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Optical spectroscopy of Classical Be stars in open clusters

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Abstract. We present a spectroscopic study of 150 Classical Be stars in 39 open clusters using medium resolution spectra in the wavelength range 3800 – 9000 Å. One-third of the sample (48 stars in 18 clusters) has been studied for the first time. All these candidates were identified from an extensive survey of emission stars in young open clusters using slitless spectroscopy (Mathew et al. 2008). This large data set covers CBe stars of various spectral types and ages found in different cluster environments in largely northern open clusters, and is used to study the spectral characteristics of CBe stars in cluster environments. About 80% of CBe stars in our sample have Hα equivalent width in the range -1 – -40 Å. About 86% of the surveyed CBe stars show FeII lines. The prominent FeII lines in our surveyed stars are 4584, 5018, 5169, 5316, 6318, 6384, 7513 and 7712 Å. We have identified short- and long-term line profile variability in some candidate stars through repeated observations.

Keywords : stars: formation – stars: emission-line, Be – (Galaxy:) open clusters and associations: general – surveys

1. Introduction

A Classical Be (CBe) star is defined as a non-supergiant B-type star whose spectrum has, or had at some time, one or more Balmer lines in emission (Collins 1987). The emission lines are produced in a circumstellar disc through recombination process from reprocessed stellar radiation. They rotate at 70−80% of their critical speed and hence the reason for the formation of disc may not be equatorial mass loss mechanism (Porter & Rivinius 2003). The formation and structure of circumstellar envelopes and the evolutionary status of CBe stars are some of the unresolved

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problems. Some of these problems can be tackled better through the study of CBe stars in open clusters since we know the age, distance and evolutionary state of these candidates.

McSwain & Gies (2005) conducted a photometric survey of 55 southern open clusters and identified 52 definite CBe stars and 129 probable candidates. They found that the spin-up during the Terminal Age Main Sequence (TAMS) cannot produce the observed distribution of CBe stars while 73% of the candidates could be spun-up by binary mass transfer. McSwain et al. (2008) and McSwain, Huang & Gies (2009) discovered a large number of highly active CBe stars in NGC 3766 as well as eight other southern open clusters. They used Hα spectroscopy to study the physical properties of the CBe stars in these clusters. Using high- and medium-resolution spectroscopy of CBe stars and binary stellar systems in young open clusters, Malchenko & Tarasov (2008) found that CBe stars mostly appear at an age of 10 Myr and their concentration reaches a maximum at 12$-$20 Myr. Mathew, Subramaniam & Bhatt (2008) performed a survey to identify emission stars in young open clusters using slitless spectroscopy. They observed 207 open star clusters and 157 emission stars were identified in 42 clusters. They found 54 new emission stars in 24 open clusters, of which 19 clusters were found for the first time to host these stars. Most of the emission stars in their survey belonged to CBe class ($\sim$92%) while a few were Herbig Be (HBe) stars ($\sim$6%) and Herbig Ae (HAe) stars ($\sim$2%). From the distribution of CBe stars with respect to spectral type and age, they found that CBe stars in the spectral range B0$-$B1 have evolved into CBe phase while others are born as CBe stars. They also found that CBe stars are present in different evolutionary phases and hence the CBe phenomenon is unlikely to be only due to core contraction near the turn-off. From an Hα spectroscopic survey of CBe stars in the SMC open clusters, Martayan, Baade & Fabregat (2009) found that certain CBe stars could be born as CBe stars while others evolve to that phase.

Following the survey (Mathew et al. 2008), the spectra of the identified CBe stars were obtained to study their spectral properties. The survey identified a large number of stars covering a wide spectral and age range, thus making the sample ideal for statistical analysis of various spectral characteristics. Using photometric and spectroscopic analysis we confirmed that 5 out of the total sample of 157 CBe stars belong to Herbig Ae/Be (HAeBe) category (Mathew et al. 2010). These are excluded from the present study. NGC 1624(1) (see Mathew et al. (2008) for nomenclature) is found to be a late O-type emission star and hence removed from the present analysis. NGC 436(3) is also removed from the list since the spectral features do not confirm it to be a CBe star. Thus, we present the spectral line details and the main results obtained from the spectral line analysis of 150 CBe stars. In this sample, one third of the stars (48/150) are studied for the first time. This is the largest sample of CBe stars present in northern open clusters, and the data presented here is a homogeneous set. This large data set covers CBe stars of various spectral types and ages, found in different cluster environments of the northern open clusters. This data set is used to identify interesting candidates for follow up observations as well as spectral variability studies.

The paper is arranged as follows. The following section addresses the details of spectral observations. Section 3 explains the major results from the spectral line analysis. CBe stars which show spectroscopic variability are addressed. We have also given a collective analysis of the metallic lines in the spectra of CBe stars. The results are summarized in Section 4.

2. Observations

The spectroscopic observations were done using the Himalayan Faint Object Spectrograph Camera (HFOSC) available with the 2.0m Himalayan Chandra Telescope (HCT), located at Hanle and operated by the Indian Institute of Astrophysics (IIA). The CCD used for imaging is a 2K×4K CCD, where the central 500×3500 pixels were used for spectroscopy. The pixel size is 15 μm with an image scale of 0.297 arcsec/pixel. Slit spectra of CBe stars were taken using Grism 7 (3800 Å – 6800 Å) and 167 μm slit combination in the blue region which gives an effective resolution of 10 Å around the Hβ line. The spectra in the red region is taken using Grism 8 (5500 Å – 9000 Å) /167 μm slit setup, which gives an effective resolution of 7 Å around the Hα line. The spectra were found to have good signal to noise ratio. The log of the observations is given in Table 1. All the observed spectra were wavelength calibrated and corrected for instrument sensitivity using the Image Reduction and Analysis Facility (IRAF) tasks. The calibrated spectra were normalized and continuum fitted using IRAF tasks. The equivalent width (EW) of the spectral lines were estimated using routines in IRAF, which effectively measures the area under the line profile. The equivalent width is measured by marking two continuum points around the line to be measured. The linear continuum is subtracted and the flux is determined by simply summing the pixels with partial pixels at the ends. Therefore, this method calculates the area under the profile irrespective of the profile shape. The typical error in the measurement is around 10%. The telluric bands were not removed since the lines of interest were not affected by them.

The spectral type was estimated by comparing the absorption intensities of higher order Balmer lines and HeI 4026, 4144, 4471 Å lines with a stellar library (Pickles 1998). The Balmer lines of wavelength higher than Hδ are found to show filled-in emission features and hence not used for spectral type estimation. The estimated spectral types are bluer than the photometric estimates since the stellar flux is reddened by the cicumstellar disc (Slettebak 1985).

3. Results and discussion

The coordinates, spectral type, Hα EW and age of the CBe stars are given in Table 1. The age of the CBe star corresponds to the age of the cluster with which it is associated, as identified in Mathew et al. (2008). From the slitless spectroscopic survey (Mathew et al. 2008) we identified 49 new CBe stars in 19 open clusters. These clusters were not known to have any CBe stars, as seen from WEBDA database. Among these, Bochum 6(1) was removed from the list of new CBe stars since it is suspected to be a HBe star (Mathew et al. 2010). The newly identified 48 CBe stars in 18 clusters in the improved list are shown in boldface in Table 1. The spectral analysis of this sample of new CBe stars is valuable and some of these show interesting spectral features, as shown in Table 2. The Table shows the nature of the Hβ profile, presence of metallic lines and other features. It can be noticed that the iron emission lines are present in abundance in some stars, on the other hand they are totally absent in others. The presence or absence of the spectral emission lines can be used to understand the distribution of material in the circumstellar disc as a function of temperature and density. We plan to do a detailed study by modeling the spectral features. Repeated observations showed spectroscopic variability in the case of some candidates and these are explained below.

