Accidentally Light Scalars from Large Representations

Giacomo Ferrante

based on

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arXiv:2406.02531 w/ F. Brümmer & M. Frigerio

LABORATOIRE UNIVERS & PARTICULES MONTPELLIER

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Light Scalars in QFT

Glossary

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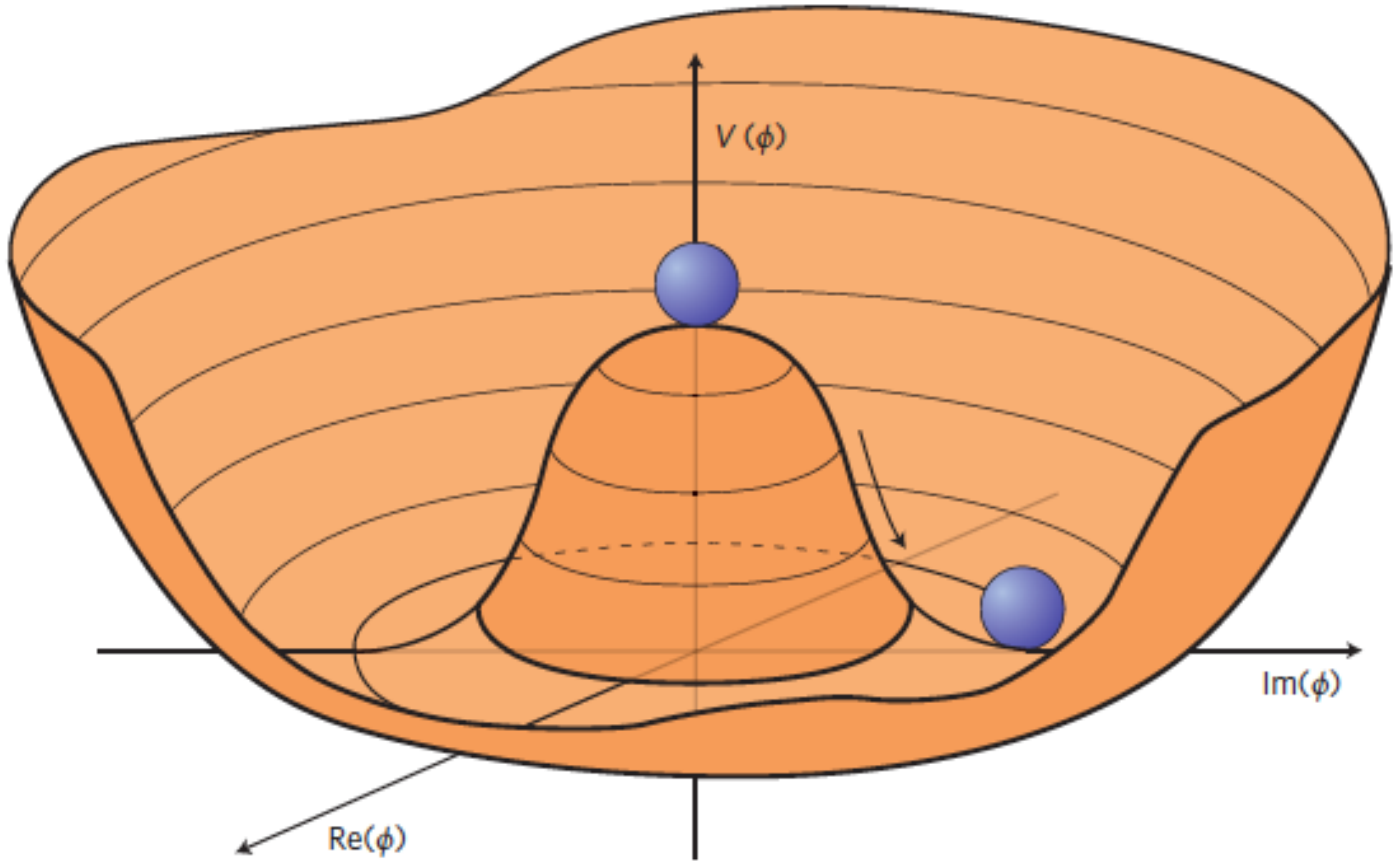
Glossary

1. Nambu-Goldstone bosons:

   - SSB: $\mathrm{U}(1) \to \emptyset$

   - Massless at all orders



Credit: CERN

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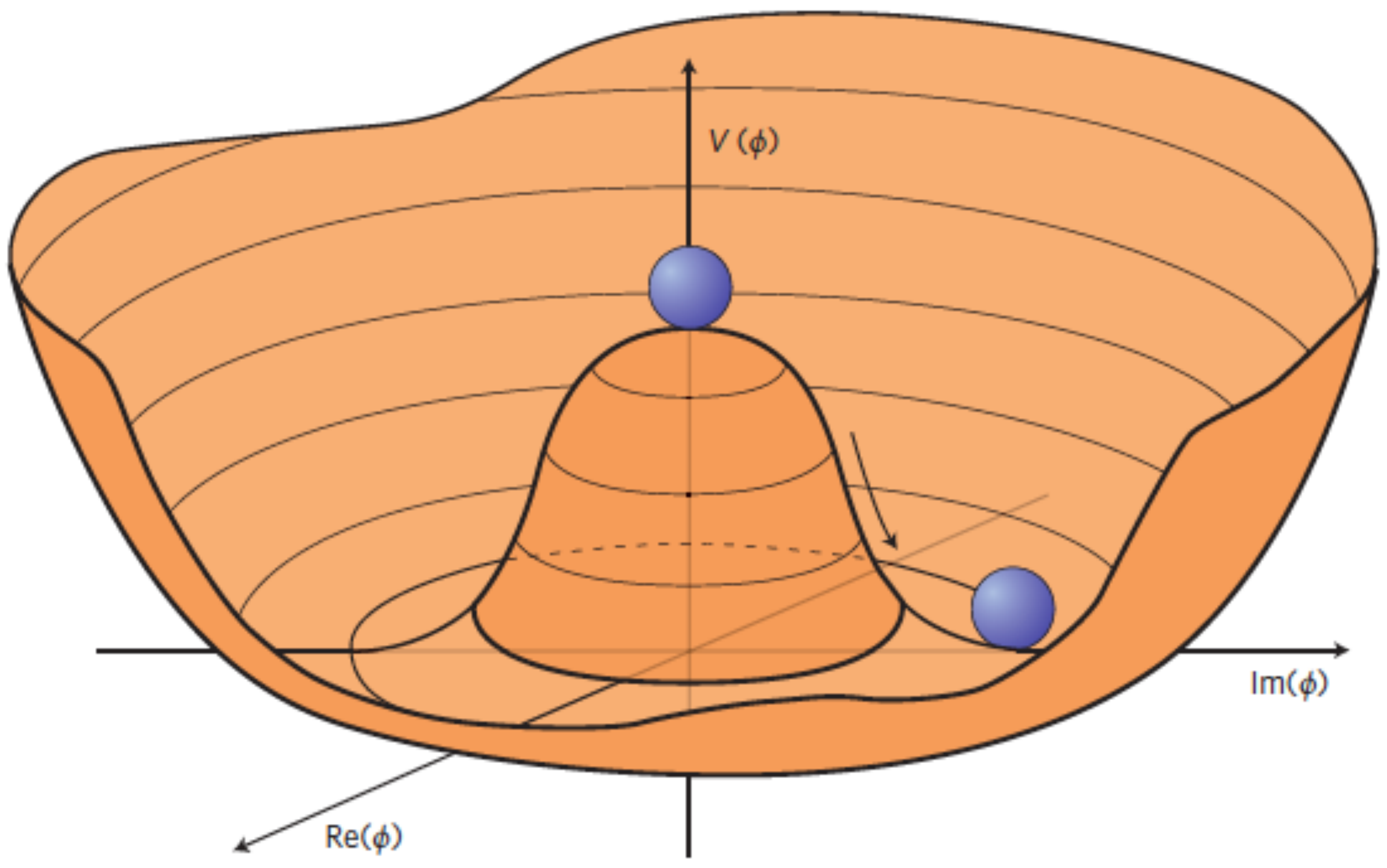
2. Pseudo Nambu-Goldstone bosons:
    - SSB + explicit symmetry breaking terms



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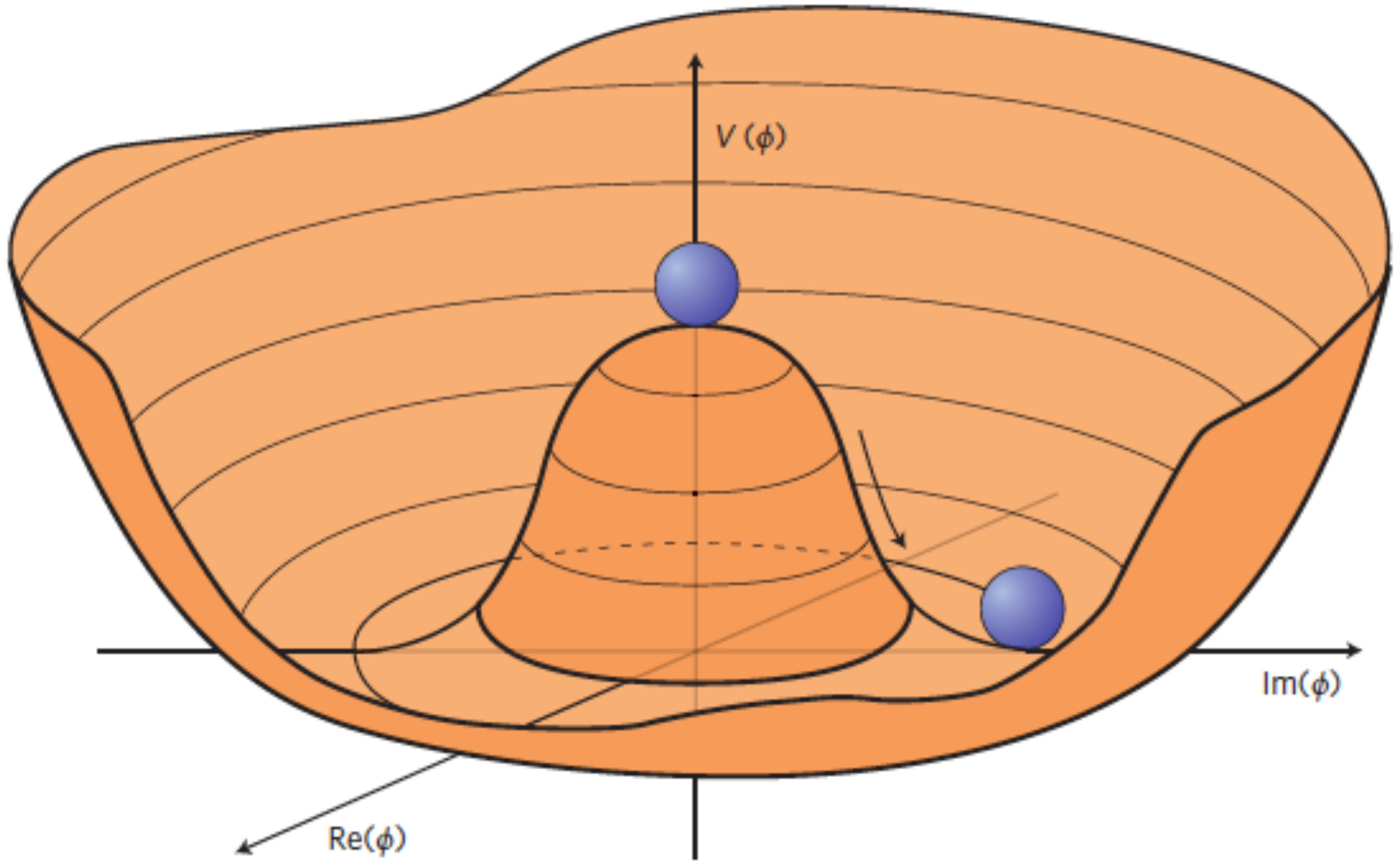

