1993A&A...270..426G

Astron. Astrophys. 270, 426–431 (1993)

ASTRONOMY
AND
ASTROPHYSICS

Anomalous dust in the environment of Herbig Ae/Be stars

U. Gorti and H.C. Bhatt

Indian Institute of Astrophysics, Bangalore 560034, India

Received August 12, accepted October 15, 1992

Abstract. Photometric data in the UBVRI bands of Herbig Ae/Be stars has been analysed to study the wavelength dependence of extinction to these objects. The colour excess ratios E(U−B)/E(B−V), E(V−R)/E(B−V), E(V−I)/E(B−V) and E(V−I)/E(V−R) for these stars have been computed and compared with those for the mean interstellar extinction. The colour excess ratios for Herbig Ae/Be stars are found to be anomalous. For a majority of the Herbig Ae/Be stars the values of the colour excess ratios imply that the dust causing extinction to these stars is dominated by grains that are larger in size than the average dust grain in the interstellar medium.

Key words: Herbig Ae/Be stars – circumstellar dust – reddening – dust grain size

1. Introduction

Herbig Ae/Be stars are believed to be young, intermediate mass stars, contracting on their way to the main sequence. A list of 26 stars was first made by Herbig (1960) in an attempt to find higher mass counterparts to the low mass, pre-main-sequence T Tauri stars. This list was extended by Finkenzeller & Mundt (1984) to include 57 objects, and to the present day other observers (e.g. Hu et al. 1989; Bergner et al. 1990) have added new candidates taking the catalogue to a total of more than 70 stars. Herbig Ae/Be stars show large near and far infrared excesses, attributed by various authors to thermal emission by dust distributed in circumstellar disks or shells (e.g. Tjin a djie & Thé 1978; Catala 1983; Yamashita et al. 1989). Spectroscopy in the infrared region has revealed characteristic dust emission features at 3.3μm and 9.7μm providing unmistakable evidence for the presence of dust grains in the circumstellar environments of these young stars (e.g. Cohen 1973; Whittet et al. 1983). The relatively large degree of polarization and its variation on short time scales, further indicates scattering dust in the close neighbourhood of these stars (e.g. Vrba et al. 1979; Jain et al. 1990; Grinin et al. 1991).

Dust in the environment of young stars is found to differ from that in the general interstellar medium. It has been suggested by many authors that the dust around the Herbig Ae/Be stars is anomalous (Thé et al. 1981; Steenman & Thé 1989; Yamashita et al. 1989; Sorell 1990; Bibo & Thé 1992) Large values of R, the ratio of total to selective extinction have been deduced from the UBV data for some stars. Others have suggested the presence of dense clouds with large grains in a less dense envelope of small grains near the star to provide possible explanations for the variability among these stars (Voshchinnikov 1990; Bibo & Thé 1990; Bibo & Thé 1991; Grinin et al. 1991). An observable effect of circumstellar dust is extinction and reddening of starlight. The wavelength dependence of extinction is determined by the dust grain composition and size distribution. If the circumstellar dust around Herbig Ae/Be stars is different from the mean interstellar dust, one may expect the wavelength dependence of the extinction by this dust to be different from the mean interstellar extinction law (Savage & Mathis 1979; Steenman & Thé 1989; Steenman & Thé 1991). The wavelength dependence of extinction to the star in the optical and near infrared regions can be described by the colour excesses (e.g., E(B−V) = $(B-V)_{observed} - (B-V)_{intrinsic}$, where the intrinsic colours are those for an unreddened main sequence star) and the colour excess ratios E(U−B)/E(B−V), E(V−R)/E(B−V), E(V−I)/E(B−V), and E(V−I)/E(V−R). These colour excess ratios can be computed from stellar photometric measurements in the UBVRI bands. For the mean interstellar extinction law (Savage & Mathis 1979) they have the following values: E(U−B)/E(B−V) = 0.80, E(V−R)/E(B−V) = 0.78, E(V−I)/E(B−V) = 1.60 and E(V−I)/E(V−R) = 2.05. The variation of the colour excess ratios with the mean dust grain radius in the grain size distribution has been studied by McMillan (1979) and Steenman & Thé (1991). McMillan (1979) computed the theoretical colour excess ratios for homogeneous spherical grains using the Mie theory. These ratios have been plotted by McMillan (1979) against grain size parameter a_o which is proportional to the mean grain size. All colour excess ratios E(V−λ)/E(B−V) with the wavelength λ longward of the V band, increase as the mean grain size increases. The ratio E(V−I)/E(V−R) is rather insensitive to variations in a_o and increases only marginally. E(U−B)/E(B−V) has a different behaviour and decreases with increasing mean grain size. Similar behaviour of the colour