3.1 Spectroscopic variability

CBe stars are found to show long- and short-term variability in spectral features. The long-term variability can be due to activity in the circumstellar disc. To understand the variability in spectral features we took multiple spectra of most of the CBe stars and those which show major changes are given below. The candidates which only showed variability in Hα line profile are discussed in the next subsection.

NGC 659(2): The Hα profile changed from normal state when observed on 21-11-2005 to core emission on 30-09-2006 with a significant reduction in emission strength, -10 to -4.1 Å (see Fig. 1). OI 7772 Å (unresolved triplet of 7772, 7774, 7775), CaII triplet and Paschen absorption lines were absent/structured during initial observations while OI 8446 Å was seen in emission. After a period of 10 months it can be seen that these lines disappeared from the spectra. Paschen, HeI and all the Balmer lines other than Hα are present in absorption, with no visible emission component. The circumstellar disc was getting dissipated during the period of the observations.

NGC 663(13): The Hα profile was in absorption when observed on 22-11-2005 which changed to a double-peaked emission profile on 09-10-2006 (Fig. 2). This is associated with decrease in absorption strength for other Balmer lines. The Paschen lines were found to be unchanged while CaII lines got intensified, as identified from the deepening of absorption component in CaII 8662 Å and P13 line complex. Hence we have identified the formation of a circumstellar disc in NGC 663(13) over a period of 1 year, from which emission lines of Hα and CaII are formed.

NGC 884(1): The Hα emission strength appear enhanced in the spectra taken on 15-12-2007 (-16.5 Å) when compared with the observations on 22-01-2006 (-10 Å). The emission component in Hβ absorption line also increased, as shown in Fig. 3. FeII 5169, 5235, 5316, 7513, 7712 Å and OI 7772 Å appeared in emission when observed on 15-12-2007. This is also associated with an increase in the emission strength of OI 8446 Å, CaII triplet and Paschen lines P11, P12, P14 and P17. The circumstellar disc has grown thick over a period of 23 months, which can be deduced from the increase in intensity of low- and high-volt recombination lines.

3.2 Hα equivalent width

We have measured the Hα EW for 150 CBe stars. The measured EW values are corrected for stellar absorption using the theoretical values from the Kurucz database (Kurucz 1979). We have used the values corresponding to log(g) = 4.0, assuming the candidates to be main-sequence stars. The corrected Hα EWs are given in Table 1.

Table 1. The journal of observations with integration time in sec, coordinates, spectral type, Hα EW and age. Newly identified CBe stars are shown in boldface. Log of repeated observations are also given.

Emission Star	Date	Int. time	RA(J2000) hh:mm:ss	Dec(J2000) deg:min:sec	Sp.type	Hα EW Å	Age Myr
Berkeley 62(1)	13-10-2005	900	01:01:25.82	+63:58:25.5	B7V	−14.6	10
Berkeley 63(1)	07-12-2005	600	02:19:32.26	+63:43:46.4	B2-3V	−31.9	
	01-10-2006	600				−32.5	
Berkeley 86(9)	27-06-2005	900	20:20:10.75	+38:37:30.9	B1V	−5.6	10
Berkeley 86(26)	27-06-2005	900	20:20:20.43	+38:37:36.7	B1V	−24.9	10
Berkeley 87(1)	09-10-2005	900	20:21:59.99	+37:26:24.1	B1V	−9.5	8
Berkeley 87(2)	09-10-2005	600	20:21:24.81	+37:22:48.3	B0-1V	−28.1	8
Berkeley 87(3)	08-10-2005	900	20:21:28.36	+37:26:18.9	B2	−7.9	8
	25-10-2005	900				−7.4	
Berkeley 87(4)	09-10-2005	900	20:21:33.55	+37:24:52.2	B0-1V	−40.2	8
Berkeley 90(1)	28-08-2006	1200	20:35:41.56	+46:46:48.9	B0V	−35.3	
Bochum 2(1)	21-11-2005	600	06:49:07.43	+00:21:56.3	B5-7V	−18.4	4.6
Collinder 96(1)	21-11-2005	120	06:30:17.69	+02:50:52.8	B0-1V	−19.2	63
Collinder 96(2)	21-11-2005	180	06:30:30.02	+02:53:22.0	B5-7V	−5.3	63
IC 1590(3)	28-09-2006	720	00:52:44.38	+56:37:03.3	B1V	−6.2	4
IC 4996(1)	15-07-2005	600	20:16:29.03	+37:38:52.3	B3	−20.5	8
King 10(A)	29-07-2005	900	22:54:53.19	+59:09:33.3	B1V	−19.5	50
	30-09-2006	600				−23.4	
King 10(B)	30-07-2005	900	22:55:12.43	+59:07:46.5	B0V	−19.4	50
	01-10-2006	900				−19.9	
King 10(C)	30-07-2005	900	22:55:06.47	+59:13:10.6	B2V	−12.6	50
	31-07-2005	900				−12.1	
	01-10-2006	900				−18.8	
King 10(E)	31-07-2005	900	22:54:56.64	+59:10:22.7	B3V	−15.9	50
	01-10-2006	900				−11.8	
King 21(B)	06-07-2007	900	23:49:46.84	+62:42:35.3	B5V	−18.9	30
King 21(C)	06-07-2007	600	23:49:57.83	+62:42:07.4	B1V	−6.6	30
King 21(D)	07-07-2007	900	23:49:59.04	+62:46:21.9	B3V	−16.0	30
NGC 146(S1)	01-10-2006	400	00:32:44.72	+63:18:15.6	B3V	−21.1	10
NGC 146(S2)	01-10-2006	900	00:33:18.17	+63:18:37.8	B5-7V	−20.6	10
NGC 436(1)	09-01-2007	600	01:15:56.29	+58:48:12.4	B5-7V	−14.0	40
NGC 436(2)	10-01-2007	700	01:15:20.56	+58:50:03.1	B5-7V	−35.2	40
NGC 436(4)	09-01-2007	600	01:15:41.14	+58:49:02.0	B5-7V	−16.3	40
NGC 436(5)	09-01-2007	600	01:15:58.66	+58:49:14.5	B3V	−25.8	40
NGC 457(1)	29-09-2006	600	01:19:02.36	+58:19:20.2	B3V	−16.5	20
NGC 457(2)	29-09-2006	300	01:19:32.98	+58:17:25.5	B3V	−20.0	20
NGC 581(1)	28-09-2006	300	01:33:41.87	+60:42:19.4	B2V	−25.6	12.5
NGC 581(2)	28-09-2006	600	01:33:24.25	+60:39:44.9	B2V	−31.6	12.5