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3. Accidents

The SU(2) five-plet

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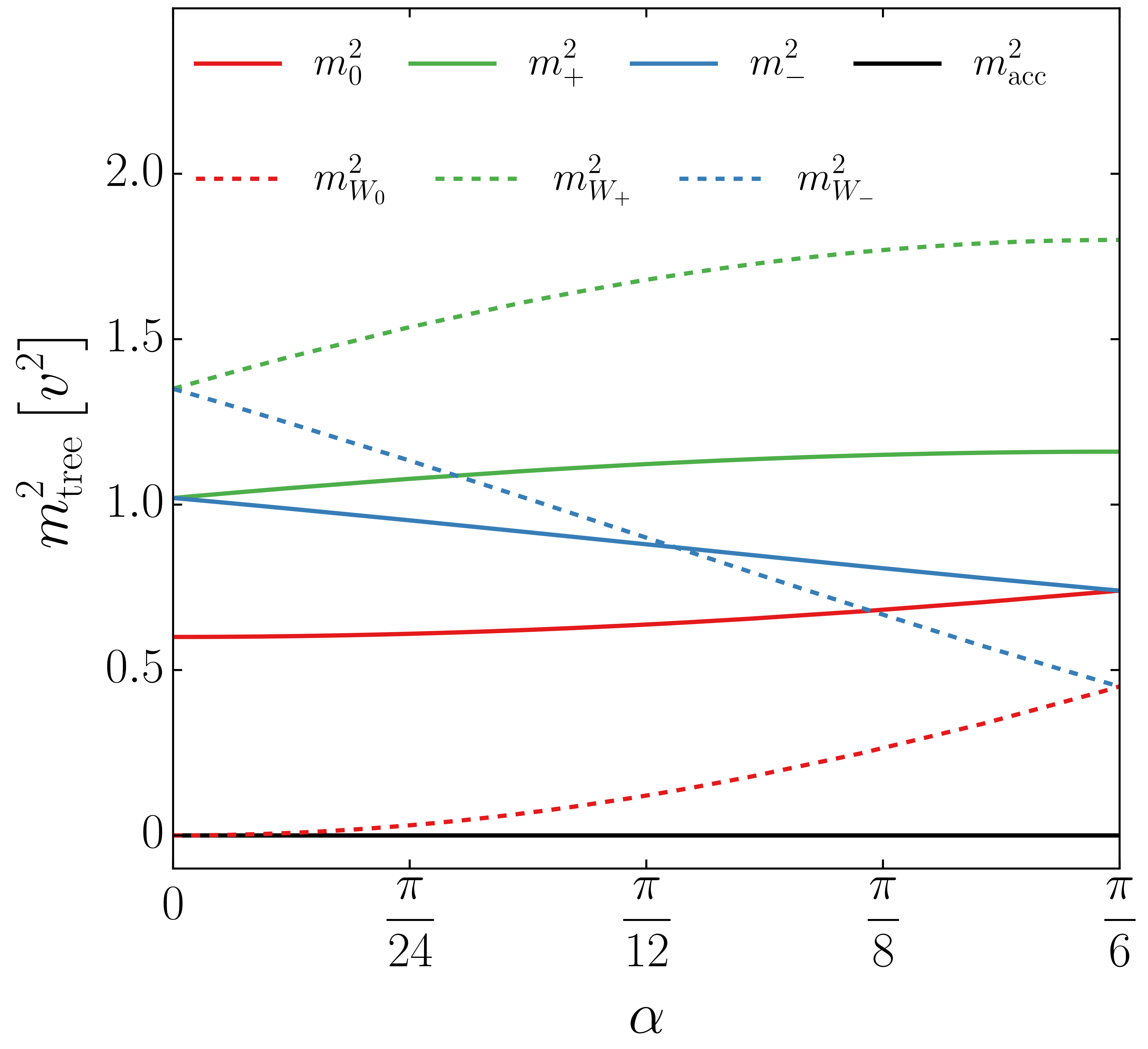

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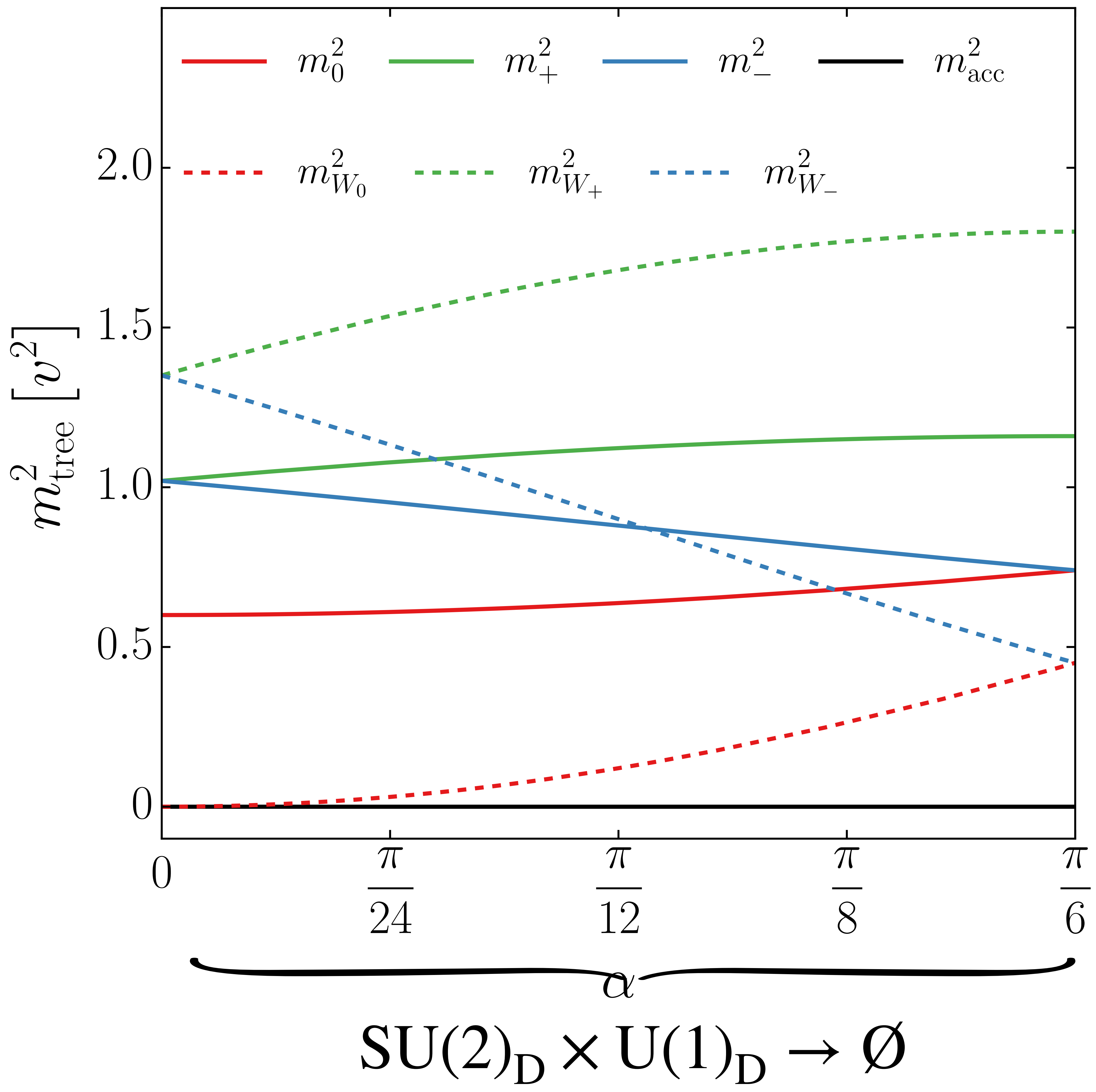

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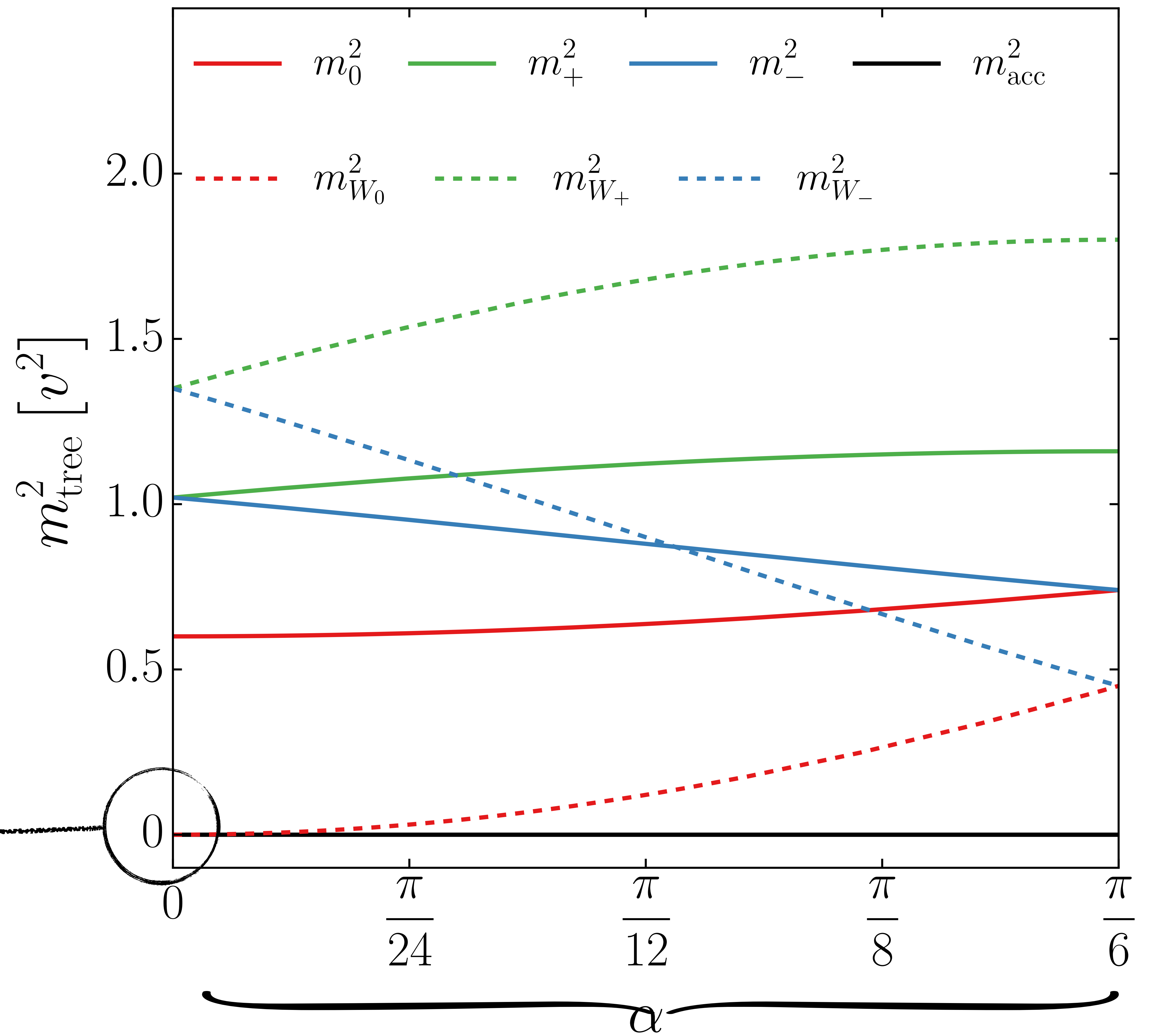

