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Study of variability of the polarization in Herbig Ae/Be stars*

S.K. Jain† and H.C. Bhatt

Indian Institute of Astrophysics, Bangalore 560034, India

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Abstract. — We report our measurements of linear polarization of a number of Herbig Ae/Be stars made at several epochs during the period 1989-1993. These results together with the observations compiled from the published sources have been analysed to study the variability of polarization in Herbig Ae/Be stars. It is found that polarimetric variability is a common feature of this class of objects. Most of the objects are variable on time scales $\geq$1 yr. Some objects have shown large variations on time scales as short as $\sim$ 1 month indicating structural changes in the distribution of circumstellar matter close to the star within a few tens of stellar radii. Variations in the polarization position angle are not always correlated with variations in the degree of polarization.

Key words: stars: emission-line, Ae — polarization — stars: variable — stars: pre-main-sequence

1. Introduction

Herbig Ae/Be stars are now well recognized as the intermediate mass counterparts of T Tauri stars, though many significant differences in their properties with respect to the latter class of objects have been identified. The evolutionary status of Herbig Ae/Be stars as the pre-main-sequence (PMS) objects has been established i) by the observations of infra-red excess in a majority of them, ii) their physical association with dark clouds and iii) their position in the HR diagram. A majority of these objects show photometric as well as spectroscopic variability (see, for example, Catala 1989 for a review). In the original survey, Herbig (1960) had identified a total of 26 objects belonging to this class. The catalogue was later expanded by Finkenzeller & Mundt (1984) to include 57 stars and since their study, other observers (e.g. Hu et al. 1989; Bergener et al. 1990) have added new candidates taking the catalogue to include more than 70 objects.

The presence of circumstellar material around Herbig Ae/Be stars has been established by the observations of strong IR excess and the presence of the infrared emission features (cf. Strom et al. 1971; Strom et al. 1972; Cohen 1973; Whittet et al. 1983; Bhatt & Gorti 1993) and the strong UV depletion (Sitko et al. 1981; Catala 1983; The′ et al. 1986). This is supported by the observations of relatively large degree of polarization in a number of these stars (cf. Breger 1974; Vrba et al. 1979; Jain et al. 1990)

The nature and geometry of the circumstellar material around Herbig Ae/Be stars, however, remains a controversial issue. Both spherical distributions and flattened disks have been invoked for this purpose. For example, Hillenbrand et al. (1992 and the references therein) have analyzed the spectral energy distribution (SED) of 47 catalogued Herbig Ae/Be stars and conclude that these stars can be classified into three groups. The SED of the Group I objects consisting of 30 members can be explained by invoking a geometrically thin, optically thick circumstellar accretion disk. The inner regions of these disks must be optically thin to account for the inflections in their observed near infrared spectra. Group II objects (11 in number) appear as young intermediate-mass stars or star/disk systems surrounded by gas and dust which is not confined to a disk. The rest 6 stars, belonging to Group III, have very little infrared excess, and appear similar to classical Be stars. This view is supported, in part, by a high sensitivity survey of radio continuum emission from Herbig Ae/Be stars (Skinner et al. 1993). A different view point is, however, presented by Berrilli et al. (1993) who show that their IR observations in J, H, K, L, M, and 8-13 μ bands of Herbig Ae/Be stars located in the southern hemisphere can be explained more easily by the spherical geometry for the dust distribution, rather than a flattened structure. This is supported in part by the infrared studies of Natta et al. (1993) who surmise that at least three components contribute to the observed infrared emission:

* Table 1 is available via an anonymous ftp facility in electronic form at CDS, Strasbourg: see the Editorial in A&AS 1994, Vol. 103, No. 1

† Deceased on 17th November 1994

the central star, a circumstellar disk, and an extended, almost spherically symmetric, envelope.

Polarimetric measurements provide an important tool to study the problem of the nature and geometry of the circumstellar material. In this paper we report our measurements of linear polarization, extending over a period of about four years, of 24 stars. The methods of observations and data reduction are discussed in Sect. 2. The results are discussed in Sect. 3. In order to study the variability aspect, we have compiled the observations available in the published literature and present them along with our own observations. The results are discussed in Sect. 4. Finally, we list the main conclusions of our study in Sect. 5.

