Self-interacting dark matter model without dark energy in cosmology

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ABSTRACT

1. Introduction

2. The basic equations in the IDM model

We assume that the total density of the cosmic fluid obeys the collisional Boltzmann equation()

$$\dot{\rho} + 3H\rho + \kappa\rho^2 - 2\Psi = 0, \tag{1}$$

where ρ is the total energy-density of the cosmic fluid, containing dark matter, baryons, and any type of exotic energy, Ψ is the rate of creation of DM particle pairs, and the annihilation parameter $\kappa(\geq 0)$ is given by:

$$\kappa = \frac{\langle \sigma u \rangle}{M_x}, \tag{2}$$

where σ is the cross-section for annihilation, u is the mean particle velocity, and M_x is the mass of the DM particle. Compared to the usual fluid equation, the effective pressure term is

$$P = \frac{\kappa\rho^2 - \Psi}{3H}. \tag{3}$$

When $\kappa\rho^2 - \Psi < 0$, what means that the IDM particle creation term is larger than the annihilation item, IDM may serve as a negative pressure source in the global dynamics of the Universe, like the role of Dark Energy in the general cosmolgical models.

Basilakos & Plionis (2009) identified two functional forms for which the previous Boltzmann equation can be solved analytically. Refering to Appendix B in (), only one of these two is of interest because it provides a "$\propto a^{-3}$" dependence of the scale factor, which is

$$\Psi(a) = aH(a)R(a) = C_1(n+3)a^n H(a) + \kappa C_1^2 a^{2m}. \tag{4}$$

And the total energy density is

$$\rho(a) = C_1 a^n + \frac{a^{-3}F(a)}{C_2 - \int_1^a x^{-3} f(x)F(x)\mathrm{d}x}, \tag{5}$$

where $f(a) = -\kappa/[aH(a)]$, and the kernal function $F(a)$ has the form

$$F(a) = \exp\left[-2\kappa C_1 \int_1^a \frac{x^{n-1}}{H(x)}\mathrm{d}x\right]. \tag{6}$$

The first term of Eq.(5) is the density corresponding to the residual matter creation that results from a possible disequilibrium between the particle creation and annihilation processes, while the second term can be viewed as the energy density of the self-IDM particles that are dominated by the annihilation process.

2.1. Model 1: relation to the ΛCDM model

If $n = 0$, the global density evolution can be transformed as

$$\rho(a) = C_1 + a^{-3}\frac{e^{-2\kappa C_1(t-t_0)}}{C_2 - \kappa Z(t)}, \tag{7}$$

where $Z(t) = \int_{t_0}^{t} a^{-3} e^{-2\kappa C_1(t'-t_0)}\mathrm{d}t'$(). Using the usual unit-less Ω-like parameterization, we obtain that

$$\left(\frac{H}{H_0}\right)^2 = \Omega_{1,0} + \frac{\Omega_{1,0}\Omega_{2,0}a^{-3}e^{-2\kappa C_1(t-t_0)}}{\Omega_{1,0} + \kappa C_1 \Omega_{2,0} Z(t)}, \tag{8}$$

where $\Omega_{1,0} = 8\pi G C_1/3H_0^2$ and $\Omega_{2,0} = 8\pi G/3H_0^2 C_2$, which related to Ω_Λ and Ω_m in the ΛCDM model, respectively. From Eq.(2), we can also give the mass of the DM particle related to the range of κC_1(in the unit of Gyr^{-1})

$$M_x = \frac{3.325 \times 10^{-12}}{\kappa C_1}\frac{\langle \sigma u \rangle}{10^{-23}} h^2 (1 - \Omega_{2,0})\,\mathrm{GeV}, \tag{9}$$

where $h \equiv H_0/[100\mathrm{km/s/Mpc}]$.

2.2. Model 2 : relation to the wCDM model

If $\kappa = 0$, the global density evolution can be written as

$$\rho(a) = \mathcal{D}a^{-3} + C_1 a^n, \tag{10}$$

where $\mathcal{D} = C_2 - C - 1$. The conditions in which the current model acts as a quintessence cosmology are given by $\mathcal{D} > 0, C_1 > 0$, and $w_{\mathrm{IDM}} = -1 - n/3$. This solution is mathematically equivalent to that of the gravitational matter creation model of(). The Hubble flow is now given by

$$\left(\frac{H}{H_0}\right)^2 = \Omega_{2,0}a^{-3} + \Omega_{1,0}a^n, \tag{11}$$

where $\Omega_{2,0} = 8\pi G\mathcal{D}/3H_0^2$ and $\Omega_{1,0} = 8\pi G C_1/3H_0^2$, respectively.()

3. Observational data

4. Constraint results

5. Conclusions