Non-Abelian dark matter and large scale structure

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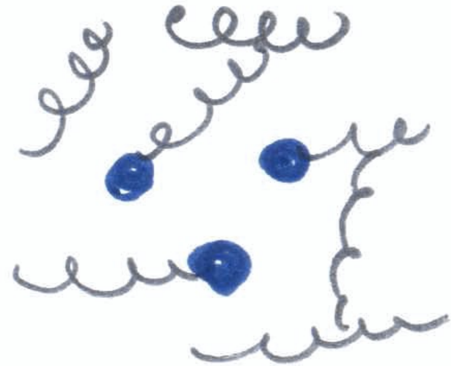
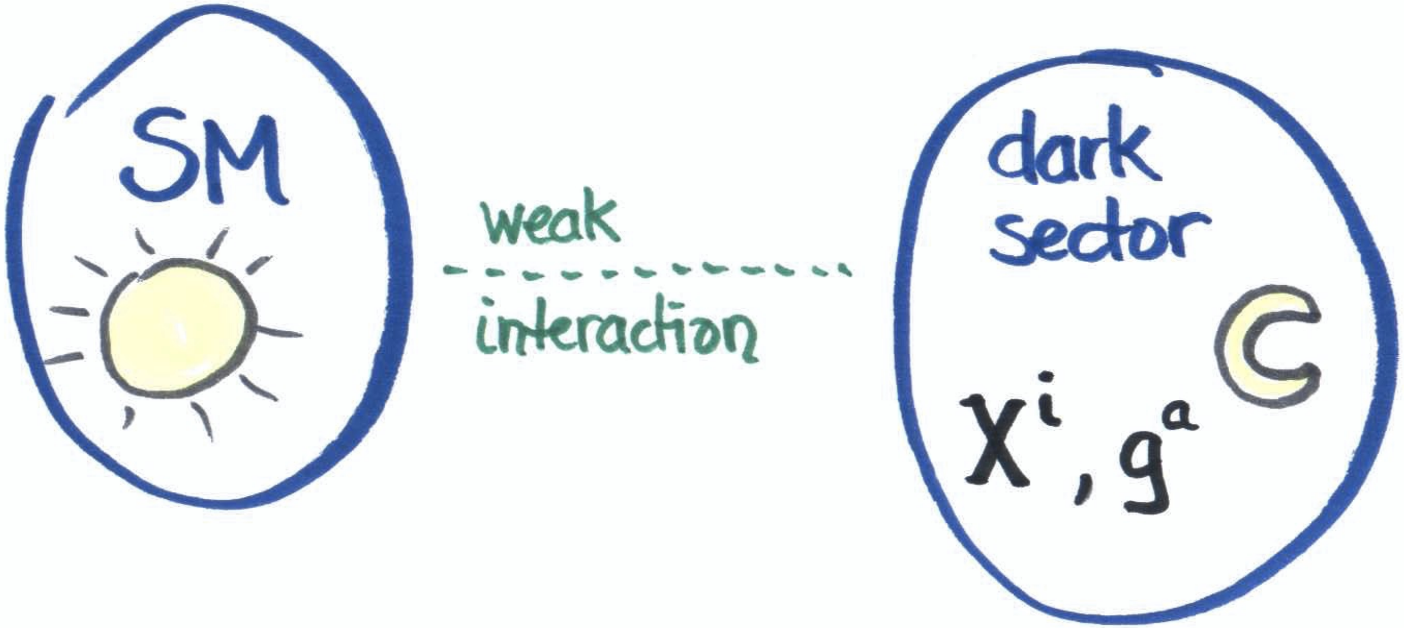


1505.03542

1507.04351

Dark matter with multiplicity



$i = 1 \ldots N$

$a = 1 \ldots N^2 - 1$

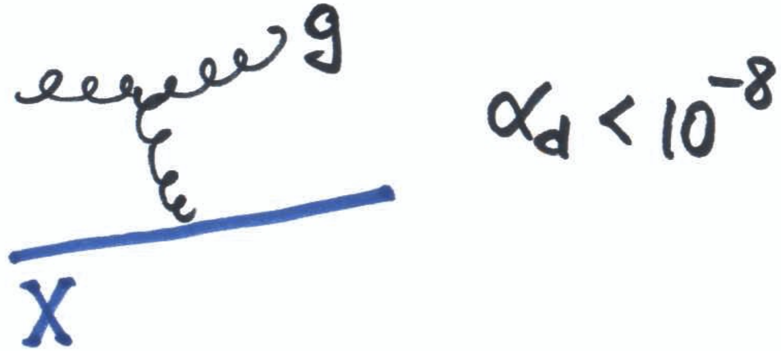
$\alpha_d \sim 10^{-8}$

3 short stories:

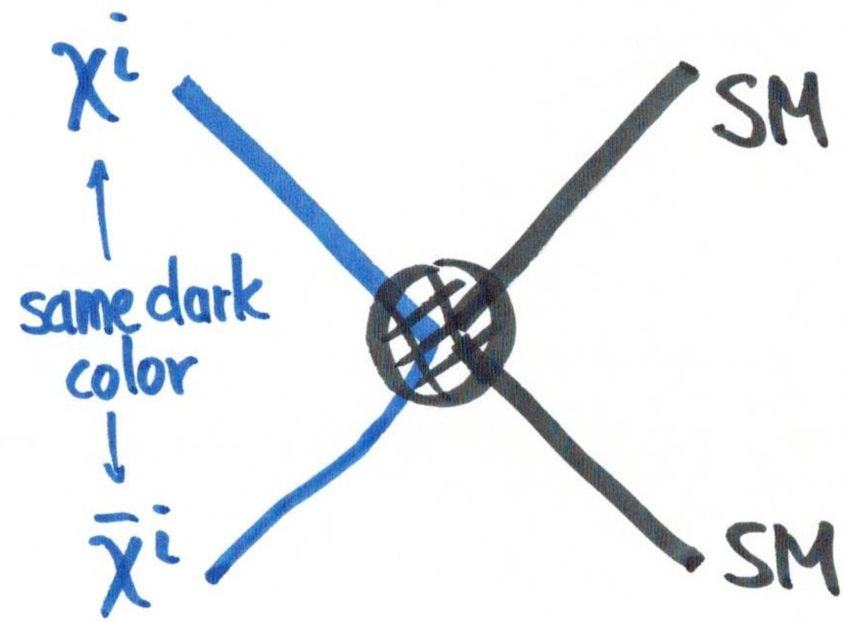
1. X^i multiplicity factors

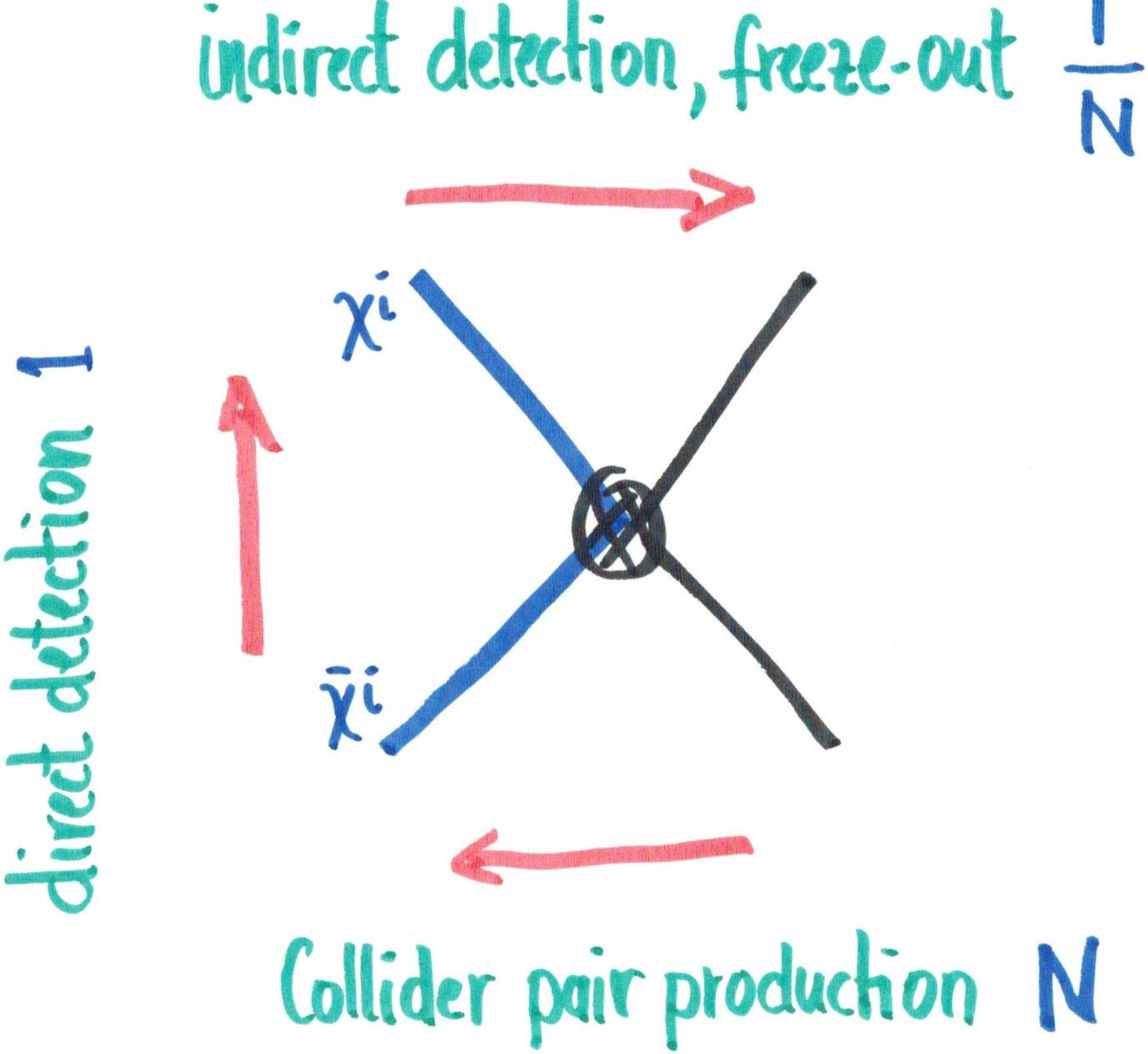
2. g^a dark radiation

3. dark matter drag



1. dark matter multiplicity




indirect detection, freeze-out $\frac{1}{N}$
χ^i
$\bar{\chi}^i$
direct detection 1
Collider pair production N

Example: multiple "winos"

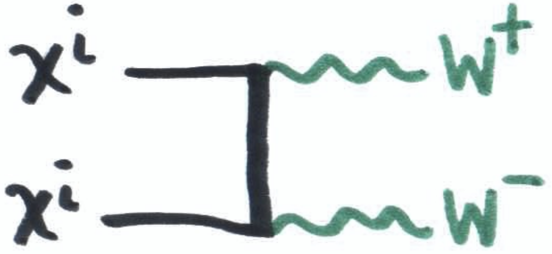
$SU(2)_W$ triplet $\longrightarrow$ $\chi^{\pm i}$ —— } 160 MeV
χ^{0i} ——

$\sim$ TeV Dirac mass $\quad m\bar{\chi}\chi$

χ^{0i} = dark matter

DM abundance

$$\Omega_{DM} \sim 1/\langle \sigma v \rangle$$

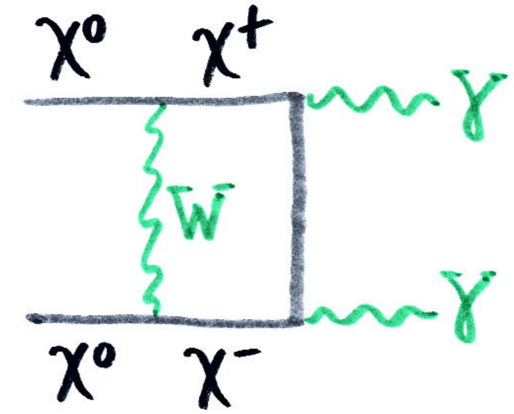


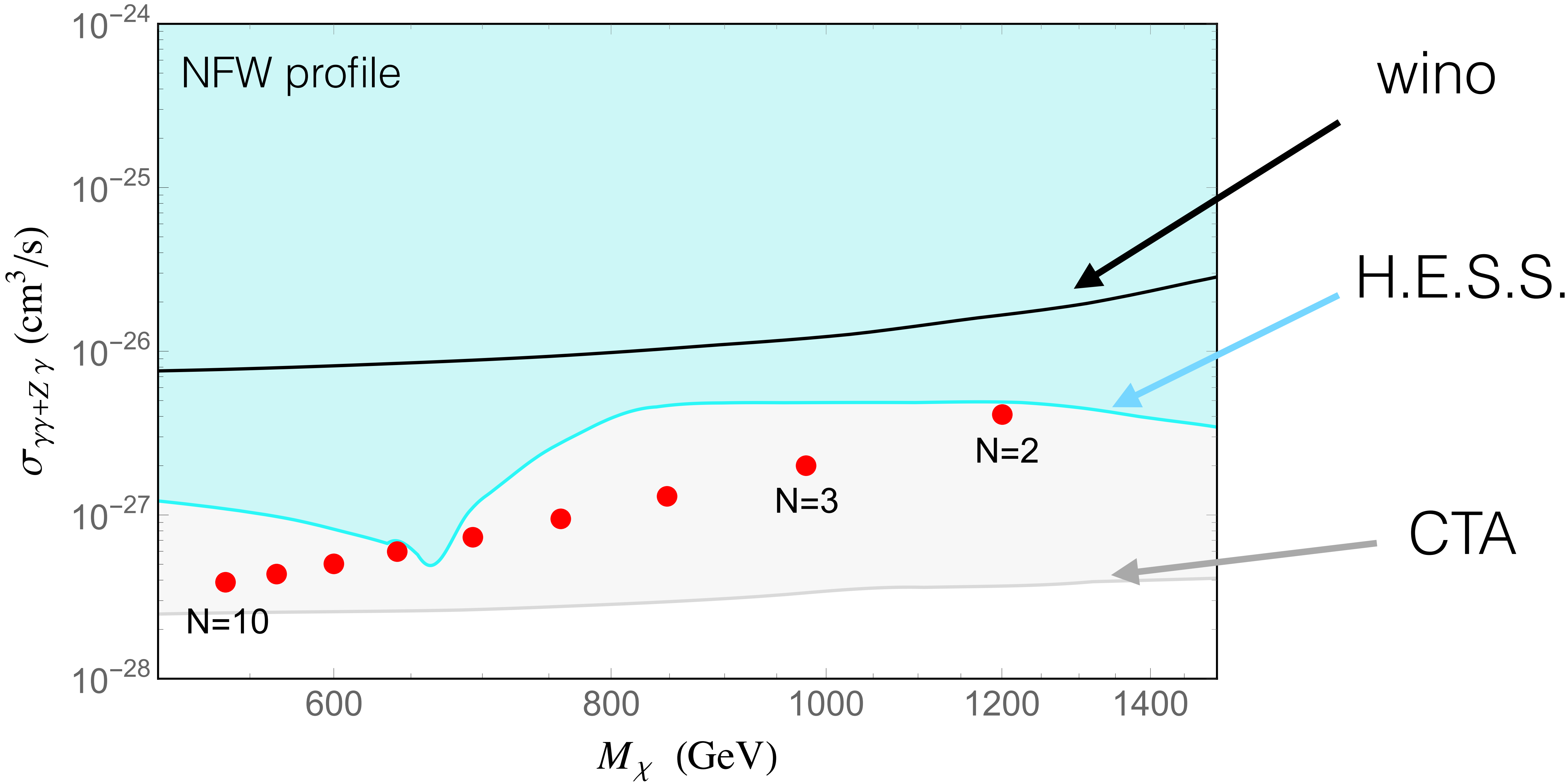
$$\langle \sigma v \rangle \sim \frac{1}{2N} \frac{\alpha_w^2}{M_\chi^2}$$

