Deep mixing due to convective penetration during the red giant branch luminosity bump

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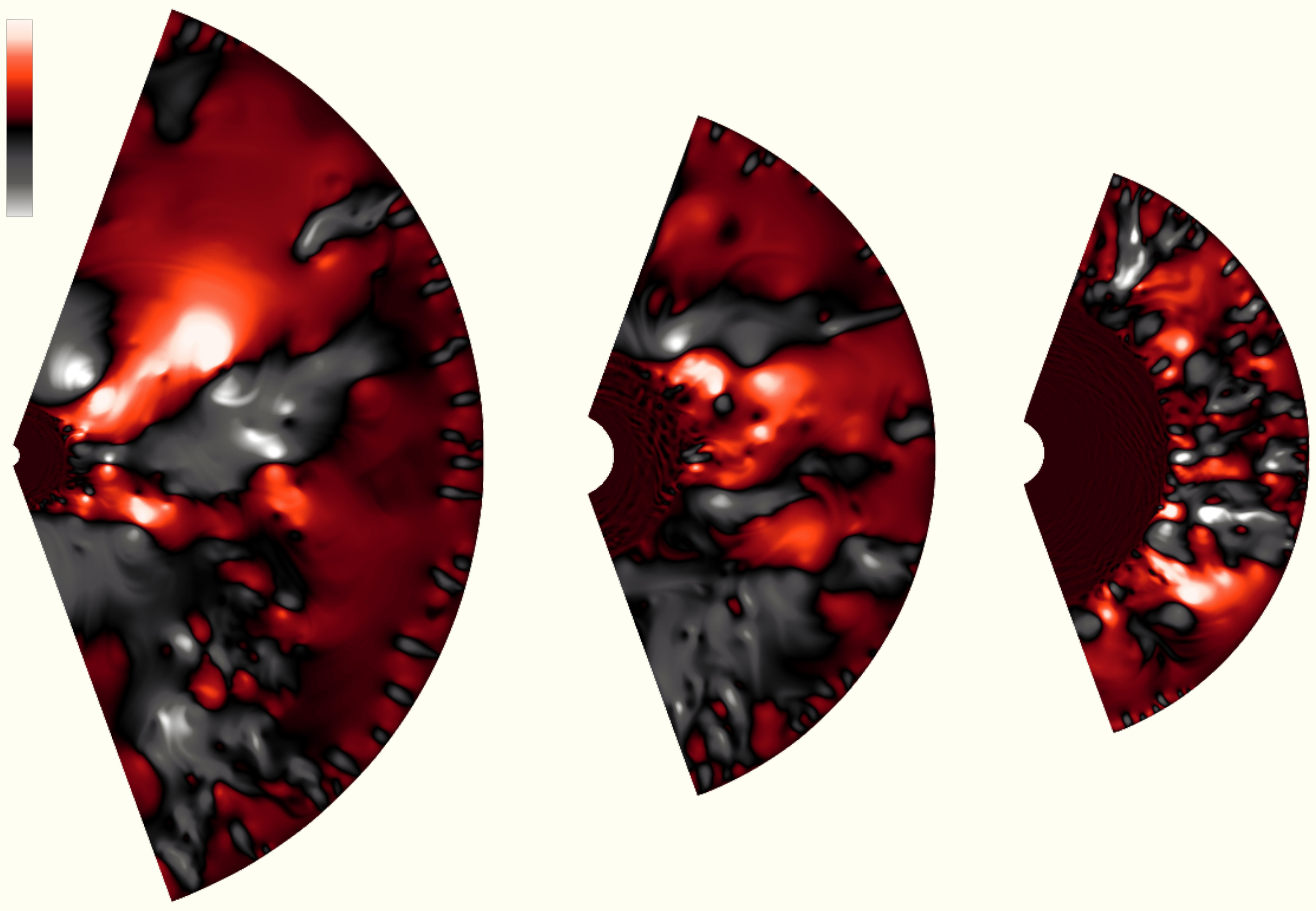

3.296e8 yrs
3 $M_\odot$ red giant
$R_{CB} = 0.13 R_\odot$

3.327e8 yrs
3 $M_\odot$ red giant
$R_{CB} = 0.304 R_\odot$

3.402e8 yrs
3 $M_\odot$ red giant
$R_{CB} = 0.49 R_\odot$

Radial velocity in a star descending the red giant luminosity bump and following the first dredge up.