---

Send offprint requests to: U. Gorti

1993A&A...270..426G

excess ratios is obtained from the analysis of Steenman & Thé (1991). They have studied the wavelength dependence of extinction with particular reference to Herbig Ae/Be stars, for different values of the lower grain size cutoff in a power law distribution of grain sizes ($dn(a) \propto a^{-3.5}da$). An increase in the value of the lower cutoff results in an increase in the mean grain size and indicates an absence of very small grains that cause extinction in the ultraviolet.

From photometric data for the Herbig Ae/Be stars we can derive the values of these ratios and compare with those for mean interstellar extinction. In this paper we present the results of such a study.

2. Photometric data and analysis

Photometric data for the UBVRI bands has been taken from the literature for known and candidate Herbig Ae/Be stars and is listed in Table 1. The R and I band data were converted from the Cousins system to the Johnson system, where necessary, by using the transformations given by Bessel (1979). Many Herbig stars are known to be variables and therefore only simultaneous measurements have been considered. Very few Herbig Ae/Be stars have been monitored photometrically. When simultaneous measurements for a given star are available at many epochs, we have considered measurements corresponding to the epoch of maximum visual brightness. As our interest lies in the properties of the dust in the vicinity of these objects, only those with a large colour excess have been considered so that the circumstellar dust contributes substantially to the observed extinction. We have restricted our analysis to stars showing an E(B−V) excess larger than 0.32, which corresponds to an extinction of about 1 magnitude in the visual band for an interstellar R, the ratio of total to selective extinction. Colour excesses E(U−B),E(B−V),E(V−R) and E(V−I) have been calculated by subtracting the intrinsic colours for the corresponding spectral type from the observed colours U−B, B−V, V−R, and V−I. The intrinsic or unreddened colours of main sequence stars have been taken from Johnson (1966). Ratios of these colour excesses viz. E(U−B)/E(B−V), E(V−R)/E(B−V), E(V−I)/E(B−V) and E(V−I)/E(V−R) have been computed and are listed in Table 2 with their probable errors. The errors involved in the photometric magnitude determinations are usually of the order of 0.02 magnitudes or in some cases, lower. A conservative error of 0.02 magnitudes has been adopted for all the stars. There is also an uncertainty involved in the determination of spectral type, which would cause an error in the values of the colour excesses. In order to assess these errors, an uncertainty of one subclass in the determined spectral type is assumed, and where a spectral type range has been assigned by the the authors the range has been used. The uncertainties in spectral classification have been converted into the corresponding uncertainties in intrinsic colours of the stars. Our analysis has not been extended to the near infrared JHK bands as there may be flux contamination by non-stellar sources such as *thermal dust emission*, *free-free* and *bound-free* emission. For the optical bands, UBVRI, the contribution from these sources is negligible. As Herbig stars are emission line stars, the photometric magnitudes measured may also be affected by the flux contained in the emission lines. An estimate can be made for the flux contribution by the Hα line to the R band , which is the strongest emission line observed. However, even for an equivalent width of 50 Å the contribution of the emission line flux to photometry is less than ~ 0.03 magnitudes. Simple calculations show that the contributions of the free-free and free-bound processes are of the same order of magnitude as the emission line flux. The errors introduced in the photometric measurements in the optical bands is thereby small, and has been neglected. Contamination of the UBVRI bands by thermal emission from dust can be estimated by considering the spectral energy distributions of these stars (see for e.g. Hillenbrand et al. 1992). In general, the flux contribution of thermal emission by dust is negligible. However, there are a few stars viz. LKHA 198, V380 Ori, R CrA, T CrA, LKHA 233, MWC 1080, NX Pup and MWC 342, where there appears to be some contamination and these have been excluded from the analysis. As we have considered only those stars with an E(B-V) colour excess greater than 0.32 magnitudes, the errors introduced in the values of the colour excess ratios due to flux contribution by these various sources in the UBVRI bands, are reduced.

