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Observations of Bn and An stars: New Be stars

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Abstract. From a survey of spectra of Bn/An stars, we have detected seven new Be stars: HR 1056 (A0Vn), 1544 (A1Vn), 2191 (A0Vnn), 2300 (B8Vn), 3134 (B9.5 Vn), 3878 (B0.5 IIIn) and 4552 (B9IIIpSi). H_α profiles of these stars are presented. Measured values of equivalent widths, full widths at half intensity maximum, and the peak-separations of the H_α emission profiles are also tabulated in this paper. We have also computed the radii of emission disks of the newly detected Be stars.

Key words: stars: emission-line, Be

1. Introduction

Several B and A stars in the Bright Star Catalogue (Hoffleit & Jaschek 1982) have been designated as Bn and An stars. The "n" tag was given by Adams & Joy (1923) meaning the spectroscopic lines are "nebulous" in contrast to "sharp" lines seen in other stars. The "nebulous" nature of the lines presumably results from the fast rotation of the stars, that leads to the large broadening of the lines. Several surveys have been made to search for newly Be stars using different criteria (Irvine 1975; Irvine & Irvine 1979; Irvine 1990; Cote & van Kerwijk 1993 and references therein). It may be seen from both the Bright Star (Hoffleit & Jaschek 1982) and the Be star (Jaschek & Egret 1982) Catalogues that there are many Bn and An stars that have been identified as Be stars. We suspect that the Bn An stars that are listed in the Bright StarCatalogue (Hoffleit & Jaschek 1982), may contain many latent Be and Be-shell stars. During January - February 1997, we have obtained high resolution (∼0.17 Å pixel^{-1}) and moderate-resolution (∼ 1 Å pixel^{-1}) spectra of 33 Bn and 49 An stars. The selection of these Bn and An stars was dictated by the accessibility to our telescope and the limit of the spectrograph to obtain good signal-to-noise ratio spectra. Also to compare the spectra of Bn and An stars we obtained the spectra of 17 B and A stars of high rotational velocities ($v \sin i > 200$ km s^{-1}) and another 7 B stars with very low rotational velocities ($v \sin i < 35$ km s^{-1}), using the same instrumentation that were used for Bn and An stars. Close inspection of the spectra of 82 Bn and An stars (Table 1 presents the list of observed Bn and An stars with HR and HD numbers, spectral types, V_{mag}, $B-V$ and $v \sin i$ values) reveals seven new Be stars (Be star designation also includes Oe and Ae stars). Results of spectral analysis of these seven new Be stars are presented here. Section 2 describes the observations and data analysis. Results and discussion are given in Sect. 3. Section 4 presents the conclusion.

2. Observations and data analysis

Spectra of the newly detected Be stars were obtained on four nights during January - February 1997, using the Universal Astronomical Grating Spectrograph (UAGS) at the Cassegrain focus and also using the Echelle spectrograph at the Coudé focus of the 1 m reflector of VBO, with a CCD system. Iron-Argon or Iron-Neon and Thorium-Argon source spectra were used for wavelength calibration for UAGS and Echelle spectrograph, respectively. Dome flat-field frames were obtained to remove the pixel to pixel quantum efficiency variations. The reciprocal dispersions of UAGS and Echelle spectrograph are 19.6 Å mm^{-1} at H_α (0.45 Å pixel^{-1}) and 7.4 Å mm^{-1} at H_α (0.14 Å pixel^{-1}), respectively. The spectra were analyzed using IRAF software package installed on the SUN SPARC CLASSIC

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Workstation. The following steps were followed for the reductions:

i) Trimming of the bias, the flat-field and the star spectrum CCD frames.
ii) Bias subtraction from the flat-field and the star spectrum CCD frames.
iii) Normalization of the flat-field frame and the division of the star spectrum frame by the normalized flat-field frame.
iv) Extraction of different orders of star and the comparison spectra.
v) Wavelength calibration of the stellar spectra using the coefficients of a high order polynomial fit to the comparison spectra.
vi) Normalization of the stellar spectra.
vii) Measurements of different parameters (equivalent width, full width at half intensity maximum by fitting a Gaussian profile, intensities of emission and absorption components, peak-separations, etc.) of stellar absorption and emission profiles.