Dirac Color

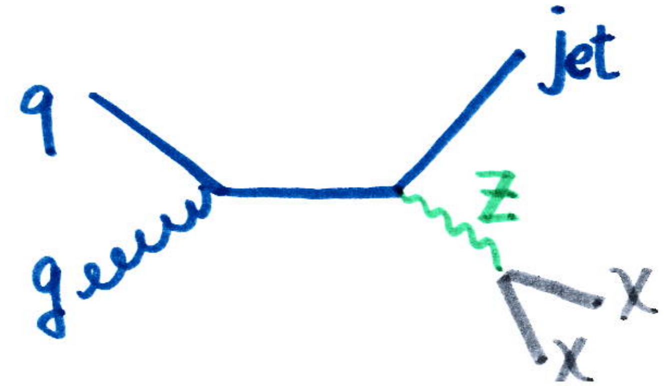
$$\Longrightarrow \quad M_\chi = M_\chi^{N=1} / \sqrt{2N}$$

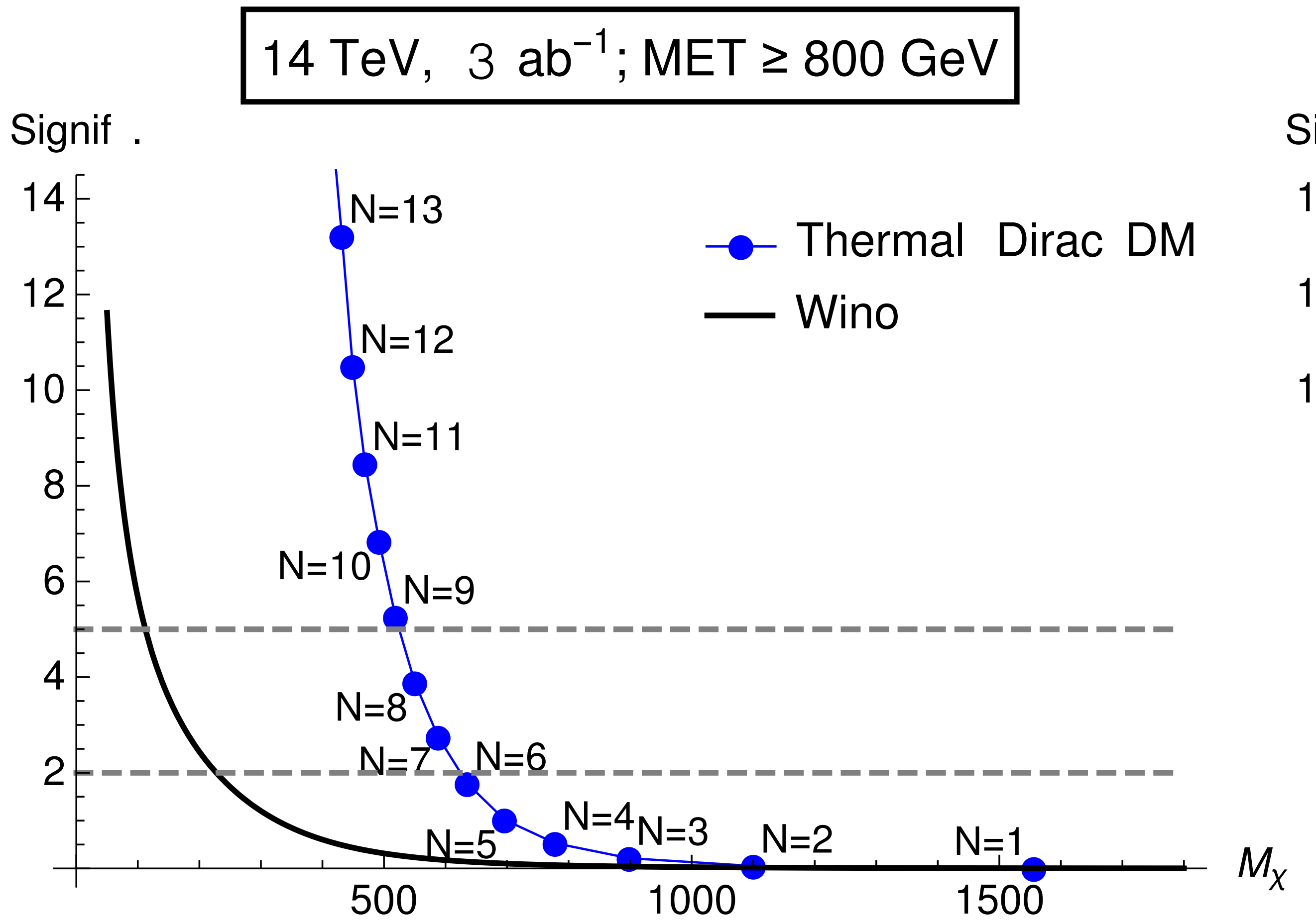
Indirect detection



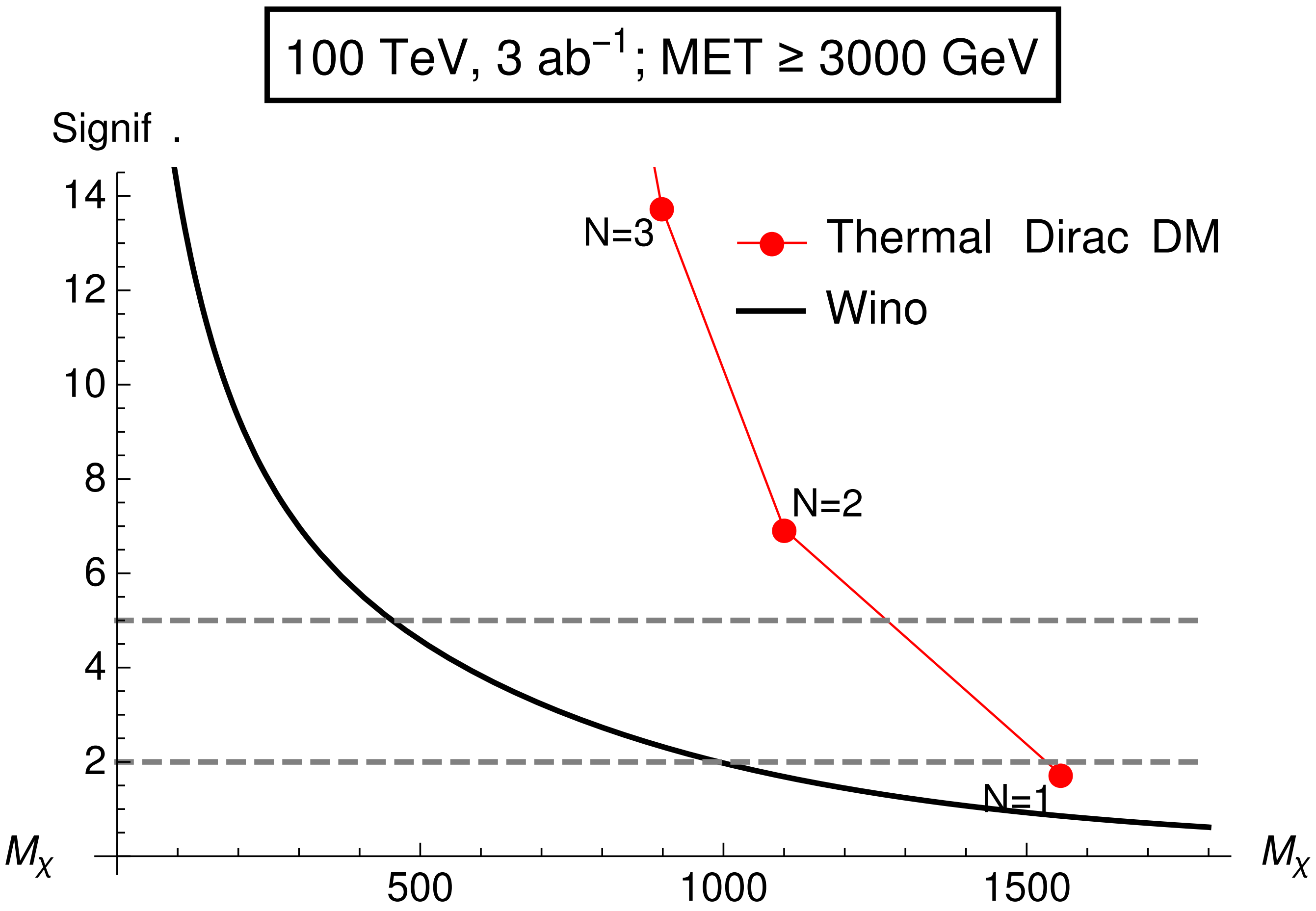


Colliders: mono-jets





HL-LHC



100 TeV

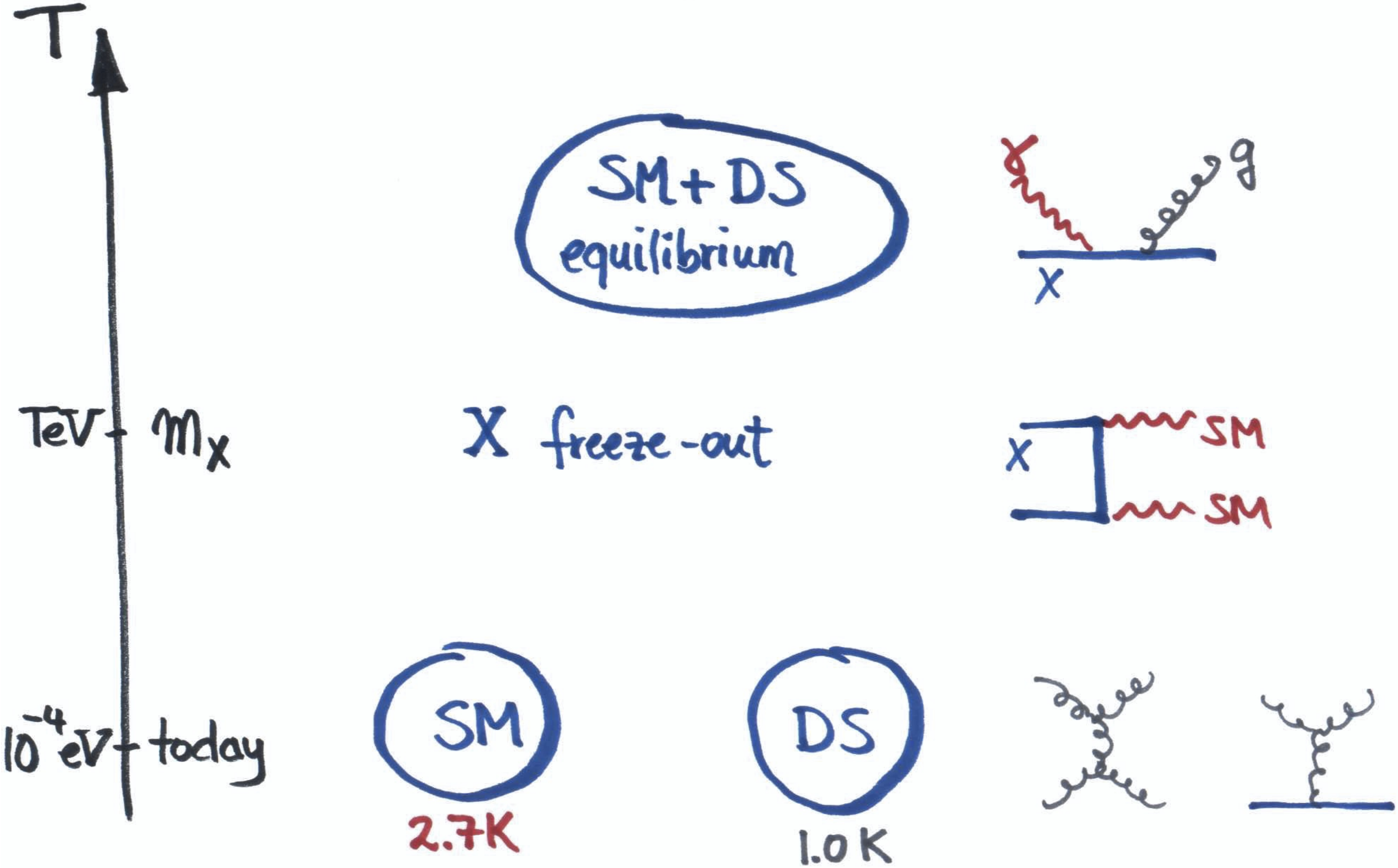
Cosmology for model builders

to decide if a process is important compare

$$\Gamma_{\text{process}} \quad \text{vs.} \quad H_{\text{ubble}}$$

