CIRCUMSTELLAR DISKS OF A GROUP OF THE AEBE HERBIG TYPE STARS

N. .Z Ismailov [a*], ***U. Z. Valiyev*** [b], ***N. S. Dzhalilov*** [a]

[a] *Shamakhy Astrophysical Observatory named after N.Tusi of the National Academy of Sciences of Azerbaijan, Shamakhy, Azerbaijan*

[b] *Batabat Astrophysical Observatory, Nakhichevan Branch of the National Academy of Sciences of Azerbaijan, Nakhichevan, Azerbaijan.*

In the work is analyzed the spectral energy distribution (SED) curves for a group of the young Herbig AeBe type stars (HAeBe). It is shown that in the group of 19 HAeBe stars, only 3 stars have signs of a residual disk, and they are classified as type III in terms of spectrum. The rest of the stars show type II SED curves. The main fundamental parameters and the evolutionary status of the sample stars are determined.

Keywords: AeBe Herbig stars–circumstellar disks–fundamental parameters

1. INTRODUCTION

Ae/Be Herbig type stars (H Ae/Be) are known as young objects (ages t < 10 Myr), visible in the optical range, they are at the Pre-Main sequence (PMS) stage of evolution. These stars have a typical spectral type A or B, sometimes F, emission lines in the spectrum, masses from 2 to 12 $M_{\odot}$, exhibite a circumstellar excess of radiation in the infrared (IR) range. The original list, which contained a dozen sources [1], was supplemented with new following catalogs (for example, [2–6]), and today more than 300 H Ae/Be stars are known. This is much less than the number (more than a thousand) of known T Tauri (TTS) stars, which have smaller masses (M $\leq$ 2.0 $M_{\odot}$). Therefore, statistical studies of H Ae/Be stars are generally less reliable than studies of TTS.

H Ae/Be stars are of considerable interest as possible progenitors of β Pic and Vega type stars [7], which have intermediate masses and already have reached the MS and have residual disks. The interest in H Ae/Be stars is also due to the fact

* E-mail: ismailovnshao@gmail.com

that, in comparison with more massive young stars, the evolution of intermediate-mass stars is significantly different. The brighter and more massive stars, due to the processes of photoevaporation, faster dissipates its circumstellar matter. This can lead to the thermal and chemical evolution of the star [8]. Circumstellar disks can significantly affect the formation and evolution of planets [9].

This paper is a continuation of our series of works by Ismailov et al. [10–12] devoted to the analysis of SED curves for young stars of low and intermediate masses. In this paper, we present the results of a study of the SED curves for a selected group of H Ae/Be type stars.

2. OBSERVATION DATA AND RESULTS

19 H Ae/Be-type stars were selected from the catalog [4], their list is given in Table 1. The columns of the table contain: the name of the object, the equatorial coordinates of the equinox 2000.0, the distance to the object given in the SIMBAD database and refined from the Gaia DR3 archive (https://gea.esac.esa.int/archive/), interstellar extinction Av, equivalent width emission line $H\alpha$, spectral types and effective temperatures corresponding to them, adapted according to the version of [13]. The last column of Table1 lists the numbers of the cited literature related to the selected observational data. The list of references to table 1 is given in the note.

The main part of the data on broadband photometry of UBVRI-JHK was collected from the literature, according to the VizieR catalogs (https://vizier.cds.unistra.fr/viz-bin/VizieR), the list of references is given in the last column of Table 1. Photometric data in the near and far IR regions were collected from the 2MASS [14], DENIS [15], WISE [16], and IRAS [17] catalogs. For individual stars, the values of interstellar extinction given in the literature by different authors can differ significantly. In such cases, using the B-V color index for normal MS stars, we redefined the value of the Av parameter, assuming that the normal law of interstellar extinction is observed and the extinction coefficient is $R = 3.1$.

Typical brightness variability for H Ae/Be stars in the V band are $\Delta V \approx 0.1 - 0.5\,mag$, so the expected maximum change in the flux in this band can be about 35%. The maximum changes in the K band (2.2 μm) are about $\Delta K \approx 0.3$ mag [18], which can introduce an error in the fluxes in this band by about 25%. The methodological part of constructing the energy distribution curves in the spectra of stars was described in detail in our papers [10, 11]. In the model approximation of the observational data, we assumed that the contribution of radiation in the inner boundary layer of the disk in the R band is negligible (see, for example, [19]), the errors due to interstellar reddening in the VRI bands are

Table 1. List of program stars and some its data collected from literature.

