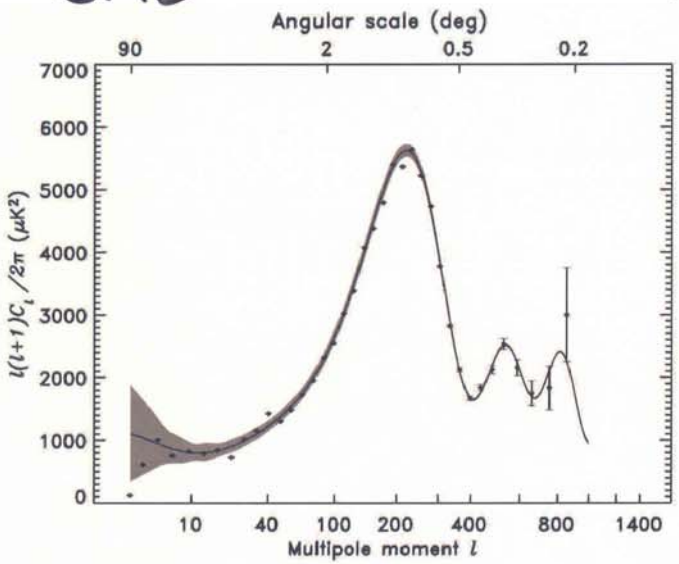
LEPTOGENESIS AND SCALAR FIELD DYNAMICS AND GRAVITINO

KOICHI HAMAGUCHI
(DESY)

@ DESY THEORY WORKSHOP '03

Baryon Asymmetry in the Universe

CMB

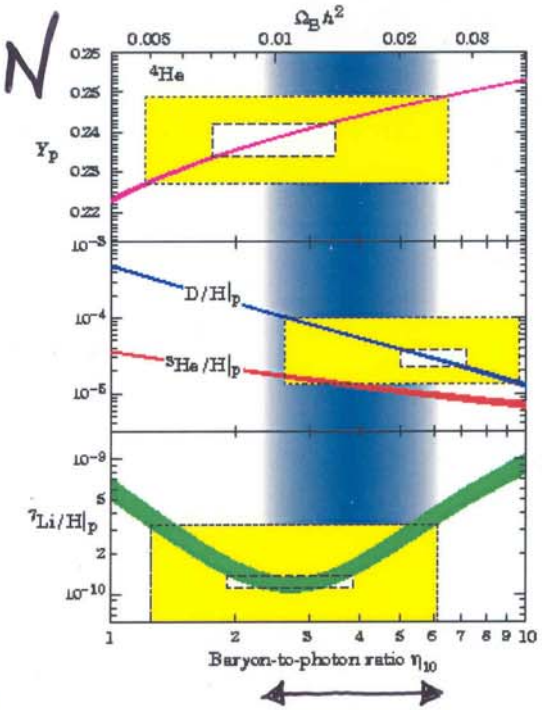


WMAP + other CMB exp.s

$\Omega_B h^2 = 0.0224 \pm 0.0009$ [WMAP '03]

$\Leftrightarrow \dfrac{n_B}{s} = (0.87 \pm 0.04) \times 10^{-10}$ (1σ)

BBN



$\eta = \dfrac{n_B}{n_\gamma} = (2.6 - 6.3) \times 10^{-10}$

[Particle Data Group '02]

$\Leftrightarrow \dfrac{n_B}{s} = (0.36 \sim 0.90) \times 10^{-10}$

BARYOGENESIS SCENARIOS

- GUT BARYOGENESIS
- ELECTROWEAK BARYOGENESIS [specific MSSM spectrum]

TODAY

- LEPTOGENESIS
  - by N_R (right-handed neutrino) decay
    - thermal → N_R [$m_{\nu_i} < 0.12\,eV$]
    - inflaton decay → N_R
    - coherent oscillation of $\tilde{N}_R$
  - by triplet Higgs
  - Dirac Leptogenesis
  - .....
  - via the LH_u flat direction [$m_{\nu_1} \simeq 10^{-9}\,eV$]
  - .....
- AFFLECK-DINE BARYOGENESIS
  - other flat directions
    [··→ Q-ball ····→ $\tilde{H}$ or $\tilde{W}$ LSP dark matter]
- .....

