Affleck-Dine Leptoflavorgenesis

Koichi Hamaguchi (Tokyo U.)

@2025 CERN-CKC joint workshop with the 13th KIAS Workshop
on Particle Physics and Cosmology, November 16-21, Busan.

Based on
[arXiv:2509.08175], “Affleck-Dine Leptoflavorgenesis”
Kensuke Akita, KH, **Maksym Ovchynnikv.**

See also
[arXiv:2507.20659], “Maximal parameter space of sterile neutrino dark matter with lepton asymmetries”
Kensuke Akita, KH, **Maksym Ovchynnikv.**

Q: Can **large lepton-flavor asymmetries (with total L = 0)** be naturally generated in the early universe?

Benchmark point: $(Y_{L_e}, Y_{L_\mu}, Y_{L_\tau}) \simeq (0.06, -0.03, -0.03)$ $\left(Y_L = \sum_\alpha Y_{L_\alpha} = 0 \right)$

at $T \gtrsim 10$ MeV. $Y_X = \dfrac{n_X - n_{\overline{X}}}{s}$ $\begin{cases} n_X : & X\text{'s nunmber density} \\ s : & \text{entropy density} \end{cases}$ $\left(\text{c.f.} \quad Y_B \simeq 8.8 \times 10^{-11}\right)$

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Why this benchmark?

1. Consistent with BBN/CMB
2. May help reduce the helium-4 tension.
3. Can give the right baryon asymmetry (size the sign).
4. Enhance sterile-ν DM production.

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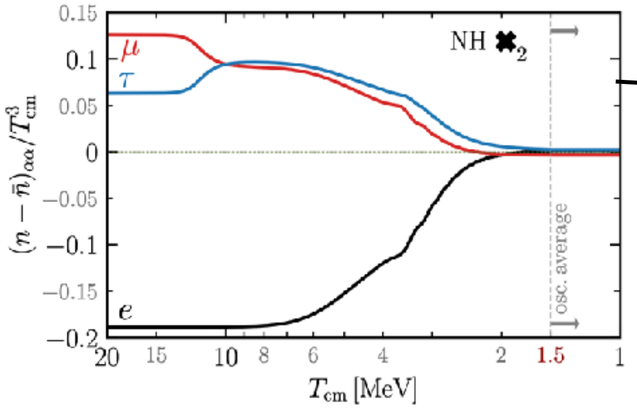
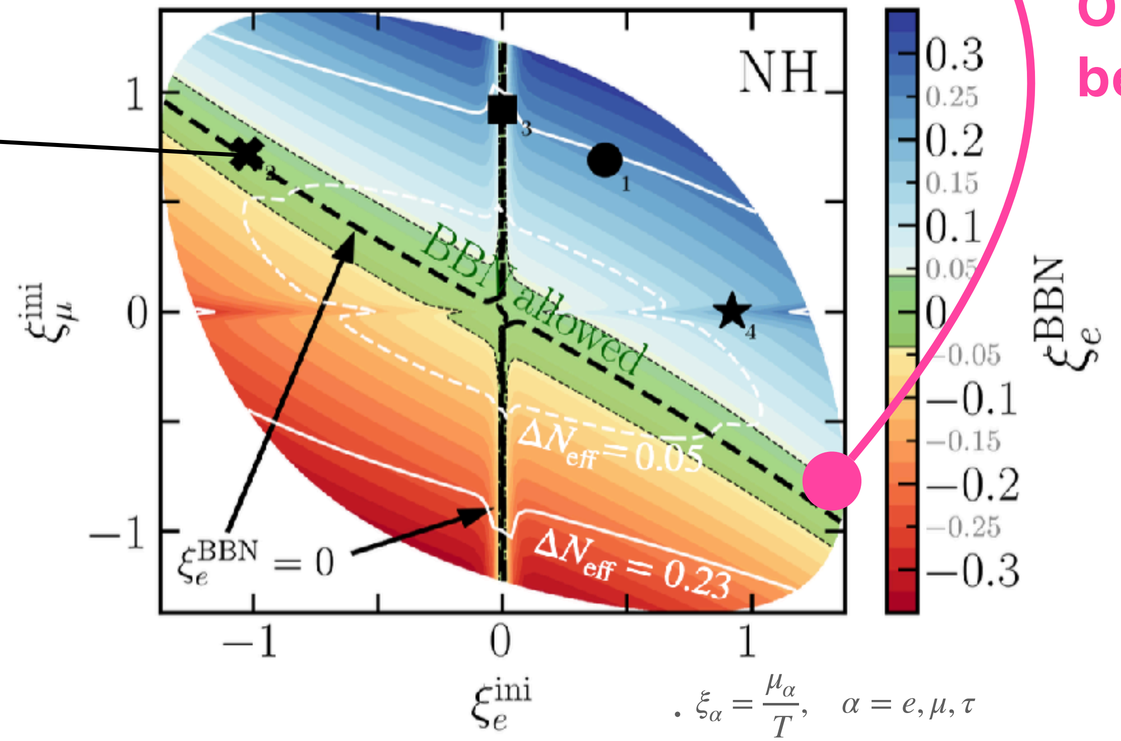


V. Domcke, M. Escudero, M. Fernandez Navarro, S. Sandner
[arXiv:2502.14960]



Our benchmark

- $\xi_\alpha = \frac{\mu_\alpha}{T}, \quad \alpha = e, \mu, \tau$
- Our benchmark corresponds to $(\xi_e^{\rm ini}, \xi_\mu^{\rm ini}) \simeq (1.4, -0.8)$

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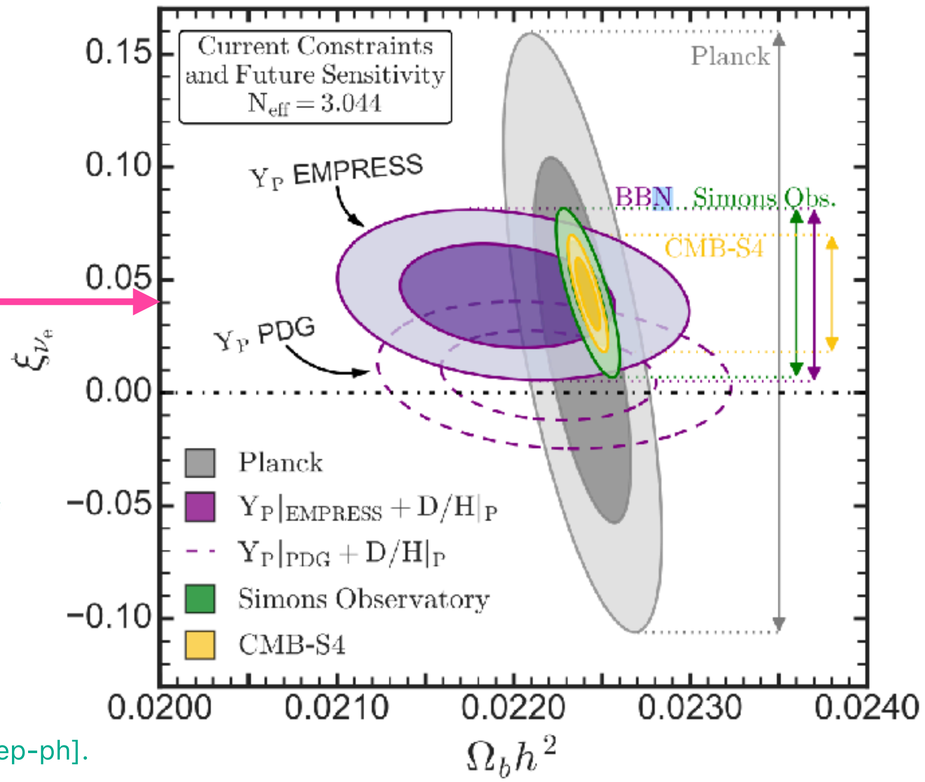
2. **May help reduce the helium-4 tension.**

Benchmark → $\xi_e^{\rm BBN} \simeq 0.04$



M. Escudero, A. Ibarra, V. Maura, [arXiv:2208.03201]

cf.
- A. Matsumoto et al., arXiv:2203.09617 [astro-ph.CO].
- A K. Burns, T. M. P. Tait, and M. Valli, arXiv:2206.00693 [hep-ph].
- J. Froustey and C. Pitrou, arXiv:2405.06509 [hep-ph].
- V. Domcke, M. Escudero, M. Fernandez Navarro, and S. Sandner, arXiv:2502.14960 [hep-ph].
- H. Yanagisawa et al., arXiv:2506.24050 [astro-ph.GA].

