Gravitino Overproduction from Inflaton Decay

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@SUSY-07

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M. Endo, K. Hamaguchi and F.T., hep-ph/0602061, 0605091

M. Kawasaki, F.T. and T. Yanagida, hep-ph/0603265, 0605091

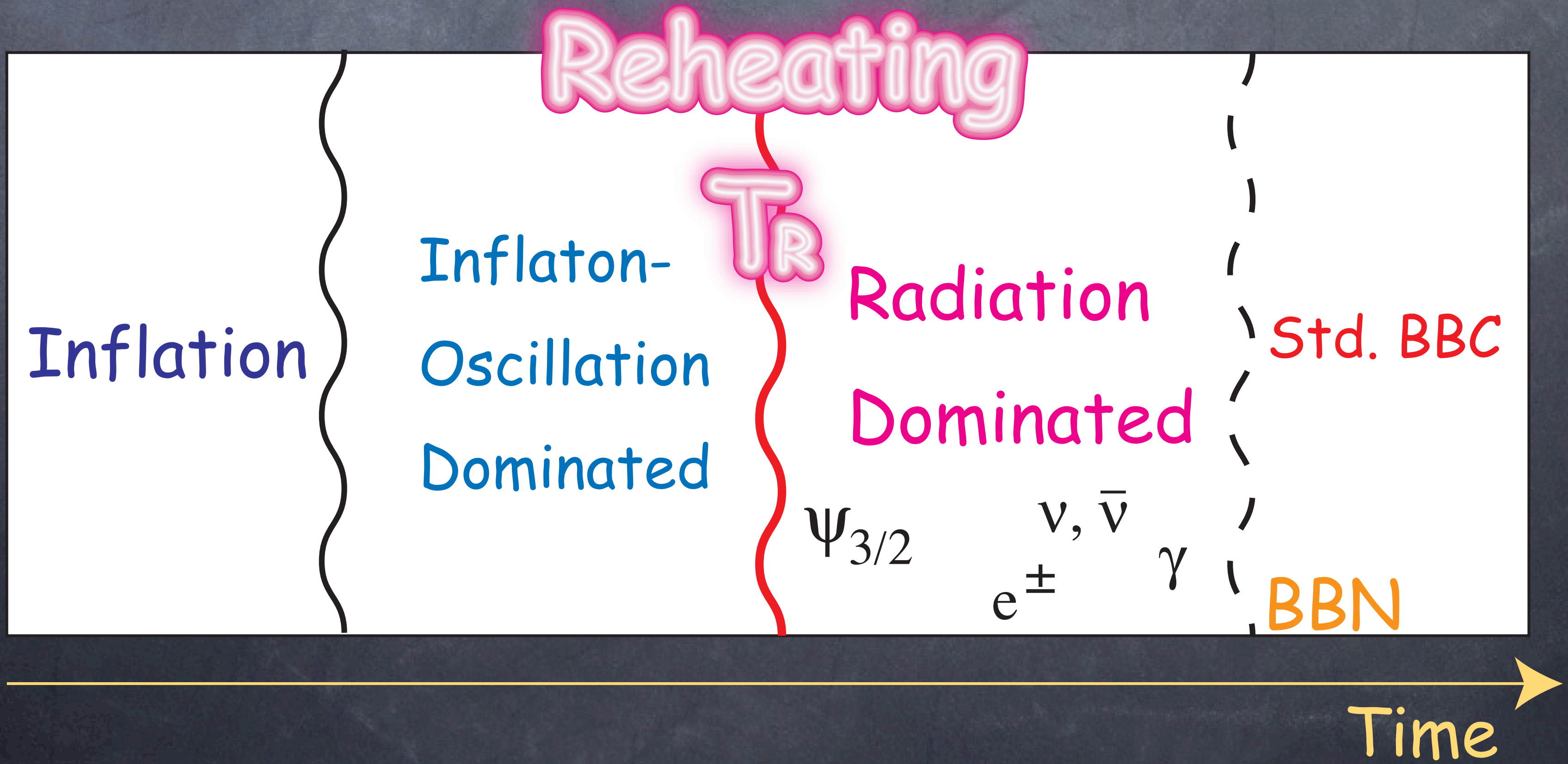
M. Endo, M. Kawasaki, F.T. and T. Yanagida, hep-ph/0607170

M. Endo, F.T. and T. Yanagida, hep-ph/0701042, arXiv:0706.0986

Thermal history after inflation

- Inflaton-decay reheats the universe.
- Severe constraints on T_R come from thermally produced gravitinos. (assuming SUGRA)

→ Talk by Pradler



So far,

- ✓ couplings was introduced ad hoc by hand.
- ✓ subject only to the (thermal) gravitino problem.
- ✓ decay into unwanted relics such as the gravitinos was dropped by hand without any definite grounds.

It was far from full understanding of the thermal history...

We have found

- ✓ inflaton decays into the visible sector via the top Yukawa coupling and SU(3)c gauge interactions.

- ✓ gravitinos are non-thermally produced by inflaton decay.

Good : reheating is naturally induced.

Bad(?) : new gravitino problem!

