Oscillating Composite Asymmetric Dark Matter

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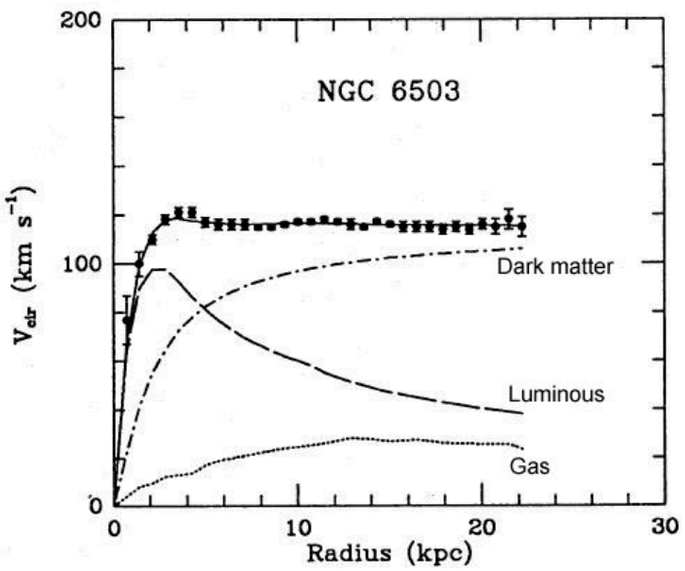
Talk plan

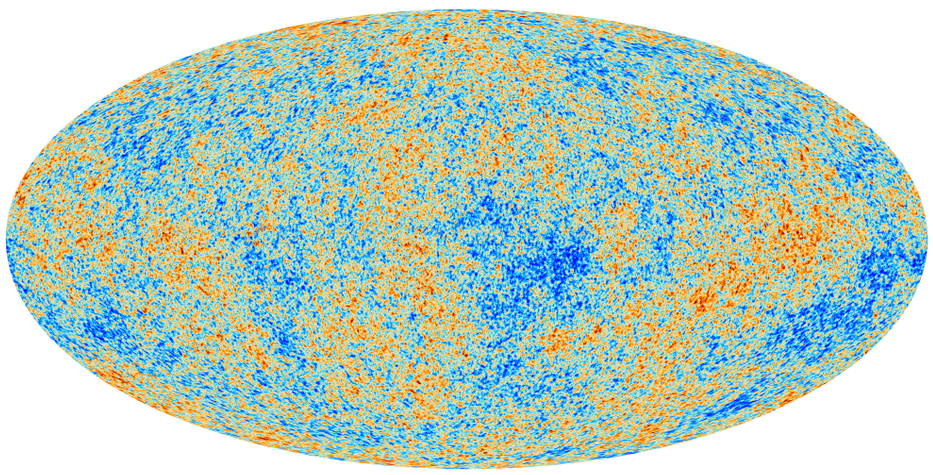
- Intro: ADM hypothesis
- Composite ADM model
- Phenomenology
- Summary

Dark Matter



Begeman et. al. (1991)

Clowe et. al. (2006)



Plank (2013)

“Cosmic Pie”

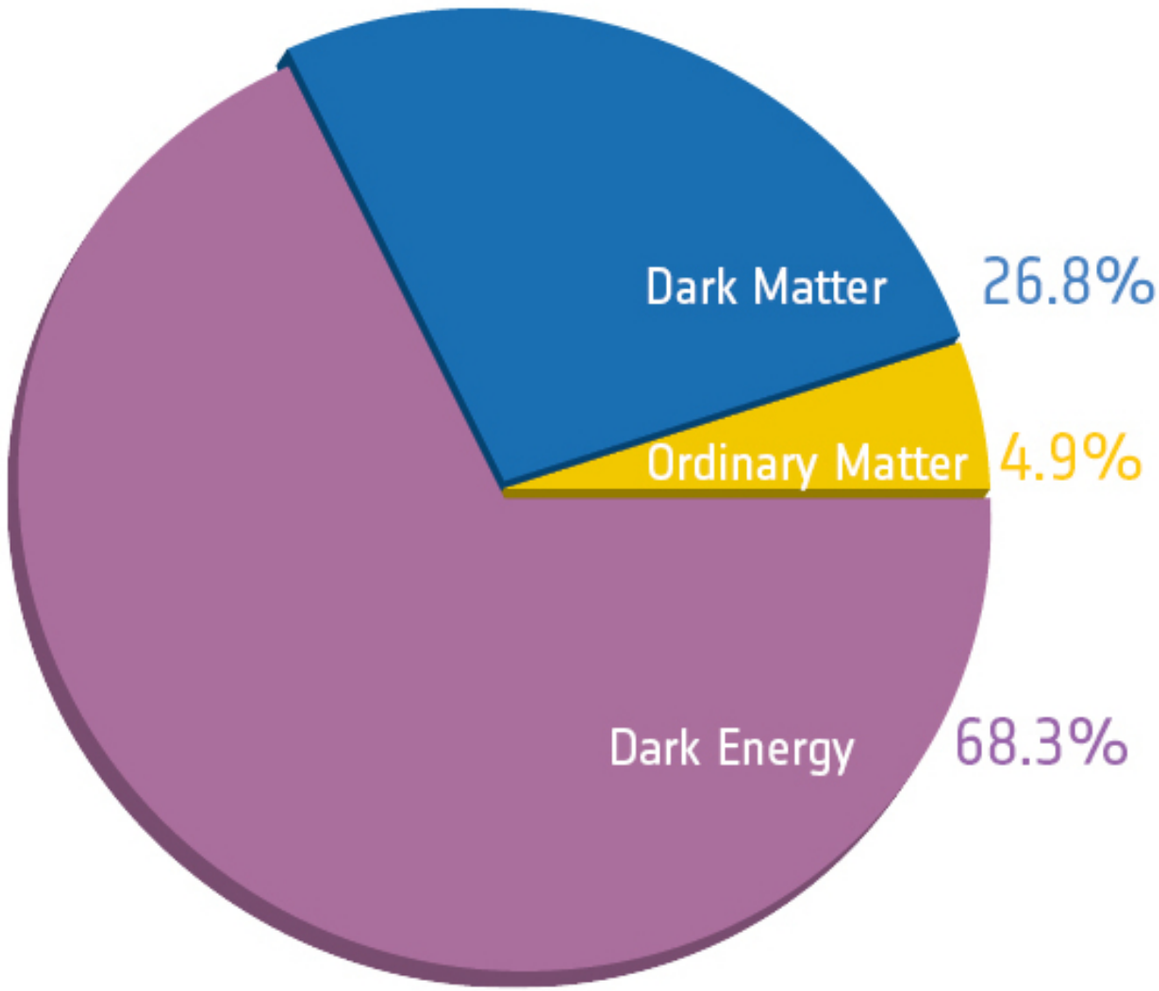


Image credit: ESA and Planck

"Cosmic Pie"

$$\Omega_{\rm DM} \sim 5\,\Omega_{\rm Matter}$$

$$\Omega_{\rm DM} \sim 1000\,\Omega_{\nu} \quad \left(\sum m_\nu = 0.1\,{\rm eV}\right)$$

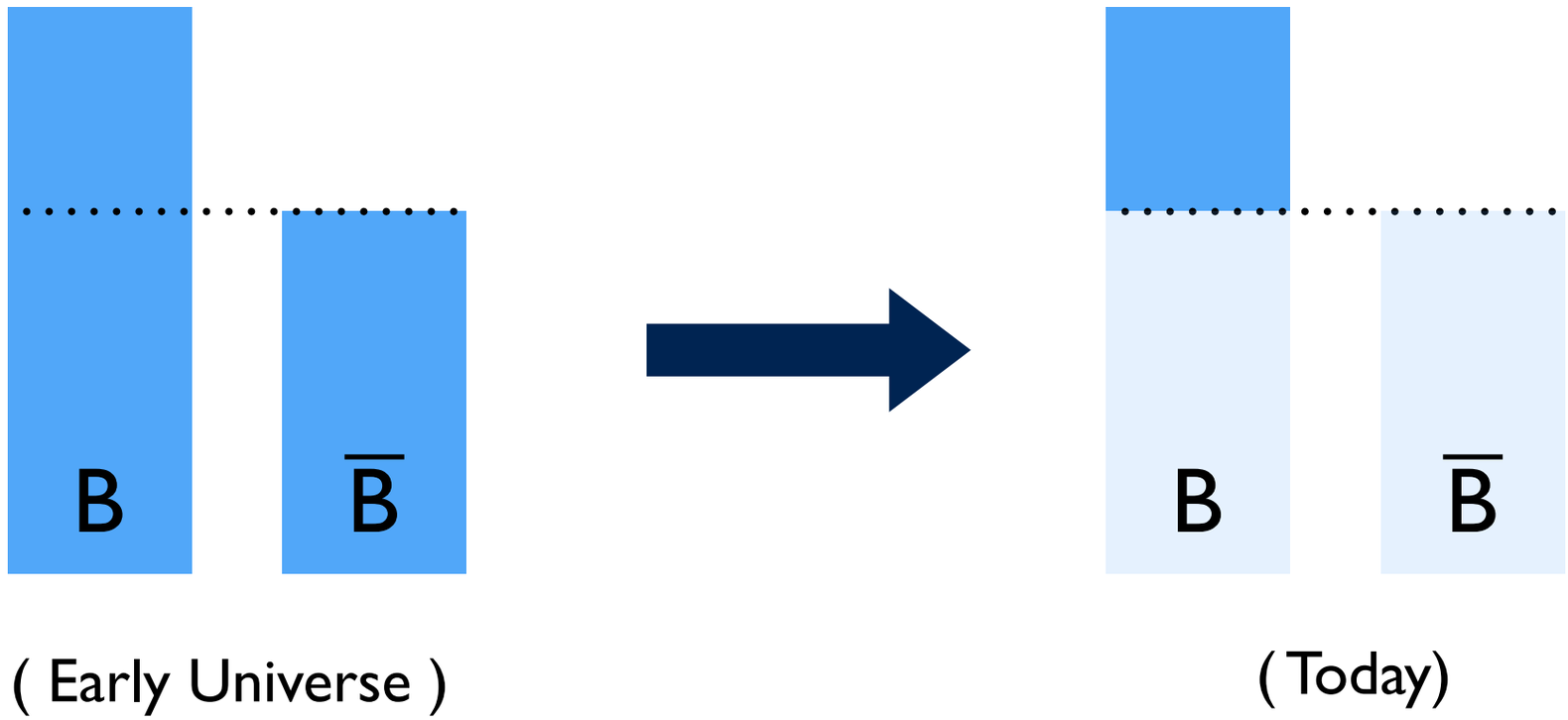
Cosmic coincidence ?

