Microphysics on the Macroscale: The Big Impact of Small Parameters in Stellar Evolution

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Abstract

There exists an important free parameter in stellar evolution calculations known as the mixing length (α). Its value is calibrated according to the sun. By tuning all of the other parameters of a stellar model to their solar values, a mixing length can be determined by toggling α until the model reproduces solar data as accurately as possible. Historically, the solar value of α is then used de facto in any and every other type of stellar calculation. An obvious problem with this technique is that the evolutionary parameters of other model stars may differ from the sun significantly. Recent evidence (Creevey et al., 2015) suggests that the solar mixing length is invalid for models of stars with very low metallicities. In this work, we investigate the impact of varying mixing length in low–metallicity stellar models.

Heat Transport in Stellar Interiors

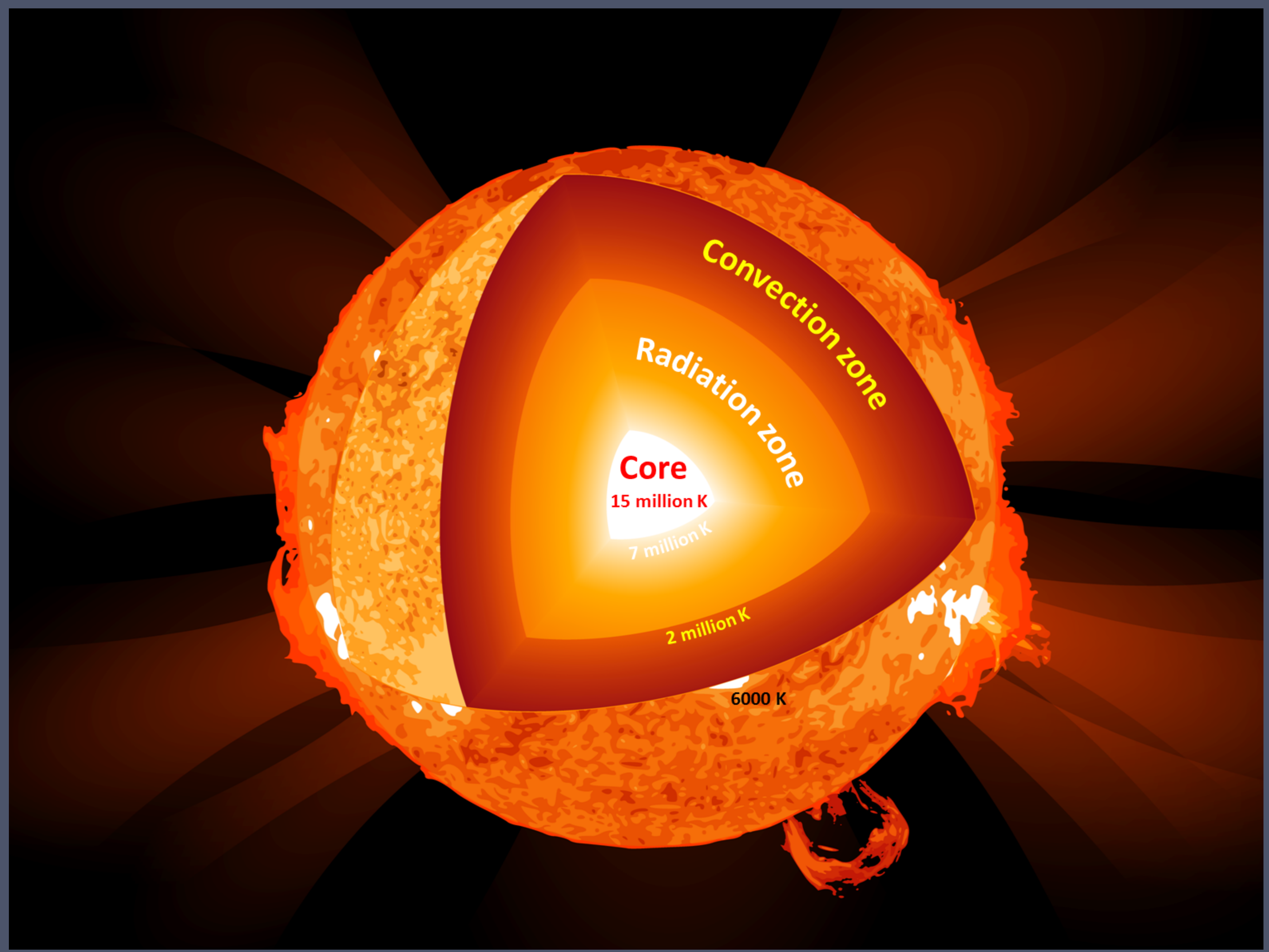
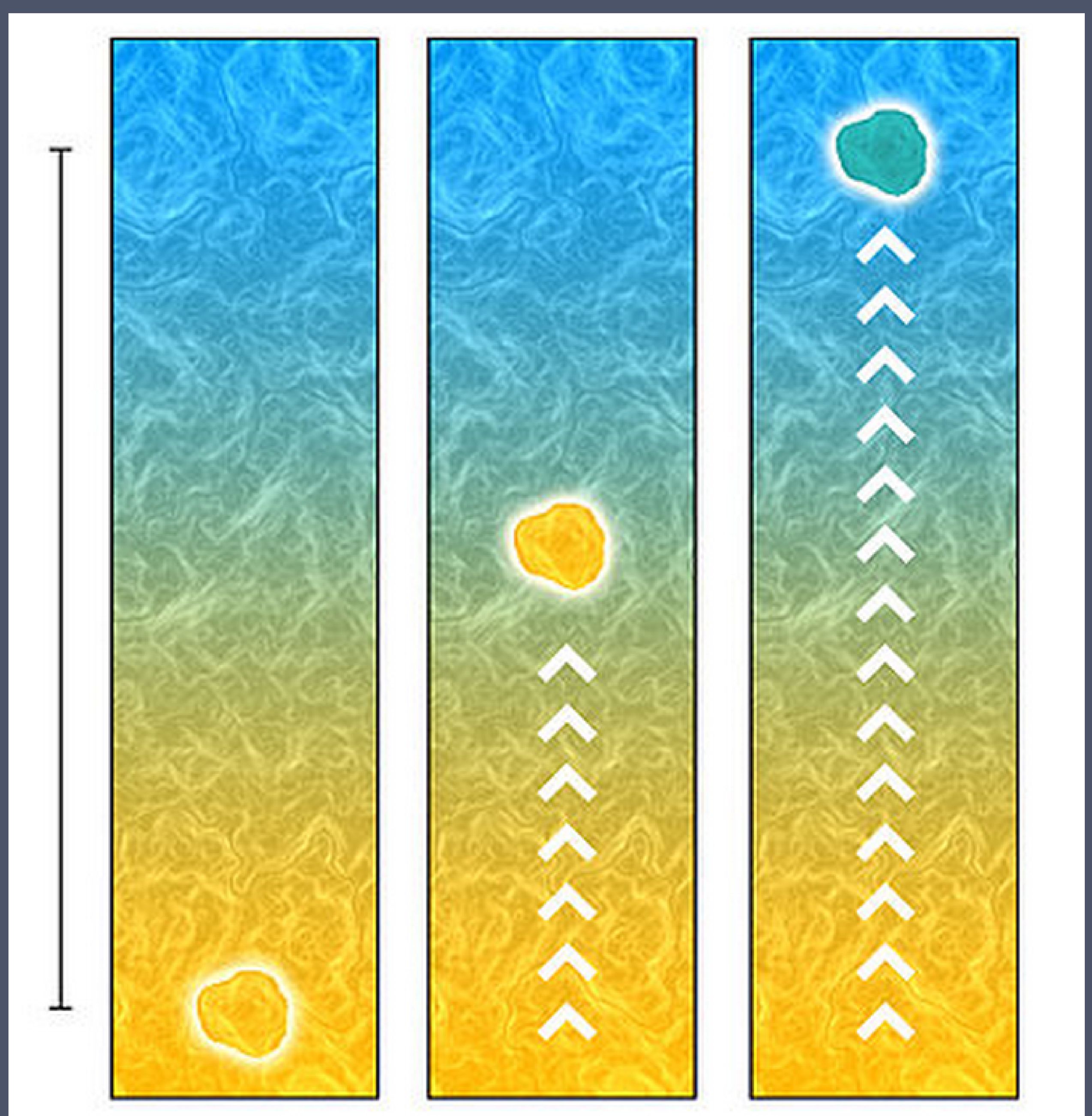


