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A study of ISO spectra for Herbig Ae/Be stars

Kyung-Won Suh, Mi-Ryang Kim, & Ji-Hye Baek
Department of Astronomy and Space Science, Chungbuk National University, Chengju-city, 361-763, Korea
E-mail : kwsuh@chungbuk.ac.kr

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ABSTRACT

We present the infrared spectra of Herbig Ae/Be stars including the Infrared Space Observatory (ISO) data. To investigate the overall properties of their circumstellar dust envelope and/or disk, we combine the IR spectra with photometric data ranging from the UV through the optical into the sub-mm region. We study the general characteristics of the spectral energy distributions using simple analysis. We plot the positions on the HR-diagram to compare with the theoretical pre-main-sequence evolution tracks.

Keywords : stars: pre-main-sequence - circumstellar matter - dust, extinction.

1. INTRODUCTION

Herbig Ae/Be (HAEBE) stars are generally believed to be intermediate-mass pre-main-sequence (PMS) stars ($\sim$ 2-10 $M_{\odot}$). They are surrounded by a gas and dust envelope and/or disc (e.g. Water & Waelkens 1998). To understand the physical and chemical properties of the envelope or the disk, the detailed spectral observations at IR are required. The recent ISO mission has provided the essential data.

In this paper, we present the infrared spectra of HAEBE stars including the ISO data. To investigate the overall properties of their circumstellar dust envelope and/or disk, we combine the IR spectra with photometric data ranging from the UV through the optical into the sub-mm region. We study the general characteristics of the spectral energy distributions using simple analysis. We identify various dust features. We plot the positions on the HR-diagram to compare with the theoretical PMS evolution tracks.

2. The SEDs of the program stars

Table 1 lists 43 program HAEBE stars. For each star, the table lists the number of available ISO Short Wavelength Spectrometer (SWS; λ = 2.4 - 45.2 μm) and Long Wavelength Spectrometer (LWS; λ = 43 - 197 μm) data sets and the ISO data reduction information. The observation start date and time (UTCS) of the actually used data set for the SED comparison are presented in the parenthesis of the SWS or LWS column. For a number of stars, the ISO scientifically validated and good quality data are taken from the basic science data product archive in online ISO data centre without further reduction. For others, the reduced ISO SWS and LWS data from Meeus et al. (2001) are taken. The details of the data and reduction processes are described in the reference.

Table 1. ISO spectral data for the program Herbig Ae/Be stars.