Why $\Omega_{\rm DM} \sim 5\,\Omega_{\rm Matter}$?

- suggests DM/Matter have the common origin ?

Baryon Asymmetry

- Ω_{Matter} is determined by baryon-asymmetry.

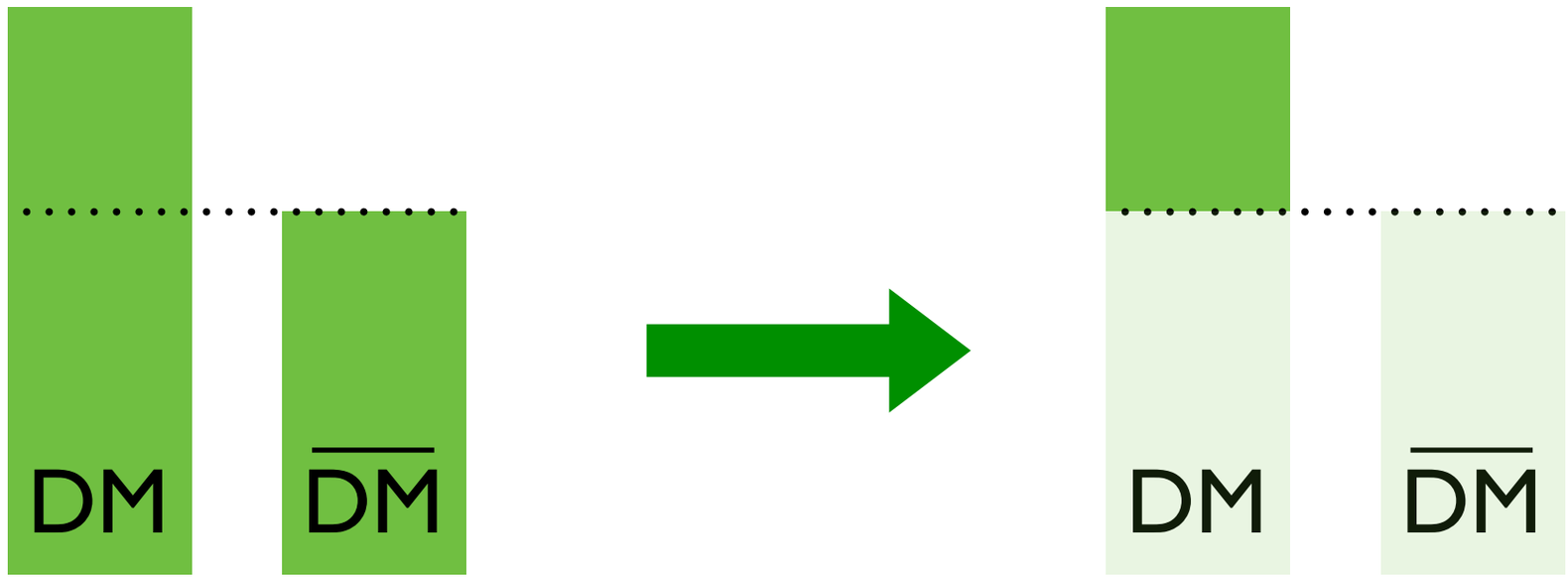


- The scenario is strongly supported by observations.

ADM hypothesis

- Ω_{DM} is determined by DM-asymmetry.

Nussinov (1985)
Barr, Chivukula, Farhi (1990)
Kaplan (1992)
Kaplan, Luty, Zurek (2009)



(Early Universe)　　(Today)

- Prediction: $\Omega_{\rm DM} \sim (m_{\rm DM}/m_{\rm B})\Omega_B$
- We obtain observed abundance for m_{DM} ~ 5-15 GeV.

ADM hypothesis

- ADM scenario requires

  - Long-lived, light particle
  - Large $\sigma_{annihilation}$
  - Asymmetry

- can be realized by SM + **QCD' + N_R.**

Ibe, Kamada, Kobayashi, Nakano, Kuwahara

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QCD'

- Let us consider QCD' sector with

$$\mathcal{L} = m_{U'}\bar{U}'U' + m_{D'}\bar{D}'D'$$

- Confinement at $\Lambda_{\mathrm{QCD}'}$

π'	$\sim \bar{U}'U', \bar{D}'D'$	$m \sim \sqrt{m_{Q'}\Lambda_{\mathrm{QCD}'}}$
ρ'	$\sim U'U'D'$	$m \sim \Lambda_{\mathrm{QCD}'}$
n'	$\sim U'D'D'$	$m \sim \Lambda_{\mathrm{QCD}'}$

- We assume $m_{Q'} \ll \Lambda_{\mathrm{QCD}'}$

QCD'

- Let us assign $U(1)_{B\text{-}L}$ charges as

$$U',\ D' \ :\ 1/3 \qquad \bar{U}',\ \bar{D}' \ :\ -1/3$$

- This makes p'/n' stable

$$\text{Mass} \ \simeq \ \Lambda_{\mathrm{QCD}'}$$

$$\sigma_{\text{annihilation}} \ \simeq \ 4\pi\Lambda_{\mathrm{QCD}'}^{-2} \quad \text{strong int}$$

- If we take $\Lambda_{QCD'} \sim$ GeV, p'/n' can be ADM !

Composite ADM scenario

- SM + QCD' + N_R

  - Long-lived, light particle
  - Large $\sigma_{annihilation}$

) QCD'

  - Asymmetry

Asymmetry

- Right-handed neutrino plays an important role.

$$\mathcal{L} = \frac{1}{2} M_N \bar{N}\bar{N} + yLH\bar{N} + h.c.$$

SM sector

- N decay generates (B-L) asymmetry.

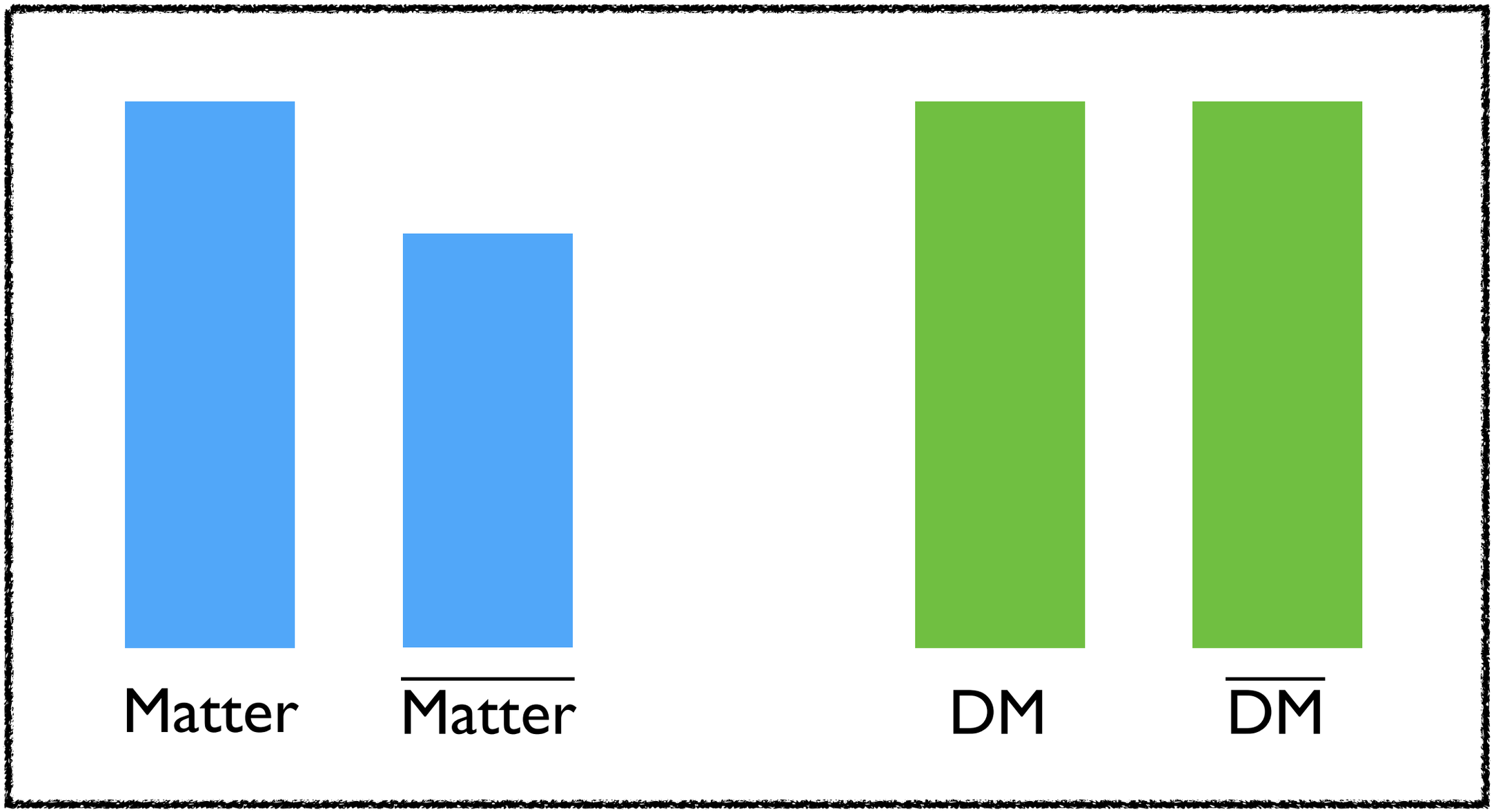
"Leptogenesis" Fukugita, Yanagida (1986) +

