(Asymmetric) Dark Matter in Stars

$$0.8 \leq M_\star / \mathrm{M}_\odot \leq 5.0$$

Troy Raen

LSST Dark Matter Workshop

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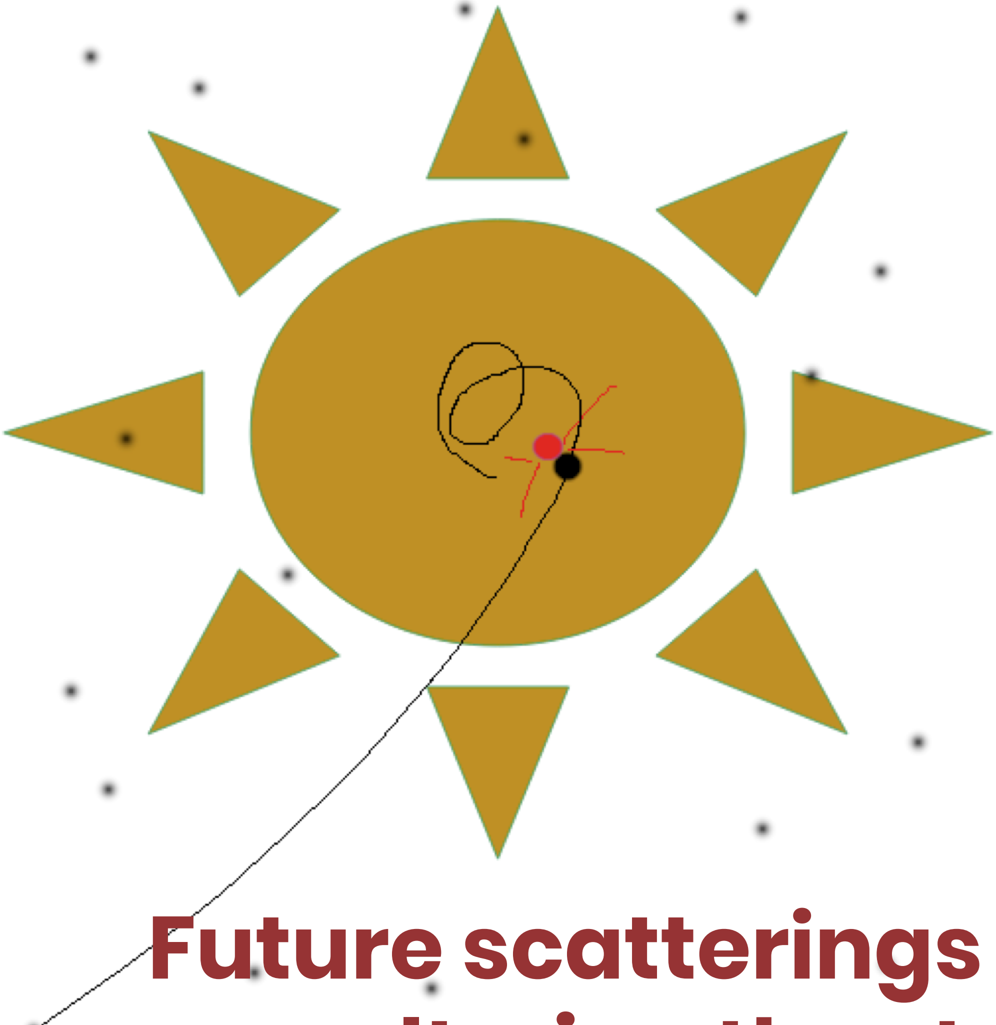
Dark Matter effects on Stars



Basic Idea

DM captured by stars via scattering.

Proposed by

Press & Spergel 1985.

Also see:

Gould ‘87 & ‘92
Zentner & Hearin ‘11
Iocco+ ‘12
Hurst ‘16

Future scatterings transport energy, altering the star’s evolution.

Dark Matter effects on Stars

For a given star, the

effectiveness of energy transport relies only on:

1. σ_{DM} (cross section)
2. m_{DM} (mass)
3. N_{DM} (number of particles captured)

Dark Matter effects on Stars

Asymmetric Dark Matter

- Product of primordial asymmetry with antiparticle
  => no present day annihilation
  => stars can build up a large quantity of DM

- Predicted mass and cross section
  => effective energy transport

- **Spin Dependent ADM:**
  Scatters primarily with protons during the MS.
- Spin Independent ADM:
  Scatters primarily with post-MS helium.

Dark Matter effects on Stars

Parameters

$$\sigma_{DM} = 10^{-37}\ \mathrm{cm}^2$$

$$\Rightarrow \mathrm{MFP} \sim R_\star$$

$$m_{DM} = 5\ \mathrm{GeV}$$

$$\Rightarrow \text{orbital radius} \sim 0.1\ R_\star$$

$$N_{DM} \propto \Gamma_B = \begin{cases} 0 & \text{No DM} \\ 1 & \text{Sun's conditions} \\ 10^6 & \text{Highest reasonable} \end{cases}$$

Dark Matter effects on Stars

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Capture Rate

$N_{DM} = Ct$

Scattering Cross Section

Boost above Sun's Capture Rate

Sun's Capture Rate

Stellar Properties

$$C \propto \sigma_{DM} \frac{\rho_{DM}}{v_{DM}} C_{\odot} M_{\star} v_{esc}^{2}$$

Gould 1992

Dark Matter effects on Stars

Capture Rate

$N_{DM} = Ct$

Scattering Cross Section

Boost above Sun's Capture Rate

Sun's Capture Rate

Stellar Properties

$$C \propto \sigma_{DM} \frac{\rho_{DM}}{v_{DM}} C_{\odot} M_{\star} v_{esc}^2$$

$$\Gamma_B \equiv \frac{\bar{\rho}_{DM}}{\bar{v}_{DM}}$$

Environmental Boost Factor parameterizes the star's DM environment relative to conditions near the sun.

