Inflaton Decay in Supergravity

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

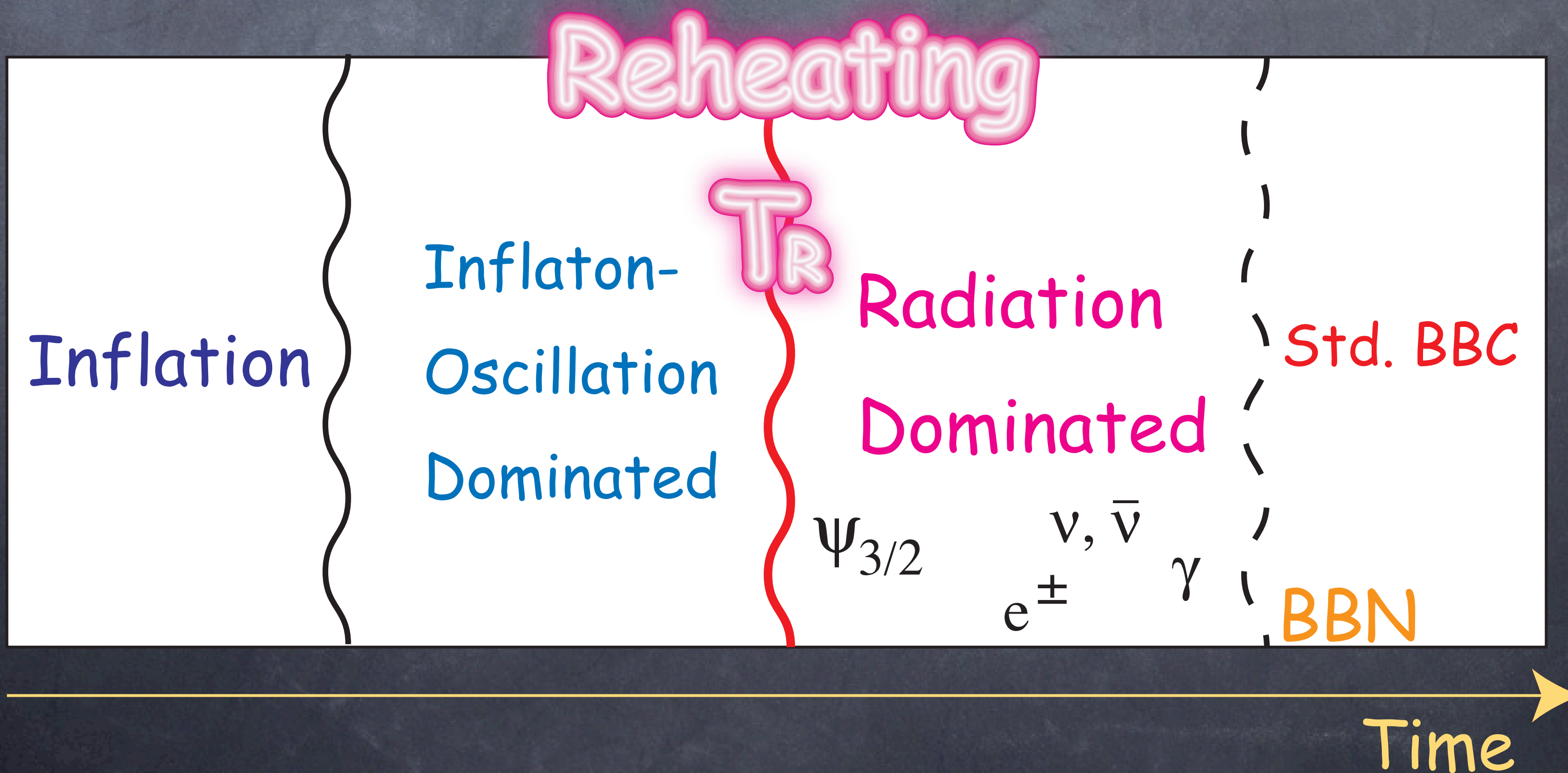
M. Kawasaki, F.T. and T. Yanagida, hep-ph/0603265, 0605091

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

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

Thermal history after inflation

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



- So far,
  - ✓ couplings are introduced ad hoc by hand
  - ✓ subject to the gravitino problem
    (due to thermally produced gravitinos)
- We have found
  - ✓ inflaton decays via the top Yukawa coupling.
  - ✓ gravitinos are non-thermally produced by inflaton decay.