QCD' sector $\mathcal{L} = \frac{1}{M^3}(\bar{U}'\bar{D}'\bar{D}')LH + h.c.$

- (B-L) asymmetry is shared until $T_D \sim M(M/M_{\rm PL})^{1/5}$

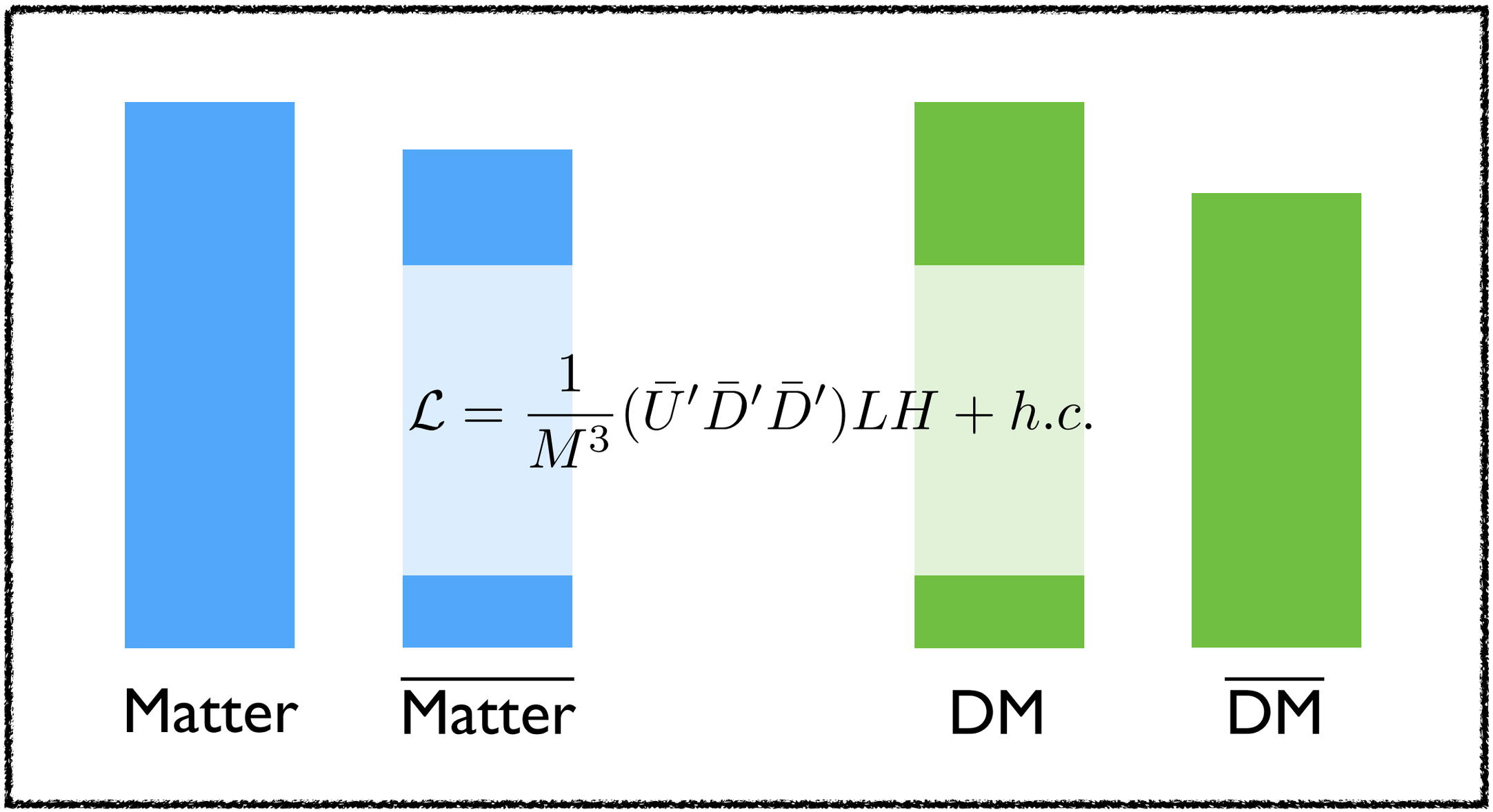
Cosmic history

$T \sim M_N$



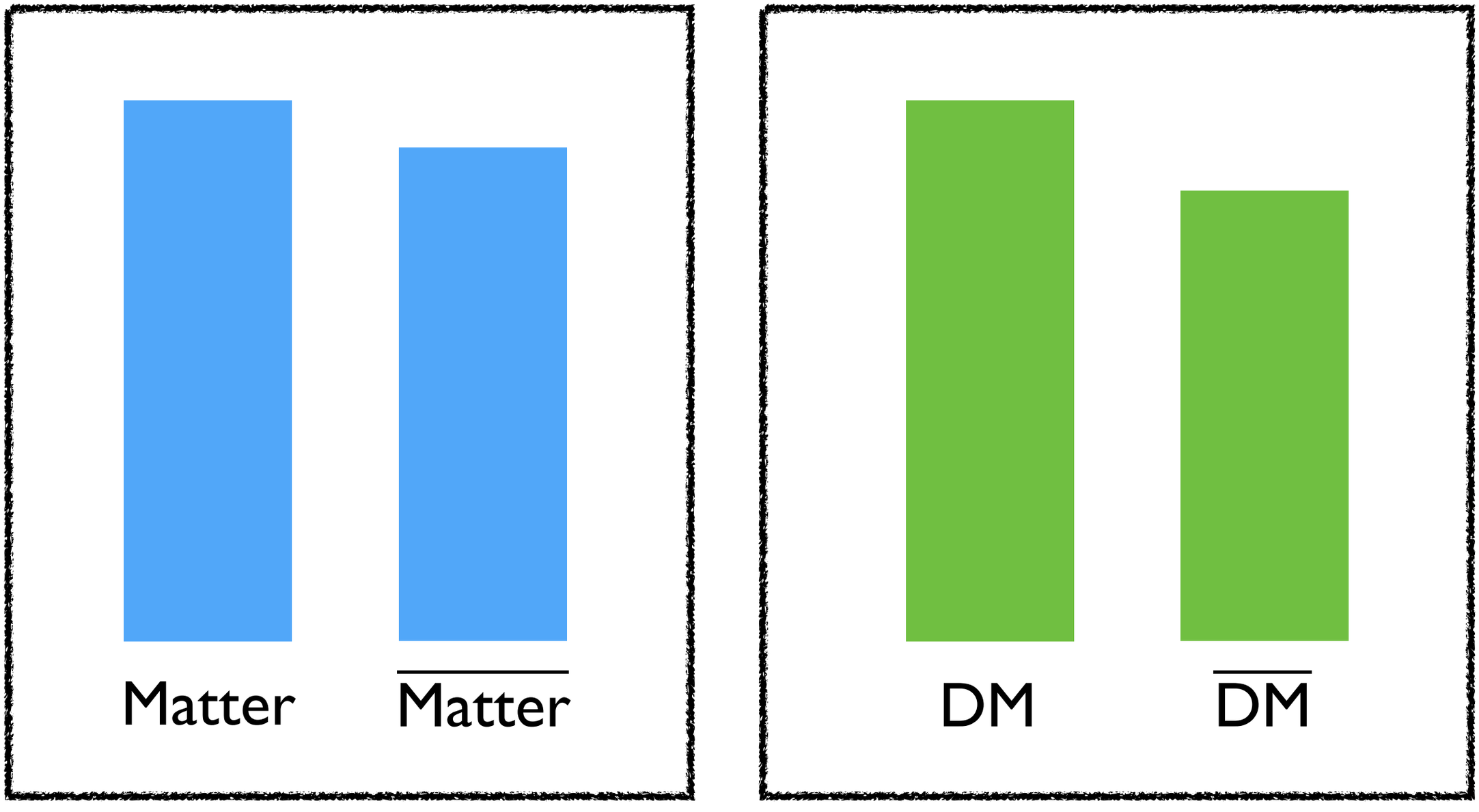
Cosmic history

$T_D < T < M_N$



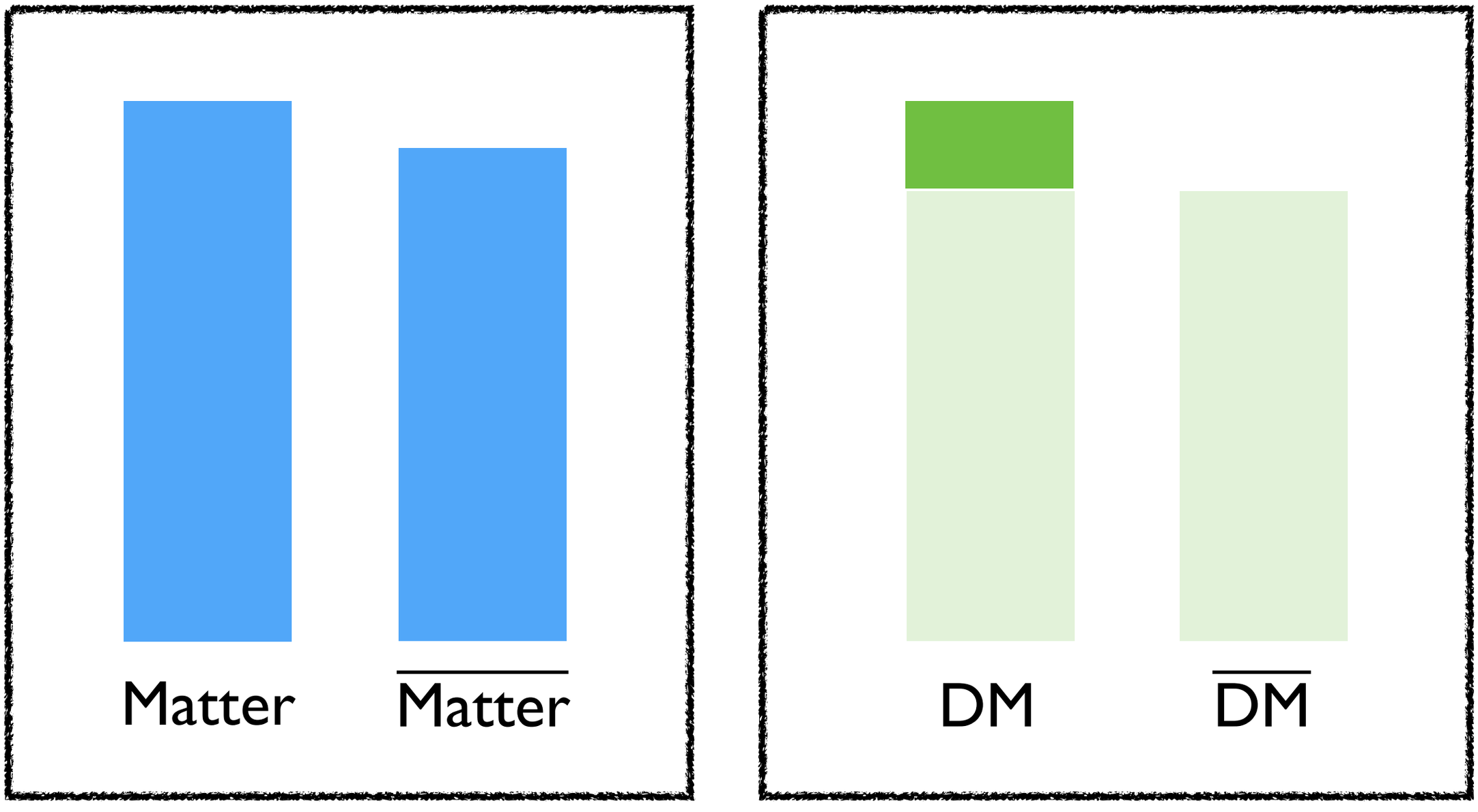
Cosmic history

$T \sim T_D$



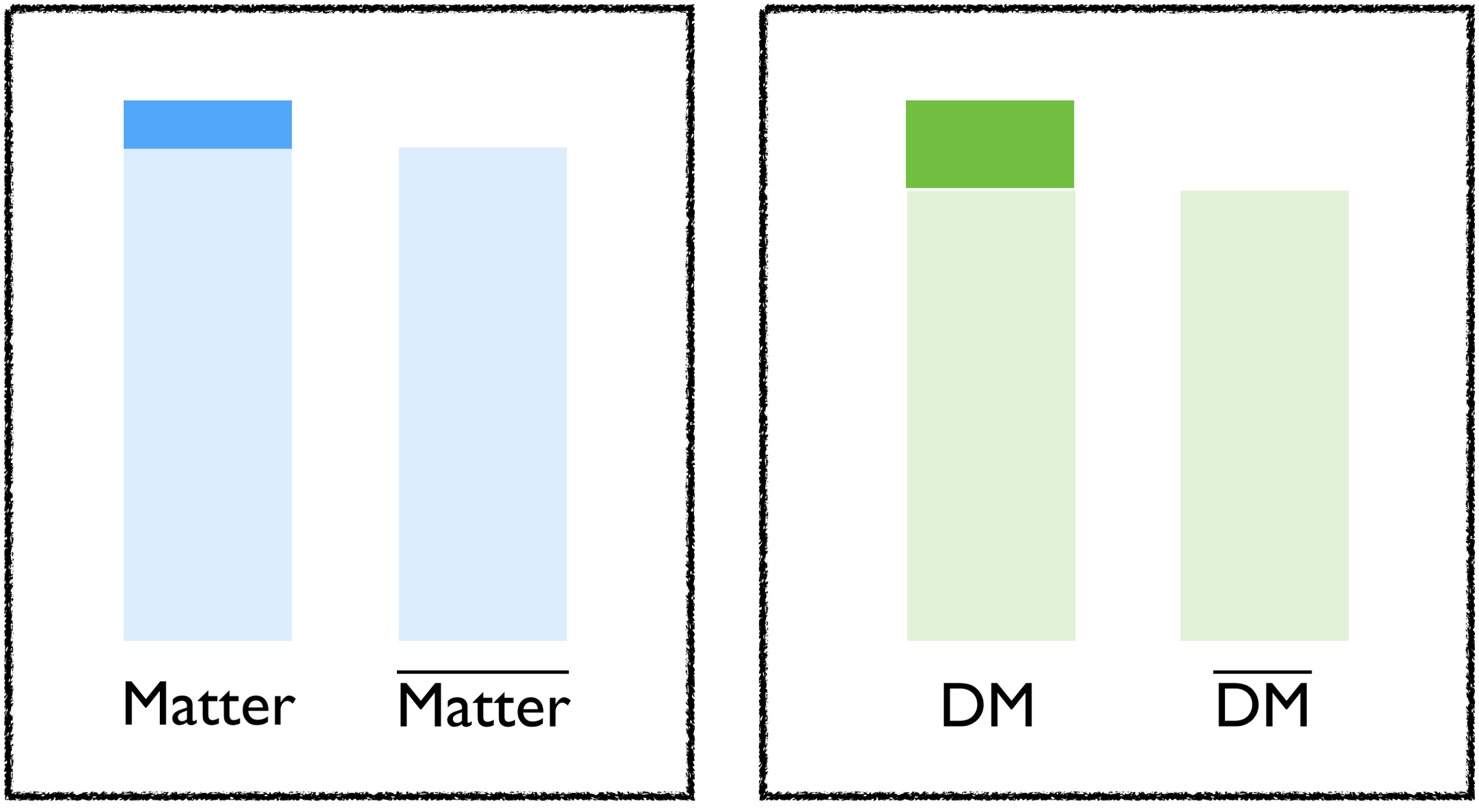
Cosmic history

$T \sim \Lambda_{QCD'}$



