

Gravitino and Inflation

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KEK Cosmo Group Inaugural Conference
"Accelerators in the Universe"

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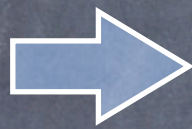
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Kadota, Olive

1. Introduction

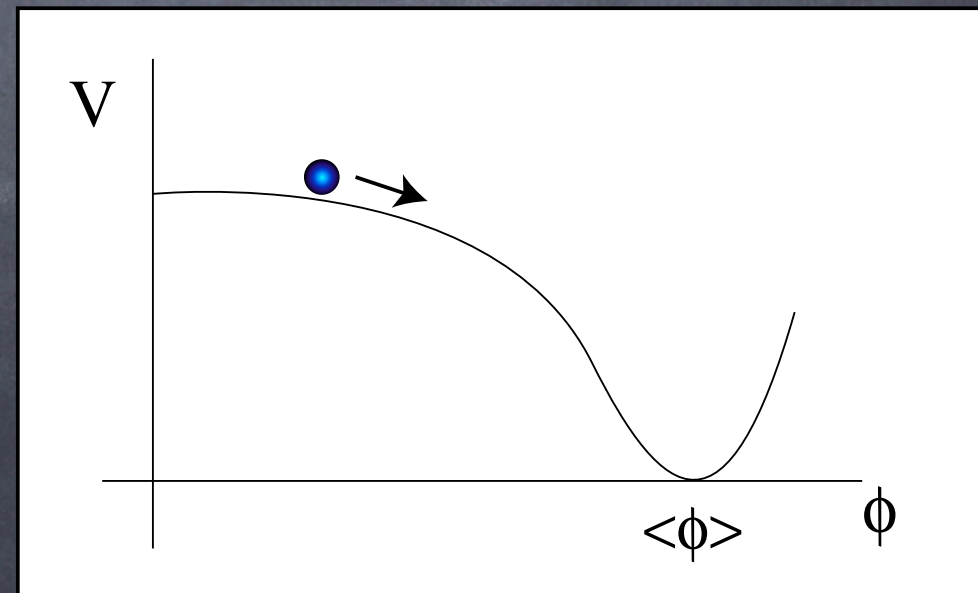
Inflation

: a phase of the exponential expansion.



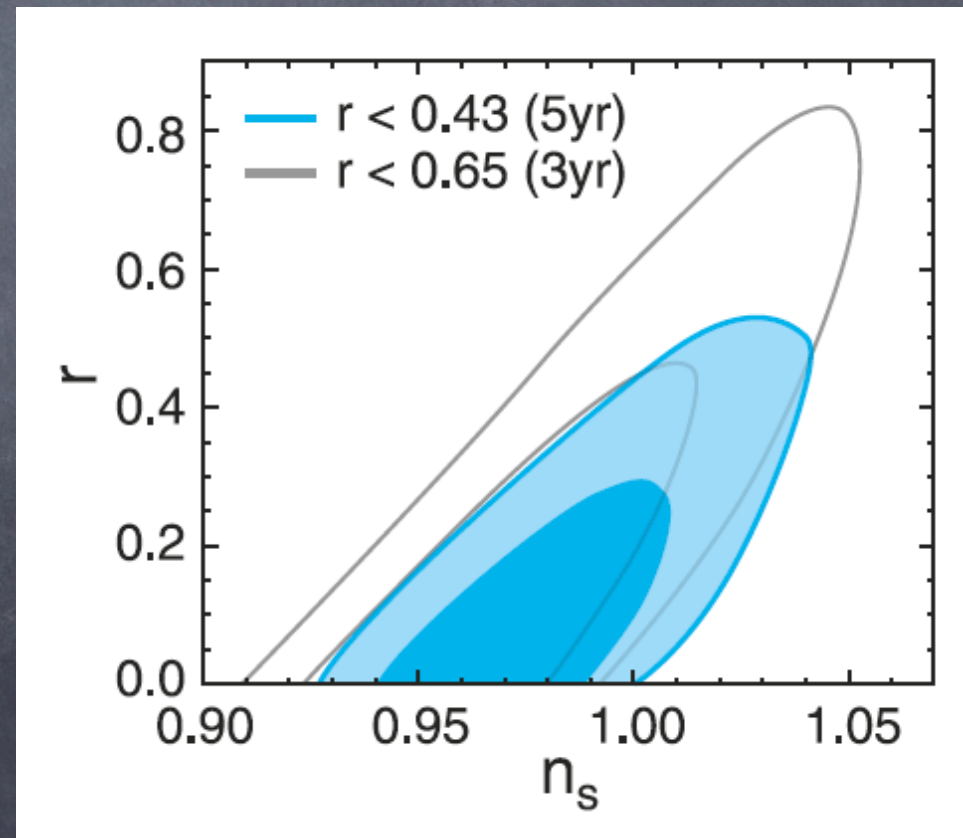
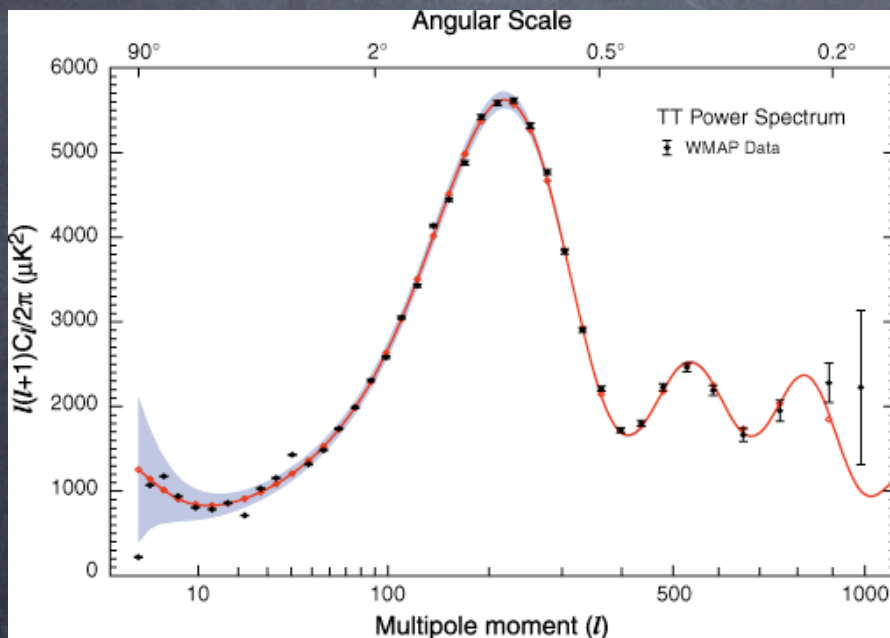
solves the horizon and flatness problems.

