THE PURE NONCOLLISIONAL BLUE STRAGGLER POPULATION
IN THE GIANT STELLAR SYSTEM $\omega$ CENTAURI

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ABSTRACT

We have used high spatial resolution data from the Hubble Space Telescope (HST) and wide-field ground-based observations to search for blue straggler stars (BSSs) over the entire radial extent of the large stellar system $\omega$ Centauri. We have detected the largest population of BSSs ever observed in any stellar system. Even though the sample is restricted to the brightest portion of the BSS sequence, more than 300 candidates have been identified. BSSs are thought to be produced by the evolution of binary systems (formed either by stellar collisions or mass exchange in binary stars). Since systems like Galactic globular clusters (GGCs) and $\omega$ Centauri evolve dynamically on timescales significantly shorter than their ages, binaries should have settled toward the center, showing a more concentrated radial distribution than the ordinary, less massive single stars. Indeed, in all GGCs that have been surveyed for BSSs, the BSS distribution is peaked at the center. Conversely, in $\omega$ Centauri we find that the BSSs share the same radial distribution as the adopted reference populations. This is the clearest evidence ever found that such a stellar system is not fully relaxed even in the central region. We further argue that the absence of central concentration in the BSS distribution rules out a collisional origin. Thus, the $\omega$ Centauri BSSs are the purest and largest population of noncollisional BSSs ever observed. Our results allow the first empirical quantitative estimate of the production rate of BSSs via this channel. BSSs in $\omega$ Centauri may represent the best local template for modeling the BSS populations in distant galaxies where they cannot be individually observed.

Subject headings: binaries: close — blue stragglers — globular clusters: individual (NGC 5139) — stars: evolution

1. INTRODUCTION

Blue straggler stars (BSS) define a sparsely populated sequence extending to higher luminosity than the turnoff (TO) point of normal hydrogen-burning main-sequence (MS) stars in the color-magnitude diagrams (CMDs) of stellar aggregates like Galactic globular clusters (GGCs). Superficially, they appear to be MS stars with masses larger than expected for the cluster age as determined from the MSTO. There are two mechanisms thought to produce BSSs: the first is mass exchange in a binary system, the second is the merger of two stars induced by stellar interactions, i.e., collisions (between either single or binary stars) in a dense stellar environment. In either scenario, BSSs are significantly more massive than normal cluster stars. Because of the high stellar density, collisions are more frequent in cluster centers. In addition, clusters evolve dynamically, and more massive objects sink toward the center on a timescale known as the relaxation time. Both factors suggest that BSSs should be more concentrated in the central regions with respect to the other cluster stars, and this has been found to be the case in all GGCs with adequate observations of the center.

Among the stellar systems that populate the Galactic halo, $\omega$ Centauri is beyond any doubt the most surprising. The entire body of evidence collected so far—kinematics, spatial distribution, and chemical composition peculiarities—make $\omega$ Centauri a unique object if classed as usual among the globular clusters of the Milky Way (GGCs). It is more massive ($M \approx 2.9 \times 10^6 M_\odot$; Merritt et al. 1997) and luminous than any other GGC. It differs dynamically from ordinary GGCs; it is one of the most flattened clusters (Meylan 1987; White & Shawl 1987) and is partially supported by rotation (Meylan 1987; Merritt et al. 1997). The most astonishing peculiarity of $\omega$ Centauri is its metallicity spread measured both spectroscopically (Norris et al. 1996; Suntzeff & Kraft 1996) and photometrically (Lee et al. 1999; Pancino et al. 2000; Hilker & Richtler 2000; Frinchaboy et al. 2002; Sollima et al. 2005). Being the only halo stellar system with such a large chemical inhomogeneity, it has been suspected that it is not a "genuine" globular cluster but the remnant of a dwarf galaxy that merged with the Milky Way in the past. Because of its proximity, this giant system is a cornerstone in our understanding of the formation, chemical enrichment, and dynamical evolution of stellar systems.

2. THE CENTRAL BSS POPULATION

The results presented here are based on a high-resolution sample obtained with the Advanced Camera for Surveys (ACS) on board HST through B and R filters. The observations are organized...
in a mosaic of $3 \times 3$ pointings covering the $9' \times 9'$ around the cluster center. Preliminary results based on this database (dealing with the complex structure of the subgiant branch [SGB]-TO region) have already been published (Ferraro et al. 2004b). Here we focus our attention on the BSS population.