$$\Gamma_{\text{process}} \leftarrow n \langle \sigma v \rangle \qquad H_{\text{ubble}} \leftarrow \frac{T^2}{M_{pl}}$$

Thermal history



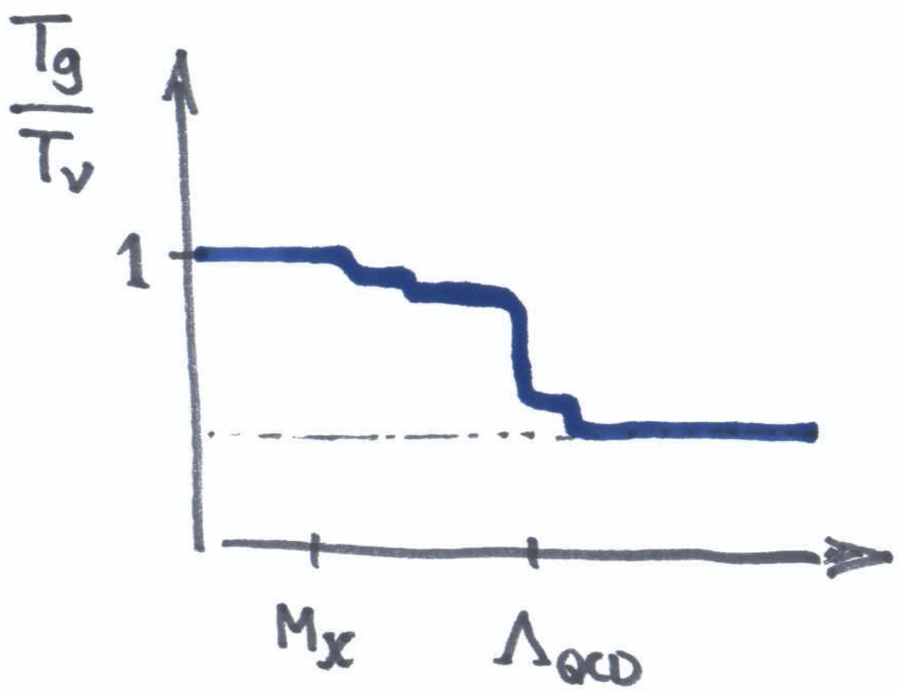
2. dark radiation, ΔN_{eff}

energy density in dark gluons?

$$\rho_g \sim (N^2-1)\, T_g^4$$

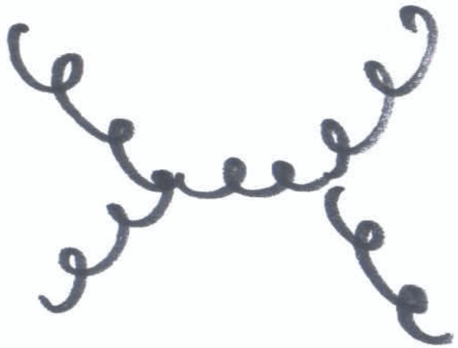
$$\equiv (N^2-1)\, \underbrace{\frac{T_g^4}{T_\nu^4}}\, T_\nu^4$$