Inflaton Decay Processes:

✓ I. Gravitino pair production $\phi \rightarrow 2\psi_{3/2}$

Kawasaki, F.T. and Yanagida, hep-ph/0603265, 0605297
Asaka, Nakamura and Yamaguchi, hep-ph/0604132
Dine, Kitano, Morisse and Shirman, hep-ph/0604140
Endo, Hamaguchi, FT, hep-ph/0605091

✓ II. Spontaneous decay into

- any fields in superpotential (at tree level) Endo, Kawasaki, FT, Yanagida hep-ph/0607170

- any gauge fields (at one-loop level) Endo, FT, Yanagida hep-ph/0701042

I. Gravitino Pair-Production

Kawasaki, F.T. and Yanagida, hep-ph/0603265, 0605297
Asaka, Nakamura and Yamaguchi, hep-ph/0604132

- Relevant interactions:

$$e^{-1}\mathcal{L} = -\frac{1}{8}\epsilon^{\mu\nu\rho\sigma}\left(G_\phi \partial_\rho \phi + G_z \partial_\rho z - \mathrm{h.c.}\right)\bar{\psi}_\mu \gamma_\nu \psi_\sigma$$

$$-\frac{1}{8}e^{G/2}\left(G_\phi \phi + G_z z + \mathrm{h.c.}\right)\bar{\psi}_\mu \left[\gamma^\mu, \gamma^\nu\right]\psi_\nu,$$

ϕ : inflaton field

z : SUSY breaking field, w/ $G^z G_z \simeq 3$

$$G \equiv K + \ln|W|^2$$

Taking account of the mixings,

$$G_\phi \sim \langle\phi\rangle \frac{m_{3/2}}{m_\phi} \quad \text{for} \quad m_\phi < m_z$$

Gravitino Pair Production Rate:

$$\Gamma_{3/2} \simeq \frac{|G_\phi|^2}{288\pi} \frac{m_\phi^5}{m_{3/2}^2 M_P^2} \simeq \frac{1}{32\pi} \left(\frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2}$$

Endo, Hamaguchi and F.T., hep-ph/0602061
Nakamura and Yamaguchi, hep-ph/0602081

for $m_\phi < m_z$

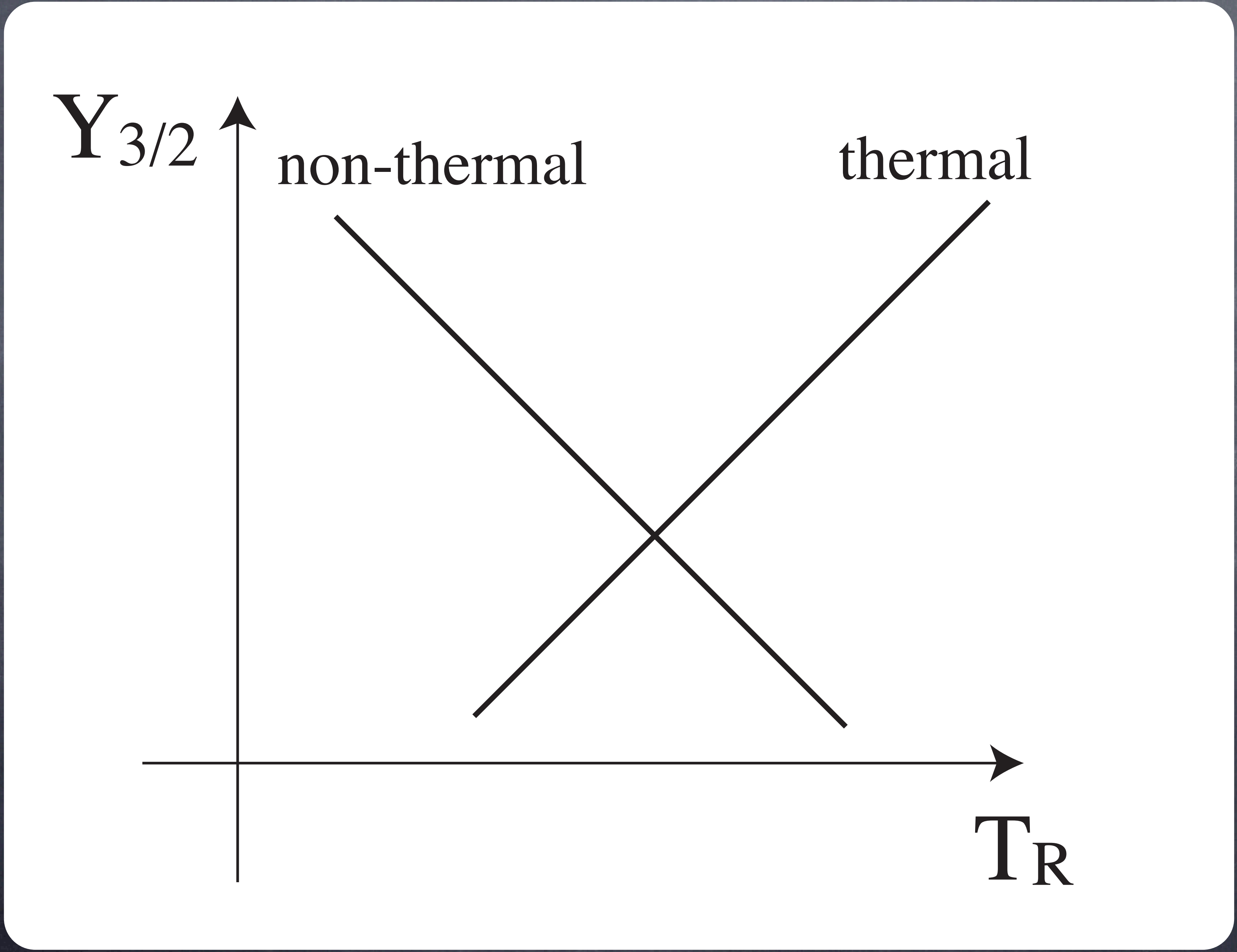
- Gravitino pair production is effective especially for low-scale inflation models.
- Gravitino abundance is inversely proportional to the reheating temperature!