Target name	α (2000)	δ (2000)	D, pc	Av	W(Hα) Å	Sp type	T_{eff}	literature
HD 35929	05 27 42.79	-08 19 38.4	380	0.39	7.2	A5	7250	4, 1
HD 36112	05 30 27.53	+25 19 57.0	155	0.155	16.5	A5 V	8080	12, 4
V^* BF Ori	05 37 13.26	-06 35 00.5	382	0.33	10.0	A6,9	7800	10, 3,2
HD 37357	05 37 47.08	-06 42 30.2	465	0.5	9.9	A1/2V	9200	12, 16, 1
V^* VY Mon	06 31 06.92	+10 26 04.9	800	5.68	50.0	B6-B7	13000	10, 9
HD259431	06 33 05.19	+10 19 19.9	653	1.26	55.0	B6 e	14500	13, 1, 2
HD 52721	07 01 49.51	-11 18 03.3	444	0.868	19.6	B2 Vn	20600	12, 2
HD 85567	09 50 28.54	-60 58 02.9	1047	1	42.8	B5Vne	15700	19, 1, 2
HD 97048	11 08 03.31	-77 39 17.4	184	0.87	38.0	B9.5 Ve	10400	8, 11, 1
HD 100546	11 33 25.44	-70 11 41.2	108	0.15	39.5	B9Vne	10700	14, 5, 2
HD 104237	12 00 05.09	-78 11 34.5	106	0.31	20.0	A7Ve	7800	12, 10, 1
HD 132947	15 04 56.06	-63 07 52.6	379	0.2976	1.6	B9V	10700	15, 1, 4
HD 141569	15 49 57.75	-03 55 16.3	111	0.29	10.4	B9.5V	10400	5, 14, 4
HD 144432	16 06 57.95	-27 43 09.7	154	0.62	11.8	A7V	7800	4, 6, 13
V^* V856 Sco	16 08 34.29	-39 06 18.3	158	0.38	7.0	A7 e ııı ıv	7800	10, 5, 20
HD 163296	17 56 21.29	-21 57 21.8	100	0.54	1.6	A1Vep	9200	7, 9
MWC 297	18 27 39.53	-03 49 52.1	417	8.47	594.5	B0e, O9e	31500	18, 1
V^* TY Cra	19 01 40.83	-36 52 33.8	159	1.488	19.0	B9, B9e	10700	12, 1, 2
HD 200775	21 01 36.92	+68 09 47.7	354	0.52	63.8	B3	17000	17, 1, 2

Note: literature citations which are presented in the last column of table (1) Cutri R.M. et al., 2003yCat, 2246, 0; (2) Ducati J. R. 2002yCat, 2237, 0; (3) Cutri R.M. et al., 2014yCat., 2328, 0; (4) Høg E. et al., 2000A&A, 355L, 27; (5) Lasker B.M. et al., 2008 AJ, 136, 735; (6) Lawrence A. et al., 2007 MNRAS, 379, 1599; (7) Lucas P.W. et al., 2008 MNRAS, 391, 136; (8) Stelzer B. et al., 2004 A&A, 423, 1029; (9) Mora A. et al., 2001 A&A, 378, 116; (10) Tısserand P. et al., 2013A&A, 551, 77; (11) Irvıne N.J.et al.,1977PASP, 89, 347 (12) Vıeıra S.L.A. et al., 2003AJ, 126, 2971; (13) Houk N.,1982 MSS, C03, 0 (14) Gray R.O. et al., 2017 AJ, 154, 31; (15) Levenhagen R.S. and Leıster N.V. 2006 MNRAS, 371, 252; (16) Hsu W.-H. et al., 2013ApJ, 764, 114; (17) Guetter H.H. 1968 PASP, 80, 197; (18) Drew J.E. et al.,1997 MNRAS, 286, 538; (19) Houk N. and Cowley A.P.1975 MSS, C01, 0; (20) Bessell M.S. and Eggen O.J. 1972 ApJ,177,209.

insignificant, therefore, when approximating the observational data, preference was given to data in VRI bands as the points with the lowest IR excess value.