⦿ Slow-roll inflation explains the origin of the density fluctuations.



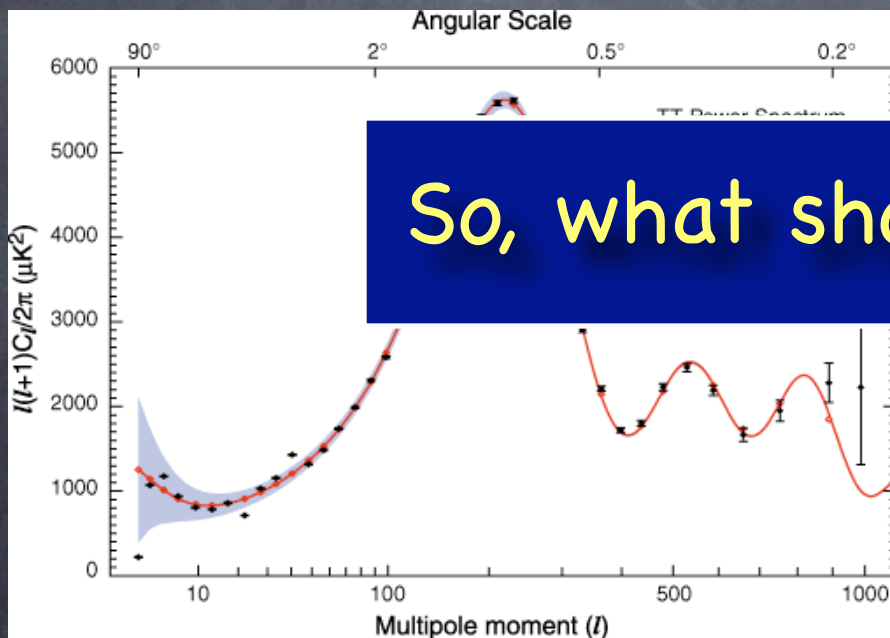
- Inflation is now strongly supported by observations such as WMAP.

Power-law LCDM model fits the WMAP data quite well.

