Non-emission-line young stars of intermediate mass

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ABSTRACT

We present optical spectra of four intermediate-mass candidate young stellar objects that have often been classified as Herbig Ae/Be stars. Typical Herbig Ae/Be emission features are not present in the spectra of these stars. Three of them, HD 36917, HD 36982 and HD 37062, are members of the young Orion nebula cluster (ONC). This association constrains their ages to be $\lesssim 1$ Myr. The lack of appreciable near-infrared excess in them suggests the absence of hot dust close to the central star. However, they do possess significant amounts of cold and extended dust as revealed by the large excess emission observed at far-infrared wavelengths. The fractional infrared luminosities ($L_{ir}/L_{\star}$) and the dust masses computed from *IRAS* fluxes are systematically lower than those found for Herbig Ae/Be stars but higher than those for Vega-like stars. These stars may thus represent the youngest examples of the Vega phenomenon known so far. In contrast, the other star in our sample, HD 58647, is more likely to be a classical Be star, as is evident from the low $L_{ir}/L_{\star}$, the scarcity of circumstellar dust, the low polarization, the presence of Hα emission and near-infrared excess, and the far-infrared spectral energy distribution consistent with free–free emission similar to other well-known classical Be stars.

Key words: circumstellar matter – stars: early-type – stars: emission-line, Be – stars: pre-main-sequence – infrared: stars.

1 INTRODUCTION

Pre-main-sequence (PMS) stars of intermediate mass ($2 \leq M/M_{\odot} \leq 8$) which show emission lines in their spectra are called Herbig Ae/Be (HAEBE) stars. They were first discussed as a group by Herbig (1960). He identified 26 stars which are of spectral type A or B, located in obscured star-forming regions and illuminating a bright nebulosity in its immediate vicinity. Additions to the original list were made by Finkenzeller & Mundt (1984) and Herbig & Bell (1988). Recently, a more extended catalogue of HAEBE stars and related objects was published by Thé, De Winter & Perez (1994). In this catalogue, 287 HAEBE stars and related objects are listed in five tables, which include stars with later spectral type (G0 or earlier) and those found relatively isolated from star-forming clouds. Of these, only 109 stars, which are listed in table 1 of the catalogue, are recognized as either HAEBE stars or potential candidate members. Other stars listed in the catalogue are either of very uncertain or unknown spectral type, or have not been identified to belong to any specific group.

The following set of properties are often taken as a working definition of HAEBE stars (Waters & Waelkens 1998): *(a) spectral type B or A with emission lines; (b) infrared excess due to hot or cool circumstellar dust, or both; (c) luminosity class III to V.* The emission lines are believed to be formed in a stellar wind originating from a hot and extended chromosphere around the star (Bouret & Catala 1998), and are closely connected with the accretion-related disc activity. The near- and far-infrared excesses which characterize the spectral energy distribution (SED) of these stars are attributed to the presence of significant amounts of circumstellar dust with a wide range in temperature (e.g. Hillenbrand et al. 1992). Submillimetre and millimetre observations have clearly established the existence of dust. Dust masses estimated from these studies range from $\sim 10^{-5}$ to 10^{-1} M$_{\odot}$ (Waters & Waelkens 1998, and references therein). Scattering of central star light by the circumstellar dust is manifested by large values of intrinsic polarization measured for HAEBE stars (e.g. Grinin 1994). However, the geometry of the circumstellar environment of HAEBE stars is still a matter of debate. Evidence for the presence of discs as well as envelopes has been found. Recently, Natta et al. (2001) have argued that irradiated discs with a puffed-up inner wall of optically thick dust provide a good fit to the observations over the entire range of wavelengths.

Although the PMS nature of the HAEBE stars is now well established, several questions concerning their PMS evolution remain to be answered. Do all PMS stars of intermediate mass go through the HAEBE phase? What happens to the attendant circumstellar material around a HAEBE star by the time it evolves

