Stars and their variability observed from space
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ASTEROSEISMIC BINARIES AS NON-SOLAR MIXING LENGTH CALIBRATORS

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Abstract. We report on a preliminary investigation into the utility of various binary systems exhibiting solar-like oscillations as empirical calibrators of the convective mixing length parameter, $\alpha_{\rm MLT}$, in one dimensional (1-D) stellar models.

Keywords: Stars: evolution, asteroseismology, convection

1 Introduction

Asteroseismic binaries, especially those systems comprising solar analogs, are ideal laboratories in which to test our stellar modeling formalisms. One such formalism under recent scrutiny is the ad hoc adoption of a solar-calibrated value of the one-dimensional convective mixing length parameter, $\alpha_{\rm MLT}$, in models of highly non-solar stars.

The recent work of Joyce & Chaboyer (2018b) and Joyce & Chaboyer (2018a) has demonstrated that the assumption of solar-calibrated $\alpha_{\rm MLT}$ no longer constitutes a reliable method in 1-D stellar evolution modeling. This calls into question the use of current stellar evolution databases, all of which assume solar-calibrated mixing lengths in their isochrones.

These calibrations, however, require tight constraints and thus rely on high precision observations in many arenas: classical brightness measurements, interferometry, spectroscopy, and asteroseismology. In light of unprecedented observational scope and precision—thanks to Gaia, TESS, and stable, high resolution spectroscopy—the number of candidates for non-solar calibration is increasing.

Among recent, successful candidates for empirical mixing length calibrations are the metal-poor subgiant HD 140283 and α Centauri A and B (Creevey et al. 2015, 2017; Joyce & Chaboyer 2018b,a). This proceeding discusses the methods used to perform these calibrations, the necessary observational constraints, and the feasibility of extending this analysis to future TESS targets and members of known doubly oscillating or eclipsing binary systems, especially Procyon A.

2 Modeling technique

In Joyce & Chaboyer (2018b), it was discovered that the best-fitting mixing lengths for high-precision, 1-D stellar evolution models of α Cen A and B differed systematically at the level of $10-30\%$. This finding was robust against changes in the adopted surface boundary conditions, efficiency of diffusion, and use of convective overshoot in the models, all of which were computed with the Dartmouth Stellar Evolution Program (DSEP; Dotter et al. 2008).

Before seismic considerations were applied, models were optimized in accordance with classical observational constraints (e.g. radius, luminosity, surface abundance) and binary considerations: common initial helium and heavy metal abundances and a common present-day age. In requiring only that independently run grids of models for α Cen A and α Cen B satisfy their respective photometric, spectroscopic, and interferometric constraints at any common age, we discovered a clear bifurcation in the best-fitting convective mixing lengths for both stars, regardless of the other assumptions in the modeling physics. This behavior is shown in Figure 1.

The application of seismic constraints reduced the viable parameter space considerably, producing a set of fundamental parameter estimates for the α Cen system that is highly consistent with the literature. The impact of including a seismic agreement criterion in the reduced χ^2 score on the viable age range is shown in Figure 2.

