Inflationary Constraints on Late Time Modulus Dominated Cosmology

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arXiv: 1409.7037

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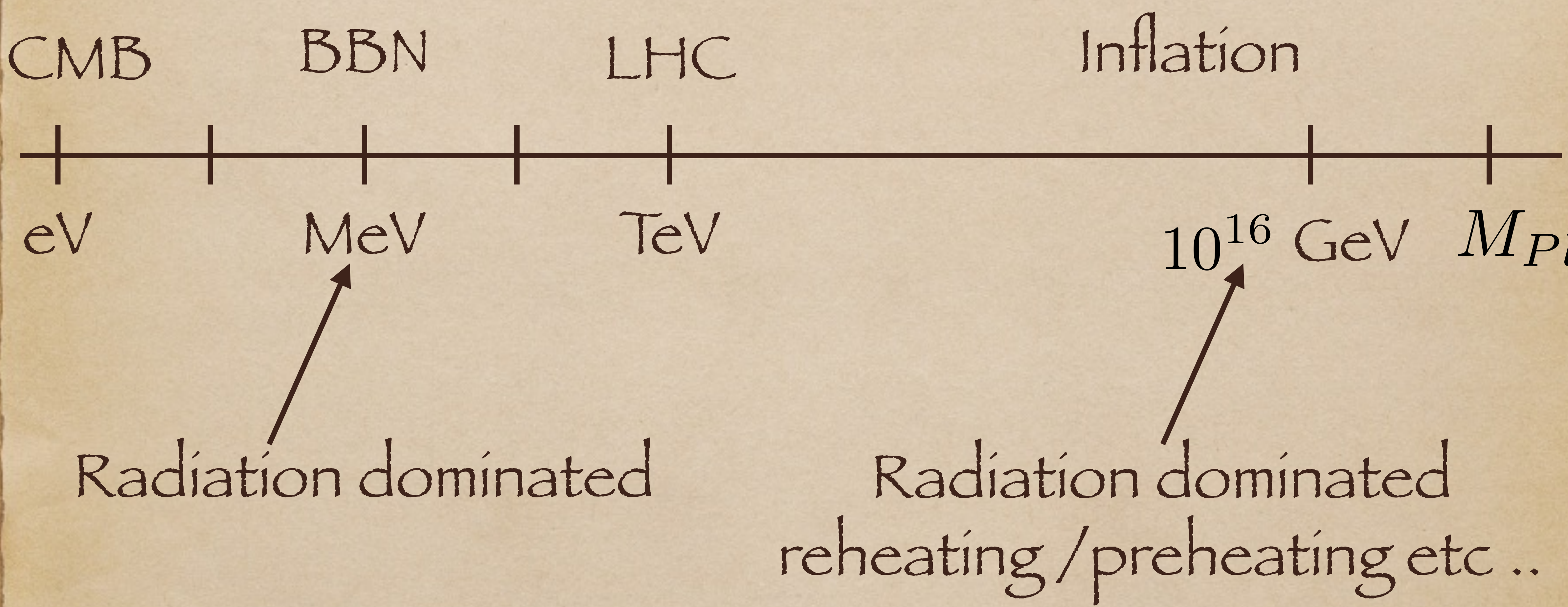
Cosmic History