Name	*ISO* SWS (01,others)	*ISO* LWS (01,others)	data reduction[a] (SWS;LWS)	Figure
HD 142527	(1,0)(SWS01;1996-02-29T12:42:16)	(1,0)(LWS01;1996-02-29T13:53:16)	(2;2)	Fig. 1a
HD 100453	(1,0)(SWS01;1996-08-02T17:41:20)	–	(2;–)	Fig. 1b
HD 100546	(1,0)(SWS01;1996-08-18T23:21:25)	(1,0)(LWS01;1996-02-29T04:17:06)	(2;2)	Fig. 1c
Elias 1	(1,4)(SWS01;1997-09-19T01:03:47)	–	(1;–)	Fig. 2a
AB Aur	(1,1)(SWS01;1997-09-26T05:26:35)	(1,0)(LWS01;1998-02-27T20:46:42)	(2;1)	Fig. 2b
HD 144432	(1,0)(SWS01;1997-02-08T08:28:30)	(1,0)(LWS01;1996-09-07T19:28:26)	(2;1)	Fig. 2c
HD 150193	(1,0)(SWS01;1996-02-07T07:02:19)	(1,0)(LWS01;1997-03-01T14:57:06)	(2;1)	Fig. 3a
HD 163296	(1,1)(SWS01;1996-10-10T21:05:00)	–	(2;–)	Fig. 3b
HD 104237	(1,1)(SWS01;1996-07-07T11:37:28)	(1,0)(LWS01;1997-06-22T09:33:43)	(2;1)	Fig. 3c
Lk Ha 198	(1,0)(SWS01;1997-01-24T17:00:14)	(3,0)(LWS01;1996-08-24T22:02:00)	(1;1)	
V376 Cas	(1,0)(SWS01;1997-01-24T17:00:14)	(3,0)(LWS01;1996-08-24T22:02:00)	(1;1)	
HD 144668	(2,1)(SWS01;1996-09-01T02:46:48)	–	(1;–)	
HD 31648	(1,1)(SWS01;1998-02-27T19:47:48)	(1,0)(LWS01;1998-02-27T16:17:08)	(1;1)	
51 Oph	(1,2)(SWS01;1996-03-03T15:26:50)	(1,0)(LWS01;1997-02-20T20:37:56)	(2;1)	
HD 135344	(1,1)(SWS01;1998-03-26T22:08:38)	(1,1)(LWS01;1996-09-02T23:49:42)	(2;1)	
HD 139614	(1,0)(SWS01;1996-09-09T03:28:45)	(1,0)(LWS01;1997-09-22T06:28:17)	(2;1)	
HD 142666	(1,0)(SWS01;1997-02-07T19:12:46)	(1,0)(LWS01;1997-02-12T10:10:13)	(2;1)	
HD 169142	(1,0)(SWS01;1996-04-01T09:46:06)	(1,0)(LWS01;1997-03-01T14:57:06)	(2;1)	
HD 179218	(1,0)(SWS01;1996-10-05T03:27:54)	–	(2;–)	
HD 97048	(3,1)(SWS01;1997-07-26T08:30:31)	(3,0)(LWS01;1996-08-04T01:20:59)	(1;1)	
TY CrA	(5,4)(SWS01;1996-10-15T15:20:58)	(4,4)(LWS01;1996-10-29T17:52:10)	(1;1)	
T CrA	(6,16)(SWS01;1997-10-04T18:11:15)	(5,2)(LWS01;1996-10-16T01:25:14)	(1;1)	
WW Vul	(1,7)(SWS01;1996-05-10T23:54:57)	–	(1;–)	
HD 34282	(1,0)(SWS01;1998-02-25T18:57:46)	(1,0)(LWS01;1998-03-27T20:45:03)	(1;1)	
HD 36112	(0,1)(SWS02;1998-03-30T23:02:08)	(1,0)(LWS01;1998-03-30T22:19:16)	(1;1)	
HD 141569	(1,0)(SWS01;1997-08-05T04:40:44)	(1,0)(LWS01;1997-08-04T07:01:27)	(1;1)	
MWC 137	(1,0)(SWS01;1998-03-13T22:51:26)	(1,0)(LWS01;1998-03-13T23:24:02)	(1;1)	
V921 Sco	(3,1)(SWS01;1997-08-24T11:11:16)	(1,0)(LWS01;1996-02-09T16:08:28)	(1;1)	
MWC 297	(1,0)(SWS01;1997-10-23T18:56:23)	(2,0)(LWS01;1997-10-23T16:29:25)	(1;1)	
R CrA	(9,14)(SWS01;1997-10-19T20:12:45)	(5,4)(LWS01;1997-03-25T18:30:49)	(1;1)	
MWC 1080	(1,0)(SWS01;1996-08-25T23:15:57)	(3,0)(LWS01;1996-08-25T22:52:21)	(1;1)	
BD +40 4124	(3,5)(SWS01;1998-03-22T08:51:15)	(2,0)(LWS01;1997-12-23T00:19:23)	(1;1)	
V1686 Cyg	(3,5)(SWS01;1998-03-22T08:51:15)	(2,0)(LWS01;1997-12-23T00:19:23)	(1;1)	
HD 200775	(4,27)(SWS01;1996-10-21T03:36:10)	(27,33)(LWS01;1996-10-21T04:34:28)	(1;1)	
BD +65 1637	(0,1)(SWS02;1996-04-17T01:47:02)	(6,1)(LWS01;1997-05-24T04:06:08)	(1;1)	
LkHa 234	(0,1)(SWS02;1996-04-17T01:47:02)	(6,1)(LWS01;1997-02-15T11:52:36)	(1;1)	
V 380 Ori	(0,2)(SWS02;1998-02-20T01:37:36)	(3,0)(LWS01;1997-10-06T03:45:19)	(1;1)	
BD +46 3471	–	(1,0)(LWS01;1996-10-28T14:15:56)	(–;1)	
VV Ser	(0,4)(SWS02;1996-03-05T08:14:04)	–	(1;–)	
UX Ori	(0,1)(SWS02;1998-03-21T23:53:26)	–	(1;–)	
HD 124237	(1,0)(SWS01;1996-08-19T08:12:42)	–	(1;–)	
HD 95881	(1,0)(SWS01;1996-02-29T05:04:40)	–	(1;–)	
HD 143006	(1,0)(SWS01;1997-08-05T06:24:36)	(1,0)(LWS01;1997-09-01T08:07:55)	(1;1)	

[a] 1 : the *ISO* data are taken from the basic science data product archive in online *ISO* data centre without further reduction.
2 : Meeus et al. 2001

To show the characteristics of the observed SEDs, we choose the first 9 HAEBE stars listed in Table 1 for which good ISO SWS (and LWS) data are available as well as the $IRAS$ PSC (Point Source Catalog, Joint IRAS Science Working Group 1986a), $IRAS$ LRS (Low Resolution Spectrograph, Joint IRAS Science Working Group 1986b), and ground based observational data. The detailed SEDs of the nine stars are displayed in Fig. 1 through Fig. 3.

