Leptogenesis, the Gravitino Bound and Discrete Flavor Symmetries

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Motivations

1) Gravitino Problem vs SUSY Leptogenesis

- Thermal leptogenesis only requires SM and 3 RH neutrinos with (Fukugita,Yanagida,Davidson,Ibarra,...)

$$M_N > 10^9 \mathrm{GeV}$$

- but at $T_{RH} \gtrsim 10^6 \mathrm{GeV}$ too many gravitinos produced
  - their highly energetic decay products compromize BBN

2) Leptogenesis in models with realistic (tribimaximal) neutrino mixing

Previous Work

- Gravitino Problem
  - Resonant Leptogenesis
    (Pilaftsis,Underwood,Hambye,March-Russell,West,...)
  - Non-Thermal Leptogenesis
    (Giudice,Riotto,Peloso,Tkachev,Zaffaroni,Asaka,Hamaguchi,Kawasaki,Yanagida,..)
  - Gravitino Very Heavy/Light/Stable/Degenerate..
    (Buchmuller,Covi,Hamaguchi,Ibarra,Yanigida,Roszkowski,deAustri,Choi,Boubiker...)

- Leptogenesis in A4-based models
  (Bertuzzo,diBari,Feruglio,Nardi,Adhikary,Ghosal,Hagerdon,Molinaro,Petcov)

$$T_{RH} \gtrsim 10^{12}\mathrm{GeV}$$

However...

- If RH neutrinos N obtain mass through spontaneous symmetry breaking:

$$W = \lambda' \varphi N^2 + \lambda H l N + ... \quad \Rightarrow \quad M_N^2 = \lambda'^2 \langle \varphi \rangle^2$$

- Symmetries that are spontaneously broken today are restored in the early universe!

→ In this case, the RH neutrinos were mass-less and in thermal equilibrium down to

$$T \sim T_{\rm PT}$$

rather than $T \sim M_N$

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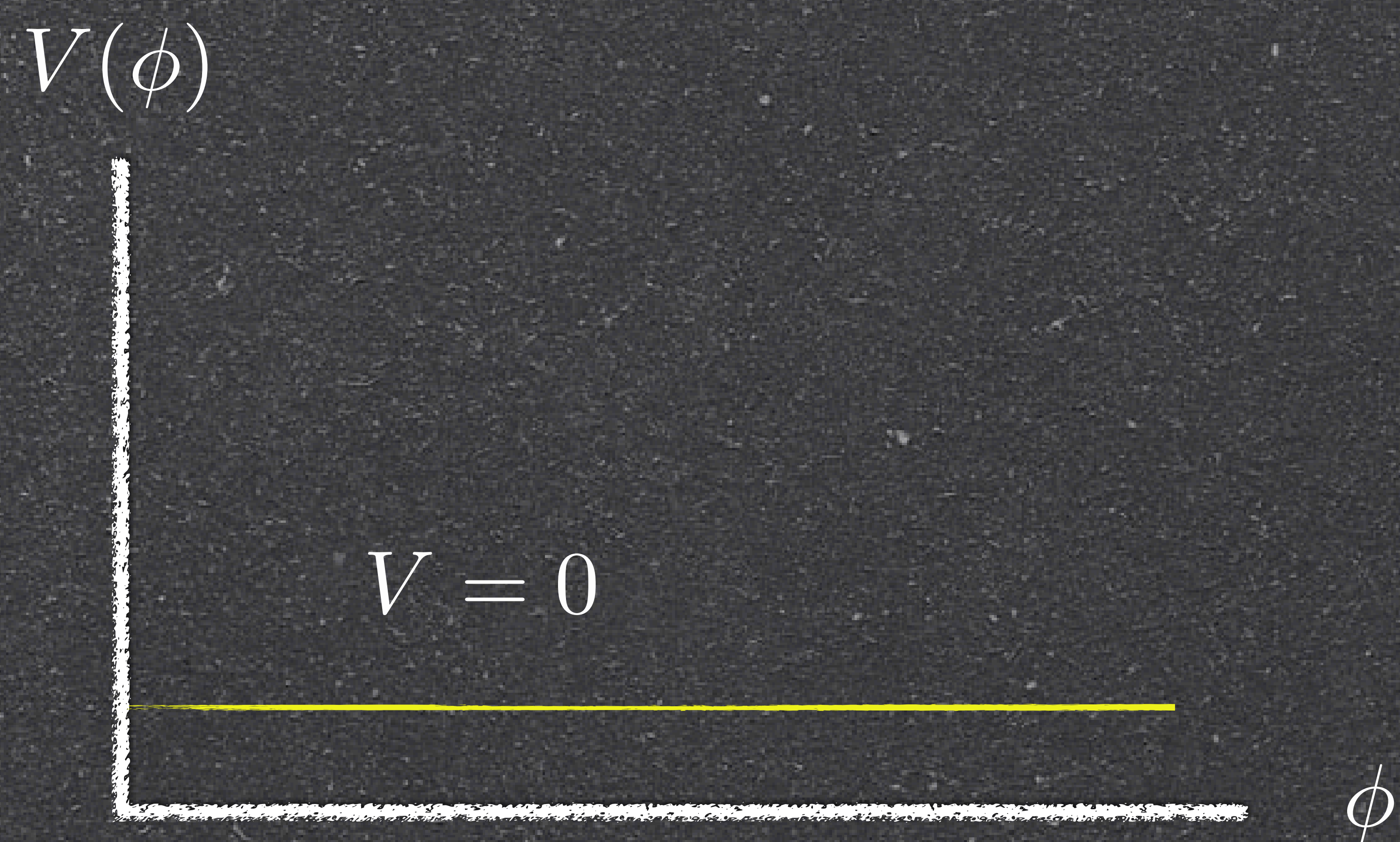
rather than $T \sim M_N$