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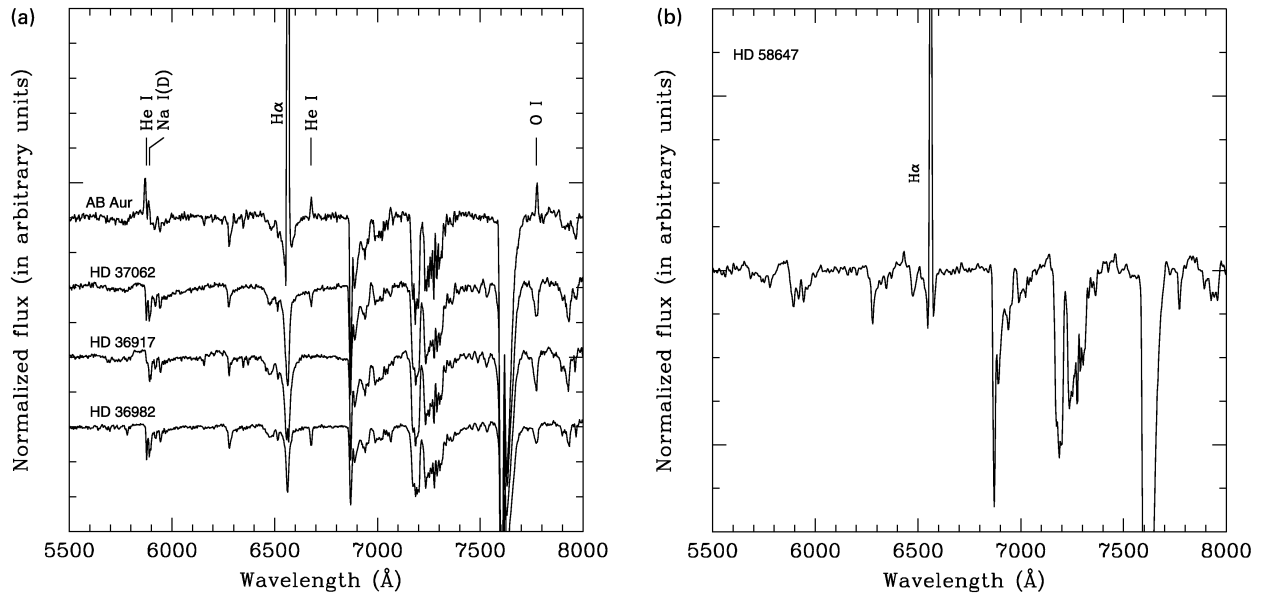
Figure 1. (a) Optical spectra of the Orion nebula cluster (ONC) member stars and AB Aur. In HD 37062, HD 36917 and HD 36982, typical Herbig Ae/Be emission lines are absent. (b) Optical spectrum of HD 58647. Apart from Hα, no Herbig Ae/Be emission lines are present.

into a main-sequence (MS) star? There have been suggestions in the literature that HAEBE stars evolve into Vega-like stars (e.g. Malfait, Bogaert & Waelkens 1998; Waters & Waelkens 1998). Vega-like stars are characterized by a substantial far-infrared excess due to cool dust, a relatively low near-infrared excess, low polarization, and a lack of emission lines in their spectra. The dust masses found around them are a few orders of magnitudes lower than those of HAEBE stars. Also, Vega-like discs in general are gas-depleted (Lagrange, Backman & Artymowicz 2000). Do all HAEBE stars pass through a Vega-like phase with gas-depleted discs? These questions are critical to our understanding of the nature of the PMS evolution of intermediate-mass stars.

A study of non-emission-line young stellar candidate objects listed in table 5 of the catalogue by Thé et al. (1994) may shed some light on the issues raised above. There are 14 stars listed in this table. Typical PMS properties are less clearly seen in these stars. One of them, β Pic, is a *bona fide* Vega-like star. The evolutionary status of other stars is not very clear. They are believed to be, as the authors suggest, transition objects between the PMS and MS phases.

In this paper we present the results of a study of four non-emission-line stars listed in the afore-mentioned catalogue. Spectroscopic and polarimetric observations of these stars were carried out. In Section 2 we present our observations. Together with the information available from literature in different wavelength ranges, we discuss the structure of the circumstellar environment and the evolutionary status of these stars in Section 3. A summary of our study is presented in Section 4.

2   OBSERVATIONS

Medium-resolution ($\lambda/\Delta\lambda \sim 3000$) optical CCD spectra were obtained for stars HD 36917 (V372 Ori), HD 36982 (LP Ori) and HD 37062 (V361 Ori) with the Optometrics Research (OMR) spectrograph on the 2.3-m Vainu Bappu Telescope (VBT), and for HD 58647 with the Universal Astronomical Grating Spectrograph (UAGS) on the 1-m telescope at the Vainu Bappu Observatory, Kavalur, India. A log of spectroscopic observations is given in

**Table 1.** Log of spectroscopic observations.

Object	Date of Observation	Exposure Time (s)
AB Aur	23 December 2000	600
HD 36917	27 February 2002	600
HD 36982	27 February 2002	600
HD 37062	26 February 2002	300
HD 58647	22 December 2000	600