3. Results and discussion

The colour excess ratios obtained for Herbig Ae/Be stars (Table 2) can be compared with their mean interstellar values. Our results show that the colour excess ratios for extinction towards these stars deviate from the normal interstellar values systematically. In Fig. 1, they have been plotted against the effective temperature T_{eff} of the central star for the corresponding spectral type. It can be seen from the plots that the points representing the Herbig Ae/Be stars deviate from the interstellar values depicted by the dashed lines. In the following we discuss the behaviour of the different colour excess ratios in relation with the theoretical analyses by McMillan (1979) and Steenman & Thé (1991).

3.1. E(V−I)/E(V−R)

As predicted by the theoretical analyses of McMillan (1979) and Steenman & Thé (1991), this colour excess ratio is rather insensitive to grain size, increasing only slightly with increasing mean grain size. It can be seen from Fig. 1 that most of the points lie close to the interstellar value and the scatter is very small. The mean for the dust around Herbig Ae/Be stars is 1.95 with a dispersion of 0.16. The small dispersion for this ratio and a mean value similar to that for interstellar extinction i.e.,2.05, indicates that the colour excesses observed are indeed due to extinction and that the flux contributions due to non-stellar sources like scattering, thermal dust emission, free-free and bound-free processes etc., are small.

Table 1. Photometric data for Herbig Ae/Be stars. J and C refer to R and I magnitudes in the Johnson and Cousins systems respectively.

Star	Sp.type	ref.	U	B	V	R	I	ref.
BD +61154	B8 eq	(9)	10.70	10.96	10.38	9.92C	9.40C	(16)
RR TAU	A3-A5	(26)	11.79	11.52	11.07	10.75C	10.40C	(16)
LKHA 208	B5-B9e	(14)	12.32	12.05	11.62	11.33C	11.04C	(16)
LKHA 215	B7-B8e	(26)	10.88	10.86	10.36	9.94C	9.48C	(18)
HD 259431	B2e	(9)	8.42	8.96	8.670	8.34C	8.07C	(18)
R MON	B0	(7)	12.43	12.80	12.18	11.58C	11.00C	(18)
LKHA 218	B6e	(7)	12.49	12.30	11.87	11.55C	11.26C	(18)
HD 53367	B0 IV	(9)	6.78	7.41	6.97	6.61C	6.19C	(18)
HD 76534	B2e	(9)	7.54	8.11	7.96	7.83C	7.70C	(27)
RCW 34	A0e	(9)	12.61	12.73	11.81	–	–	(15)
Herbst 28	B5e	(15)	12.20	12.00	11.28	–	–	(15)
HD 97048	B9e	(9)	9.03	8.79	8.44	8.20C	7.94C	(18)
HD 150193	A4e	(9)	9.69	9.33	8.80	8.41C	7.97C	(18)
KK OPH	A5-A7e	(9)	11.71	11.26	10.57	10.09C	9.52C	(16)
LKHA 118	B5:Vpe	(10)	11.77	12.00	11.13	–	–	(2)
MWC 297	O9	(3)	13.84	14.54	12.17	9.45J	8.39J	(3)
VV SER	B1-B3e	(10)	13.20	12.78	11.87	11.21C	10.49C	(16)
MWC 300	B:	(30)	12.46	12.61	11.60	–	–	(14)
TY CrA	B9e	(14)	9.47	9.39	8.95	8.58C	8.52C	(18)
BD +404124	B3e	(9)	11.02	11.28	10.54	–	–	(25)
AS 442	B8e	(12)	11.84	11.50	10.87	10.38J	9.94J	(21)
LKHA 134	B8-Ae	(12)	12.23	12.03	11.40	10.88J	10.42J	(21)
V645 Cyg	A0	(11)	15.74	15.16	14.06	12.91J	–	(17)
BD +651637	B3	(9)	10.17	10.49	10.08	9.53J	9.26J	(24)
LKHA 234	B5-B7	(26)	12.63	12.79	11.90	10.90J	10.25J	(24)
HD 216629	B3e	(9)	9.82	10.01	9.29	–	–	(22)
BLJ 71	B0-B8e	(1)	11.75	11.38	10.57	–	–	(1)
HD 97300	B9 V	(28)	9.50	9.35	8.98	8.70C	8.33C	(18)
V517 Cyg	A3-A5	(21)	12.89	12.50	12.03	11.57C	–	(21)

