

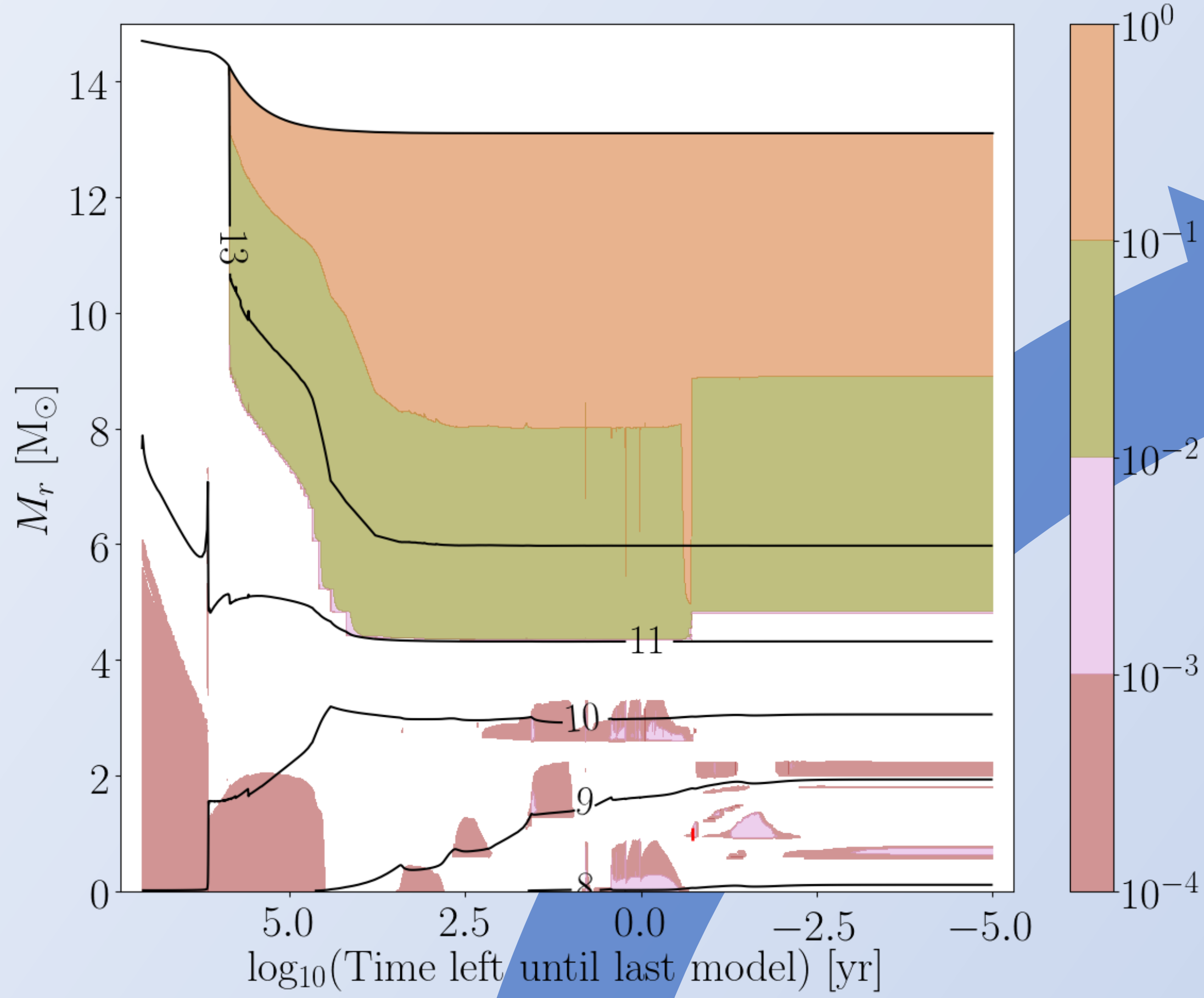
Turbulence and nuclear reactions in 3D hydrodynamics simulations of massive stars

F. Rizzuti¹, R. Hirschi^{1,2}, C. Georgy³, W. D. Arnett⁴, C. Meakin⁵ and A. StJ. Murphy⁶

¹Keele University, UK, ²Kavli IPMU (WPI), University of Tokyo, JP, ³University of Geneva, CH, ⁴University of Arizona, USA, ⁵Pasadena Consulting Group, CA, USA, ⁶University of Edinburgh, UK

The evolution of massive stars is affected by uncertainties linked to multi-dimensional processes. 3D hydrodynamics models can reproduce realistic 3D processes in stellar interiors, improving the knowledge and theory used for 1D stellar evolution models.

