

Towards a Minimal Particle-Cosmology Supersymmetric Standard Model

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- **Standard Big-Bang Cosmology and WMAP**
- F_D -Term **Hybrid Inflation**
- **Solution to Gravitino Overabundance Problem**
- **Cosmological and Particle-Physics Implications**
- **Conclusions and Future Directions**

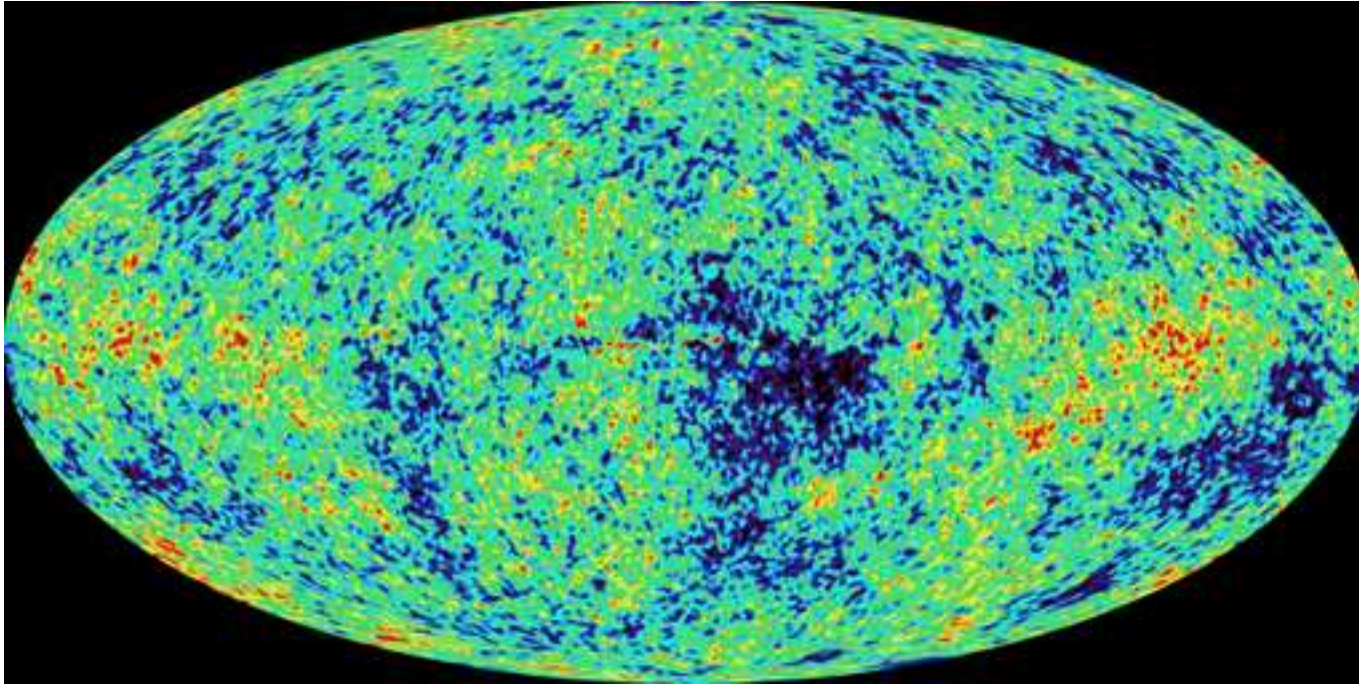
*Talk based on

B. Garbrecht and A.P., **PLB636** (2006) 154 [hep-ph/0601080];

B. Garbrecht, C. Pallis and A.P, **JHEP0612** (2006) 038 [hep-ph/0605264]

- Standard Big-Bang Cosmology and WMAP

Density perturbations as observed by WMAP



$$\frac{\delta T}{T} \sim \frac{\delta \rho}{\rho} \sim 10^{-5}$$

– Evolution of the Early Universe

Friedman–Robertson–Walker Equation:

$$H^2 - \frac{\rho}{3 m_{\text{Pl}}^2} = -\frac{K}{a^2}, \quad \text{where } H = \frac{\dot{a}}{a}, \quad m_{\text{Pl}} = 2.4 \times 10^{18} \text{ GeV}$$

$$\rightarrow \Omega - 1 = \frac{K}{a^2 H^2}, \quad \text{where } \Omega = \frac{\rho}{\rho_c}, \quad \rho_c = 3H^2 m_{\text{Pl}}^2$$

$\ddot{a} > 0 \rightarrow$ **Inflation**: accelerated expansion of the Universe.

Quantity	Inflation	Radiation	Matter
$w = P/\rho$	$-1 \leq w \ll -1/3$	$w = \frac{1}{3}$	$w = 0$
$a(t)$	$a_i e^{Ht}$	$a_f (t/t_f)^{1/2}$	$a_f (t/t_f)^{2/3}$
$H(t)$	const.	$1/(2t)$	$2/(3t)$
$\rho(t)$	const.	$\rho_f a^{-4}$	$\rho_f a^{-3}$
$d_H(t)$	H^{-1}	$\propto t^{1/2}$	$\propto t^{1/3}$
$D_H(t)$	$H^{-1} e^{Ht}$	$\propto 2t$	$\propto 3t$
$L_{\text{EH}}(t)$	$H^{-1} e^{-Ht}$	∞	∞

– Flatness Problem

SBBM prediction for a radiation dominated epoch:

$$\frac{|\Omega_0 - 1|}{|\Omega_f - 1|} = \frac{t_0}{t_f} = \frac{10^{17} \text{ sec}}{10^{-43} \text{ sec}} = 10^{60}$$

Degree of tuning required: 1 part in 10^{60} !

Solution to the **Flatness Problem** through **Inflation**:

$$\frac{|\Omega_f - 1|}{|\Omega_i - 1|} \approx \frac{a_i^2}{a_f^2} \approx e^{-2H(t_f - t_i)} \lesssim 10^{-60}$$

$$\implies \mathcal{N}_e \approx H(t_f - t_i) \gtrsim 60$$

One needs a sufficient long period of inflation of ~ 60 e -folds.

Other problems solved by inflation: horizon and homogeneity problems, dilution of unwanted relics and defects etc.

– Inflation Dynamics

[Review: D. Lyth and A. Riotto, Phys. Rept. 314 (1999) 1]

Number of e -folds:

$$\mathcal{N}_e = \int_{t_{\mathcal{N}}}^{t_{\text{end}}} dt H(t) \approx \frac{1}{m_{\text{Pl}}^2} \int_{\phi_{\text{end}}}^{\phi_{\mathcal{N}}} d\phi \frac{V}{V_{\phi}} \approx 50 - 60$$

Power spectrum of curvature perturbations:

$$P_{\mathcal{R}}^{1/2} = \frac{1}{2\sqrt{3}\pi m_{\text{Pl}}^3} \frac{V^{3/2}}{|V_{\phi}|} \approx 4.86 \times 10^{-5} \quad (k_0 = 0.002 \text{ Mpc}^{-1})$$

Spectral index:

$$n_s - 1 = \frac{d \ln P_{\mathcal{R}}^{1/2}}{d \ln k} = 2\eta - 6\varepsilon \approx -0.049_{-0.019}^{+0.015} \quad (\text{WMAP 3 years data})$$

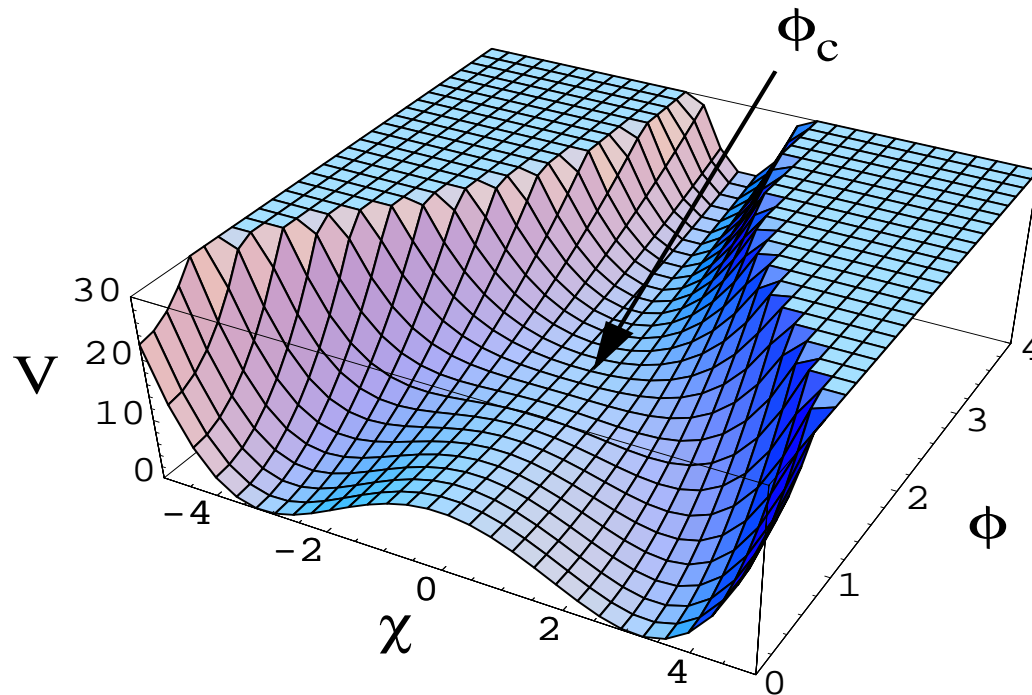
Slow-roll parameters:

$$\varepsilon = \frac{1}{2} m_{\text{Pl}}^2 \left(\frac{V_{\phi}}{V} \right)^2 \ll 1, \quad \eta = m_{\text{Pl}}^2 \frac{V_{\phi\phi}}{V} \ll 1$$