Emission Star	Date	Int. time	RA(J2000) hh:mm:ss	Dec(J2000) deg:min:sec	Sp.type	Hα EW Å	Age Myr
NGC 581(3)	28-09-2006	120	01:33:15.16	+60:41:01.7	B0-1V	−15.3	12.5
NGC 581(4)	28-09-2006	600	01:33:10.96	+60:39:30.8	B3V	−14.8	12.5
NGC 637(1)	13-10-2005	900	01:43:22.10	+64:01:18.3	B5-7V	−22.4	4
NGC 654(2)	29-09-2006	600	01:44:02.89	+61:53:18.0	B0-1	−47.9	10
NGC 659(1)	21-11-2005	600	01:44:33.09	+60:40:56.2	B2V	−27.0	20
	30-09-2006	600				−27.3	
NGC 659(2)	21-11-2005	600	01:44:28.22	+60:40:03.4	B1V	−9.9	20
	30-09-2006	600				−4.1	
NGC 659(3)	21-11-2005	600	01:44:22.80	+60:40:43.8	B1V	−14.0	20
	30-09-2006	600				−13.7	
NGC 663(1)	08-10-2005	900	01:46:02.06	+61:15:04.2	B5V	−42.1	25
NGC 663(2)	07-10-2005	300	01:46:06.09	+61:13:39.1	B0-1V	−33.2	25
NGC 663(3)	07-10-2005	600	01:46:14.01	+61:13:43.9	B5V	−15.8	25
	09-10-2006	600				−15.0	
	24-10-2007	600				−12.4	
	02-12-2007	600				+1.5	
NGC 663(4)	24-10-2005	900	01:46:30.63	+61:14:29.2	B1V	−20.8	25
NGC 663(5)	22-11-2005	600	01:45:46.39	+61:09:20.9	B1V	−37.7	25
	10-10-2006	600				−39.8	
NGC 663(6)	24-10-2005	900	01:46:24.41	+61:10:37.3	B5-7V	−8.5	25
	24-10-2005	900				−6.5	
	09-10-2006	900				−6.8	
NGC 663(7)	24-10-2005	600	01:46:35.53	+61:15:47.8	B2V	−11.7	25
NGC 663(9)	24-10-2005	900	01:46:35.60	+61:13:39.1	B1V	−54.0	25
NGC 663(11)	09-10-2005	600	01:46:20.21	+61:14:21.5	B2V	−23.8	25
NGC 663(12)	25-10-2005	600	01:45:37.81	+61:07:59.1	B2V	−37.1	25
	10-10-2006	600				−32.7	
NGC 663(12V)	21-11-2005	600	01:46:26.84	+61:07:41.7	B0-1V	−40.8	25
NGC 663(13)	22-11-2005	720	01:46:34.85	+61:06:27.7	B5V	–	25
	09-10-2006	720				−3.8	
NGC 663(14)	25-10-2005	600	01:46:59.55	+61:12:29.8	B5V	−26.8	25
NGC 663(15)	25-10-2005	600	01:47:39.34	+61:18:20.7	B1V	−42.8	25
NGC 663(16)	25-10-2005	300	01:45:18.02	+61:06:56.4	B1V	−25.1	25
	10-10-2006	300				−21.7	
NGC 663(24)	09-10-2005	600	01:46:28.61	+61:13:50.4	B3V	−8.0	25
	10-10-2006	600				−7.9	
NGC 663(P5)	14-10-2005	900	01:45:56.11	+61:12:45.41	B2V	−30.1	25
	09-10-2006	900				−25.1	
NGC 663(P6)	09-10-2006	600	01:45:59.30	+61:12:45.67	B0-1V	−8.7	25
NGC 663(P8)	14-10-2005	900	01:45:39.63	+61:12:59.6	B2V	−21.9	25
NGC 663(P23)	25-10-2005	600	01:47:03.74	+61:17:32.0	B2V	−12.0	25

Emission Star	Date	Int. time	RA(J2000) hh:mm:ss	Dec(J2000) deg:min:sec	Sp.type	Hα EW Å	Age Myr
NGC 663(P25)	22-11-2005	600	01:47:26.76	+61:08:44.2	B0-1V	−11.3	25
NGC 663(P151)	25-10-2005	900	01:47:17.46	+61:13:18.2	B5-7V	−7.3	25
	10-10-2006	900				−5.6	
NGC 869(1)	21-01-2006	140	02:19:26.65	+57:04:42.1	B0V	−67.7	12.5
	24-10-2007	140				−61.4	
	16-12-2007	140				−60.8	
NGC 869(2)	20-01-2006	900	02:19:28.95	+57:11:25.1	B0-1V	−16.3	12.5
	16-12-2007	900				−15.9	
NGC 869(3)	21-01-2006	600	02:19:28.98	+57:07:05.3	B0-1V	−17.2	12.5
	24-10-2007	600				+1.7	
	16-12-2007	600				–	
NGC 869(4)	22-01-2006	300	02:18:47.98	+57:04:03.0	B0-1V	−5.6	12.5
	24-10-2007	300				−4.9	
	16-12-2007	300				−5.2	
NGC 869(5)	20-01-2006	600	02:19:13.77	+57:07:45.0	B1V	−17.6	12.5
	24-10-2007	600				−17.3	
	16-12-2007	600				−16.1	
NGC 869(6)	22-01-2006	900	02:19:08.73	+57:03:50.0	B5V	−47.8	12.5
	24-10-2007	900				−45.5	
	16-12-2007	900				−42.9	
NGC 884(1)	22-01-2006	240	02:22:48.07	+57:12:03.6	B0-1V	−16.5	12.5
	15-12-2007	240				−10.0	
NGC 884(2)	22-01-2006	180	02:22:06.59	+57:05:24.6	B0-1V	−70.4	12.5
	15-12-2007	180				−71.0	
NGC 884(3)	29-09-2006	300	02:21:52.95	+57:09:59.3	B0-1V	−6.3	12.5
	15-12-2007	300				−6.0	
NGC 884(4)	28-09-2006	480	02:21:44.56	+57:10:53.9	B2V	−26.8	12.5
	15-12-2007	480				−25.9	
NGC 884(5)	28-09-2006	180	02:21:43.39	+57:07:31.7	B0V	−12.8	12.5
	15-12-2007	180				−11.2	
NGC 884(6)	22-01-2006	600	02:22:02.51	+57:09:21.1	B1V	−9.9	12.5
	15-12-2007	600				−9.5	
NGC 957(1)	07-12-2005	300	02:33:10.45	+57:32:52.8	B0-1V	−37.9	10
	30-09-2006	300				−37.8	
NGC 957(2)	07-12-2005	600	02:33:39.44	+57:33:51.7	B2V	−16.5	10
	30-09-2006	600				−12.7	
NGC 1220(1)	21-11-2005	900	03:11:40.86	+53:21:03.8	B5V	−35.7	60
NGC 1893(1)	21-11-2005	900	05:22:42.95	+33:25:05.3	B1V	−69.2	4
NGC 2345(2)	07-12-2005	600	07:08:10.47	−13:15:36.7	B5V	−29.0	71
NGC 2345(5)	22-11-2005	900	07:08:07.53	−13:13:20.7	B5V	−33.8	71
NGC 2345(20)	22-11-2005	900	07:08:12.49	−13:10:35.8	B3V	−31.2	71

