Warm Inflation susy models in the close-to-equilibrium regime

- Cold inflation/ Warm inflation
- Dissipative coefficient: Low T regime
- Summary

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Inflation

(Guth ‘81; Albrecht, Steinhardt ‘82;
Linde ‘82)

Early period of accelerated (quasi exponential) expansion

(Horizon problem, flat geometry, primordial spectrum,...)

Slow Roll Inflation

Scalar field rolling down its (flat) potential

“Flat” potential

$$\eta_H = m_P^2 \left| \frac{V''}{V} \right| < 1 \qquad \epsilon_H = \frac{m_P^2}{2} \left(\frac{V'}{V} \right)^2 < 1$$

Slow-roll parameters

EOM

$$\ddot{\phi} + 3H\dot{\phi} + V_\phi = 0 \Longrightarrow 3H\dot{\phi} \simeq -V_\phi$$

$$\ddot{\phi} \ll 3H\dot{\phi}, \quad \dot{\phi}^2 \ll V$$

Energy density

$$\rho = V(\phi) + \dot{\phi}^2/2 + \ldots \simeq V(\phi)$$

$\Longrightarrow$ **Cold Inflation** $\quad T \propto a^{-1} \longrightarrow 0$

$$\left(\dot{\rho}_R + 4H\rho_R = 0 \right)$$

Warm Inflation

Berera PRL ‘95;
Moss PLB,’85;
Berera and Zang, PRL ‘95

End of inflation

Inflation (vacuum dominated) → Radiation

Reheating

Inflaton interacts
with other particles

Inflation

Inflaton decay into light d. of f. → “Dissipation”

A fraction of the vacuum energy (even if small)
is converted into radiation $\rho = \rho(\phi) + \rho_R, \quad \rho_R \ll \rho(\phi)$

Effective EOM : $\ddot{\phi} + (3H + \Upsilon_\phi)\dot{\phi} + V_\phi = 0$

“Decay” into light dof
= extra friction

$$\dot{\rho}_R + 4H\rho_R = \Upsilon_\phi \dot{\phi}^2$$

“Source term”

Warm Inflation

- Inflaton ϕ~ light field during inflation
- Inflaton can “decay” through a mediating heavy field χ

light fermions

$$L = \cdots - \frac{1}{2} m_{\phi}^{2} \phi^{2} - \frac{g^{2}}{2} \phi^{2} \chi^{2} + h \chi \psi \bar{\psi} + \cdots$$

heavy $m_\chi = g\,\phi > H$

Inflaton moves down the potential, it excites χ, which decays into light dof

$$\phi \to \chi \to \psi \bar{\psi} \Longrightarrow \Upsilon(\phi, T)$$ Dissipative coefficient

$$\psi \bar{\psi} \to \rho_R \Longrightarrow$$ Thermal bath T

Berera and Ramos PRD ‘01, ‘03, ‘05; Hall and Moss PRD,’05

- Dissipative channel: generic in inflationary models

ex: Chaotic sneutrino inflation

Murayama et al. PRL’93
Ellis, Raidal, Yanagida PLB’04

$$W = \frac{M_R}{2} N_R N_R + h_N H_u L N_R + h_t H_u Q_3 U_3 + \cdots$$

sneutrino → Higgs → (s)top

(light: $M_R < H$) (heavy: $M_{Hu} >> H$) (massless)

- Adiabatic approximation:

Macroscopic $\dot{\phi}/\phi < \Gamma_\chi$

$H < \Gamma_\chi$ Microscopic

Extra friction term: $r=\Upsilon_{\phi}(\phi,T)/(3H)$

- r<<1, T<<H → Standard Cold inflation
- r<<1, T > H → Weak Dissipative Regime

Standard slow-roll

Thermal fluctuations → Primordial spectrum $P_R^{1/2}\simeq(\frac{H}{\dot{\phi}})\sqrt{TH}$

