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THE BLUE STRAGGLERS IN M67 AND SINGLE-POPULATION SYNTHESIS

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ABSTRACT

Based on the photometry of the classical open cluster M67 and the thorough membership survey, we made a color-magnitude diagram (CMD) of high-membership stars for the cluster. Apart from the stars fitted by a conventional isochrone (single-star evolutionary model) scheme, we noticed a number of features on the CMD that are usually ignored when constructing the corresponding *single stellar population* (SSP), especially the large number of blue stragglers. As for the study of the integrated properties of SSPs, we argue that the contributions from all ingredients in a single population of stars, such as the luminous blue stragglers, should be included. These bright blue objects may modify remarkably the spectral energy distribution (SED) in the blue and ultraviolet. In this paper we investigate their effects on the integrated light of single stellar populations. We will show in this work that, by using the observation of M67 in a multicolor intermediate-band system, we can assign adequate theoretical spectra to individual stars. The integrated spectrum of this cluster is dramatically different from the SSP built using isochrones only, which shows increasing enhancement toward shorter wavelengths (starting from about 5000 Å) of the spectrum. Taking this as a general case for SSPs, we can expect a considerable amount of modification to the integrated SEDs, which might cast new light on the analysis of the stellar content in the complex stellar systems.

Subject headings: blue stragglers — open clusters and associations: individual (M67) — stars: statistics

1. INTRODUCTION

Single stellar populations (SSPs) are the basic building blocks of synthetic spectra of galaxies (Bressan, Chiosi, & Fagotto 1994). In the framework of the evolutionary population synthesis study, SSPs are modeled with proper stellar evolutionary tracks of different masses and initial chemical compositions, and supplemented with an adequate library of stellar spectra. The Galactic open clusters provide valuable clues for stellar evolution theory and SSP models. Good fitting to the observed color-magnitude diagram (CMD) of open clusters is essential for an evolutionary scheme to become applicable for the purpose of population synthesis study.

The single-star evolution theory is at present a solid base for the studies of the structure and evolution of galaxies. Most, if not all, of the properties of observed CMDs for stellar objects including open and globular clusters can well be reproduced in the framework of current theory. However, star clusters, especially the open clusters, show several features which may not be reproduced by standard isochrones. It is often observed in CMDs of Galactic open clusters and those in the Magellanic Clouds that a considerable number of definite member stars occupy positions that are not expected by single-star evolution schemes. Blue stragglers, on which we will put emphasis, are examples in a number of well-studied clusters (Milone & Latham 1994). The blue stragglers possess very blue color (UV-bright; see Landsman et al. 1998) and, most important, they are very luminous; therefore properly taking these bright members of the cluster into account may change the integrated spectral properties and provide an observational constraint to the SSP corresponding to the cluster. The integrated light of star clusters can be directly observed (Bica & Alloin 1986); however, this suffers from field contamination and leakage of low-mass components. To attack these difficulties, we can build the integrated SED (ISED) of the well-studied clusters empirically based on photometry and membership data for individual stars, while the lower part of the CMD can be reproduced using conventional methods.

We present in this paper an integrated light and synthetic spectrum using our recent observational data for M67 complemented by membership survey of the available astrometry data in the literature. A short report of the observation of the cluster is given in the next section. In § 3 the observational Beijing-Arizona-Taipei-Connecticut (BATC) colors are transformed to the theoretical frame using the most recent compilation of the existing theoretical stellar spectra (Lejeune et al. 1997a, 1997b) for all the luminous blue stragglers and bright stars deviating from a given isochrone; then spectra are assigned to them by comparing the observed and theoretical SEDs. Other stars are approximated using an isochrone. The final ISED of the cluster is given by summing up all the spectra of the above individual objects in the CMD, and that of the fitted isochrone. The results of the work are concluded in § 4.

2. THE OBSERVATIONS

Open cluster observation is a long-term project in our group (Deng & Chen 1997). The observational instrument and photometry system using 15 intermediate-band filters are described by Fan et al. (1996). In brief, the observation is carried out using a 60/90 cm Schmidt telescope with a field of view 1° 2048 × 2048 CCD detector. The filter set covers a 3000–10,000 Å range. This is especially suitable for extended objects such as open clusters. Our study is based on the deep photometric observations of M67 made by Fan et al. (1996). For the current work we have done another short exposure survey in order to find the luminous member

