# Entropy-calibrated models of solar-like stars

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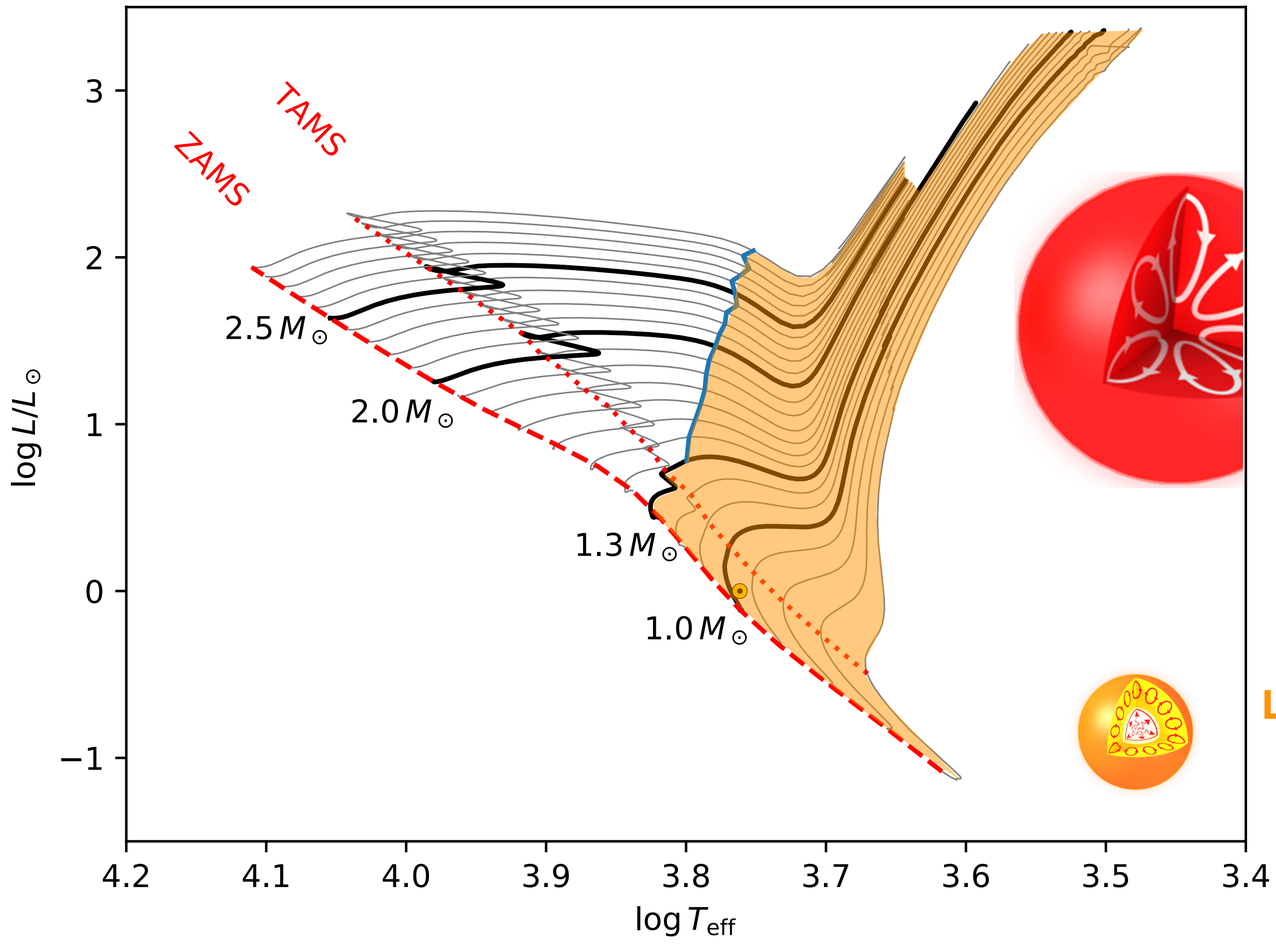
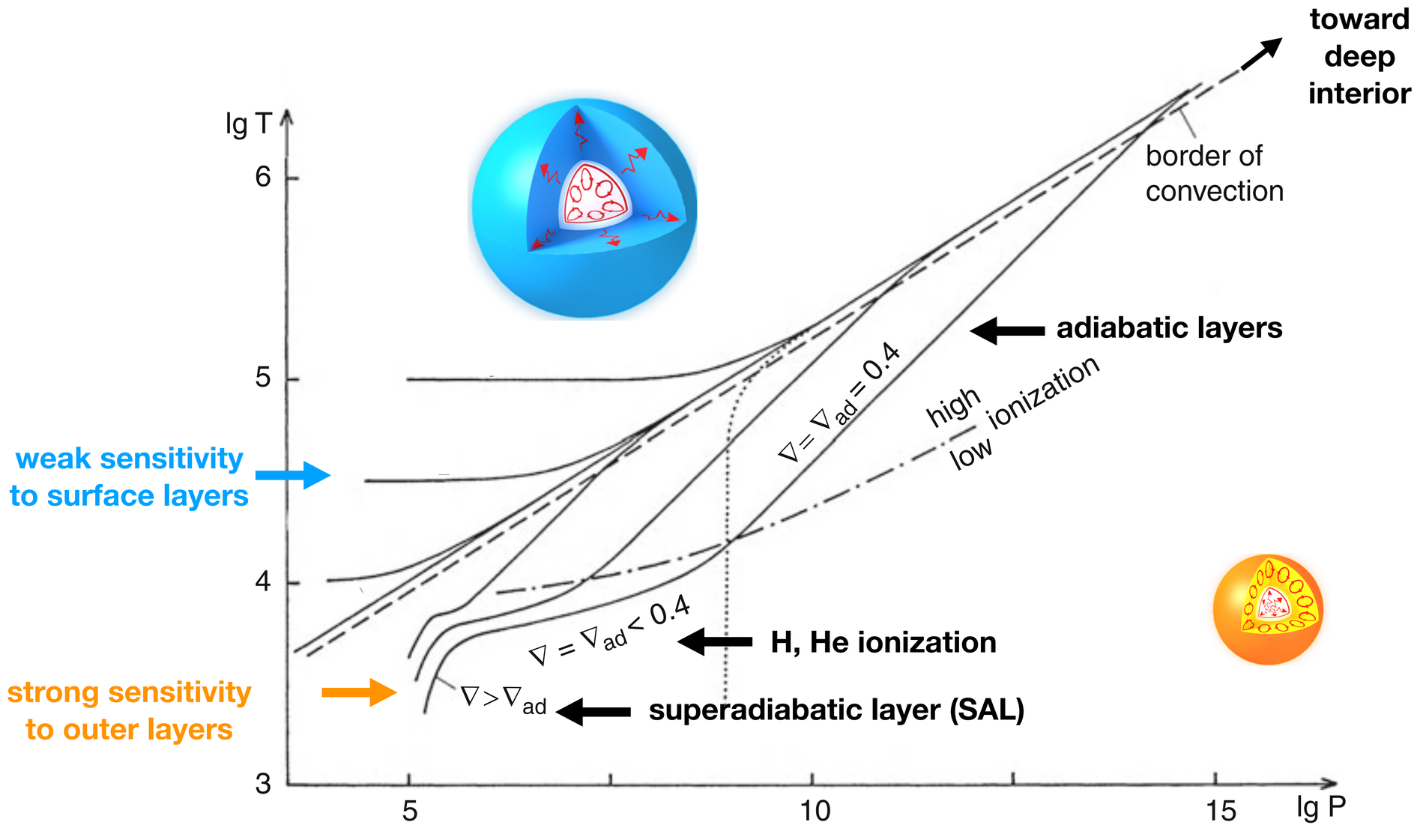
# Stars with outer convection zones




