# Primary nitrogen production in rapidly rotating Population III stellar models

**Sophie Tsiatsiou**

**Supervisors: Prof. Georges Meynet, Dr. Sylvia Ekström**

**Observatory of Geneva - Switzerland**

18th Russbach School on Nuclear Astrophysics
15/03/2023

# Population III stars

What are the Pop III stars and why are they interesting objects?

- The first generation of stars, formed from the metal-free gas produced in the Big Bang ⇒ Zero-metallicity
- Formed at redshifts $z \sim 20 - 35$
  *(e.g. Abel et al. (2002) Science.295.93, Bromm et al. (2002) ApJ.564.2)*
- Massive stars
  *(e.g. Bromm et al. (2002) ApJ.564.2)*
- Governed the early chemical evolution of galaxies
- Contributed to the reionization
  *(e.g. Murphy et al. (2021b) MNRAS.506.5731, Sibony et al. (2022) A&A.666.A199)*
- High rotation
  *(e.g. Stacy et al. (2013) MNRAS.431.1470)*

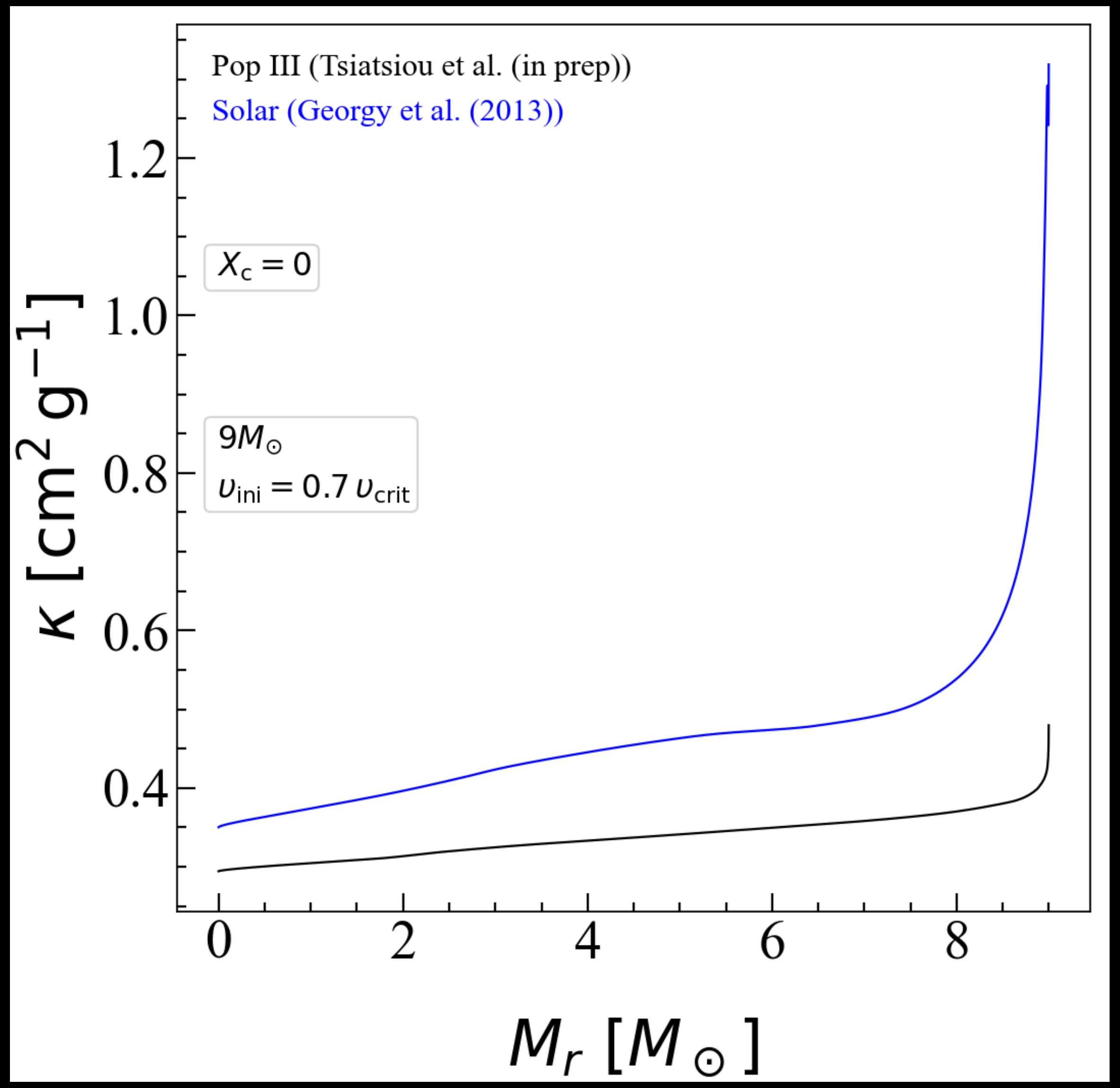
# Compactness of Pop III stars

Where does it come from?

# Compactness of Pop III stars

Where does it come from?

