

A Short Note on Planck 2018 Constraints on Decaying Cold Dark Matter

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Abstract

We report a short status note on our latest profile-likelihood analysis of decaying cold dark matter (DCDM) with invisible decay into dark radiation. The analysis uses CLASS+MONTEPYTHON with the Planck 2018 TT,TE,EE+low ℓ +lowE+lensing likelihood combination. Instead of sampling the decay rate Γ_{dcdm} freely with standard MCMC, we profile the likelihood over the remaining cosmological and nuisance parameters at fixed values of Γ_{dcdm} . After a targeted warm-start refinement of the fixed- Γ grid, the profile now shows no evidence for late dark-matter decay and continues to prefer the stable-CDM limit. The current smoothed profile brackets the one-parameter 95% crossing between $\Gamma_{\text{dcdm}} = 2.25$ and $2.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$, with linear interpolation giving $\Gamma_{\text{dcdm}} \approx 2.38 \text{ km s}^{-1} \text{ Mpc}^{-1}$. We therefore conservatively quote

$$\Gamma_{\text{dcdm}} \lesssim 2.4 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad (95\% \text{ C.L.}).$$

1 Introduction

Decaying dark matter remains an attractive phenomenological extension of the standard cosmological model because even a very weak late-time decay can suppress structure growth and alter the CMB lensing signal. In this note we revisit the simplest case in which cold dark matter decays into invisible dark radiation, parameterized by a decay rate Γ_{dcdm} expressed in $\text{km s}^{-1} \text{ Mpc}^{-1}$. Our goal is modest: to document the current state of the computation, summarize the completed profile-likelihood batch, and state the present scientific conclusion conservatively.

The main lesson of this run is straightforward. Planck 2018 does not show a convincing preference for nonzero Γ_{dcdm} . The dominant constraining power comes from late-time structure suppression and CMB lensing rather than from a dramatic distortion of the primary TT acoustic peaks. As a result, the expected bound lies at the level of a few $\text{km s}^{-1} \text{ Mpc}^{-1}$, not at much smaller values.

2 Method

The computation was performed with CLASS+MONTEPYTHON using the Planck 2018 TT,TE,EE+low ℓ +lowE likelihood set. Earlier attempts based on free- Γ_{dcdm} MCMC chains proved inefficient for a one-sided upper-limit problem, and covariant jumping strategies produced unstable behavior in the relevant parameter region. We therefore adopted a profile-likelihood strategy with separate runs at fixed values of Γ_{dcdm} while profiling over the remaining cosmological and nuisance parameters.

The initial production batch contains fixed- Γ runs at

$$\Gamma_{\text{dcdm}} = 0, 1, 1.5, 3, 5 \text{ km s}^{-1} \text{ Mpc}^{-1},$$

each extended to a total of 12000 steps through monitored restarts. We then added targeted warm-start refinement runs at

$$\Gamma_{\text{dcdm}} = 1, 1.5, 2, 2.25, 2.5 \text{ km s}^{-1} \text{ Mpc}^{-1},$$

Table 1: Current fixed- Γ_{dcdm} profile-likelihood minima from the smoothed Planck 2018 profile scan. The reference point is the stable-CDM model with $\Gamma_{\text{dcdm}} = 0$.

Γ_{dcdm} [$\text{km s}^{-1} \text{Mpc}^{-1}$]	best loglkl	Δloglkl	$\Delta\chi^2$
0.0	1388.12	0.00	0.00
1.0	1388.90	0.78	1.56
1.5	1389.17	1.05	2.10
2.0	1389.75	1.63	3.26
2.25	1389.70	1.58	3.16
2.5	1390.34	2.22	4.44
3.0	1390.48	2.36	4.72
5.0	1395.04	6.92	13.84

using best-fit seeds extracted from the already converged neighborhood. This strategy directly targets the quantity of interest for a one-sided upper limit and yields a visibly smoother profile around the 95% crossing region.

3 Results

The best profile values extracted from the full production plus warm-start refinement set are listed in Table 1. We quote the best likelihood value in the MontePython convention together with differences relative to the stable-CDM case.

Three conclusions are now robust. First, the best fit remains at $\Gamma_{\text{dcdm}} = 0$, so the data continue to prefer stable cold dark matter. Second, large decay rates such as $\Gamma_{\text{dcdm}} = 5 \text{ km s}^{-1} \text{Mpc}^{-1}$ are clearly disfavored. Third, there is still no statistically convincing decay signal anywhere in the sampled range.