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Why this benchmark?

1. Consistent with BBN/CMB
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3. **Can give the right baryon asymmetry (size the sign).**

Even if $Y_L = 0$, $\quad Y_B \simeq -0.030\left(h_e^2 Y_{L_e} + h_\mu^2 Y_{L_\mu} + h_\tau^2 Y_{L_\tau}\right) \neq 0$

h_α : Yukawa $\quad (h_\tau \simeq 0.01 \gg h_\mu \gg h_e)$

Y. Khlebnikov,M. E. Shaposhnikov, 1988
J. March-Russell, H. Murayama, A. Riotto hep-ph/9908396.
M. Laine, M. E. Shaposhnikov, hep-ph/9911473.

At the benchmark: $Y_{L_\tau} \simeq -0.03$

$\Longrightarrow Y_B \simeq -0.030 \underbrace{h_\tau^2}_{10^{-4}} \underbrace{Y_{L_\tau}}_{-0.03} \simeq 10^{-7}$ ..... **right sign!** ..... but too large? 👉 More on this later.

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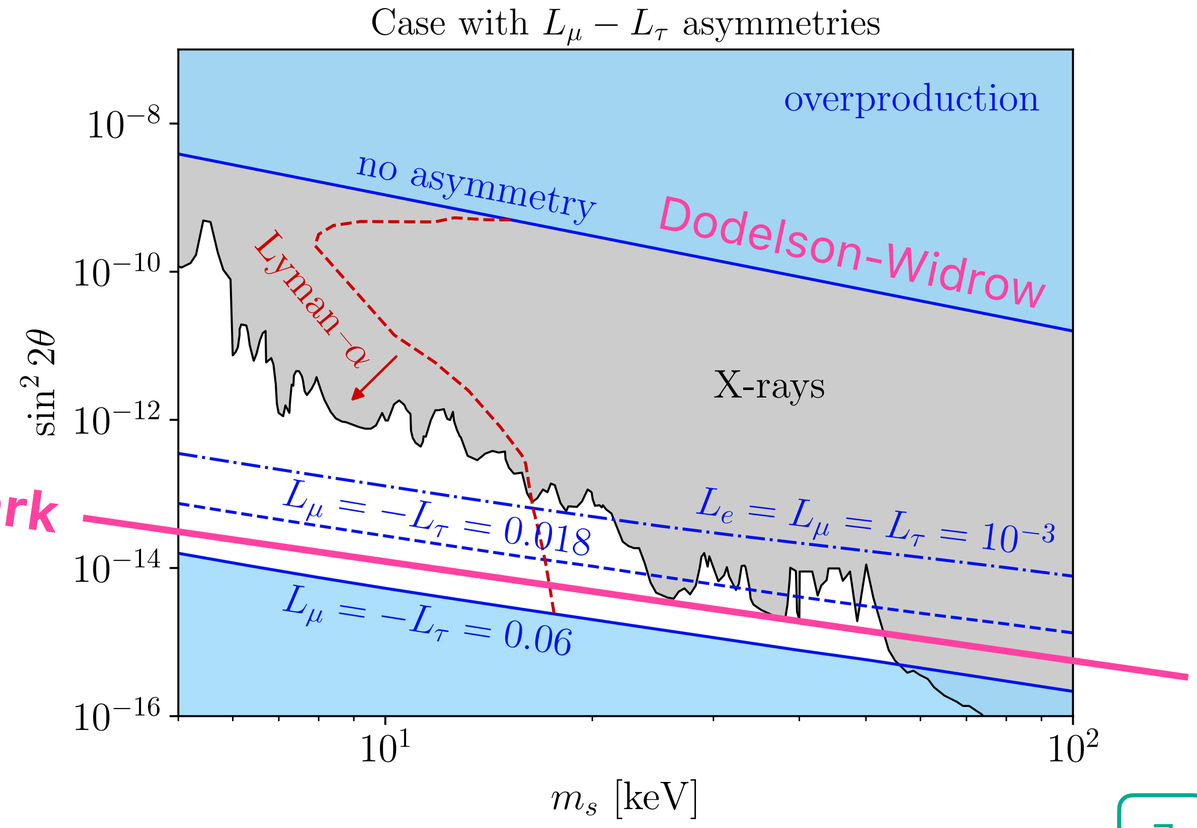
Why this benchmark?

1. Consistent with BBN/CMB
2. May help reduce the helium-4 tension.
3. Can give the right baryon asymmetry (size
4. **Enhance sterile-ν DM production.**
   - Shi-Fuller mechanism (like Dodelson-Widrow)
     - 👉 **cf. Talk by J. Ruderman yesterday**



Kensuke Akita, KH, **Maksym Ovchynnikv.** [arXiv:2507.20659],

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Answer:

Yes — such **large lepton-flavor asymmetries** can be naturally generated via

Affleck-Dine mechanism along $Q\bar{u}L\bar{e}$ flat direction with Q-ball formation.

[arXiv:2509.08175], **Kensuke Akita,** KH, **Maksym Ovchynnikv**.

"Affleck-Dine Leptoflavorgenesis" [arXiv:2509.08175], **Kensuke Akita,** KH, **Maksym Ovchynnikv.**

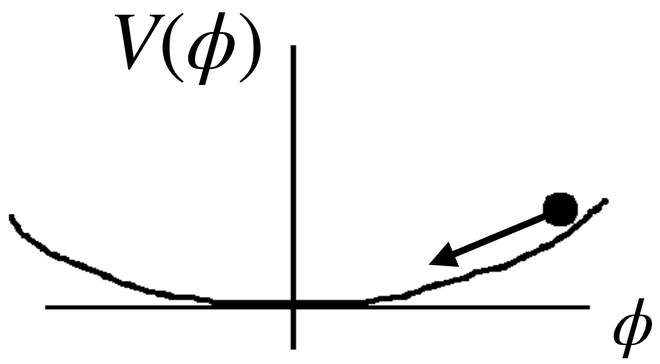
Affleck-Dine mechanism along $Q\bar{u}L\bar{e}$ flat direction with Q-ball formation.

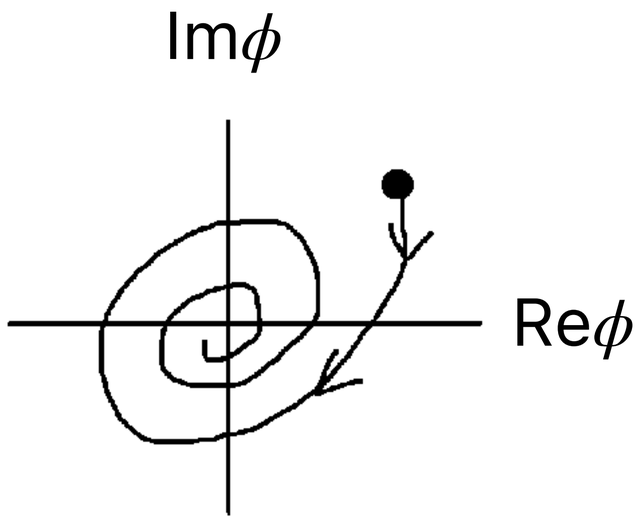
Affleck-Dine mechanism along $Q\bar{u}L\bar{e}$ flat direction with Q-ball formation.