Figure 1 shows the zoomed CMD in the BSS region. As can be seen, there is a clear, well-defined, and populated BSS sequence, cleanly separated from the MSTO stars. As a reference, the isochrones for 2 and 3 Gyr old populations (Cariulo et al. 2004) are also shown. We adopted a global metallicity $[M/H] \approx -1.5$ (Ferraro et al. 2004b) for the metal-poor, dominant population, a distance modulus $(m-M)_0 = 13.70$ (i.e., $d = 5500$ pc; Bellazzini et al. 2004), and reddening $E(B-V) = 0.11$ (Lub 2002). The mean interstellar extinction coefficients listed in Table 2 of Savage & Mathis (1979) have been adopted. As can be seen, the observed BSS sequence is nicely marked by the theoretical sequences. In particular, the positions of the brightest BSSs are similar to MSTO stars in 2–3 Gyr old clusters, while the MSTO of the dominant metal-poor population has been fitted by a $14–15$ Gyr isochrone (Ferraro et al. 2004b). The MSTO masses in 2 and 3 Gyr old clusters are 1.4 and 1.2 $M_\odot$, respectively. This is in agreement with the recent finding of Rey et al. (2004), who also concluded that the masses of BSSs detected in the Cen do not exceed $1.4 M_\odot$. Indeed, the MSTO mass in Cen is estimated to be $0.74 M_\odot$, so mass transfer in an equal-mass binary should not produce a BSS more massive than $1.5 M_\odot$.

The detection of such a clean BSS sequence allows us to perform a direct comparison with normal cluster stars. In order to be conservative and avoid any possible contamination from spurious blended objects (mainly due to MS stars), we selected only the brighter ($16 < B < 18.4$) and bluer ($B - R < 0.3$) portion of the BSS sequence.

Generally, in order to study the BSS radial distribution, both horizontal branch (HB) and red giant branch (RGB) stars are used as reference stellar populations. In most clusters the HB is clearly defined, and it has been used in previous papers (Ferraro et al. 2003) for cluster-to-cluster comparisons. On the other hand, the RGB in the same magnitude range of the BSS, including the lower RGB, is much more populous than the HB; hence, star counts are less affected by statistical fluctuations. For this reason we used both populations as reference. Particular care has been devoted in selecting the RGB sample: (1) asymptotic giant branch (AGB) stars are clearly separable from the RGB and are excluded from the reference sample, and (2) we accurately selected RGB stars belonging to the dominant metal-poor branch. The possible contamination by the more metal-rich RGB stars is always negligible.

Figure 2 shows the cumulative radial distributions of BSSs and reference populations. A Kolomogorov-Smirnoff (KS) test indicates that the radial distribution of the BSSs has a $\sim 67\%$ probability to be extracted from the same parent distribution as HB and RGB stars. This is the very first time that BSSs have been found to share the same radial distribution as normal stars of the parent cluster. Eventually, as can be seen from Figure 2, BSSs in Cen appear, if anything, even less concentrated than HB and RGB stars, contrary to what has been observed in any other cluster.

To further investigate the radial distribution of BSSs, we computed the BSS relative frequency $F_{\text{BSS}} = N_{\text{BSS}}/N_{\text{HB}}$ where $N_{\text{BSS}}$ and $N_{\text{HB}}$ are the number of BSS and HB stars, respectively, and studied its behavior as a function of the distance from the cluster center. In doing this, we divided the sampled area into a set of concentric annuli, and in each annulus we counted the number of BSS and HB stars. The relative frequencies as a function of distance from the cluster center are shown in Figure 3 (top); the distribution appears nicely constant over the entire extent of the ACS sample. Moreover, the constancy of the BSS frequency at different distances from the cluster center is independent of the choice of reference population. We emphasize that this is the first time that such behavior has been found in a globular cluster. In all

$$\sigma_F = \left( \frac{1}{N_{\text{HB}}} \sum_{i=1}^{N_{\text{HB}}} \frac{N_{\text{BSS}_i}^2}{N_{\text{HB}_i}} + \frac{N_{\text{BSS}}^2}{N_{\text{HB}}} \right)^{1/2}$$

where $\sigma_{\text{HB}}$ and $\sigma_{\text{BSS}}$ are errors derived from the Poisson statistics. 

