

Dark matter constraints from stellar evolution

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Abstract. The study of dark matter constraints from its effect on star evolution has been discussed in recent years. We propose a star evolution simulation approach to determine those constraints from properties related to star evolutionary stages and propose globular cluster observables in order to check those constraints. My work in progress (my PhD project research) employs FRANEC code to simulate complete star evolution from pre-main sequence to AGB phase, and regards several DM candidates like axions or WIMPs, motivated by different unsolved physical problems. Detailed energy production or energy loss due to DM particles are included, taking into account the expected interaction between dark matter particles and stellar plasma within different models.

1. Introduction

Dark matter (DM) remains as one of the most intriguing problems of modern physics. We actually don't know 80% of the mass in the universe. Different standard model or "beyond standard model" particles have been proposed as constituents of DM. Direct and indirect experiments are looking for evidences of these particles. We propose a complementary approach to the field, addressed, among other, by Raffelt [1]: the study of dark matter production, trapping or annihilation inside stars by means of computer simulations. Constraints to dark matter particles within different theoretical frames can be obtained from accurate enough simulations, which might even detect new effects, and star cluster population surveys.

We focus on axions and WIMPs. Theoretical motivations and features for both particles as DM particles are well established. We summarize them briefly.

1.1. Axions

- Proposed by Wilczek in the late seventies, axions are needed to explain the small value of the CP-violating terms in QCD lagrangian, $\theta (\alpha_s/8\pi) G\tilde{G}$. They are actually the quantum of a new field called Pecci-Quinn field, which practically makes the CP-violating term vanish and precludes its rising to higher values. So, axions appear by means of a spontaneous symmetry breaking mechanism. The additional term in the lagrangian includes axion scalar field, a , referred to a certain energy scale, a/f_a .

$$\mathcal{L}_\theta = (\bar{\theta} - a/f_a) (\alpha_s/8\pi) G\tilde{G} \quad (1)$$



- They are scalar zero-spin massive particles. Good properties to consider them cold dark matter candidates.
- They interact with photons, hadrons and charged leptons in some models like DFSZ and only with hadrons in hadronic models [6]. Compton effect and bremsstrahlung processes are important in first model. The axion coupling to two photons, “Primakoff” effect is present in both models.

1.2. WIMPs

- Weakly Interacting Massive Particles in the range of GeV. Related in some cases to supersymmetry theory.
- They can be trapped inside stars close to halo region, and depending on the density, modify normal stellar evolution. So they can annihilate and produce energy, becoming an additional energy source for the star [2].

2. Expected effect on stellar evolution

The effect of axion and WIMPs particles on stellar evolution depends on the energy carried away or introduced by them. Some of the expected effects are the following.

2.1. Axion effects

- In stars in the main sequence, it is expected that nuclear reactions will be enhanced by axion energy losses, because hydrostatic equilibrium implies that additional energy loss by axion must be balanced with a higher energy production inside stars [1].
- Inside red giant degenerate cores, energy losses due to axions produce a more efficient cooling that can increase the He core mass at the He ignition. Therefore red giant luminosity at tip phase should be greater [3] and, in principle, it could modify globular cluster isochrones.
- AGB thermal pulse period could be increased if axion emission is taken into account [3].
- Time of neutrino emission in supernovae should behave as a function of axion-nucleon coupling constant [1]. It decreases up to a certain coupling constant value and then raises again with coupling constant values.
- White dwarf cooling decreases, so number of WD in a bolometric magnitude range is reduced [4].

2.2. WIMPs effects

- WIMPs might release energy inside stars, because of annihilation process, and increase the expected time a star remains in the main sequence. Globular cluster isochrones are brighter in some regions when WIMPs processes are considered [2] [5].
- The smaller a star mass is, the greater the aforementioned effect becomes [2].

3. Approach and method

Our idea is to implement an energy loss code in FRANEC (Frascati Newton Raphson Evolutionary Code) program. Different DM particles will be studied. We begin with axions. In that case star additional energy loss is due mainly to axion bremsstrahlung, Compton and Primakoff processes. These processes depend strongly on stellar plasma properties, like temperature and density. Energy carried away by dark matter particles should be able to modify different stages as explained in previous section. The FRANEC code solves (employing Henyey method) a coupled differential equation system, which drives star evolution:

$$\frac{dP}{dr} = -\frac{GM(r)}{4\pi r^4} \quad (2)$$

$$\frac{dr}{dM(r)} = \frac{1}{4\pi r^2 \rho} \quad (3)$$

$$\frac{dL}{dM(r)} = \epsilon_g + \epsilon_n + \epsilon_\nu \quad (4)$$

$$\frac{dT}{dM(r)} = -\nabla \frac{GM(r) T}{4\pi r^4 P} \quad (5)$$

$$\frac{\partial X_i}{\partial t} = \frac{m_i}{\rho} \left(\sum_j r_{ji} - \sum_k r_{ik} \right) \quad (6)$$

Energy loss is driven by 4, where energy released by gravity and nuclear reactions are ϵ_g and ϵ_n and energy carried away by neutrinos is ϵ_ν . This equation can be modified including energy loss due to axions. $\frac{dL}{dM(r)} = \epsilon_g + \epsilon_n + \epsilon_\nu + \epsilon_{axion}$. That means energy loss carried by axion has an influence on stellar evolution and should be detected in our simulations, accelerating, or delaying evolutionary phases. Moreover, we can take into account WIMPs and modelize a star evolution affected by both, energy released by WIMPs annihilation or WIMPs transport of energy inside a star, by adding suitable terms in 4.

4. Observables

The observables we are looking for in order to check our simulations and finally constrain DM properties are mainly related to globular clusters (GC) and high precision spectroscopy, this last focused on nucleosynthesis in certain kind of stars, like AGB. We plan review several astrophysical catalogues and, perhaps, take advantage of new data acquired by different missions like GAIA. On the other hand, it's important to consider all uncertainties (experimental and due to theoretical bias) in order to achieve reliable constraints.

5. References

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