The error in wavelength calibration for Coudé and Cassegrain spectra was around 0.05 Å to 0.10 Å respectively. To reduce the error in normalization we normalized each spectrum, at least, three to four times and finally these spectra were averaged. Around 2% of the local continuum is estimated to be the error in normalization. The instrumental broadening was computed by measuring the *FWHM* of the narrowest line of the comparison spectral lines and this value of the *FWHM* was taken as the instrumental broadening of the spectrograph. The values of instrumental broadening for the UAGS and the Echelle spectrographs are 0.5 Å and 0.2 Å respectively, at H_α. These values were used to correct for instrumental broadening of the measured *FWHM* values of Be stars. Using the expression of σ(EW), given in Ghosh (1988) and Ghosh et al. (1990), the errors in equivalent width measurements were computed.

3. Results and discussion

Spectra of 33 Bn, 49 An and 24 B and A stars were analyzed. It has been found from the spectra of 82 Bn and An stars that seven stars displayed the presence of emission in their H_α. These are the new emission-line Bn and An stars. Also we have independently detected H_α-emission in two more Bn and An stars (Fig. 1) that were earlier reported as emission-line stars (HR 1037, Cote & van Kerwijk 1993 and HR 2244, Irvine 1990). Comparison of Fig. 3 of Cote & van Kerwijk (1993) and Fig. 1 of the present paper, clearly shows that the H_α-emission strength of HR 1037 decreased between August 1990 and January 1997. However, the H_α-emission strength of HR 2244 increased considerably since Irvine's detection (from the comparison of Fig. 1 of the present paper and Fig. 3 of Irvine 1993).

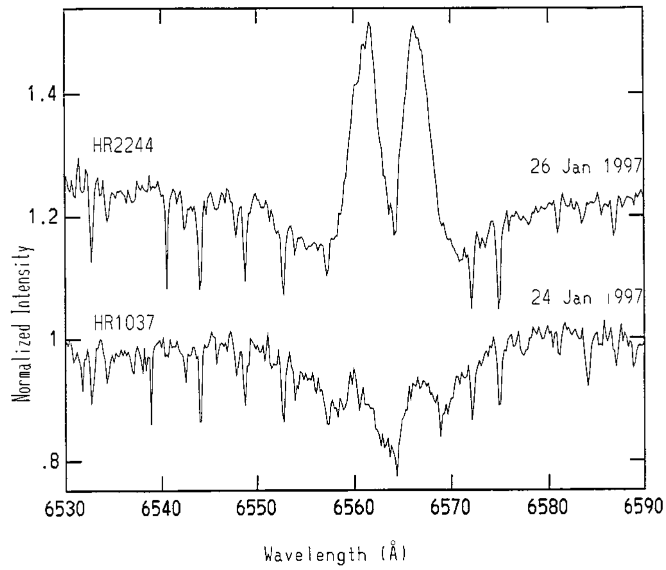

Fig. 1. Coudé Echelle H_α profiles of two known Be stars, HR 1037 and HR 2244. Sharp lines present throughout the spectra are H_2O telluric absorption features

Observed H_α-emission profiles of seven new Be stars (four Bne and three Ane stars) are shown in Figs. 2a-c. Figure 2a shows the $H_\alpha$emission profiles of HR 1544 and HR 4552 that were observed using the Coudé Echelle spectrograph. It appears from this figure that the emission in H_α profile may be doubtful. To check this we also obtained the spectrum of HR 2155 that has similar spectral type, luminosity class and rotational velocity as that of HR 1544. Lower part of Fig. 2b presents superimposed H_α profiles of HR 1544 (A1Vn and $v \sin i = 212$ km s^{-1}) and HR 2155 (A1Vn and $v \sin i = 211$ km s^{-1}). From the comparison of these two profiles, it may be seen that HR 1544 is an emission-line star (subtracted spectrum is presented in the upper part of Fig. 2b). Cassegrain spectra of five new Be stars are shown in Fig. 2c. We have computed the projected rotational velocities ($v \sin i$) of three Bn and An stars, using the full width at half intensity maximum (*FWHM*) values of He I lines (5876 Å and 6678 Å) where the He I lines have been assumed to be Gaussian profiles. Under this assumption the $v \sin i$ values were computed using the following formula (Buscombe 1969):