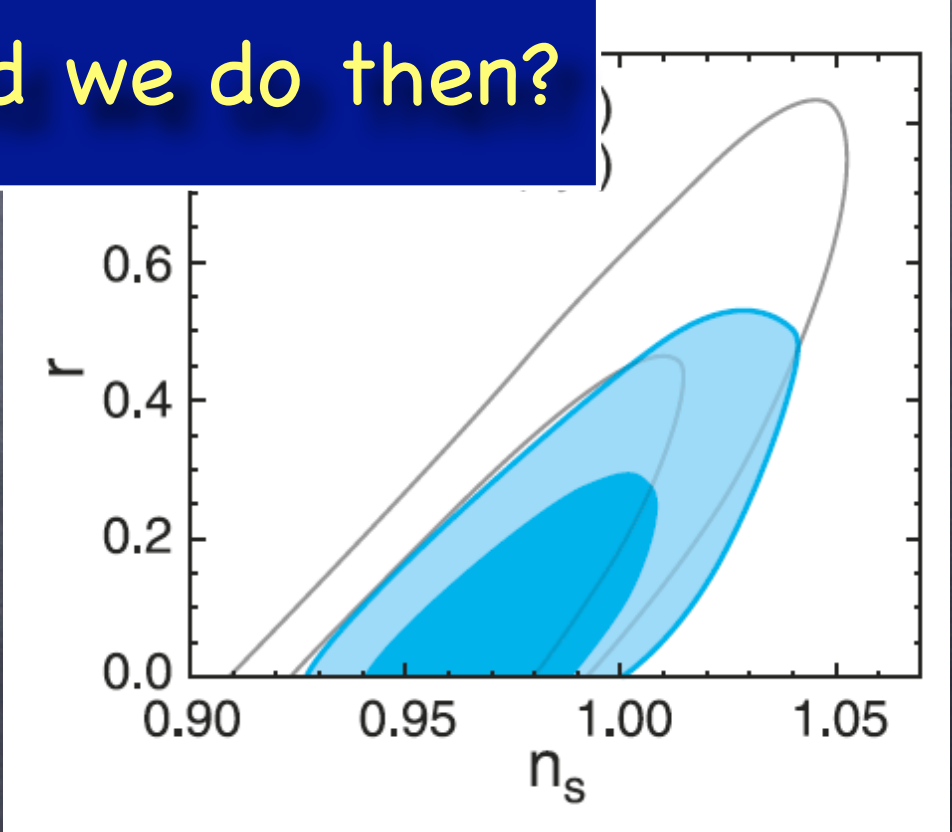


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So, what should we do then?

