Dark Matter in Non-standard Cosmologies

Based on:

NB, Catarina Cosme & Tommi Tenkanen 1803.08064 [hep-ph]

NB, Catarina Cosme, Tommi Tenkanen & Ville Vaskonen 1806.11122 [hep-ph]

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MOCa

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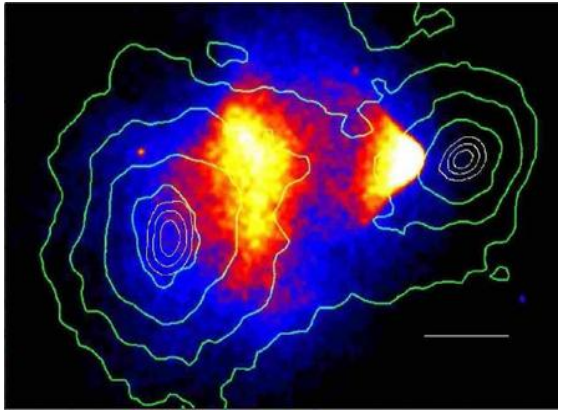
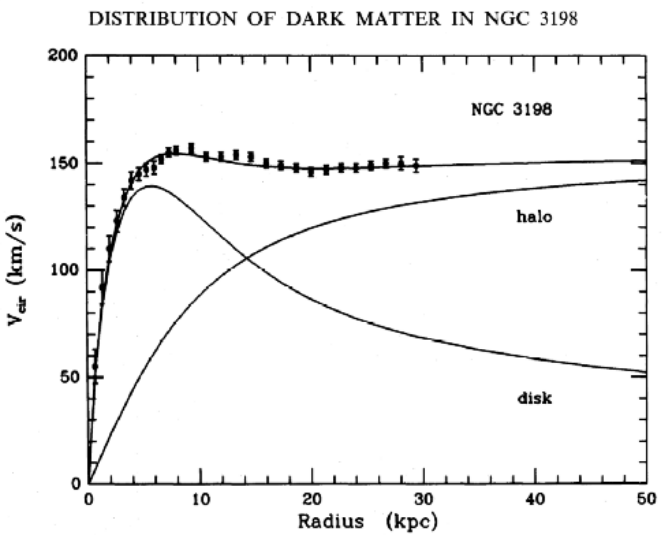
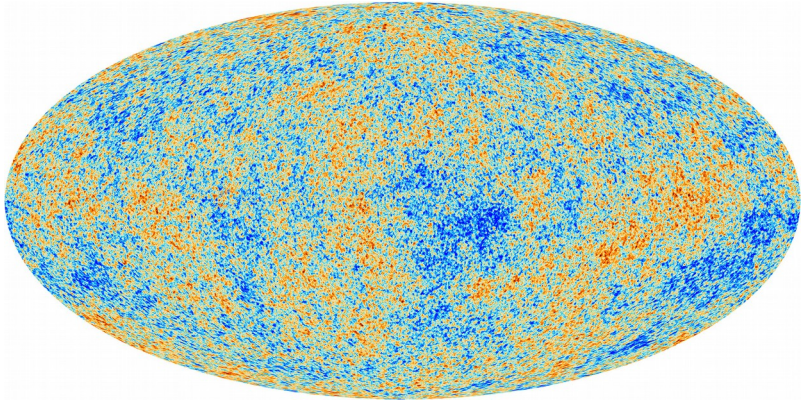
Evidences for Dark Matter

Several observations indicate the existence of non-luminous Dark Matter (missing force) at very different scales!

* Galactic rotation curves
* RC in Clusters of galaxies
* Clusters of galaxies
* CMB anisotropies







Standard Cosmology

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Standard Cosmology

We typically assume that the Universe is **radiation dominated** (RD) during all its evolution from the reheating until now.

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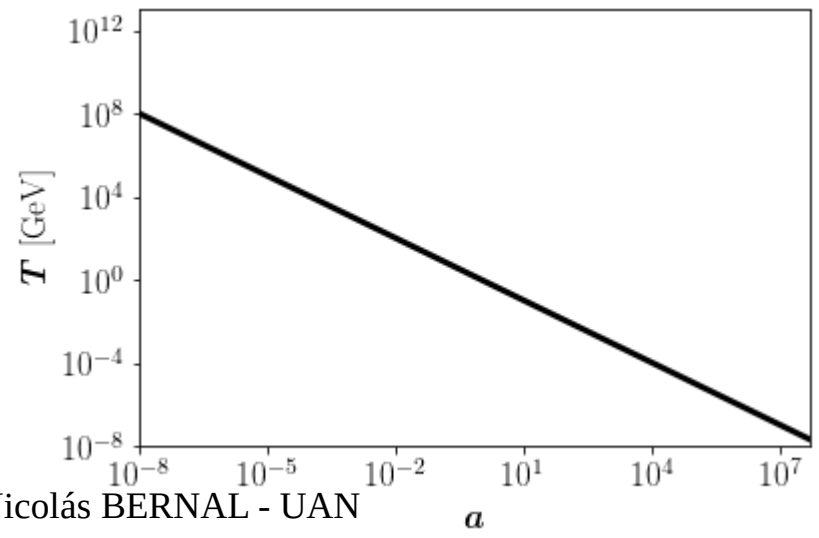
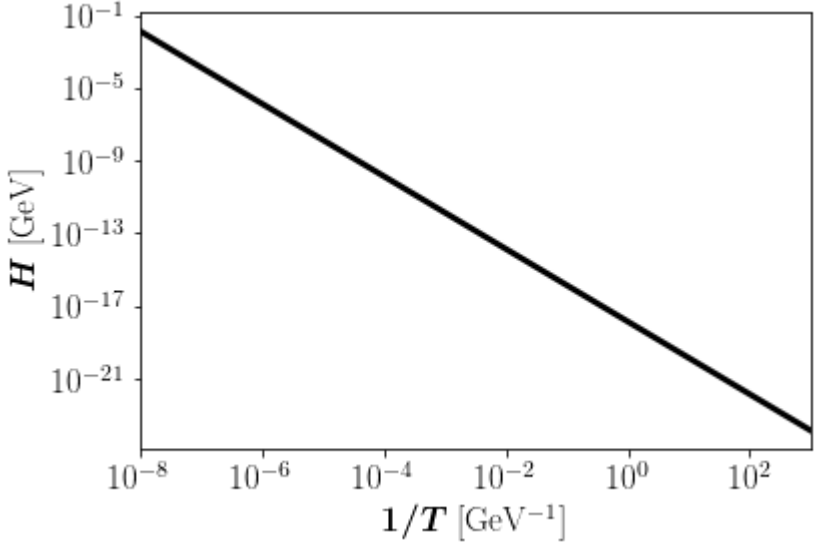
T ~ 1/a



H ~ T²/M_P



Standard Cosmology?