- F_D -Term Hybrid Inflation

- Hybrid Inflation

[A.D. Linde, PLB259 (1991) 38]



$$V = \frac{\lambda}{4}(|\chi|^2 - M^2)^2 + \frac{1}{2}g|\chi|^2|\phi|^2 + \frac{1}{2}m^2|\phi|^2$$

Inflation starts, when $\phi \gg \phi_c \sim M$, $\chi = 0 \rightarrow V \simeq \frac{\lambda}{4}M^4 + \frac{1}{2}m^2|\phi|^2$

Inflation ends with the so-called **waterfall mechanism**

– *F*-Term Hybrid Inflation

[E. Copeland, A. Liddle, D. Lyth, E. Stewart, D. Wands, PRD49 (1994) 6410;
G. Dvali, Q. Shafi, R. Schaefer, PRL73 (1994) 1886]

Superpotential:

$$W = \kappa \hat{S} (\hat{X}_1 \hat{X}_2 - M^2)$$

Real Potential determined from *F* terms:

$$\begin{aligned} V &= |\partial W / \partial S|^2 + |\partial W / \partial X_1|^2 + |\partial W / \partial X_2|^2 \\ &= \kappa^2 |X_1 X_2 - M^2|^2 + \kappa^2 S^2 (|X_1|^2 + |X_2|^2) \end{aligned}$$

Start of inflation: $S^{\text{in}} > M$, $X_{1,2}^{\text{in}} = 0$, with $V = \kappa^2 M^4$.

$X_{1,2}$ -Mass Matrix:

$$M_{X_{1,2}}^2 = \begin{pmatrix} |\kappa|^2 |S|^2 & -\kappa^2 M^2 \\ -\kappa^{*2} M^2 & |\kappa|^2 |S|^2 \end{pmatrix}$$

End of inflation: $S < M \rightarrow \det M_{X_{1,2}}^2 < 0 \rightarrow$ waterfall mechanism.

– Slope of the Potential

Potential is **too flat!** $\partial V/\partial S = 0$.

Radiative lifting of the S -flat direction:

$$V_{1\text{-loop}} = \frac{\kappa^4 M^4}{16\pi^2} \ln \left(\frac{|S|^2}{M^2} \right)$$

SUGRA corrections: $V_{\text{SUGRA}} = -c_H^2 H^2 |S|^2 + \kappa^2 M^4 \frac{|S|^4}{2 m_{\text{Pl}}^4} + \dots$

Number of e -folds:

$$\mathcal{N}_e = \frac{4\pi^2}{\kappa^2} \frac{(S^{\text{in}})^2}{m_{\text{Pl}}^2} \approx 55$$

For $10^{-3} \lesssim \kappa \lesssim 10^{-2} \longrightarrow S^{\text{in}} \lesssim 10^{-1} m_{\text{Pl}} \rightarrow$ **predictive scenario**

Power spectrum: $P_{\mathcal{R}}^{1/2} = \sqrt{\frac{4\mathcal{N}_e}{3}} \left(\frac{M}{m_{\text{Pl}}} \right)^2 = 5 \times 10^{-5} \rightarrow M \sim 10^{16} \text{ GeV}$.

M close to the **GUT** or **gauge-coupling unification** scale!

Spectral index: $n_s - 1 = -\frac{1}{\mathcal{N}_e} \approx -0.02$ (mSUGRA).

– F_D -Term Hybrid Inflation

[B. Garbrecht and A.P., hep-ph/0601080]

$$W = \kappa \hat{S} (\hat{X}_1 \hat{X}_2 - M^2) + \lambda \hat{S} \hat{H}_u \hat{H}_d + \frac{\rho}{2} \hat{S} \hat{N}_i \hat{N}_i \\ + h_{ij}^\nu \hat{L}_i \hat{H}_u \hat{N}_j + W_{\text{MSSM}}^{(\mu=0)}$$

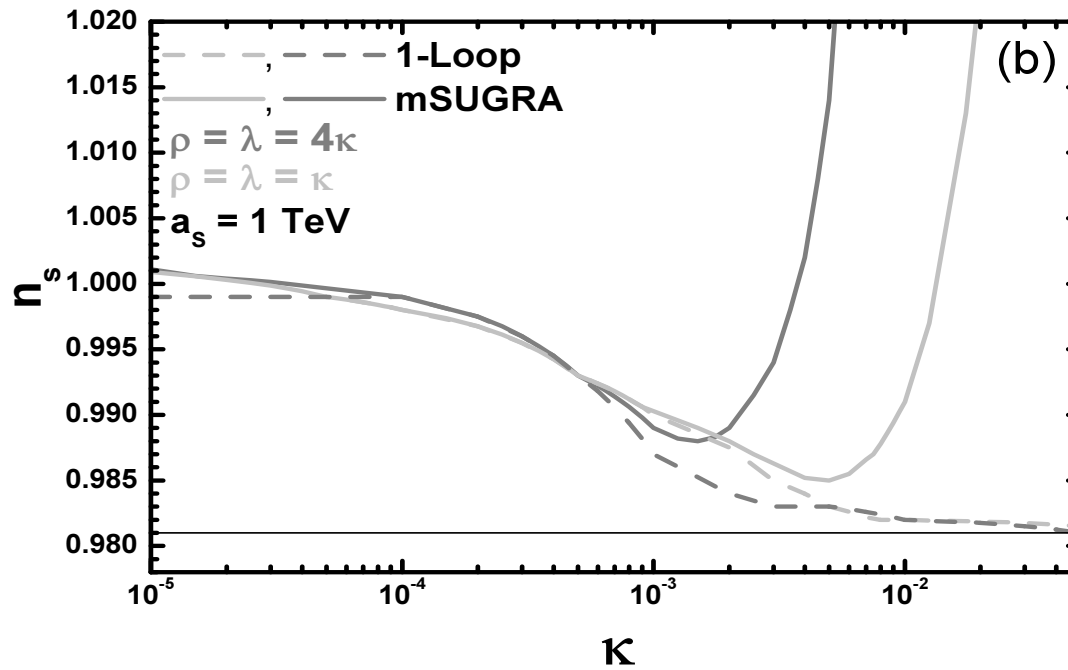
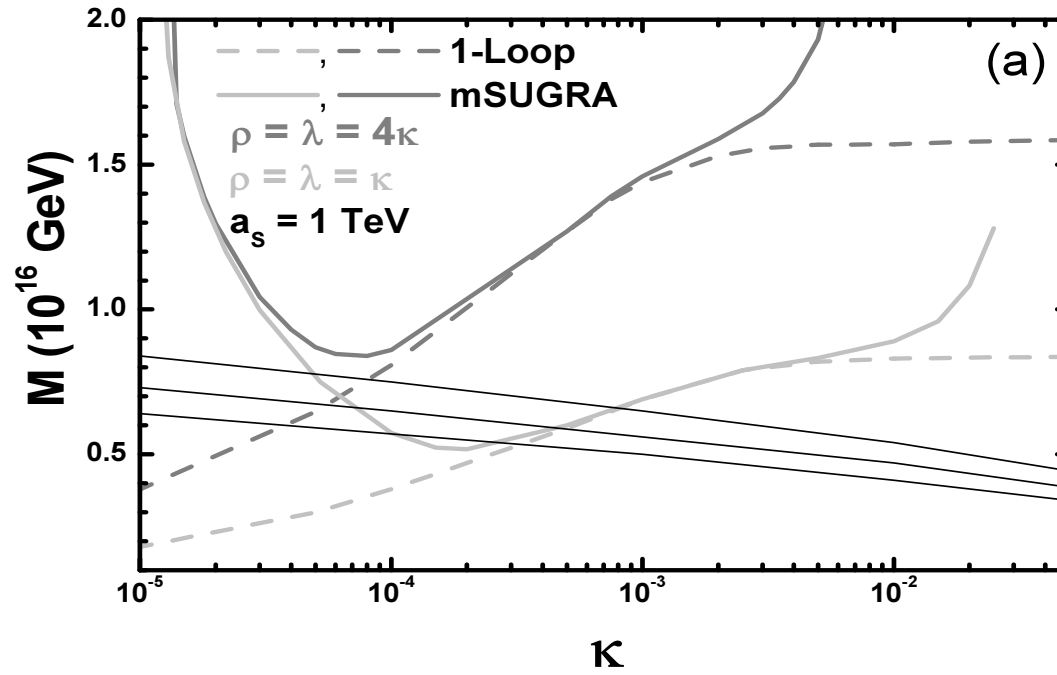
+ Subdominant FI D -term of $U(1)_X$: $-\frac{g_X}{2} m_{\text{FI}}^2 D_X$