Flat Directions

- Super and gauge symmetry → V constrained → some combinations of scalar fields ϕ have V=0 in limit of <u>exact</u> SUSY

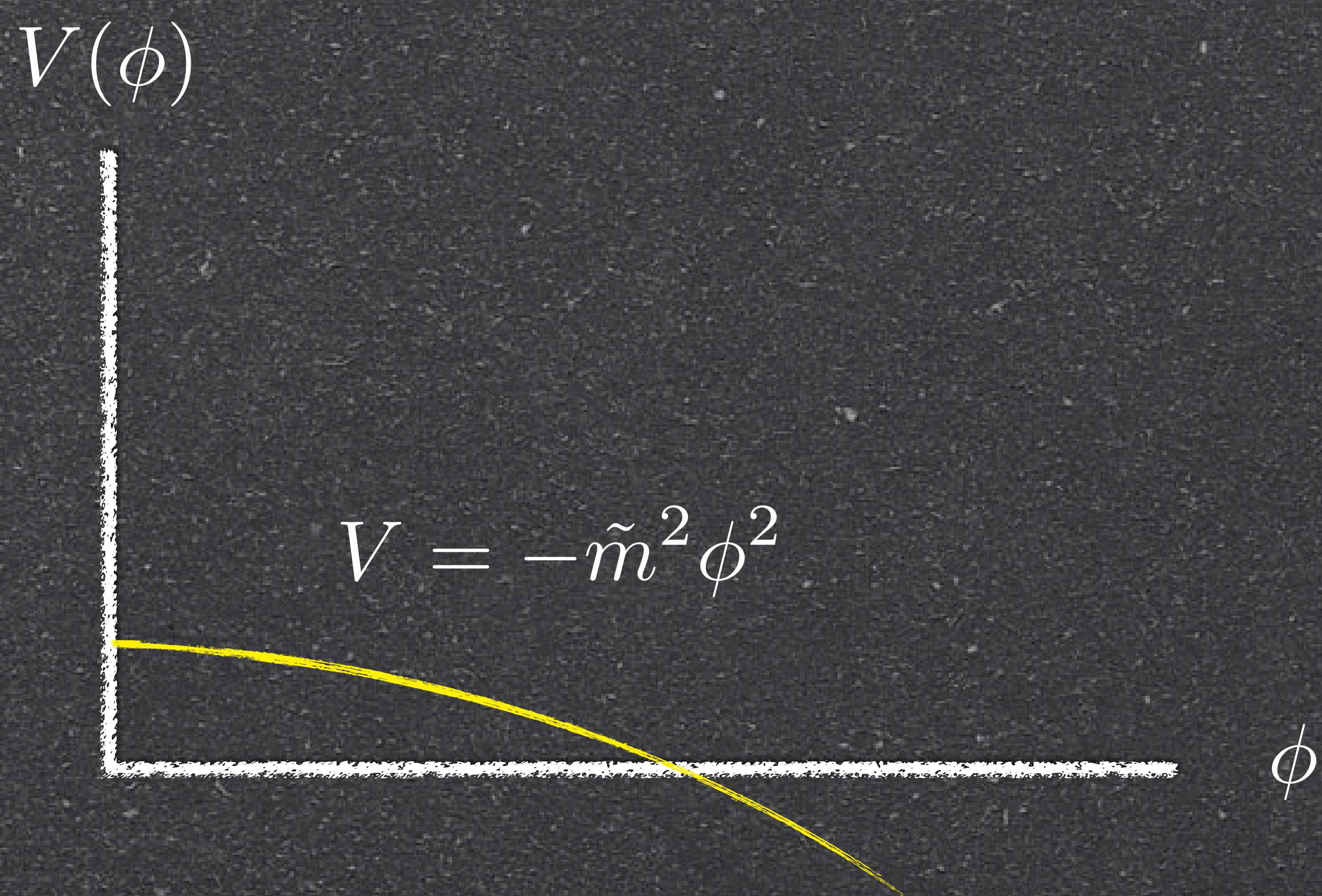


$T = 0$

Flat Directions