Table 1. The prototype Herbig Ae/Be star AB Aur was also observed with the UAGS on the 1-m telescope, and is included in Table 1. All spectra were bias-subtracted, flat-field-corrected, extracted and wavelength-calibrated in the standard manner using the IRAF[1] reduction package. In view of the presence of surrounding diffuse H II region nebulosity in the direction of three of the programme stars, the background sky subtraction was performed in the following way. The stellar spectra were extracted by summing up over 10 pixels (plate scale = 0.2 arcsec pixel^{-1}) perpendicular to the dispersion axis. The sky background subtracted was obtained by summing up 10 pixels, 10 pixels (2 arcsec) away from the star on either side. The spectra were corrected for the instrumental response, and brought to a relative flux scale using the spectrophotometric standard observed on the same night. Each spectrum spans a wavelength range of $\sim 2400\,\text{Å}$, centred roughly at Hα($\lambda \sim 6562\,\text{Å}$). Reduced spectra of HD 36917, HD 36982 and HD 37062, along with that of AB Aur, are presented in Fig. 1(a), and that of HD 58647 in Fig. 1(b). Optical linear polarization measurements were made with a fast star-and-sky chopping polarimeter (Jain & Srinivasulu 1991) coupled at the $f/13$ Cassegrain focus of the 1-m telescope at the Vainu Bappu Observatory, Kavalur of the Indian Institute of Astrophysics. A dry-ice-cooled R943-02 Hamamatsu photomultiplier tube was used as the detector. All measurements were made in the *V* band

Table 2. Polarization observations from Kavalur.

Object	Date of Observation	P (per cent)	ϵP (per cent)	θ (°)	ϵ_θ (°)
HD 36982	12 March 1999	0.53	0.11	55	8
HD 58647	03 March 2000	0.23	0.07	123	7
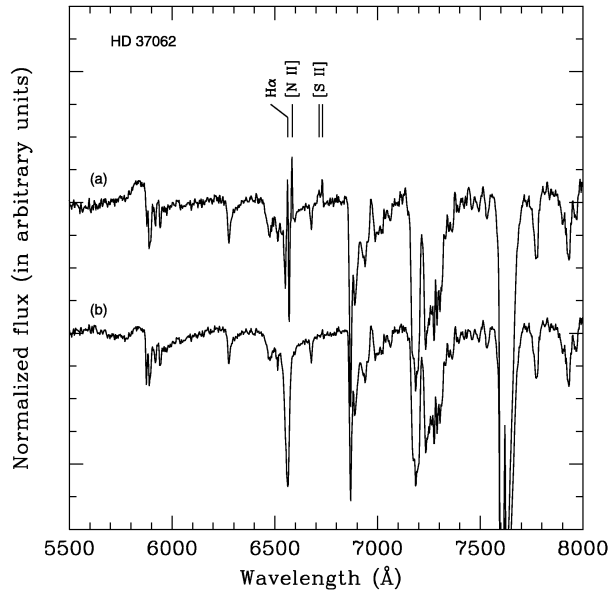
Figure 2. (a) The raw spectrum of HD 37062 with nebular lines superimposed. (b) The reduced spectrum after subtraction of the surrounding nebulosity.

Table 3. Polarization measurements in the *V* band, compiled from literature.

Object	P (per cent)	ϵ_P (per cent)	θ (°)	ϵ_θ (°)	Reference[a]
HD 36917	0.97	0.032	43	0.9	1
HD 36982	1.01	0.021	56	0.6	1
HD 37062	0.41	0.032	162	2.2	1
HD 58647	0.22	0.04	133.3	4.6	2

[a]1. Heiles (2000). 2. Oudmaijer et al. (2001).

with an aperture of 15 arcsec. The instrumental polarization was determined by observing unpolarized standard stars from Serkowski (1974). It was found to be ~0.1 per cent, and has been subtracted vectorially from the observed polarization of the programme stars. The zero of the polarization position angle was determined by observing the polarized standard stars from Hsu & Breger (1982). The position angle is measured from the celestial north, increasing eastward. Observed polarizations and position angle values are presented in Table 2. The object names and the dates of observations are presented in columns 1 and 2 of the table. The percentage polarizations in the *V* band and the probable errors in their measurement are given in columns 3 and 4, and the position angles and their probable errors in columns 5 and 6.

It can be seen from Figs 1(a) and (b) that emission lines are not present in the spectra of these stars except HD 58647. In Fig. 1(a) we have also included a spectrum of AB Aur, a prototype Herbig Ae star, in the same wavelength range and of similar resolution as the other spectra for comparison. Typical HAEBE emission

features such as Hα, He I ($\lambda\lambda$5875, 6678) and O I (λ7774), which are prominent in AB Aur, are not seen in the spectra of HD 36917, HD 36982 and HD 37062. In contrast, HD 58647 has a strong Hα line in emission, but does not show any other characteristic HAEBE emission features. These stars cannot be unequivocally classified as HAEBE stars.

