Constraints on the Nature of Self-Interacting Dark Matter via Two-Component Virial Estimates

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MOTIVATION

Constraining the nature of dark matter (DM) is presently one of the most relevant problems in cosmology and particle physics.

It is usually assumed that the DM particle is cold and non-interacting (CDM scenario).

Some difficulties of the CDM on galactic scales:

- Presence of finite DM cores in dwarf and LSB galaxies [1] whereas CDM N-body simulations predict cuspy central DM density profiles [2];

- Prediction of an over-abundant formation of satellites orbiting the Galaxy [3].

Among several solutions, the idea that the DM may be self-interacting (SIDM) has been suggested (Spergel & Steinhardt 2000, [4]).

Dantas et al. (2000, [5]) formulate a version of the virial theorem for two-component (barionic + DM halo) self-gravitating systems.

The results by Dantas et al. are in good agreement with the observed scaling relations of these systems.

They find that the central DM halo density in the scale of galaxies is:

$$\boxed{\rho_{\rm DM} \sim 2.3 \times 10^{-2}\ [\mathrm{M}_\odot/\mathrm{pc}^3]}$$

OBJECTIVES

Considering that the study of fine-scale ($\sim$ kpc) structure can be a powerful probe of the properties of the DM, we estimate the mass (m_x), freezing temperature (T_f) and elastic scattering cross section (σ_{xx}) of the DM particle

- using the estimated value of $\rho_{\rm DM}$ found by Dantas et al.;
- assuming the SIDM hypothesis of Spergel & Steinhardt.

CONSTRAINTS ON THE SIDM NATURE

First, under the assumptions that:

- there exists just one kind of SIDM particles in galactic halos;
- the DM annihilation cross-section is much smaller than its scattering cross-section;
- $\sigma_{xx} = 4\pi a^2$, where a is the scattering length, defined as a multiple (α) of the Compton wavelength of the DM particle*;

then it can be shown that ($c = \hbar = 1$):

$$m_x = \left(\frac{\lambda}{1\ Mpc}\right)^{1/3} 0.24\ \alpha^{2/3}\ \ \text{GeV} \quad (1)$$

where λ is the mean free path of the SIDM particle.

*We assume DM scatters through strong interactions similar to low energy neutro-neutron scattering.

Second, Spergel & Steinhardt assume that:

- $\lambda > 1$ kpc, in order to avoid that SIDM shocks in the inner parts of the halos;

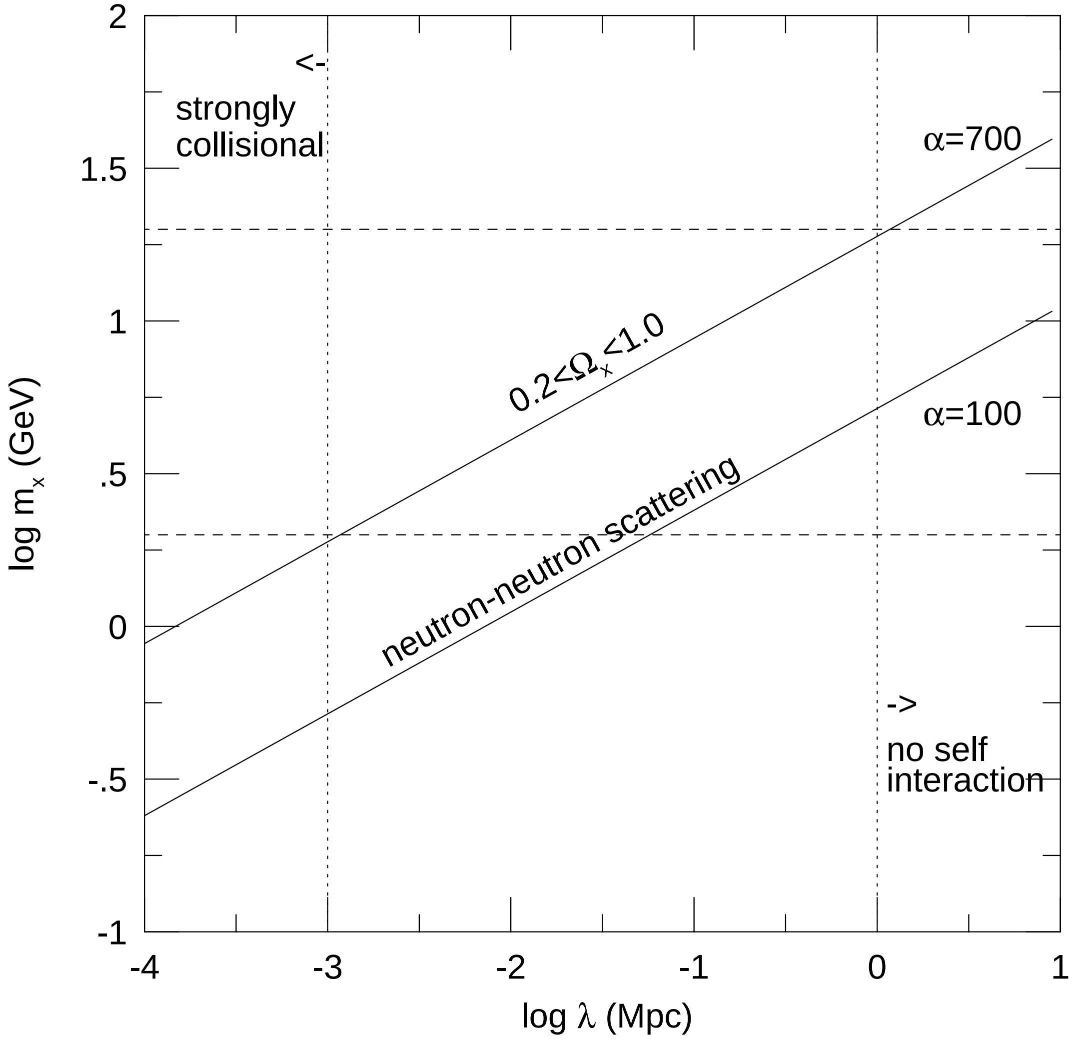
- $\lambda < 1$ Mpc, so that DM self-interactions are not completely negligible.