We typically assume that the Universe is **radiation dominated** (RD) during all its evolution from the reheating until now...

However that may not be the case!

We only know that *the Universe was effectively RD at **BBN**.*

That may have not been the case during the DM production!

Non-standard Cosmologies

Alternative cosmologies lead to interesting observational ramifications + well-motivated:

- **Matter dominated** (MD) era due to a heavy metastable particle

Non-standard Cosmologies

Alternative cosmologies lead to interesting observational ramifications + well-motivated:

- **Matter dominated** (MD) era due to a heavy metastable particle
- Fluid with a general equation of state $\boldsymbol{p = \omega \rho}$

  p: pressure

  ρ: energy density

  ω in [-1, 1]

  $\omega = 0$: Matter

  $\omega = 1/3$: Radiation

which dominates the total energy density of the Universe.

Non-standard Cosmologies

- Energy densities described by the Boltzmann equations:

$$\frac{\mathrm{d}\rho_\phi}{\mathrm{d}t} + 3(1+w)H\rho_\phi = -\,\Gamma_\phi\,\rho_\phi$$

$$\frac{\mathrm{d}\rho_\mathrm{R}}{\mathrm{d}t} + 4H\rho_\mathrm{R} = +\,\Gamma_\phi\,\rho_\phi$$

  * ρ_R and ρ_ϕ energy densities of radiation and ϕ, respectively
  * ϕ decays into radiation with a decay width Γ_ϕ

- Hubble expansion rate: $H^2 = \dfrac{\rho_\phi + \rho_\mathrm{R}}{3\,M_P^2}$

Non-standard Cosmologies

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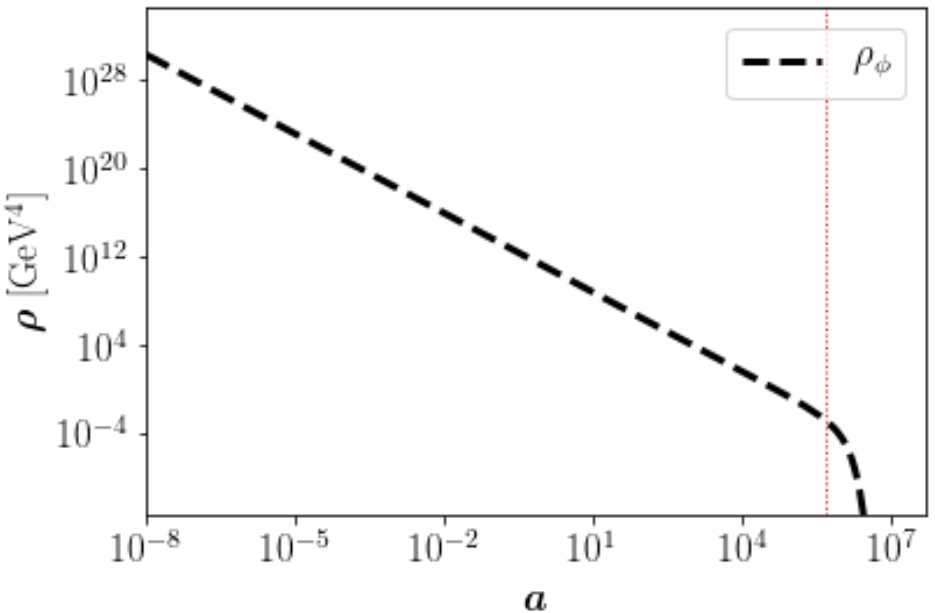

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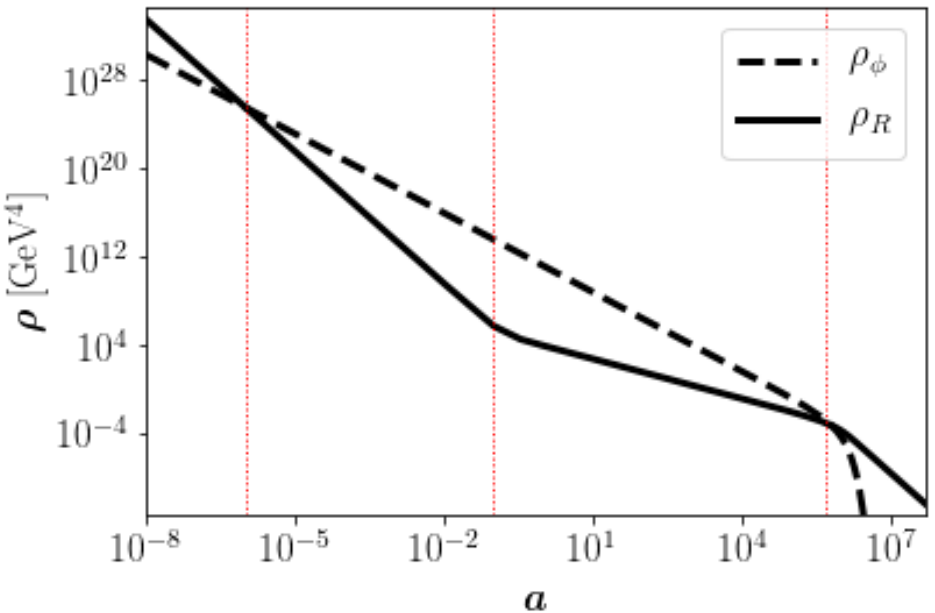