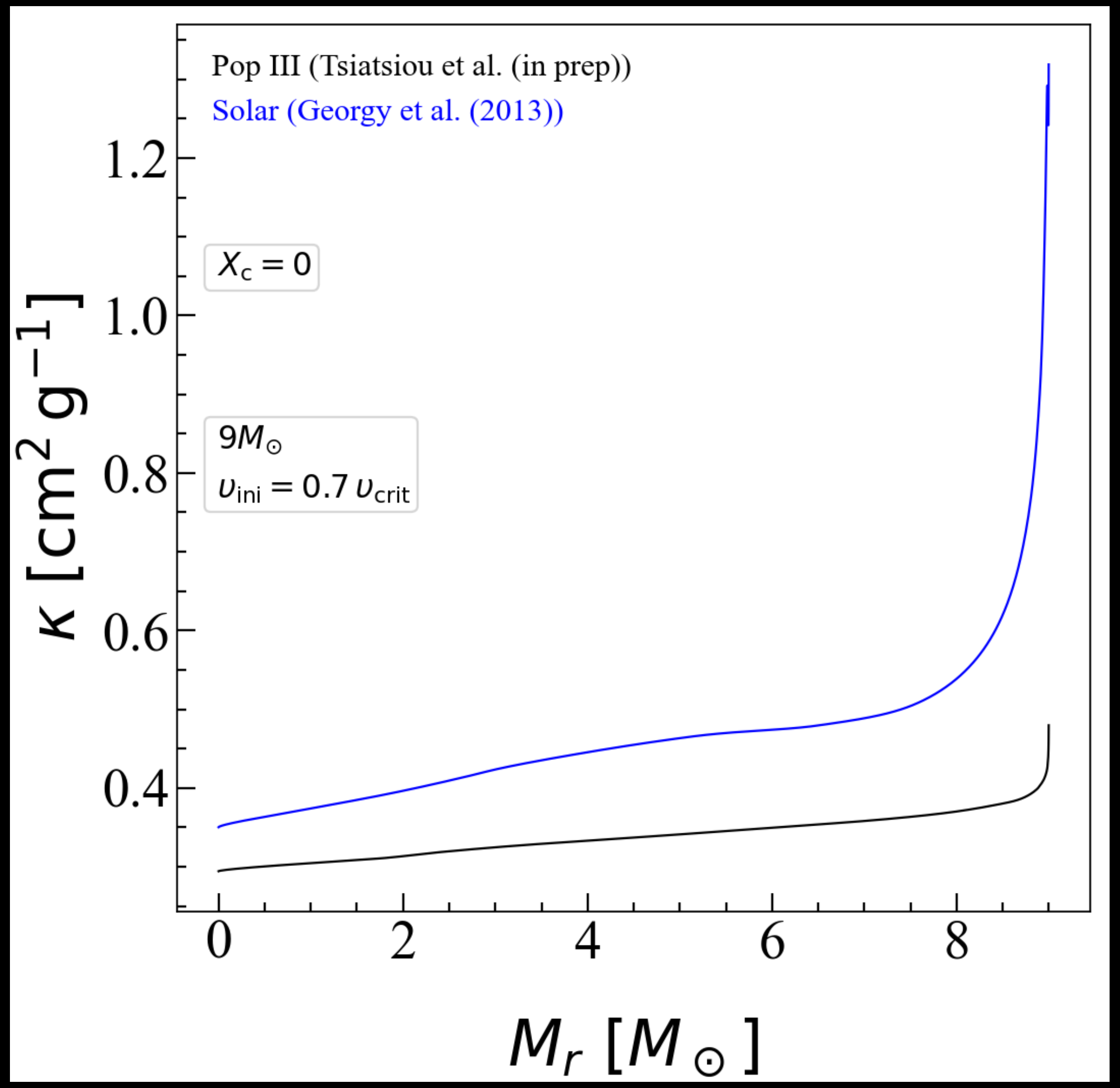
→ Opacity

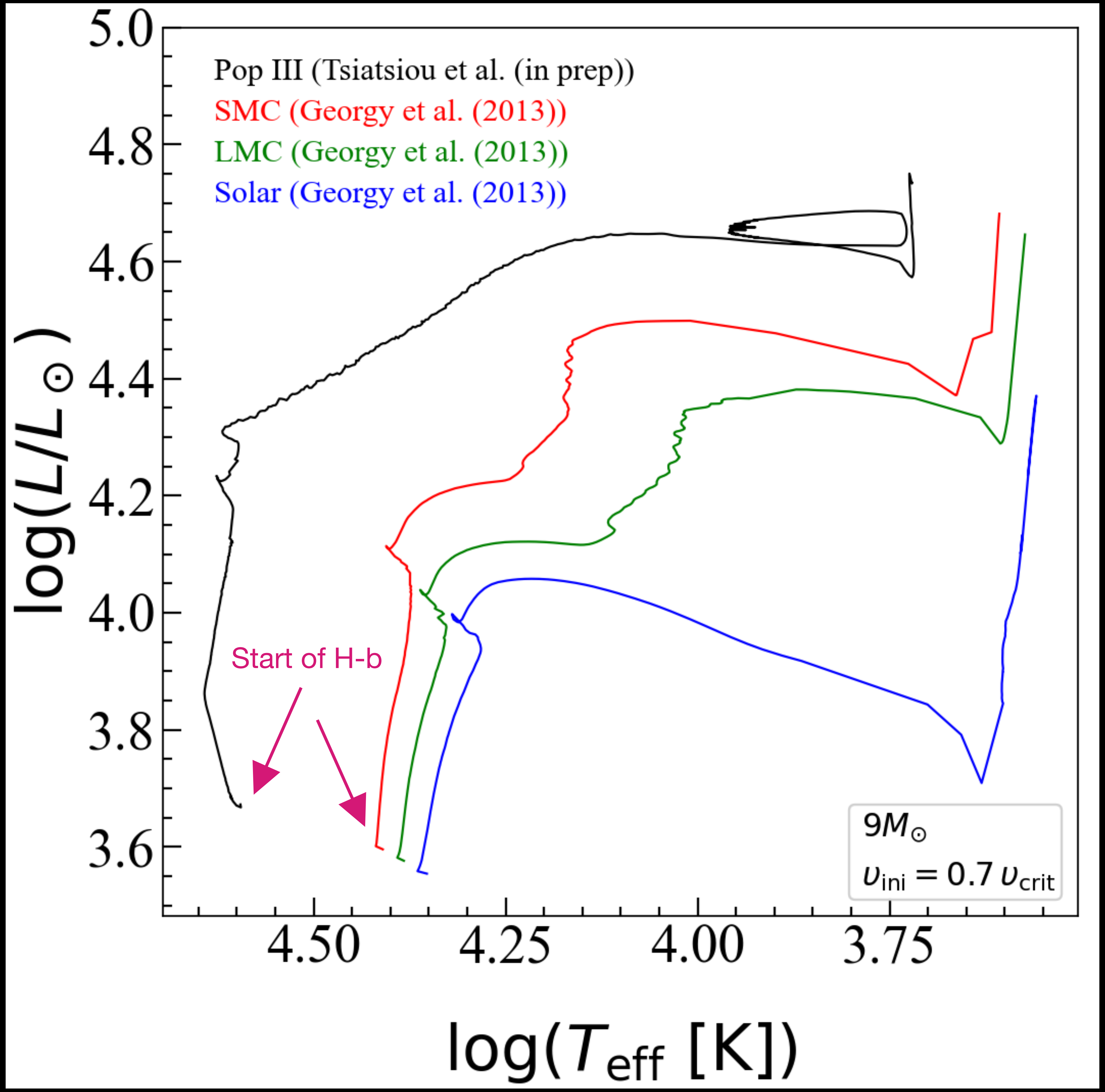


# Compactness of Pop III stars

Where does it come from?