$$\equiv \Delta N_{eff} \sim \frac{N^2-1}{16.4}$$



→ CMB : N = 2, 3

important difference to ν's : g selfinteractions

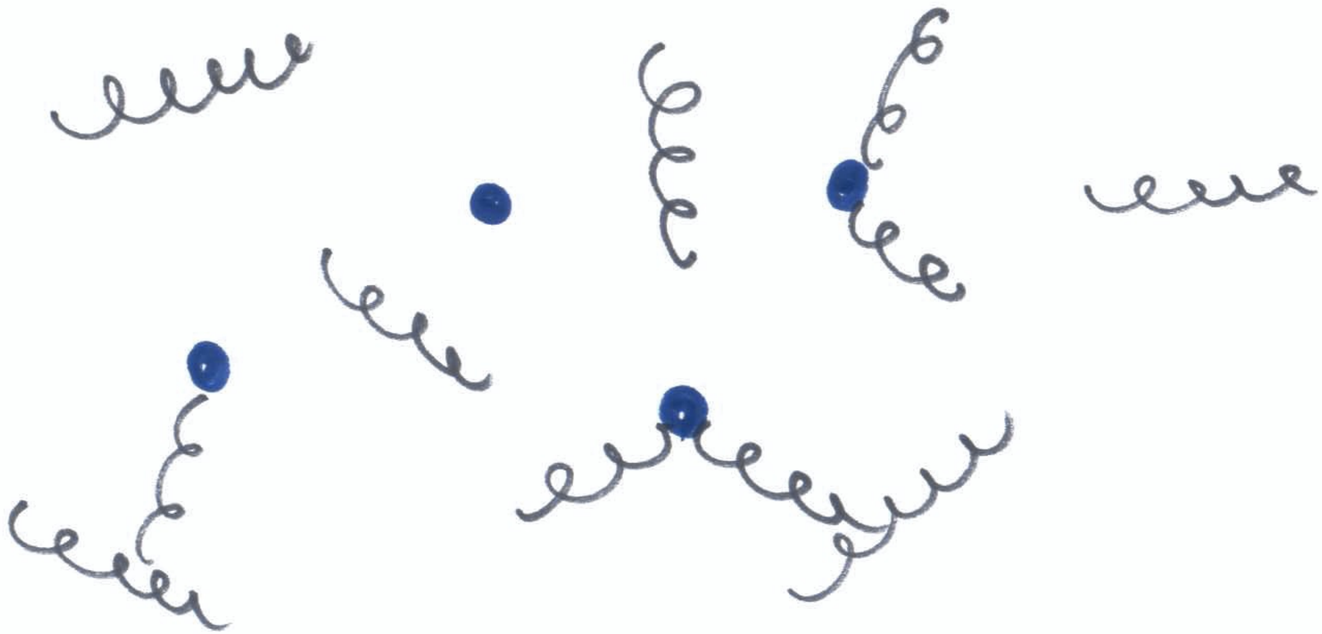


rate $\Gamma \sim \alpha_d^2 T \gg H$

dark gluons do not free-stream → "perfect fluid"

CMB can distinguish !

3. dark matter - dark radiation coupling



weakly coupled fluids. Jmpact on structure formation?

dark matter "drag"

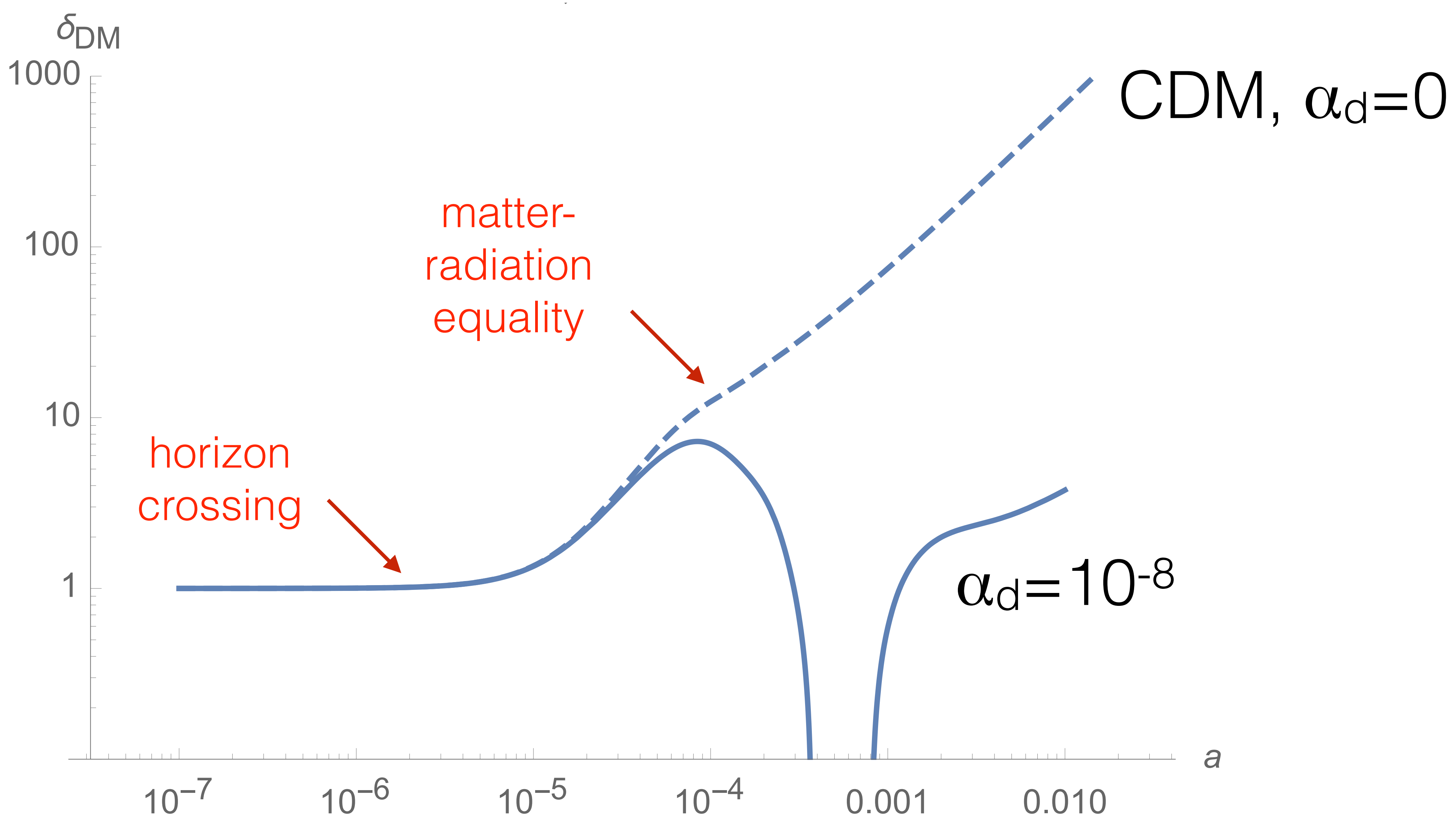
$$\Gamma_p \equiv \frac{\dot{p}}{p} = -\alpha_d^2 \log \alpha_d^{-1} \frac{T_d^2}{M_X}$$

Same scaling as Hubble!