**Red giants**

**Lower main sequence stars ($M_* < 1.3\,M_\odot$)**

# Stellar structure is sensitive to convective envelopes



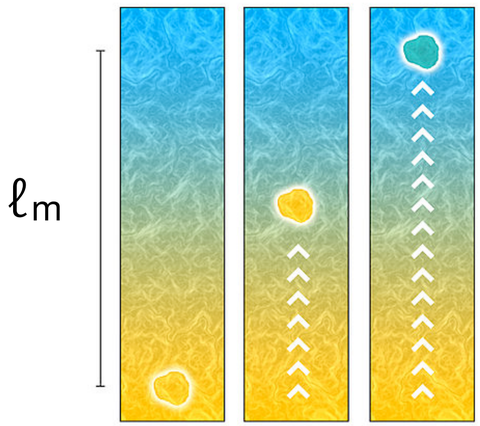

Kippenhahn, Weigert, Weiss, "Stellar Structure and Evolution" (2012)

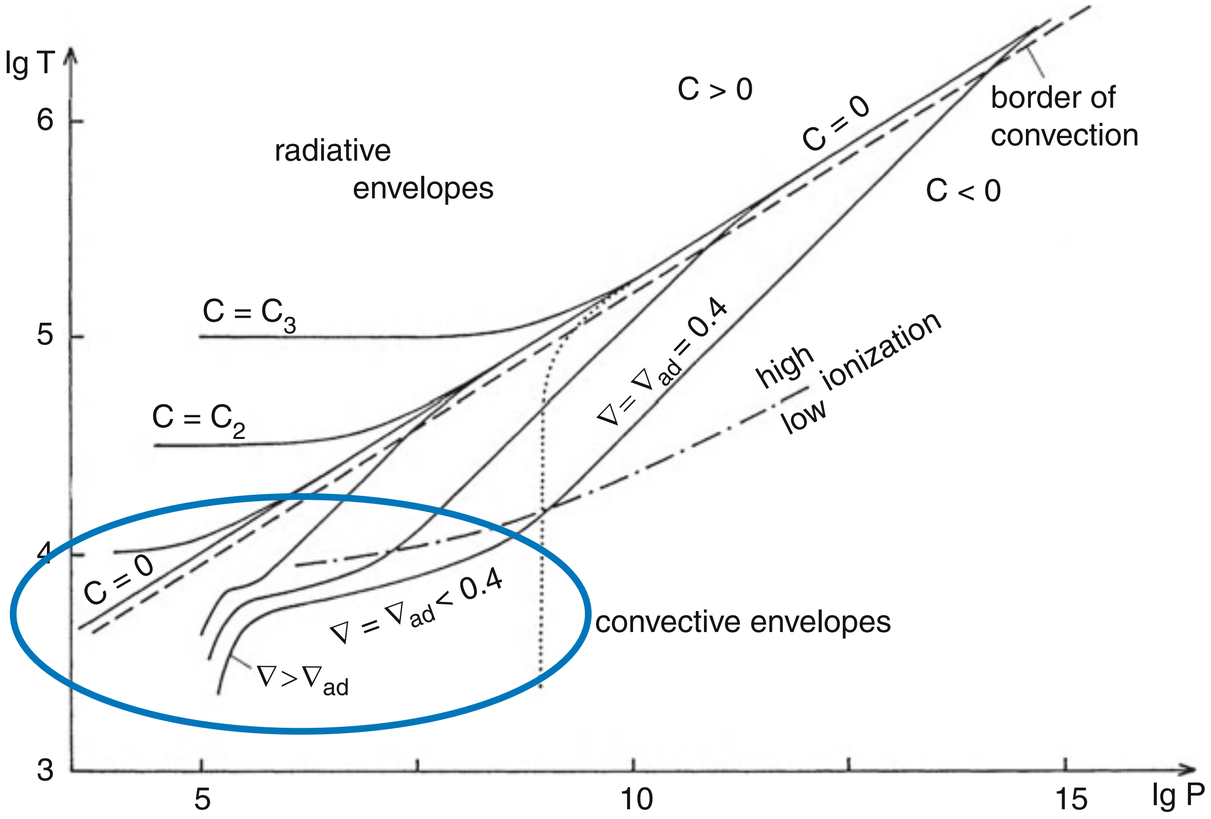
# The mixing length theory (MLT) requires calibration