Table 2 lists the 43 stars again for further details. For each star, the table lists $IRAS$ PSC number, the availability of $IRAS$ LRS data, and the temperature and luminosity of the central star from various references. The table also lists the identified dust features, the IR slope (see section 3.2 for explanation) and the references for the observational data.

3. The analysis

3.1 The central stars

We use the model SEDs from Kurucz (1979) for the central stars of the HAEBE stars. For all the models we have used the surface gravity of 1000 cm s $^{-2}$ and the solar metalicity. They are displayed in the 9 panels of Fig. 1 through Fig. 3.

3.2 The characteristics of SEDs

As pointed out by Wilking, Lada, & Young (1989), the IR slope is useful to classify the general properties of the SEDs. The IR slope (N) defined by

$$N = \frac{d\log(\lambda F_\lambda)}{d\log\lambda} \tag{1}$$

in the wavelength range 2.2 to 25 μm.

Unlike AGB stars, PMS stars have the dust grains that are much more complicated in chemical and physical properties. Silicates (amorphous, crystalline, and hydrous silicates), carbon grains (amorphous grains, smaller graphite grains, and polycyclic aromatic hydrocarbon grains), and water ice grains are believed to be the major components of the dust grains in the envelopes or disks around PMS stars. The SEDs of them are usually difficultly fitted with any mixture of candidate dust grains.

We identify various dust features for the 9 stars from the SEDs displayed in Fig.1 - Fig.3. We find that most HAEBE stars show the amorphous silicate features at 10 and 18 μm in emission. In our Galaxy, silicates are most widely spread in interstellar medium because of abundant O-rich AGB stars. Only a few HAEBE stars show evident crystalline silicate features. This is in contrast to the fact that many AGB stars show prominent crystalline silicate features (Suh 2002). We list the identified dust features in Table 2.

3.3 The positions on the HR-diagrams

Using the stellar parameters listed in Table 2, we plot the positions of 35 program HAEBE stars on the HR-diagram to compare with the theoretical PMS tracks. In upper panel of Fig.4, we compare the positions with theoretical evolutionary tracks from Bernasconi (1996). In lower panel of Fig.4, we compare with theoretical evolutionary tracks for higher mass range PMS stars from Behrend & Maeder (2001). We find that there is no direct correlation between the IR slopes and the positions on the HR-diagram for HAEBE stars. Wilking, Lada, & Young (1989) argued that the slope is related with the evolutionary stage. The argument would be valid for a large sample of T Tauri stars in lower mass range. However, for smaller sample of HAEBE stars in higher mass range, the evolution time is so short that the simple analysis would not be useful. Further investigations including detailed radiative transfer model calculations are necessary.

