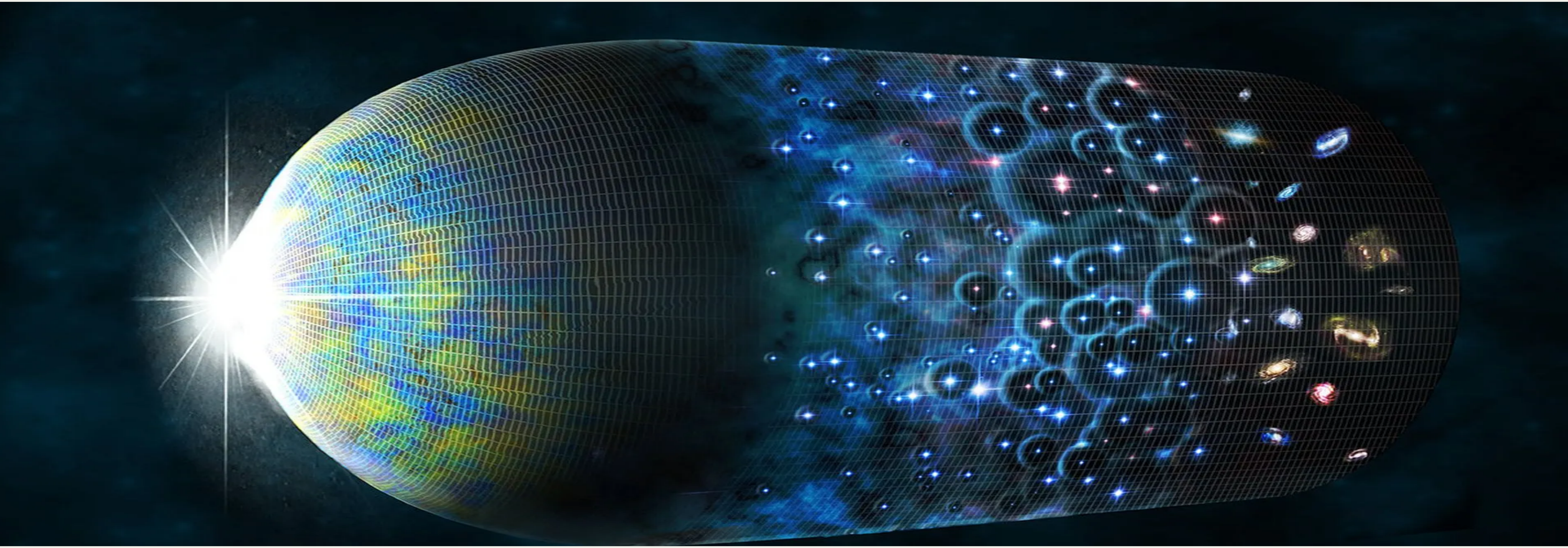
Dark Matter production after Inflaton Fragmentation

Francisco Barreto Basave

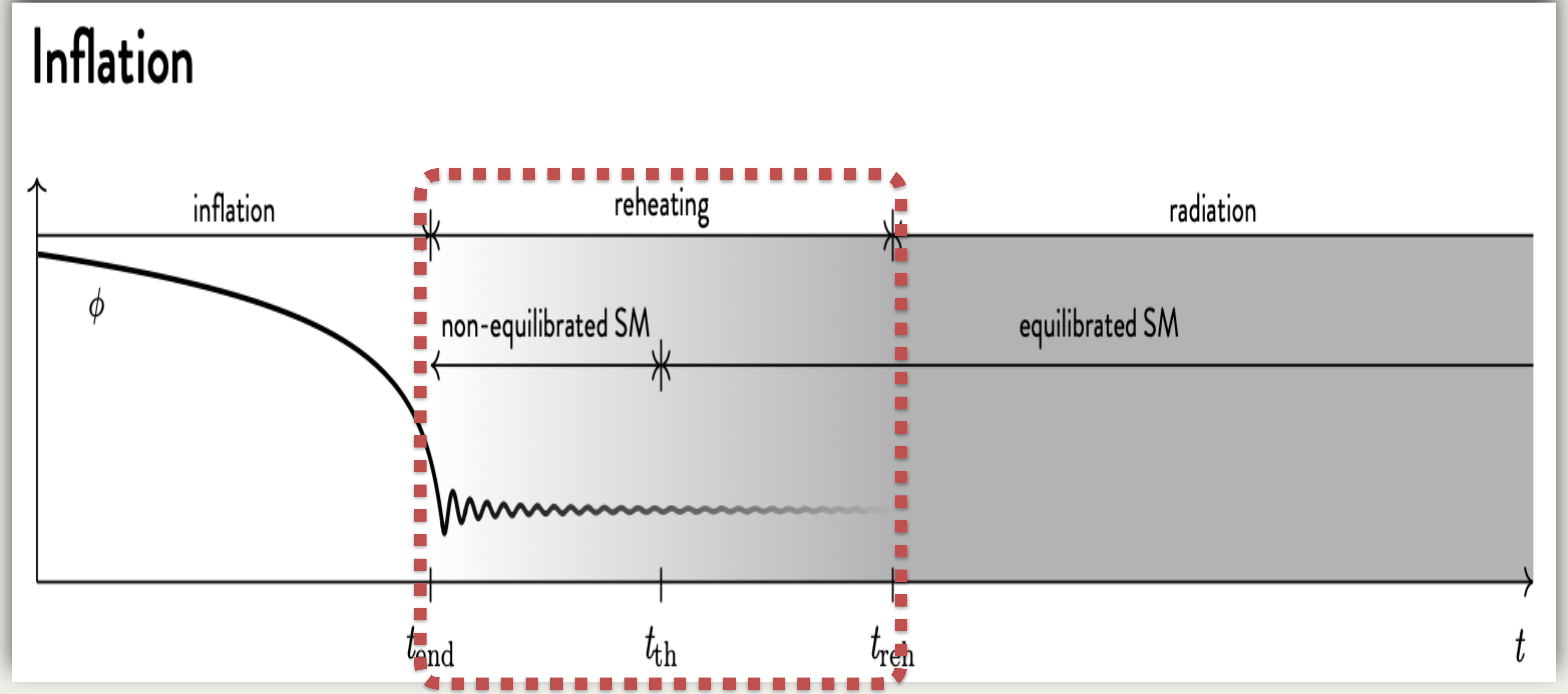


Advisor: Marcos Alejandro García García

SUSY 2024 Theory Meets Experiment

June 10, 2024

The need for Reheating



Inflaton field evolution, from inflation to radiation domination

Dark Matter

After phase space integration, Boltzmann equation in FLRW reads:

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

Notation:

$n_\chi = n_{DM} \equiv n,$

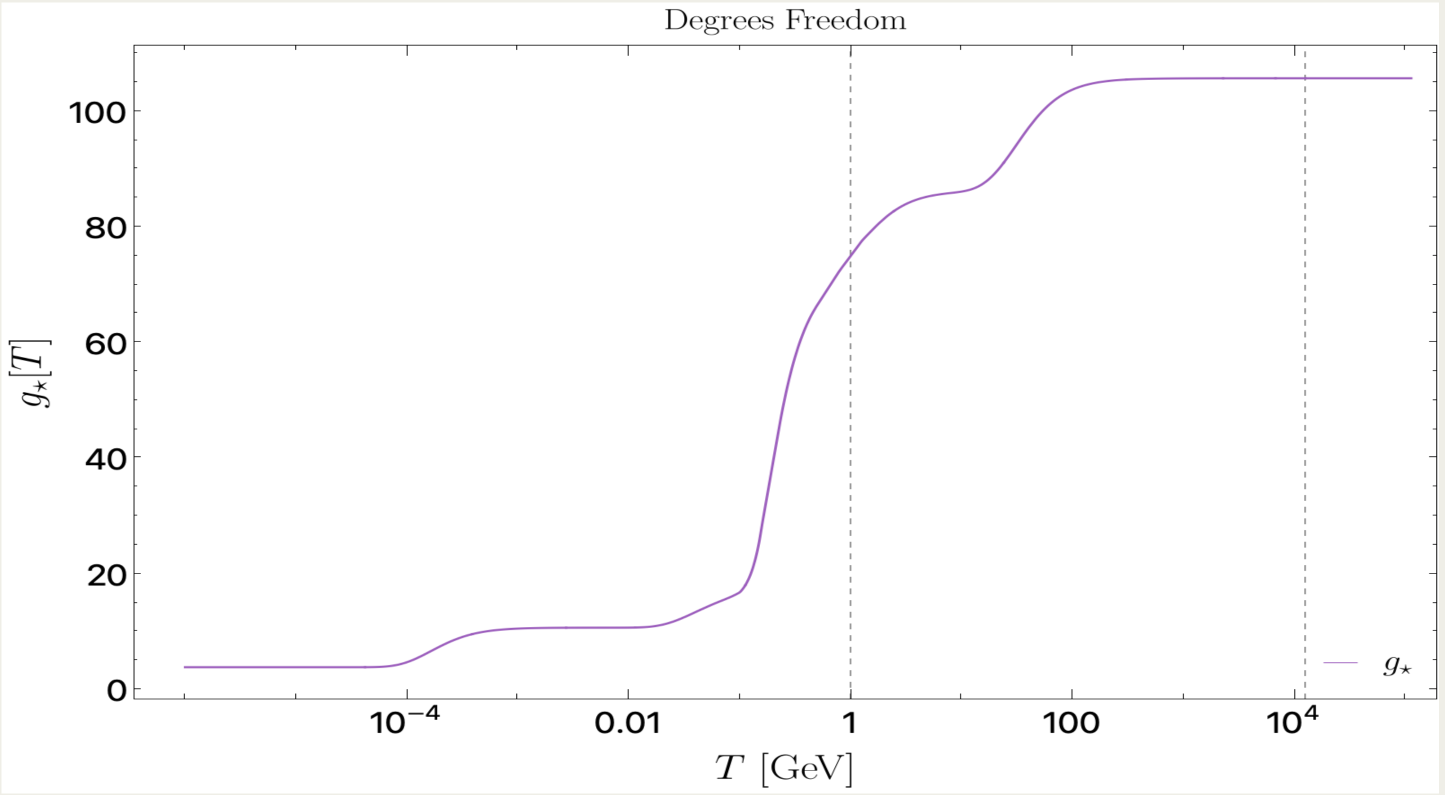
$\langle\sigma_{\chi\chi\to\gamma\gamma}v\rangle \equiv \langle\sigma v\rangle$

We define the yield as: $Y \equiv \frac{n}{T^3}$, using e-folds $N \equiv \ln\left(\frac{a}{a_{end}}\right)$,

$$\frac{dY}{dN} + 3Y\left(1 + \frac{1}{T}\frac{dT}{dN}\right) = \frac{\langle\sigma v\rangle T^3}{H(N)}\left(Y_{eq}^2 - Y^2\right).$$

The Temperature is given by

$$T = \left(\frac{30}{\pi^2 g_\star}\rho_R\right)^{\frac{1}{4}},$$



arXiv.astro-ph/0304281v2

Reheating [arXiv.hep-ph/2012.10756v2]

Radiation energy density satisfies the next Boltzmann equation:

$$\frac{d\rho_R}{dt} + 4H\rho_R = +\frac{2k}{2+k}\Gamma_\phi \rho_\phi,$$

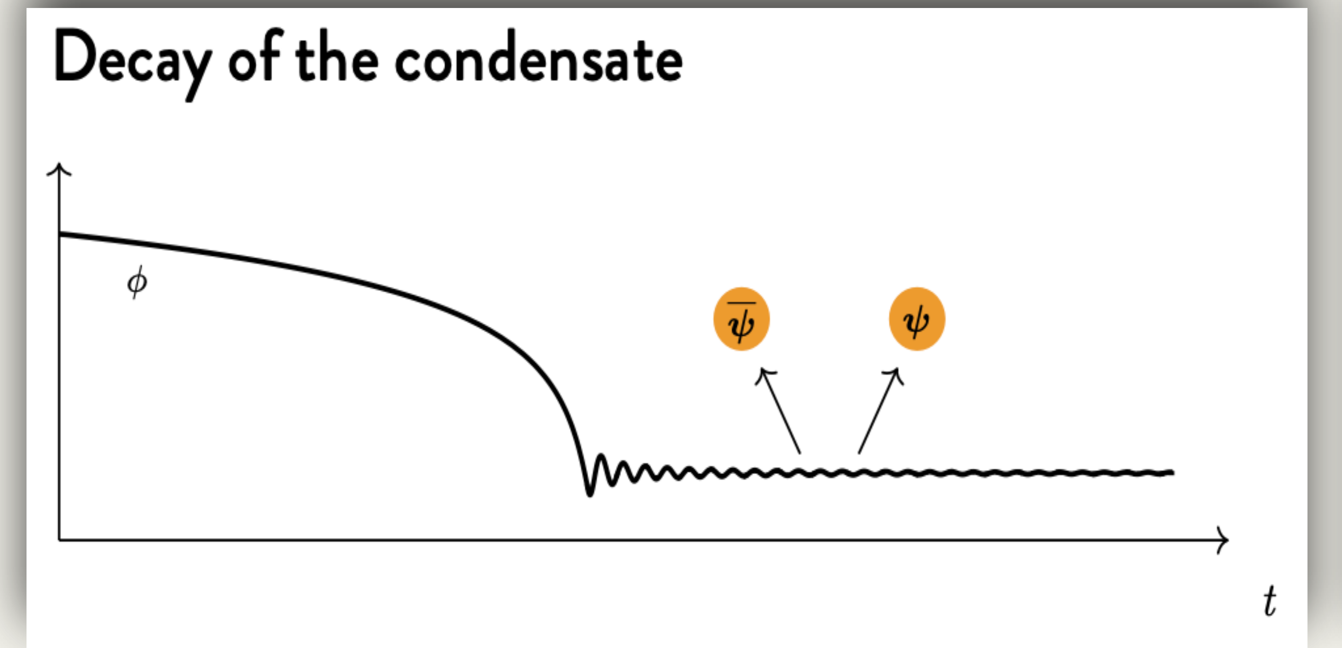
The inflaton energy density satisfies Boltzmann's equation:

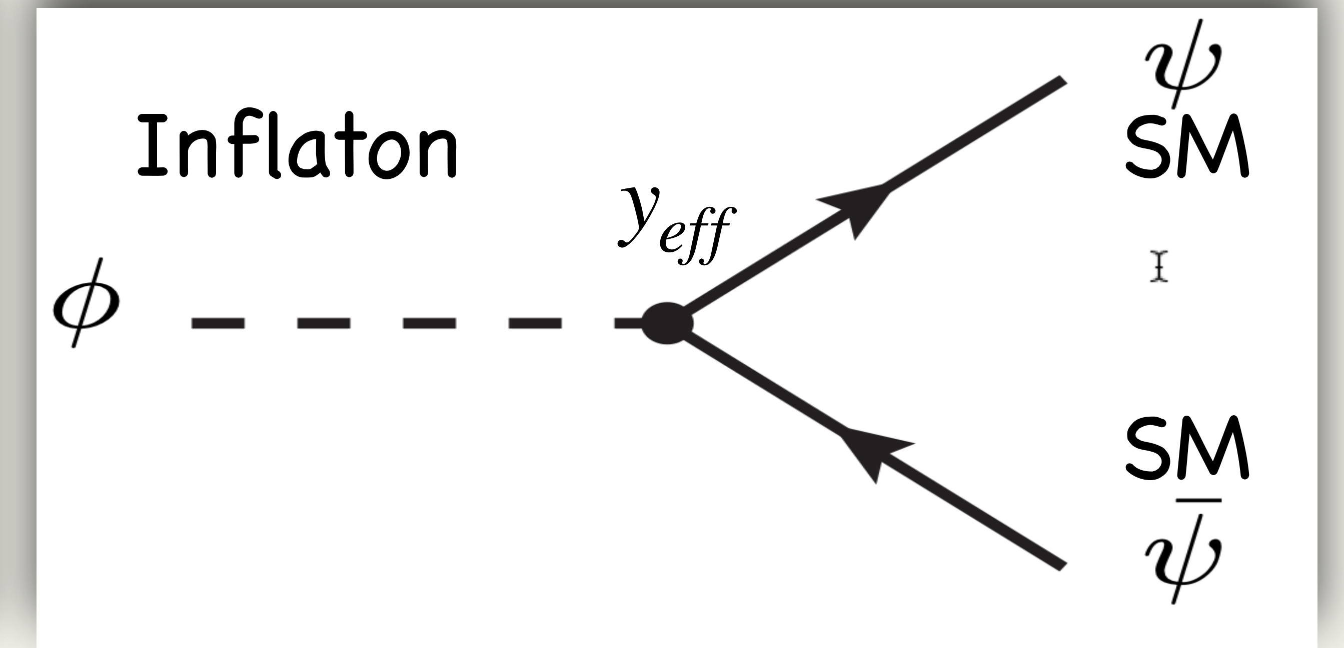
$$\frac{d\rho_\phi}{dt} + \frac{6k}{k+2}H\rho_\phi = -\frac{2k}{2+k}\Gamma_\phi \rho_\phi,$$

Finally, Friedmann's equation:

$$H^2 = \frac{1}{3Mpl^2}\left(\rho_\phi + \rho_R\right),$$

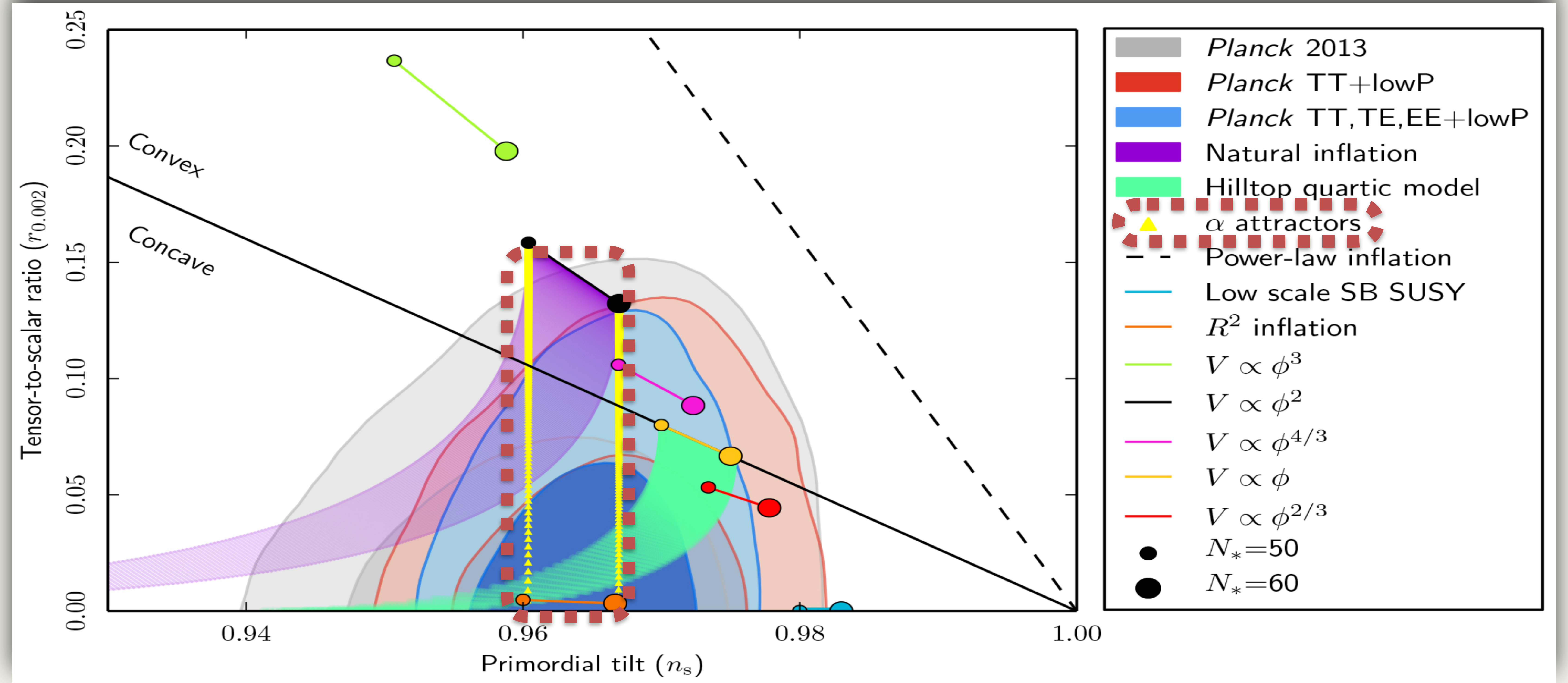
Considering a Yukawa coupling by the Inflaton to SM fermions,





$$\Gamma_\phi = \frac{y_{eff}^2}{8\pi} m_\phi,$$

Inflationary Models [arXiv.astro-ph.CO/1502.02114]



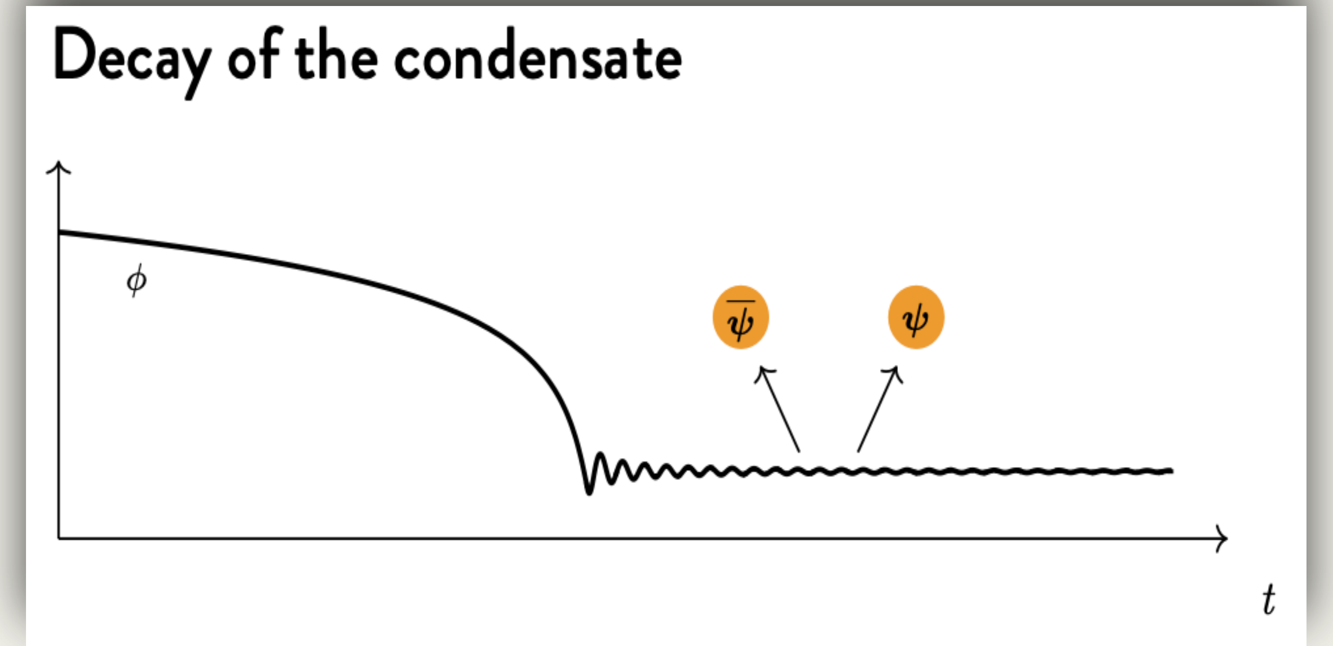
$$V = \lambda M_{pl}^4 \left[\sqrt{6}\tanh\left(\frac{\alpha\phi}{\sqrt{6}M_{pl}}\right)\right]^k \approx \lambda \frac{\phi^k}{M_{pl}^{k-4}}, \qquad \lambda = \frac{18\pi^2 As}{6^{\frac{k}{2}} * Ns^2}$$