Cosmic history

$T \sim \Lambda_{QCD}$



Cosmic history

~ Present

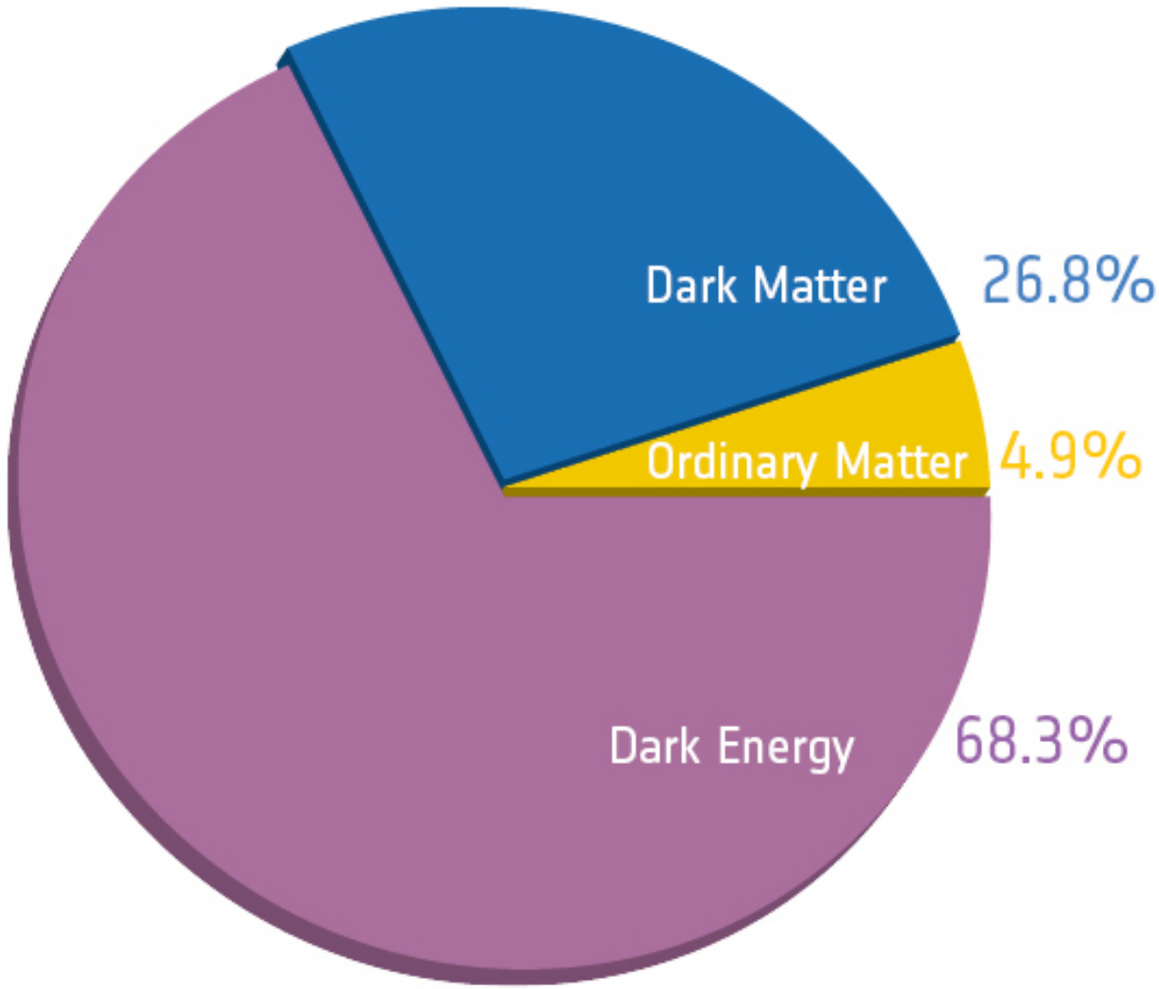


Image credit: ESA and Planck

Summary so far

- $\Omega_{DM} \sim \Omega_B$ suggests an ADM scenario.
- We discussed SM + **QCD' + N_R** model.
  - Baryon' can be an ADM.
  - N_R decay generates B-L asymmetry.
  - The asymmetry is shared with both SM and DM sector through portal interaction.
- Can we test the ADM scenario?

