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A Spectroscopic Study of Blue Stragglers in M67

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Abstract. Spectrophotometric observations of the complete sample of twenty four blue stragglers (BSs) in the old galactic open cluster M67 (NGC2682) have been collected, using the Guillermo Haro Observatory in Cananea, Mexico. All the calibrated spectra were re-calibrated by the Beijing Arizona Taipei Connecticut (BATC) photometric system which includes fluxes in 11 photometric bands covering ∼3600–10000 Å. The goal of the current work is to provide observational constraints on spectral properties of BSs by determining the effective temperature ($T_{\rm eff}$) and surface gravity ($\log g$). The overall results, obtained by applying the flux fitting method, indicate that $T_{\rm eff}$ and surface gravities of BSs in M67 are fully compatible with those expected for main sequence stars.

Keywords. Stars: blue stragglers – Stars: Hertzsprung-Russell (HR) diagram – Galaxy: open clusters and associations: individual: M67

1. Introduction

BSs were first discovered in the globular cluster M3 by Sandage (1953). They lie above the turn off point of main sequence as a brighter and bluer extension of cluster's main sequence and appear to straggle away from their regular evolutionary processes, hence their name *blue stragglers*. Through decades of research since their discovery, blue stragglers are widely observed in almost all kinds of stellar systems, such as open clusters, galactic halo and even dwarf galaxies (Stryker 1993).

Nowadays, based on observational and theoretical studies, it is generally believed that the popular formation ways of blue stragglers are all correlated with interactions between stars, such as stellar collisions in high density and mass transfer in close binaries (Ahumada 1999; Bacon *et al.* 1996; Ferraro *et al.* 1997; Gilliland *et al.* 1992; Leonard 1989; Livio 1993; Ouellette & Pritchet 1998; Piotto *et al.* 1999; Stryker 1993; Tian *et al.* 2006). Due to their peculiar nature, it is very important to study BSs, because in a stellar population they are among the most massive and luminous stars, whose contribution to the integrated light of their host stellar systems could not be predicted by the standard theory of stellar evolution (Bressan *et al.* 1993). In fact, BSs greatly affect the spectral energy distribution (SED) of the whole population, particularly at ultraviolet and blue wavelengths (Deng *et al.* 1999; Manteiga *et al.* 1989; Xin *et al.* 2007, 2008).

However, in spite of many investigations, a conceivably definite explanation of the BS phenomenon has not been reached. Generally, they are historically regarded as core

Table 1. The blue straggler population of M67.

Name	R.A. (2000)	Dec. (2000)	ExpTime (s)	n
BS005	8:51:11.78	11:45:22.24	2400	4
BS018	8:52:10.75	11:44:06.07	1200	2
BS025	8:51:27.04	11:51:52.22	1200	3
BS029	8:51:48.65	11:49:15.36	2400	4
BS034	8:51:34.31	11:51:10.23	2400	4
BS038	8:51:32.61	11:48:52.02	1200	2
BS040	8:51:26.45	11:43:50.75	1200	2
BS043	8:51:14.37	11:45:00.70	2400	4
BS046	8:51:20.82	11:53:25.65	2400	4
BS047	8:51:03.52	11:45:02.68	1200	2
BS065	8:51:21.77	11:52:38.00	2400	4
BS093	8:51:32.57	11:50:40.42	1200	2
BS111	8:51:19.92	11:47:00.50	1500	2
BS115	8:51:37.72	11:37:03.54	1200	2
BS116	8:50:55.70	11:52:14.50	2400	4
BS126	8:49:21.49	12:04:23.00	1200	2
BS131	8:51:28.40	12:07:38.30	1200	2
BS139	8:51:39.24	11:50:03.66	1500	2
BS143	8:51:21.25	11:45:52.63	1200	2
BS182	8:51:15.47	11:47:31.74	1800	2
BS184	8:50:47.69	11:44:51.33	3300	4
BS185	8:51:28.17	11:49:27.06	3000	4
BS206	8:48:59.84	11:44:51.66	600	1
BS216	8:51:20.59	11:46:16.36	1500	2

hydrogen burning stars (Benz & Hills 1987, 1992) and it has been usually assumed that the spectral properties of BSs are compatible with those of main sequence stars at the same loci on the CMD. However, whether or not the spectral properties of BSs can be actually represented by main sequence objects, has not yet been fully investigated. Our goal is to provide observational constraints on spectral properties of BSs by determining the effective temperature and surface gravity.