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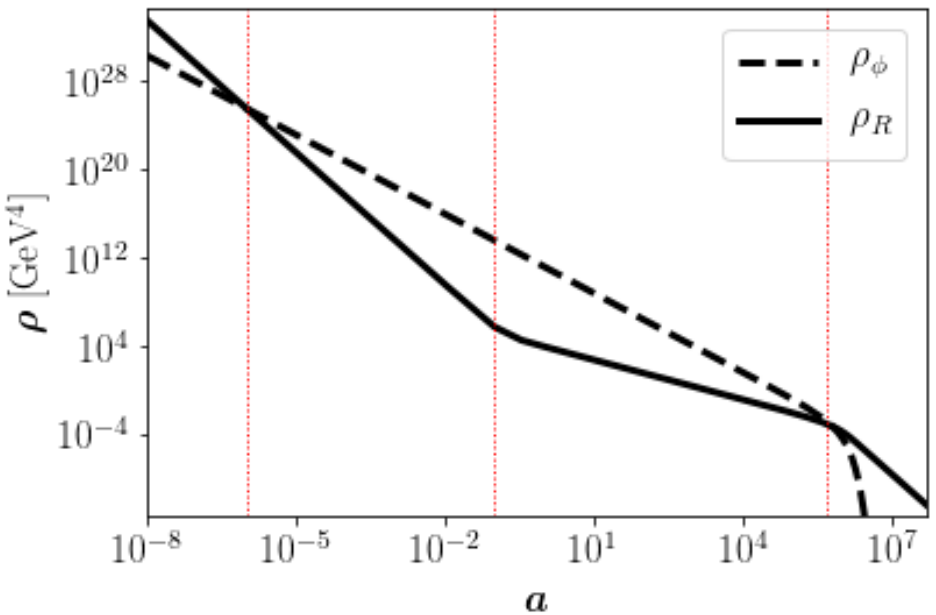

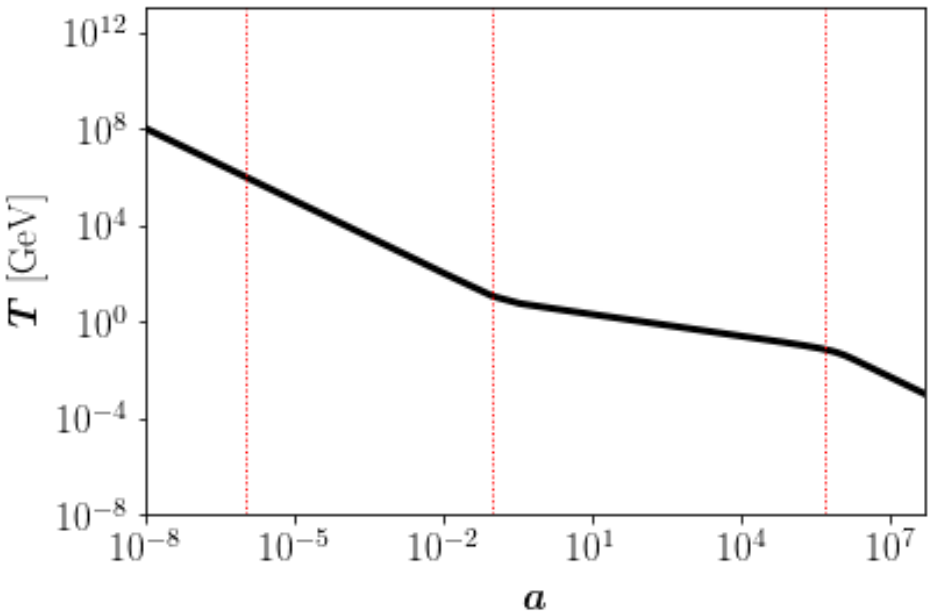

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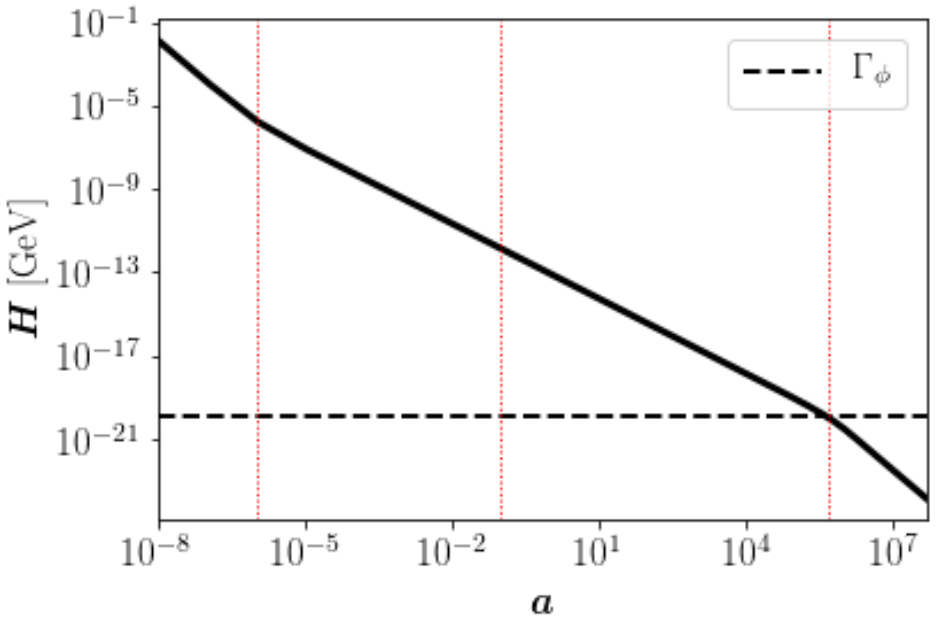
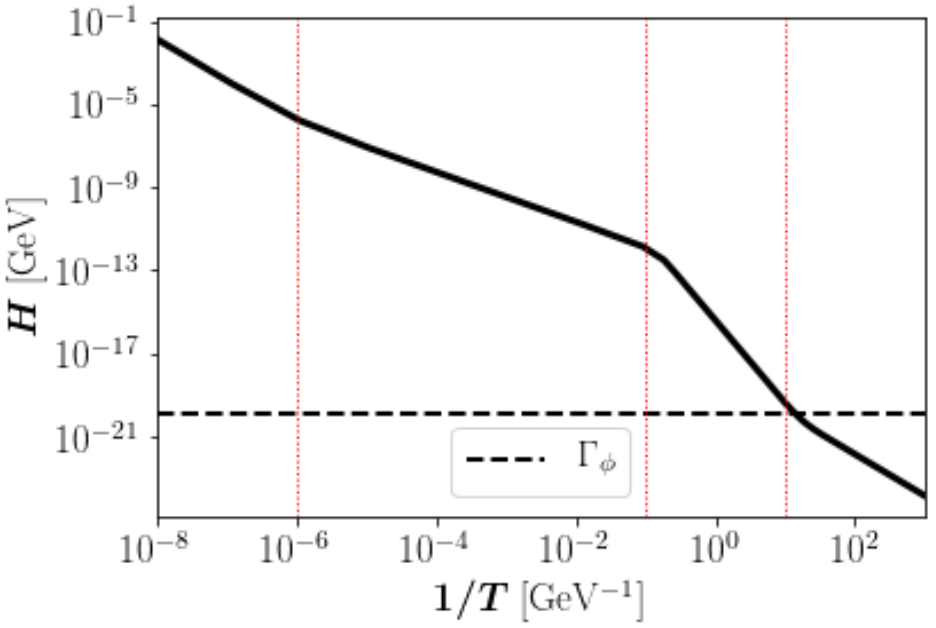
$$H^2 = \frac{\rho_\phi + \rho_\mathrm{R}}{3\,M_P^2}$$