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TABLE 1

BLUE STRAGGLERS OBSERVED IN M67

ID[a] (1)	R.A.(1950.0) (2)	Decl.(1950.0) (3)	b[e] 3890 (4)	d 4550 (5)	f 5270 (6)	g 5795 (7)	h 6075 (8)	i 6660 (9)	j 7050 (10)	m 8280 (11)	n 8480 (12)	o 9190 (13)	p 9745 (14)	P[b] (15)	S[c] (16)	F[d] (17)
5	8 48 27.71	11 56 38.8	9.851	9.84	9.94	10.05	10.12	10.30	10.32	10.50	10.47	10.48	10.53	99	977	F81
18	8 49 26.74	11 55 25.3	10.87	10.57	10.63	10.68	10.71	10.83	...	10.97	10.92	10.89	10.88	97	1434	F280
25	8 48 42.88	12 03 09.6	11.16	10.87	10.89	10.95	11.01	11.12	11.15	11.26	11.24	11.17	11.18	99	1066	F156
29	8 49 04.55	12 00 33.9	11.30	10.90	10.89	10.89	10.89	11.06	11.02	11.08	11.04	11.00	11.00	99	1267	F238
34	8 48 50.17	12 02 28.0	11.38	10.95	10.92	10.90	10.93	10.98	10.99	11.04	11.00	10.94	10.94	99	1284	F190
38	8 48 48.50	12 00 09.7	11.48	11.06	11.08	11.05	11.08	11.16	11.17	11.23	11.20	11.15	11.15	99	1263	F185
40	8 48 42.41	11 55 08.1	11.51	11.21	11.23	11.29	11.31	11.44	11.46	11.56	11.51	11.50	11.49	99	968	F153
43	8 48 30.31	11 56 17.4	11.64	11.12	10.95	10.83	10.87	10.80	10.76	10.79	10.75	10.72	10.68	90	975	F90
46	8 48 36.64	12 04 42.7	11.86	11.38	11.22	11.12	11.11	11.10	11.09	11.07	11.01	10.94	10.95	99	1082	F131
47	8 48 19.45	11 56 18.8	11.85	11.40	11.32	11.28	11.29	11.35	11.32	11.38	11.32	11.29	11.29	99	752	F55
65	8 48 37.60	12 03 55.1	12.33	11.65	11.35	11.18	11.15	11.06	11.05	10.97	10.91	10.83	10.81	99	1072	...
93	8 48 48.44	12 01 58.1	12.69	12.29	12.23	12.23	12.24	12.27	12.29	12.34	12.31	12.28	12.26	99	1280	F184
111......	8 48 35.83	11 58 17.5	12.86	12.37	12.16	12.07	12.01	11.99	11.96	11.96	11.89	11.85	11.83	99	997	F124
115......	8 48 53.79	11 48 21.5	12.92	12.47	...	12.26	12.28	12.25	12.20	12.26	12.16	12.16	12.15	99	1195	F207
116......	8 48 11.52	12 03 30.2	12.95	12.28	12.01	11.86	11.85	11.78	11.74	11.68	11.64	11.55	11.55	99	792	...
126......	8 46 37.06	12 15 33.6	13.08	12.42	12.37	12.69	12.07	12.11	11.94	11.92	11.98	11.81	11.81	93	277	...
139......	8 48 55.12	12 01 21.7	13.20	12.53	12.31	12.15	12.11	12.05	12.09	12.00	11.91	11.87	11.86	99	1273	...
143......	8 48 37.18	11 57 09.7	13.21	12.58	12.33	12.18	12.11	12.06	12.03	11.99	11.91	11.85	11.85	99	984	...
182......	8 48 31.37	11 58 48.5	13.49	12.92	12.73	12.60	12.57	12.53	12.52	12.48	12.41	12.37	12.36	99	1005	...
184......	8 48 03.61	11 56 06.6	13.50	12.93	12.74	12.60	12.60	12.56	12.55	12.51	12.43	12.41	12.40	99	751	...
185......	8 48 44.05	12 00 44.5	13.50	12.99	12.84	12.70	12.69	12.64	12.63	12.61	12.51	12.48	12.44	99	1036	...
206......	8 46 15.69	11 56 01.1	13.61	13.06	...	12.84	12.84	12.91	...	12.76	12.71	12.66	12.74	94	145	...
216......	8 48 36.51	11 57 33.4	13.63	13.09	12.93	12.82	12.80	12.77	12.77	12.75	12.68	12.65	12.63	98	2204	...
131......	8 48 43.98	12 18 56.1	13.15	12.77	12.60	...	12.48	...	12.50	...	...	...	...	98	2226	...

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[a] Star identities from Fan et al. 1996.

[b] The membership probabilities.

[c] Star identities of Sanders 1977.

[d] Fagerholm number.

[e] The lowercase letters (b, d, ..., o, p) denote the filter names; the corresponding wavelengths in angstroms are also given.