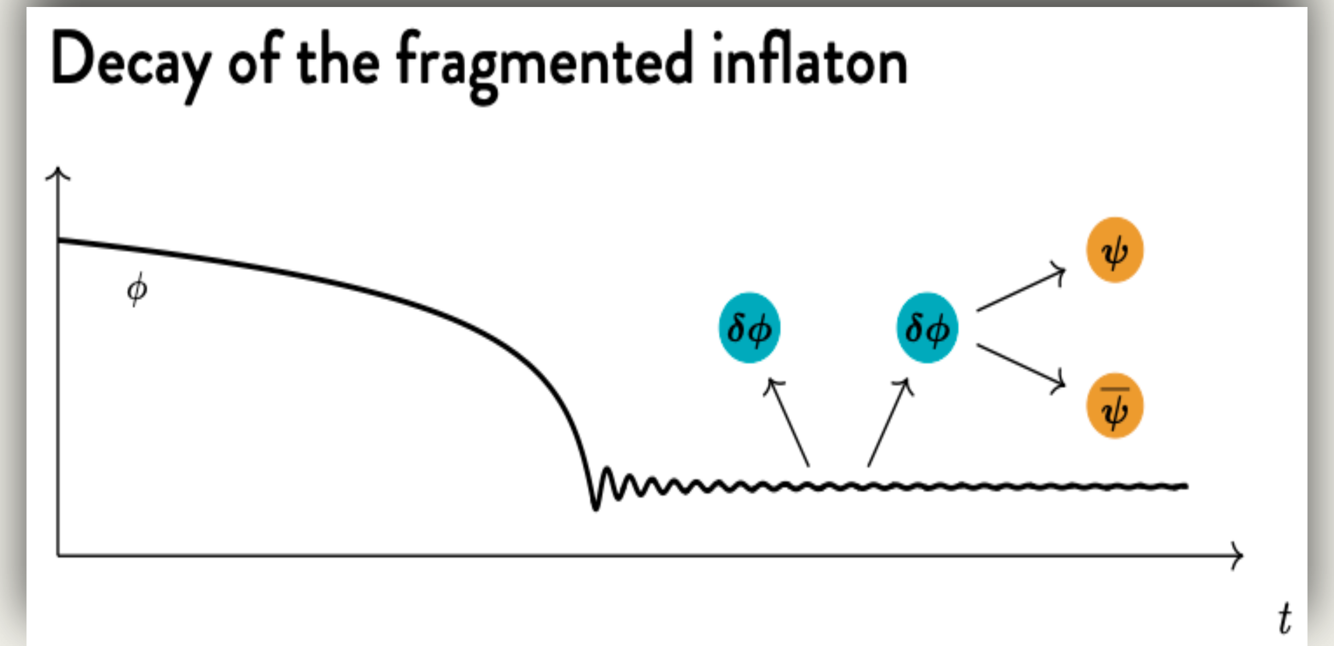
Planck 2015 results. XX. Constraints on inflation.

Inflaton Fragmentation [arXiv.hep-ph/2306.08038v2]

R.H.S. of the Boltzmann eq. for the inflaton $\phi = \phi(t) + \delta\phi(x,t)$

$$R(t) = \int \frac{d^3p}{(2\pi)^3} P^0 C = R_\phi + R_{\delta\phi},$$





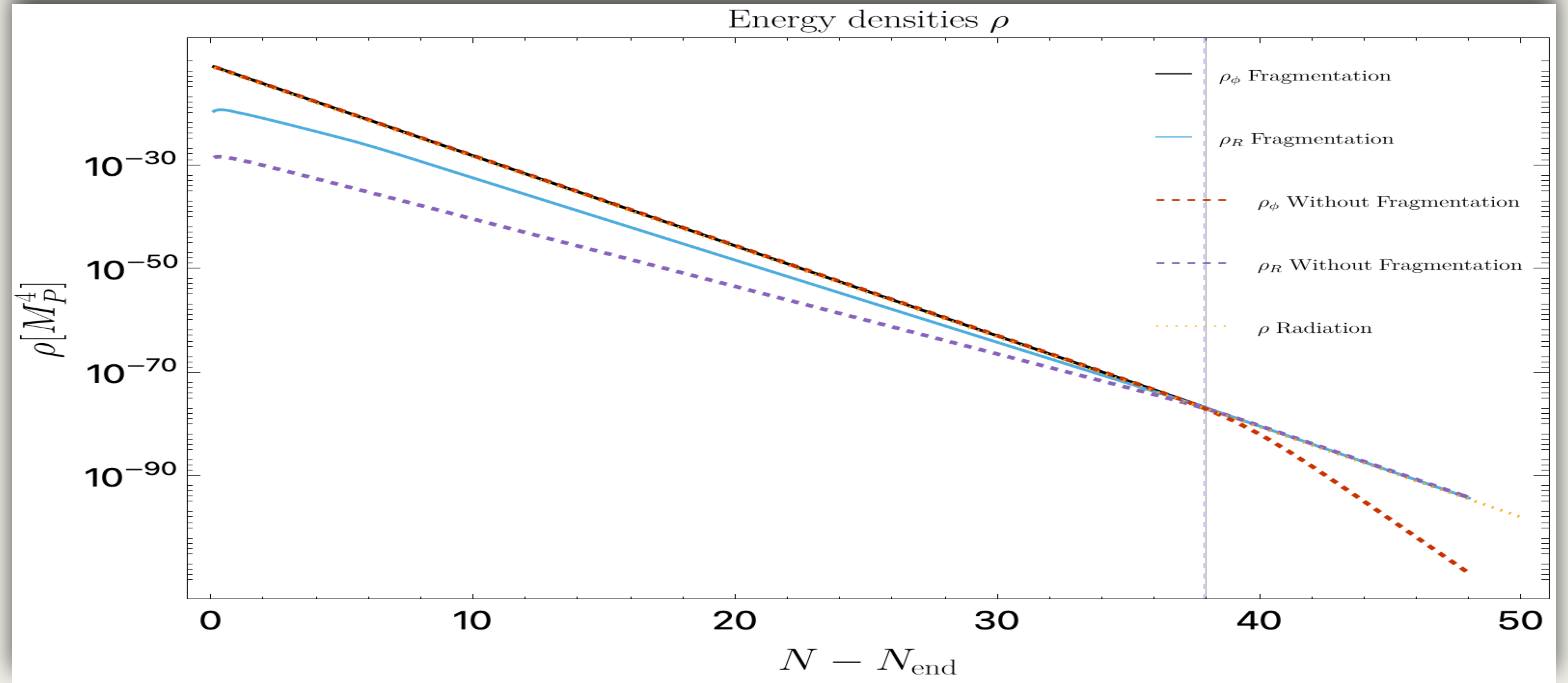
$$C_{\delta\phi} = \frac{1}{P^0} \int \Pi_k \Pi_{p'} (2\pi)^4 \delta^4 \left(k - p - p'\right) \left| M_{\delta\phi \to \bar{\psi}\psi} \right|^2 f_{\delta\phi}(k)$$

$$R(t) = \frac{y^2}{8\pi} m_\phi \left(\frac{4}{3} \alpha^2 \bar{\rho}_\phi + n_{\delta\phi} m_\phi \right).$$