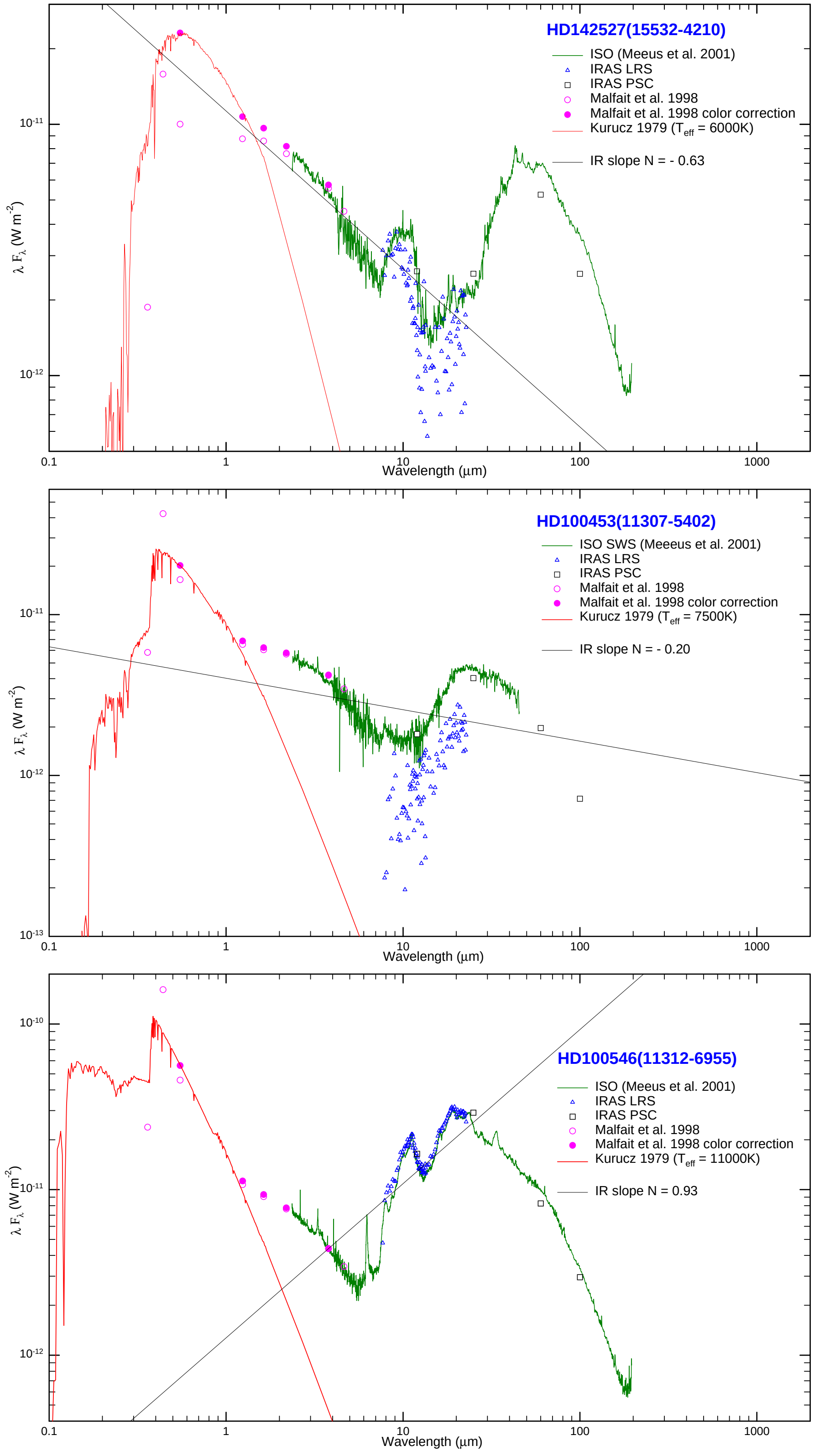


Fig.1. The SEDs for HD 142527, HD 100453, HD 100546