The Simplest DM model ever: Singlet Scalar Dark Matter

just as an example :-)

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Singlet Scalar DM

McDonald '07

S is a singlet scalar, protected by a Z_2

$$V = \mu_S^2 S^2 + \lambda_S S^4 + \lambda_{HS} |H|^2 S^2$$

3 free parameters:

* m_S DM mass
* λ_{HS} Higgs portal
* λ_S DM quartic coupling

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} ← Concentrated on this

← ~ Ignored!

DM Production Mechanisms: WIMP

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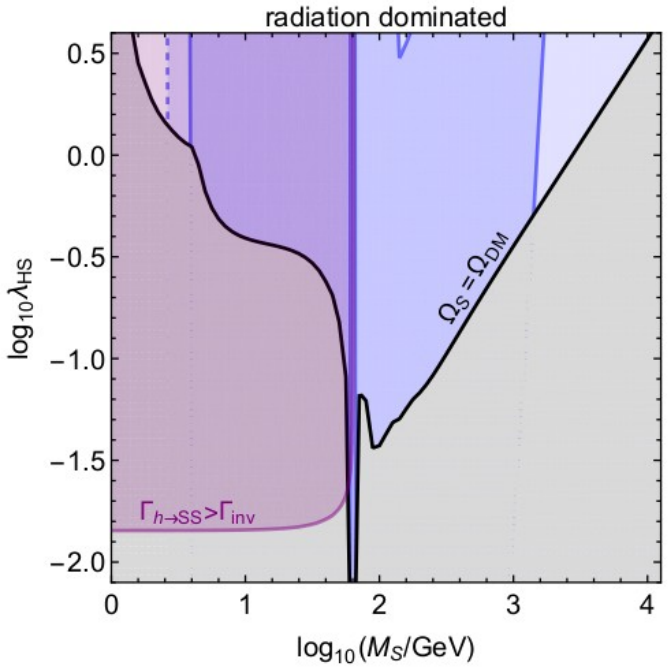
Singlet Scalar DM: WIMP

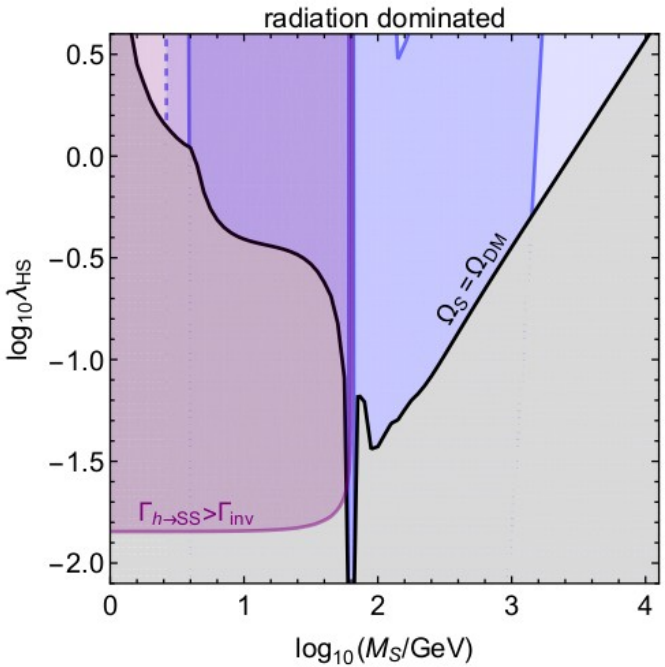
Usual case: Radiation Dominated Universe