Gravitino Abundance:

$$
\begin{aligned}
Y_{3/2} &\simeq 2\,\frac{\Gamma_{3/2}}{\Gamma_{\rm total}}\frac{3}{4}\frac{T_R}{m_\phi}, \\
&\sim 10^{-14}\left(\frac{g_*}{200}\right)^{-\frac{1}{2}}\left(\frac{T_R}{10^6\,{\rm GeV}}\right)^{-1} \\
&\quad \times\left(\frac{\langle\phi\rangle}{10^{15}\,{\rm GeV}}\right)^2\left(\frac{m_\phi}{10^{10}\,{\rm GeV}}\right)^2
\end{aligned}
$$

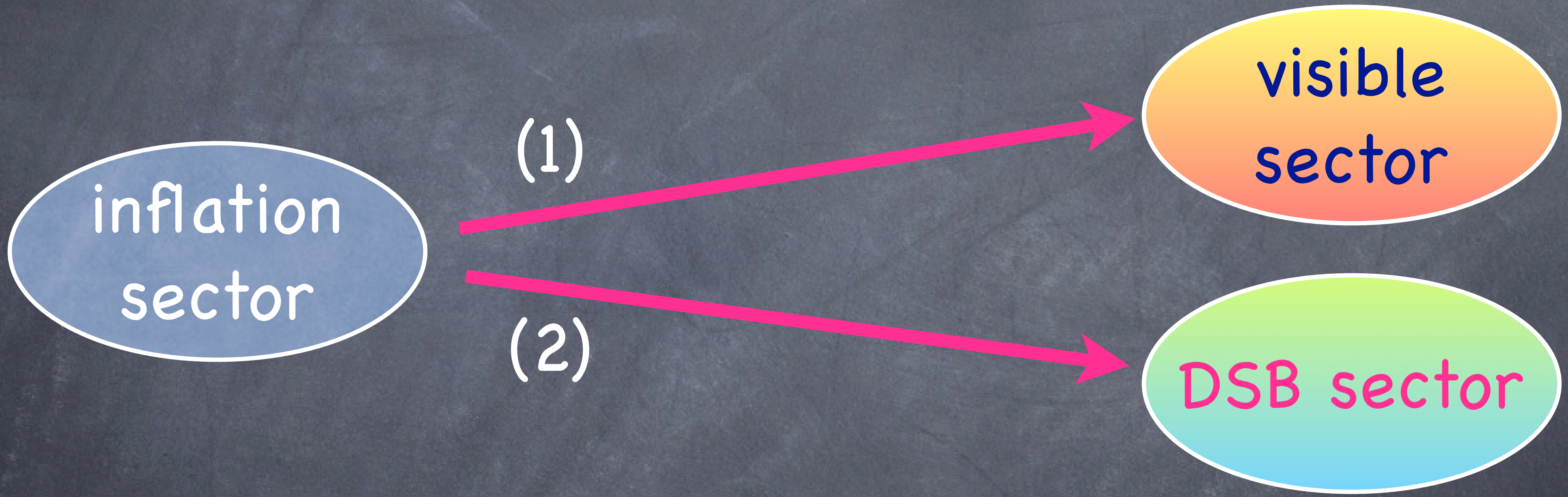
Note: $\Gamma_{\rm total} \sim \frac{T_R^2}{M_P}$

Gravitino Abundance



II. Spontaneous Decay Processes

- Inflaton couples to all the fields in the superpotential, through the SUGRA effects.



