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Spectral analysis of sdB stars from the Hamburg ESO survey

H. Edelmann, U. Heber, R. Napiwotzki, M. Lemke

Dr. Remeis Sternwarte, Sternwartstraße 7, 96049 Bamberg, Germany

N. Christlieb

Hamburger Sternwarte, Gojenbergsweg 112, 21029 Hamburg, Germany

Abstract. We aim at the compilation of a statistically complete sample of sdB stars in the southern hemisphere. Candidates are selected from the database of digitized spectra of the Hamburg/ESO objective prism survey. First simulations and independent test samples indicate a completeness of the order of 95 %. A total of ~ 600 sdB candidates of $12^{m}_{.}5 < B_J < 17^{m}_{.}5$ have been isolated from a survey area of ~ 5900 $\deg^2$. During the first three observing runs medium resolution spectra of 90 stars brighter than $B = 16^{m}_{.}0$ were obtained, 85 (or 94%) turned out to be sdB or HBB stars. Fundamental parameters (effective temperature, gravity and helium abundance) of all sdB and HBB stars were derived by means of LTE and NLTE model atmospheres in order to determine spectroscopic distances. We derive a scale height for the sdB stars of $z_0 = 350$pc and a space density of $d = 1.5 \cdot 10^{-6}$ pc^{-3}.

1. Introduction

Subluminous B (sdB) stars dominate the population of faint blue stars to $16^{m}_{.}5$ at high galactic latitudes. For example 40% of all stars in the Palomar Green (PG) catalog are sdB stars. They were found both in the old disk and in the halo population. Although some time ago, spectroscopic analysis have revealed that sdB stars are extreme horizontal branch (EHB) stars and direct progenitors of white dwarfs with low to intermediate masses, their origin is still unclear. Their scale height, space density and birthrate are poorly known and recent results are in conflict with earlier ones. But these quantities are important for clarifying their unknown origin.

First estimates of the space density were derived from a small stellar sample by Heber (1986), who observed 12 stars at the South Galactic Pole. He derived a space density of 4×10^{-6}pc^{-3} and a scale height of about 200 pc. Subsequent spectroscopic analyses (i.e. Moehler et al. 1990a), which were based mainly on small subsamples of the PG survey gave results consistent with the first estimate.

Saffer & Liebert (1994) presented an analysis of a large sample of about 100 sdB stars selected from the Palomar Green (PG) catalog. Their scale height of about 500pc, however, is about twice as large as the previous results and their space density consequently is lower by a factor of four ($7.5 \times 10^{-7}\mathrm{pc}^{-3}$). The advantages of their work are the large sample size and the fainter limiting magnitude of $B \leq 15\overset{m}{.}6$ whereas the others only had a limiting magnitude of about $14\overset{m}{.}0$. But the completeness of the PG survey on which Saffer & Liebert's results are based on, might be smaller than assumed up to now (Homeier et al., 1998). Part of this incompleteness is probably due to large uncertainties of the PG photometry.

The first photometric analyses of a large sample of PG sdB stars were carried out by Villeneuve et al. (1995). Temperatures and distances of 209 sdB stars were determined from Strømgren photometry by assuming plausible gravities and masses of their program stars. Their exponential scale height of (450 ± 150) pc, however, is twice as large as the spectroscopic results of Heber (1986) and their space density of $(3 \pm 1) \times 10^{-7}\mathrm{pc}^{-3}$ is a factor of about 10 times lower than the results of Heber (1986), but in reasonable agreement with the results of Saffer & Liebert (1994). The advantages of this analysis are also the large sample size and the limiting magnitude of $B \leq 15\overset{m}{.}0$. The disadvantages are again the possible incompleteness of the PG survey and the usage of 'plausible' gravities, whereas in the spectroscopic analyses individual gravities can be derived.

Finally, kinematic analyses of de Boer et al. (1997) who observed 41 stars from the PG survey yielded a scale height of about 1 kpc, which is much larger than any other result.