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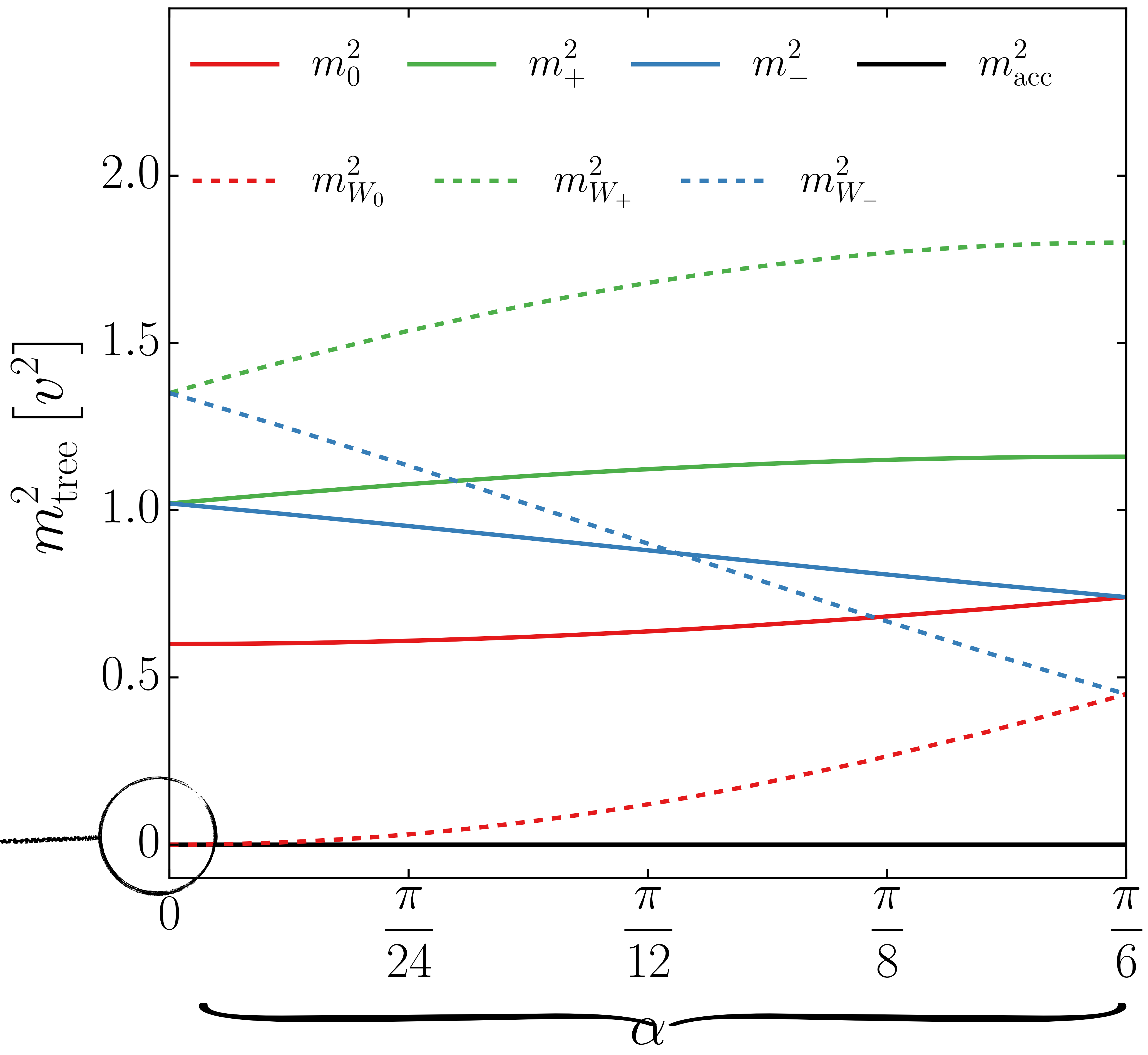

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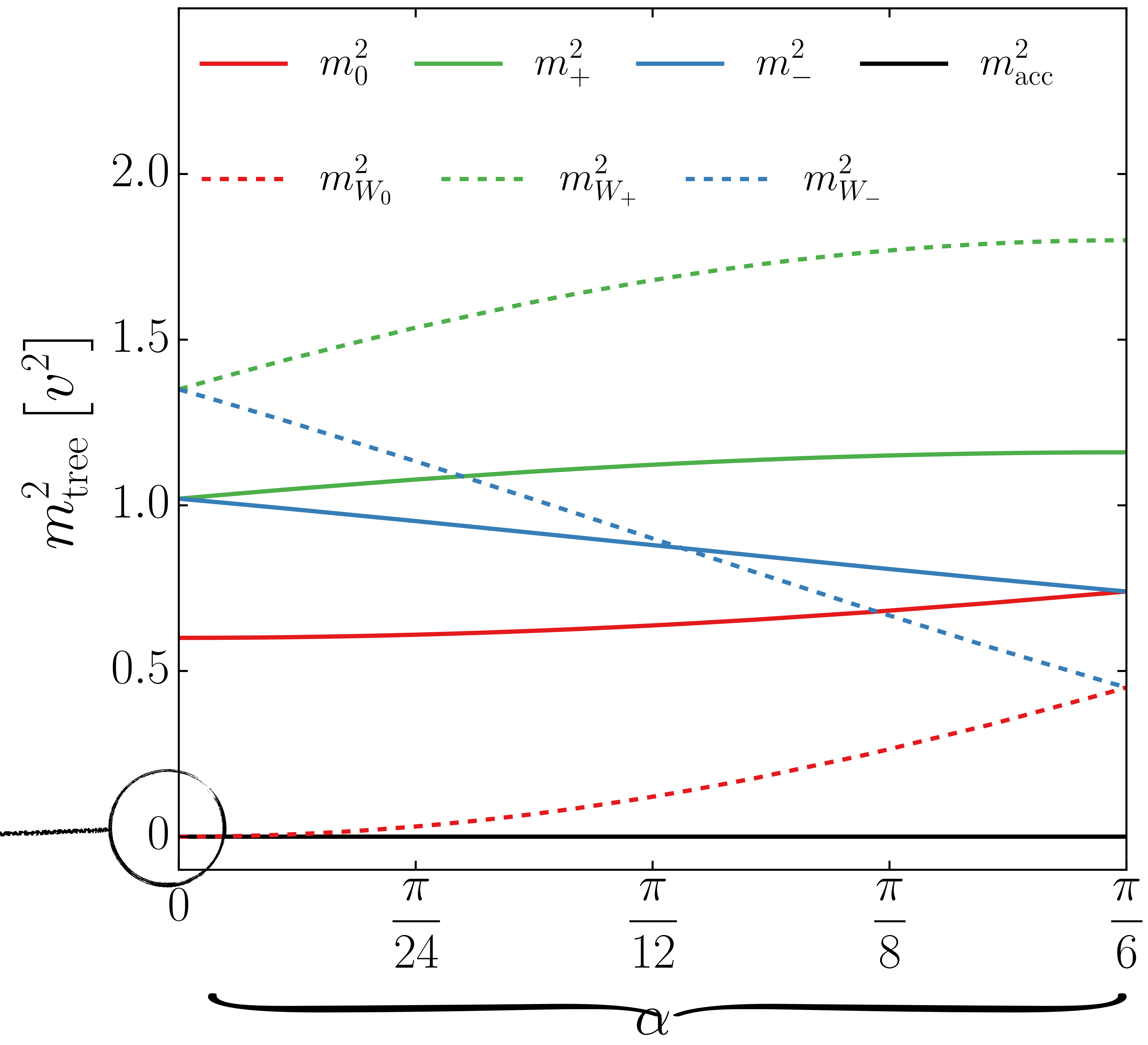

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No symmetry protection $\overset{\text{1-loop}}{\Longrightarrow}$ $V_{\mathrm{eff}}(\alpha) \simeq \frac{c_1 v^4}{64\pi^2}\cos\alpha$

Possible Applications

Abelian Higgs

Dark matter

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DM candidate

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More in the Backup!!!

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Small field Inflation requires: flat potential

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Phys.Rev.Lett. 65 (1990) 3233-3236

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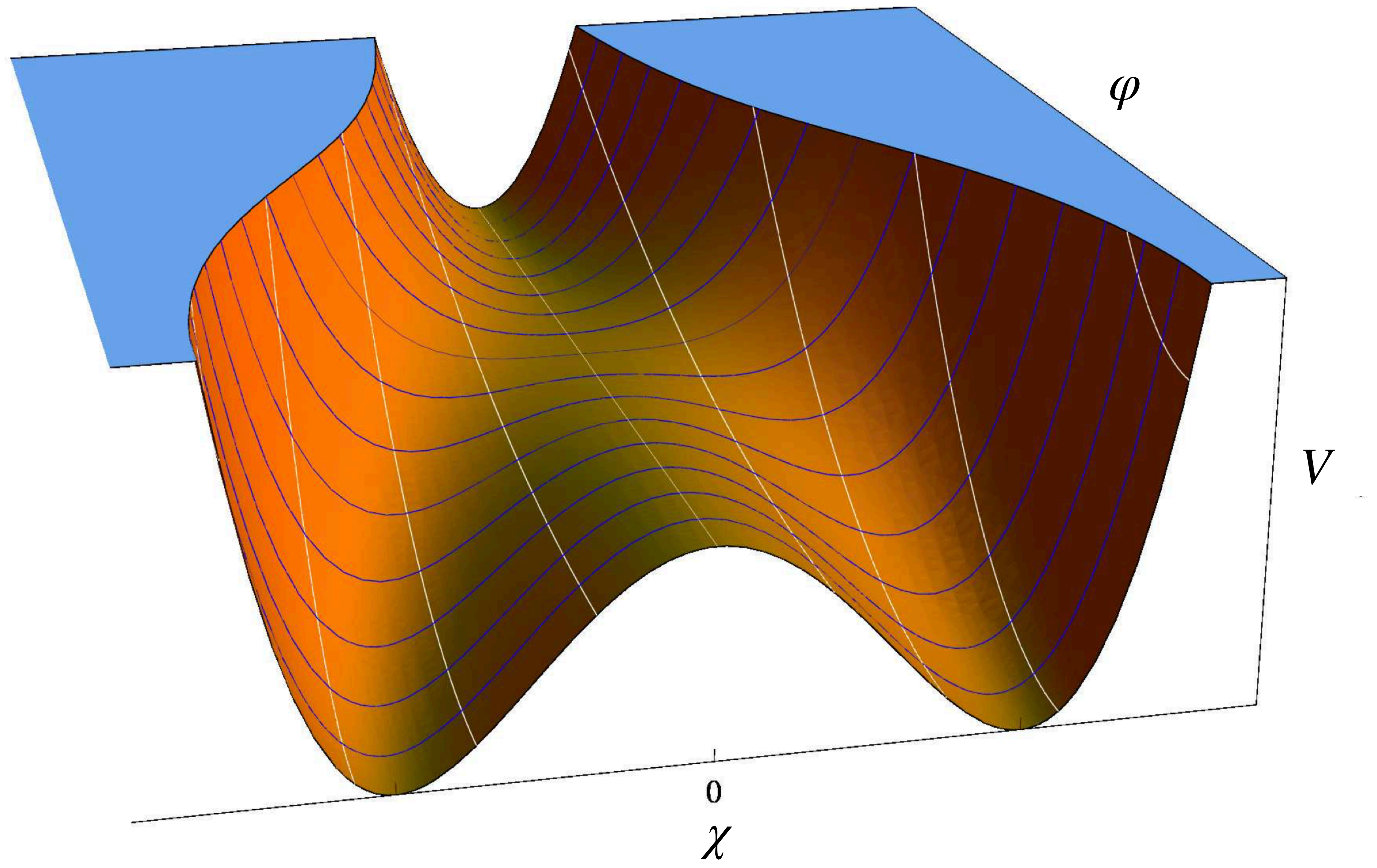