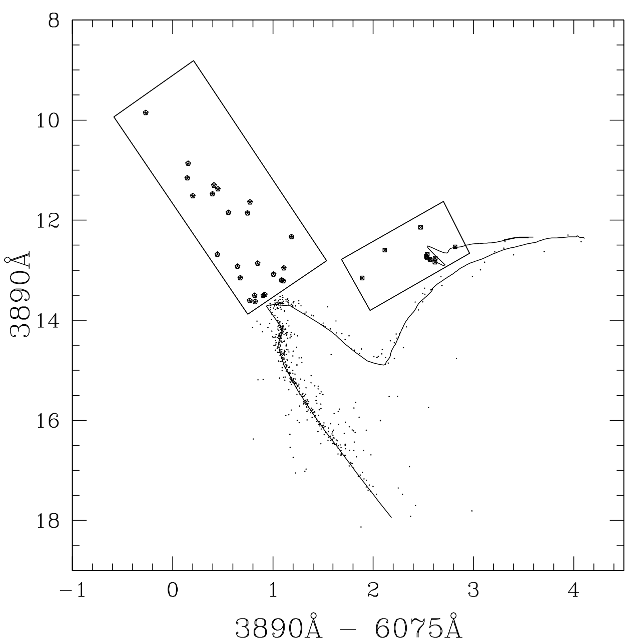

FIG. 1.—Observed CMD for M67. The axes are the color and magnitude labeled with the central wavelengths. The pentagonal points are the blue stragglers more luminous than the main-sequence turnoff, the squares the intermediate-color stragglers and clump giants, including one possible AGB star. The small dots are the other member stars; the solid line is the best-fit isochrone of solar metallicity. The two rectangles single out stars whose contribution to the integrated light of the cluster are to be determined observationally.

stars (Chen et al. 1999). The membership data are mainly from Girard et al. (1989), supplemented by data from Sanders (1977) in case no proper-motion data are available in the previous data set.

Figure 1 shows the observed CMD for M67, fitted with the 4 Gyr $Z = 0.020$ Padova isochrone. According to the membership probability already quoted, we picked up stars with probability over 50% as the members. Naturally, the bright stars can well be separated even by a much more stringent criterion; the blue stragglers and other stars shown in Figure 1 that are more luminous than the turnoff possess membership probabilities exceeding 90%, and the blue stragglers are almost 100% members from both proper motion and radial velocity observations. We divided all the member stars into two groups, as indicated in the figure, basically according to their location in the CMD. The first group of stars is bounded by the two rectangles as indicated

TABLE 2

MEAN CONCENTRATION RADII

Stars	$\bar{R}$	Number
Clump giants	7.097	7
Blue stragglers	8.117	24
Red giants.....................	13.630	35
Subgiants......................	13.078	86
Main−sequence stars[a]......	12.717	137
All.............................	13.705	560

[a] Between 14.5 and 15.5 mag in the 3890 Å filter.

in Figure 1. The first rectangle at the high-luminosity extension of the main sequence contains 24 stars, which we will refer to in this work as blue stragglers.

The detailed photometric data are given in Table 1, where column (1) gives our final star identification number as a combination of Fan et al. (1996) and Chen et al. (1999); the position information is given in columns (2) and (3); columns (4)–14 are the observed intermediate-band magnitudes with the central wavelengths of the passbands indicated; column (15) gives the membership probabilities; column 16 is the Sanders (1977) star number; and the last column gives the Fagerholm (1906) star identification number when present in the work of Milone & Latham (1994) and the UIT observation of Landsman et al. (1998). Our sample of blue stragglers contains the blue stragglers as classified by other investigators, including all of the 11 blue stragglers shown on the UIT images by Landsman et al. (1998). The 13 blue stragglers in the radial velocity catalog of Milone & Latham (1994) are also a subset of our selection. The other rectangle region bounds all stars in the intermediate colors, including the seven red clump giants and some so-called yellow and red colored stragglers. Our attention is focused on the blue stragglers, which are expected to provide new information to the study of SSPs. The nature of these stars is still very uncertain, but their connection to a close binary system is thought of as a good approach. Theoretical work toward a better explanation for the blue stragglers has made good progress (e.g., Pols & Marinus 1994). The second group of stars contains all other stars in Figure 1, which are located close to an isochrone and can be represented by a conventional SSP model.