References to Table 1

1.Assousa, Herbst & Turner,1977
2.Bastian & Mundt,1979
3.Bergner,Kozlov,Krivtsov et al. 1988
4.Bergner et al. ,1990
5.Breger,1974
6.Cohen & Schwartz,1976
7.Cohen & Kuhi,1979
8.Dibai,1969
9.Finkenzeller,1985
10.Finkenzeller & Mundt,1984
11.Goodrich,1986
12.Herbig,1958
13.Herbig,1960
14.Herbig & Rao,1972
15.Herbst,1975
16.Hillenbrand,Strom,Vrba et al. 1992
17.Humphreys et al. 1980
18.Kilkenny,Whittet,Davies et al. 1985
19.Marraco & Rydgren,1981
20.Mendoza,1968
21.Petrova & Shevchenko,1987
22.Racine,1968
23.Reipurth,1983
24.Shevchenko & Yakubov,1989
25.Strom,Strom,Breger M. et al. 1972
26.Strom,Strom,Yost et al. 1972
27.Thé,Felenbok,Cuypers et al. 1985
28.Thé,Wesselius,Tjin a Djie et al. 1985
29.Tjin a Djie,Remijn & Thé,1984
30.Wolf & Stahl,IAU Symp. 116

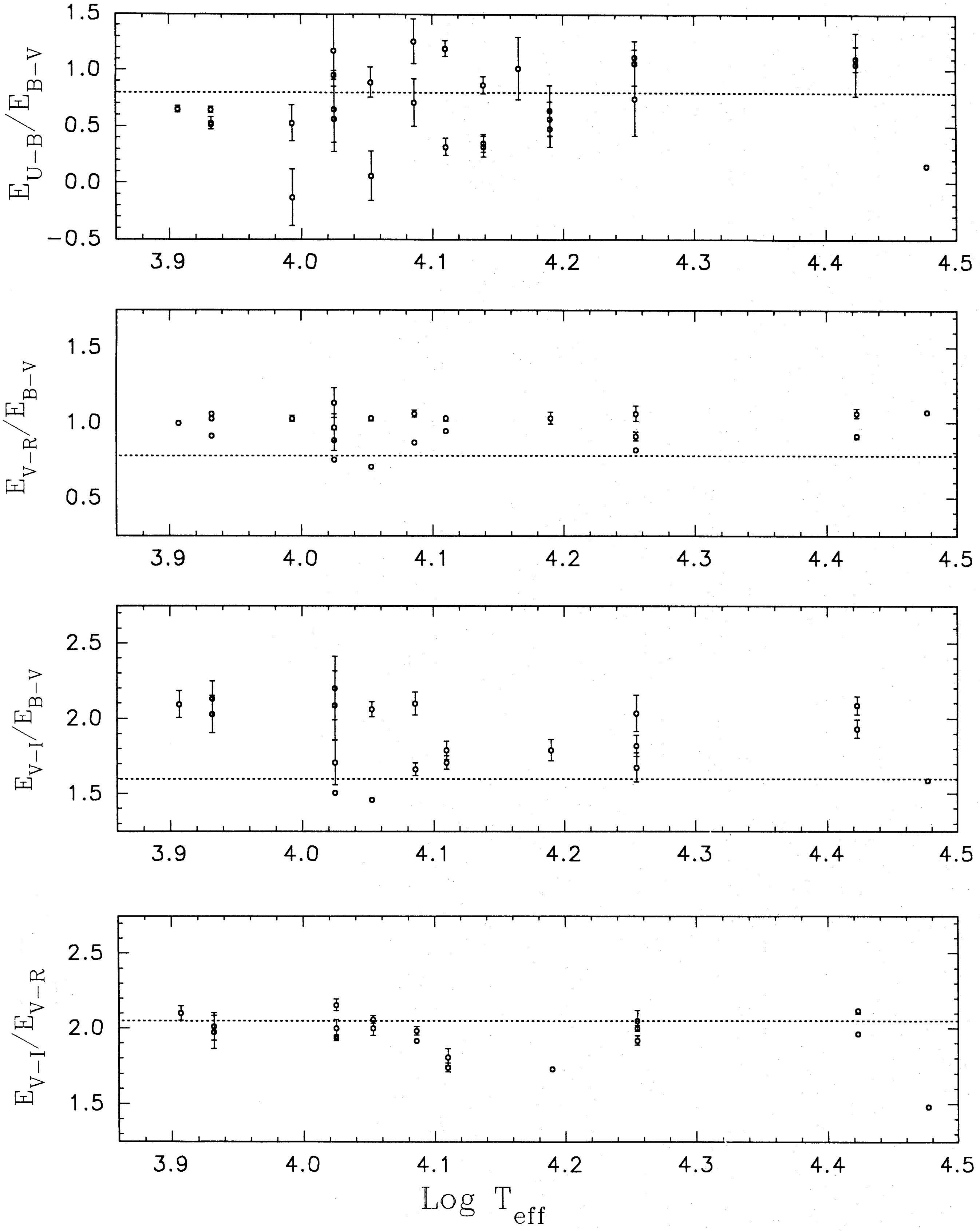

Fig. 1. Various colour excess ratios are plotted against Log T_{eff}. The dashed lines indicate the interstellar values for the different ratios. In some cases, the errors are too small to appear on the plot

Table 2. The E(B−V) colour excess and various colour excess ratios of stars with corresponding errors.

Star	E(B−V)	E(U−B)/E(B−V)	E(V−R)/E(B−V)	E(V−I)/E(B−V)	E(V−I)/E(V−R)
BD +61154	0.67 ± 0.06	0.06 ± 0.22	1.03 ± 0.02	2.06 ± 0.05	2.00 ± 0.01
RR TAU	0.34 ± 0.06	0.53 ± 0.05	1.03 ± 0.01	2.03 ± 0.12	1.97 ± 0.11
LKHA 208	0.55 ± 0.08	1.25 ± 0.20	0.87 ± 0.02	1.66 ± 0.04	1.91 ± 0.01
LKHA 215	0.62 ± 0.07	0.71 ± 0.21	1.06 ± 0.02	2.10 ± 0.08	1.98 ± 0.03