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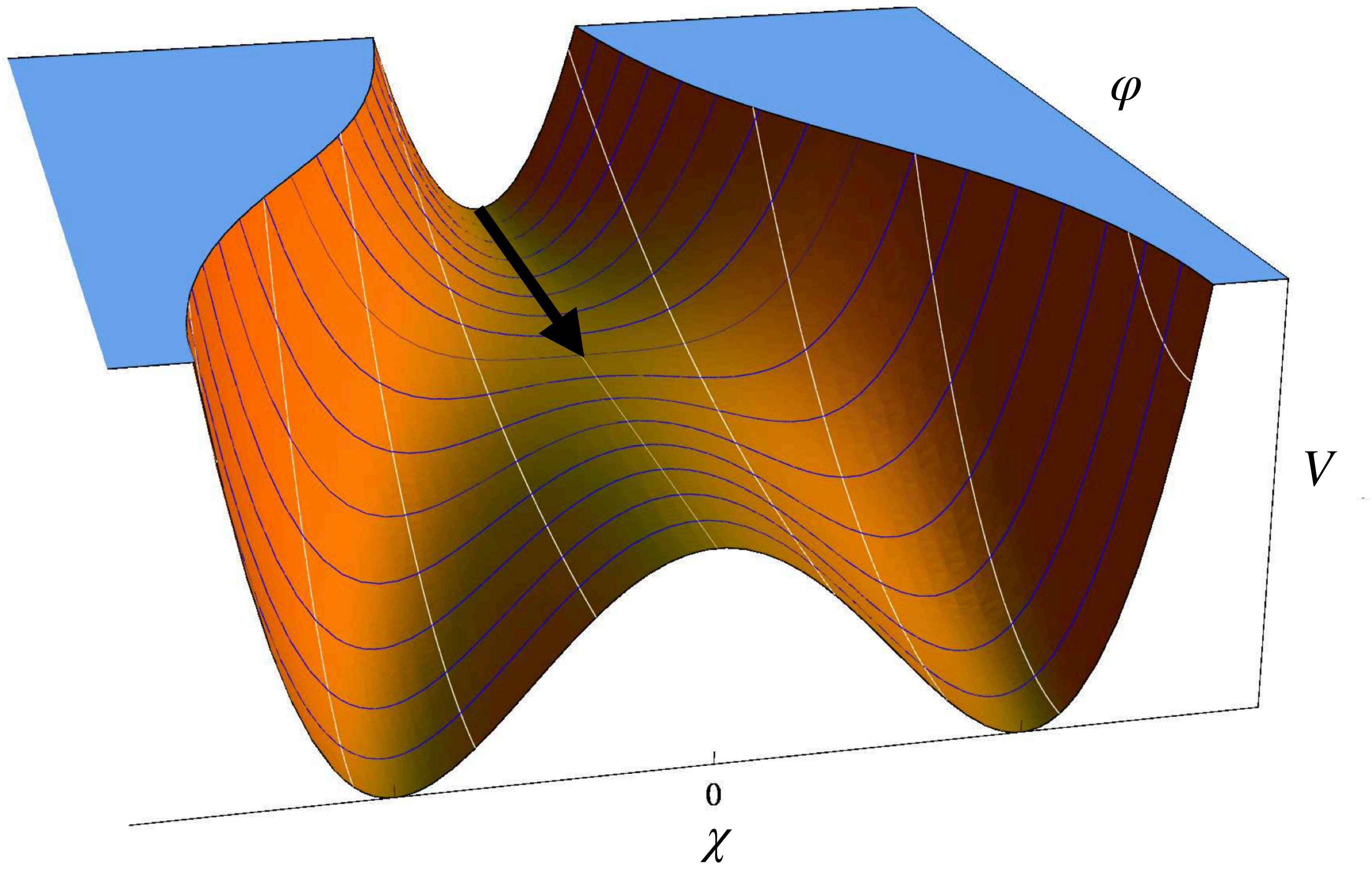

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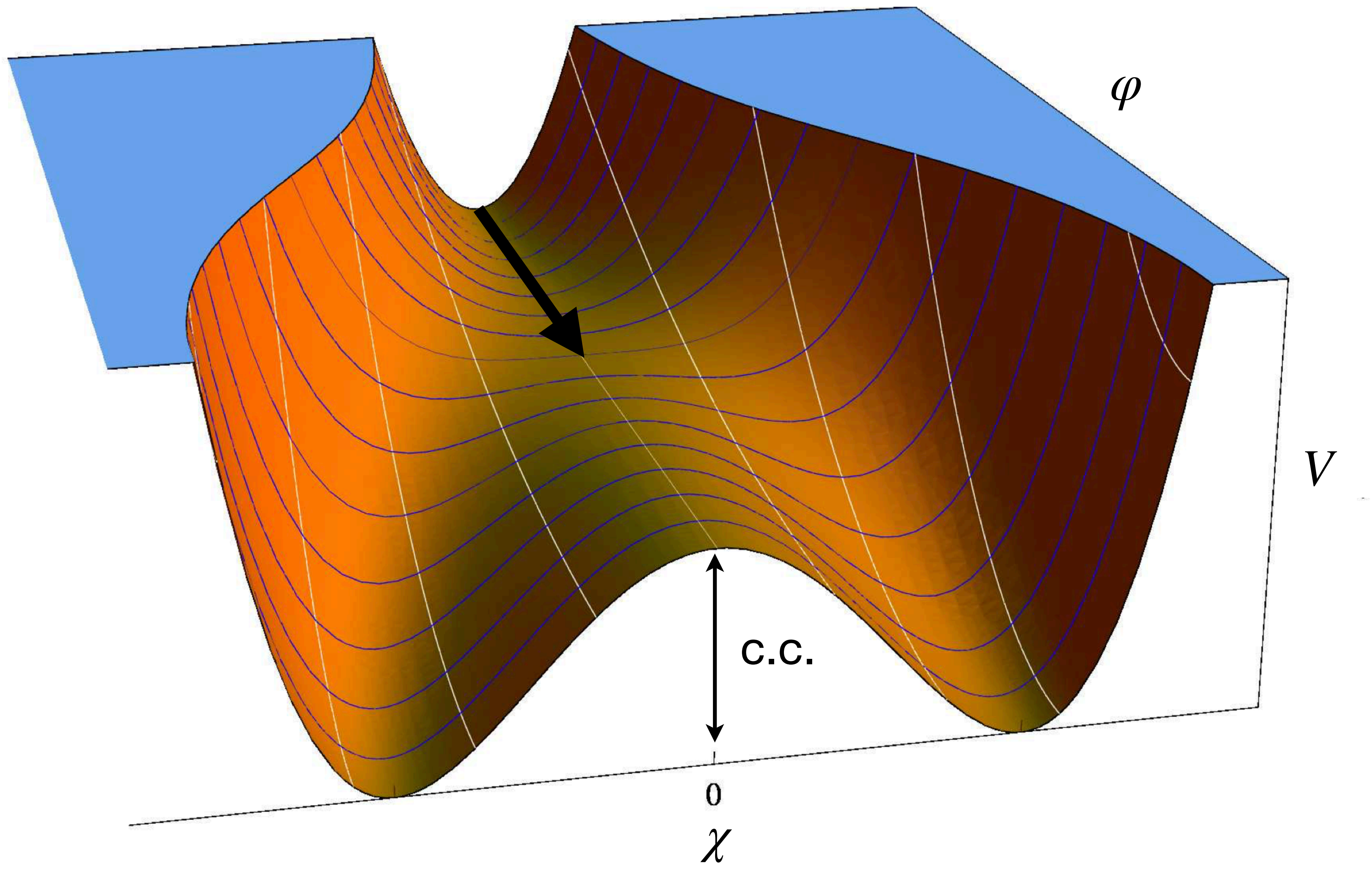