As can be seen from Fig.1, the plotted SED curves show a wide range of infrared radiation characteristics: from an almost flat distribution with a large IR excess radiation extending over the entire spectrum, to a minimum excess in the far IR range. We determined the types of SED curves according to the Lada scheme of the classification [21]. The parameter α, which shows the degree of slope of the SED curves, was determined for the range 2.2 - 12 μm. Of the 19 program stars, 3 have the coefficient α in the range $-3 < \alpha < -2$, which indicates a significant attenuation of gas radiation in the disk (type III). Such stars have a residual disk, and protoplanetary disks are close to complete dissipation. For the remaining stars, $-1 < \alpha < 0$, which indicates an optically thick disk in most program stars (type II). All defined types of SED curves are indicated in the last column of Table 2.

The logarithm of the ratio of the fluxes of the star $F^*_{2.2}$ and the model standard $F^m_{2.2}$ of the same spectral type in the K band [22] (Shtrom et al. 1989) was taken as a possible excess measure in the near-IR range,

$$\Delta K = logF^*_{2.2} - logF^m_{2.2} = logF^*_{2.2}/F^m_{2.2} \quad (1)$$

For the value of ΔK, the expected error of determination should be at the level of errors in the approximation of the observational data of the model curve (± 0.07). Therefore, all stars with $\Delta K \geq 0.07$ will be considered as having a real excess. The results of calculating the parameter ΔK are given in Table 2. As can be seen, except from type III stars, almost all stars have significant excess radiation in the $2.2 \mu m$ band.

To quantify the value of the integrated excess radiation in the spectra of H Ae/Be stars, we applied a method that is demonstrated by the example of the SED curves of two T Tauri stars, DoAr 51 and V999 Tau (Fig. 2). On the graphs showing the dependence of the values log $F^*/Fm \sim log\lambda$, sections are highlighted that can characterize the amount of total excess radiation in the UV and IR parts of the spectrum, designated as S(UV) and S(IR). To calculate the integral excess radiation in the spectral region $\lambda_2 - \lambda_1$ (where $\lambda_2 > \lambda_1$), one can apply the expression

$$S = \int_{\lambda_1}^{\lambda_2} \log \frac{F_*}{F_m} d\lambda \quad (2)$$

Here λ_1 and λ_2 are the initial and final wavelengths of the excess radiation region. To calculate this integral, it is practically necessary to calculate the areas of the figures on these graphs, marked with a dotted lines. The obtained values of S(UV) and S(IR) are characterize the integral value of excess radiation in the corresponding parts of the spectrum.