HD 259431	0.53 ± 0.07	1.06 ± 0.20	1.06 ± 0.05	2.03 ± 0.12	1.92 ± 0.03
R MON	0.92 ± 0.07	1.10 ± 0.11	1.06 ± 0.03	2.09 ± 0.06	1.96 ± 0.01
LKHA 218	0.57 ± 0.05	1.19 ± 0.07	0.95 ± 0.01	1.71 ± 0.04	1.81 ± 0.06
HD 53367	0.74 ± 0.07	1.05 ± 0.28	0.91 ± 0.02	1.93 ± 0.06	2.12 ± 0.02
HD 76534	0.39 ± 0.07	0.74 ± 0.33	0.82 ± 0.02	1.68 ± 0.10	2.05 ± 0.07
RCW 34	0.92 ± 0.09	-0.13 ± 0.25	–	–	–
Herbst 28	0.88 ± 0.05	0.86 ± 0.08	–	–	–
HD 97048	0.41 ± 0.09	1.17 ± 0.32	0.88 ± 0.07	1.71 ± 0.15	1.94 ± 0.02
HD 150193	0.42 ± 0.06	0.64 ± 0.03	1.06 ± 0.01	2.13 ± 0.11	2.01 ± 0.09
KK OPH	0.52 ± 0.07	0.65 ± 0.03	1.00 ± 0.02	2.09 ± 0.09	2.10 ± 0.05
LKHA 118	1.03 ± 0.05	0.32 ± 0.09	–	–	–
MWC 297	2.67 ± 0.04	0.15 ± 0.02	1.07 ± 0.01	1.59 ± 0.01	1.48 ± 0.01
VV SER	1.15 ± 0.09	1.11 ± 0.07	0.91 ± 0.03	1.82 ± 0.07	2.00 ± 0.02
MWC 300	1.17 ± 0.05	0.35 ± 0.08	–	–	–
TY CrA	0.50 ± 0.09	0.65 ± 0.29	1.13 ± 0.10	2.20 ± 0.21	1.95 ± 0.01
BD +404124	0.94 ± 0.06	0.48 ± 0.16	–	–	–
AS 442	0.72 ± 0.06	0.89 ± 0.13	0.71 ± 0.01	1.46 ± 0.01	2.06 ± 0.03
LKHA 134	0.69 ± 0.16	0.57 ± 0.29	0.75 ± 0.01	1.51 ± 0.02	2.00 ± 0.06
V645 Cyg	1.10 ± 0.09	0.53 ± 0.16	1.03 ± 0.02	–	–
BD +651637	0.61 ± 0.07	0.64 ± 0.22	1.03 ± 0.04	1.79 ± 0.07	1.73 ± 0.01
LKHA 234	1.03 ± 0.07	0.32 ± 0.08	1.03 ± 0.02	1.79 ± 0.06	1.74 ± 0.03
HD 216629	0.92 ± 0.07	0.57 ± 0.15	–	–	–
BLJ 71	0.99 ± 0.14	1.02 ± 0.28	–	–	–
HD 97300	0.43 ± 0.09	0.96 ± 0.04	0.97 ± 0.09	2.09 ± 0.23	2.16 ± 0.04
V517 Cyg	0.36 ± 0.07	0.51 ± 0.02	0.91 ± 0.01	–	–