We note that three of the programme stars, HD 36917, HD 36982 and HD 37062, are towards the direction of the Orion nebula, and the diffuse H II region present there is projected on to the line of sight to these stars. Therefore a careful subtraction of the surrounding nebular emission from the observed spectra is very important. This is illustrated in Fig. 2, which presents the raw spectrum with superimposed nebular lines, and the reduced spectrum with surrounding nebular emission subtracted, for HD 37062.

In Table 3 we present polarization data for these stars already existing in the literature. The polarization values measured are typical of that of PMS stars except, again, for HD 58647, which shows a relatively low value of polarization. Also, LP Ori, for which we have more than one polarization measurement, shows variability, which is again an indicator of the youth of the star.

3 DISCUSSION

All the stars in our sample have previously been treated as HAEBE stars by different authors (e.g. Malfait et al. 1998; Valenti, Johns-Krull & Linsky 2000; Yudin 2000), although in the catalogue by Thé et al. (1994) they are identified as non-emission-line stars. Spectra presented in Fig. 1 show that the characteristic HAEBE emission features (He I $\lambda\lambda$5875, 6678 and O I λ7774) are absent in these stars. Their classification as HAEBE stars is therefore doubtful. A strong Hα emission is present in HD 58647 but, as argued later in this paper, this star is likely to be a classical Be star. Weak Hα emission, filling in the absorption core, is present in HD 36917, even after subtraction of the possible contribution of the surrounding nebulosity. By comparing with synthetic spectra (Pickles 1985) of normal spectrophotometric standard stars of similar spectral type, we determine the equivalent width of the Hα emission in this star to be 2.5 Å. This upper limit (for any residual nebular emission) to the Hα equivalent width for HD 36917 is much smaller than those for typical HAEBE stars (for the HAEBE prototype star AB Aur we find the Hα emission equivalent width to be 44 Å). Interpreted as a measure of accretion rate (e.g. Hillenbrand et al. 1992; Muzerolle, Calvet & Hartmann 2001), this Hα emission-line flux implies a mass accretion rate ($\dot{M}$) of order ~10^{-7}, which is much smaller (by a factor of 10 to 100) than those in typical HAEBE stars ($\dot{M} \sim 10^{-6}$–10^{-4} M$_\odot$ yr^{-1} depending on the spectral type; Hillenbrand et al. 1992).

Three of the stars that we have observed, HD 36917, HD 36982 and HD 37062, are in the direction of the known H II region (Sharpless No. 281) towards the Orion nebula. From proper motion and radial velocity studies it has been established that these stars are kinematically connected with the Orion nebula cluster (ONC), which is at the north-western end of Orion A cloud (McNamara 1976; McNamara & Huels 1983; van Altena et al. 1988; Tian et al. 1996; Hillenbrand 1997). They belong to the stellar population in the inner ~2.5 pc of the ONC, which is at a distance of 470 $\pm$ 70 pc (Walker 1969; Genzel et al. 1981; Tian et al. 1996; Hillenbrand 1997). The ONC is characterized by a mean age of <1 Myr and an age spread which is probably less than 2 Myr, with an internal velocity dispersion of ~2 km s^{-1} (Tian et al. 1996; Hillenbrand 1997). The kinematic association with the ONC

Table 4. Data compiled from the literature, and quantities estimated from them.

Object	Sp. Type	$v \sin i$ km s^{-1}	B mag	V mag	J mag	H mag	K mag	$E(B-V)$ mag
HD 36917[a]	B9.5+A0.5	117	8.18	8.06	7.269	7.012	6.615	0.14
HD 36982	B1.5V	98	8.48	8.44	7.754	7.762	7.521	0.29
HD 37062	B4V	78	7.80	8.24	7.850	7.725	7.576	-0.26
HD 58647	B9IVe	280	6.82	6.85	6.464	6.115	5.433	0.10