Emission Star	Date	Int. time	RA(J2000) hh:mm:ss	Dec(J2000) deg:min:sec	Sp.type	Hα EW Å	Age Myr
NGC 2345(24)	22-11-2005	900	07:08:11.59	−13:09:27.8	B3V	−27.3	71
	15-12-2007	900				−23.8	
NGC 2345(27)	28-12-2007	900	07:08:16.09	−13:10:03.6	B3V	−30.9	71
	26-02-2008	900				−31.0	
NGC 2345(32)	22-11-2005	900	07:08:19.58	−13:09:41.0	B5V	−19.6	71
	09-10-2006	900				−20.3	
NGC 2345(35)	22-11-2005	300	07:08:22.84	−13:10:16.5	B2V	−11.2	71
	15-12-2007	300				−8.4	
NGC 2345(44)	07-12-2005	600	07:08:25.55	−13:12:01.8	B3V	−11.5	71
	09-10-2006	600				−11.3	
NGC 2345(59)	07-12-2005	600	07:08:28.04	−13:15:35.8	B3V	−39.0	71
NGC 2345(61)	07-12-2005	600	07:08:29.85	−13:13:14.7	B5V	−16.2	71
NGC 2345(X1)	07-12-2005	600	07:07:58.15	−13:10:59.6	B5V	−26.9	71
NGC 2345(X2)	15-12-2007	300	07:08:12.50	−13:09:55.8	B5V	−27.3	71
	27-02-2008	300				−24.9	
NGC 2414(1)	07-12-2005	900	07:33:06.38	−15:26:35.8	B1V	−26.8	10
NGC 2414(2)	07-12-2005	600	07:33:20.44	−15:27:07.0	B1V	−26.1	10
NGC 2421(1)	21-01-2006	600	07:36:06.68	−20:37:57.5	B1V	−43.7	80
	16-12-2007	600				−34.8	
NGC 2421(2)	21-01-2006	600	07:36:02.96	−20:37:39.1	B5V	−13.3	80
	16-12-2007	600				−11.3	
NGC 2421(3)	16-12-2007	400	07:36:00.06	−20:38:46.0	B5V	−25.6	80
NGC 2421(4)	16-12-2007	300	07:36:21.95	−20:37:09.6	B5V	−21.8	80
NGC 6649(1)	09-06-2007	300	18:33:28.27	−10:24:07.3	B0V	−35.7	25
	06-07-2007	300				−35.0	
NGC 6649(2)	16-07-2006	900	18:33:26.16	−10:23:35.9	B5-7V	−15.2	25
	09-06-2007	900				−14.5	
NGC 6649(3)	09-06-2007	1200	18:33:23.95	−10:24:41.2	B5V	−22.0	25
NGC 6649(4)	09-06-2007	1200	18:33:36.29	−10:22:52.4	B5V	−28.7	25
NGC 6649(5)	10-06-2007	900	18:33:25.34	−10:20:51.5	B5V	−13.2	25
NGC 6649(6)	10-06-2007	1200	18:33:34.10	−10:26:04.8	B5V	−24.3	25
NGC 6649(7)	10-06-2007	1200	18:33:12.32	−10:25:13.5	B2V	−41.1	25
NGC 6756(2)	24-10-2005	900	19:08:40.15	+04:43:51.2	B5V	−20.8	125
NGC 6756(3)	24-10-2005	900	19:08:46.24	+04:40:23.2	B5V	−7.5	125
NGC 6834(1)	07-10-2005	900	19:52:06.48	+29:24:37.7	B5V	−38.9	40
	05-07-2007	900				−37.5	
NGC 6834(2)	07-10-2005	600	19:52:09.53	+29:23:34.0	B1V	−42.5	40
	06-07-2007	600				−41.7	
NGC 6834(3)	07-10-2005	600	19:52:21.21	+29:20:20.4	B5V	−14.5	40
	07-07-2007	600				−12.8	
NGC 6834(4)	07-10-2005	600	19:52:16.62	+29:25:15.0	B3V	−9.2	40

Emission Star	Date	Int. time	RA(J2000) hh:mm:ss	Dec(J2000) deg:min:sec	Sp.type	Hα EW Å	Age Myr
NGC 6910(A)	29-07-2005	900	20:23:11.74	+40:43:25.9	B3V	−36.2	6.3
NGC 6910(B)	29-07-2005	300	20:23:09.74	+40:45:53.0	B3V	−10.5	6.3
NGC 7039(1)	21-11-2005	900	21:11:00.95	+45:39:41.4	B1-3V	−46.6	1000
NGC 7128(1)	14-10-2005	900	21:44:02.92	+53:42:12.4	B1V	−43.6	10
NGC 7128(2)	14-10-2005	900	21:44:05.25	+53:42:36.8	B5V	−8.1	10
NGC 7128(3)	14-10-2005	900	21:43:33.57	+53:45:32.3	B1V	−18.9	10
NGC 7235(1)	14-10-2005	900	22:12:19.54	+57:16:04.1	B0-1V	−36.2	12.5
	25-10-2005	900				−39.4	
NGC 7261(1)	07-12-2005	600	22:19:51.44	+58:08:53.5	B0V	−48.1	46
NGC 7261(2)	07-12-2005	600	22:20:10.09	+58:06:34.3	B1V	−14.4	46
NGC 7261(3)	07-12-2005	600	22:20:13.31	+58:07:45.5	B0-1V	−38.8	46
NGC 7380(1)	17-07-2006	900	22:47:42.62	+58:07:46.8	B5-7V	−28.0	10
	01-08-2007	900				−28.6	
NGC 7380(2)	17-07-2006	600	22:47:40.12	+58:09:03.7	B1-3V	−36.7	10
NGC 7380(3)	17-07-2006	300	22:47:49.56	+58:08:49.6	B1-3V	−21.9	10
NGC 7419(A)	15-07-2005	900	22:54:36.68	+60:48:35.2	B0V	−45.3	25
NGC 7419(B)	27-06-2005	900	22:54:27.12	+60:48:52.2	B0V	−52.1	25
NGC 7419(C)	31-07-2005	900	22:54:25.62	+60:49:01.4	B1V	−7.0	25
NGC 7419(D)	15-07-2005	900	22:54:23.76	+60:49:31.0	B1V	−41.2	25
NGC 7419(E)	31-07-2005	900	22:54:24.36	+60:47:36.2	B6	−62.1	25
	09-10-2005	900				−55.2	
NGC 7419(F)	21-01-2006	900	22:54:24.28	+60:47:01.6	B0V	−39.3	25
	01-12-2008	900				−41.8	
NGC 7419(G)	08-08-2005	900	22:54:20.49	+60:49:52.5	B0V	−51.6	25
NGC 7419(H)	15-07-2005	1200	22:54:19.54	+60:48:52.0	B1-3V	−9.9	25
	08-08-2005	1200				−8.6	
	09-10-2006	1200				−3.4	
NGC 7419(I)	15-07-2005	1200	22:54:19.65	+60:48:35.8	B0V	−20.6	25
NGC 7419(I1)	09-10-2005	900	22:53:53.24	+60:48:08.3	B1-3V	−20.6	25
NGC 7419(J)	08-08-2005	900	22:54:15.34	+60:49:49.9	B0V	−15.3	25
NGC 7419(K)	21-01-2006	900	22:54:20.47	+60:48:53.9	B1V	−1.2	25
	09-10-2006	900				−1.5	
NGC 7419(L)	15-07-2005	1200	22:54:17.86	+60:48:57.2	B0V	−52.3	25
NGC 7419(M)	08-08-2005	900	22:54:14.55	+60:48:39.1	B0V	−34.1	25
NGC 7419(N)	08-08-2005	900	22:54:15.90	+60:47:49.2	B2.5	−61.0	25
	09-10-2006	900				−57.4	
NGC 7419(O)	08-08-2005	900	22:54:07.03	+60:48:18.0	B8V	−32.4	25
	09-10-2006	900				−27.9	
NGC 7419(P)	08-10-2005	900	22:54:13.97	+60:46:20.4	B0V	−19.5	25
	10-10-2006	900				−22.8	

Emission Star	Date	Int. time	RA(J2000) hh:mm:ss	Dec(J2000) deg:min:sec	Sp.type	Hα EW Å	Age Myr
NGC 7419(Q)	08-10-2005	900	22:54:14.83	+60:51:22.7	B1-3V	−64.3	25
NGC 7419(R)	08-10-2005	900	22:54:17.07	+60:51:37.6	B4V	−48.3	25
	10-10-2006	900				−39.3	
NGC 7419(1)	07-10-2005	900	22:54:29.22	+60:49:08.0	B0V	−51.4	25
	09-10-2006	900				−48.4	
NGC 7419(2)	07-10-2005	900	22:54:26.46	+60:49:06.3	B1V	−21.1	25
NGC 7419(3)	08-08-2005	900	22:54:22.56	+60:49:53.1	B0V	−49.5	25
	09-10-2006	900				−53.7	
NGC 7419(4)	07-10-2005	900	22:54:23.00	+60:50:04.4	B0V	−34.3	25
NGC 7419(5)	07-10-2005	900	22:54:07.58	+60:50:22.9	B0V	−62.3	25
NGC 7419(6)	08-10-2005	900	22:54:26.05	+60:47:57.1	B5	−37.5	25
	09-10-2006	900				−33.7	
NGC 7510(1A)	24-10-2005	900	23:10:57.76	+60:33:57.1	B0V	−36.1	10
NGC 7510(1B)	12-10-2005	900	23:11:08.53	+60:35:03.9	B1V	−23.8	10
NGC 7510(1C)	13-10-2005	600	23:10:47.75	+60:31:52.7	B0V	−58.1	10
Roslund 4(1)	25-10-2005	900	20:04:50.44	+29:11:06.1	B3V	−37.7	16
	03-12-2008	900				−48.0	
Roslund 4(2)	25-10-2005	120	20:04:47.07	+29:10:03.2	B0V	−62.6	16

The Hα EW distribution of 150 CBe stars is shown in Fig. 4 with a bin size of 10 Å, which is higher than the measurement errors. The Hα EW distribution of candidate CBe stars peak in the $-10 - -30$ Å range, with 36 stars each in $-10 - -20$ Å and $-20 - -30$ Å bin. We found 21 CBe stars in $-1 - -10$ Å, 27 in $-30 - -40$ Å and 16 stars in $-40 - -50$ Å EW bins. There are 14 CBe stars whose Hα EW values are less than -50 Å with NGC 884(2) showing the extreme value of -70.4 Å. About 80% of our sample of CBe stars have Hα EW in the range $-1 - -40$ Å, with 48% in the range $-10 - -30$ Å.