Motivation

- Convective penetration leads to chemical mixing that can change the course of stellar evolution.
- New, improved 1D model that characterizes mixing from convective penetration: Pratt, Baraffe, et al. 2017. Extreme value statistics for two-dimensional convective penetration in a pre-Main Sequence star. A&A 604 (2017): A125.

$$D_{\rm EVT}(r) = D_0 {\rm Pe_B}^{1/2}\left(1 - \exp\left(-\exp\left(-\frac{(r_B - r) - \mu}{\lambda}\right)\right)\right)$$

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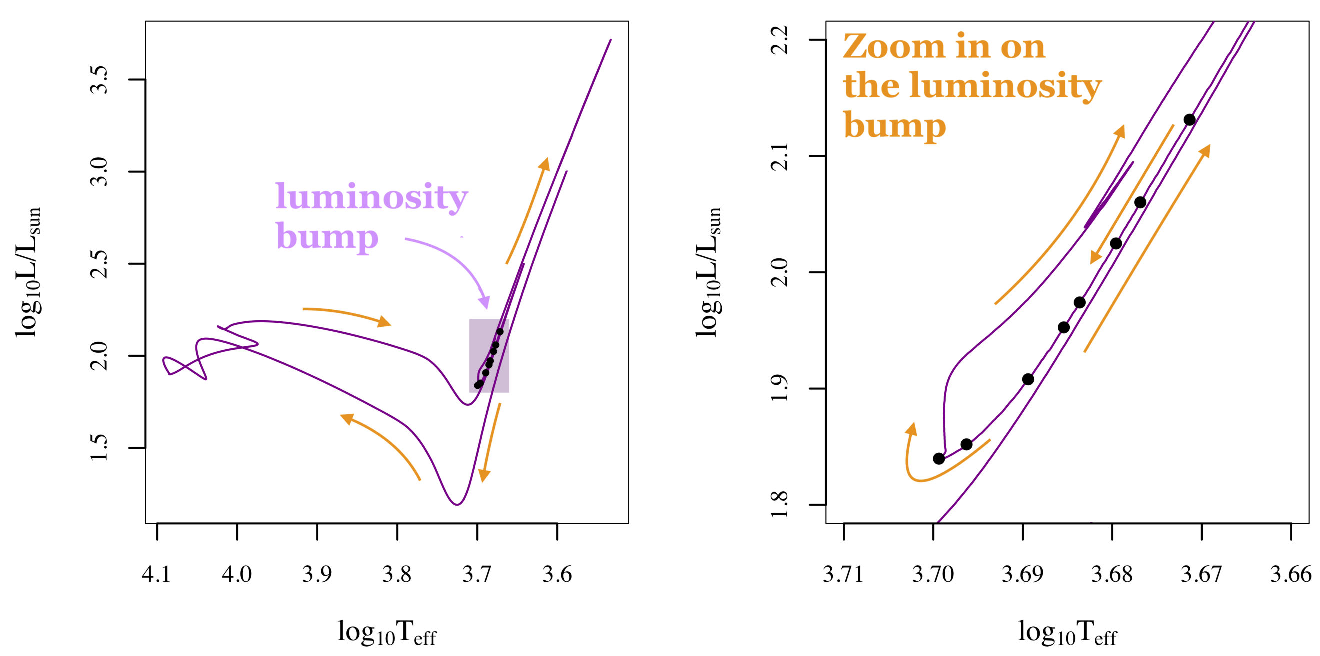
- This model was supported by 3D simulations: Pratt, Baraffe, et al. 2020. Comparison of 2D and 3D compressible convection in a pre-main sequence star." A&A 638: A15.
- Convective penetration is expected to depend on convective velocities, as well as more complex quantities like the shape and size of convective plumes, that might be expected to change differently than the pressure scale height.
- **Question: how should convective overshooting/penetration prescriptions change as the star evolves?**

Following the evolutionary track of a $3M_\odot$ star:

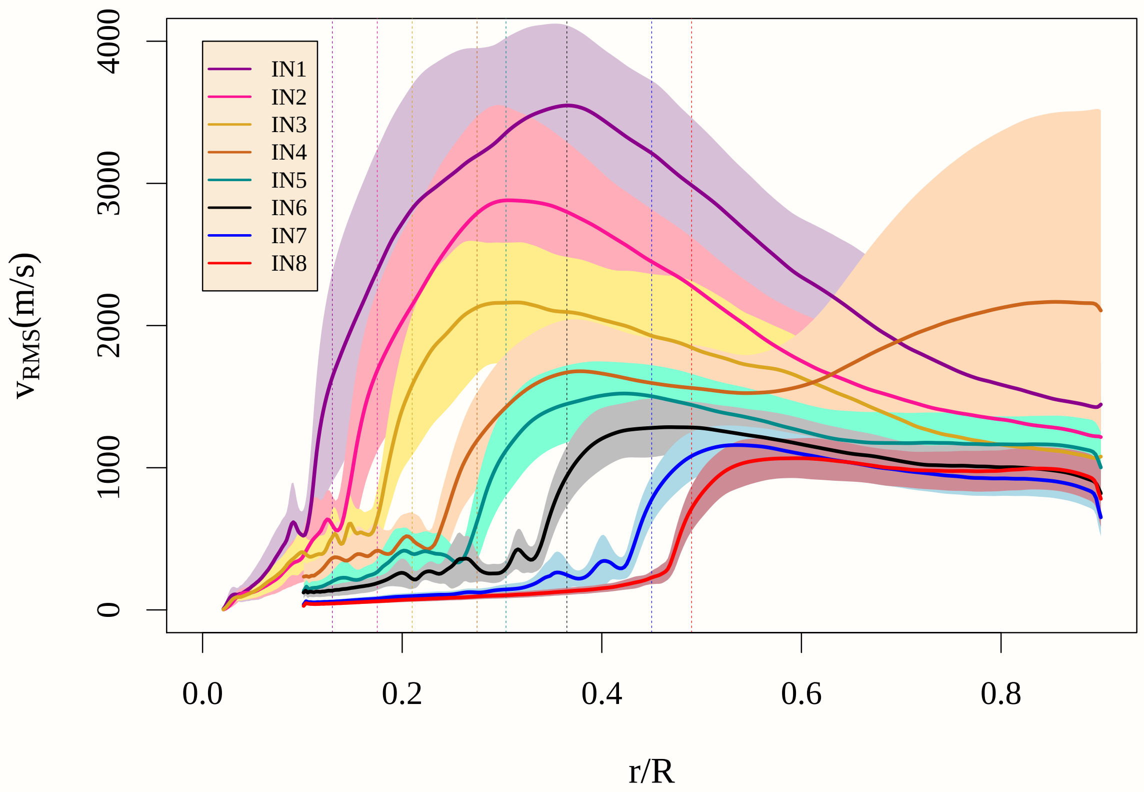
- 8 models of $3M_\odot$ red giants produced with MESA using solar composition.



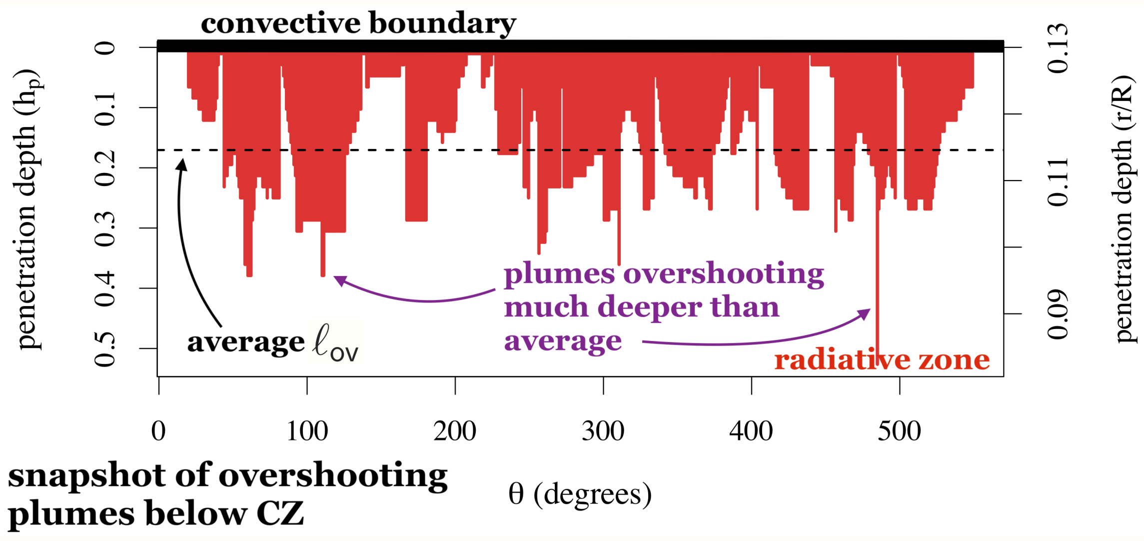
- The structure of the star changes rapidly following the first dredge-up, as the convective boundary recedes.
- This is an ideal laboratory for examining convection.
- Orange arrows on the above HR diagrams indicate the path of time evolution. Black dots indicate the stellar structures that we examine with 2D hydrodynamic simulations.