Purpose of My Talk

- To compare several Leptogenesis scenarios by N_R decay (thermal / inflaton decay / coherent $\widetilde{N}_R$) paying attention to the gravitino problem,

- To show that, in higher dimensional set-up, (e.g., gaugino mediation)

~~gravitino problem~~ → gravitino = cold dark matter

$\Omega_{3/2} \simeq \Omega_{CDM}$

quite naturally !!

LEPTOGENESIS BY N_R DECAY

AND GRAVITINO PROBLEM

Leptogenesis by N_R decay (overview)

$$? \xrightarrow{①} N_R \xrightarrow{②} \begin{cases} \ell H \\ \bar{\ell}\bar{H} \end{cases} (n_L = n_\ell - n_{\bar{\ell}} \neq 0) \xrightarrow{③} n_B \neq 0.$$

$$\left[\frac{n_B}{s}\right] = \frac{n_{N_R}}{s} \times \frac{n_L}{n_{N_R}} \times 0.35$$

① ② ③ sphaleron

① depends on the scenario (Next Pages ...)

② $$\frac{n_L}{n_{N_{R1}}} = \frac{\Gamma(N_1 \to \ell H) - \Gamma(N_1 \to \bar{\ell}\bar{H})}{\Gamma(N_1 \to \ell H) + \Gamma(N_1 \to \bar{\ell}\bar{H})} \equiv \epsilon_1$$

Covi Roulet Vissani '96
Flanz Paschos Sarkar '95
Buchmüller Plümacher '97

$$= \cdots = 2\times10^{-6}\left(\frac{M_{R1}}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{m_{\nu_3}}{0.05\,\mathrm{eV}}\right) f_{\mathrm{eff}}$$

for $M_{R1} \ll M_{R2}, M_{R3}$

$f_{\mathrm{eff}} \leq 1$
KH. Murayama Yanagida '01
Davidson Ibarra '02

thermal leptogenesis

Fukugita Yanagida '86
.....
Buchmüller DiBari Plümacher '02–'03
→ Talk by M. Plümacher

$$\left[\frac{n_B}{s}\right] = \frac{n_{NR}}{s} \times \frac{n_L}{n_{NR}} \times 0{,}35$$

$$\frac{n_L}{n_{NR}} \simeq 2\times 10^{-6}\left(\frac{M_{R1}}{10^{10}\,\text{GeV}}\right)\left(\frac{m_{\nu 3}}{0{,}05\,\text{eV}}\right)\delta_{\text{eff}}$$

$$\frac{n_{NR}}{s} \simeq 0{,}3\,\frac{g_{NR}^{\text{eff}}}{g_*}\,\kappa \simeq 4\times 10^{-3}\,\kappa$$

κ: efficiency factor. $\lesssim 0.3$

simple!