$$\frac{v \sin i}{c} = \frac{FWHM}{2\lambda_0 (\ln 2)^{1/2}} \qquad (1)$$

where λ_0 is the laboratory wavelength and c is the velocity of light. The $v \sin i$ values of other four Bn and An stars were obtained from the Bright Star Catalogue (Hoffleit & Jaschek 1982). Measured equivalent widths [$W(\alpha)$], *FWHM* (instrumental broadening corrected) and the peak separations ($\Delta V_{\rm peak}$) of seven new Be stars are given in Table 2, along with the $v \sin i$ values. We have also

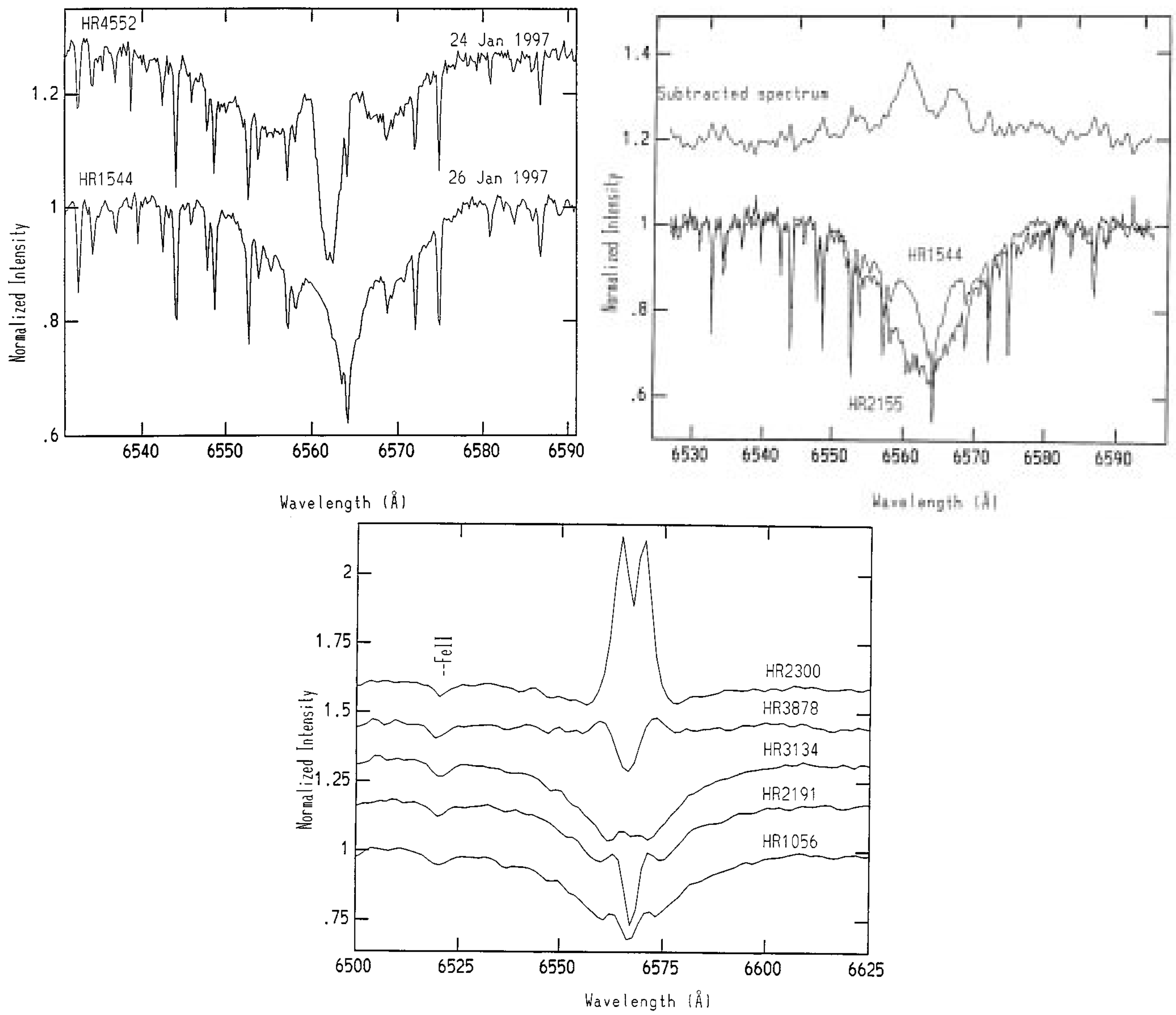

Fig. 2. a) Same as Fig. 1, but for two new Be stars, HR 1544 and HR 4552. **b)** Same as Fig. 1, but for the new Be star, HR 1544 and the B type star HR 2155 of similar spectral type and rotational velocity as that of HR 1544. For comparison, the H_α profiles of these two stars are plotted one over the other and the subtracted spectrum (the H_α profile of HR 1544 minus the H_α profile HR 2155) is presented on the top that shows the presence of emission in the H_α profile of HR 1544. **c)** Same as Fig. 1, but for the Cassegrain spectra of five new Be stars, HR 1056, HR 2191, HR 2300, HR 3134, and HR 3878