2. Observations and reductions

Our working sample is 24 BSs in M67, which have nearly 100% membership probabilities as determined with both proper motion and radial velocity observations (Girard *et al.* 1989; Sanders 1977). The catalog is shown in Table 1, where we give, in columns (1) to (5), the BSs identification numbers from Fan *et al.* (1996), the equatorial coordinates, the integrated exposure times, and the number of spectra collected for each object. Observations were carried out during a three-night run in February 2005, using the 2.12 m telescope of the Guillermo Haro Observatory at Cananea, Mexico. The spectra were at a low-resolution of 3.2 Å per pixel with wavelength coverage roughly from 3600 to 6900 Å. For the data reduction we followed the standard procedures using IRAF packages. The flux calibrated spectra were subsequently re-calibrated by using photometric magnitudes in the Beijing-Arizona-Taipei-Connecticut (BATC) system (Deng *et al.* 1999). The BATC system includes 15 intermediate-band filters covering the interval 3500–10000 Å.

Figure 1 shows the observed spectral energy distribution (SED) of the BSs. The spectra are roughly ordered in a temperature sequence decreasing from top to bottom. Vertical dotted lines indicate the location of four major spectral features, namely, H_α (6562 Å), H_β (4860 Å), H_γ (4340 Å), and Ca_K (3933 Å).

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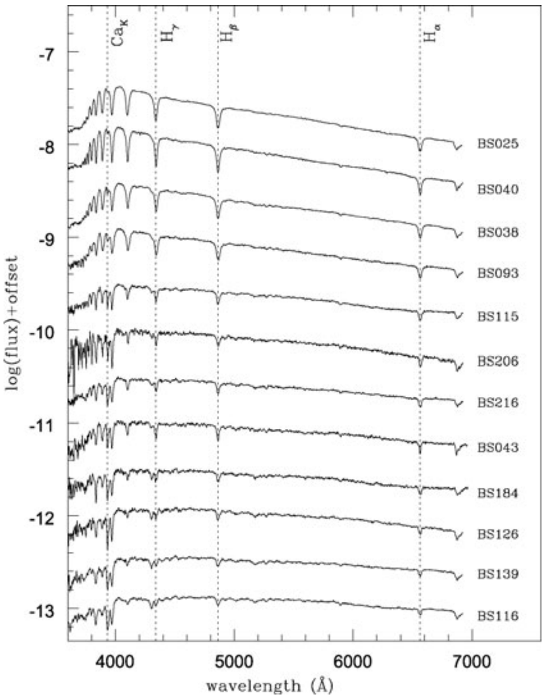

Figure 1. The relative flux-calibrated spectra of BSs. The spectra are roughly ordered in a temperature sequence decreasing from top to bottom.

3. Spectral fitting and analysis

We applied the flux fitting method to determine the effective temperature and surface gravity of our sample stars. For this task, we made use of three different spectral libraries, both observed and theoretical, namely, the Pickles (1998) empirical library, the Lejeune *et al.* (1997, 1998) data set (which is mainly based on Kurucz grid of low resolution fluxes), and the high resolution BLUERED theoretical library (Bertone *et al.* 2004, 2008). In all cases, we assumed a solar chemical composition for BSs (Bressan & Tautvaišiene 1996, Hobbs & Thorburn 1991). Each calibrated spectrum was compared to every entry from the spectral atlases. The algorithm we have applied finds the spectrum that produced the minimum standard deviation σ of the flux residuals, computed at each λ point.

Figure 2 presents the best fits for two representative BSs, BS038 and BS139. The smaller panels below each spectrum correspond to the residuals between observed and theoretical spectra, and dotted lines indicate the loci of 3σ values. The model spectra very well reproduce the observed ones, except at blue and ultraviolet wavelengths, where discrepancies can be ascribed to uncertainties associated to both observational and theoretical spectra.