## $\alpha_{\mathrm{MLT}}$ controls the radius of the model

**MLT parameter:**

$\alpha_{\mathrm{MLT}} = \ell_m / H_P$

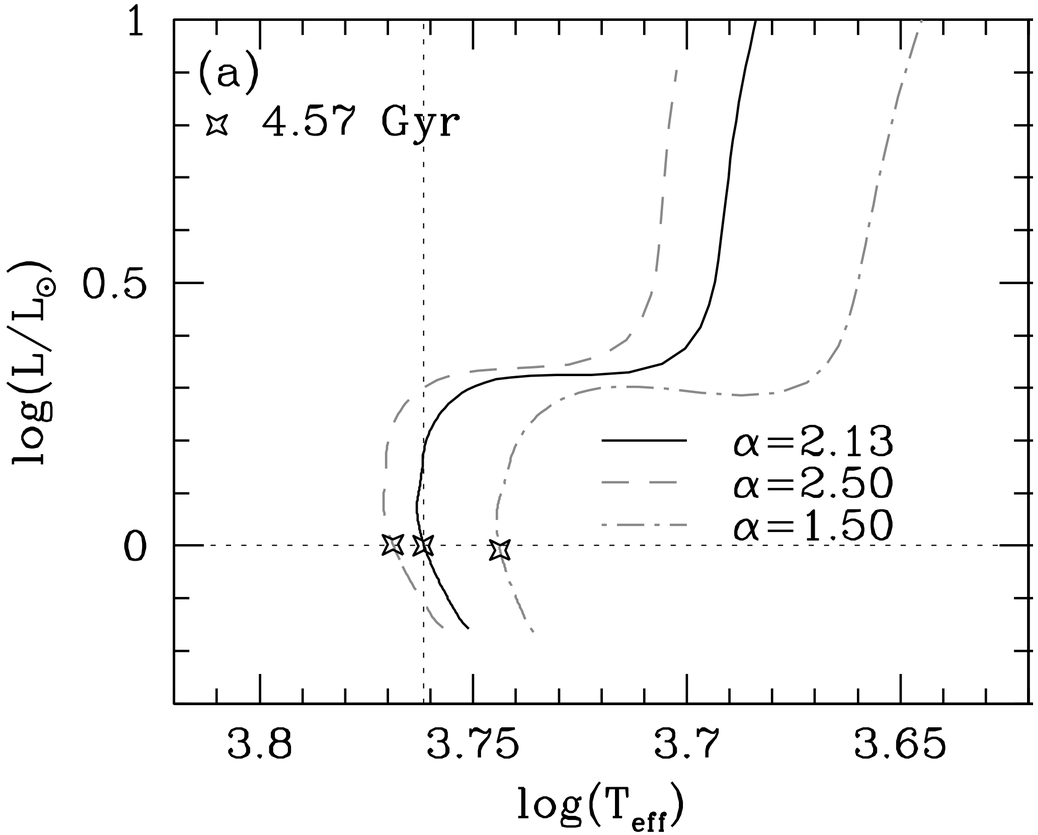



**Kippenhahn, Weigert, Weiss,**
**"Stellar Structure and Evolution" (2012)**

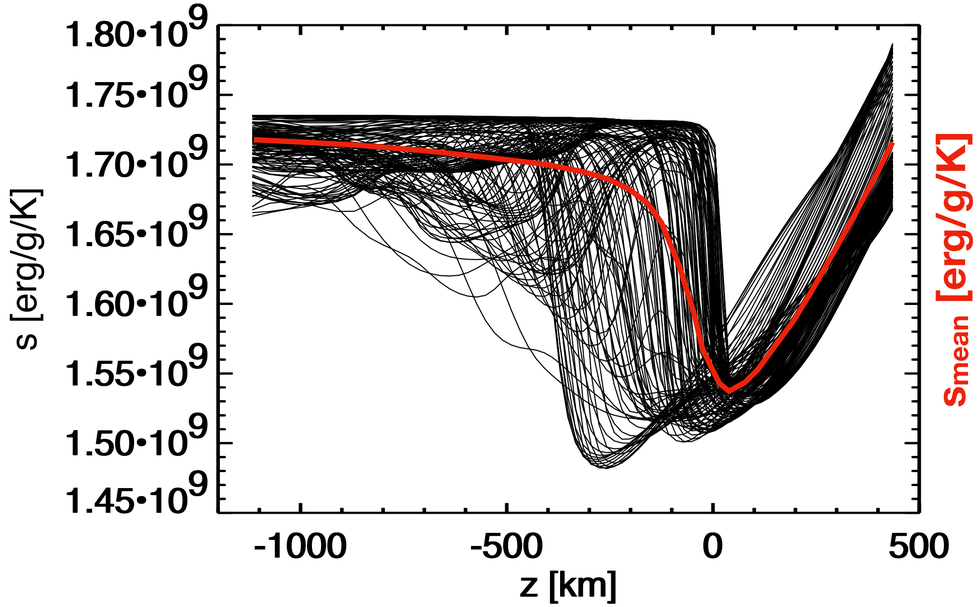
# Standard approach: calibration of $\alpha_{\rm MLT}$ on the Sun

- Possible because mass, radius, and age of the Sun are independently known
- Use the same value of $\alpha_{\rm MLT}$ to model other stars



