Advancing globular cluster constraints on the axion-photon coupling

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Matthew Dolan, **Frederick Hiskens**, Raymond Volkas

Part One

globular cluster constraints on the axion-photon coupling

ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

THE UNIVERSITY OF MELBOURNE

POSTERA CRESCAM LAUDE

Part Two

THE ISSUE WITH globular cluster constraints on the axion-photon coupling

Part Three

Advancing globular cluster constraints on the axion-photon coupling

Axions

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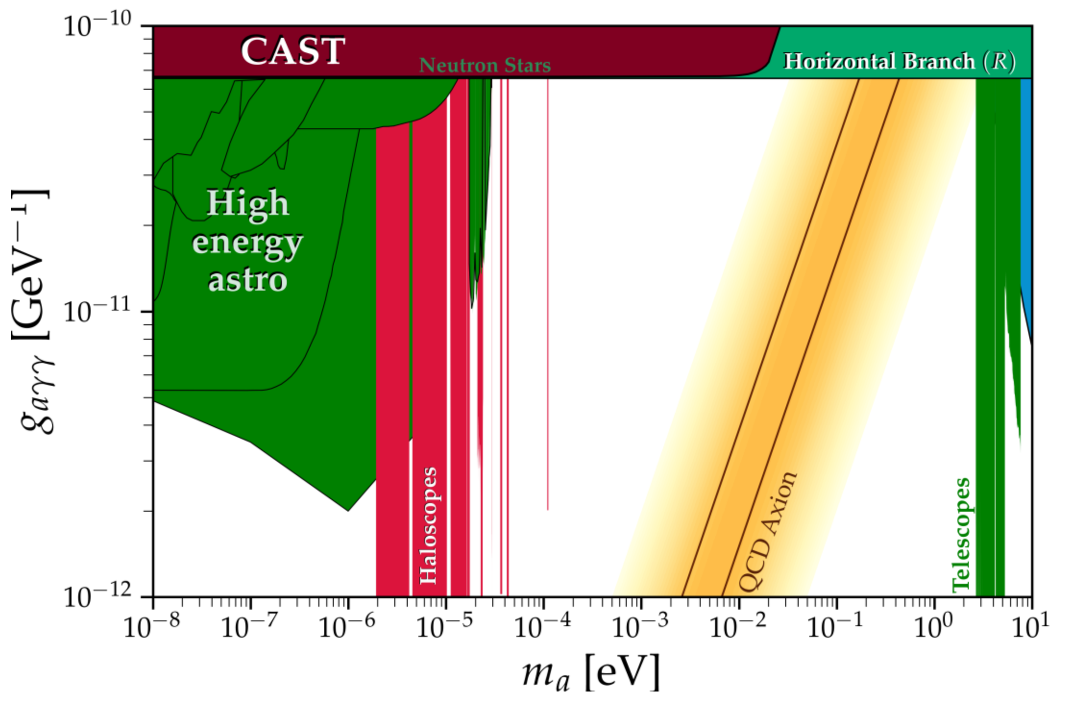
Haloscopes (ADMX, etc)

Cosmology
High energy astrophysics
Stellar cooling



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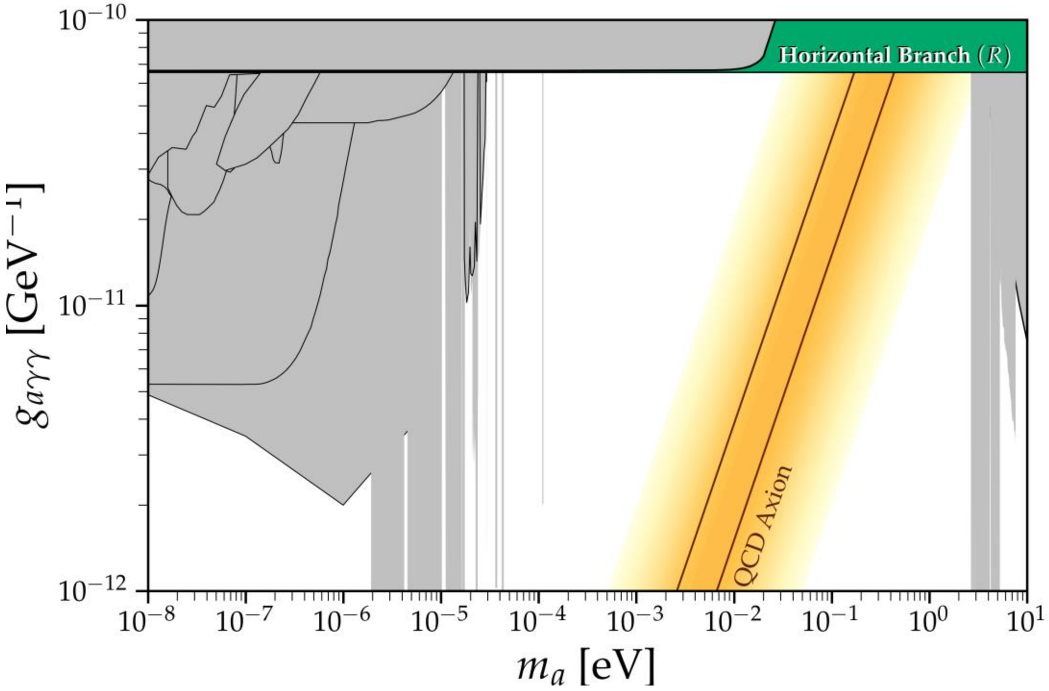

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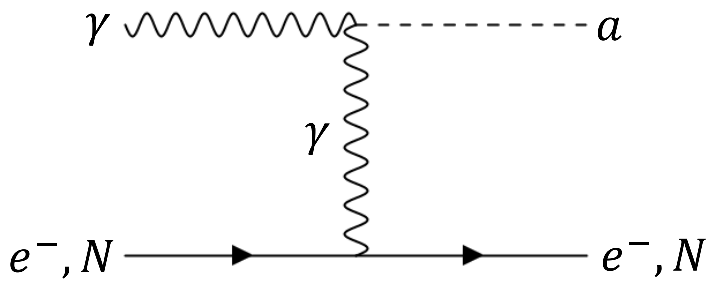

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$$\epsilon_P = \frac{g_{a\gamma\gamma}^2 T^7}{4\pi\rho} G\left(\frac{k_{DH}}{T}\right)$$

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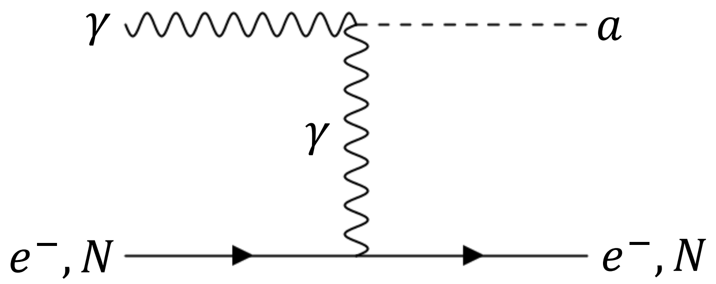

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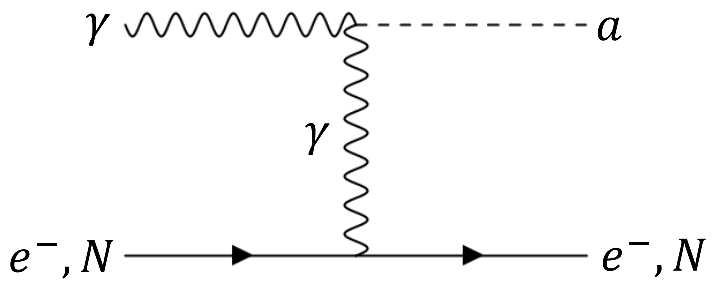

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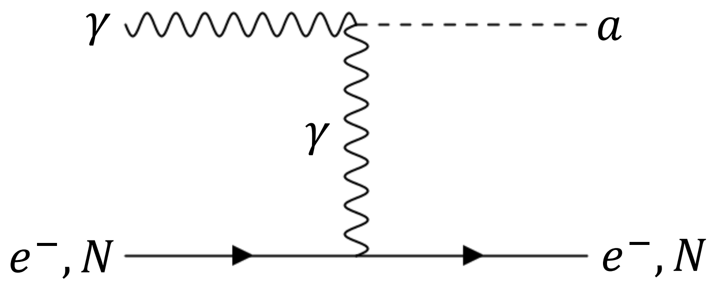

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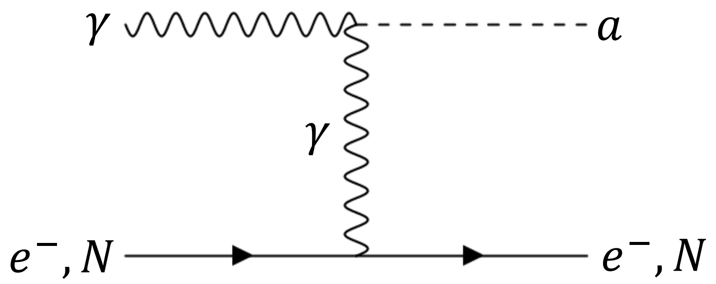
Burning region loses energy → Region contracts and heats → Nuclear burning intensifies



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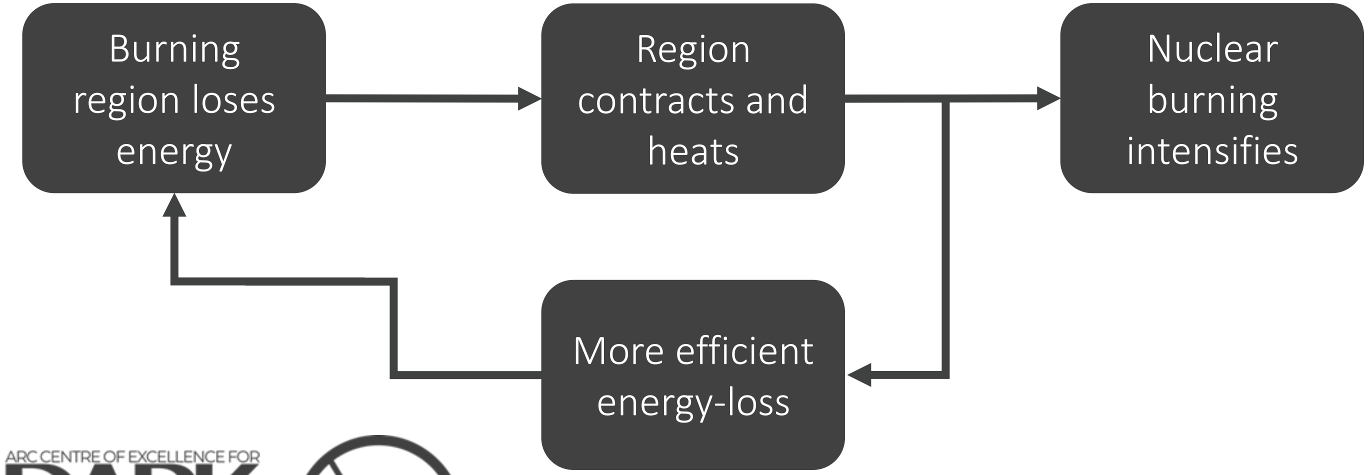

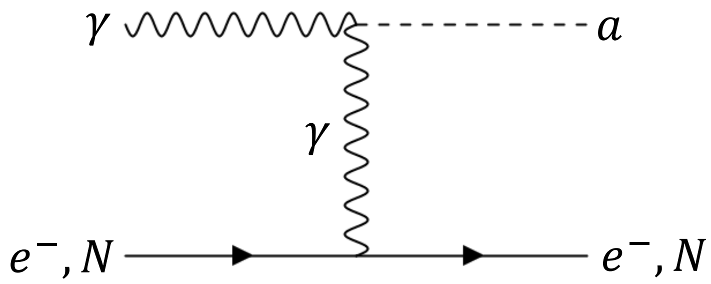

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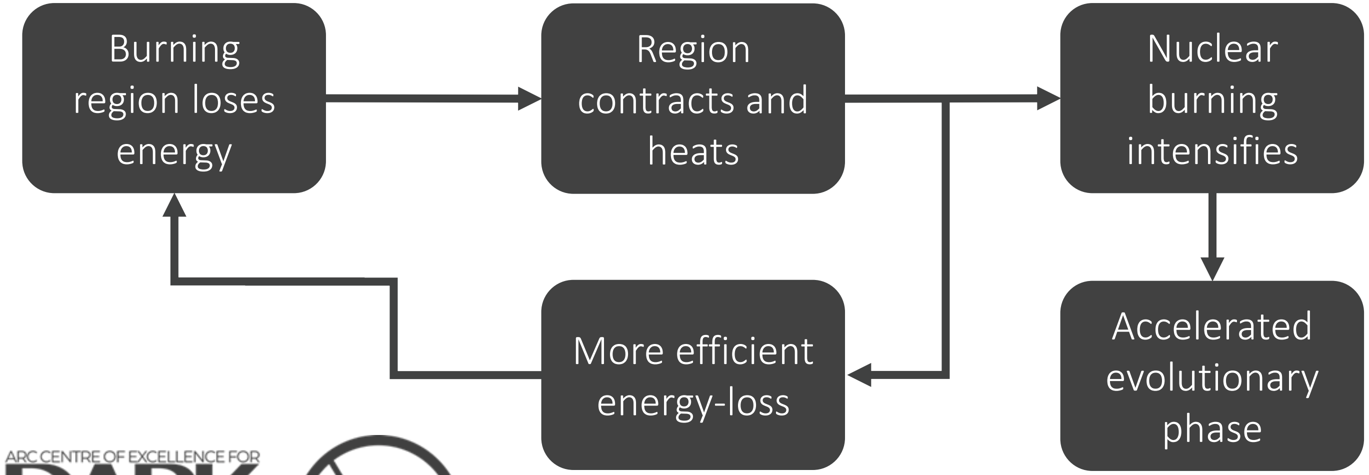