- When SUSY breaking (scale $\tilde{m} \sim \mathcal{O}(100)\mathrm{GeV}$) and supergravity (scale M_P) are taken into account

$\longrightarrow$ $V \neq 0$



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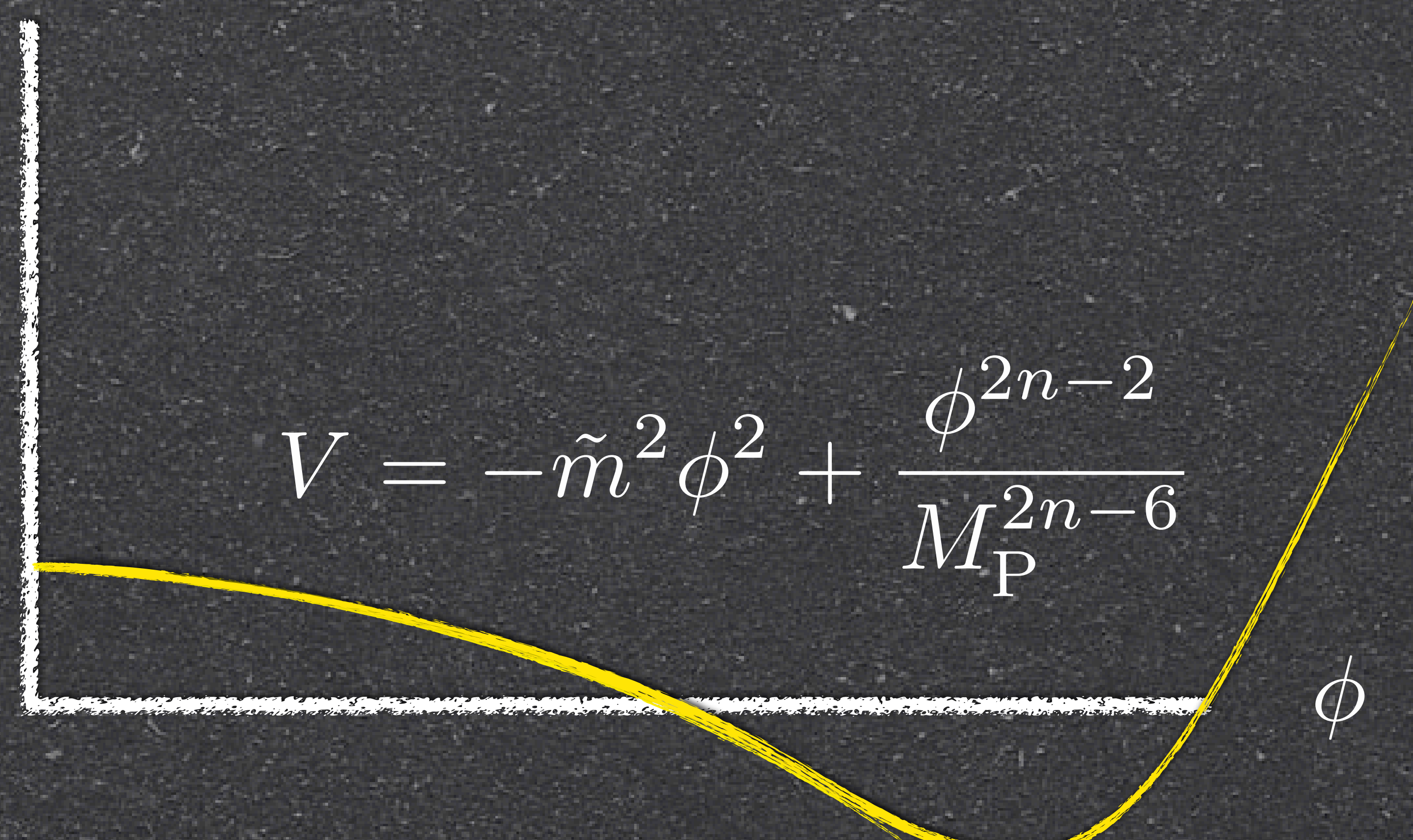
$V(\phi)$