- A scalar field ϕ carrying *B*-number (and/or *L*-number).
- If the potential $V(\phi)$ is flat enough, ϕ can have a large field value during inflation.
- After inflation, ϕ rotates in the field space, if *B*-violation (and/or *L*-violation) exists.

$$n_{B/L} \propto n_\phi = i(\phi^*\dot{\phi} - \dot{\phi}^*\phi) = 2|\phi|^2\dot{\theta} \neq 0$$

"Affleck-Dine mechanism"
[I. Affleck and M. Dine, 1985]





Affleck-Dine mechanism along $Q\bar{u}L\bar{e}$ flat direction with Q-ball formation.

- In the Minimal SUSY Standard Model (MSSM),
  ϕ = a linear combination of squark and slepton fields.
- For the Affleck-Dine mechanism to work,
  ϕ must correspond to a flat direction along the scalar potential.

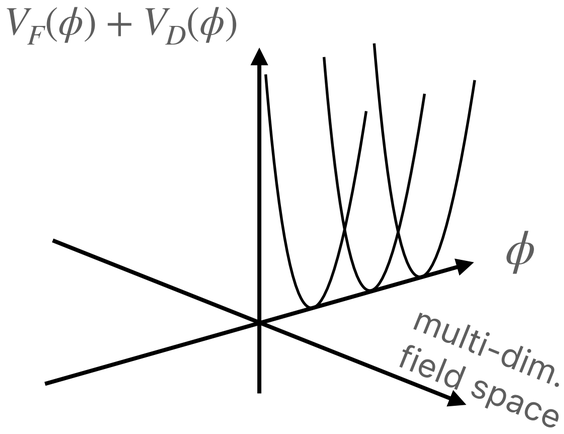


Table 3: The basis B of gauge-invariant monomials

	B−L	Always lifted by $W_{\rm renorm}$?
LH_u	-1	
H_uH_d	0	
udd	-1	
LLe	-1	
QdL	-1	
QuH_u	0	√
QdH_d	0	√
LH_de	0	√
QQQL	0	
QuQd	0	
QuLe	0	
uude	0	
$QQQH_u$	1	√

T. Gherghetta, C. Kolda, S. P. Martin
[hep-ph/9510370]

The simplest one which
- conserves lepton number,
- but violate lepton flavor:

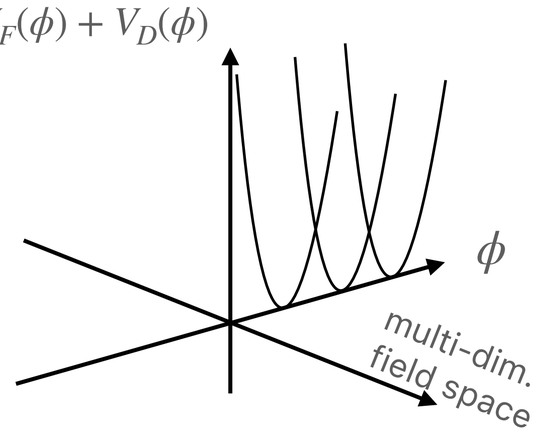
👉 $Q\bar{u}L\bar{e}$ **direction**

cf. Other possibilities in the context of AD mechanism:

A. Casas, W. Y. Cheng, G. Gelmini [hep-ph/9709289]
J. March-Russel, H.Murayama, A.Riotto [hep-ph/9908396]
M. Kawasaki, F. Takahashi, M. Yamaguchi [hep-ph/0205101]
M. Kawasaki, K. Murai [arXiv:2203.09713]
K. Kasai, M. Kawasaki, K. Murai [arXiv:2402.11902]

Affleck-Dine mechanism along $Q\bar{u}L\bar{e}$ flat direction with Q-ball formation.

- **$Q\bar{u}L\bar{e}$ directions:**
  ***L*-conserving but lepton-flavor-violating.**



$$Q = \frac{1}{2}\begin{pmatrix}\phi & 0 & 0\\ 0 & 0 & 0\end{pmatrix}, \quad \bar{u} = \frac{1}{2}\begin{pmatrix}\phi & 0 & 0\end{pmatrix}, \quad L_\alpha = \frac{1}{2}\begin{pmatrix}0\\ \phi\end{pmatrix}, \quad \bar{e}_\beta = \frac{\cos\chi}{2}\phi, \quad \bar{e}_\gamma = \frac{\sin\chi}{2}\phi,$$

color, SU(2)

$$(\alpha, \beta, \gamma = e, \mu, \tau, \quad \alpha \neq \beta, \alpha \neq \gamma, \quad \chi = \text{arbitrary})$$

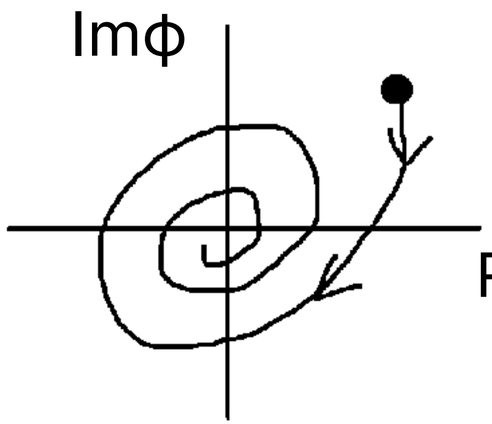
Benchmark: $(\alpha, \beta, \gamma) = (e, \mu, \tau)$ and $\chi = \pi/4$:

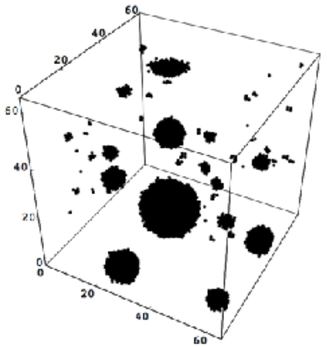
$$\left(n_{L_e}, n_{L_\mu}, n_{L_\tau}\right) = \left(+\frac{1}{4}, -\frac{1}{8}, -\frac{1}{8}\right) n_\phi$$

- AD mechanism generates ϕ-number → lepton-flavor asymmetries.
- Total *L*-number conservation is guaranteed by *D*-flatness.

Affleck-Dine mechanism along $Q\bar{u}L\bar{e}$ flat direction with Q-ball formation.

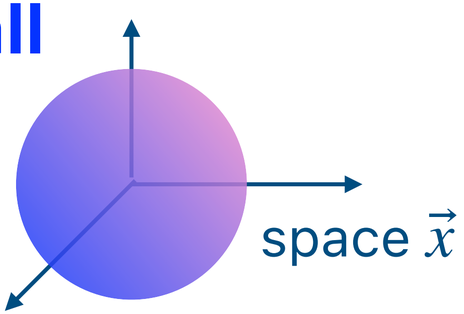
When the AD potential is sufficiently flat, AD field fragments into **Q-balls**





Kasuya-Kawasaki
[hep-ph/9909509]