[a]Spectroscopic binary (Levato & Abt 1976).
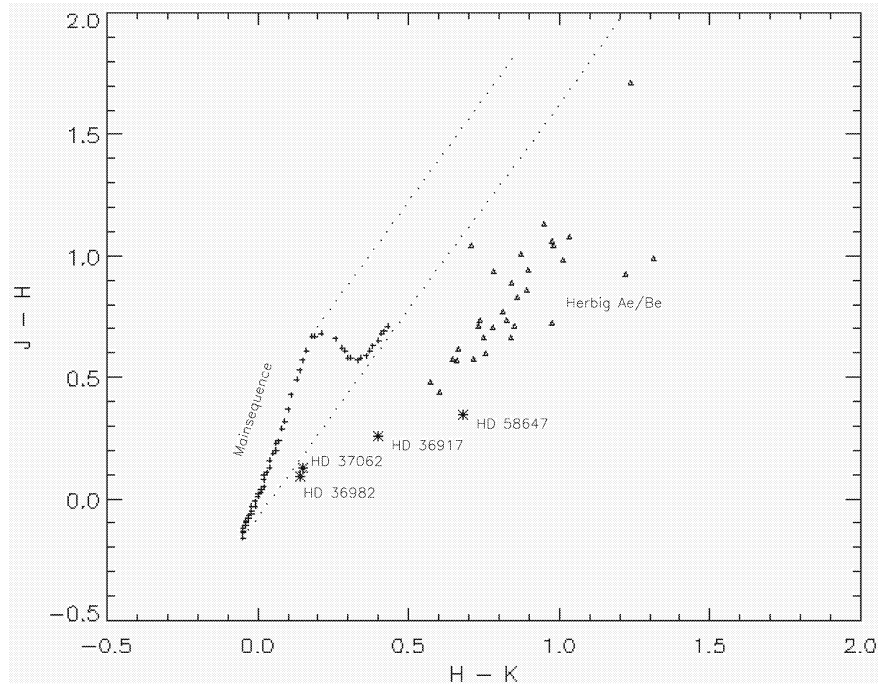
Figure 3. Near-infrared colour–colour diagram for the stars. Also plotted are Herbig Ae/Be stars (triangles) and main-sequence stars (crosses).

strongly constrains the ages of these stars to within a few $\sim 10^6$ years. They are young stars of intermediate mass. In the following we use the average distance to the ONC (470 pc) as the distance to its member stars.

To complement our observations, we have collated available information from the literature on our sample stars. We present this information in Table 4. The spectral types are taken from SIMBAD, except that of HD 36917 which is from Levato & Abt (1976). Values of $v \sin i$ are taken form van den Ancker et al. (1998) and Yudin (2000). The optical B and V magnitudes are derived from Tycho magnitudes, except for HD 37062 for which the B and V magnitudes are from SIMBAD. Tycho photometric errors are less than 0.02 mag. The J, H and K magnitudes are from the 2MASS catalogue. Errors in the J, H and K magnitudes are less than 0.07 mag. The reddening $E(B-V)$, estimated from spectral types and photometric magnitudes, is listed in column 9.

We have constructed a near-infrared colour–colour diagram (Fig. 3) from the 2MASS magnitudes for our programme stars. Along with the four programme stars, HAEBE stars and main-sequence stars are also plotted in the diagram. The colours for the main-sequence stars are from Koornneef (1983). HAEBE stars are taken from Thé et al. (1994), and their colours are derived from 2MASS magnitudes. The two parallel dotted lines form the reddening band for normal stellar photospheres. These lines are

parallel to the reddening vector and bound the range in the colour–colour diagram within which stars with purely reddened normal stellar photospheres can fall (Lada & Adams 1992). It can be seen that all four stars are distinctly separated from the region occupied by HAEBE stars. Their near-infrared characteristics are different from those of HAEBE stars. The near-infrared excesses of all four stars are considerably lower than those of HAEBE stars. HD 36982 and HD 37062 have very little near-infrared excess, if any. The near-infrared excess in HAEBE stars is attributed to reradiation from hot dust less than ~ 1 au from the star. The low near-infrared excess shown by our programme stars would thus strongly suggest the absence of submicron-sized dust grains close to the star.

In Table 5 we present far-infrared data for the stars and the quantities estimated from them, except for HD 37062 which does not have an *IRAS* entry. HD numbers of the stars, their *IRAS* source names and the *IRAS* flux densities at 12, 25, 60 and 100 µm are listed in the first six columns. In column 7 we list the fractional infrared luminosity ($L_{ir}/L_{\star}$) estimated from *IRAS* fluxes, $L_{ir} = 4\pi d^2 F_{ir}$, with

$$F_{ir} = (20.653 f_{12} + 7.53 f_{25} + 4.578 f_{60} + 1.762 f_{100})$$
$$\times 10^{-14} \, \mathrm{W \, m^{-2}},$$

and d being the distance to the star (Cox 2000). The *IRAS* flux

Table 5. Far-infrared data for the stars, and the quantities estimated from them.

Object	*IRAS* source Name	*IRAS* flux densities, f_ν (Jy)				$L_{ir}/L_\star$	T_d (K)	$M_d/M_\oplus$
		f_{12}	f_{25}	f_{60}	f_{100}			
HD 36917	05323−0536	5.73	3.37	37.8*	740*	0.13	≥70	≤2
HD 36982	05327−0529	33.9	367	4800	24.5*	0.17	68	230
HD 58647	07236−1404	4.95	2.87	0.47	7.36*	0.01	†10^4	†5×10^{-10}

