MAX-PLANCK-GESELLSCHAFT

On Using the Color-Magnitude Diagram Morphology of M67 to Test Solar Abundances

Z. Magic, A. Serenelli and A. Weiss
Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany
magic@mpa-garching.mpg.de

Max-Planck-Institute
for Astrophysics

Aim of this work

The chemical composition of the Sun had been assumed to be known very accurately, e.g. see Grevesse et al. 1998 (**GS98**). However, a recent determination by Asplund et. al 2005 (**AGS05**) revised the **solar abundances** (SA), in particular CNO-elements, downward by more than 30%. The open cluster M67 has solar metallicity and an age of about 4 Gyr. The morphology of the **color-magnitude diagram (CMD) of M67** around the turnoff (TO) shows a clear **hook-like feature**, a direct sign that stars close to the TO have a **convective core** (CC). VandenBerg et al. 2007 (VG07) investigated the possibility of using the morphology of the M67 TO to put **constraints on the solar metallicity**. Here, we extend their work, filling the gaps in their analysis. To this aim, we compute isochrones appropriate for M67 using new (low metallicity) and old (high metallicity) SA and study whether the **characteristic TO of M67 can be reproduced or not**. We also study the importance of other constitutive physics on determining the presence of such a hook, particularly **element diffusion**, **overshooting** and **nuclear reaction rates**. The presented findings are already published in Magic et al. 2010.

Recovering VG07

In the first place, we were able to confirm the findings of VG07. Therefore, we computed isochrones with our stellar evolution code (**GARSTEC**, see Weiss et al. 2008 for a detailed description) for both SA and applied the same color-transformation and photometrical parameters for M67, which are shown in Fig. 1. The new SA (AGS05) lacks clearly the hook-like TO morphology, while the old composition (GS98) reproduces it well. This comes due to the fact that the development of a CC on the main-sequence, as a result of the dominance of the CNO-cycle over the pp-chain, is less likely by virtue of the lower metallicity.

Inclusion of diffusion

As already mentioned by VG07, the inclusion of atomic diffusion (AD) leads to an enrichment of heavier elements in the core over time due to **gravitational settling**. This in turn supports the occurrence of a CC, so that now both SA have the same TO morphology, as given in Fig. 2. Since M67 has a similar age as the Sun (4.57 Gyr), AD is also mandatory in order to fit the helioseismic inferences correctly. The same results were already made by Michaud et al. 2004, they could match the TO of M67 by just including AD.

Overshooting

VG07 needed to include a small amount of overshooting (OS). OS extends the border of the CC due to the **non-zero inertia** of the up-flowing material. When a small CC is already present, OS can increase its size such that the TO morphology can be altered considerably (see Fig. 3) depending on the respective amount of OS and its implementation. It should be stressed that both with its free parameter cannot be taken as granted, since OS is still a subject of current research.

Nuclear reaction rates

We considered the influence of the nuclear reaction rates as well, in particular the important **"bottle neck" rates** $^{14}\mathrm{N}(p,\gamma)^{15}\mathrm{O}$ and $^{17}\mathrm{O}(p,\alpha)^{14}\mathrm{N}$. New lab measurements (Marta et al. 2008, Moazen et al. 2007) have revised the former rate by almost a factor of two compared to the NACRE rate (Angulo et al. 1999). Now both SA show no sign of a CC, since the CNO-cycle depends also on the reaction rates. Only after taking AD and OS into account, the TO morphology of M67 can be reproduced for **both** SA, see Fig. 4. Nevertheless, we note that for GS98 it is easier to do so.

Comparison with other codes

At last, we compared our findings with two other independently developed stellar evolution codes (**LPCODE, Dartmouth**). In Fig. 5, it can easily be seen that models with both codes show a very similar evolution along the HRD; differences are hardly noticeable. Therefore, the isochrones are correspondingly of a similar quality, as shown in Fig. 6, which holds also for other choices of constitutive physics. We can rule out any systematical uncertainties and the conclusions of our work are assured.

