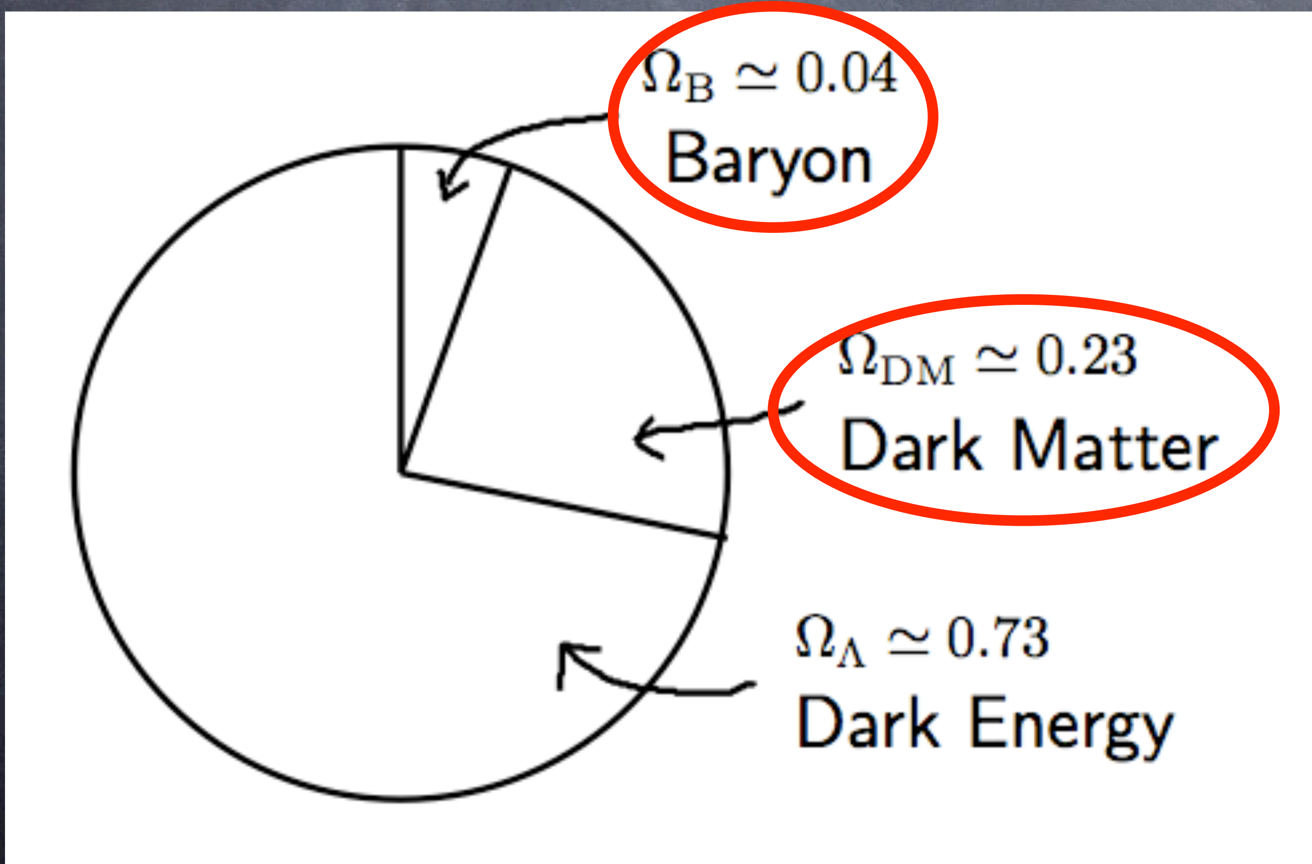
Baryogenesis and Dark Matter

浜口幸一（東京大学）

@「宇宙初期における時空と物質の進化」

2007年5月、東京大学

Baryogenesis
and Dark Matter



学)

の進化」

Baryogenesis and Dark Matter

浜口幸一（東京大学）

@「宇宙初期における時空と物質の進化」

2007年5月、東京大学

Baryogenesis and Dark Matter

in SUSY

浜口幸一（東京大学）

@「宇宙初期における時空と物質の進化」

2007年5月、東京大学

Introduction: SUSY

	spin
quarks q	$\frac{1}{2}$
leptons ℓ	$\frac{1}{2}$
gauge bosons A_μ	1
Higgs bosons H	0

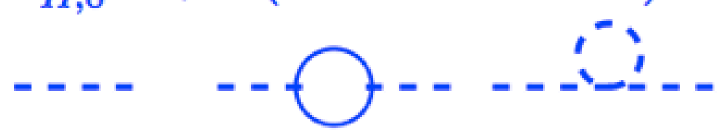
Introduction: SUSY

Supersymmetry (SUSY)

	spin			
quarks q	$\frac{1}{2}$	$\longleftrightarrow$	0	squarks $\tilde{q}$
leptons ℓ	$\frac{1}{2}$	$\longleftrightarrow$	0	sleptons $\tilde{\ell}$
gauge bosons A_μ	1	$\longleftrightarrow$	$\frac{1}{2}$	gauginos λ
Higgs bosons H	0	$\longleftrightarrow$	$\frac{1}{2}$	higgsinos $\tilde{h}$

- protects the Higgs mass from radiative correction

$$m_H^2 = m_{H,0}^2 + (\Lambda^2 - \Lambda^2)$$

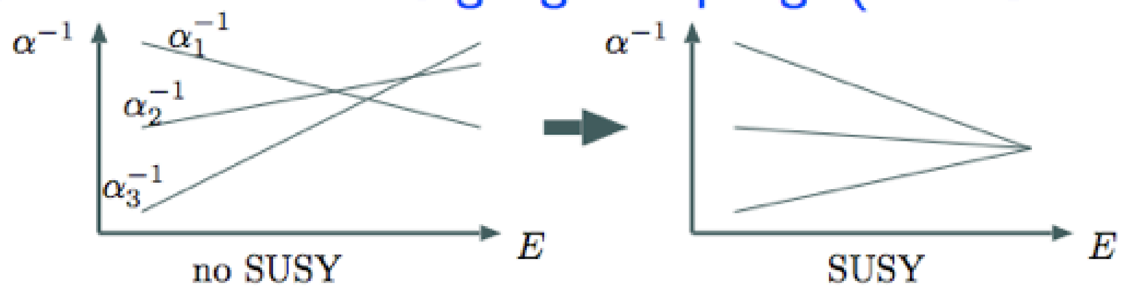


Introduction: SUSY

Supersymmetry (SUSY)

		spin		
quarks q	$\frac{1}{2}$	$\longleftrightarrow$	0	squarks $\tilde{q}$
leptons ℓ	$\frac{1}{2}$	$\longleftrightarrow$	0	sleptons $\tilde{\ell}$
gauge bosons A_μ	1	$\longleftrightarrow$	$\frac{1}{2}$	gauginos λ
Higgs bosons H	0	$\longleftrightarrow$	$\frac{1}{2}$	higgsinos $\tilde{h}$

- Unification of the 3 gauge couplings ($\longleftrightarrow$ Grand Unified Theory)



Introduction: What is Gravitino ??

Supersymmetry (SUSY)

	spin			
quarks q	$\frac{1}{2}$	$\longleftrightarrow$	0	squarks $\tilde{q}$
leptons ℓ	$\frac{1}{2}$	$\longleftrightarrow$	0	sleptons $\tilde{\ell}$
gauge bosons A_μ	1	$\longleftrightarrow$	$\frac{1}{2}$	gauginos λ
Higgs bosons H	0	$\longleftrightarrow$	$\frac{1}{2}$	higgsinos $\tilde{h}$

graviton e_μ^α

Introduction: What is Gravitino ??

Supergravity

Supersymmetry (SUSY)

	spin			
quarks q	$\frac{1}{2}$	$\longleftrightarrow$	0	squarks $\tilde{q}$
leptons ℓ	$\frac{1}{2}$	$\longleftrightarrow$	0	sleptons $\tilde{\ell}$
gauge bosons A_μ	1	$\longleftrightarrow$	$\frac{1}{2}$	gauginos λ
Higgs bosons H	0	$\longleftrightarrow$	$\frac{1}{2}$	higgsinos $\tilde{h}$
graviton e_μ^α	2	$\longleftrightarrow$	$\frac{3}{2}$	gravitino $\tilde{G}$

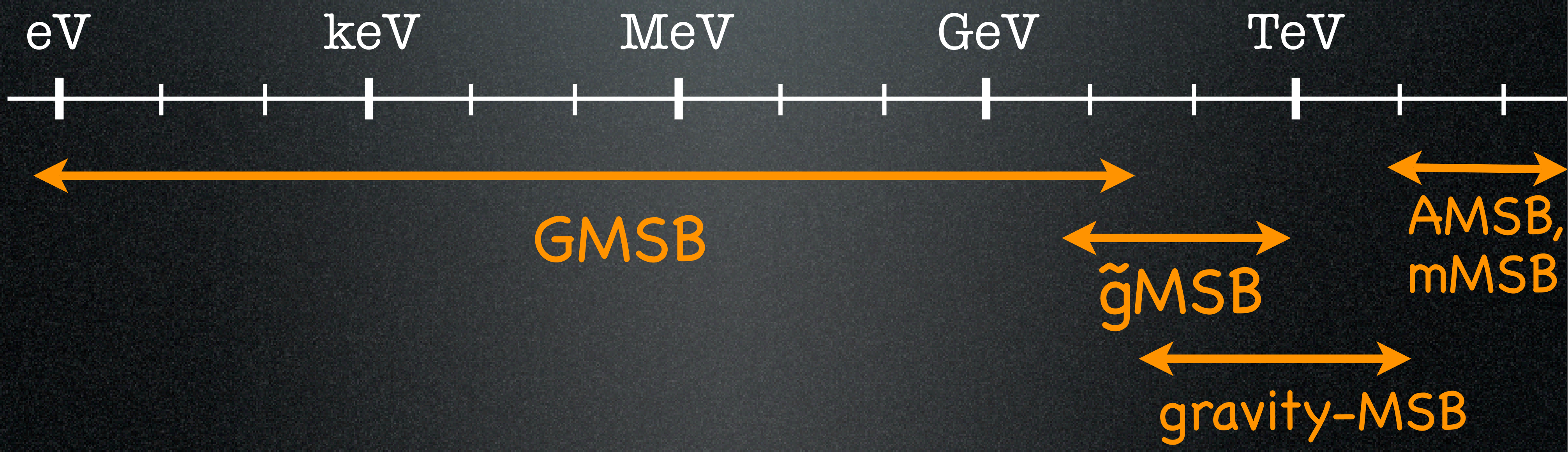
- interaction $\propto 1/M_{\rm P}$ $\cdots$ extremely weak
- mass: $m_{\tilde{G}} \sim \mathcal{O}(\rm eV) \cdots \mathcal{O}(100~\rm GeV)$.

Gravitino

- Gravitino Interaction: extremely weak

  suppressed by $\sim \dfrac{1}{M_{\mathrm{P}}}$ (or $\sim \dfrac{1}{F} \sim \dfrac{1}{M_{\mathrm{P}} m_{\tilde{G}}}$)

- Gravitino Mass: model dependent



Plan

- Dark Matter in SUSY
- Baryogenesis
- Dark Matter and Baryogenesis in SUSY

Dark Matter in SUSY

Introduction: Dark Matter and SUSY

- R-parity $\cdots$ to avoid too rapid baryon/lepton number violation

$$\boldsymbol{q},\quad \boldsymbol{\ell},\quad \boldsymbol{A}_\mu,\quad \boldsymbol{H},\quad \boldsymbol{e}_\mu^\alpha,\quad \cdots \qquad \text{R-parity } + \text{ (even)}$$

$$\widetilde{\boldsymbol{q}},\quad \widetilde{\boldsymbol{\ell}},\quad \boldsymbol{\lambda},\quad \widetilde{\boldsymbol{h}},\quad \widetilde{\boldsymbol{G}},\quad \cdots\cdots \qquad \text{R-parity } - \text{ (odd)}$$

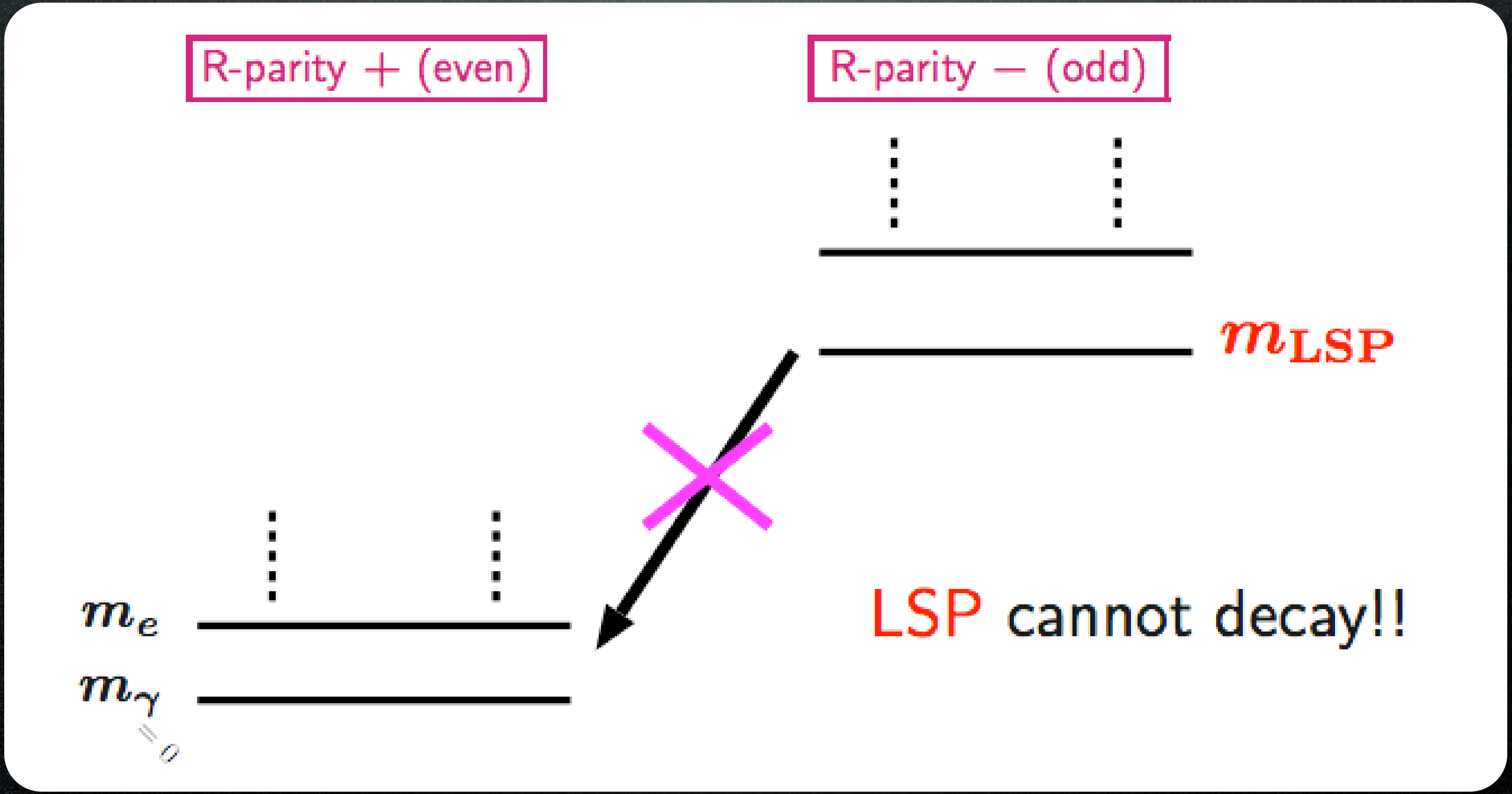
e.g.,

$$\underset{(-)}{\overset{\text{squark}}{\widetilde{\boldsymbol{q}}}} \longrightarrow \underset{(+)}{\overset{\text{quark}}{\boldsymbol{q}}} + \underset{(-)}{\overset{\text{gaugino}}{\boldsymbol{\lambda}}}$$

- The Lightest SUSY Particle (= LSP) becomes stable

Dark Matter in SUSY

In SUSY models + conserved R-parity, the Lightest SUSY Particle (= LSP) is stable.



→ If neutral, Dark Matter candidate.

Dark Matter candidates in SUSY Standard Model

In SUSY Standard Model in SUGRA,.....

$$\textbf{squarks}: \begin{pmatrix} \widetilde{u_L} \\ \widetilde{d_L} \end{pmatrix}_i \quad \begin{matrix} \widetilde{u_{Ri}} \\ \widetilde{d_{Ri}} \end{matrix} \qquad \textbf{sleptons}: \begin{pmatrix} \widetilde{\nu_L} \\ \widetilde{e_L} \end{pmatrix}_i \quad \widetilde{e_{Ri}}$$

$$\textbf{gauginos and higgssinos}: \widetilde{\chi_i^0}, \quad \widetilde{\chi_i^{\pm}}, \quad \tilde{g}$$

$$\textbf{gravitino}: \tilde{G}$$

Dark Matter candidates in SUSY Standard Model

In SUSY Standard Model in SUGRA,.....

$$\text{squarks}: \begin{pmatrix} \widetilde{u_L} \\ \widetilde{d_L} \end{pmatrix}_i \quad \widetilde{u_{Ri}} \quad \widetilde{d_{Ri}} \qquad \text{sleptons}: \begin{pmatrix} \widetilde{\nu_L} \\ \widetilde{e_L} \end{pmatrix}_i \quad \widetilde{e_{Ri}}$$

$$\text{gauginos and higgsinos}: \widetilde{\chi_i^0}, \quad \widetilde{\chi_i^\pm}, \quad \widetilde{g}$$

$$\text{gravitino}: \widetilde{G}$$

neutral and color-singlet

Dark Matter candidates in SUSY Standard Model

In SUSY Standard Model in SUGRA,.....

squarks : $\begin{pmatrix} \widetilde{u_L} \\ \widetilde{d_L} \end{pmatrix}_i \quad \widetilde{u_{Ri}} \quad \widetilde{d_{Ri}}$ sleptons : $\begin{pmatrix} \widetilde{\nu_L} \\ \widetilde{e_L} \end{pmatrix}_i \quad \widetilde{e_{Ri}}$

gauginos and higgssinos : $\widetilde{\chi_i^0}, \quad \widetilde{\chi_i^\pm}, \quad \widetilde{g}$

gravitino : $\widetilde{G}$

neutral and color-singlet

excluded by direct detection experiments
(cf. Falk, Olive, Srednicki,'94)

Dark Matter candidates in SUSY Standard Model

In SUSY Standard Model in SUGRA,.....

squarks : $\begin{pmatrix} \widetilde{u_L} \\ \widetilde{d_L} \end{pmatrix}_i \quad \widetilde{u_{Ri}} \quad \widetilde{d_{Ri}}$

sleptons : $\begin{pmatrix} \widetilde{\nu_L} \\ \widetilde{e_L} \end{pmatrix}_i \quad \widetilde{e_{Ri}}$

gauginos and higgssinos : $\widetilde{\chi_i^0}, \quad \widetilde{\chi_i^\pm}, \quad \widetilde{g}$

gravitino : $\widetilde{G}$

excluded by direct detection experiments (cf. Falk, Olive, Srednicki,'94)

neutral and color-singlet

Only Neutralino and Gravitono are viable candidates!