$\bar{x} \equiv x / x_{\odot}$

Dark Matter effects on Stars

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Dark Matter effects on Stars

MESA
Modules for Experiments in Stellar Astrophysics

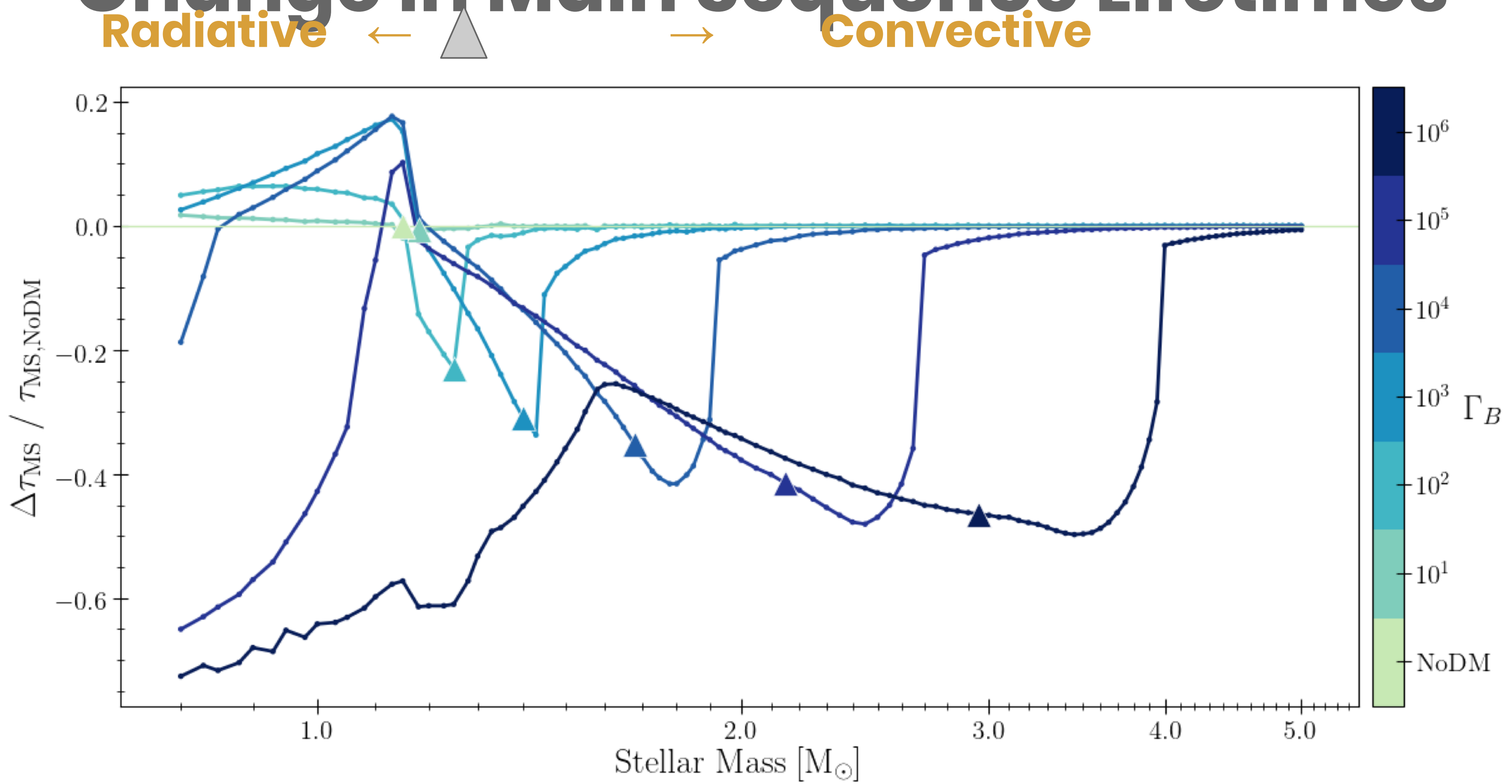
We use MESA to model the evolution of stars in varying DM environments.

$$0.8 \leq M_{\star}/\mathrm{M}_{\odot} \leq 5.0$$

$$0 \leq \Gamma_{B} \leq 10^{6}$$

Dark Matter effects on Stars

Change in Main Sequence Lifetimes



MS Lifetimes can be significantly reduced.

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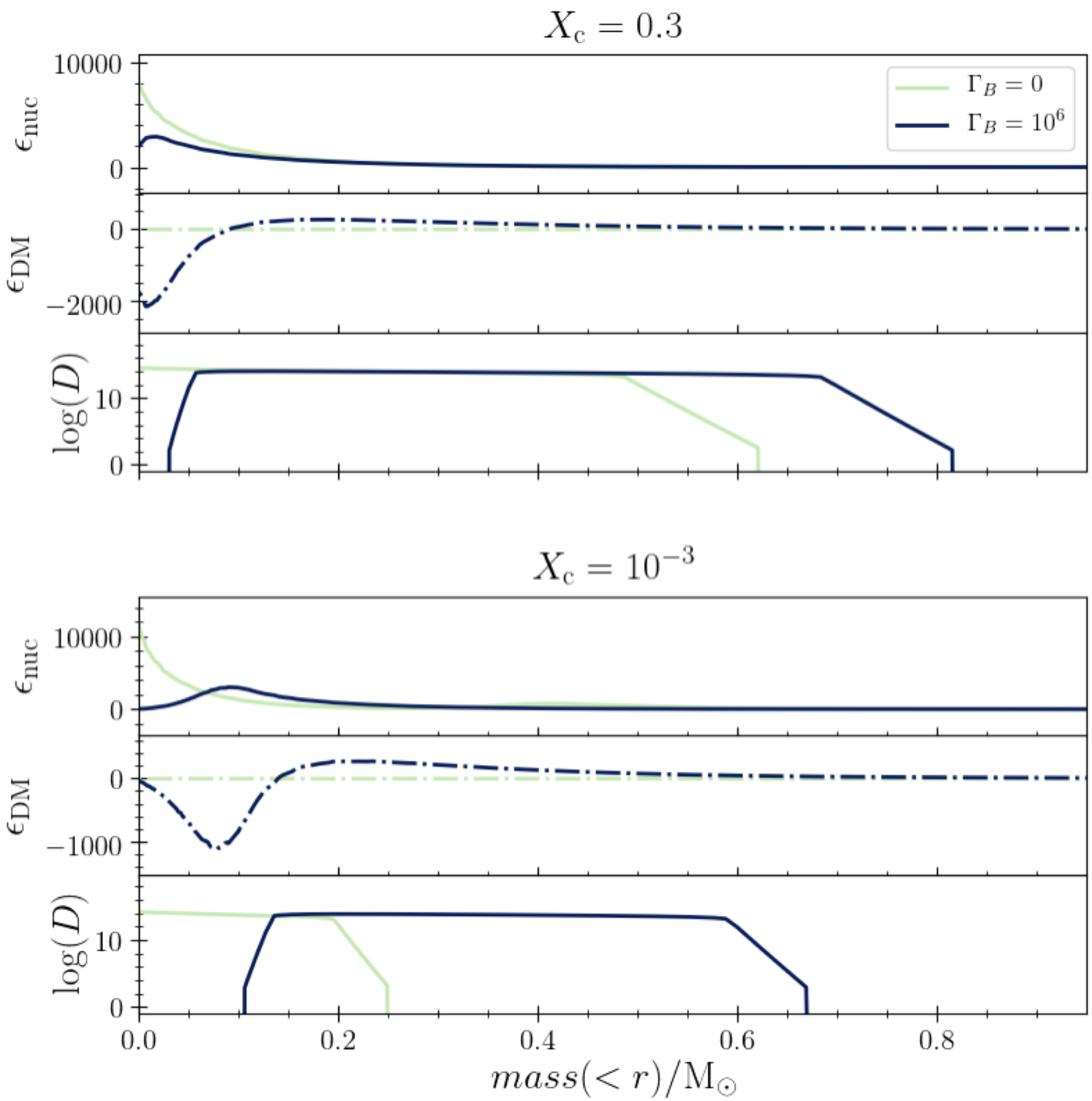