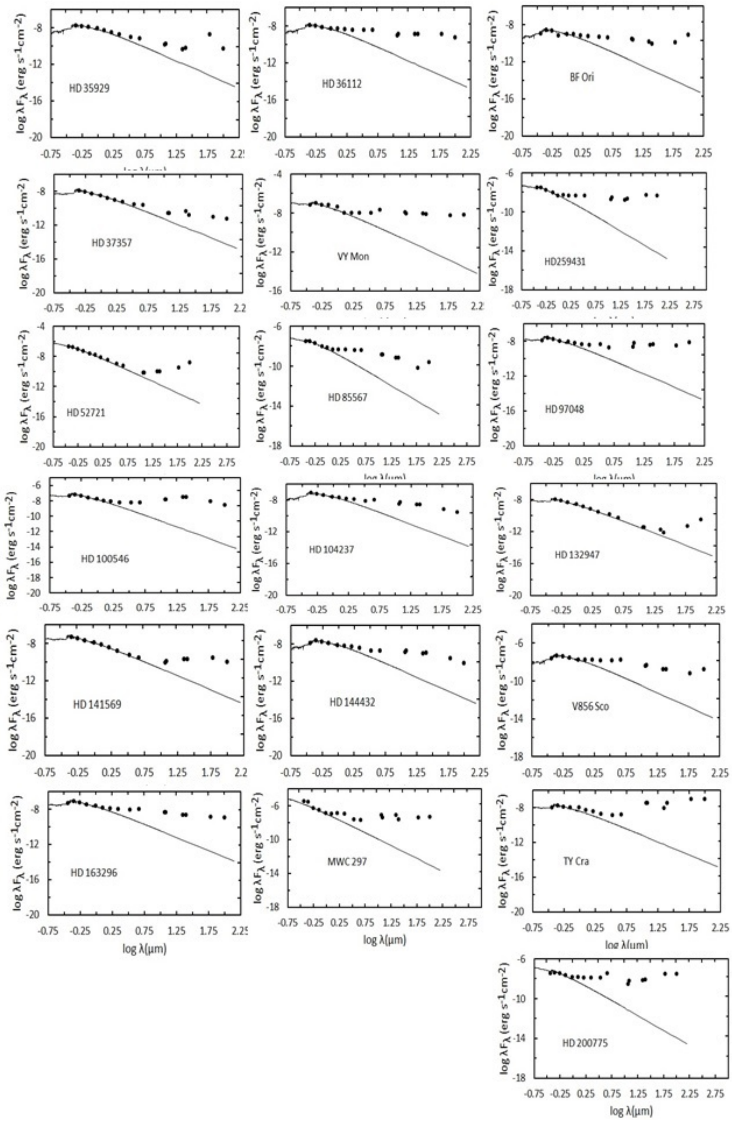

Fig. 1. SED curves of program stars. The solid curves show the distribution of the model star of the corresponding effective temperature according to the model [20].

No excesses are found in our program stars in the UV region. All integral excesses calculated in this way in the IR range of the spectrum S(IR) are given in Table 2.

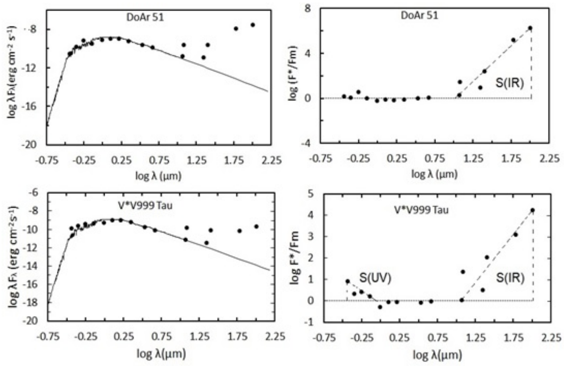

Fig. 2. On the left panel is the SED curve of the star; on the right is the residual between the spectra of the star and the standard model. The dotted line indicates the areas which is characterized the measure of excess radiation.

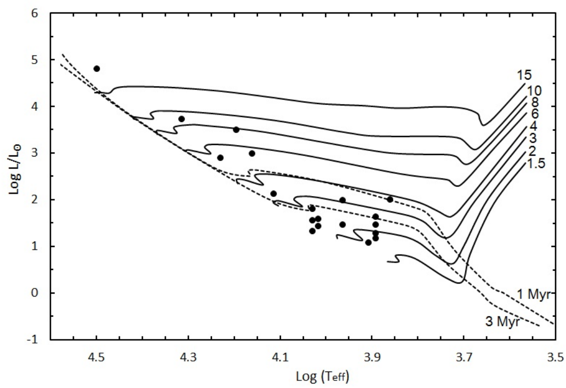

Fig. 3. Location of program stars on the HR diagram with evolutionary tracks according to the data of [23] and [24]. The numbers on the solid lines indicate the masses, and near the dotted lines, the ages (1 and 3 Myrs).

3. PHYSICAL PARAMETERS OF STARS

Based on the V value cleaned of interstellar reddening, the distances to the stars, and bolometric corrections taken from [13], we calculated the absolute bolometric stellar magnitudes Mv. Knowing the absolute luminosity of the sun $Mv_{\odot} = 4.83$ mag, we calculated the absolute luminosities of stars in units of solar luminosity $L/L_{\odot}$. Further, knowing the effective temperatures T_{eff} and luminosity, we calculated the radii of the stars in units of the solar radius $R/R_{\odot}$. The solar effective temperature $T_{\odot}$ was taken equal to 5800 K.

Using theoretical evolutionary tracks [23,24], the masses and ages of stars were also determined. All obtained parameters for individual stars are given in Table

Table 2. Calculated parameters of the program stars.