2. Observations

All the observations were made with a star and sky chopping polarimeter coupled at the $f/13$ cassegrain focus of the 1 m telescope at Vainu Bappu Observatory, Kavalur. the instrument and the method of data reduction are described elsewhere (Jain & Srinivasulu 1991). A dry ice cooled EMI 9658-R (extended S-20) photo-multiplier tube, coupled with Fernie (1974) combination of glass filters has been used throughout the observations. The average instrumental polarization, determined every night by observing unpolarized standard stars (Serkowski 1974), was $P \sim 0.1\%$. It was subtracted vectorially from the measured polarization of the program stars. The zero of the position angle was determined by observing the polarized standard stars (Hsu & Breger 1982).

3. Results

The results of our observations are given in Table 1 (accessible in electronic form) and shown in Fig. 1. Also tabulated in Table 1 are the results compiled from the published sources. The entries in Table 1 are as follows.

Column 1:	Serial number
Column 2:	Object identity
Column 3:	Date of observations. In case of the compiled data, only the month and year of observation are given as information about the dates is not available
Columns 4-7:	Degree of polarization P (in percentage) standard error ε_p (at 1 σ level), position angle θ (in degrees) and the standard error in position angle ε_θ (in degrees), in U filter.
Columns 8-23:	Same as in Cols. 4-7, but in filters B, V, R and I respectively.
Column 24:	Reference

A dash against an entry means that no datum is available.

In Fig. 1, error bars have been omitted to retain the clarity of the plots.

The measurements in the U band were restricted to the bright objects. In other cases, the errors were generally large owing to very low photon flux. Similarly, not all the stars were observed in the B band. In some cases, measurements could be done in only one or two bands.

4. Discussion

We discuss two aspects of the results presented in Table 1: the general polarimetric properties of the objects as a class and the peculiarities of some individual objects. Since our main objective was to investigate the variability of polarization, no efforts were made to estimate the interstellar component, as the latter is not expected to show any variability.

4.1. *General behaviour of Herbig Ae/Be stars as a class*

The percentage polarization in different wavelength bands for the stars observed varies from very small values ($< 0.1\%$ for AB Aur) to values as large as $\sim 6\%$ (MWC 137). It can be seen from Table 1 that:

i) For most of the stars the polarization, measured at a given epoch, does not show a wavelength dependence that is characteristic of the interstellar polarization which generally peaks in the V band. For the stars observed, the wavelength dependence of polarization is either nearly flat (e.g. LkH$_\alpha$ 215, March 1989; HD 53367, 1972-73) or peaks at wavebands other than V (e.g. HD 76534, Z CMa). The wavelength dependence of the degree of polarization also changes with time for most of the objects. This indicates that in most of the Herbig Ae/Be stars the observed polarization has a substantial component produced by circumstellar matter.

ii) At a given epoch the position angle of polarization does not show any significant dependence on wavelength for most of the objects. the position angle can however change with time. the wavelength independence of position angle indicates that in the optical region the geometry of the circumstellar matter is the same for all wavelengths. Optically thick discs scattering off the central starlight could cause such a behaviour.

iii) Measurements made at different epochs show that most of the Herbig Ae/Be stars are polarimetrically variable. To investigate the variability of the degree of polarization and position angle for these objects we computed the weighted mean of the observed (at different epochs) degree of polarization $< P >$ and position angle $< \theta >$ for each object in each band separately. Then the deviation of each observation from the mean was computed. The maximum values of these deviations ΔP and $\Delta\theta$ together with the standard errors ϵ_P

and ϵ_θ of the corresponding measurements are given in Table 2. The deviations are a measure of the variability and the largest observed deviations (irrespective of the wave band) ΔP and $\Delta\theta$ have been plotted against the corresponding standard errors of measurement ϵ_p and ϵ_θ in Fig. 2 and Fig. 3 respectively. It can be seen from Fig. 2 that of the 21 stars, 18 (86%) show deviations in the degree of polarization larger than the standard error of measurement ($\Delta P > \epsilon_P$). 12 stars (57%) have $\Delta P > 2\epsilon_P$ while 8 stars (38%) have $\Delta P > 3\epsilon_P$. Only 3 stars (14%) have $\Delta P \leq \epsilon_P$. These are HD 37490, HD 52721 and HD 163296. Interestingly the first two of these objects have SEDs characteristic of Group III (Hillenbrand et al. 1992). Another Group III object in our sample, HD 53367, also shows only very small variations in polarization ($\Delta P < 0.25\%$). It may then be concluded that most of the Herbig Ae/Be stars undergo large ($\Delta P > 0.25\%$) variations in the degree of polarization except those belonging to the Group III which generally have variations $\Delta P < 0.25\%$.