3.5 $M_\odot$

At $\Gamma_B = 10^6$, DM transports enough energy to replace convection.

Without convective mixing repleneshing the fuel supply, these stars burn out and leave the MS much earlier.

MS lifetimes are shortened.

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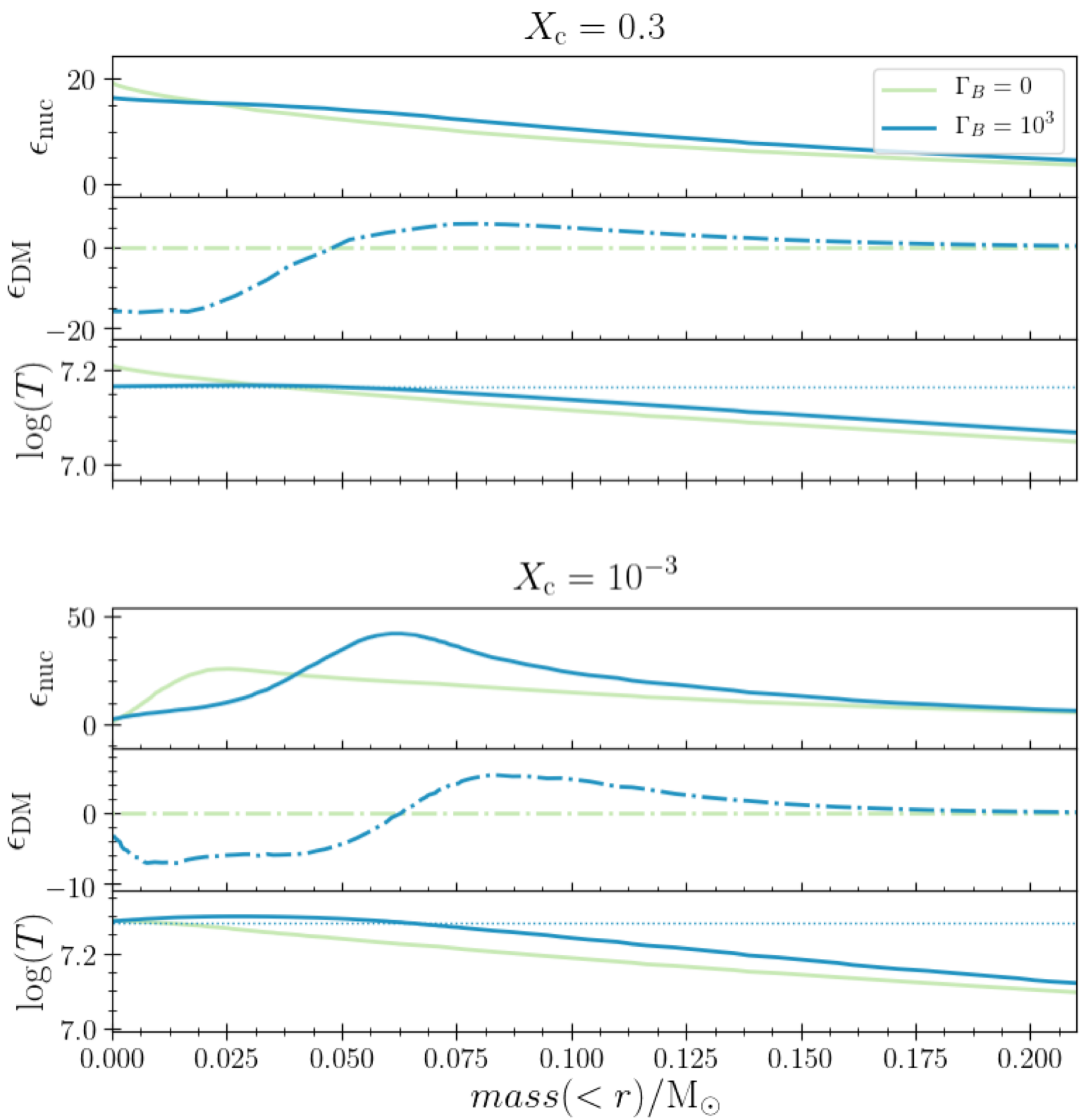


$1.0\ M_\odot$

$|\epsilon_{DM}| \sim \epsilon_{nuc}$ at $\Gamma_B = 10^3$

Central burning is reduced, shell burning is increased.