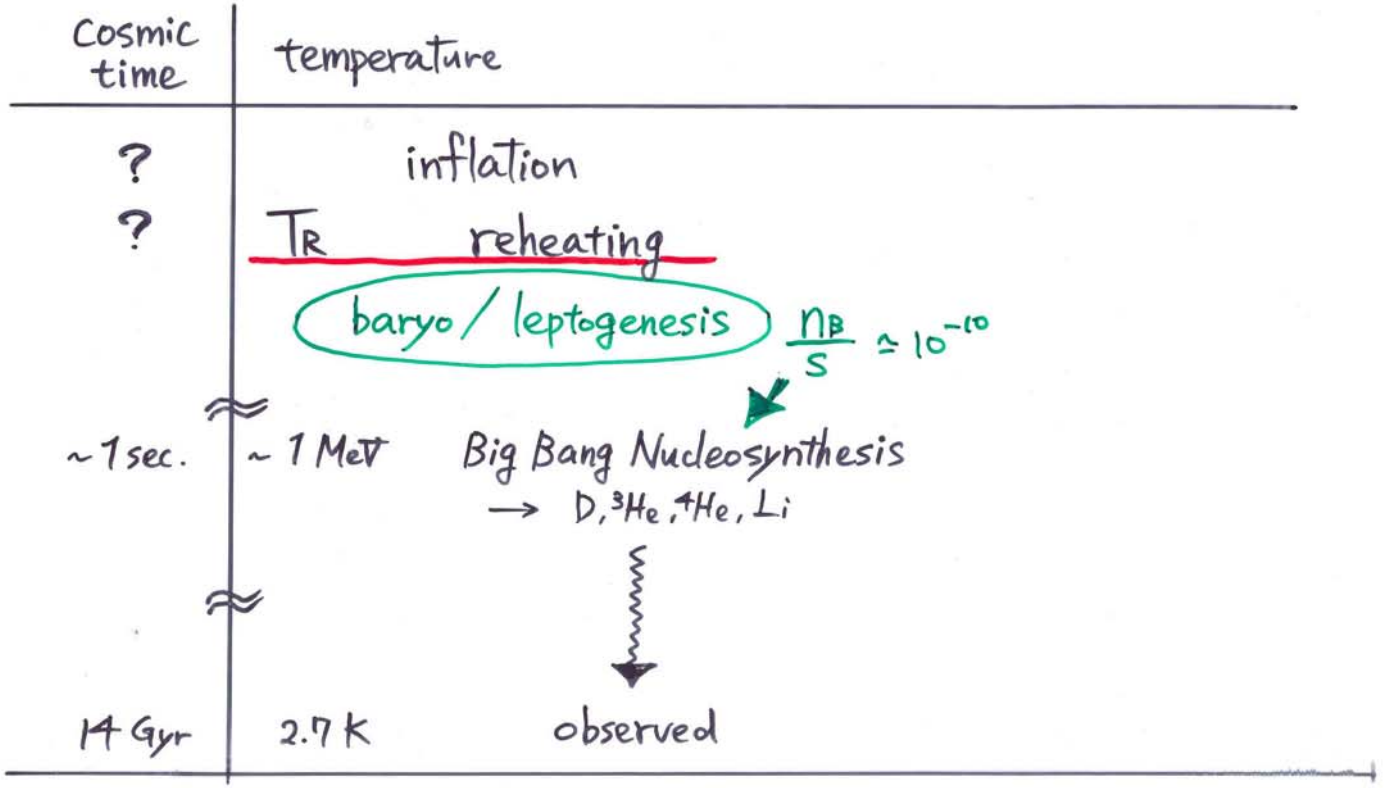
$$\Rightarrow \left[\frac{n_B}{s}\right] = 10^{-10}\left(\frac{M_{R1}}{10^{9}\,\text{GeV}}\right)\left(\frac{\kappa}{0{,}3}\right) \times \left(\frac{m_{\nu 3}}{0{,}05\,\text{eV}}\right)\delta_{\text{eff}}$$

$T_R \gtrsim M_{R1} \geq 10^9\,\text{GeV}$ is required .....

→ gravitino problem ?!