The targeted warm-start refinement removes the large numerical kink present in the earlier coarse scan and leaves only a mild residual scatter between the $\Gamma_{\text{dcdm}} = 2$ and 2.25 nodes. Crucially, the 95% crossing is now cleanly bracketed by the two neighboring points

$$\Gamma_{\text{dcdm}} = 2.25 \text{ km s}^{-1} \text{Mpc}^{-1} \quad (\Delta\chi^2 = 3.16) \quad \text{and} \quad \Gamma_{\text{dcdm}} = 2.5 \text{ km s}^{-1} \text{Mpc}^{-1} \quad (\Delta\chi^2 = 4.44),$$

which implies by linear interpolation

$$\Gamma_{\text{dcdm}} \approx 2.38 \text{ km s}^{-1} \text{Mpc}^{-1} \quad (95\% \text{ C.L.}).$$

For the paper-level summary adopted here, we conservatively round this to

$$\Gamma_{\text{dcdm}} \lesssim 2.4 \text{ km s}^{-1} \text{Mpc}^{-1} \quad (95\% \text{ C.L.}).$$

This status is illustrated in Figure 1, where the stable-CDM point remains preferred and the 95% crossing is now localized in a narrow bracket.

4 Physical Interpretation

Expressed as a lifetime, this bound implies that any invisible decay of the dark matter component must be extremely slow. Since

$$1 \text{ km s}^{-1} \text{Mpc}^{-1} \simeq 3.24 \times 10^{-20} \text{ s}^{-1},$$

the current bound corresponds to a lifetime of order

$$\tau_{\text{dcdm}} = \Gamma_{\text{dcdm}}^{-1} \gtrsim 4.1 \times 10^{11} \text{ yr},$$

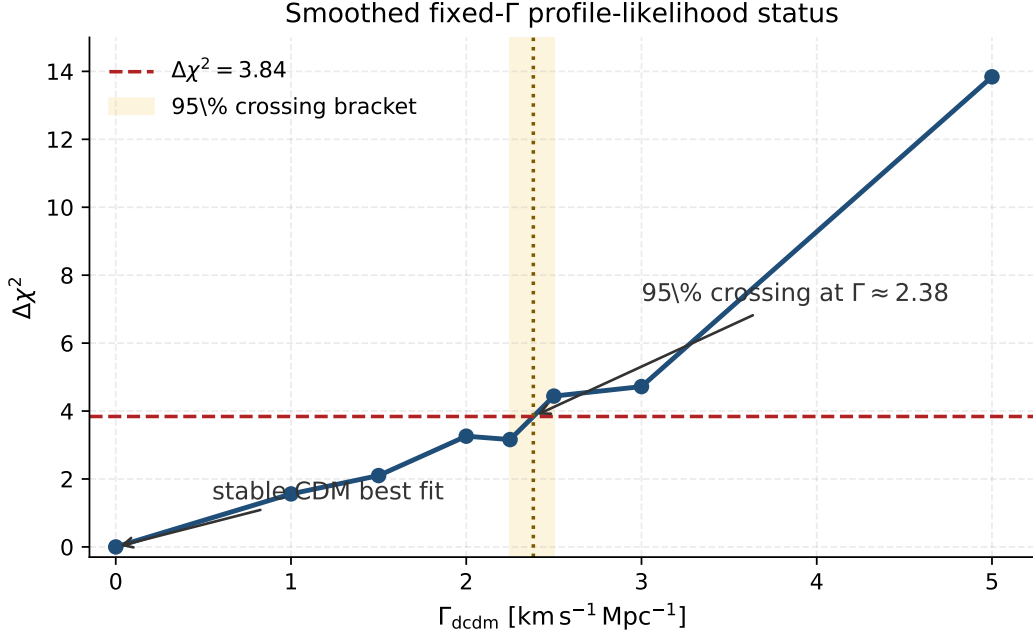


Figure 1: Smoothed fixed- Γ_{dcdm} profile-likelihood status from the full production plus warm-start refinement scan. The horizontal dashed line marks the nominal $\Delta\chi^2 = 3.84$ threshold for a one-parameter 95% limit, the shaded band brackets the crossing between the sampled nodes at $\Gamma_{\text{dcdm}} = 2.25$ and 2.5 , and the dotted line shows the interpolated value $\Gamma_{\text{dcdm}} \approx 2.38 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

namely more than four hundred billion years, far longer than the age of the Universe. Figure 2 makes this scale explicit by comparing the decay lifetime associated with different Γ_{dcdm} values to the cosmic age. The present constraint is therefore best understood as a late-time structure and lensing bound rather than a probe of very early-Universe physics.