"drag" inhibits growth of DM density perturbations

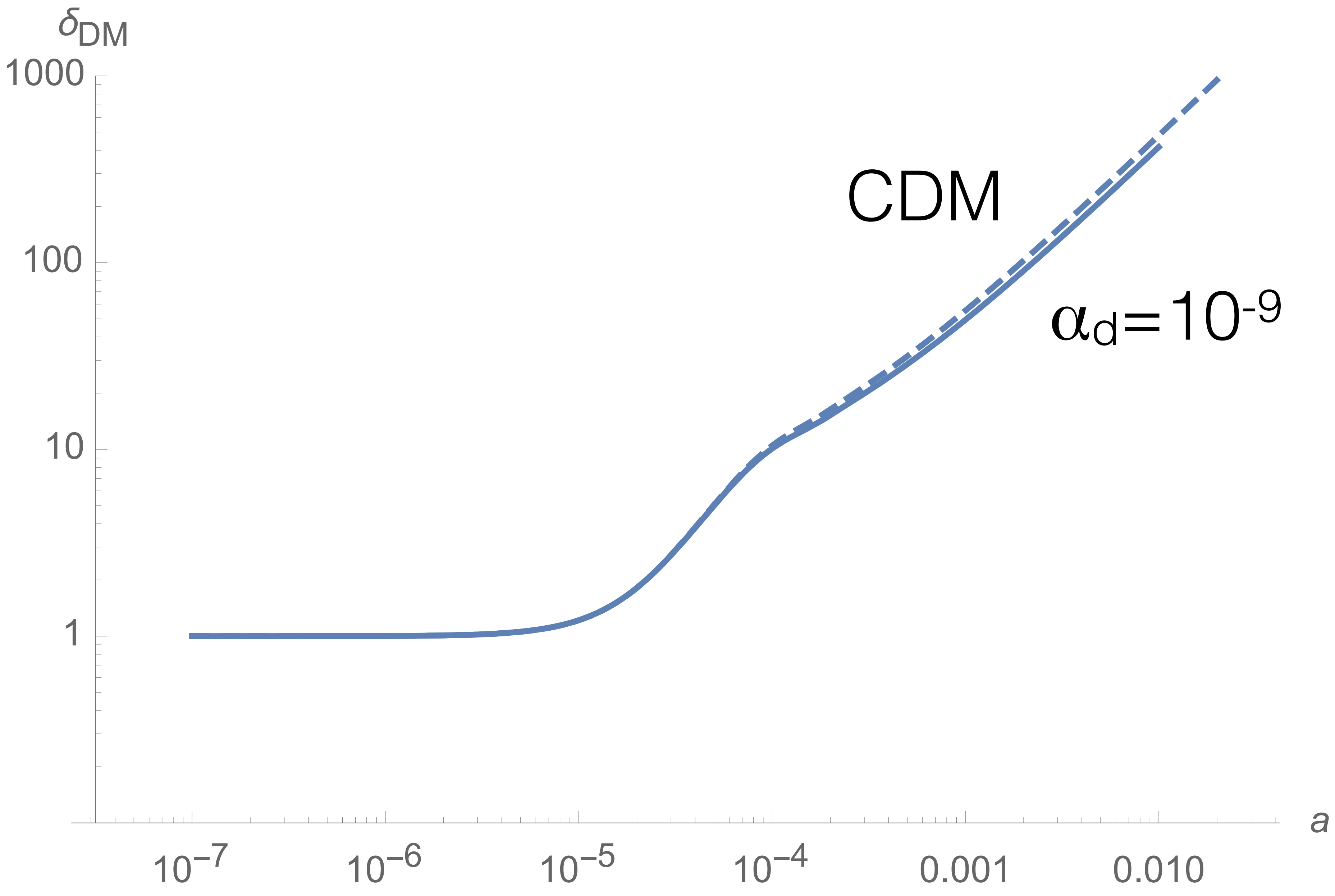
growth of perturbations

$k = 0.2\ \mathrm{Mpc}^{-1}$

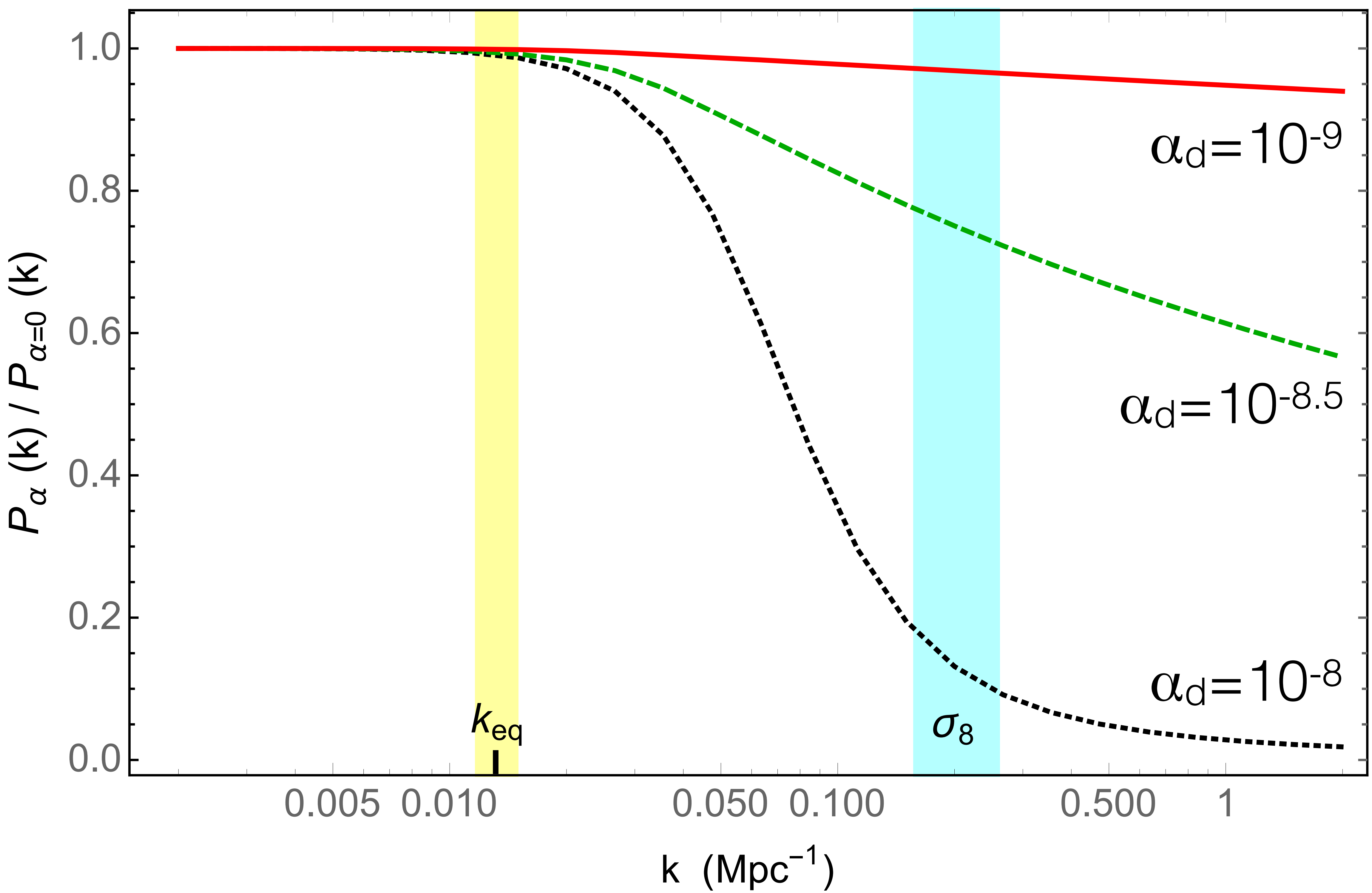


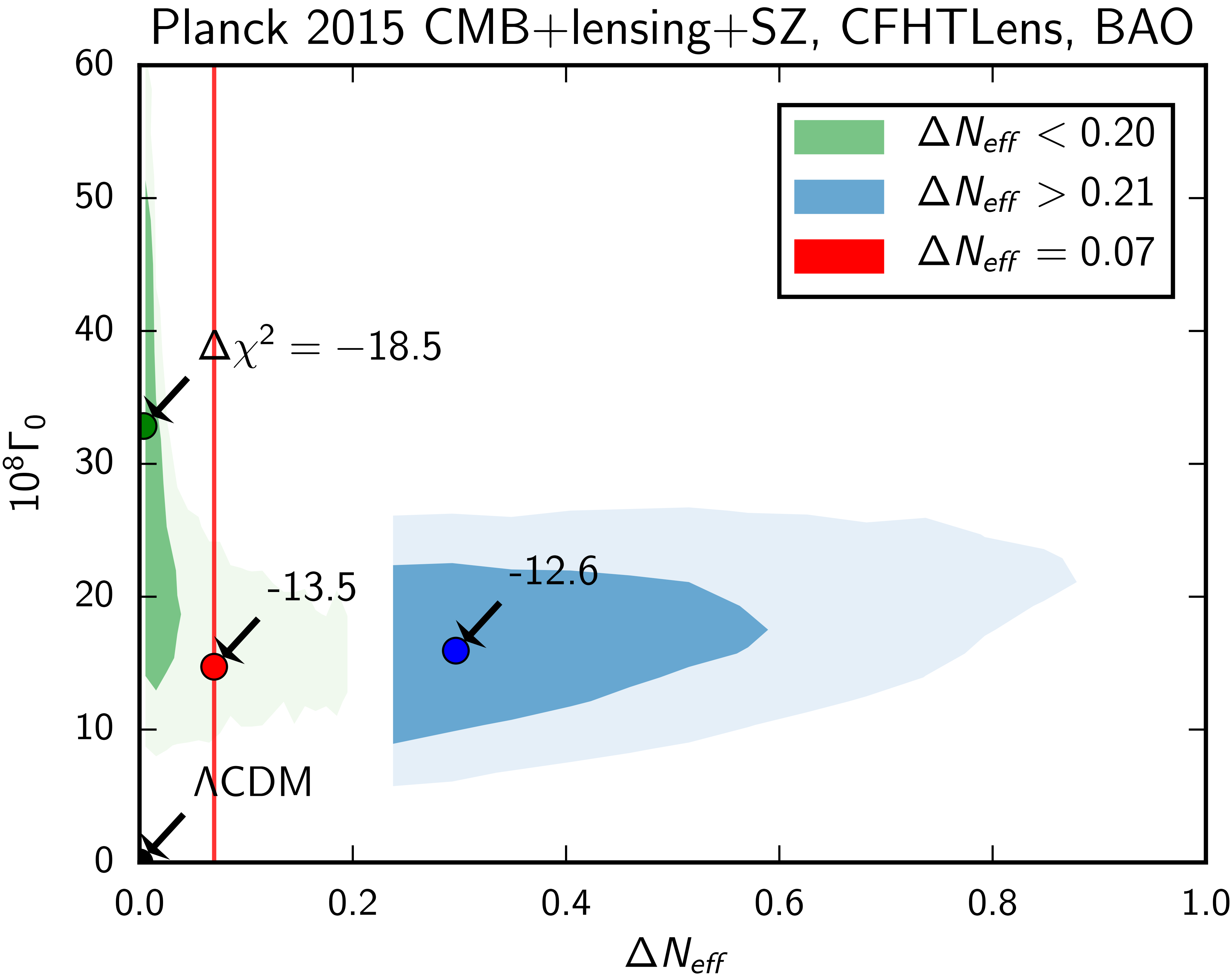
growth of perturbations

k=0.2 Mpc^{-1}

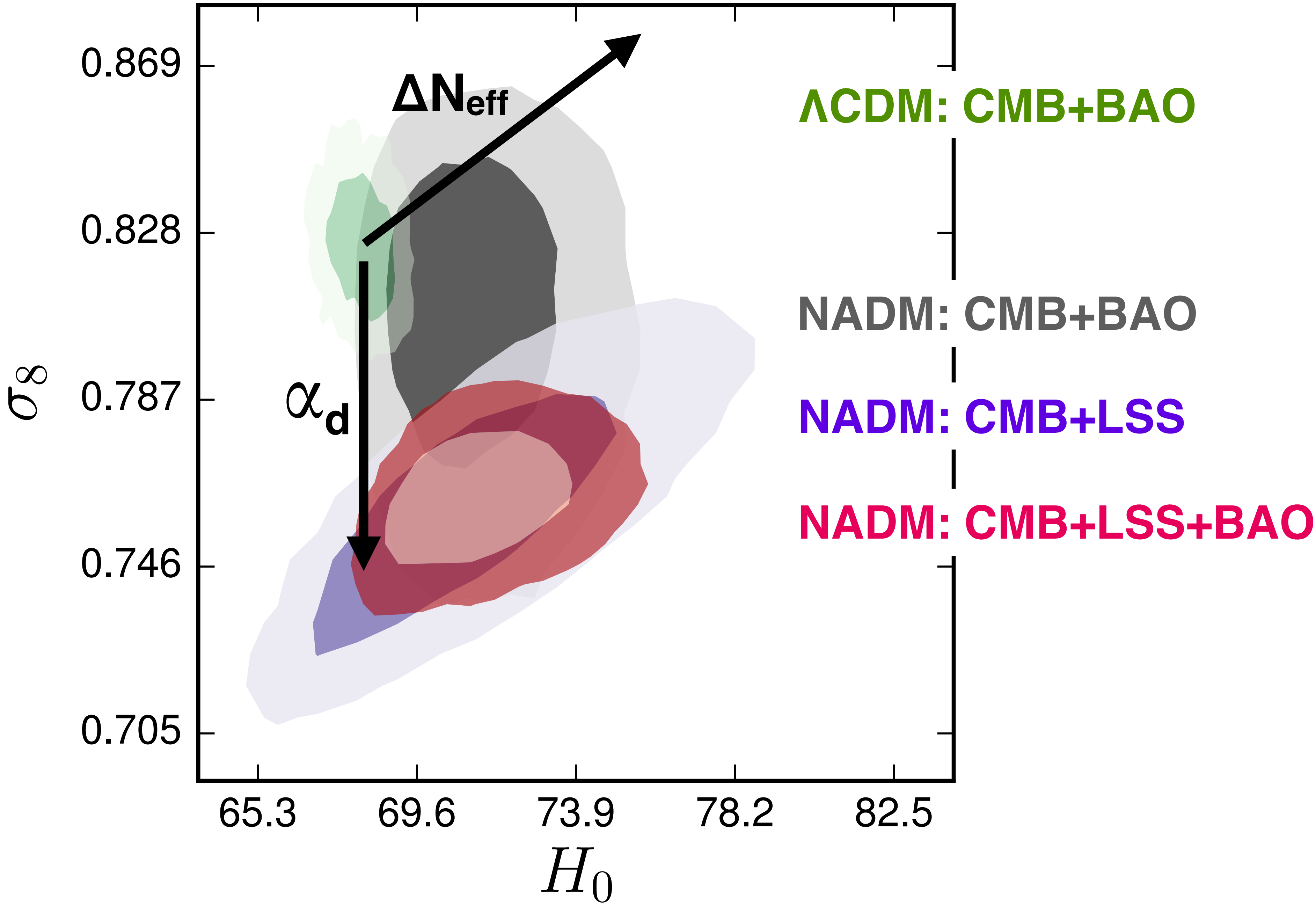


power spectrum change





Planck 2015 CMB+lensing+SZ, CFHTLens, BAO
$\Delta N_{eff} < 0.20$
$\Delta N_{eff} > 0.21$
$\Delta N_{eff} = 0.07$
$\Delta\chi^2 = -18.5$
-13.5
-12.6
ΛCDM