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**Fig. 1.**—Zoomed CMD in the BSS region for the HST ACS sample. Two isochrones (by Cariulo et al. 2004) at $Z = 0.0006$ and $t = 2$ and 3 Gyr are overplotted.

**Fig. 2.**—Left: Cumulative radial distributions for the BSS (solid line) in the ACS sample with respect to RGB stars (dashed line) and HB stars (dotted line) as a function of their projected distance ($r$) from the cluster center. Right: Cumulative radial distributions for the cluster X-ray sources (dashed line) and BSSs (solid line).
previously surveyed clusters the central regions show a significant 
overabundance of BSSs. Typically, the specific frequency drops 
by a factor of 4 or more over a few core radii. Note that BSSs 
have been found to be significantly more centrally concentrated, 
even in clusters with significantly lower central density than \(\omega\) Cen (see, e.g., NGC 288; Bellazzini et al. 2002).

3. SAMPLING THE ENTIRE CLUSTER

In order to further investigate the peculiar distribution of BSSs 
in this stellar system, we extended the analysis to the external 
regions. To do this we used the wide-field photometry previously 
obtained by our group using the Wide Field Imager (WFI) on the 
2.2 m ESO-MPI telescope at the European Southern Observa-
tory (ESO) at La Silla. The WFI is a mosaic of 8 CCD chips 
each with a field of view of \(8' \times 16'\) giving a global field of 
view of \(33' \times 34'\). The images were obtained using \(B\) and \(I\) filters 
and have previously been used (Pancino et al. 2000) to identify 
an additional, previously unknown RGB (RGB-a; see also Lee 
et al. 1999). Since the cluster center is slightly off-center in that 
data set, we also supplement the sampling of the external region 
with the \(B, V\) catalog by Rey et al. (2004). The final catalog samples 
the cluster population over (complete) concentric annuli up 
to a distance of \(20'\) from the cluster center.

All the catalogs were transformed to the same absolute astro-
metric system by using the Space Telescope Guide Star Catalog II, 
and then photometrically matched by using the stars in common. 
Note that all three data sets have the \(B\) passband in common. To 
be conservative and prevent any possible incompleteness due to 
poor spatial resolution, we excluded the innermost region \((r < 8')\) 
of the WFI sample and used the Rey et al. catalog only in the most 
external region not sampled by our WFI observations.

3.1. The Star Density Profile

As a first step, we used the selected sample of RGB/SGB 
in the magnitude range \(16 < B < 18.4\) to obtain a new density 
profile for the cluster. The analysis was performed using almost 
23,000 stars. The surveyed region was divided into 27 concentric 
annuli. Each annulus was split into a number of subsectors 
(generally octants or quadrants). Then the number of stars lying 
within each subsector was counted and averaged. Star density 
was obtained by dividing the average star number by the corre-
sponding subsector area (in \(\text{arcsec}^2\)). The resulting profile can be 
nicely reproduced by a King model characterized by two para-
eters: the core radius, \(r_c\), and the concentration, \(c\). We redeter-
mined these parameters using our observations and the projected 
star density from a standard isotropic single-mass King model 
(Sigurdsson & Phinney 1995). The result is shown in Figure 4; 
we found \(r_c = 153''\) and \(c = 1.31\), in good agreement 
with the values \((c = 1.24\) and \(r_c = 155'')\) listed by Trager et al. 
(1995).

3.2. The BSS Population over the Entire Cluster

We selected the BSSs following the criteria adopted for the 
ACS sample. Only BSSs in the magnitude range \(16 < B < 18.4\) 
were considered. We used isochrones (Cariulo et al. 2004) to 
convert the red edge of the selection box from the \((B - R)\) color 
into \((B - I)\) and \((B - V)\) colors. We found that the adopted red 
edge in the ACS sample \((B - R = 0.7)\) corresponds to \((B - I) \approx 1.0\) 
and \((B - V) \approx 0.42\).