5 Discussion and Next Steps

From a scientific standpoint, the main result is now clear enough for a short paper: Planck 2018 prefers nearly stable CDM and does not require a decaying component. From a numerical standpoint, the targeted refinement has already accomplished the essential task of smoothing the crossing region and stabilizing the upper limit.

Further local sampling between $\Gamma_{\text{dcdm}} \simeq 2.3$ and $2.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$ could still refine the last decimal place of the quoted limit, but it is no longer necessary for the central scientific statement. The essential physical message is stable: any allowed invisible dark-matter decay must be very slow, and current Planck data provide no evidence for a departure from the stable-CDM limit.

6 Conclusion

Our latest Planck 2018 profile-likelihood study of decaying cold dark matter finds no convincing evidence for nonzero Γ_{dcdm} . The stable-CDM limit remains the global best fit, while rapid decay is disfavored. After targeted warm-start smoothing, the profile-likelihood crossing of the nominal 95% threshold occurs at

$$\Gamma_{\text{dcdm}} \approx 2.38 \text{ km s}^{-1} \text{ Mpc}^{-1},$$

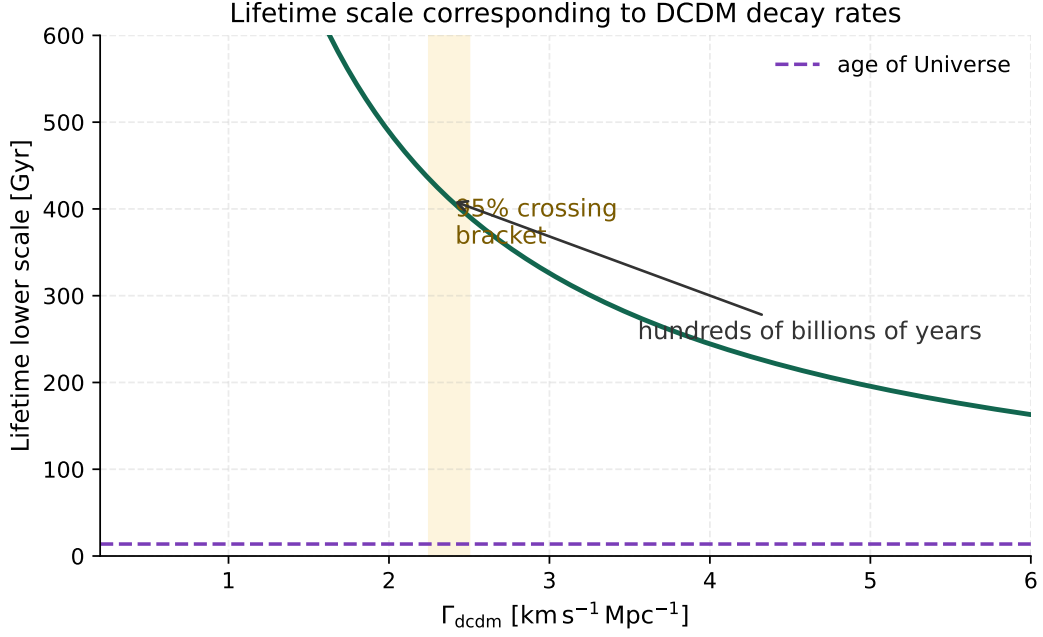


Figure 2: Lifetime scale associated with the DCDM decay rate. The shaded region brackets the current 95% crossing interval between $\Gamma_{\text{dcdm}} = 2.25$ and $2.5 \text{ km s}^{-1} \text{ Mpc}^{-1}$, corresponding to lifetimes of order 4×10^{11} years, comfortably above the age of the Universe.

so we conservatively quote

$$\Gamma_{\text{dcdm}} \lesssim 2.4 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad (95\% \text{ C.L.}).$$

This already implies that any invisible dark-matter decay must occur on timescales of at least about 4×10^{11} years, vastly longer than the present age of the Universe.