$10^8\Gamma_0$
ΔN_{eff}
0
10
20
30
40
50
60
0.0
0.2
0.4
0.6
0.8
1.0



0.869
0.828
0.787
0.746
0.705
σ_8
65.3
69.6
73.9
78.2
82.5
H_0
ΔN_{eff}
α_d
ΛCDM: CMB+BAO
NADM: CMB+BAO
NADM: CMB+LSS
NADM: CMB+LSS+BAO

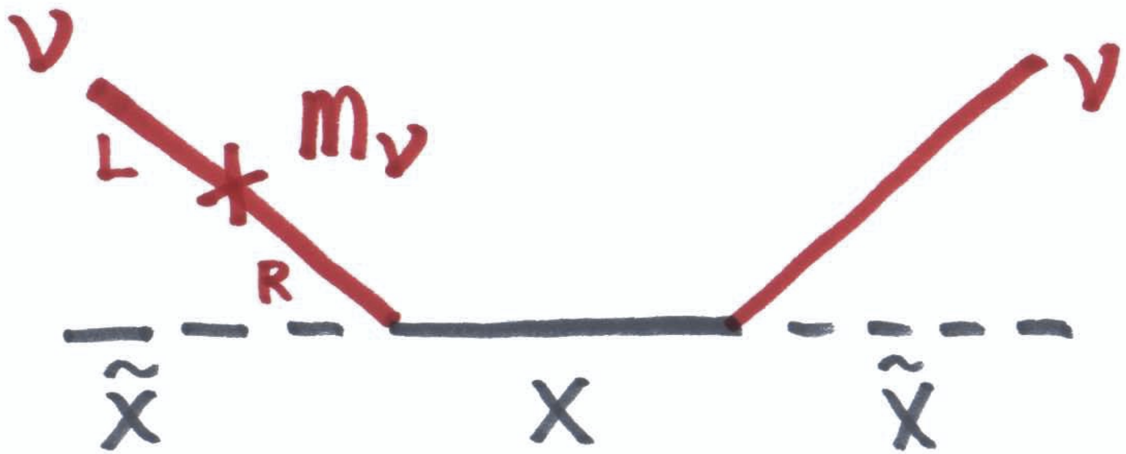
Summary: 3 stories

1. dark matter multiplicity → N-factors

2. self-interacting radiation ΔN_{eff}, 

3. LSS prefers DM drag $> 3\sigma$

dark matter–neutrino "drag"?



$$\sim \left(\frac{m_\nu}{M_X}\right)^2 \alpha^2 \; \frac{T_\nu^2}{M_X}$$

back up!