→ Opacity



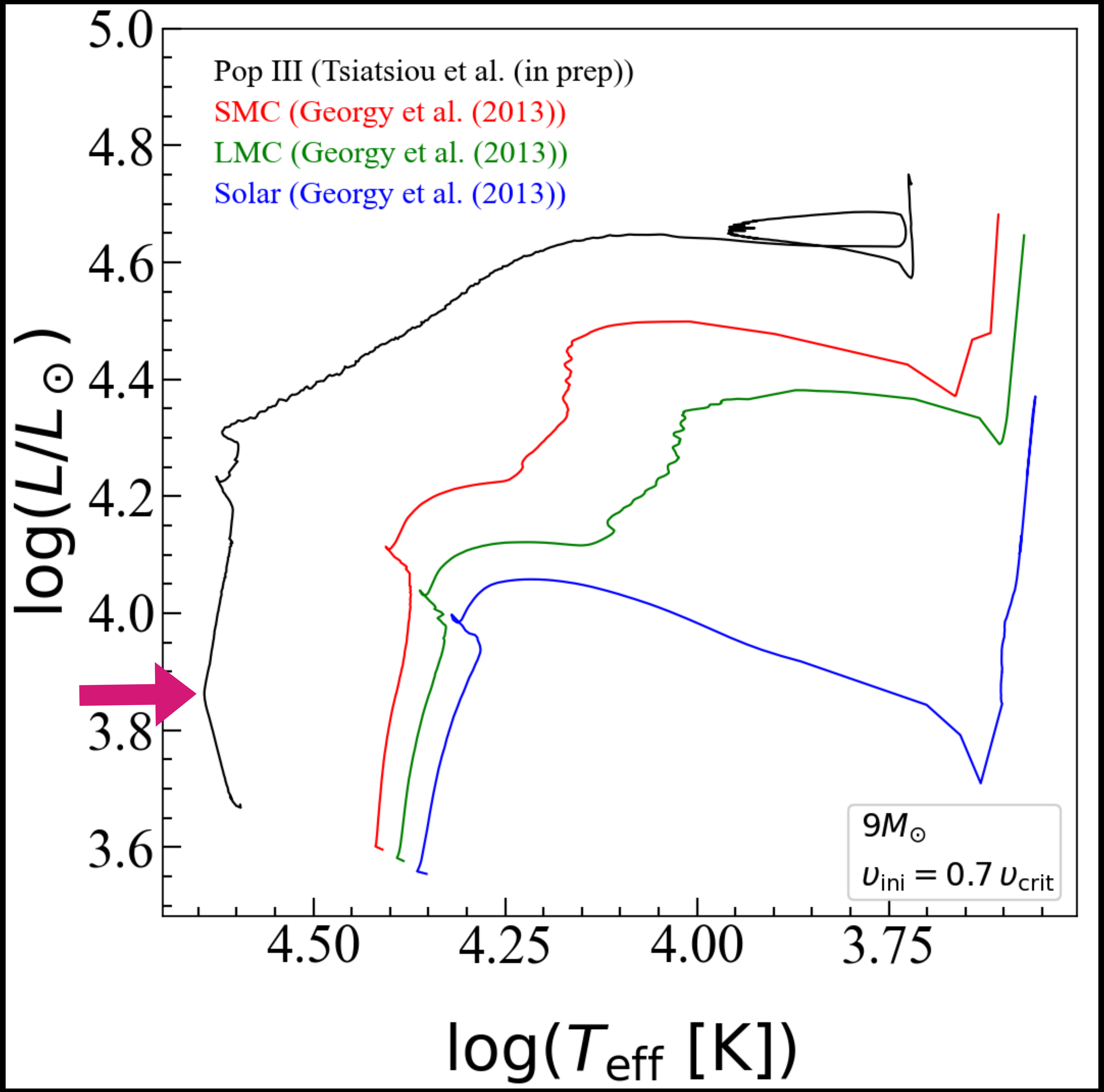
# Compactness of Pop III stars

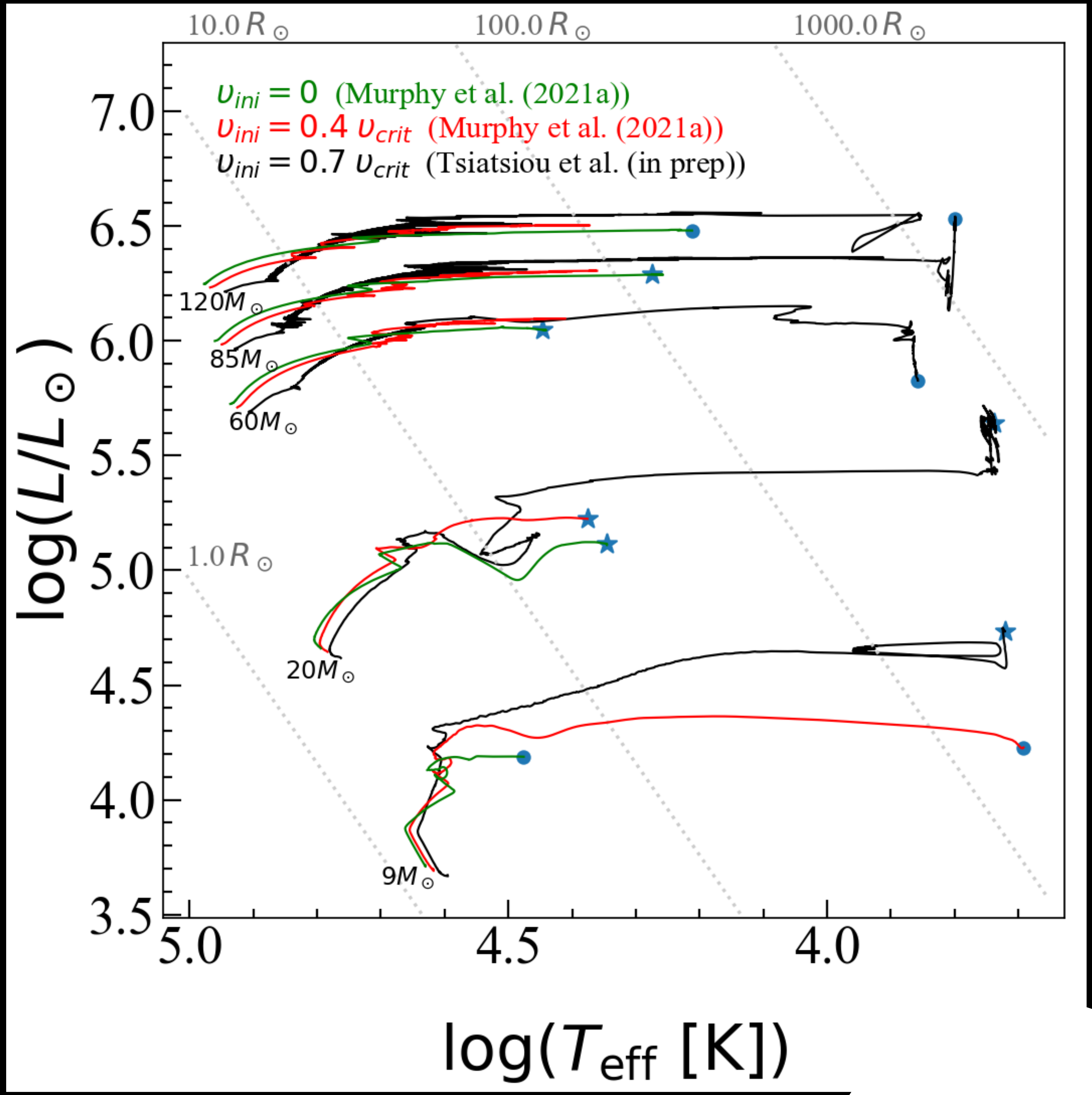
Where does it come from?

→ Opacity

→ Lack of the CNO elements

$$\epsilon_{\rm pp} \propto T^4$$
$$\epsilon_{\rm CNO} \propto T^{20}$$







# GENEC stellar evolution code

Initial composition: X=0.7516, Y=0.2484, Z=0

Reaction rates: NACRE database

$$D_{shear} = \frac{K}{\frac{\varphi}{\delta}\nabla_{\mu} + (\nabla_{ad} - \nabla_{rad})} \times \frac{H_p}{g\delta}\left[f_{energ}\left(\frac{9\pi}{32}\Omega\frac{d\ln\Omega}{d\ln r}\right)^2 - (\nabla' - \nabla)\right]$$