computed the radii of the emission disk of the Be stars, using the following equation (Huang 1972):

$$\frac{R_e}{R_*} = \left(\frac{2v\sin i}{\Delta V_{peak}}\right)^{1/j} \quad (2)$$

where R_e is the radius of the emission-disk and R_* is the photospheric radius and j is an exponent that characterizes the rotation law ($j = 0.5$ for Keplerian rotation of the disk and $j = 1.0$ for rotation with conservation of angular momentum). To compute the values of R_e/R_*, we have used $j = 0.5$. Computed values of R_e/R_* of the new Be stars are given in the last column of Table 2. Errors in $W(\alpha)$ measurements were computed using the expression of $\sigma[W(\alpha)]$ given in Ghosh (1988) and Ghosh et al. (1990) and the errors in $FWHM$, ΔV_{peak}, R_e/R_* were computed using the errors of wavelength calibration. Brief discussion about the seven new Be stars is given below:

HR 1056, HD 21620 (A0Vn)

This star has a moderate $v\sin i$ value (230 km s^{-1}). The spectrum shows double-peaked weak emission inside the photospheric absorption core of the H_α profile. After the photospheric absorption correction, the equivalent width of the emission component is 1.88 ± 0.05 Å. Value of $FWHM$ of the emission component, measured through

