Searching for Classical Be Stars from LAMOST DR1

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Abstract We report on searching for Classical B-type emission-line (CBe) stars from the first data release (DR1) of the Large Sky Area Multi-Object fiber Spectroscopic Telescope (LAMOST; also named the Guoshoujing Telescope). A total of 192 (12 known CBes) objects were identified as CBe candidates with prominent He I λ 4387, He I λ 4471, and Mg II λ 4481 absorption lines, as well as H β λ 4861 and H α λ 6563 emission lines. These candidates significantly increases current CBe sample of about 8%. Most of the CBe candidates are distributed at the Galactic Anti-Center due to the LAMOST observing strategy. Only two of CBes are in the star clusters with ages of 15.8 and 398 Myr, respectively.

Key words: stars: emission-line, Be, stars: early-type, open clusters and associations: general

1 INTRODUCTION

Classical Be stars (CBes) are non-supergiants B-type stars symbolized by Balmer series, mostly emit at $H\alpha \ \lambda 6563$ and $H\beta \ \lambda 4861$ lines. Apart from the emission phenomenon, CBes have fast rotation with an equatorial speed up to 70 - 80% of breakup velocity (Porter & Rivinius 2003). CBes exist not only in young or intermediate age star clusters but also isolated in the field. In the past, the astronomers concentrated on analysis of the properties of bright CBe with their individual observational data. Nowadays, large sky photometric surveys have made it possible to study homogeneously and completely of CBes, e.g., Zhang et al. (2005) analyzed the infrared color of 1185 CBes stars with the 2MASS (Cutri et al. 2003) data. Raddi et al. (2015) present a catalogue of 247 photometrically and spectroscopically confirmed CBes in the direction of the Perseus Arm of the Milky Way from the IPHAS (Drew et al. 2005). Furthermore, Chojnowski et al. (2015) discovered 128 new CBes and increased the total number of known CBe sample by ~ 6% from SDSS-III/APOGEE (Eisenstein et al. 2011, Majewski 2012).

Recently, the Be Star Spectra database (BeSS¹) with no more than 3000 CBes was created by Neiner et al. (2011), in order to collect all existing and future Be star spectra for the statistical studies in the Be star community. However, the sample of CBes remains inhomogeneous because the wide-field spectroscopic observations are time consuming and often limited to bright stars. On the other hand, the sample of CBes is incomprehensive due to the insufficient information of ages or distances. With a large field of view and the highest spectral acquisition rate, the Large Sky Area Multi-Object Spectroscopic Telescope (LAMOST) survey thus provides us an excellent opportunity to conduct a systematic survey for CBes.

We report on a search of CBes from the LAMOST First Data Release, hereafter LAMOST DR1. We have developed an algorithm to identify CBes, and visually inspected their spectra for confirmation. In Section 2, we described the acquisition of the observations and the methodology of recognizing H α emission stars. In Section 3, we discuss the results and give a summary of this study in section 4.

¹ http://basebe.obspm.fr

2 THE DATA AND SEARCHING METHODOLOGY

The major dataset used for this study was from the LAMOST DR1. Additionally, the 2MASS point source catalog has also been used to supplement the photometric analysis.

2.1 The LAMOST DR1

The LAMOST², also named the Guoshoujing Telescope, is a quasi-meridian reflecting Schmidt telescope located at Xinglong Observing Station in the Hebei province of China. The telescope has an effective aperture of 3.6–4.9 m, and a field of view of about 5° in diameter. A total of 16 low-resolution spectrographs, 32 CCDs, and 4000 fibers are mounted on the telescope. Each spectrograph has a spectral resolution of $R \sim 1800$ in the wavelengths ranging from 3700 Å to 9000 Å (Cui et al. 2012; Zhao et al. 2012).

The LAMOST DR1 includes more than two million spectra with a limiting magnitude of $r \sim$ 18.5 mag that are obtained from the pilot survey and first year general survey (Luo et al. 2012; Luo et al. 2015). The LAMOST DR1 also has stellar catalogs of about 1.2 million spectroscopically classified stars with their atmospheric parameters such as radial velocities, effective temperatures, surface gravities, and metallicities. About a quarter of million stars are somehow un-classified or not well-classified, which might be due to the interstellar extinction at the short wavelength range resulting the fitting failure in the LAMOST DR1. In order to identify a large sample of CBe candidates, we analyzed the whole LAMOST DR1 dataset with the mean signal-to-noise ratio $SNR \ge 10$.