Results

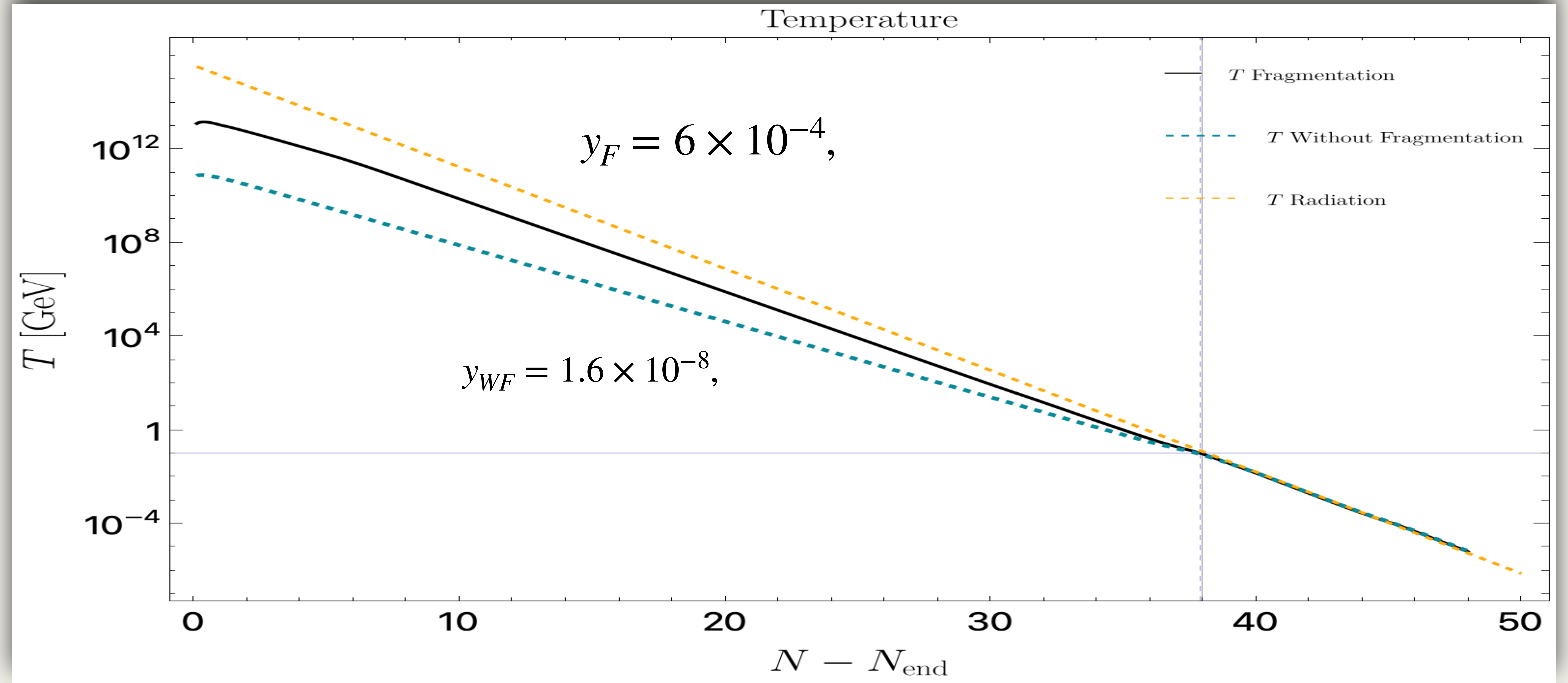
$k = 4$

Energy densities



Radiation and Inflaton energy densities during reheating in the case k = 4. Numerical Solution.

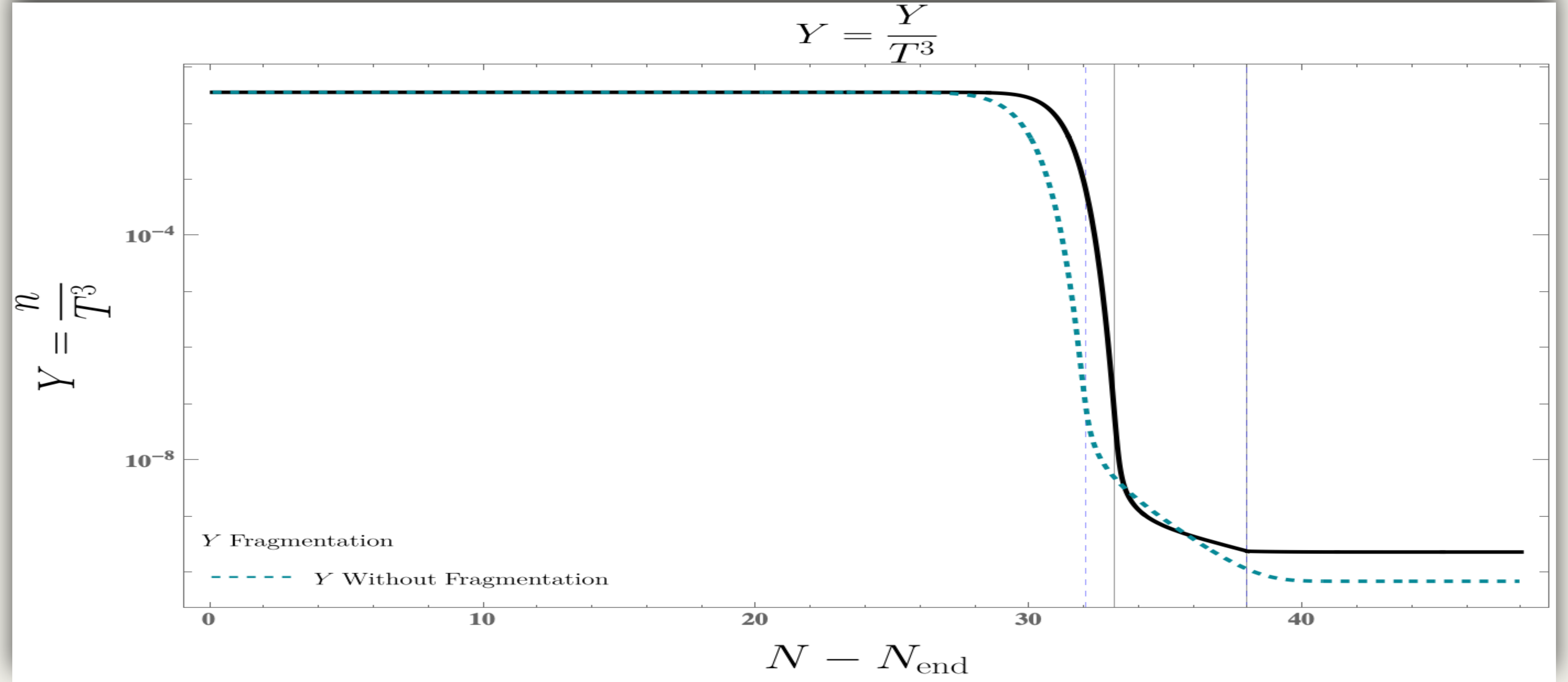
Temperature



Temperature as a function of number of e-folds during reheating in k = 4.