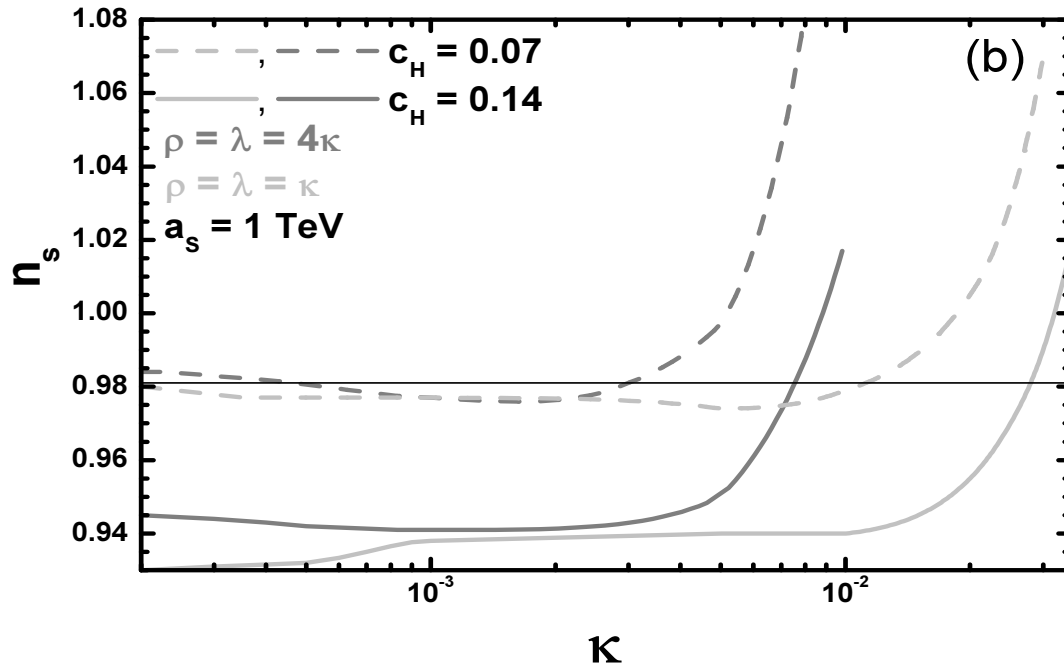
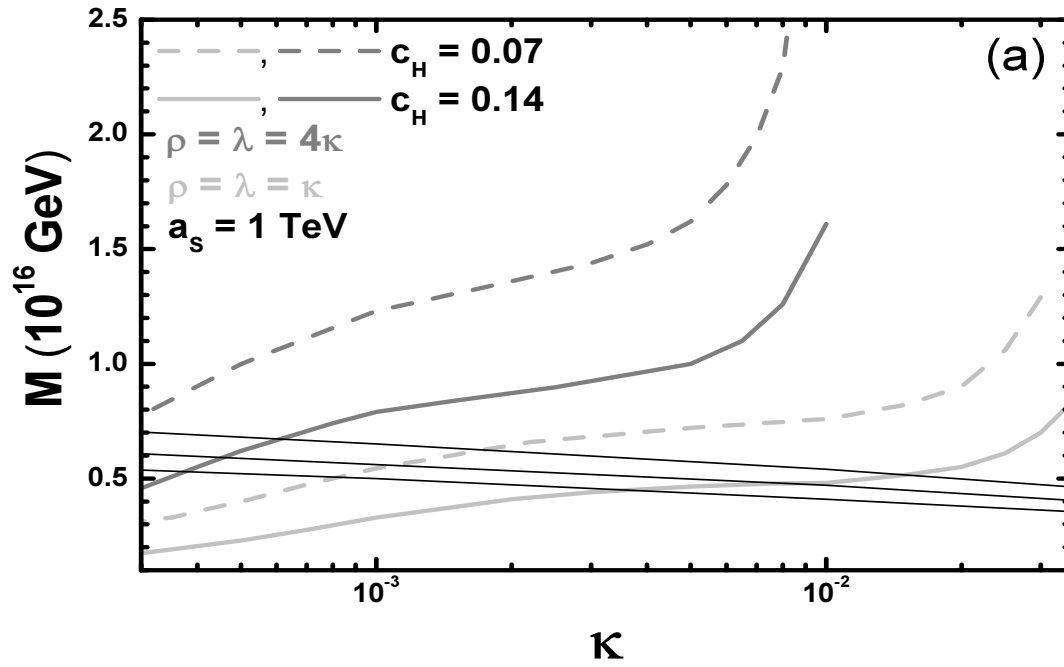
Remarks:

- **Mass scales:** m_{Pl} , M , m_{FI} and M_{SUSY} . Gauge-coupling unification scale may reduce the number of scales, e.g. $M = M_X \approx 10^{16}$ GeV.
- $\langle S \rangle \sim \frac{1}{\kappa} M_{\text{SUSY}}$ sets the **Electroweak** and the **Singlet Majorana** scale:

$$\mu = \lambda \langle S \rangle, \quad m_N = \rho \langle S \rangle$$

- **Lepton Number Violation** mediated by right-handed neutrinos N_i occurs at the **EW** scale $\mu \sim m_N$.
→ **BAU** may be explained by thermal **EW**-scale **resonant leptogenesis**.



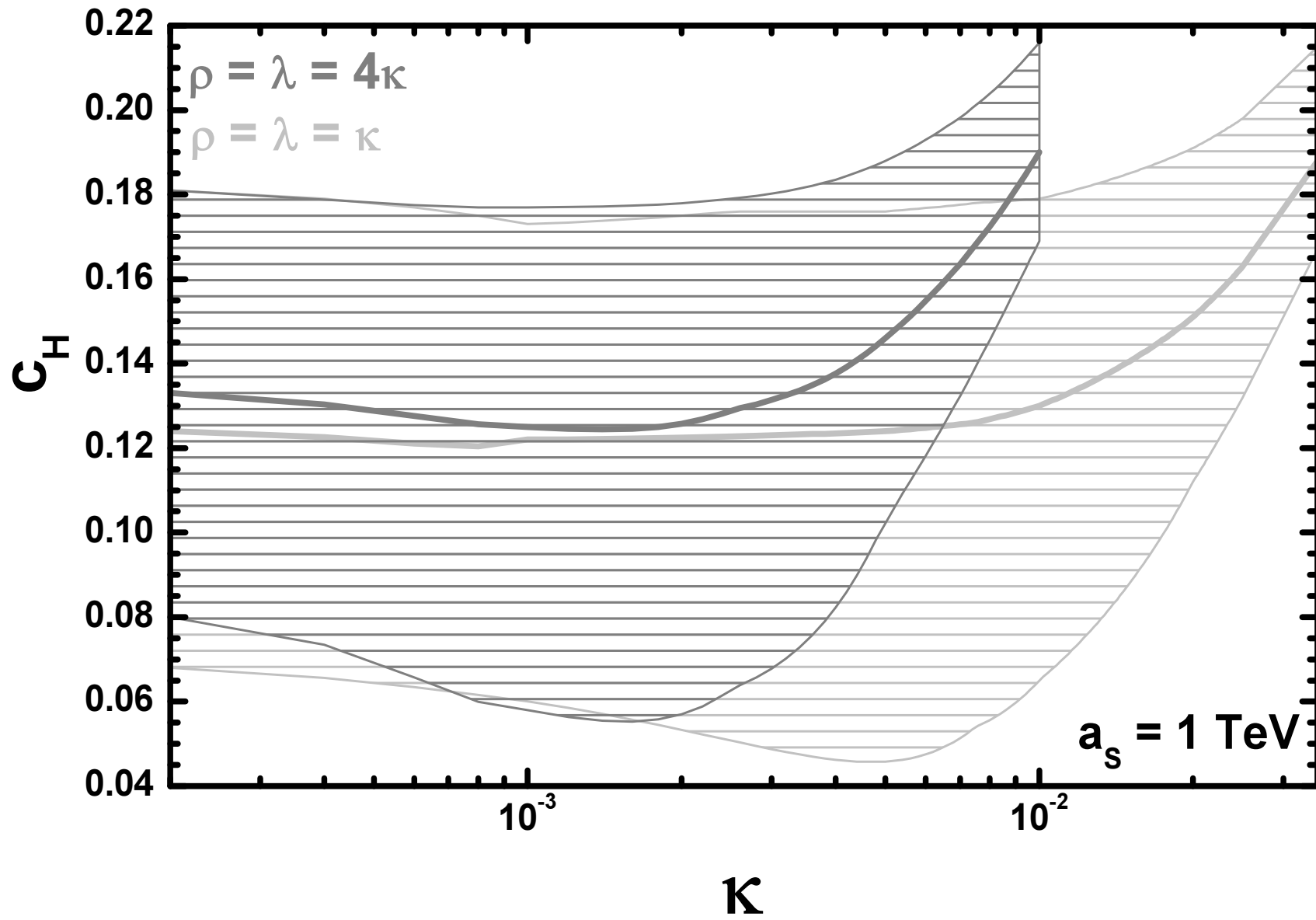


$$n_s - 1 \approx -\frac{1}{N_e} - c_H^2$$

Related considerations:

L. Boubekur and D.H. Lyth, JCAP **0507** (2005) 010.

M. Bastero-Gil, S.F. King and Q. Shafi, hep-ph/0604198.



M (in units of 10^{16} GeV), ϕ_{\min} , ϕ_{\max} , ϕ_{exit} (in units of $\sqrt{2}M$)

κ	c_H	M	ϕ_{\min}	ϕ_{\max}	ϕ_{exit}	Δ_{exit}	c_H	M	ϕ_{\min}	ϕ_{\max}	ϕ_{exit}	Δ_{exit}
	$n_s = 0.913$						$n_s = 0.951$					
$\lambda = \rho = \kappa$												
0.01	0.179	0.34	73.6	11.9	11.3	0.050	0.130	0.53	32.0	10.8	8.75	0.19
0.005	0.176	0.34	73.1	6.0	5.7	0.053	0.120	0.53	32.2	6.2	4.48	0.18
0.001	0.173	0.25	95.6	1.64	1.6	0.028	0.120	0.38	45.0	1.55	1.42	0.09
0.0005	0.165	0.19	121	1.23	1.21	0.014	0.116	0.28	58.8	1.19	1.15	0.04
$\lambda = \rho = 4\kappa$												
0.01	0.216	0.56	49	23.0	22.0	0.046	0.190	0.83	23.0	21.9	17.0	0.22
0.005	0.188	0.61	41	11.4	10.8	0.050	0.146	0.96	26.0	9.1	8.30	0.19
0.001	0.177	0.57	43	2.48	2.38	0.043	0.125	0.89	24.6	2.28	1.96	0.14
0.0005	0.178	0.46	54	1.53	1.49	0.028	0.129	0.68	26	1.45	1.33	0.08

Fine-tuning parameter:

$$\Delta_{\text{exit}} = \frac{\phi_{\max} - \phi_{\text{exit}}}{\phi_{\max}}$$

– Post-inflationary Dynamics

$$X_{\pm} = \frac{1}{\sqrt{2}} (X_1 \pm X_2) = \langle X_{\pm} \rangle + \frac{1}{\sqrt{2}} (R_{\pm} + iI_{\pm}),$$

$$\text{with } \langle X_+ \rangle = \sqrt{2}M \text{ and } \langle X_- \rangle = \frac{v}{\sqrt{2}} = \frac{m_{\text{FI}}^2}{2\sqrt{2}M}$$

Sector	Boson	Fermion	Mass	<i>D</i> -parity
Inflaton (κ -sector)	S, R_+, I_+	$\psi_{\kappa} = \begin{pmatrix} \psi_{X_+} \\ \psi_S^{\dagger} \end{pmatrix}$	$\sqrt{2}\kappa M$	+
U(1) _X Gauge (g -sector)	$V_{\mu} [I_-], R_-$	$\psi_g = \begin{pmatrix} \psi_{X_-} \\ -i\lambda^{\dagger} \end{pmatrix}$	gM	–

$$\Gamma_{\kappa} = \frac{1}{32\pi} (4\lambda^2 + 3\rho^2) m_{\kappa}, \quad \Gamma_g = \frac{g^2}{128\pi} \frac{m_{\text{FI}}^4}{M^4} m_g.$$

– Reheat Temperature and Gravitino Constraint

The decays of the inflaton field end its coherent oscillations. The Universe then becomes radiation dominated, when $\Gamma_\kappa \gtrsim H(T_\kappa^{\text{reh}})$:

$$T_\kappa^{\text{reh}} = \left(\frac{90}{\pi^2 g_*} \right)^{1/4} \sqrt{\Gamma_\kappa m_{\text{Pl}}}$$

Gravitino constraint ($T_\kappa^{\text{reh}} \lesssim 10^9 \text{ GeV}$) implies

$$\kappa \left(\lambda^2 + \frac{3}{4} \rho^2 \right) \lesssim 3 \cdot 10^{-15} \times \left(\frac{T_\kappa^{\text{reh}}}{10^9 \text{ GeV}} \right)^2 \left(\frac{10^{16} \text{ GeV}}{M} \right)$$

For $\kappa \approx \lambda \approx \rho \rightarrow \kappa, \lambda, \rho \lesssim 10^{-5}$

This is a bit **unnatural**, since all couplings must be suppressed.

– The Waterfall X -Sector

$$V(X_{\pm}) = \frac{\kappa^2}{4} |X_+^2 - X_-^2 - 2M^2|^2 + \frac{g^2}{8} (X_+^* X_- + X_-^* X_+ - m_{\text{FI}}^2)^2$$

If $m_{\text{FI}}^2 = 0 \rightarrow V$ is invariant under the discrete symmetry (D -parity):

$$X_{\pm} \rightarrow \pm X_{\pm}$$

This is true, even after the SSB of the $U(1)_X$, because $\langle X_- \rangle = 0$.

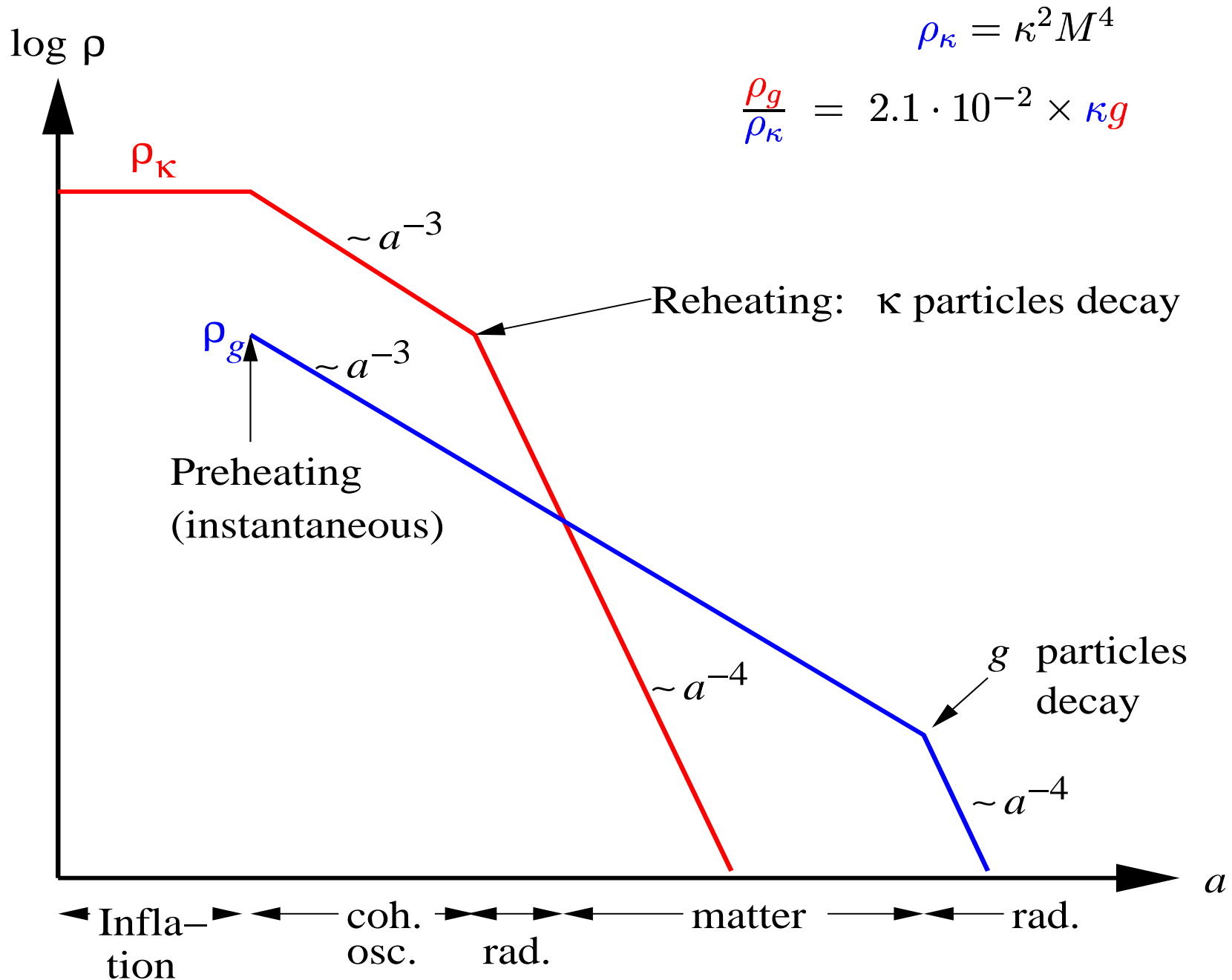
Disasterous Consequence:

Without a FI D -term ($m_{\text{FI}}^2 = 0$), the g -sector particles would be stable, i.e. $\Gamma_g = 0$.