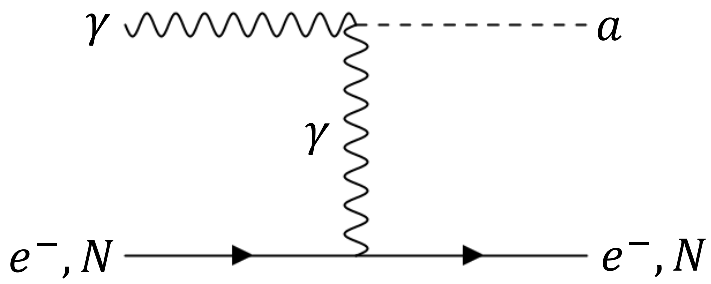

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Constraints derived in this manner are examples of **stellar cooling** bounds

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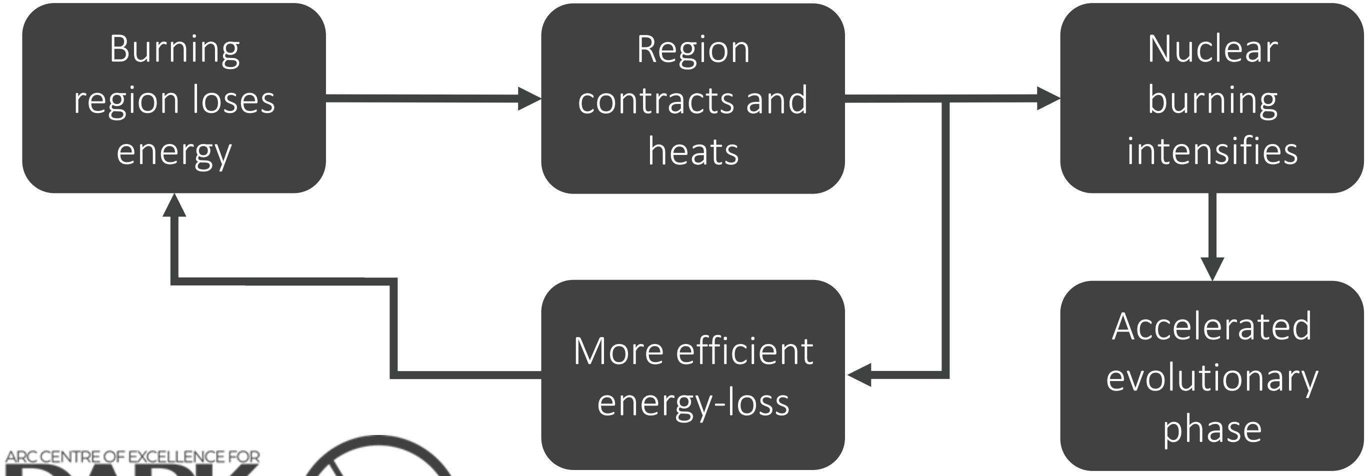
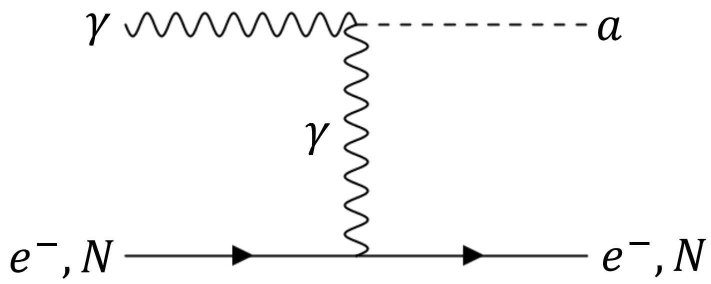
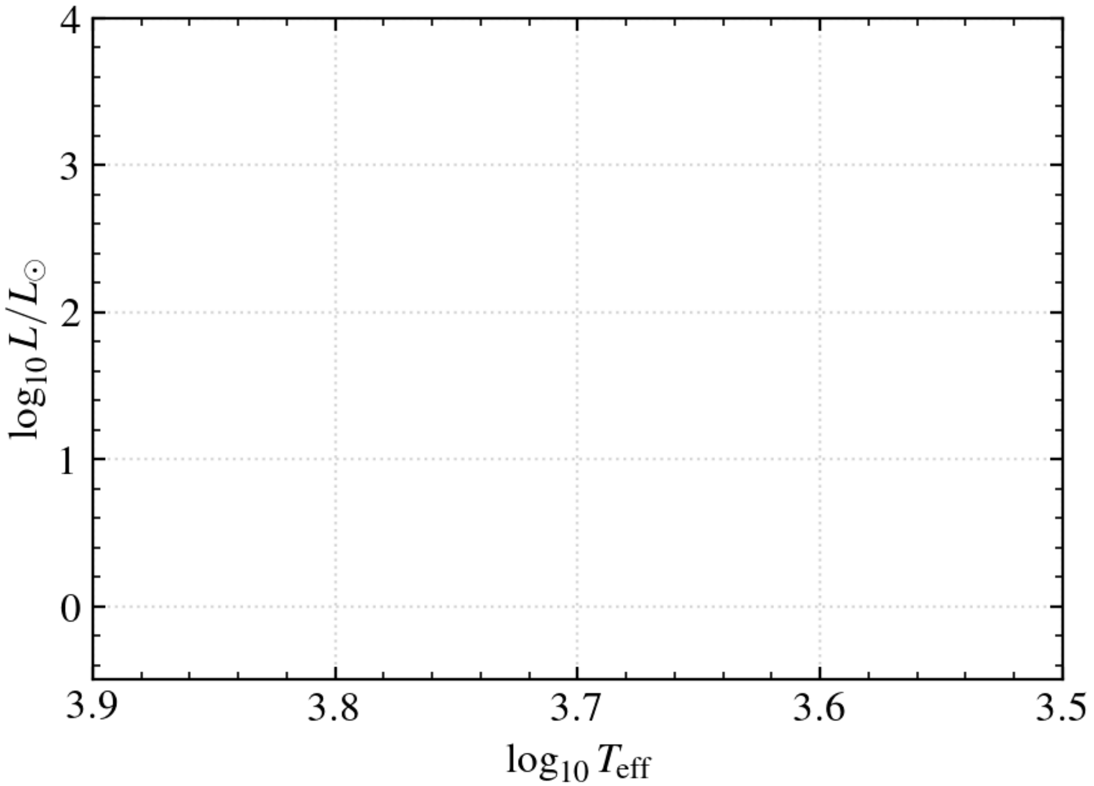




Evolution of a low mass star ($\lesssim 1.5 M_\odot$)



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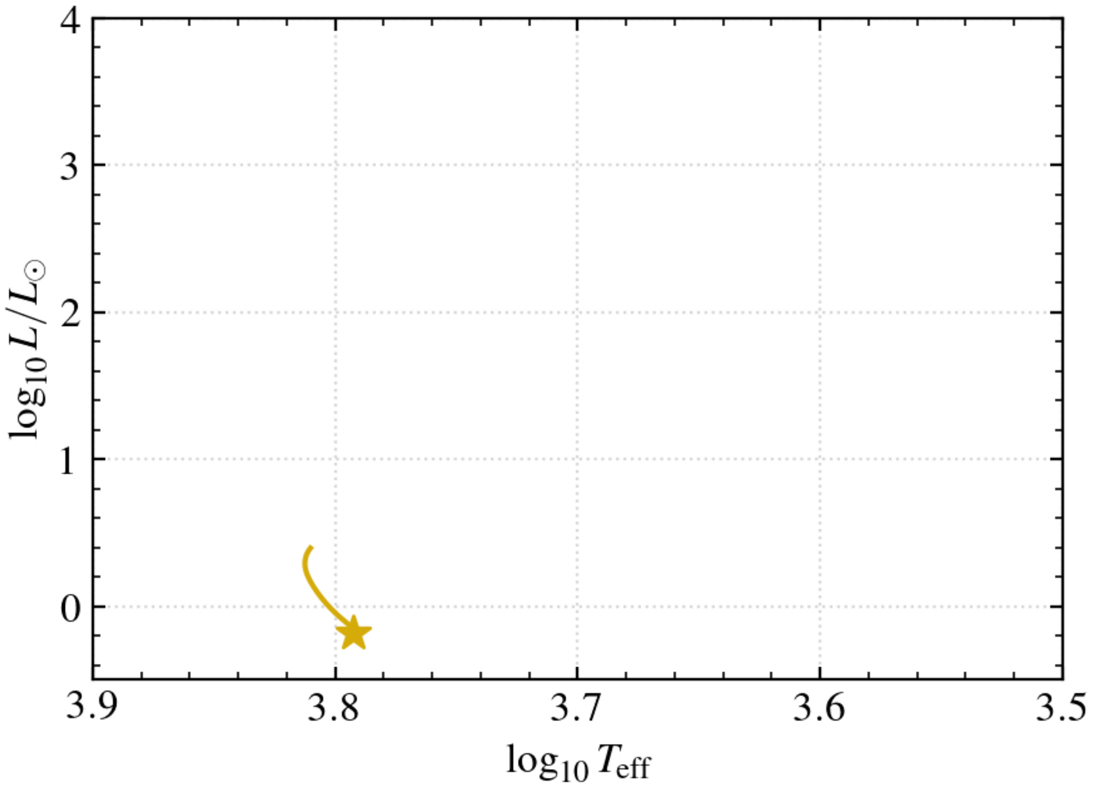

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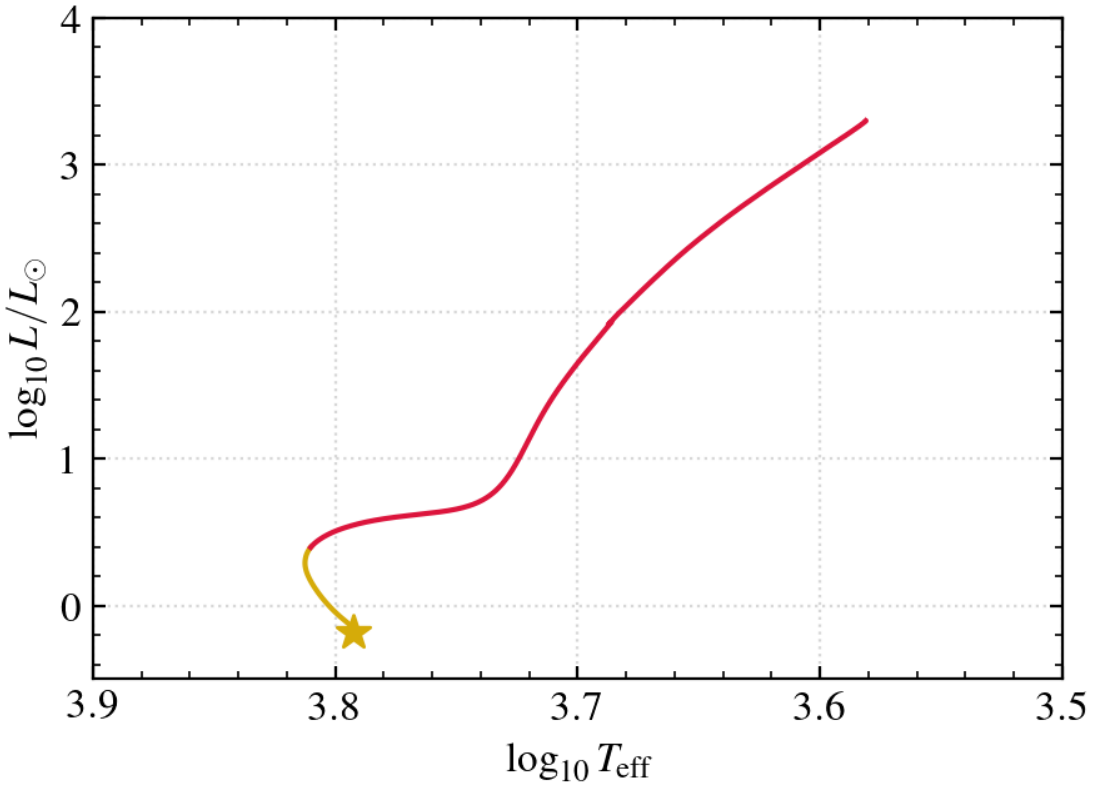

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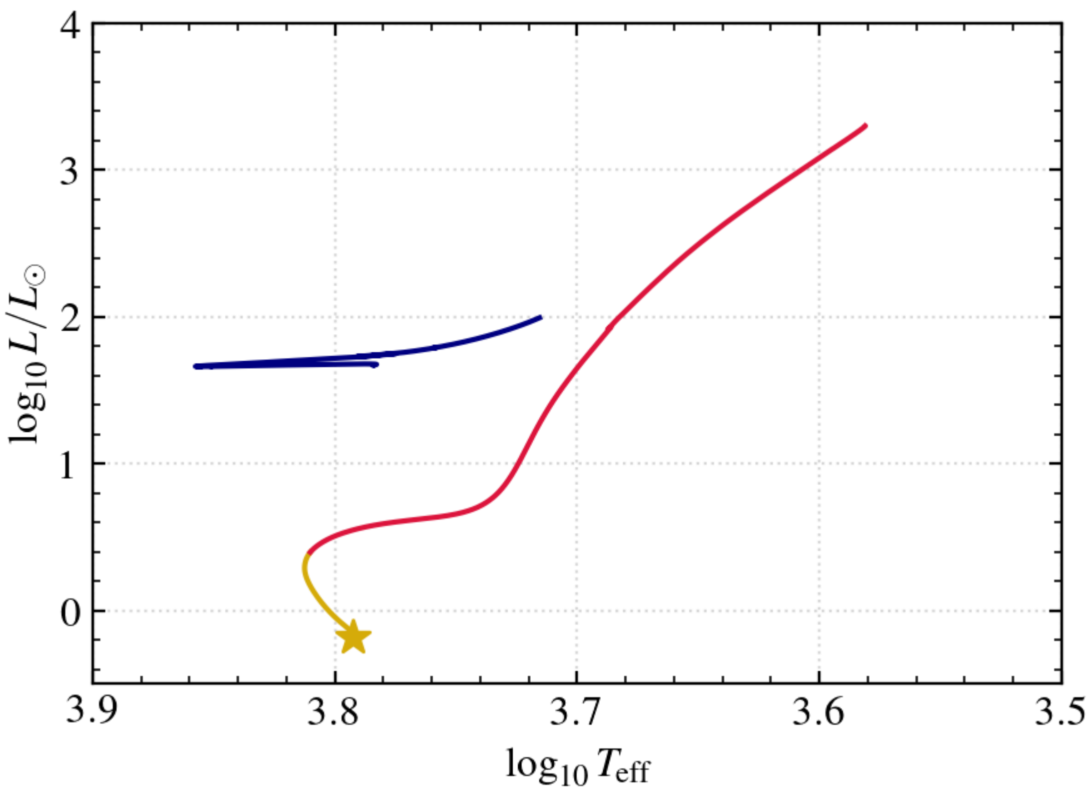
Horizontal branch (HB): Central helium-burning phase. Helium converted to carbon/oxygen in convective core.