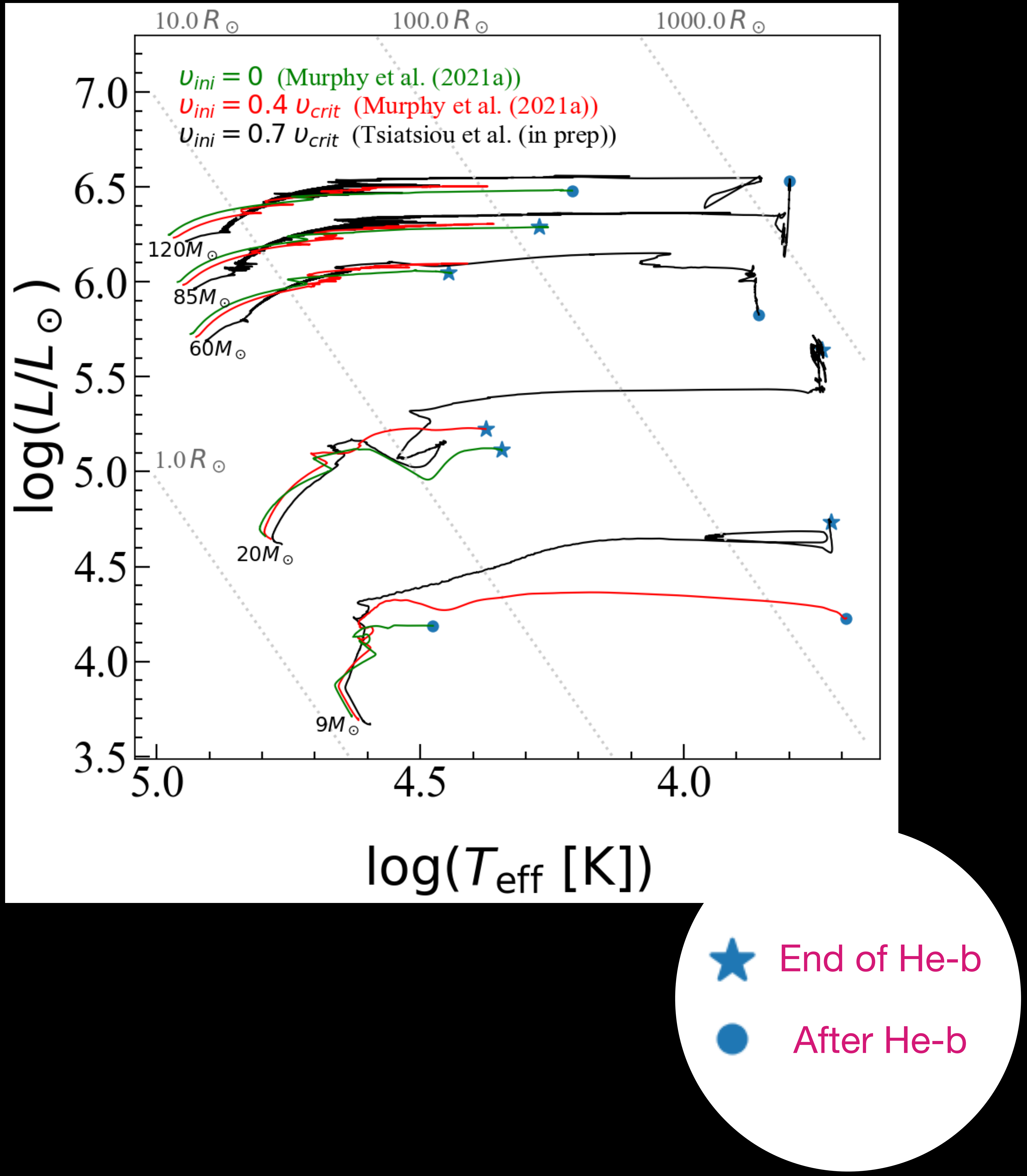
Maeder (1997) A&A 321 134

$$D_{eff} = \frac{1}{30}\frac{\left|rU(r)\right|^2}{D_h}$$

Zahn (1992) A&A 265 115

Convective zones: Schwarzschild criterion

Overshoot parameter $d_{\rm over}/H_{\rm p} = 0.1$




# GENEC stellar evolution code

Initial composition: X=0.7516, Y=0.2484, Z=0

Reaction rates: NACRE database

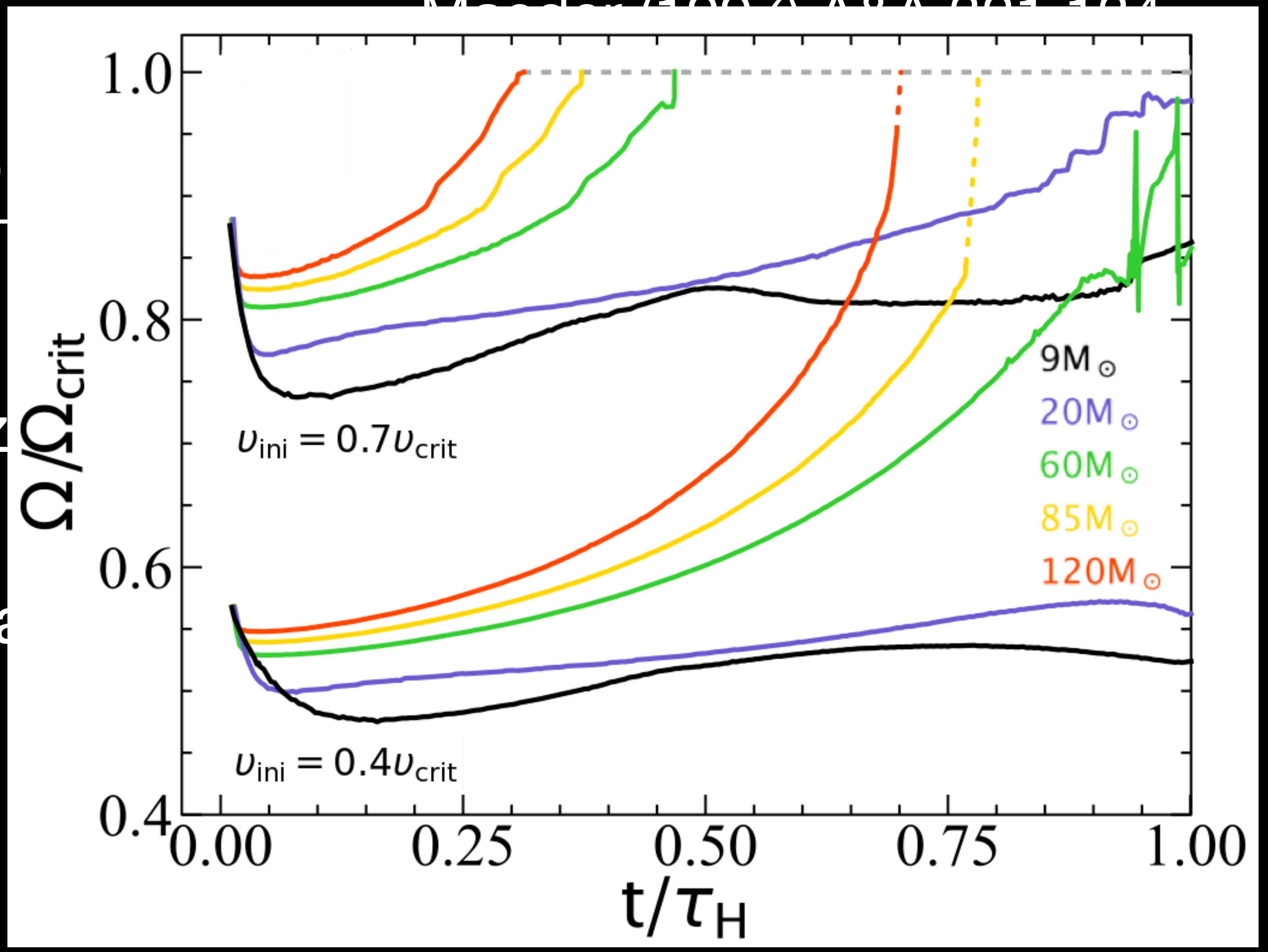
$$D_{shear} = \frac{K}{\frac{\varphi}{\delta}\nabla_\mu + (\nabla_{ad} - \nabla_{rad})} \times \frac{H_p}{g\delta}\left[f_{energ}\left(\frac{9\pi}{32}\Omega\frac{d\ln\Omega}{d\ln r}\right)^2 - (\nabla' - \nabla)\right]$$