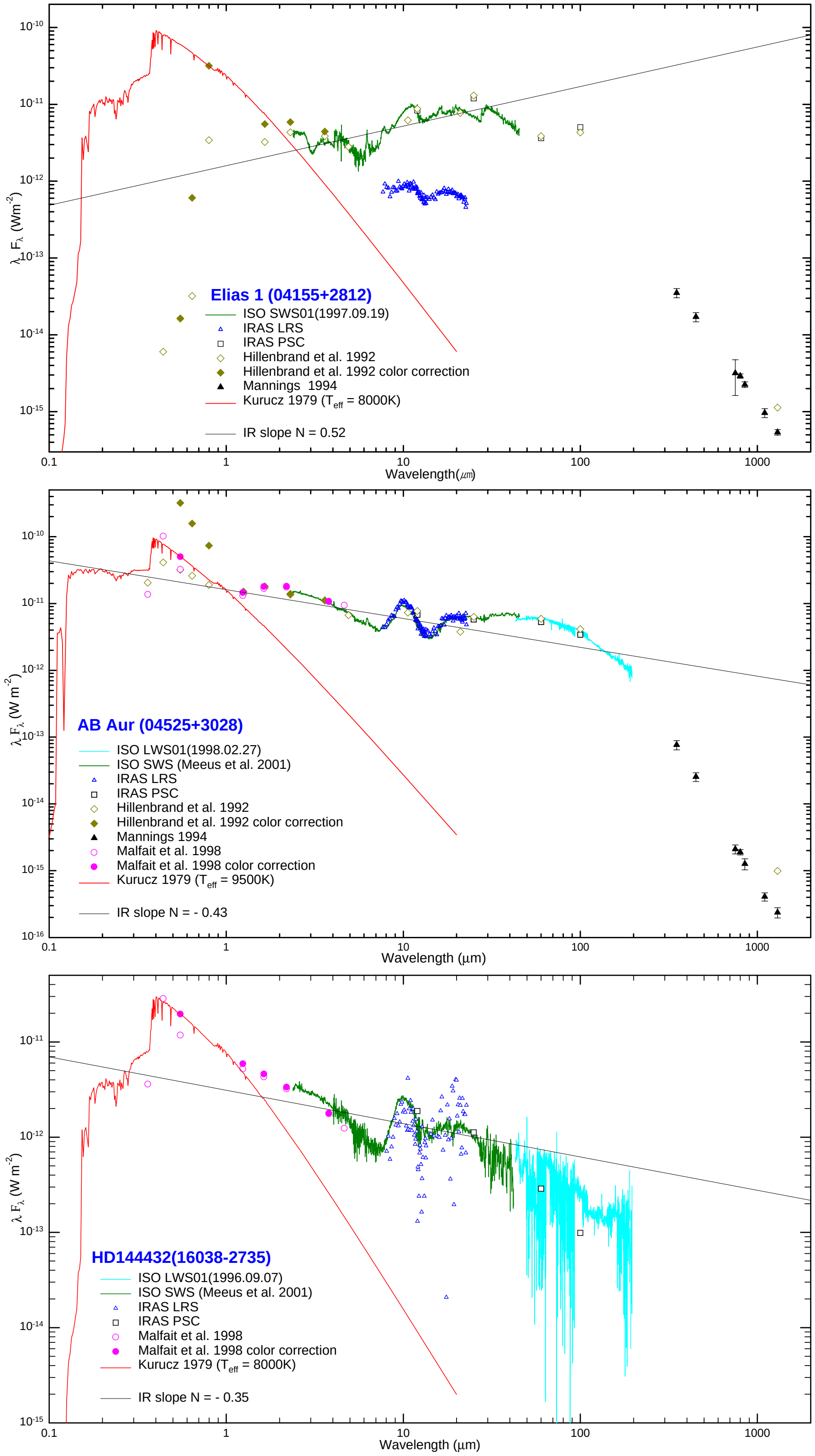


Fig.2. The SEDs for Elias 1, AB Aur, HD 144432