Dark Matter effects on Stars

$1.0\ M_\odot$

$\Gamma_B = 10^6$

$|\epsilon_{DM}| >> \epsilon_{nuc}$

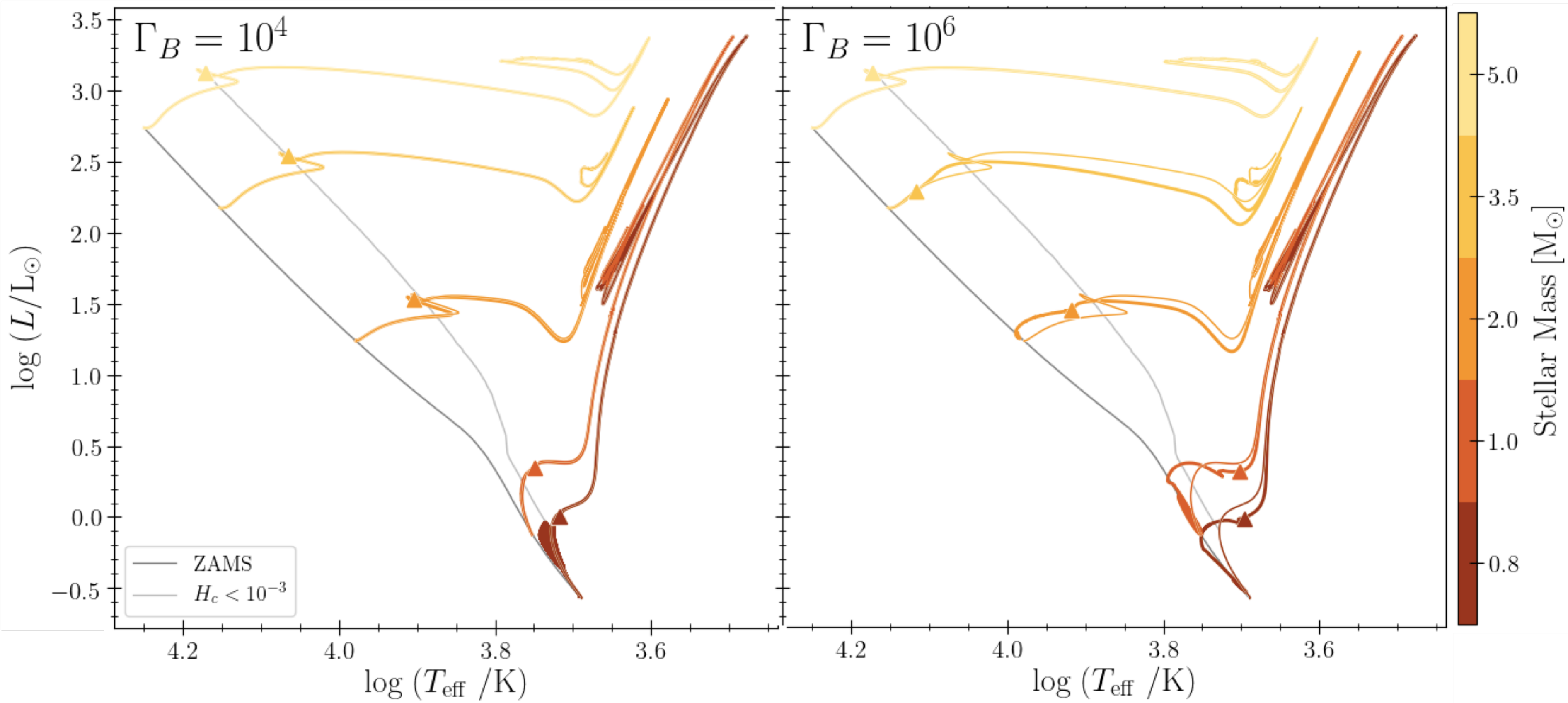
destabilizes the core...

... causing oscillations in burning intensity and extent (along with many other variables)...

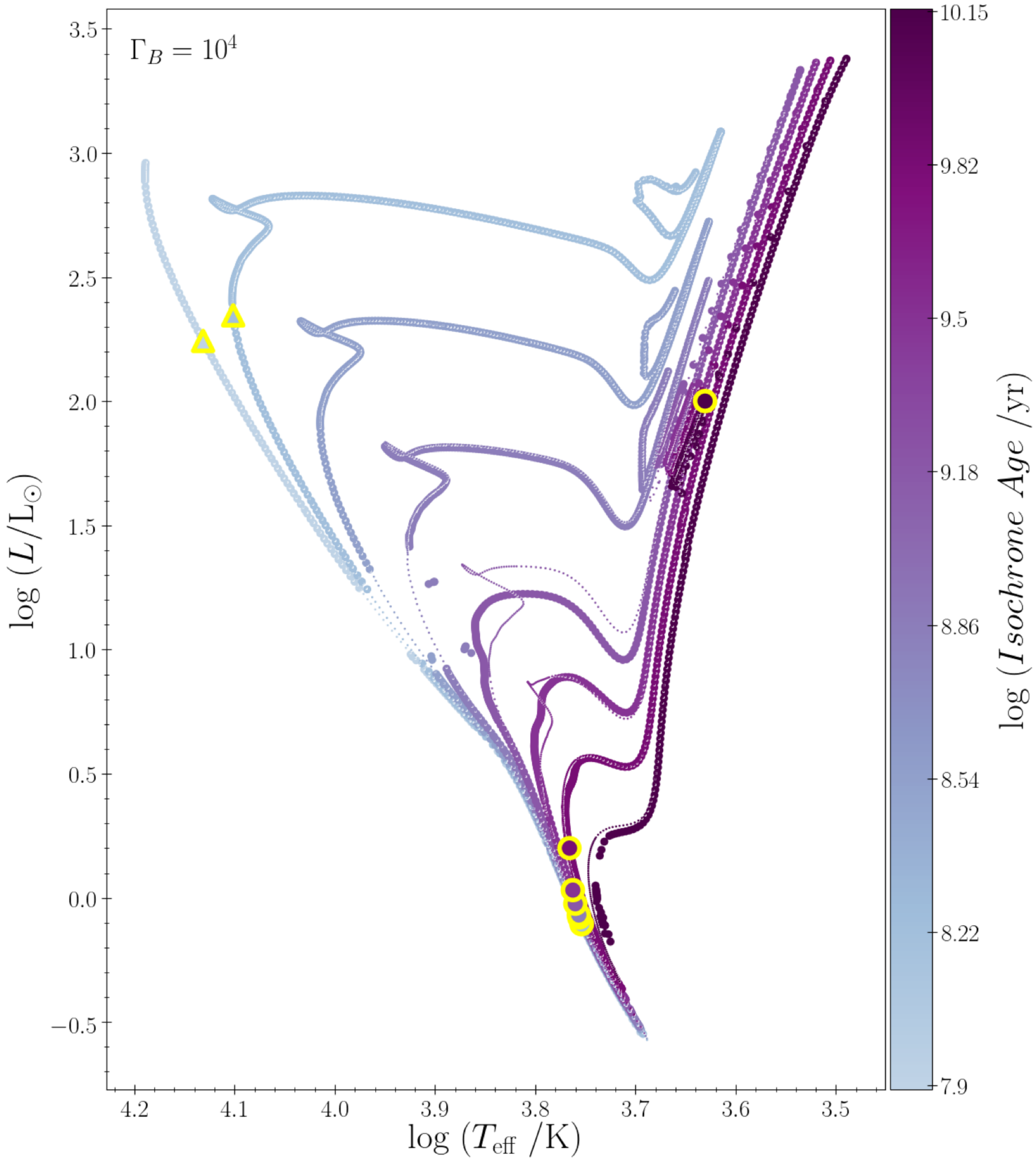
... until it finds a new stable structure, with the core supported by electron degeneracy pressure.