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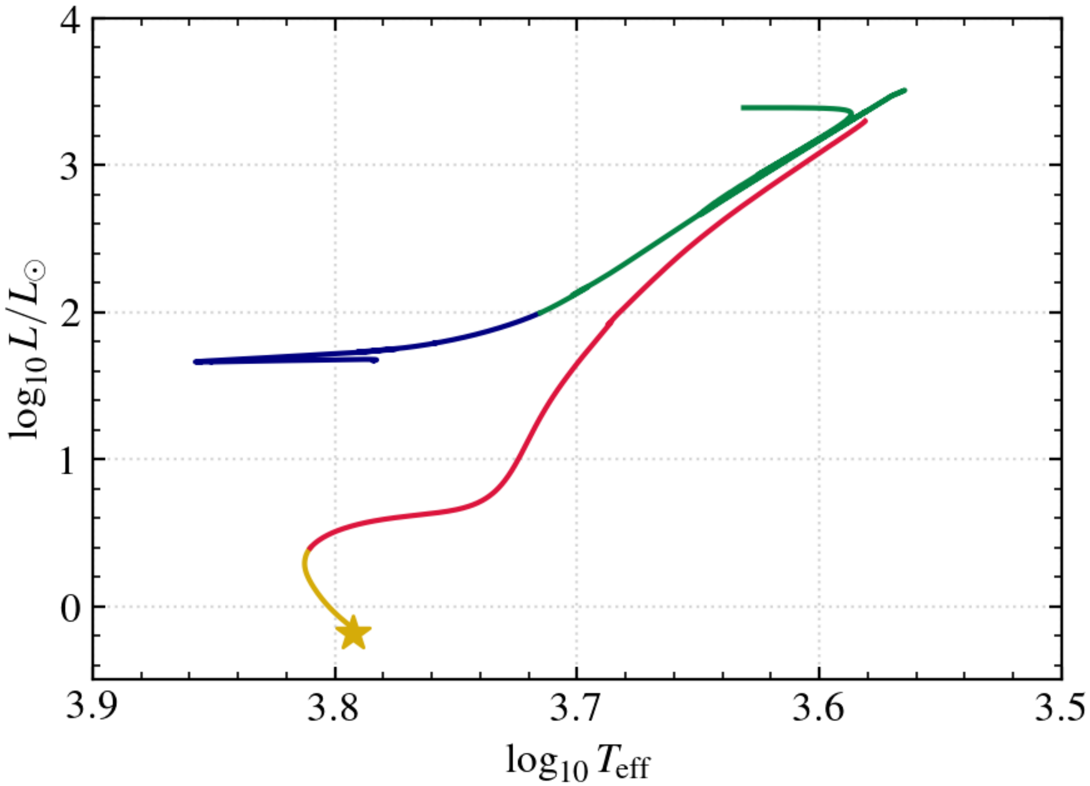

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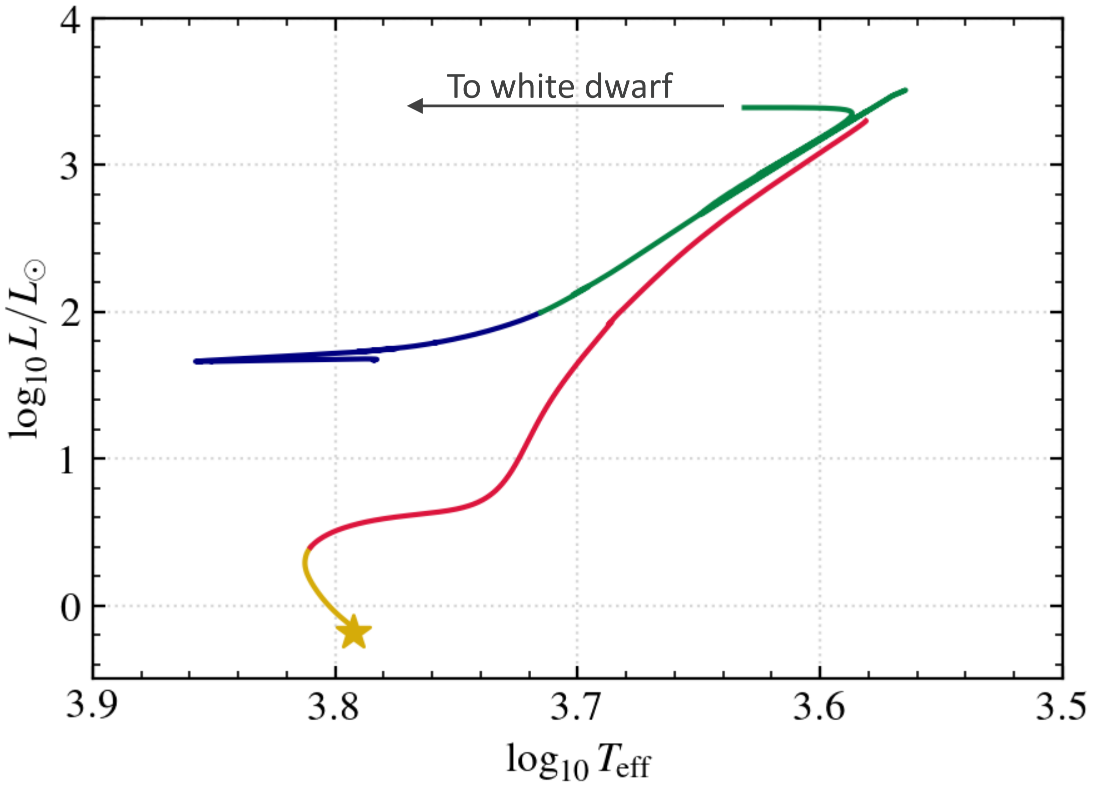

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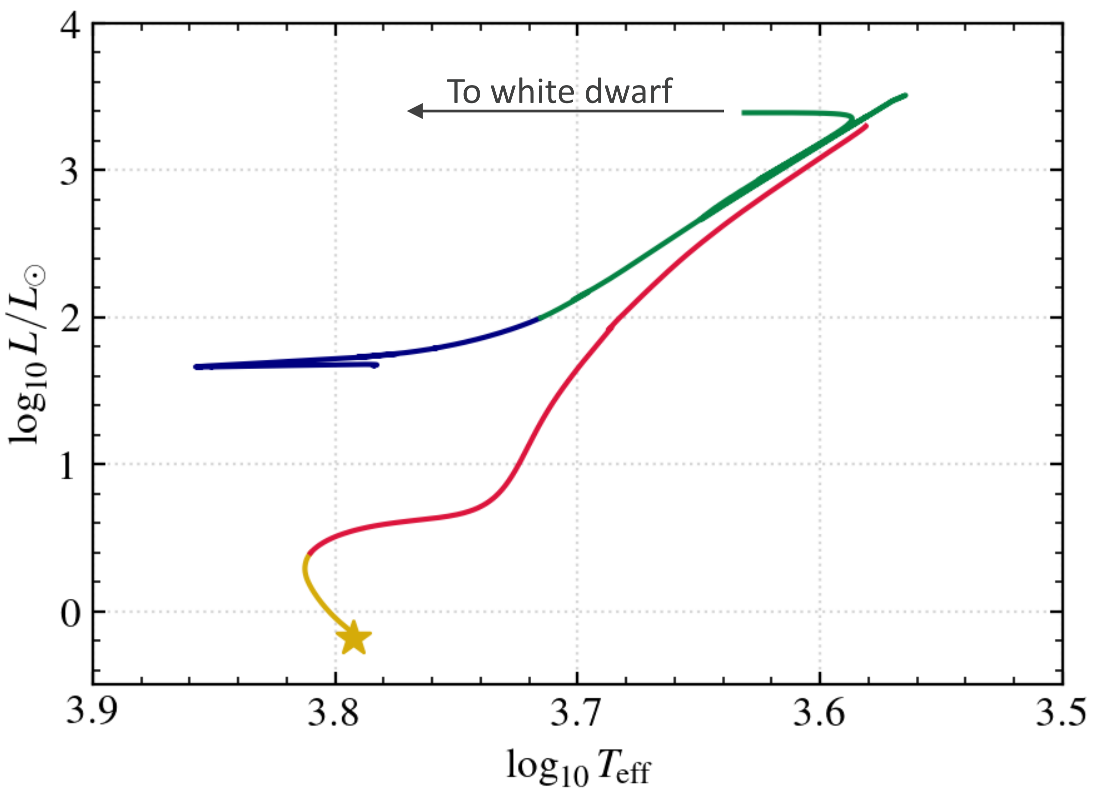

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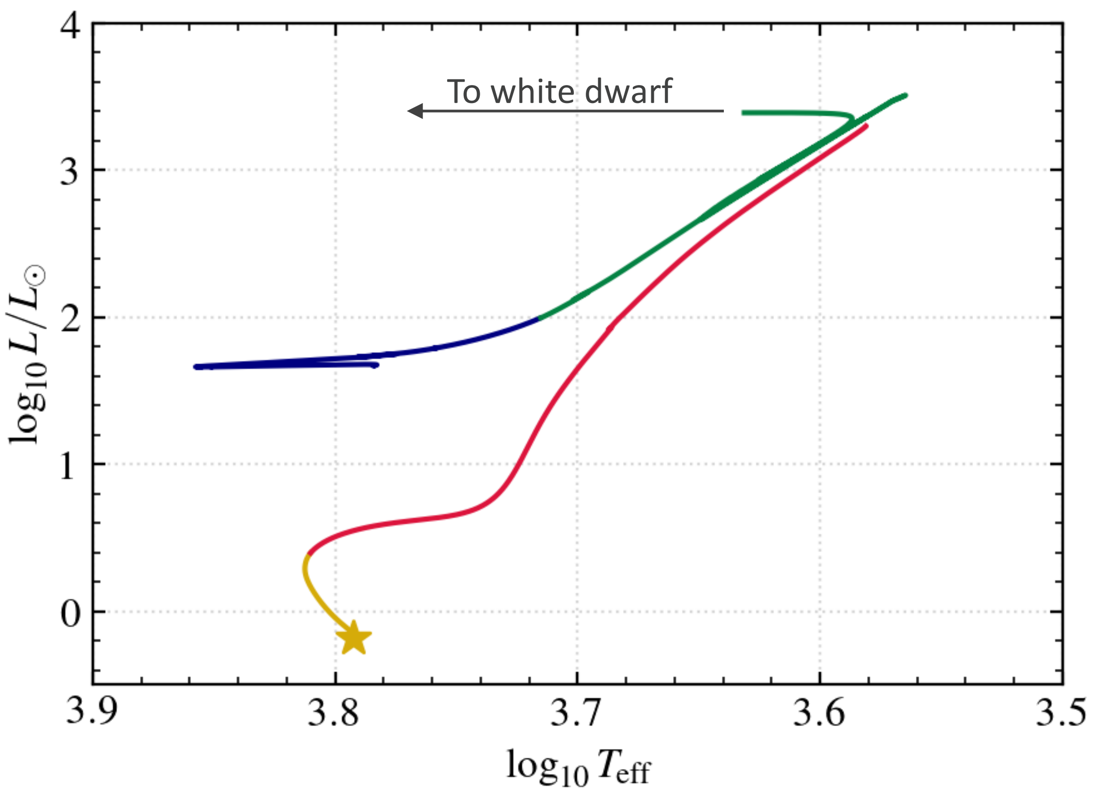

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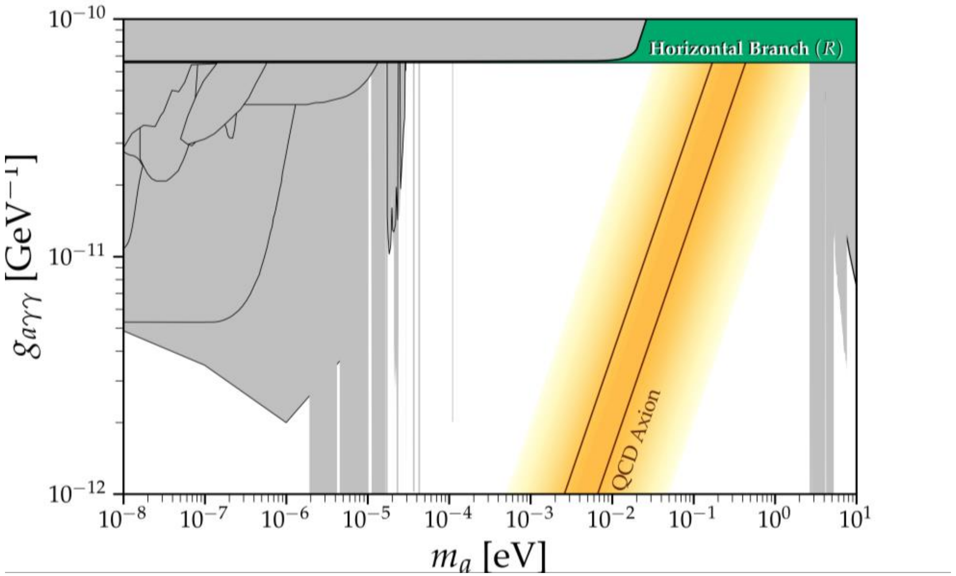
Globular Clusters

Globular clusters – large gravitationally bound collections of old, metal poor stars