Variation in position angles is also a common feature of Herbig Ae/Be stars. It can be seen from Fig. 3 that 18 stars (86%) show variations in position angle $\Delta\theta > \epsilon_\theta$, 14 stars (67%) have $\Delta\theta > 2\epsilon_\theta$ and 9 stars (43%) have $\Delta\theta > 3\epsilon_\theta$. Only 3 stars (14%) have $\Delta\theta < \epsilon_\theta$. These are HD 37490, MWC 137 and HD 76534. It is to be noted that HD 37490 and HD 76534 are Group III objects. Another Group III object HD 52721 also shows a very small variation in position angle ($\Delta\theta = 6°$). There is no significant correlation between ΔP and $\Delta\theta$. Thus some stars undergo large varations in both the degree of polarization and the position angle (e.g. BD + 46° 3471), while others show large variations only in the degree of polarization (e.g. BD + 61° 154) or in the position angle (e.g. HD 163296). Stars showing large variations in position angle without any corresponding large variations in the degree of polarization are generally those that have small values of the degree of polarization. Even minor changes in the distribution of circumstellar matter in these stars may cause significant changes in the polarimetric properties.

4.2. *Comments on some individual objects*

XY Per: This object shows a moderately large degree of polarization ($P_V \sim 1.7\%$) which does not vary significantly with time. The wavelength dependence of polarization follows the typical interstellar pattern. The position angle is wavelength independent and also does not show any significant variation with time. It is possible that the observed polarization for this object is dominated by the interstellar component.

T Ori, BF Ori and HD 76534: These objects have shown a polarization peak in the R band at one epoch or the other. This may be related to the phenomenon of "R filter bump" discussed by Vrba (1975) and Vrba et al.

Table 2. Variations in polarization of Herbig Ae/Be stars

S.No.	Object	Filter	Polarization P(%)			Position angle θ (o)			Number of observations
			<P>	ΔP	ϵ_P	$<\theta>$	$\Delta\theta$	ϵ_θ	N
1	BD + 61° 154	U	1.27	0.05	0.22	93	15	5	2
		B	1.68	0.25	0.22	100	11	1	3
		V	1.83	0.91	0.44	102	11	1	4
		R	1.93	0.65	0.21	97	6	6	4
		I	1.69	0.06	0.14	95	1	3	2
2.	XY Per	B	0.94	0.21	0.38	138	13	10	3
		V	1.70	0.17	0.21	131	7	4	4
		R	1.62	0.20	0.11	133	9	2	4
		I	1.44	0.27	0.16	130	9	4	4
3.	AB Aur	U	0.41	0.06	0.12	49	88	12	2
		B	0.30	0.26	0.06	52	52	22	6
		V	0.35	0.31	0.06	59	72	52	7
		R	0.33	0.41	0.04	74	78	21	7
		I	0.14	0.09	0.12	70	68	22	4
4	HK Ori	B	1.12	0.24	0.14	158	7	3	2
		V	1.08	0.23	0.18	161	68	52	4
		R	0.69	2.42	0.66	133	48	9	4
5.	T Ori	B	0.45	0.22	0.17	56	26	24	3
		V	0.26	1.38	0.82	53	53	13	6
		R	0.20	3.76	0.60	53	78	11	7
		I	0.33	0.33	0.20	54	29	10	2
6.	V 380 Ori	U	0.12	2.52	1.53	126	12	16	4
		B	0.67	0.38	0.32	95	56	21	5
		V	0.78	0.46	0.34	95	25	8	7
		R	0.73	1.11	0.60	96	22	3	5
		I	0.66	0.59	0.18	90	25	9	3
7	BF Ori	V	0.63	0.43	0.26	68	2	7	2
		R	0.79	0.38	0.17	75	30	12	2
8.	HD 37490	V	0.18	0.10	0.10	53	16	52	2
9	HD 250550	U	0.85	0.38	0.33	175	65	12	3
		B	0.83	0.37	0.11	179	12	2	3
		V	1.19	0.78	0.17	182	19	12	5
		R	0.73	0.30	0.05	170	14	4	5
		I	0.95	0.48	0.21	174	1	4	3
10	MWC 137	V	6.27	1.68	1.56	162	7	10	2
		R	5.91	0.91	0.70	159	5	14	2
11	Lk H $_\alpha$ 215	U	0.94	0.09	0.22	61	5	7	2
		B	1.03	0.25	0.12	69	12	7	3
		V	1.18	0.38	0.10	78	15	9	5
		R	1.00	0.12	0.20	80	43	14	5
		I	1.07	0.12	0.13	78	19	7	3
12	HD 259431	U	0.49	0.12	0.25	103	43	19	2
		B	1.04	0.65	0.22	106	19	16	6
		V	0.92	0.13	0.11	112	13	4	6
		R	0.91	0.46	0.18	106	16	4	7
		I	0.93	0.24	0.06	104	4	5	5
13.	HD 52721	B	1.21	0.07	0.13	18	6	4	3
		V	1.30	0.10	0.10	20	4	3	3
		R	0.99	0.08	0.08	15	2	3	3
14.	ZCMa	B	0.72	0.79	0.34	156	19	19	3
		V	0.78	0.64	0.16	159	62	52	5
		R	0.81	0.28	0.50	161	65	27	5
		I	1.14	0.61	0.03	159	87	28	3
15.	HD 53367	U	0.56	0.18	0.09	29	10	3	2
		B	0.55	0.15	0.13	30	11	5	4
		V	0.50	0.16	0.09	35	7	8	4
		R	0.35	0.25	0.06	56	50	16	4
16.	HD 76534	V	0.61	0.22	0.24	126	4	11	2
		R	0.72	0.54	0.13	130	7	14	2
20.	HD 150193	B	4.29	1.03	2.03	60	16	11	3
		V	4.98	0.14	0.14	60	17	8	4
		R	4.79	0.27	0.22	59	2	1	3
		I	4.38	0.99	0.58	59	7	5	3