From the star counts and distribution statistics of our data set, we find that the concentration toward cluster center for different types of stars matches the dynamical trend very well. The red clump giant and the blue stragglers show the tightest concentration. The clump giants are initially the most massive among the stars that are still alive in the cluster, while the blue stragglers can be even more massive if the binary scenario is adopted. This is explained by the mass segregation effect due to the tidal force of the Galaxy. The mean spatial concentration radii for the main-sequence stars, the subgiants, and the red giant branch (RGB) stars are larger than those of the blue stragglers and clump giants; the values are given in Table 2. These data give strong support for the membership of the luminous stars. Furthermore, because tidal effects affect mainly the low-mass component, it is very likely that the massive stars we are dealing with constitute a complete sample.

3. SYNTHETIC SED OF M67

Based on the data described above, we performed a population synthesis for M67. The schedule of the process is the following: the observed CMD for M67 members are divided into two groups in order to simplify our work. The first group includes all stragglers in the two rectangles indicated in Figure 1; this makes up the main modification to the conventional SSP model. The second group is approximated using an isochrone truncated at the RGB tip, which accounts for all stars that are fitted well by the isochrone method. The integrated light of the later one makes the conventional SSP. Because of the tidal effect and the completeness limit of our observational data, simply integrating the light of the stars in the second group cannot represent the contributions of low-mass stars of a population. Therefore, it is impossible to build a full empirical ISED using the observational data. For the same reason, direct observation of stellar clusters cannot include all the light of a stellar population.

3.1. *Fitting the Observed SEDs for Brightest Members*

For all the luminous high membership probability stragglers, among which 24 are classified as blue stragglers (more luminous and bluer than the main-sequence turnoff point) as listed in Table 1, we have 11 filters covering 3890–9190 Å that well define the SED for each star; therefore we can pick up the corresponding spectra star by star, by comparing the observed SED of a star to the recent compilation of the theoretical stellar spectra library of Kurucz models supplemented with the work of Allard & Hauschildt (1995), Fluks et al. (1994), and Bessell et al. (1991), which is described in Lejeune et al. (1997a, 1997b).

In order to determine the intrinsic SED for these stars, we corrected the observed magnitudes for the reddening adopting $E(B-V) = 0.02$, as obtained from the isochrone fitting method and the fiducial reddening law of Schefflers (1982); see Fan et al. (1996) for details. Figure 2 shows the result of our fitting procedure for the four blue stragglers F280, F156, F190, and F90. In that figure the open squares correspond to our observations, the thin line is the best-fitting Kurucz model, and the solid line connects the values obtained by convolving the spectral model with our filter response. For these four stars, there exist *IUE* spectra and well-fitted Kurucz models (Fig. 3 of Landsman et al. 1998). The fitting chart, Figure 2, of the four blue stragglers serves as an example of our method.

This process is performed for all stars selected from Figure 1 in the two rectangles; the rms of the fitting is below 0.02 m for all SEDs, which is quite satisfactory.

The results of such a fitting are given in Table 3, where columns (3) and (4) list the Fagerholm (1906) and Sanders (1977) numbers, column (5) gives the effective temperature determined by fitting the Kurucz model to our observed SED, and column (6) gives the effective temperature determined from *IUE* and Kurucz spectra by Landsman et al. (1998). An inspection of Table 3 shows that the effective temperature obtained by the UV fitting method (Landsman et al. 1998) is quite different from what we derived from optical SEDs. In general, the effective temperature of our fitting is lower than that of Landsman et al. (1998) by several hundred degrees; the extreme case is for F81, where the temperature differed by 2000 K. In order to clarify the origin of this difference, we performed a new fitting adopting a different spectral library (Pickles 1998). We notice that the temperature determined this way is in between previous values. To show this discrepancy, we plot the fittings using Landsman et al.'s UV-determined Kurucz model, the Kurucz spectra and Pickles's atlas both determined from our observed SED for F280, in Figure 3. The fitting of the surface gravity to the Kurucz spectra is insensitive using our data. The crosses are the observed magnitudes, the solid line is our selection of the Kurucz spectrum, and the dashed line is determined by Landsman et al. (1998) using the Kurucz model that fits the UV light. The dotted line is our best fitting with the Pickles atlas (Pickles 1998); all the theoretical flux has been transformed into monochromatic AB magnitudes and then normalized to the number 7 BATC filter (5795 Å). The fitting obtained with the Kurucz library provides the coolest temperature, so that the integrated spectra