Maeder (1997) A&A 321 134

$$D_{eff} = \frac{1}{30}\frac{|rU(r)|}{D_h}$$

Convective z

Overshoot pa

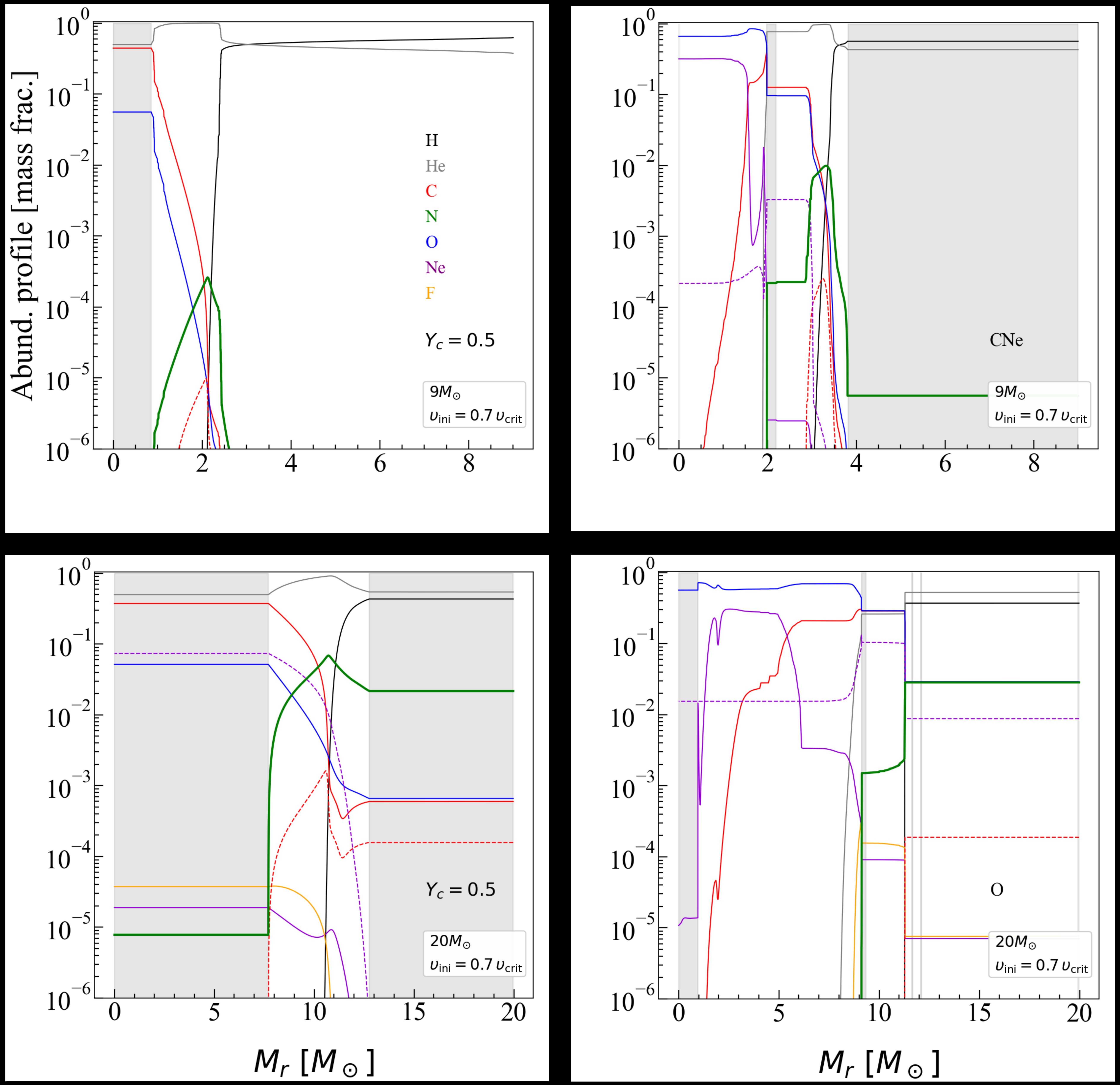


# Chemical mixing

In the interior of the Pop III stars

Compact objects ⇒
smaller distances between
the burning zones

**Primary nitrogen ⟶**
produced by hydrogen and helium,
and not pre-existing CNO elements



# Chemical Evolution Model

Why the study of primary nitrogen is important?

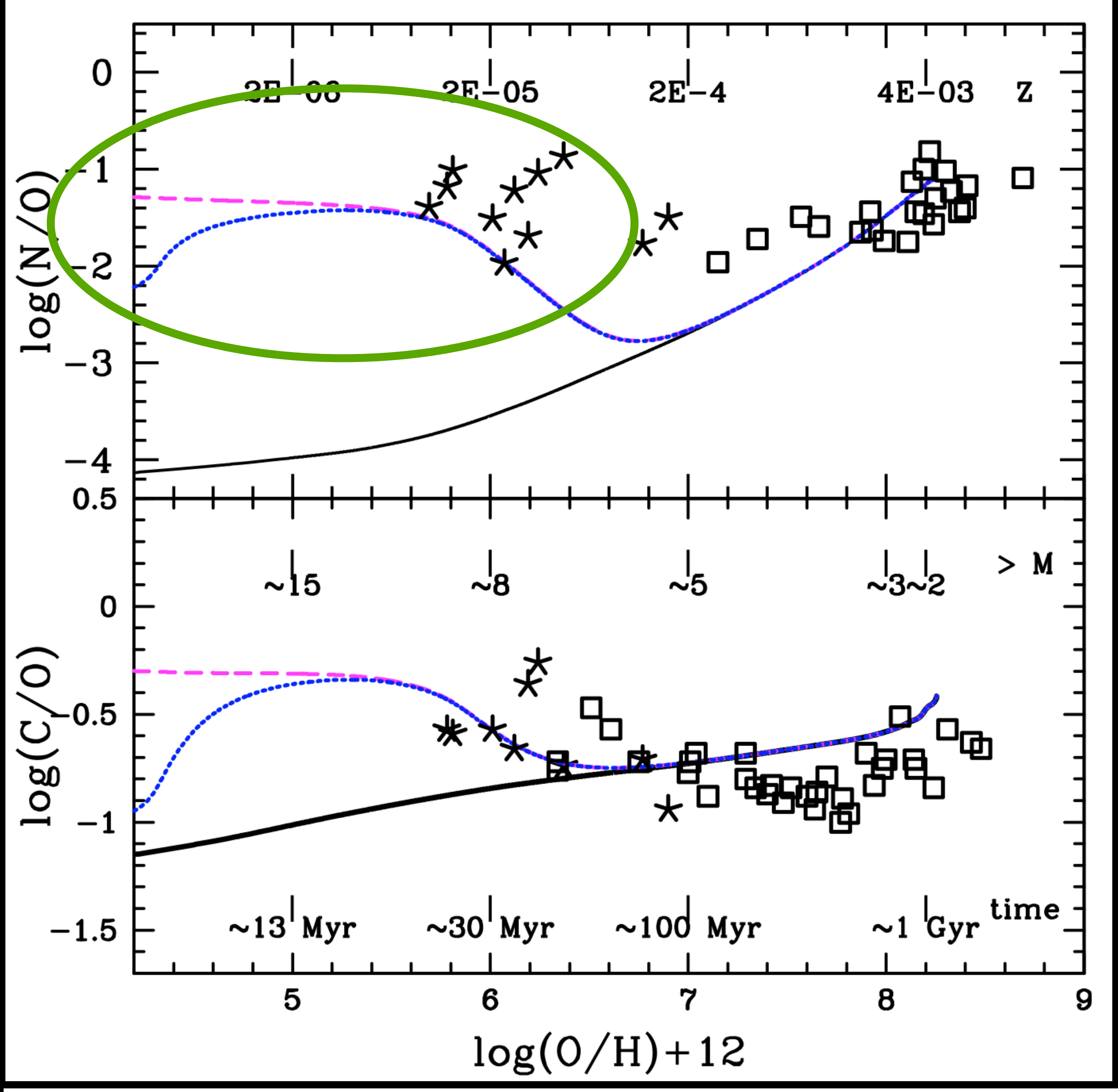



**Fig. 9.** Solid (black) curve: the CEM obtained with the stellar yields of slow rotating $Z = 10^{-5}$ models from Meynet & Maeder (2002) and Hirschi et al. (2004). Dashed (magenta) line includes the yields of fast rotating $Z = 10^{-8}$ models from Hirschi (2007) at very low metallicity. Dotted (blue) curve is obtained using the yields of the $Z = 0$ models presented in this paper up to $Z = 10^{-10}$. *Left:* evolution of the N/O and C/O ratios. Data points are from Israelian et al. (2004, open squares) and Spite et al. (2005, stars).