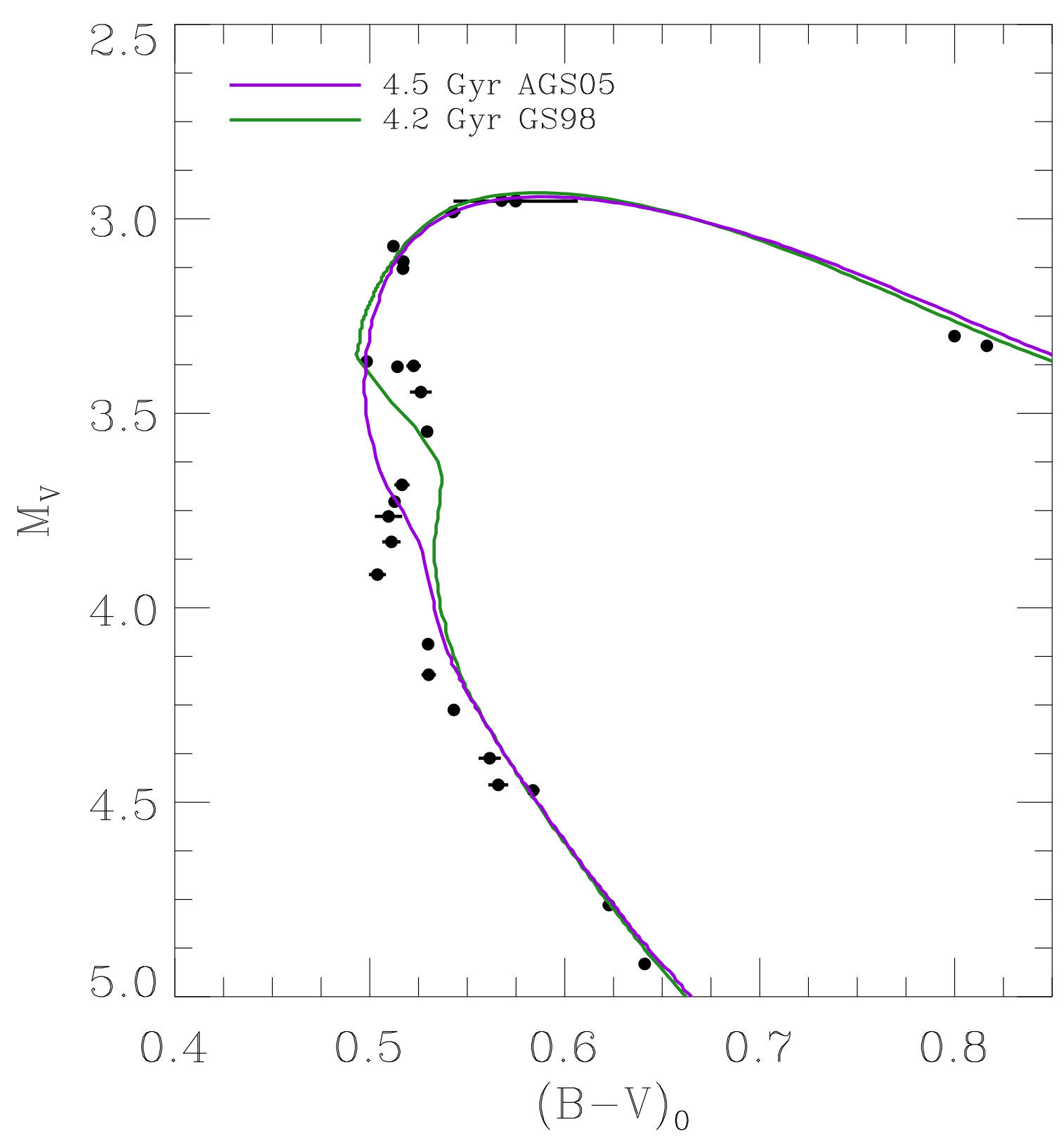

Fig. 1: CMD of M67 (Sandquist 2004) with isochrones for the two SA AGS05 and GS98 in agreement with **VG07**.