3.2.1 *Variability of Hα profile*

McSwain et al.(2009) found 12 new transient CBe stars and confirm 17 additional CBe stars with relatively stable discs from Hα spectroscopy of 296 stars in eight open clusters. Of the total sample of 150 CBe stars in 39 open clusters we identified Hα variability in 9 stars from multiple observations over a period of a few years. A description of the profile variability in these stars, which belong to 6 clusters, are listed below. In the present discussion we have not included the candidates which show slight change (EW of few Å) in emission strength.

Berkeley 87(3) : The observations of this star were made in 08-10-2005 and 25-10-2005. The profile changed from absorption to emission during this period, as shown in Fig. 5.

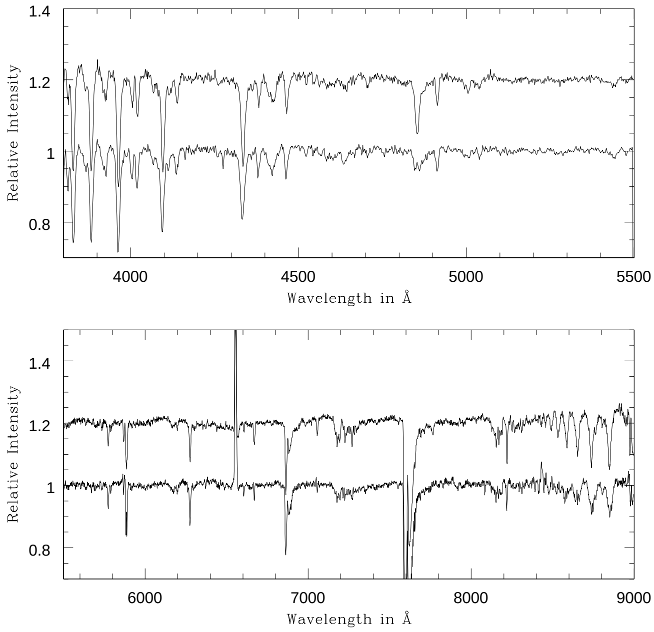

Figure 1. Spectra of CBe star NGC 659(2) in the wavelength range 3800 – 9000 Å. The spectra are from observations done on 21-11-2005 (lower) and 30-09-2006 (upper).

NGC 659(2) : The profile changed from normal state when observed on 21-11-2005 to core-emission on 30-09-2006 with a significant reduction in emission strength.

NGC 663(3) : The emission profile was single peaked when observed on 07-10-2005 which changed to asymmetric emission on 09-10-2006. When observed on 24-10-2007 the profile was found to show a double-peaked feature.

NGC 663(13) : The Hα profile was in absorption when observed on 22-11-2005 which changed to a double-peaked emission profile on 09-10-2006. This is a clear case of the formation of a circumstellar disc in a CBe star.

NGC 869(4) : The profile changed from a symmetric emission profile when observed on 22-01-2006 to an asymmetric profile on 24-10-2007. On subsequent observations on 16-12-2007 the emission strength decreased.

NGC 884(1) : The emission strength of Hα profile was enhanced when observed on 15-12-2007 compared with that on 22-01-2006.

Table 2. Spectral lines identified in CBe stars.

CBe star	Nature of Hβ	FeII	OI	Other features
Berkeley 62(1)	Hβ(a)	none	8446(e)	–
Berkeley 63(1)	Hβ(eina)	4e	7772(a), 8446(e)	–
Berkeley 86(9)	Hβ(a)	2a, 1e	7772(a), 8446(e)	–
Berkeley 86(26)	Hβ(e)	4a, 3e	7772(a), 8446(e)	–
Berkeley 87(1)	Hβ(eina)	none	8446(e)	–
Berkeley 87(2)	Hβ(e)	2e,1a	8446(e)	–
Berkeley 87(3)	Hβ(a)	none	7772(e), 8446(e)	–
Berkeley 87(4)	Hβ(e)	7e,1a	7772(e), 8446(e)	–
Berkeley 90(1)	Hβ(e)	7e	7772(e), 8446(e)	–
Bochum 2(1)	Hβ(fill-in)	1(a)	7772(a), 8446(e)	6347, 6371(SiII,a)
Collinder 96(1)	Hβ(e)	4e	7772(e), 8446(e)	–
Collinder 96(2)	Hβ(a)	none	7772(a)	–
IC 1590(3)	Hβ(a)	none	7772(a)	–
IC 4996(1)	Hβ(a)	1e	8446(e)	–
King 10(A)	Hβ(e)	2e,1a	8446(e)	6347(SiII,a)
King 10(B)	Hβ(e)	1e	8446(e)	–
King 10(C)	Hβ(eina)	1e	8446(e)	–
King 10(E)	Hβ(eina)	1e	8446(e)	–
King 21(B)	Hβ(eina)	1e	7772(a), 8446(e)	–
King 21(C)	Hβ(a)	none	8446(e)	–
King 21(D)	Hβ(eina)	none	8446(e)	–
NGC 146(S1)	Hβ(eina)	11a,1e	7772(a), 8446(e)	6347, 6371(SiII,a)
NGC 146(S2)	Hβ(eina)	none	8446(e)	–
NGC 436(1)	Hβ(a)	none	7772(a), 8446(e)	6347, 6371(SiII,a)
NGC 436(2)	Hβ(eina)	9e	7772(e), 8446(e)	–
NGC 436(4)	Hβ(a)	3a,1e	7772(a), 8446(e)	6347, 6371(SiII,a)
NGC 436(5)	Hβ(eina)	8e	7772(e), 8446(e)	–
NGC 457(1)	Hβ(eina)	none	8446(e)	–
NGC 457(2)	Hβ(eina)	8a,2e	7772(a), 8446(e)	6347, 6371(SiII,a)
NGC 581(1)	Hβ(eina)	2e	7772(e), 8446(e)	–
NGC 581(2)	Hβ(eina)	4a,3e	7772(a), 8446(e)	6347, 6371(SiII,a)
NGC 581(3)	Hβ(eina)	4e,1a	7772(e), 8446(e)	–
NGC 581(4)	Hβ(a)	none	7772(a), 8446(e)	6347, 6371(SiII,a)

e - emission profile, a - absorption, dpe - double-peaked emission
eina - emission in absorption, ce - core-emission