Baryogenesis

Motivation

観測されている宇宙のbaryon asymmetry

(物質・反物質の非対称性) を説明したい。

$$\frac{n_B}{s} = (0.87 \pm 0.03) \times 10^{-10}$$

WMAP 3 years (2006)

バリオン数密度

エントロピー密度
(〜 7×photon密度)

thermal history

time	temperature	
???	???	inflation $\dfrac{n_B}{s} \to 0$
???	???	
$\sim$ 1 sec	$\sim$ 1 MeV	Big Bang Nucleosynthesis $\Longrightarrow$ $\mathbf{D}, {}^4\mathbf{He}, \cdots$
	$\sim$ 1 eV	matter-radiation equality
	$\sim$ 0.3 eV	Last Scattering Surface (photon becomes free)
$\sim$ 14 Gyr	$\sim$ 2.75 K	CMBR observed

thermal history

time	temperature	
???	???	inflation $\frac{n_B}{s} \to 0$
???	???	Baryogenesis $\to \frac{n_B}{s} \sim 10^{-10}$
$\sim$ 1 sec	$\sim$ 1 MeV	Big Bang Nucleosynthesis $\Longrightarrow \mathbf{D},^4\mathbf{He},\cdots$
	$\sim$ 1 eV	matter-radiation equality
	$\sim$ 0.3 eV	Last Scattering Surface (photon becomes free)
$\sim$ 14 Gyr	$\sim$ 2.75 K	CMBR observed

Baryon asymmetry in BBN and CMB

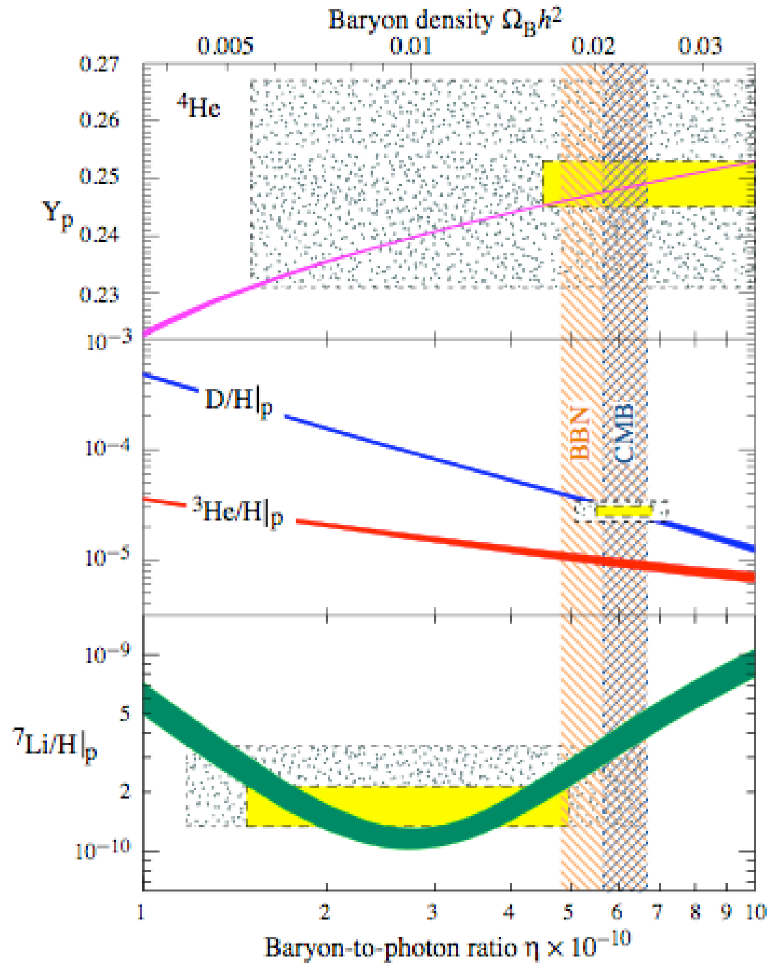


Figure 20.1: The abundances of ^4He, D, ^3He and ^7Li as predicted by the standard model of big-bang nucleosynthesis. Boxes indicate the observed light element abundances (smaller boxes: 2σ statistical errors; larger boxes: $\pm 2\sigma$ statistical and systematic errors). The narrow vertical band indicates the CMB measure of the cosmic baryon density. See full-color version on color pages at end of book.

Particle Data Group 2006

Baryon asymmetry is small ?!

At high temperature......

300,000,000 + 1

$$\frac{n_{\rm baryon}}{s} \sim 0.03$$

Baryon

300,000,000

$$\frac{n_{\rm anti-baryon}}{s} \sim 0.03$$

Anti-Baryon

Baryon asymmetry is small ?!

Today.....

^{1}

Baryon $\frac{n_B}{s} = 0.87 \times 10^{-10}$

Baryon asymmetry is large ?!

- If there were no baryon asymmetry......

At high temperature......

300,000,000	300,000,000
$\frac{n_{\mathrm{baryon}}}{s} \sim 0.03$	$\frac{n_{\mathrm{anti-baryon}}}{s} \sim 0.03$
Baryon	Anti-Baryon

Baryon asymmetry is large ?!

- If there were no baryon asymmetry......

Today.....

$$\frac{n_{\rm baryon}}{s} \sim 10^{-18}$$

$$\frac{n_{\rm anti-baryon}}{s} \sim 10^{-18}$$

Baryon

Anti-Baryon

Baryon asymmetry is large ?!

- If there were no baryon asymmetry......

Today.....

$$\frac{n_{\mathrm{baryon}}}{s} \sim 10^{-18}$$

$$\frac{n_{\mathrm{anti-baryon}}}{s} \sim 10^{-18}$$

$$\ll 10^{-10} \quad !!$$

Baryon

Baryon

Sakharov's 3 conditions

Sakharov '67

(1) $\not{B}$

(2) $\not{C}$ and $\not{CP}$

$\Delta B > 0$ process

$\Delta B < 0$ process

different rate

(3) Departure from equilibrium

$$B = 0 \rightleftharpoons B > 0$$

many baryogenesis scenarios...

many baryogenesis scenarios...

talk by M.Shaposhnikov at DESY workshop'04

(Too) many baryogenesis scenarios...

talk by M.Shaposhnikov at DESY workshop'04

Progress over last 25 years

Today we know exactly 42 different ways to create baryons in the Universe!

DESY 2004, 30 September – p.6

(Too)
many baryogenesis scenarios...

talk by M.Shaposhnikov at DESY workshop'04

How to create baryons

1. GUT baryogenesis
2. GUT baryogenesis after preheating
3. Baryogenesis from primordial black holes
4. String scale baryogenesis
5. Affleck-Dine (AD) baryogenesis
6. Hybridized AD baryogenesis
7. No-scale AD baryogenesis
8. Single field baryogenesis
9. Electroweak (EW) baryogenesis
10. Local EW baryogenesis
11. Non-local EW baryogenesis
12. EW baryogenesis at preheating

(Too) many baryogenesis scenarios...

talk by M.Shaposhnikov at DESY workshop'04

How to create baryons

13. SUSY EW baryogenesis
14. String mediated EW baryogenesis
15. Baryogenesis via leptogenesis
16. Inflationary baryogenesis
17. Resonant baryogenesis
18. Spontaneous baryogenesis
19. Coherent baryogenesis
20. Gravitational baryogenesis
21. Defect mediated baryogenesis
22. Baryogenesis from long cosmic strings
23. Baryogenesis from short cosmic strings
24. Baryogenesis from collapsing loops

(Too) many baryogenesis scenarios...

talk by M.Shaposhnikov at DESY workshop'04

How to create baryons

25. Baryogenesis through collapse of vortons
26. Baryogenesis through axion domain walls
27. Baryogenesis through QCD domain walls
28. Baryogenesis through unstable domain walls
29. Baryogenesis from classical force
30. Baryogenesis from electrogenesis
31. B-ball baryogenesis
32. Baryogenesis from CPT breaking
33. Baryogenesis through quantum gravity
34. Baryogenesis via neutrino oscillations
35. Monopole baryogenesis
36. Axino induced baryogenesis

(Too) many baryogenesis scenarios...

talk by M.Shaposhnikov at DESY workshop'04

How to create baryons

37. Gravitino induced baryogenesis
38. Radion induced baryogenesis
39. Baryogenesis in large extra dimensions
40. Baryogenesis by brane collision
41. Baryogenesis via density fluctuations
42. Baryogenesis from hadronic jets

Please tell me if something is missing!

Dark Matter and Baryogenesis in SUSY

まずはお気に入りの Baryogenesis を選ぶ。

→ Dark Matterについて考える。

→ テストする方法を考える。

- Thermal Leptogenesis by right-handed neutrino.

- Affleck-Dine Baryogenesis (Q-ball, non-thermal DM)

- Thermal Leptogenesis by right-handed neutrino.

☛ This talk.

- Simplest !! 標準模型に right-handed neutrino を入れるだけ。
- 何にもしないで熱浴に入れて放っておけば出来る。

- Affleck-Dine Baryogenesis (Q-ball, non-thermal DM)

☛ see the Next Talk by Nakayama-san.

Leptogenesis by N_R decay: Overview

? $\longrightarrow$ N_R (② decay) $\to \ell + H$, $\bar{\ell} + H^*$

① depends on the scenario

$$\left(n_L = n_\ell - n_{\bar{\ell}} \neq 0 \right)$$

③ $\xrightarrow{\text{sphaleron}}$ $n_B \neq 0$

$$\frac{n_B}{s} = \frac{n_{N_R}}{s} \times \frac{n_L}{n_{N_R}} \times \frac{n_B}{n_L}$$

① ② ③

Thermal Leptogenesis （答だけ）

$$\frac{n_B}{s} = \frac{n_{N_{R1}}^{\mathrm{eq}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

Thermal Leptogenesis （答だけ）

0.35

$$\frac{n_B}{s} = \frac{n^{\rm eq}_{N_{R1}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

Thermal Leptogenesis （答だけ）

0.004 　　0.35

$$\frac{n_B}{s} = \frac{n^{\mathrm{eq}}_{N_{R1}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

Thermal Leptogenesis （答だけ）

$$\frac{n_B}{s} = \frac{n^{\rm eq}_{N_{R1}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

0.004

0.35

$\lesssim 0.18$

Thermal Leptogenesis （答だけ）

$$\frac{n_B}{s} = \frac{n^{\rm eq}_{N_{R1}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

0.004

ϵ_1

0.35

$\lesssim 0.18$

Thermal Leptogenesis （答だけ）

$$\frac{n_B}{s} = \frac{n_{N_{R1}}^{\rm eq}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

0.004 ϵ_1 0.35 $\lesssim 0.18$

$$\epsilon_1 \simeq -\frac{3}{16\pi}\frac{M_1}{\langle H\rangle^2}\frac{{\rm Im}\left(h\, m_\nu^*\, h^T\right)_{11}}{(hh^\dagger)_{11}}$$

$$= -\frac{3}{16\pi}\frac{M_1}{\langle H\rangle^2} m_{\nu 3}\,\delta_{\rm eff} \qquad \delta_{\rm eff} \le 1$$

neutrino mass!

KH, Murayama, Yanagida,'01

The

KH, Dr.thesis,'02.

$$\delta_{\rm eff} = \frac{{\rm Im}\left[(\tilde{h}_{13})^2 + (\tilde{h}_{12})^2 \frac{m_{\nu 2}}{m_{\nu 3}} + (\tilde{h}_{11})^2 \frac{m_{\nu 1}}{m_{\nu 3}}\right]}{|\tilde{h}_{13}|^2 + |\tilde{h}_{12}|^2 + |\tilde{h}_{11}|^2}$$

where $\tilde{h}_{ij} = h_{i\alpha} U^*_{\alpha j}$ $\qquad (m_\nu)_{\alpha\beta} = U_{\alpha i} U_{\beta i} {m_\nu}_i^{\rm diag}$

$$\frac{n_B}{s} =$$

$$\epsilon_1 \simeq -\frac{3}{16\pi} \frac{M_1}{\langle H \rangle^2} \frac{{\rm Im}\left(h\, m_\nu^*\, h^T\right)_{11}}{(hh^\dagger)_{11}}$$

$$= -\frac{3}{16\pi} \frac{M_1}{\langle H \rangle^2} m_{\nu 3}\, \delta_{\rm eff} \qquad \delta_{\rm eff} \leq 1$$

neutrino mass!

KH, Murayama, Yanagida,'01

Thermal Leptogenesis （答だけ）

$$\frac{n_B}{s} = \frac{n^{\rm eq}_{N_{R1}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

0.004 ϵ_1 0.35 $\lesssim 0.18$

$$\epsilon_1 \simeq -\frac{3}{16\pi}\frac{M_1}{\langle H\rangle^2}\frac{{\rm Im}\left(h\, m^*_\nu\, h^T\right)_{11}}{(hh^\dagger)_{11}}$$

$$= -\frac{3}{16\pi}\frac{M_1}{\langle H\rangle^2} m_{\nu 3}\,\delta_{\rm eff} \qquad \delta_{\rm eff} \leq 1$$

neutrino mass!

KH, Murayama, Yanagida,'01

Thermal Leptogenesis （答だけ）

0.004 $\quad \epsilon_1 \quad$ 0.35 $\quad \lesssim 0.18$

$$\frac{n_B}{s} = \frac{n^{\rm eq}_{N_{R1}}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

$$= 0.25 \times 10^{-10} \left(\frac{M_1}{10^9\ \mathrm{GeV}}\right) \left(\frac{m_{\nu 3}}{0.05\ \mathrm{eV}}\right) \delta_{\rm eff} \left(\frac{\kappa}{0.18}\right)$$

Thermal Leptogenesis （答だけ）

0.004 ϵ_1 0.35 $\lesssim 0.18$

$$\frac{n_B}{s} = \frac{n_{N_{R1}}^{\rm eq}}{s} \times \frac{n_L}{n_{N_{R1}}} \times \frac{n_B}{n_L} \times \kappa$$

$$= 0.25 \times 10^{-10} \left(\frac{M_1}{10^9 \text{ GeV}}\right) \left(\frac{m_{\nu 3}}{0.05 \text{ eV}}\right) \delta_{\rm eff} \left(\frac{\kappa}{0.18}\right)$$

To explain the observed baryon asymmetry,

$n_B/s \simeq (0.87 \pm 0.03) \times 10^{-10}$

→ $M_1 \gtrsim 3 \times 10^9$ GeV → $T_R \gtrsim 3 \times 10^9$ GeV

Davidson, Ibarra, '02, Buchmuller, Di Bari, Plumacher, '02

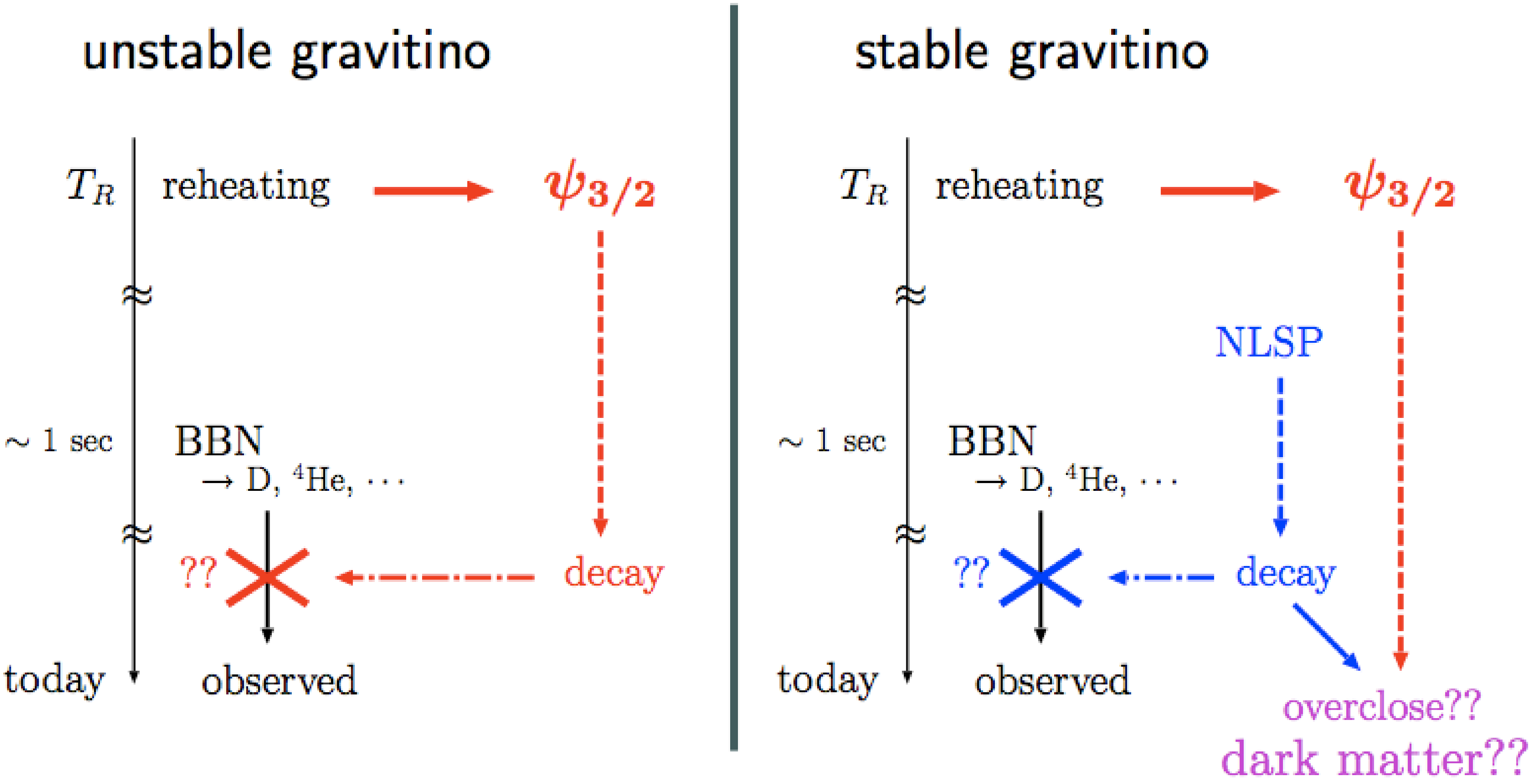
gravitino problems

<u>thermal history</u>

time	temperature	
??	~ 0	inflation
??	T_R	reheating
$\approx$		baryogenesis $\to n_B/s \simeq 10^{-10}$
~ 1 sec	~ 1 MeV	Big Bang Nucleosynthesis $\to$ D, ^{4}He, $\cdots$
$\approx$		$\downarrow$
14 Gyr	2.7 K	observed