Figure 5 shows the zoomed CMDs in the BSS region for the 
ACS and WFI samples. The selection boxes are shown in each 
panel. The BSS population appears as a clear sequence diagonally 
crossing each box. To be conservative, we selected only those 
stars within the two dashed lines. This accounts for the bulk of the 
BSS populations, with only a few objects being excluded from the 
selection. Following these criteria, we have identified 158 BSSs

\[ \frac{N_{\text{BSS}}}{N_{\text{RGB}}} = \frac{9.8 \pm 0.2}{0.010 \pm 0.001} \]

\[ \frac{N_{\text{BSS}}}{L_{\text{GB}}} = 2.0 \pm 0.2 \]

\[ \log(\text{density}) \]
in the HST ACS and 155 in the external sample (r > 8', with 117 found in the region sampled by the WFI and 38 in the Rey et al. [2004] sample), for a total of 313 BSSs. This is the cleanest and largest BSS sample detected in the cluster. However, the global BSS population in ω Cen is probably significantly larger (>400) since (1) we sampled ≈70% of the cluster light, and (2) we limit our selection to the brightest and cleanest portion of the BSS sequence.

Of course, each photometric sample has its own incompleteness, and for this reason we analyzed them separately. According to §2, each BSS population is referred to the RGB population of the corresponding catalog in the same magnitude range (16 < B < 18.4) of the selected BSSs.

To compare the samples we used the doubly normalized ratio \( R_{\text{BSS}} \), which gives the fraction of BSSs counted in concentric annuli at different distances from the cluster center with respect to the fraction of light sampled in each annulus. The sample presented here covers the cluster extent up to 20' from the center. Hence, the entire surveyed area has been divided into six concentric annuli, excluding only the region between 320" and 480". The cluster light sampled in each annulus has been computed by integrating the King profile (King 1966) fitted to the observed cluster density profile shown in Figure 4. The same ratio has been computed for the reference population. As emphasized in Ferraro et al. (1993), for a stellar population that is distributed accordingly with the integrated cluster light, this ratio is 1. The result is shown in Figure 6, and as can be seen the normalized BSS ratio is nicely constant and fully consistent with the reference population.

In other clusters (M3, Ferraro et al. 1997; 47 Tuc, Ferraro et al. 2004a; NGC 6752, Sabbi et al. 2004; M55, Zaggia et al. 1997), not only does the normalized BSS population peak at the center, it rises again in the cluster periphery. This effect probably arises because primordial binaries whose orbits are confined to the cluster exterior have low collision rates and thus remain in the exterior, where some eventually become BSSs. BSS progenitors at intermediate radii drift inward, where they are either "ionized" or driven to merge by collisions. Dynamical simulations have demonstrated this phenomenon in 47 Tuc (Mappeli et al. 2004).

Since this result seems to be quite peculiar, a natural question arises: Is there any other evidence that can support our findings? First we note that there is no convincing evidence of equipartition effects in the radial distribution of MS stars of ω Cen (Anderson 2002). What about the radial distribution of other subpopulations significantly more massive than normal cluster stars? Interacting binaries containing a compact object (like a neutron star or white dwarf) in which mass transfer is occurring are expected to show X-ray emission. These are among the most massive objects we can currently find in an old stellar population. We used the recent XMM-Newton observations (Gendre et al. 2003) in order to check it. There are 42 X-ray sources lying in the field of view covered by the ACS observations. The radial distribution of these sources is compared with that of BSSs in Figure 2 (right). As can be seen, the radial distribution of the X-ray sources is the same or even less centrally concentrated than the BSSs. A K-S test shows that BSSs and X-ray sources have a ~12% probability of being extracted from the same parent distribution. However, due to the small sample of detected X-ray sources, we can conservatively conclude that the difference between the two distributions is not significant. In conclusion, neither of the two most massive star populations in the cluster (BSSs and X-ray sources) shows any signature of radial segregation with respect to the normal stars in the cluster.

Since relaxation is the major dynamical process that differentiates stars according to their mass (Meylan & Heggie 1997), the observational facts presented here represent the cleanest evidence found so far that the system is still far from being completely relaxed, even in the core region.