2.2 The Search Algorithm

The major indicator of a B-type star is the set of hydrogen Balmer absorption lines and in conjunction with some neutral helium (He I) absorption lines or an ionized magnesium (Mg II) absorption line. CBes in particular feature hydrogen emission lines mostly at H α and H β , but fade through the rest of the Balmer series. Therefore, we focus on searching for stars with prominent He I λ 4387, He I λ 4471, and Mg II λ 4481 absorption lines, as well as those with H β λ 4861 and H α λ 6563 emission lines.

To quantify these line indexes, we calculated the equivalent width (EW_{λ}) of each line by the following equation

$$EW_{\lambda} = \int 1 - f_l / \bar{f}_c \, d\lambda,\tag{1}$$

where f_l is the flux of each line and \bar{f}_c is the average of local pseudo-continuum estimated within 140 Å width at each line. The integration range covered a width of 10 Å. The empirical line EW_{λ} of known CBes observed by the LAMOST are estimated and summarized in Table 1. The CBe candidates are required to be satisfied with the similar EW_{λ} of known CBes at He I λ 4387, He I λ 4471, and Mg II λ 4481 lines and those with EW_{λ} less than 0.33 Å and 0.50 Å at H β λ 4861 and H α λ 6563 lines, respectively.

To rule out contamination of B[e] or Herbig Ae/Be stars, the CBe candidates are also required to have the similar colors of known CBes. We defined a "Be region" with J - H versus $H - K_s$ colorcolor diagram. The Be region could cover most Be stars that were collected from the literatures (Zhang et al. 2005). As shown in Figure 1, gray contours represent over 1000 known CBes. Assuming that most CBes have similar infrared colors, we thus could select CBe candidates inside the gray-dotted region in the color-color diagram. From the LAMOST DR1, we finally identified 192 CBe candidates. Among these candidates, 180 are newly discovered CBe candidates and 12 are known CBes. Figure 2 demonstrates one example of the CBe candidates with the H α emission line, a very weak emission superposes on the H β absorption line, and He I λ 4387 and He I λ 4471 absorption lines.

² http://www.lamost.org/

3 RESULTS AND DISCUSSION

Although there are more than 3000 CBes that have been presented by previous studies (Neiner et al. 2011; Zhang et al. 2005; Raddi et al. 2015), only 23 CBes were cross-matched in the LAMOST DR1. Among these observed CBes, 12 ones are re-identified. Some CBes are not re-identified due to low SNR (5 stars) and poor calibration (4 stars). Another un-identified known CBe K03, also named GSC 02342-00359, is a young stellar object and classified to be an F0-G4 star in NGC 1333 with large reddening as seen in Figure 1 (Liu et al. 1980). The reason may imply to the H α variability of CBes so that we probably could not identify its H α emission line phenomenon at certain epoch (Rivinius et al. 2013). There is only one known CBe K10, missed to be re-identified because of the weak Mg II absorption. Therefore, excluding the spectra with poor calibration and low SNR, the detection rate of CBes is about 85%. The known CBes are listed with the 2MASS magnitudes in Table 2 and some bright (J < 9 mag) CBes with matched radii larger than 5" are listed below the star K13.

The new CBe sample significantly increases about 8% of current sample. The CBe candidates are listed with the 2MASS magnitudes in Table 3 and the SIMBAD³ objects are noted in the last column. Although some of these candidates have been identified as emission line stars by Kohoutek & Wehmeyer (1997)⁴, the spectral types were not yet confirmed until the LAMOST observations. The spatial distribution of CBe candidates from LAMOST DR1 is shown in Figure 3. Most of CBe candidates were found along the Galactic plane that is similar to the trend seen in previous studies. And CBe candidates are more concentrated toward the Galactic Anti-Center because of the observing strategy.