(1) Lower limit on the reheating temperature

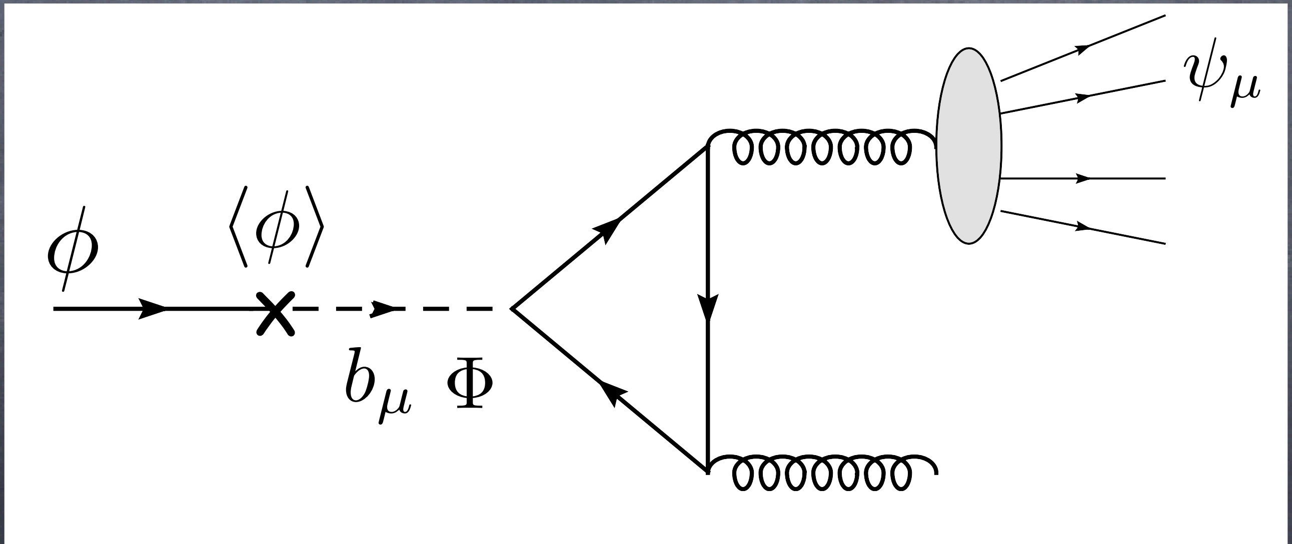
(2) Decay into DSB sector produces gravitinos

Decay into SUSY breaking sector

Endo, F.T, Yanagida hep-ph/0701042

- through Yukawa interactions at tree level
- through anomalies in SUGRA (at one-loop)

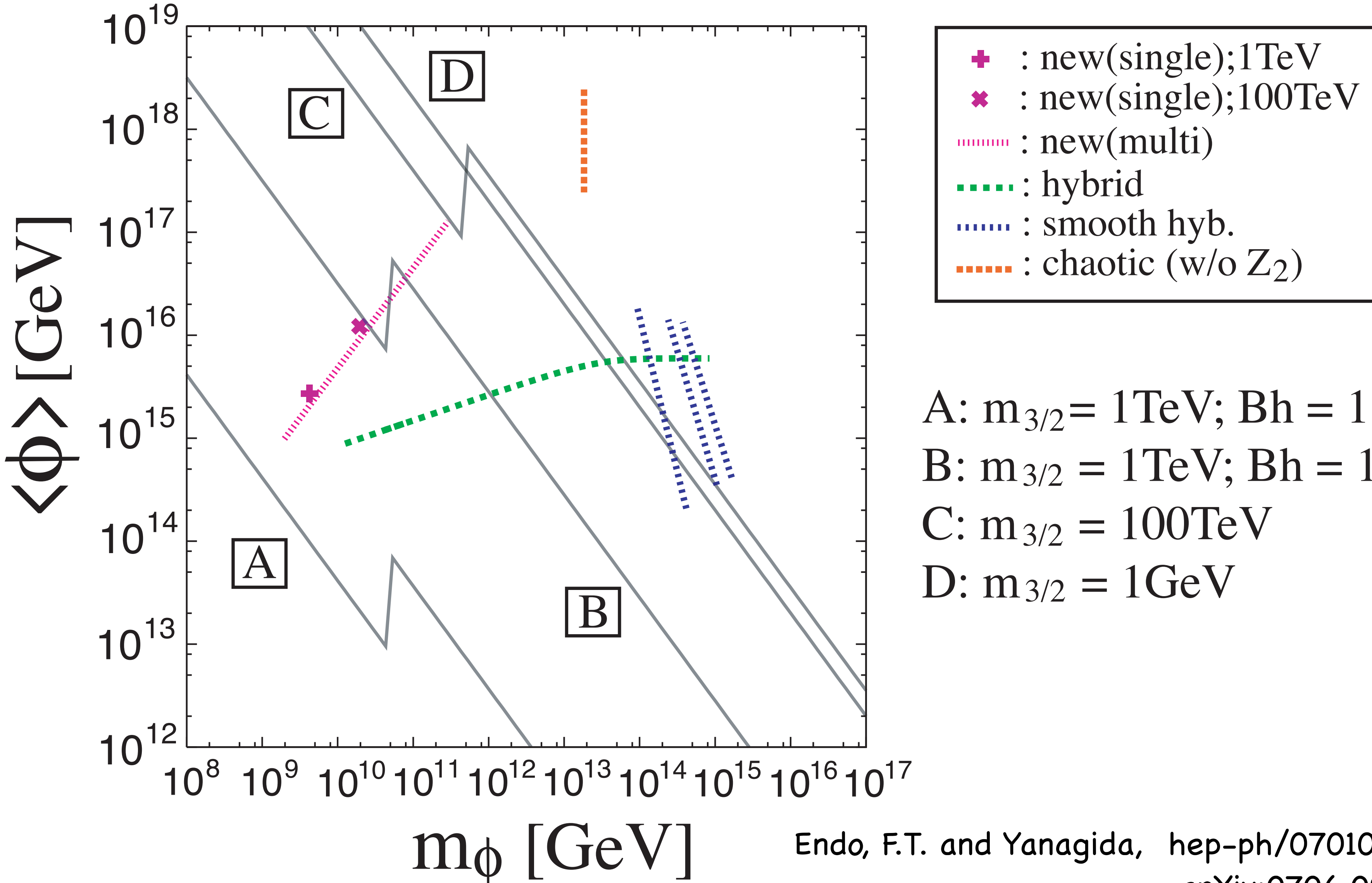
$$\Gamma_{\rm DSB} = \frac{N_g^{(h)}\alpha_h^2}{256\pi^3}(T_G^{(h)} - T_R^{(h)})^2 \left(\frac{\langle\phi\rangle}{M_P}\right)^2 \frac{m_\phi^3}{M_P^2}$$



