

## THE BLUE STRAGGLER STARS OF GALACTIC CLUSTERS

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The origin and evolution of blue straggler stars (BS) in clusters is still an unsolved problem for our understanding of stellar evolution. Several rivalling theories exist, of which that of Saio & Wheeler (1980) is the most interesting one since it assumes additional mixing of fuel in the interior of BS. This theory predicts larger luminosity-to-mass ratios for a given position in the HR diagram compared to the standard evolution theory. This theory has been tailored for the old galactic cluster NGC 7789 which contains many bona fide BS, but it can also be used for other clusters of similar ages. The other theories rely on the standard theory of stellar evolution and assume (1) binary mass exchange or even merging, or (2) delayed star formation. In either case follows a “normal” luminosity-to-mass ratio. We report here on a careful spectroscopic investigation in order to discriminate between these rivalling theories.

### THE OBSERVATIONS, FITTING PROCEDURE, AND INTERPRETATION

We observed B- and A-type BS in the clusters NGC 7789, M 67, NGC 752, and NGC 2632 (Praesepe) with the Coudé spectrograph of the 2.2 m telescope at the Calar Alto Observatory, equipped with a RCA CCD. The (reciprocal) dispersion was 9 Å/mm, and most images were centered on H $\gamma$  or H $\beta$ . Some images contained the He I 4471 Å line. Additional spectrograms were obtained for bright, well known stars to serve as comparisons.

Effective temperatures were derived by using existing photometric data ( $uvby\beta$ ) according to the prescriptions of Moon & Dworetsky (1985). This temperature determination appears to be very accurate ( $\approx \pm 150$  K) and agrees very well with that based on UV fluxes (Napiwotzki et al. 1992; Wenske & Schönberner 1992).

With  $T_{\text{eff}}$  fixed, surface accelerations, (projected) rotational velocities and Helium-to-Hydrogen ratios (if feasible) were derived by matching theoretical line profiles, computed with Kurucz’s fully line blanketed model atmospheres, to the observed ones. The results are listed in Table 1. The fit error of  $\log g$  is in most cases smaller than 0.05 dex. Together with the temperature uncertainty, the total error of  $\log g$  is not larger than only 0.1 dex!

Earlier attempts to solve the BS riddle by a direct mass determination failed because of insufficient data quality and distance errors (note that distance enters squared into any direct mass determination). We use the luminosity to mass ratio,  $L/M \sim g^{-1}T_{\text{eff}}^4$  which is a distance independent quantity. Actually, we compare the relative luminosity-to-mass ratio,  $(L/M)_{\text{ZAMS}}/(L/M) = g/g_{\text{ZAMS}}$  with  $R/R_{\text{ZAMS}}$  at the same temperature.  $R_{\text{ZAMS}}(T_{\text{eff}})$  and  $g_{\text{ZAMS}}(T_{\text{eff}})$  can be

TABLE I Temperatures, gravities, and rotation of BS

Cluster	No.	$T_{\text{eff}}$ (K)	$\log g$			He/H	$v \sin i$ ( $\frac{\text{km}}{\text{s}}$ )
			$H_{\beta}$	$H_{\gamma}$	adopted		
NGC 7789	M 459	10800	3.67		3.67		100
	M 460/K 282	9400	3.64	3.62	3.63		80
	M 502/K 342	10600	3.95	4.01	3.98		100
	M 574/K 453	11650	4.02	4.04	4.06		120
	M 747/K 677	10650	4.12				
			3.55	3.59	3.57		40
M 67	F 81	12730		4.25	4.25	0.10	80
NGC 752	Hm 209	9690	4.22	4.22	4.22		50
NGC 2632	40 Cnc	9580		3.91	3.91		20
	$\gamma$ Gem	9260		3.51	3.51		$\leq 20$
	$\alpha$ CMa	9970		4.30	4.30		$\leq 20$
	$\beta$ Leo	8850		4.05	4.05		120
	$\alpha$ Lyr	9660		4.03	4.03		$\leq 20$

taken from theory (e.g. Hejlesen 1980), and the distance enters only linearly.

If we plot a diagramme  $g/g_{\text{ZAMS}}$  vs.  $R/R_{\text{ZAMS}}$ , with both ratios taken at the same  $T_{\text{eff}}$ , the ZAMS is projected into the origin, and the evolutionary tracks of different mass into virtually one single line ( $T_{\text{eff}} \geq 6500$  K). The artificially mixed models of Saio & Wheeler (1980) run steeper and depend on the parameter  $q_{\text{mix}} = M_{\text{mix}}/M$  which indicates the mass fraction that is kept chemically homogenous. The differences to the standard evolution is quite noticeable for  $q_{\text{mix}} \geq 0.8$  (Fig. 1). Homogeneous evolution ( $q_{\text{mix}} \approx 1$ ) proceeds nearly vertically!