The g -sector particles can be produced via preheating.

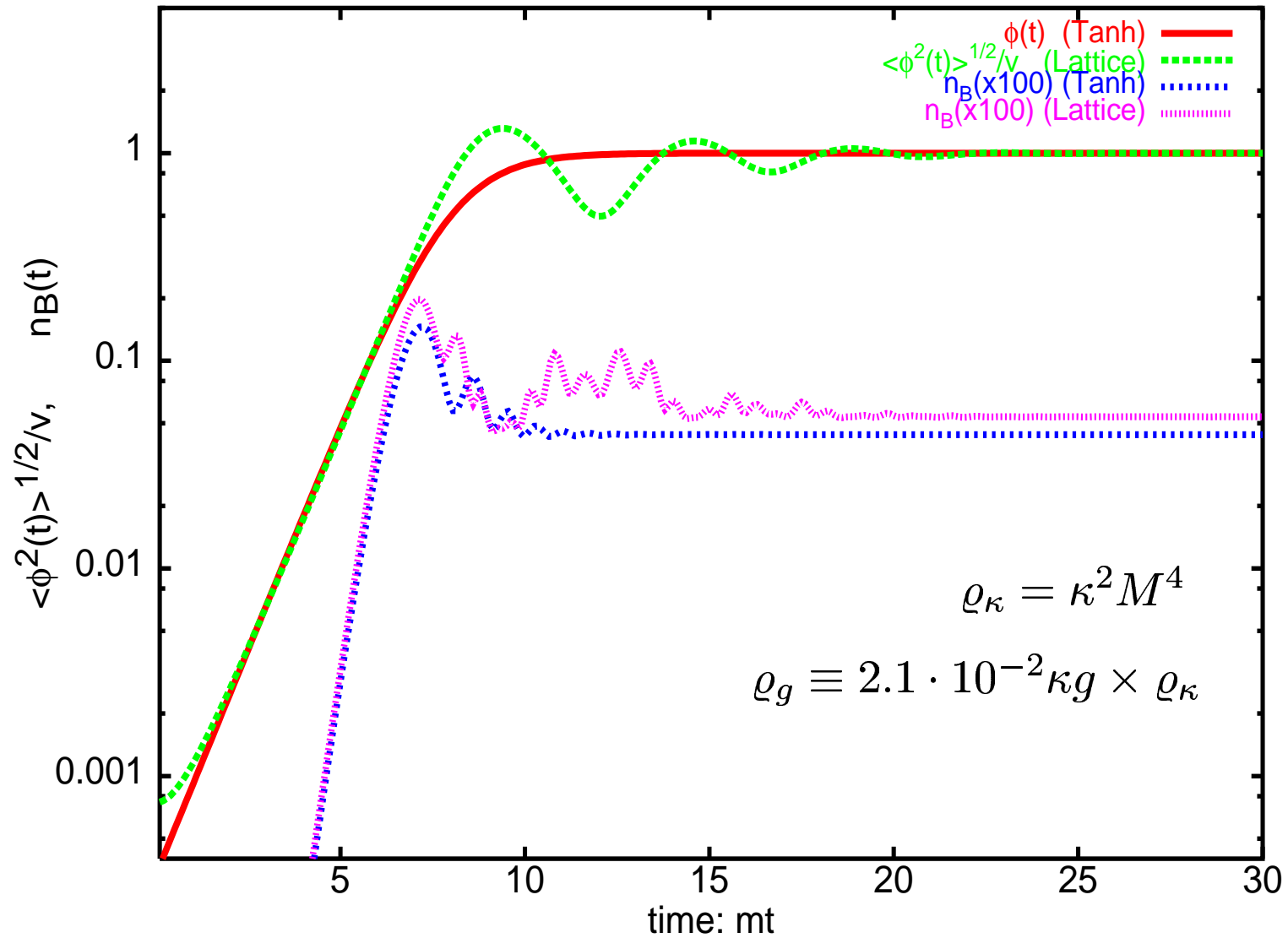
If they were produced abundantly, they could overclose our Universe!