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Inflaton Decay Processes:

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

  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:

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

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

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:

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

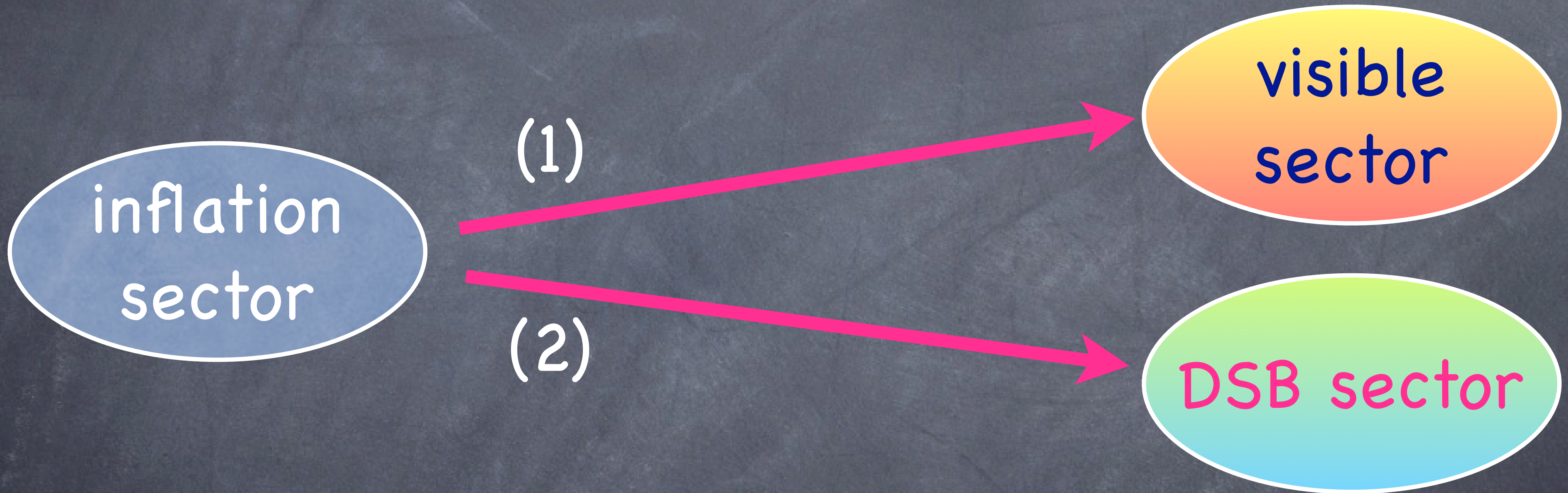
Endo, Hamaguchi and F.T., hep-ph/0602061
Nakamura and Yamaguchi, hep-ph/0602081

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!