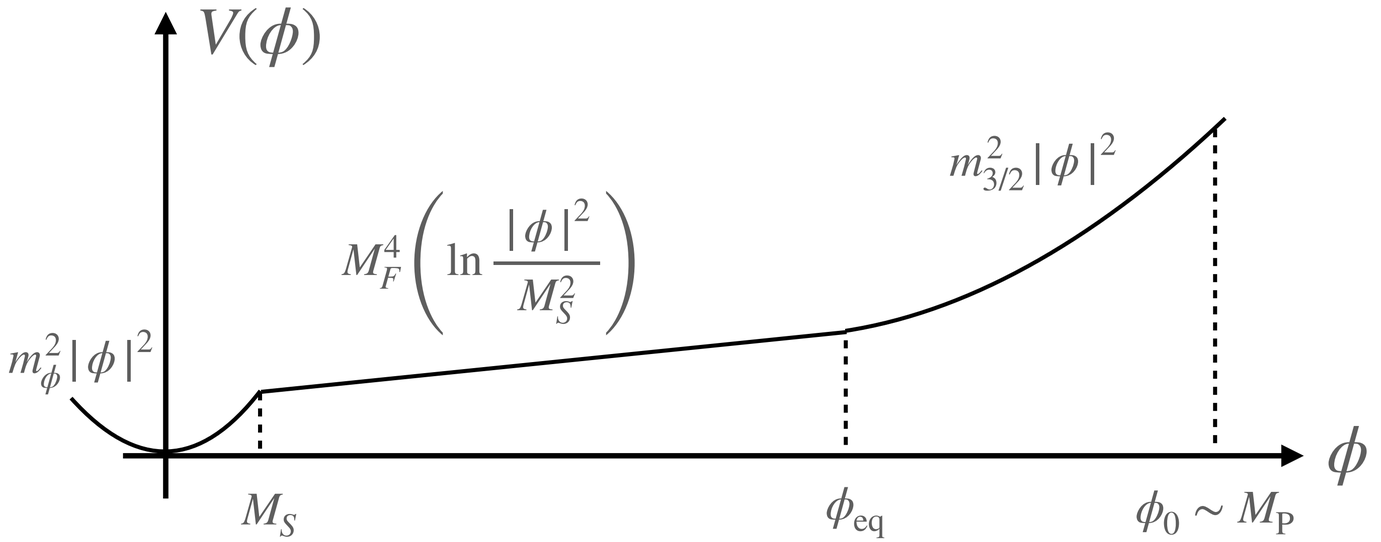
Q-ball



- A non-topological soliton. [Coleman, 1985]
- A spherically symmetric scalar field configuration which is (meta-)stable due to a global symmetry.
- Large charge (= ϕ-number).

Model Setup:

- Gauge-mediated SUSY breaking.
- No nonrenormalizable superpotential which lifts the AD field ϕ.

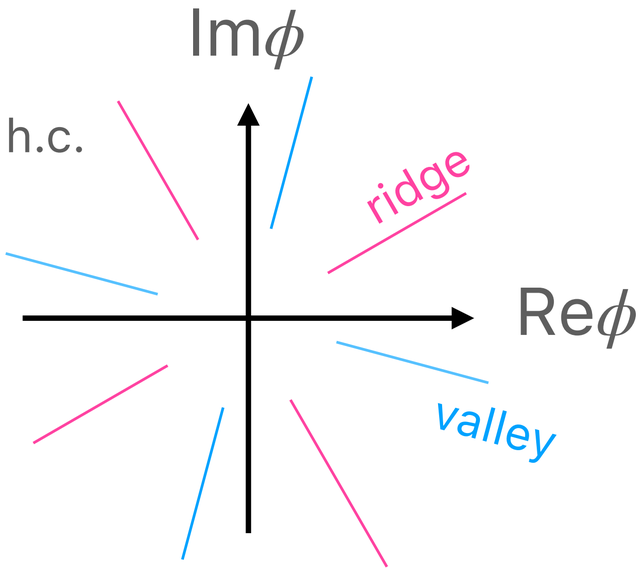


- Lepton-flavor violating the Kahler potential:

$$K = \lambda_{\alpha\beta}\frac{ZZ^\dagger}{M_P^2}Q\bar{u}L_\alpha\bar{e}_\beta + \text{h.c.}$$

which leads to

$$V_{\rm phase}(\phi) \simeq \frac{\lambda m_{3/2}^2}{4M_{\rm P}^2}\phi^4 + \text{h.c.}$$



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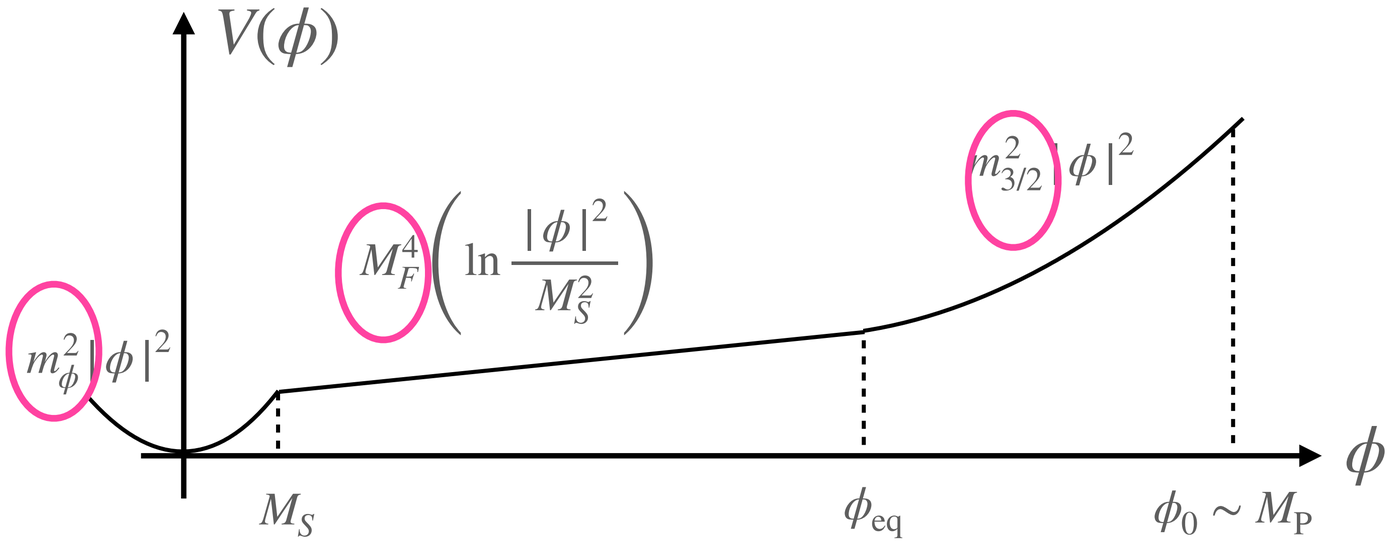