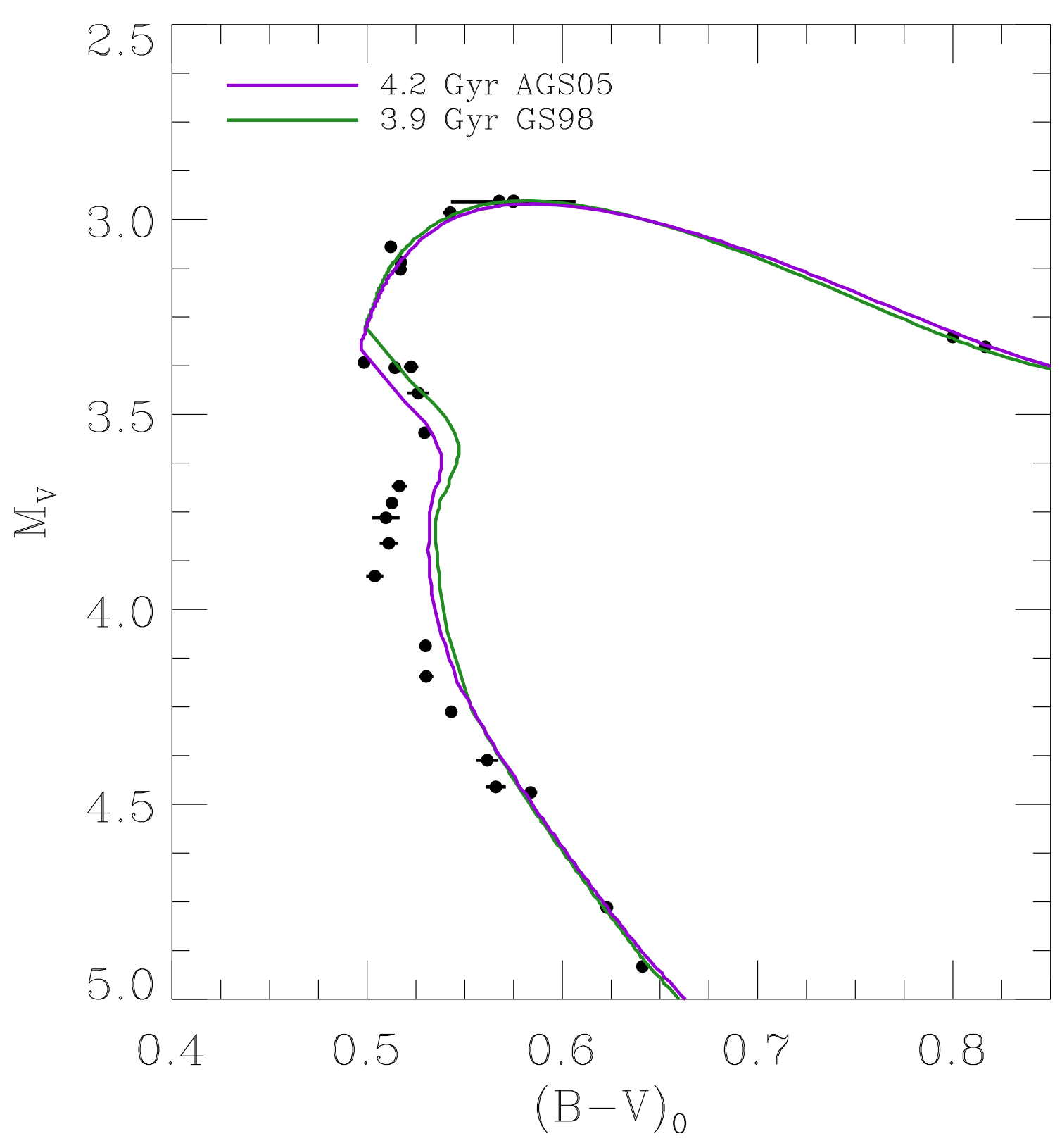

Fig. 2: Isochrone fit to M67 including **diffusion** in both solar calibration and tracks for M67 ; no overshooting was considered.