gravitino problems

thermal history with gravitino $\psi_{3/2}$



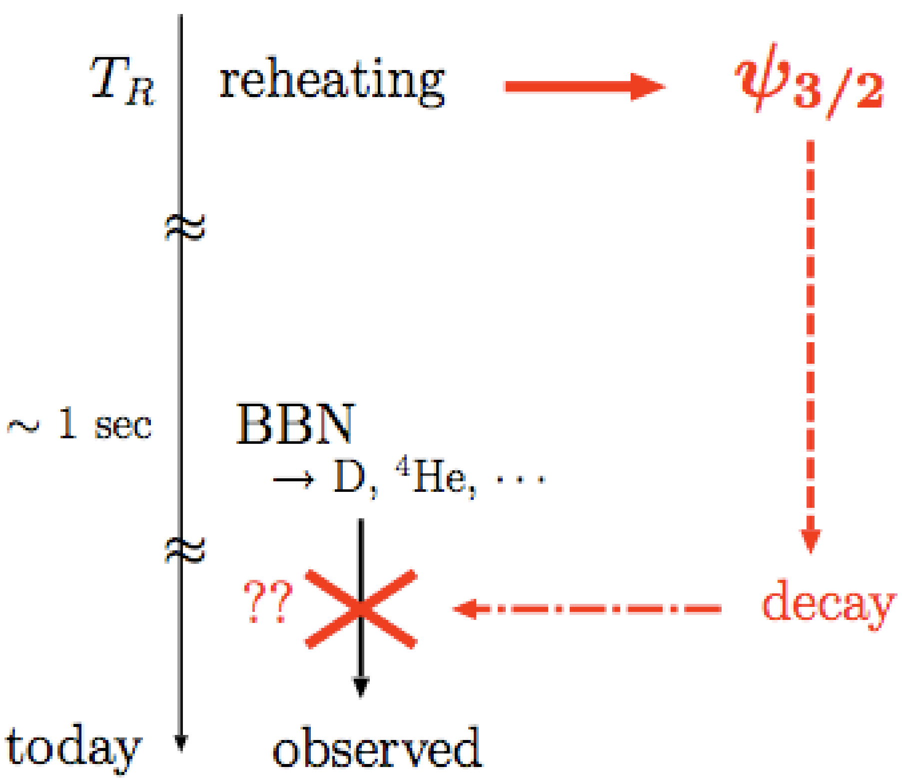
gravi

therma

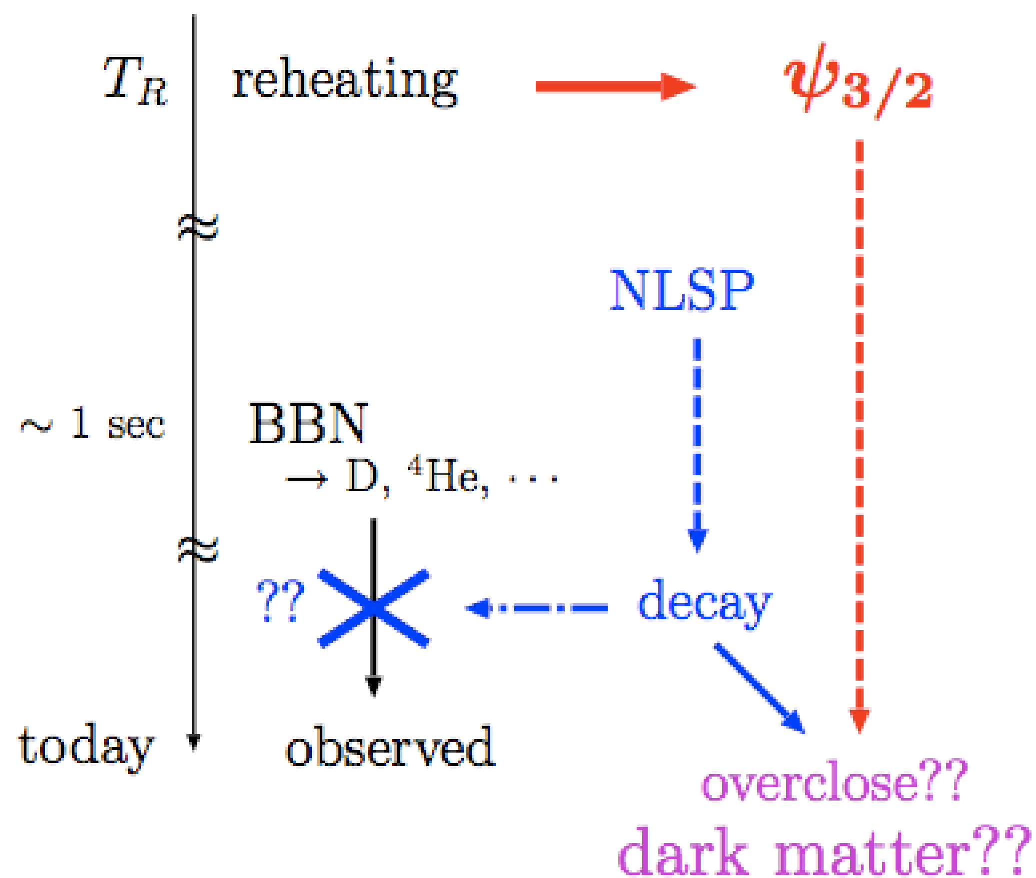
注意：
インフラトンから直接作られる
成分もかなり厳しい。

☛ see the Talk by Takahashi(F)-kun.