CBe star	Nature of Hβ	Fe II	O I	Other features
NGC 637(1)	Hβ(eina)	none	8446(e)	–
NGC 654(2)	Hβ(e)	10e,2a	7772(e), 8446(e)	–
NGC 659(1)	Hβ(eina)	2dpe	7772(dpe), 8446(e)	–
NGC 659(2)	Hβ(a)	none	7772(a), 8446(a)	–
NGC 659(3)	Hβ(eina)	none	7772(e), 8446(e)	–
NGC 663(1)	Hβ(eina)	2a,1e	7772(e), 8446(e)	–
NGC 663(2)	Hβ(e)	5e,5a	7772(e), 8446(e)	–
NGC 663(3)	Hβ(fill-in)	5a,2e	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 663(4)	Hβ(eina)	5e	7772(e), 8446(e)	7896(Mg II,e)
NGC 663(5)	Hβ(eina)	10e	7772(e), 8446(e)	6347(Si II,e) 7896(Mg II,e)
NGC 663(6)	Hβ(a)	3a	none	6371(Si II,a)
NGC 663(7)	Hβ(a)	1e	7772(a), 8446(e)	6347(Si II,a)
NGC 663(9)	Hβ(e)	15e	7772(e), 8446(e)	–
NGC 663(11)	Hβ(eina)	5e	7772(e), 8446(e)	–
NGC 663(12)	Hβ(eina)	7e	8446(e)	–
NGC 663(12V)	Hβ(e)	12e	7772(e), 8446(e)	–
NGC 663(13)	Hβ(eina)	3a,1e	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 663(14)	Hβ(eina)	4e,2a	7772(e), 8446(e)	–
NGC 663(15)	Hβ(e)	12e	7772(e), 8446(e)	–
NGC 663(16)	Hβ(e)	1e	8446(e)	–
NGC 663(24)	Hβ(a)	1a,1e	7772(a)	–
NGC 663(P5)	Hβ(eina)	7e	7772(e), 8446(e)	7896(Mg II,e)
NGC 663(P6)	Hβ(fill-in)	1e	8446(e)	–
NGC 663(P8)	Hβ(eina)	2a,2e	8446(e)	–
NGC 663(P23)	Hβ(fill-in)	6e	7772(e), 8446(e)	6371(Si II,a)
NGC 663(P25)	Hβ(eina)	5e	7772(a), 8446(e)	6371(Si II,a)
NGC 663(P151)	Hβ(a)	3a	7772(a), 8446(e)	6371(Si II,a)
NGC 869(1)	Hβ(e)	21e	7772(e), 8446(e)	6347(Si II,e) 7896(Mg II,e)
NGC 869(2)	Hβ(eina)	7e,1a	7772(e), 8446(e)	–
NGC 869(3)	Hβ(a)	2e	7772(e), 8446(e)	–
NGC 869(4)	Hβ(a)	5e	7772(a), 8446(e)	–
NGC 869(5)	Hβ(eina)	9e	7772(e), 8446(e)	–
NGC 869(6)	Hβ(e)	6a,3e	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 884(1)	Hβ(eina)	none	7772(e), 8446(e)	–
NGC 884(2)	Hβ(e)	24e	7772(e), 8446(e)	6347, 6371(Si II,e) 7896(Mg II,e)

CBe star	Nature of Hβ	Fe II	O I	Other features
NGC 884(3)	Hβ(fill-in)	3e	7772(e), 8446(e)	–
NGC 884(4)	Hβ(fill-in)	6e	7772(e), 8446(e)	–
NGC 884(5)	Hβ(e)	1e	7772(e), 8446(e)	6347, 6371(Si II,e)
NGC 884(6)	Hβ(a)	6e,2a	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 957(1)	Hβ(e)	9e	7772(e), 8446(e)	6347, 6371(Si II,e) 7896(Mg II)
NGC 957(2)	Hβ(eina)	6e,1a	7772(e), 8446(e)	7896(Mg II)
NGC 1220(1)	Hβ(eina)	2e	7772(e), 8446(e)	–
NGC 1893(1)	Hβ(e)	19e	7772(e), 8446(e)	6347(Si II,e)
NGC 2345(2)	Hβ(fill-in)	2e	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 2345(5)	Hβ(eina)	5e	8446(e)	6347(Si II,a)
NGC 2345(20)	Hβ(eina)	3e	8446(e)	–
NGC 2345(24)	Hβ(eina)	none	8446(e)	–
NGC 2345(27)	Hβ(eina)	14e	7772(e), 8446(e)	6347(Si II,a)
NGC 2345(32)	Hβ(fill-in)	none	8446(e)	6347, 6371(Si II,a)
NGC 2345(35)	Hβ(a)	none	8446(e)	6347, 6371(Si II,a)
NGC 2345(44)	Hβ(fill-in)	none	7772(a)	6371(Si II,a)
NGC 2345(59)	Hβ(eina)	4e	7772(e), 8446(e)	–
NGC 2345(61)	Hβ(a)	none	7772(a), 8446(e)	6347(Si II,a)
NGC 2345(X1)	Hβ(eina)	2e	8446(e)	6371(Si II,a)
NGC 2345(X2)	Hβ(eina)	5e	7772(e), 8446(e)	–
NGC 2414(1)	Hβ(eina)	4e	7772(a), 8446(e)	–
NGC 2414(2)	Hβ(eina)	2e	7772(e), 8446(e)	–
NGC 2421(1)	Hβ(eina)	12e	7772(e), 8446(e)	–
NGC 2421(2)	Hβ(a)	none	8446(e)	–
NGC 2421(3)	Hβ(eina)	4e	7772(e), 8446(e)	–
NGC 2421(4)	Hβ(eina)	5e	7772(e), 8446(e)	–
NGC 6649(1)	Hβ(e)	11e	7772(e), 8446(e)	–
NGC 6649(2)	Hβ(fill-in)	5e	7772(a), 8446(e)	–
NGC 6649(3)	Hβ(fill-in)	4e	7772(e), 8446(e)	6371(Si II,a)
NGC 6649(4)	Hβ(fill-in)	5e	7772(e), 8446(e)	6347, 6371(Si II,a)
NGC 6649(5)	Hβ(fill-in)	2e	8446(e)	6371(Si II,a)
NGC 6649(6)	Hβ(fill-in)	5e	8446(e)	6371(Si II,a)
NGC 6649(7)	Hβ(eina)	14e	7772(e), 8446(e)	6347, 6371(Si II,a)
NGC 6756(2)	Hβ(eina)	4e,1a	8446(e)	–
NGC 6756(3)	Hβ(a)	1e,1a	8446(e)	–
NGC 6834(1)	Hβ(eina)	18e	7772(e), 8446(e)	5463(N II,e)
NGC 6834(2)	Hβ(eina)	18e,2a	7772(e), 8446(e)	–