The results for the full stellar sample are reported in Table 2, where columns (1)–(7) list, respectively, the object ID, the parameter pairs ($T_{\rm eff}$, $\log g$) and the identification numbers of Sanders (1977), for easing cross identification. Note that effective temperatures derived from the data sets are in good agreement (the discrepancy is of the order of a few percent, apart from the BLUERED estimate of BS005, which is significantly lower). The same is true for the surface gravities, which closely match the luminosity classes, when comparing the results from the two low-resolution libraries; the $\log g$

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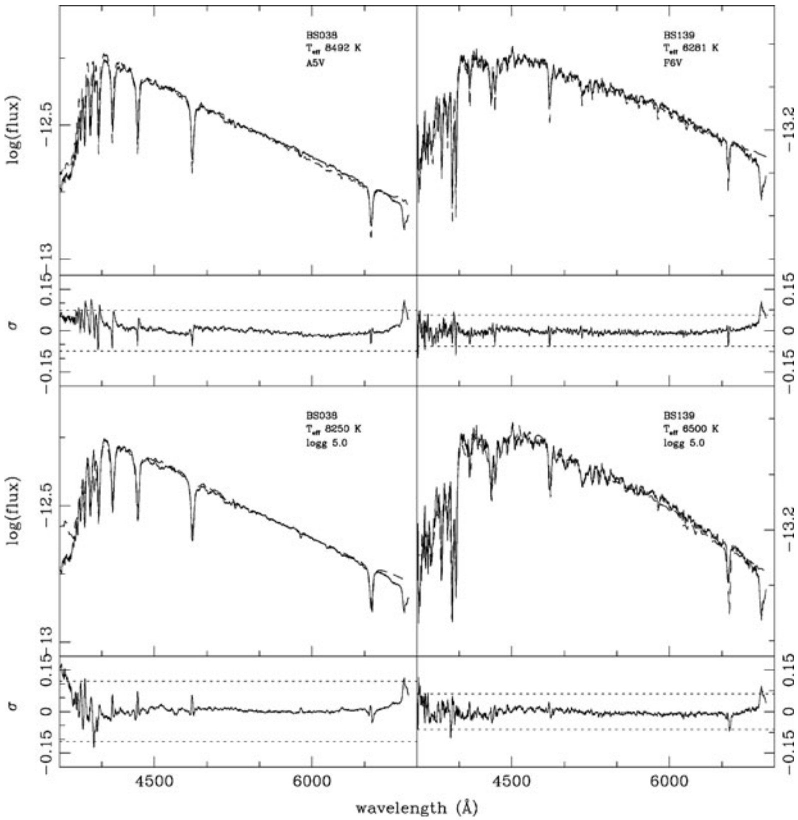

Figure 2. Best fits for two representative BSs, BS038 and BS139. Solid lines and dashed lines indicate, respectively, the observed spectra and the best fitting reference ones from the Pickles spectra (top panels) and the Lejeune *et al.* library (bottom panels).

estimates from BLUERED are sistematically a bit higher. The overall results indicate that BSSs in M67 span a wide range in $T_{\rm eff} \sim 5600 - 12600$ K and surface gravities that are fully compatible with those expected for main sequence objects ($\log g = 3.5 - 5.0$ dex).

There are eight binary candidates in our sample as revealed by other people previous observations. BS029 (S1267), BS043 (S975), BS047 (S752), BS111 (S997), and BS115 (S1195) were identified as spectroscopic binaries with long periods. BS034 (S1284) has been considered as a BS in its final stage of mass transfer with a white dwarf companion. BS046 (S1082) was detected to be a complex unusual eclipsing binary system, or even a triple system, whose SED could be explained by the sum of a close binary and another main sequence star. BS184 (S1036) is observed as a W UMa type binary with small amplitude light variations.

Even though the limited resolution of the observations prevents us from corroborating their binary nature, our analysis demonstrates that both spectral libraries provide equally good fits for single and binary objects.