The gravitinos are produced from the hidden hadron decay.

Conservative

Constraints on the inflation models;



A: $m_{3/2}$ = 1TeV; Bh = 1

B: $m_{3/2}$ = 1TeV; Bh = 10^{-3}

C: $m_{3/2}$ = 100TeV

D: $m_{3/2}$ = 1GeV

Endo, F.T. and Yanagida, hep-ph/0701042, arXiv:0706.0986

Solutions:

(i) Postulate a symmetry on the inflaton.

e.g.) chaotic inflation

$$V = \frac{1}{2}m^2\phi^2 \ \text{ w/ } \ \phi \leftrightarrow -\phi$$

(ii) AMSB, GMSB

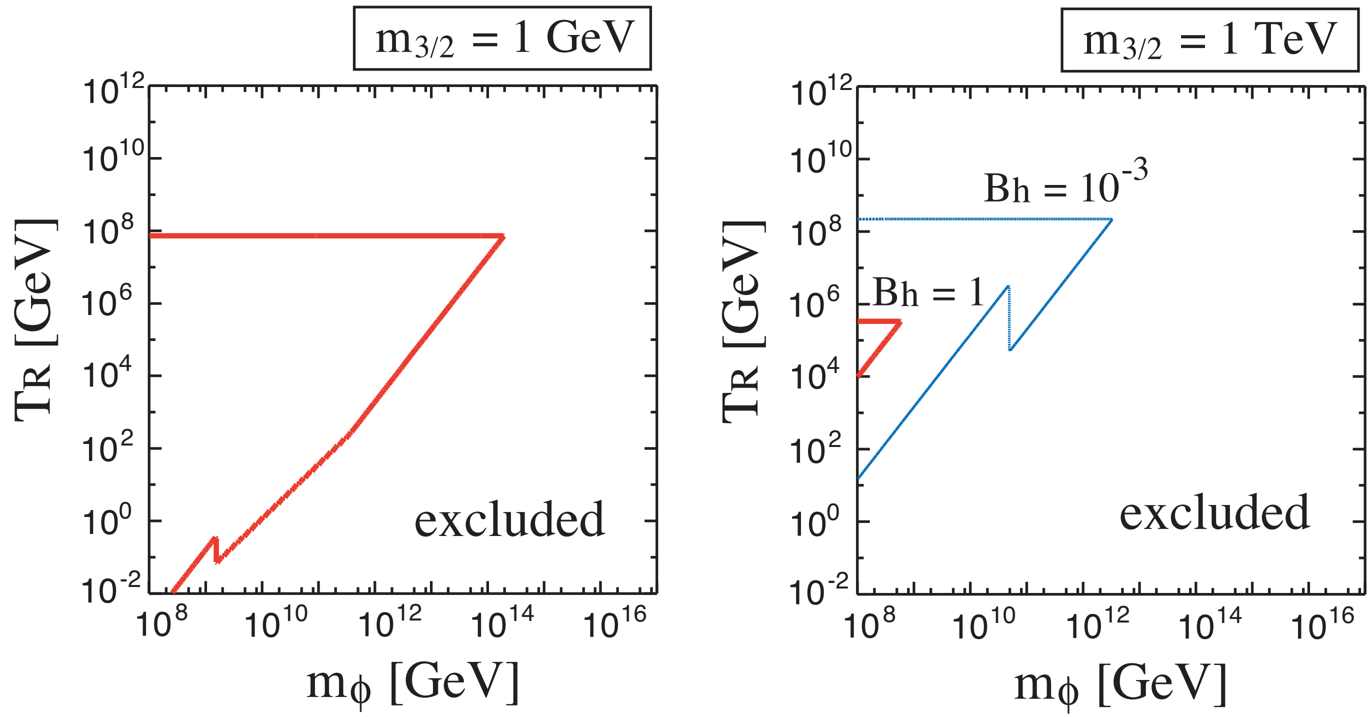
cosmological constraints are relaxed.