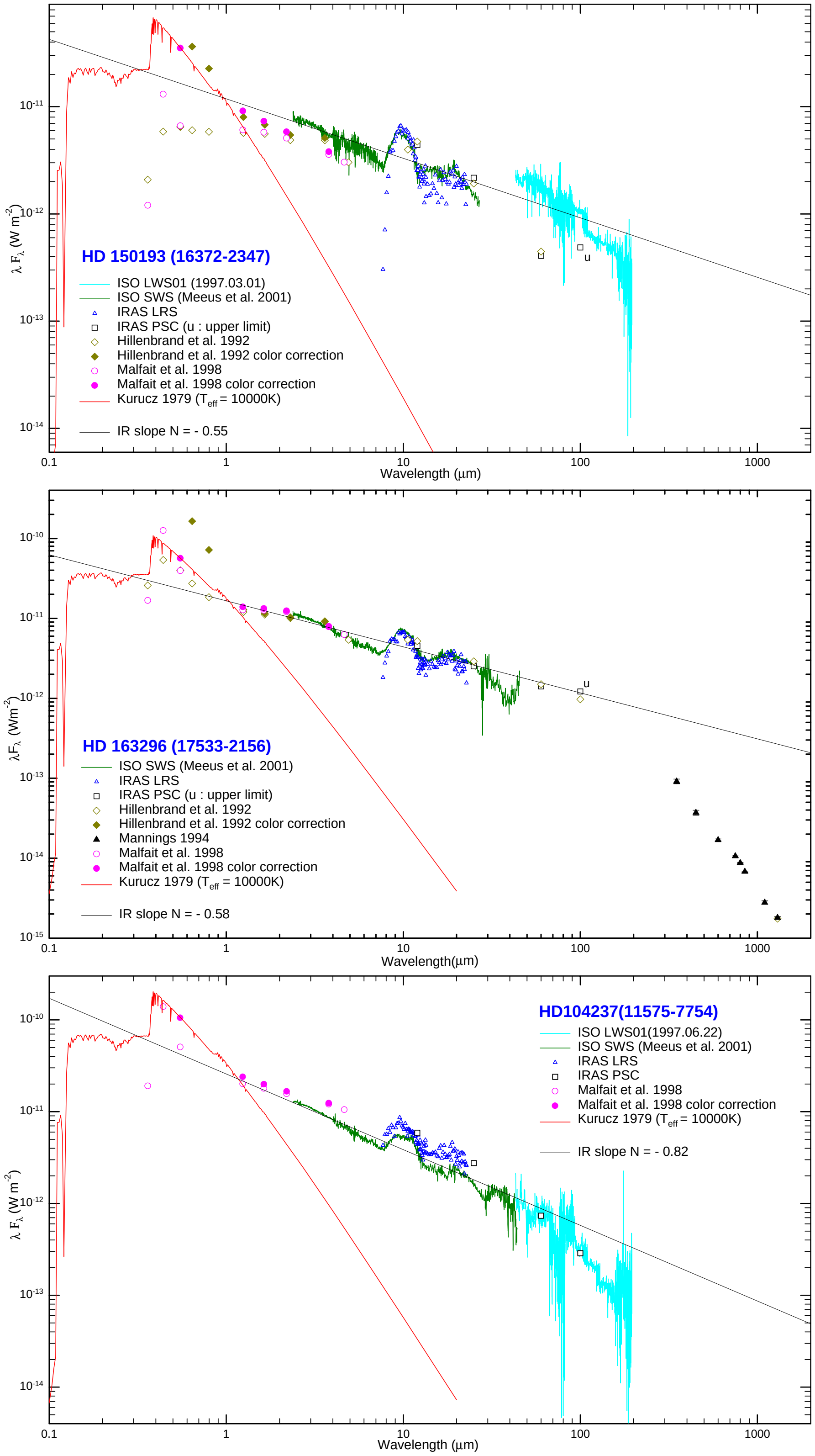
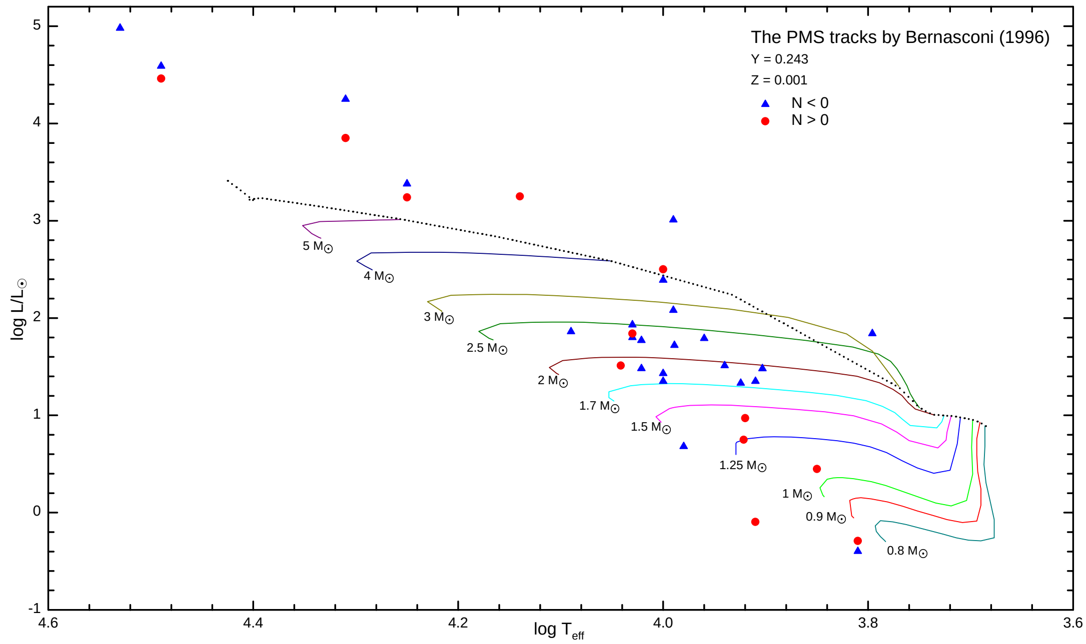