CBe star	Nature of Hβ	Fe II	O I	Other features
NGC 6834(3)	Hβ(a)	5e	8446(e)	–
NGC 6834(4)	Hβ(a)	2e	7772(a), 8446(e)	–
NGC 6910(A)	Hβ(eina)	5e,4a	7772(a), 8446(e)	7896(Mg II,e) 6347, 6371(Si II,a)
NGC 6910(B)	Hβ(a)	2e	none	–
NGC 7039(1)	Hβ(eina)	16e	7772(e), 8446(e)	–
NGC 7128(1)	Hβ(eina)	14e	7772(e), 8446(e)	–
NGC 7128(2)	Hβ(a)	2a	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 7128(3)	Hβ(eina)	3a,1e	8446(e)	–
NGC 7235(1)	Hβ(ce)	16e	7772(e), 8446(e)	–
NGC 7261(1)	Hβ(ce)	13e	7772(e), 8446(e)	7896(Mg II,e) 6347, 6371(Si II,e)
NGC 7261(2)	Hβ(eina)	1e	8446(e)	–
NGC 7261(3)	Hβ(e)	13e	7772(e), 8446(e)	7896(Mg II,e) 6347, 6371(Si II,e)
NGC 7380(1)	Hβ(eina)	none	7772(a), 8446(e)	6347, 6371(Si II,a)
NGC 7380(2)	Hβ(e)	5e	7772(e), 8446(e)	–
NGC 7380(3)	Hβ(eina)	11e	7772(e), 8446(e)	5942(N II,e)
NGC 7419(A)	Hβ(e)	13e	7772(e), 8446(e)	6371(Si II,e)
NGC 7419(B)	Hβ(e)	10e	7772(e), 8446(e)	–
NGC 7419(C)	Hβ(a)	1e	7772(a), 8446(e)	5005(N II,e)
NGC 7419(D)	Hβ(eina)	6e	7772(e), 8446(e)	6347(Si II,e) 7877, 7896(Mg II,e)
NGC 7419(E)	Hβ(e)	4e	7772(e), 8446(e)	–
NGC 7419(F)	Hβ(a)	1e	8446(e)	–
NGC 7419(G)	Hβ(e)	11e	7772(e), 8446(e)	–
NGC 7419(H)	Hβ(a)	4e	7772(a), 8446(e)	–
NGC 7419(I)	Hβ(eina)	9e	7772(e), 8446(e)	4131(Si II,a)
NGC 7419(I1)	Hβ(eina)	none	7772(a), 8446(e)	–
NGC 7419(J)	Hβ(eina)	5e	7772(e), 8446(e)	–
NGC 7419(K)	Hβ(a)	4e	7772(a), 8446(e)	–
NGC 7419(L)	Hβ(e)	15e	7772(e), 8446(e)	6347(Si II,e), 5530(N II,e)
NGC 7419(M)	Hβ(e)	14e	7772(e), 8446(e)	6371(Si II,a)
NGC 7419(N)	Hβ(e)	12e	7772(e), 8446(e)	7896(Mg II,a)
NGC 7419(O)	Hβ(a)	3e	7772(e), 8446(e)	7877(Mg II,e)
NGC 7419(P)	Hβ(a)	5e	7772(a), 8446(e)	5684(N II,e) 6371(Si II,a), 7896(Mg II,a)

CBe star	Nature of Hβ	FeII	OI	Other features
NGC 7419(Q)	Hβ(e)	12e,1a	7772(e), 8446(e)	6347(SiII,a),7877(MgII,a)
NGC 7419(R)	Hβ(e)	5e	7772(a), 8446(e)	–
NGC 7419(1)	Hβ(e)	5e	7772(e), 8446(e)	7896(MgII,a)
NGC 7419(2)	Hβ(a)	2e	7772(a), 8446(e)	–
NGC 7419(3)	Hβ(e)	9e	7772(e), 8446(e)	7896(MgII,a)
NGC 7419(4)	Hβ(e)	7e	8446(e)	–
NGC 7419(5)	Hβ(e)	6e,1a	7772(e), 8446(e)	5711(NII,e), 7896(MgII,a) 6347, 6371(SiII,e),
NGC 7419(6)	Hβ(e)	8e	8446(e)	6347(SiII,a)
NGC 7510(A)	Hβ(e)	7e,3a	7772(a), 8446(e)	–
NGC 7510(B)	Hβ(eina)	5e,1a	7772(a), 8446(e)	–
NGC 7510(C)	Hβ(e)	12e	7772(a), 8446(e)	7877, 7896(MgII,e) 6347, 6371(SiII,e)
Roslund 4(1)	Hβ(a)	1e,2a	7772(a), 8446(e)	–
Roslund 4(2)	Hβ(e)	17e,1a	7772(a), 8446(e)	6347, 6371(SiII,a) 7896(MgII,e)

NGC 7419(H) : The emission strength of Hα decreased during the observations on 15-07-2005, 08-08-2005 and 09-10-2006, where the profile shows a core-emission feature.

NGC 7419(K) : The profile resembled that of a typical CBe shell star, since the absorption component over the emission dips below the continuum level. The Hα profile was double-peaked, with the violet part more intense than red (V/R $>$ 1), when observed on 21-01-2006. The absorption component on emission deepened and fell below the continuum in the normalized spectra of 09-10-2006.

NGC 7419(P) : The profile was double-peaked when observed on 08-10-2005 with the violet part of the double profile fading in intensity to a single profile on 10-10-2006.

The observed shape of Hα emission line profile can be due to density related effects in the circumstellar disc and is a function of viewing angle. Some of the candidates show double-peaked profile with differences in the intensities of violet and red peaks (V $\neq$ R), which have been used conventionally to understand the global oscillations in circumstellar discs (Mennickent, Sterken & Vogt 1997). In the case of Berkeley 87(3), the circumstellar disc is formed during a short period ($\sim$17 days). The V/R ratio of NGC 663(P151) and NGC 869(6) were found to change over a period of time, suggesting the turbulent nature of the circumstellar disc. From Hα line profile analysis NGC 7419(K) is suspected to be a CBe shell star.

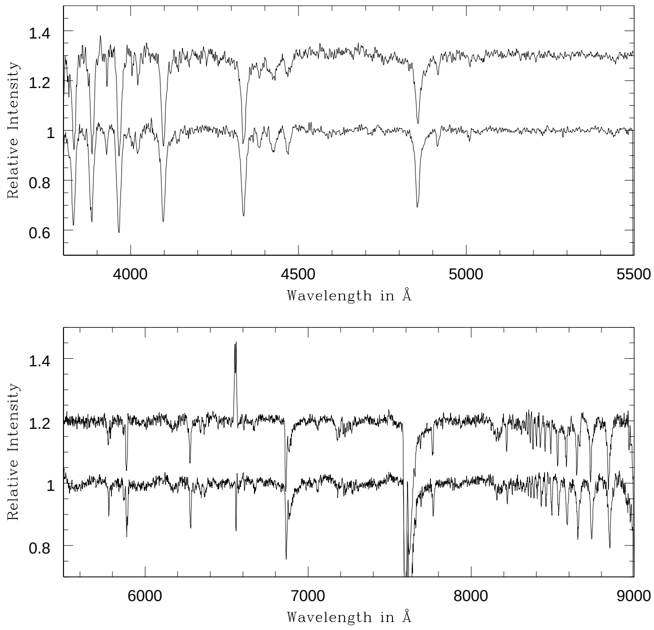

Figure 2. Spectra of CBe star NGC 663(13) in the wavelength range 3800 – 9000 Å. The spectra are from observations done on 22-11-2005 (lower) and 09-10-2006 (upper).

3.3 Metallic lines

Emission lines of metallic species, viz., FeII, CaII, OI, SiII, MgII, NII, form in the circumstellar discs of Be stars which are not affected by the stellar absorption features, unlike in the case of Balmer lines (Hanuschik 1987). Also, FeII lines are least affected by broadening due to thermal effects and Thomson scattering and hence they can be used to trace the density and velocity structure of the envelope (Hanuschik 1988). The list of observed FeII, SiII, MgII, CaII, OI and NII lines of 150 CBe stars are shown in Table 3.

We found that 131 (86%) CBe stars show FeII lines in their spectra. Among these, 92 have FeII only in emission, while 5 have FeII absorption lines. We identified 45 different FeII spectral lines. Bochum 2(1) and NGC 146(S2) have only one FeII absorption line while NGC 7128(2) has two and NGC 663(P151) has three lines. These stars have the least number of FeII lines among the surveyed candidates. On the other hand, NGC 884(2) has 25 FeII emission lines and NGC 869(1) shows 19 lines. The prominent FeII lines present in the spectra are 4584(36), 5018(52), 5169(84), 5316(86), 6318(64), 6384(82), 7513(70) and 7712(57) Å. The number of candidates which show these lines are given in brackets.