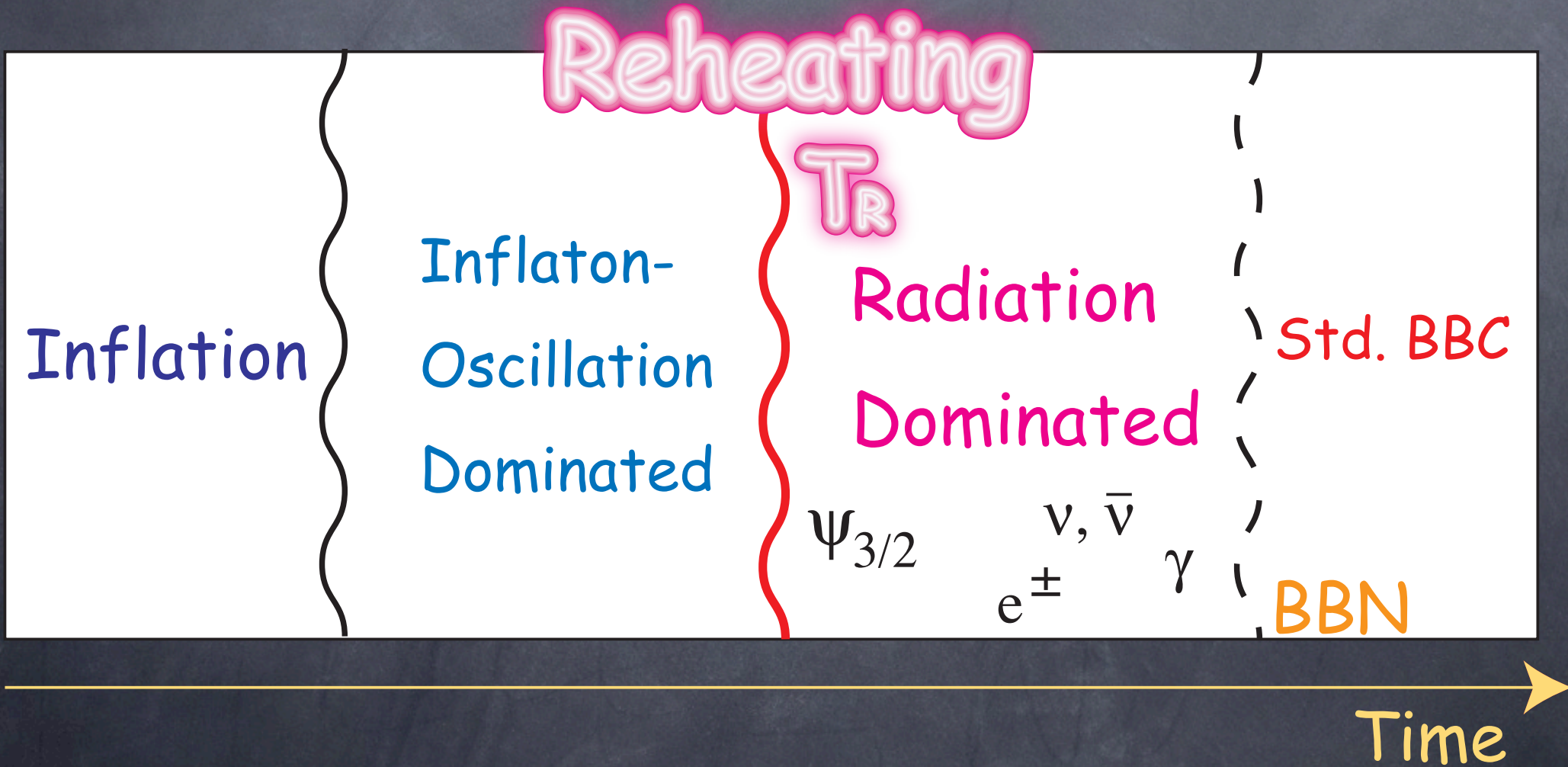


There are still many things
we do not know yet!

1. Which inflation model is
actually realized in nature?

2. How did the universe evolve
after inflation?

Thermal history after inflation



- One approach to the first question is to study **the properties of the fluctuations.**

(running) scalar spectral index, scalar-to-tensor ratio, isocurvature perturbations, non-Gaussianities, B-mode, etc..

(many interesting talks on these topics tomorrow)

In particular, the **GWs** produced during inflation, if (in)directly observed, can pin down the inflation scale. Moreover, GWs can be a probe into the thermal history!

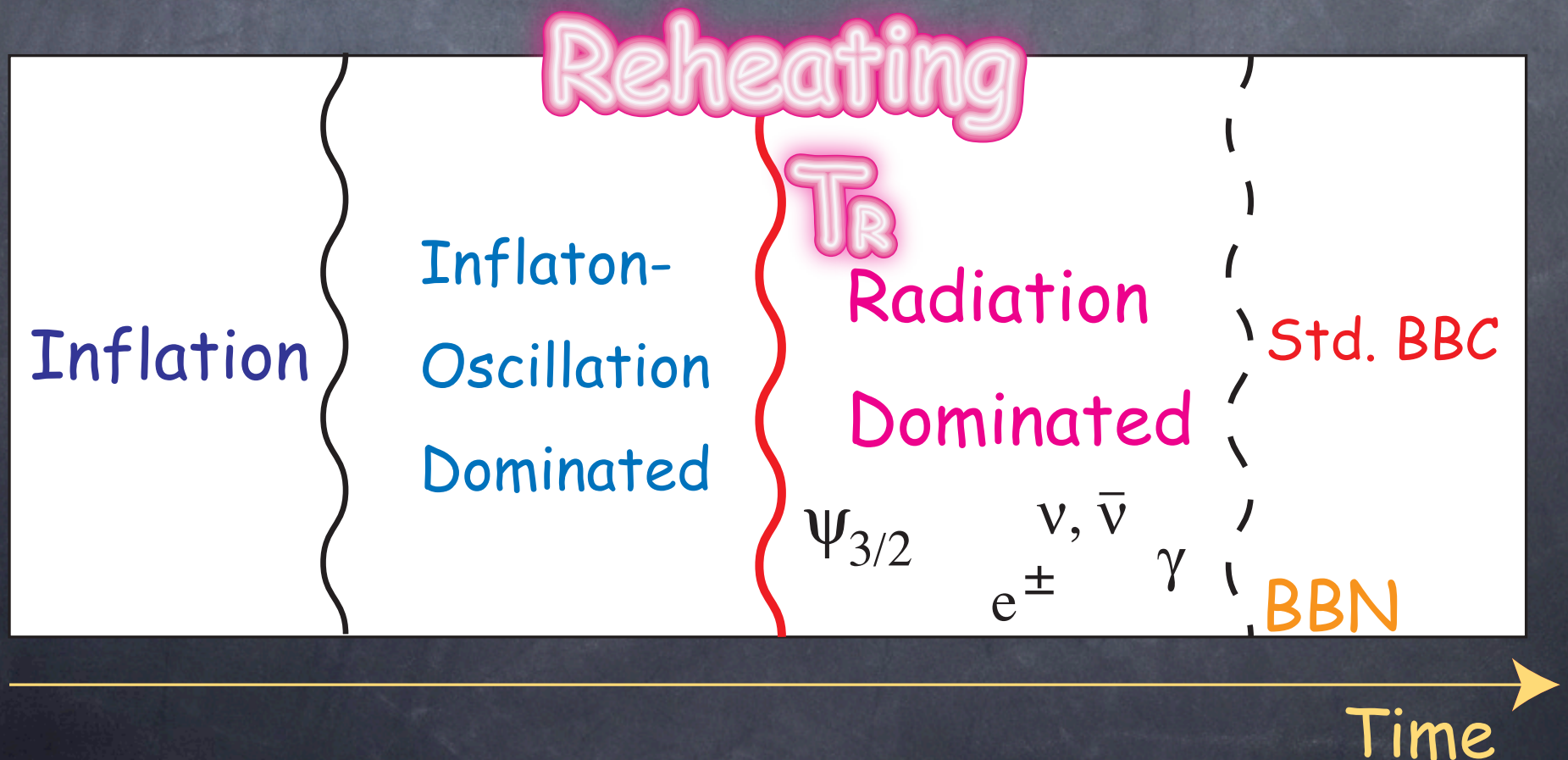
(talks by Yokoyama)

• The approach I take here is
to study **the reheating processes!**

This turns out to be a viable
approach to the both questions.