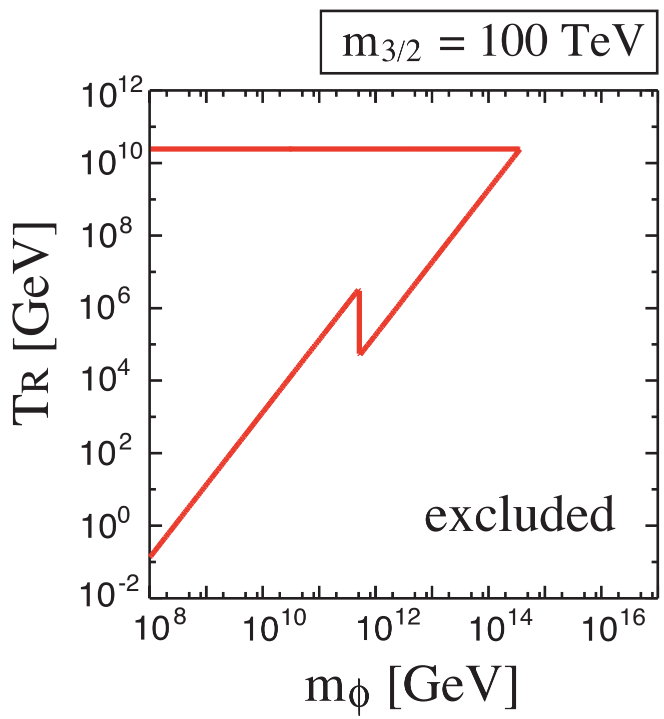
(iii) late-time entropy production

Summary:

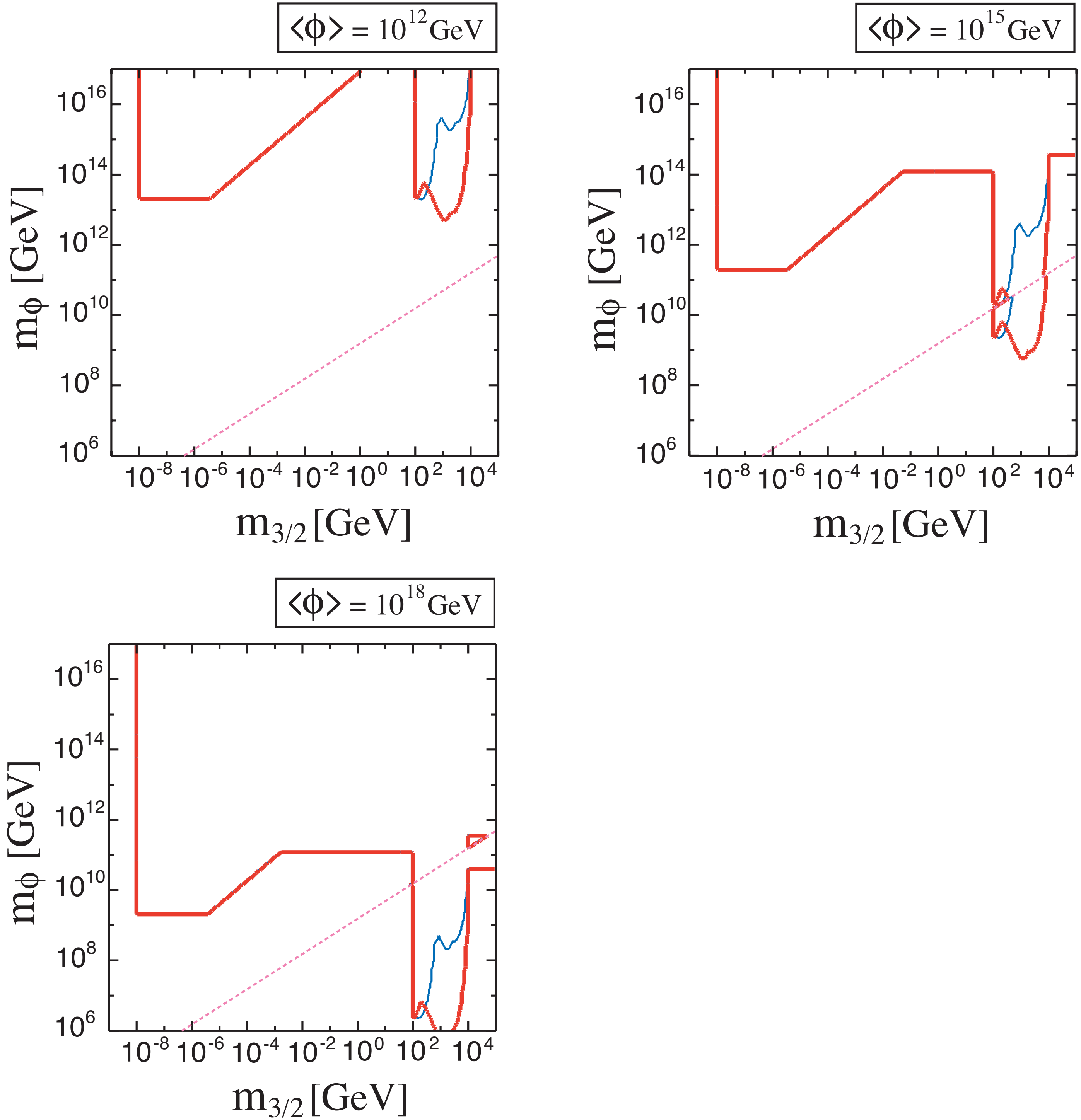
We have discovered that gravitinos are generically produced from an inflaton decay.