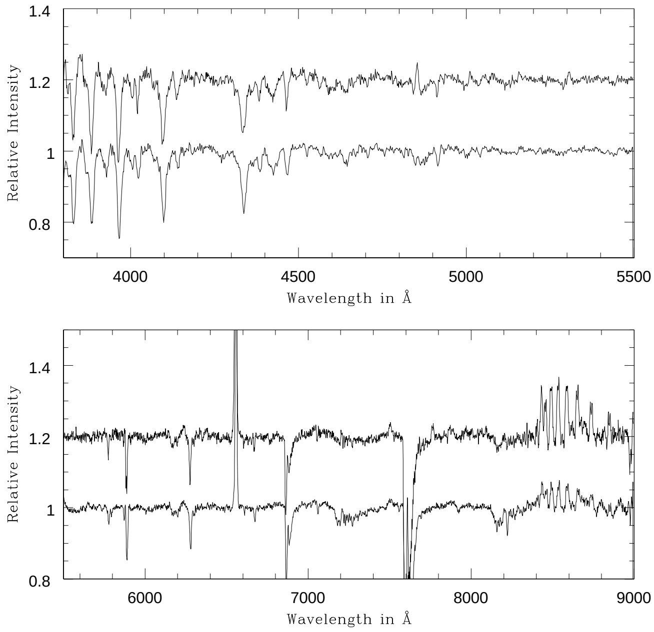

Figure 3. Spectral variability in CBe star NGC 884(1) when observed on 22-01-2006 (lower spectra) and 15-12-2007 (upper spectra).

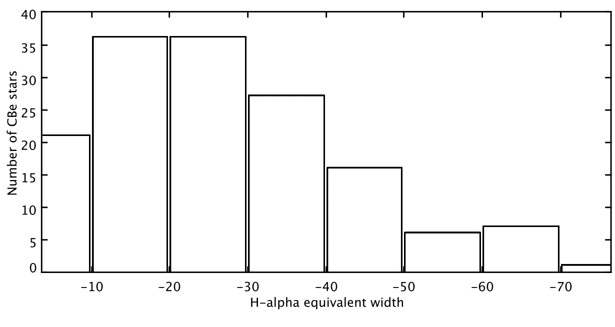

Figure 4. The distribution of Hα EW of CBe stars.

The spectra of all but three stars in our sample show 8446 Å line. Only 116 stars have both 7772 Å and 8446 Å oxygen lines in their spectra, where 71 stars (47%) have both lines in emission. On the other hand, 36 stars (24%) show only the 8446 Å oxygen line in their spectra.

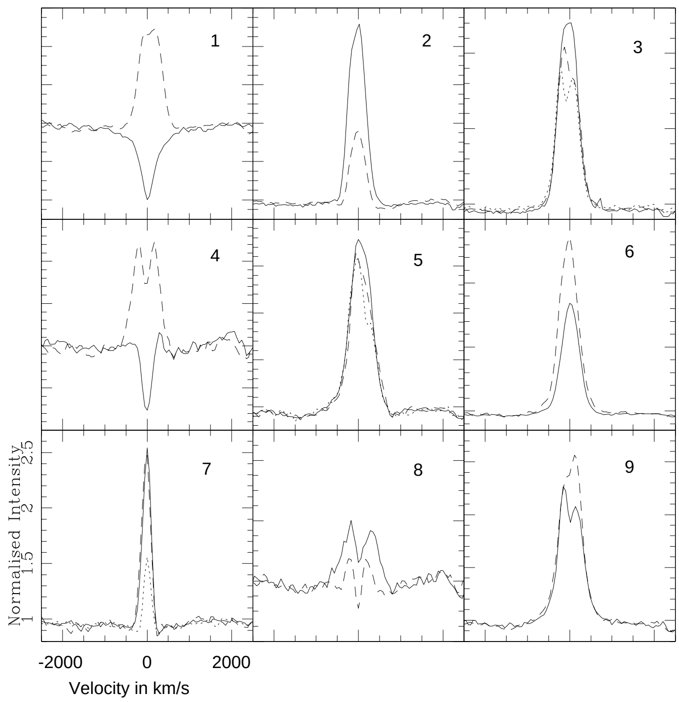

Figure 5. The variation in Hα profile for e-stars (1) Berkeley 87(3), (2) NGC 659(2), (3) NGC 663(3), (4) NGC 663(13), (5) NGC 869(4), (6) NGC 884(1), (7) NGC 7419(H), (8) NGC 7419(K), (9) NGC 7419(P) are shown. Initial observations are shown as solid lines followed by repeated observations in dashed and dotted lines respectively.

Either of the SiII lines 6347 Å and 6371 Å is seen in 32% of the spectra in absorption or emission. For 24 stars these SiII lines are seen together either in emission or absorption.

The prominent MgII lines in the spectra are of wavelengths 7877 Å and 7896 Å, either of which are present in 20 stars. The NII 5005 Å line is present in emission in NGC 7419(C), 5463 Å in NGC 6834(1), 5530 Å in NGC 7419(L), 5684 Å in NGC 7419(P) and 5942 Å in NGC 7380(3). The presence of NII lines has to be confirmed through repeated observations.

The CaII triplet (8498, 8542, 8662 Å) is found to be blended with Paschen lines (P16, P15 and P13 respectively) in our sample of CBe stars. CaII triplet is seen together either in absorption or emission in 130 stars. 92 (60%) stars show CaII triplet in emission in their spectra. We found 100 stars to show Paschen 14 (8598 Å) in emission while 144 have this line either in emission or absorption. About 117 candidates show more than 5 lines in Paschen series in their spectra.

Table 3. Spectral lines identified in the candidate CBe stars, with the number of emission and absorption profiles in brackets.

Fe II				
4173(17e,7a)	4233(8e,4a)	4303(2e,2a)	4352(3a)	4385(2e)
4417(2e,1a)	4515(6e,1a)	4520(8e,2a)	4523(3e,3a)	4549(7e,1a)
4556(5e,3a))	4584(30e,6a)	4629(23e,1a)	4924(4e)	5018(51e,1a)
5169(65e,19a)	5198(23e,1a)	5235(34e,10a)	5276(28e,7a)	5316(79e,7a)
5363(11e,1a)	5425(8e,1a)	5480(4e)	5496(1a)	5535(7e,1a)
5814(1a)	5957(1e)	5991(4e)	6084(1e)	6103(1a)
6148(12e,1a)	6248(9e)	6318(60e,4a)	6384(79e,3a)	6417(2e)
6432(1e)	6456(32e,7a)	6483(2e)	6516(35e)	7222(3e)
7308(1e)	7321(1e)	7462(8e)	7513(68e,2a)	7712(56e,1a)
O I				
7772(71e,45a)	8446(145e,3a)			
Ca II				
8498(103e,33a)	8542(104e,39a)	8662(98e,48a)		
Si II				
6347(11e,28a)	6371(6e,33a)			
Mg II				
7877(3e,1a)	7896(8e,7a)			

4. Conclusions

1. We have presented the spectral details of 150 CBe stars of which 48 have been studied for the first time. This large data set covers CBe stars of various spectral types and ages found in different cluster environments of the northern open clusters. About 80% of our sample of CBe stars have Hα EW in the range $-1 - -40$ Å, with 48% in the range $-10 - -30$ Å.

2. Apart from the Balmer lines in emission, spectra of most of the stars show FeII, Paschen and OI lines in emission. About 86% of the surveyed CBe stars show FeII lines in their spectra. The prominent FeII lines in our surveyed stars are 4584, 5018, 5169, 5316, 6318, 6384, 7513 and 7712 Å.

3. We found long ($\sim$ years) and short (few days) term Hα variability in 9 CBe stars which belong to 6 open clusters. In Berkeley 87(3) the profile is found to change from absorption to emission in 17 days. For a few stars the V/R ratio changes over a period of 1 year. NGC 7419(K) is suspected to be a shell CBe star.

4. NGC 884(1) shows the presence of FeII, OI, CaII triplet and Paschen emission lines in their spectra over a period of 23 months.

5. The Hα emission profile of the star NGC 663(13) changed from absorption to a double-peaked profile, which is a clear case of the formation of a circumstellar disc over a period of $\sim$1 year. This is accompanied by the formation of CaII triplet absorption lines, which trace the cooler part of the disc.

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