3.2. E(V−R)/E(B−V),E(V−I)/E(B−V)

These colour excess ratios have mean values that are larger than the interstellar, consistent with a large dust grain population. The deviations from the interstellar value are large . E(V−R)/E(B−V) has a mean value of 0.97 compared to the interstellar 0.78. The mean of E(V−I)/E(B−V) is 1.87 whereas the interstellar ratio is 1.60.

3.3. E(U−B)/E(B−V)

The mean value for this ratio is 0.69 which is lower than 0.80, the number expected for normal interstellar extinction, and is interpreted as due to the presence of larger dust grains. There are some stars that lie above the interstellar value which would indicate that the mean grain size is smaller than the interstellar, but the other colour excess ratios for the same stars are inconsistent with such an explanation. There may possibly be two distinct populations of grains in the circumstellar regions of these stars, one with a larger mean dust grain size and the other a smaller mean grain size than the interstellar dust. The plot also shows one star (RCW 34), with a negative value of E(U−B), which may be due to a spectral type misclassification. The star may be of an earlier spectral type than that given in the literature.

The mean colour excess ratios obtained for the dust causing extinction towards Herbig stars indicate a possibly different grain size distribution, with a larger mean grain size. This further implies that the ratio of total to selective extinction R given by $A_V/E(B-V)$ is larger towards these stars. The visual extinction A_V obtained for a star by assuming an interstellar R= 3.1 is hence an underestimate. The photometric brightness of the star would therefore also be underestimated. It is to be noted that the extinction determined is the total extinction to the star which includes extinction by intervening interstellar dust grains along the line of sight. The colour excesses are therefore due to interstellar as well as circumstellar dust. To cause the large deviations observed in the colour excess ratios, the dust grains in the neighbourhood of Herbig Ae/Be stars must be significantly larger than the average interstellar dust grain. It should be noted here that for a given star, the characteristics of the dust grains inferred in this analysis correspond to the epoch of measurements. The photometric variability of Herbig Ae/Be stars is usually explained as due to an obscuration of the central star caused by drifting dust clouds in its immediate neighbourhood. Thus, the anomaly in the dust grain characteristics can vary with the variability of the central star. An inference drawn from photometric measurements made at an epoch of decreased brightness, gives the characteristics of a dust grain population that includes the dust in the obscuring cloud. In any case, the values of colour excess ratios obtained imply the presence of an anomalous dust grain size distribution in the system, as a whole. If the grain size distribution in the circumstellar environment of Herbig Ae/Be stars is a power law similar to that for the interstellar dust ($dn(a) \propto a^{-3.5}da$), then the mean grain size can be increased by increasing the lower cutoff size in the distribution. The results presented here may thus indicate the depletion of very small dust grains around Herbig Ae/Be stars as suggested by Steenman & Thé (1991). Such a grain size distribution also explains the anomalously low extinction observed in the ultraviolet.

4. Conclusions

We have analysed photometric data in the optical bands for Herbig Ae/Be stars and obtained the colour excess ratios, in order to study the wavelength dependence of extinction towards these young stars. These values have been compared with the theoretically expected behaviour of the colour excess ratios as a function of grain size. The ratio E(V−I)/E(V−R) is fairly constant as expected which seems to indicate that the observed colour excesses are largely due to extinction. E(V−R)/E(B−V) and E(V−I)/E(B−V) are larger than that for the mean interstellar extinction law whereas E(U−B)/E(B−V) is lower, consistent with a grain size distribution having a large mean grain radius. Grain growth and depletion of small grains are two possible mechanisms that can lead to a large average grain size of a grain size distribution. The latter mechanism is however preferred as it also explains the low extinction observed towards these stars in the ultraviolet region.