Dark Matter effects on Stars

Stellar Tracks



Dark Matter effects on Stars

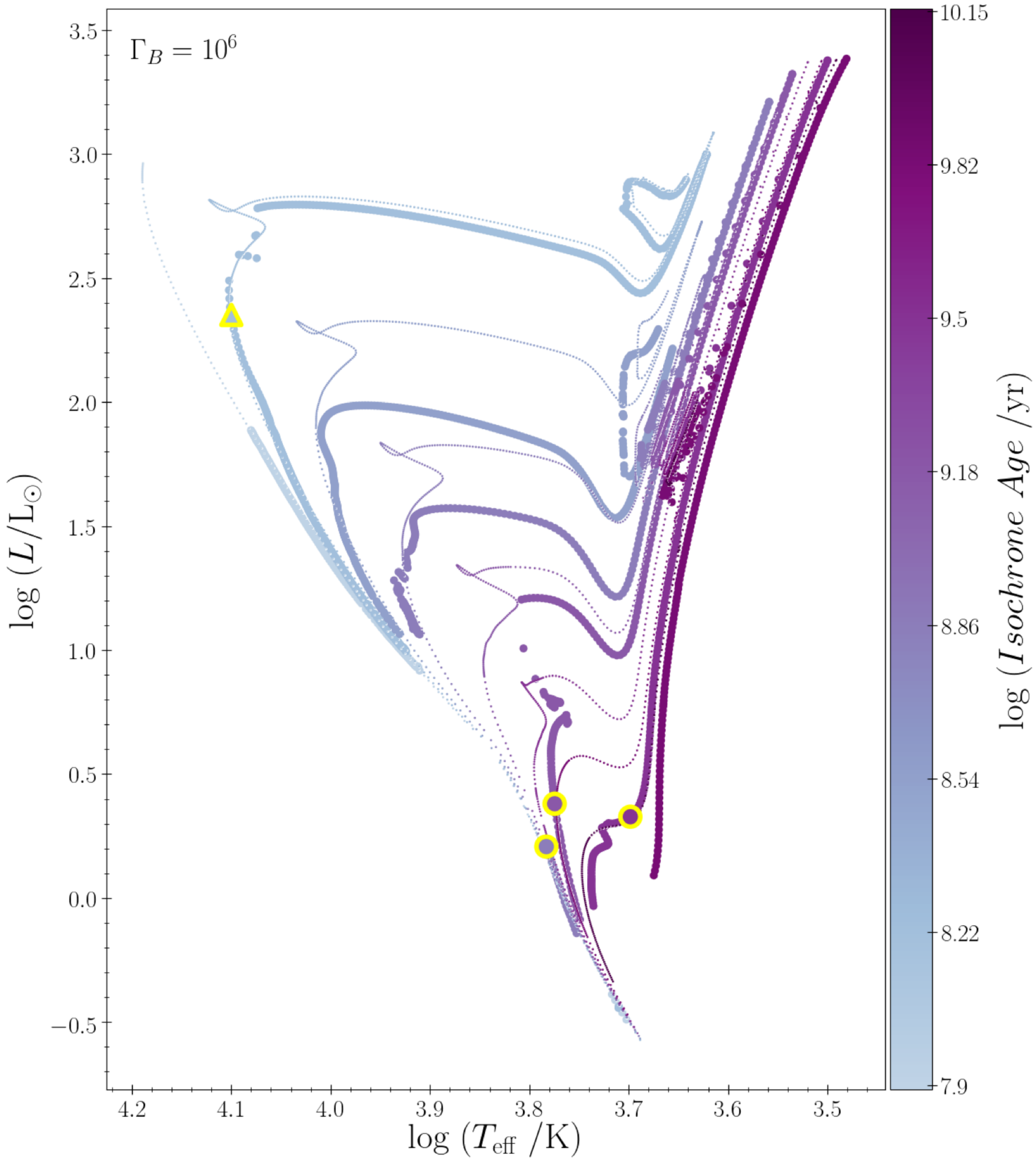


Star Cluster Isochrones

△ 3.5 $M_\odot$

○ 1.0 $M_\odot$

Dark Matter effects on Stars



Star Cluster Isochrones

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Populations in high Γ_B environments look older!