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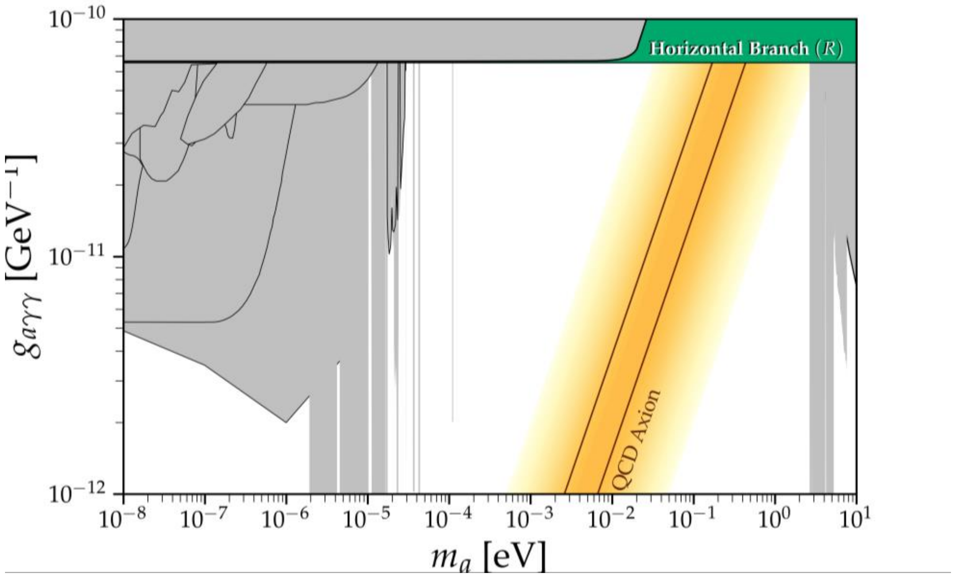

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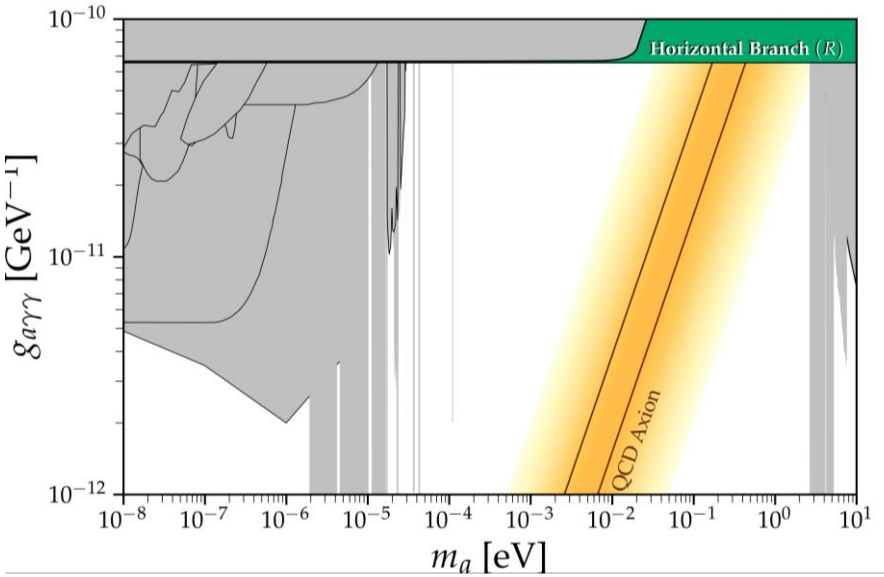

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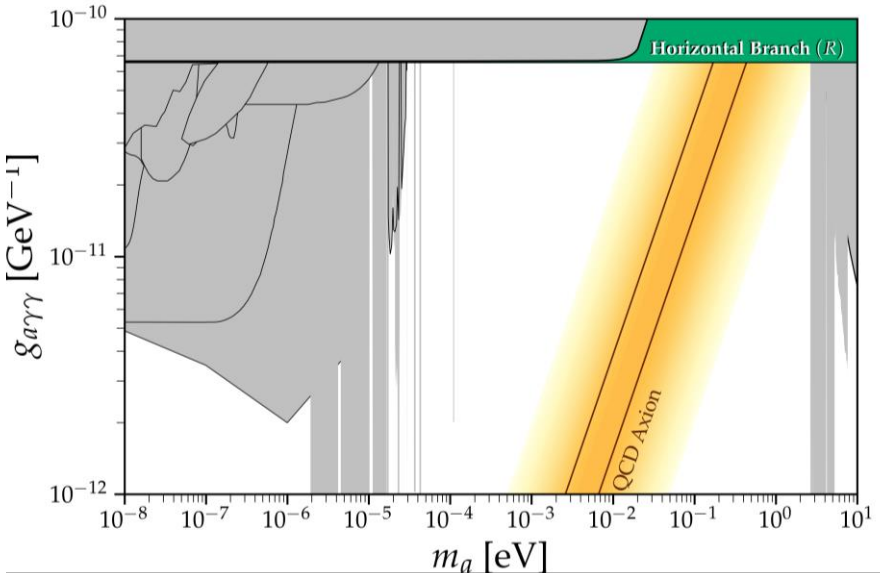

***R*-parameter constraint**

- In globular clusters, HB and RGB are populated by stars of approximately the same mass $(0.8M_{\odot})$

$$R = \frac{N_{\rm HB}}{N_{\rm RGB}} \approx \frac{\tau_{\rm HB}}{\tau_{\rm RGB}}$$

- For $g_{10} = \frac{g_{a\gamma\gamma}}{10^{-10}\ GeV^{-1}} \sim 1$ energy loss via the **Primakoff process** efficiently drains energy from HB cores, decreasing τ_{HB}
- Process is inefficient in RGB stars $\Longrightarrow \tau_{RGB}$ is unaffected
- For $g_{10} \geq 0.66$ predictions contradict observed limit
- Include effects of electron degeneracy on ϵ_P

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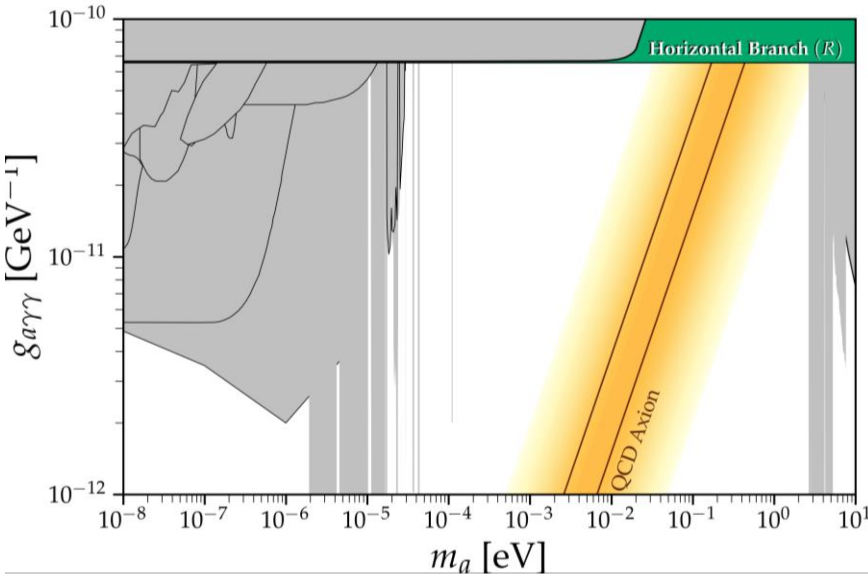

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Stellar evolution code *Modules for Experiments in Stellar Astrophysics* (MESA) is furnished with four different schemes

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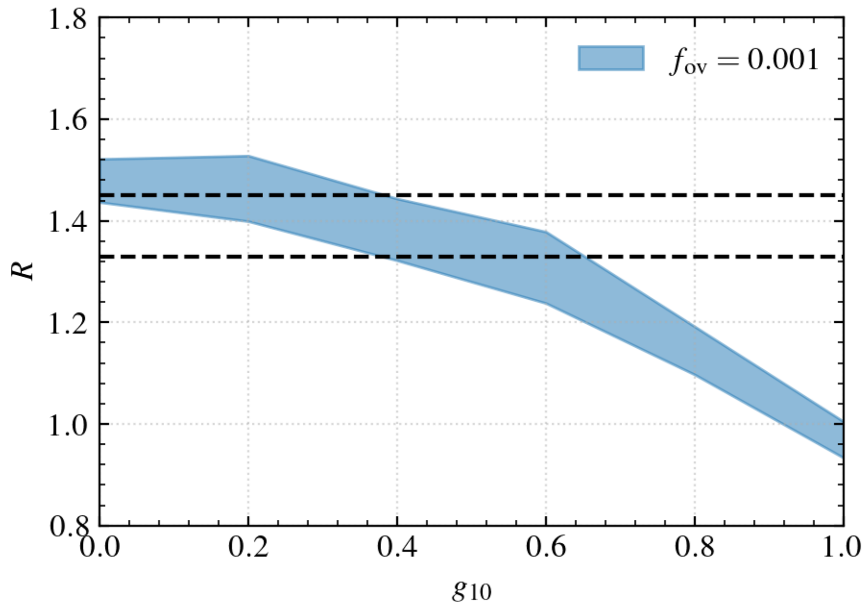

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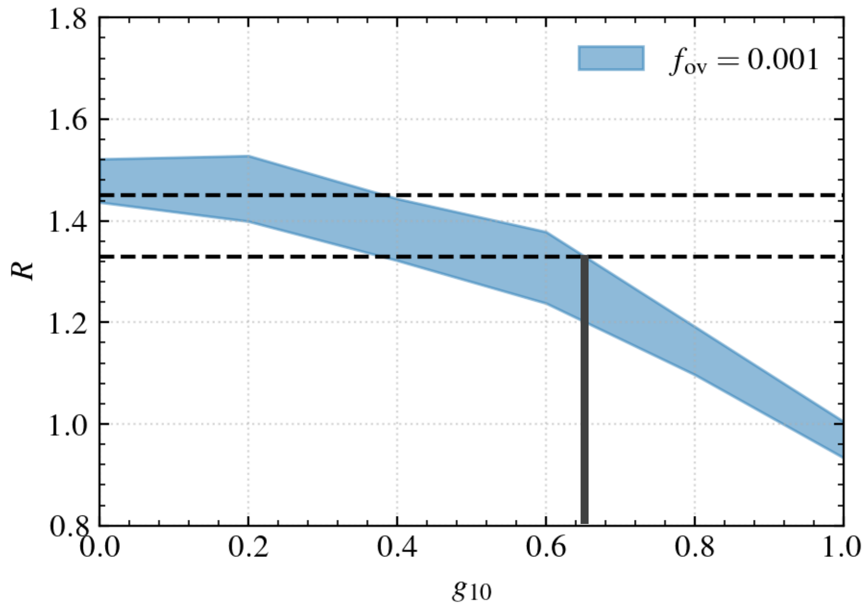

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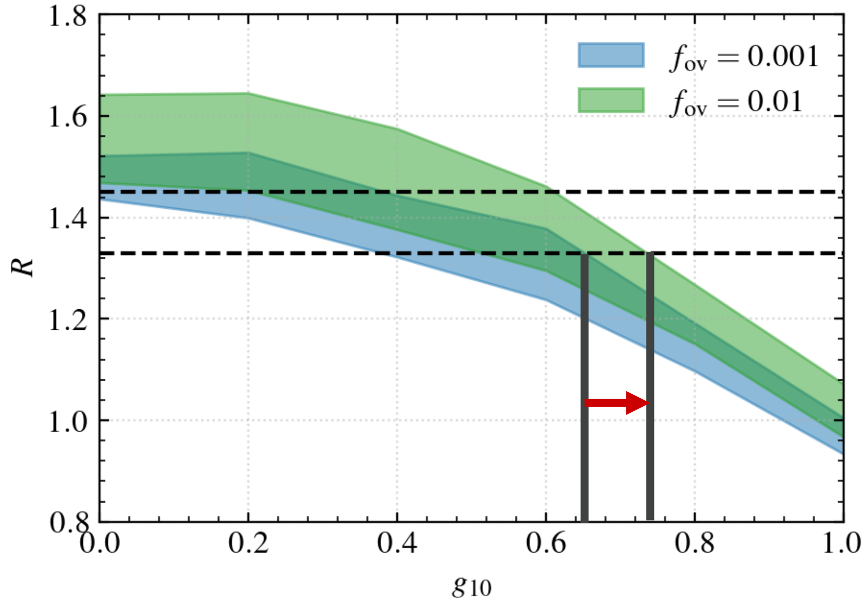

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Choice of f_{ov} systematically shifts R

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Which value of f_{ov} do we take?

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Dominguez et al., *MNRAS* **456** (1999) L1

New, more statistically significant observed bounds are available – have never been used to constrain BSM physics

Constantino et al., *MNRAS*, **456** (2016) 3866

The R_2-parameter

Other globular cluster parameters exist which can provide complementary constraints on $g_{a\gamma\gamma}$

The ratio of AGB to HB stars – the R_2-parameter – is a particularly appealing candidate for this

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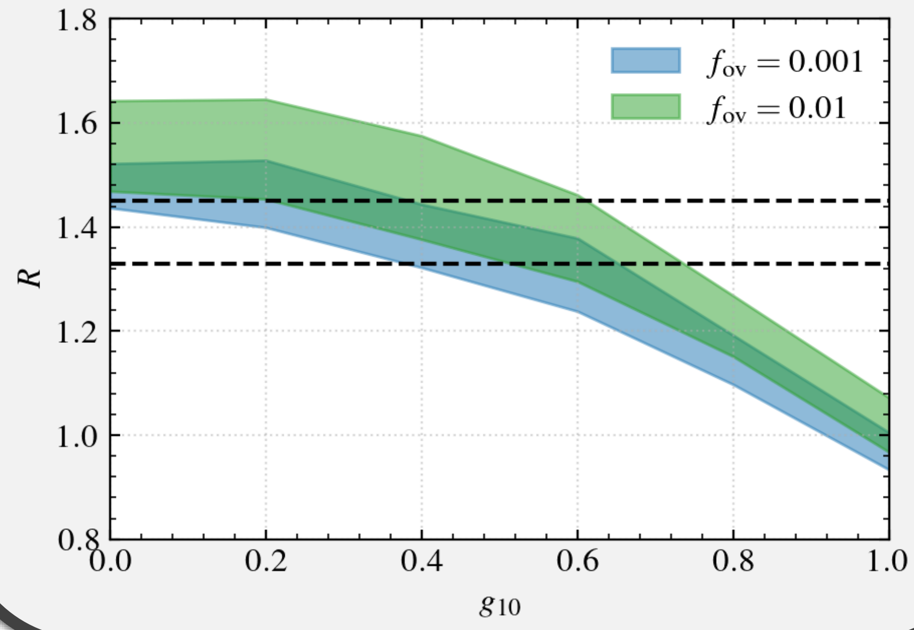
Historically used to constrain the effects of mixing across convective boundaries

