IAS workshop on ‘New perspectives on cosmology’

Structure Formation of the Universe in the Long Lifetime Decaying Dark Matter (DDM) Models

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The decaying dark matter (DDM):

One type of dark matter convert to another type in cosmic time scale

$$\mathrm{DDM} \rightarrow \mathrm{DM} + l$$

or

$$\mathrm{DDM} \rightarrow \mathrm{DM} + \mathrm{DM}$$

The new born dark matter has additional kinetic energy

$$V_k = \Delta M / M \cdot c$$

or

$$V_k = \sqrt{2 \Delta M / M} \cdot c$$

Two decay parameters:

$$(\tau, V_k)$$

Additional coupling:

$$\frac{\mathrm{d}f_M(\mathbf{x},\mathbf{v},t)}{\mathrm{d}t} = -\lambda f_M(\mathbf{x},\mathbf{v},t)$$

$$\frac{\mathrm{d}f_D(\mathbf{x},\mathbf{v},t)}{\mathrm{d}t} = \int \lambda \frac{1}{4\pi V_k^2} f_M(\mathbf{x},\mathbf{v}^{'},t)\delta(|\mathbf{v}^{'}-\mathbf{v}|-V_k)\mathrm{d}^3\mathbf{v}^{'}$$

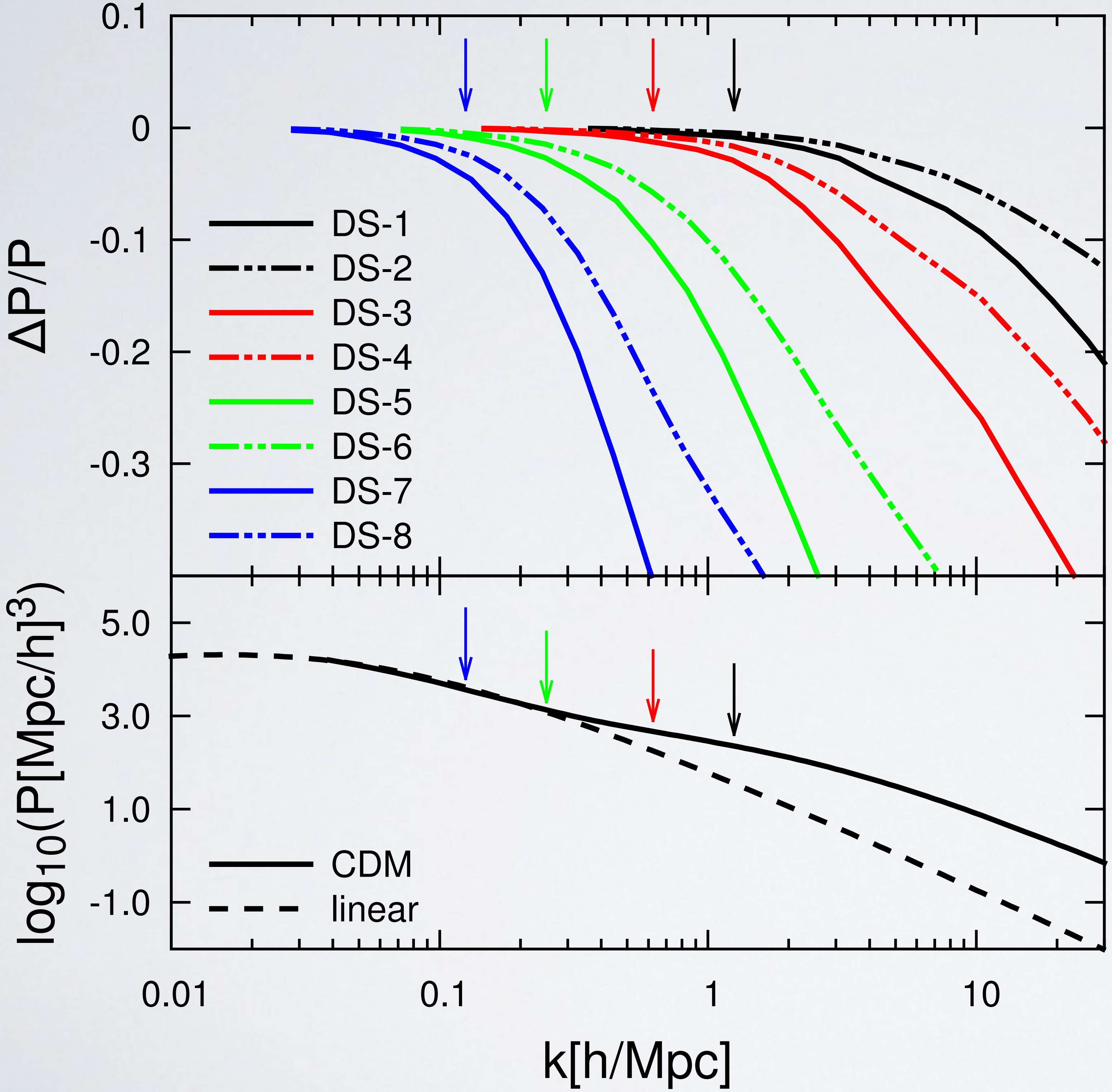
$$\delta\rho = \int [f_M(\mathbf{x},\mathbf{v},t) + f_D(\mathbf{x},\mathbf{v},t)]\mathrm{d}^3\mathbf{v}$$

$$\lambda = \ln(2)/\tau$$

$$\nabla^2\delta\Phi = 4\pi G\delta\rho$$

$$\frac{\mathrm{d}\mathbf{v}}{\mathrm{d}t} = -\nabla\delta\Phi$$

Suppression on non-linear scales:

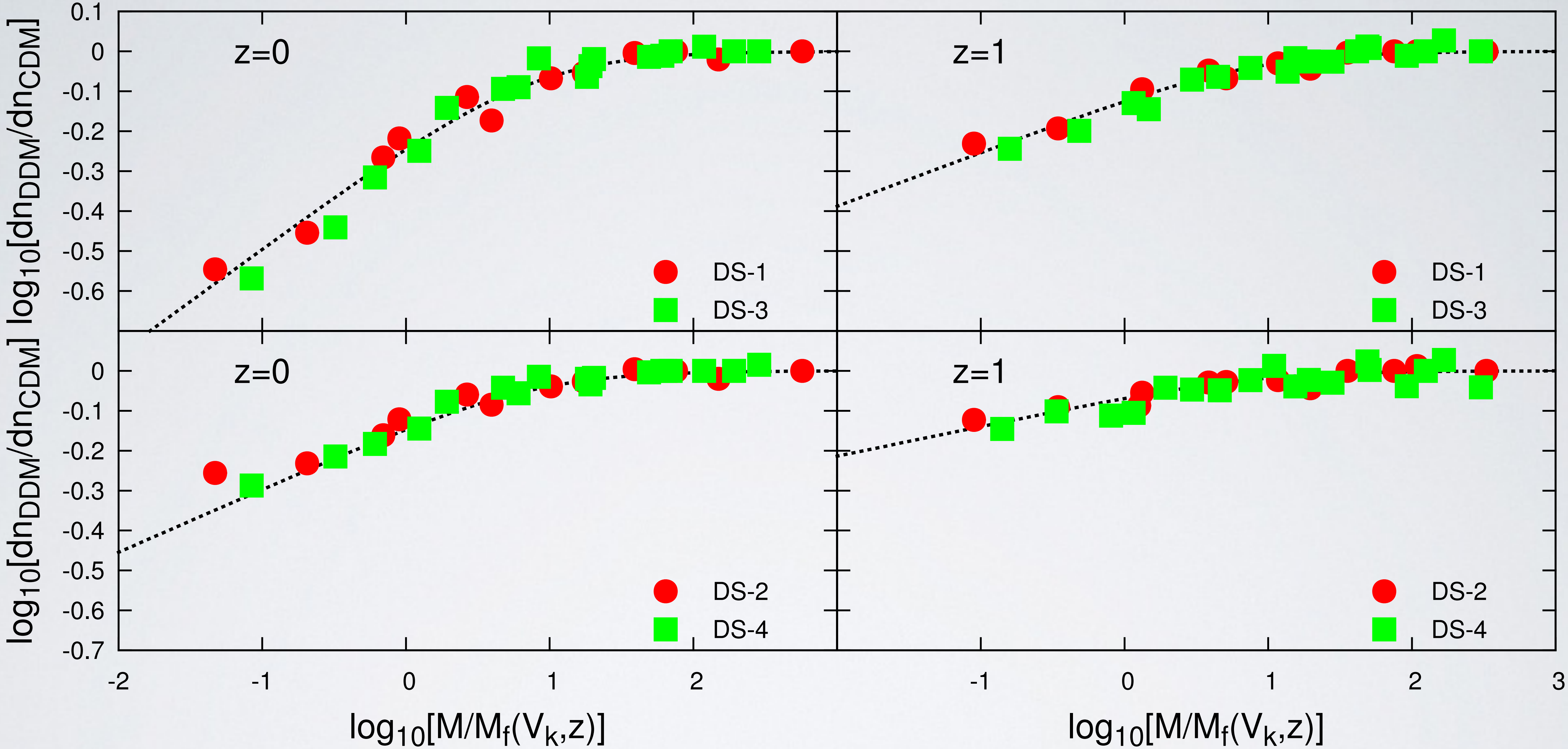


Label	τ[Gyr]	V_k[km/s]
DS-1	13.79	100
DS-2	26.80	100
DS-3	13.79	200
DS-3a	13.79	200
DS-3b	13.79	200
DS-4	26.80	200
DS-5	13.79	500
DS-6	26.80	500
DS-7	13.79	1000
DS-8	26.80	1000

The DDM effects are mixed with the non-linear effects of gravity

$$k_s \sim 1/l_{\max}(z)$$

Scaling laws of DDM MF and c-M relation:

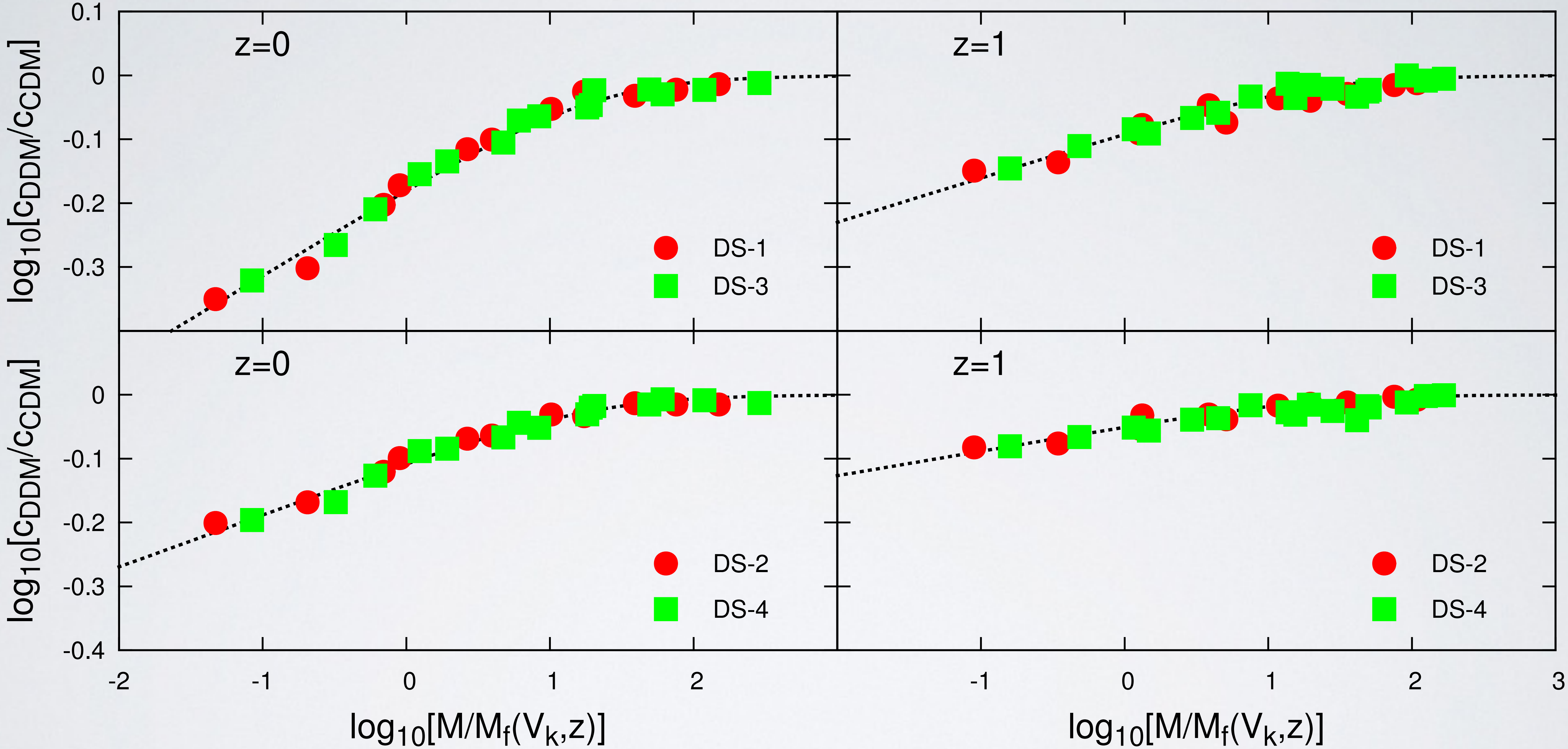


$$M_f \propto [1/k_s(V_k, z)]^3$$

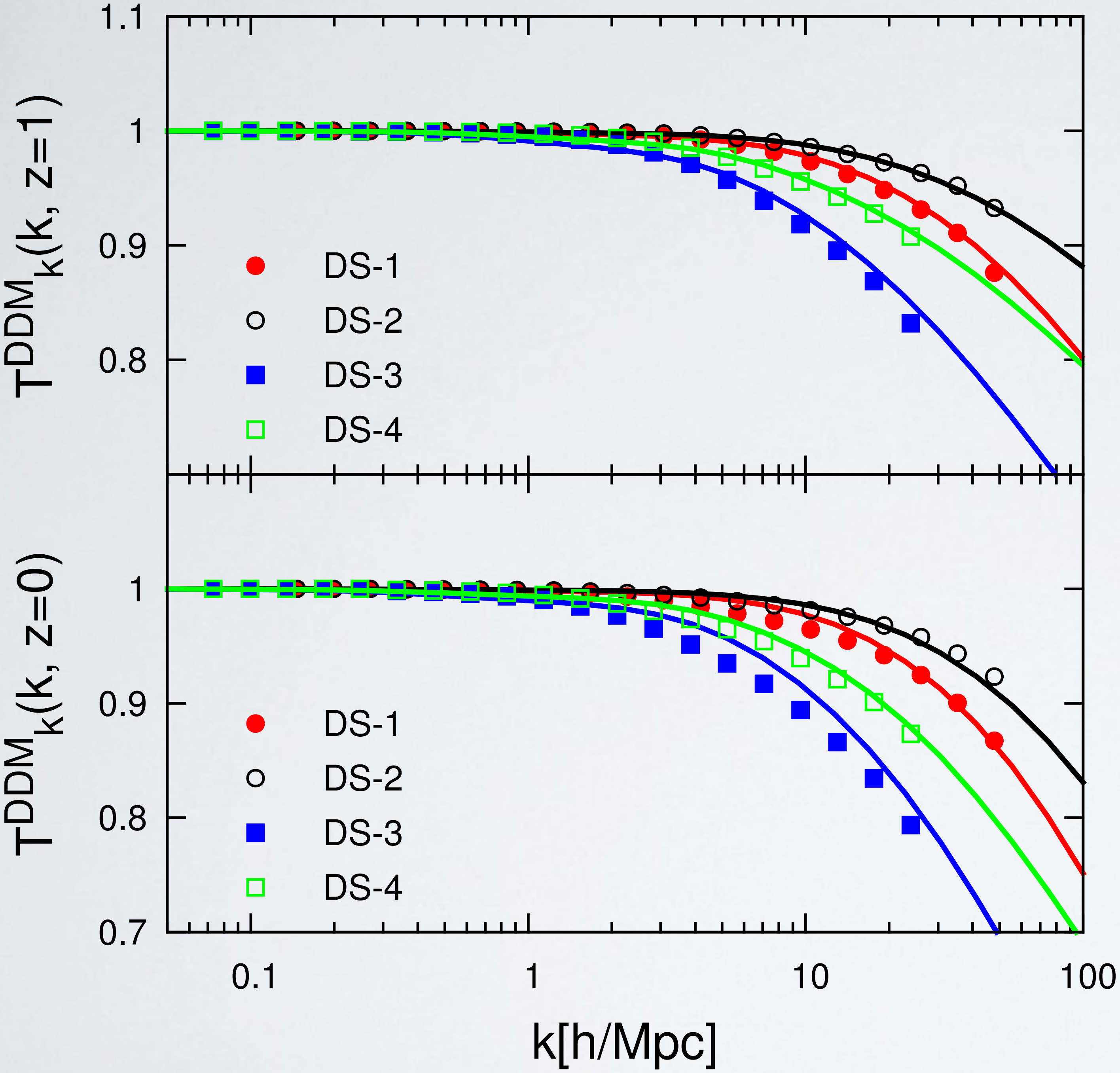
f_d: Decayed fraction

$$\frac{dn_{\rm DDM}(M,z)}{dn_{\rm CDM}(M,z)} = \left(1 + \beta \frac{M_f}{M}\right)^{-\alpha f_d}$$

Similar for c-M relation:



The PS:



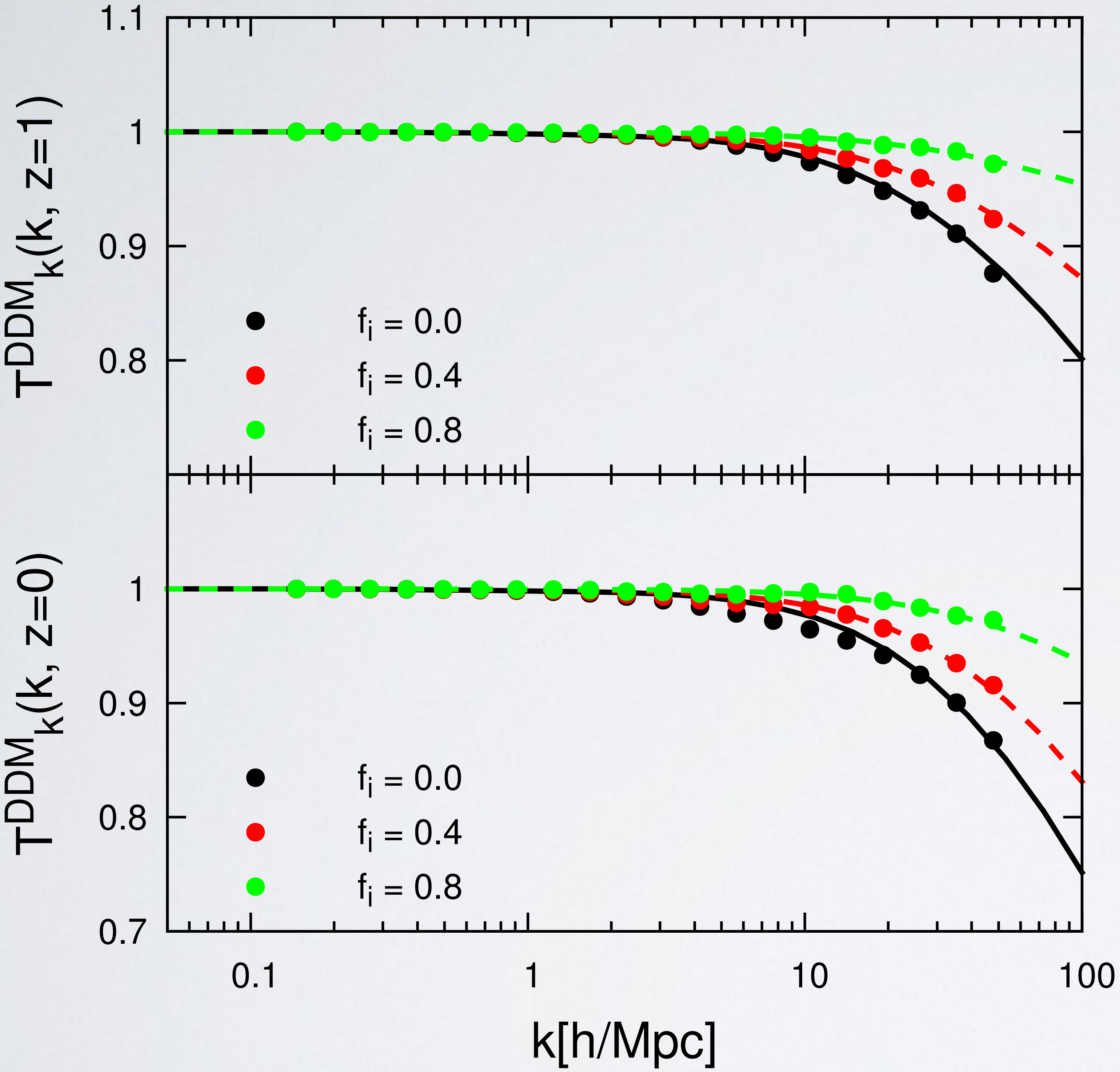
Reconstruct the PS with halo model with smooth component:

$$P_{\delta\delta}(k) = (1-f)^2 P_{ss}(k) + 2f(1-f)P_{sh}(k) + f^2 P_{hh}(k)$$

$$T_k^{\mathrm{DDM}}(k,z) = \sqrt{\frac{P_{\mathrm{DDM}}(k,z)}{P_{\mathrm{CDM}}(k,z)}}.$$

The modelling is accurate to percentage level on the non-linear scales, as function of the decay parameters and also redshfit.

$(\tau, V_k) \to (\tau, V_k | f_i)$



$$\tau \sim H_0^{-1}$$

(1) If $\tau \gg H_0^{-1}$

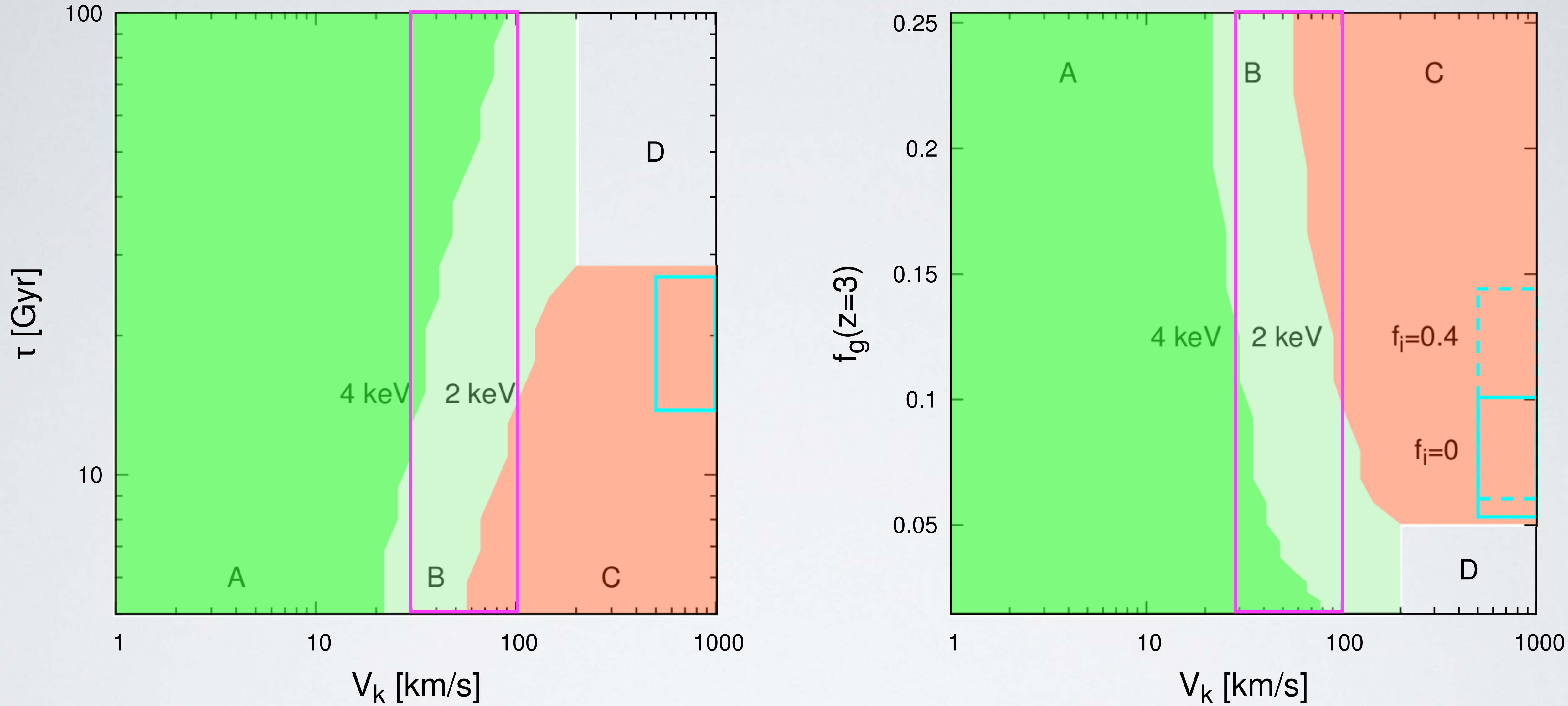
$$\tau_{\rm eff} = \frac{\tau}{1 - f_i}$$