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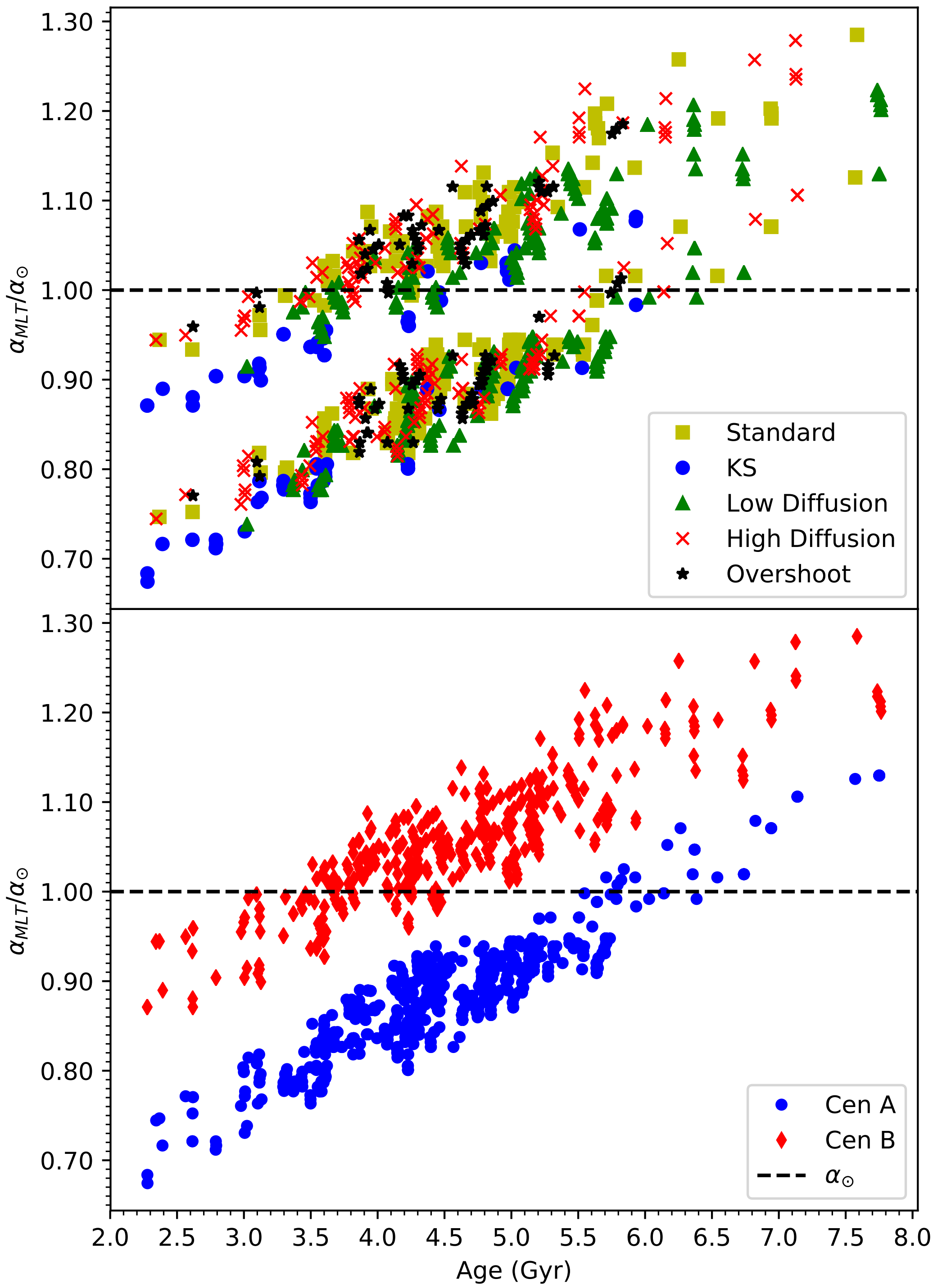

Fig. 1. Bifurcation of the optimal mixing length for α Cen A and B is found regardless of age at which their respective classical parameters are satisfied in large grids of stellar tracks. This figure was originally used in Joyce & Chaboyer (2018a).

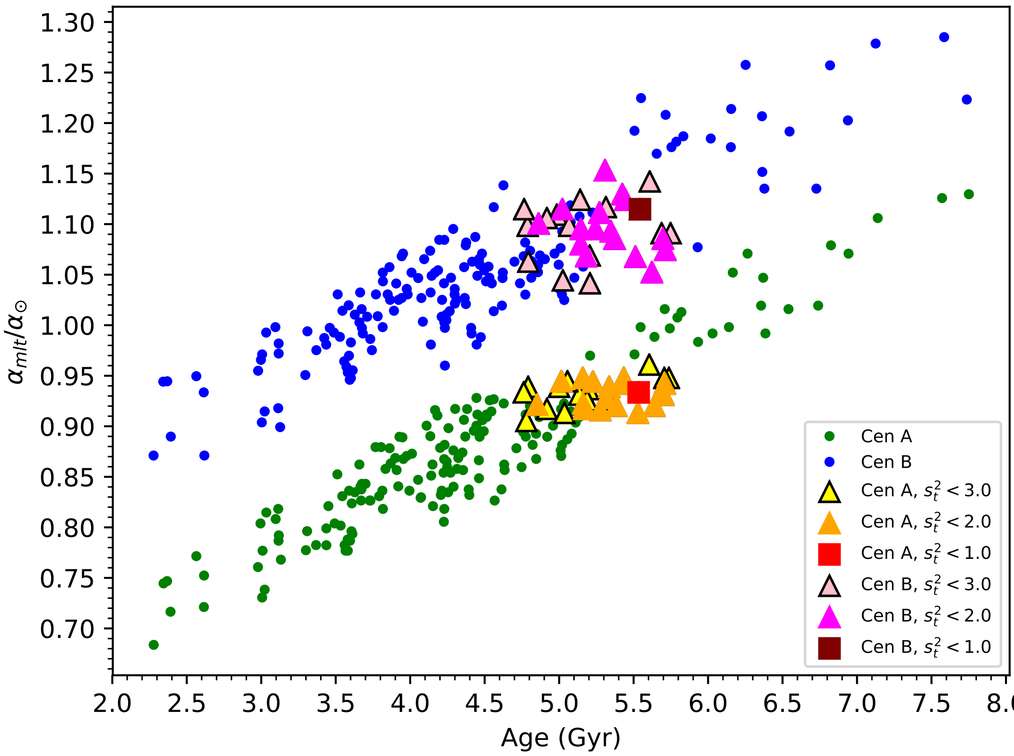

Fig. 2. Impact on Figure 1 of the inclusion of seismic constraints for both stars. This figure was originally used in Joyce & Chaboyer (2018a).