2. Sample

To improve our knowledge of the scale height and space density we aim at their determination from an independent, large and statistically complete survey. The Hamburg ESO objective prism survey (Wisotzki 1996), meets these requirements. We have chosen several sky fields, some of them overlapping with the Slettebak & Brundage (1971) survey. SdB stars from the latter survey have already been studied by Heber (1986). Our aim is to increase the sample size to about 100 stars.

But the problem is to isolate all sdB candidates from the HE survey. We are using different steps to pre-classify the stars:

- First step: A color index is measured from the calibrated photographic plates (checked with CCD photometry, Altmann 2000, priv. comm.) to prevent cool stars getting in the sample.

- The digitized spectra selected in step 1 are inspected by eye for the presence of Balmer lines and the absence of ionized helium lines, which classifies subluminous B stars.

These two steps are sufficient for the brighter stars, where the S/N of the objective prism spectra are pretty good. But for the fainter ones this results in two problems: First, we could not identify all sdB stars, so the completeness of the survey is not guaranteed and there are misclassifications.

So we took a third identification step:

- The flux classification. Here we used model flux distributions folded with the photographic density curve of the HE photographic plates and compared them with the digitized HE spectra by adding noise to the theoretical spectra.

This 3rd step yielded about 600 sdB candidates with $12\overset{m}{.}5 < B_J < 17\overset{m}{.}5$ isolated from a survey area of about 5900 deg^2.

Our aim is to observe all sdB's with $B \leq 16$mag from 36 HE survey fields. With our classification scheme we found 97 candidates. Until now, 90 stars have already been observed at the ESO 1.52m telescope using the Boller and Chivens spectrograph covering a spectral range from 3500...7000Å, and at the ESO 1.54m Danish telescope using the Danish Faint Object Spectrograph and Camera (DFOSC) Instrument covering a spectral range from 3500...5500Å. The spectral resolution is about 5.5 and 5.3 Å, respectively.

85 stars, which is about 94% of all stars, turned out to be sdB (69) or HBB (16) stars (classification like Moehler et al. 1990b). The others where two hydrogen rich sdO's, one hot DA white dwarf, one normal main sequence B star and one DBA white dwarf.