Not to scale



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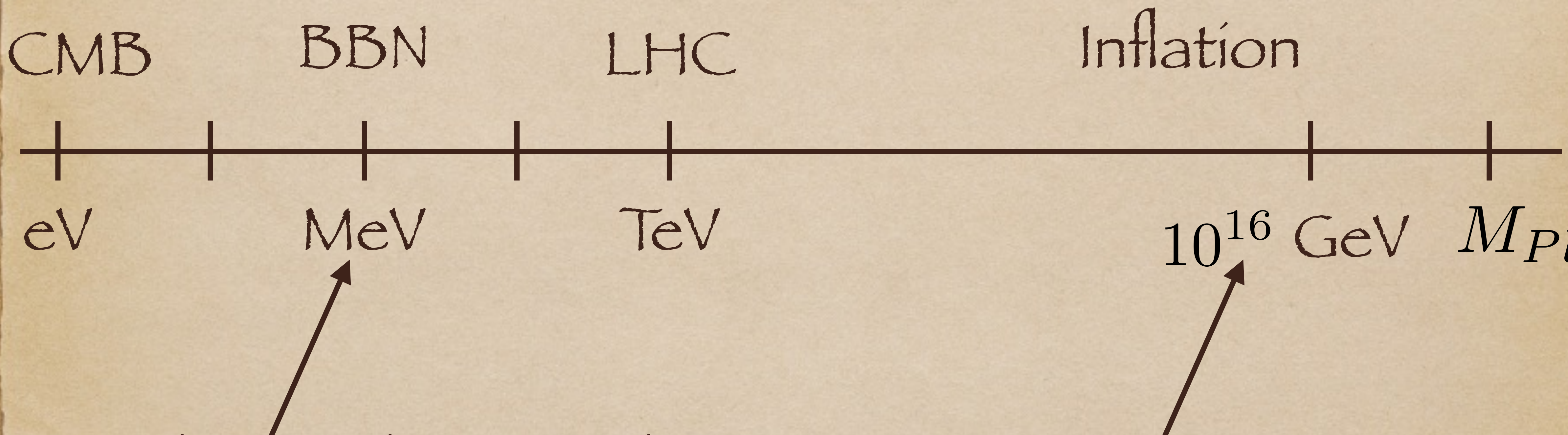

Radiation dominated

Radiation dominated
reheating /preheating etc ..

No observational evidence between
MeV and Inflationary scale

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Late Decaying Field

$$\Gamma_\varphi \sim \frac{m_\varphi^3}{M_{Pl}^2}$$

Planck suppressed couplings

e.g moduli, flat directions

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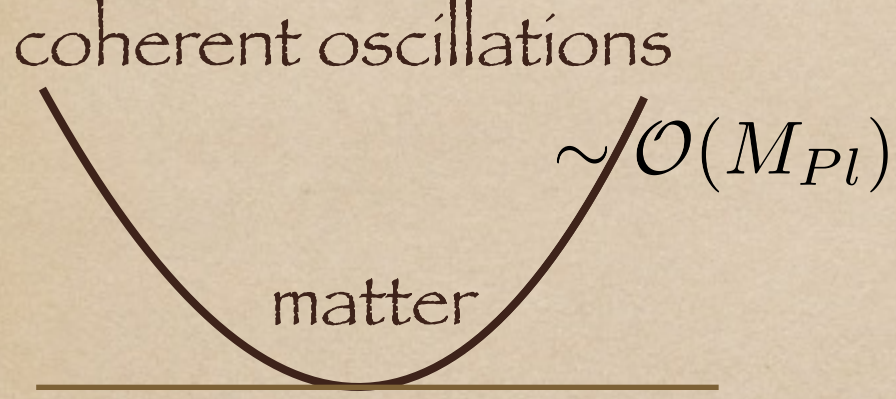


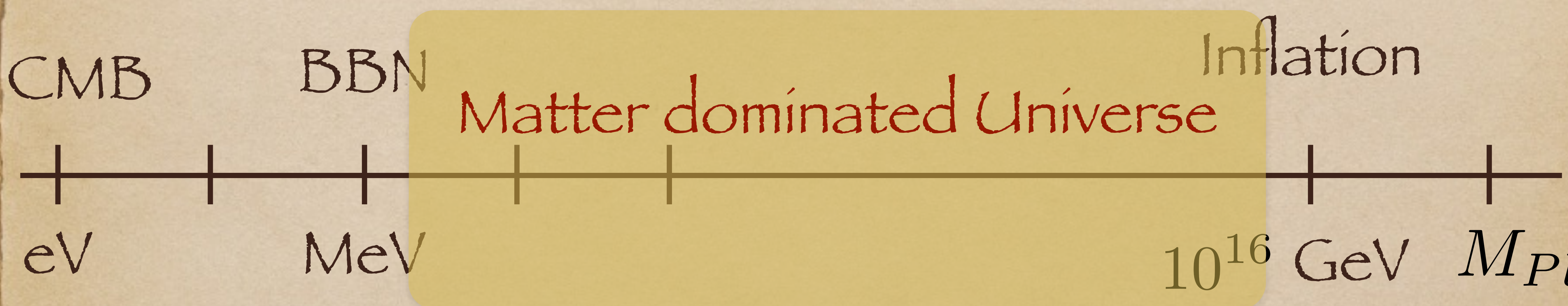
$$T_{RH} \sim 10^{-3}\ MeV \left(\frac{m_\varphi}{1\ TeV}\right)^{3/2}$$