Constantino et al., *MNRAS*, **456** (2016) 3866

Comparing R and R_2

R



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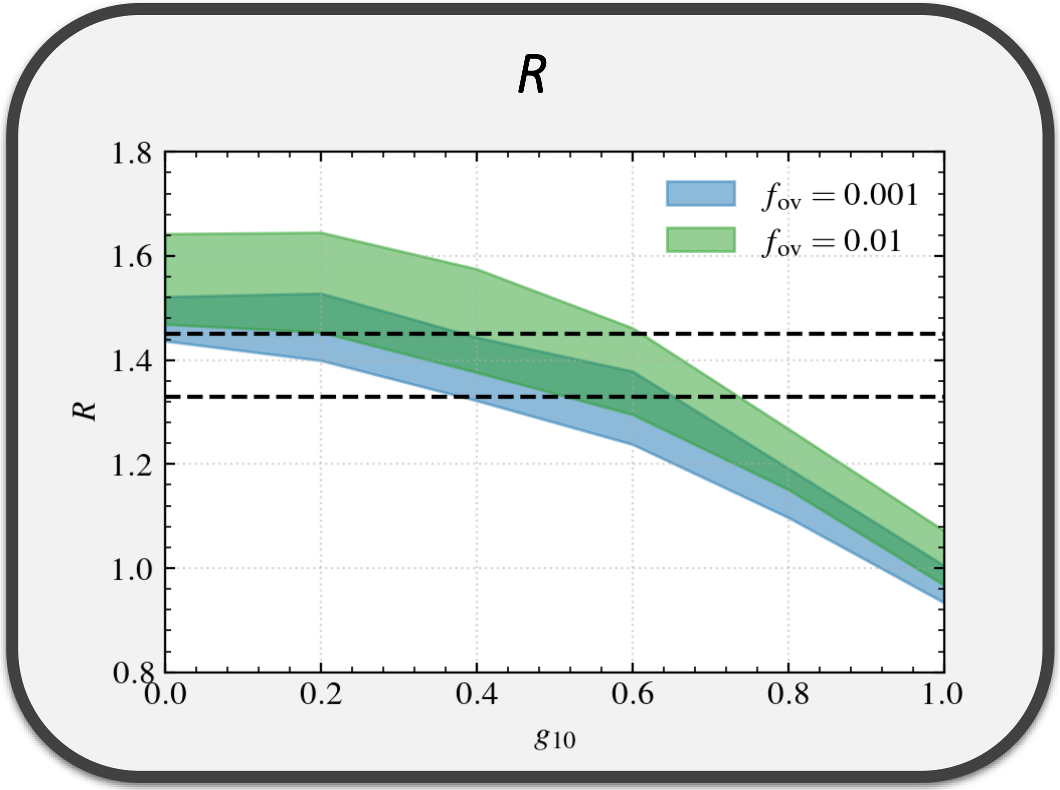

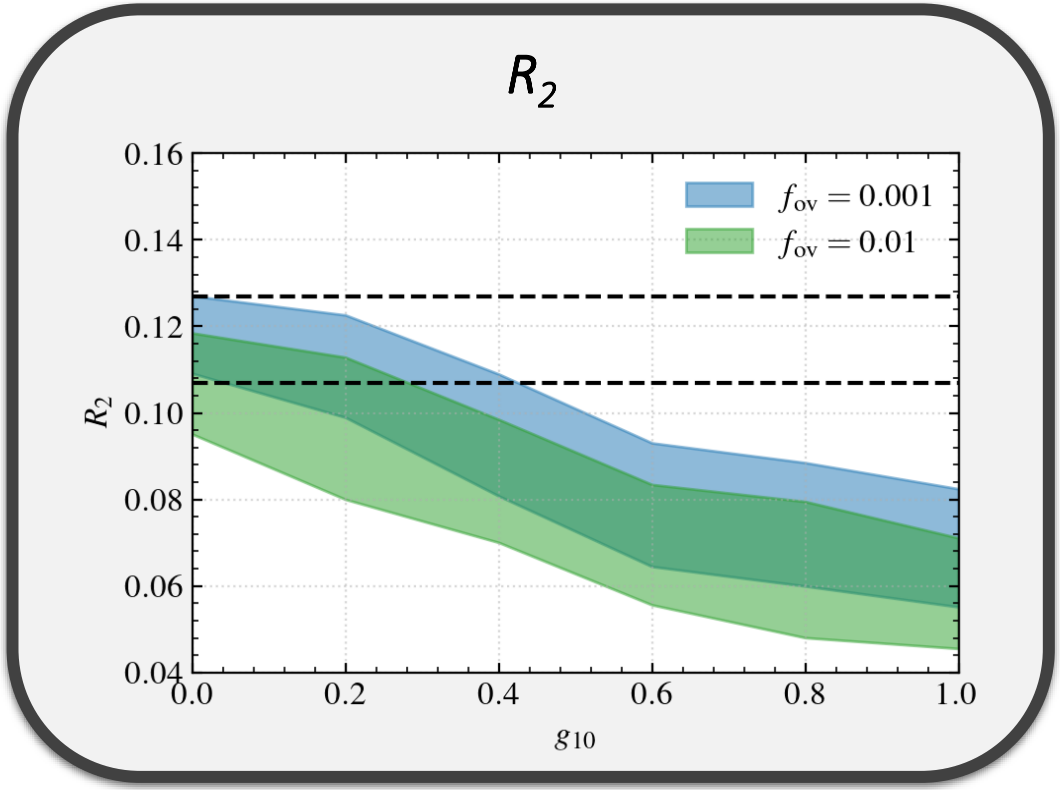

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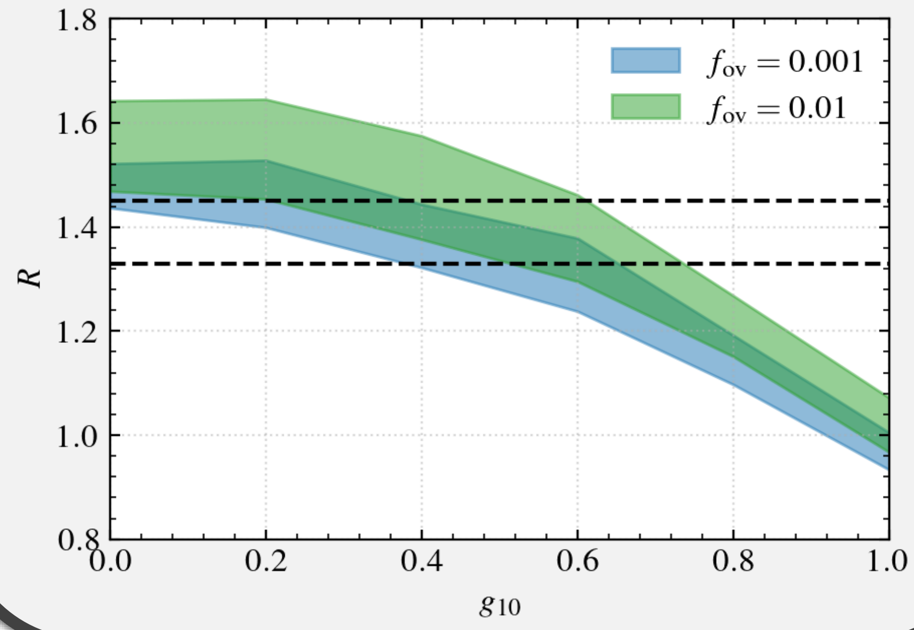

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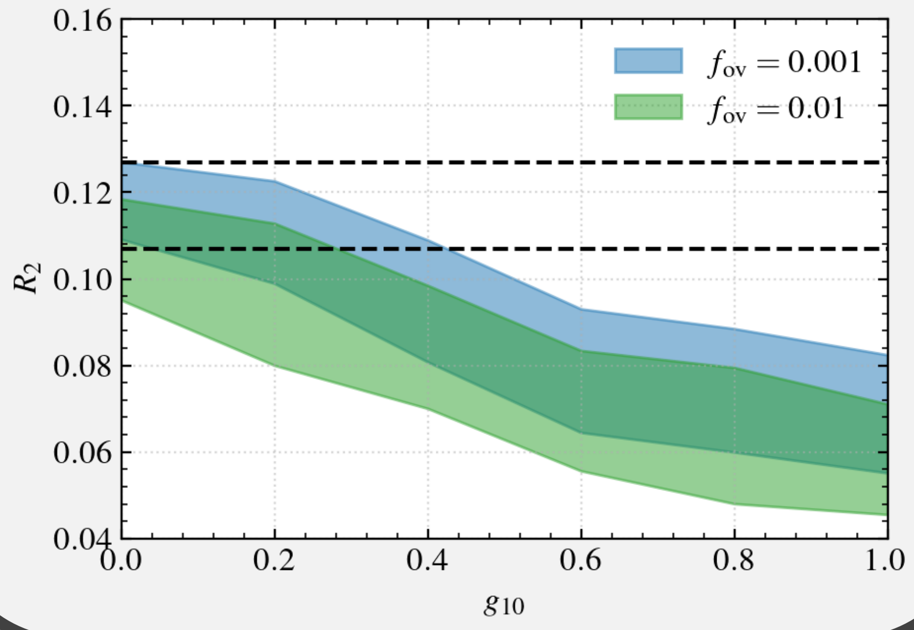
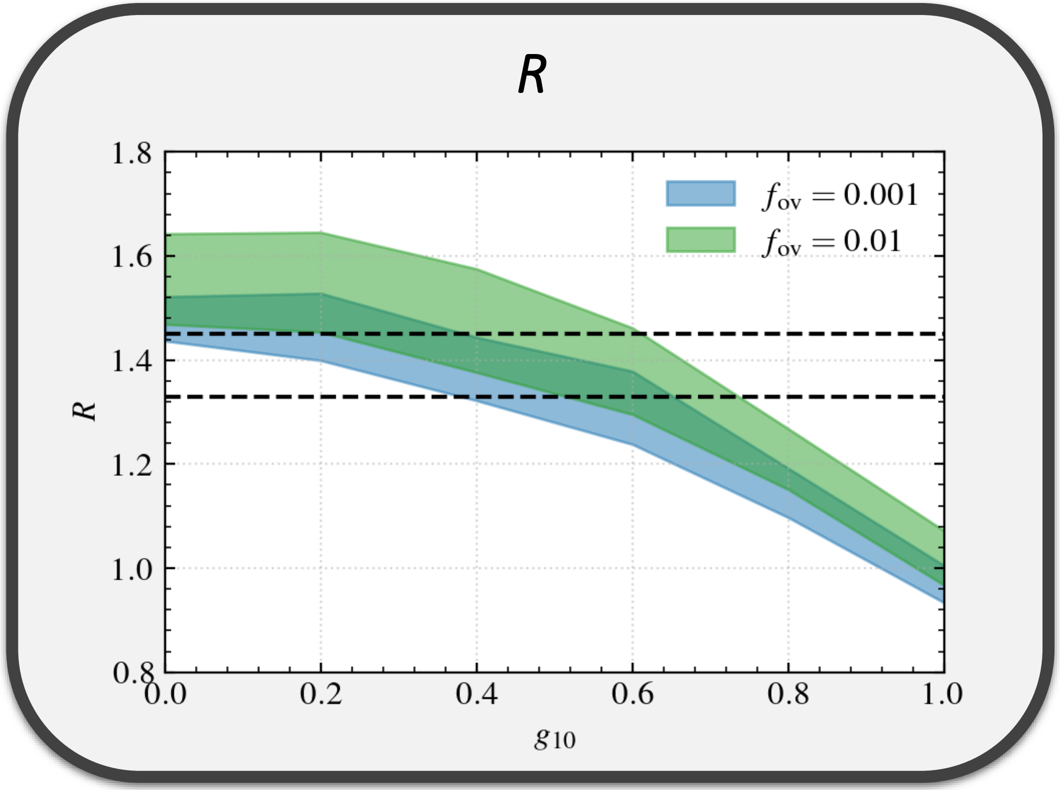
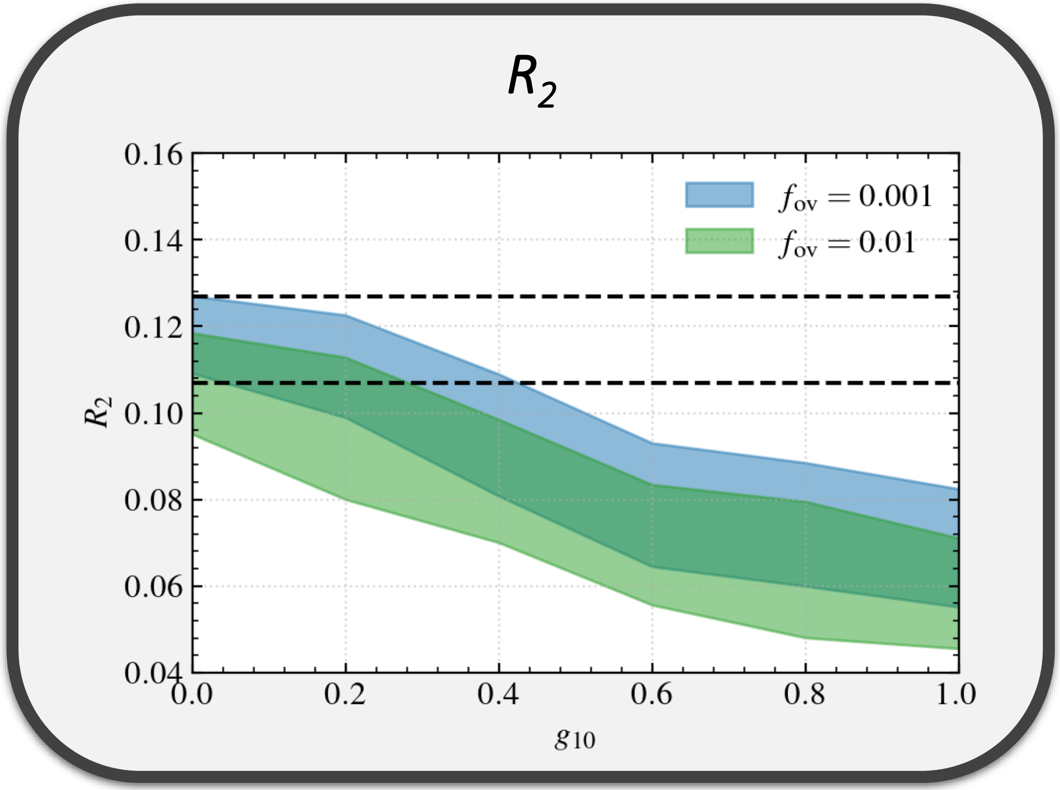


Convective boundary model parameter(s) affect constraints oppositely

Comparing R and R_2





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Both R and R_2 decrease with g_{10}.