II. Spontaneous Decay Processes

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



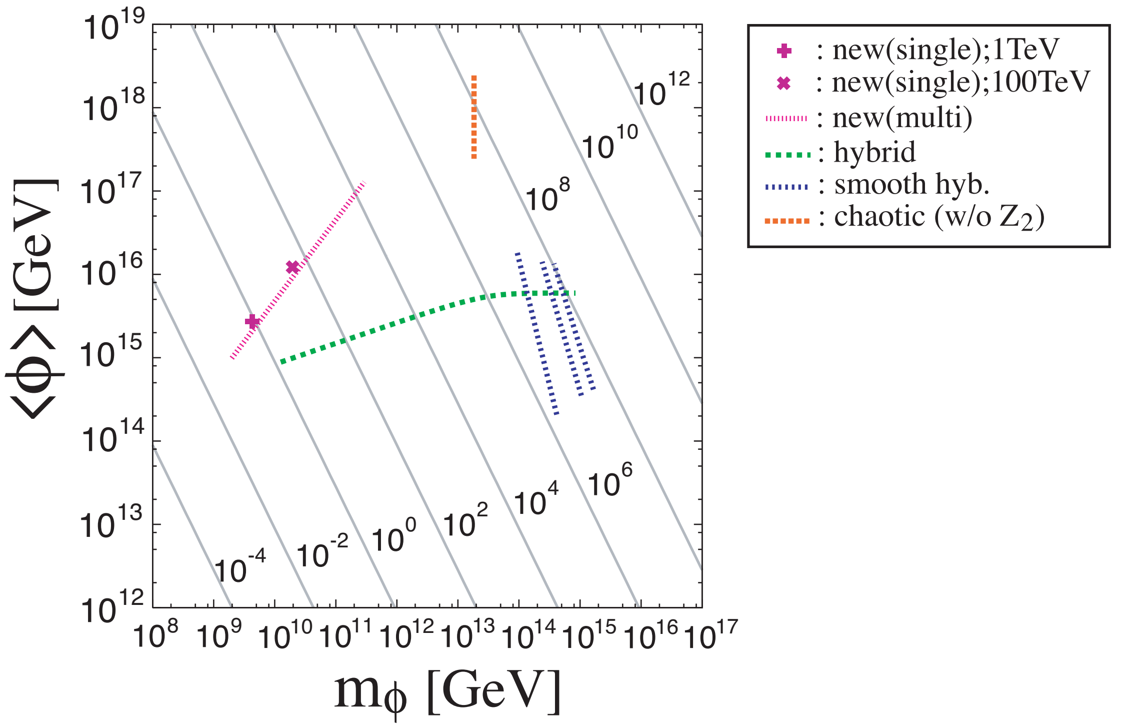
(1) Lower limit on the reheating temperature