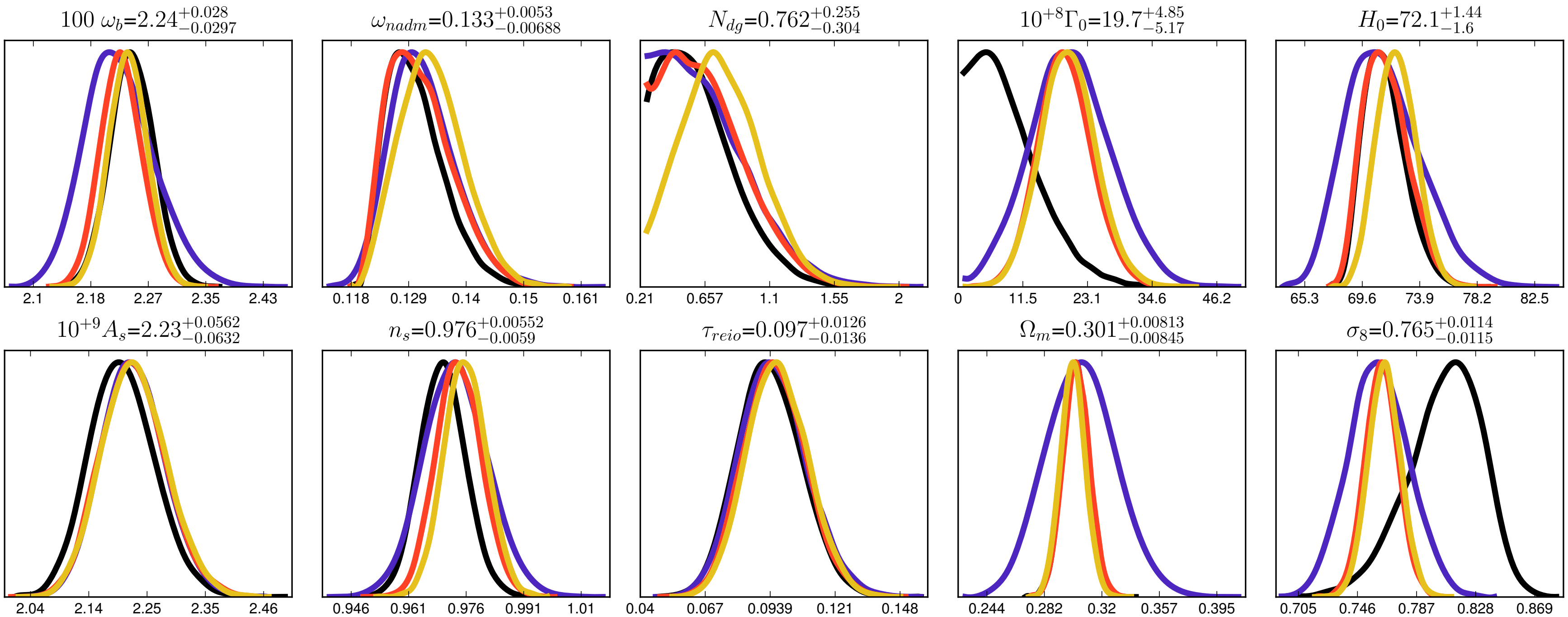


FIG. 5: Posterior probabilities for the eight parameters forming the basis of our model and for two derived parameters (Ω_m, σ_8), for CMB data combined with BAOs (black), LSS (blue), BAO+LSS (red), BAO+LSS+H_0 (yellow). See the text for details on parameter definitions and units, and for the precise content of each dataset.

linear perturbations in fluids

δ density pert.

θ velocity pert.

⋮

DM, DR, SM

↓

γ, ν, B

linear perturbations

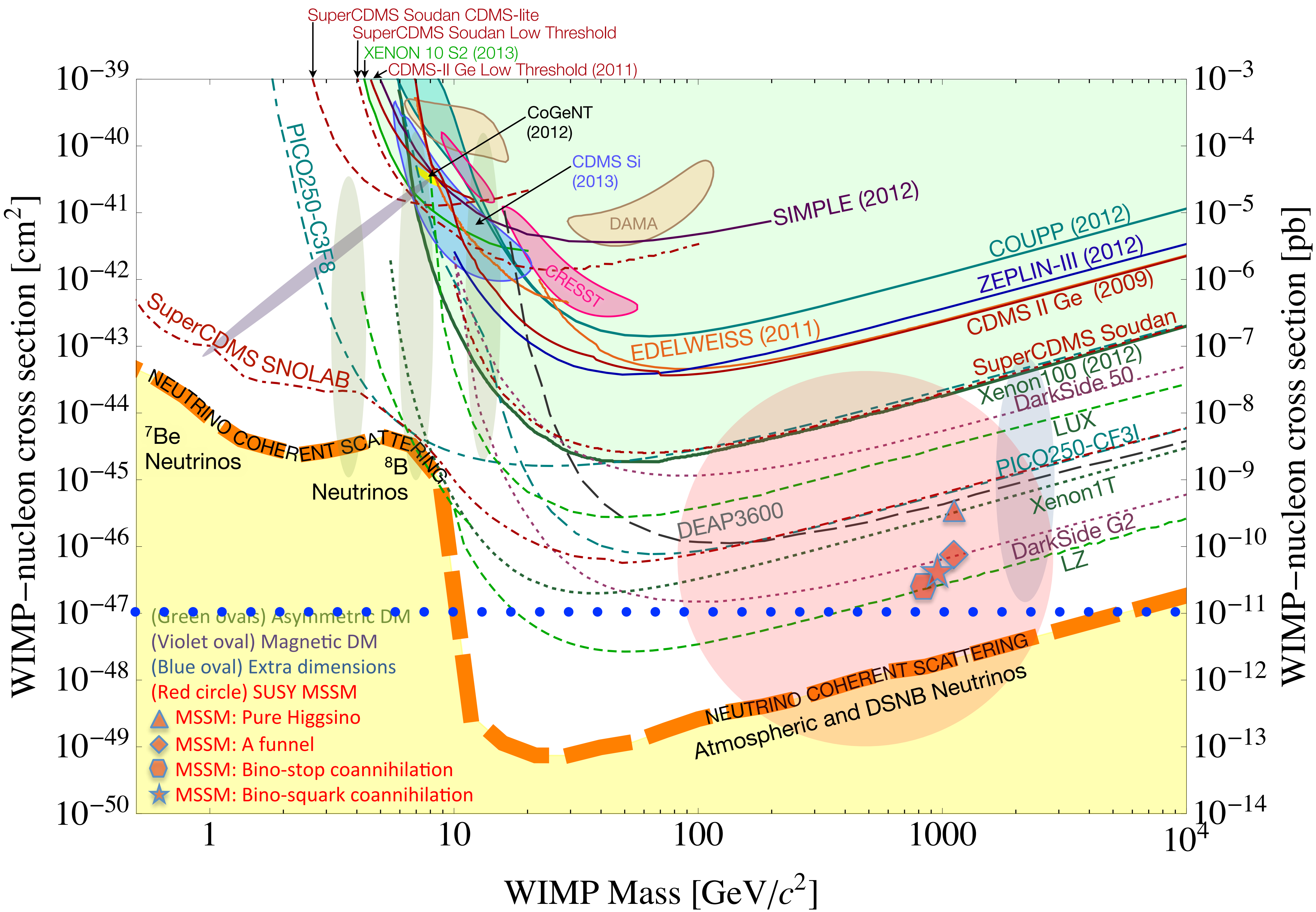
$$\dot{\delta}_{DM} = -\theta_{DM} + 3\dot{\psi}$$

$$\dot{\theta}_{DM} = -\frac{\dot{a}}{a}\theta_{DM} + a\mathbf{\Gamma}_V(\theta_{DR} - \theta_{DM}) + k^2\psi$$

$$\dot{\delta}_{DR} = -\frac{4}{3}\theta_{DR} + 4\dot{\psi}$$

$$\dot{\theta}_{DR} = k^2\frac{\delta_{DR}}{4} + k^2\psi + \frac{3}{4}\frac{\rho_{DM}}{\rho_{DR}}a\mathbf{\Gamma}_V(\theta_{DM} - \theta_{DR})$$

$$\sigma_{SI} = 1.3 \times 10^{-47}\ \text{cm}^2$$



Snowmass CF1 Summary: WIMP Dark Matter Direct Detection arxiv:1310.8327