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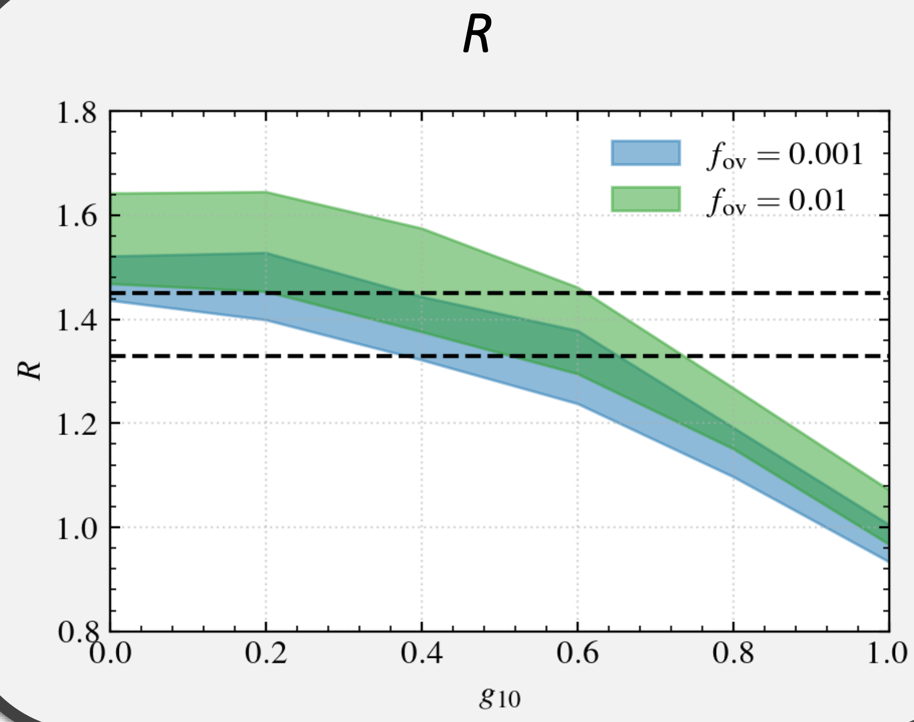

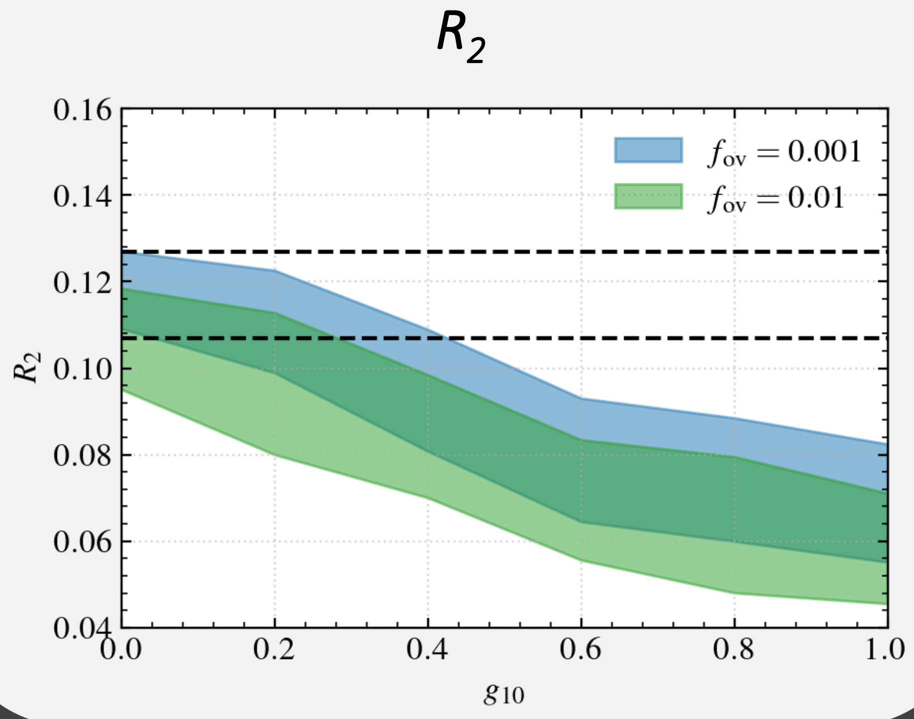

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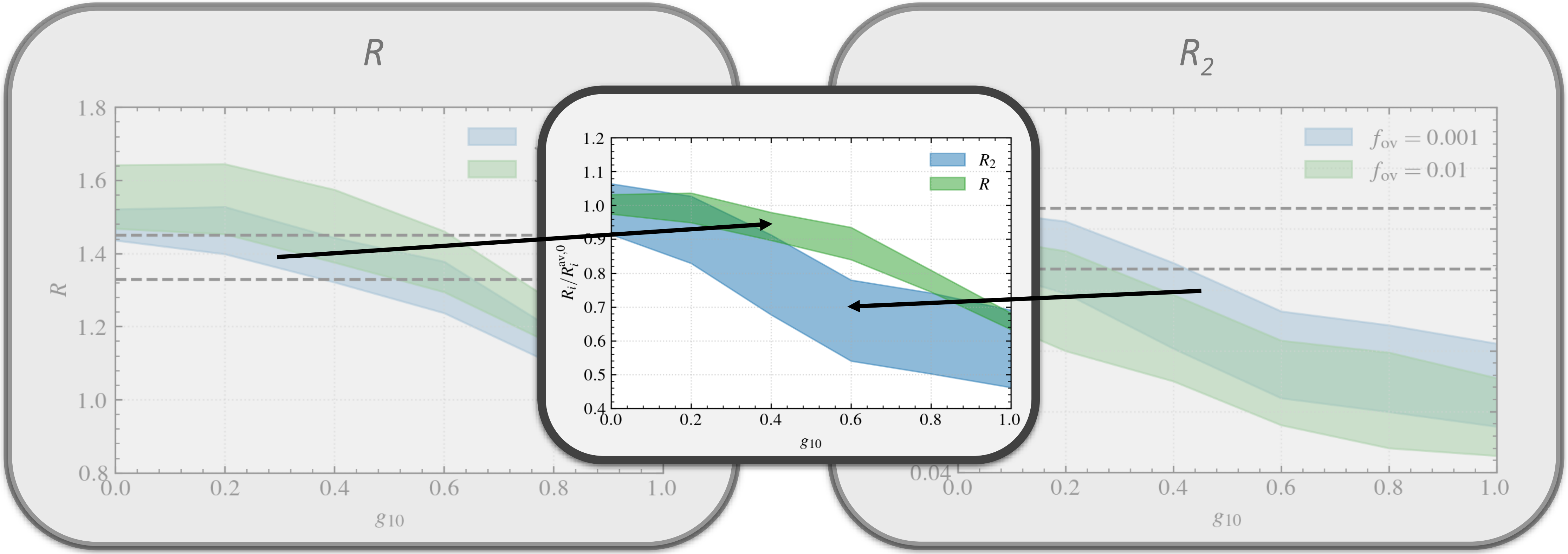

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The goal: calculate a bound on g_{10} which accounts for the sizeable uncertainty related to mixing across CBs

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≡**realisation** of a scheme

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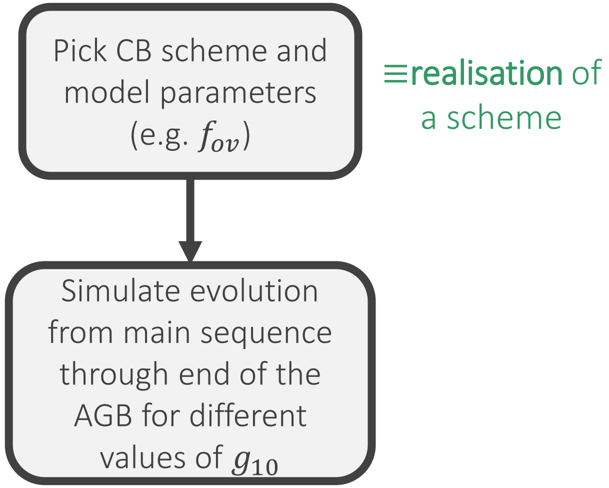

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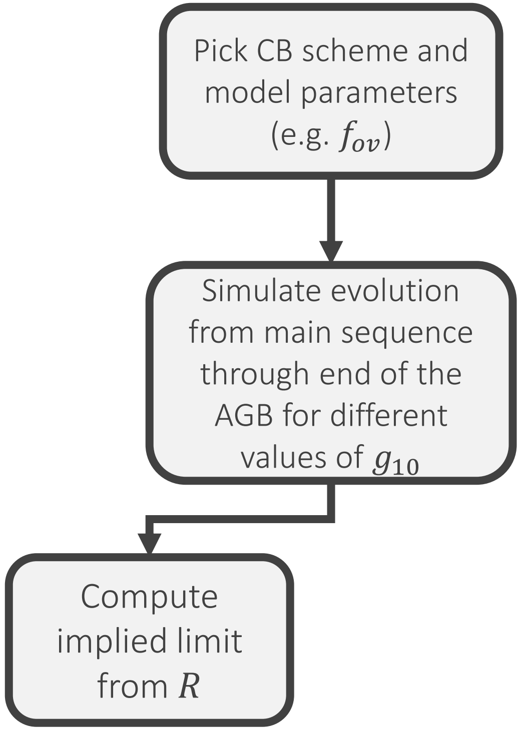

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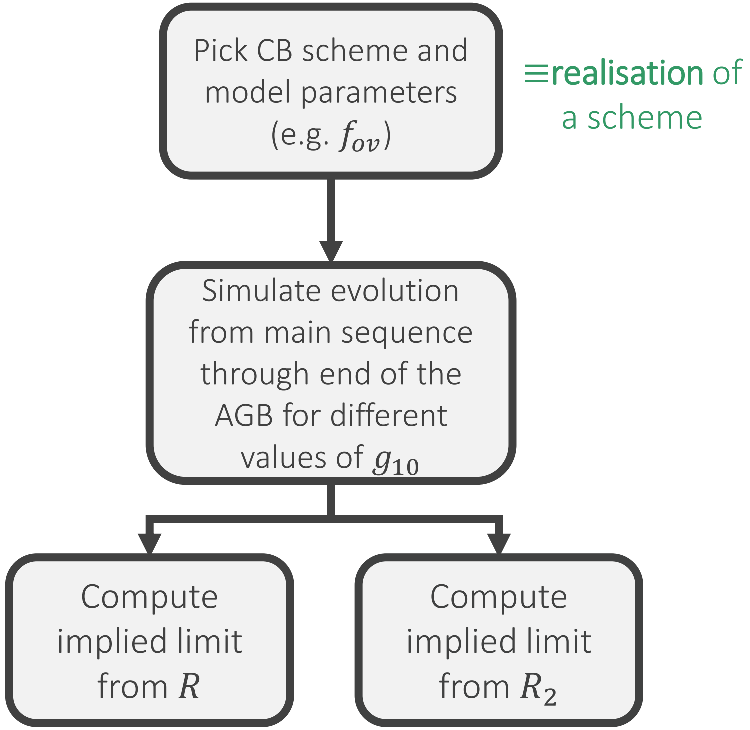

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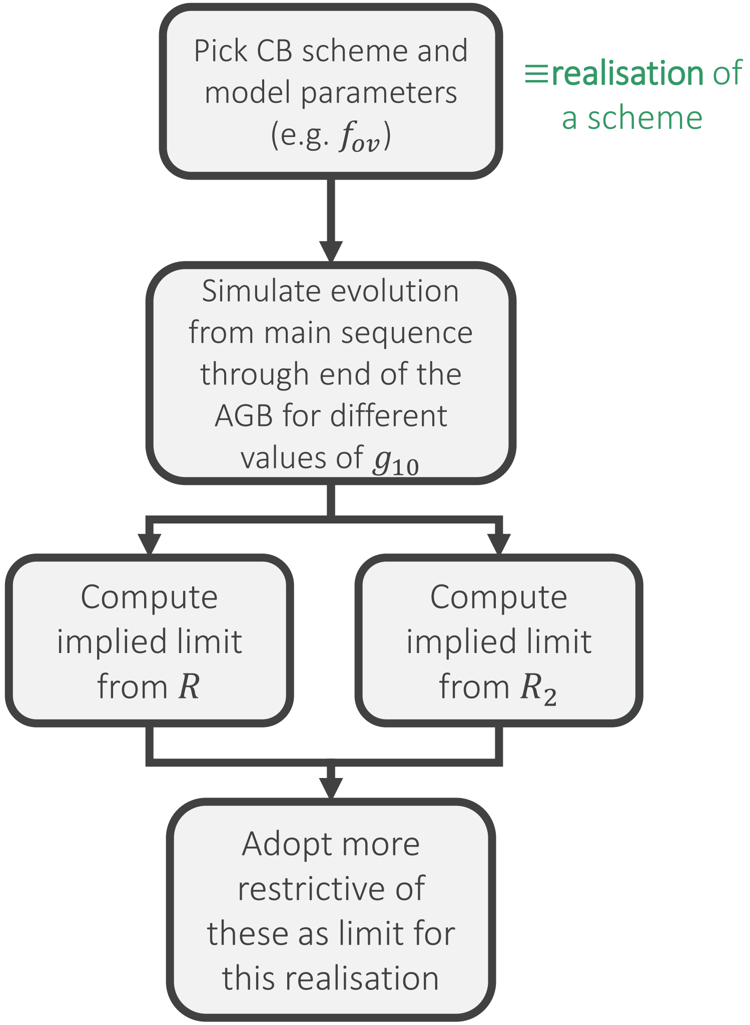