Spectral index: $n_S-1\neq 2\eta_H-6\epsilon_H$ depends on Υ_{ϕ}

- r>1, T > H → Strong Dissipative Regime

Slow-roll conditions change:

$$\boxed{\eta=|\eta_H|/(1+r)\ll 1,\ \ \epsilon=\epsilon_H/(1+r)\ll 1,\ \ \epsilon_{H\Upsilon}=(\frac{V_{\phi}}{3H^2})\frac{\Upsilon_{\phi}^{'}}{\Upsilon_{\phi}}\frac{1}{(1+r)}}$$

Primordial spectrum:

$$P_R^{1/2}\simeq(\frac{3H^3}{V_{\phi}})r^{5/4}\sqrt{\frac{T}{H}}$$

Strong dissipative regime: $r = \Upsilon(\phi, T)/(3H) > 1$

- It solves the “η” problem in SUGRA models:

$$\eta = \eta_H/(1+r) < 1 \quad \text{but} \quad \eta_H > 1, \quad m_\phi^2 > H^2$$

- Longer period of inflation → smaller initial values

BG, Berera PRD’05

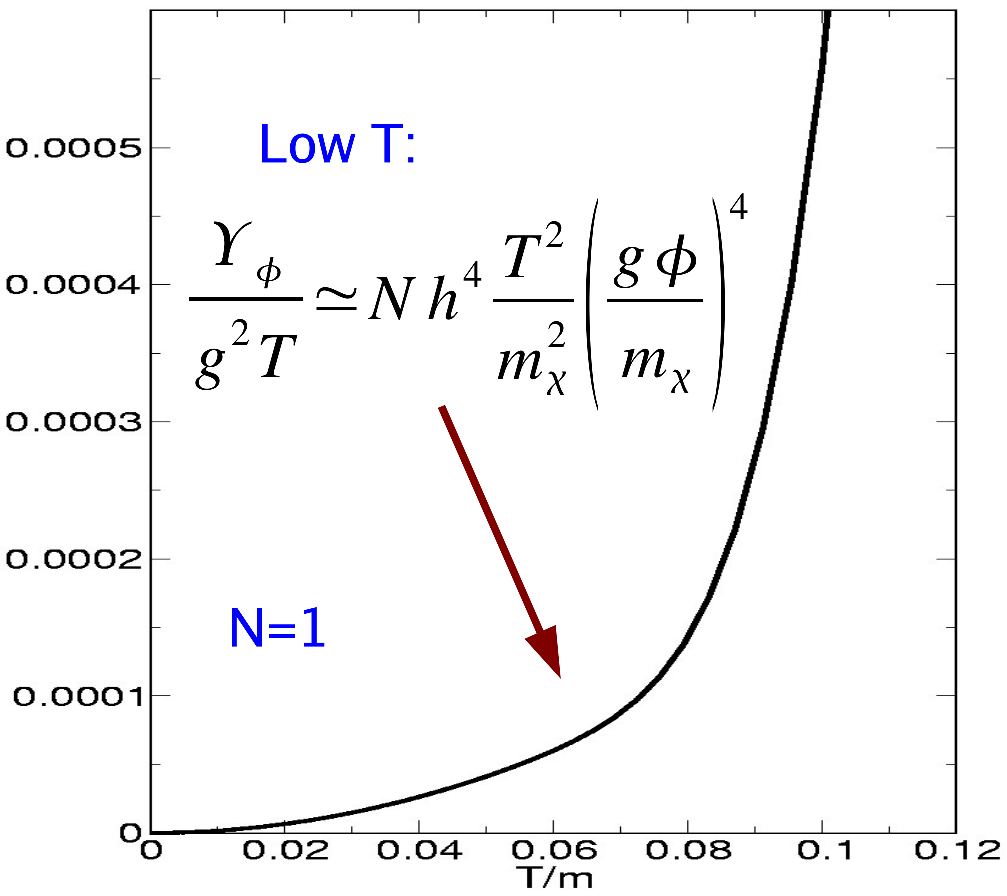
Chaotic models: $\phi_{60} < m_P$

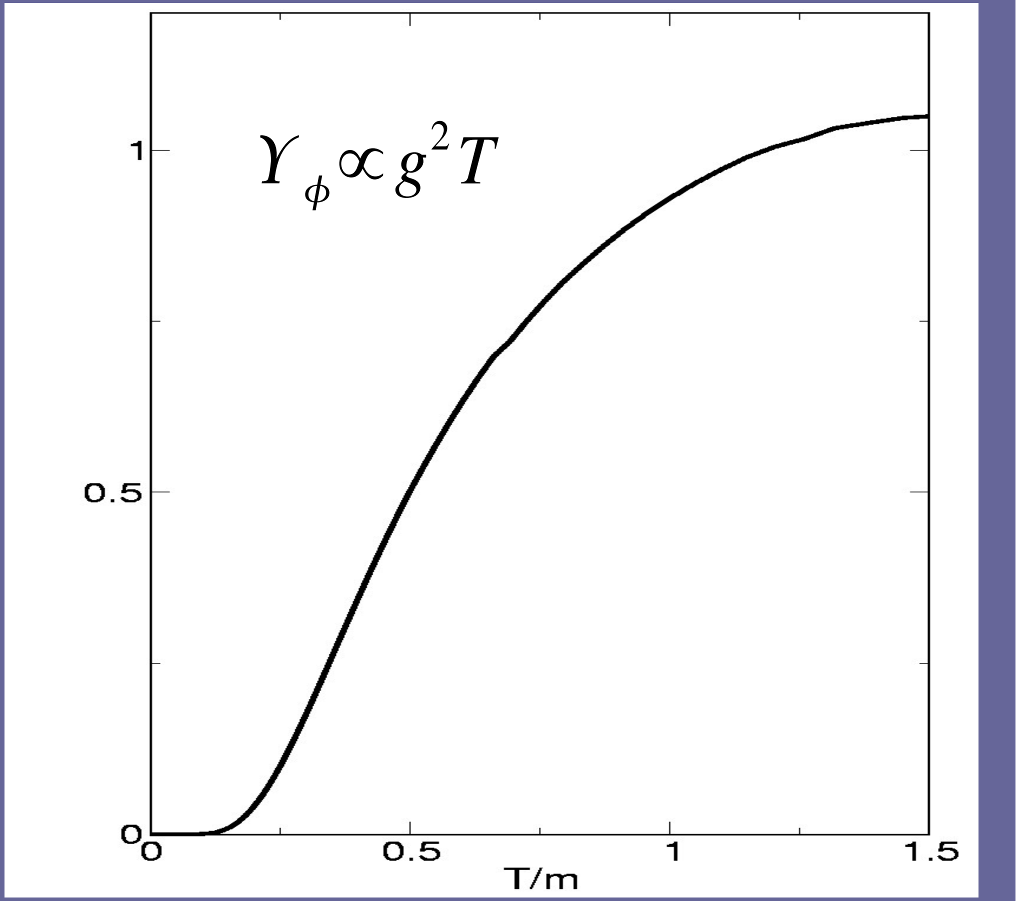
Field values below Planck
No tensor contribution (r<< 1)

Dissipative coefficient:

- Non-thermal heavy propagator: (open issue)
  strong dissipation proportional to decay rate
- Thermal propagator:
  dissipation proportional to $T(T/m_\chi)^\alpha$

Moss, Xiong ‘06





Strong dissipation in the low T regime:

BG, Berera '06

(T < heavy mediating mass, T > H)