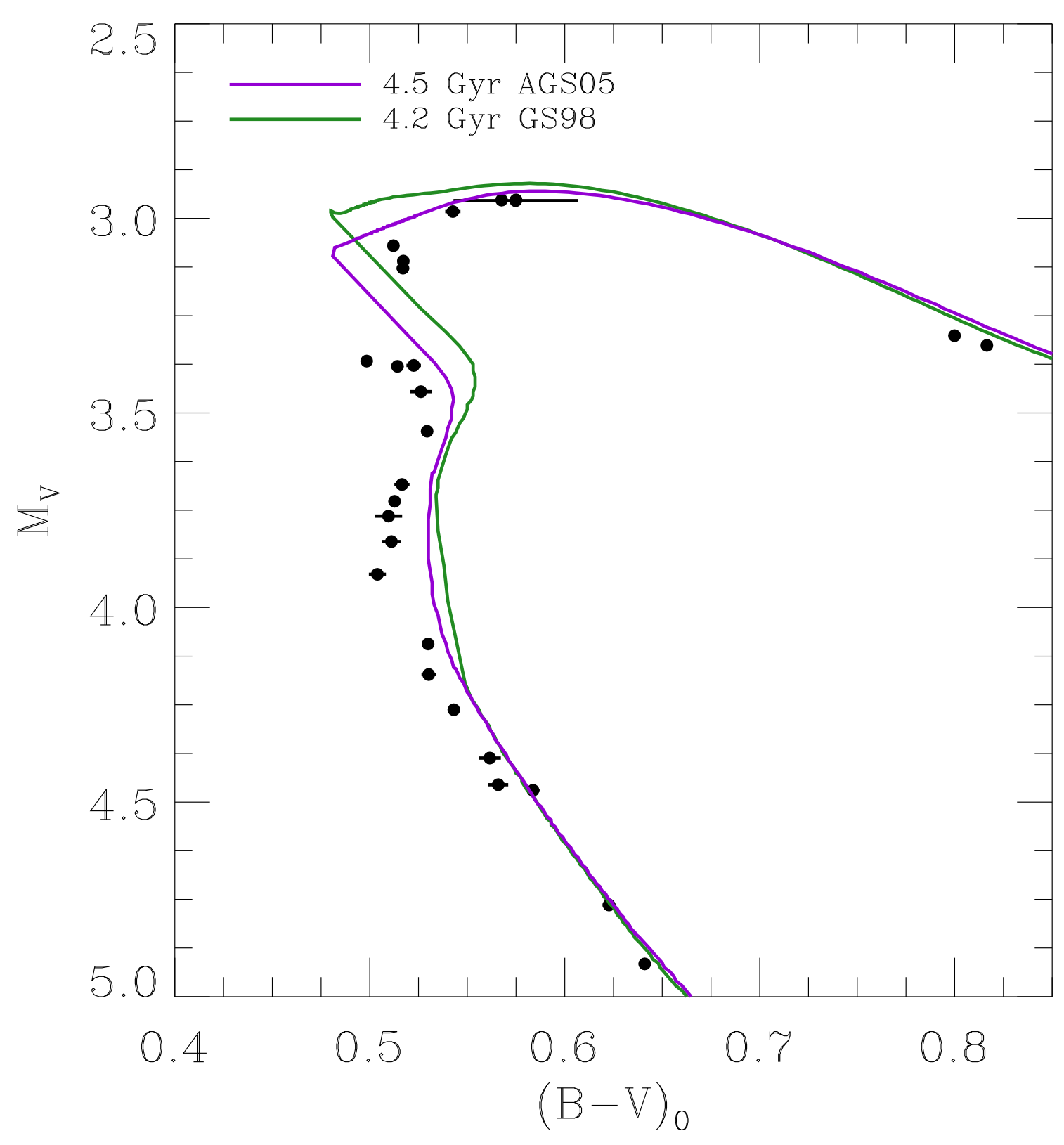

Fig. 3: Isochrone fit to M67 with **overshooting** taken into account; no diffusion was considered.