unstable gravitino



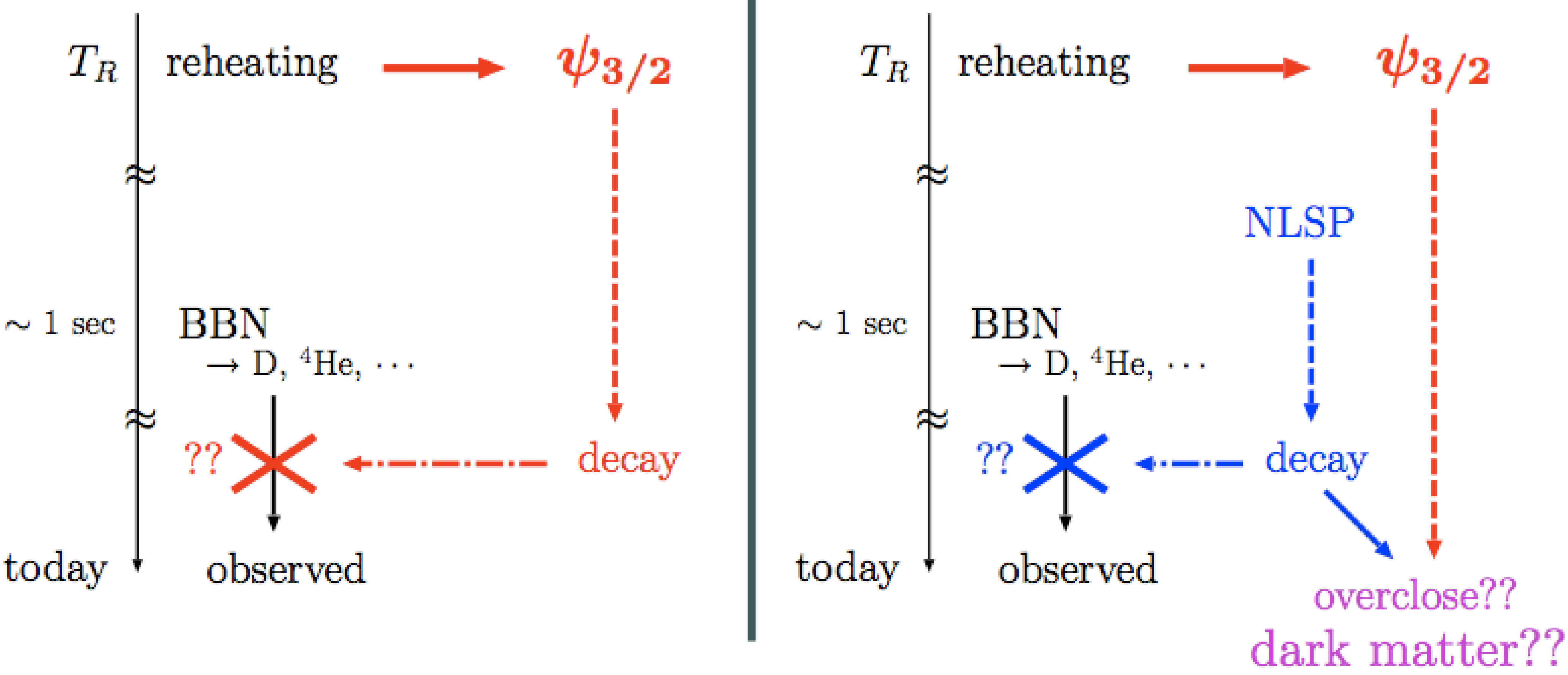
stable gravitino



gravitino problems

thermal history with gravitino $\psi_{3/2}$

unstable gravitino | stable gravitino



gravitino problems

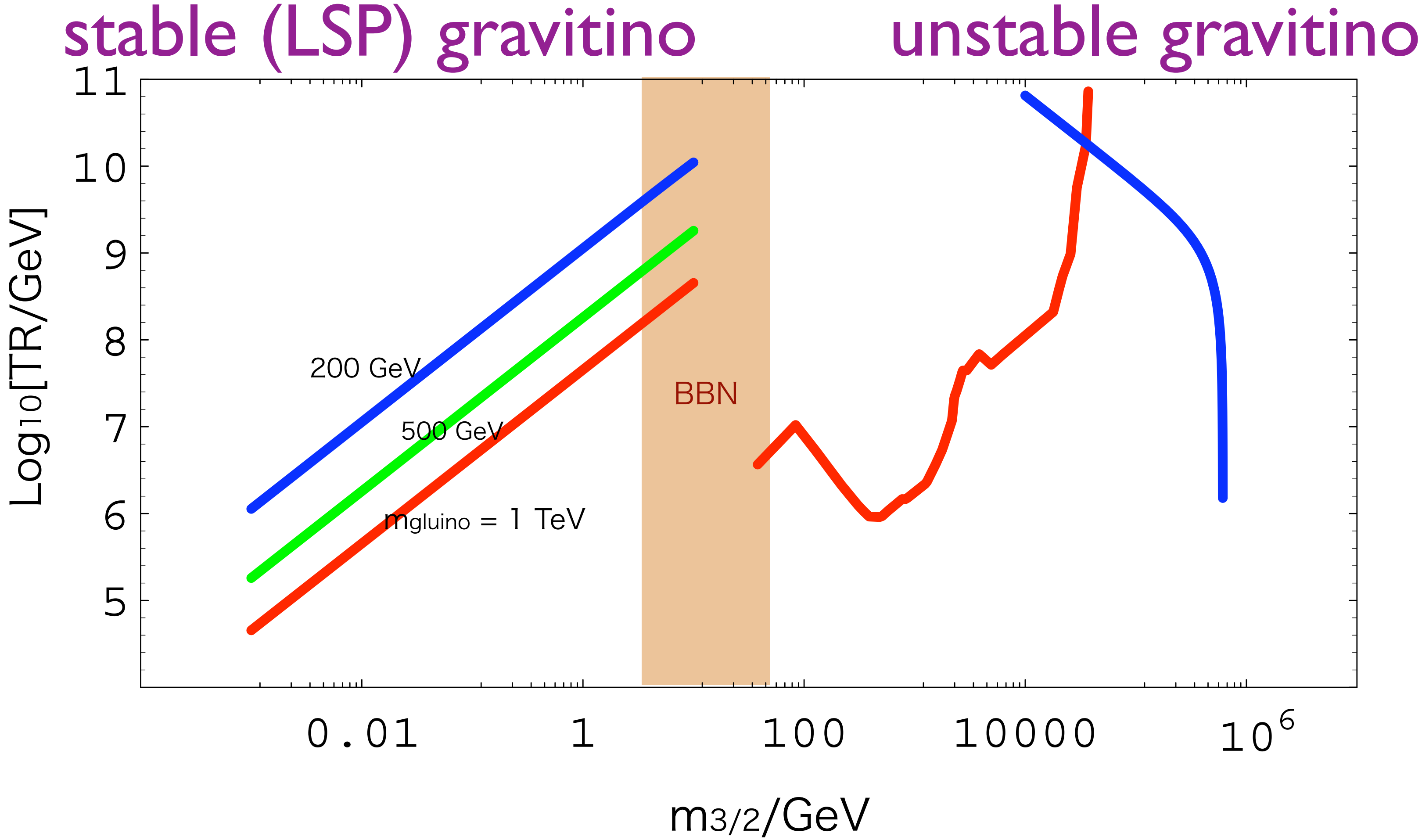


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

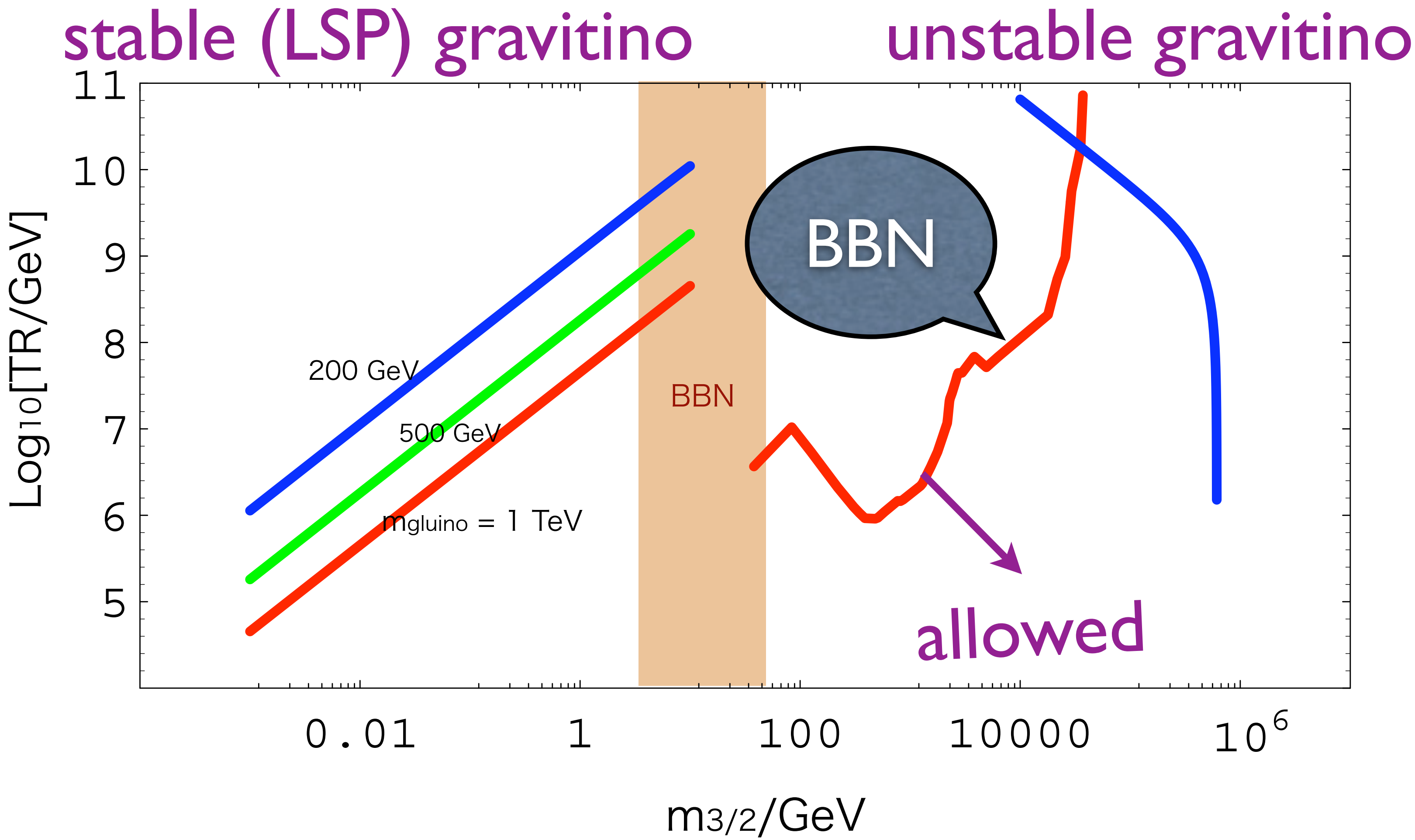


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

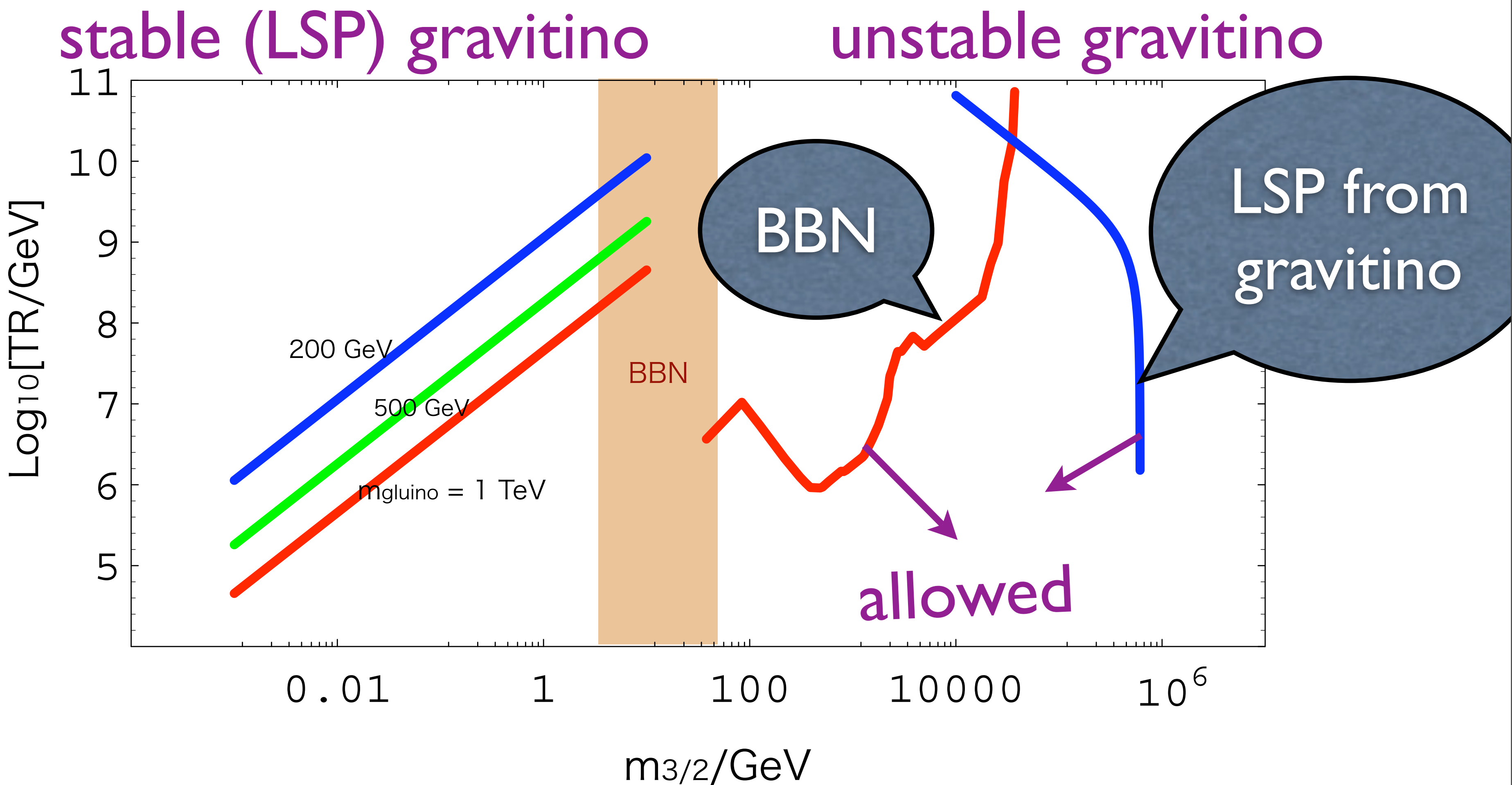


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

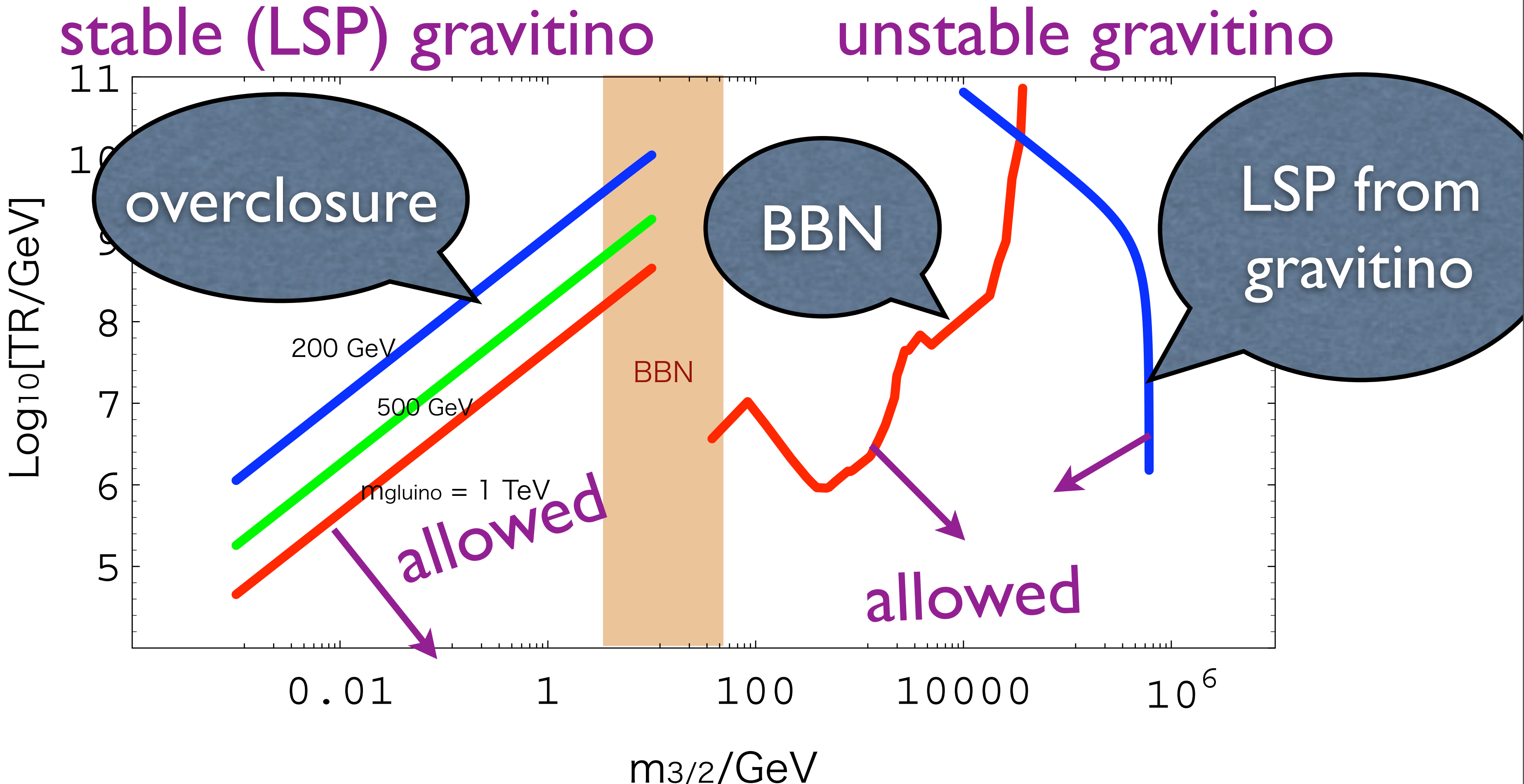


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