Ekström et al. (2008) A&A 489 685

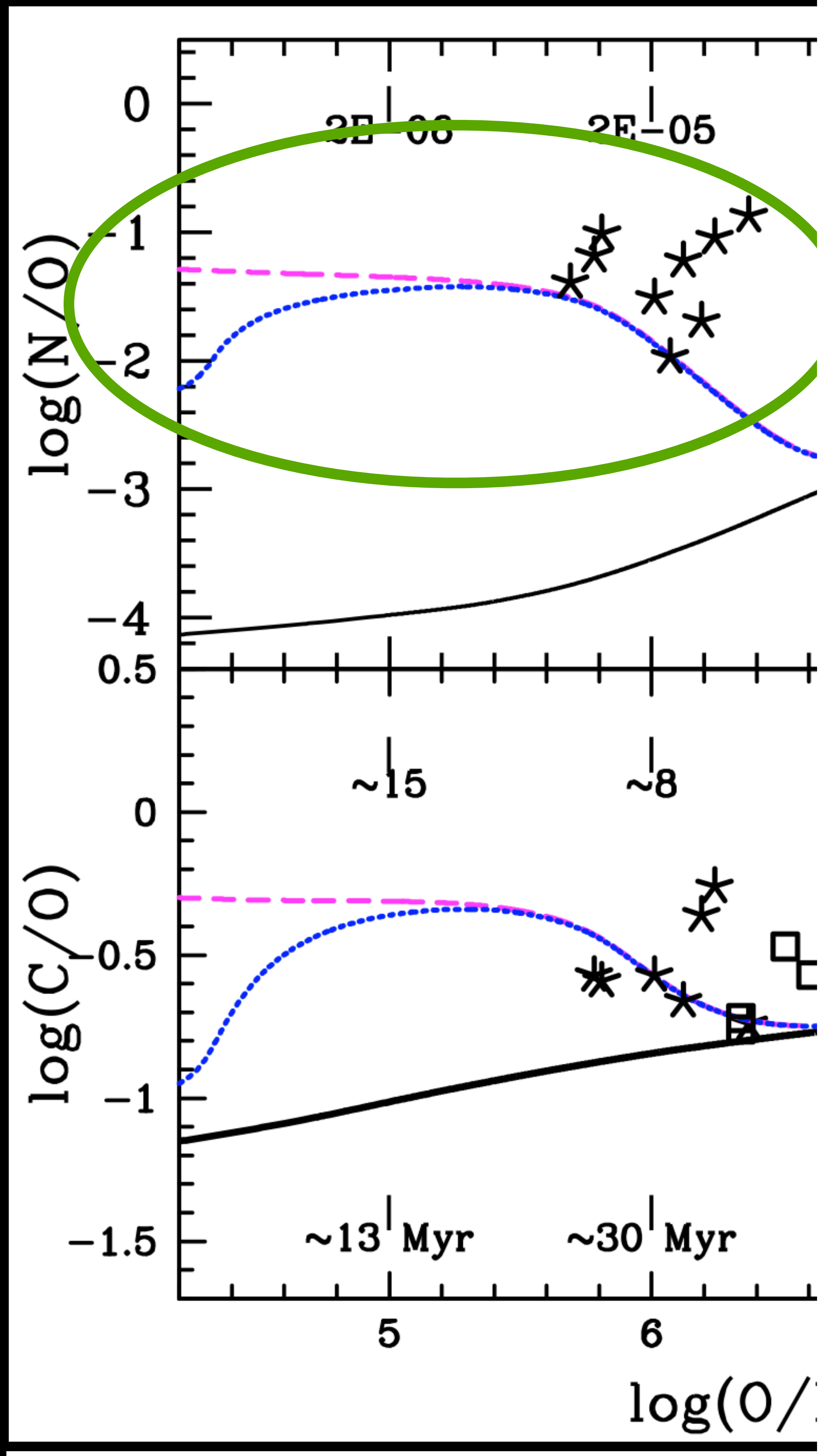
Ekström et al. (2008) ⟶
how the evolution and the chemical signature can be changed due to the rotation on the Pop III stars.

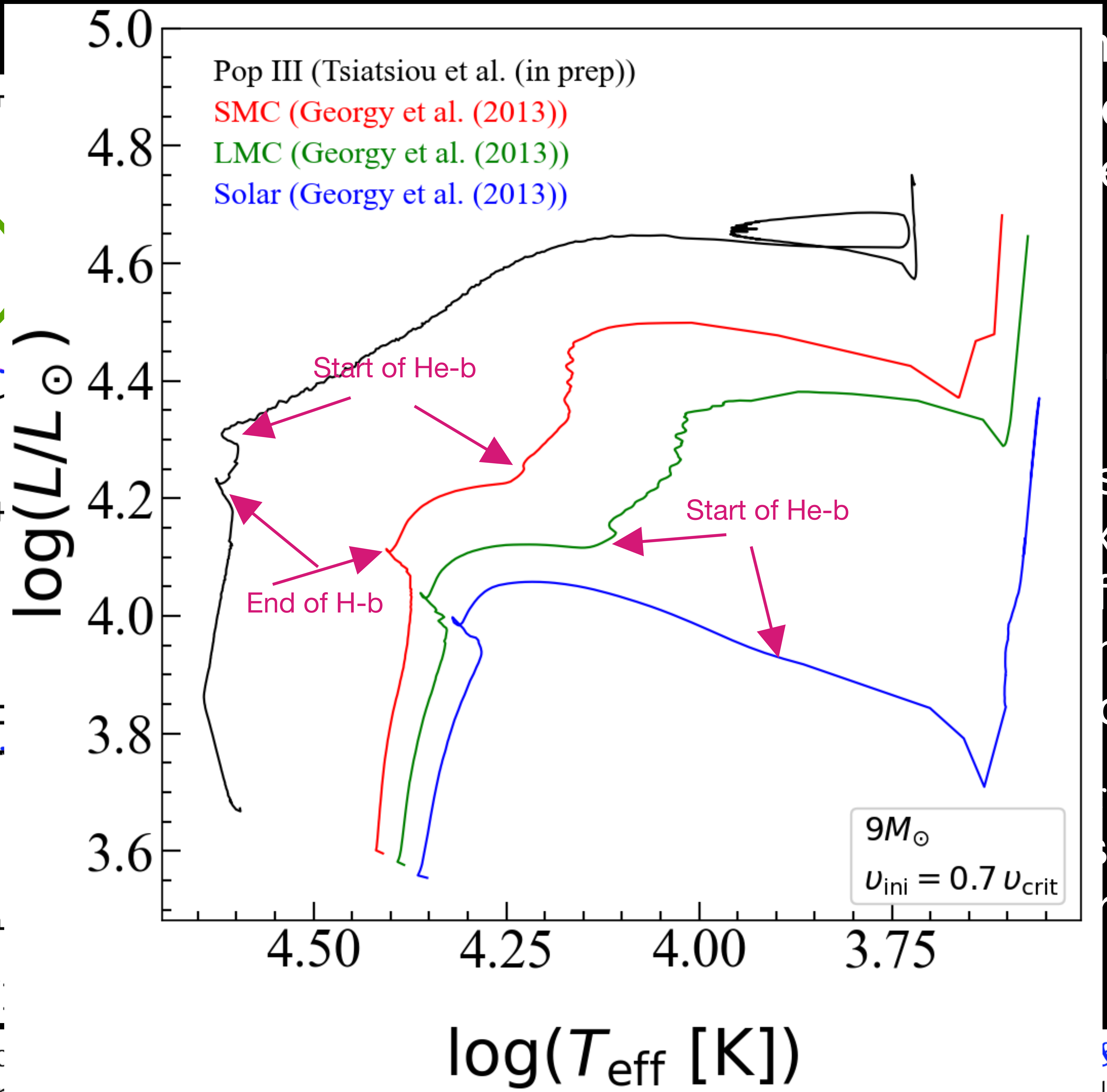
- Differences in physics:

1. Opacities at low temperatures.
   Alexander & Ferguson (1994)
2. Shear diffusion coefficient
   Talon & Zahn (1997)
3. Overshooting parameter.
   $$d_{\rm over}/H_{\rm p} = 0.2$$
4. Mass loss prescription
   Kudritzki (2002)

# Chemical Evolution Model

Why the study of primary nitrogen is important?




n et al. (2008) ⟶
d the chemical signature can be
e rotation on the Pop III stars.

n physics:

s at low temperatures.
xander & Ferguson (1994)
ffusion coefficient
n & Zahn (1997)
oting parameter.
$/H_p = 0.2$
s prescription
ritzki (2002)

**Fig. 9.** Solid (black) curve: the CEM c… & Maeder (2002) and Hirschi et al. (2004). Dashed (magenta) line includes the yields of fast rotating $Z = 10^{-8}$ models from Hirschi (2007) at very low metallicity. Dotted (blue) curve is obtained using the yields of the $Z = 0$ models presented in this paper up to $Z = 10^{-10}$. *Left:* evolution of the N/O and C/O ratios. Data points are from Israelian et al. (2004, open squares) and Spite et al. (2005, stars).