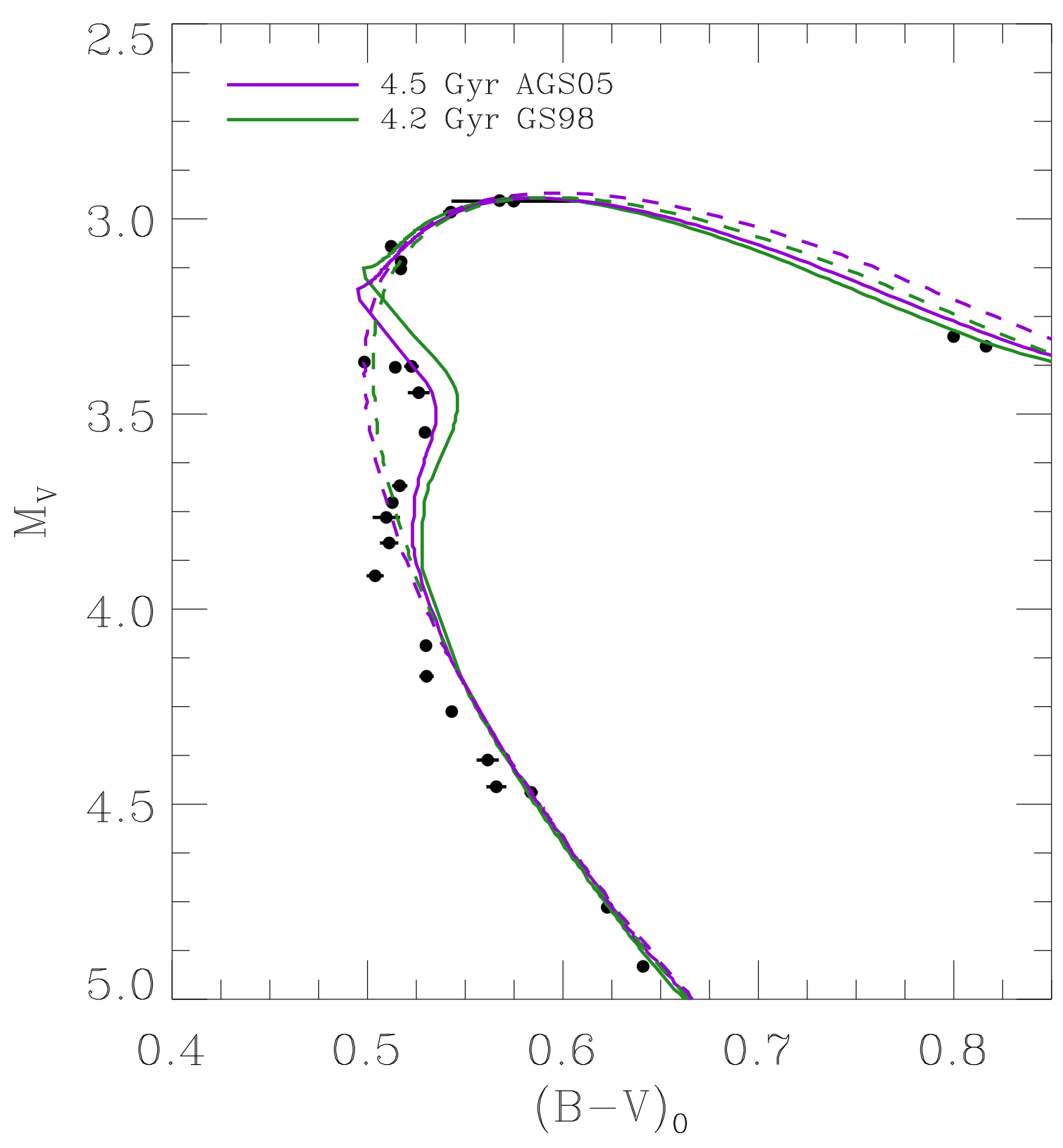

Fig. 4: Isochrones with updated **nuclear reaction rates** (dashed) and including also both diffusion and overshooting (solid).