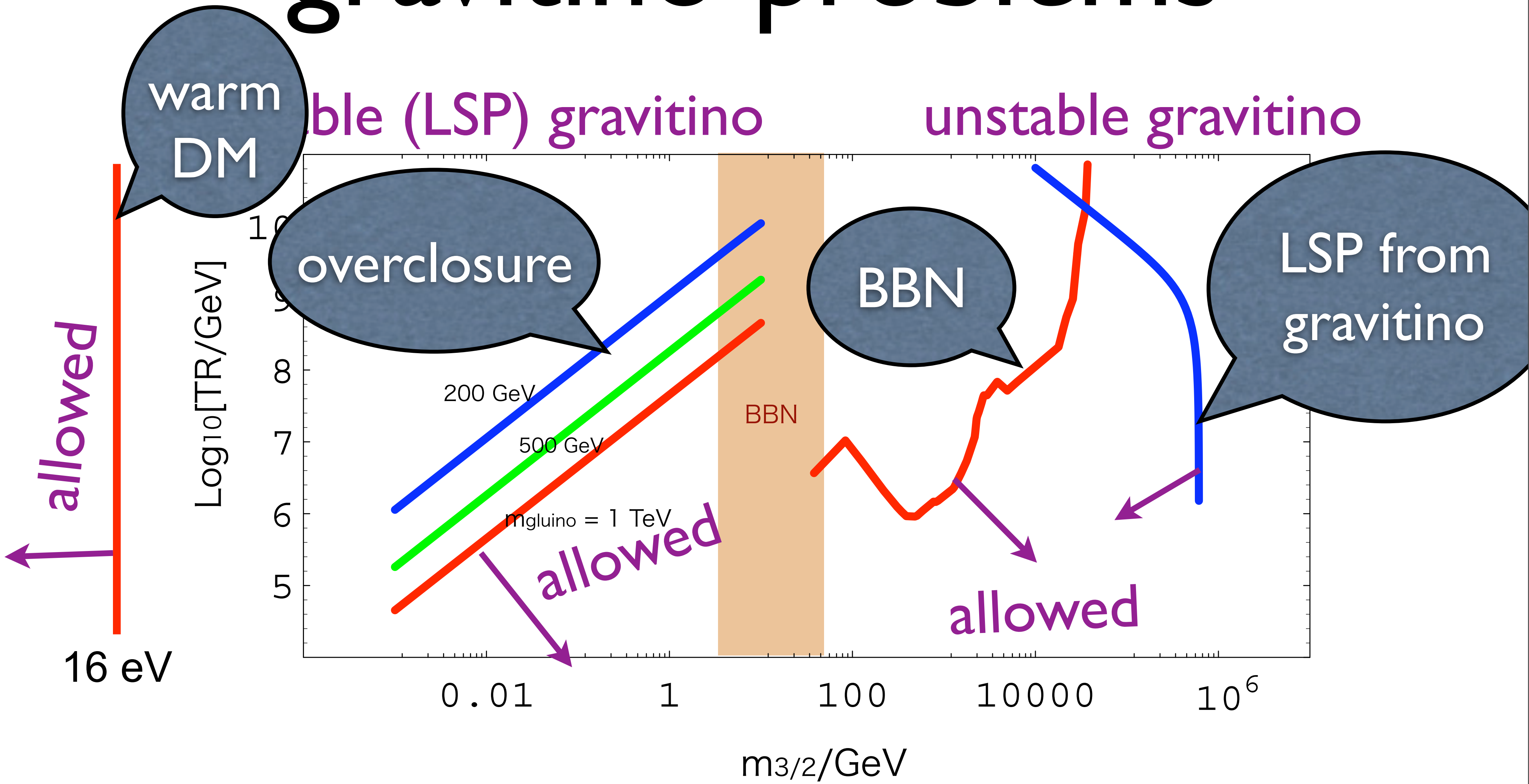


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

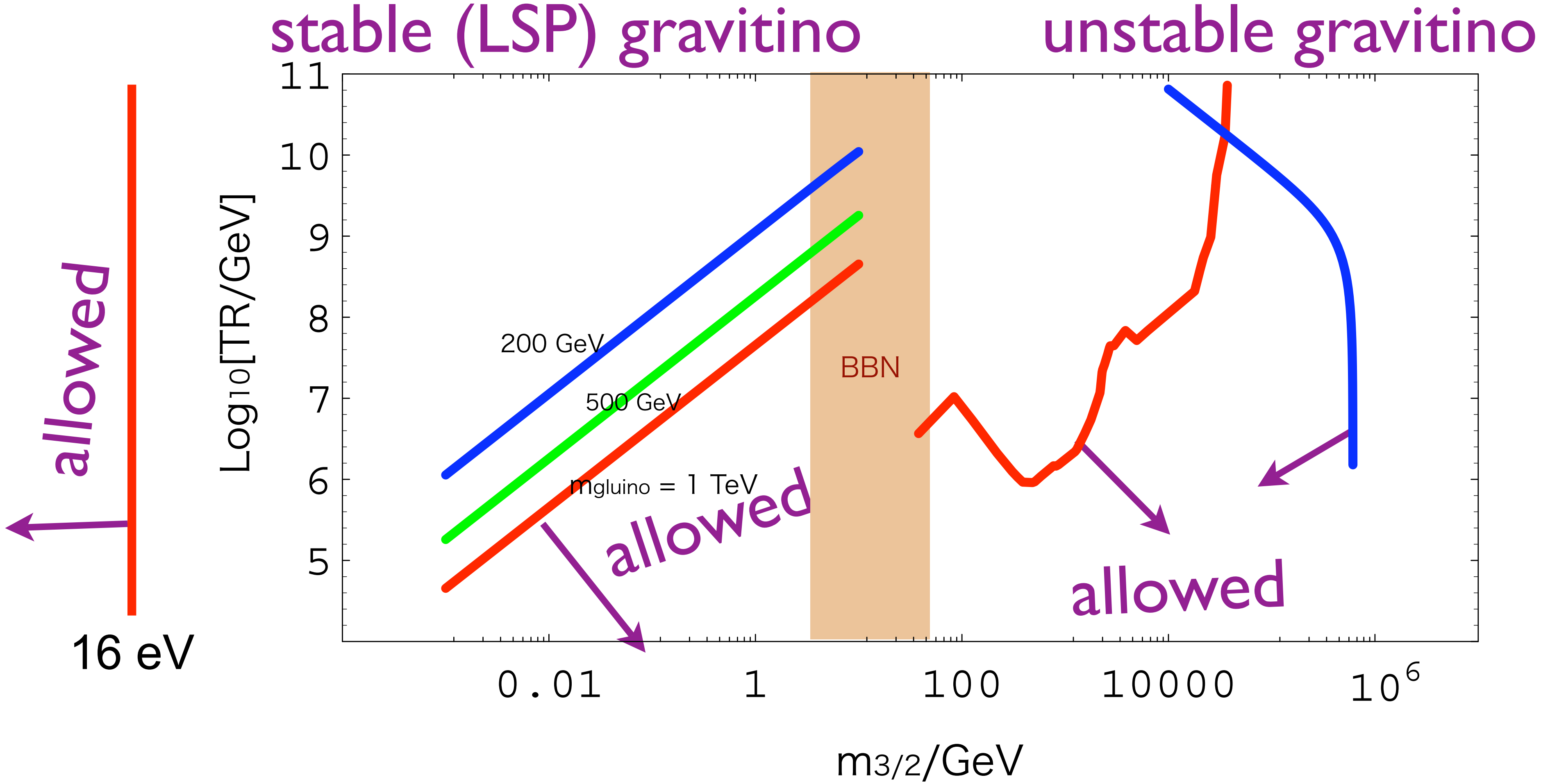


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

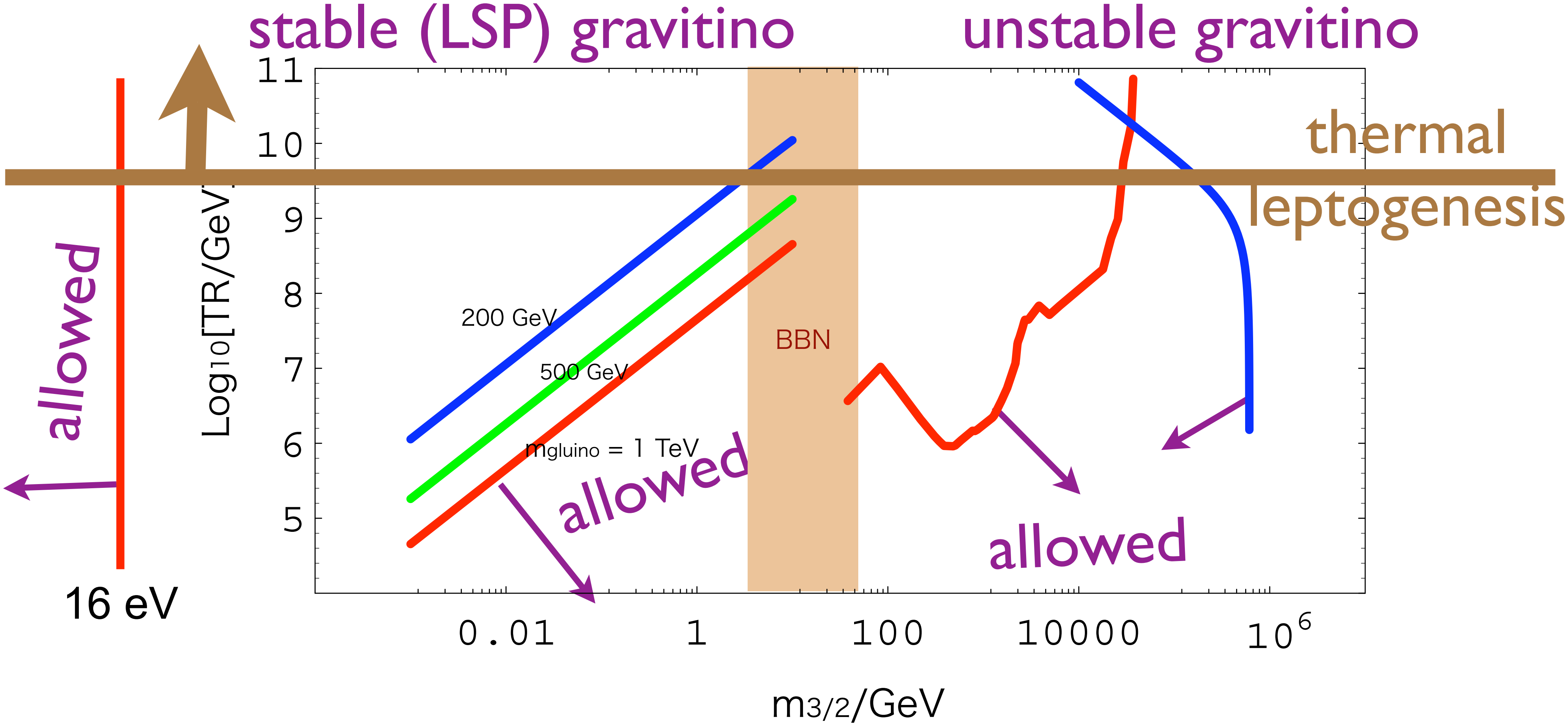


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

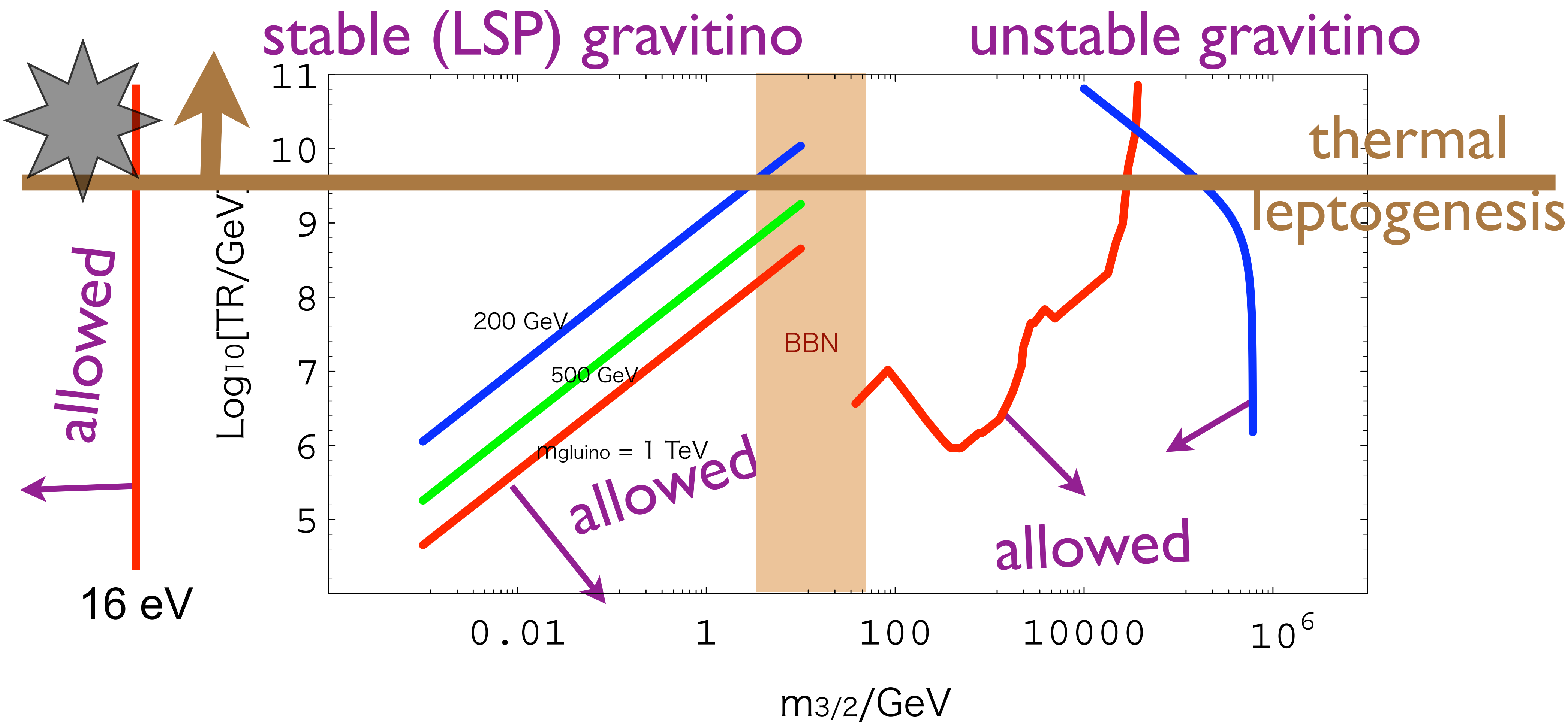


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

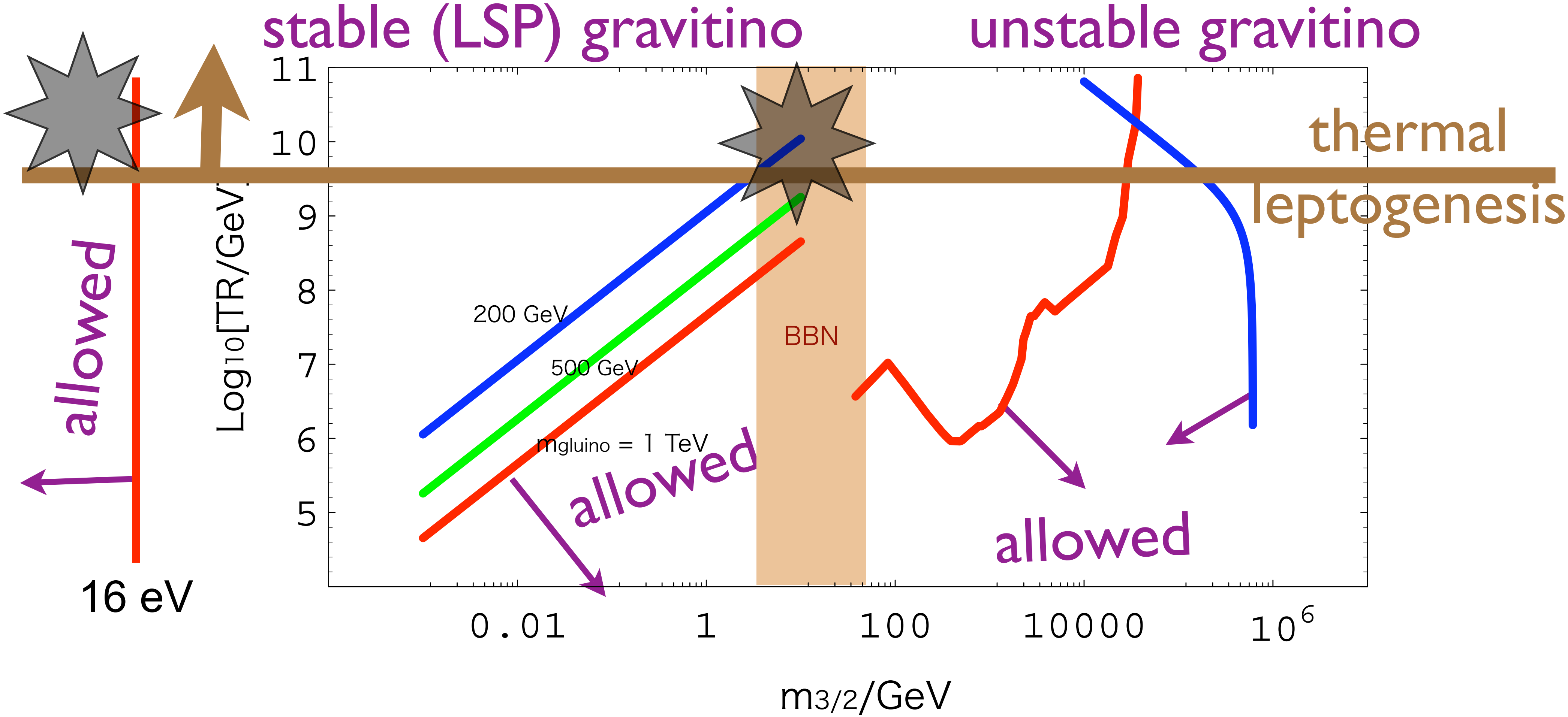


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

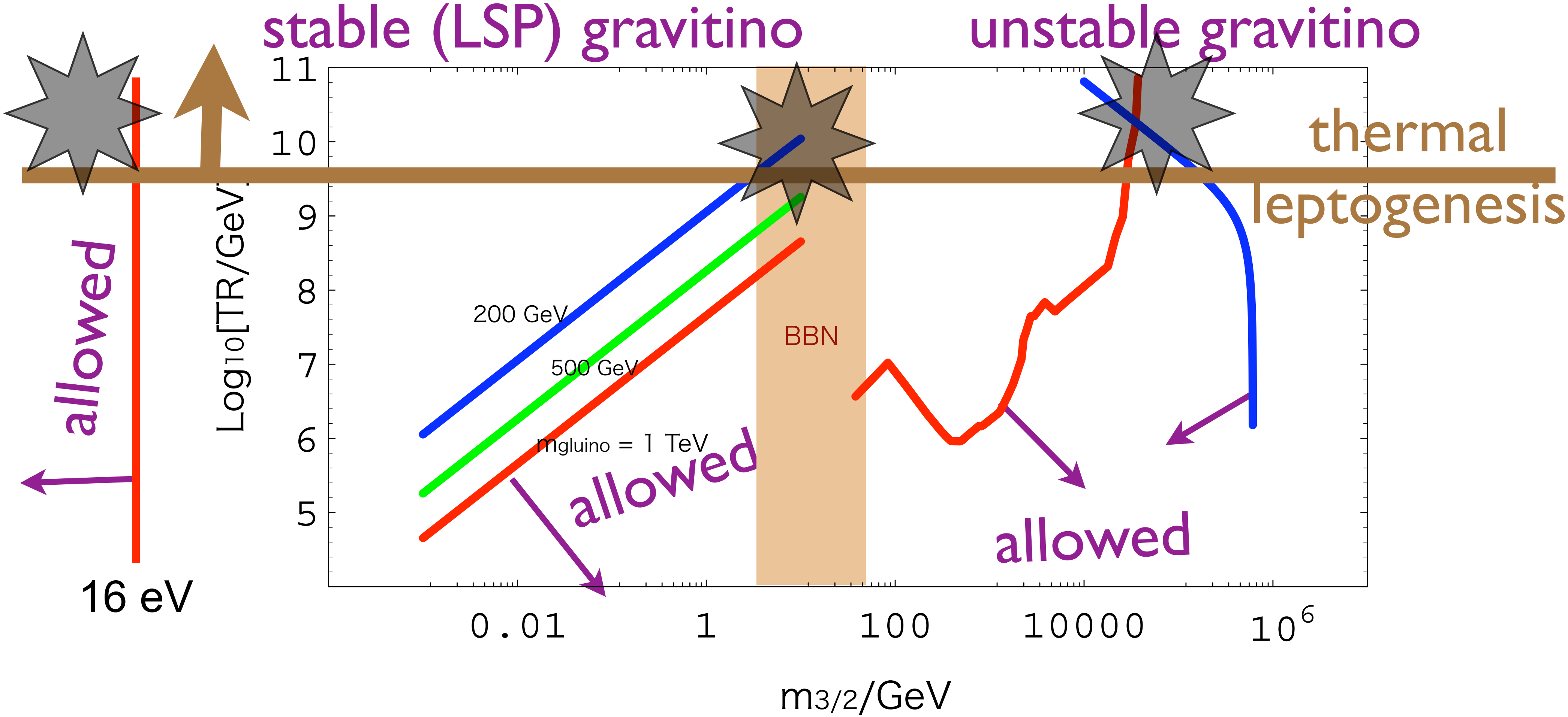
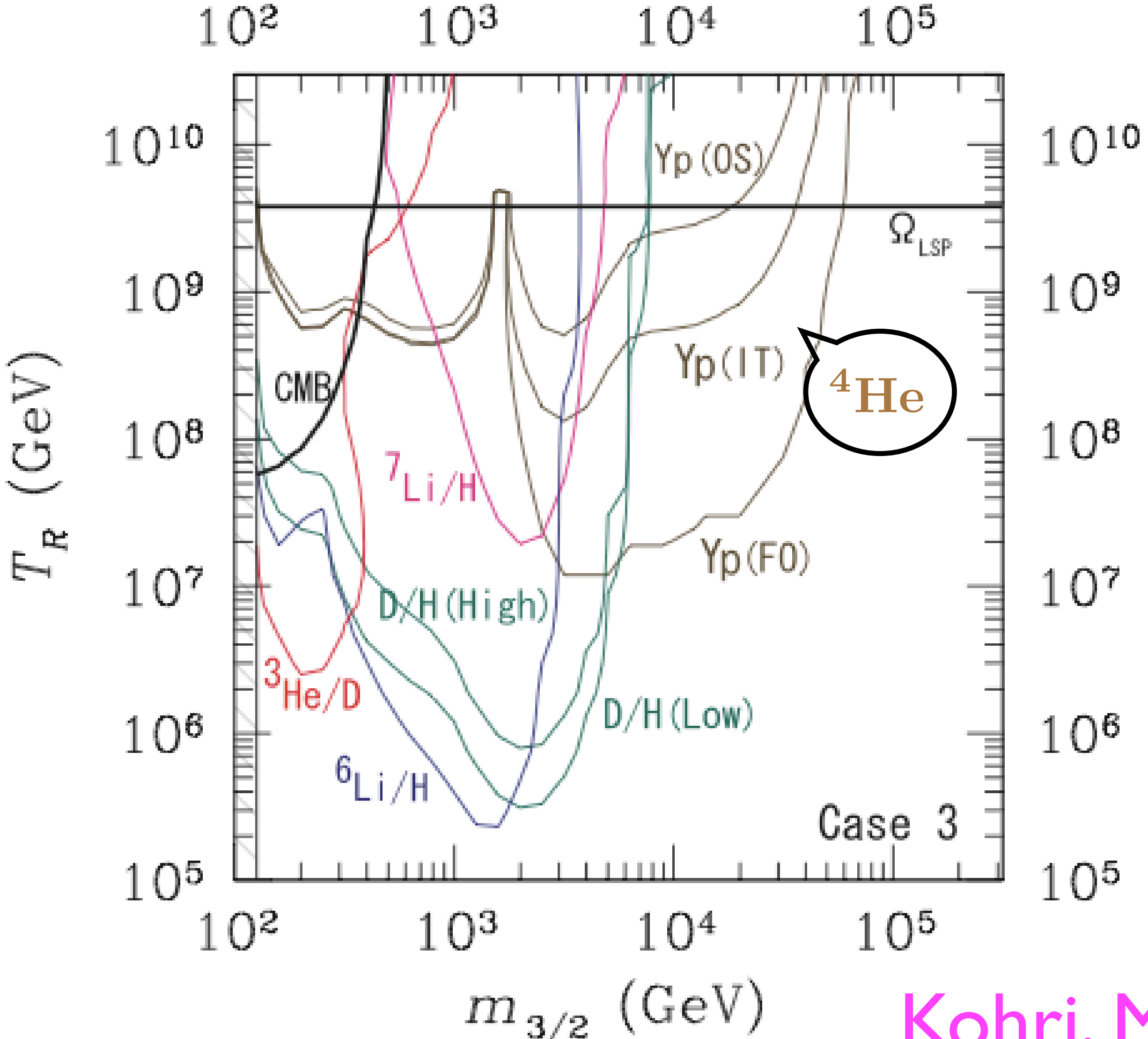