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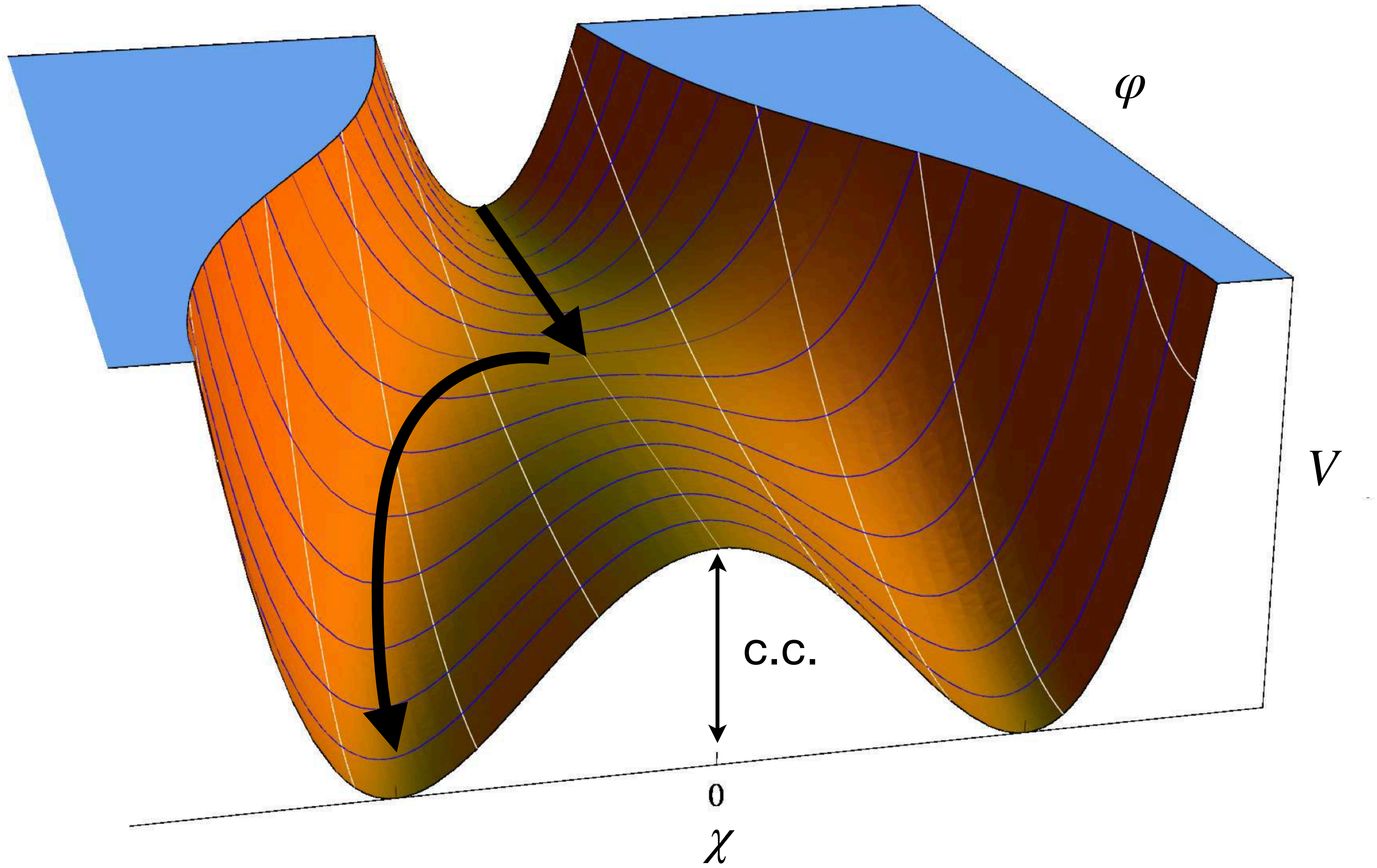

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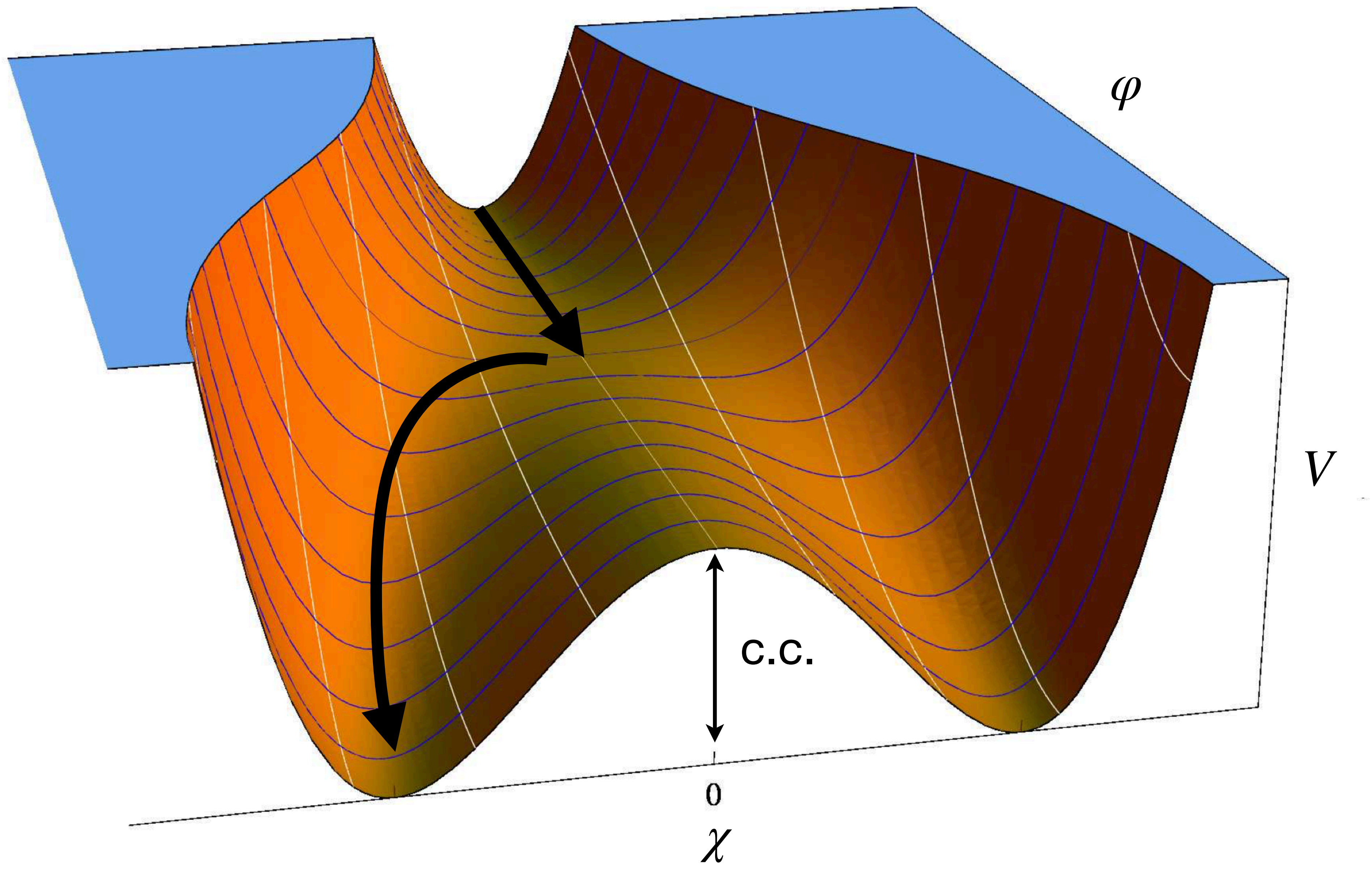

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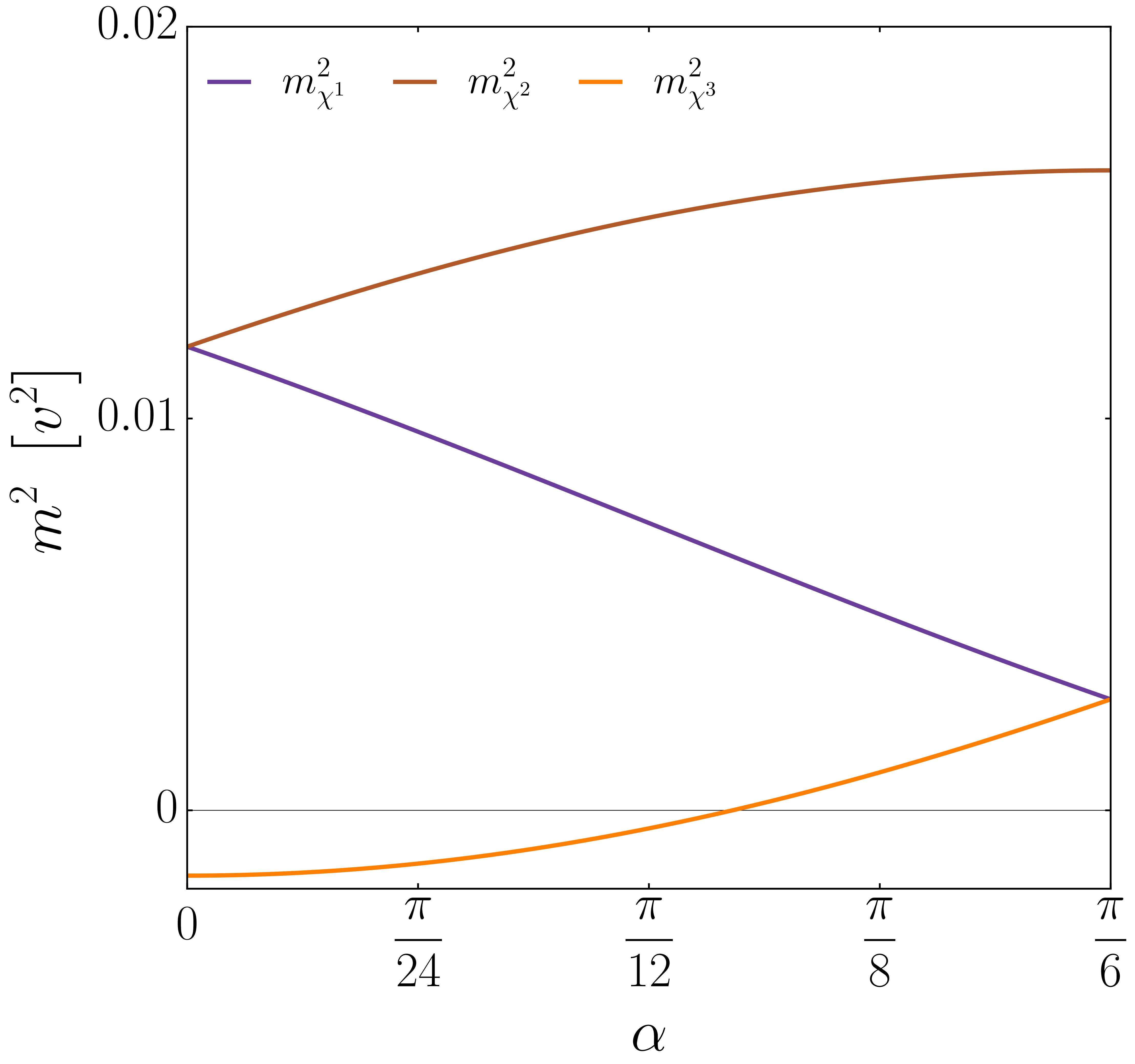