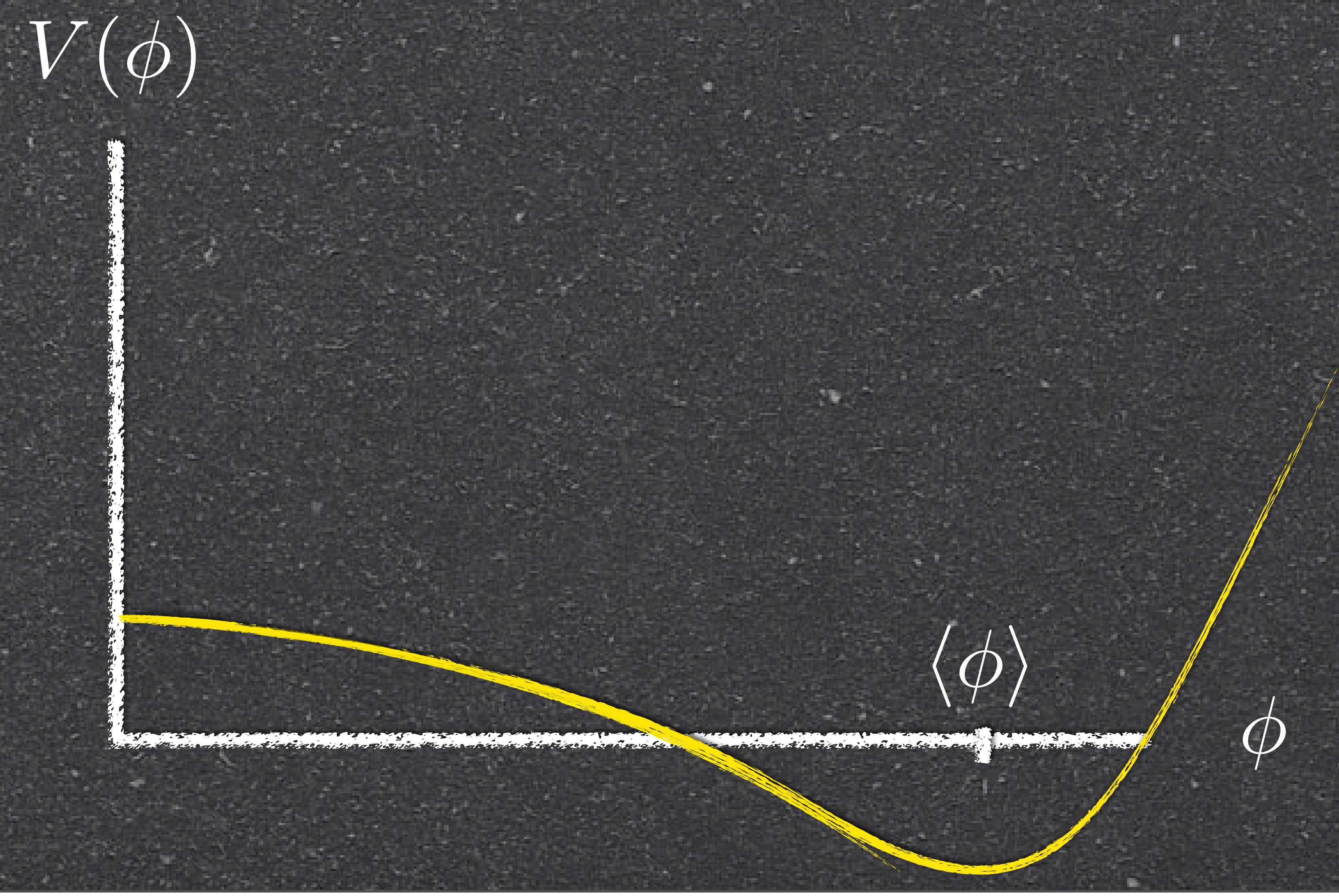
$$V = -\tilde{m}^2\phi^2 + \frac{\phi^{2n-2}}{M_{\mathrm{P}}^{2n-6}}$$

