Stars and their variability observed from space
C. Neiner, W. W. Weiss, D. Baade, R. E. Griffin, C. C. Lovekin, A. F. J. Moffat (eds)

THE AGE OF ZERO AGE MAIN SEQUENCE STARS AS AN ANALYTIC FUNCTION OF MASS

T. Steindl[1] and K. Zwintz[1]

Abstract. We discuss the need for an improved theoretical definition of the zero age main sequence (ZAMS) for stellar evolution models. We show that this may be achieved by creating an analytic function of the ZAMS age as a function of stellar mass by investigating the hydrogen abundance throughout the star. To achieve this, the most probable ZAMS model for different stellar masses in the range 0.5–6.0 $M_\odot$ is determined. The corresponding ages are then fitted with a piecewise power law function.

Keywords: Stars: pre-main sequence, methods: numerical

1 Introduction

The computation of stellar models is very important for the understanding of stellar structure and evolution. The typical approach is to create stellar models for different sets of input physics that define the characteristics of each evolutionary calculation. Different stellar models, calculated with two distinct sets of such input physics, are compared at the same relative evolutionary stage so as to infer information about the structure of a star.
During evolution on the main sequence, the core hydrogen abundance may be used as a proxy for age and therefore relative evolutionary stage, as has been demonstrated in the past (e.g. Aerts et al. 2018). Pre-main-sequence stars do not exhibit full equilibrium hydrogen burning and therefore a similar approach can not be applied to infer relative ages.
For the study of pre-main-sequence stars it is important to find stellar properties that can play the same role as the central hydrogen abundance does for main-sequence stars. This may be achieved by considering stellar properties relative to their values at the zero age main sequence (ZAMS) as a reference point, where the pre-main-sequence phase ends. We therefore need a reliable definition of the ZAMS. Any such method should be reliable for the whole mass range of pre-main-sequence stars.
Different definitions of the ZAMS have been considered in the past. We find that they all show problems for stars in specific mass ranges. We discuss how the hydrogen profile throughout the star in element diffusion-free models may be used to infer the most probable ZAMS model for pre-main sequence models of any mass in the range 0.5–6.0 $M_\odot$. All of our models have been calculate using version 11701 of the stellar-evolution code "Modules for Experiments in Stellar Astrophysics" (`MESA`) (Paxton et al. 2011, 2013, 2015, 2018, 2019).

2 ZAMS age as an analytic function of mass

Stars originate from clouds of molecular matter. It is therefore reasonable to assume uniform element abundances at the beginning of their evolution. Those abundances become changed by different physical mechanisms, e.g. nuclear reactions or chemical mixing. Furthermore, dynamical instability leads to constant abundances in convective regions and therefore to discontinuities of the hydrogen abundance at convective boundaries.
Figure 1 shows the hydrogen abundance X_{H} towards the end of the pre-main-sequence lifetime. Hydrogen burning in a convective stellar centre introduces a discontinuity in the hydrogen profile. A subsequent change of the position of the convective boundary then introduces multiple discontinuities (in this case two as depicted in Fig. 1). Mixing gradually reduces the size of the discontinuity until the hydrogen profile is again continuous. The right panel of Fig. 1 shows only one discontinuity at the convective boundary; it corresponds to a main-sequence star.
As this effect is present in all our stellar models, we use it to define the ZAMS. The most probable ZAMS model is therefore the first stellar model that shows no discontinuities (apart from the convective core) in the

[1] Institute for Astro and Particle Physics, 6020 Innsbruck, Austria

hydrogen profile.
We acknowledge the fact that more efficient mixing or the inclusion of element diffusion and gravitational settling might induce changes to the profiles identified as the most probable ZAMS model. It remains to be seen if this influences the hydrogen profile to such an extent that it renders that definition unfeasible, but at this stage we have no reason to believe so.
We have calculated a total of 100 stellar models, and searched for the most probable ZAMS model. The resulting ages seem to be described well by a piecewise power law. Fitting a piecewise power law function then provides the ZAMS age as an analytic function of mass. We find that the resulting ages agree well with previous definitions for corresponding mass ranges.

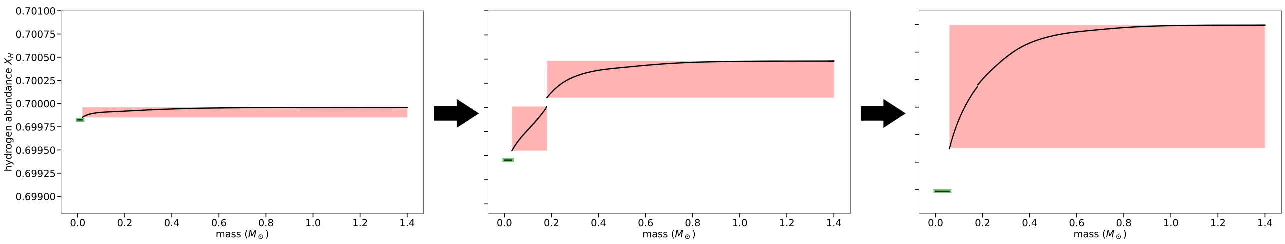

Fig. 1. The hydrogen abundance (black) as a function of mass for a $1.4\,M_\odot$ star. The green area shows the convective region; non-convective zones of continous hydrogen abundance are shaded in red. The hydrogen burning convective centre introduces a change in the hydrogen abundance. The moving position of the convective boundary then lets discontinuities appear. The hydrogen abundance of main-sequence stars shows no discontinuities, apart from the convective core.

3 Conclusions

We provided a possible new definition of the ZAMS age for stellar models. It relies on the hydrogen profile throughout the star to define the most probable ZAMS model for a MESA evolution of a pre-main-sequence star. While it remains to be shown that this methodology works for models that include higher amount of mixing as well as element diffusion and gravitational settling, it provides a reliable way of inferring ZAMS ages for all masses in the range 0.5–6.0 $M_\odot$.

References

Aerts, C., Molenberghs, G., Michielsen, M., et al. 2018, ApJS, 237, 15
Paxton, B., Bildsten, L., Dotter, A., et al. 2011, ApJS, 192, 3
Paxton, B., Cantiello, M., Arras, P., et al. 2013, ApJS, 208, 4
Paxton, B., Marchant, P., Schwab, J., et al. 2015, ApJS, 220, 15
Paxton, B., Schwab, J., Bauer, E. B., et al. 2018, ApJS, 234, 34
Paxton, B., Smolec, R., Schwab, J., et al. 2019, ApJS, 243, 10