gravitino problem

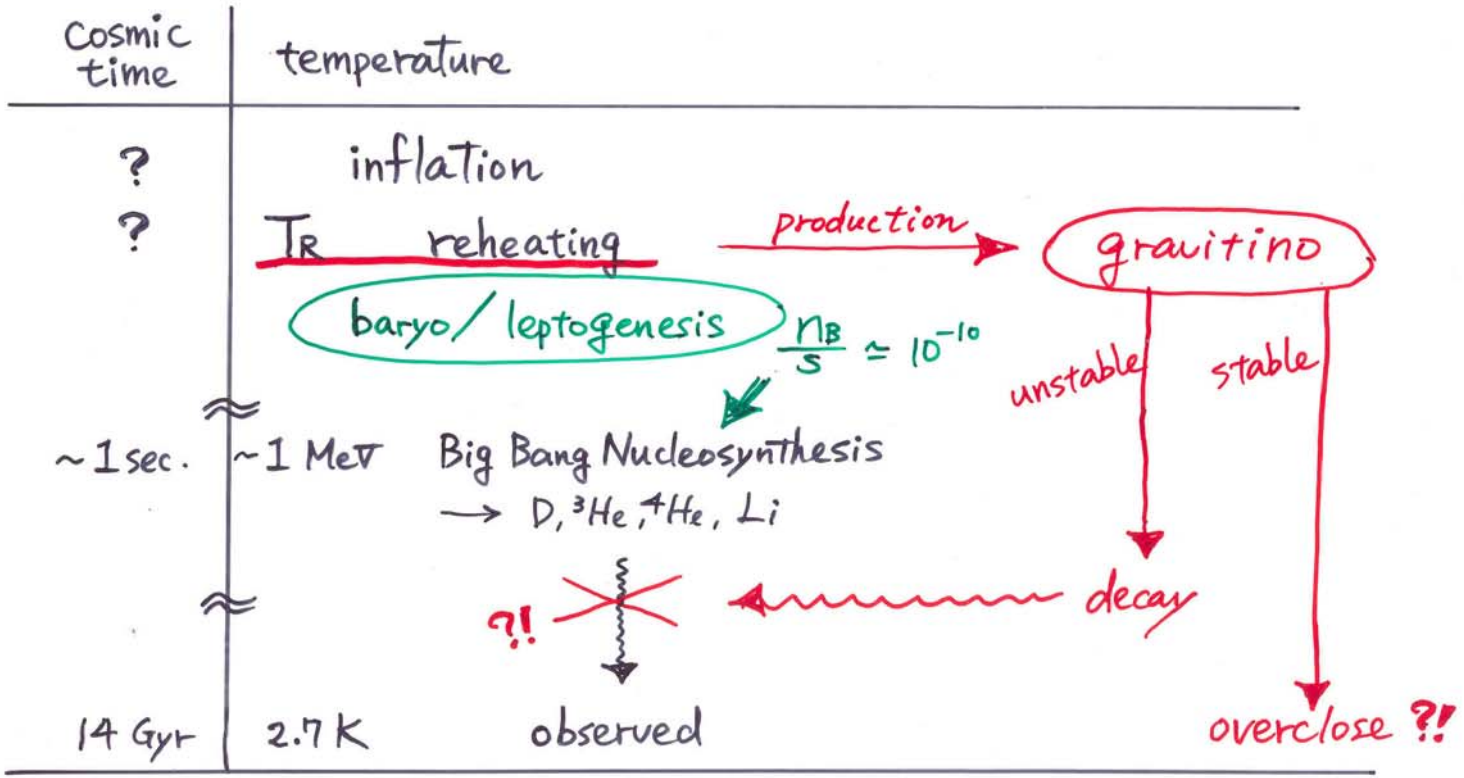
thermal history



gravitino problem

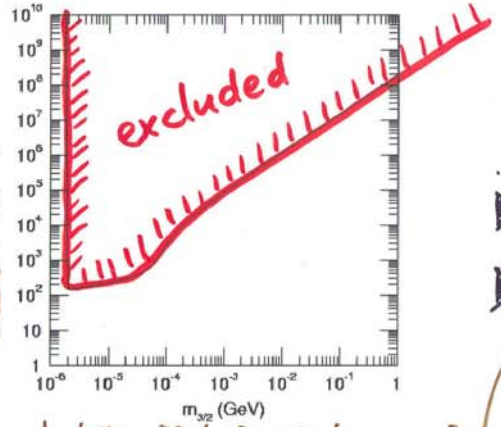
Weinberg '82 / Pagels Primack '82
Khlopov Linde '84
Ellis Kim Nanopoulos '84 / Maroi Murayama Yamaguchi '93

thermal history with gravitino



gravitino problem

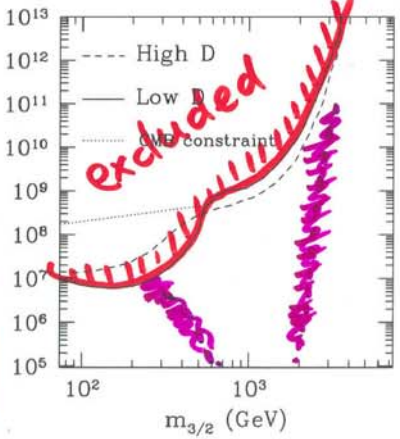
stable (LSP)



[Gouvêa Moroi Murayama '97]

★ recent calculation [Bolz Brandenburg Buchmüller '00]

unstable



[Kawasaki Kohri Moroi '01]

Thermal Leptogenesis ($\rightarrow T_R > 10^9$ GeV) is consistent ONLY IF the gravitino is

- stable and $m_{3/2} \lesssim$ keV , or
- unstable and $m_{3/2} \gg$ TeV , or
- (stable & $m_{3/2} \simeq 100$ GeV & NLSP = $\tilde{\tau}$ (or $\tilde{H}$)
  [Bolz Buchmüller Plümacher '98; Asaka KH Suzuki '00] or
  [But difficult ... ? (hadron) → T. Yanagida's talk; Gherghetta Giudice Riotto '98])
- decays only to the axino , or
  [Asaka Yanagida '00]
- There is a late-time entropy production
  [e.g., in GMSB, Fujii Yanagida '02; Fujii Ibe Yanagida '03]
- or, ... (see 2nd topic of my talk!)

leptogenesis via inflaton decay

Lazarides Shafi '91
Kumekawa Moroi Yanagida '94
.....
Asaka KH Kawasaki Yanagida '99
.....