4. DISCUSSION

The evidence presented here demonstrates that ω Cen, the largest stellar system of the Galactic halo, does not share the
dynamical characteristics of GGCs. Indeed, because of its mass, previous hints and arguments have led, in the past, to the suspicion that \( \omega \) Cen is not completely relaxed (Mayor et al. 1997). Since \( \omega \) Cen is 1 order of magnitude more massive than a typical halo GGC, its relaxation timescale is also expected to be significantly larger. Previous estimates (Djorgovski 1993) of the central relaxation time for \( \omega \) Cen give \( \log t_{\text{rc}} = 9.76 \), i.e., \( t_{\text{rc}} \approx 5.7 \) Gyr, adopting a distance of \( d \approx 4900 \) pc. This distance is shorter than that currently adopted here (\( d \approx 5500 \) pc). For this reason we recomputed the relaxation time for this stellar system, adopting the new distance and structural parameters obtained in \( \S \) 3.1. Under these assumptions, the physical size of the core radius turns out to be \( r_c \approx 4.1 \) pc. Adopting the observed integrated magnitude \( M_V = 3.68 \) (Harris 1996) produces a central relaxation time \( \log t_{\text{rc}} = 9.82 \), i.e., \( t_{\text{rc}} \approx 6.6 \) Gyr. Although larger, this new determination of the relaxation time is still a factor of 2 shorter than the cluster age (12–14 Gyr); hence, some segregation should be visible, at least in the central regions. A good indication of the expected segregation timescale for an object of mass \( m \), can be obtained by considering the half-mass relaxation timescale (Davies et al. 2004). Using equation (10) of Davies et al. (2004), we found that roughly half of the \( m = 1.0 \ M_\odot \) BSSs should have sunk to the core after only 2 Gyr.

Is the lack of segregation connected to the origin of this peculiar stellar system? Can the history of a stellar system influence its internal dynamical status? Is it due to rotation?

According to Davies et al. (2004), heavier stars tend to take longer to sink in the core of more massive systems. If we accept the hypothesis that \( \omega \) Cen is the relic of a dwarf galaxy partially disrupted by the tidal field of the Milky Way, then this system was significantly more massive in the past than what we observe today. According to Tsuchiya et al. (2004), the initial mass of \( \omega \) Cen could have been \( M \approx 10^8 \ M_\odot \), and the cluster should have remained more massive than \( 10^7 \ M_\odot \) for a few Gyr. Equations (10) of Davies et al. (2004) suggests that the “sinking time” is a factor 7–8 longer for a system 10\(^2\) times larger than the current \( \omega \) Cen. In such a scenario, the stormy past of this stellar system could have extended the sinking time needed for the heaviest population to reach the cluster center to a time larger than the cluster age.

Rotation can also play a role. Relaxation time is expected to be longer for rotating systems, since angular momentum tends to keep stars out of the core, counteracting mass segregation (Spurzem 2001). There is evidence for large rotation of the \( \omega \) Cen system (Meylan & Mayor 1986; Merritt et al. 1997; van Leeuwen & Le Poole 2002). Moreover, while the metal-poor giants (\( [(Ca/H)] < -1.2 \) belonging to the dominant cluster population form a rotating system, the metal-rich ones do not show any significant rotation (Norris et al. 1997). Such evidence suggests a clear correlation between dynamical and chemical properties of \( \omega \) Cen. Perhaps the lack of equipartition observed could be related to the origin of the multiple populations inside the cluster.

Although we do not fully understand why \( \omega \) Cen is not relaxed yet, we still feel safe in concluding that stellar collisions have played a minor role in generating exotic binary systems in \( \omega \) Cen. We have previously made detailed studies of nine clusters. Our major conclusion is that the overall population of BSSs in a typical GGC turns out to be a complex conglomeration of collisional BSSs and mass-exchanging binaries. Still, while several puzzles remain, some firm facts are emerging. Among these are that, except possibly for NGC 288, all clusters have some collisional BSSs, and those BSSs are strongly centrally concentrated. This is hardly surprising, since the collision rate is higher at the center; and since the BSSs are more massive than the typical cluster star, they will not migrate outward. It is possible that a “kick” produced by the collision ejects them from the core (Sigurdsson et al. 1994; but see the discussion in Mapelli et al. 2004). However, Figure 6 shows that the number of BSSs nicely scales with the sampled luminosity in the central region as well as in the outer regions. It would be most remarkable if some combination of collision rate and kicks managed to produce the observed flat BSS distribution. Applying Occam’s razor, the simplest explanation is that the BSSs observed today in \( \omega \) Cen are the progeny of primordial binaries whose radial distribution has not yet been significantly altered by collisions.