$$m_\varphi > \mathcal{O}(100 TeV)$$

Cosmological moduli problem (CMP)

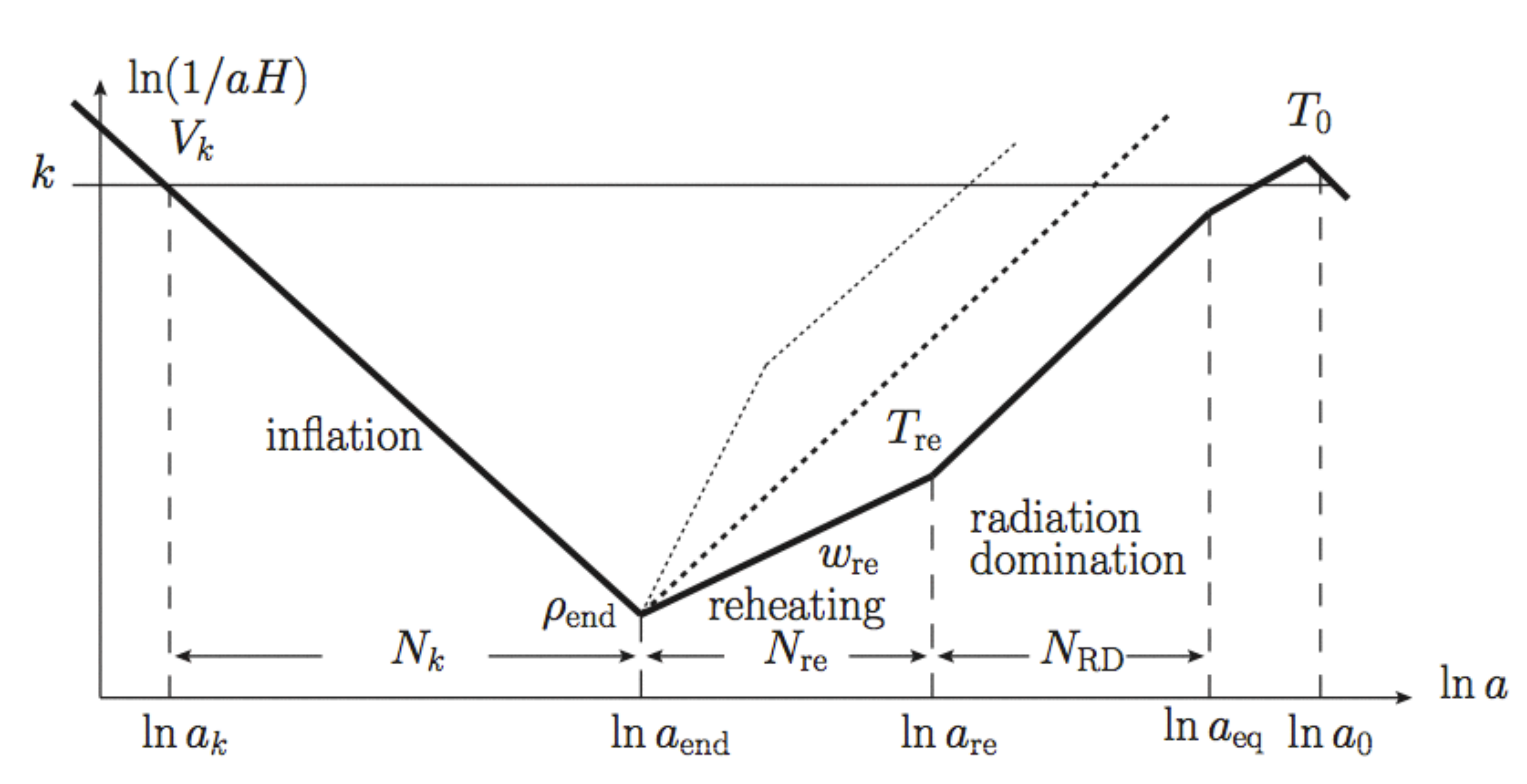
Coughlan, Fischler, Kolb, Raby, Ross
Banks, Kaplan, Nelson
Carlos, Casas, Quevedo