$$\left[\frac{n_B}{s}\right] = \frac{n_{N_R}}{s} \times \frac{n_L}{n_{N_R}} \times 0.35$$

$$\frac{n_L}{n_{N_R}} = 2\times 10^{-6}\left(\frac{M_{Ri}}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{m_{\nu 3}}{0.05\,\mathrm{eV}}\right)\delta_{\mathrm{eff}}$$

inflaton → N_R + N_R

$$\frac{n_{N_R}}{s} = \frac{3}{2} B_r \frac{T_R}{m_{\mathrm{inf}}}$$

$B_r = B_r(\mathrm{inflaton} \to 2N_R)$

m_{inf} = inflaton mass

depends on the inflation model.

$$\Rightarrow \left[\frac{n_B}{s}\right] = 10^{-10}\, B_r \left(\frac{T_R}{10^6\,\mathrm{GeV}}\right)\left(\frac{M_{Ri}}{m_{\mathrm{inf}}}\right) \times \left(\frac{m_{\nu 3}}{0.05\,\mathrm{eV}}\right)\delta_{\mathrm{eff}}$$

$B_r \le 1$

$\frac{M_{Ri}}{m_{\mathrm{inf}}} \le 1/2$

exception : preheating
[Giudice Peloso Riotto Tkachev '99]
(But, ~~$B_r \frac{M_{Ri}}{m_{\mathrm{inf}}} \le \frac{1}{2}$~~)

T_R can be as low as 10^6 GeV.

⇒ wider gravitino mass range can be consistent !

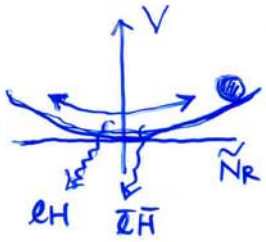
($m_{3/2} <$ keV and $m_{3/2} \gtrsim 10$ MeV)

leptogenesis from $\tilde{N}_R$ dominated universe

(Murayama Suzuki Yanagida Yokoyama '93)
Murayama Yanagida '93
KH Murayama Yanagida '01
.....
Hebecker March-Russel Yanagida '02
Ellis Raidal Yanagida '03

$$\left[\frac{n_B}{s}\right] = \frac{n_{NR}}{s} \times \frac{n_L}{n_{NR}} \times 0.35$$

$$\frac{n_L}{n_{NR}} = 2\times 10^{-6}\left(\frac{M_{R1}}{10^{10}\,\mathrm{GeV}}\right)\left(\frac{m_{\nu 3}}{0.05\,\mathrm{eV}}\right)\delta_{\mathrm{eff}}$$