-Thermal corrections under control

- Models with strong diss. regime require large nos. of fields

$N = N_\chi N^2_{decay} >>$

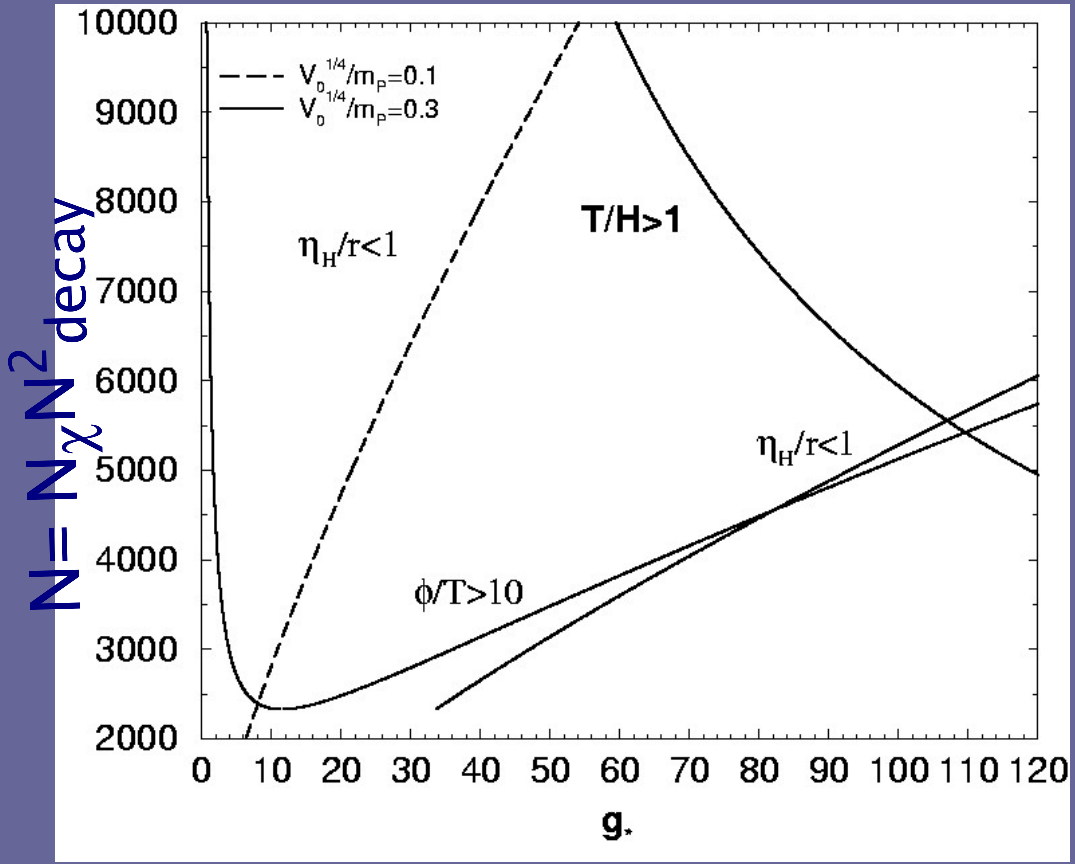
➡ (a) Monomial Potentials: $$V = V_0 \left(\frac{\phi}{m_P} \right)^n$$

➡ (b) Hybrid like models: $$V = V_0 \left(1 + \left(\frac{\phi}{M} \right)^n \right)$$

(c) Small field models: $$V = V_0 \left(1 - \left(\frac{\phi}{M} \right)^2 \right)$$

(talk by J. C. Bueno-Sanchez)