Convective velocities

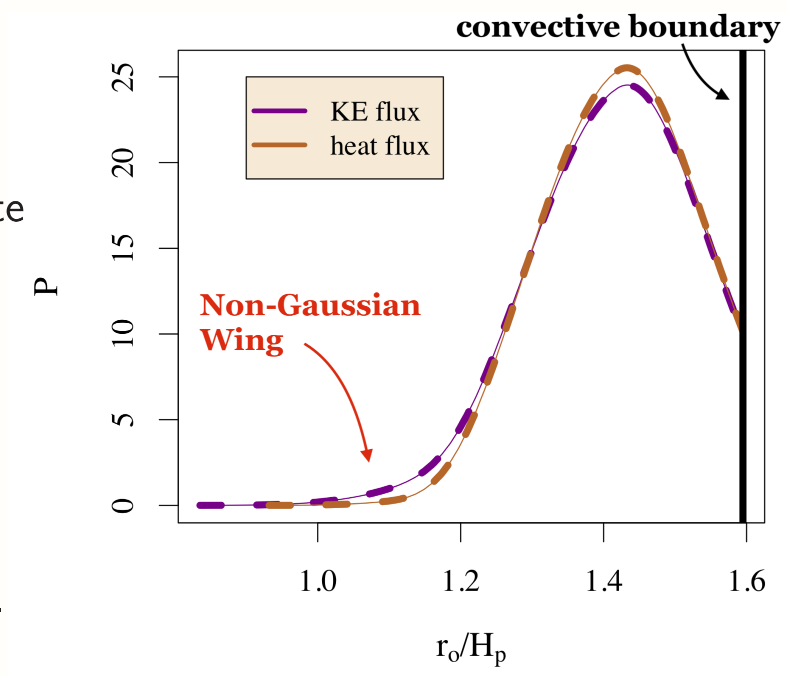
- 8 hydrodynamic simulations with similar resolution of the pressure scale height at the bottom of the convection zone.



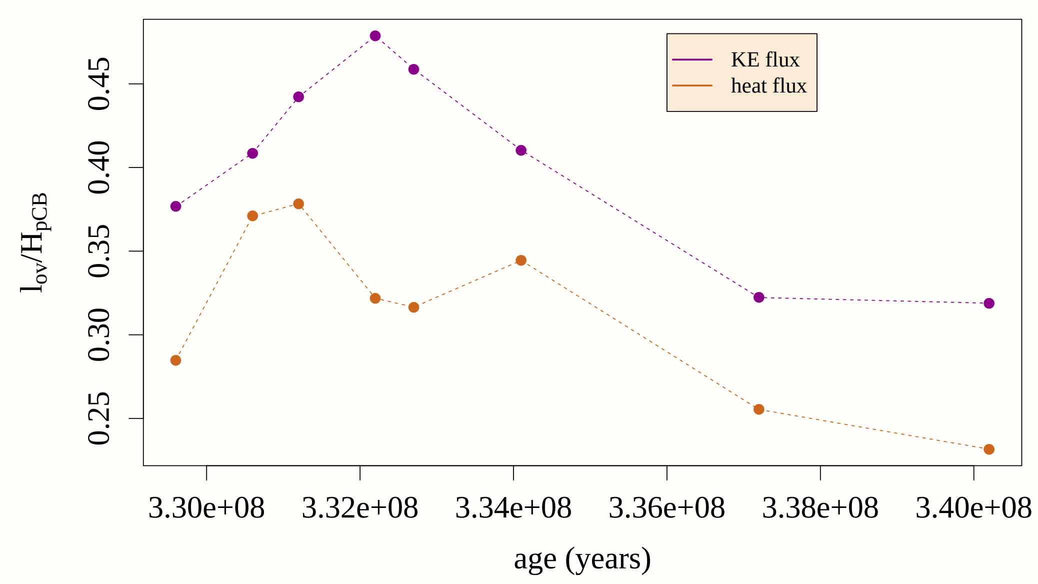
Penetration beneath the convection zone



- The maximum distance of overshooting at each time defines the depth of the overshooting layer better than an average. Above this is calculated using the vertical kinetic flux (KE flux). Below this is also calculated using the vertical heat flux.
- How far plumes penetrate into the overshooting layer, r_o, can be characterized by a probability distribution function P. Here that is shown in units of the pressure scale height H_p.



- A basic overshooting length ℓ_{ov} can be estimated from the location parameter of the extreme value distribution.



Summary & Future Work

- This analysis is preliminary.
- The overshooting length (relative to the pressure scale height) clearly changes as the star ages, even when effects like simulation resolution are taken into account.
- During this short period after the first dredge-up, the overshooting length changes by a factor of ~ 2.
- Analysis of additional stars is needed to make clear predictions. Those efforts are underway.