Table 2. continued

21.	HD 163296	B	0.38	0.02	0.38	2	15	27	2
		V	0.25	0.14	0.17	37	62	13	2
		R	0.31	0.07	0.12	27	26	9	2
22.	MWC 297	B	0.93	0.37	0.21	97	28	16	3
		V	1.79	0.36	0.16	96	2	1	4
		R	2.03	0.87	0.36	97	2	3	4
		I	2.09	0.09	0.05	98	2	1	4
23.	BD + 40°4124	B	1.24	0.14	0.09	15	6	2	3
		V	1.13	0.85	0.20	12	51	21	3
		R	1.19	0.32	0.15	18	61	15	3
24.	BD + 46°3471	U	0.61	0.60	0.40	13	42	23	2
		B	1.26	4.65	2.57	24	42	12	2
		V	1.49	0.91	0.11	23	51	3	3
		R	1.25	0.74	0.41	16	31	12	3

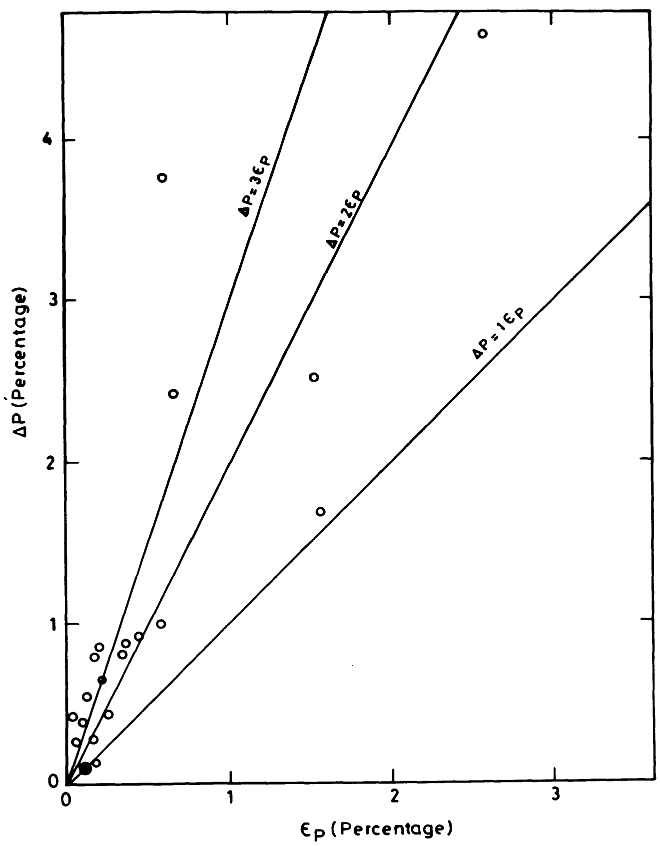

Fig. 2. The largest deviation (ΔP) in the observed degree of polarization is plotted against the standard error (ϵ_p) of the measurements

(1979). A relatively large value of polarization in the R band at some epoch is also shown by H K Ori and V 380 Ori.