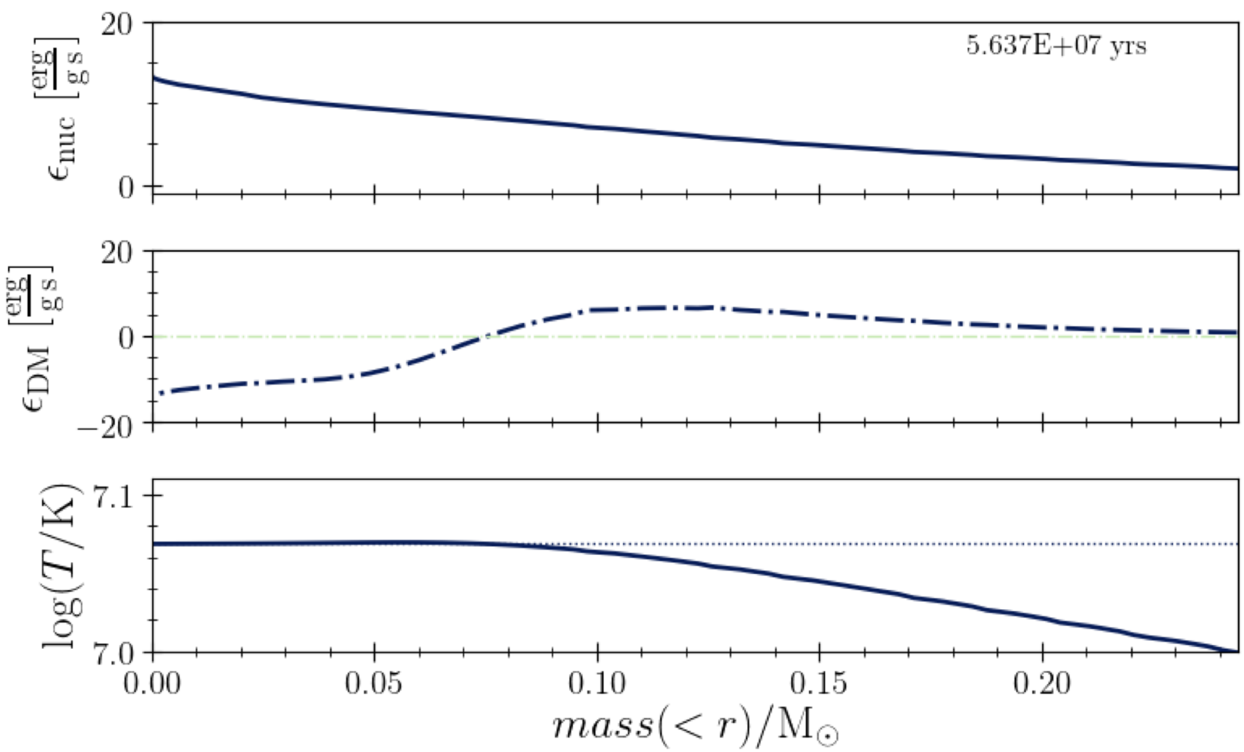
Conclusions

ADM predicts DM with properties that result in effective energy transport in stars.

These effects may be observable in star clusters that are in high density and/or low velocity DM environments.

There is more parameter space to explore (e.g. mass/cross section, spin independent models, self-interacting models).

Dark Matter effects on Stars



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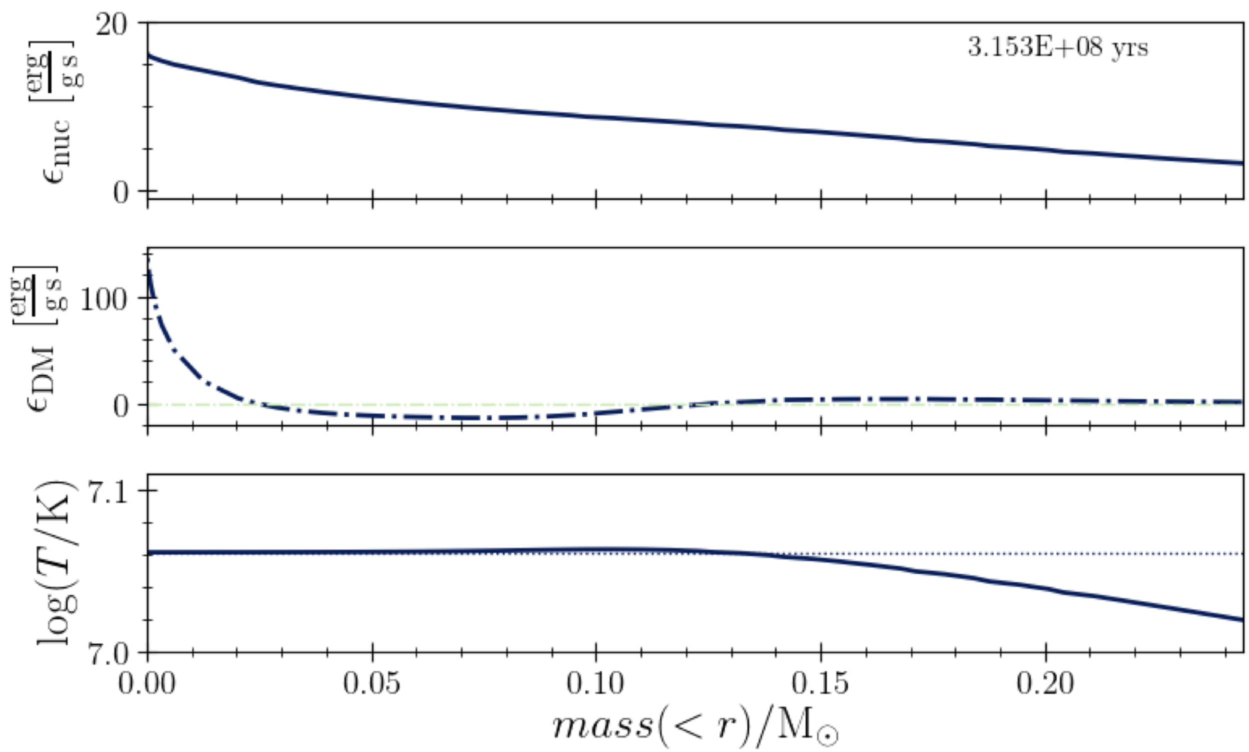

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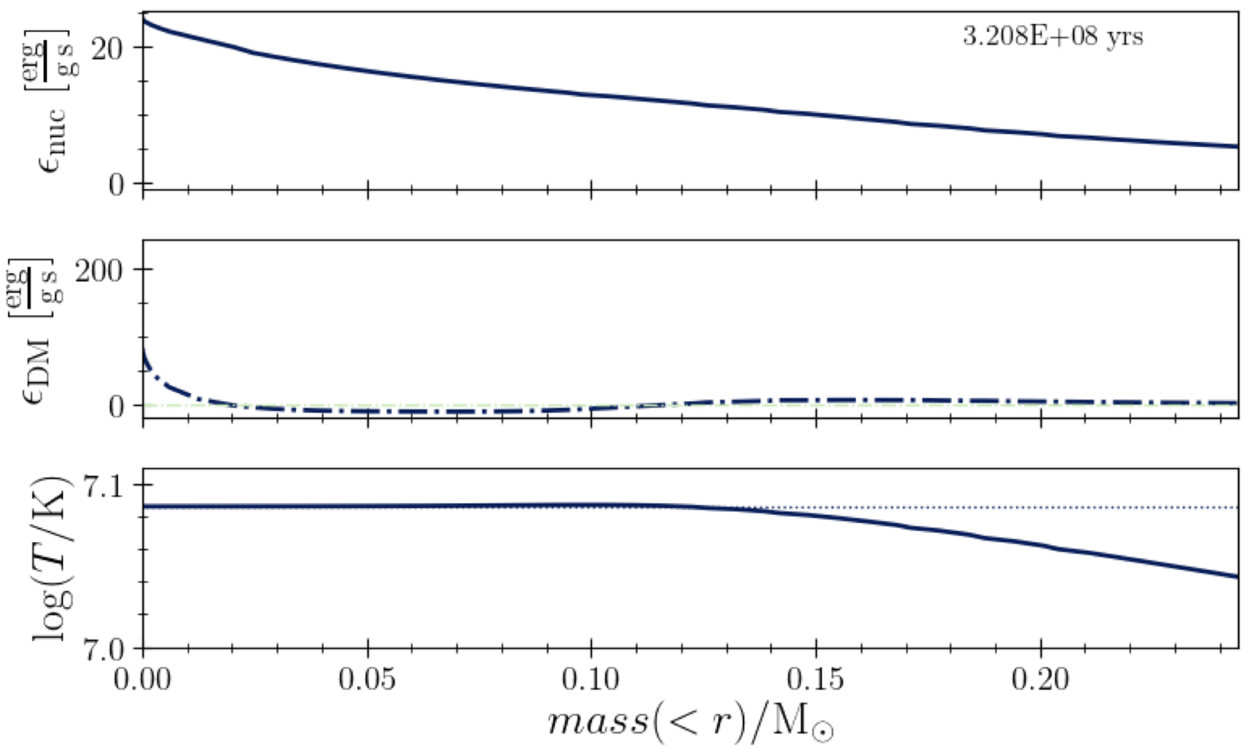