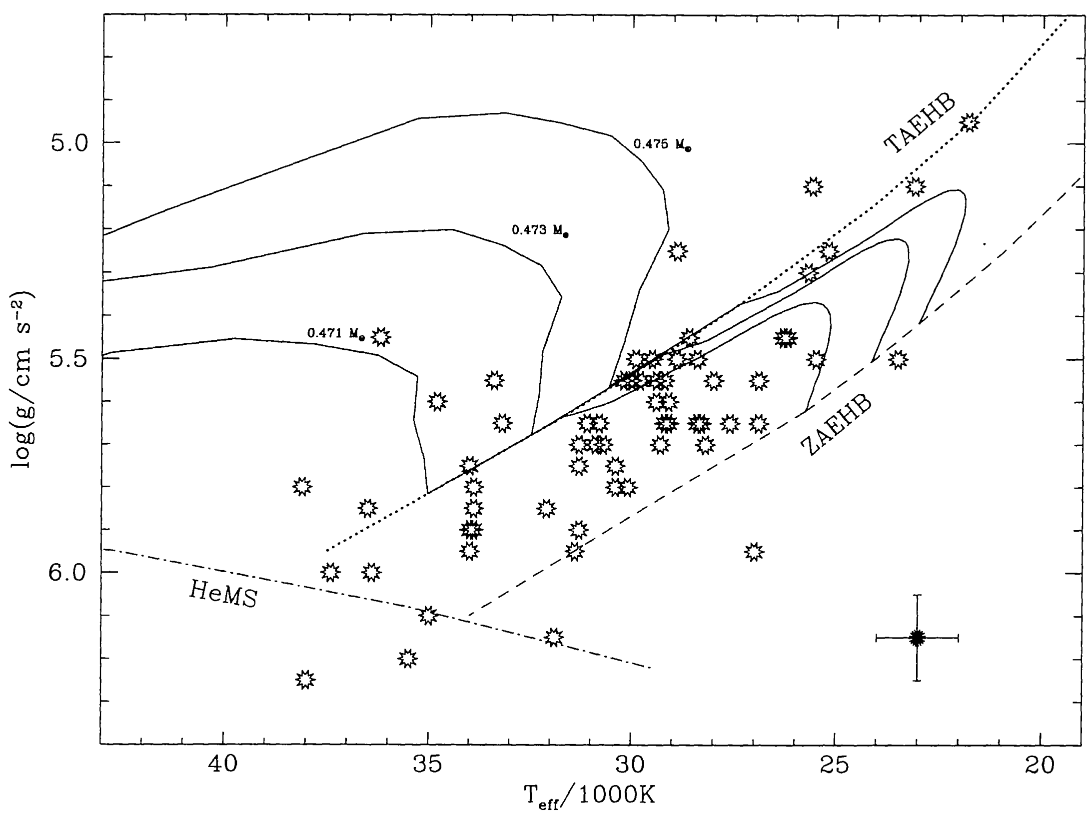

Figure 1. Distribution of the complete (by now) sample in the T$_{\rm eff}$ – log(g) plane.

3. Model atmosphere analyses

The fundamental parameters (effective temperature, gravity and helium abundance) of all sdB's were derived from the spectra by means of a χ^2 fit (fitting procedure of Bergeron et al. 1992 and Saffer et al. 1994) using fully line blanketed LTE model atmospheres (updated version of the code of Heber 1986) as well as Hydrogen and Helium blanketed NLTE model atmospheres (Napiwotzki 1997).

Results for 69 sdB stars are shown in Fig. 1 in a theoretical Hertzsprung Russell Diagram (gravity versus effective temperature). The Zero Age Extended Horizontal Branch (ZAEHB), the Terminal Age Extended Horizontal Branch (TAEHB), which indicates the end of the helium-core-burning, the helium-main sequence, and evolution tracks for extended horizontal branch stars from Dorman et al. (1993) for three different stellar masses are shown for comparison. Almost all sdB stars lie between the ZAEHB and the TAEHB (at least to within their observational errors).

4. Scale height and space density determination

The canonical mass for a sdB star of 0.5 $M_\odot$ is adopted to derive spectroscopic distances. Together with the derived gravities, we can determine the radius of the stars. By comparing the model atmosphere flux with the flux observed one at the earth, the angular diameter of the star could be determined. ¿From radius and angular diameter of the star, the distance from the earth follows immediately. The reddening of all our observed sdB stars is negligible ($E(B-V) < 0.03$).

Assuming a barometric number density distribution, the cumulative counts to a given limiting magnitude (here $16\overset{m}{.}0$) and distance z from the plane is given by $f_{cum}(< z) \propto 2 - e^{-\mu}(\mu^2 + 2\mu + 2); \mu = z/z_0$. Theoretical curves for scale heights from 200pc to 600pc are plotted in Fig. 2. Our (preliminary) result matched best by a scale height of about 350 pc. (It may be noted, that here only the 44 stars from the 30 complete fields are plotted.)

With our apparent magnitude limit of $B = 16\overset{m}{.}0$ and the derived scale height of $z_0 = 350$pc the local space density can be derived by calculating the maximum density weighted volume accessible to each object $V'_m(i)$ (Green 1980). Each HE survey field has a size of $5° \times 5°$, resulting in an effective field size of $27.4° \times 27.4°$. The space density d can be calculated using the $1/V'_m(i)$ method and summing over the sample with

$$V'_m(i) = 4[\sin(b)]^{-3}[\tan(13.7°)]^2 \int_0^{z_{\rm lim}(i)} e^{-z/z_0} z^2 \, dz \quad (b \text{ is the Galactic latitude}).$$

resulting in $d = 1.5 \cdot 10^{-6}$ stars/pc^3.