MWC 137: This object has shown the largest polarization ($\sim$ 6%) in our sample. The observed polarization does not show any significant variability. Finkenzeller & Mundt (1984) call it unusual in several respects. The object shows one of the strongest and broadest H_α emission lines. The star is also highly reddened ($E(B-V) \approx 1.5$).

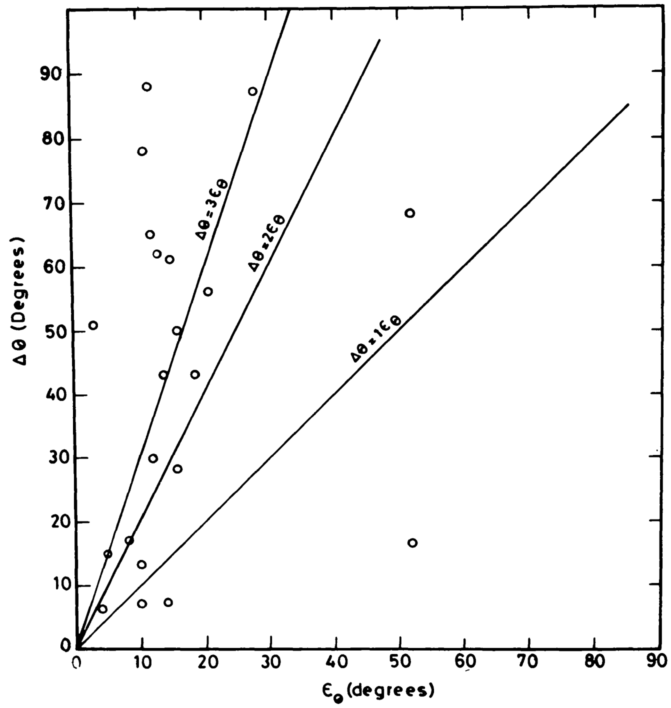

Fig. 3. The largest deviation ($\Delta\theta$) in the observed polarization position angle is plotted against the standard error (ϵ_θ) of the measurements

RCW 34: There is only one set of observations in the V and R bands. The high degree of polarization fits in well with the Group II classification by Hillenbrand et al. (1992).

4.3. *Variability time scales*

Herbig Ae/Be stars have not been monitored continuously at regular intervals. Only a few multiple polarization measurements at intervals ranging from a few days to about twenty years are available. Most of the objects do show significant polarimetric variability on time scales $\geq$ 1 yr. Some stars (e.g. HK Ori, T Ori, HD 250550, HD 76534) have shown large variations in polarization on time scales $\sim$ 1 month. If the variability is due to clumps of scattering material moving with typical Keplerian velocities such short time scales of variability imply structural changes in the distribution of circumstellar material close to the star within a few tens of stellar radii ($\sim 3\ 10^{12}$ cm). This region may correspond to the optically thin inner holes in the circumstellar discs inferred to exist around Herbig Ae/Be stars (Hillenbrand et al. 1992).

5. Conclusions

We have presented the results of our measurements of linear polarization of Herbig Ae/Be stars made at several epochs during the past four years (1989-1993). From these, and other measurements compiled from the literature, the following conclusions can be drawn.

i) For most of the Herbig Ae/Be stars the degree of polarization does not show the wavelength dependence that is characteristic of interstellar polarization and the observed wavelength dependence can change with time indicating the presence of a substantial component produced by circumstellar matter.
ii) At a given epoch the polarization position angle does not show any significantly large variation with wavelength for most of the objects. Temporal variations in the position angle are however common.
iii) Most of the objects are polarimetrically variable. Only 3 stars (14%) in our sample show variations in the degree of polarization $\triangle P$ that are smaller than the corresponding standard errors in the measurements ϵ_P. It is found that the Group III objects (Hillenbrand et al. 1992) generally have smaller variations in polarization.
iv) There is no significant correlation between the variation in the degree of polarization ($\triangle P$) and the variation in the polarization position angle ($\triangle\theta$).
v) Most of the observed Herbig Ae/Be stars are polarimetrically variable on time scales $\geq$ 1 yr. However, some objects have shown large variations in polarization on time scales as short as $\sim$ 1 month indicating structural changes in the distribution of circumstellar material close to the star within a few tens of stellar radii.