Table 1. List of observed An/Bn stars

HR	HD	Spectral type	$V_{\rm mag}$	$B-V$	$v \sin i$ (km s^{-1})
1	3	A1 Vn	6.71	+0.07	210
10	256	A6 Vn	6.19	+0.13	220
26	560	B9 Vn	5.54	−0.06	275
55	1141	B8 Vnn	6.35	−0.07	
113	2626	B9 IIIn	5.94	+0.01	225
118	2696	A5 Vn	5.18	+0.12	150
123	2772	B8 Vn	4.73	−0.10	
266	5408	B9 IVn	5.57	−0.09	178
283	5789	B9.5 Vn	5.70	−0.33	300
336	6829	A0 Vnn	5.29	−0.02	315
474	10161	B9 Vn	6.69	−0.08	
491	10425	B8 IIIn	5.78	+0.02	130
567	11946	A0Vn	5.26	+0.01	290
615	12885	B9 IV-Vn	6.15	−0.03	300
708	15130	B9.5 Vn	4.89	−0.03	230
809	17036	B9 Vn	5.77	−0.01	350
875	18331	A1 Vn	5.17	+0.08	300
893	18546	A0 Vn	6.41	−0.03	
932	19275	A2 Vnn	4.87	+0.02	
933	19279	A3 Vnn	6.41	+0.12	285
1037	21362	B6 Vn	5.57	−0.03	385
1038	21364	B9 Vn	3.73	−0.08	
1055	21610	A0 Vn	6.57	+0.03	190
1056	21620	A0 Vn	6.28	+0.08	230
1305	26670	B5 Vn	5.70	−0.14	
1315	26793	B9 Vn	5.22	−0.01	350
1392	28024	A8 Vn	4.30	+0.24	225
1477	29459	A5 Vn	6.22	+0.16	180
1479	29488	A5 Vn	4.70	+0.14	154
1494	29722	A1 Vn	5.29	0.00	195
1544	30739	A1 Vn	4.36	+0.01	212
1565	31209	A1 Vn	6.61	+0.04	250
1610	32040	B9 Vn	6.66	−0.07	350
1621	32309	B9.5 Vn	4.90	−0.04	237
1678	33296	A7 Vn	6.50	+0.21	290
1748	34748	B1.5 Vn	6.33	−0.10	280
1786	35407	B4 Ivn	6.32	−0.15	450
1798	35532	B2Vn	6.24	−0.07	
1806	35640	B9.5 Vn	6.23	−0.06	280
1863	36646	B4 Vn	6.46	−0.09	215
1989	38545	A3 Vn	5.72	+0.04	175
1997	38670	B9 Vn	6.07	−0.08	175
1998	38678	A2Vann	3.60	+0.05	245
2039	39421	A2 Vn	5.97	+0.10	215
2155	41695	A0 Vn	4.67	+0.06	250
2191	42477	A0 Vnn	6.04	0.00	335
2198	42545	B5 Vn	4.98	−0.17	310
2209	42818	A0 Vn	4.80	+0.03	220
2244	43445	B9 Vn	5.10	−0.08	235
2300	44783	B8 Vn	6.26	+0.08	300
2324	45230	A3 Vn	5.87	+0.08	250
2398	46553	A0 Vnn	5.27	−0.03	149
2441	47431	B8 IIIn	6.57	−0.07	
2521	49643	B8 IIIn	5.75	−0.10	
2585	50973	A2 Vn	4.90	+0.03	215
2589	51104	B8 Vn	5.92	−0.08	
2645	52860	B9 IIIn	6.39	−0.05	
2751	56169	A4 IIIn	5.05	+0.13	222
2753	56221	A5 Vn	5.87	+0.17	195
2757	56386	A0 Vn	6.19	+0.02	
2886	60107	A1 Vn	5.25	+0.05	163
2901	60357	A0 Vnn	5.81	−0.02	240
2946	61497	A3 IVn	4.99	+0.08	210
3008	62832	A1 Vnn	5.30	+0.01	
3039	63586	A0 Vn	6.38	−0.18	325
3134	65873	B9.5 Vn	5.99	−0.02	185
3492	75137	A0 Vn	4.36	−0.04	142
3594	77327	A1 Vn	3.60	0.00	185
3638	78702	A0/A1 Vn	5.73	0.00	205
3766	82165	A7 Vn	6.18	+0.23	
3846	83650	A0 Vn	6.31	−0.03	
3878	84567	B0.5 IIIn	6.45	−0.13	256
3889	85040	A7 IVn	6.09	+0.25	18
4000	88372	A2 Vn	6.25	+0.01	215
4024	88960	A0 Vn	5.51	+0.01	235
4172	92245	A0 Vn	6.04	0.00	235
4189	92769	A4 Vn	5.51	+0.17	195
4192	92825	A3 Vn	5.08	+0.09	154
4203	93152	A1 Vn	5.24	−0.06	
4368	98058	A7 IVn	4.50	+0.18	250
4372	98161	A3 Vn	6.27	+0.09	
4468	100889	B9.5 Vn	4.69	−0.06	192
4552	103192	B9 IIIpSi	4.28	−0.10	80

Table 2. The new Be stars

HR	$W(\alpha)$ (Å)	$FWHM$ (Å)	$\Delta\ V_{\rm peak}$ (Å)	$R_{\rm e}/R_*$
1056	01.88 ± 0.05	10.88 ± 0.15	8.83 ± 0.12	1.20 ± 0.10
1544	01.30 ± 0.04	06.22 ± 0.11	7.98 ± 0.10	1.23 ± 0.08
2191	02.30 ± 0.05	10.58 ± 0.16	8.70 ± 0.12	2.07 ± 0.16
2300	10.62 ± 0.13	09.56 ± 0.14	5.20 ± 0.07	3.62 ± 0.22
3134	01.26 ± 0.05	07.50 ± 0.12	4.10 ± 0.05	2.57 ± 0.19
3878	04.88 ± 0.07	16.00 ± 0.18	6.77 ± 0.09	2.00 ± 0.14
4552	01.81 ± 0.06	07.50 ± 0.12	6.05 ± 0.08	2.23 ± 0.17

Gaussian profile fitting, is 10.88 ± 0.15 Å. The peak separation between the blue and the red emission components is 8.8 ± 0.09 Å (∼402 km s^{-1}). Computed value of the emission disk radius is 1.2 times the stellar radius.