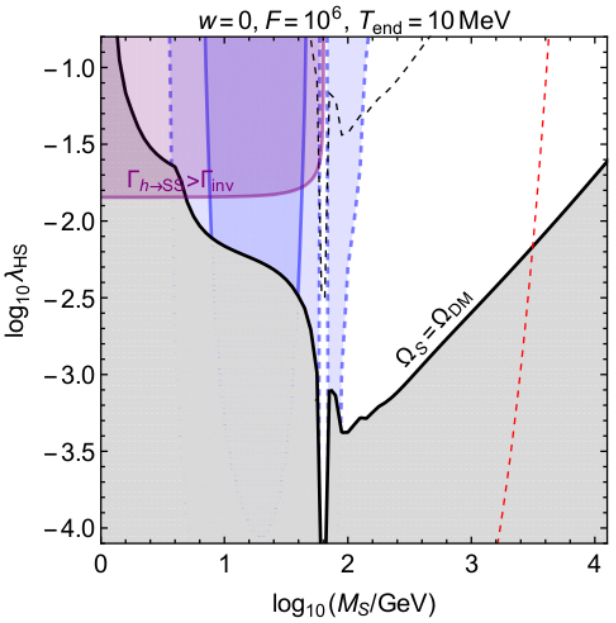


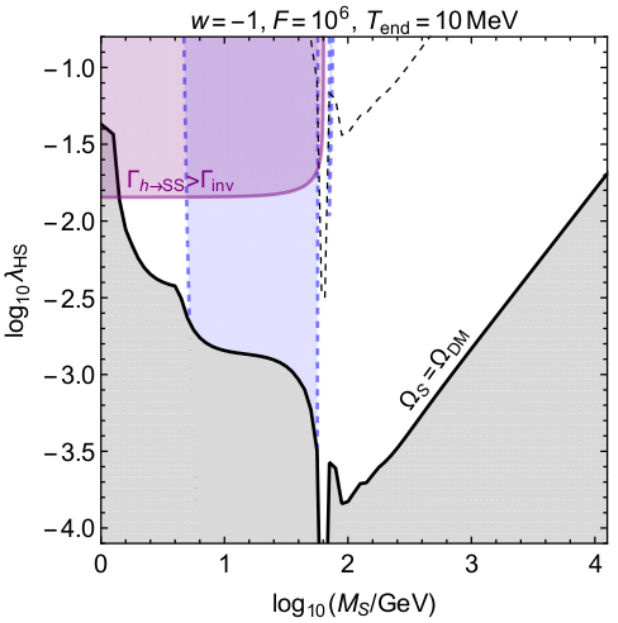
$$\frac{\mathrm{d}n_{\mathrm{S}}}{\mathrm{d}t} + 3Hn_{\mathrm{S}} = -\langle\sigma_{\mathrm{ann}}v\rangle\left[n_{\mathrm{S}}^2 - (n_{\mathrm{S}}^{\mathrm{eq}})^2\right]$$