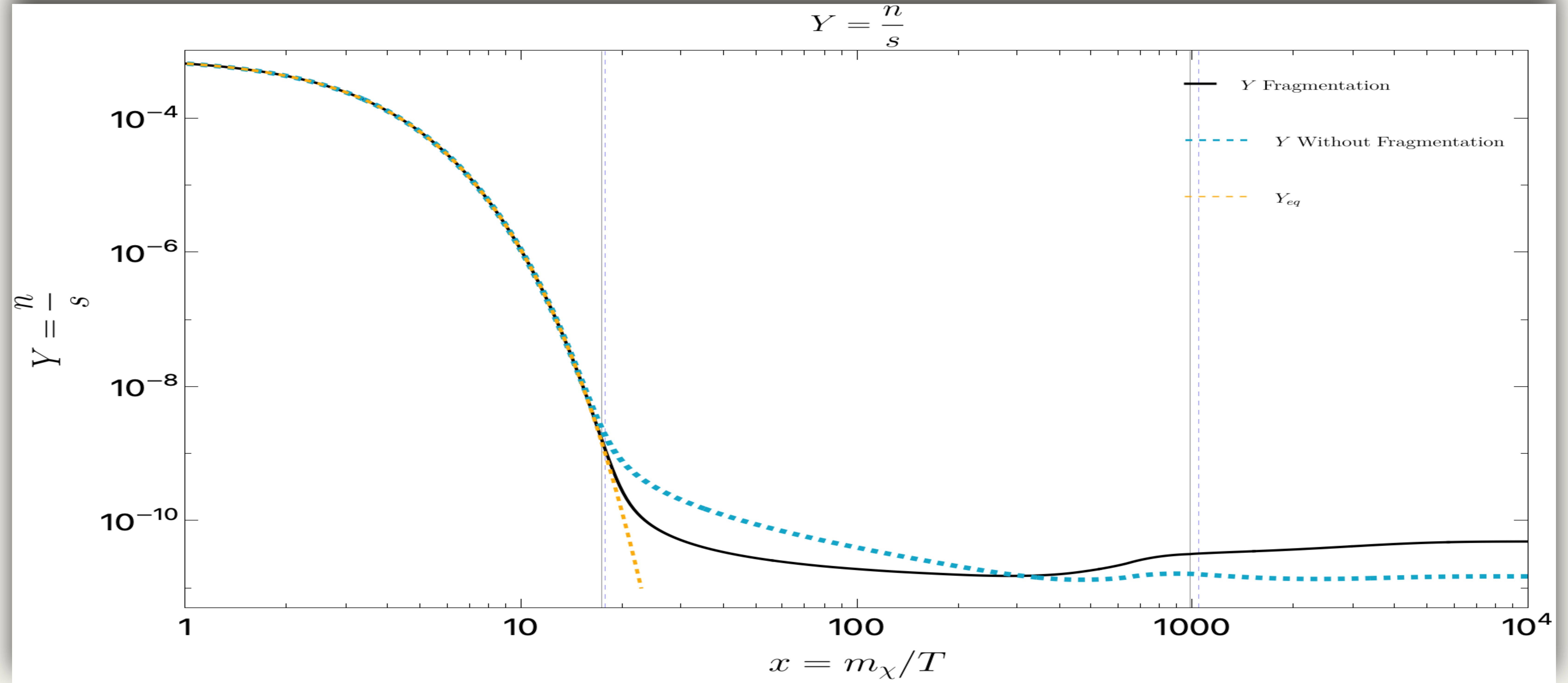
$\langle \sigma v \rangle = 0.1$ GeV

DM Yield



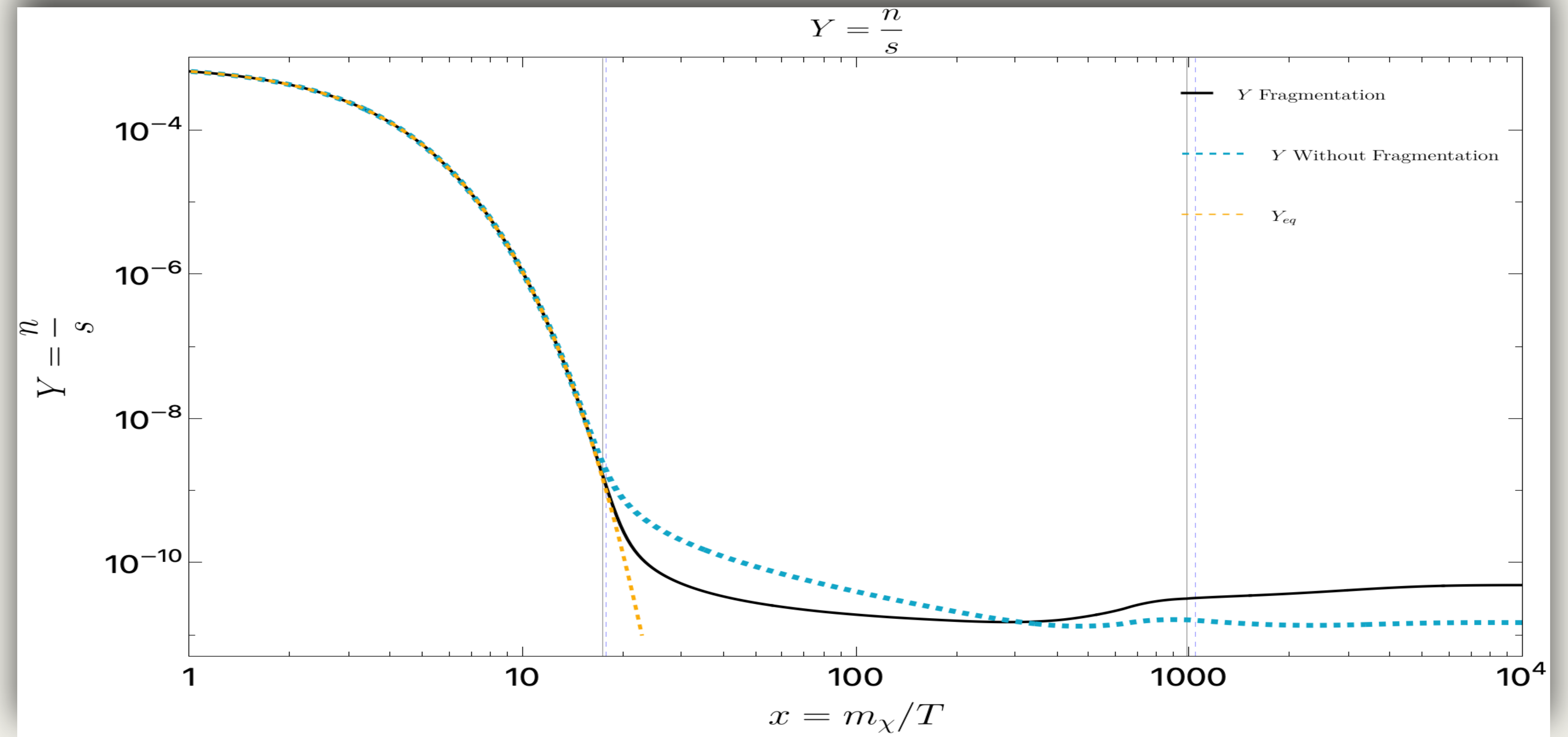
DM Yield, in Black is with Fragmentation and the blue dashed line corresponds to reheating without fragmentation.