image credit: phys.org

What is a Mixing Length?

The mixing length is a free parameter used in 1-D stellar evolution calculations to parametrize a highly simplified model of convection. It describes the length of the mean free path over which a parcel of convective material can travel within a stellar interior before it denatures. Mixing length theory (MLT) was devised in the 1920s to simplify problems in fluid dynamics. Despite its physical simplicity, it remains the default framework in stellar models.



M92: Taken with MDM 2.4m

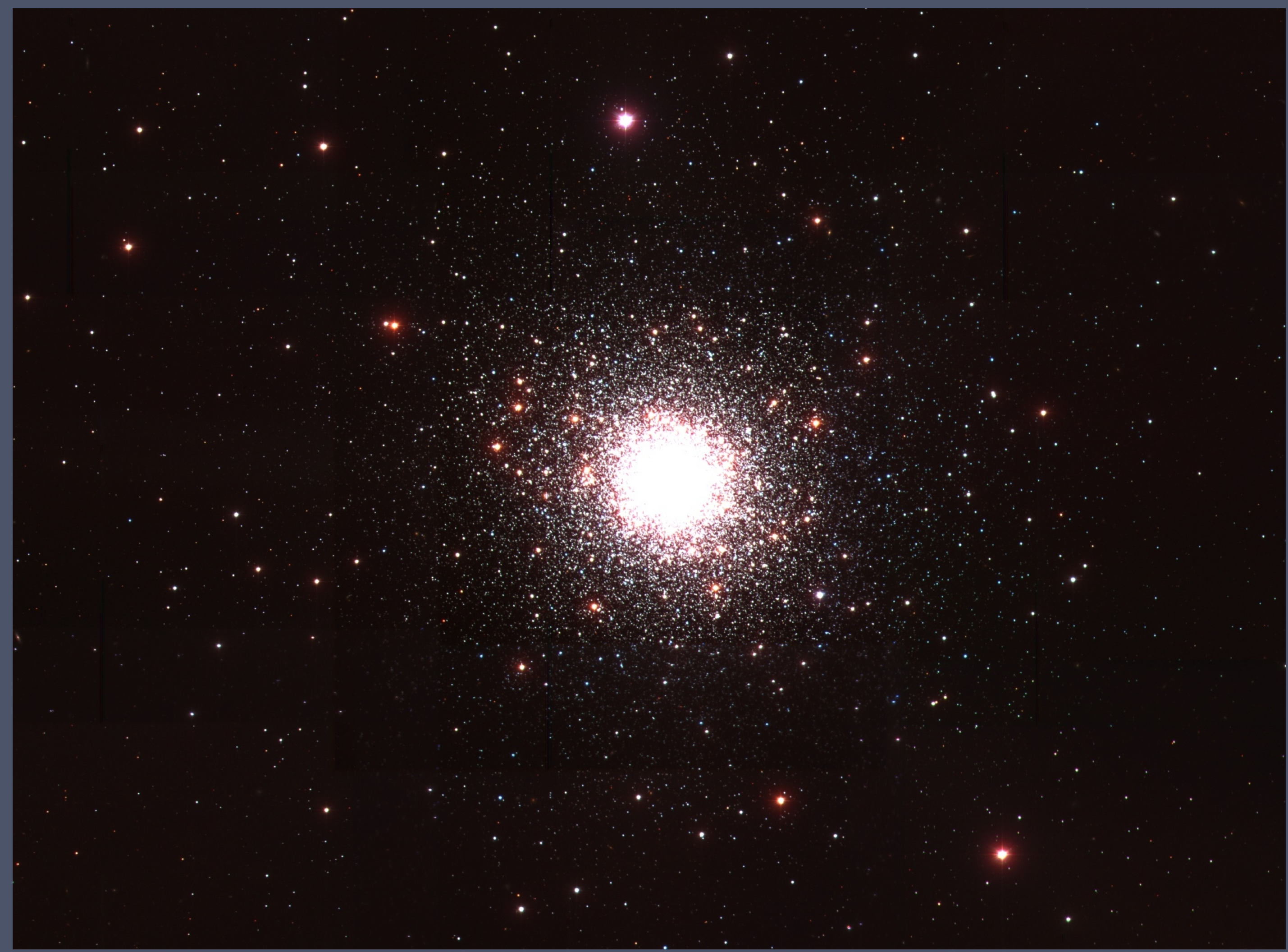
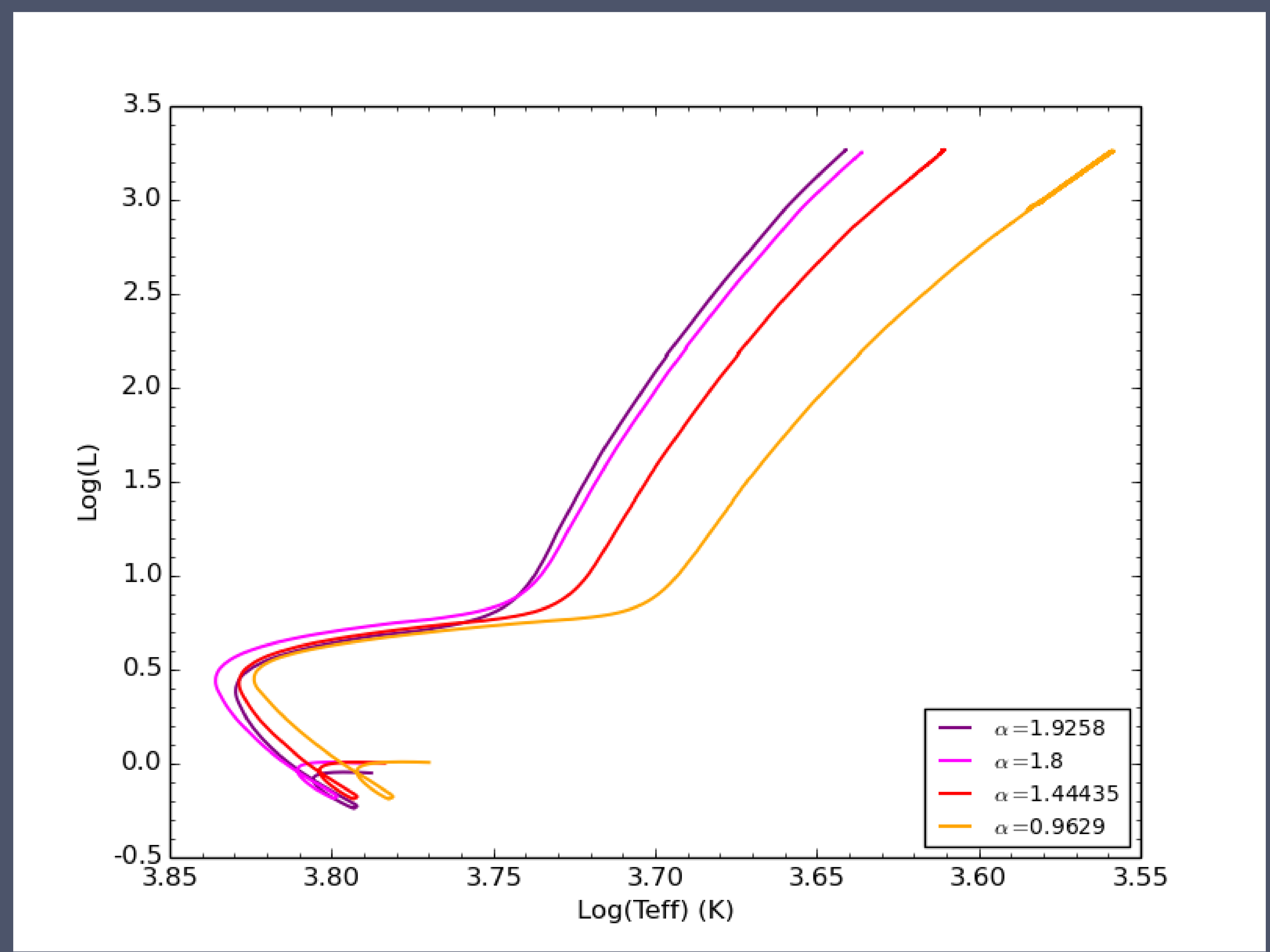