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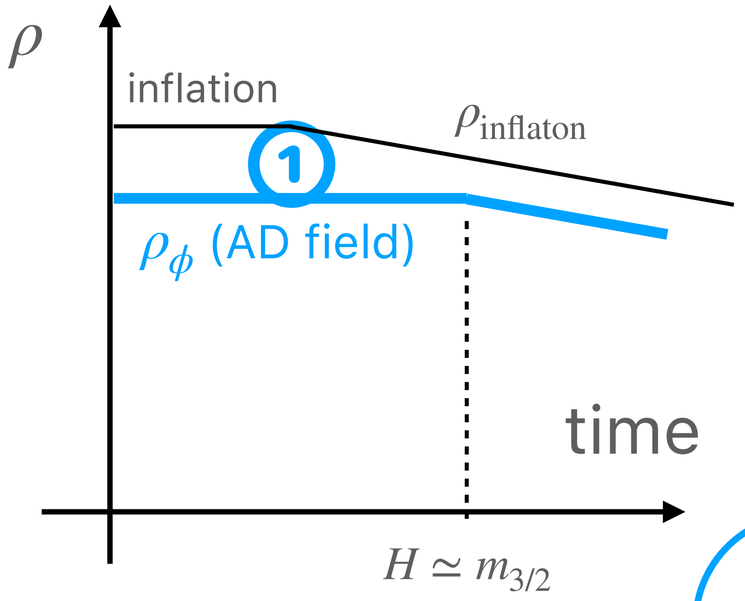
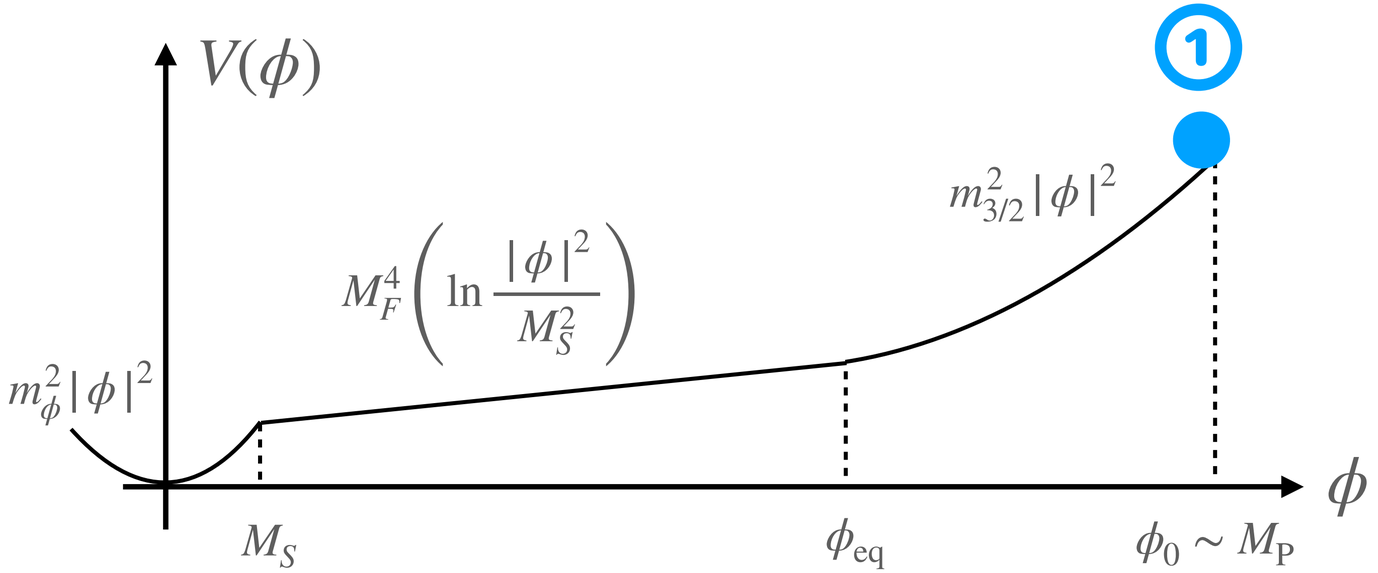
Benchmark point

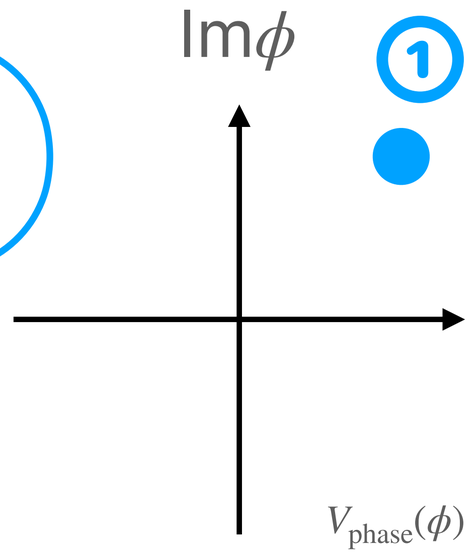
- m_ϕ (AD field mass) $\simeq 10^4$ GeV
- $m_{3/2}$ (gravitino mass) $\simeq 7$ GeV
- M_F (corresponds to SUSY breaking scale) $\simeq 6 \times 10^6$ GeV

Time evolution:





1 During inflation, $|\phi_0| \sim M_{\rm P}$.



$$V_{\rm phase}(\phi) \simeq \frac{\lambda m_{3/2}^2}{4M_{\rm P}^2}\phi^4 + \text{h.c.}$$

cf. earlier works:
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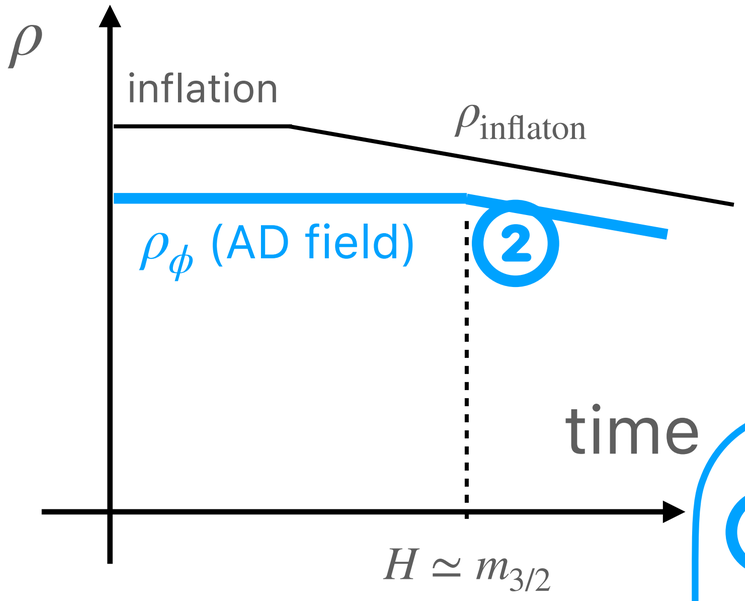
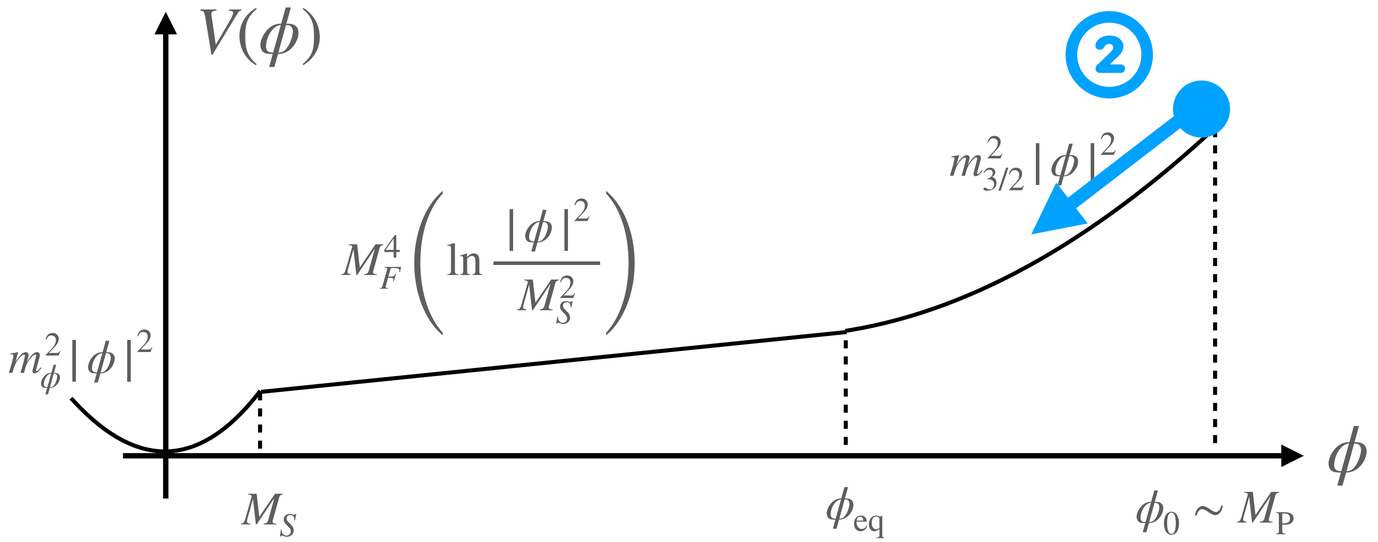
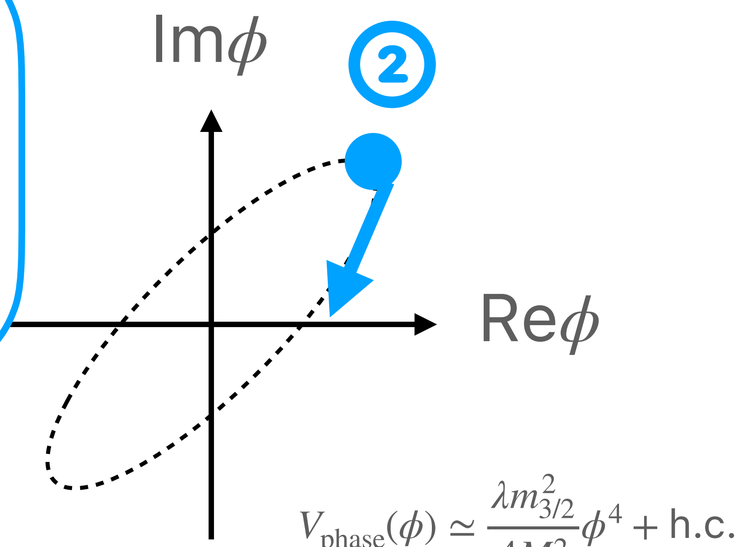