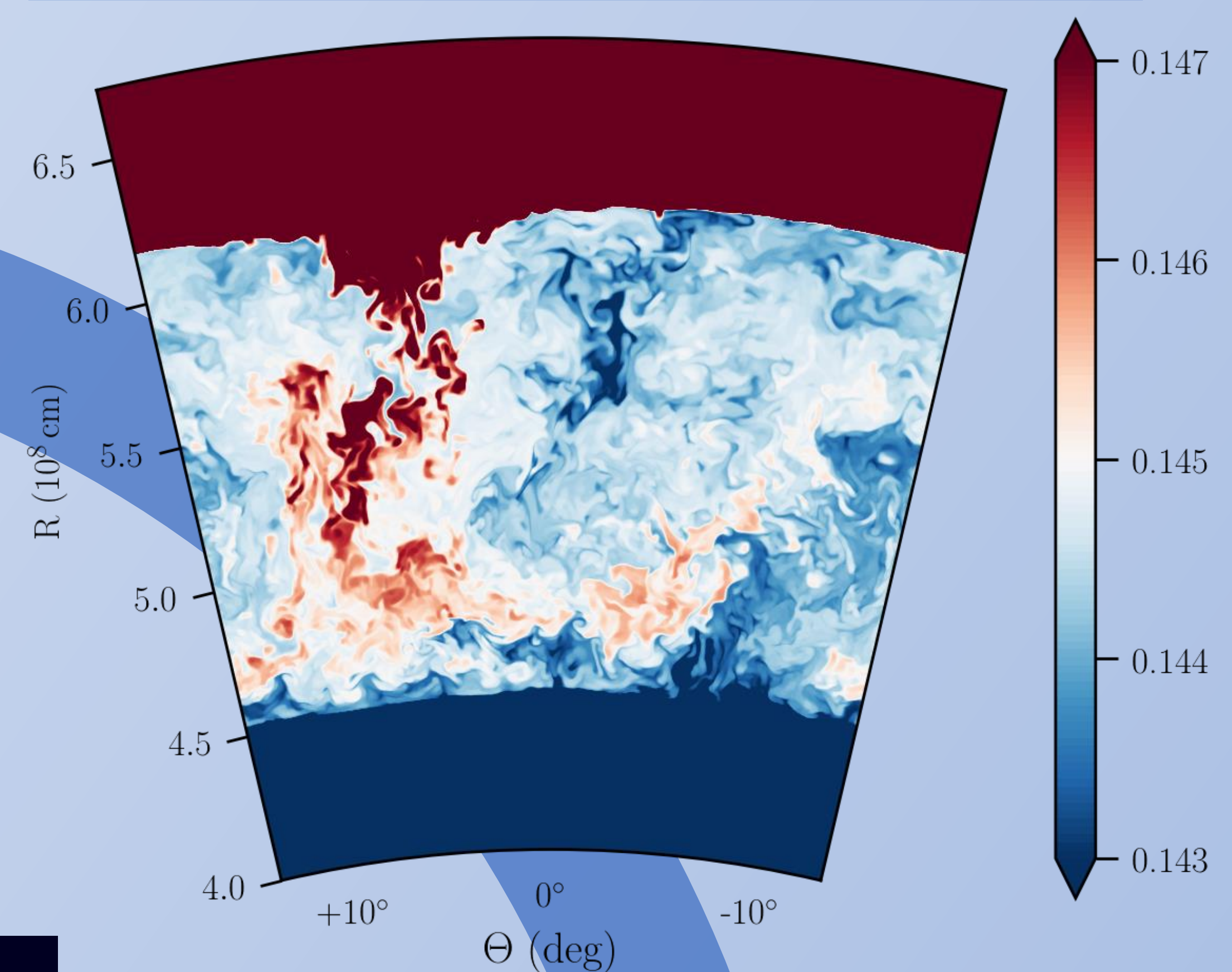
Structure evolution diagram of a 1D stellar evolution model



We computed a set of 3D hydrodynamics simulations of a neon-burning shell in a $15 M_\odot$ star with the PROMPT code. The simulations follow the box-in-a-star approach.

