 

# 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 $\rho$ is the total energy-density of the cosmic fluid, containing dark matter, baryons, and any type of exotic energy, $\Psi$ 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 $\sigma$ 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 Basilakos & Plionis (2009), 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 $\Lambda$CDM 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 $Z(t) = \int_{t_0}^{t} a^{-3} e^{-2\kappa C_1(t'-t_0)}\mathrm{d}t'$(Basilakos & Plionis (2009)). Using the usual unit-less $\Omega$-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 $\Omega_\Lambda$ and $\Omega_m$ in the $\Lambda$CDM model, respectively. From Eq.(2), we can also give the mass of the DM particle related to the range of $\kappa C_1$(in the unit of $\mathrm{Gyr}^{-1}$)

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

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.(Basilakos & Plionis (2009))

## 3. Observational data

To constrain the relevant IDM models (Basilakos & Plionis (2009)), we use the newly revised observational $H(z)$ data (OHD)(Zhang et al. (2014);Simon et al. (2005); Moresco et al. (2012);Moresco et al. (2016);Ratsimbazafy et al. (2017);Moresco (2015)), the Pantheon+ set of 1701 SNe Ia (), the CMB data from Planck 2018 and the BAO data from DESI 2024.

### 3.1. The observational H(z) data

It is widely known that the Hubble parameter $H(z)$ depends on the differential age as a function of redshift $z$ in the form

$$H(z) = -\frac{1}{1+z}\frac{dz}{dt}, \tag{12}$$

which provides a direct measurement on $H(z)$ based on $dz/dt$. OHD measurements have recently been acquired mainly employing cosmic chronometers (CC). The CC method is used to provide 33 observational data points, which are taken in the redshift range [0, 1.965]. The Table 1 lists the OHD dataset used in this analysis. In this case, $\chi^2$ can be defined as

$$\chi^2_{\rm OHD} = \sum_i^{33} \frac{(H_{\rm th} - H_{\rm data})^2}{\sigma_i^2}. \tag{13}$$

**Table 1.** The OHD dataset

| $z$ | $H(z)$ | $1\sigma$ uncertainty | Reference |
|---|---|---|---|
| 0.07 | 69 | ±19.6 | Zhang et al. (2014) |
| 0.09 | 69 | ±12 | Simon et al. (2005) |
| 0.12 | 68.6 | ±26.2 | Zhang et al. (2014) |
| 0.17 | 83 | ±8 | Simon et al. (2005) |
| 0.179 | 75 | ±4 | Moresco et al. (2012) |
| 0.199 | 75 | ±5 | Moresco et al. (2012) |
| 0.2 | 72.9 | ±29.6 | Zhang et al. (2014) |
| 0.27 | 77 | ±14 | Simon et al. (2005) |
| 0.28 | 88.8 | ±36.6 | Zhang et al. (2014) |
| 0.352 | 83 | ±14 | Moresco et al. (2012) |
| 0.3802 | 83 | ±13.5 | Moresco et al. (2016) |
| 0.4 | 95 | ±17 | Simon et al. (2005) |
| 0.4004 | 77 | ±10.2 | Moresco et al. (2016) |
| 0.4247 | 87.1 | ±11.2 | Moresco et al. (2016) |
| 0.4497 | 92.8 | ±12.9 | Moresco et al. (2016) |
| 0.47 | 89 | ±34 | Ratsimbazafy et al. (2017) |
| 0.4783 | 80.9 | ±9 | Moresco et al. (2016) |
| 0.48 | 97 | ±62 | Stern et al. (2010) |
| 0.593 | 104 | ±13 | Moresco et al. (2012) |
| 0.68 | 92 | ±8 | Moresco et al. (2012) |
| 0.75 | 98.8 | ±33.6 | Borghi et al. (2022) |
| 0.781 | 105 | ±12 | Moresco et al. (2012) |
| 0.8 | 113.1 | 15.1 | Jiao et al. (2023) |
| 0.875 | 125 | ±17 | Moresco et al. (2012) |
| 0.88 | 90 | ±40 | Stern et al. (2010) |
| 0.9 | 117 | ±23 | Simon et al. (2005) |
| 1.037 | 154 | ±20 | Moresco et al. (2012) |
| 1.3 | 168 | ±17 | Simon et al. (2005) |
| 1.363 | 160 | ±33.6 | Moresco (2015) |
| 1.43 | 177 | ±18 | Simon et al. (2005) |
| 1.53 | 140 | ±14 | Simon et al. (2005) |
| 1.75 | 202 | ±40 | Simon et al. (2005) |
| 1.965 | 186.5 | ±50.4 | Moresco (2015) |

### 3.2. The observational SNe Ia data

SNe Ia have long been used as "standard candles". It is

## 4. Constraint results

## 5. Conclusions

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