(2) Decay into DSB sector produces gravitinos

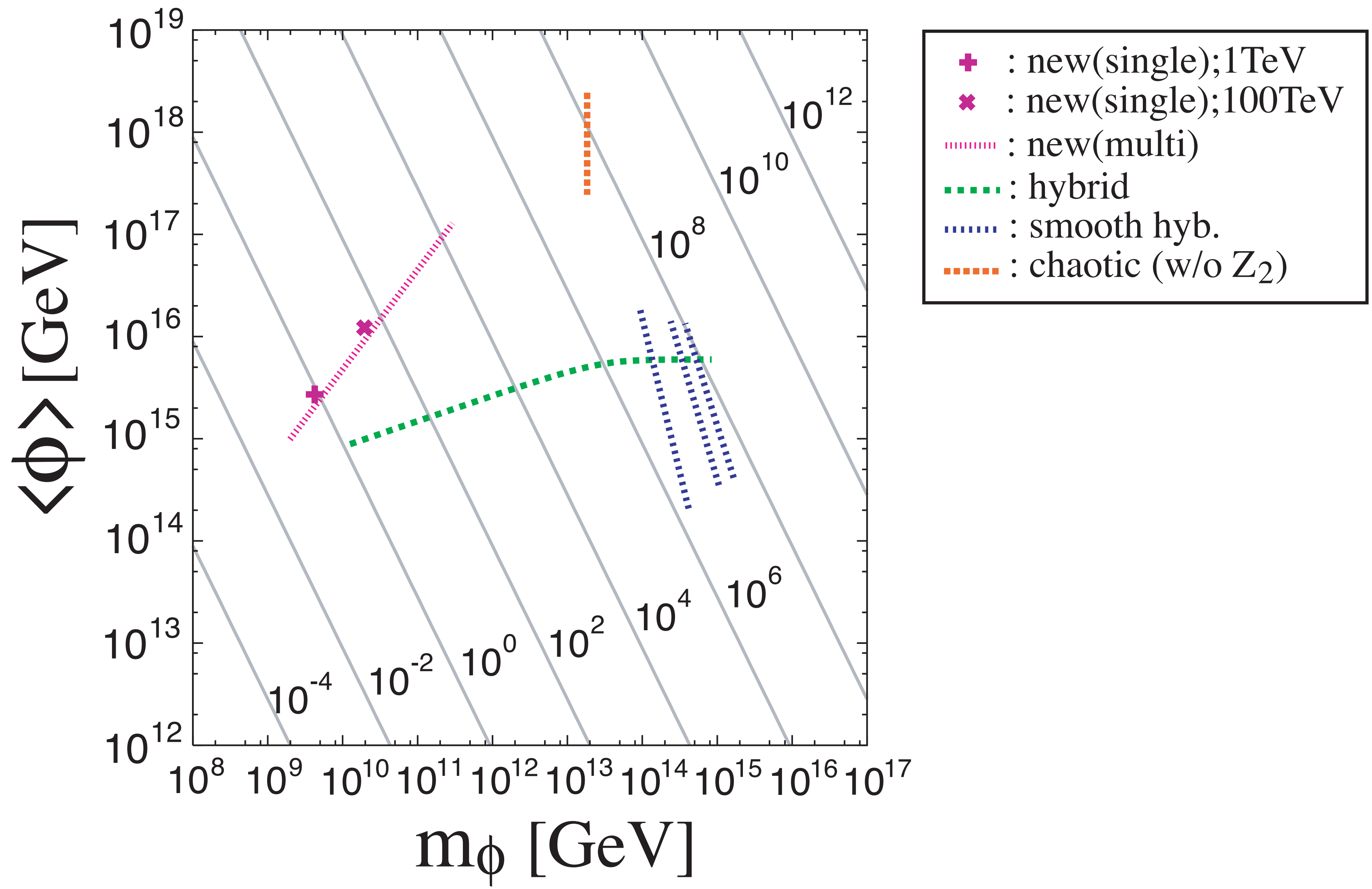
- Decay Rate through the Top Yukawa coupling:

$$\Gamma_T = \frac{3}{128\pi^3}|Y_t|^2\left(\frac{\langle\phi\rangle}{M_P}\right)^2\frac{m_\phi^3}{M_P^2},$$

- Lower limit on the reheating temperature



- Decay Rate through the Top Yukawa coupling:



(2) 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)

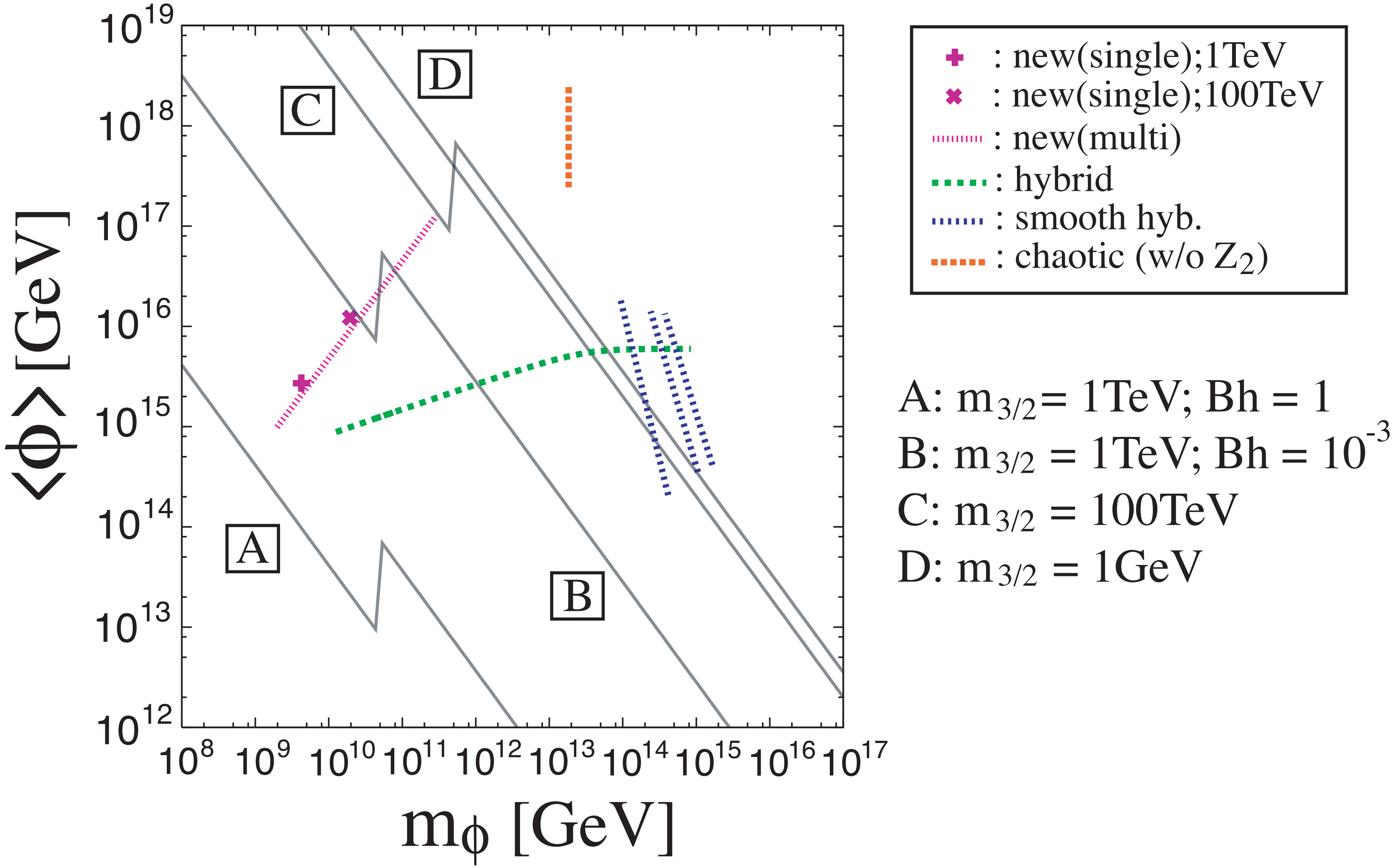
$$\Delta\mathcal{L} = -\frac{g^2}{(16\pi)^2}\int d^2\theta\, W^\alpha W_\alpha \frac{\bar{D}^2}{\partial^2}\Big[4(T_R - 3T_G)R^\dagger - \frac{T_R}{3}D^2K + \frac{T_R}{d_R}D^2 \log\det K|_R''\Big] + \text{h.c.}$$