Non-standard History



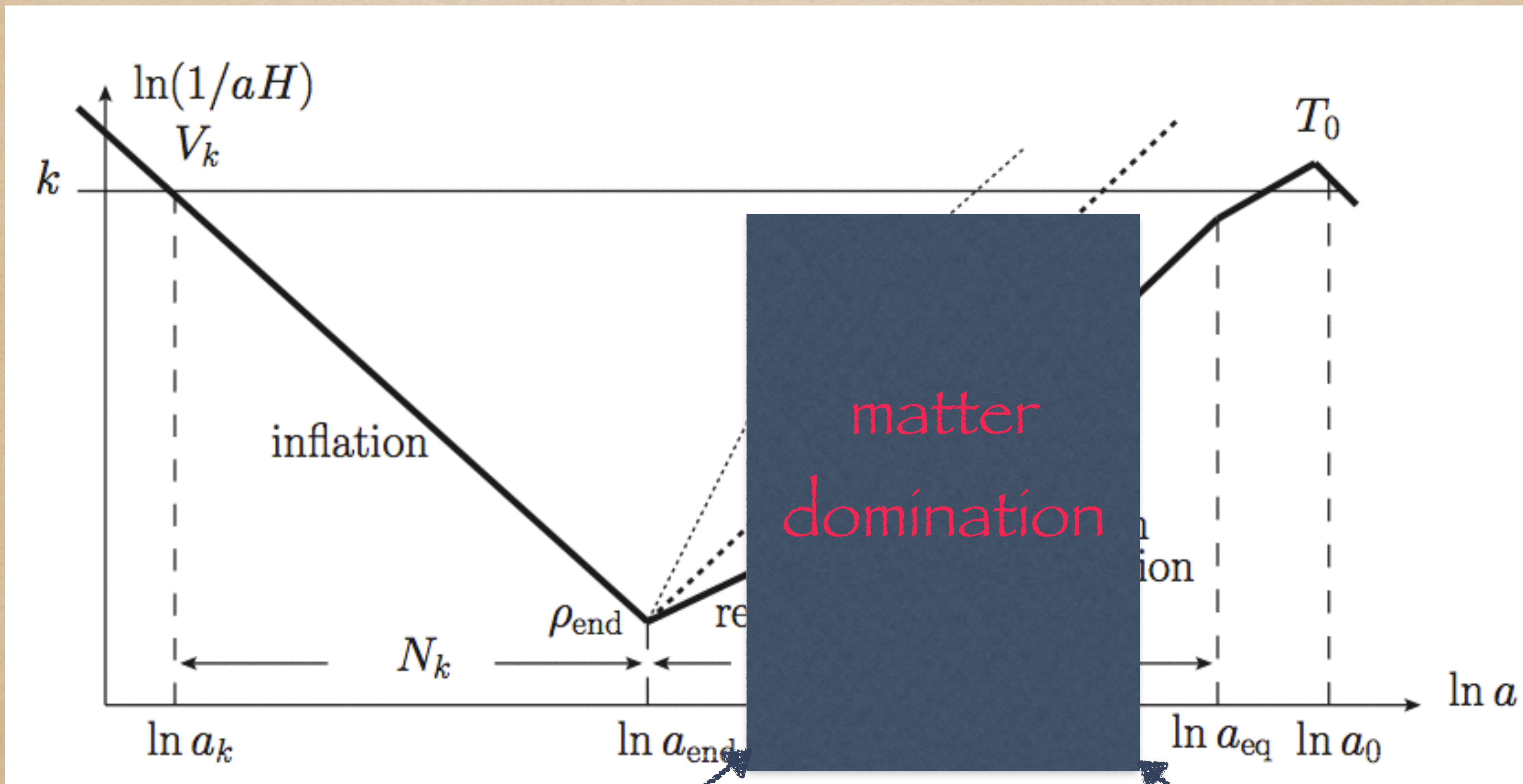
Phenomenology: Boby Acharya, Gordy Kane, Piyush Kumar, Kuver Sinha, Bhaskar Dutta, Michele Cicoli, Scot Watson, R. Allahverdi ....