Singlet Scalar DM: WIMP

Non-standard Cosmologies

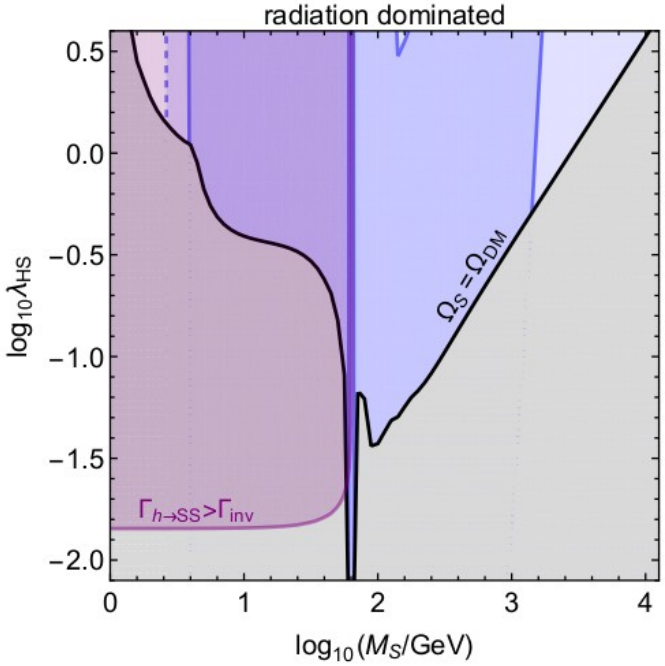


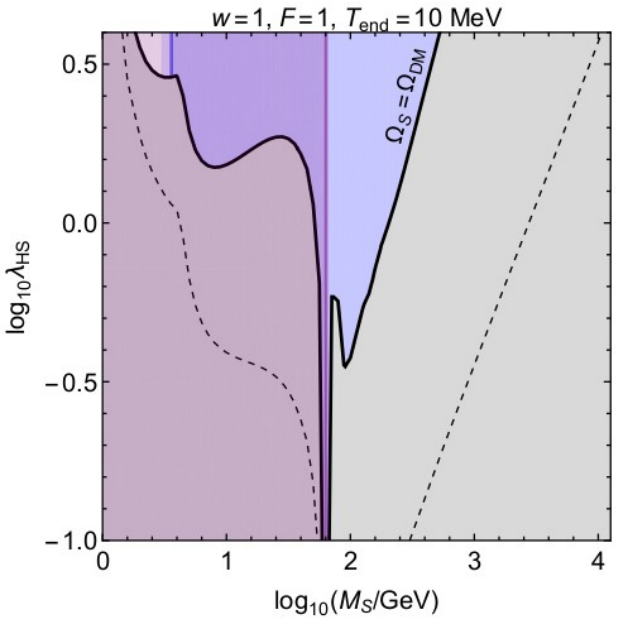




Singlet Scalar DM: WIMP

Non-standard Cosmologies





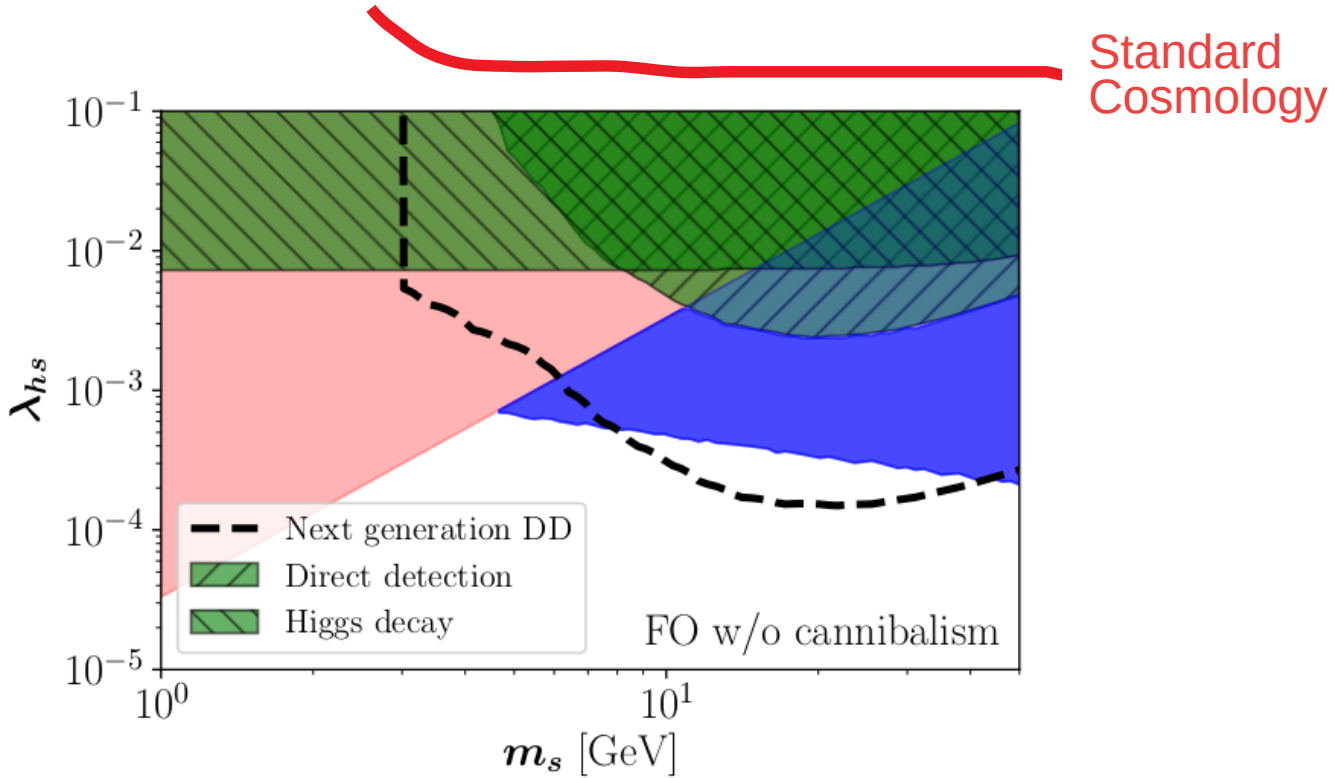
Singlet Scalar DM: WIMP

Non-standard Cosmologies in the WIMP scenario give two effects:

- The freeze-out temperature → Increases λ_{HS}
- The dilution due to decay of ϕ → Decreases λ_{HS} (typically dominant!)

Singlet Scalar DM: WIMP

Intensive scan for a Matter Dominated period



DM Production Mechanisms: FIMP

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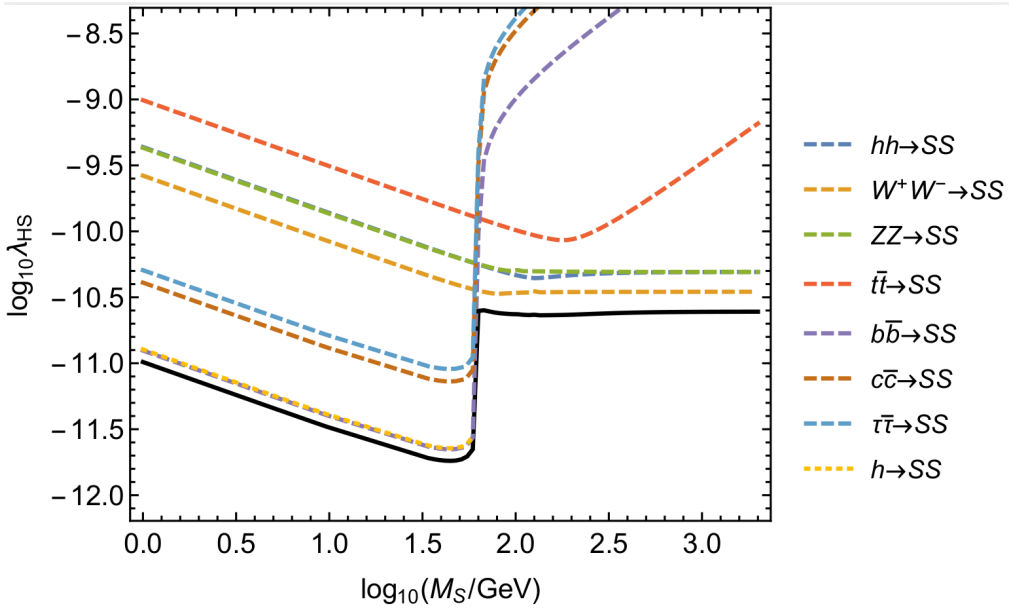
Singlet Scalar DM: FIMP

Usual case: Radiation Dominated Universe



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Singlet Scalar DM: FIMP

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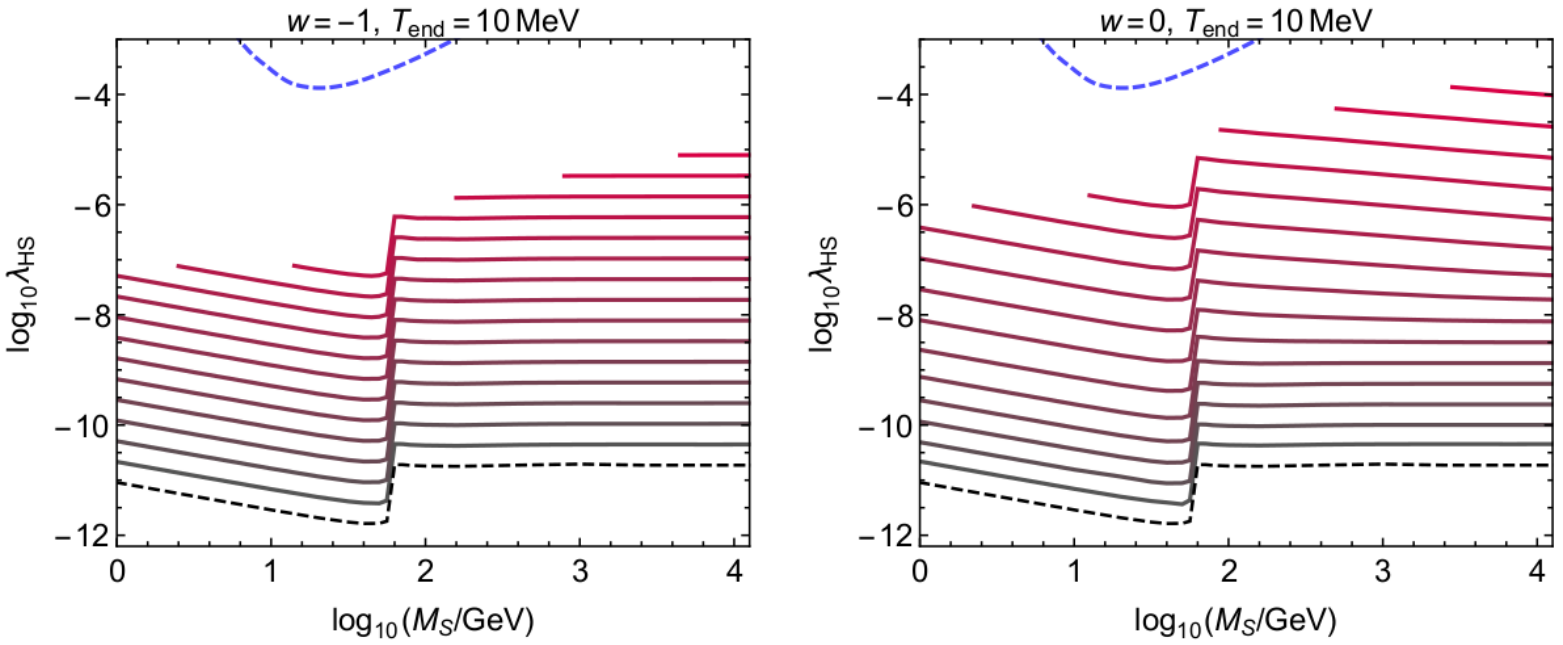