Thermal history after inflation

- Inflaton-decay reheats the universe.
- Reheating contains information on the inflaton.



The reheating process itself has not been intensively studied!

- ✓ Couplings were introduced ad hoc **by hand**.
- ✓ Decay into unwanted relics such as the gravitinos was neglected **without definite grounds**.
- ✓ The reheating was constrained only by the gravitino problem (from thermal processes).

It was far from full understanding...

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Reheating:

....Because the nature of the inflaton is not known, this process is still poorly understood..... [from Wikipedia]

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◉ We have found

- ✓ gravitinos are non-thermally produced by inflaton decay.
- ✓ inflaton decays into the visible sector via the top Yukawa coupling and $SU(3)_c$ gauge interactions.

Good : reheating is naturally induced.

Bad(?) : new gravitino problem!

Gravitino

- the superpartner of the graviton.
- It becomes massive by eating the **goldstino** when the local SUSY is spontaneously broken. (**super-Higgs mechanism**)
- Interactions are very weak, and suppressed by M_p or $F \sim \sqrt{m_{3/2} M_P}$
 long lifetime!

Gravitino Problem: (from thermal scatterings)

Weinberg 82, Krauss 83

For high T_R , too many gravitinos are thermally produced, leading to cosmological difficulties.

Gravitino abundance (from thermal scattering)

Moroi, Murayama, Yamaguchi 93,

Bolz, Brandenburg, Buchmueller 01; Pradler, Steffen 06

$$Y_{3/2} \sim 10^{-12} \left(\frac{T_R}{10^{10} \text{ GeV}} \right)$$

Upper bounds on T_R

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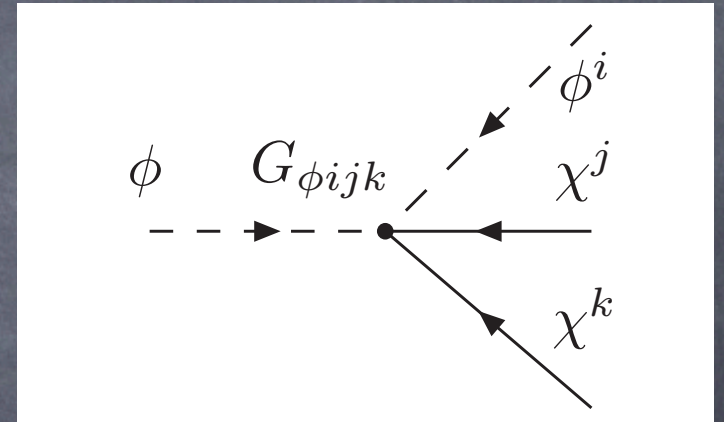
2. Decay into the SM sector

Spontaneous decay at tree level

$$W = Y \phi^i \phi^j \phi^k$$

$$\mathcal{L} = -\frac{1}{2} e^{G/2} G_{\phi ijk} \hat{\phi} \phi^i \chi^j \chi^k + \text{h.c.}$$

$$G_{\phi ijk} = -\frac{W_\phi}{W} \frac{W_{ijk}}{W} + \frac{W_{\phi ijk}}{W}$$
$$\simeq \boxed{K_\phi \frac{W_{ijk}}{W}} + \frac{W_{\phi ijk}}{W},$$



• Decay Rate through the Yukawa coupling:

$$\Gamma_Y = \frac{|C_{ijk}^{(3)}|^2}{256\pi^3} m_\phi^3$$

$$C_{ijk}^{(3)} \equiv e^{G/2} G_{\phi ijk}$$

The inflaton decays into the visible sector through the top Yukawa coupling:

$$W = Y_t T Q H_u,$$

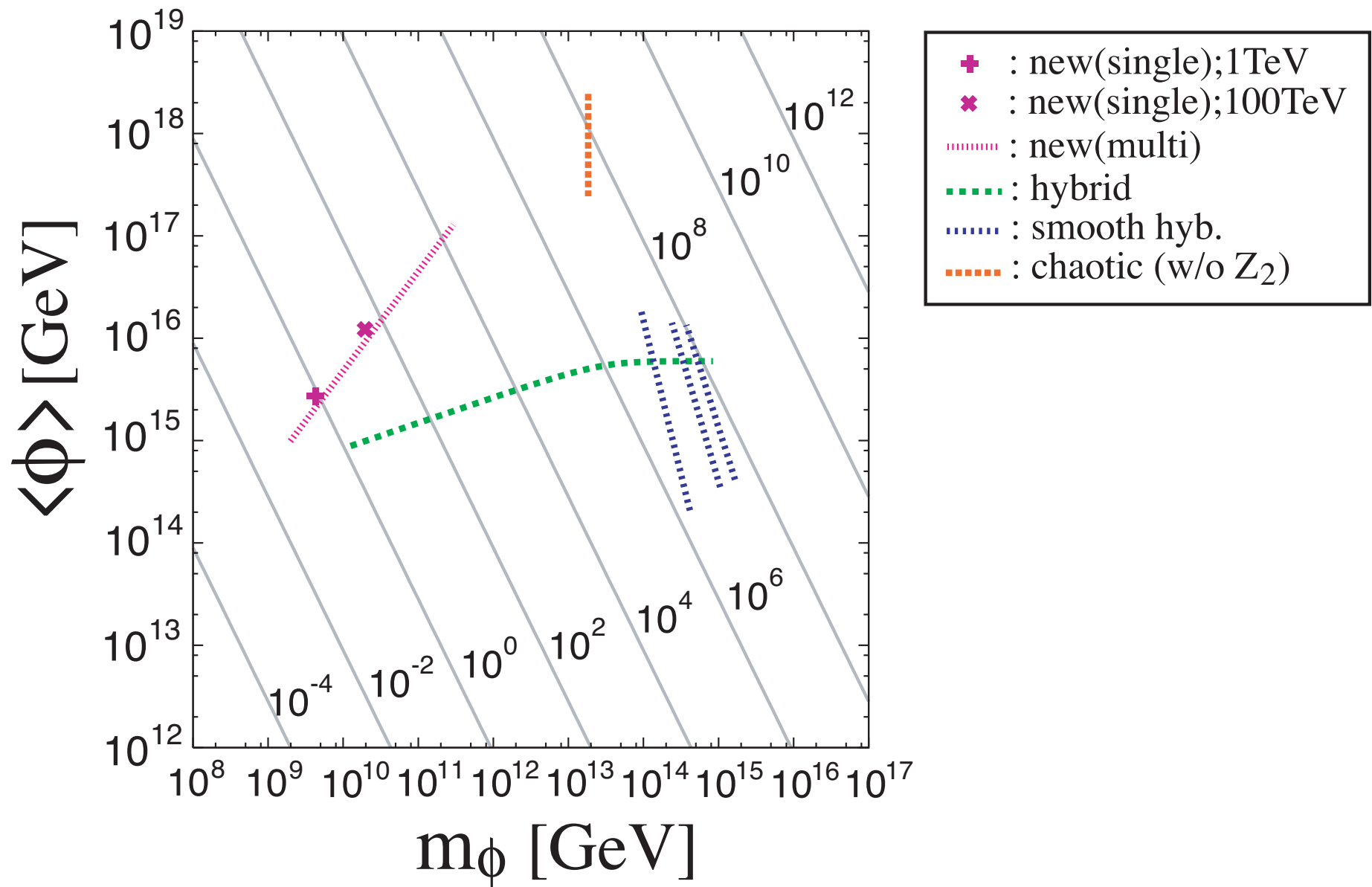
The decay rate is given by

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

(minimal Kahler is assumed)

The reheating temperature is
bounded below!!

Lower limit on the reheating temperature:

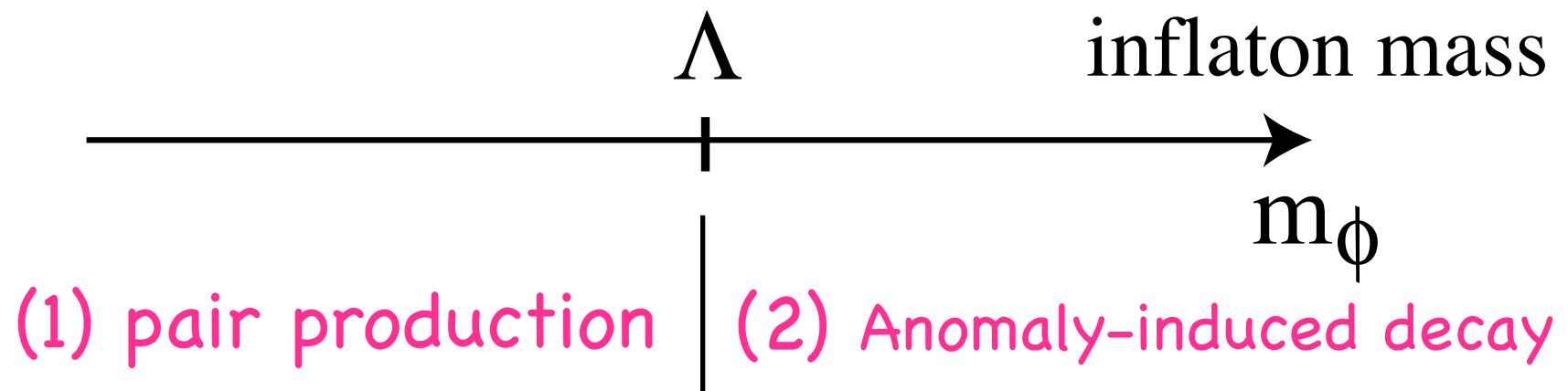


3. Decay into the gravitinos

Gravitino Production:

- (1) Gravitino pair production (direct) :
(induced by the mixing between ϕ and z)
- (2) Anomaly-induced decay (indirect) :
(decay into the hidden gauge sector)

SUSY breaking scale



Summary on the gravitino production rates:

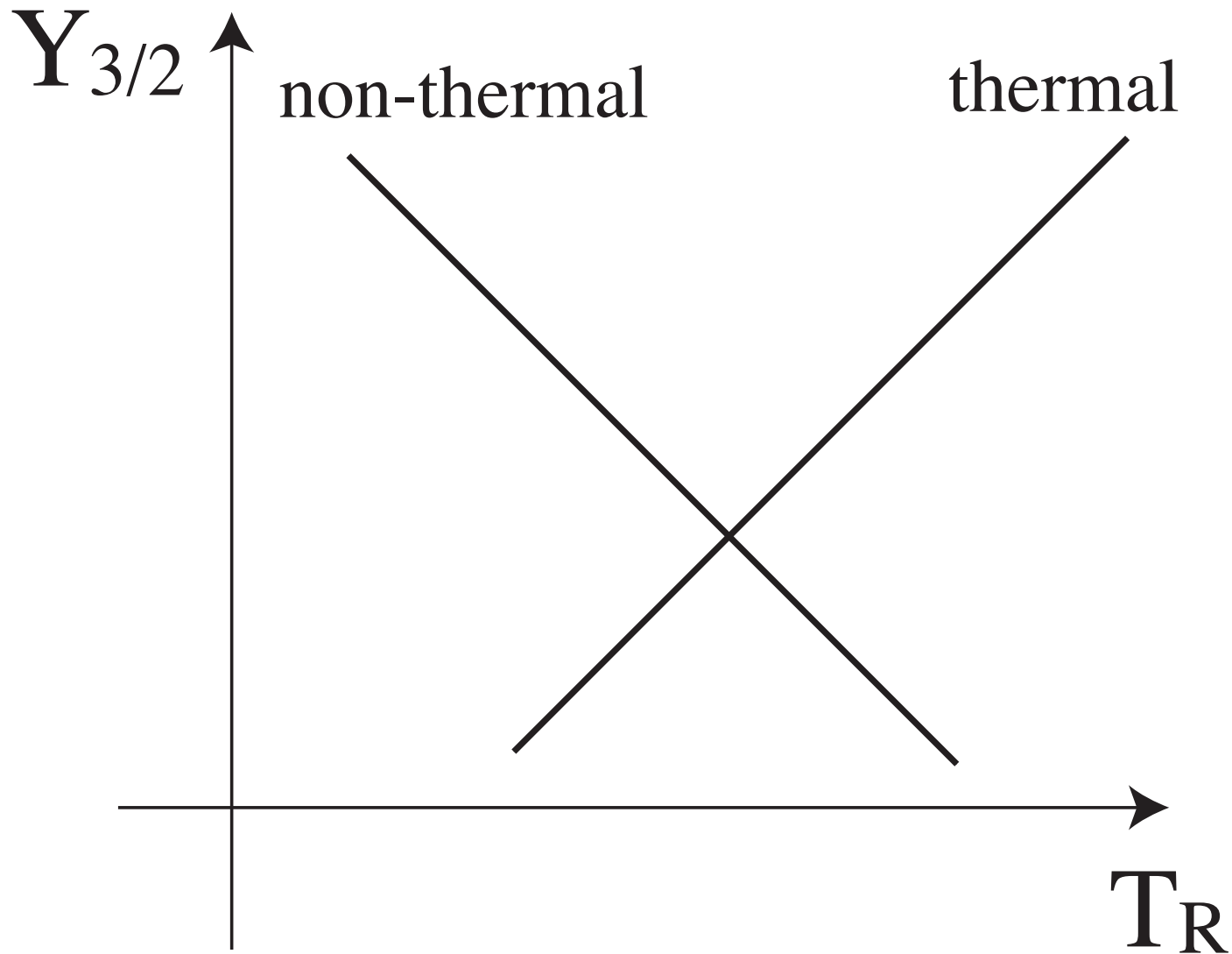
$$\Gamma_{3/2} \simeq \begin{cases} \frac{1}{32\pi} \left(\frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2}, & \text{for } m_\phi < \Lambda \\ \frac{\alpha^2}{256\pi^3} \left(\frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2}, & \text{for } m_\phi > \Lambda \end{cases}$$