5. Conclusion

The subsample of 44 stars from the Hamburg ESO objective prism survey shows that our preliminary result of the sdB scale height, $z_0 = 350$pc, is within the error limit consistent with the photometric result of Villeneuve et al. (1995) and

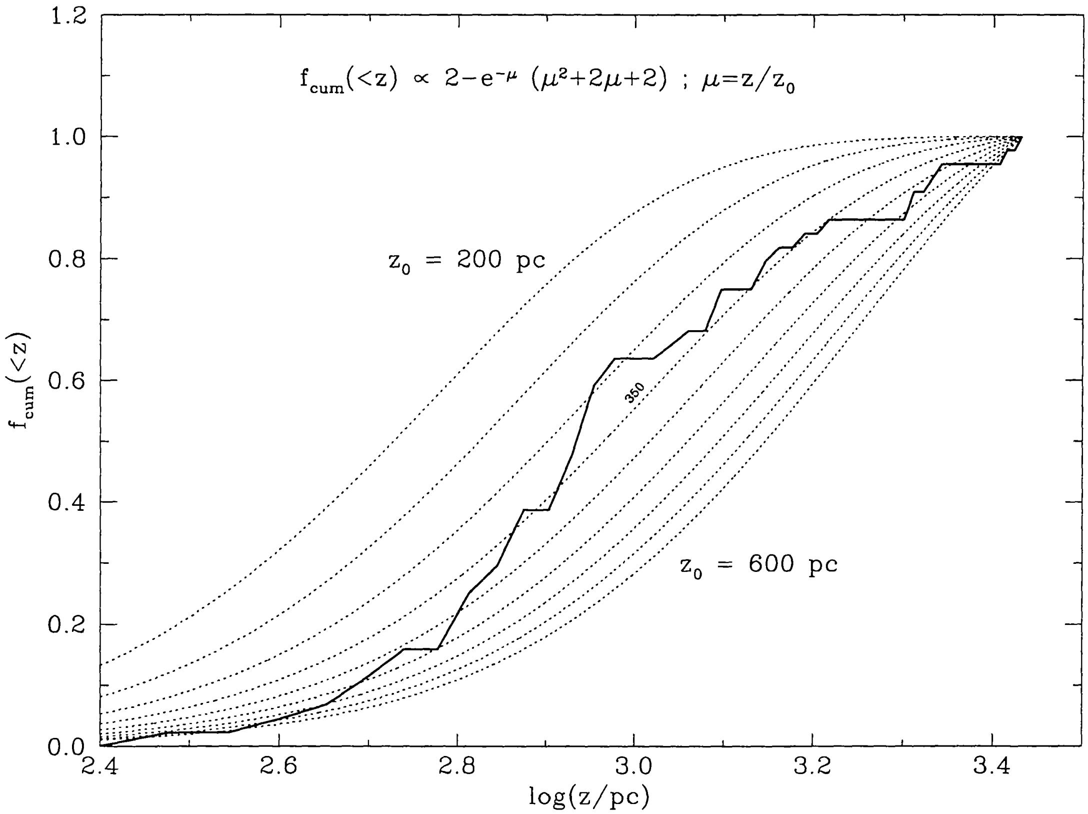

Figure 2. Cumulative scale height determination (solid line) from 44 stars within the 30 complete survey fields compared to theoretical predictions (dotted) for scale heights of 200pc to 600pc in steps of $\Delta z = 50$pc.

lies in between the spectroscopic results of Heber (1986) and Saffer & Liebert (1994). Our estimate of the space density, $d = 1.5 \cdot 10^{-6}$ pc^{-3} lies also in between the spectroscopic results of Heber (1986) and Saffer & Liebert (1994) but is larger than the photometric result of Villeneuve et al. (1995) by a factor of about 5. This demonstrates the importance of determining individual gravities. Observations of 7 sdB candidates are still necessary to complete our sample.

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