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems

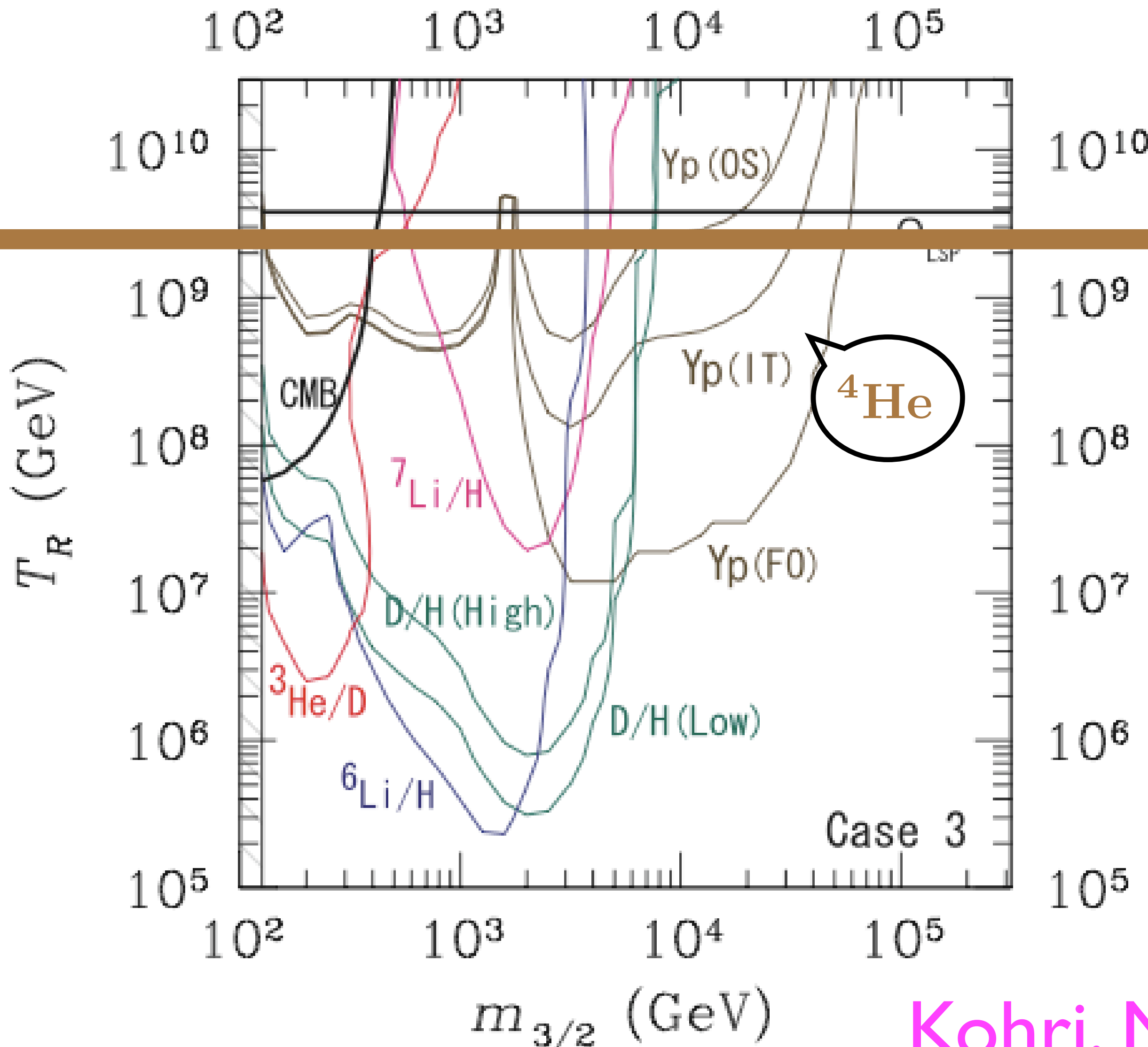
unstable gravitino



Kohri, Moroi, Yotsuyanagi, '05

gravitino problems

unstable gravitino



thermal leptogenesis

$m_{3/2} \gtrsim 10(?)$ TeV

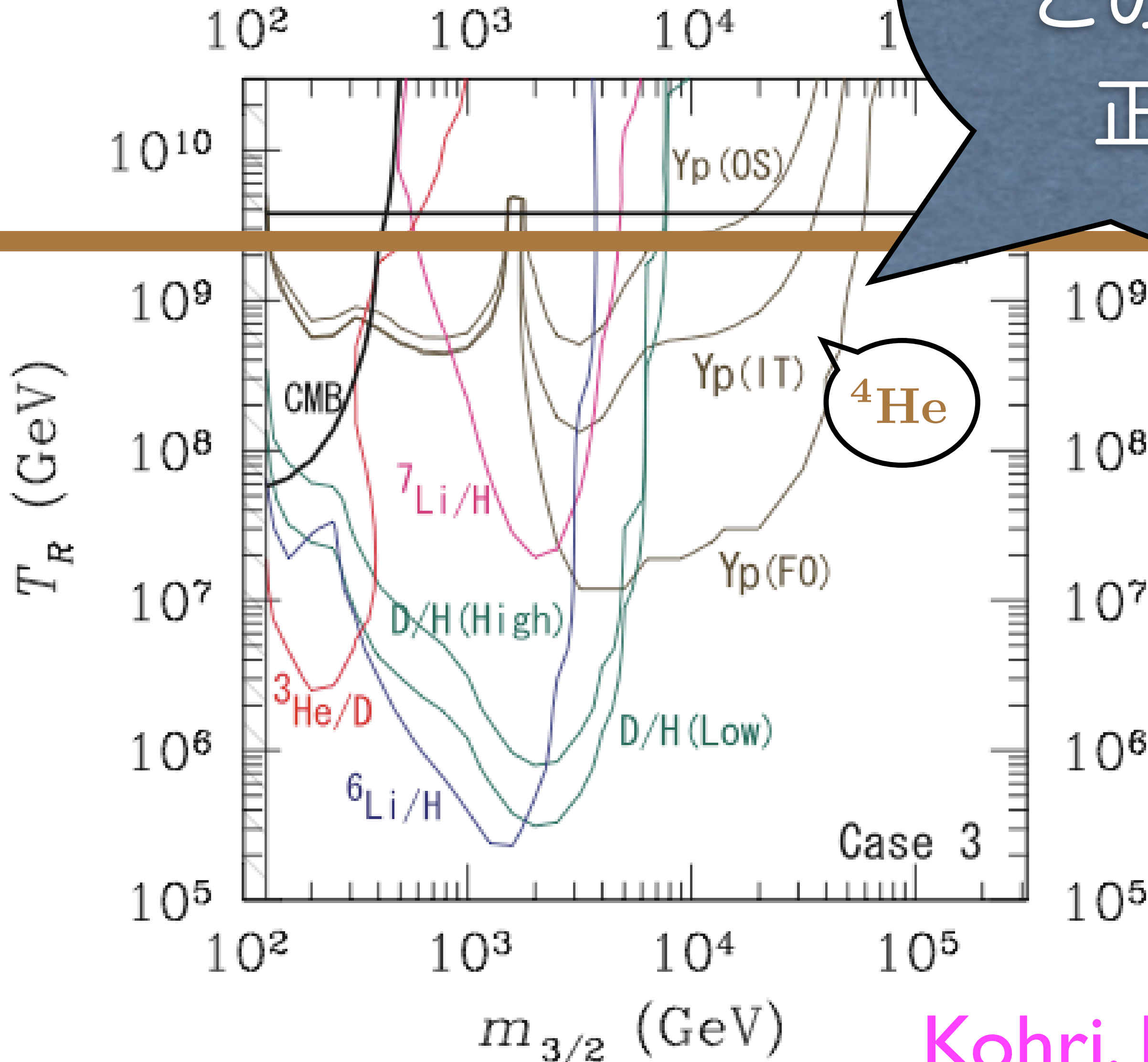
(6 TeV?)

Kohri, Moroi, Yotsuyanagi, '05

gravitino p

先生（川崎さん）
質問！
この３つの線はどれが
正しいのですか？

unstable gravitino



leptogenesis

$m_{3/2} \gtrsim 10(?)$ TeV

(6 TeV?)

Kohri, Moroi, Yotsuyanagi, '05

gravitino problems

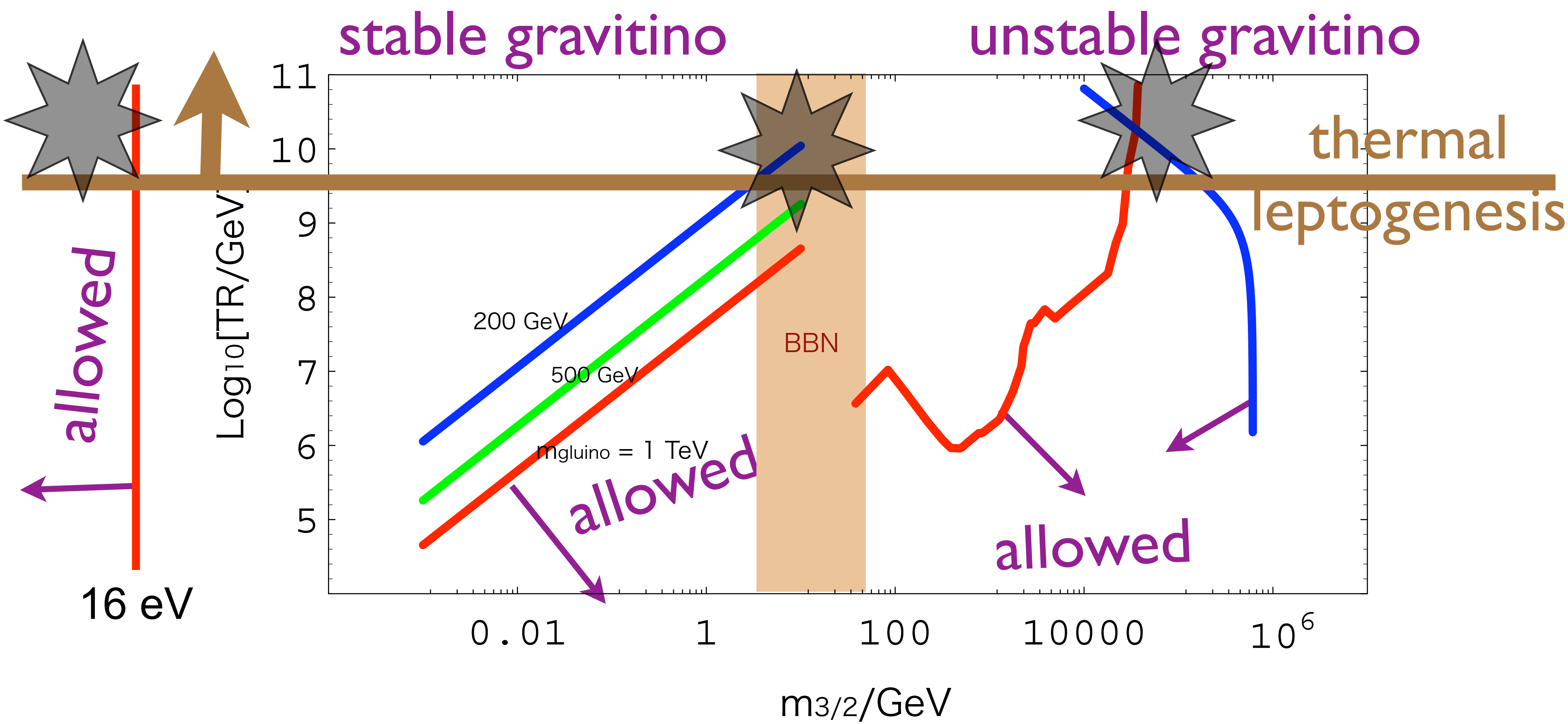
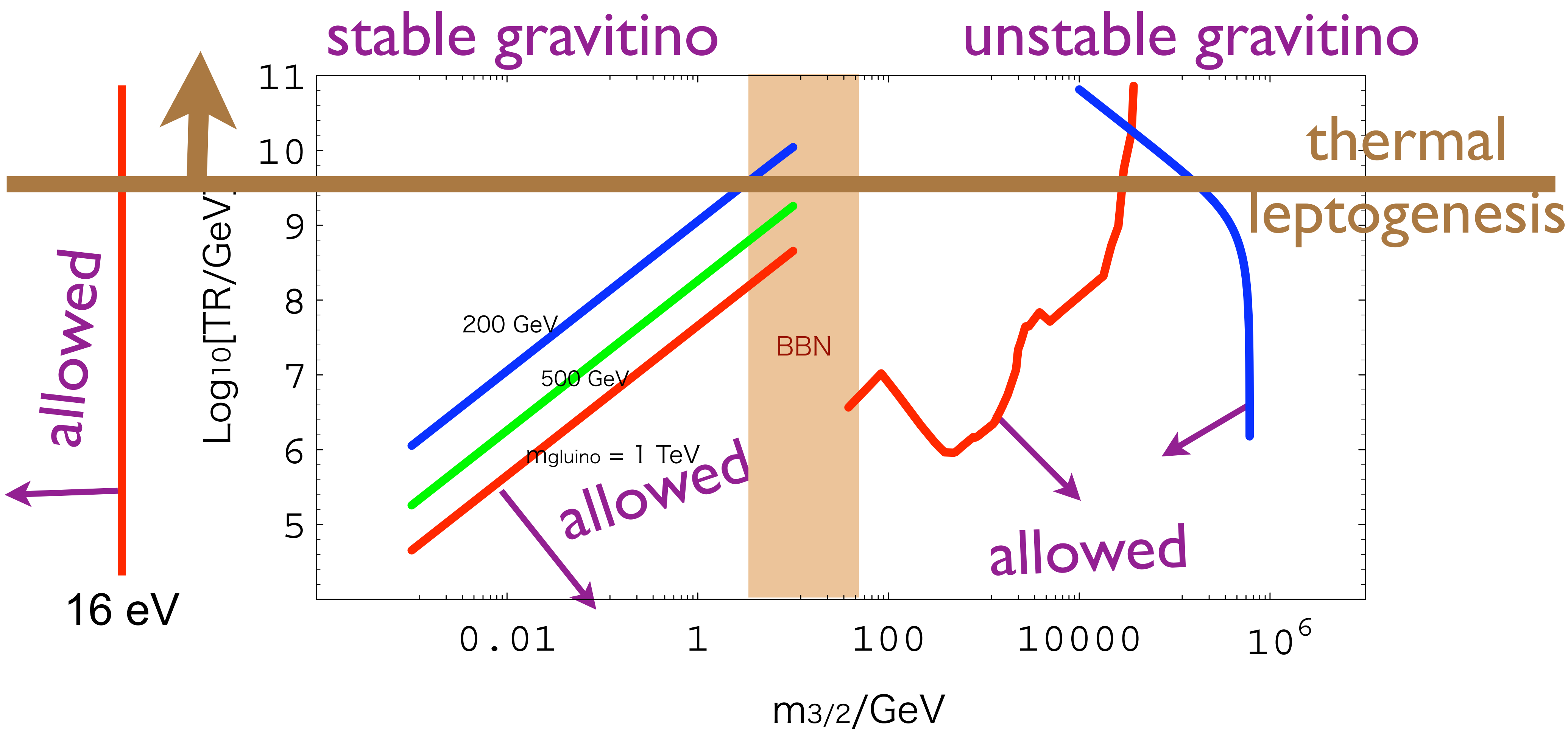


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems



Dark Matter の観点からこの図を眺めてみる。

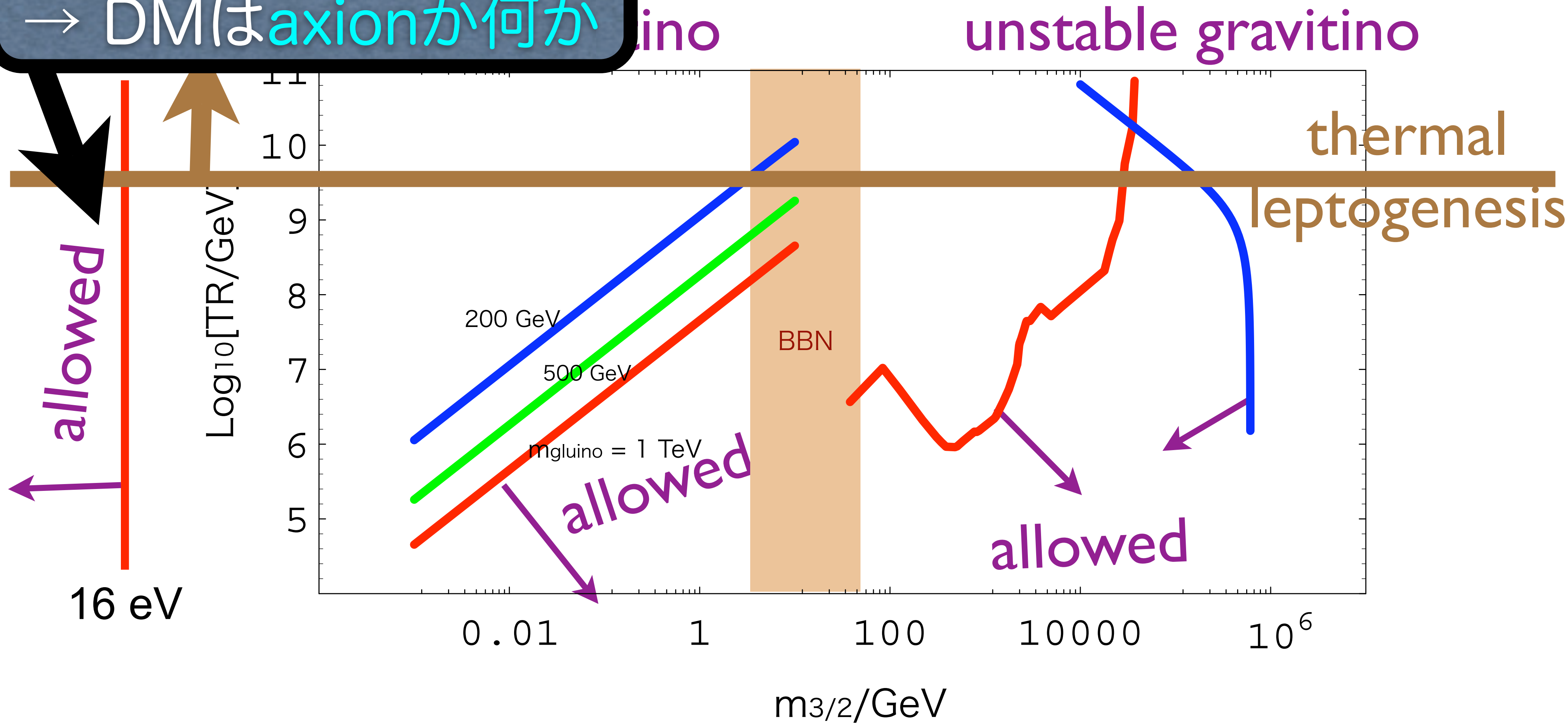
Ibe.

dated.)

no problems

gravitino LSP
でもCDMじゃない。
→ DMはaxionか何か

ino



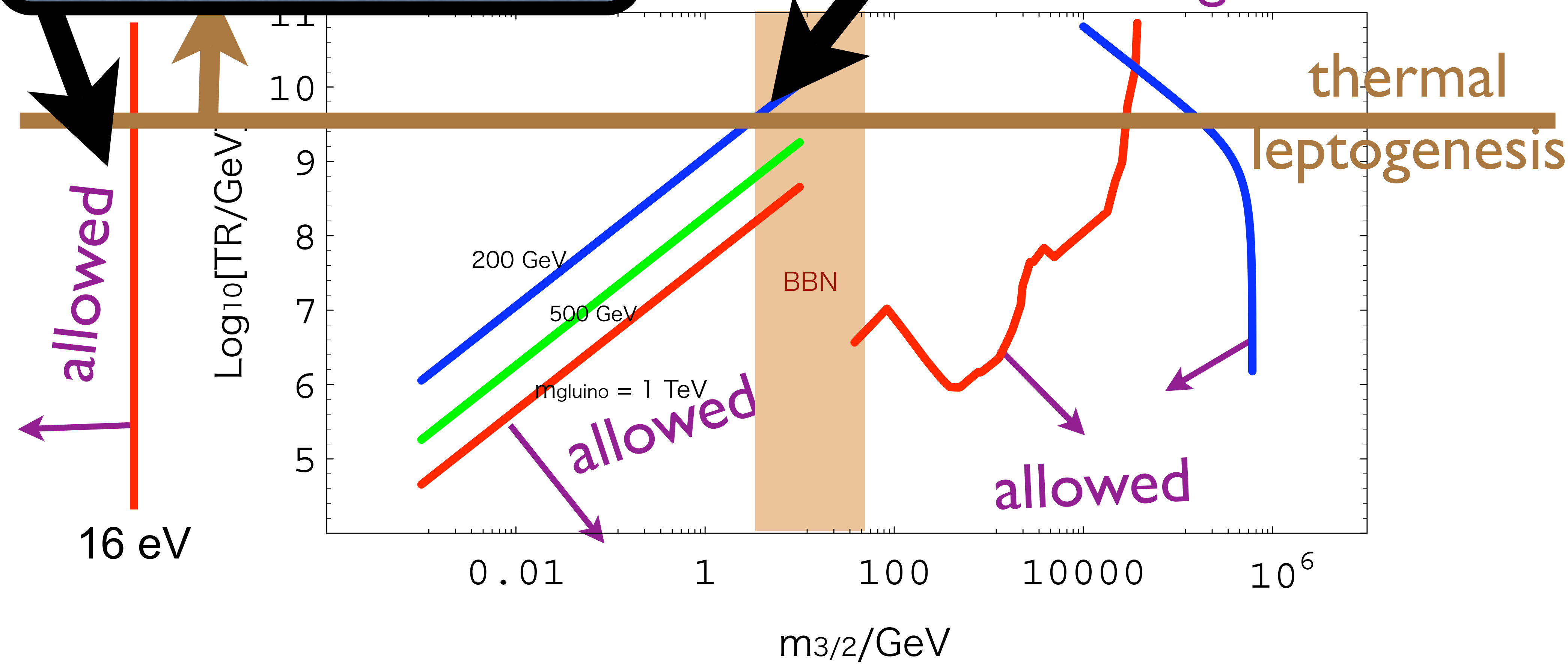
Dark Matter の観点からこの図を眺めてみる。

lbe.

dated.)