Gravitino Abundance:

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

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

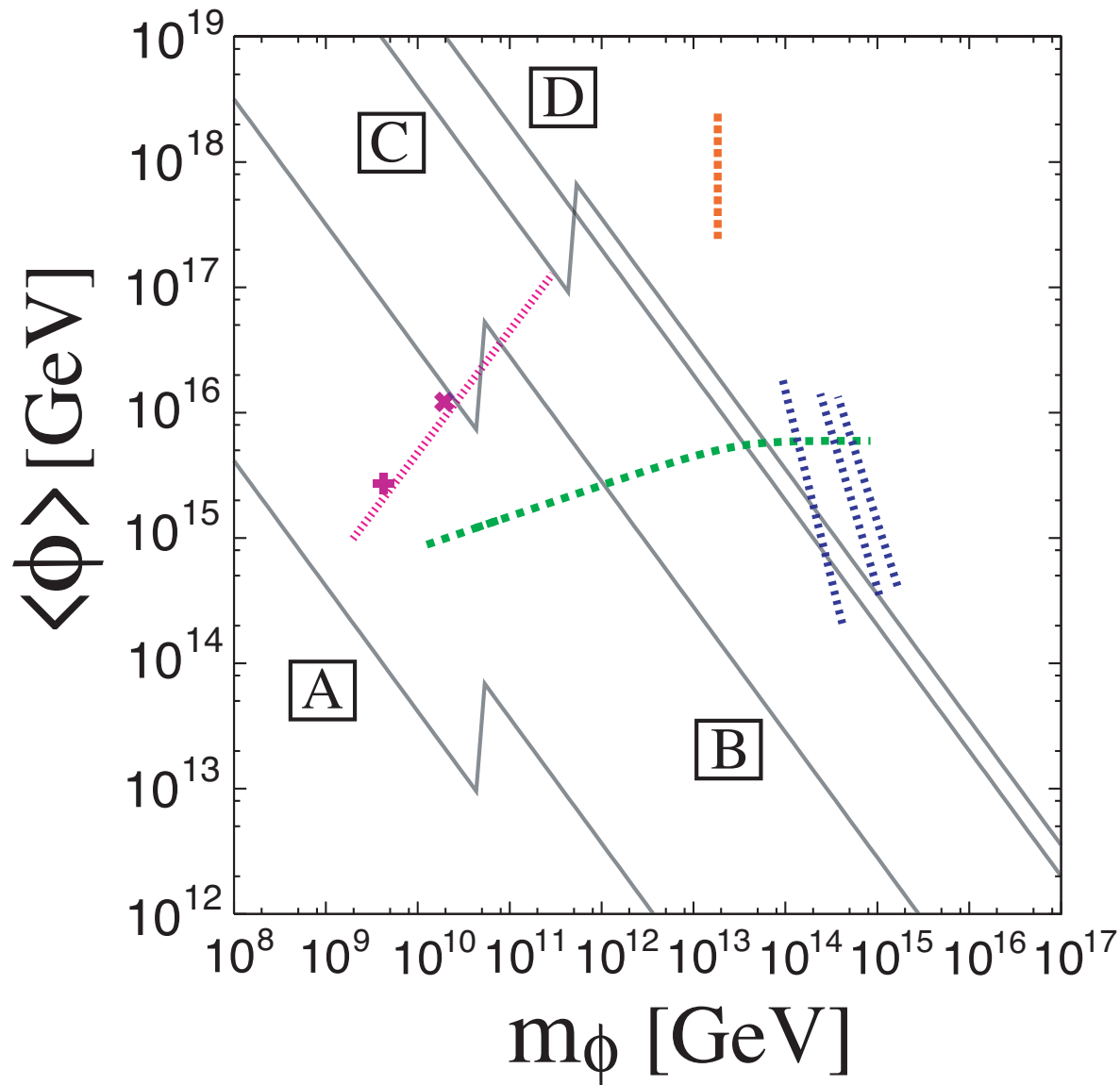
Gravitino Abundance



4. Cosmological Constraints (gravitino production)

Conservative

Constraints on the inflation models;



- A: $m_{3/2} = 1\text{TeV}; Bh = 1$
B: $m_{3/2} = 1\text{TeV}; Bh = 10^{-3}$
C: $m_{3/2} = 100\text{TeV}$
D: $m_{3/2} = 1\text{GeV}$

Solutions:

(i) Postulate a symmetry on the inflaton.

e.g.) chaotic inflation

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

(ii) AMSB, GMSB

cosmological constraints are relaxed.

(iii) late-time entropy production

(iv) conformal sequestering

5. Conclusion

We have discovered that the inflaton naturally decays into both the visible and SUSY breaking sectors.

(1) **New gravitino problem:**

non-thermal production of the gravitinos

(2) Natural way to induce the reheating.

We obtained severe constraints on the inflation models and the SUSY breaking scenarios.