For the 4 comparison stars in Table 1, stellar radii are known from parallaxes and angular diameter measurements (Code et al. 1976), and they are also shown in Fig. 1. We conclude that our method can separate stars that evolve according to the standard rules from those that behave as proposed by Saio & Wheeler, provided distances and gravities are sufficiently well known, and  $q_{\text{mix}} \geq 0.7$ !

According to Saio & Wheeler (1982) the brightest BS of NGC 7789 still close to the ZAMS can only be explained with  $q_{\text{mix}} \approx 0.7 \dots 0.95$ . Likewise,  $q_{\text{mix}} > 0.95$  is needed for F 81 in M 67,  $q_{\text{mix}} \approx 0.9$  for Hm 209 in NGC 752, and  $q_{\text{mix}} \approx 0.5$  for 40 Cnc in NGC 2632. To compute individual radii, we used the  $V$  fluxes of the Kurucz models for the appropriate  $T_{\text{eff}}$  and compared them to the observed fluxes from  $V_0$ , which yields angular diameters. With the cluster distances  $d$  follows then  $R$ . The cluster distances are taken from the literature. That of NGC 7789 is the most uncertain one, with  $\Delta(V - M_V) = \pm 0.2$ . Our mean value of  $V - M_V = 11.40$  corresponds to the recent determination of Twarog & Tyson (1985). Further we used  $V - M_V = 9.55$  for M 67, 8.20 for NGC 752, and 6.00 for NGC 2632. With the radii known, these BS can be also plotted into the  $g/g_{\text{ZAMS}} - R/R_{\text{ZAMS}}$  diagramme of Fig. 1. This figure shows very convincing that all investigated BS have evolved according to standard evolutionary theory! The regression line,  $\Delta \log g = -0.002 - 1.663 \Delta \log R$ , nearly coincides with the

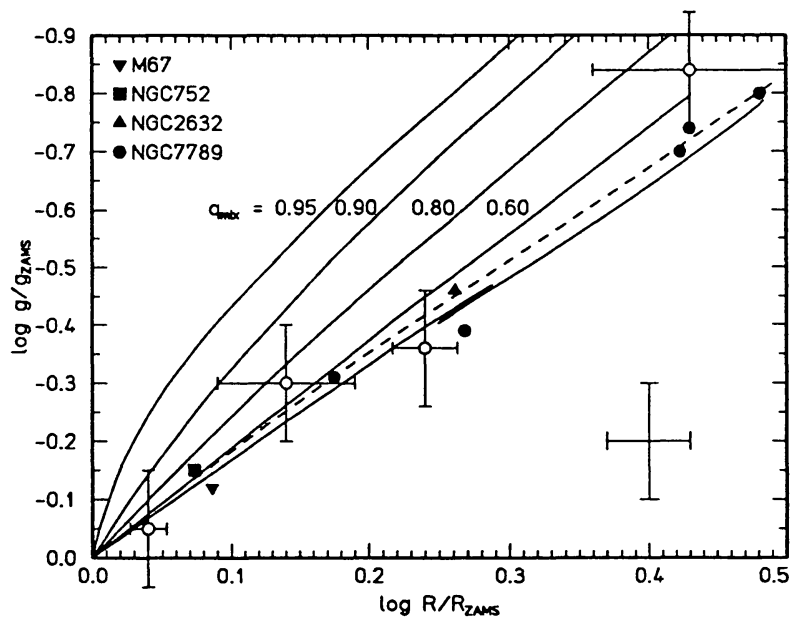


FIGURE 1  $g/g_{ZAMS}$ - $R/R_{ZAMS}$  diagramme for BS (filled symbols) and comparison stars (open symbols). A typical error bar for the BS parameters is given in the lower right corner.

predictions of this theory. Saio & Wheeler's "mixing theory" would predict a large scatter in Fig. 1 according to the various mixing parameters assigned to these objects ( $q_{\text{mix}} \approx 0.7 \dots 1$ ).

## CONCLUSIONS

We disproved by a careful spectroscopic analysis of BS stars in various open clusters the possibility of additional mixing processes as proposed by Saio & Wheeler (1980) and (Wheeler 1979). The investigated BS stars are in an evolutionary state consistent with standard evolution theory. BS stars must be the result of either (1) binary star evolution (mass exchange or merger), or (2) delayed star formation.

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