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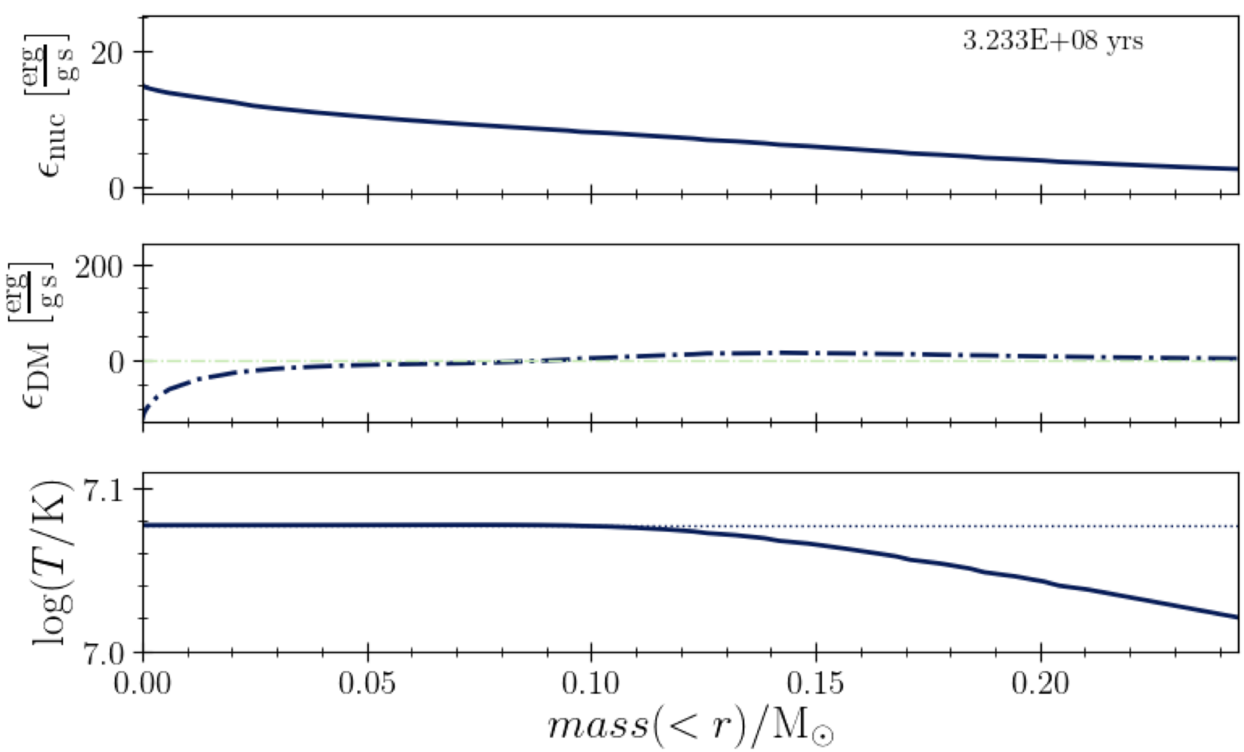

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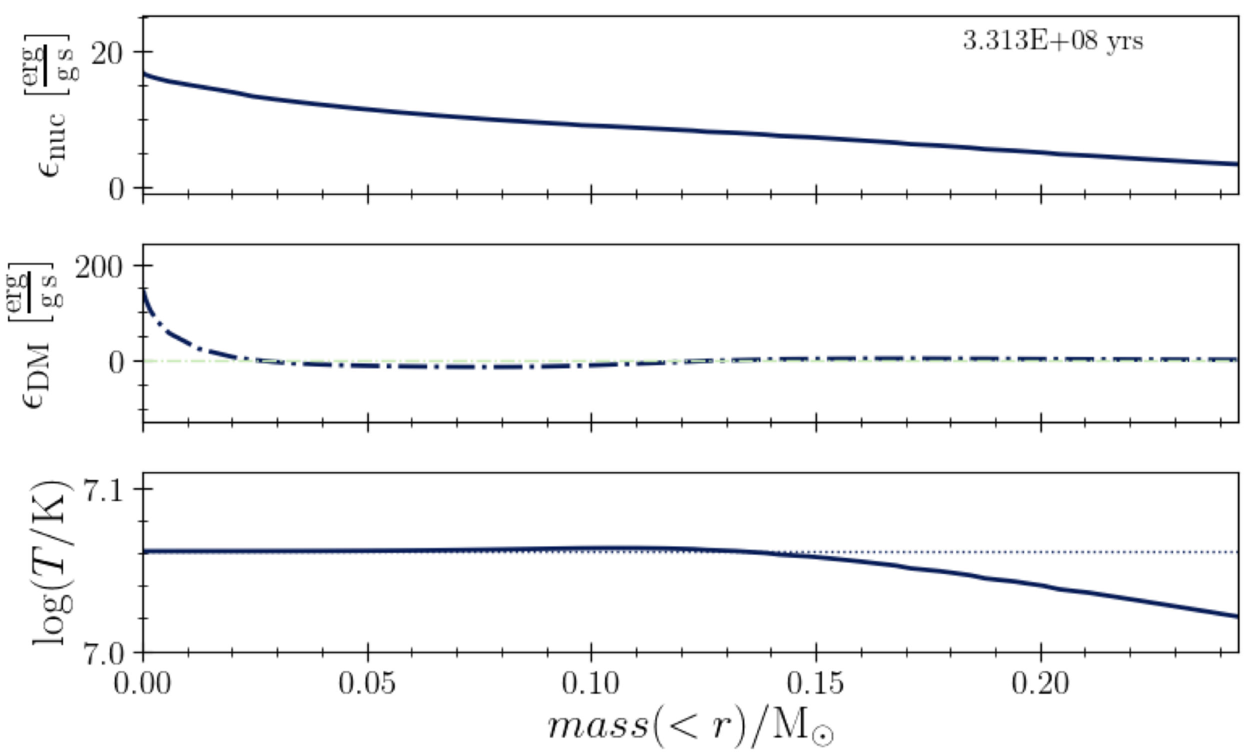