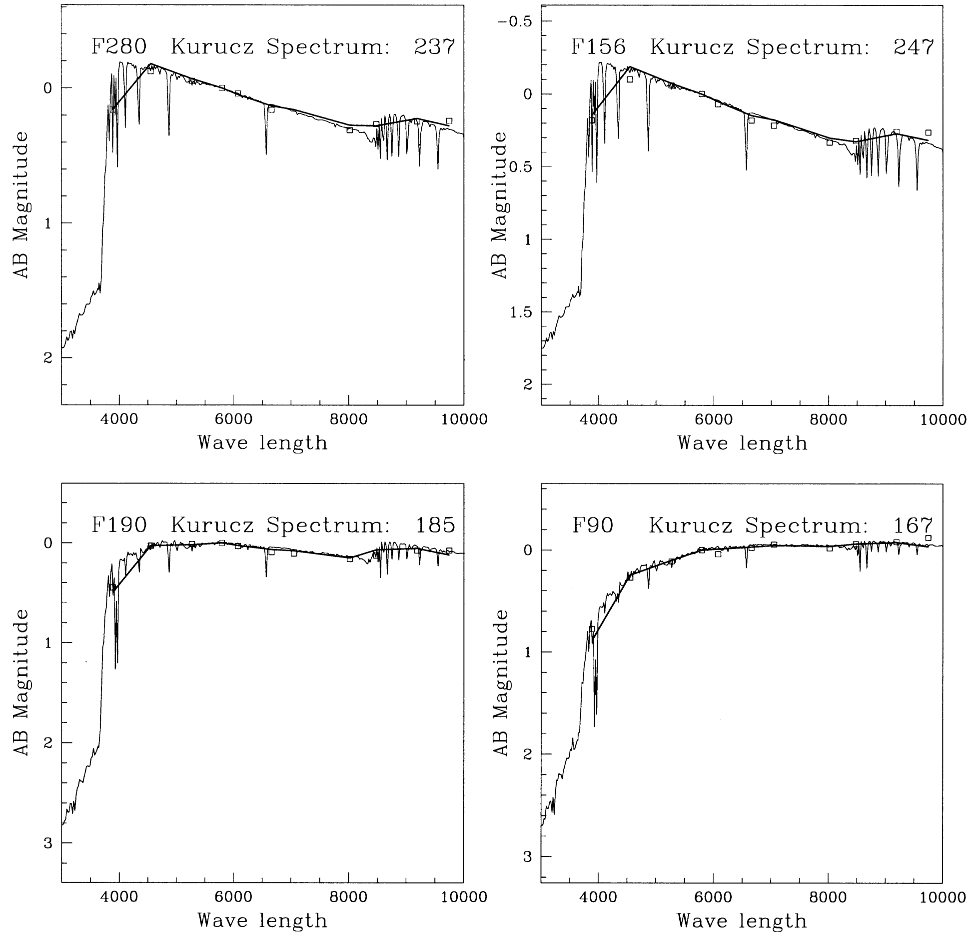

FIG. 2.—Fitting the observed SEDs of the four blue stragglers that have *IUE* spectra and Kurucz model spectra fitting at UV (Fig. 3 of Landsman et al. 1998). The star identifications and the fitted Kurucz spectrum numbers ([Fe/H] = −0.1) are labeled. The open squares are our observed magnitudes; the solid lines overlying the model spectra are the magnitudes convolved using our filters. The vertical axes are in AB magnitudes.

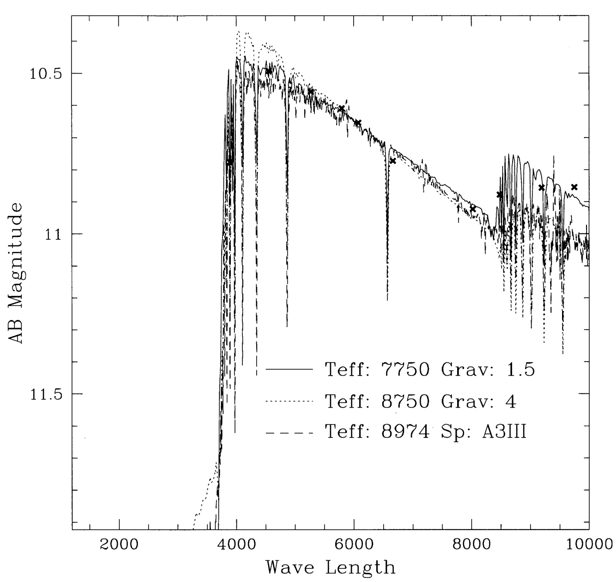

FIG. 3.—Fitting the observed SED (*crosses*) for the blue straggler F280. The three different choices are respectively the best fitting using our SED (*continuous line*), the spectrum that best fits the UV light as given by Landsman et al. (1998) (*dotted line*), and our best fit to Pickles's (1998) atlas (*dashed line*). The fitting parameters are also indicated.

obtained in this way must be considered as the lower limit for the very blue part (below 4000 Å).