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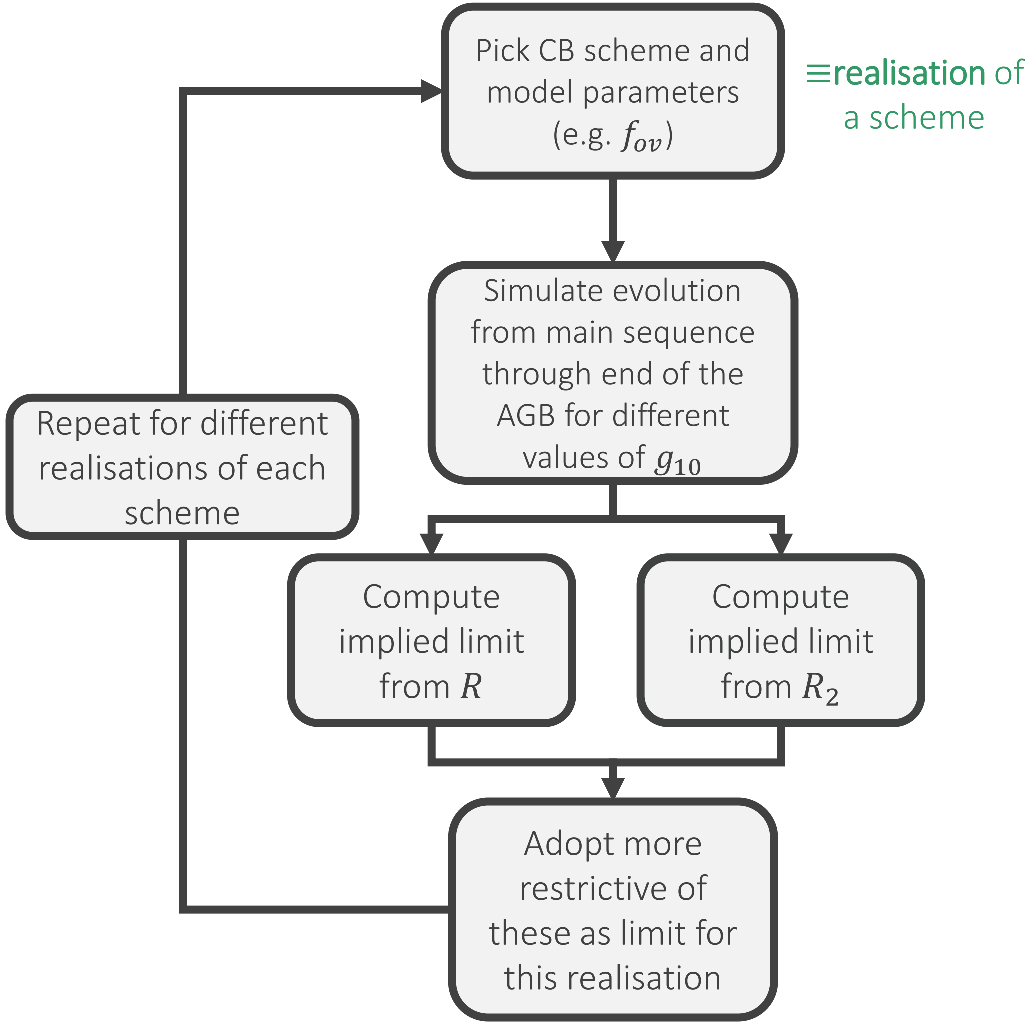

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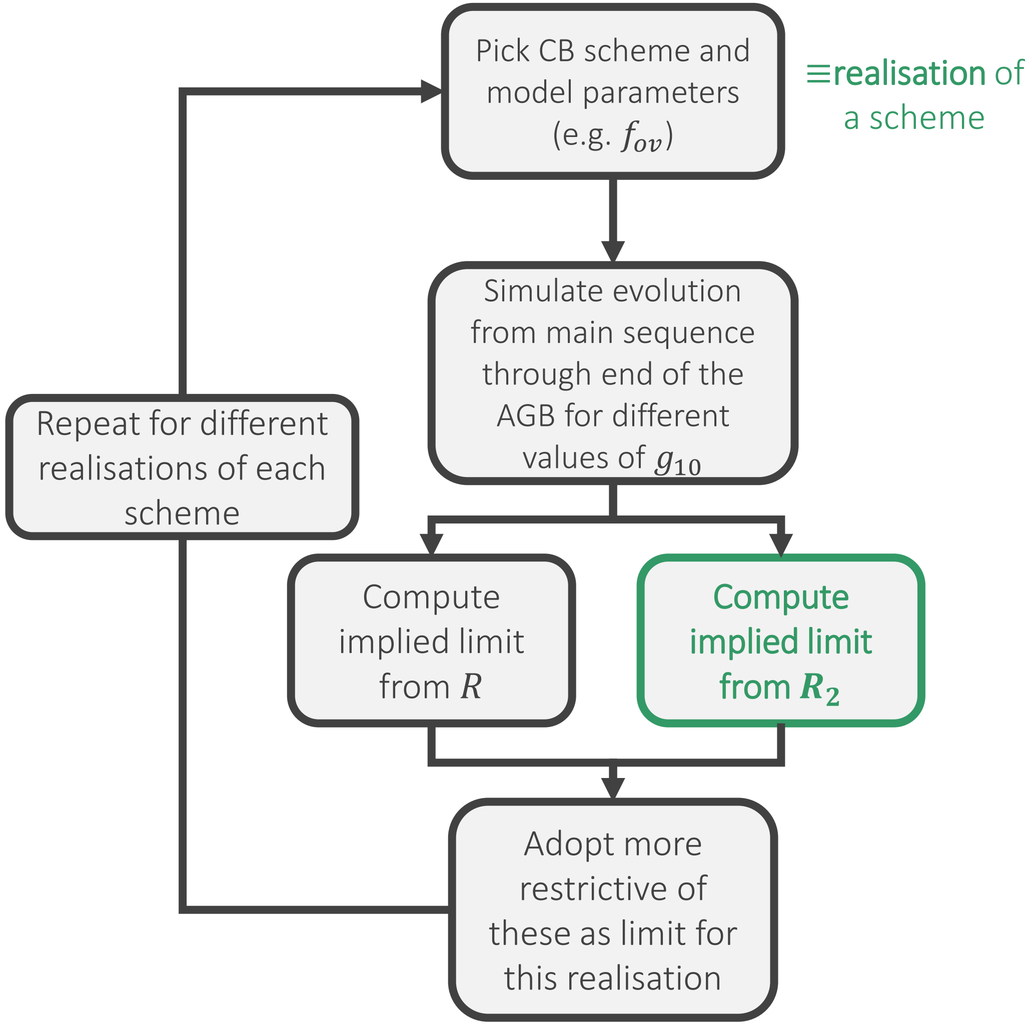

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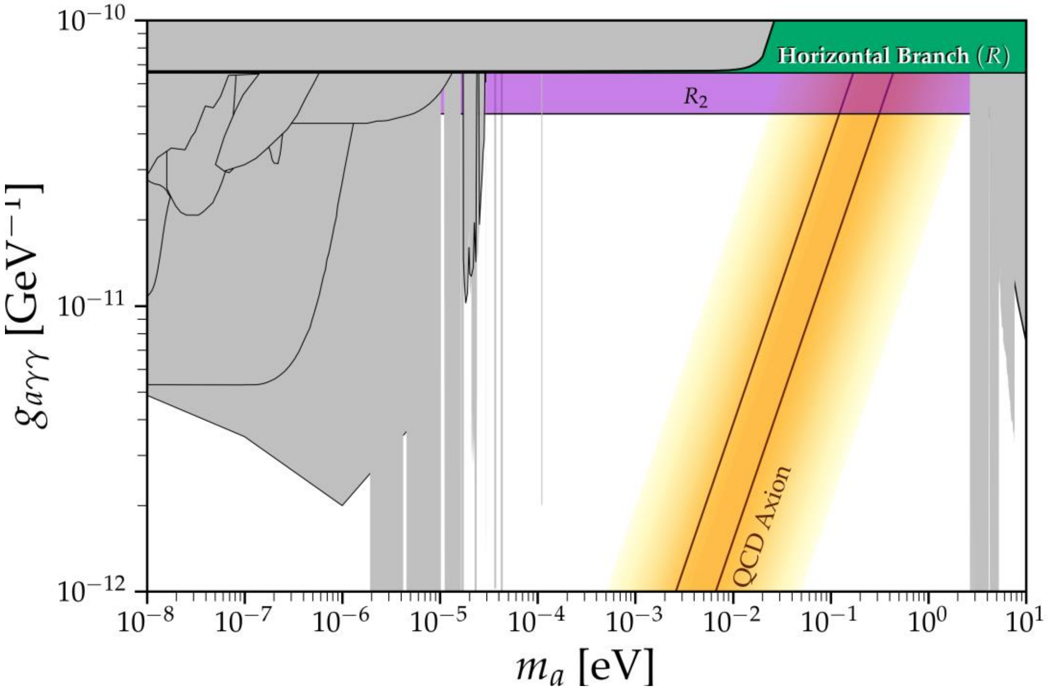

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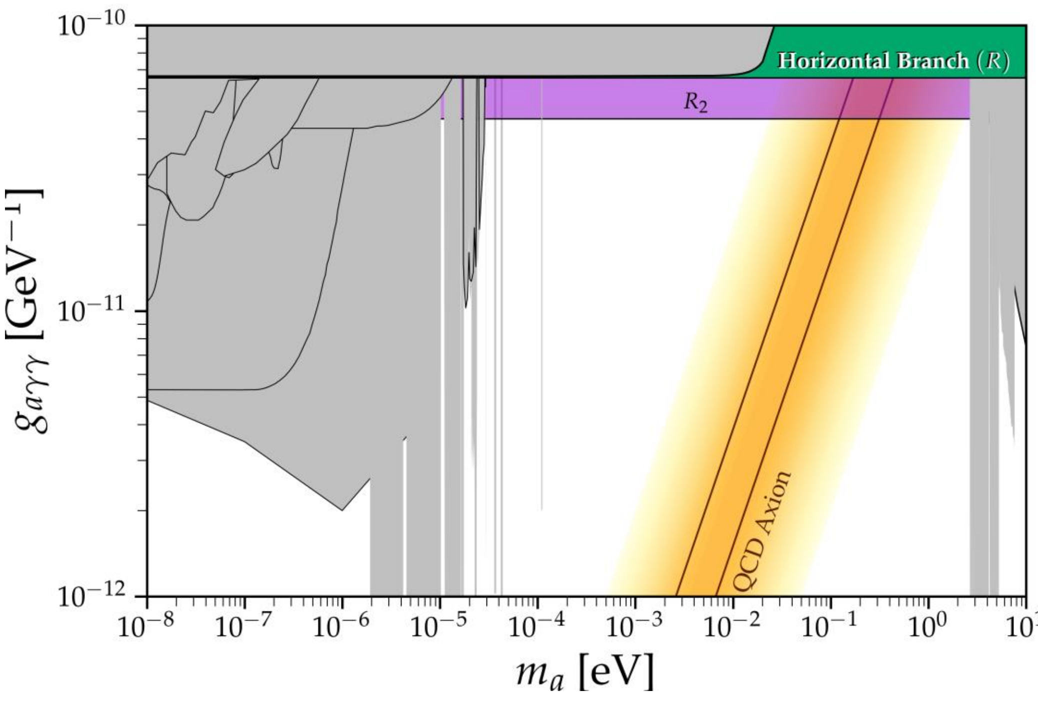

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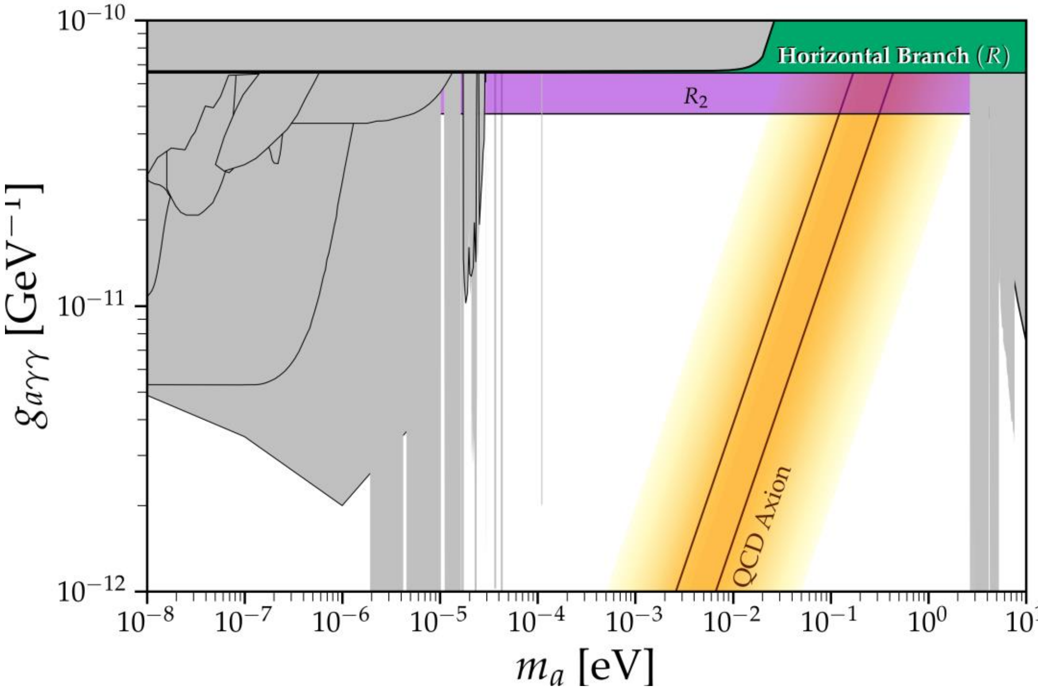

