How Dark Matter Shapes Stellar Evolution

Licenciatura em Engenharia Física e Tecnológica (LEFT)

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UIDB/00099/2025

Why do we need Dark Matter

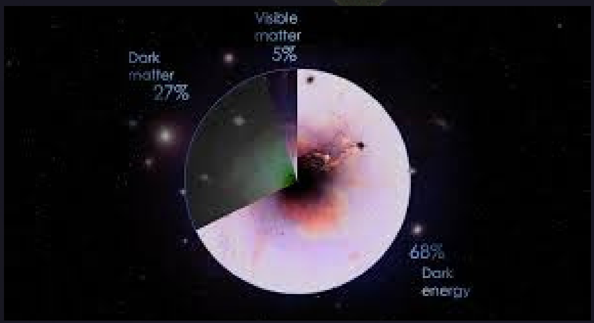


Fig.1 - Content of the Universe
Source: NASA's Goddard Space Flight Center

Dark matter is five times more abundant than ordinary matter in the Universe, and its presence is essential to explain the large-scale structure of the galaxies.

WIMPs

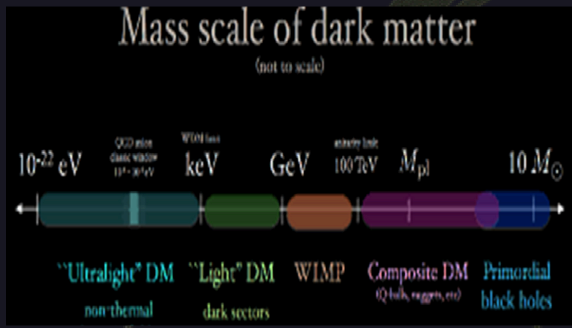


Fig.2 - Main Candidates of Dark Matter
Source: Tongyan Lin, arXiv:1904.07915

WIMPs are among the main candidates for Dark Matter. Inside stars, WIMPs can be **captured, annihilated, evaporated,** and **transport energy** through collisions with the plasma.

Following Stars through Simulations

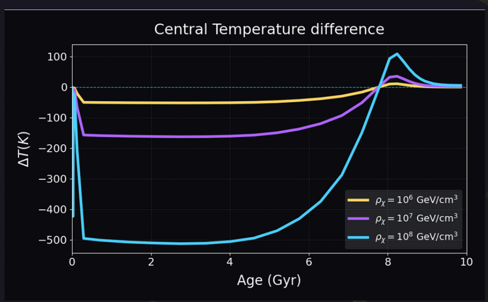
We simulated the evolution of a 1.00 M⊙ star with Z = 0.02 using the MESA code. The Dark Matter effects were introduced with the dmEFT module, developed at CENTRA, allowing variations in particle mass and halo density to be tested against a standard model.

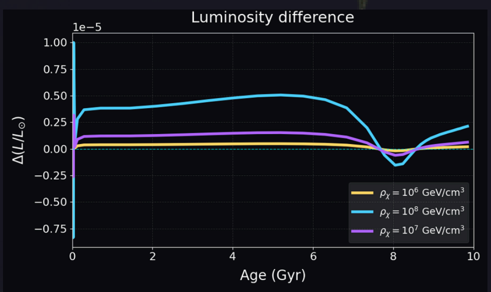
Effects on Main Sequence

The number of WIMPs inside the star is inversely proportional to **the particle mass** and directly proportional to **the halo density**.

Dark matter annihilation provides **extra energy** to the star, reducing the need for nuclear fusion to sustain hydrostatic equilibrium, **increasing Main Sequence lifetime**.

The core is the most affected region by WIMPs, which alter central temperature and density, luminosity, elemental abundances (and more).



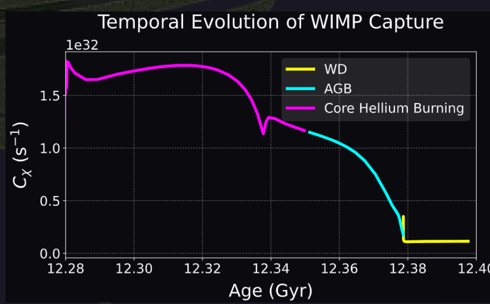


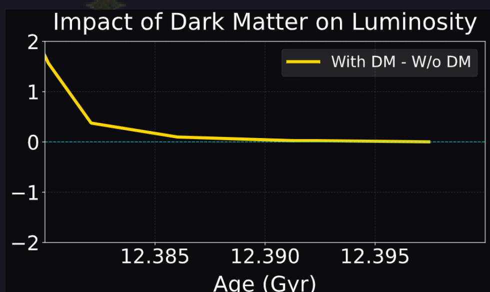
Figs. 3 & 4 show the variation of central temperature and luminosity in three models with different halo densities, for mχ= 10GeV.
As can be seen, ΔTc<0 during most of the main sequence, while ΔL>0 over the same period. This provides clear evidence for the presence of Dark Matter, since annihilation reduces nuclear fusion (which lowers Tc) and supplies additional energy to the star, increasing L. At the end of the main sequence, the model without DM exhausts core hydrogen first, leading to a reversal of ΔTc and ΔL.

Effects on White Dwarf

The number of WIMPs drops drastically from the end of the Main Sequence to the White Dwarf stage.

Annihilation decreases due to fewer WIMPs, and the differences in Tc and L between models **fade out during the WD stage.**





Figs. 5 & 6 show the variation of the capture rate from the helium flash to the white dwarf stage, and the difference of luminosity between models with and without dark matter. The drastic decrease in capture is due to the absence of hydrogen in the star.
Since the spin-dependent interaction dominates and hydrogen is the only non-negligible stellar constituent with nuclear spin, the capture rate drops when hydrogen disappears.

Conclusions

WIMP annihilation delays nuclear fusion in the Main Sequence, increasing its lifetime.
ρχ affects the quantity of WIMPs in the star, while mχ influences the processes, such as capture, transport, and annihilation.
In the White Dwarf Cooling stage, the number of WIMPs steadily decreases over time until exhaustion due to annihilation and the stopping of capture.

Acknowledgements: CENTRA – Centro de Astrofísica e Gravitação

10/09/2025