Track your modes: Standard



arXiv:1404.6704

Track your modes



reheating ends

φ decays

Track your modes

$$k = a_\mathrm{k} H_\mathrm{k}$$

$$k = \frac{a_\mathrm{k}}{a_\mathrm{end}} . \frac{a_\mathrm{end}}{a_\mathrm{re}} . \frac{a_\mathrm{re}}{a_\mathrm{eq}} . \frac{a_\mathrm{eq}}{a_\mathrm{decay}} . a_\mathrm{decay} H_k$$

$$N_\mathrm{matdom} = -N_\mathrm{k} - N_\mathrm{re} - N_\mathrm{rad} - \ln k + \ln(a_\mathrm{decay}) + \ln H_k$$

Track your energy densities

$$-N_{\rm matdom} = \frac{1}{3}\ln\left(\frac{\rho^{\rm matter}_{\rm decay}}{\rho^{\rm matter}_{\rm eq}}\right)$$

$$\rho^{\rm matter}_{\rm decay} \approx \rho_{\rm decay} = \left(\frac{\pi^2}{30}\right) g_{\rm rh2} T^4_{\rm rh2}$$

$$T_{\rm rh2} = \left(\frac{43}{11 g_{\rm s,rh2}}\right)^{1/3} (a_0/a_{\rm decay})\, T_0$$

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$$\ln(\rho^{\rm matter}_{\rm eq}) = \ln\left(\frac{\rho^{\rm radiation}_{\rm eq}}{\rho_{\rm re}}\right) + \ln\left(\frac{\rho_{\rm re}}{\rho_{\rm end}}\right) + \ln(\rho_{\rm end})$$

$$-\frac{3}{4}N_{\rm matdom} = \frac{1}{4}\ln\left(\frac{\pi^2 g_{\rm rh2}}{30}\right) + \frac{1}{3}\ln\left(\frac{43}{11 g_{\rm s,rh2}}\right) + \ln\left(\frac{a_0 T_0}{a_{\rm decay}}\right) + N_{\rm rad}$$
$$-\frac{1}{4}\ln(\rho_{\rm end}) + \frac{3}{4}(1+w_{\rm re})N_{\rm re}$$

combine ..

$$\frac{1}{4}N_{\rm matdom} = \frac{1}{4}\ln\left(\frac{\pi^2 g_{\rm rh2}}{30}\right) + \frac{1}{3}\ln\left(\frac{43}{11 g_{\rm s,rh2}}\right) - N_k - \ln\left(\frac{k}{a_0 T_0}\right) + \ln H_k - \frac{1}{4}\ln(\rho_{\rm end}) - \frac{1}{4}(1-3w_{\rm re})N_{\rm re}$$

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$$\frac{1}{4}N_{\rm matdom} = \frac{1}{4}\ln\left(\frac{\pi^2 g_{\rm rh2}}{30}\right) + \frac{1}{3}\ln\left(\frac{43}{11 g_{\rm s,rh2}}\right) - N_k - \ln\left(\frac{k}{a_0 T_0}\right) + \ln H_k - \frac{1}{4}\ln(\rho_{\rm end}) - \frac{1}{4}(1-3w_{\rm re})N_{\rm re}$$