DM Yield



DM Yield, in Black is with Fragmentation, in blue dashed line corresponds to reheating without fragmentation and in Yellow the equilibrium yield.

Dark matter relic density



$$\Omega_{DM}h^2 = \frac{\rho_{DM}}{\rho_c h^{-2}} = \frac{m_{DM} Y^0_{DM} s_0}{\rho_{c,0} h^{-2}} = \begin{cases} \Omega_{DM}h^2 = 0.123489 & \text{With Fragmentation,} \\ \Omega_{DM}h^2 = 0.0371646 & \text{Without Fragmentation,} \end{cases}$$

$$\Omega_{DM}h^2 = 0.1430 \pm 0.0011 \text{ Planck's result.}$$

arXiv.astro-ph.CO/1807.06209v4

Conclusion

The evolution of the radiation bath depends on the spin of the SM particles at the final state.

DM is out thermal equilibrium before radiation domination.

DM yield changes when considering fragmentation.

Thank you!

Gracias!

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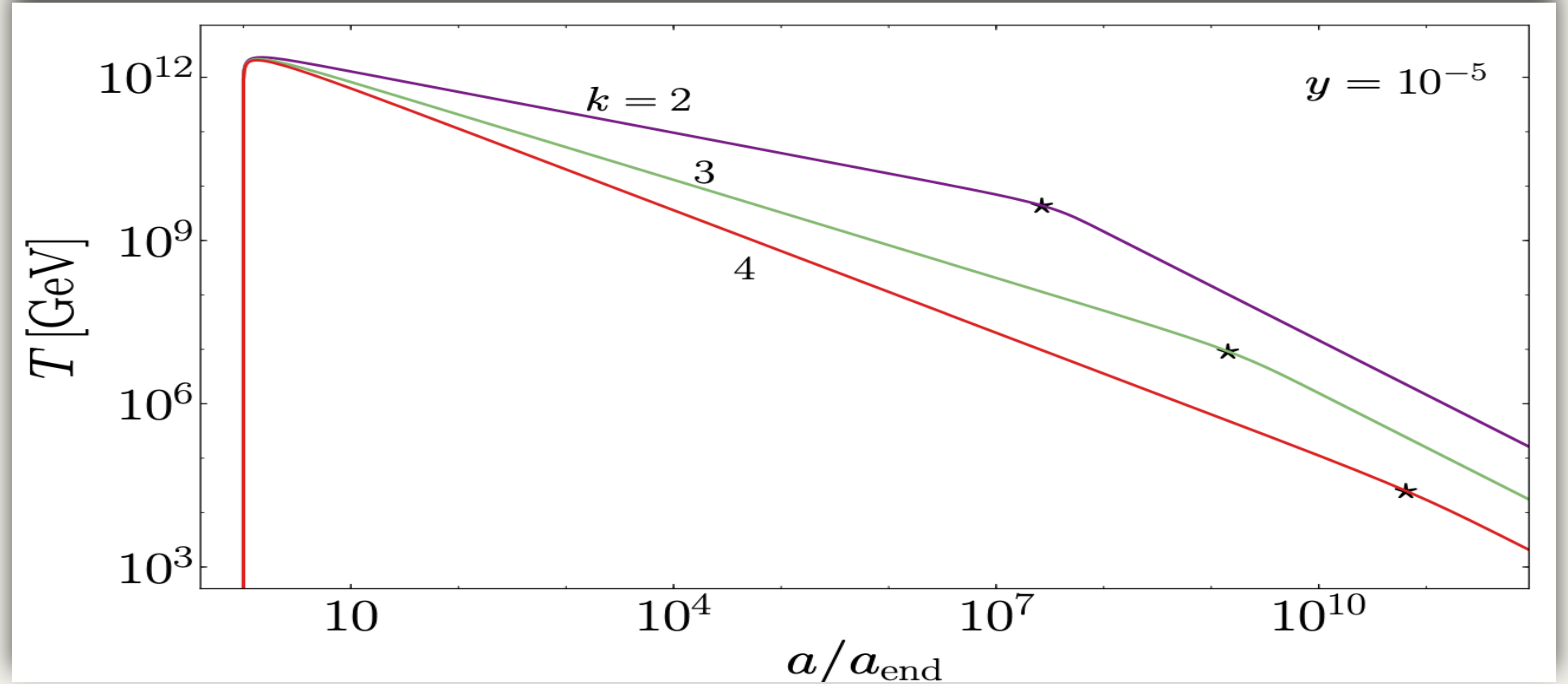
June 10, 2024

Temperature



Temperature during reheating as a function of scale factor and a generic k.
arXiv.astro-ph/2011.14861v2.