Talk plan

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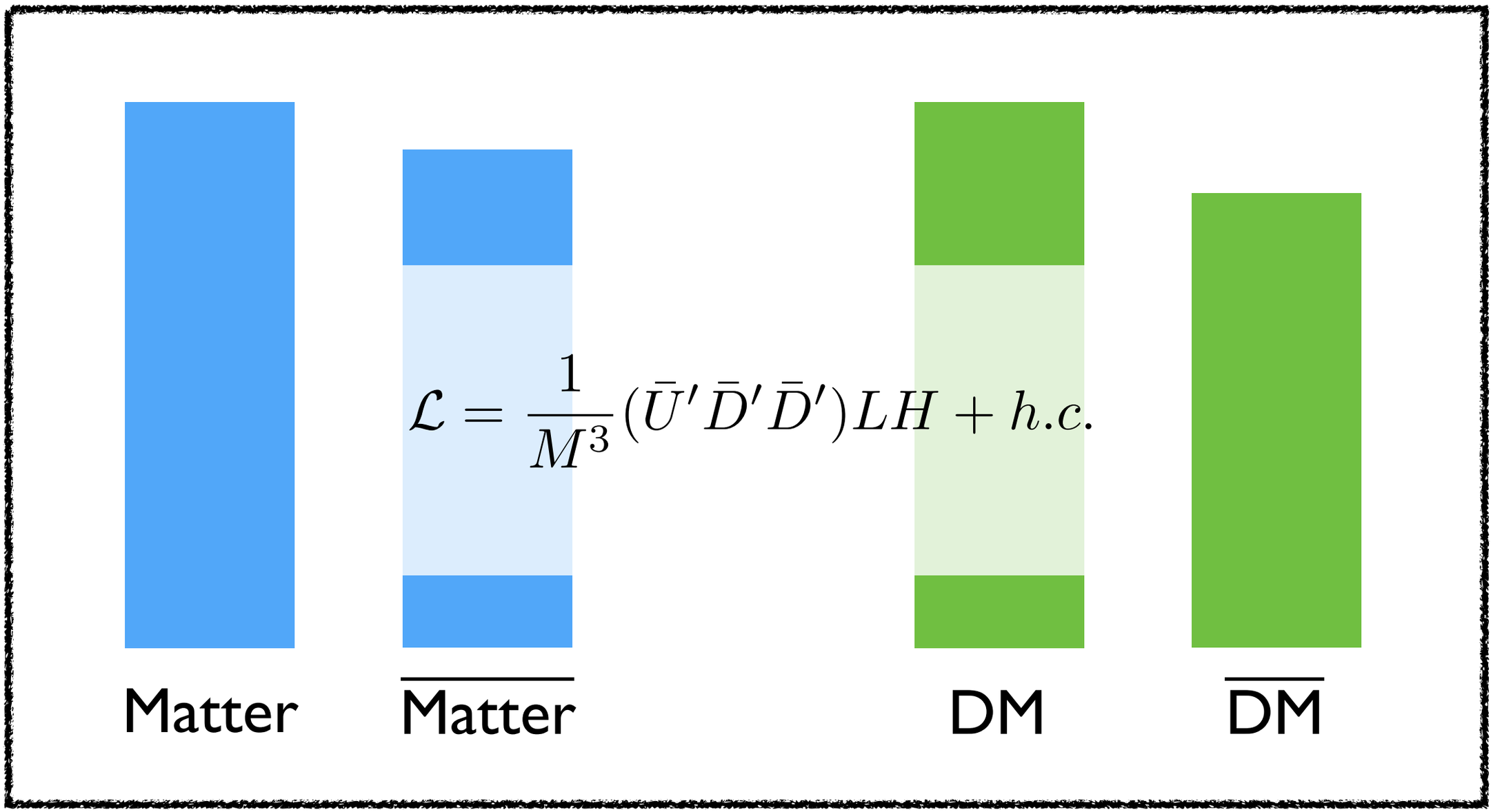
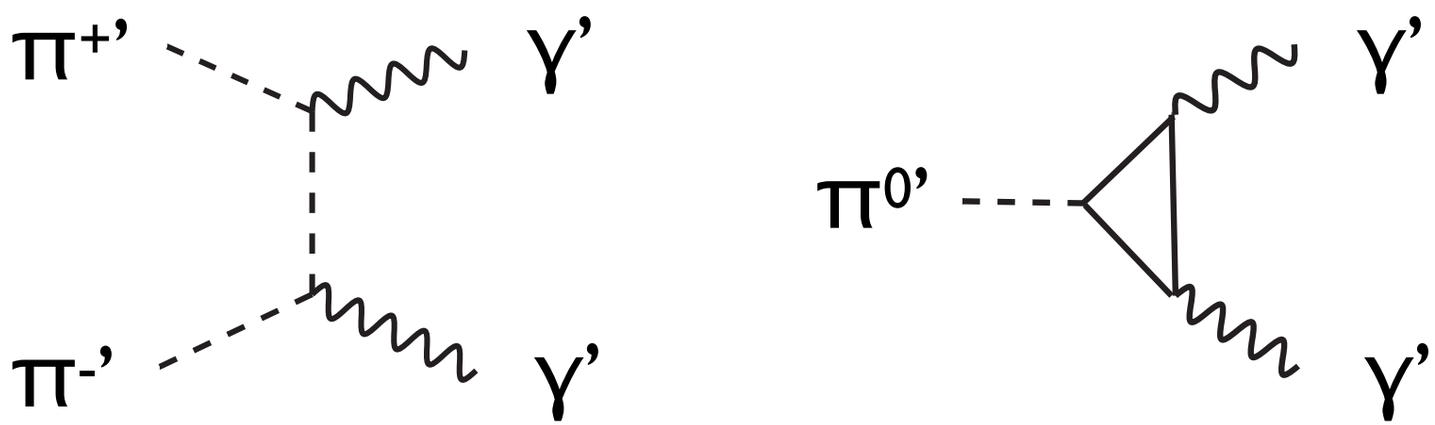
Cosmic history

$T_D < T < M_N$



QED'

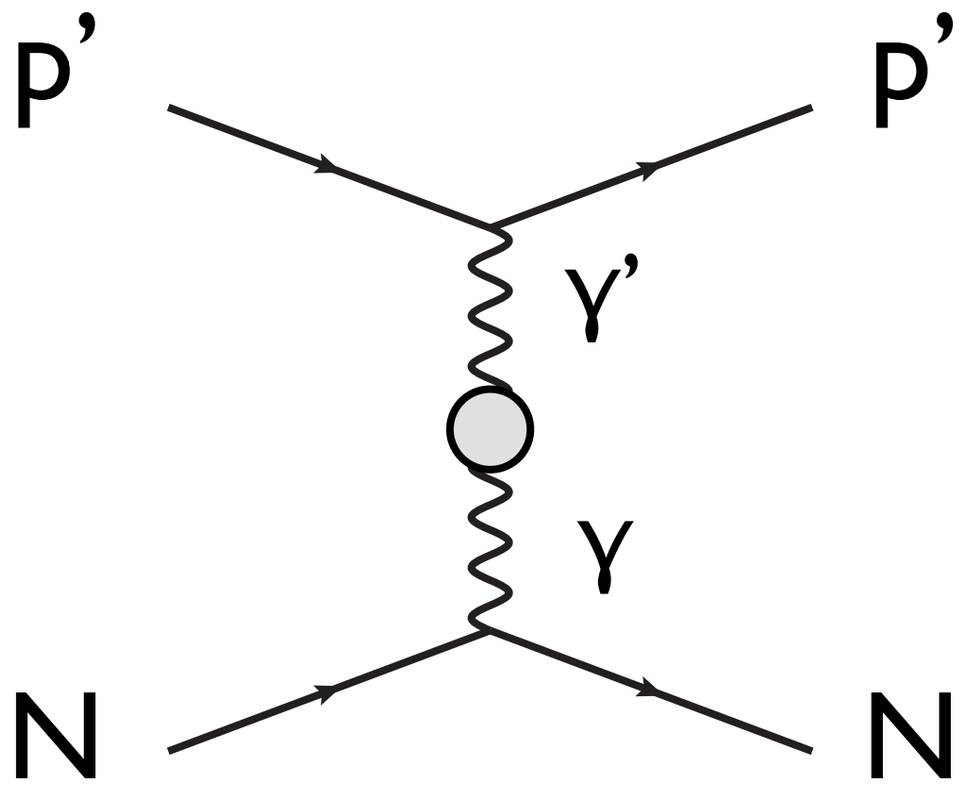
- $(\text{entropy})_{DM} \sim (\text{entropy})_{SM}$.
- To release $(\text{entropy})_{DM}$, we turn on QED' interaction.