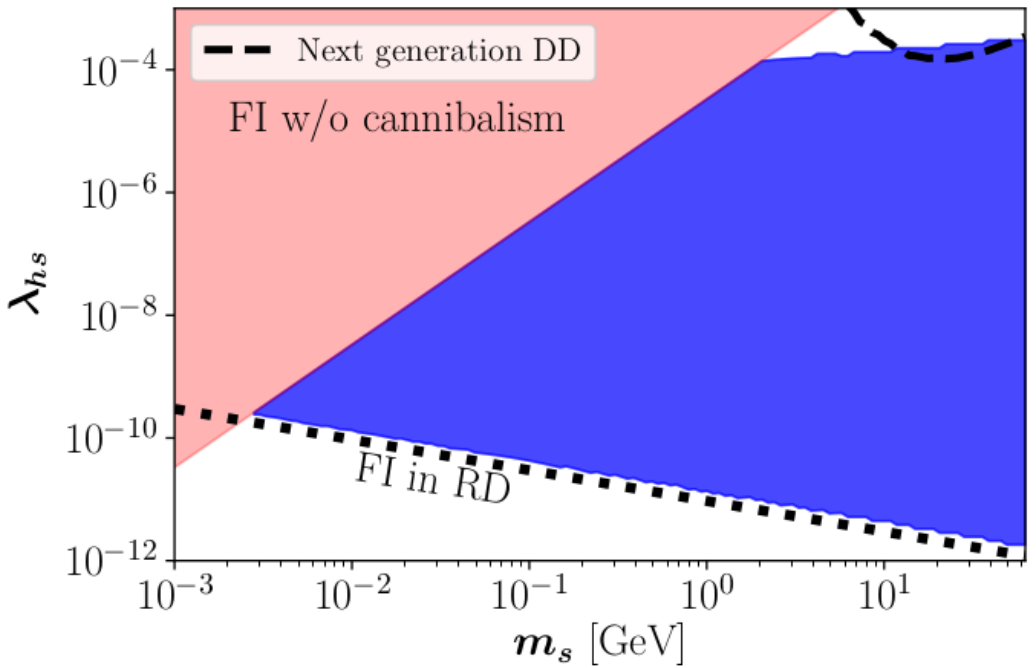
Singlet Scalar DM: FIMP

Non-standard Cosmologies in the FIMP scenario give two effects:

- Change on H → Increases λ_{HS}
- The dilution due to decay of ϕ → Increases λ_{HS}

Singlet Scalar DM: FIMP

Intensive scan for a Matter Dominated period

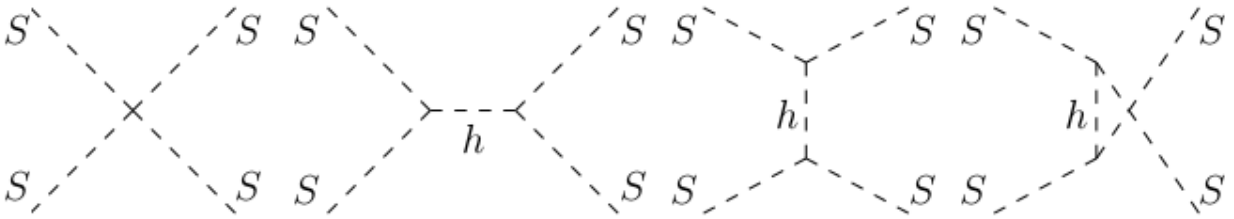


Conclusions & Outlook

- Dark Matter exists! Its nature is still unknown.
- Typically assumed that the Universe was radiation-dominated since the reheating era.
- But no indispensable reasons! Alternative cosmologies not only can lead to interesting observational ramifications but are also well-motivated.
- Two effects: * Freeze-out temperature
  * Dilution
- For WIMPs, couplings decreased → evade strong constraints :-)
- For FIMPs, couplings increased → boost detection possibilities :-)

Muchas gracias!

Dark Matter Self-Interactions



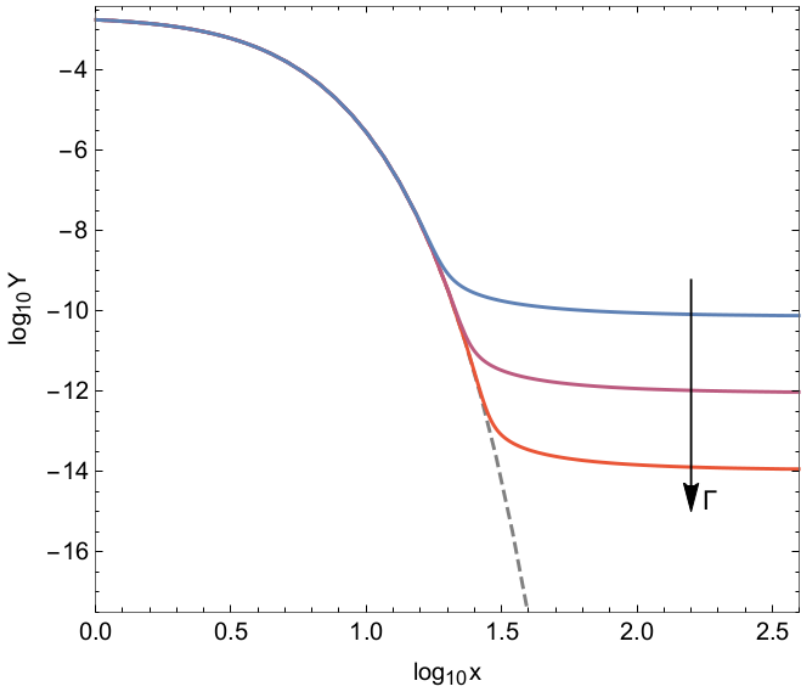
$$\frac{\sigma_{SS}}{m_S} \sim \frac{9}{8\pi}\,\frac{\lambda_S^2}{m_S^3}$$