Acknowledgements. We thank the referee, Prof. P. S. Thé, for valuable comments that led to many improvements in the paper.

References

Assousa G.E., Herbst W. & Turner K.C., 1977, ApJ, 218, L13
Bastian U.& Mundt R., 1979, A&AS, 36, 57
Bergner Y.K., Kozlov V.P., Krivtsov A.A. et al. 1988 SvA, 28, 313
Bergner Y.K. et al. 1990, Astrophysics, 32, 23
Bessel M.S., 1979, PASP, 91, 589
Breger M., 1974, ApJ, 188, 53
Bibo E.A. & Thé P.S., 1990, A&A, 236, 155
Bibo E.A. & Thé P.S., 1991, A&AS, 89, 319
Bibo E.A. & Thé P.S., 1992, A&A, 260, 293
Catala C., 1983, A&A, 125, 313
Cohen M., 1973, MNRAS, 161, 105
Cohen M.& Schwartz R.D., 1976, MNRAS, 174, 137
Cohen M.& Kuhi L.V., 1979, ApJSS, 41, 373
Dibai E.A., 1969, Astrophysics, 5, 115
Finkenzeller U. & Mundt R., 1984, A&AS, 55, 109
Finkenzeller U., 1985, A&A, 151, 340
Goodrich R.W., 1986, ApJ, 311, 882
Grinin V.P., Kiselev N.N., Minikulov N.Kh. et al. 1991, Ap&SS, 186, 283
Herbig G.H., 1958, ApJ, 128, 259
Herbig G.H., 1960, ApJSS, 4, 337
Herbig G.H. & Rao N.K., 1972, ApJ, 174, 401
Herbst W., 1975, AJ, 80, 212
Hillenbrand L.A., Strom S.E., Vrba F.J. et al. 1992, preprint
Hu J.Y.,Thé P.S. & de Winter D., 1989, A&A, 208, 213
Humphreys et al. 1980, ApJ, 237, L17
Jain S.K.,Bhatt H.C. & Sagar,R., 1990, A&AS, 83, 237
Johnson H.L., 1966, ARA&A, 4, 193
Kilkenny D.,Whittet D.C.B.,Davies J.K.,et al. 1985, S.African Astron. Obs.Circ., 9, 55
Marraco H.G. & Rydgren A.E., 1981, AJ, 86, 62
McMillan R.S., 1979, ApJ., 225, 880
Mendoza E.E., 1968, ApJ, 151, 977
Petrova N.N.& Shevchenko V.S., 1987, SvA Lett., 13, 289
Racine R., 1968, AJ, 73, 233
Reipurth B., 1983, A&A, 117, 183
Savage B.D., Mathis J.S., 1979, ARA&A, 17, 73
Shevchenko V.S.& Yakubov S.D., 1989, SvA, 33, 370
Sorell W.H., 1990, ApJ, 361, 150
Steenman & Thé P.S., 1989, Ap&SS, 161, 99
Steenman & Thé P.S., 1991, Ap&SS, 184, 9
Strom K.M., Strom S.E., Breger M.,et al. 1972, ApJ, 173, LL65
Strom S.E., Strom K.M., Yost J.,et al. 1972, ApJ, 173, 353
Thé P.S., Tjin a Djie H.R.E., Bakker R. et al. 1981, A&AS, 44, 451
Thé P.S., Felenbok P., Cuypers H. & Tjin a djie H.R.E. 1985, A&A, 149, 429
Thé P.S., Wesselius P.R., Tjin a Djie H.R.E. et al. 1985, A&A, 155, 347
Tjin a djie H.R.E. & Thé P.S., 1978, A&A 70, 311
Tjin a Djie H.R.E., Remijn L.,& Thé P.S., 1984, A&A, 134, 273
Voshchinnikov N.V., 1990, Astrophysics, 30, 313
Vrba F.J., Schmidt G.D. & Hintzen, P.M. 1979, ApJ, 227, 185
Whittet,D.C.W. et al. 1983, A&A, 123, 301
Wolf & Stahl, IAU Symp. 116, 248
Yamashita T.,Sato S.,Nagata T. et al. 1989, ApJ, 336, 832

This article was processed by the author using Springer-Verlag LaTeX A&A style file version 3.