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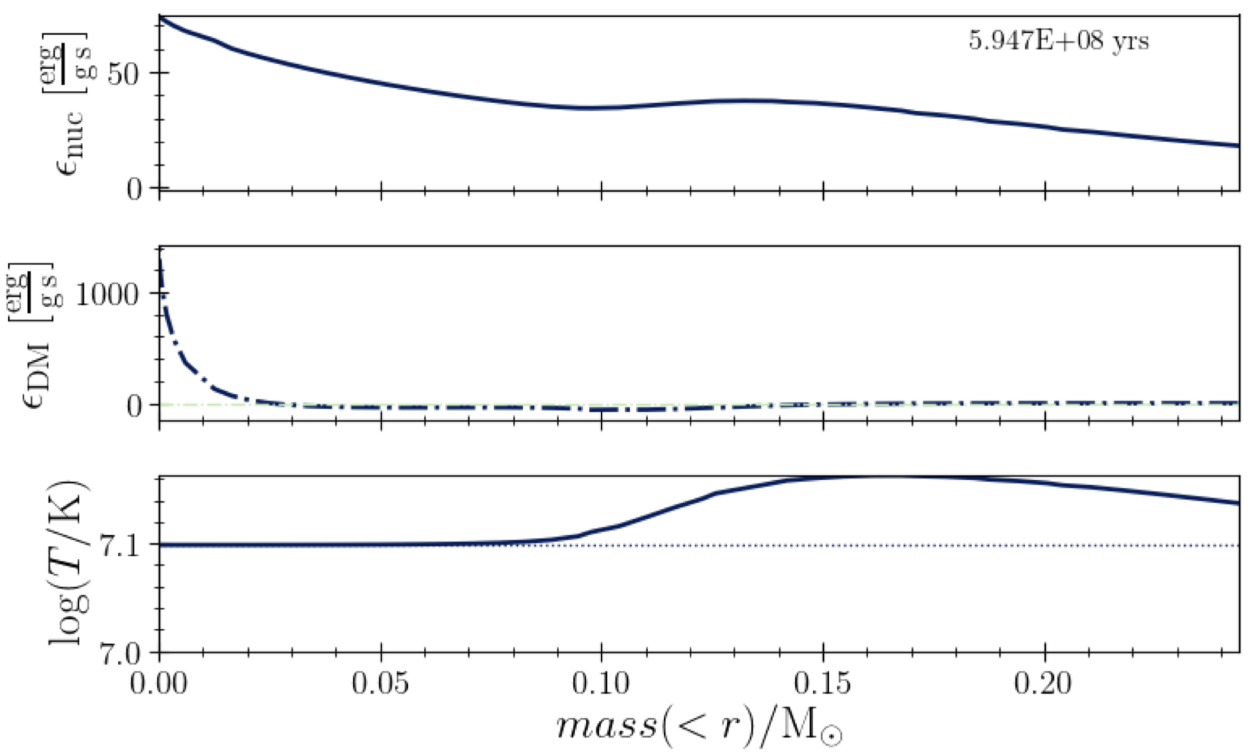

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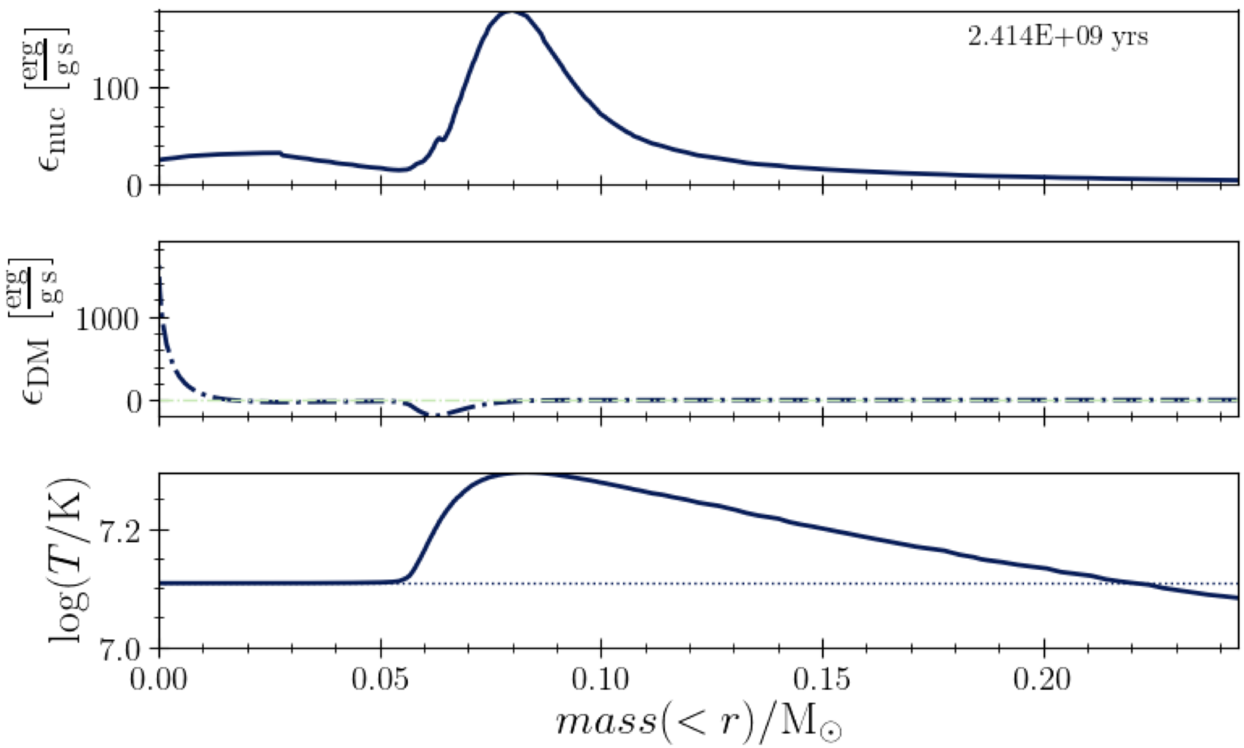

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