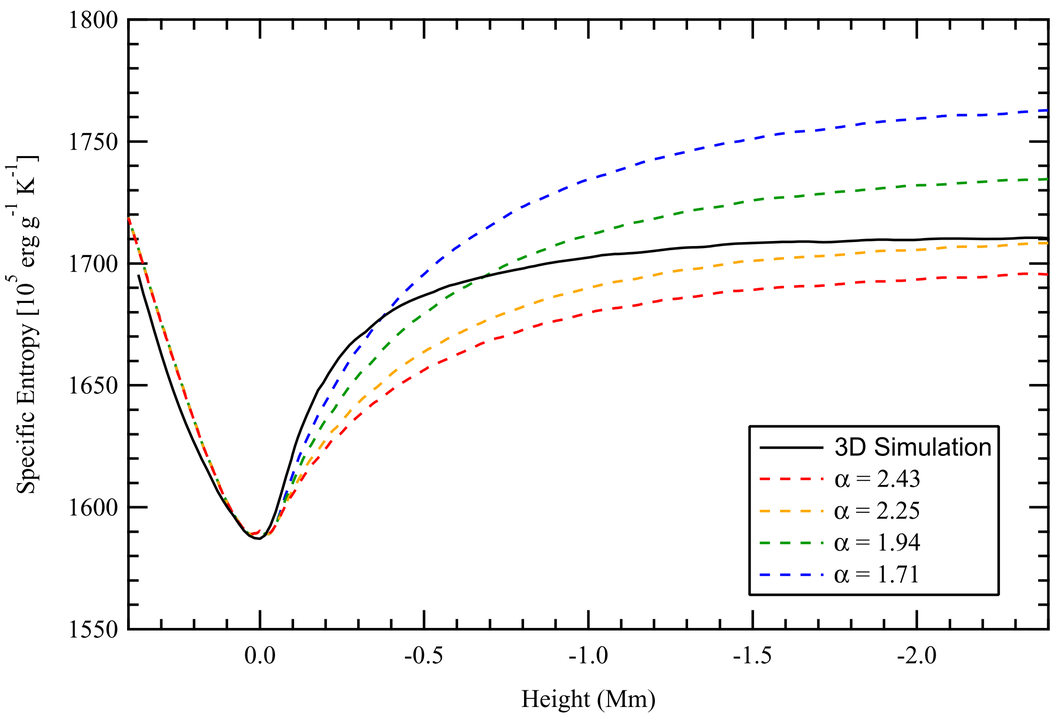

Basu & Antia 2008, Phys. Rep., 457, 217

# This work: entropy calibration of $\alpha_{\mathrm{MLT}}$ using RHD simulations




Ludwig et al. 1999, A&A 346, 111

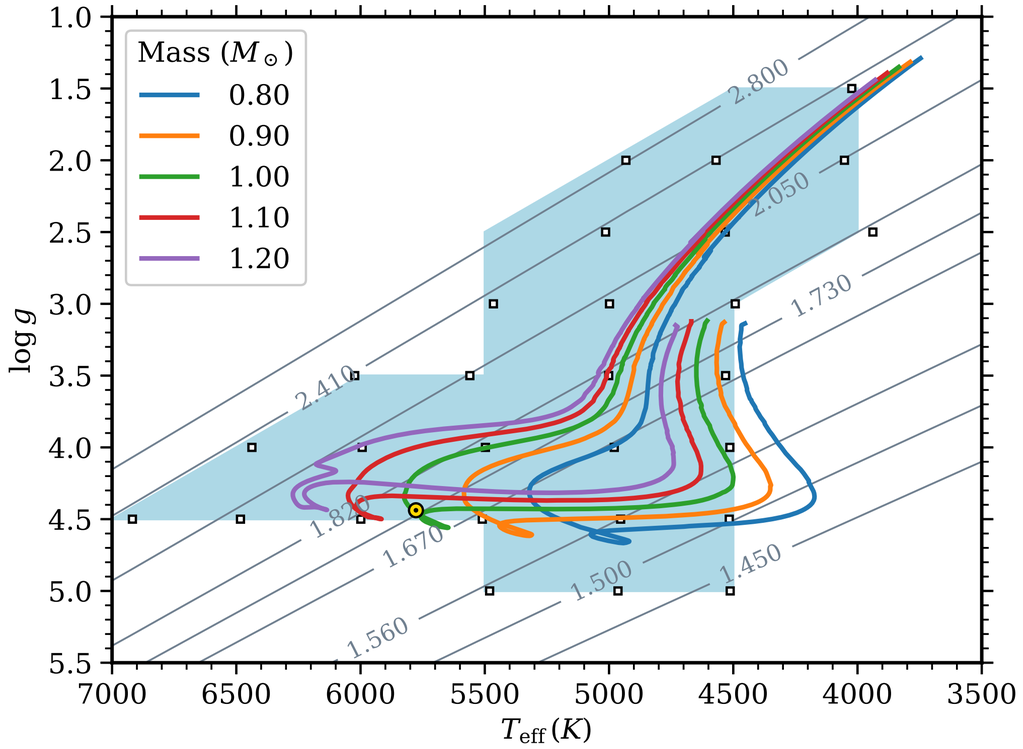
horizontal and temporal mean profile of s