*Upperlimits.
†Unphysical, since the colour temperature is much larger than the dust sublimation temperature (see text).
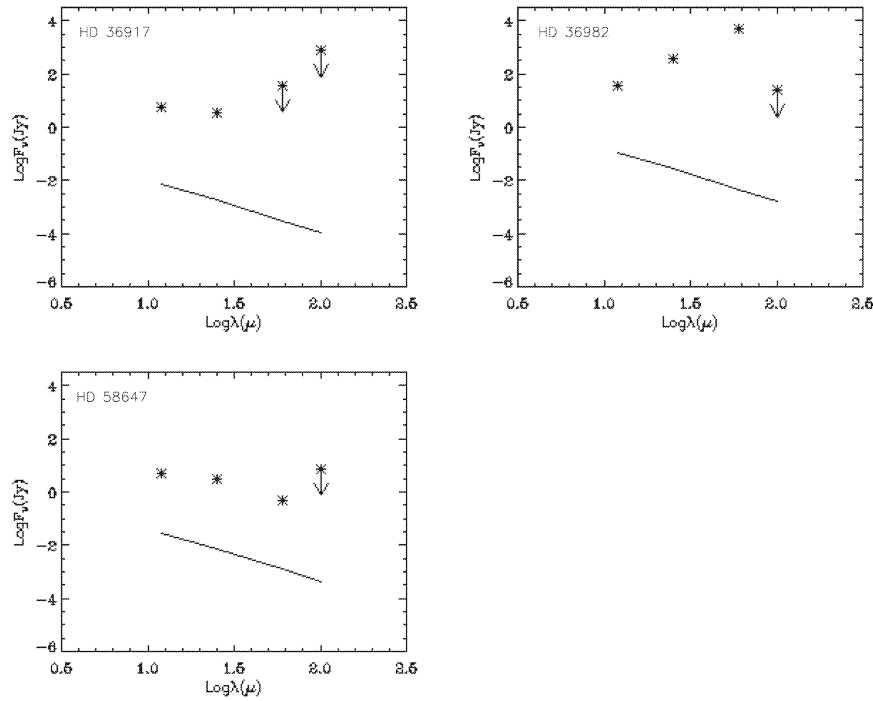
Figure 4. Far-infrared spectral energy distributions for the stars. The solid line represents the photospheric flux density expected from the star at *IRAS* wavelengths. Asterisks are *IRAS* flux densities measured for the stars. An arrow pointing downwards indicates that the flux density given is an upper limit.

densities (Jy) at 12, 25, 60 and 100 μm are given by f_{12}, f_{25}, f_{60} and f_{100} respectively. $L_\star$ is computed from M_v using standard bolometric corrections (Cox 2000), where M_v is evaluated from the dereddened V magnitude and the distance to the star. Since the star HD 36982 is located below the ZAMS in the colour–magnitude diagram (CMD) (cf. Fig. 4), $L_\star$ for this star is taken to be the ZAMS luminosity expected for its spectral type. The blackbody colour temperatures derived from the ratio of fluxes at 25 and 60 μm are considered to be the dust temperatures, and are listed in column 8. The dust temperature derived for HD 36917 is a lower limit, since the *IRAS* 60-μm flux density is only an upper limit. Dust masses (in units of $M_\oplus$; the mass of the Earth = 6×10^{27} g) listed in column 9 are computed using the relation

$$M_d = 4\pi a\rho_d d^2 F_{ir}/3Q_\nu\sigma T_d^4,$$

assuming a grain size $a = 1$ μm, a dust grain material density $\rho_d = 2$ g cm^{-3}, an absorption efficiency $Q_\nu = 0.5$, and with F_{ir} computed from the flux densities at four *IRAS* bands. Since *IRAS* flux densities at 100 μm- are upper limits for all the stars, we have used the flux densities expected at 100 μm for the derived colour temperatures in estimating F_{ir}.

The fractional infrared luminosities $L_{ir}/L_\star$ estimated for HD 36917 and HD 36982 are quite significant ($L_{ir}/L_\star \sim 0.15$). Here it is assumed that the *IRAS* flux densities quoted do represent emission from these sources, and are not due to other sources in the *IRAS* beam. We note that *IRAS* point sources 05323−0536, 05327−0529 and 07236−1404 have positional coincidences with HD 36917, HD 36982 and HD 58647 to within 4, 2 and 2 arcsec respectively. The surface density of *IRAS* point sources in this region is $\sim 3 \times 10^{-3}$ to 10^{-2} sources arcmin^{-2}. Therefore, for a given star, in the 12- and 25-μm bands, the probability that an unrelated *IRAS* point source is in the *IRAS* beam (0.75×4.5 arcmin^2) is only 1−3 per cent. If the *IRAS* fluxes observed for these stars are dominated by thermal emission from the circumstellar dust present around these stars, which is probably the case in view of the relatively low surface density of *IRAS* point sources and the low probability of chance projections, then for the derived dust temperatures listed in Table 5 the emitting dust is at distances of ~ 10 au (HD 36917) and ~ 100 au (HD 36982) from the central star, assuming the dust to be distributed in an optically thick disc as in some models of HAEBE stars (Hillenbrand et al. 1992). On the other hand, if the dust is distributed in optically thin shells as in Vega-like stars, then the dust is located at ~ 100 au (HD 36917) and ~ 1000 au (HD 36982) from the stars. These dimensions of dust shells or rings are quite similar to those of