gravitino LSP
でもCDMじゃない。
→ DMはaxionか何か

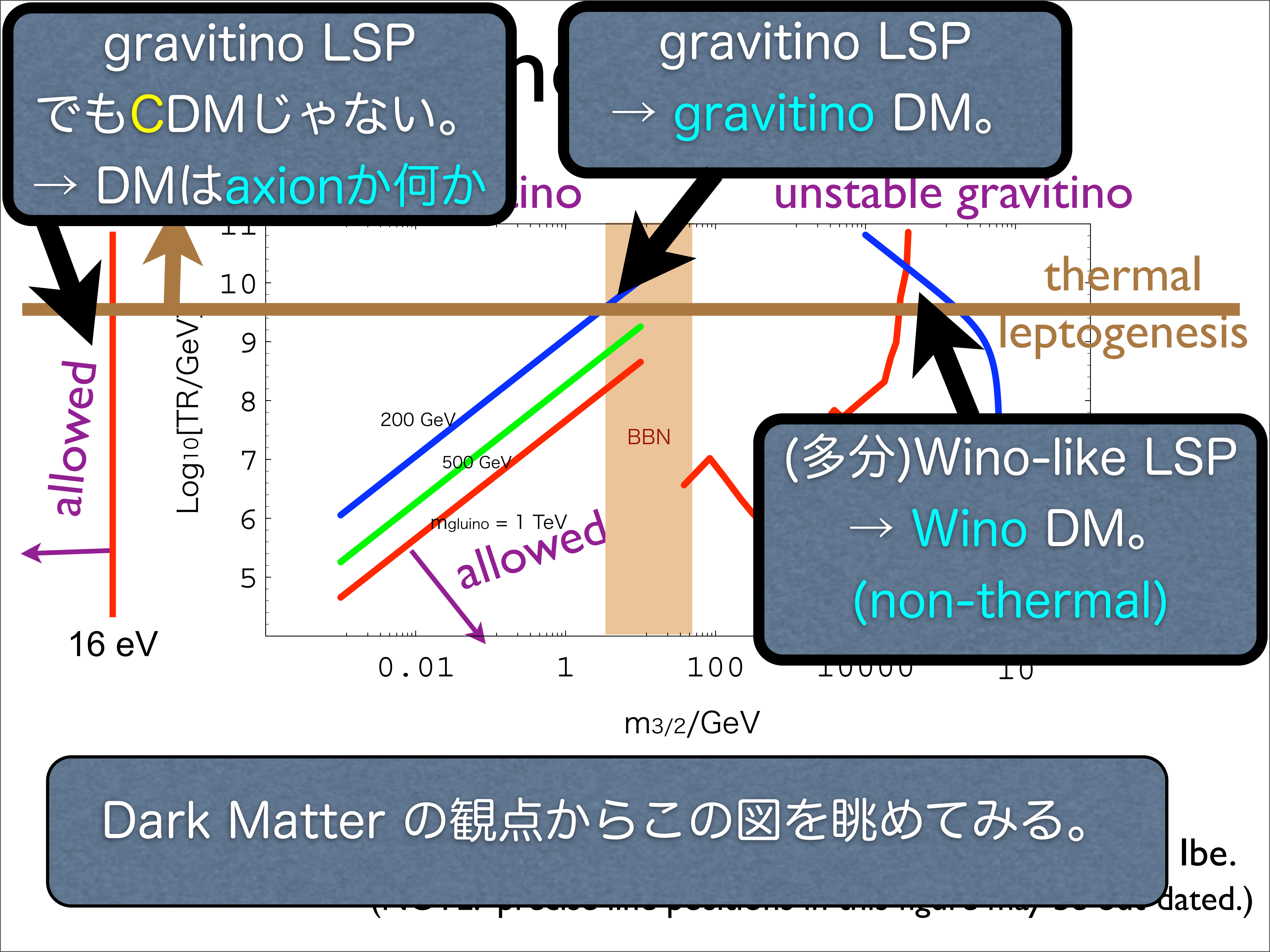
gravitino LSP
→ gravitino DM。

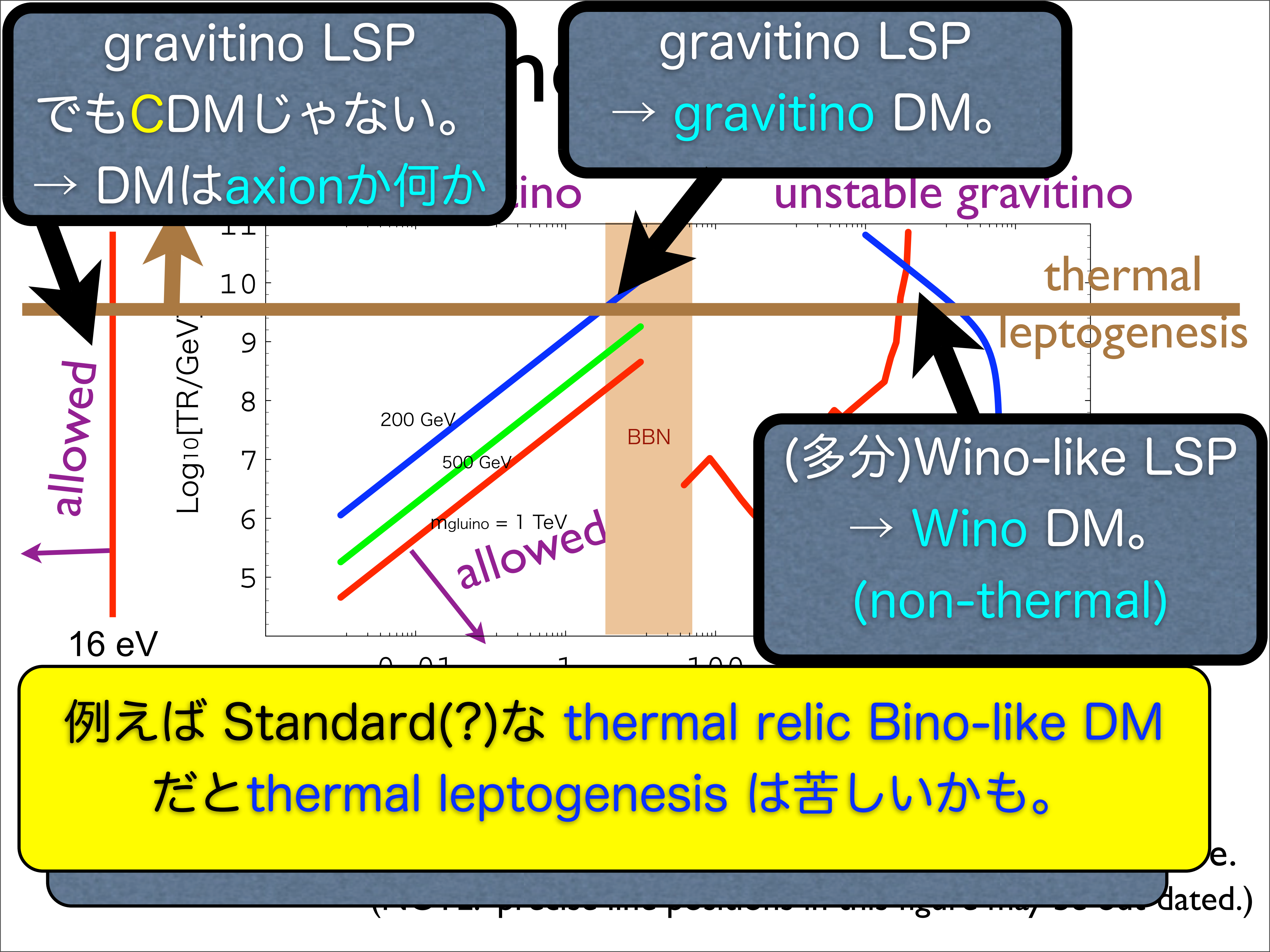


Dark Matter の観点からこの図を眺めてみる。

Ibe.

dated.)


gravitino LSP
でもCDMじゃない。
→ DMはaxionか何か
gravitino LSP
→ gravitino DM。
unstable gravitino
thermal
leptogenesis
allowed
16 eV
Log10[TR/GeV]
10
9
8
7
6
5
200 GeV
500 GeV
mgluino = 1 TeV
BBN
allowed
0.01
1
100
m3/2/GeV
(多分)Wino-like LSP
→ Wino DM。
(non-thermal)
Dark Matter の観点からこの図を眺めてみる。
Ibe.



gravitino LSP
でもCDMじゃない。
→ DMはaxionか何か
gravitino LSP
→ gravitino DM。
ino
unstable gravitino
thermal
leptogenesis
allowed
16 eV
10
9
8
7
6
5
Log10[TR/GeV]
200 GeV
500 GeV
mgluino = 1 TeV
BBN
allowed
0.01
1
100
(多分)Wino-like LSP
→ Wino DM。
(non-thermal)
例えば Standard(?)な thermal relic Bino-like DM
だとthermal leptogenesis は苦しいかも。
e.
dated.)

gravitino problems

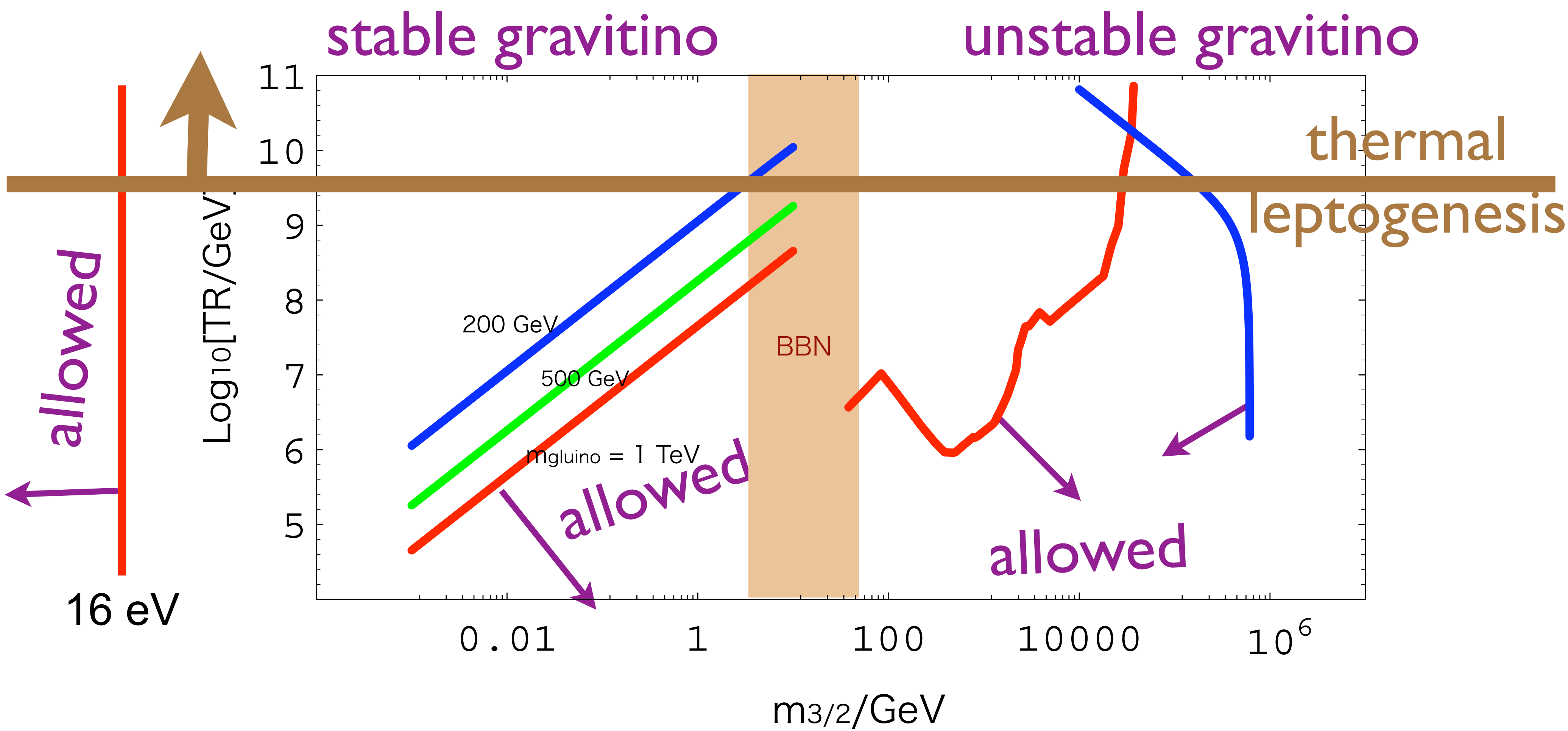
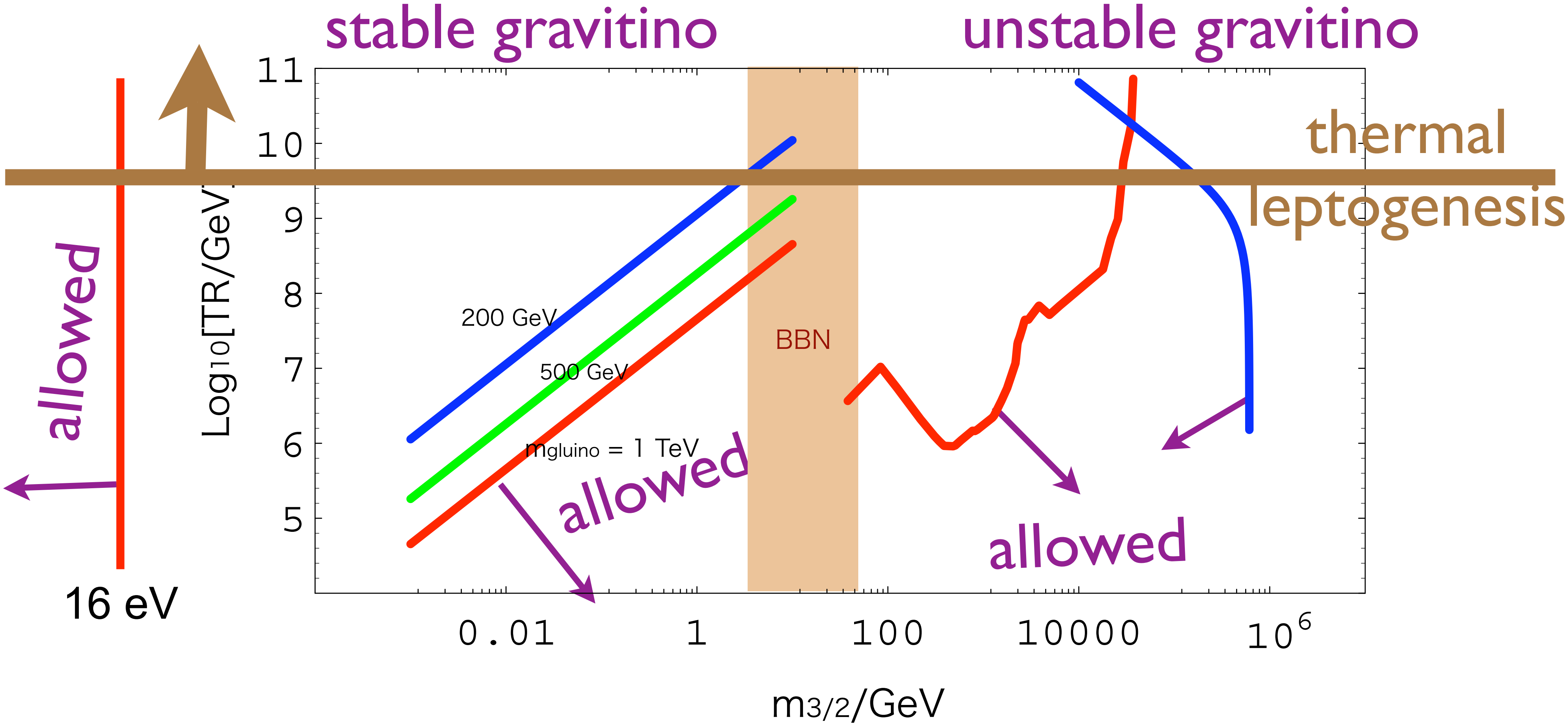


Fig. from Masahiro Ibe.