In Figure 1, we plot curves following (1) for two different values of α, and delimit the bounds on λ given by Spergel & Steinhardt.

We find that $\alpha \sim 700$ results from the diagonal of the retangle obtained by the further constraint $0.2 \leq \Omega_x \leq 1.0$, under the assumption that $(\Omega_x/\Omega_b) \sim (m_x/m_{proton})$. This results in:

$$\boxed{1.95 \leq m_x \leq 18.92\text{GeV}}$$

Figure 1:



2
1.5
1
.5
0
-.5
-1
-4
-3
-2
-1
0
1
log λ (Mpc)
log m_x (GeV)
<-
strongly
collisional
α=700
α=100
0.2<Ω_x<1.0
neutron-neutron scattering
->
no self
interaction

We estimate the freezing temperature T_f at which the non-relativistic SIDM particles decouple from the primeval plasma (c.f. [6]), and find a relation between m_x and T_f:

$$T_f \approx \left(\frac{T_0^3 m_x^{5/2}}{\rho_c \Omega_x}\right)^{\frac{2}{3}} \left(\frac{k}{4\pi\hbar^2}\right) e^{\left(\frac{-2fc^2}{3k}\right)}$$

where T_0 is the CBR temperature, ρ_c is the critical density of the universe, and $f \equiv \left(\frac{m_x}{T_f}\right)$.