4. Conclusions

Low resolution spectra of the complete sample of 24 blue stragglers in the old galactic open cluster M67 (NGC2682) has been collected. The whole data set was implemented

Table 2. Parameters derived from fittings.

Name[a]	BATC-Pickles $T_{\rm eff}$ (K)	Sp.Type	BATC-Lejeune $T_{\rm eff}$ (K)	log g (dex)	BATC-BLUERED $T_{\rm eff}$ (K)	log g (dex)	S^b
BS005	12589	B6IV	12625	5.00	11050	3.1	977
BS018	8790	A3V	8500	4.50	8500	4.0	1434
BS025	8492	A5V	8500	4.25	8950	5.0	1066
BS029*	8054	A7V	7813	4.38	8100	5.0	1267
BS034*	8054	A7III	7688	4.38	7900	5.0	1284
BS038	8054	A7III	7750	4.00	8050	5.0	1263
BS040	8790	A3V	8625	4.75	8450	4.2	968
BS043*	6469	F5V	6500	3.50	6700	4.7	975
BS046*	6776	F2V	6625	3.88	6850	4.7	1082
BS047*	7586	F0III	7250	4.00	7500	4.8	752
BS065	5636	G2V	5750	3.50	6000	4.2	1072
BS093	7586	F0III	7625	4.25	7800	5.0	1280
BS111*	6281	F6V	6500	3.50	6600	4.6	997
BS115*	6776	F2V	7000	4.25	7050	4.7	1195
BS116	6039	F8V	5938	3.75	6150	4.5	792
BS126	6281	F6V	6250	3.50	6450	4.8	277
BS131	6776	F2V	6875	4.75	6950	4.7	1273
BS139	6039	F8V	6000	3.50	6200	4.6	984
BS143	6039	F8V	6000	3.50	6100	4.1	1005
BS182	6281	F6V	6250	4.00	6500	4.7	751
BS184*	6281	F6V	6375	4.25	6500	4.6	1036
BS185	6531	F5V	6438	4.00	6700	4.7	145
BS206	6776	F2V	6750	4.50	6900	4.7	2204
BS216	6531	F5V	6500	4.50	6700	4.7	2226

NOTE: a, stellar identification from Fan *et al.* (1996); b, Sanders number (Sanders 1977); *, binary population.

for a comparison with three different stellar atlases aimed at determining the effective temperature and surface gravity. All objects have effective temperature and surface gravity values in agreement to the expected values for objects in the hydrogen-burning stage (see details in Liu *et al.* 2008). Therefore, in terms of spectral properties, blue straggles can indeed be represented by empirical or theoretical data of main sequence stars independently of the distinctive formation mechanisms and different physical nature.

Limited by the spectral resolution of the current observational data set, it is not possible to assess binarity and the formation mechanism of the sample of BSs in M67. We anticipate that a detailed chemical abundance analysis at high resolution for the sample will show signatures of these dynamical and physical processes.

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Discussion

Fernandes: Why do you think that the database of Lejeune (that was built to “normal” stars) can be used for BS stars?

Liu: The formation mechanism and evolutionary state of BSs are not clear, limited by few spectral observations. BSs’ loci on CMD (above turn off point and as an extension of main sequence) indicate that the spectral properties of BSs could be similar with normal main sequence stars. So, it could be worthy to test spectral properties of BS with Lejeune spectra.

Langer: Could you constrain the He-abundance from the colours derived from your observations?

Liu: We could not do this based on current low resolution observation. We anticipate that a detailed chemical abundance including He-abundance analysis at high resolution for the sample will be good for this purpose.

STEPIEN: Could you see any signatures of binarity among the observed stars?

LIU: Limited by the spectral resolution of the current observational data, no firm conclusion of binarity can be draw.

POLS: Can you obtain any constraints on the abundances (e.g. the He abundance) from your spectra? To have such information for a complete sample of blue stragglers could be very interesting.

LIU: Yes, I also think the abundance information of BSs is interesting. But our observations are made in low resolution which does not allow abundance determination.