Independent condition:

$$N_{\rm matdom} = -\frac{2}{3}\ln 3 - \frac{5}{3}\ln 2 + \frac{2}{3}\ln m_\varphi \tau + \frac{8}{3}\ln Y$$

initial displacements

Constraint

$$\frac{1}{6}\ln\left(\frac{16\pi M_{Pl}^2}{m_\varphi^2}\right)+\frac{1}{4}(1-3w_{\rm re})N_{\rm re}+\frac{2}{3}\ln Y=55.43+\frac{1}{4}\ln r-N_k-\frac{1}{4}\ln\left(\frac{\rho_{\rm end}}{\rho_{\rm k}}\right)$$

post inflationary physics　　　　inflationary physics

Constraint

$$\frac{1}{6}\ln\left(\frac{16\pi M_{Pl}^2}{m_\varphi^2}\right) + \frac{1}{4}(1-3w_{\rm re})N_{\rm re} + \frac{2}{3}\ln Y = 55.43 + \frac{1}{4}\ln r - N_k - \frac{1}{4}\ln\left(\frac{\rho_{\rm end}}{\rho_{\rm k}}\right)$$

post inflationary physics

inflationary physics

$$m_\varphi \gtrsim \sqrt{16\pi} M_{\rm pl} Y^2 \; e^{-3\left(55.43 - N_k + \frac{1}{4}\ln(\rho_{\rm k}/\rho_{\rm end}) + \frac{1}{4}\ln r\right)}$$

model independent constraint

surveying models ..

polynomial: $N = \frac{1}{2}\frac{\alpha + 2}{1 - n_s}$ natural inflation $\alpha = 2$

Hilltop $V(\phi) \sim \Lambda\left(1 - \frac{\phi^n}{\mu^n} + ...\right)$ $n \geq 4$ PLANCK

$$N = \frac{2(n-1)}{n-2}\frac{1}{1-n_s}$$

Hybrid $N = \left(1 + \frac{3}{2}\alpha\right)\frac{1}{1-n_s}$

R + R^2 .. Higgs inflation ..

LVS fibre inflation

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PLANCK $n_s - 1 = -0.0397 \pm 0.0073$

EUCLID/PRISM error $\sim 10^{-3}$

'small field' case ..

$$m_\varphi \gtrsim \sqrt{16\pi} M_{\rm pl} Y^2 e^{-3\left(54.28 - N_{\rm k}\right)} \qquad r \sim 0.01$$

‘small field’ case ..

$$m_\varphi \gtrsim \sqrt{16\pi} M_{\rm pl} Y^2 e^{-3\left(54.28 - N_{\rm k}\right)} \qquad r \sim 0.01$$

$$N_{\rm k} \approx \frac{\beta}{1 - n_s} \qquad n_s = 0.9603 \qquad \beta \approx 2$$

PLANCK central value

$$N_k \sim 50, \qquad Y \sim 1/10$$

$$m_\varphi \gtrsim 4.5 \times 10^8 \ \text{TeV}$$

robust constraint - independent of CMP

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robust constraint - independent of CMP

PLANCK upper limit: super heavy modulus

PLANCK lower limit: $m_\varphi \gtrsim 0.1 \ \text{TeV}$

‘large field’ case ..

polynomial potential

$$N_{\rm k} = \frac{(2+\alpha)}{2(1-n_s)}, \quad r = \frac{8\alpha(1-n_s)}{(\alpha+2)}$$

$$m_\varphi \gtrsim \sqrt{16\pi} M_{\rm pl} Y^2 e^{-3\left(55.85 - \frac{(2+\alpha)}{2(1-n_s)}\right)}$$

$$\alpha = 2 \qquad\qquad m_\varphi \gtrsim 10^7 \ \text{TeV}$$

for linear potential CMP bound stronger

PLANCK $n_s - 1 = -0.0397 \pm 0.0073$

EUCLID/PRISM error $\sim 10^{-3}$

Conclusion

arXiv: 1409.7037

- late decaying scalar field generic in BSM physics
- non-thermal matter dominated universe

inflationary constraint

$$m_\varphi \gtrsim \sqrt{16\pi} M_{\rm pl} Y^2 \; e^{-3\left(55.43 - N_k + \frac{1}{4}\ln(\rho_{\rm k}/\rho_{\rm end}) + \frac{1}{4}\ln r\right)}$$