Fig.3. The SEDs for HD 150193, HD 163296, HD 104237

Table 2. Parameters for the program stars

Name	*IRAS* PSC	*IRAS* LRS	T_{eff} (K)	d (pc)	L_* ($L_\odot$)	silicate features	crystalline silicates	N	Reference[a] for SED
HD 142527	15532−4210	Y	6250[5]	200[5]	69.18[6]	10,18	?	-0.63	4, 5
HD 100453	11307−5402	Y	7500[5]			none	-	-0.20	4, 5
HD 100546	11312−6955	Y	11000[5]	103[5]	32.36[6]	10,18	Y	0.93	4, 5
Elias 1	04155+2812	Y	8128[1]	160[1]	0.8[1]	10,18	?	0.52	1, 2
AB Aur	04525+3028	Y	9750[5]	144[5]	52.48[6]	10,18	-	-0.43	1, 2, 4, 5
HD 144432	16038−2735	Y	8000[5]	200[6]	30.20[6]	10,18	-	-0.35	4, 5
HD 150193	16372−2347	Y	10000[5]	150[5]	26.9[1]	10,18	-	-0.55	1, 3, 4, 5
HD 163296	17533−2156	Y	10500[5]	122[5]	30.20[6]	10,18	?	-0.58	1, 2, 4, 5
HD 104237	11575−7754	Y	10500[5]	116[5]	58.88[6]	10,18	?	-0.82	3, 4, 5
Lk Ha 198	00087+5833	Y	8318[1]	600[1]	5.6[1]			0.05	1, 2
V376 Cas	–	N	7079[1]	600[1]	2.8[1]			0.09	1, 2
HD 144668	16052−3835	N	9772[1]	160[1]	120.2[1]			-1.08	1, 4
HD 31648	04555+2946	Y	8710[6]	131[6]	32.36[6]			-0.64	3, 4
51 Oph	17283−2355	Y	10000[5]	131[5]	245.47[6]			-1.01	4, 5
HD 135344	15126−3658	N	6750[5]	84[5]				-0.47	4, 5
HD 139614	15373−4220	N	8000[5]	151[5]				0.22	4, 5
HD 142666	15537−2153	Y	8500[5]	116[5]				-0.30	4, 5
HD 169142	18213−2948	N	10500[5]	145[5]				-0.20	4, 5
HD 179218	19089+1542	Y	10000[5]	240[5]	316.23[6]			0.40	4, 5
HD 97048	11066−7722	Y	10715[1]	215[1]	69.18[1]			0.16	1
TY CrA	18583−3657	Y	8318[1]	130[1]	9.33[1]			0.63	1
T CrA	–	N	6457[1]	130[1]	0.51[1]			0.07	1
WW Vul	19238+2106	N	8400[6]	440[6]	21.38[6]			-0.30	3
HD 34282	–	N	9550[6]	160[6]	4.79[6]			-0.72	4
HD 36112	05273+2517	N	8128[6]	200[6]	22.39[6]			-0.57	4
HD 141569	15473−0346	N	10000[6]	99[6]	22.39[6]			-0.50	4
MWC 137	06158+1517	Y	30900[1]	1300[1]	28840.3[1]			0.44	1, 2
V921 Sco	16555−4237	Y	12300[1]	160[1]	72.4[1]			-0.36	1, 2
MWC 297	18250−0351	Y	33880[1]	450[1]	95499.3[1]			-0.72	1, 2
R CrA	18585−3701	Y	6457[1]	130[1]	0.4[1]			-0.40	1, 2
MWC 1080	23152+6034	Y	30900[1]	1000[1]	38904.5[1]			-0.91	1, 2
BD +40 4124	20187+4111	Y	20417[1]	1000[1]	7079.46[1]			1.17	1
V1686 Cyg	–	N	13800[1]	1000[1]	1778.28[1]			1.17	1
HD 200775	–	N	20417[1]	600[1]	17782.79[1]			-0.85	1
BD +65 1637	–	N	17783[1]	1000[1]	2398.83[1]			-1.0	1
LkHa 234	21418+6552	Y	17783[1]	1000[1]	1737.80[1]			1.42	1
V 380 Ori	05339−0644	N	10715[1]	460[1]	85.11[1]			-0.48	1
BD +46 3471	21506+4659	N	9772[1]	900[1]	1023.29[1]			-0.94	1
VV Ser	18262+0006	N	10715[1]	440[1]	63.10[1]			-0.93	1
UX Ori	05020−0351	N	9120[1]	460[1]	61.66[1]			-0.72	1
HD 124237	–	N						-0.57	4
HD 95881	11002−7114	Y						-1.47	4
HD 143006	15556−2248	Y						-0.74	4

[a] 1:Hillenbrand et al. 1992, 2:Mannings 1994, 3:Miroshnichenko et al. 1997, 4:Malfait et al. 1998, 5:Meeus et al. 2001, 6:van den Ancker 1997