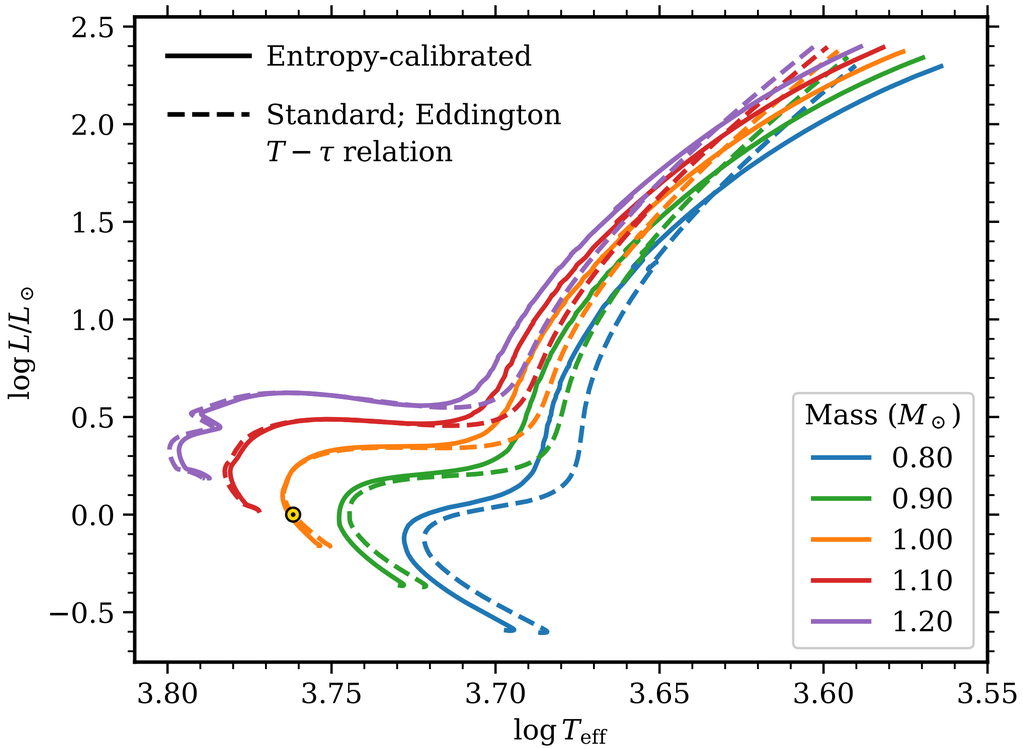



**Entropy-calibration: tuning $\alpha_{\mathrm{MLT}}$ until the adiabatic specific entropy in the MLT model matches that of the RHD simulation**

Tanner et al. 2016, ApJL 822, L17

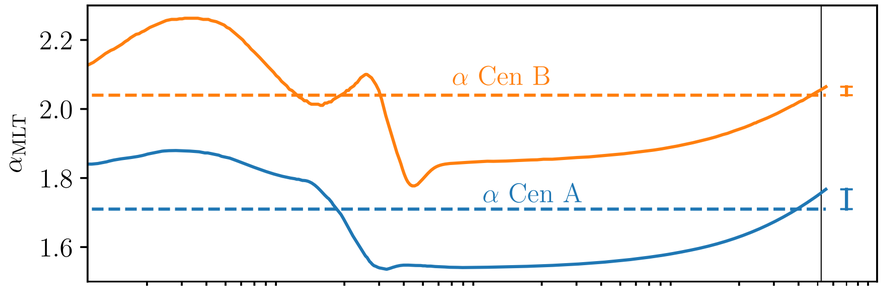
# Entropy-calibrated evolutionary tracks