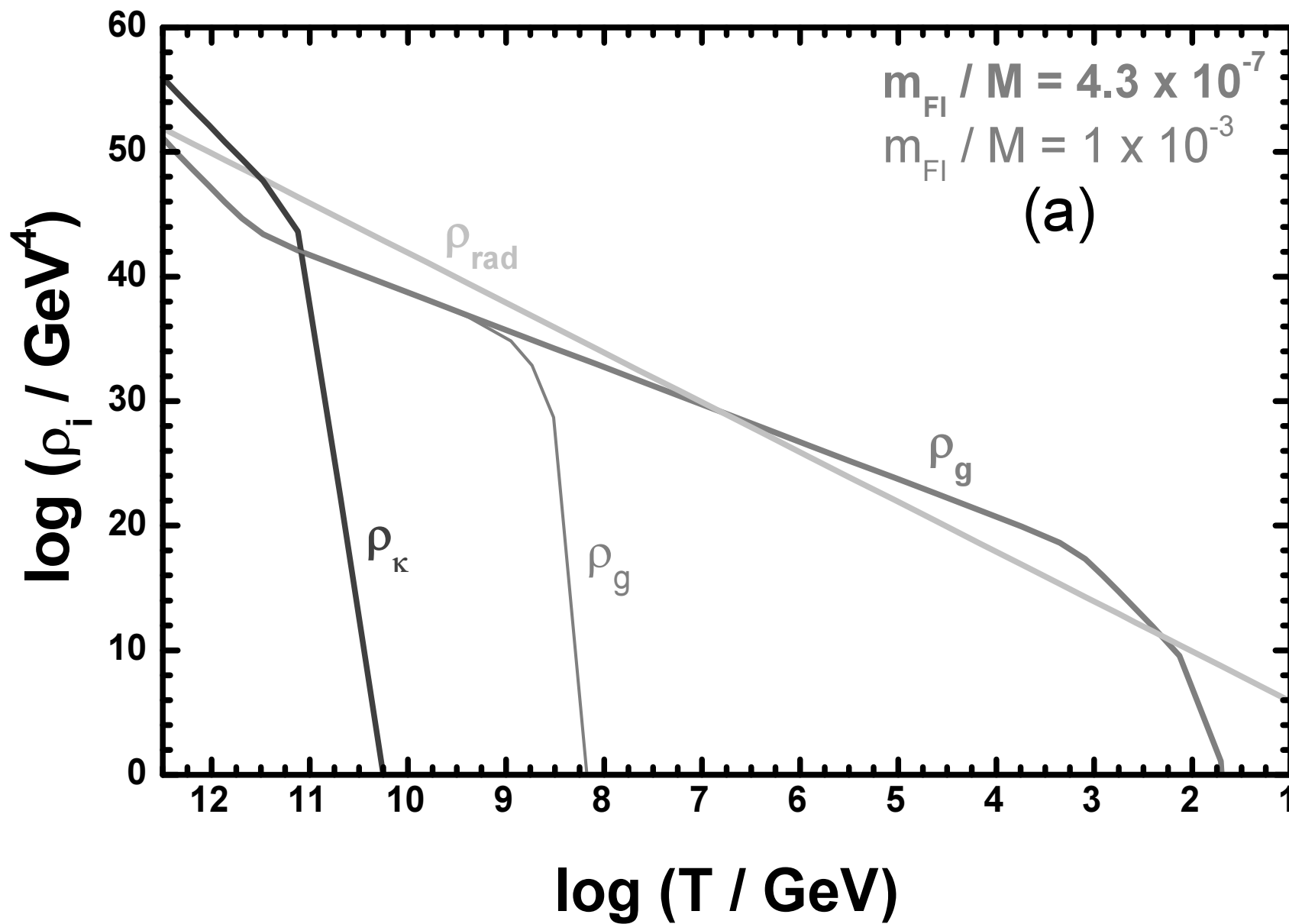
– Thermal History of the Universe

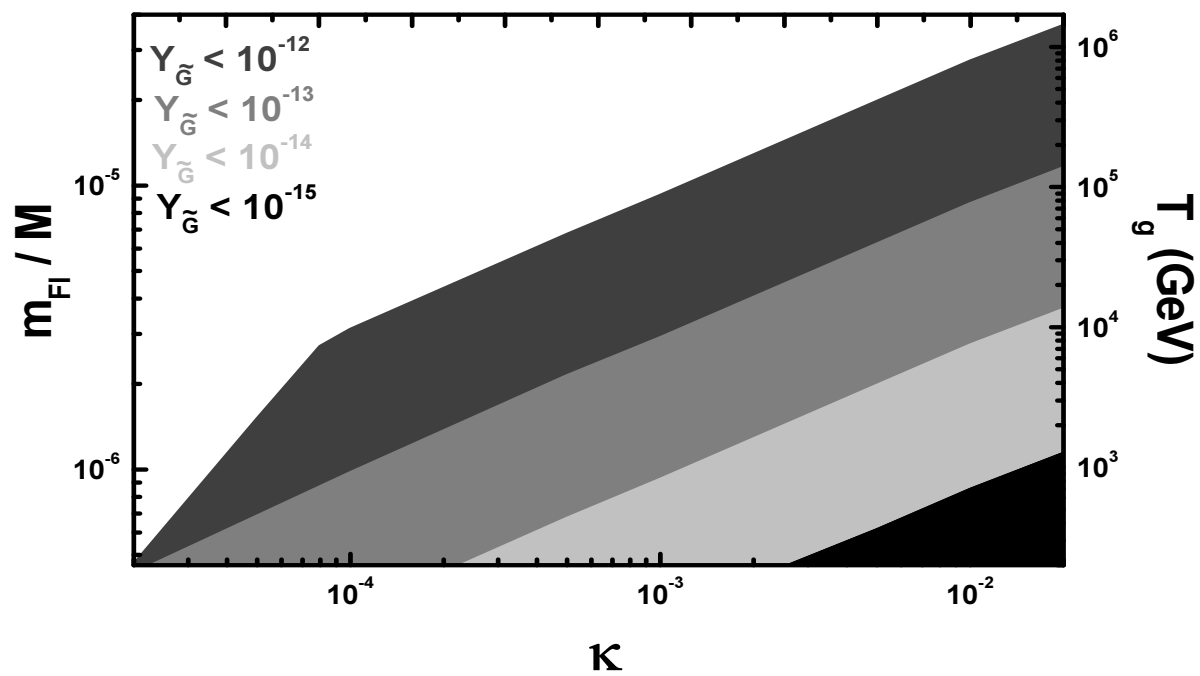
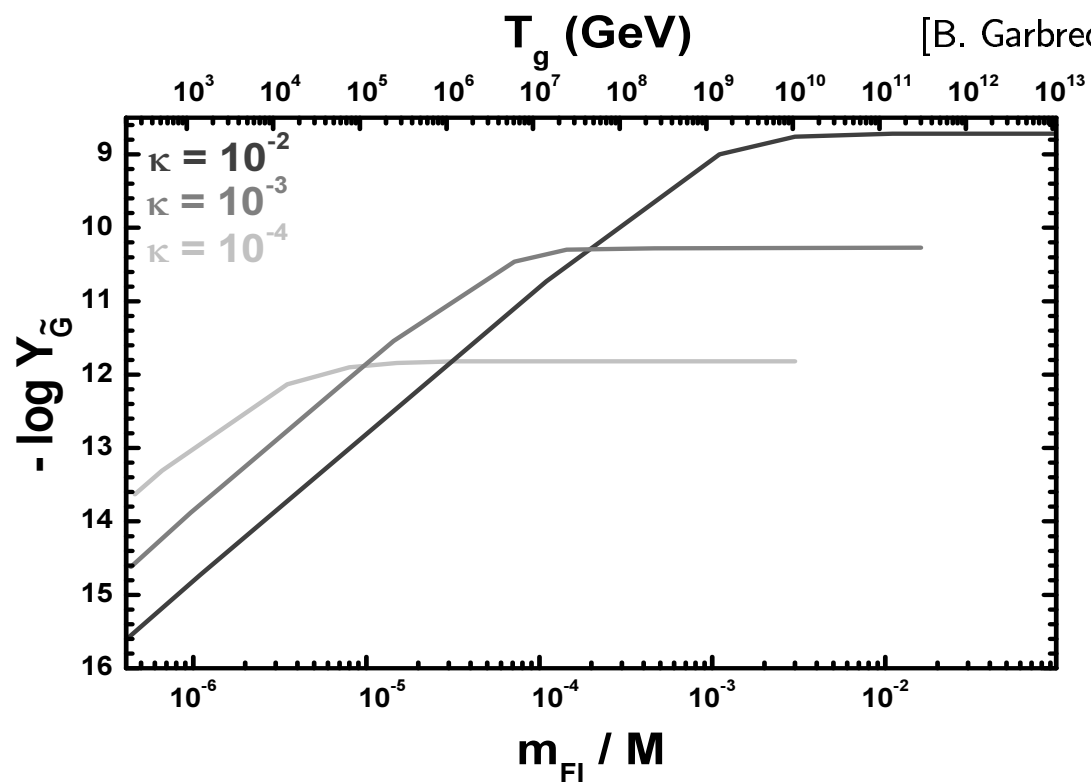


– Preheating

[J. Garcia-Bellido, E. Ruiz Morales, PLB536 (2002) 193;
LATICEEASY: G. Felder and I.I. Tkachev, hep-ph/0011159]







– $SU(2)_X$ Waterfall Gauge Sector

$$\mathcal{L}_{\text{kin}} = \int d^4\theta \left[\frac{1}{2} \text{Tr} (W^\alpha W_\alpha) \delta^{(2)}(\bar{\theta}) + \frac{1}{2} \text{Tr} (\bar{W}_{\dot{\alpha}} \bar{W}^{\dot{\alpha}}) \delta^{(2)}(\theta) \right. \\ \left. + \hat{X}_1^\dagger e^{2g\hat{V}_X} \hat{X}_1 + \hat{X}_2^\dagger e^{-2g\hat{V}_X^T} \hat{X}_2 \right].$$

D -parities:

$$D_1: \quad \hat{X}_1 \leftrightarrow \hat{X}_2, \quad \hat{V}_X \rightarrow -\hat{V}_X^T, \quad (W_\alpha \rightarrow -W_\alpha^T)$$

$$D_2: \quad \hat{X}_{1(2)} \rightarrow \tau^3 \hat{X}_{1(2)}, \quad \hat{V}_X \rightarrow \tau^3 \hat{V}_X \tau^3, \quad (W_\alpha \rightarrow \tau^3 W_\alpha \tau^3).$$

Consequences:

$\langle X_1 \rangle = \langle X_2 \rangle = (M, 0)^T$ invariant under $D_{1,2} \rightarrow D$ -parities survive after the SSB of $SU(2)_X$.

D -parity conservation \rightarrow all g -sector particles remain stable, i.e. $\Gamma_g = 0$.

$SU(2)_X \rightarrow \mathbf{I} \rightarrow$ No cosmic strings and monopoles!

– Particle Spectrum of the $SU(2)_X$ Waterfall Gauge Sector

Sector	Boson	Fermion	Mass	D_1 -parity	D_2 -parity
Inflaton (κ -sector)	$S, {}^+R_+, {}^+I_+$	$\psi_\kappa = \begin{pmatrix} \psi_{+X_+} \\ \psi_S^\dagger \end{pmatrix}$	$\sqrt{2}\kappa M$	+	+
$SU(2)_X$ Waterfall Gauge (g -sector)	$V_\mu^1[-I_-],$ $-R_-;$	$\psi_g^1 = \begin{pmatrix} \psi_{-X_-} \\ -i\lambda^{1\dagger} \end{pmatrix}$	gM	–	–
	$V_\mu^2[-R_+],$ $-I_+;$	$\psi_g^2 = \begin{pmatrix} i\psi_{-X_+} \\ -i\lambda^{2\dagger} \end{pmatrix}$	gM	+	–
	$V_\mu^3[{}^+I_-],$ ${}^+R_-$	$\psi_g^3 = \begin{pmatrix} \psi_{+X_-} \\ -i\lambda^{3\dagger} \end{pmatrix}$	gM	–	+

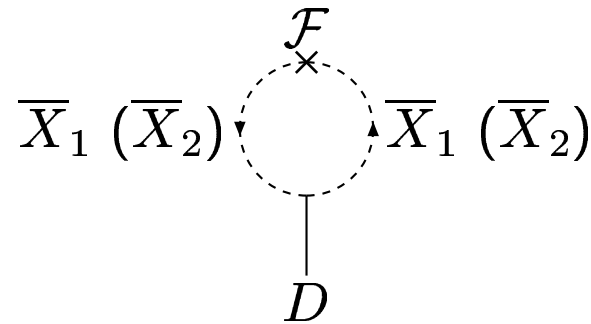
Convention:

$$Z = \begin{pmatrix} {}^+Z \\ -Z \end{pmatrix}$$

– How to Get Small D -Parity Violation in a $U(1)$ Waterfall Sector

Introduce a pair of Planck-scale superfields $\widehat{X}_{1,2}$ with $Q(\widehat{X}_{2(1)}) = +(-)1$:

$$W_{IW}^{\text{ext}} = \kappa \widehat{S} (\widehat{X}_1 \widehat{X}_2 - M^2) + \xi m_{\text{Pl}} \widehat{X}_1 \widehat{X}_2 + \xi_1 \frac{(\widehat{X}_1 \widehat{X}_1)^2}{2 m_{\text{Pl}}} + \xi_2 \frac{(\widehat{X}_2 \widehat{X}_2)^2}{2 m_{\text{Pl}}} \dots$$