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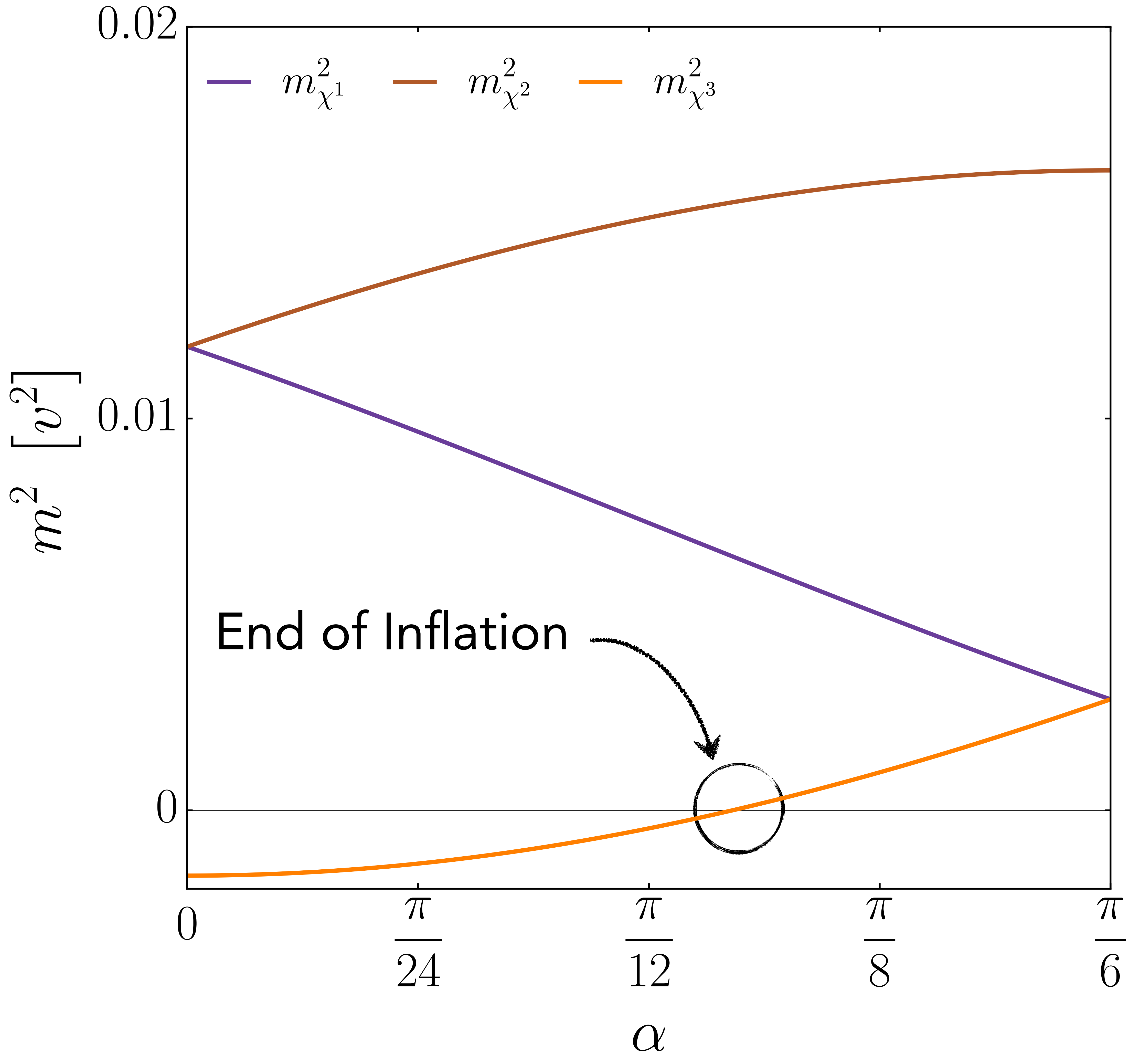

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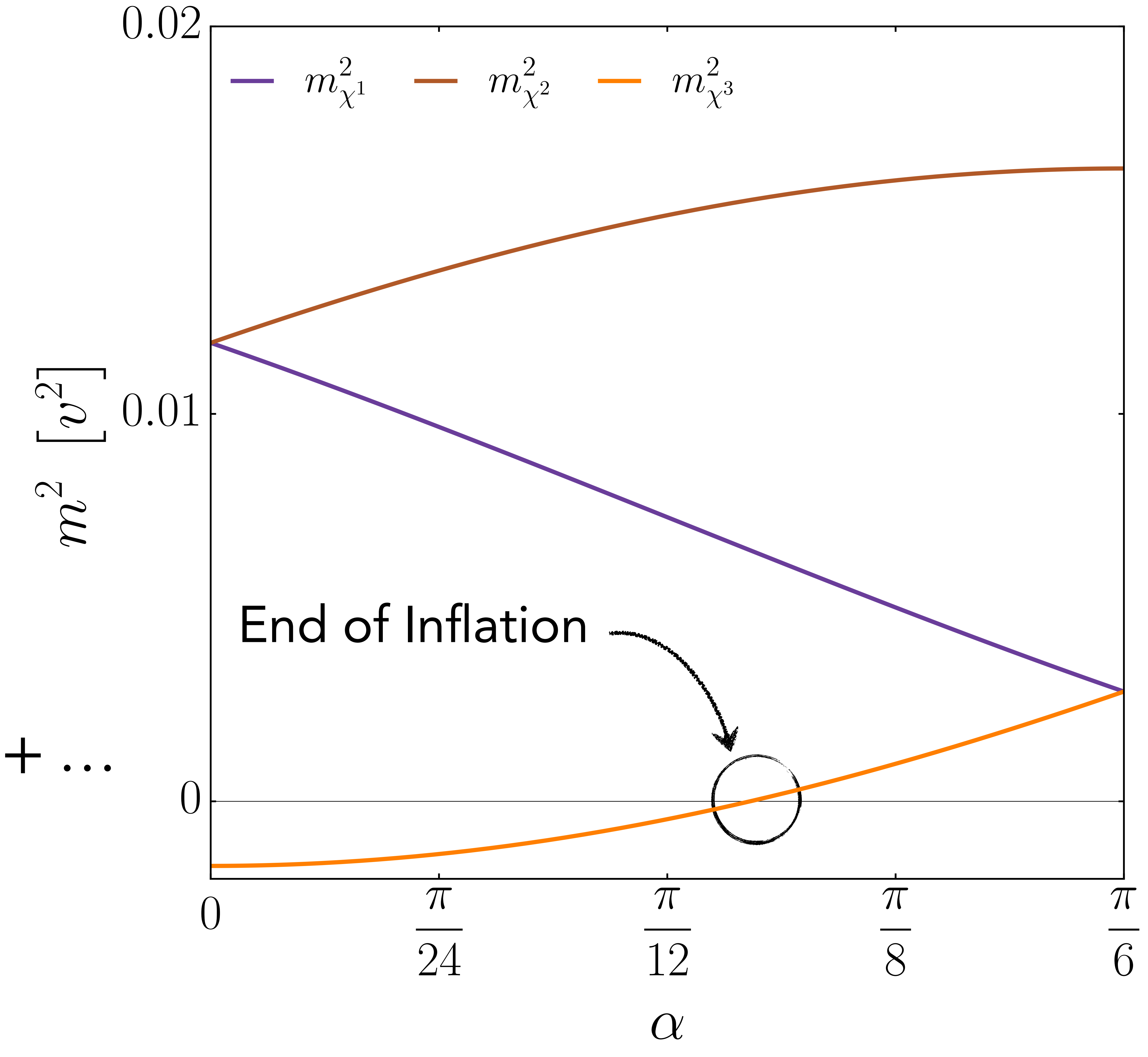