HR 1544, HD 30739 (A1Vn)

In the BSC, this star has been classified as a spectroscopic binary. Due to the superposition of H_α profiles of two stars of the binary system may appear as a single-peak emission at the absorption core of the line. However, in the case of HR 1544, the H_α profile displays double-peak emission at the core of this line which is very similar to the H_α profiles of classical Be stars. Also the observed velocity difference between the two absorption cores is about 505 km s^{-1} and this value is not consistent with the orbital parameters. The H_α profile (Fig. 2a) shows weak emission at both the wings that may not be clearly evident. To check this, we have compared the H_α profiles of HR 1544 (A1Vn and $v \sin i$ = 212 km s^{-1}) and HR 2155 (A1Vn and $v \sin i$ = 211 km s^{-1}) and they are shown in Fig. 2b. It can be clearly seen from the subtracted spectrum (shown on the upper part of Fig. 2b) that HR 1544 displays emission at H_α. Measured parameters of the H_α-emission profile and the computed value of the radius of the emission disk are presented in Table 2.

HR 2191, HD 42477 (A0Vnn)

The $v \sin i$ value of this star is given as 160 km s^{-1} in the BSC. However, we have measured this value as 355 km s^{-1}, using Eq. (1) and the $FWHM$ value of the He I (6678 Å) line of this star. This computed value of $v \sin i$ is in good agreement with that computed using the $FWHM$ value of He I line profile of 5876 Å. The observed velocity difference between the two absorption cores is about 670 km s^{-1}. This value indicates that the weak emission is not due to the superposition of two absorption line stars. The double-peak emission of H_α separated by a strong absorption component may be due to the shell absorption. The measured values of $W(\alpha)$, $FWHM$, $\Delta V_{\rm peak}$ and the computed value of $R_{\rm e}/R_*$ are presented in Table 2.

HR 2300, HD 44783 (B8Vn)

The revised value of $v \sin i$ (300 km s^{-1}) of this star is taken from the remarks part of BSC. Also our computed value of $v \sin i$, using the measured $FWHM$ value of He I (6678 Å), is in close agreement (~310 km s^{-1}) with this value. Strong double-peak H_α-emission profile is separated by an absorption component. The radius of the emission disk is almost four times the radius of this star. Table 2 shows the measured parameters of the emission profile of H_α.

HR 3134, HD 65873 (B9.5 Vn)

This star is a spectroscopic binary with radial velocity of about −12 km s^{-1} (BSC). The rotational velocity of this star is 185 km s^{-1}. The double-peak emission of H_α suggest that this emission is not due to the superposition of two H_α absorption profiles of the binary system. Also the observed velocity difference between the two absorption cores is very high (~450 km s^{-1}). Even though the emission is weak, but the radius of the emission disk is almost three times the radius of the star.

HR 3878, HD 84567 (B0.5 IIIn)

The $v \sin i$ value of this star is not available in the BSC. Also the SIMBAD database does not contain any information about the $v \sin i$ value of this star. We computed the value of $v \sin i$ using the $FWHM$ value of He I (6678 Å) profile and the computed value is 255 km s^{-1} (Table 2). H_α profile of HR 3878 displays two broad emission components with an central absorption that is similar to quasi-reversal H_α profiles of classical Be stars. From Table 2 it can be seen that the $FWHM$ value of the H_α profile (after photospheric correction and interpolation) is about 731 km s^{-1} (16.0 Å). This indicates that probably the projected rotational velocity of this star may be larger than that we have computed ($v \sin i \sim 255$ km s^{-1}). Future high resolution line profile of He I(4471 Å) may help to resolve this problem.