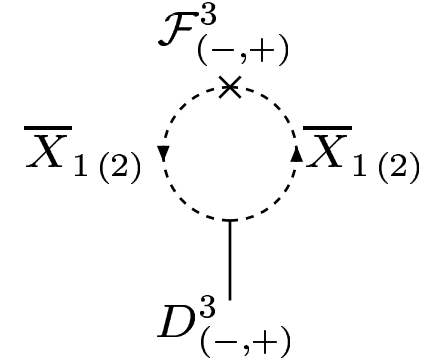
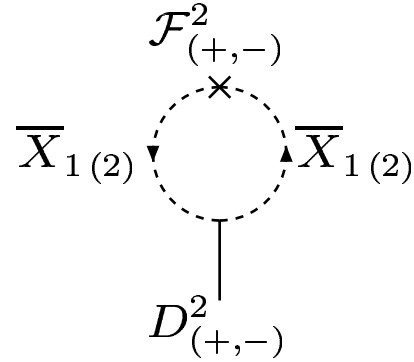
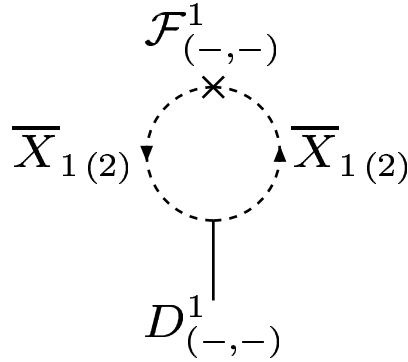


$$\mathcal{D}_{\bar{X}} = -\frac{g}{2} (|\bar{X}_1|^2 - |\bar{X}_2|^2), \quad \mathcal{F} = (\xi_1^2 - \xi_2^2) \frac{M^4}{2 m_{\text{Pl}}^2} (|\bar{X}_1|^2 - |\bar{X}_2|^2)$$

$$m_{\text{FI}}^2 \approx \frac{\xi_1^2 - \xi_2^2}{8\pi^2} \frac{M^4}{m_{\text{Pl}}^2} \ln \left(\frac{m_{\text{Pl}}}{M} \right)$$

For $\xi_{1,2} \lesssim 10^{-3}$ and $M = 10^{16}$ GeV $\implies m_{\text{FI}}/M \lesssim 10^{-6} \longrightarrow T_g \sim 1$ TeV.

– ***D*-Parity Violation in the $SU(2)_X$ Waterfall Sector**



$$W_{IW}^{\text{ext}} = \xi m_{\text{Pl}} \widehat{\overline{X}}_1^T \widehat{\overline{X}}_2 + \theta_1 \frac{(\widehat{\overline{X}}_1^T \widehat{\widehat{X}}_1) (\widehat{\overline{X}}_2^T \widehat{\widehat{X}}_2)}{m_{\text{Pl}}} + \theta_2 \frac{(\widehat{\overline{X}}_1^T i\tau^2 \widehat{\widehat{X}}_2) (\widehat{\overline{X}}_2^T i\tau^2 \widehat{\widehat{X}}_1)}{m_{\text{Pl}}} \\ + \zeta_1 \frac{(\widehat{\overline{X}}_1^T i\tau^2 \widehat{\widehat{X}}_2) (\widehat{\overline{X}}_2^T \widehat{\widehat{X}}_2)}{m_{\text{Pl}}} + \zeta_2 \frac{(\widehat{\overline{X}}_1^T \widehat{\widehat{X}}_1) (\widehat{\overline{X}}_2^T i\tau^2 \widehat{\widehat{X}}_1)}{m_{\text{Pl}}} + \dots$$

$$\mathcal{D}_{\overline{X}}^a = -\frac{g}{2} (\overline{X}_1^T \tau^a \overline{X}_1^* - \overline{X}_2^\dagger \tau^a \overline{X}_2)$$

$$(m_{\text{FI}}^{1,2,3})^2 = -\frac{[\text{Re}(\theta_- \zeta_-^*), \text{Im}(\theta_- \zeta_+^*), \text{Re}(\zeta_+ \zeta_-^*)]}{4\pi^2} \frac{M^4}{m_{\text{Pl}}^2} \ln\left(\frac{m_{\text{Pl}}}{M}\right)$$

For $\theta_{\pm}, \zeta_{\pm} \sim 10^{-3} \rightarrow m_{\text{FI}}^{1,2,3}/M \lesssim 10^{-6} \rightarrow T_g \lesssim 1 \text{ TeV}$

• Further Cosmological Implications

– Can **Thermal Right-Handed Sneutrinos** be the **CDM**?

$\Delta(B - L) = 0$ or $2 \longrightarrow F_D$ -Term Hybrid Model conserves R -parity.

Right-handed sneutrino mass matrix:

$$\mathcal{M}_{\tilde{N}}^2 = \begin{pmatrix} \rho^2 v_S^2 + M_{\tilde{N}}^2 & \rho A_\rho v_S + \rho \lambda v_u v_d \\ \rho A_\rho^* v_S + \rho \lambda v_u v_d & \rho^2 v_S^2 + M_{\tilde{N}}^2 \end{pmatrix}$$

$$\longrightarrow m_{\tilde{N}_{\text{LSP}}}^2 = \rho^2 v_S^2 + M_{\tilde{N}}^2 - (\rho A_\rho v_S + \rho \lambda v_u v_d).$$

New LSP interaction:

$$\mathcal{L}_{\text{int}}^{\text{LSP}} = \frac{1}{2} \lambda \rho \tilde{N}_i^* \tilde{N}_i^* H_u H_d + \text{H.c.}$$

Process: $\tilde{N}_{\text{LSP}} \tilde{N}_{\text{LSP}} \rightarrow \langle H_u \rangle H_d \rightarrow W^+ W^-$ ($m_{\tilde{N}_{\text{LSP}}} > M_W$)

$$\Omega_{\text{DM}} h^2 \sim \left(\frac{10^{-4}}{\rho^2 \lambda^2} \right) \left(\frac{\tan \beta M_H}{g_w M_W} \right)^2 \longrightarrow \lambda, \rho \gtrsim 0.1$$

Process: $\tilde{N}_{\text{LSP}}\tilde{N}_{\text{LSP}} \rightarrow \langle H_u \rangle H_d \rightarrow b\bar{b}$ ($M_{H_d} \approx 2m_{\tilde{N}_{\text{LSP}}} < 2M_W$)

$$\Omega_{\text{DM}} h^2 \sim 10^{-4} \times B^{-1}(H_d \rightarrow \tilde{N}_{\text{LSP}}\tilde{N}_{\text{LSP}}) \times \left(\frac{M_H}{100 \text{ GeV}} \right)^2 \longrightarrow \lambda, \rho \gtrsim 10^{-2}$$

[F. Deppisch and A.P., work in progress.]

– Matter–AntiMatter Asymmetry

$$\eta_B^{\text{CMB}} = \frac{n_B}{n_\gamma} = 6.1_{-0.2}^{+0.3} \times 10^{-10} \quad (\eta_B^{\text{BBN}} = 3.4\text{--}6.9 \times 10^{-10}, \text{ at 95\% CL})$$

Sakharov's conditions for generating the BAU:

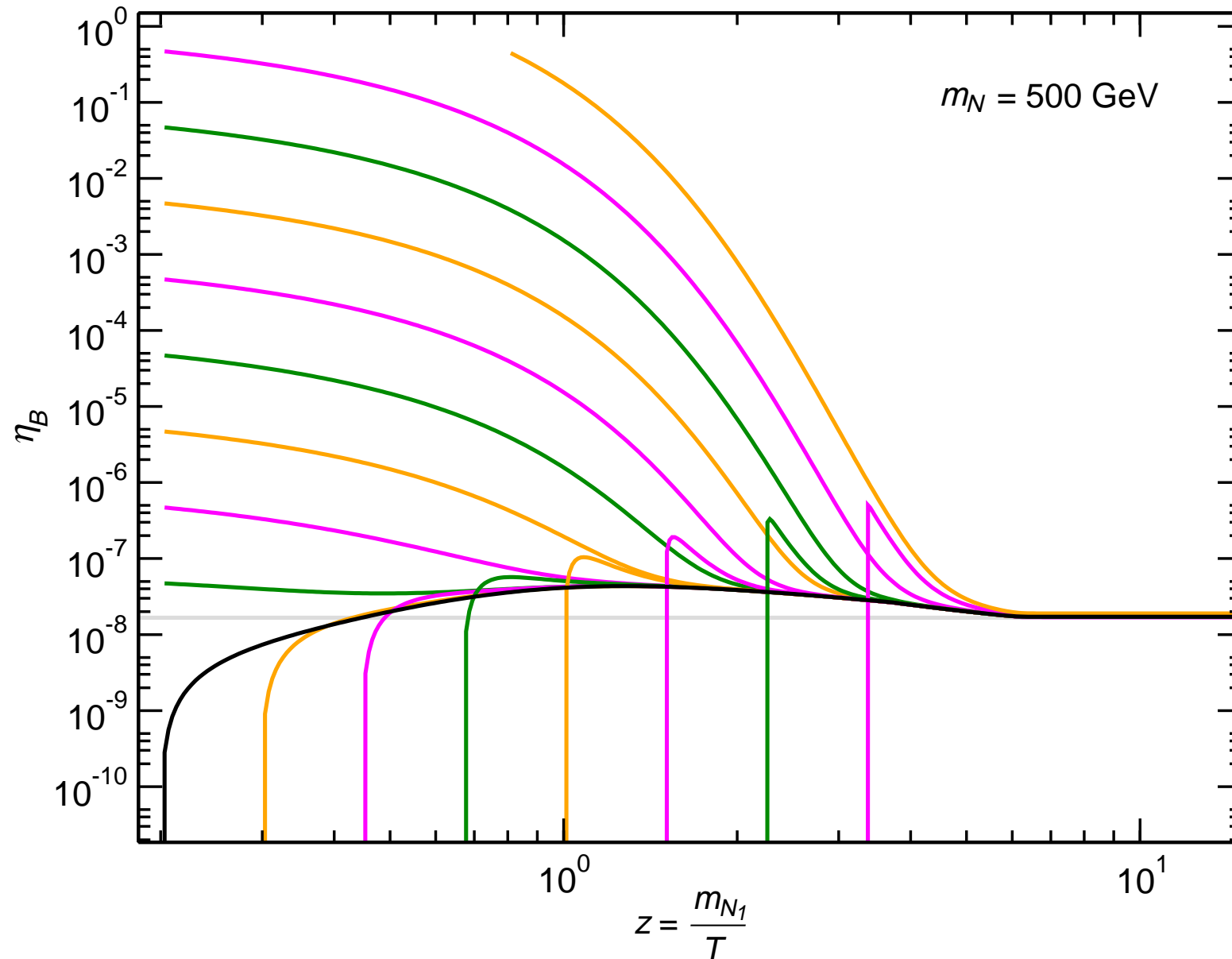
- B-violating interactions
- C and CP violation
- Out-of-equilibrium dynamics

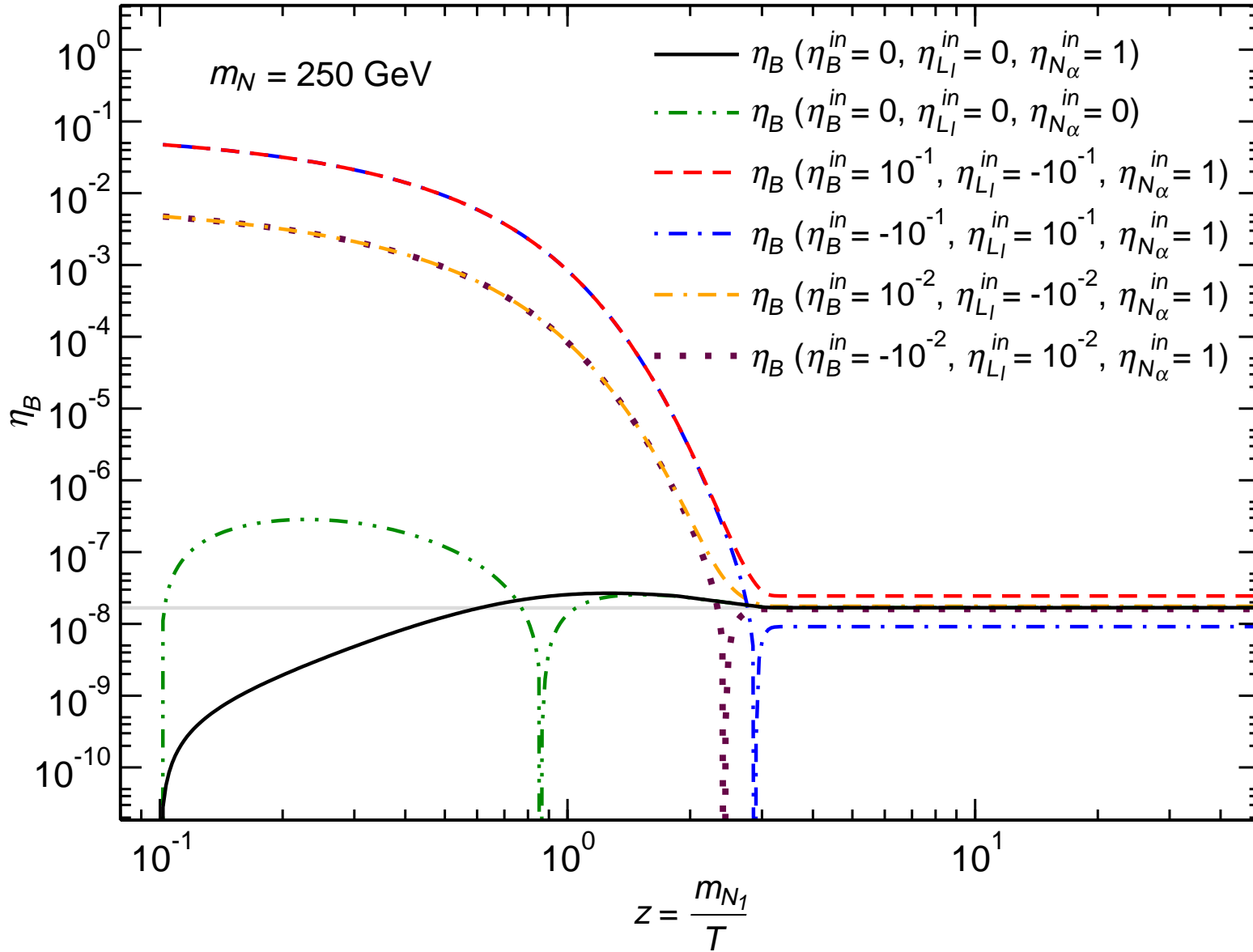
Quality Factor: Degree of (in)dependence of the observed BAU on the initial conditions: $Q = \eta_B^{\text{in}} / \eta_B^{\text{fin}}$.

– Resonant Flavour-Leptogenesis at the Electroweak Scale

[A.P., PRL95 (2005) 081602; A.P. and T. Underwood, PRD72 (2005) 113001]

LeptoGen





• Conclusions

- F_D -Term Hybrid Inflation provides an interesting framework for building a Minimal Particle-Physics and Cosmology Model.
- The μ -parameter of the MSSM is tied to an universal Majorana mass m_N , via the VEV of the inflaton field.
- The entropy release from the late D -tadpole-induced decays of the g -sector particles offers a simple solution to the gravitino problem.
- Waterfall Sector: $SU(2)_X \rightarrow 1 \implies$ No cosmic strings and monopoles.
- Baryon Asymmetry in the Universe can be explained by thermal Electroweak-Scale Resonant Leptogenesis, in a way independent of any pre-existing lepton or baryon-number abundance.

- **Further Particle-Physics Implications:**

- **Higgs phenomenology** of large μ -scenarios, such as **CPX**, where $\mu = 4M_{SUSY}$ and $A_t = 2M_{SUSY}$.

[M. Carena, J. Ellis, A.P., C. Wagner, PLB495 (2000) 155;

D.K. Ghosh, R.M. Godbole, D.P. Roy, PLB628 (2005) 131.]

- **Observable Signatures:** $B(\mu \rightarrow e\gamma) \sim 10^{-13}$, $B(\mu \rightarrow eee) \sim 10^{-14}$,
 $B(\mu \rightarrow e) \sim 10^{-13}$.

[A.P. and T. Underwood, PRD72 (2005) 113001.]

- **Invisible Higgs Decays** into \tilde{N}_{LSP} . [F. Deppisch and A.P., work in progress.]

- **CP and Lepton Number Violation** at the **LHC**

[S. Bray, J.S. Lee and A.P., NPB786 (2007) 95.]

• Future Directions

- Further improvements in the **theory** of the (pre-inflationary), inflationary and post-inflationary **dynamics**.
- Study of **Cold Dark Matter (CDM)** abundances, e.g. of \tilde{N}_{LSP} .
- Further **connections** between **inflation**, **leptogenesis**, **CDM**, **neutrino-mass** parameters, **Higgs physics** and other **laboratory observables** in constrained **minimal** versions of the **F_D -Term Hybrid Model**.
- **Possible realizations** of the **F_D -Term Hybrid Model** in **GUTs**.
[e.g. $E(7) \rightarrow SU(2)_X \otimes SO(12) \rightarrow SU(2)_X \otimes SO(10) \otimes U(1)$]

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