$$\frac{n_{NR}}{s} = \frac{3}{4}\frac{T_{N1}}{M_{R1}}$$

$$T_{N1} = 0.45 \times \sqrt{\Gamma_{N_1} M_{Pl}}$$

$$= 0.13 \times \sqrt{(y^\dagger y)_{11} M_{R1} M_{Pl}}$$

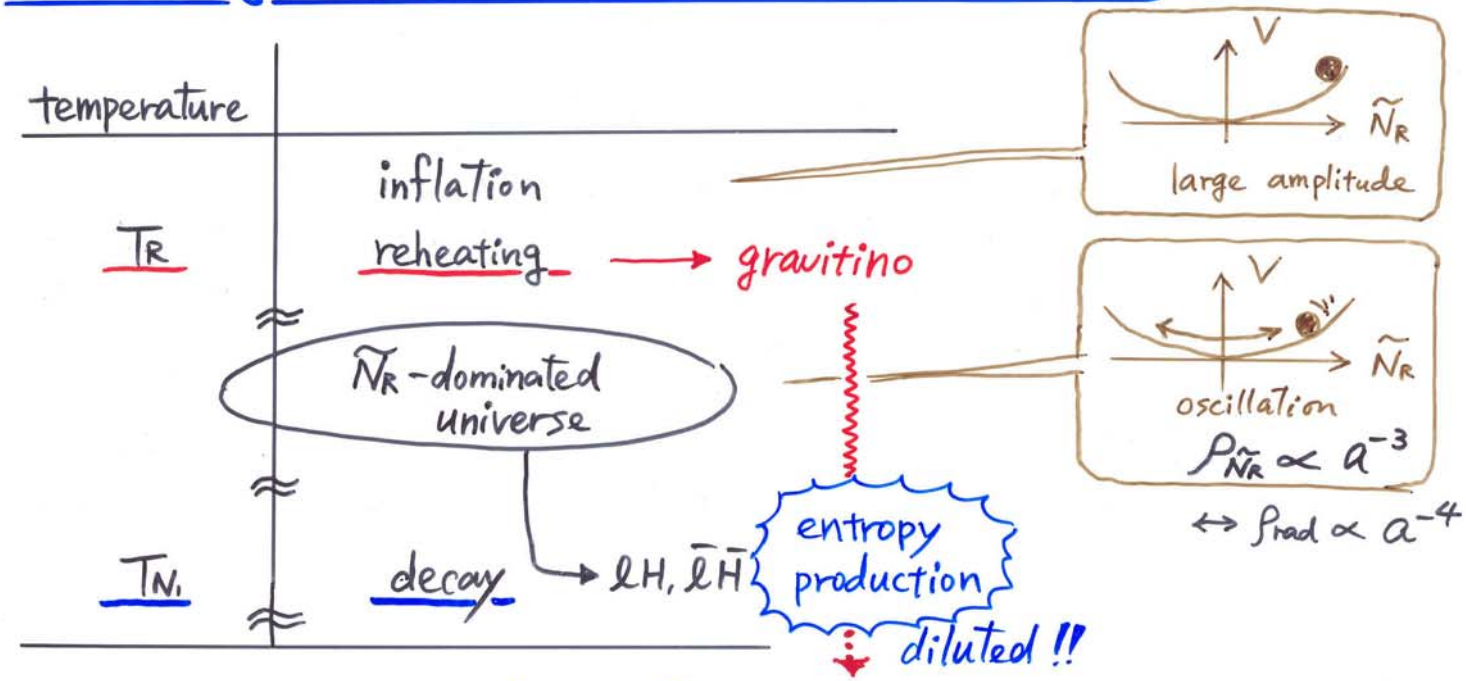
depends **ONLY** on seesaw parameters

$$\Rightarrow \left[\frac{n_B}{s}\right] = 0.5\times 10^{-10}\left(\frac{T_{N1}}{10^6\,\mathrm{GeV}}\right) \times \left(\frac{m_{\nu 3}}{0.05\,\mathrm{eV}}\right)\delta_{\mathrm{eff}}.$$

Baryon asymmetry is explained if $T_{N1} \simeq 10^6 - 10^7$ GeV.

Moreover, ...

leptogenesis from $\tilde{N}_R$ dominated universe



- gravitino → diluted !!
  ($m_{3/2} < keV$ & $m_{3/2} \gtrsim 10\,MeV$ can be consistent.)
- $\tilde{N}_R$ can generate density fluctuation (curvaton [Enqvist Sloth '01; Lyth Wands '01; Moroi Takahashi '01])
  (or inflaton [Murayama Suzuki Yanagida Yokoyama '93; Ellis Raidal Yanagida '03]) → Moroi Murayama '02

	simplicity	gravitino problem	comment
thermal	☆☆☆	☆*	$m_{\nu_i} < 0.12$ eV
inflaton decay	☆ (☆) depends on the inflation*	☆☆	*naturally embedded in some GUT models SO(10) / Hybrid inflation [e.g., Asaka '03]
$\tilde{N}_R$-dominated	☆☆(☆)	☆☆☆ diluted !?	curvaton ?! or inflaton ?!

* However, ... → See Next Topic

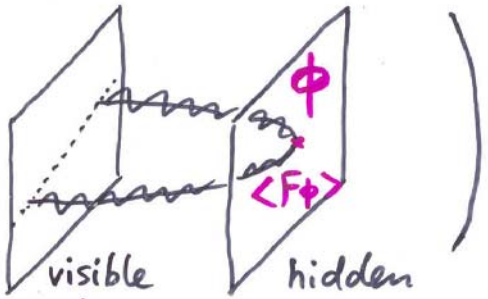
DIMINISHING GAUGE COUPLINGS AT HIGH TEMPERATURE AND GRAVITINO ABUNDANCE

W. Buchmüller, KH, M. Ratz hep-ph/0307181

gauge coupling at high T and gravitino abundance

Buchmüller, KH, Ratz '03

In higher dimensional theory, ... (e.g., gaugino mediation [Kaplan Kribs Schmaltz '99; Chacko Luty Nelson Pontón '99])



$$\mathcal{L}_{4d}^{\text{eff}} = \left(\frac{1}{g_0^2} + \frac{\Phi}{M} + \cdots\right)\left(-\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + \text{gaugino}\right)$$