2 oscillation + rotation at $H \simeq m_{3/2}$

Lepton flavor asymmetries are generated via AD mechanism.



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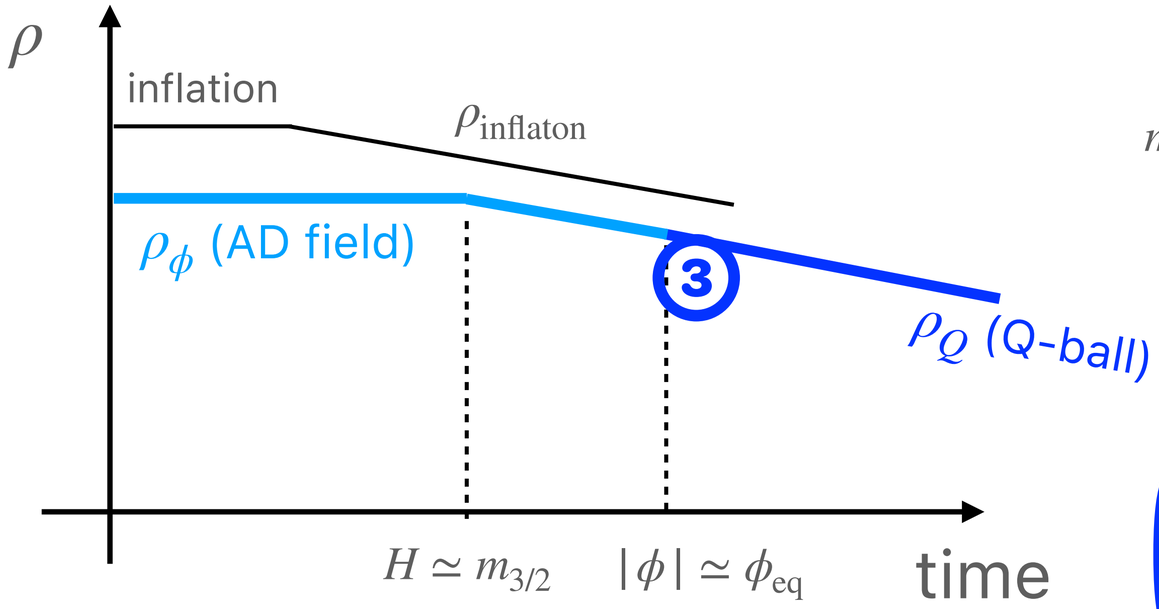
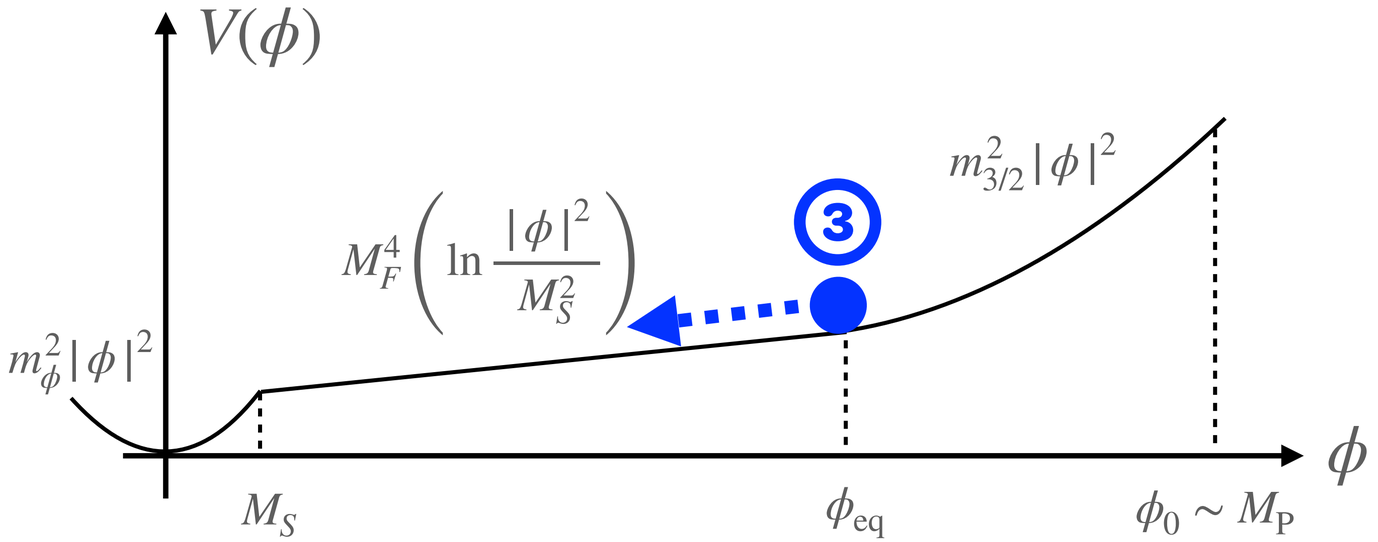
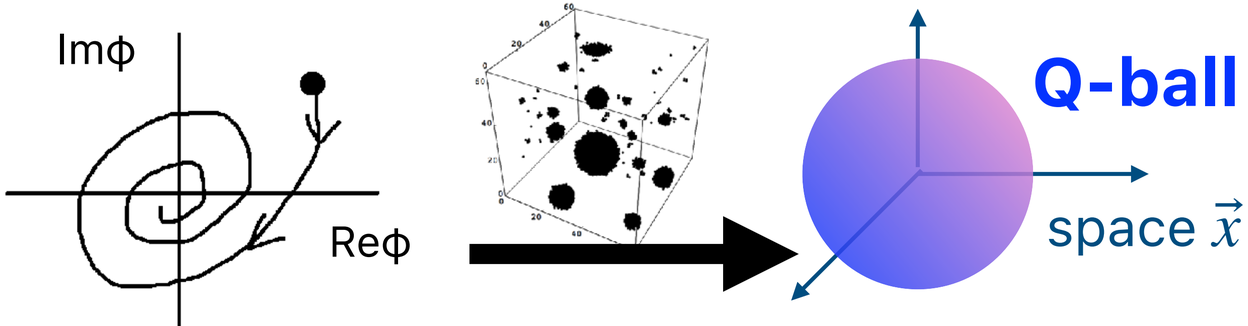




③ At $|\phi_0| \simeq \phi_{\rm eq}$, **Q-balls** are formed.