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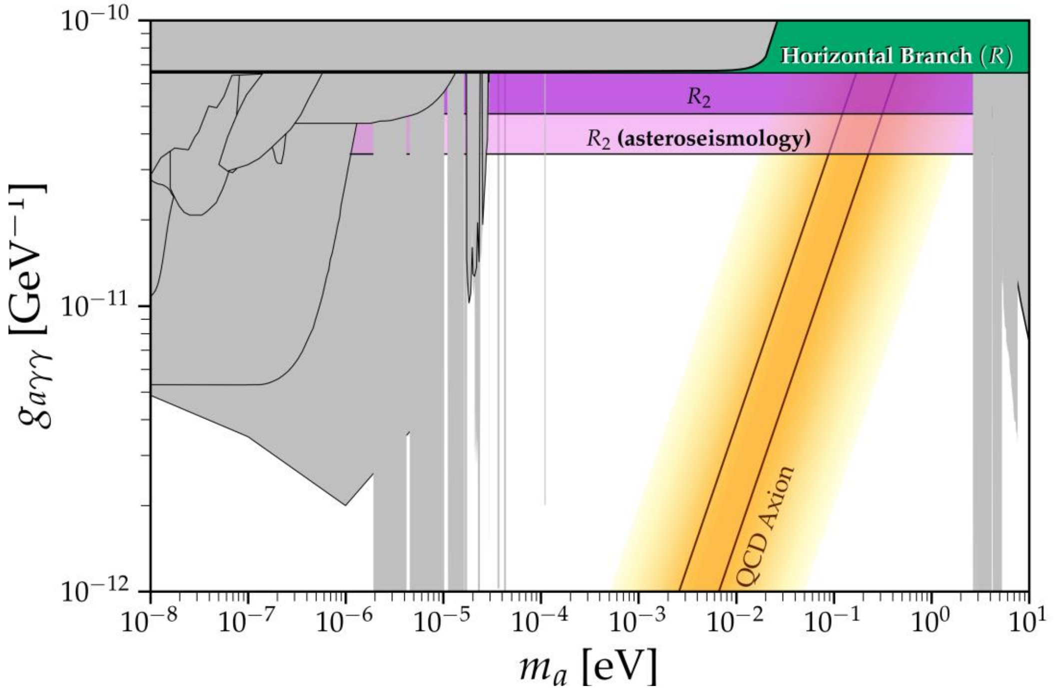
Evidence not yet conclusive…



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This may improve to $g_{10} = 0.34$ or better as uncertainty surrounding mixing across convective boundaries decreases (e.g. through asteroseismology)

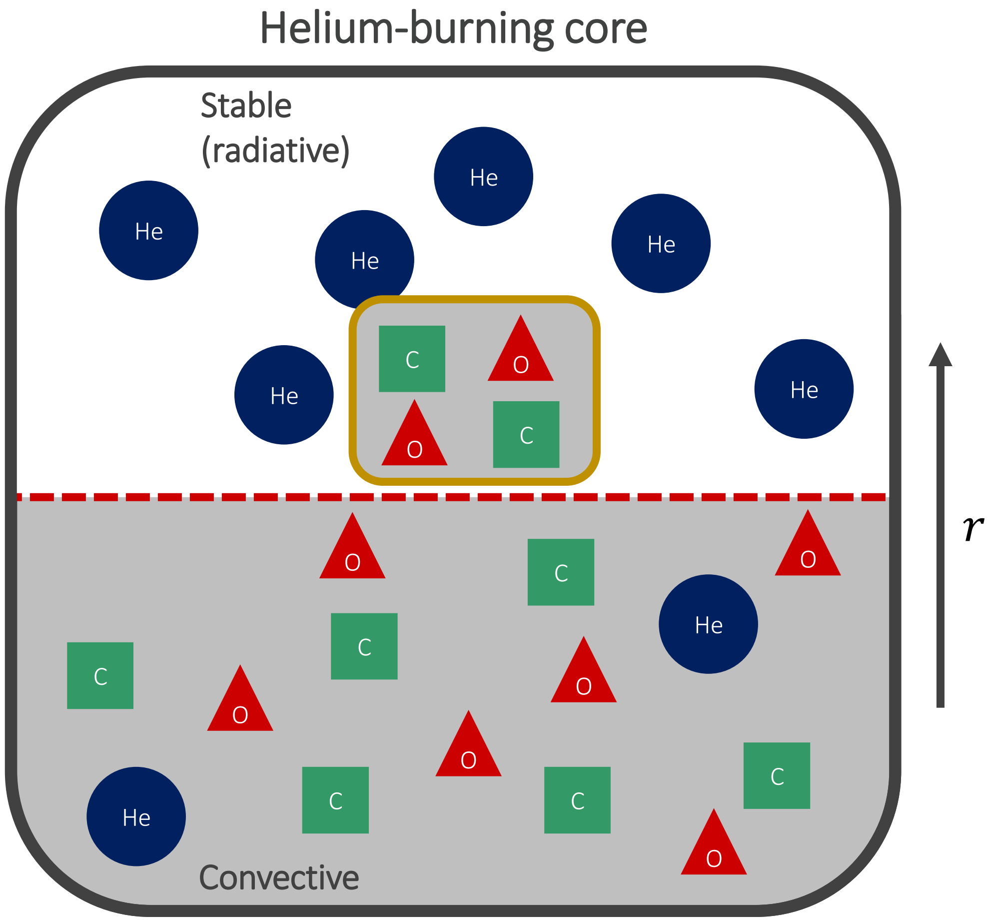
Backup Slides

Mixing across convective boundaries

Convective boundary separates C/O rich convective region below and He-rich stable region above

Convective elements arrive at the boundary with non-zero momentum and penetrate the stable region: **convective overshoot**

C/O are more opaque than He $\Longrightarrow$ convective region grows



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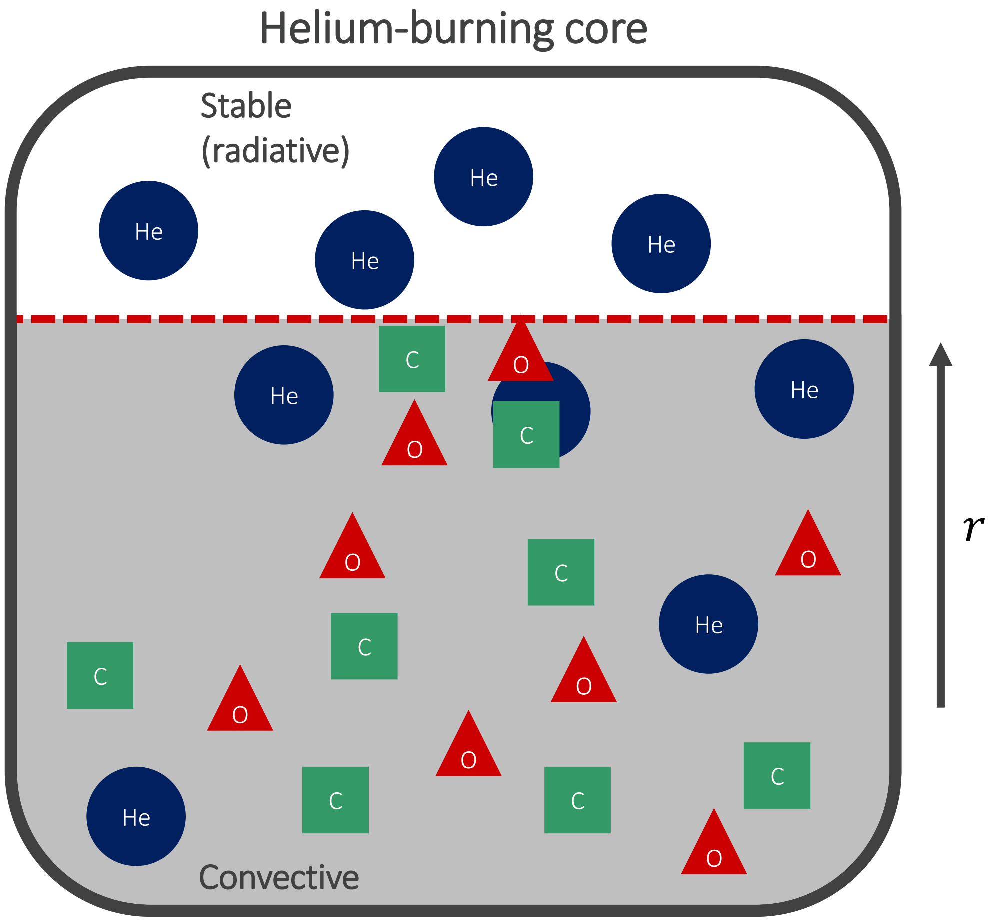

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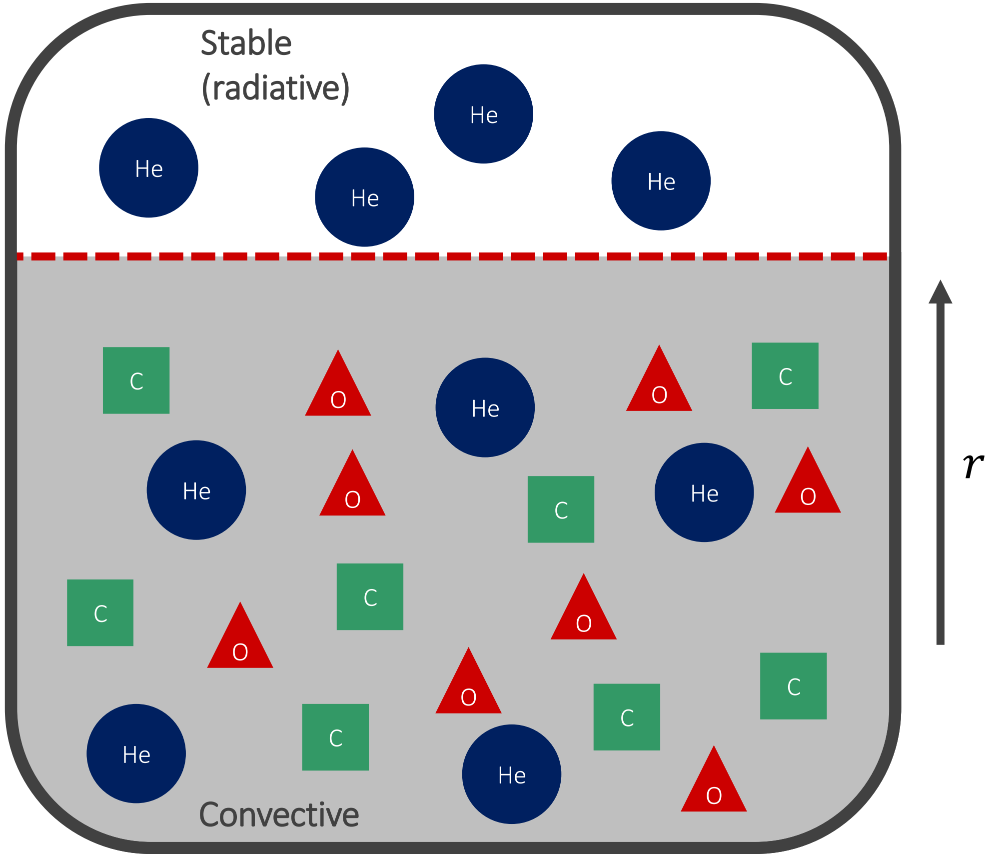
Helium-burning core



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Result: evolution of the core boundary is not stable

Effects are dire if they occur near the end of the HB $\Longrightarrow$ large convective episodes which significantly elongate the HB

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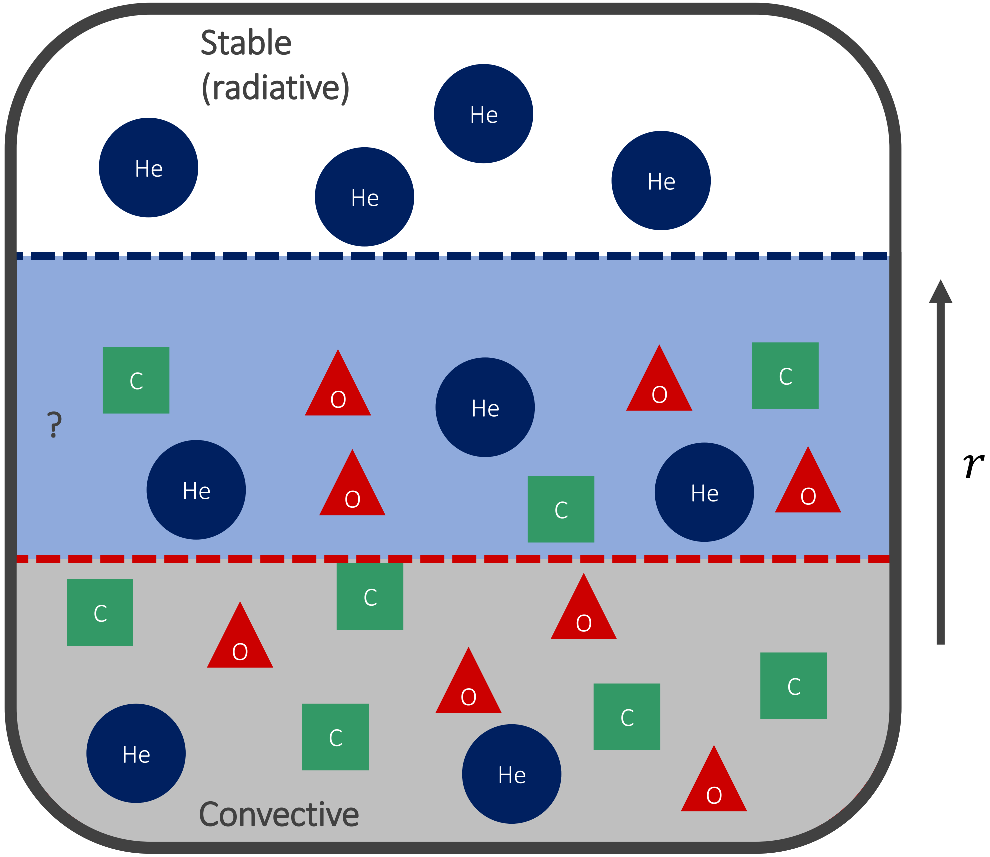

Calculating R_2

Simulate evolution of $\sim 0.8 M_\odot$ star through MS, RGB, HB and AGB

Convert results of simulation to probability density function of $\Delta \log_{10} L_{HB} = \log_{10} L - \log_{10} L_{HB}$

$$P(\Delta \log L) = \frac{1}{\tau} \sum_{i=1}^{n} \frac{\Delta t_i}{\sigma \sqrt{2\pi}} \exp\left(- \frac{(\Delta \log L - \Delta \log L_i)^2}{2\sigma^2} \right)$$

A clear minimum exists between HB and AGB peaks

Calculate R_2 as ratio of the areas either side of this minimum

Repeat for non-zero values of g_{10}