A more complete interpretation of the results of polarimetric studies would be possible only when simultaneous photometric and spectroscopic measurements are also available. Herbig Ae/Be stars need to be monitored more regularly with such simultaneous obervations for a better understanding of the young stellar objects of intermediate mass.

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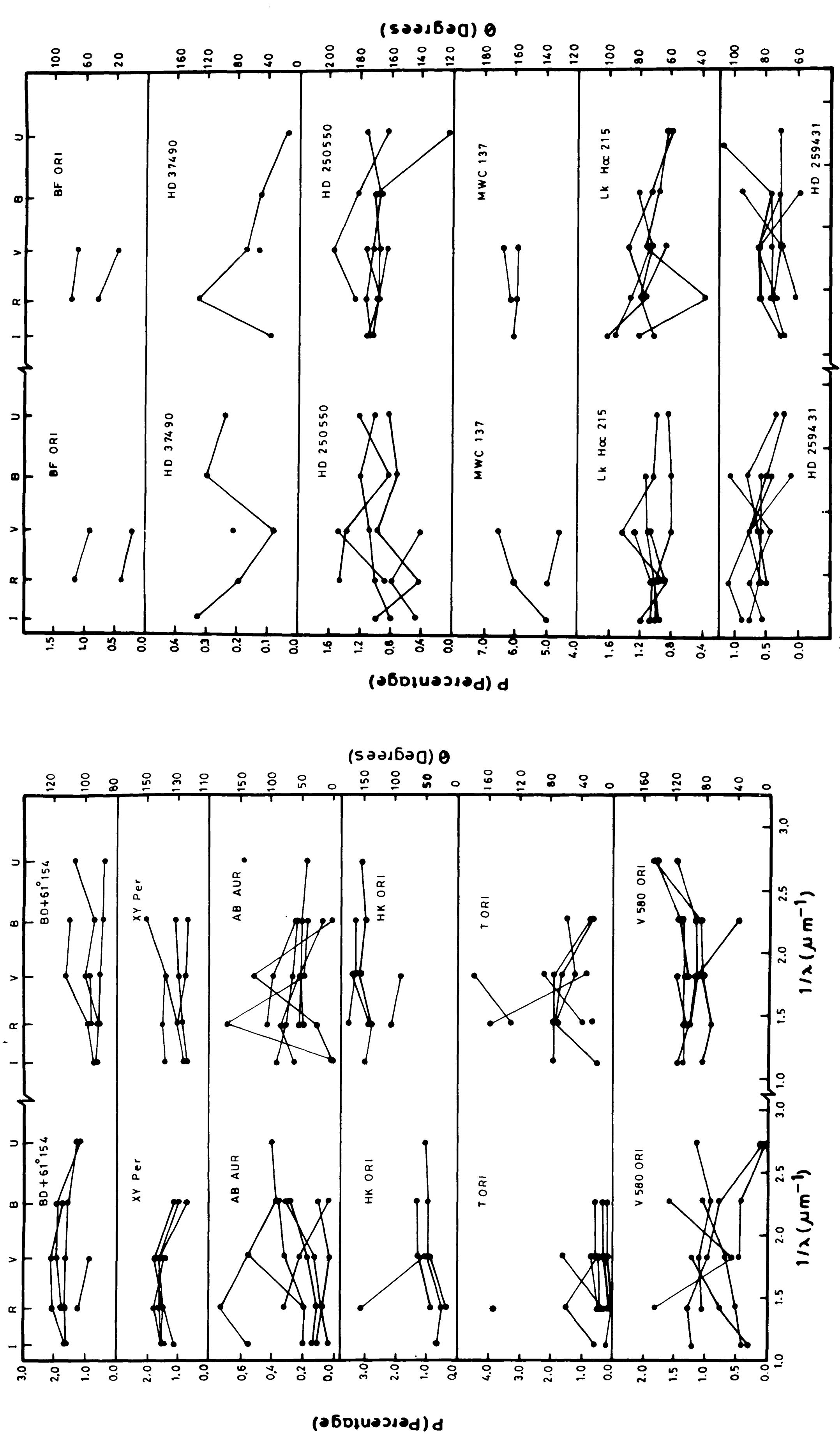