Recently, Piotto et al. (2004) and Davies et al. (2004) showed from a large survey of BSSs in 56 GGCs that the total number of BSSs is largely independent of the cluster luminosity and collision rate, suggesting that no single process produces BSSs in GGCs (in accordance with Baily & Fusi Pecci 1992); hence, binary evolution and collisions could both be active processes in producing BSSs in different environments. In particular, Davies et al. (2004) developed a model for the production of BSSs in GGCs. In the low-mass systems (\( M_V > \sim -8 \)), BSSs arise mostly from mass exchange in primordial binaries. In more massive systems, collisions produce mergers of the primordial binaries early in the cluster history. BSSs resulting from these mergers evolved away long ago. Once the primordial binaries were used up, BSSs produced via this channel disappeared. In the cores of the most massive systems (\( M_V < \sim -9 \)), collisional BSSs are produced (Fig. 6 of Davies et al.).

Detailed cluster-to-cluster comparison has shown that the scenario is much more complex than that proposed by Davies et al. (2004). The dynamical history of each cluster apparently plays a role in determining the origin and radial distribution of BSS content. For example, (1) clusters with comparable luminosity show vastly different BSS populations; see, for example, the pairs M3/M13 (\( M_V \sim -8.7 \) and \( -8.5 \), respectively; Ferraro et al. 2003) and NGC 6752/M80 (\( M_V \sim -7.7 \) and \( -7.9 \), respectively; Sabbi et al. 2004; Ferraro et al. 1999); and (2) studies of the BSS population over the entire cluster extension (M3, Ferraro et al. 1997; 47 Tuc, Ferraro et al. 2004a; NGC 6752, Sabbi et al. 2004) have further supported the complexity of the emerging scenario that the central population of BSSs is only a component of the entire BSS population of each cluster. In addition to a strongly centrally segregated population, these GGCs also have a population of external BSSs, which we argue arise from primordial binaries. At intermediate radii there is a paucity of BSSs of either type, because the collision rate is low and primordial binaries settled to the center and probably became BSSs long ago.

How does \( \omega \) Cen fit into the Davies et al. (2004) picture? Following that scenario, since \( \omega \) Cen is very luminous, its primordial binaries would have been destroyed long ago, while a population of several hundred collisional BSSs should populate the core of the cluster (see Fig. 6 of Davies et al. 2004). Hence, we would expect to see a population of collisional BSSs in the core and possibly a population of surviving primordial binaries in the outer cluster. This would possibly produce a bimodal distribution as observed in other clusters, or even a single centrally peaked distribution, but in any case it cannot produce the flat distribution shown in Figure 6.8 From Figure 1 of Piotto et al. (2004) with \( M_V \sim -10 \), we would expect \( F_{\text{BSS}} \sim 0.1 \). Curiously, both \( F_{\text{BSS}} \) and the number of BSSs are close to what we observe. The curiosity

8 Unless one assumes (1) that the collision rate has the same efficiency in producing collisional BSSs in both the center and the cluster periphery or (2) that the efficiency of the collision rate in the center and the survival rate of primordial binaries in the outer region is the same.
arises because we argue that the BSSs originated from primordial binaries, while the Davies et al. scenario would suggest that they were all collisional.

We can compare the expected collision rate for \( \omega \) Cen (under the assumption that neither rotation nor the cluster history has made the estimate invalid) to that expected in other massive GGCs such as 47 Tuc. According to Davies et al. (2004), the collision rate is \( \Gamma_{\text{coll}} = 5 \times 10^{-15} (r_c \Sigma_0)^{1/2} \) in units of collisions per year (where \( \Sigma_0 \) is the central surface brightness in units of \( L_{\odot} \) \( \text{pc}^{-2} \) [equivalent to \( \mu_V = 26.41 \)] and \( r_c \) is the core radius. By assuming that \( r_c = 0.42 \) pc (Mapelli et al. 2004) and \( r_c = 4.1 \) pc for 47 Tuc and \( \omega \) Cen, respectively, we find that the expected collision rate is only 5–8 times larger in 47 Tuc than in \( \omega \) Cen (approximately 50–60 collisions \( \text{Gyr}^{-1} \) in the core of 47 Tuc compared to 6–11 in the core of \( \omega \) Cen), depending on the adopted central surface brightness values (Harris 1996; Djorgovski 1993). In any case, this difference does not seem sufficient to explain the quite different BSS content in the two clusters. This evidence further supports the complexity of the BSS formation and evolution scenario and suggests that the dynamical state of the cluster and its history play an important role in determining the BSS content.