$T = 0$

Flat Directions

✓ In this case:

$$\sqrt{M_P \tilde{m}} \sim \quad \langle\phi\rangle \gg \tilde{m}$$



$T = 0$

Flat Directions

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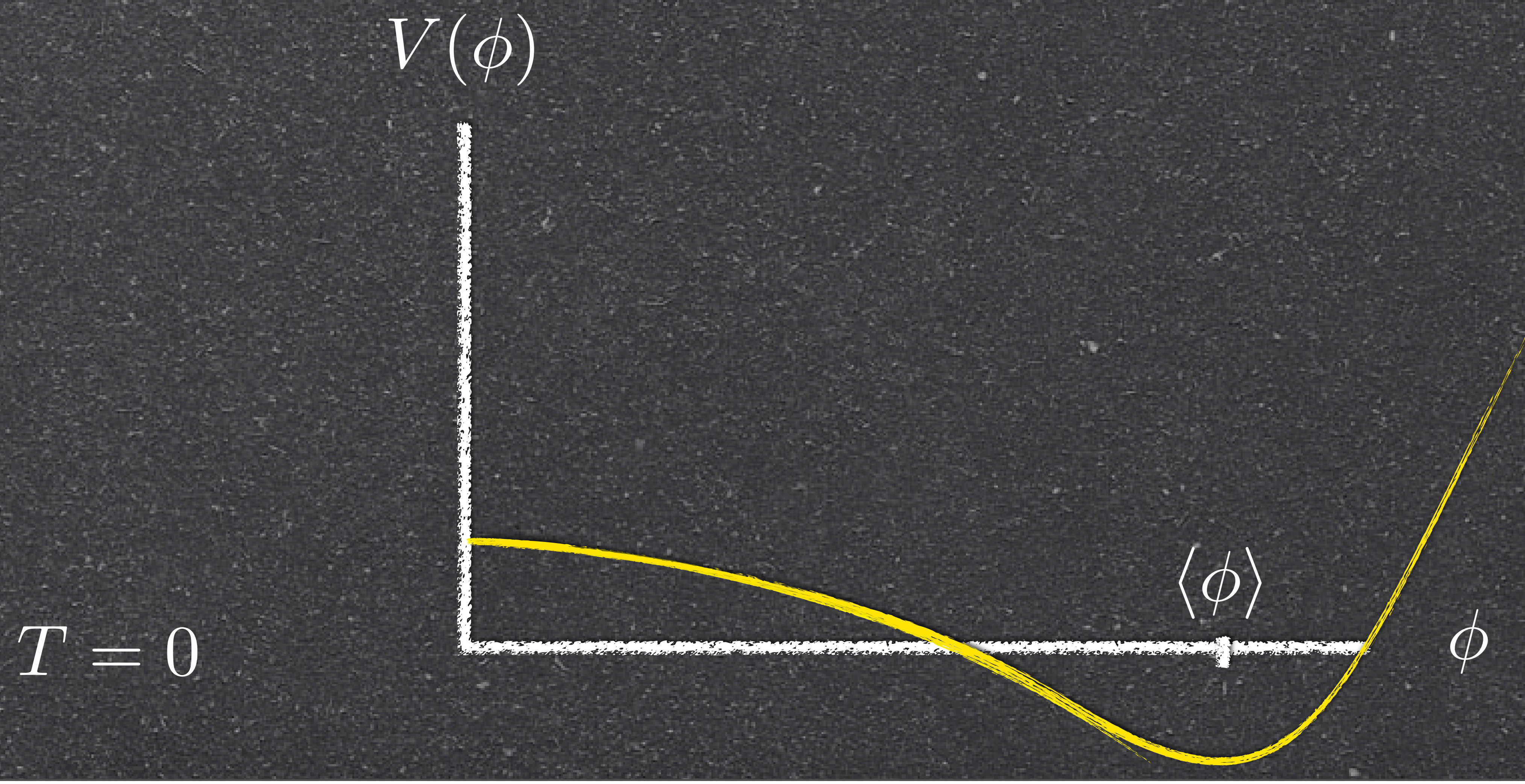
$$\sqrt{M_P \tilde{m}} \sim \langle\phi\rangle \gg \tilde{m}$$

Big M_N at T_{PT} small!



