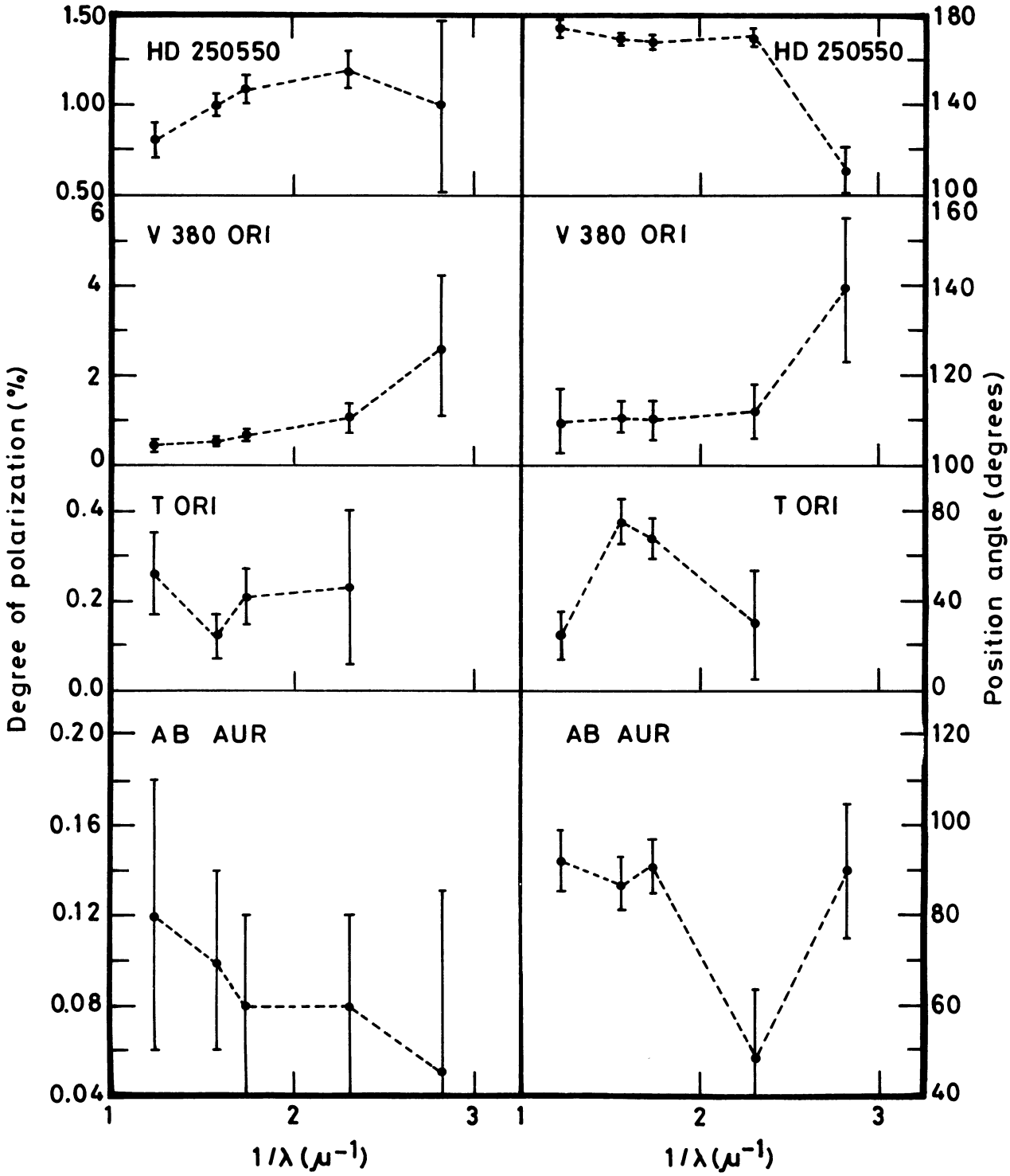

FIGURE 1 (*continued*)