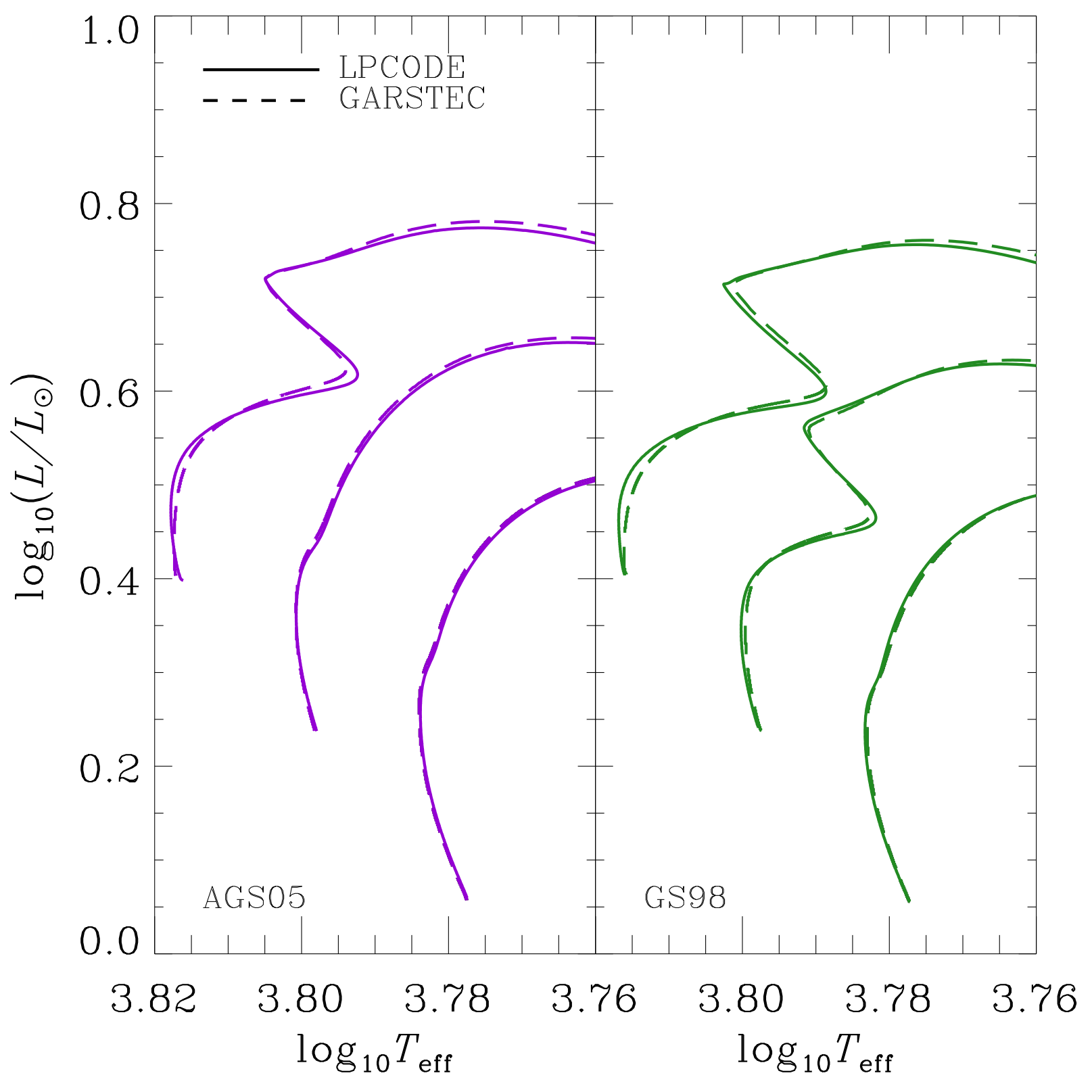

Fig. 5: Comparison between **LPCODE** and GARSTEC. Here, tracks (1.1, 1.2, and 1.3 $M_\odot$) used for Fig. 4 are shown.