image credit: Nathaniel Paust, Ph.D '06

Mixing Length and Temperature

The figure below demonstrates the considerable impact mixing length has on the synthetic star's temperature. Within the convective envelope, heat is transferred in bulk and stellar material is well-mixed. In this context, we can think of the mixing length as "characteristic range," or physical distance, over which a relatively homogenous pocket of stellar material can travel within the envelope. Hence, the reason for the decrease in temperature is that shortening the mixing length is effectively a proxy for shrinking the size of the convective envelope. The solar value calibrated for DSEP is $\alpha = 1.9258$. Halving this value corresponds to a decrease in temperature of hundreds of degrees (K) for certain portions of the star's life cycle. For stars like the sun, this is a change in temperature of up to 10%.

The Impact of α on Properties of Synthetic Stars



Acknowledgements

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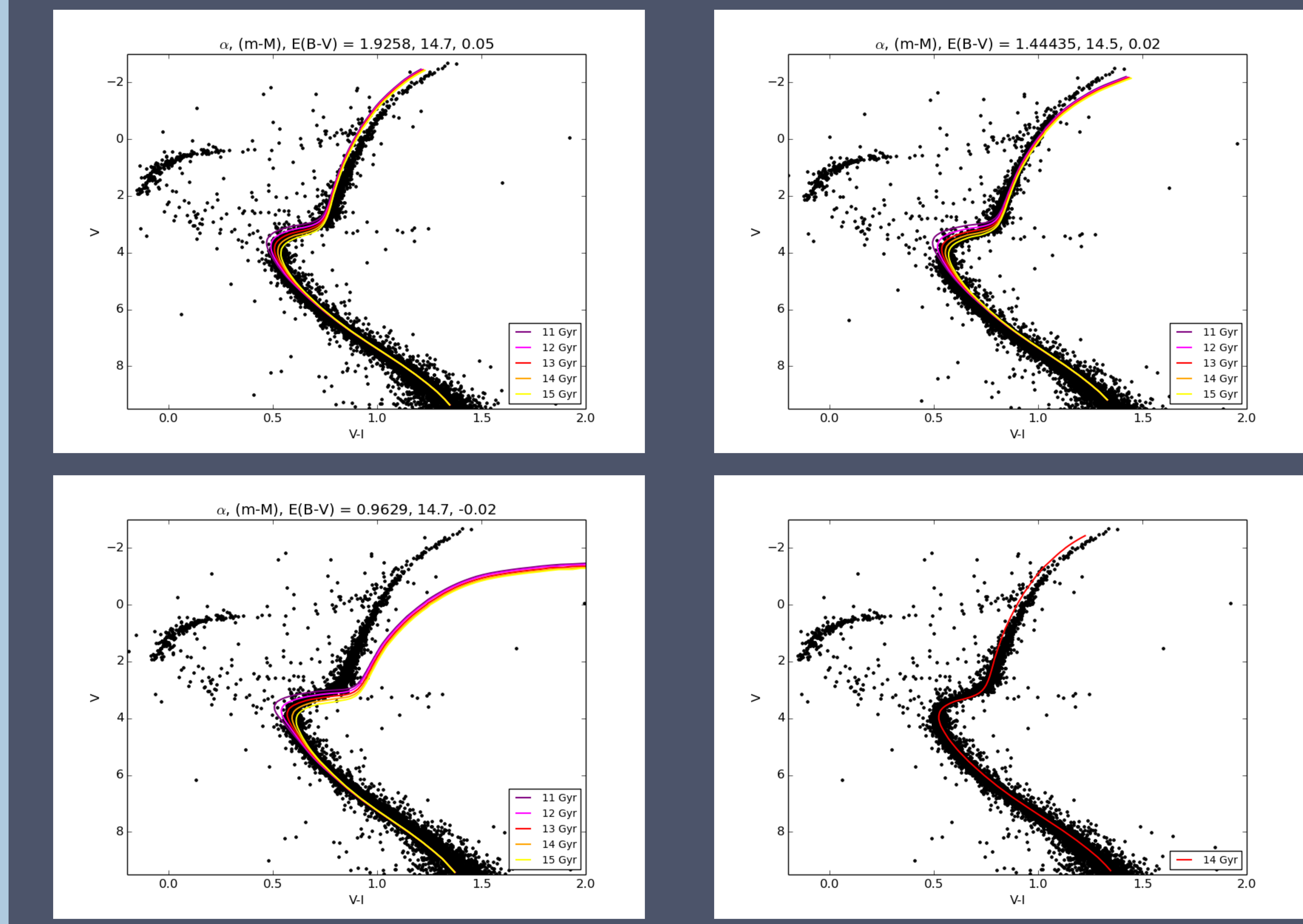
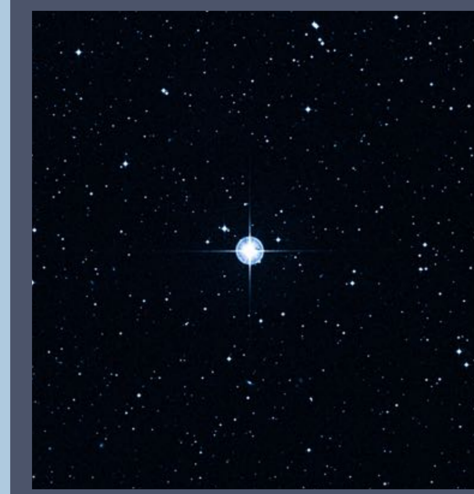
M. Joyce and B. Chaboyer. *ApJ*, 814:142, December 2015.
O. L. Creevey et al. *A&A*, 575,A26, 2015
S. R. Bjork and B. Chaboyer. *ApJ*, 641:1102–1112, April 2006.

Fit to M92 Across Ages and Alphas



Using HD 140283 as a Test of Stellar Models



The nearby star HD 140283 has the same composition as M92. Due to its proximity, we can observe its distance directly, which means we can obtain its luminosity. More importantly, it is the only metal–poor star that we can resolve, which means we can measure its radius. We can then convernt the measured radius is to an effective temperature via $L = 4\pi R^2 Teff^4$, and so HD 140283's known parameters can serve as a rigid test of the stellar models.

The figure below shows DSEP–generated stellar tracks whose metallicity and chemical composition are tuned to the metallicity and chemical composition of HD 140283 (and hence M92). The mass and mixing length of each of these stellar models is also specifiable. A range of masses and a range of mixing lengths are chosen to investigate the combinations that result in stellar models whose synthetic temperatures and luminosities fall within the error bounds of HD 140283's observed properties. This figure is modeled after Figure 7 in Creevey et al.(2015), who find that a mixing length much shorter than the solar α is needed to fit HD 140283.

Exploring Mass–Mixing Length Parameter Space with DSEP