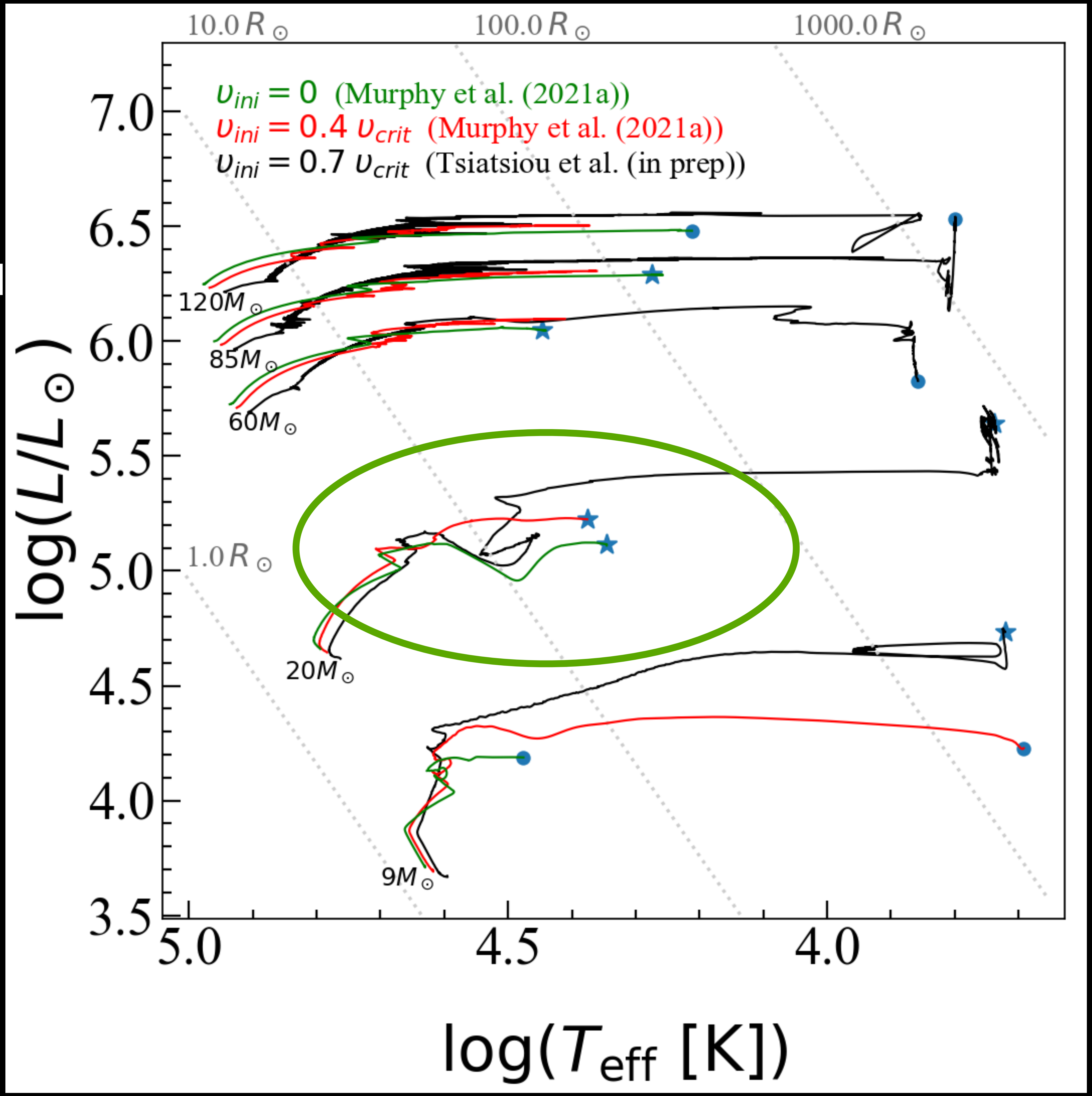
Ekström et al. (2008) A&A 489 685

# CNO pulses

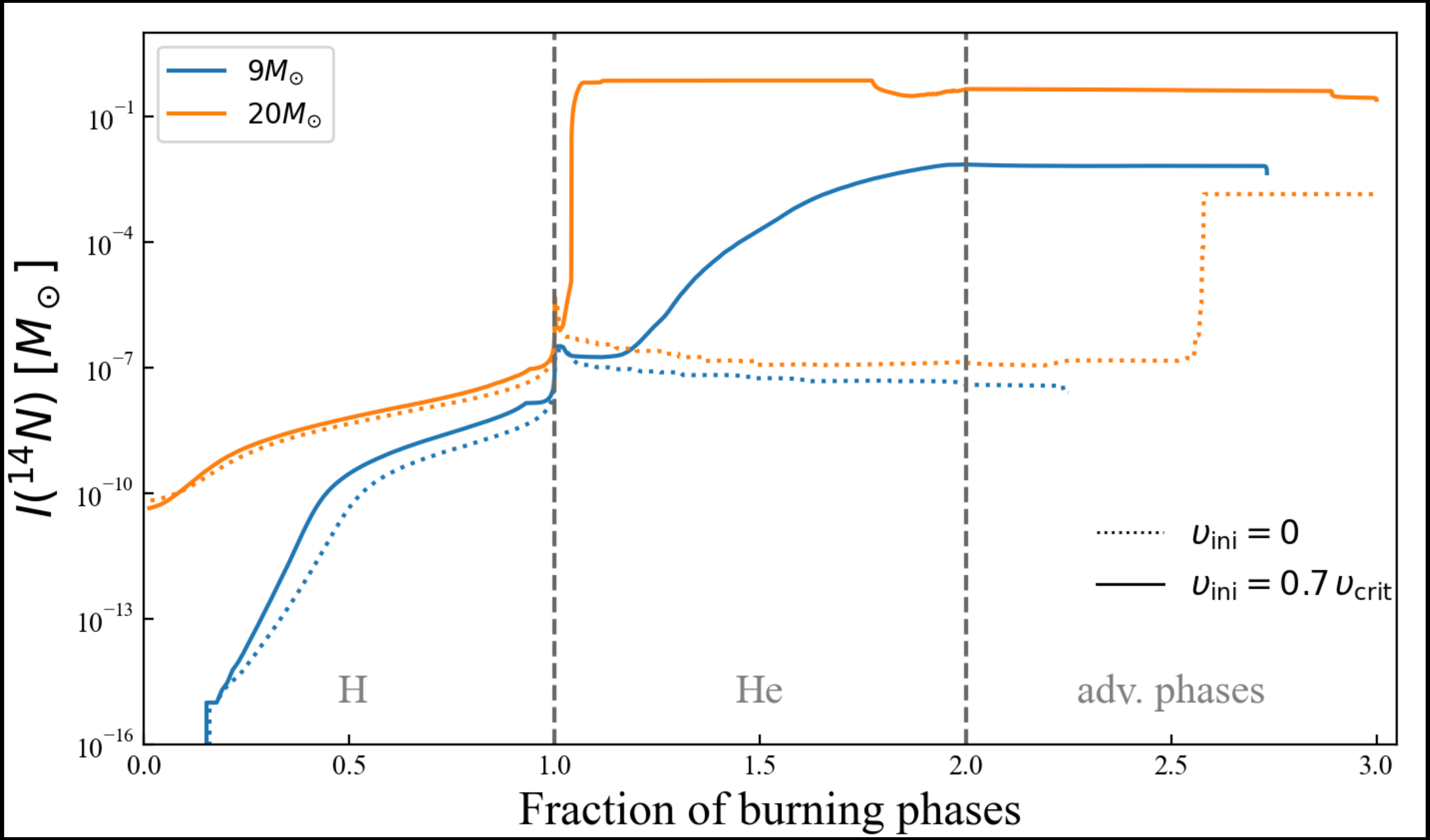
- During He-burning, C is injected to the H-burning shell.
- N will be produced in the H-burning shell.
- The mixing induces a huge boost of nuclear energy (It may changes the evolution and nucleosynthesis of the star)
- H-burning shell will become convective.

# CNO pulses

- During He-burning, C is injected to the H-bu
- N will be produced in the H-burning shell.
- The mixing induces a huge boost of nuclear and nucleosynthesis of the star)
- H-burning shell will become convective.