- Additional Slides





$$\langle \phi \rangle = 10^{15}\,\mathrm{GeV}$$



⟨ϕ⟩ = 10^12 GeV
⟨ϕ⟩ = 10^15 GeV
⟨ϕ⟩ = 10^18 GeV
m_ϕ [GeV]
m_3/2 [GeV]

Effects of Preheating

Whether the preheating occurs strongly depends on the global structure of the scalar potential and the interactions of the inflaton.

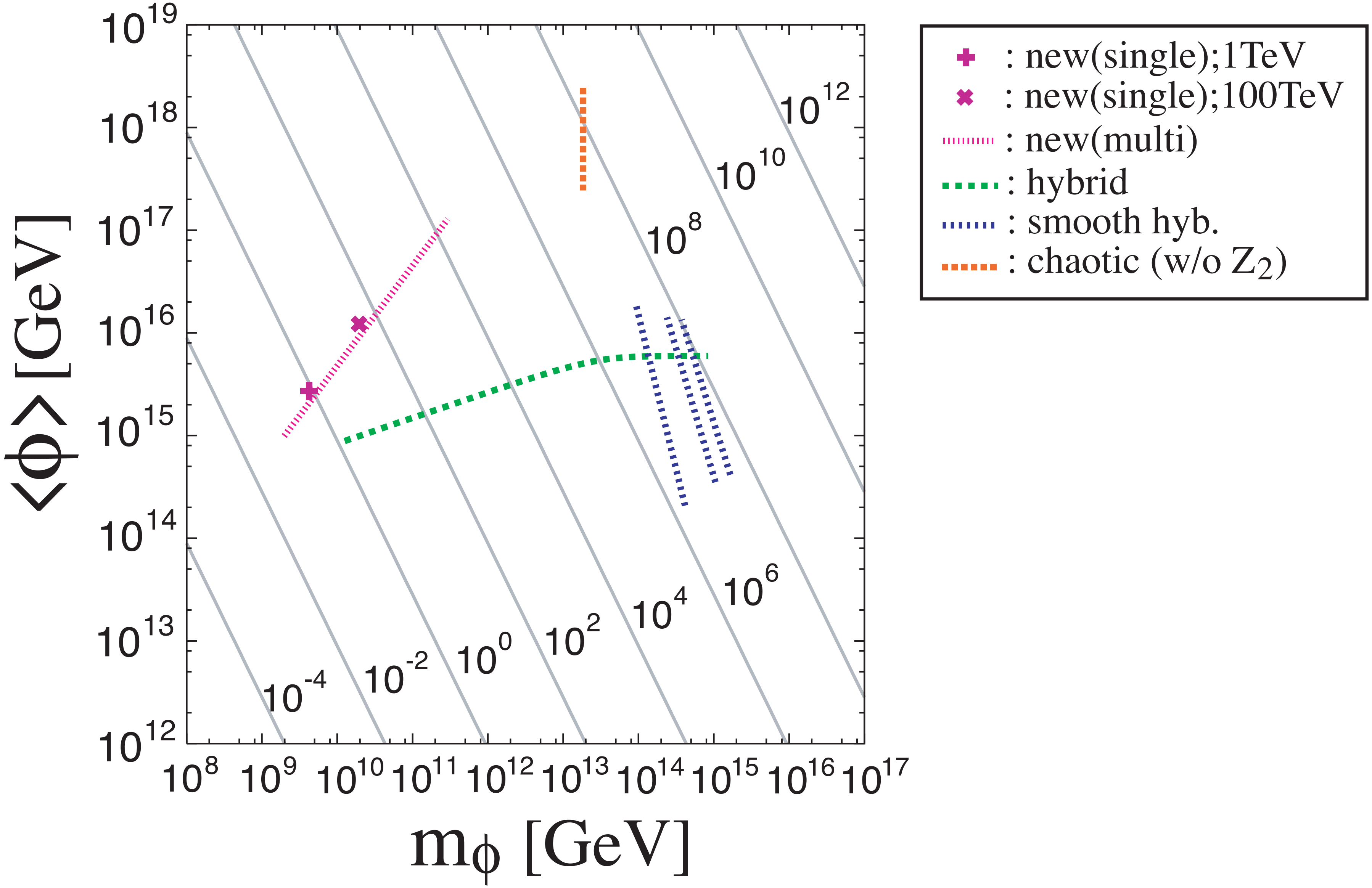
If the preheating is efficient:

too many gravitinos will be produced by thermal scatterings as usual.

If the preheating is inefficient (due to back reaction)

the residual inflaton will dominate the universe in the end, and reheat via perturbative decays.