Using the well-populated BSS sequence in \( \omega \) Cen, we can determine the production rate of BSSs in a noncollisional system. From the top panel of Figure 3 it is easy to derive that the primordial-binary BSS-specific frequency \( F_{\text{BSS}} \) is 0.08. Note that values up to 1 order of magnitude larger \( (F_{\text{BSS}} \approx 1) \) have been detected in the central region of GGCs (Ferraro et al. 2003). An even more useful quantity for the study of an unresolved stellar population is the ratio of the number of BSSs to the sampled luminosity in units of \( 10^4 L_{\odot} \). \( S_{\text{BSS}} = N_{\text{BSS}} / L_o \) (Ferraro et al. 1995). \( S_{\text{BSS}} \) varies from cluster to cluster (ranging from 0.2 to 30), possibly tracing the generation/destruction effect of stellar interactions in collisional systems like the dense cores of GGCs. The bottom panel of Figure 3 shows the radial behavior of \( S_{\text{BSS}} \) within \( \omega \) Cen. The rate of production is constant throughout the system, despite the large variation of stellar density. If \( S_{\text{prim}} \) refers to primordial binary BSSs, our results suggest that \( S_{\text{prim}} \sim 2 \) BSSs can be found for each \( \sim 10^4 L_{\odot} \) of sampled light. This value can be used to estimate the expected number of BSSs generated by primordial binaries for each fraction of sampled light in any stellar system.

Of course, the specific frequency of primordial BSSs is expected to depend on the fraction of primordial binaries contained in the stellar system under consideration. This fraction is still largely unknown; it has been estimated in only a few traditional GGCs (NGC 6752, Rubenstein & Bailyn 1997; NGC 288, Bellazzini et al. 2002; 47 Tuc, Albrow et al. 2001) and some lower density systems (Pal 13, Clark et al. 2004; E3, Veronese et al. 1996). In one of these (47 Tuc), the determination has been obtained in the very dense central region, where binaries are created, destroyed, and hardened by stellar collisions. It would be highly desirable to directly measure the binary fraction in \( \omega \) Cen. Sadly, the technique used by Bellazzini et al. (2002) and Rubenstein & Bailyn (1997) can hardly be applied to \( \omega \) Cen, because its MS is broadened by the abundance spread.

How does the BSS-specific frequency in \( \omega \) Cen compare with the field? The BSS-specific frequency \( (F \sim 0.1) \) measured here turns out to be 40 times lower than that \( (F \sim 4) \) found by Preston & Sneden (2000) in the field. Indeed, such a large frequency has never been observed in any GGC. One possible origin of this discrepancy is that GGCs never harbored the sort of primordial binaries that produce the long-period BSS binaries found in the field by Preston & Sneden. However, it must be noted that their value is only an indirect estimate derived from a chain of assumptions based on the observed fraction (60%) of the blue metal-poor field stars.

Indeed, the low BSS frequency compared to the field and the lack of segregation in \( \omega \) Cen are hard to reconcile. Strong cluster rotation, for example, could depress the frequency of collisional BSSs but would probably not affect the primordial binary population of the cluster. Thus, if the data in the field are eventually confirmed, the observations presented here strongly point at a substantial difference between the binary population in the field and the cluster.

As a final consideration, we note that there is now growing interest in determining the age of distant stellar systems from their integrated spectra. The main age discriminants arise from stars at the MSTO. Since BSSs are both hotter and more luminous than MSTO stars, a significant population of BSSs can make a system appear younger. Because the stellar density in galaxies is low enough that collisional BSSs are probably not important, BSSs in galaxies should have properties similar to those detected in \( \omega \) Cen. Hence, this BSS population can represent a suitable template for estimating the contribution of BSSs to the global spectral energy distribution of distant galaxies.

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