Vega-like stars, and are compatible with the dust responsible for emission being part of the circumstellar environment. It is clear from Table 5 that these two stars have significant amounts of cold circumstellar dust present around them. The dust masses estimated are systematically lower than those for HAEBE stars, but higher than those found around Vega-like stars.

In Fig. 4 we present the far-infrared SEDs for the three stars. Their *IRAS* flux densities are plotted against the wavelength, together with the expected photospheric flux densities at *IRAS* wavelengths (Song et al. 2001) for a star of that spectral type. It is clearly seen that HD 36917 and HD 36982 have considerable excess at far-infrared wavelengths, whereas HD 58647 has a low excess and an energy distribution that is decreasing with wavelength.

It is clear from the above discussion that the three member stars of the ONC are extremely young and lack emission lines in their spectra. This would imply the absence of hot and extended chromospheres around them, where the emission lines are thought to be formed. In the case of HD 36982 and HD 37062, which are early B-type stars, it is possible that this is an evolutionary effect. They are possibly at the end of their PMS phase, which is roughly ~ 1–2 Myr. The absence of He I lines in emission, which is an indicator of accretion, also suggests that these stars are beyond their accretion phase. The almost complete absence of near-infrared excesses further supports the absence of an inner accretion disc. This evolutionary picture is further supported by the fact that HD 36917, which is of a later spectral type and thus has a longer PMS lifetime, shows an near-infrared excess, though at a much lower level than those seen in HAEBE stars. Binarity of the star cannot account for the near-infrared excess. The $J - H$ and the $H - K$ colours computed by adding up the individual fluxes expected for each component of the binary (B9.5+A0.5) and estimating the combined magnitudes, are only 0.006 and -0.002, whereas the observed colours are 0.257 and 0.397 respectively. Thus it could be concluded that the inner disc has not been completely disrupted in this star.

However, we do not rule out the possibility of the stars not passing through a HAEBE phase with emission lines and an near-infrared excess. A different formation mechanism or a very destructive cluster environment can drastically alter the PMS properties and evolutionary sequence that a young star passes through.

In any case, these stars fit well with the definition of Vega-like stars, although the far-infrared excesses, the fractional infrared luminosities ($L_{ir}/L_{\star}$), and the dust masses computed for HD 36982 and HD 36917 are much higher than that for the prototype Vega-like stars and for 'old PMS' (OPMS) and 'young main-sequence' (YMS) systems discussed recently by Lagrange et al. (2000). Their circumstellar dust may not be the debris product, but rather what is left over from their PMS phase. These stars, then, are the youngest Vega-like stars hitherto known.