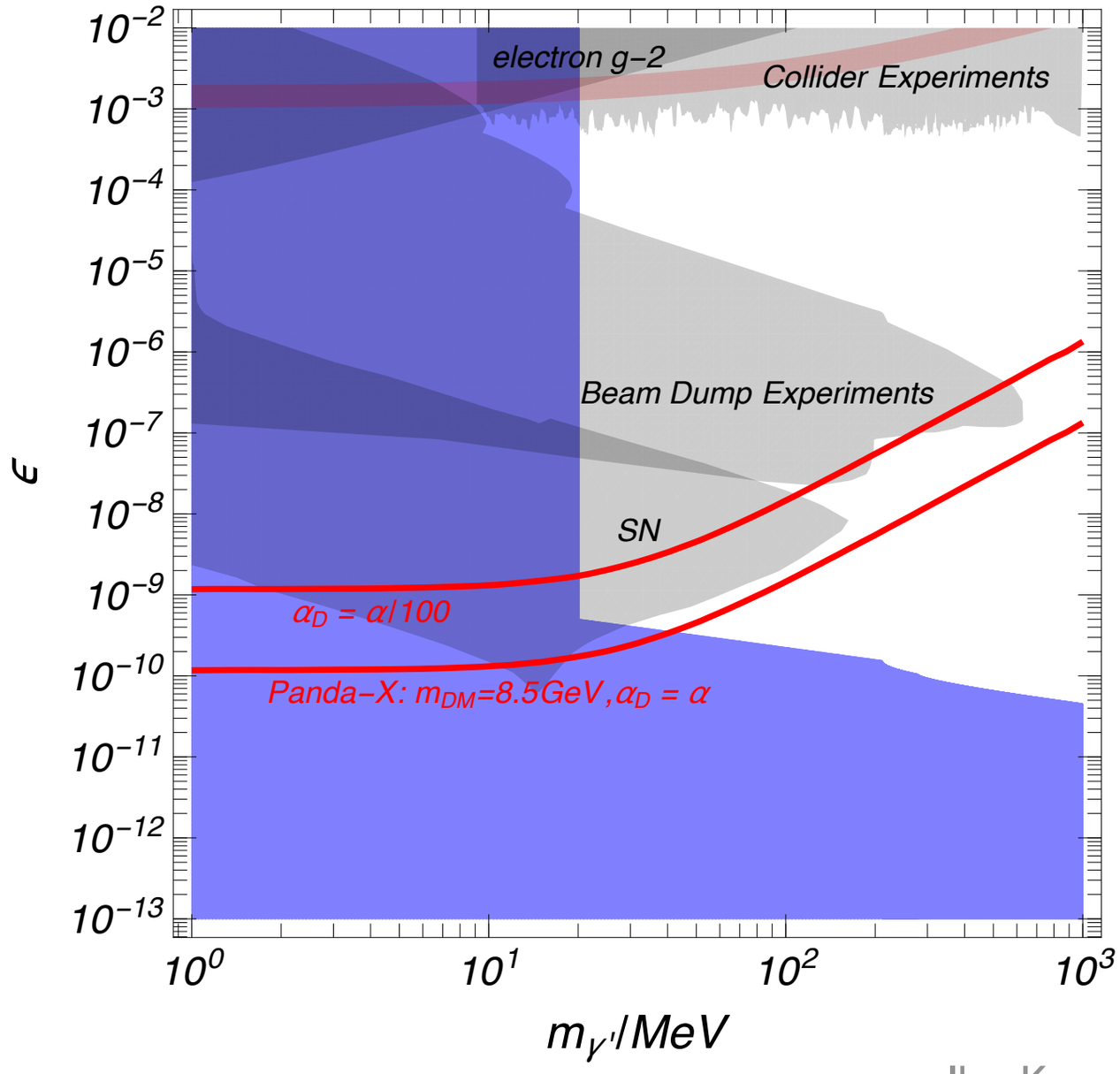
- We further assume $\mathcal{L} = \frac{1}{2}\epsilon F^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m^2_{\gamma'}A'_\mu A'^\mu$
- γ' can couple with QED charged particles.

Composite ADM signal

Scattering



Composite ADM signal



Ibe, Kamada, Nakano, Kobayashi (2018)

Composite ADM signal

Scattering
- p'N → p'N

Decay
- n' → π⁰' + $\overline{\nu}$

$$\mathcal{L} = \frac{1}{M^3}(\bar{U}'\bar{D}'\bar{D}')LH + h.c.$$

$$\tau \sim 10^{24}\,\mathrm{sec}\left(\frac{M}{10^9\,\mathrm{GeV}}\right)^6\left(\frac{m_{\mathrm{DM}}}{10\,\mathrm{GeV}}\right)^{-5}$$

- SK : $M \gtrsim 3\times 10^8\,\mathrm{GeV}$

Feldstein, Fitzpatrik (2010)
Fukuda, Matsumoto, Mukhopadhyay (2014)

Annihilation
- No signal.

NOT true!

Portal interaction

- The portal int.

$$\mathcal{L} = \frac{1}{M^3}(\bar{U}'\bar{D}'\bar{D}')LH + h.c.$$

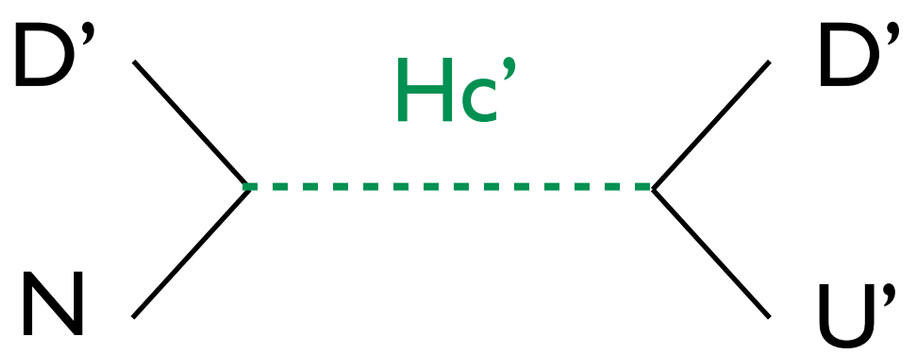
Portal interaction

- The portal int. comes from

$$\mathcal{L} = \frac{1}{2} M_N \bar{N}\bar{N} + yLH\bar{N} + \frac{1}{M_*^2}(\bar{U}'\bar{D}'\bar{D}')\bar{N} + h.c.$$

N_R couples to both SM and DM sector

- UV completion



Ibe, Kamada, Kobayashi, Nakano, Kuwahara

Portal interaction

- The portal int. comes from

$$\mathcal{L} = \frac{1}{2} M_N \bar{N}\bar{N} + yLH\bar{N} + \frac{1}{M_*^2}(\bar{U}'\bar{D}'\bar{D}')\bar{N} + h.c.$$

- Integrating out N,

$$\mathcal{L} = -\frac{y^2}{2M_N}(LH)(LH) \qquad \text{Neutrino mass}$$

$$-\frac{y}{M_*^2 M_N}(\bar{U}'\bar{D}'\bar{D}')(LH) \qquad \text{Portal int.}$$

$$-\frac{1}{2M_*^4 M_N}(\bar{U}'\bar{D}'\bar{D}')(\bar{U}'\bar{D}'\bar{D}') + h.c. \qquad \text{Majorana mass !}$$

ADM oscillation

- ADM oscillation time scale

$$t_{\rm osc} \sim \frac{M_N M_*^4}{\Lambda_{\rm QCD'}^6}$$

$$\sim 10^{21}\,{\rm sec} \left(\frac{\Lambda_{\rm QCD'}}{2\,{\rm GeV}}\right)^{-6} \left(\frac{M_N}{10^9\,{\rm GeV}}\right) \left(\frac{M_*}{3\times 10^9\,{\rm GeV}}\right)^4$$

($t_0 \sim 10^{17}$ sec)

- Some fraction of n' converts to $\bar{n}$' at late time!

Composite ADM signal

n'/p'

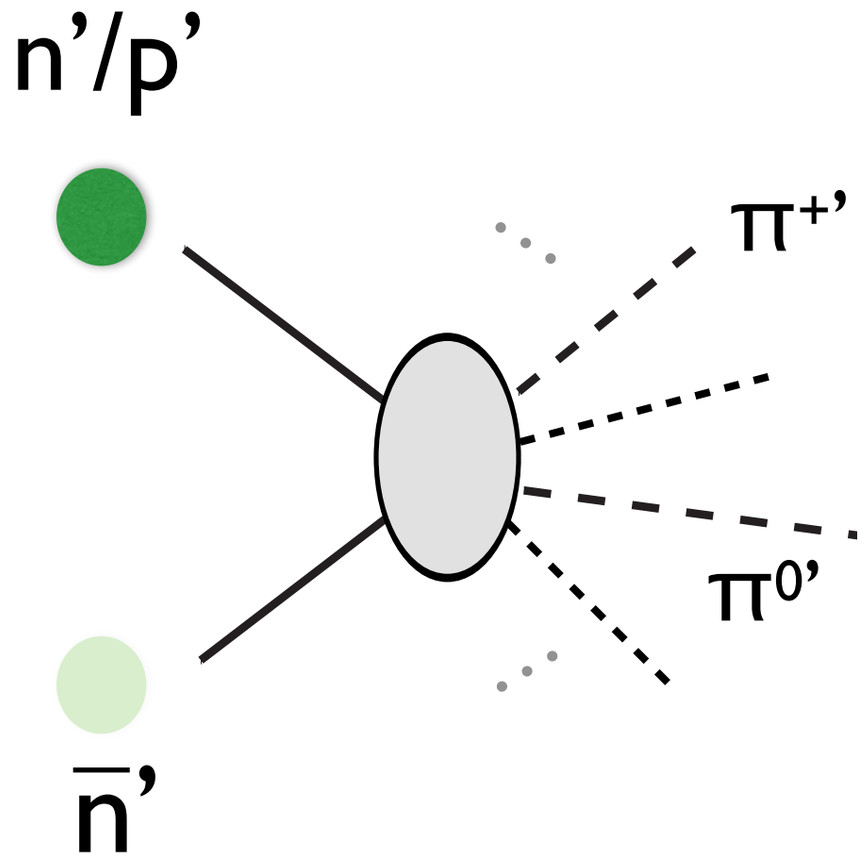
Composite ADM signal

n’/p’

$\bar{n}$’