3 Necessity of high-precision observational constraints

The successful characterization of α Cen A and B and subsequent discovery of a robust bifurcation in optimal $\alpha_{\rm MLT}$between the two stars was made possible by a confluence of excellent observational measurements. We obtained the masses of α Cen A and B kinematically, the radii interferometrically, the luminosities from photometry, the shared surface abundance from high resolution spectroscopy, and the stellar interior constraints from asteroseismic analysis of p-mode frequencies.

This set of inference methods is, unfortunately, not reproducible for any other system at this time. Contenders we have investigated include doubly-oscillating *Kepler* targets, catalogs of eclipsing binaries, and catalogs of low-mass stars with interferometry. In all cases where the precision of some observational quantity is sufficient, other types of observations are missing.

Though we cannot rebuild the full suite of constraints available for α Cen A and B for any other candidate, we anticipate that some candidates fulfill enough of the requirements that meaningful inferences about their interior mixing can still be made. We believe the most effective candidates for follow-up are Procyon A and 16 Cyg A and B. In the case of Procyon A, we must grapple with difficulties in reproducing the observed seismic signature, which is more physically complex than for α Cen A or B (Compton et al. 2019). In the case of 16 Cyg A and B, preliminary tests have suggested that its observational constraints are simply too weak to restrict the domain of consistency of $\alpha_{\rm MLT}$, as shown in Figure 3. These setbacks aside, our modeling efforts are ongoing.

4 Conclusions

We are unable to reproduce the seismic analysis performed on α Cen A and B for Procyon A using similar methods at this time. However, we are continuing our search for other viable candidates and exploring adjustments to the modeling methodology such that it may be become better adapted to stars with weaker (and

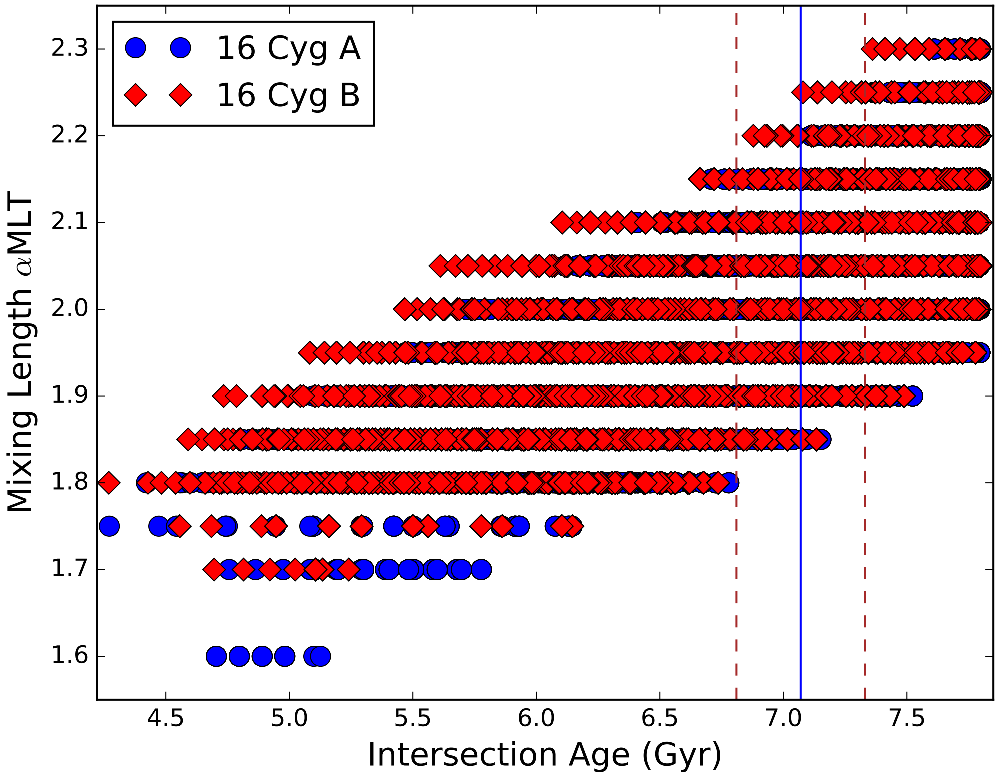

Fig. 3. Lack of $\alpha_{\rm MLT}$bifurcation across wide age range for 16 Cyg A and B, likely due to relative weakness of observational constraints compared to α Cen A and B. Vertical lines mark literature age estimates and their uncertainty.

fewer) observational constraints.

An understanding of the relationships between $\alpha_{\rm MLT}$ and other fundamental stellar parameters, grounded by direct observational data, will contribute to the development of more sophisticated stellar tracks and isochrones. Such science is necessary to maintain the utility of 1-D stellar structure and evolution models in the current observational landscape.

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