The distance and age of CBes can be determined if they are members of star clusters. Using the method of membership identification presented by Yu et al. (2015) that is based on photometric isochrone, spatial distribution, and proper motions, we found that only two CBes are the member of open clusters. The CBe L032 is a member of open cluster Kronberger 18 with an age of \sim 15.8 Myr and with a distance of 2700 pc (Kharchenko et al. 2013). The other CBe L056 is a member of open cluster FSR 1025 with an age of \sim 398 Myr and with a distance of 2095 pc (Kharchenko et al. 2013). The upper limit of the CBes age thus extends to 398 Myr which is older than the previous studies by McSwain & Gies (2005).

4 SUMMARY

We report on a search for CBes from the LAMOST DR1. A total of 192 (12 known CBes) objects were identified as CBes with prominent He I λ 4387, He I λ 4471, and Mg II λ 4481 absorption lines, as well as H β λ 4861 and H α λ 6563 emission lines. These candidates significantly increased current CBe sample of about 8%. Most of the CBe candidates are distributed at the Galactic Anti-Center due to the LAMOST observing strategy. Only two CBe candidates, L032 and L056, were found to be the memberships of the star clusters with ages of 15.8 and 398 Myr, respectively.

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³ http://simbad.u-strasbg.fr/simbad/

⁴ http://www.hs.uni-hamburg.de/DE/Ins/Per/Kohoutek/index.html

Table 1 Empirical EW_{λ} of Known CBes in LAMOST

Line	EW_{λ} (Å)
He I $\lambda 4387$	0.387 ± 0.185
He I $\lambda 4471$	0.663 ± 0.265
Mg II $\lambda 4481$	0.291 ± 0.141
$\check{H}\beta \lambda 4861$	< 0.33
$H\alpha \lambda 6563$	< 0.50

 Table 2
 23 Known CBes Observed in the LAMOST DR1

ID	DR1 index	Designation 2MASS	J mag	ΔJ mag	H mag	ΔH mag	K_s mag	ΔK_s mag	Remark
K01	558648	J063259.37+045622.5	9.158	0.027	9.158	0.036	9.087	0.032	detected
K02	356675	J035358.25+465351.8	9.287	0.022	9.049	0.028	8.826	0.023	detected
K03	1542080	J032910.40+312159.2	9.368	0.030	7.987	0.031	7.173	0.023	variant
K04	555829	J063337.49+044847.0	9.395	0.024	8.946	0.023	8.644	0.023	poor calibrated
K05	567874	J052314.90+374253.6	9.644	0.020	9.582	0.015	9.475	0.015	detected
K06	500325	J051502.46+364155.0	9.971	0.020	9.828	0.019	9.737	0.018	low SNR
K07	436313	J035447.92+445619.6	10.318	0.022	10.218	0.030	10.000	0.023	detected
K08	1752150	J055554.66+284706.3	10.966	0.036	10.914	0.033	10.872	0.027	detected
K09	589106	J063129.76+045449.1	11.449	0.024	10.887	0.025	9.690	0.021	low SNR
K10	588035	J063241.74+045338.4	11.927	0.021	11.822	0.025	11.664	0.024	missed
K11	1745288	J060559.66+280247.7	12.023	0.021	11.341	0.020	11.208	0.018	poor calibrated
K12	510383	J044927.22+450443.8	12.284	0.020	12.083	0.021	11.873	0.018	low SNR
K13	1556719	J051427.40+324756.8	13.802	0.030	13.177	0.025	12.906	0.031	poor calibrated
K14	1718553	J051214.46+411300.8	6.373	0.024	5.896	0.033	5.621	0.016	poor calibrated
K15	587291	J063354.40+043935.2	6.996	0.020	6.945	0.040	6.866	0.023	detected
K16	1768331	J070534.82+142831.7	7.156	0.020	7.220	0.024	7.238	0.024	detected
K17	589139	J063259.01+054756.6	7.640	0.023	7.390	0.049	6.966	0.020	low SNR
K18	638021	J151811.89+313849.2	7.907	0.020	7.713	0.031	7.706	0.016	detected
K19	1749404	J054853.75+290801.7	7.959	0.024	8.015	0.047	8.035	0.029	detected
K20	1496502	J075704.21+025655.6	8.020	0.034	7.917	0.061	7.806	0.024	detected
K21	1620649	J062404.17+252508.1	8.042	0.024	7.916	0.016	7.752	0.018	low SNR
K22	321794	J044440.68+503202.1	8.123	0.020	7.956	0.023	7.865	0.020	detected
K23	447292	J065513.76+052554.4	8.293	0.024	8.425	0.047	8.440	0.021	detected

Notes: The K14-K23 are matched from the 2MASS point source catalog with radii larger than 5".