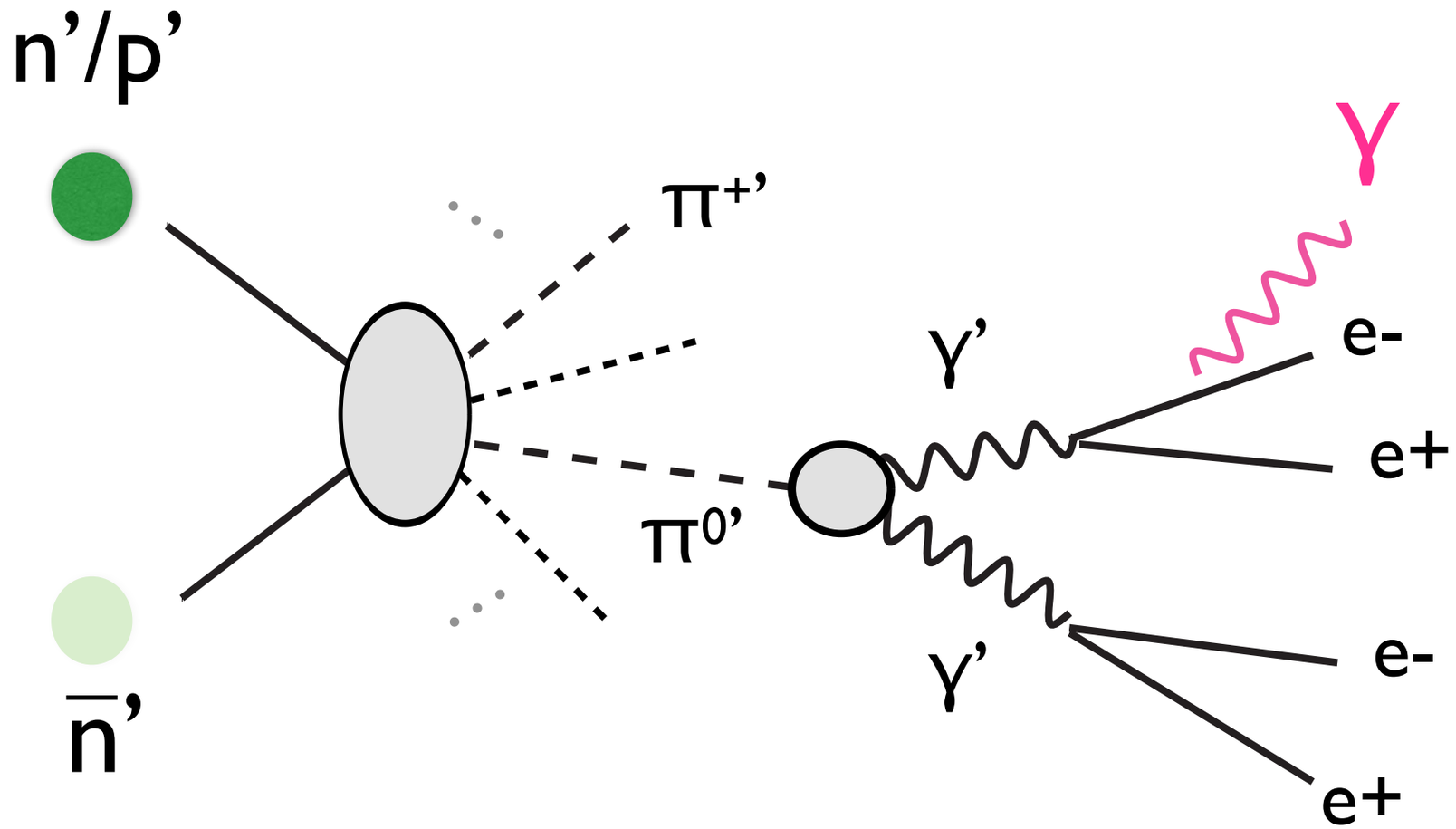
Oscillation !

Composite ADM signal



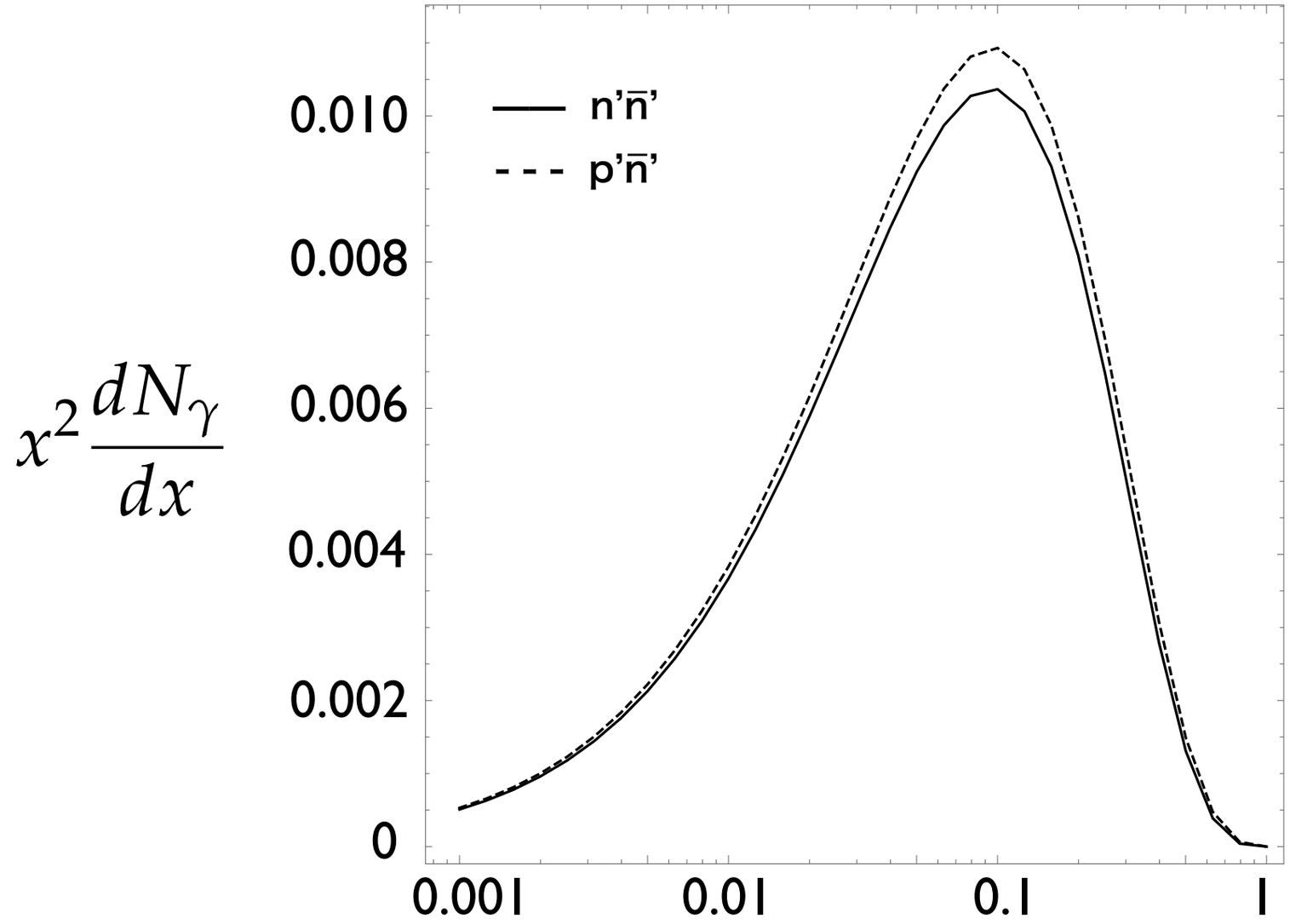
Oscillation !

Composite ADM signal



Oscillation !

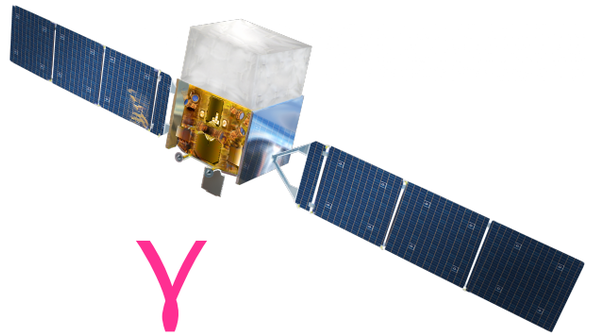
Composite ADM signal



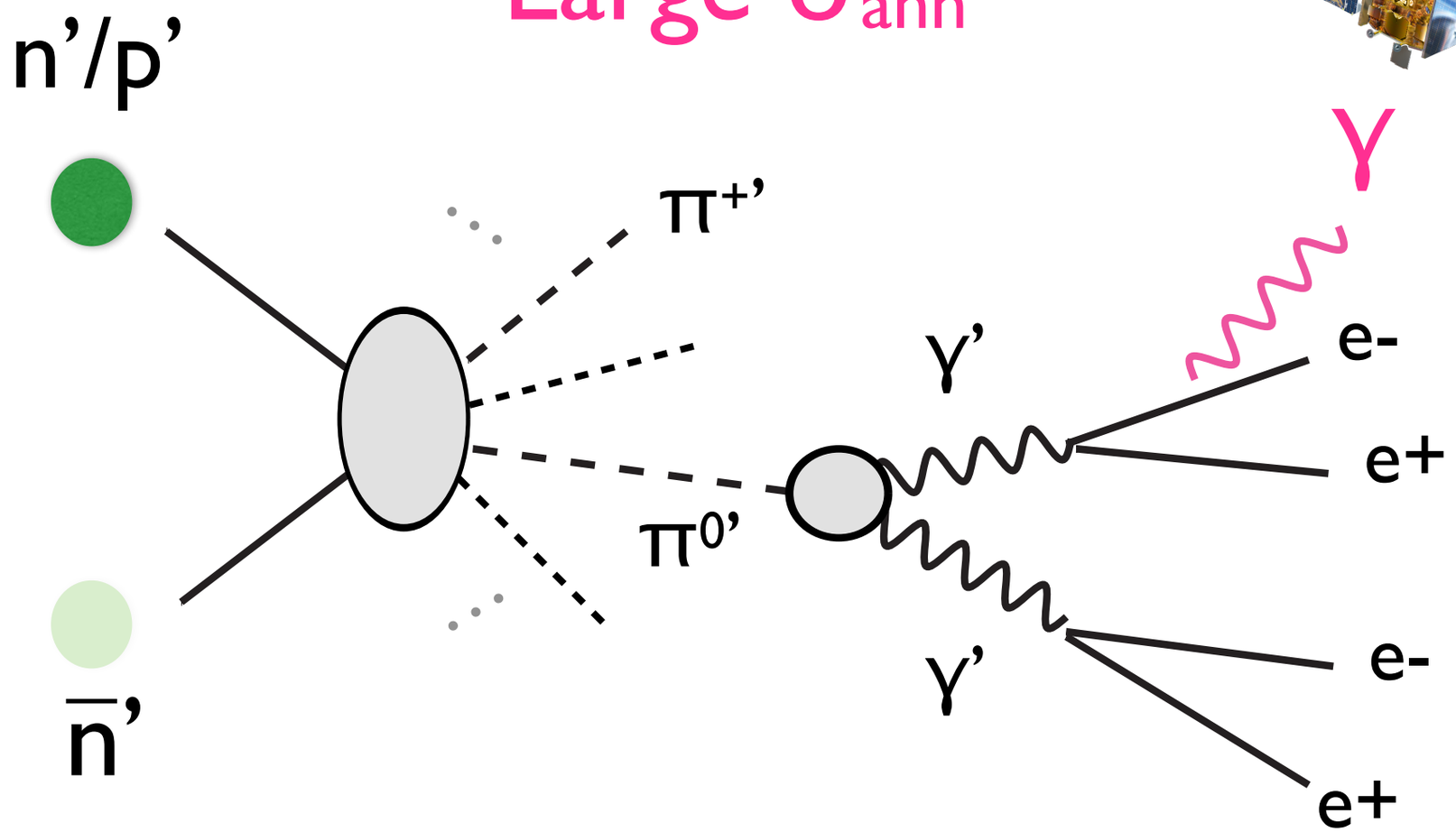
Ibe-Nagai-Nakano-Kobayashi (2019)