Leptogenesis

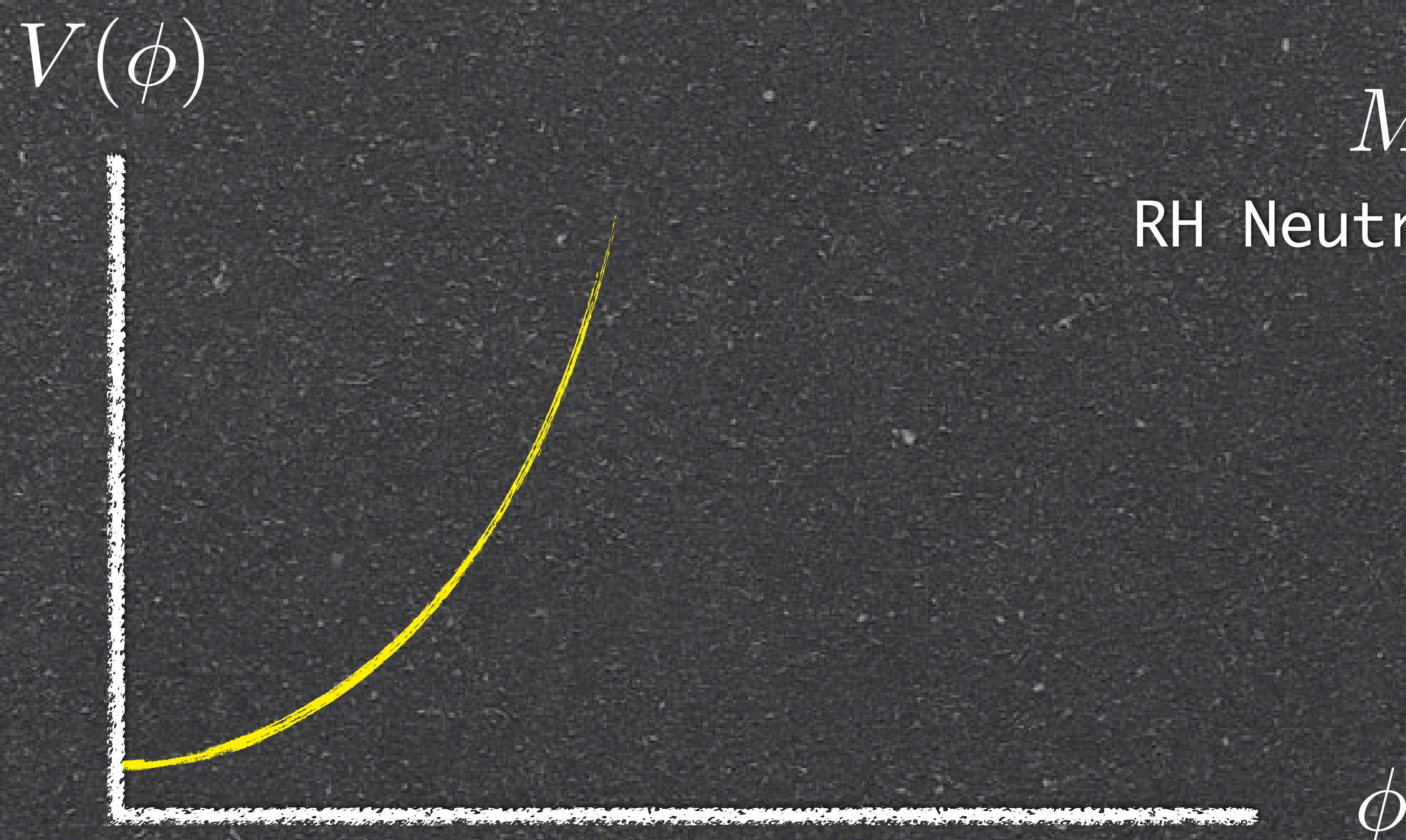
During early universe → symmetry restored

$$T, H \gg \tilde{m}$$

- During Inflation $V = H^2\phi^2$
- After Inflation $V = T^2\phi^2$

$\Big\} \ \langle\phi\rangle = 0$ → $M_N = 0$

RH Neutrinos massless!