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Fig. 1 The 2MASS color-color diagram. The black dashed lines show the giant (upper) and dwarf (lower) loci (Bessell & Brett 1988) converted to the 2MASS system. The arrow represents the reddening direction (Rieke & Lebofsky 1985) for typical Galactic interstellar extinction (RV = 3.1). The gray contours demonstrate known CBes distribution, and the dotted-box is defined as Be region to include most of CBes. The black crosses are CBe candidates. The known CBes are marked with white asterisks and grey filled circles for identified and unidentified, respectively.

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Fig. 2 A spectrum of one newly found CBe in LAMOST DR1. The flux in upper panel is relative flux. Blue dashed lines indicate the Balmer series, and red dashed lines represent some major lines. The lower panel shows normalized spectra with respect to the pseudo-continuum. Color version can be seen online.

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This paper was prepared with the RAA LATEX macro v1.2.



Fig. 3 The spatial distribution of CBes. The small gray dots are known CBes from Zhang et al. (2005), Neiner et al. (2011), and Raddi et al. (2015). The large dots are the LAMOST CBe candidates. The Galactic Center/Anti-Center and Magellanic Clouds are marked.

	Table 3	CBe	Candidates
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ID	Designation	J	ΔJ	Н	ΔH	K_s	ΔK_s	SIMBAD
	6	mag	mag	mag	mag	mag	mag	
L001	J043131.26+475750.7	9.062	0.027	8.721	0.015	8.435	0.019	EM* MWC 474, Em*
L002	J043953.63+540146.1	9.102	0.021	8.867	0.015	8.598	0.014	BD+47 1000, Em*
L003	J062753.84+003329.1	9.145	0.029	9.010	0.023	8.814	0.021	HD 291668
L004	J054520.88+290928.1	9.164	0.022	9.165	0.021	9.150	0.017	HD 247042
L005	J052948.83+373100.0	9.176	0.024	9.098	0.032	9.018	0.022	BD+37 1207, Em*
L006	J050543.34+353110.7	9.181	0.023	9.068	0.031	8.861	0.023	HD 280498, Em*
L007	J063131.81+053051.7	9.416	0.023	9.285	0.022	9.057	0.021	HD 258983, Em*
L008	J044324.22+542816.5	9.471	0.021	9.119	0.015	8.891	0.021	TYC 3737-1292-1
L009	J054538.09+185753.7	9.508	0.021	9.500	0.024	9.484	0.022	HD 247221, Em*
L010	J064433.60+045757.7	9.669	0.023	9.532	0.021	9.264	0.019	HD 263072, Em*
$L032^{1}$	J065029.43+063621.0	10.453	0.026	10.404	0.023	10.328	0.023	TYC 160-841-1
$L056^{2}$	J051841.29+374030.0	10.975	0.019	10.966	0.028	10.946	0.026	HD 280870, Em*
 T 171								
L171	J053549.34+271917.2	14.988	0.036	14.574	0.049	14.451	0.063	new
L172	J003135.88+434905.3	15.252	0.044	15.185	0.087	15.111	0.123	V* HQ And, Nova
L173	J065742.53+175352.4	15.302	0.067	15.158	0.114	15.197	0.140	new
L174	J004339.36+411008.6	15.616	0.072	15.395	0.107	15.343	0.166	[HIB95] 29-13
L175	J003720.64+401637.6	15.745	0.068	15.486	0.126	15.374	0.196	new
L176	J004510.03+413657.6	15.766	0.070	15.636	0.122	15.562	0.177	new
L177	J052416.11+331819.9	15.803	0.073	15.363	0.103	15.006	0.140	new
L178	J004623.13+413847.4	15.829	0.064	15.697	0.128	15.602	0.170	LGGS J004623.14+413847.5
L179	J052432.28+332654.3	15.916	0.086	15.364	0.085	15.145	0.170	new
L180	J013420.91+303039.6	15.989	0.066	15.887	0.147	15.847	0.209	LGGS J013420.95+303039.9
Notes:								

1. a member of the open cluster FSR 1025

2. a member of the open cluster Kronberger 18