(a) Monomial Potentials: $V = V_0 \left(\frac{\phi}{m_P} \right)^n$



$\rho_R = g_*/(30\,\pi^2)T^4$

$\eta_H / r, \; T / H$ increase during inflation

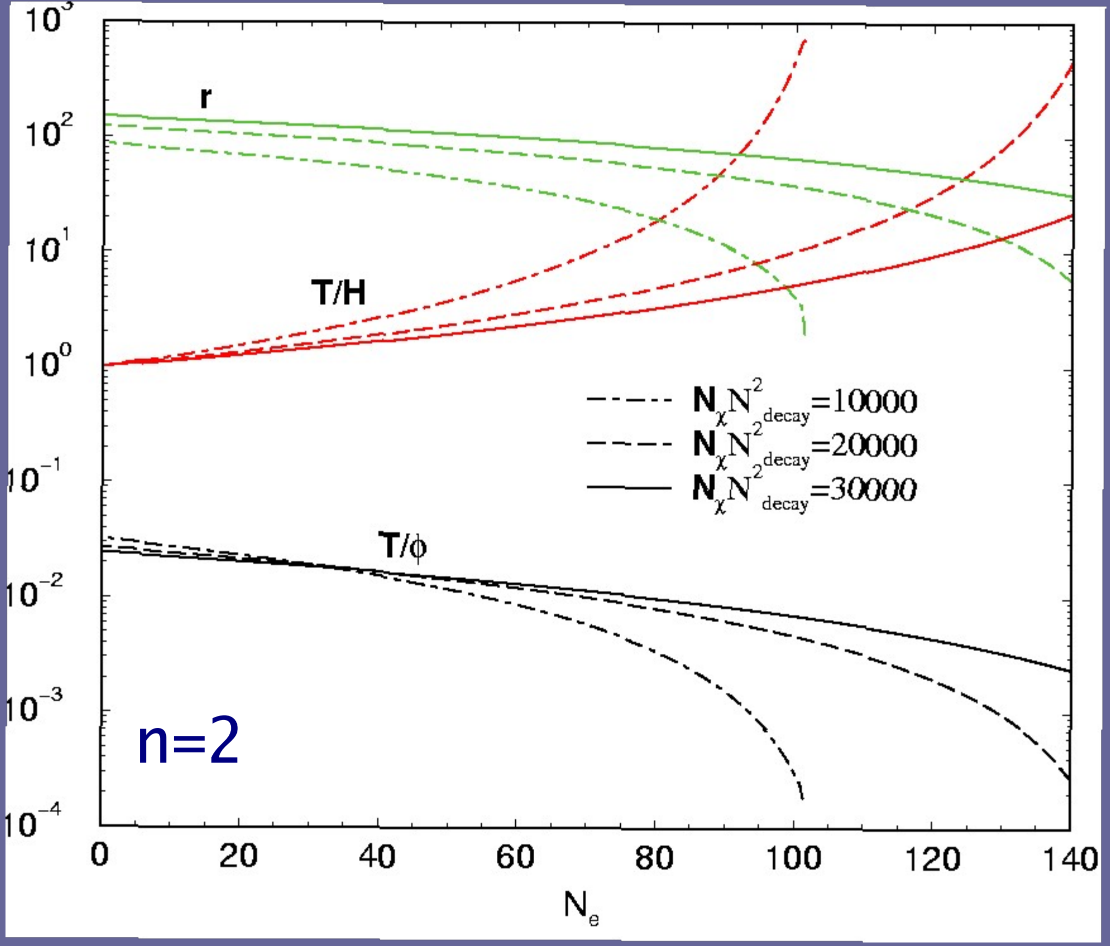
$(\rho_R / V \propto \; \eta_H / r)$ Rad. increase

T / ϕ increases for n<5

Either $\rho_R \simeq V$ or $T > m_\chi$

But P_R too large unless $N > O(10^6)$!

(b) Hybrid like models: $V = V_0 \left(1 + \left(\frac{\phi}{M} \right)^n \right)$