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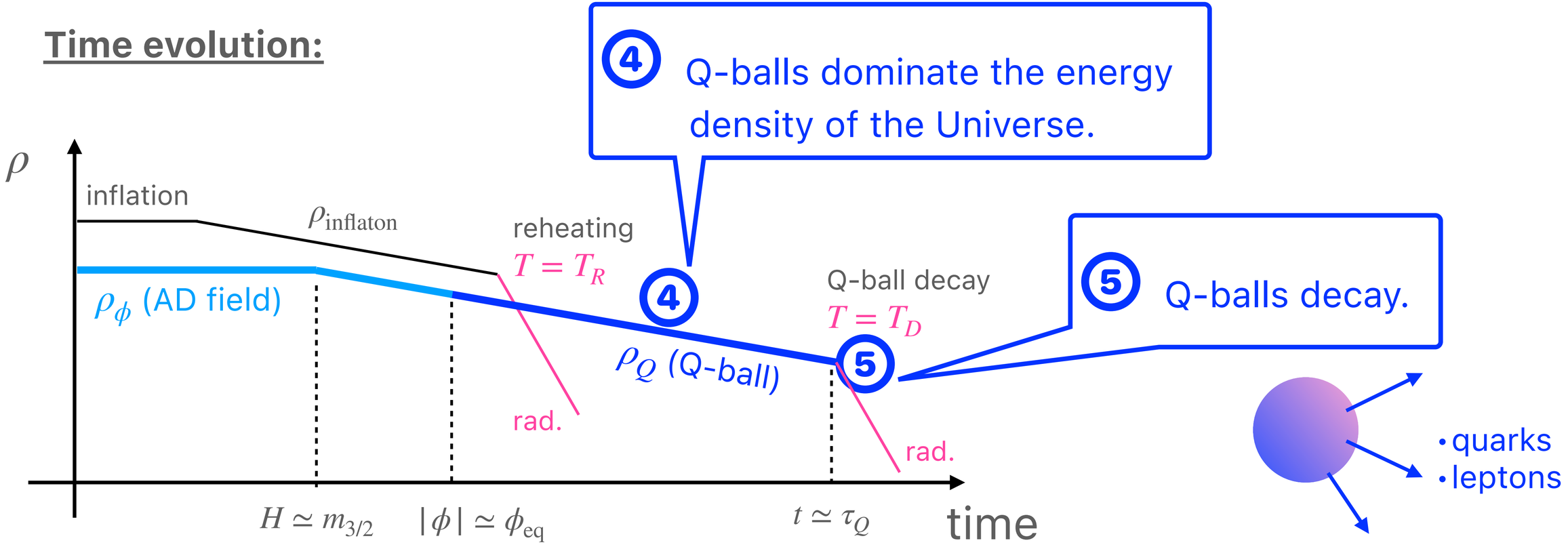


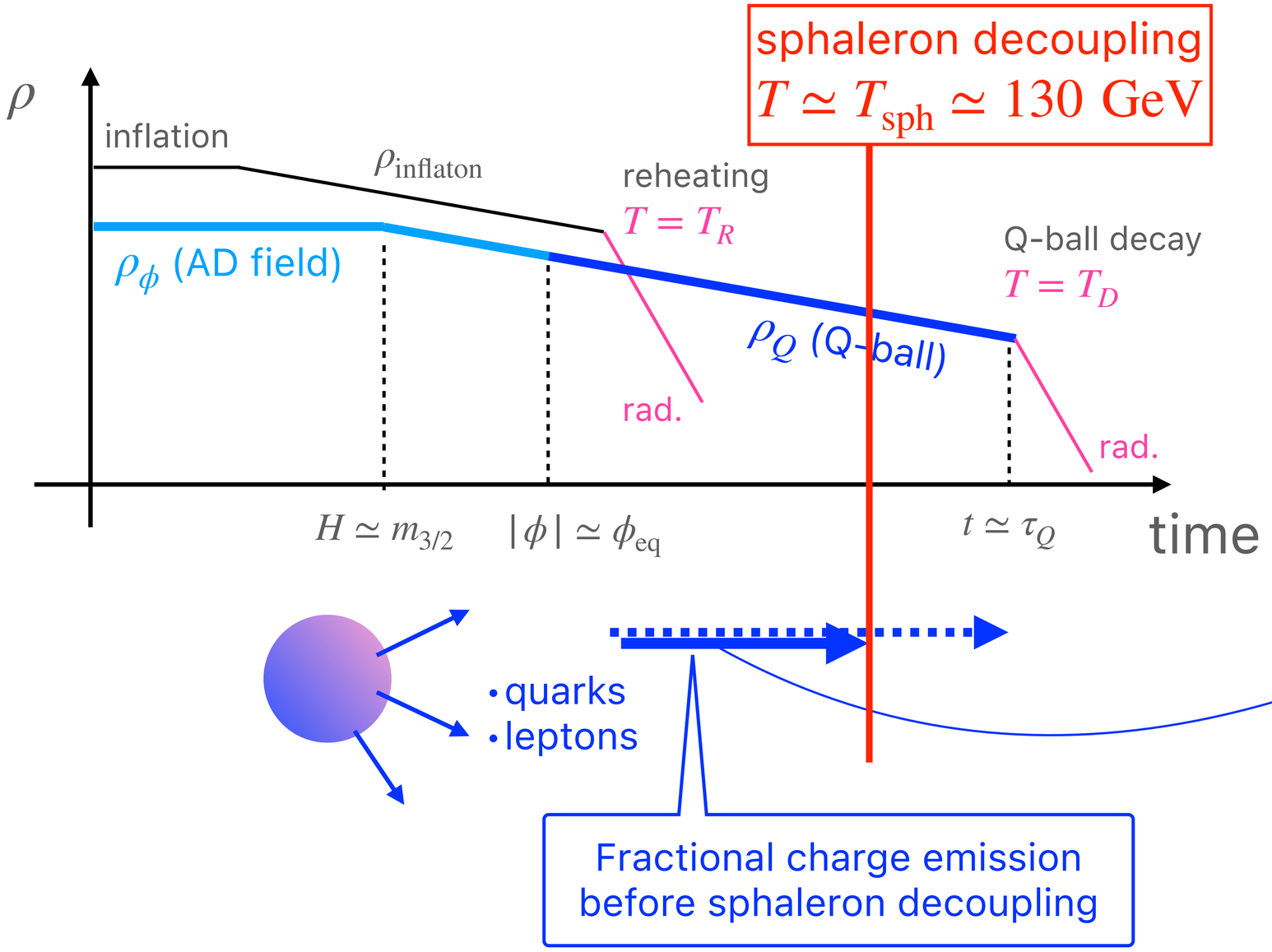
At the benchmark:

Q-ball lifetime: $\tau_Q \simeq 8 \times 10^{-4}$ sec (↔ temperature: $T_D \simeq 17$ GeV)

leading to: $(Y_{L_e}, Y_{L_\mu}, Y_{L_\tau}) \simeq (0.06, -0.03, -0.03)$.