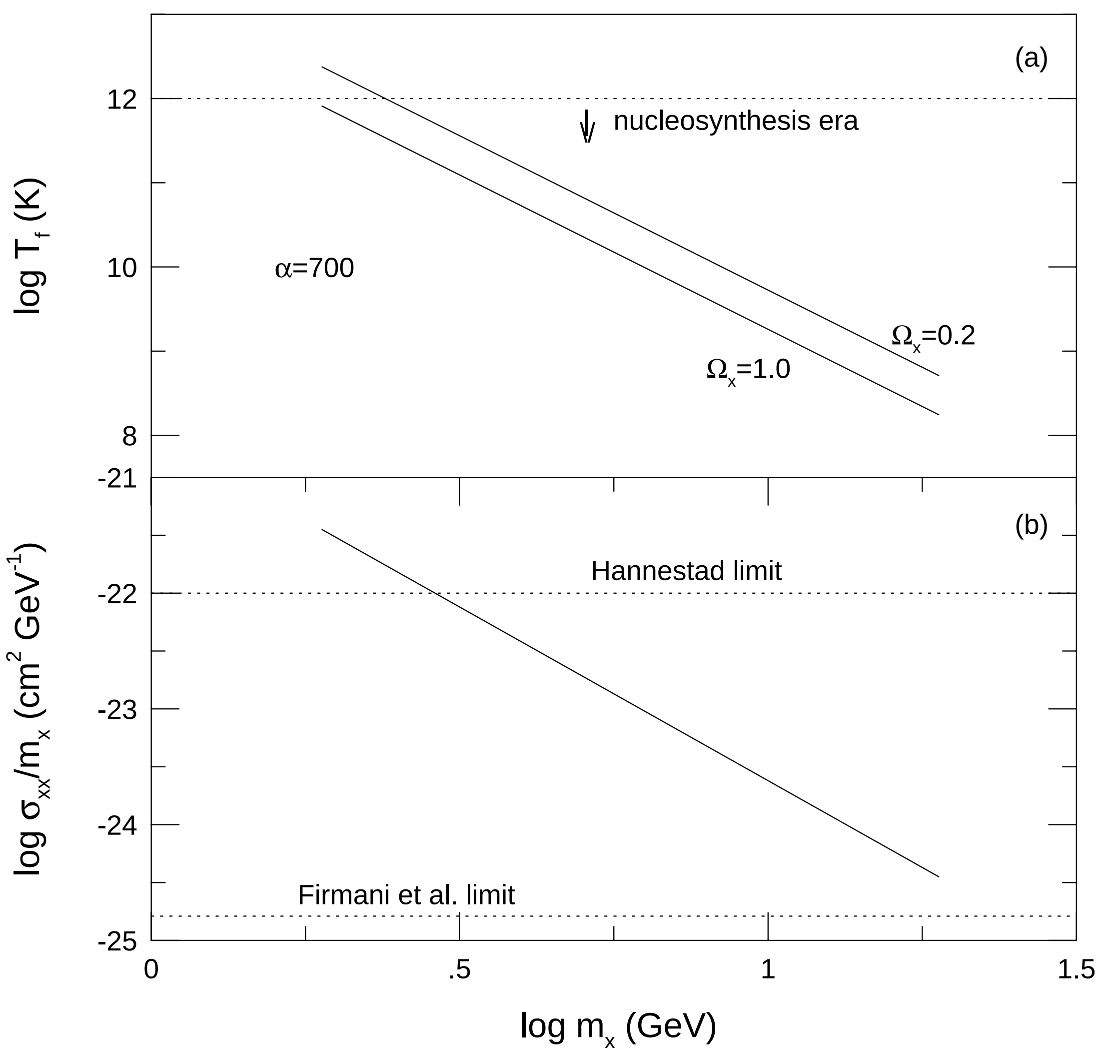
In Figure 2a we show the results for the m_x and T_f relation:

- $T_f = 10^{12.4} - 10^{8.7}\ K\ (\Omega_x = 0.2)$;
- $T_f = 10^{11.9} - 10^{8.2}\ K\ (\Omega_x = 1.0)$.

In Figure 2b we plot the relation between m_x and σ_{xx}, where we see the cross section of the dark particles in the range $10^{-25} - 10^{-21}$ cm^2 GeV^{-1}. Our DM candidate is probably in the intermediate self-interaction regime, resulting in:

$$\sigma_{xx} \sim 10^{-23} - 10^{-21} \mathrm{cm}^2 \mathrm{GeV}^{-1}$$

Figure 2:


(a)
12
10
8
log T_f (K)
nucleosynthesis era
α=700
Ω_x=0.2
Ω_x=1.0
(b)
-21
-22
-23
-24
-25
log σ_xx/m_x (cm^2 GeV^-1)
Hannestad limit
Firmani et al. limit
0
.5
1
1.5
log m_x (GeV)

CONCLUSIONS

Using the central density of DM in galaxy halos estimated by Dantas et al. and assuming that DM particles interact each other, we infer on some properties of these particles.

Our results indicate that they probably have masses of $m_x \sim 2 - 20$ GeV, with a corresponding scattering length of $\sim 700(\hbar/c)m_x^{-1}$. The scattering cross-section is in the interval $10^{-23} - 10^{-21}$ cm^{2}GeV^{-1}.

The estimated freezing temperature range is interestingly at $T_f \lesssim 10^{12}\ K$, which is the condition to decouple protons, neutrons and eletrons from the primeval plasma. Our SIDM seem to emerge over the nucleosynthesis era.

Our results favour a cold dark matter relic in the universe, in special those particles which emerge in the framework of supersymmetric theories since, in most models, the lightest supersymmetric particles (LSP) are stable in the mass range: $1 - 10^4$ GeV.

REFERENCES

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