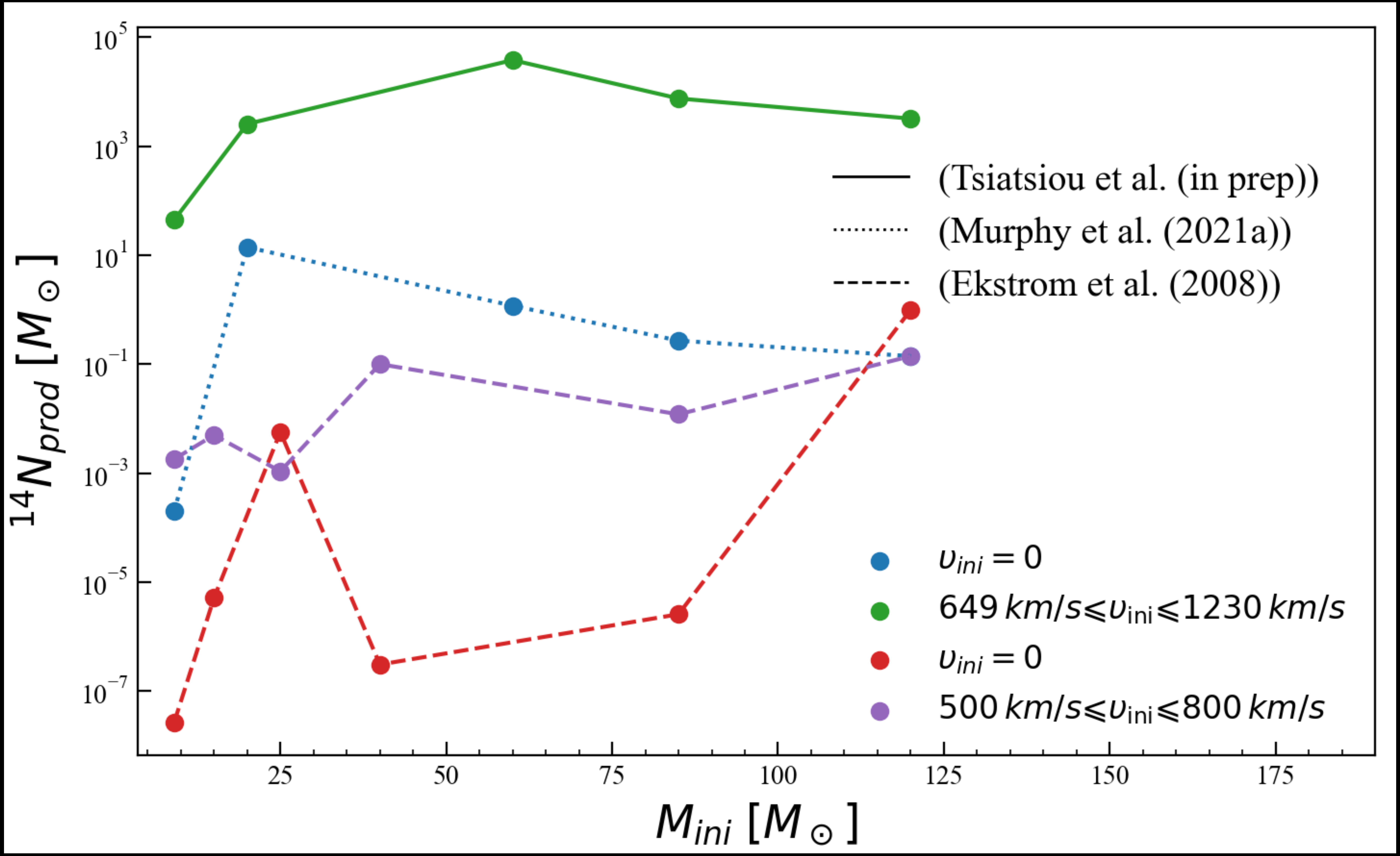


# Primary nitrogen production

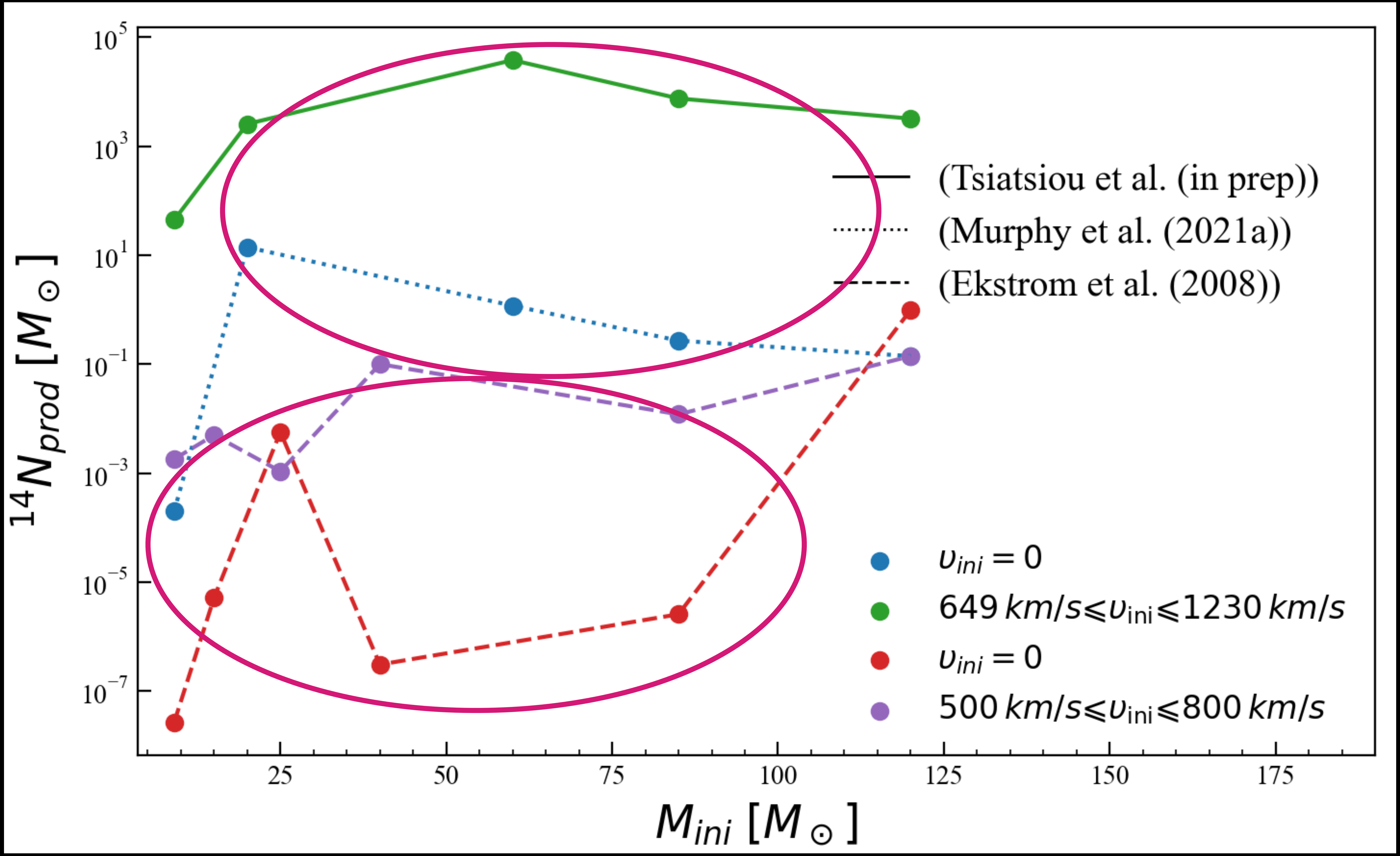



CNO pulses ⟶
important role in the production

# Chemical yields



# Chemical yields



# Overview

- Different initial rotations can impact the evolution of the first stars and the production of primary nitrogen.
- Higher primary nitrogen production for models with higher initial rotation.
- CNO pulses are of great importance for the production of primary nitrogen and other elements.

# Future work

- Analysing the chemical yields for models with different initial masses, different initial rotations, and different metallicities.
- What can change in the evolution of the models if we change the physics?
- Consider magnetic field.

Thank you