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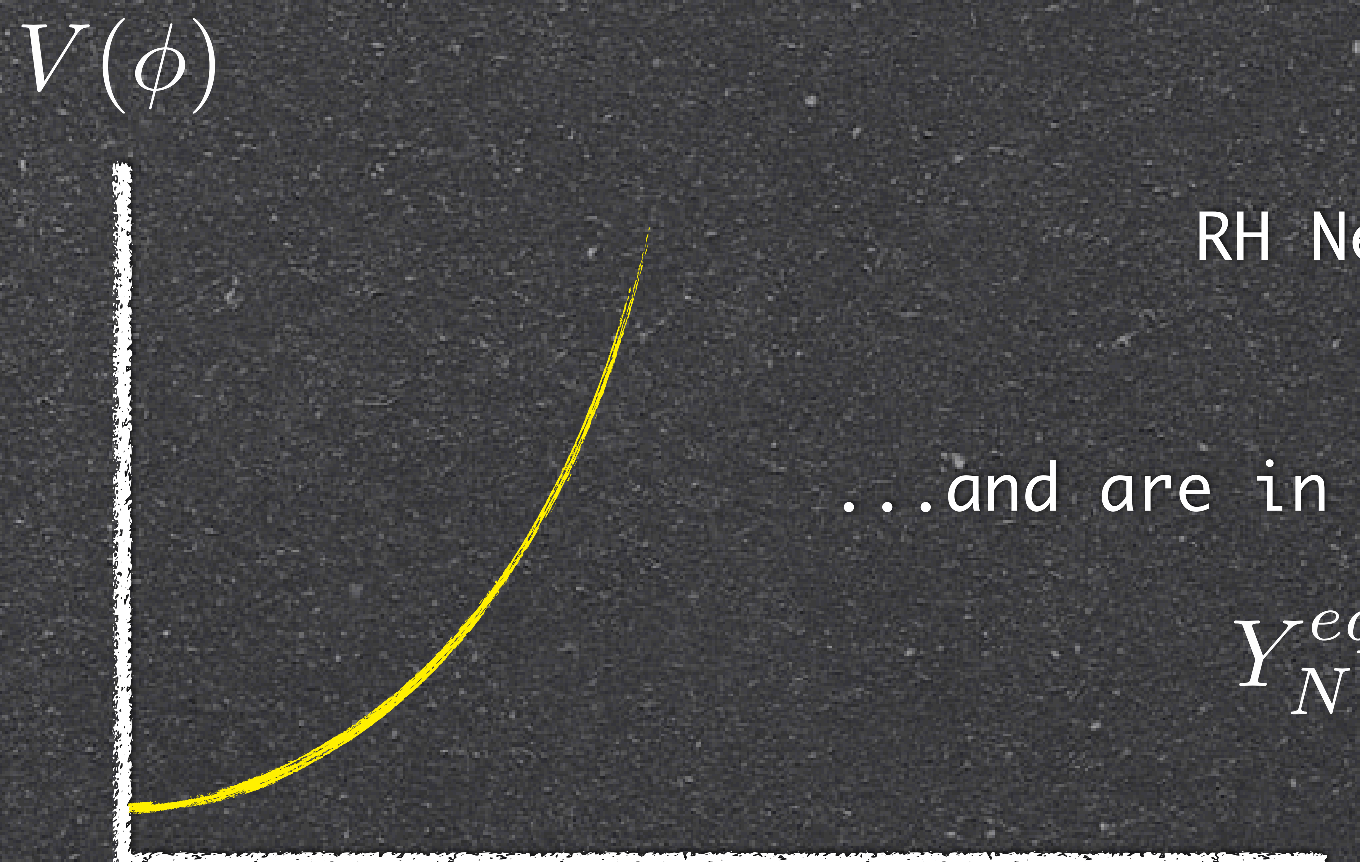
RH Neutrinos massless!

↓

...and are in thermal equilibrium!