- Decay Rate through the Top Yukawa coupling:



Potential minimization

$$V = e^G \left(G^i G_i - 3 \right)$$

Differentiating V w.r.t. ϕ

$$\Rightarrow \quad G^\phi \nabla_\phi G_\phi + G^z \nabla_\phi G_z + G_\phi = 0$$

$$\nabla_\phi G_\phi \sim \frac{W_{\phi\phi}}{W} \sim \frac{m_\phi}{m_{3/2}} \gg 1$$

$$\nabla_\phi G_z \sim \frac{W_\phi}{W} \frac{W_z}{W} \sim \langle \phi \rangle$$

$$\Rightarrow \quad G_\phi \sim \langle \phi \rangle \frac{m_{3/2}}{m_\phi}$$

Mass Matrix in SUGRA

$$V = e^G \left(G^i G_i - 3 \right)$$

$$M^2_{ij*} = \frac{\partial^2 V}{\partial \varphi^i \partial \varphi^{\dagger j}} = e^G \left(\nabla_i G_k \nabla_{j*} G^k - R_{ij^* k\ell^*} G^k G^{\ell *} + g_{ij^*} \right),$$

$$M^2_{ij} = M^2_{ji} = \frac{\partial^2 V}{\partial \varphi^i \partial \varphi^j} = e^G \left(\nabla_i G_j + \nabla_j G_i + G^k \nabla_i \nabla_j G_k \right),$$

$$\nabla_\phi G_\phi \sim \frac{W_{\phi\phi}}{W} \sim \frac{m_\phi}{m_{3/2}} \gg 1$$

$$\nabla_\phi G_z \sim \frac{W_\phi}{W} \frac{W_z}{W} \sim \langle \phi \rangle$$

⇨ $M^2_{\phi \bar{z}} \neq 0$

New inflation model

Izawa and Yanagida ,`97

$$
\begin{aligned}
K(\phi, \phi^\dagger) &= |\phi|^2 + \frac{k}{4}|\phi|^4, \\
W(\phi) &= v^2\phi - \frac{g}{n+1}\phi^{n+1}.
\end{aligned}
$$

Successful inflation & density fluc. is realized if

$$v = 4 \times 10^{-7}(0.1/g)^{1/2}$$

$$k \lesssim 0.03 \qquad \text{for } n = 4$$

$$\langle\phi\rangle \simeq (v^2/g)^{1/n} \qquad m_\phi \simeq nv^2/\langle\phi\rangle$$

Chaotic Inflation

Kawasaki, Yamaguchi and Yanagida ,`00

$$K(\phi+\phi^\dagger) = c\,(\phi+\phi^\dagger) + \frac{1}{2}(\phi+\phi^\dagger)^2 + \cdots$$

$$W = m\phi\psi$$

Normalization: $m = 2\times 10^{13}\,\mathrm{GeV}$

Hybrid Inflation Models in supergravity

$$W(\phi,\psi,\tilde{\psi}) = \phi(\mu^2 - \lambda\tilde{\psi}\psi),$$

R-charge: $\phi(+2),\ \psi\,\tilde{\psi}(0)$

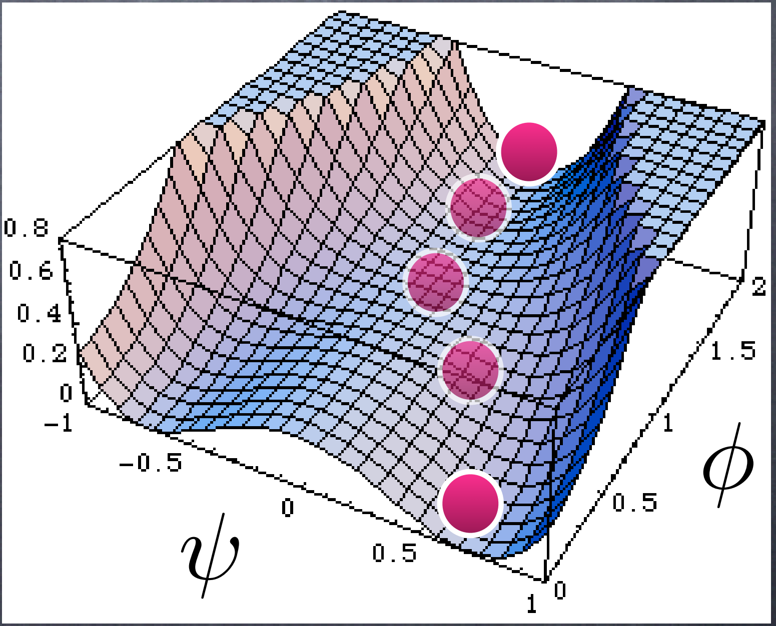
w/ minimal Kahler

U(1) gauge: $\phi(0),\ \psi(1),\ \tilde{\psi}(-1)$

For $|\phi| \gg \mu/\sqrt{\lambda}$ $\quad \langle\psi\rangle = \langle\tilde{\psi}\rangle = 0$ flat potential

Global minimum is located at

$$\langle\phi\rangle = 0$$
$$\langle\psi\rangle = \langle\tilde{\psi}\rangle = \mu/\sqrt{\lambda}$$



Scalar spectral index:

$$n_s \simeq 0.98 - 1.0$$

Smooth Hybrid Inflation Models

$$W(\phi, \psi, \tilde{\psi}) = \phi \left(\mu^2 - \frac{(\tilde{\psi}\psi)^n}{M^{2n-2}} \right).$$

Global minimum is located at

$$\langle \phi \rangle = 0$$
$$\langle \psi \rangle = \langle \tilde{\psi} \rangle = (\mu M^{n-1})^{1/n}$$

The dynamics is similar to hyb. inflation, but n_s is slightly smaller.

$$n_s \simeq 0.967 - 0.97$$