Fig. 1. Multicolour polarimetric observations for Herbig Ae/Be stars. The data points represent both the results of the present study as well as those compiled from the published sources given in Table 1. Points corresponding to the same epoch have been joined by straight lines

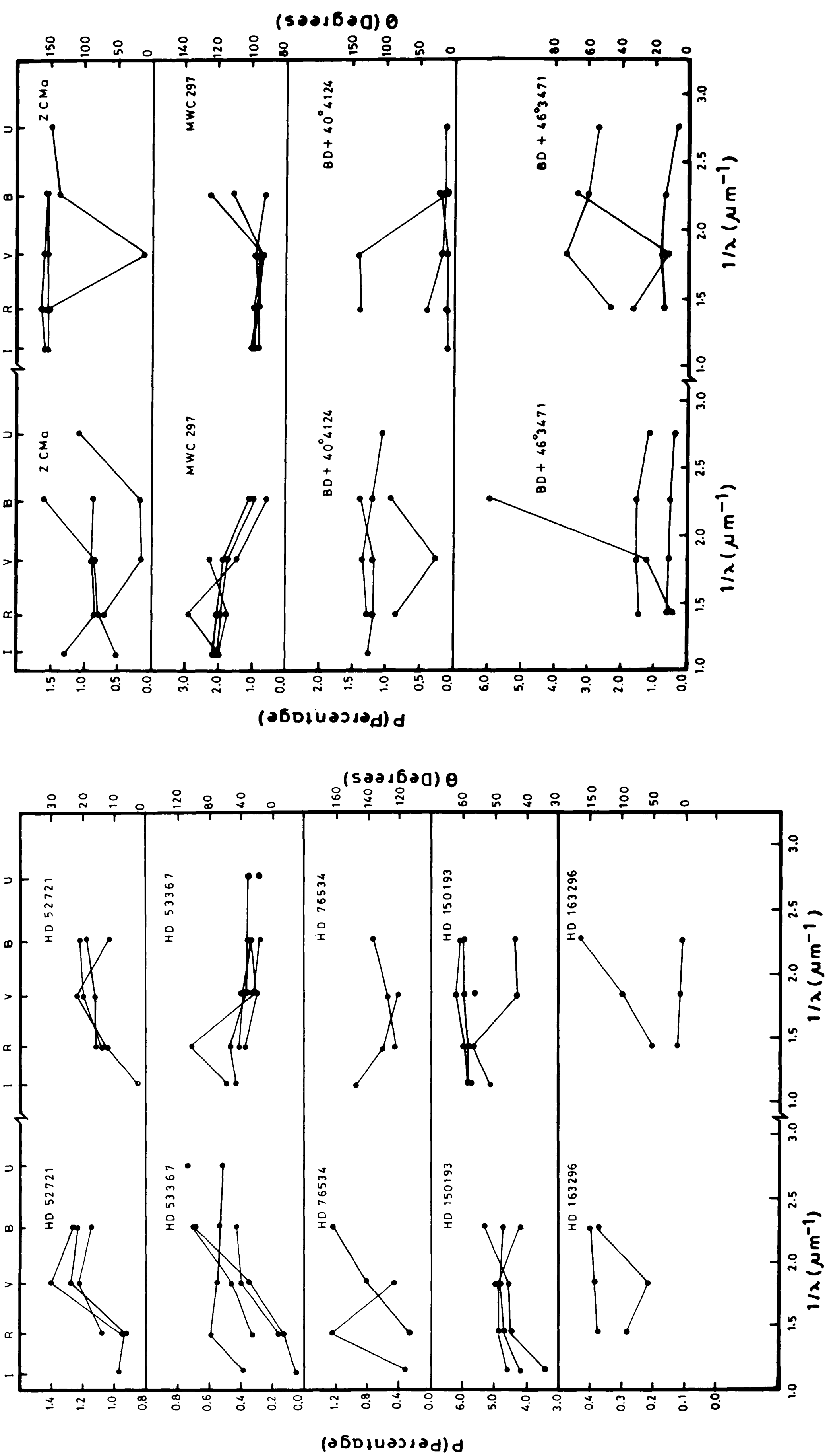

Fig. 1. continued