$$Y_N^{eq} \equiv \frac{n_N^{eq}}{s} = \frac{45}{\pi^4 g_*}$$

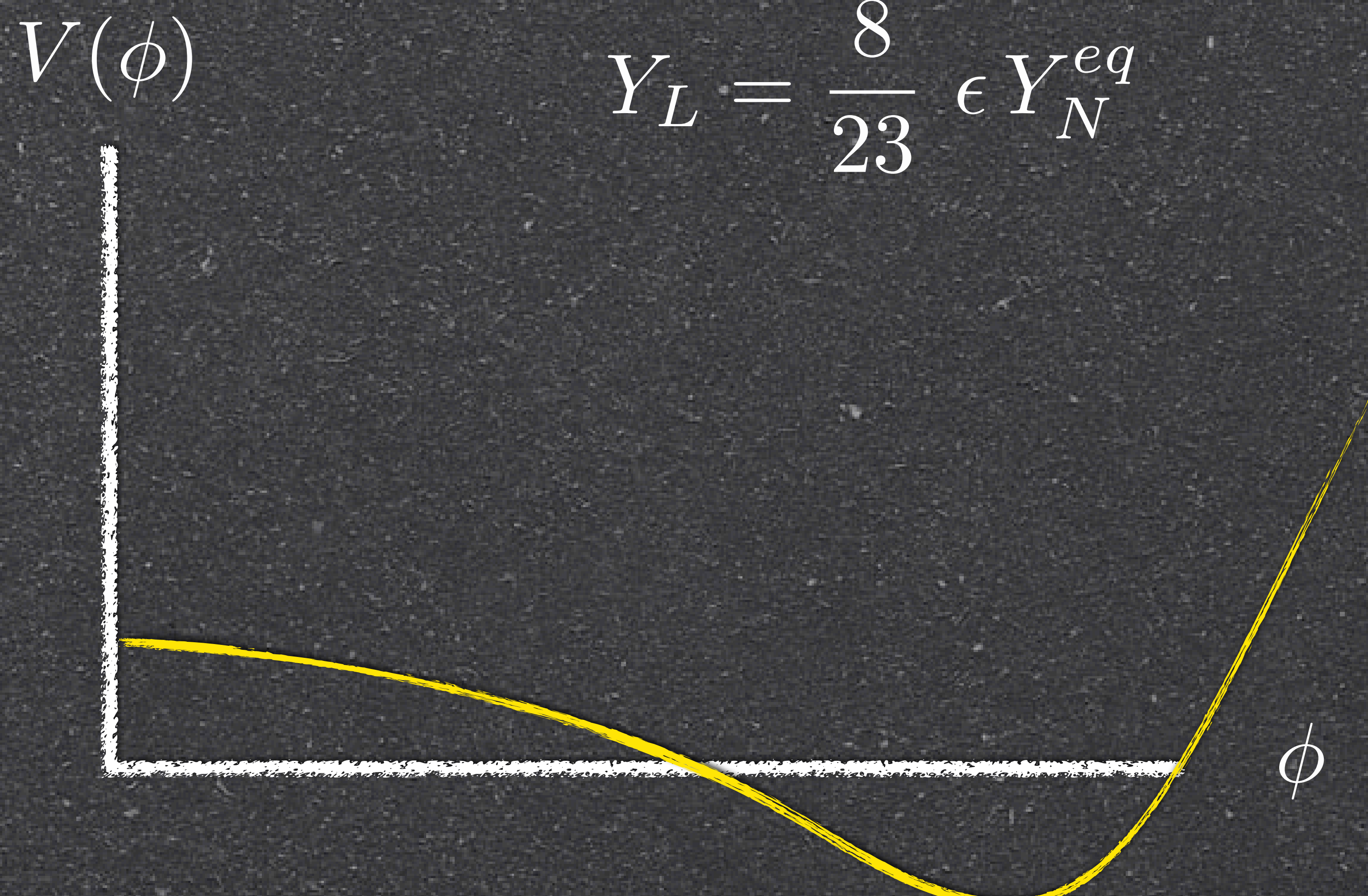


Leptogenesis

For $T \lesssim \tilde{m} \sim \mathcal{O}(100)\mathrm{GeV}$ phase transition happens

- RH neutrinos become massive $M_N \gg \tilde{m}$
- Promptly decay out of equilibrium
- Generate lepton asymmetry even at low temp

$$Y_L = \frac{8}{23}\,\epsilon Y_N^{eq}$$



Flavor Symmetries

- Models based on A4-flavor symmetry reproduce observed (tribimaximal) neutrino mixing angles (Altarelli,Feruglio,Merlo,Hagerdon,Lin,...)

	Exp.	TBM
$\sin^2\theta_{13}$	$0.01^{+0.016}_{-0.011}$	0
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$	1/2
$\sin^2\theta_{12}$	$0.304^{+0.022}_{-0.016}$	1/3

- RH neutrinos charged under A4
  → Mass term in superpotential through spontaneous symmetry breaking

$$W_l = y_e\, e^c \frac{\varphi^T}{\Lambda} l H_d + y\, N^c l H_u + x\, \varphi^S N^c N^c + \ldots$$

- Symm breaking sector (flavons) has flat direction!

Conclusions

- Right-handed neutrinos, even if very heavy ($M_N \sim 10^{14}\mathrm{GeV}$), can be produced thermally at low temperature,

$$T_{\mathrm{RH}} \sim \mathrm{TeV}$$

since during the early universe their mass is driven to $M_N^{T \gg \tilde{m}} = 0$ by restored symmetry

- This scenario is naturally realized in models with A4 flavor symmetry (Altarelli-Feruglio)