**Spada, Demarque, Kupka 2021, MNRAS 504, 3128**

# Improved accuracy of the radii of $\alpha$ Cen A and B

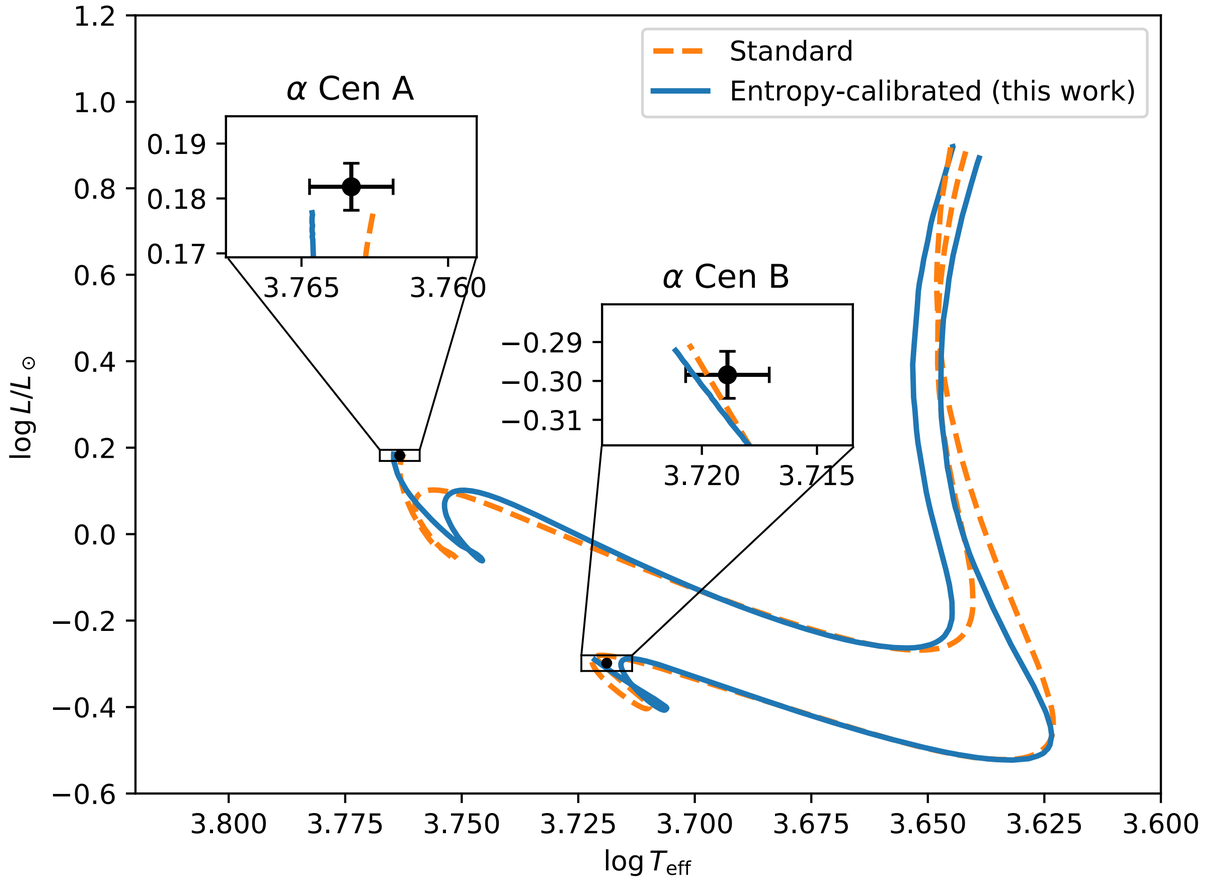



| Parameter | Observed | Standard | Entr.-cal. |
|---|---|---|---|
| | | $\alpha$ Cen A | |
| $R/\mathrm{R}_\odot$ | 1.2234 ± 0.0053 | 1.2235 | 1.2097 |
| $L/\mathrm{L}_\odot$ | 1.521 ± 0.015 | 1.5091 | 1.5045 |
| $Z/X$ | 0.039 ± 0.006 | 0.0315 | 0.0348 |
| Age (Gyr) | N/A | 5.21 | 5.21 |
| $\alpha_{\rm MLT}$ | N/A | 1.71 | 1.758 |
| $s_{\rm ad}$ | N/A | $1.876 \times 10^9$ | $1.853 \times 10^9$ |
| | | $\alpha$ Cen B | |
| $R/\mathrm{R}_\odot$ | 0.8632 ± 0.004 | 0.8647 | 0.8612 |
| $L/\mathrm{L}_\odot$ | 0.503 ± 0.007 | 0.5122 | 0.5107 |
| $Z/X$ | 0.039 ± 0.006 | 0.0346 | 0.0364 |
| Age (Gyr) | N/A | 5.21 | 5.21 |
| $\alpha_{\rm MLT}$ | N/A | 2.04 | 2.045 |
| $s_{\rm ad}$ | N/A | $1.649 \times 10^9$ | $1.639 \times 10^9$ |

*Note*. The units of adiabatic specific entropy are: erg $\mathrm{g}^{-1}\,\mathrm{K}^{-1}$.