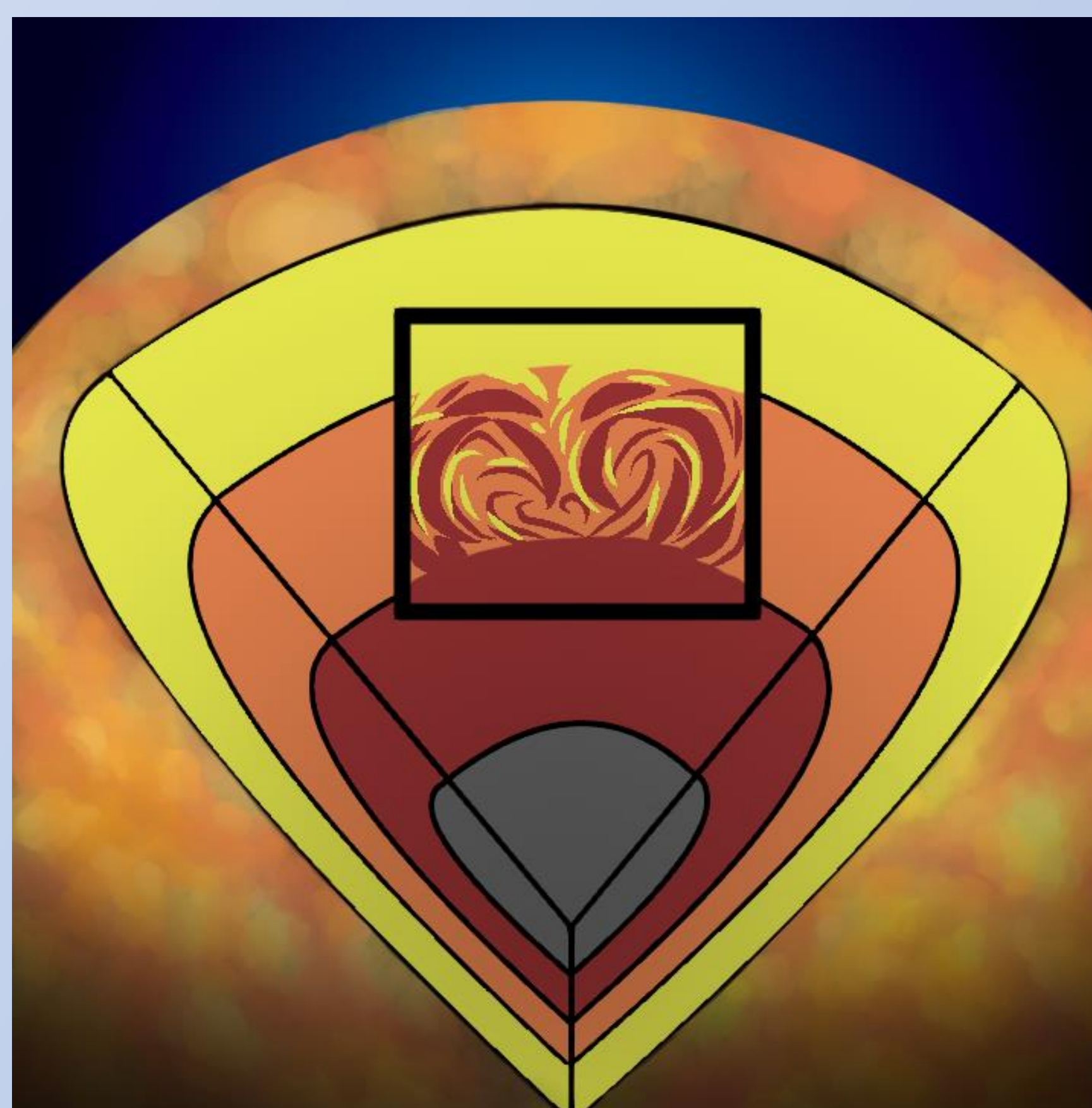
Convection is driven by the energy released by nuclear reactions involving ^{16}O , ^{20}Ne , ^{24}Mg , ^{28}Si .

Cross section of the ^{20}Ne mass fraction in the 3D model



Prescriptions from 3D hydrodynamics can be used for 1D models. What is the impact on the stellar structure? How does the initial 1D model change?