👉 **Large lepton-flavor asymmetries (with total L = 0) are generated.**

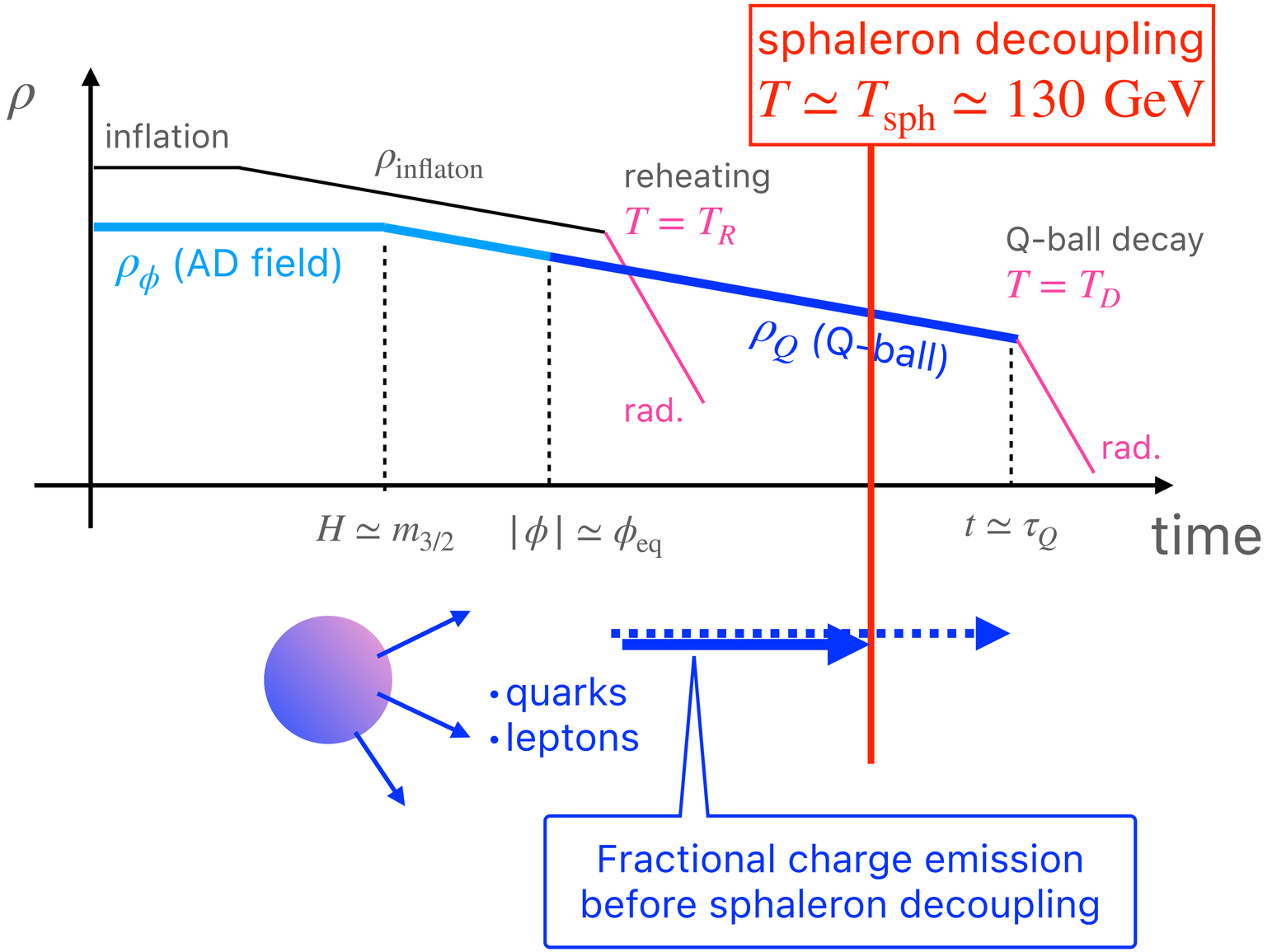
What happens to the baryon asymmetry?



$$Y_B \simeq -0.03\ h_\tau^2\ Y_{L_\tau}\Big|_{T=T_{\rm sph}}$$

$$\simeq -0.03\ h_\tau^2\ Y_{L_\tau}\ \frac{\Delta Q|_{>T_{\rm sph}}}{Q}$$

What happens to the baryon asymmetry?



$$Y_B \simeq -0.03\ h_\tau^2\ Y_{L_\tau}\Big|_{T=T_{\rm sph}}$$

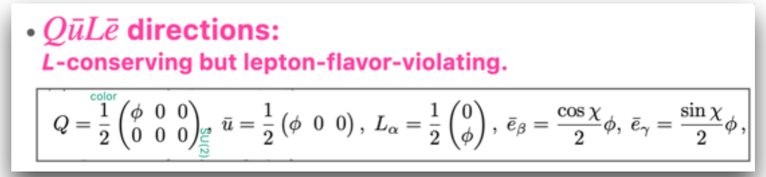
$$\simeq -0.03\ h_\tau^2\ Y_{L_\tau}\ \frac{\Delta Q|_{>T_{\rm sph}}}{Q}$$

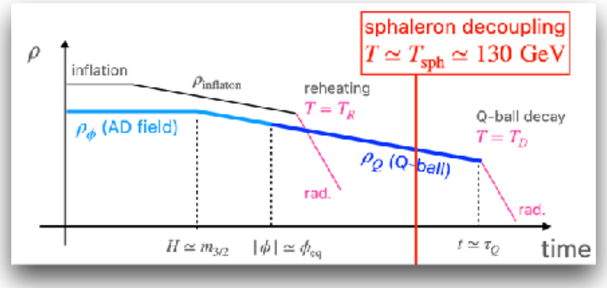
10^{-4} $\quad -0.03$ $\quad 10^{-3}$

$$\simeq 9\times 10^{-11}$$

at the benchmark.
BAU with right sign and size!

Summary





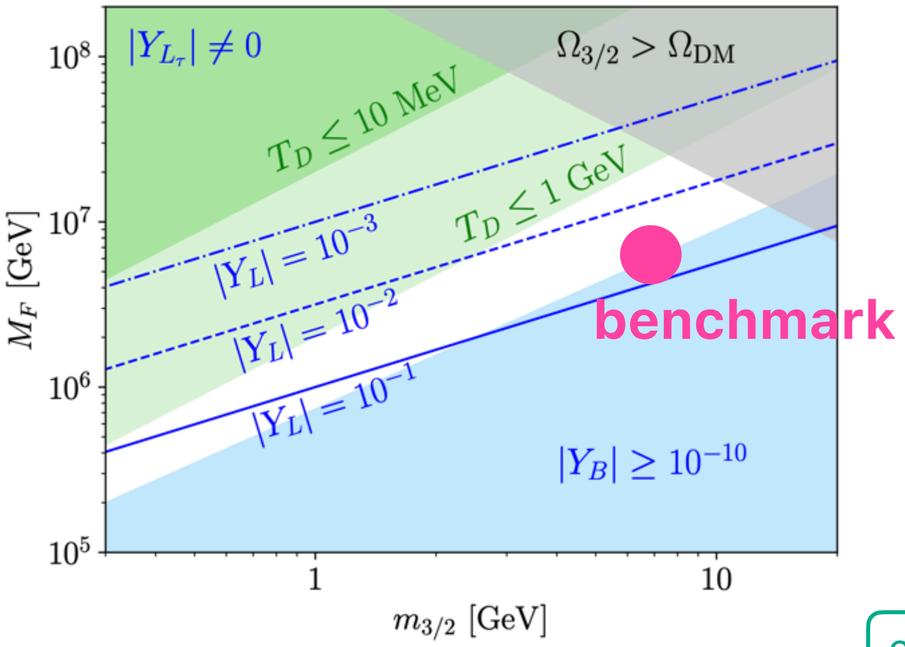
We proposed a scenario to generate large lepton-flavor asymmetries (with total L = 0), such as $(Y_{L_e}, Y_{L_\mu}, Y_{L_\tau}) \simeq (0.06, -0.03, -0.03)$,

based on the **Affleck-Dine mechanism** along $Q\bar{u}L\bar{e}$ **flat direction** with **Q-ball formation**.

Such large lepton-flavor asymmetries

1. are consistent with BBN/CMB,
2. may help reduce the helium-4 tension,
3. can give the right baryon asymmetry (size the sign),
4. and enhance sterile-ν DM production,

simultaneously.



For more general cases: see [arXiv:2509.08175] 👉

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