$\ell^{-1} < M < M_{Pl}$

$$g_{\text{eff}}^2 = g_0^2 \frac{1}{1 + g_0^2\left(\frac{\langle\Phi\rangle}{M} + \cdots\right)} \quad , \quad m_{\hat{g}} = \frac{1}{2} g_{\text{eff}}^2 \frac{F_\Phi}{M}$$

gauge coupling at high T and gravitino abundance

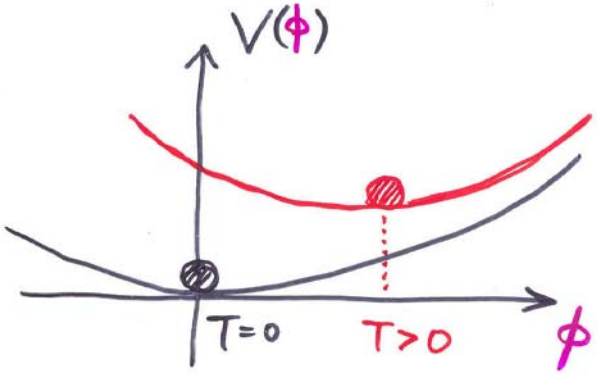
$$g_{\rm eff}^2(\phi) = g_0^2 \frac{1}{1 + g_0^2\left(\frac{\phi}{M} + \cdots\right)}$$

At high temperature

$$V(\phi) = \frac{1}{2} m_\phi^2 \phi^2 + \frac{3}{8} g_{\rm eff}^2(\phi)\, T^4$$

$$= \frac{1}{2} m_\phi^2 \phi^2 + \frac{3}{8} g_0^2 \frac{1}{1 + g_0^2\left(\frac{\phi}{M} + \cdots\right)} T^4$$

(SU(3))



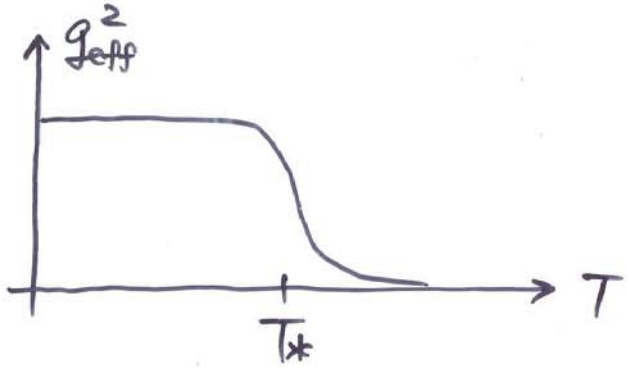
$$g_{\rm eff}^2 = g_0^2 \frac{1}{1 + \left(\frac{T}{T_*}\right)^\alpha} \qquad \alpha > 1$$

$T_* \sim \sqrt{m_\phi M}$

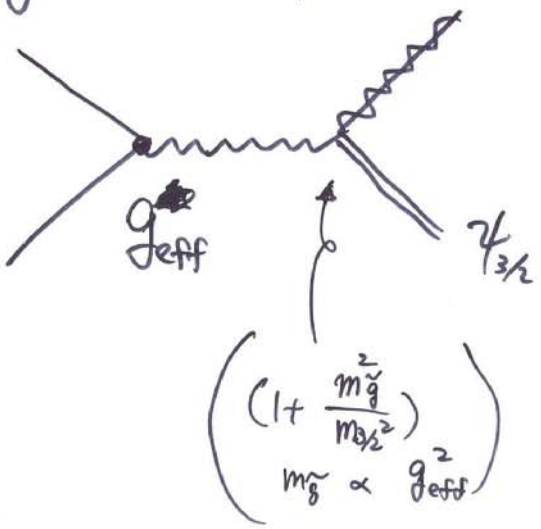
rapid decrease of coupling for $T > T_*$!!

gauge coupling at high T and gravitino abundance

$$g_{\rm eff}^2 = g_0^2 \frac{1}{1+\left(\frac{T}{T_*}\right)^\alpha}$$



gravitino production rate



suppressed for $T > T_*$!