The rate of the decay into the hidden gauge sector is

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

Conservative

Constraints on the inflation models;



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.

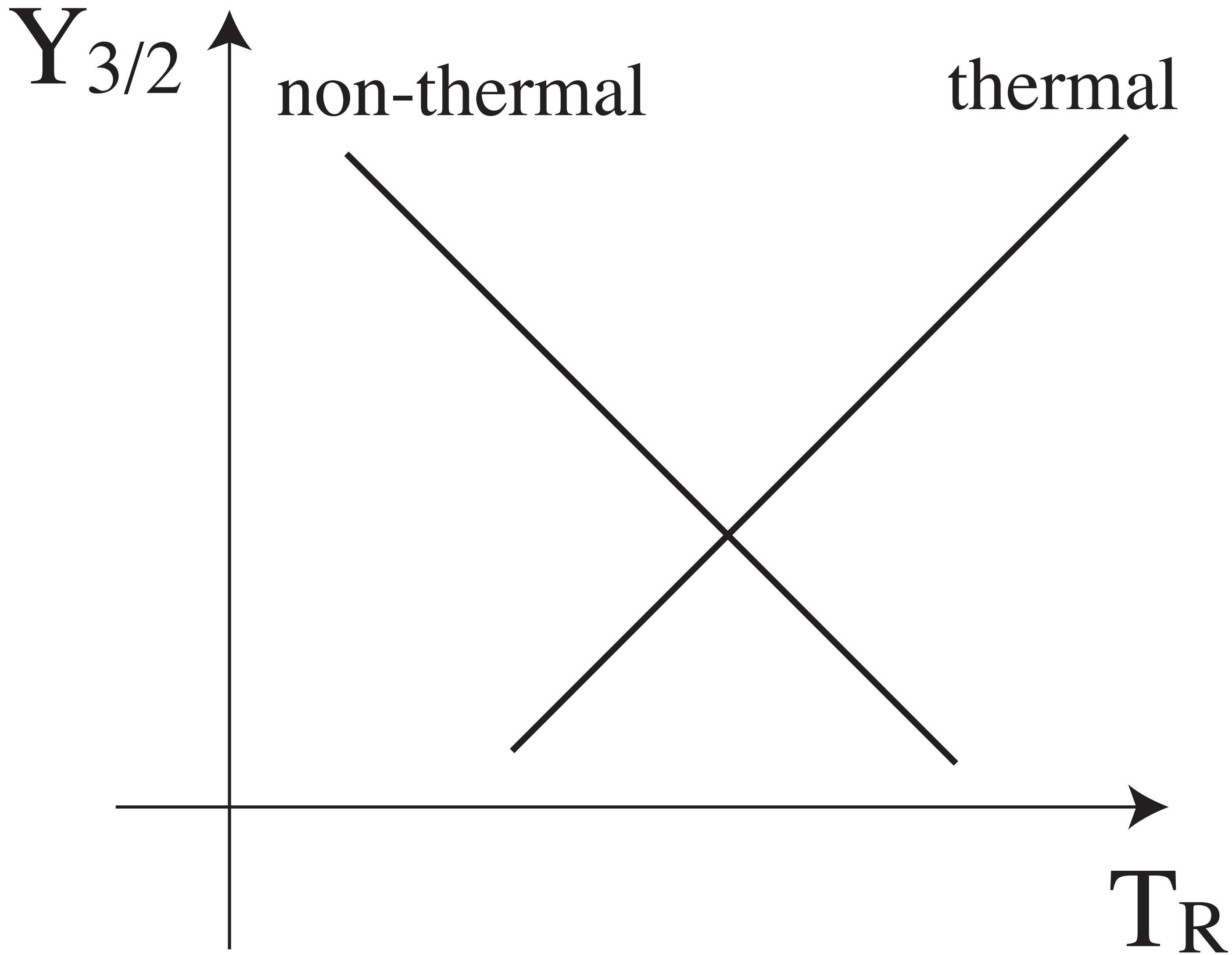
- Additional Slides

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



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

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

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

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

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

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

$\Rightarrow$ $M^2_{\phi \bar{z}} \neq 0$

New inflation model

Izawa and Yanagida ,`97

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

Successful inflation & density fluc. is realized if

$$v = 4 \times 10^{-7}\,(0.1/g)^{1/2}$$
$$k \lesssim 0.03$$

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

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

$$W = m\phi\psi$$

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

Note: $$\delta K = \frac{1}{2}\kappa(\phi+\phi^\dagger)zz + \mathrm{h.c.}$$

is allowed if z is a singlet.

Hybrid Inflation Models in supergravity

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

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

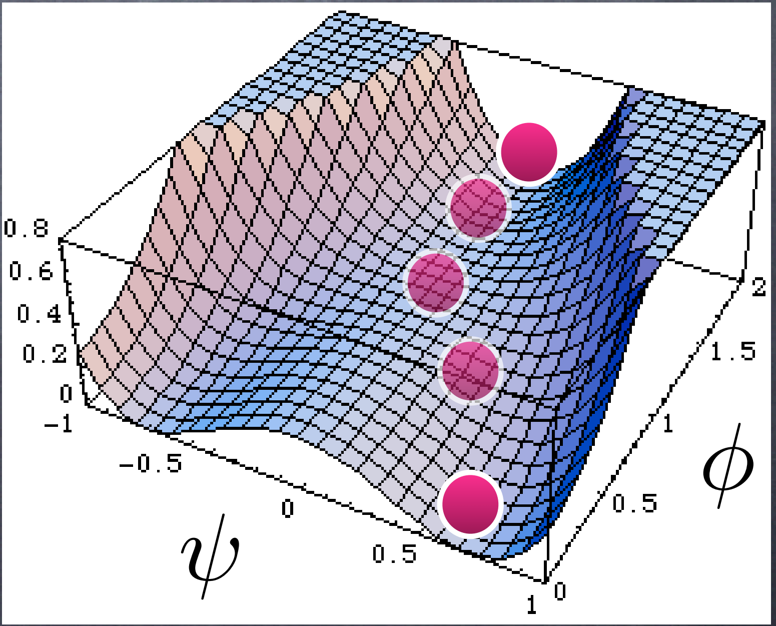
w/ minimal Kahler

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.

$$n_s \simeq 0.967 - 0.97$$