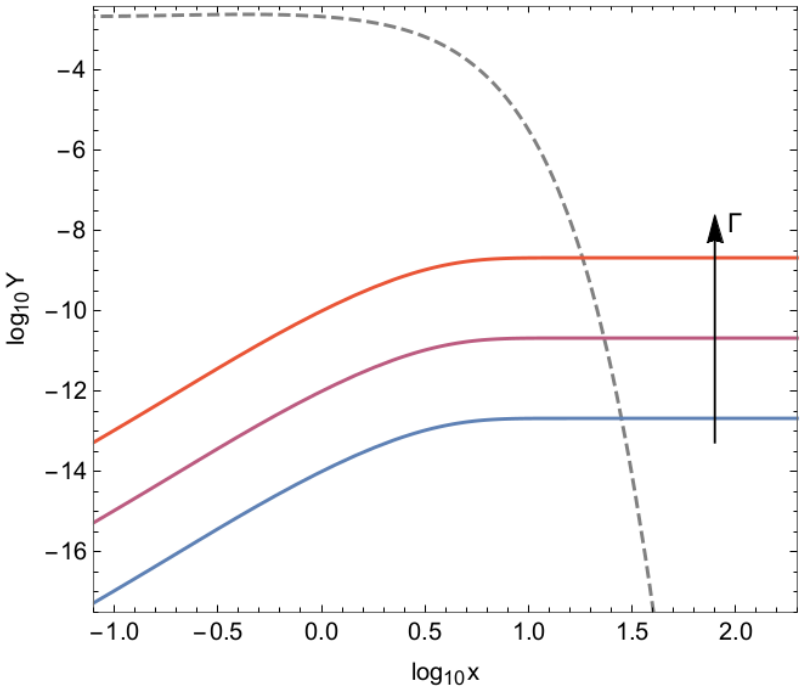
$$0.1 \lesssim \frac{\sigma_{SS}}{m_S} \lesssim 10\ \mathrm{cm}^2/\mathrm{g}$$

Implies
- $\lambda_S \sim 1$
- $m_s \sim 100$ MeV

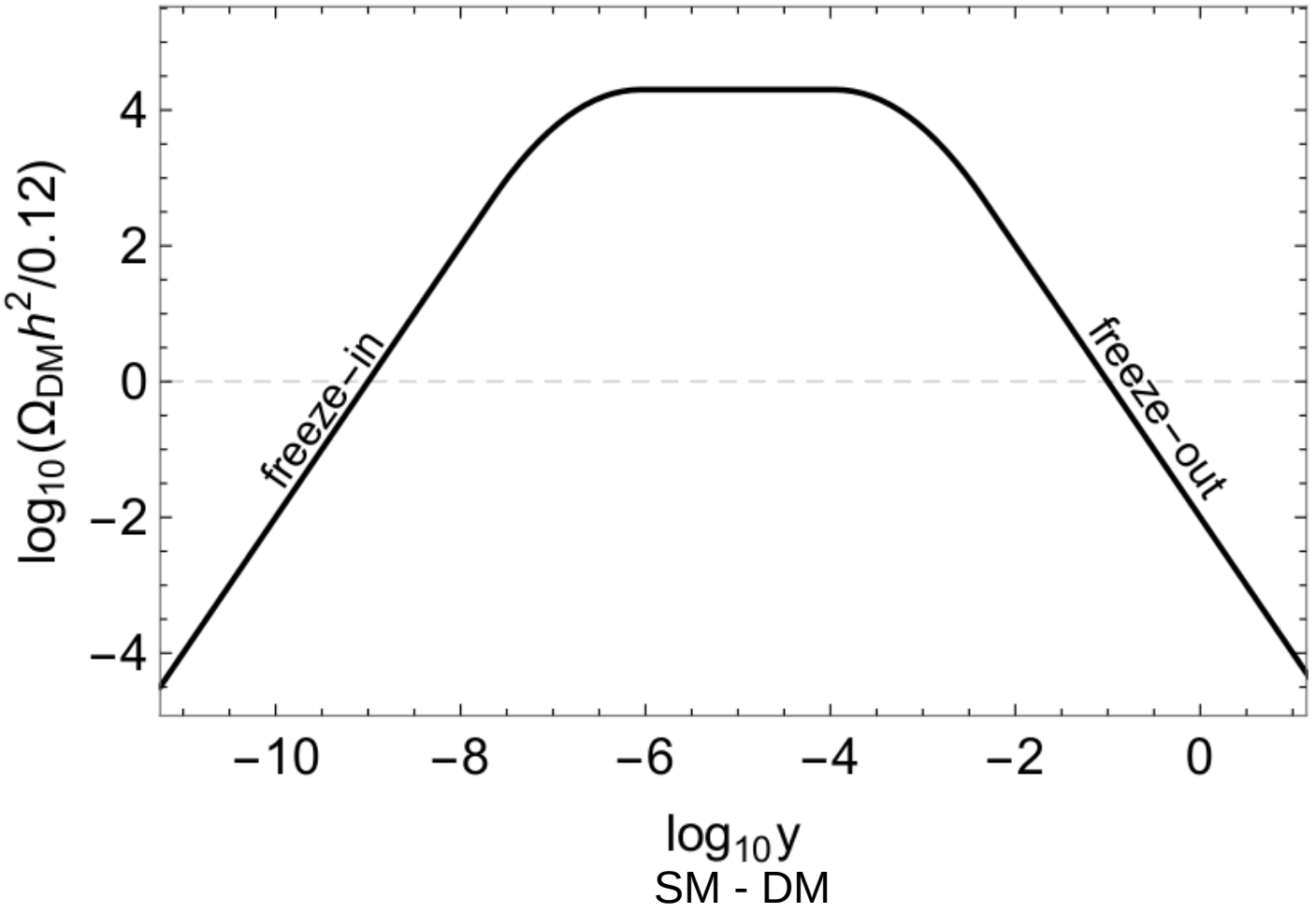
WIMP vs FIMP Dark Matter

$$\frac{dn_\chi}{dt} + 3\,H\,n_\chi = -\langle v\sigma_\chi\rangle\left[n_\chi^2 - (n_\chi^{\rm eq})^2\right]$$





FIMP / WIMP Dark Matter



SM - DM