(2) Other conditions, try a generalization

$$f_d \to f_g = (1 - f_i) f_d$$

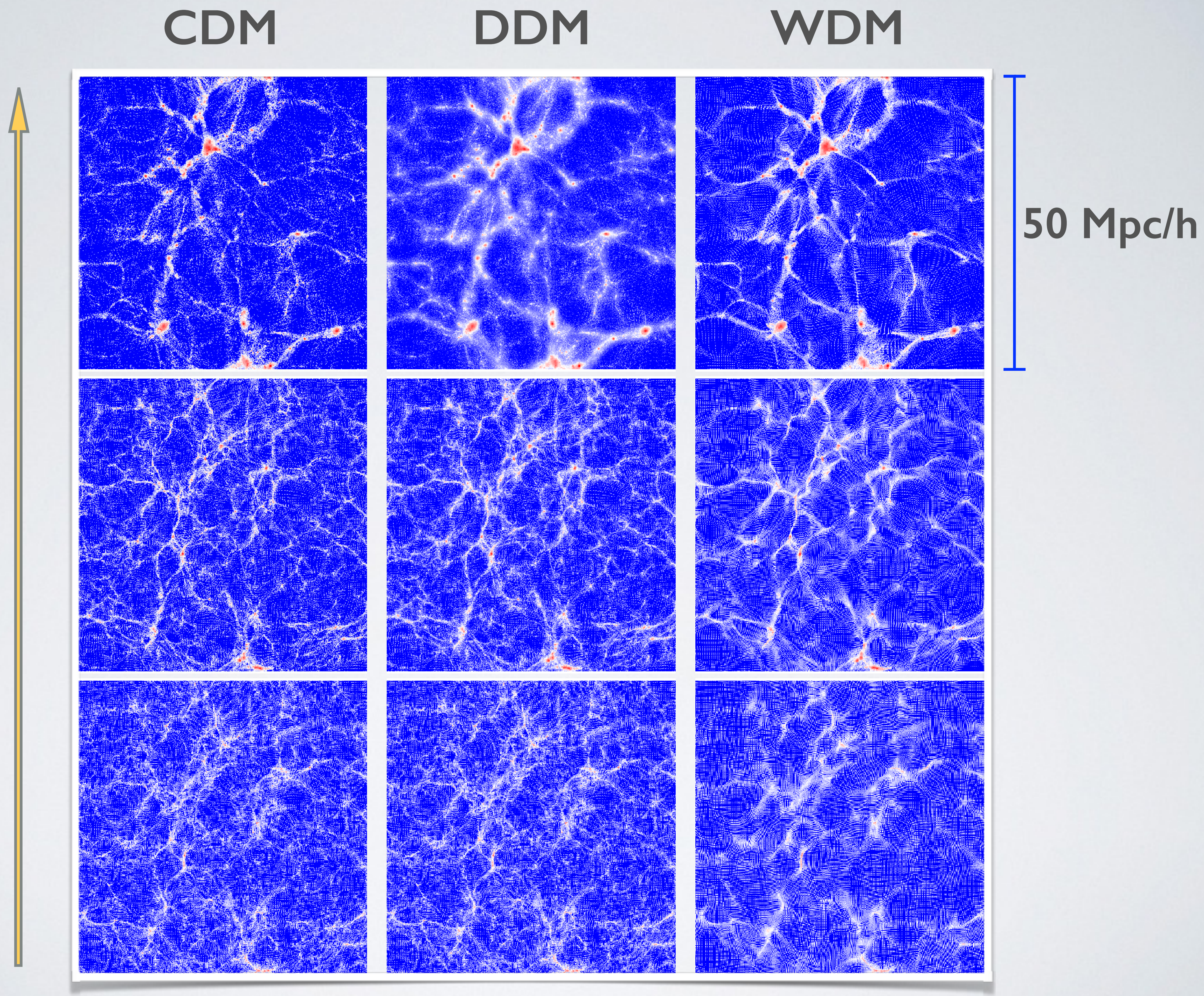
The previous result is valid even for the most generalized conditions.

The parameter space:

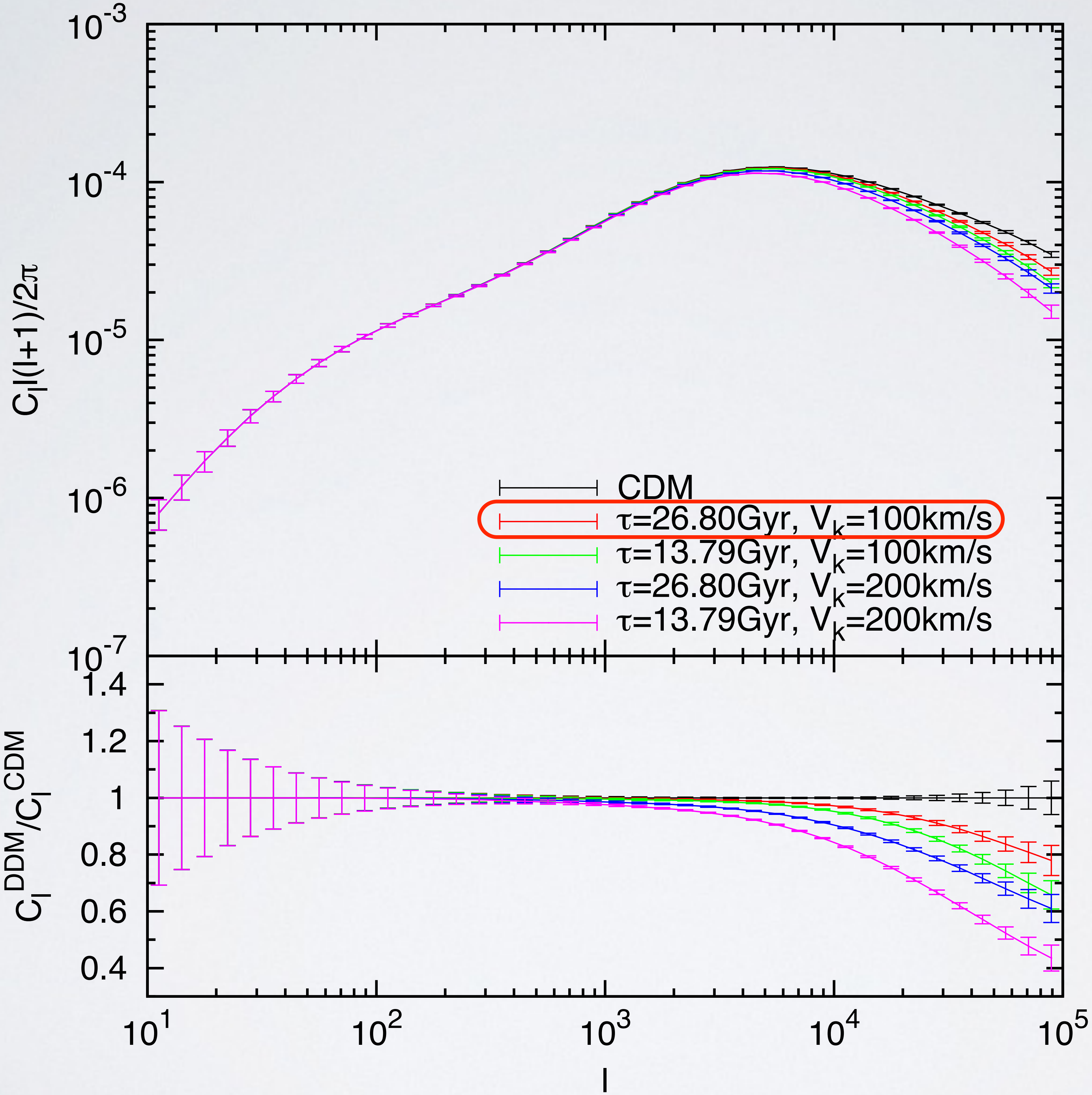


A parameter region can resolve the Planck CMB and SZ disagreement

A possible region to solve the "Too big to fail" problem of CDM

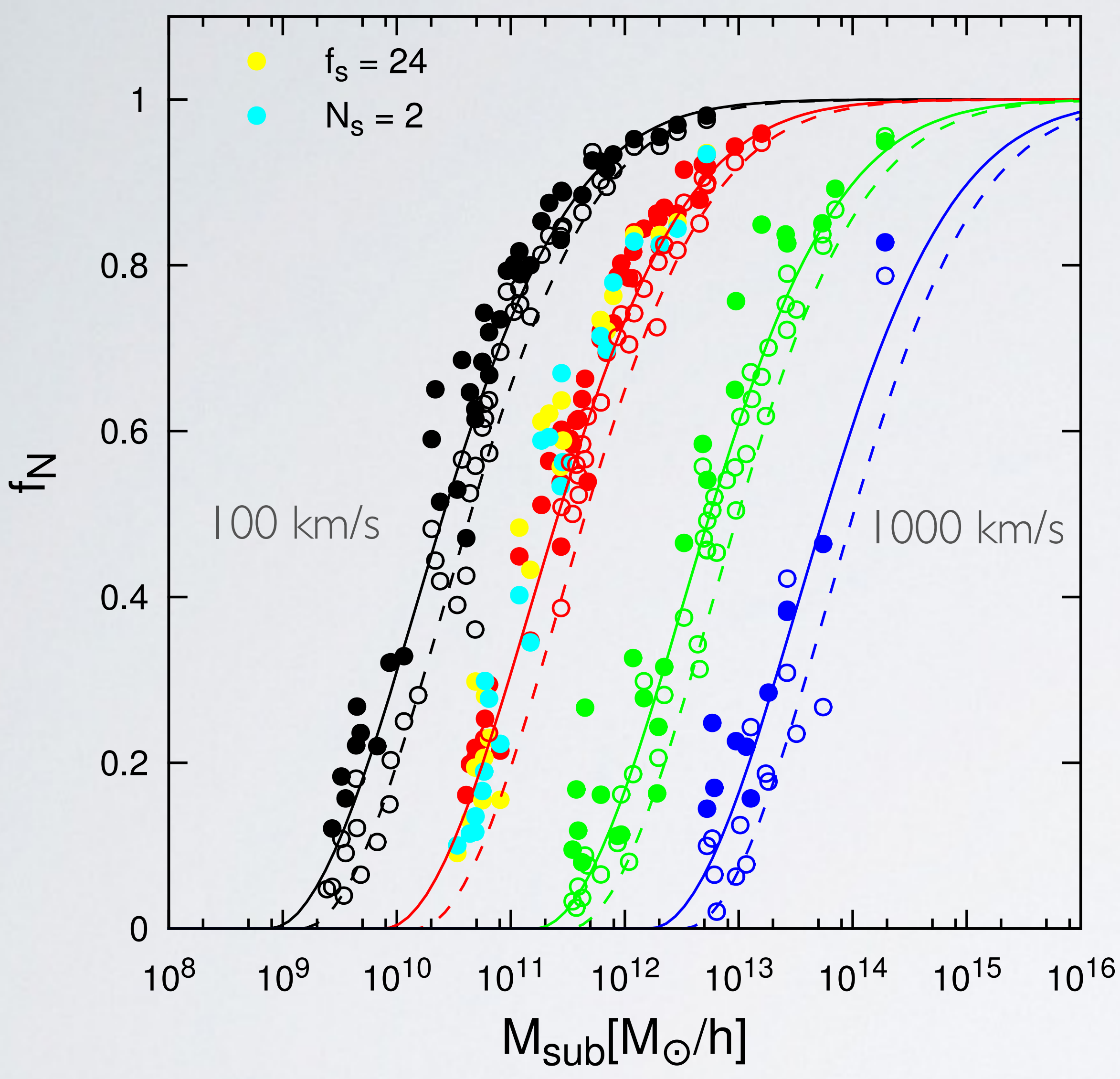

CDM
DDM
WDM
50 Mpc/h

Observation signatures:

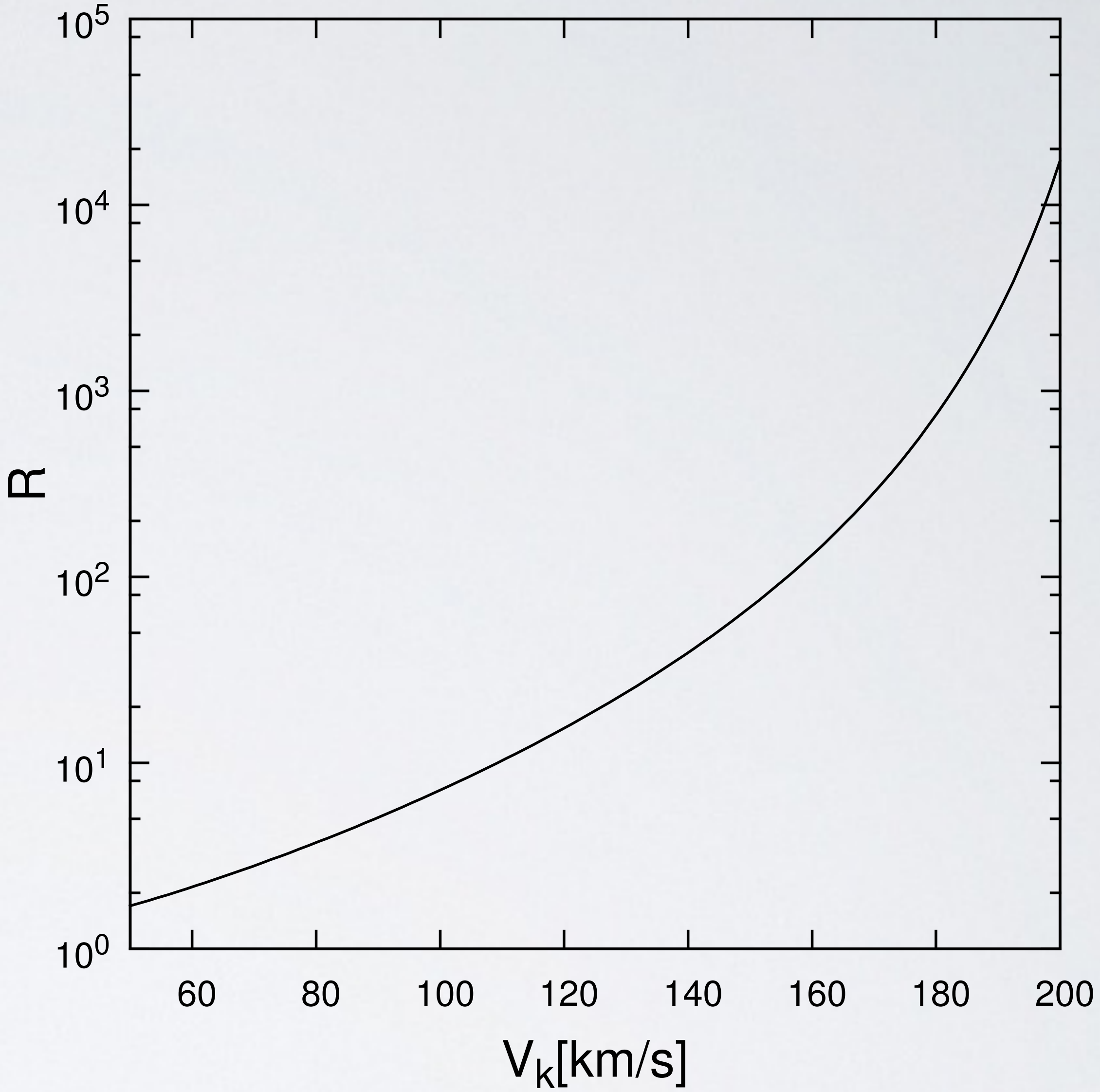


Eculid & LSST

Dark matter in-direct detections:



Fraction distribution of daughters



Raise factor of MW dwarf constraints

PAMELA/AMS: boost the annihilation cross section to explain the positron excess.

Gamma rays independently constraint this scenario

SUMMARY

- Numerical (Cosmological DDM N-body simulation, MF, CM, daughter fractions)
- Analytic (Models to capture the non-linear effects, even to generalized conditions, constraints on the parameter space.)
- Implementations(Weak lensing, dark matter in-direct detections, resolve CDM problems…)