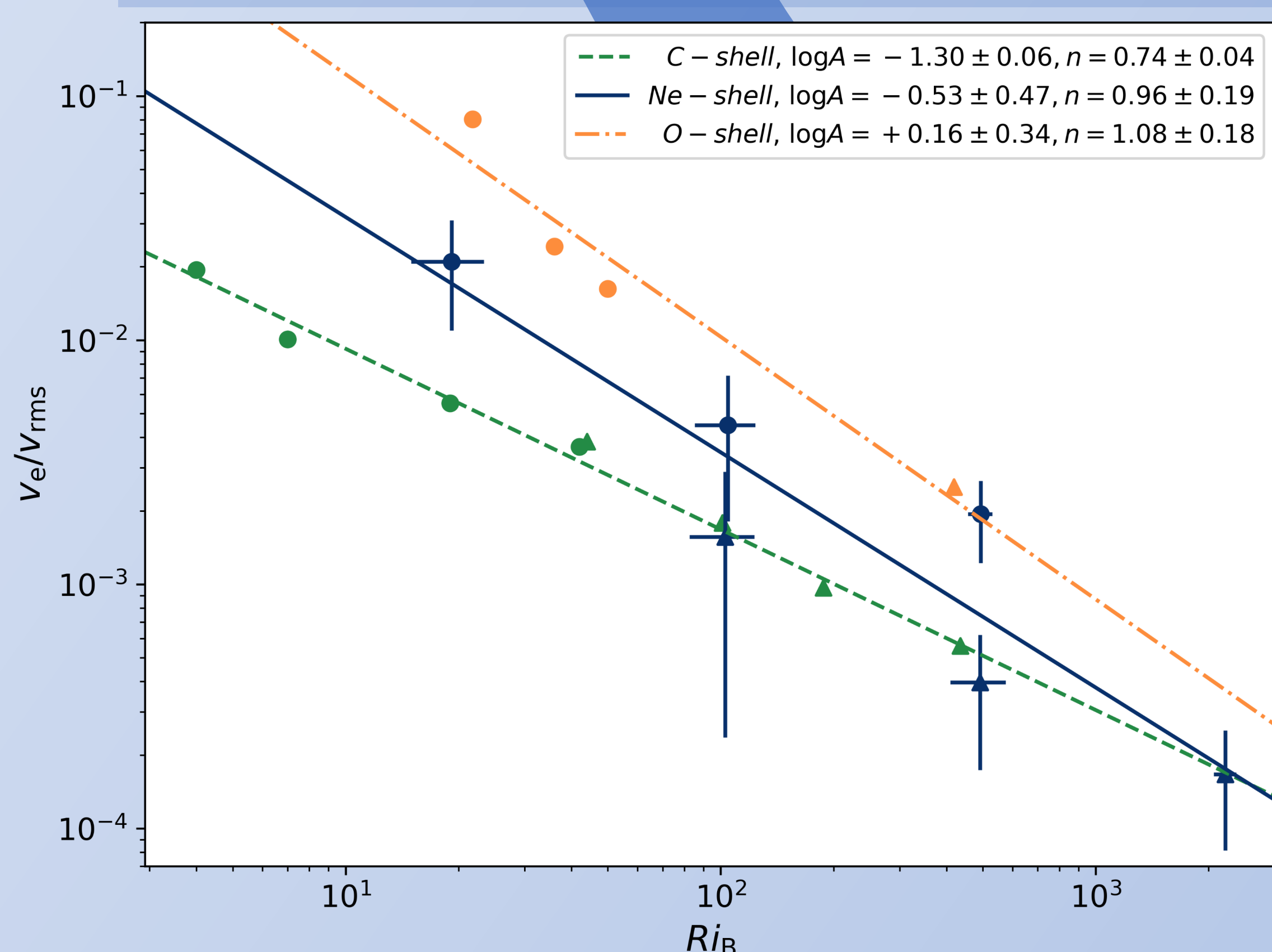
Including entrainment is an important step toward realistic stellar modelling, affecting stellar evolution, nucleosynthesis and supernova theory.



The mixing near the convective boundaries entrains material from the stable regions into the convective zone, that grows with time. This phenomenon is known as *entrainment*.

The growth rate of the convective zone depends on the boundary properties.