Target name	Mv	$L^*/L_\odot$	$R/R_\odot$	$M/M_\odot$	t, Myr	SQ	ΔK	Type
HD 35929	-0.2	100.9	8.0	3.9	1	2.77	0.28	II
HD 36112	2.1	11.9	2.5	1.8	6	4.30	0.77	II
BF Ori	1.9	14.8	2.9	1.8	5	5.54	0.62	II
HD 37357	-0.1	97.6	6.2	4	1.5	2.37	0.15	II
VY Mon	-0.5	132.0	5.1	3.5	2.8	5.23	0.65	II
HD259431	-2.6	967.0	12.4	5.8	0.5	6.07	0.95	II
HD 52721	-4.5	5325.6	20.5	9	0.4	1.97	0.18	III
HD 85567	-3.9	3132.5	20.7	8	0.3	4.48	0.92	II
HD 97048	0.9	38.5	3.5	2.5	3.4	5.36	0.73	II
HD 100546	0.9	35.8	3.2	2.5	3.2	4.32	0.51	II
HD 104237	1.2	29.3	4.0	2.3	3.3	3.11	0.54	II
HD 132947	0.3	64.9	4.4	2.8	3	1.76	0.07	III
HD 141569	1.2	27.7	2.9	2.4	3.5	2.38	0.05	III
HD 144432	1.6	18.9	3.2	2	3.3	3.74	0.54	II
V856 Sco	0.7	43.9	4.9	2.6	3	4.28	0.79	II
HD 163296	1.2	29.2	3.4	2.3	3.4	4.22	0.62	II
MWC 297	-7.2	64309.1	46.7	19.5	0.2	5.95	1.08	II
TY Cra	1.5	20.9	2.5	2.3	4.8	6.42	0.62	II
HD 200775	-2.4	792.9	9.6	5.5	1	6.31	1.10	II

2. The position on the HR diagram (Fig. 3) shows that the masses of the stars are within $2 \leq M/M_\odot \leq 20$. The expected errors of individual parameters are no more than 20%.

The search for a correlation between the parameters of excess radiation and luminosity in the $H\alpha$ line is shown in Fig. 4. The found correlation coefficient between the parameters S(IR) and ΔK is $r = 0.86 \pm 0.12$, and between the parameters log (L$H\alpha$) and δK, $r = 0.49 \pm 0.23$.

4. CONCLUSION

We have constructed and classified the SED curves for 19 typical H Ae/Be-type stars. It is shown that among the studied stars only 3 have signs of a remnant protoplanetary disk, they are assigned to type III spectrum (HD 52721, HD 132947 and HD 141569). The remaining objects were classified as type II.

A correlation was found between IR excess radiation in the near (2.2 μm) and far IR ranges (25–100 μm). In this case, a weak correlation is observed between the absolute luminosity in the $H\alpha$ line and the IR excess in the near-IR range. This indicates that the variability in the $H\alpha$ line in such stars is associated not only with a variable stellar wind, but also, possibly, with the disk accretion rate.

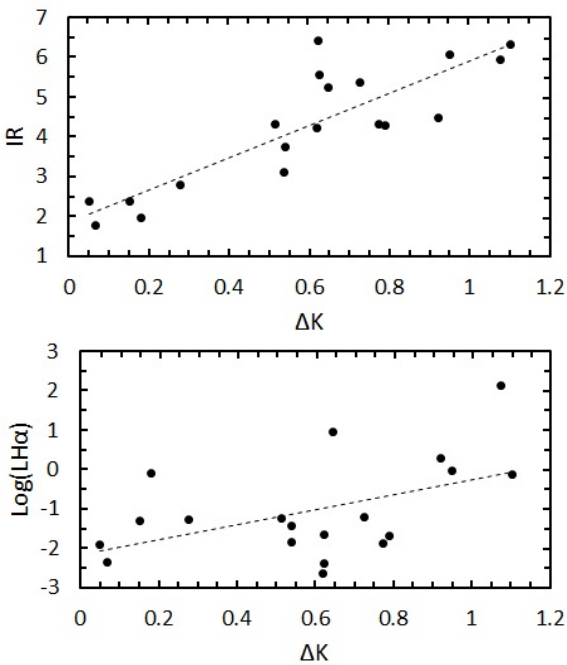

Fig. 4. Relations of the IR excess parameters in the near and far IR range (upper panel). The lower panel shows the absolute luminosity in the $H\alpha$ line versus the excess radiation index in the near-IR range. Dashed straight lines are linear approximations.

The main fundamental and evolutionary parameters of stars are calculated, which agree satisfactorily with the literature data. The masses of program stars determined from the evolutionary tracks mainly lie in the range of 2-10 $M_{\odot}$. Only one of the program stars MWC 297 showed a mass of 19.5 $\pm$ 0.5 $M_{\odot}$, which is outside the assumed mass range of H Ae/Be stars. To test this result against an even wider sample of data, we checked the latest data for 318 stars from the new HArchiBe archive (http://svo2.cab.inta-csic.es/projects/harchibe/harchibeCat/index.php?action=search) , whose kernel is based on [25, 26]. In this archive, we found quite a few stars with masses significantly exceeding $\geq 10M_{\odot}$. İt is interesting to study of the physical characteristics of such massive H Ae/Be stars.

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