(NOTE: precise line positions in this figure may be out-dated.)

gravitino problems



テスト出来るか？

Ibe.

dated.)

no problems

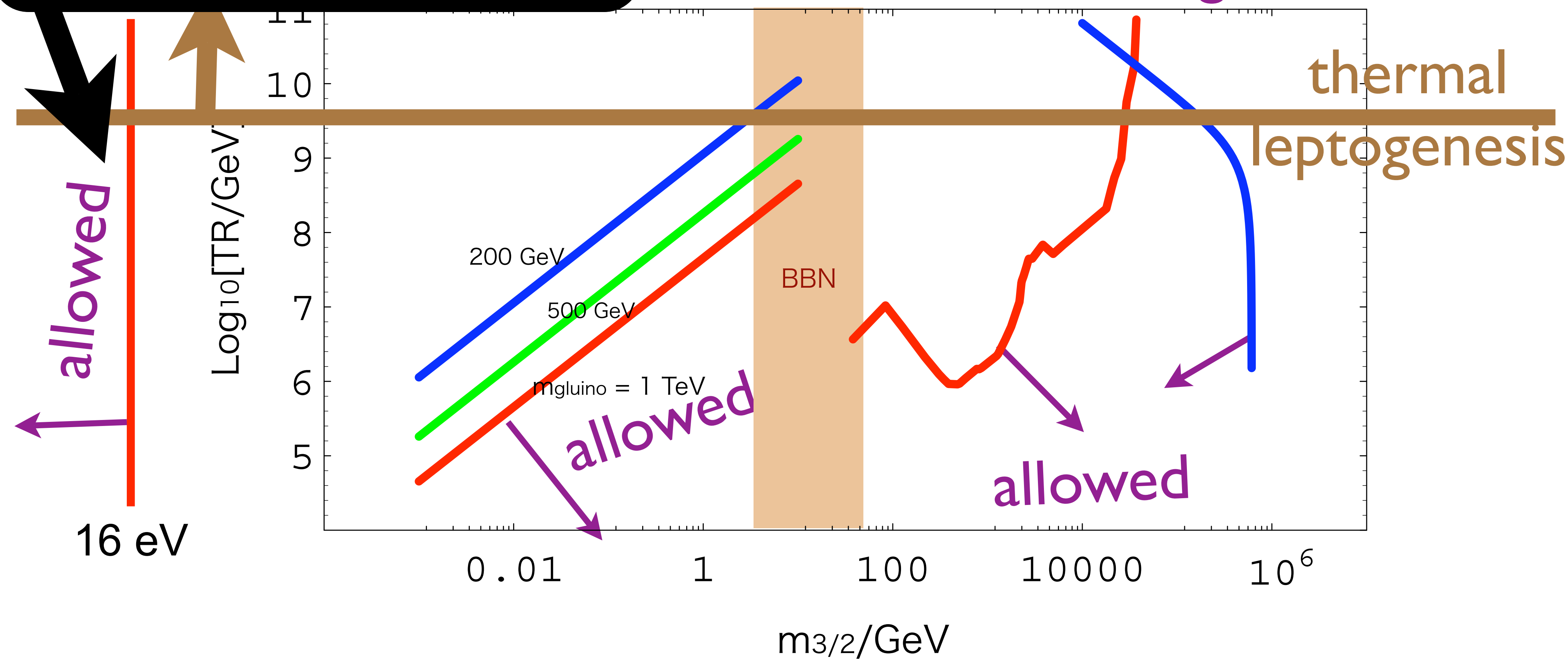
gravitino mass

LHC/ILC で測れます。

cf.) KH, Shirai, Yanagida '07

ino

unstable gravitino



テスト出来るか？

Ibe.

dated.)

gravitino mass

LHC/ILC で測れます。

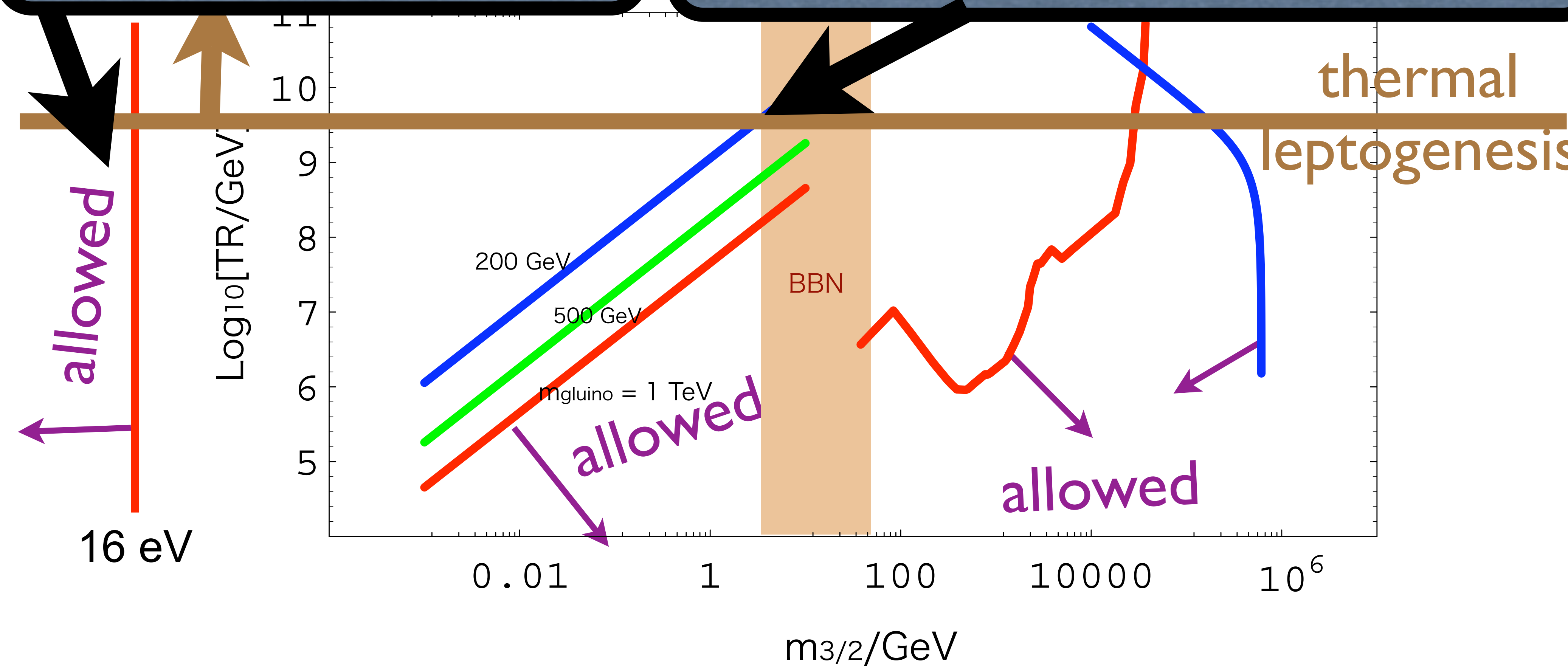
cf.) KH, Shirai, Yanagida ’07

gravitino mass (頑張れば) 測れます。

cf.) Buchmuller, KH, Ratz, Yanagida ’04

KH, Kuno, Nakaya, Nojiri ’04

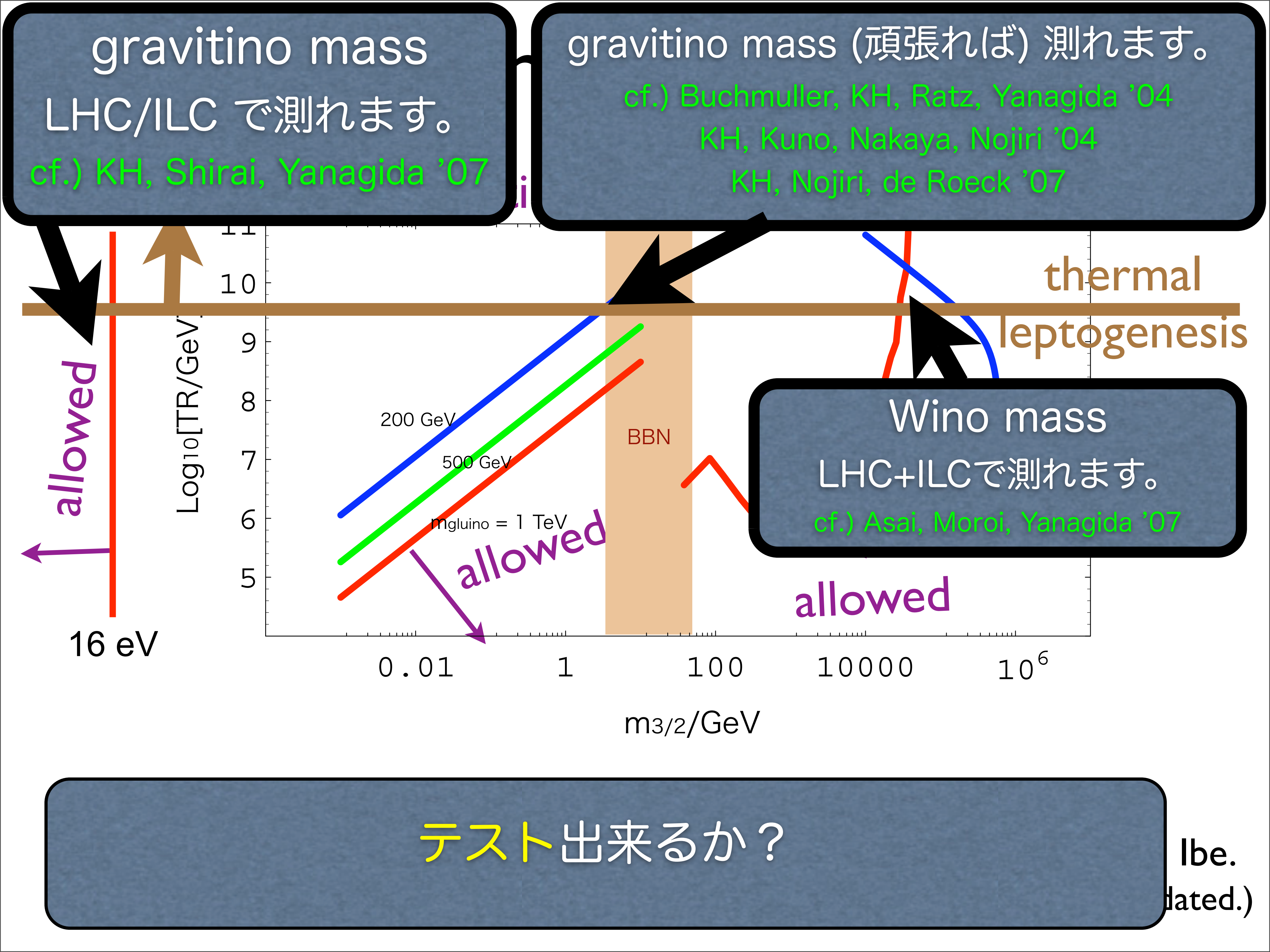
KH, Nojiri, de Roeck ’07



Ibe.

dated.)

テスト出来るか？


gravitino mass
LHC/ILC で測れます。
cf.) KH, Shirai, Yanagida '07
gravitino mass (頑張れば) 測れます。
cf.) Buchmuller, KH, Ratz, Yanagida '04
KH, Kuno, Nakaya, Nojiri '04
KH, Nojiri, de Roeck '07
thermal
leptogenesis
Wino mass
LHC+ILCで測れます。
cf.) Asai, Moroi, Yanagida '07
allowed
allowed
allowed
16 eV
Log10[TR/GeV]
10
9
8
7
6
5
200 GeV
500 GeV
mgluino = 1 TeV
BBN
0.01
1
100
10000
10^6
m3/2/GeV
テスト出来るか？
Ibe.
dated.)

gravitino mass

LHC/ILC で測れます。

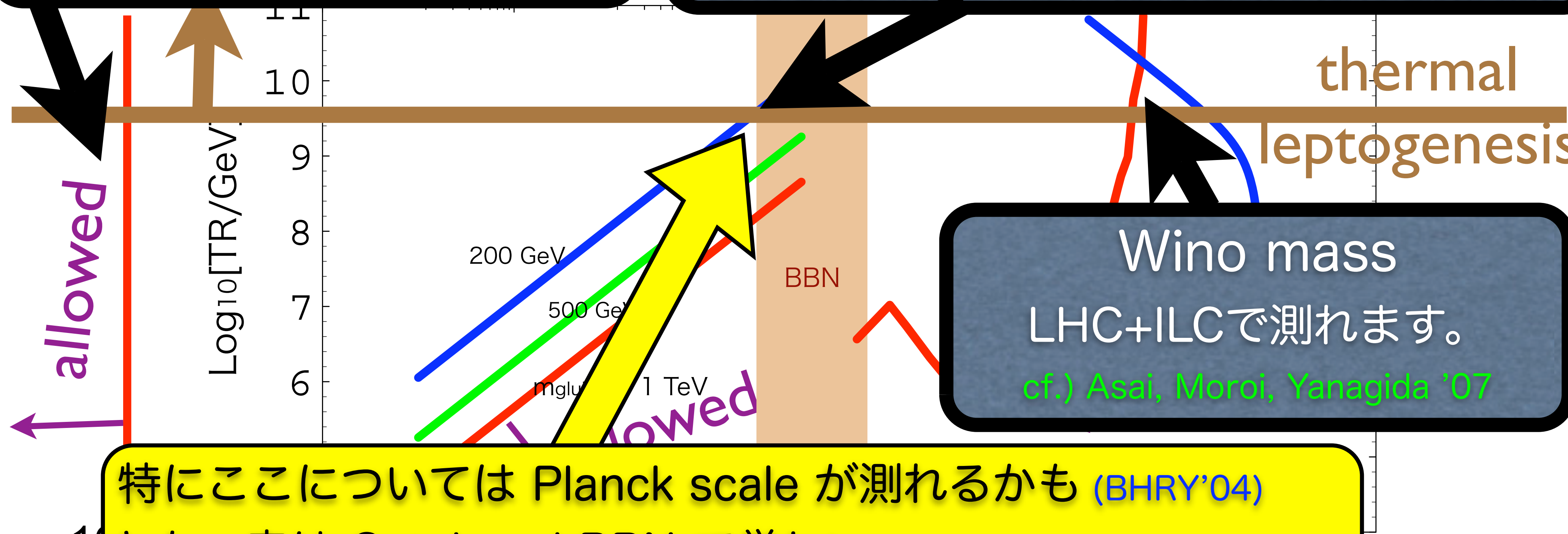
cf.) KH, Shirai, Yanagida ’07

gravitino mass (頑張れば) 測れます。

cf.) Buchmuller, KH, Ratz, Yanagida ’04

KH, Kuno, Nakaya, Nojiri ’04

KH, Nojiri, de Roeck ’07



Wino mass

LHC+ILCで測れます。

cf.) Asai, Moroi, Yanagida ’07

特にここについては Planck scale が測れるかも (BHRY’04)

とか、実は Catalyzed BBN で厳しい (Pospelov’06; KH, Hatsuda, Kamimura, Kino, Yanagida’07; Kawasaki, Kohri, Moroi ’07)

とか、でもentropy productionがあれば大丈夫 (Buchmuller, KH, Ibe, Yanagida’06) とか、R-parityが破れていても gravitino DMがviableだ (Buchmuller, Covi, KH, Ibarra, Yanagida’06)

とか、いろいろ話したい事はありますが・・・またの機会

Ibe.

dated.)

gravitino mass

LHC/ILC で測れます。

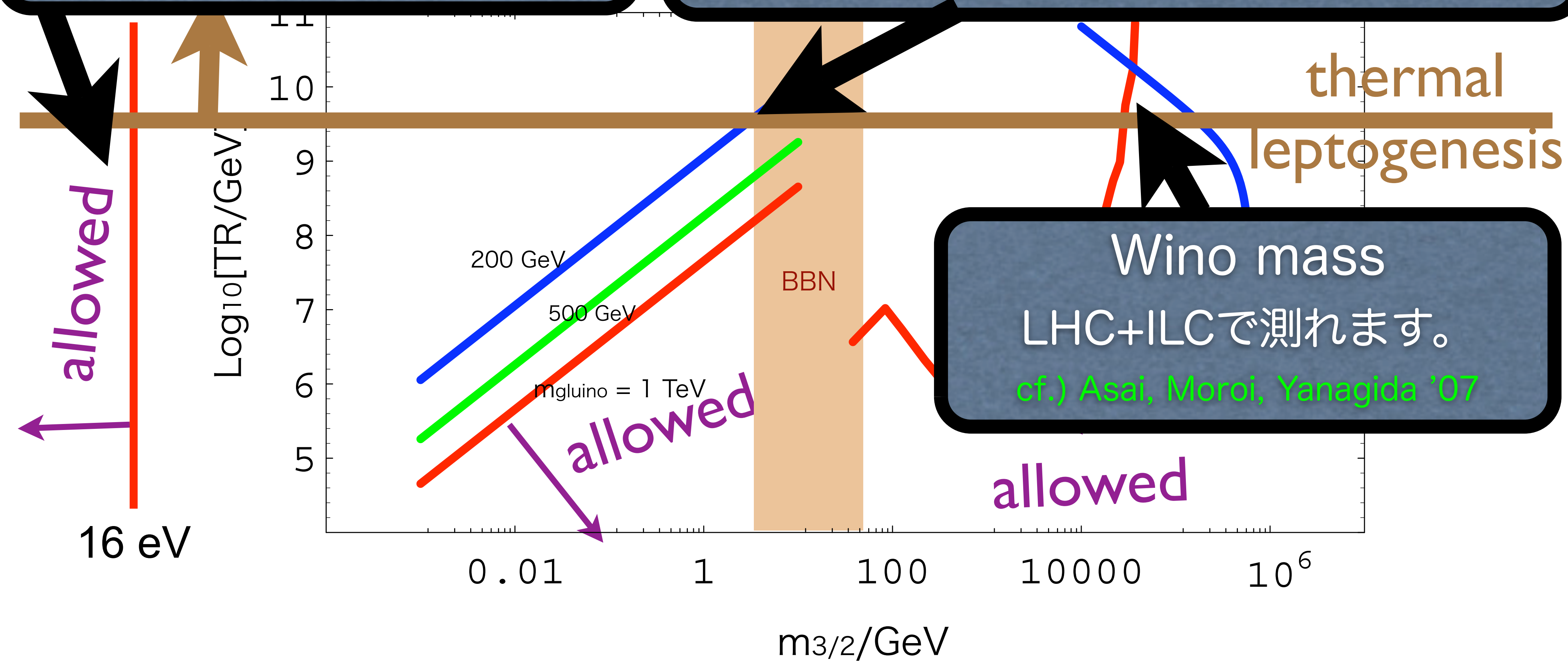
cf.) KH, Shirai, Yanagida '07

gravitino mass (頑張れば) 測れます。

cf.) Buchmuller, KH, Ratz, Yanagida '04

KH, Kuno, Nakaya, Nojiri '04

KH, Nojiri, de Roeck '07



Wino mass

LHC+ILCで測れます。

cf.) Asai, Moroi, Yanagida '07

テスト出来るか？

Ibe.

dated.)

まとめ(?) ・・・Dark Matter を見て

Baryogenesis について何か言えるか？

まとめ(?)・・・Dark Matter を見て Baryogenesis について何か言えるか？

- LHC/ILCでBino-like LSP、計算したら thermal relic ばっちり（+出来れば detection) → thermal leptogenesis は苦しめ。

まとめ(?) ・・・Dark Matter を見て Baryogenesis について何か言えるか？

- LHC/ILCでBino-like LSP、計算したら thermal relic ばっちり（+出来れば detection)
  → thermal leptogenesis は苦しめ。
- LHC/ILCでWino-like LSP、計算したら thermal relicでは足りない（+ 出来ればdetection)
  → non-thermal Wino DM
  → thermal leptogenesis OK。

(Affleck-Dine + Q-ball の可能性も面白い。)

まとめ(?) ・・・Dark Matter を見て Baryogenesis について何か言えるか？

- LHC/ILCでBino-like LSP、計算したら thermal relic ばっちり（+出来れば detection)
  → thermal leptogenesis は苦しめ。
- LHC/ILCでWino-like LSP、計算したら thermal relicでは足りない（+ 出来ればdetection)
  → non-thermal Wino DM
  → thermal leptogenesis OK。
  (Affleck-Dine + Q-ball の可能性も面白い。)
- LHC/ILCでGravitino-LSP、mass測ったら consistent, →thermal leptogenesis OK。