Entrainment rate versus bulk Richardson number from 3D

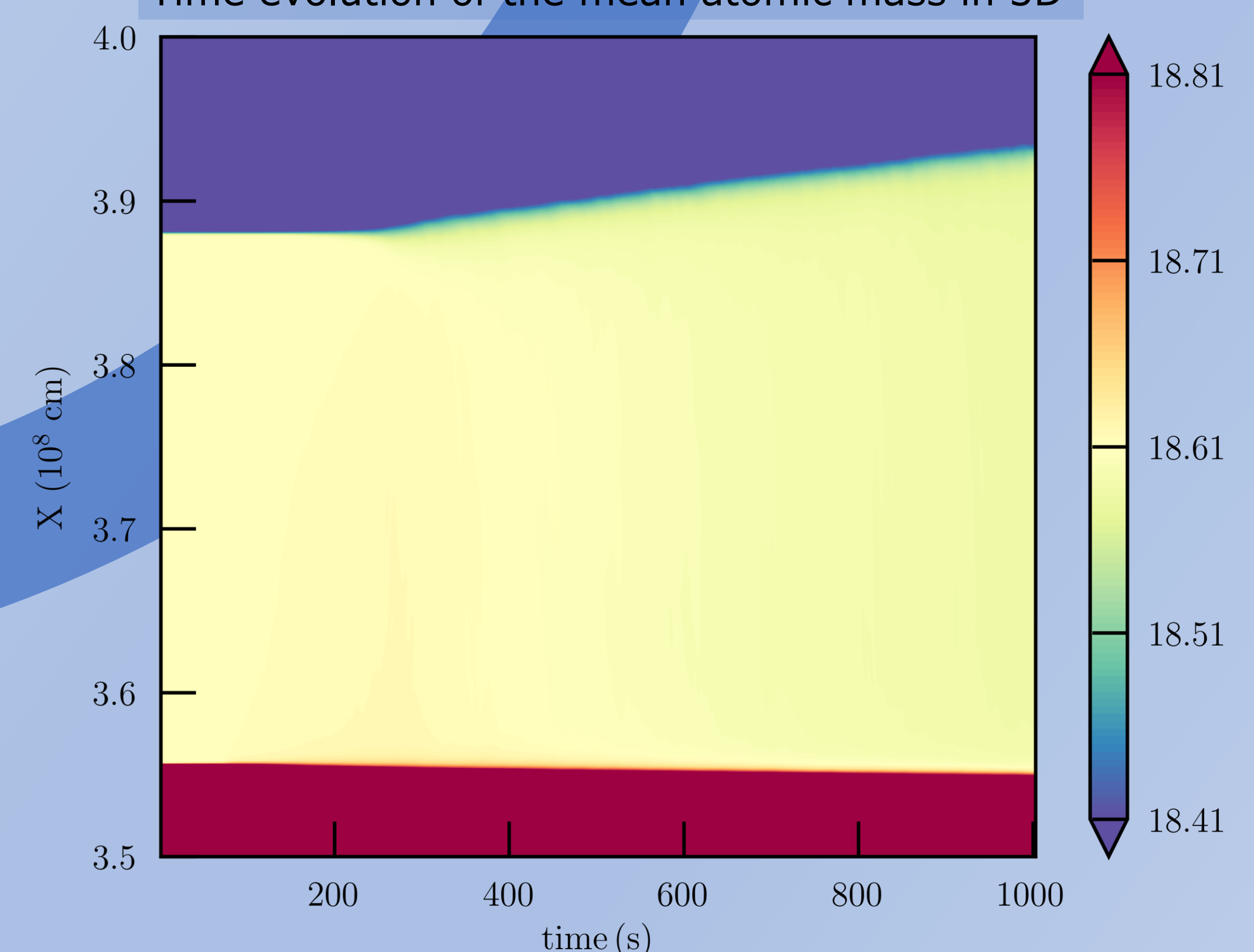


The entrainment rate can be parametrized as a function of the bulk Richardson number:

$$E = v_e/v_{rms} = A \cdot Ri_B^{-n}$$

We estimate the value of parameters $A = 0.30$, $n = 0.96$, and compare them to previous studies of different stellar phases.

Time evolution of the mean atomic mass in 3D



References

- Meakin C. A., Arnett D., 2007, ApJ, 667, 448
- Cristini A., Meakin C., Hirschi R., Arnett D., Georgy C., Viallet M., Walkington I., 2017, MNRAS, 471, 279
- Jones S., Andrássy R., Sandalski S., Davis A., Woodward P., Herwig F., 2017, MNRAS, 465, 2991
- Mocák M., Meakin C., Campbell S. W., Arnett W. D., 2018, MNRAS, 481, 2918
- Cristini A., Hirschi R., Meakin C., Arnett D., Georgy C., Walkington I., 2019, MNRAS, 484, 4645
- Horst L., Hirschi R., Edelmann P. V. F., Andrássy R., Röpké F. K., 2021, A&A, 653, A55
- Scott L., Hirschi R., Georgy C., Arnett W. D., Meakin C., Kaiser E. A., et al., 2021, MNRAS, 503, 4208
- Rizzuti F., Hirschi R., Georgy C., Arnett W. D., Meakin C., Murphy A. StJ., 2022, MNRAS, 515, 4013



Watch the movie!



Useful links