3.2. *The Integrated SED of the Cluster*

By using the above method, we determine the spectra for both blue stragglers and the intermediate-color stars, including the red clump stars. For the blue stragglers we can get the integrated spectrum $F_{\rm BS}$ simply by summing the individual spectra,

$$F_{\rm BS}(\lambda) = \sum_{i=1}^{N_{\rm BS}} f^i_{\rm BS}(\lambda) , \quad (1)$$

where $f^i_{\rm BS}(\lambda)$ is the flux determined from our observationally calibrated magnitude of a star (taking the reverse of eq. [4]), and $N_{\rm BS}$ is the total number of blue stragglers. The same is done for the stars in the other rectangle, noted as $F_{\rm YS}$(intermediate-color stragglers and clump giants).

The second group of stars stays relatively closer to the isochrone. To fit the observational CMD, we used the isochrone library from the Padova group (Bertelli, Bressan, & Chiosi 1994; Bressan et al. 1993; Fagotto, Bressan, & Chiiosi 1994a, 1994b, 1994c). For the sake of clarity we fixed the chemical composition for M67 as $Z = 0.020$; this gives

TABLE 3

PARAMETERS FITTED FOR THE BLUE STRAGGLERS

ID (1)	P (2)	F[a] (3)	S (4)	$T_{\rm eff}$[b] (5)	$T_{\rm eff}$[c] (6)	Spectral Type[d] (7)	$Tx_{\rm teff}$[e] (8)
5	99	F81	977	10500	12750	B8 V	11750
18	97	F280	1434	8000	8600	A3 III	8974
25	99	F156	1066	8000	8680	A3 III	8974
29	99	F238	1267	7250	8010	A7 V	8053
34	99	F190	1284	6750	7750	F0 I	7690
38	99	F185	1263	7000	8290	A7 III	8053
40	99	F153	968	8000	8490	A5 V	8490
43	90	F90	975	6250	6490	F5 III	6530
46	99	F131	1082	6250	6930	F5 III	6530
47	99	F55	968	6750	7620	F5 I	6640
65	99	...	1072	5750	...	G2 V	5636
93	99	F184	1280	6750	8090	F0 I	7690
111......	99	F124	997	6250	...	rF8 V	...
115......	99	F207	1195	6500	...	F2 V	6776
116......	99	...	792	6000	...	rG5 III	...
126......	93	...	277	6000	...	rF8 V	...
139......	99	...	1273	6000	...	F8 V	6040
143......	99	...	984	6000	...	rG5 III	...
182......	99	...	1005	6250	...	rF8 V	...
184......	99	...	751	6250	...	rF8 V	...
185......	99	...	1036	6250	...	F6 V	6150
206......	94	...	145	6250	...	F5 III	6530
216......	98	...	2204	6250	...	F6 V	6150
131......	98	...	2226	6750	...	F2 V	6776

[a] Fagerholm number if present in the Milone & Latham 1994 catalog.
[b] Effective temperature of our fitting.
[c] Effective temperature fitted by Landsman et al. 1998 in the UV.
[d] Spectral type of our fitting using the Pickles atlas (Pickles 1998).
[e] Effective temperature of our fitting using the Pickles atlas.

an age of 4 Gyr and $E(B-V) = 0.02$. The detailed parameter determinations for M67 can be found in Fan et al. (1996) and Chen et al. (1999). The majority of this group of stars are confined in the single-star evolution regime, therefore their integrated light can be reproduced by the conventional SSP technique. We follow the prescription by Bressan et al. (1994). The contributions from stars after the RGB tip on the CMD (Fig. 1) have already been taken into account by $F_{\rm YS}$, so we did not consider the whole isochrone but terminated the sequence at the RGB tip of the 4 Gyr Padova isochrone. As we have stated above, by using such an approximation we can account for both the stars in the photometric binary sequence and the evaporated low-mass stars that do not show on the CMD.

The integrated spectrum is thus

$$F_{\rm iso}(\lambda) = \int_{m_{\rm low}}^{m_{\rm tip}} f(\lambda) A \psi(m) dm \ , \quad (2)$$

where A is a suitable normalization constant to be fixed in such a way that the integrated spectrum is normalized to the real number of stars sampled by our observations.

To this purpose, we select a region of the CMD populated enough to minimize stochastic effects and bright enough to minimize segregation or incompleteness limitations, and impose the condition that the expected number of stars inside this region matches the observed one.

A suitable region is that in the range $14.5 < M_{3890} < 15.5$ (see Fig. 1), where we count 135 stars. Thus, with the further assumption of a Salpeter initial mass function (IMF), the normalization constant, A, is derived from the identity

$$N = A \int_{m_1}^{m_2} m^{-2.35} dm = 135 \ , \quad (3)$$

where m_1 and m_2 are the initial masses corresponding to the magnitude $M_{3890} = 15.5$ and $M_{3890} = 14.5$, respectively, as derived from our CMD fitting. The integrated flux of the isochrone is finally derived by inserting the above normalization constant in equation (2).