independent of CMP constraint

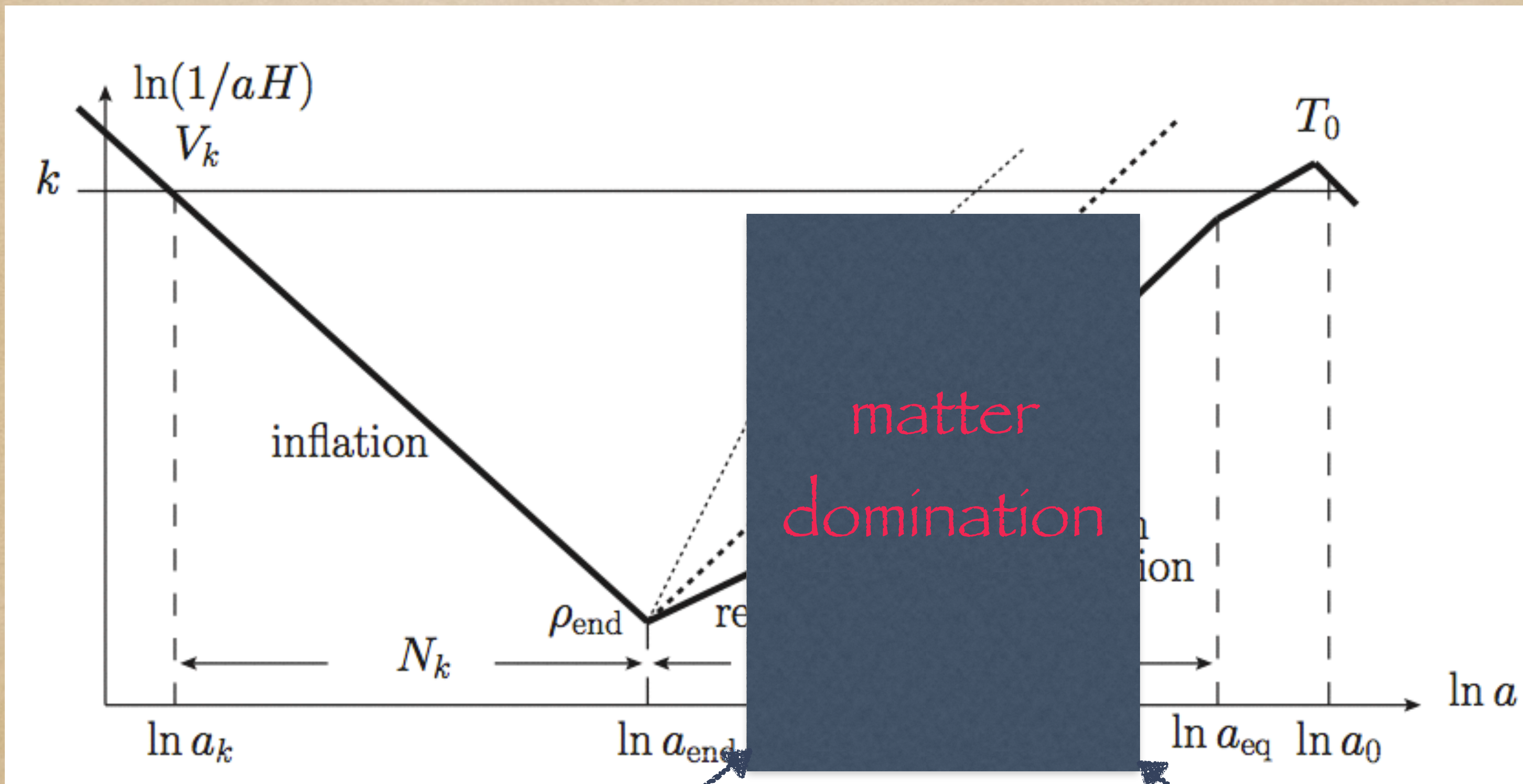
- for some inflationary models it is very stringent

  - exponential sensitivity

  e.g quadratic potential $m_\varphi \gtrsim 10^7 \text{ TeV}$

- relevance to SUSY breaking scales ..

Track your modes



reheating ends

φ *decays*

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Thank You!