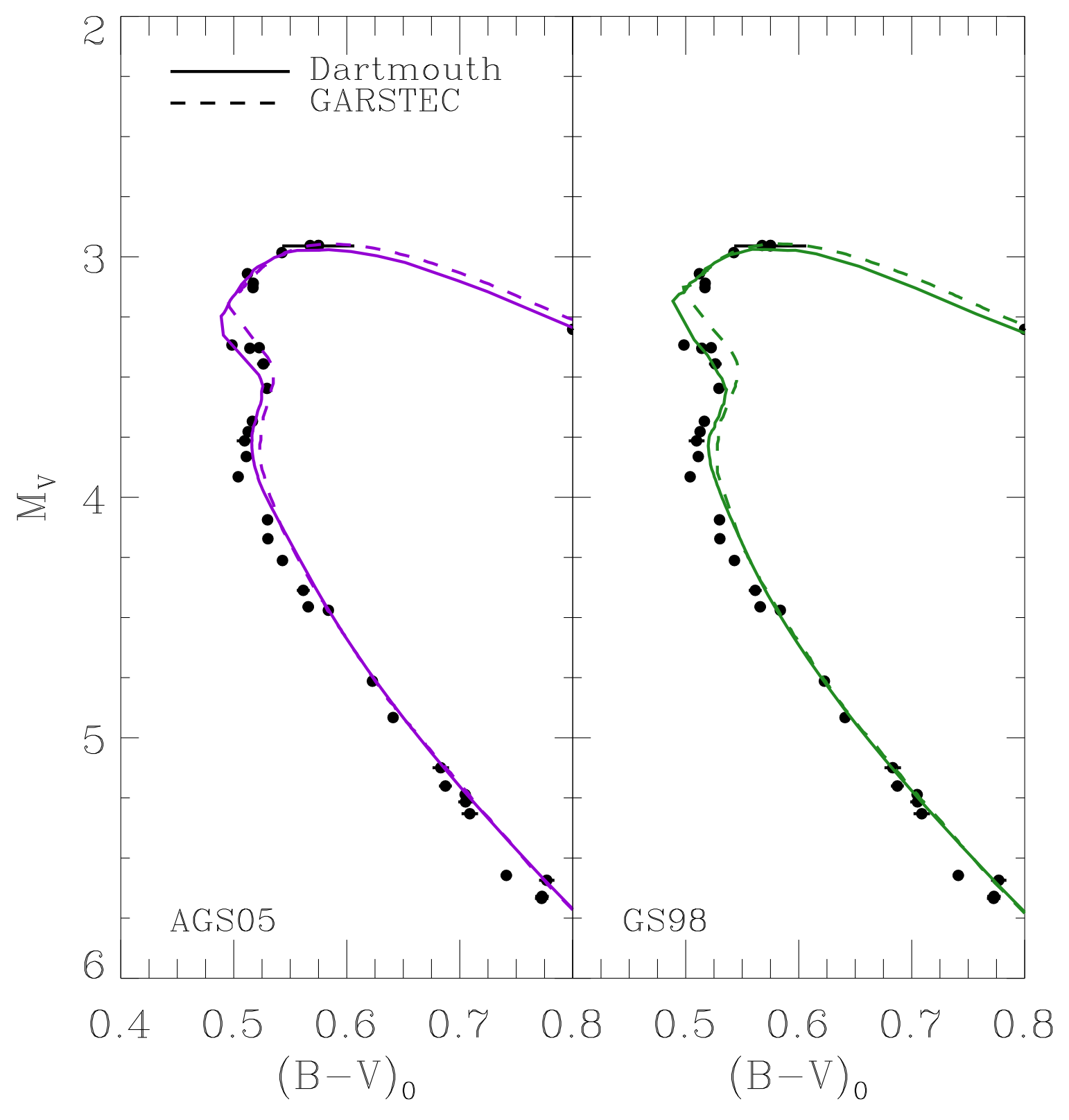

Fig. 6: Comparison between the **Dartmouth** code and GARSTEC. CMDs of M67 showing the same isochrones from Fig. 4.

Conclusions

We find that using the new SA makes it more difficult to reproduce M67. This result is in agreement with results by VandenBerg et al. However, changes in the constitutive physics of the models, particularly overshooting, can influence and alter this result to the extent that isochrones constructed with models using low CNO SA can also reproduce the TO morphology in M67. We conclude that only if all factors affecting the TO morphology are completely under control (and this is **not the case**), M67 could be used to put constraints on SA.

References

- Angulo, C., et al. 1999, Nuclear Physics A, 656, 3
- Asplund, M., Grevesse, N., & Sauval, A. J. 2005, in Astronomical Society of the Pacific Conference Series, Vol. 336
- Grevesse, N. & Sauval, A. J. 1998, Space Sci. Rev., 85, 161
- Magic, Z. Serenelli, A. Weiss, A. & Chaboyer, B. 2010, ApJ, 718, 1378
- Marta, M. et al. 2008, Phys. Rev. C, 78, 022802
- Michaud, G., Richard, O., Richer, J., & VandenBerg, D. A. 2004, ApJ, 606, 452
- Moazen, B. H. et al. 2007, Phys. Rev. C, 75, 065801
- Sandquist, E. L. 2004, MNRAS, 347, 101
- VandenBerg, D. A., Gustafsson, B., Edvardsson, B., Eriksson, K., & Ferguson, J. 2007, ApJ, 666, L105
- Weiss, A. & Schlattl, H. 2008, Ap&SS, 316, 99