From equation (3) above, it is clear that the normalization (or say the relative contributions of the isochrone component to that of the observational stragglers) depends on the quantities $m_{\rm tip}$, $m_{\rm low}$, m_1, and m_2. All but $m_{\rm low}$ are determined by the fitting of the observation using the isochrone, while $m_{\rm low}$ is taken to be 0.15 $M_\odot$, which is the lowest mass contributing to the integrated light: $m_{\rm tip} = 1.349$, $m_1 = 1.036$, $m_2 = 1.166\ M_\odot$.

To make up the final integrated spectrum of M67, we combine the integrated spectrum of the isochrone $F_{\rm iso}$ with the integrated contribution of all stars after the RGB tip and blue stragglers, $F_{\rm YS}(\lambda)$ and $F_{\rm BS}(\lambda)$, respectively.

To show the relative contributions of the blue stragglers, we plotted the total flux of the blue stragglers in different combinations, namely, the unusual blue straggler F81, all the other blue stragglers, and half of the blue stragglers in Figure 4; the total flux of all blue stragglers is also plotted using a heavy solid line. This plot shows us that F81 provides all the light below about 1700 Å and keeps dominating until 2700 Å; it still provides about one-third of the light of all blue stragglers up to 4000 Å. The flux from blue

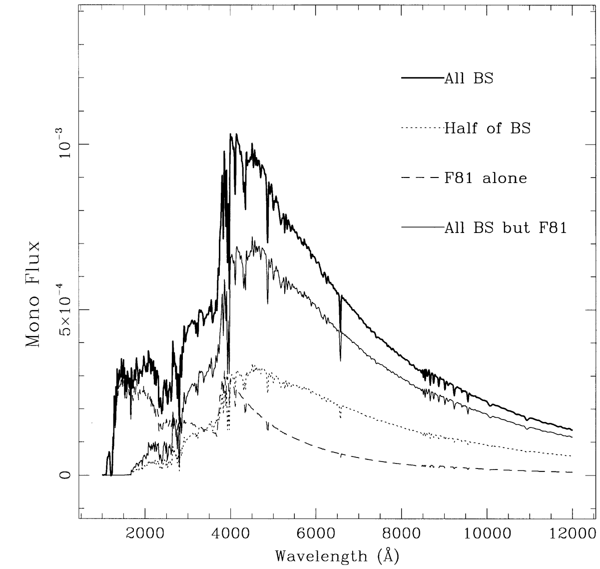

FIG. 4.—Integrated flux provided by the blue stragglers alone, considered in different proportions. *Thick solid line:* All blue stragglers. *Thin solid line:* All blue stragglers except F81. *Dotted line:* Half of the blue stragglers (evenly selected according to their 3890 Å magnitude). *Dashed line:* F81 alone.

stragglers above, say, 5000 Å is almost proportional to the number of blue stragglers.

To further demonstrate the alteration to the conventional SSP's ISED, we plotted Figure 5, where the abscissa is the wavelength in angstroms and the ordinate is the monochromatic AB magnitude, defined as,

$$m = -2.5 \log [F_\nu(\lambda)] - 48.6 , \quad (4)$$

where $F_\nu(\lambda) = F_\lambda(\lambda)\lambda^2/c$ is the monochromatic flux (in ergs $\mathrm{cm^{-2}\,s^{-1}\,Hz^{-1}}$), and c is the speed of light. This figure gives us the integrated light in our observational magnitude frame from which some observable predictions can be made. Based on the flux for each component, we can calculate the ISED in AB magnitudes for M67. In Figure 5 the heavy solid line is the component corresponding to a conventional ISED, and the other three cases are respectively such an ISED plus the three combinations of the blue stragglers: the solid line gives the total light of all observed blue stragglers as in Table 1, the dotted line is evenly chosen blue stragglers including the brightest blue straggler F81, and the dashed line is all blue stragglers except F81. At the shortest wavelength filter of our system, 3360 Å, we can expect 1–1.5 mag brighter than in the conventional case; at 3890 Å the result is 0.8–1.0 mag. These differences can well be observed and change color considerably.