HR 4552, HD 103192 (B9IIIpSi)

HR 4552 is not a Bn/An star. We observed this star as a standard star. The H_α profile of this star (Fig. 2a) shows clear double-peaked emission with strong shell absorption, embedded within the photospheric absorption line. The $v \sin i$ value of HR 4552, given in BSC, is about 72 km s^{-1}. We have also computed the value of $v \sin i$ using the $FWHM$ value of He I line (5876 Å) and our computed value is close to this value. However, using the $FWHM$ value of the H_α-emission profile, the computed value of $v \sin i$ is about 206 km s^{-1}. We have used this value of $v \sin i$ to compute the value of R_e/R_* and it is given in Table 2. The BSC lists this star as a double star and the second star is separated by 0.8″ with a magnitude difference of $0^{\rm m}_{.}9$.

It may be possible that the seven newly detected early-type emission-line stars, mentioned above, might have already been detected as emission-line stars. To check this, we have searched the SIMBAD database and found that no emissions have yet been detected in these seven stars. Spectral types of these seven stars are between B0.5 and A1. However, except one star (HR 3878 − B0.5IIIn) all the six stars have spectral types of B8 or later. These B and A-type emission-line stars may be called as Be and Ae stars. Some of these Be and Ae stars may also be Herbig Ae/Be stars. To find out whether these stars belong to Herbig Ae/Be stars group or not, we have looked for IRAS (12 μ, 25 μ, 60 μ) fluxes associated with these seven stars. We have found from the IRAS point source catalogue (Beichman et al. 1988) that only two stars of these seven stars, were detected with IRAS (HR 1544 − IRAS 04478+0848 and HR 4552 − IRAS 11503 − 3337) and this was also confirmed with the search results of the SIMBAD database. 12 μ, 25 μ and 60 μ fluxes of HR 1544 and HR 4552 and another 20 known Be stars were converted into magnitudes using the IRAS definition for the zero-magnitude. [12] − [25] color versus [12] − [60] color of Be stars and HR 1544 and HR 4552 were plotted and it has been found from this plot that HR 1544 and HR 4552 were occupying the same position as that of the Be stars in this color-color diagram. Also we plotted the (V − 12 μ) color excess versus temperature of HR 1544 and HR 4552 and compared with the Fig. 4 of Hillenbrand et al. (1992) and find that these two stars lie in a region where the Be stars are located and the Herbig Ae/Be stars lie much above the Be stars, in this diagram. Based on these results we suggest that probably these two stars do not belong to the Herbig Ae/Be stars group. Also, based on only the H_α profiles and non-detection with IRAS, it is difficult to make any comment about the Herbig Ae/Be associationship of the rest five stars (HR 1056, HR 2191, HR 2300, HR 3134 and HR 3878). Presently, we will call these seven newly detected emission-line stars as Be stars, following the definition of Be stars (rapidly rotating O, B and A-type stars of luminosity classes III-V with Balmer emission lines are known as Be stars; details can be seen in Underhill & Dozan 1982).

Presence of He I line (either 5876 Å or 6678 Å) was detected in all the stars that are listed in Table 2, except HR 1544. It may be interesting to find out whether any of these stars be Bp He-weak or He-strong. This can be checked from the He abundance measurements. High-resolution and high signal-to-noise ratio line profiles of He I (4471 Å) which is a photospheric line, are required to compute the He abundance. With our present data (He I lines of 5876 Å or 6678 Å) it may not be possible to draw any such conclusion.

Close inspection of H_α-emission profiles of these seven stars indicates that probably three of these stars may be Be-shell stars (HR 1544, HR 2191 and HR 4552).

4. Conclusion

From a survey of spectra of 82 Bn and An stars (33 Bn stars and 49 An stars) we have detected seven new H_α emission-line stars. Detection of these seven new Be stars will be useful to compute the frequency distribution of Be stars among the main-sequence B and A stars of the BSC. Among these seven Be stars, two have been detected as IRAS sources (HR 1544 and HR 4552). Three of these seven stars may be possible Be-shell stars (HR 1544, HR 2191 and HR 4552).

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