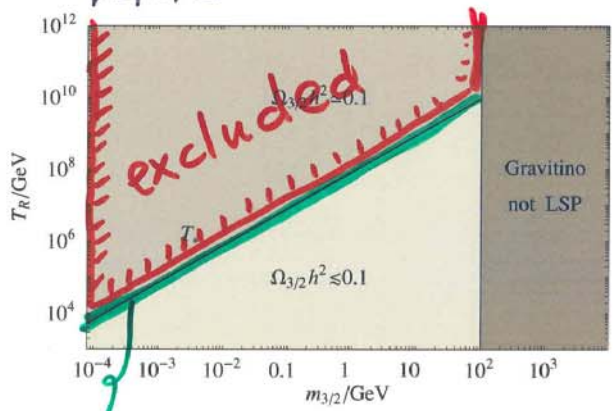
gauge coupling at high T and gravitino abundance

$$\Omega_{3/2}h^2 \propto m_{\tilde{g}}^2 \frac{T_R}{m_{3/2}} \to T_* \left(\simeq \sqrt{m_\phi M} \simeq m_{3/2}\sqrt{M_{PL}/m_{\tilde{g}}}\right)$$

$$\propto m_{\tilde{g}}^{3/2} \quad (\text{for } T_R > T_*)$$

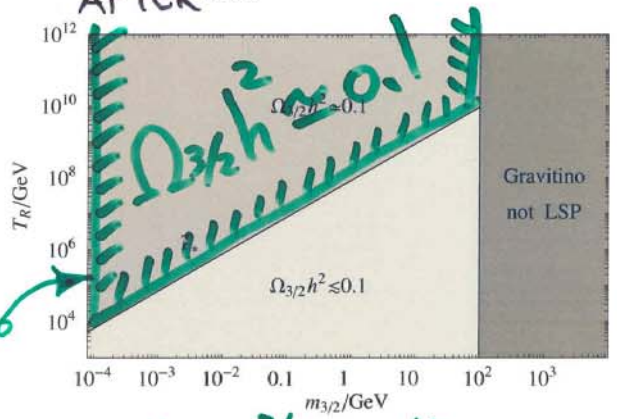
$$\begin{cases} m_\phi = m_{3/2} \\ \dfrac{m_{3/2}}{m_{\tilde{g}}} \simeq \dfrac{M}{M_{PL}} \end{cases} \text{ in the simplest case}$$

BEFORE.....



$\Omega_{3/2}h^2 \simeq 0.1$

AFTER.....

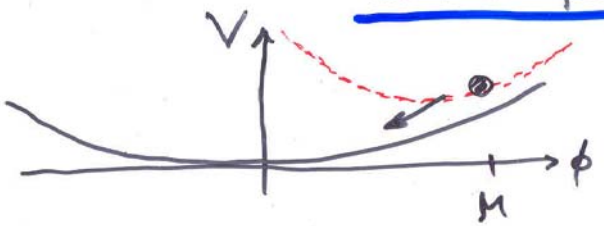


↕ thermal lepto-genesis

$$\Omega_{3/2}h^2 \simeq 0.1 \left(\frac{m_{\tilde{g}}}{1\,\text{TeV}}\right)^{3/2} \times \underbrace{\left(\frac{\xi}{\eta^2}\right)^{1/4}}_{O(1)}$$

independently of $m_{3/2}$ & T_R (for $T_R > T_*$) !!

moduli problem of ϕ ?!



possible solution :

[Discussion with W. Buchmüller M. Ratz + T. Yanagida]

<u>decay</u> $\phi \to$ massless particle

e.g. $\frac{\phi}{m_X} W_\alpha^\flat W_\alpha^\flat$, ...

hidden gauge group

$\longrightarrow$ But we need $m_X \sim m_\phi \ll M$.

unsatisfactory ?? ..... looking for better solution(s).

UNDER DISCUSSION

Summary

	simplicity	gravitino problem/abundance	comments
thermal	☆☆☆	☆ (+ ☆☆☆☆☆)	$m_{\nu_i} < 0.12\,eV$
inflaton decay	☆ (☆) depends on models	☆☆	naturally embedded in GUT models SO(10) / Hybrid Inf.
$\tilde{N}_R$-dominated	☆☆☆	☆☆☆ diluted !!	curvaton ? inflaton ?

In higher dimensional theory

$$g^2 \longrightarrow g^2_{\rm eff}(\phi(T)) \propto \frac{1}{1+\left(\frac{T}{T_*}\right)^{\alpha}}$$

$$\Omega_{3/2}h^2 \simeq 0.1\left(\frac{m_{\tilde{g}}}{1\,TeV}\right)^{3/2}$$ independently of $m_{3/2}$ & T_R !!