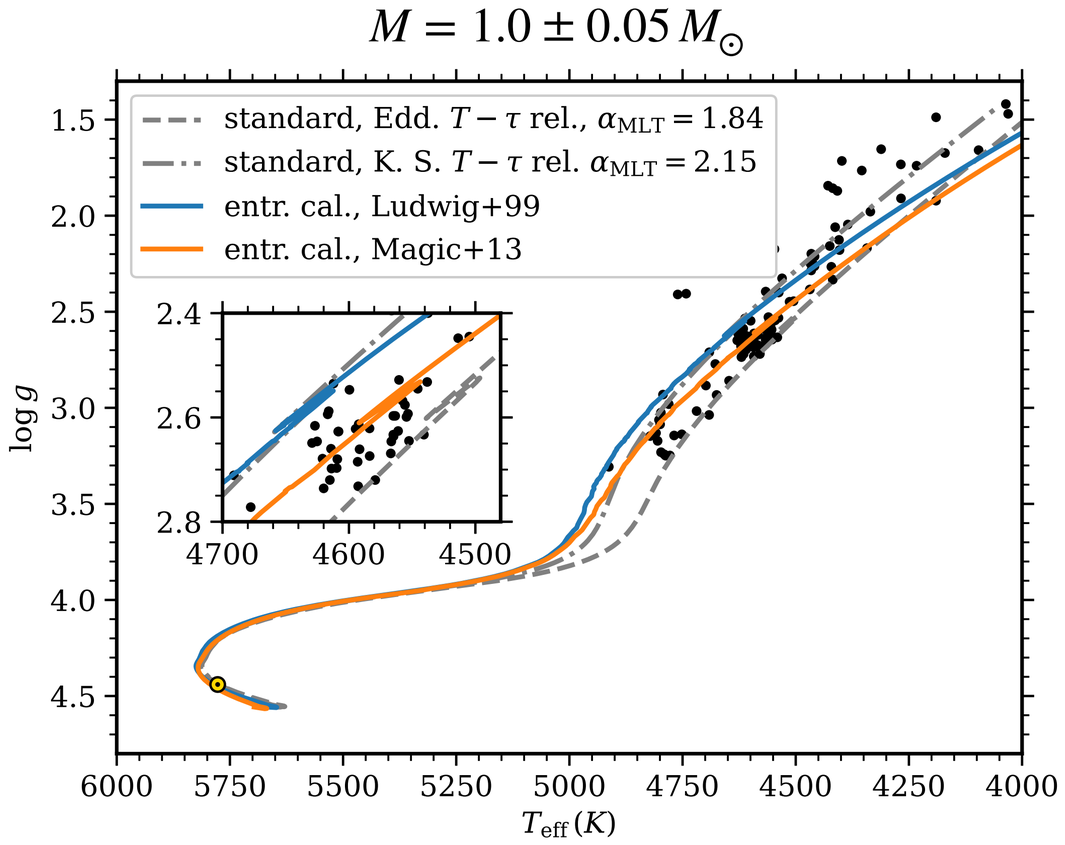
$\frac{\Delta R_*}{R_*} \sim 1.1\,\%$

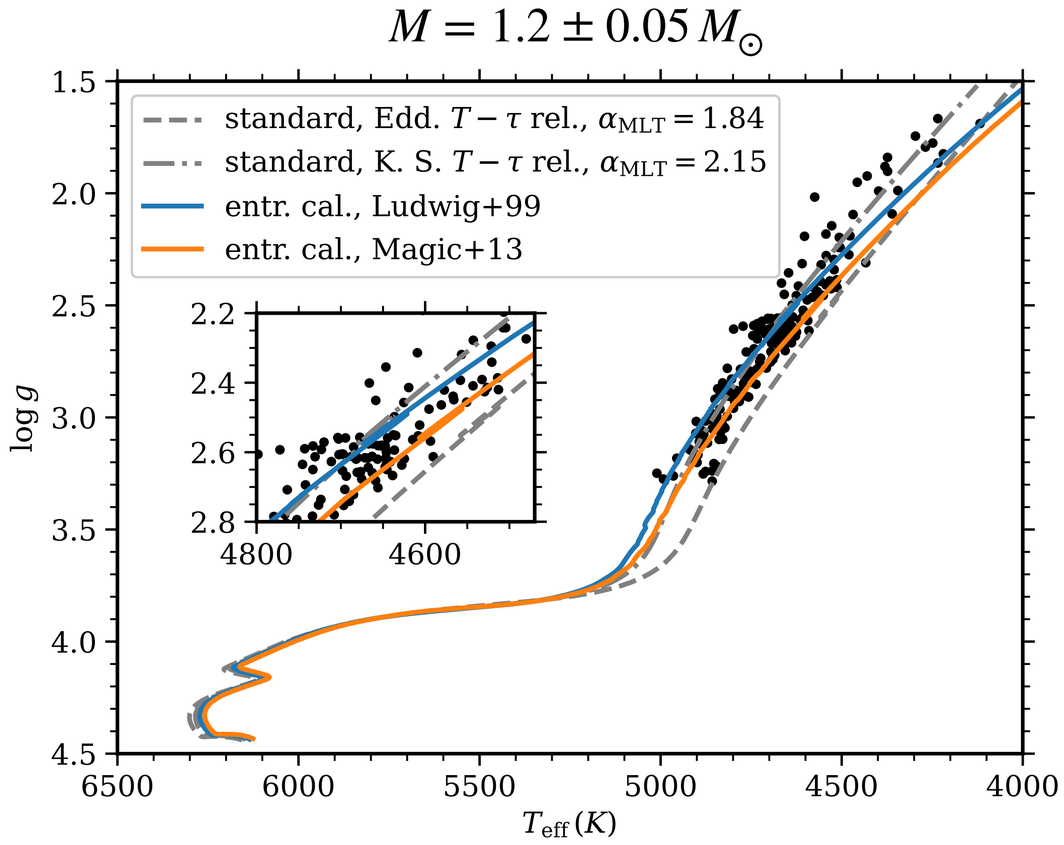
$\frac{\Delta R_*}{R_*} \sim 0.2\,\%$




**Spada & Demarque 2019, MNRAS 489, 4712**

# Improved accuracy of the $T_{eff}$ of red giants




**Spada, Demarque, Kupka 2021, MNRAS 504, 3128**

# Concluding remarks

- With respect to the solar calibration, the entropy calibration of $\alpha_{\rm MLT}$ improves the accuracy and precision of $R_*$ and $T_{\rm eff}$ for MS stars and RGs

- The entropy calibration relies on 3D RHD simulations as input: a denser, wider coverage of the ($T_{\rm eff}$, $\log\ g$) plane is needed!

# References


- Tanner, Basu, Demarque 2016, ApJL 822, L17
- Spada, Demarque, Basu, Tanner 2018, ApJ 869, 135
- Spada & Demarque 2019, MNRAS 489, 4712
- Spada, Demarque, Kupka 2021, MNRAS 504, 3128