Unlike the stars which are members of the ONC, HD 58647 may not be a young star. This object is about 30° away from the Orion complex, and is not associated with any star-forming cloud. Although it shows an excess at the near-infrared wavelengths, its far-infrared excess is small. The $L_{ir}/L_{\star}$ indicates the scarcity of dust around the star, and the low polarization observed reinforces this fact. The colour temperature derived from the *IRAS* fluxes is very high, and is much higher than the dust sublimation temperature. The dust mass estimated formally from *IRAS* fluxes is negligibly low, and is unphysical as the colour temperature does not represent the dust temperature. Clearly, the excess shown by the star in the *IRAS* wavelengths cannot be attributed to circumstellar dust. The infrared excesses, both near and far, are most likely due to free–free emission from an ionized region around the star. We suggest that HD 58647 is a classical Be star. The relatively large value of $v \sin i \sim 280\,\mathrm{km\,s^{-1}}$ supports this claim. The presence of Hα line in emission observed in the spectra is consistent with the star being a classical Be. Moreover, its *IRAS* flux density distribution varies nearly as $F_\nu \propto \nu^{0.6}$, which is very similar to that for classical Be stars (Taylor et al. 1990).
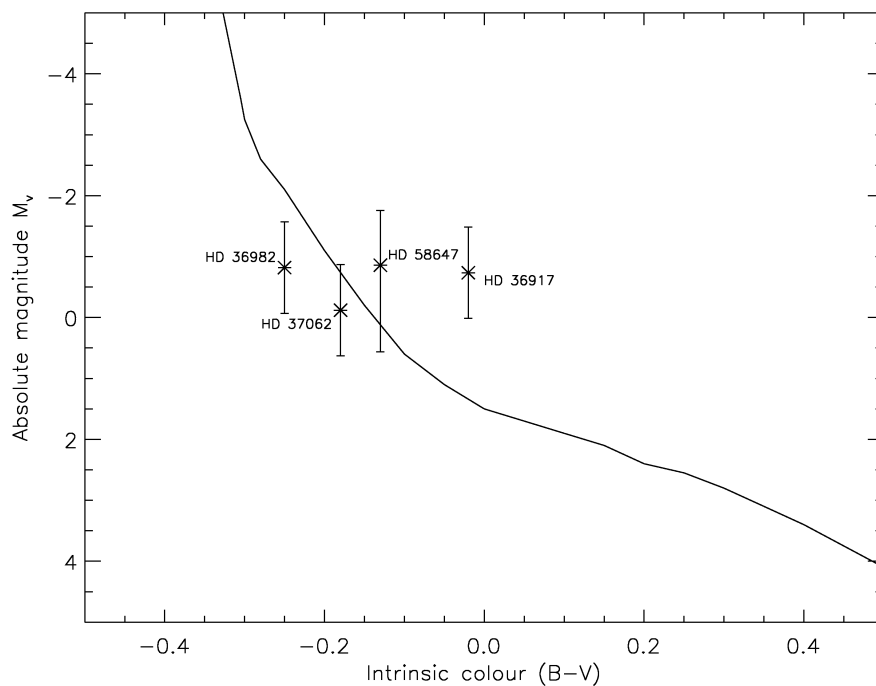
Figure 5. Colour–absolute magnitude diagram for the stars. The solid line represents the zero-age main sequence.

A colour−absolute magnitude diagram constructed for all four programme stars is shown in Fig. 5. The ZAMS data are taken from Schmidt-Kaler (1965). For the ONC member stars a distance of 470 pc is assumed, and a *Hipparcos* distance of 277 pc is used for HD 58647 in computing its absolute magnitude. The major contribution to the error bars shown in the figure results from uncertainties in distance. Further, the average interstellar value of 3.1 is used for the ratio $R = A_v/E(B − V)$. The significance of their position in the CMD is discussed below.

HD 36917, which is a spectroscopic binary (B9.5+A0.5) (Levato & Abt 1976), is found to be far above the main sequence in the CMD. The increase in the brightness caused by binarity would only account for ∼0.7 mag. Thus its location in the CMD is consistent with the star being a PMS star with an age indicated by its kinematic association with the ONC.

The other two stars which are members of the ONC, HD 36982 and HD 37062, fall below the ZAMS (in particular HD 36982) in the CMD. A possible explanation for their anomalous position is that they have an anomalous circumstellar extinction component. If they have already reached the ZAMS, then the extinctions towards HD 36982 and HD 37062, implied by their location in the CMD and computed from the observed and absolute *V* magnitudes for a distance of 470 pc, are ∼2.12 and ∼0.7 mag respectively. Such large extinctions and the rather low $E(B − V)$ cannot be produced by interstellar grains of submicron size. This would imply the presence of large grains around these stars. The neutral extinction produced by these grains can be even larger than that estimated assuming the stars to be ZAMS stars, without causing any change in the colour excess. The possibility of these stars being intrinsically brighter than a ZAMS star of similar spectral type cannot be ruled out. They could be PMS stars with very high extinction.

4 SUMMARY

We have obtained optical spectra of four non-emission-line stars listed in the catalogue by Thé et al. (1994). Emission lines which characterize the typical HAEBE spectrum are not seen in any of the stars. Also, their near-infrared properties are very unlike those of HAEBE stars. The amount of circumstellar dust present is also systematically lower than that found around HAEBE stars. We argue that these stars cannot be unambiguously classified as HAEBE stars. Nevertheless, three of the stars which are kinematic members of Orion nebula cluster are very young. This association constrains their ages to be less than a few Myr. The absence of emission lines, the low near-infrared excesses and the presence of far-infrared excesses in these objects make them somewhat similar to Vega-like stars, although the dust masses estimated for them are much higher than those of prototype Vega-like stars. These stars may then represent the youngest examples of the Vega phenomenon, and may well be the intermediate-mass counterparts of weak-line T Tauri stars. The observed reddening and estimated extinction for these stars indicate presence of larger than submicron-sized dust grains around these stars. One of the stars in our sample, HD 58647, is more likely to be a classical Be star, as is evident from the low $L_{ir}/L_\star$, the scarcity of circumstellar dust, the low polarization, the presence of Hα emission and appreciable near-infrared excess, and the far-infrared spectral energy distribution consistent with free−free emission similar to other well-known classical Be stars.

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