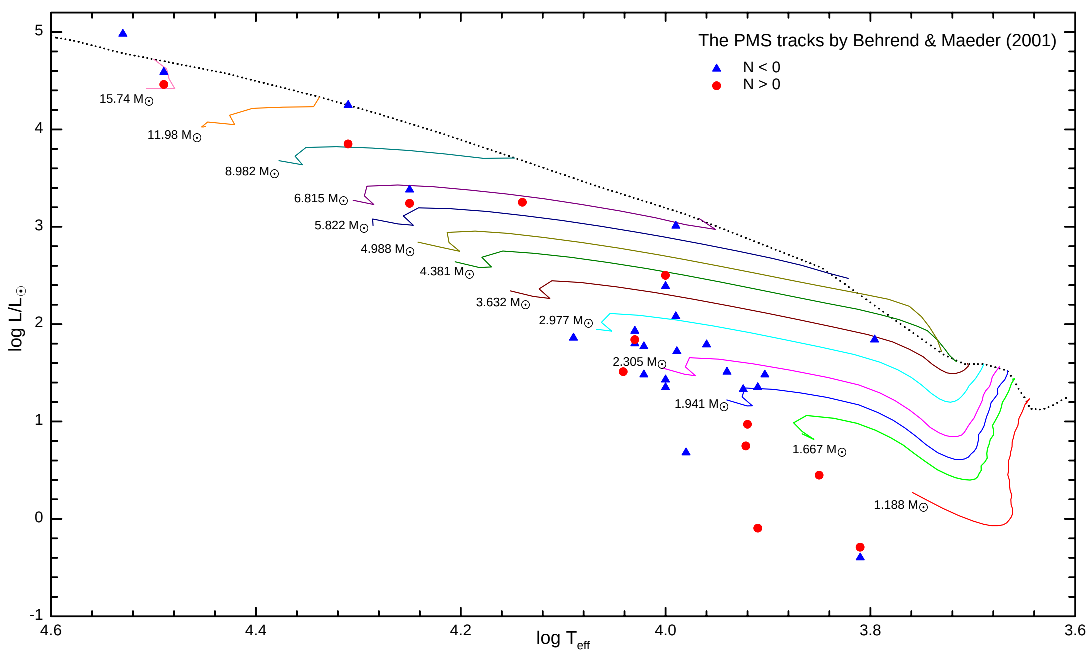


Fig.4.— HAEBE stars on HR-diagram and theoretical PMS evolution tracks by Bernasconi(1996) and Behrend & Maeder(2001)

4. Conclusions

In this paper, we have analyzed SEDs of HAEBE stars with thick dust envelopes and/or disks. We have drawn following conclusions.

1. Using the observed SEDs including the new ISO spectra for HAEBE stars, we have determined the new IR slopes.

2. We have identified various dust features from the ISO spectra. We find that most HAEBE stars show the amorphous silicate features at 10 and 18 μm in emission.

3. There is no direct correlation between the IR slopes and the positions on the HR-diagram. Further investigations are necessary.

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REFERENCES

Behrend, R., & Maeder, A. 2001, A&A, 373, 190
Bernasconi, P. A. 1996, A&AS, 120, 57
Joint IRAS Science Working Group, 1986a, $IRAS$ catalogs and atlases, Point Source Catalog (PSC), US Government Printing Office, Washington
Joint IRAS Science Working Group, 1986b, $IRAS$ catalogs and atlases, Low Resolution Spectrograph (LRS), A&AS, 65, 607
Hillenbrand, L. A., Strom, S. E., Vrba, F. J., & Keene, J. 1992, ApJ, 397, 613
Kurucz, R. L. 1979, ApJS, 40, 1
Malfait, K., Bogaert, E., & Waelkens, C. 1998, A&A, 331, 211
Mannings, V. 1994, MNRAS, 271, 587
Meeus, G., Waters, L. B. F. M., Bouwman, J., van den Ancker, M. E., Waelkens, C., & Malfait, K. 2001, A&A, 365, 476
Miroshnichenko, A., Ivezic, Z., & Elitzur, M. 1997, ApJ, 475, 41
Suh, K.-W. 2002, MNRAS, 332, 513
van den Ancker, M. E. 1999, PhD Thesis, University of Amsterdam
Water, L. B. F. M. Waelkens, C. 1998, ARA&A, 36, 233
Wilking, B. A., Lada, C. J., & Young, E. T. 1989, ApJ, 340, 823