Composite ADM signal

Fermi-LAT



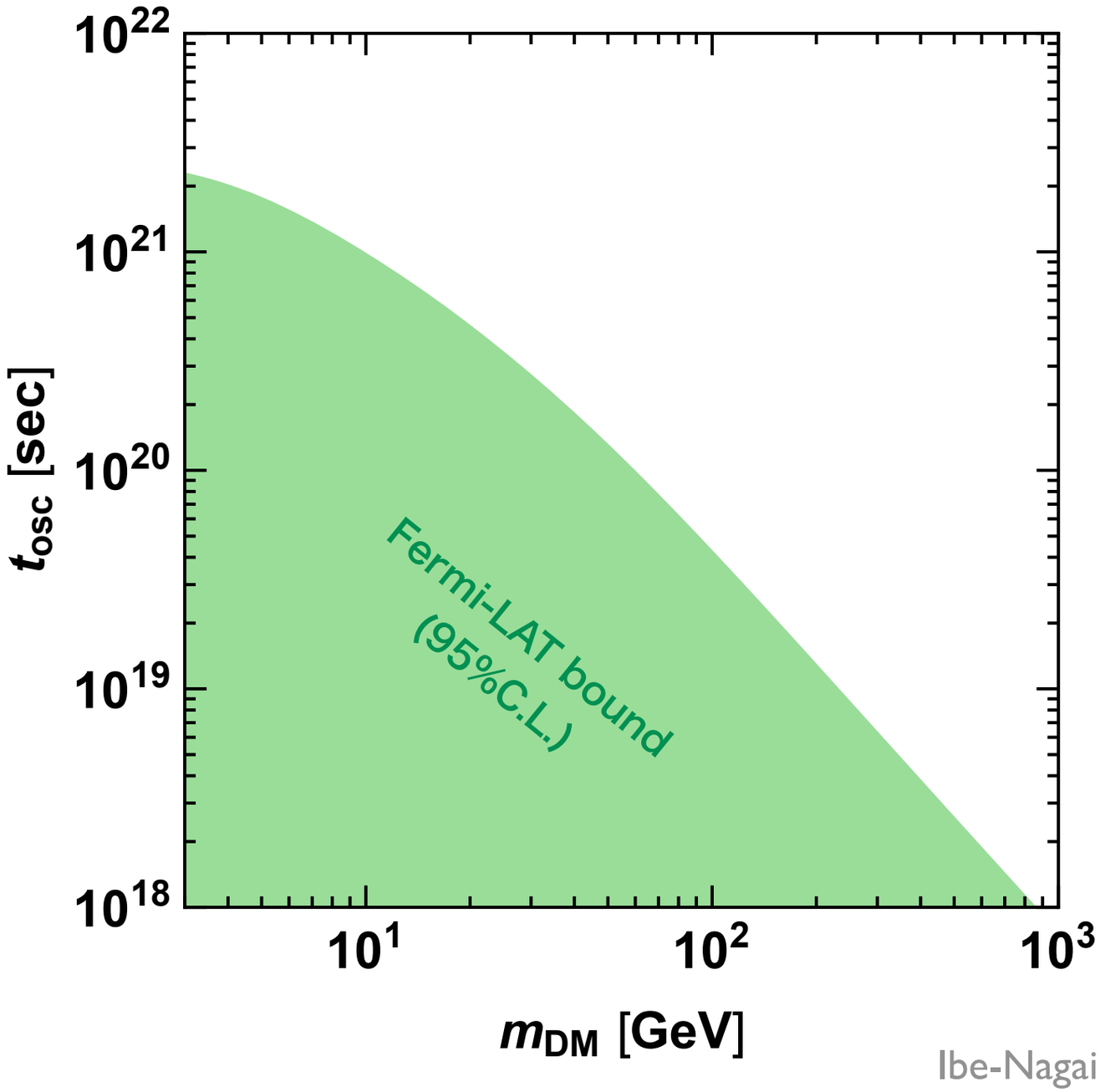
Large σ_{ann}



Oscillation !

@ dSphs

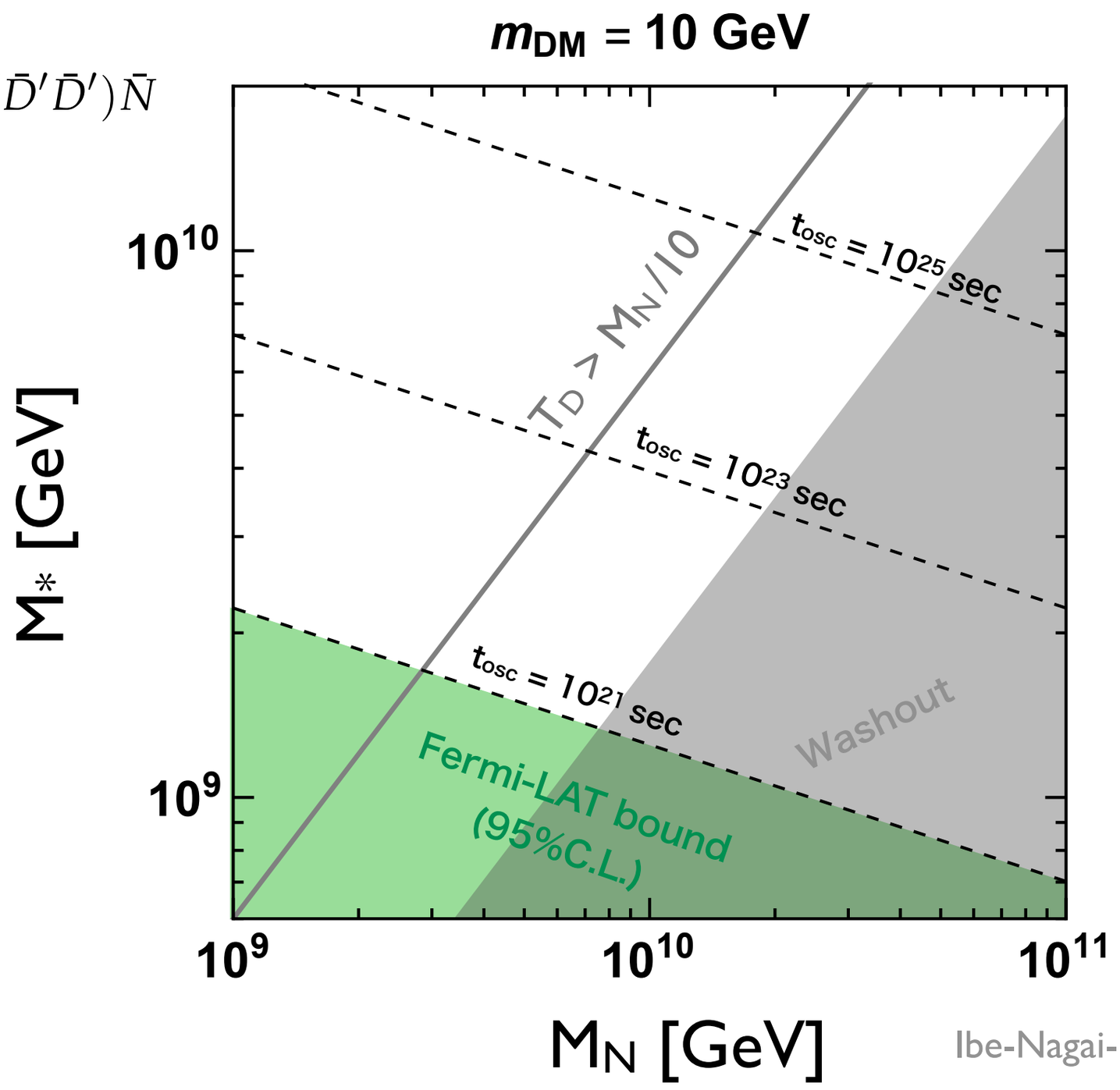
dwarf limit



Ibe-Nagai-Nakano-Kobayashi (2019)

dwarf limit

$$\mathcal{L} = \frac{1}{M_*^2}(\bar{U}'\bar{D}'\bar{D}')\bar{N}$$



Ibe-Nagai-Nakano-Kobayashi (2019)

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  - Baryon' can be an ADM.
  - N_R decay generates B-L asymmetry.
  - The asymmetry is shared with both SM and DM sector through B-L portal interaction.
  - The entropy in DM sector transfers to the SM sector through QED' interaction.
- Rich phenomenology !