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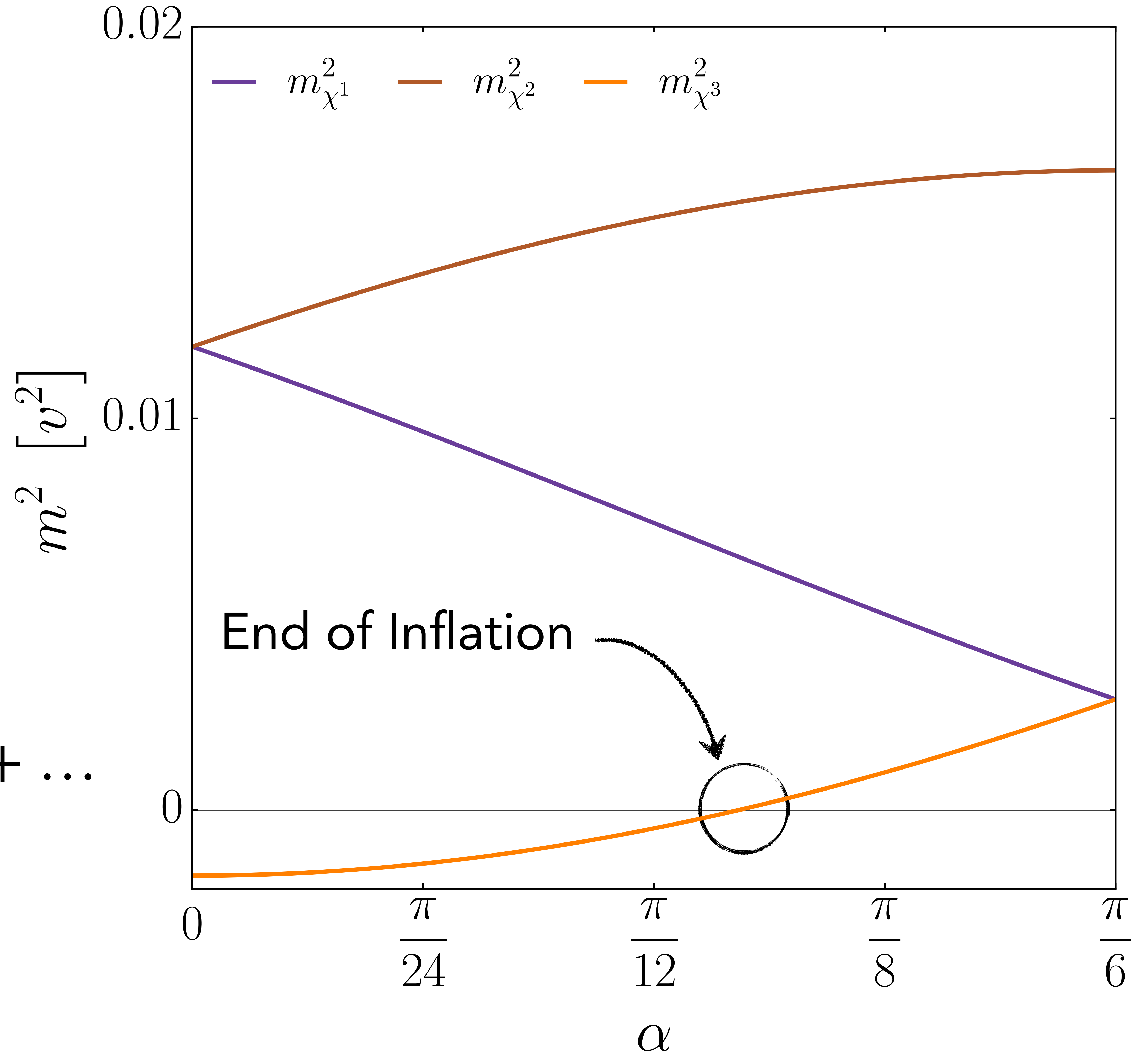
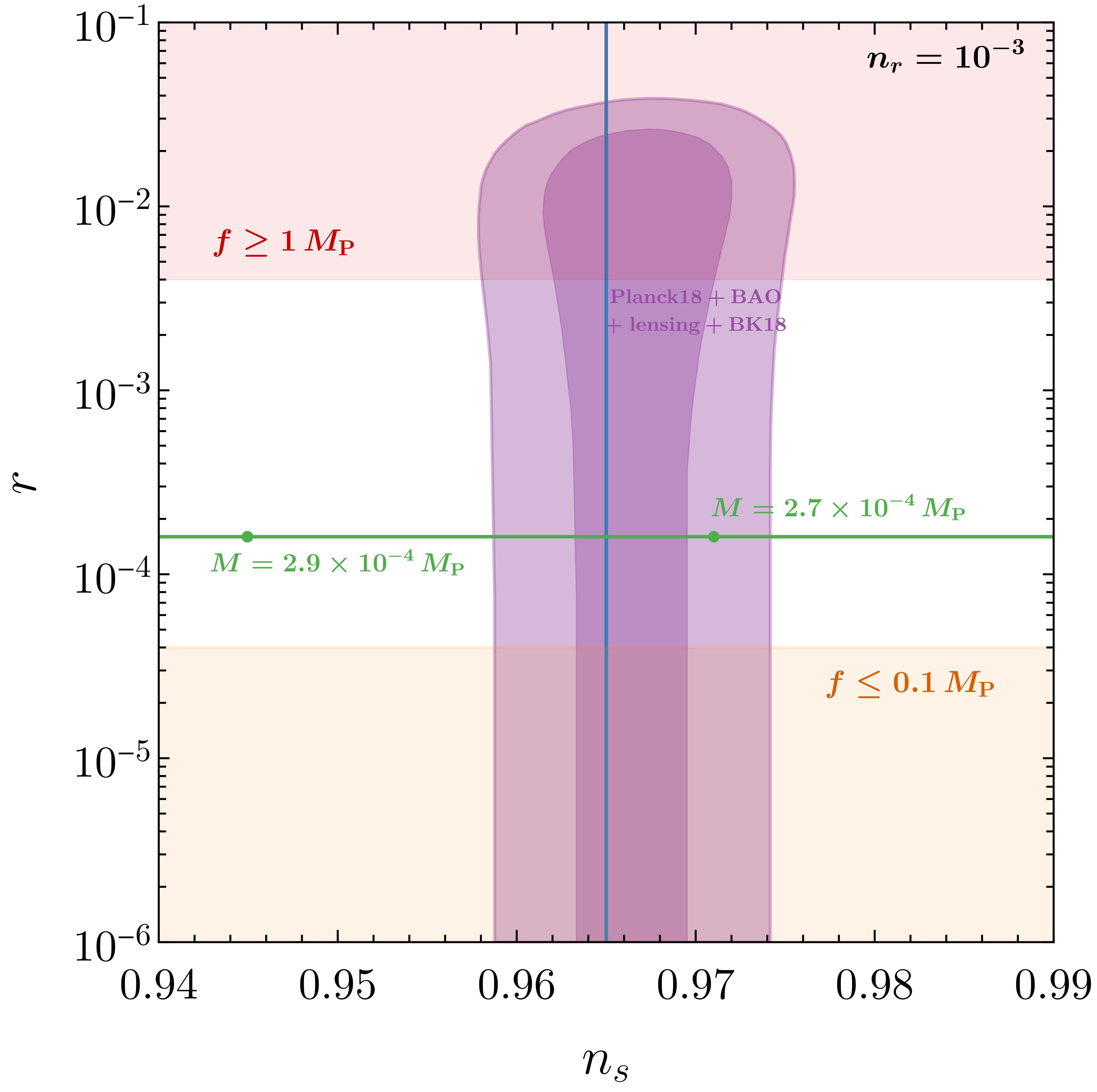
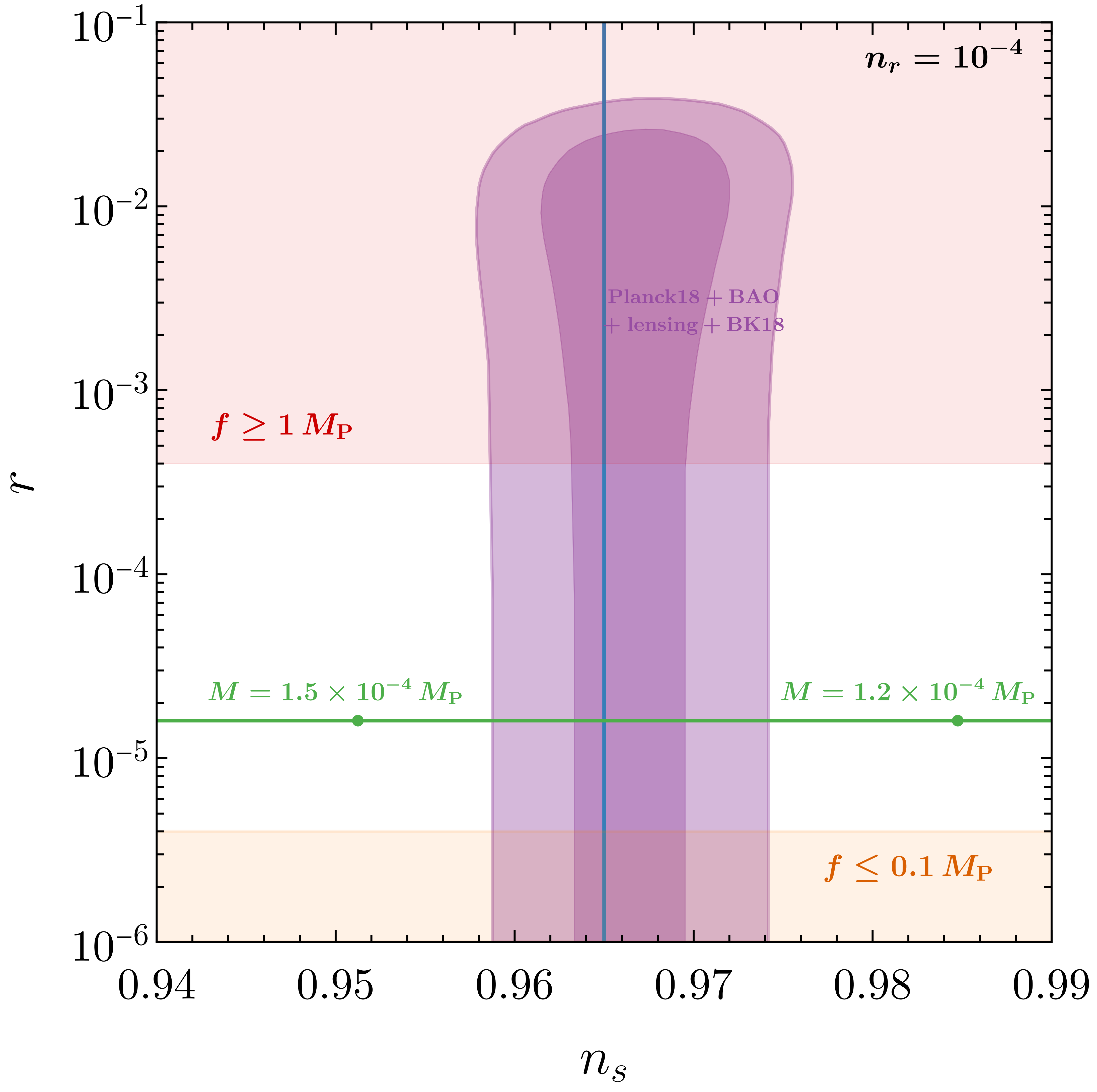


Inflaton = Accident $\Longrightarrow$ **Protection from ALL higher-order corrections**

"Accidental" Inflation

CMB





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$\mathbb{Z}_4$- symmetric model

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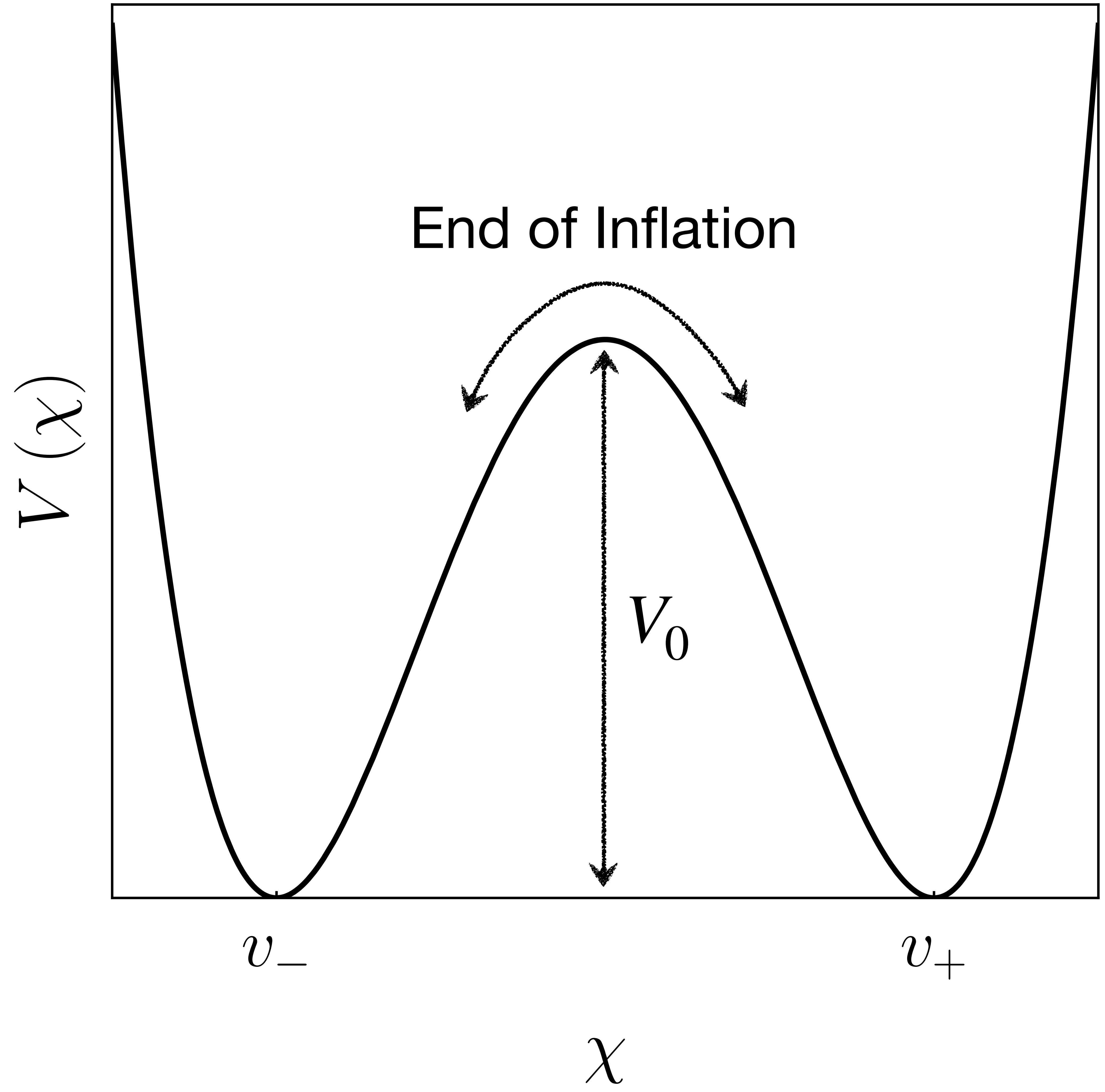