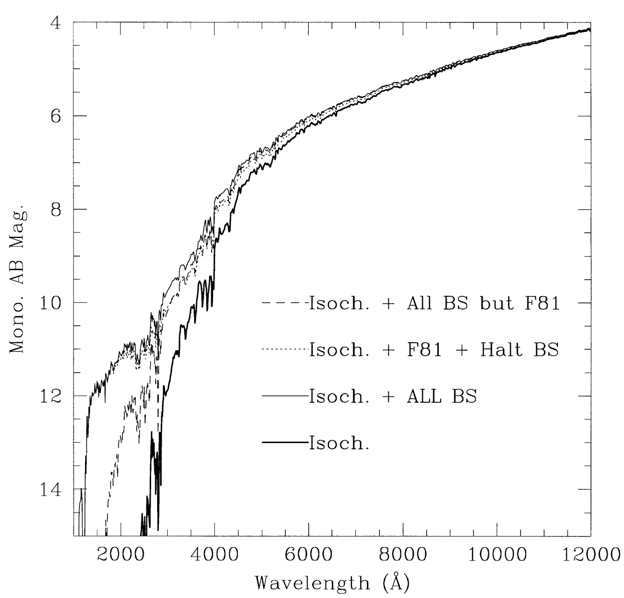

FIG. 5.—Integrated flux of M67 in AB magnitude vs. wavelength. The contribution of the blue straggler population is taken apart. *Thick solid line:* All components except the blue stragglers (isochrone up to the RGB tip, the clump giants, and the three intermediate-color stragglers). *Thin solid line:* All components. *Dashed line:* All components except F81. *Dotted line:* Isochrone, half of the blue stragglers, and F81.

4. SUMMARY AND CONCLUSIONS

In this study we computed the integrated spectral energy distribution of M67 by including a number of observed blue stragglers. Their model spectra were selected from the Kurucz library, by accurately matching their multicolor intermediate-band photometry with that of the models. As a result, the blue side of the final integrated spectrum of M67 shows an interesting enhancement, due to the presence of this anomalous population of stars, while the red side remains practically unchanged. As already pointed out by Landsman et al. (1998), we find that, owing to the presence of blue stragglers, the UV region of the integrated spectrum of M67 mimics that of a standard SSP of about 2.5 Gyr, while the CMD fitting provides an age of about 4.5 Gyr. The effect gets lower and lower when one considers longer wavelengths.

The blue straggler population of M67 is believed to be abnormally high with respect to that observed among other open clusters. Ahumada & Lapasset (1995) find that the ratio of the number of blue stragglers to that of the main-sequence stars within 2 magnitudes below the turnoff, N_{BS}/N_2, is 30/200 for this cluster. Making use of our own observations and carefully accounting for the membership probability, we find that this ratio is $N_{\mathrm{BS}}/N_2 = 24/286 N_{\mathrm{BS}}/N_2 = 24/286$, in much closer agreement with the average value found among open clusters. We conclude that the population of blue stragglers in M67 is normal and that the effect we are discussing is to be expected in any intermediate or old stellar population.

A point to be analyzed, however, is the effect of the overwhelming contribution of the brightest blue straggler F81, in a statistical sense. Such a luminous star is seemingly too bright in the current framework of the blue straggler formation scenario, and, indeed, there are not confirmed counterparts observed on other open clusters. A possible explanation would be that F81 is a post–asymptotic giant branch (post-AGB) star, in which case its contribution is already accounted for in standard SSPs that account for this phase (Bressan et al. 1994). However, from our fit to the CMD, we find that the post-AGB phase is about 7 mag brighter than the turnoff, in the visual. On the other hand, an inspection of the CMD of Figure 1 shows that F81 (the brightest blue straggler) is only about 3 mag brighter than the turnoff, in the visual. The possible origin for such a star in the cluster could be a merger of binary systems, according to the current understanding of the blue straggler and its position in the CMD, or an abnormal post-AGB star if it is to be understood by the post-AGB scenario.

We also checked the statistical significance of our finding because, when the number of stars is limited, stochastic effects can significantly affect the integrated properties of SSPs (Chiosi, Bertelli, & Bressan 1988). The total number of stars in our sample is 560, and the blue straggler (BS) population counts only 24 members. To analyze such effects, we computed the integrated spectra of the BS population alone and of the BS population plus the other components of M67, when one accounts for (*a*) all the observed blue stragglers, (*b*) half of them, (*c*) F81 alone, and finally (*d*) all the BSs but F81. The results, shown in Figures 4 and 5, provide a measure of the uncertainty related to the discrete number of BSs. Blue stragglers are quite commonly observed in all targets (Ahumada & Lapasset 1995). Because there are too many combinations of the binary system parameters in the theoretical work concerning the formation and evolution of blue stragglers, detailed analysis of clusters and their blue straggler population in terms of ISED deserves further statistical work in all star clusters with membership probability data.

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