$\eta_H / r, \; T/H$ decrease during inflation

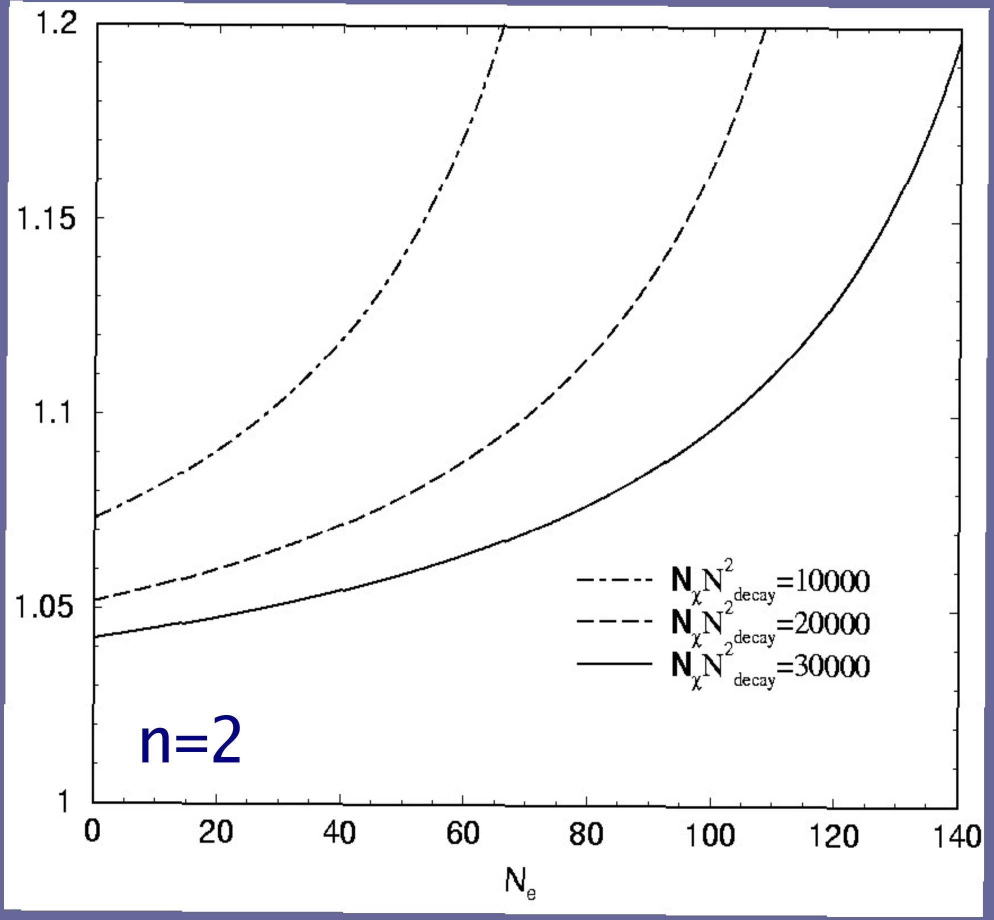
T/ϕ increases for n < 4

r increases for n < 3

n=0,2 :
strong diss. low T → highT

n=4 :
strong → weak → cold

Spectral index: N > O(10^4)



Strong diss. regime:

$$n_s - 1 \simeq \frac{3\eta_H}{7r}\left(\frac{7-n}{n-1}\right)$$

Blue tilted even for n=0 !

Weak diss. regime:

$$n_s - 1 \simeq -2\eta_H + 2\epsilon_H$$

n=0 ➡ Blue tilted
n>0 ➡ Red tilted

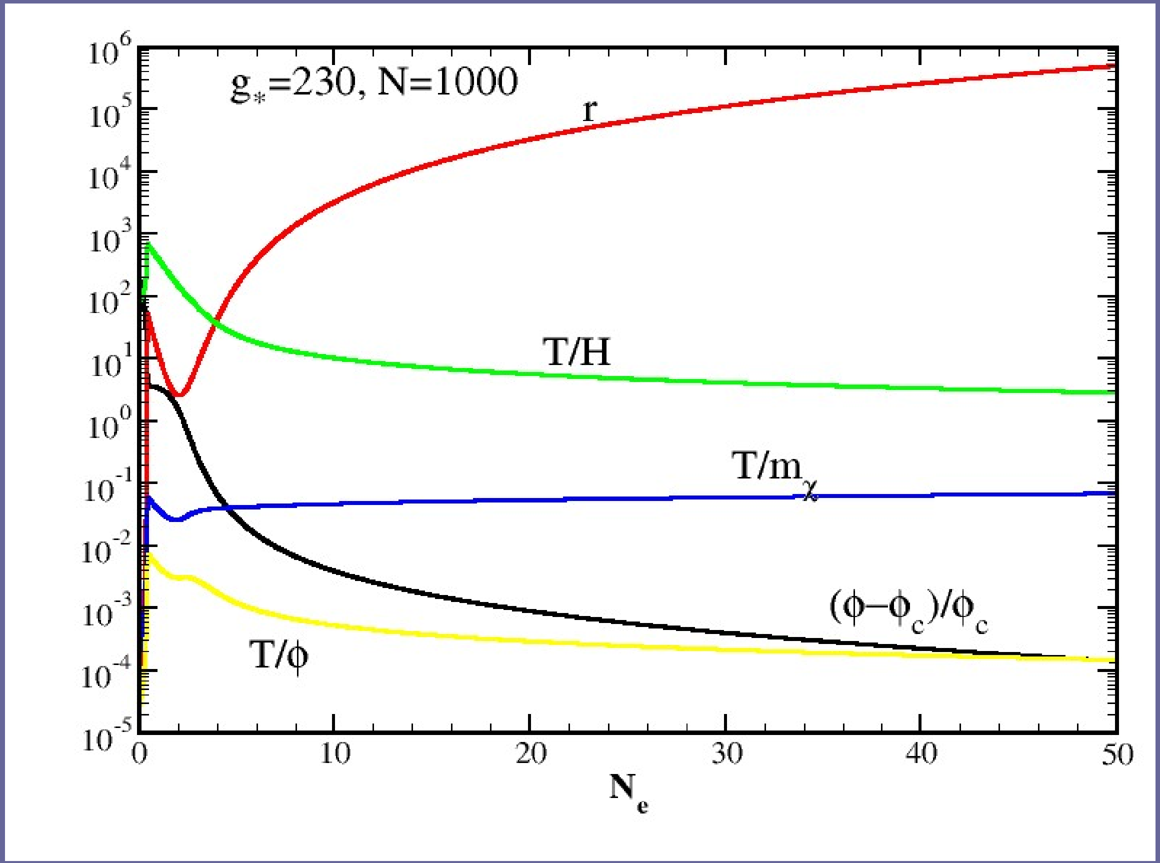
Running: $dn_s/d\ln k \approx -(n_s-1)^2 n/(3(7-n)) + O((\phi/m_P)^2)$

Allowed range: $0.97 < n_s < 1.21, \quad -0.13 < dn_s/d\ln k < 0.007$

(Kinney et al., astro-ph/0605338)

Low T → intermediate T → high T → end of inflation

- Extra no. of e-folds from low to highT?
- Hybrid mechanism: $m_\chi^2 \simeq g^2(\phi^2 - \phi_c^2)$



$$\Upsilon_\phi \propto \frac{T^3}{m_\chi^2}\left(\frac{g\,\phi}{m_\chi}\right)^4$$

Large enhancement near the critical point

Thermal corrections ending inflation?

n=2

(preliminary)

Summary

- Dissipative effects due to decaying fields can be relevant during inflation, and modify the inflationary predictions
(slow roll, primordial spectrum,...)

- Dissipative coefficient: non-equilibrium physics...

- Close-to-equilibrium approx. (thermal propagators)

Low T regime:

$$\frac{\Upsilon_\phi}{g^2 T} \simeq N h^4 \frac{T^2}{m_\chi^2} \left(\frac{g\phi}{m_\chi} \right)^4$$

Large no. of fields N needed in order to fulfill constraints
(no. of e-folds, amplitude of spectrum , spectral index)

Constraints might relax when taking into account
intermediate/high T regime + thermal corrections in hybrid models