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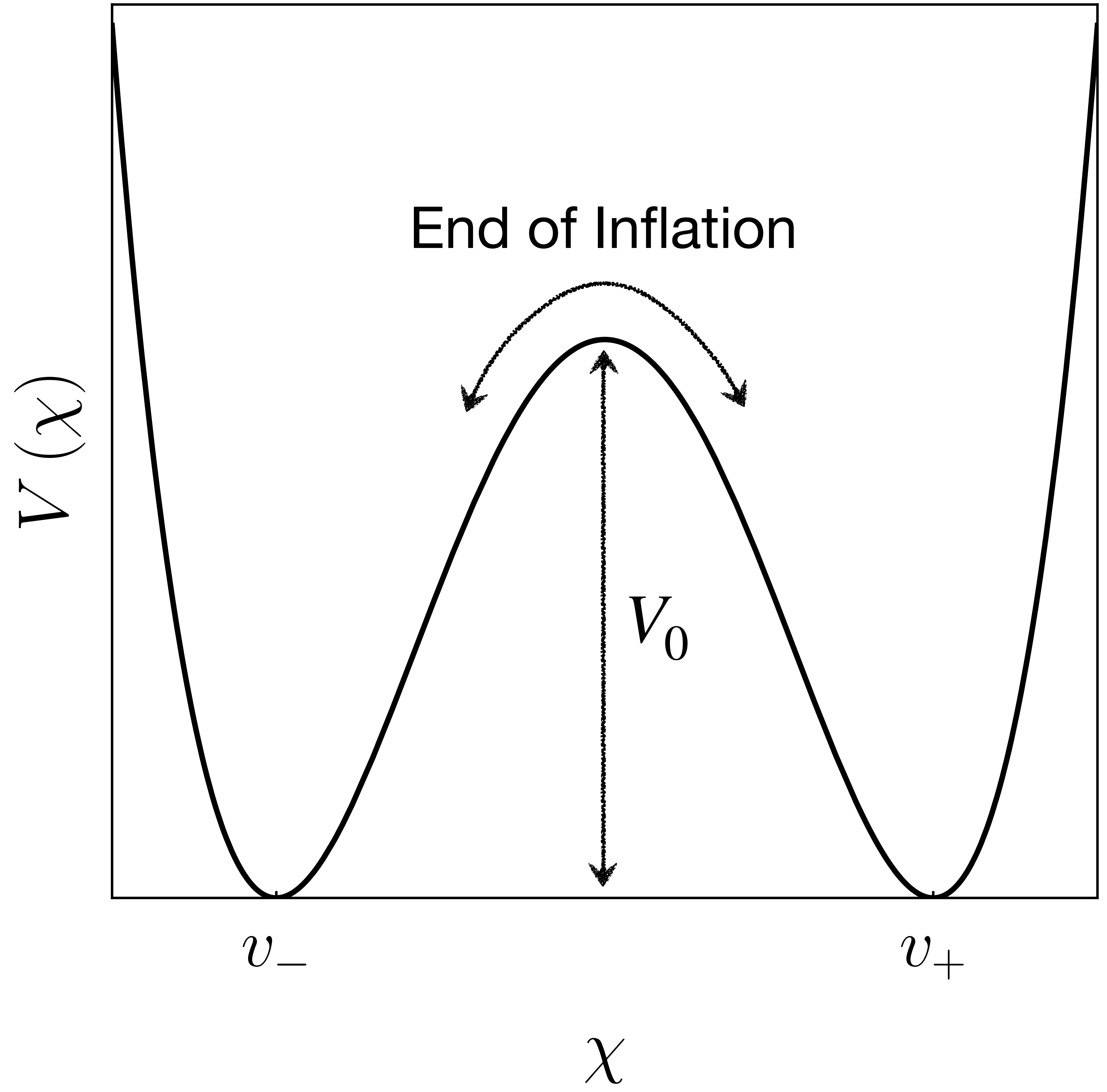

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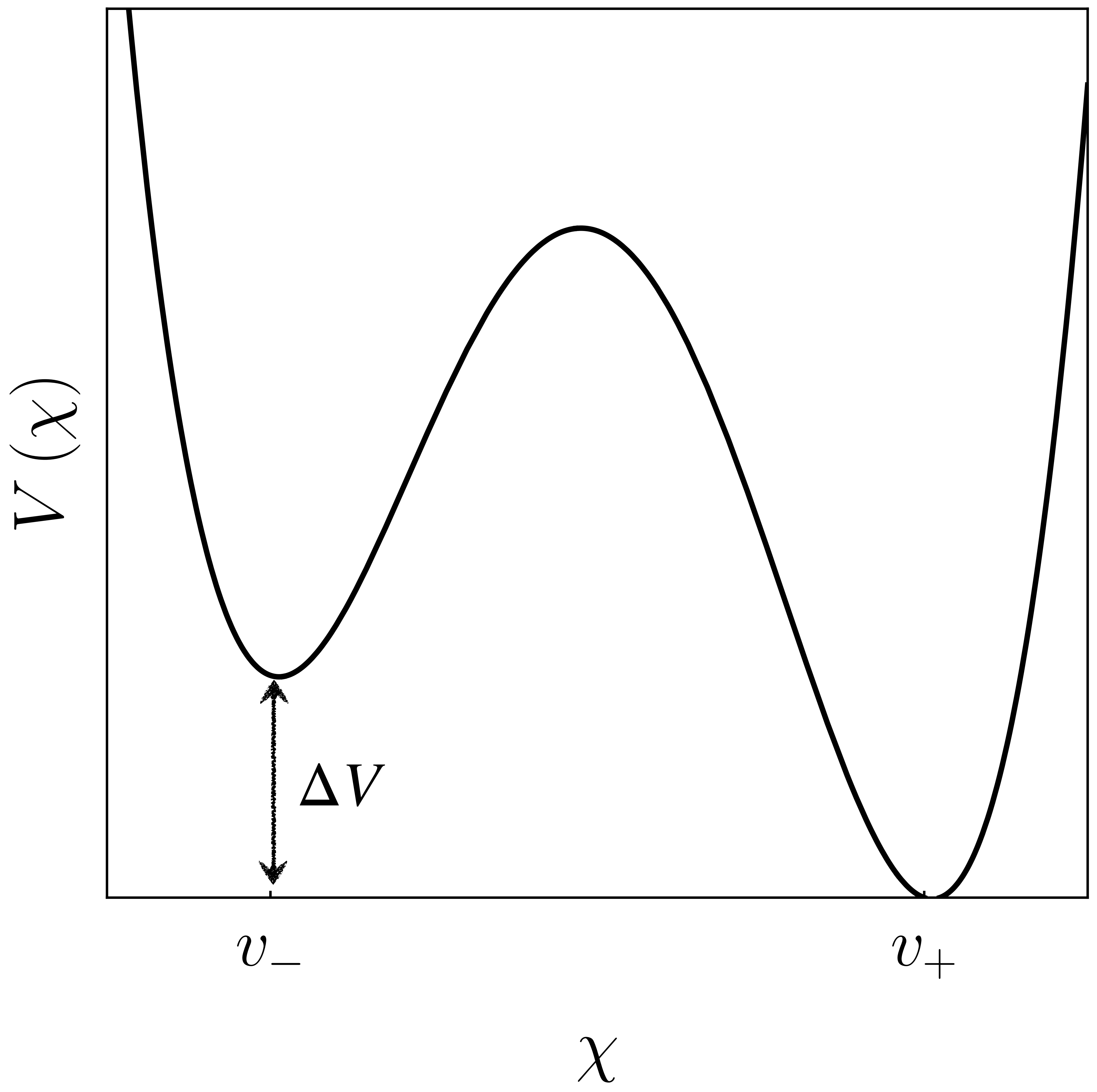

Domain Walls

$\mathbb{Z}_4$- symmetric model

$$\chi \sim \mathbf{3}$$

$$\mathrm{SU}(2) \times \mathbb{Z}_4^{(\chi)} : \chi \to i\chi$$

Add a soft breaking of $\mathbb{Z}_4$:

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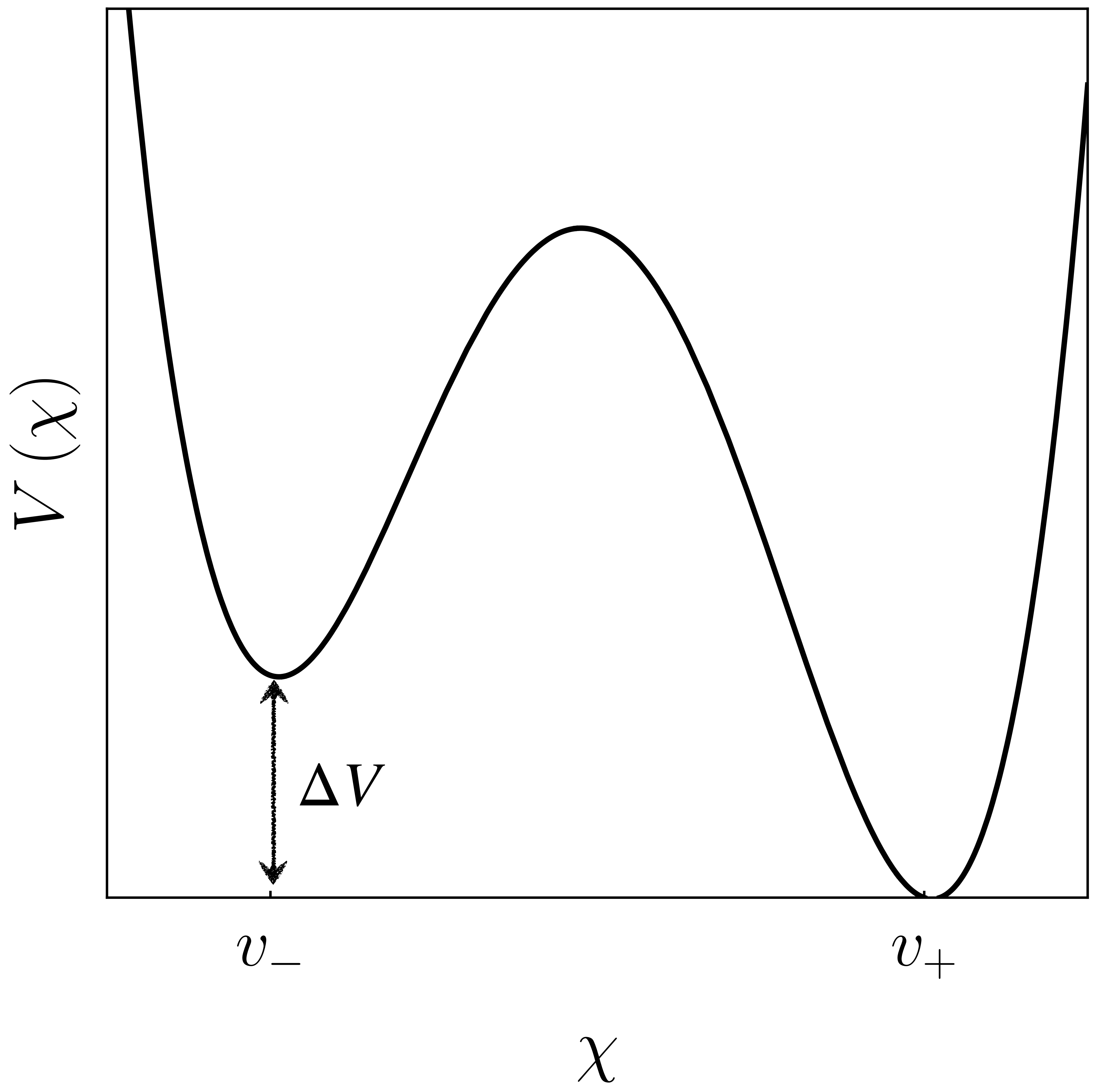
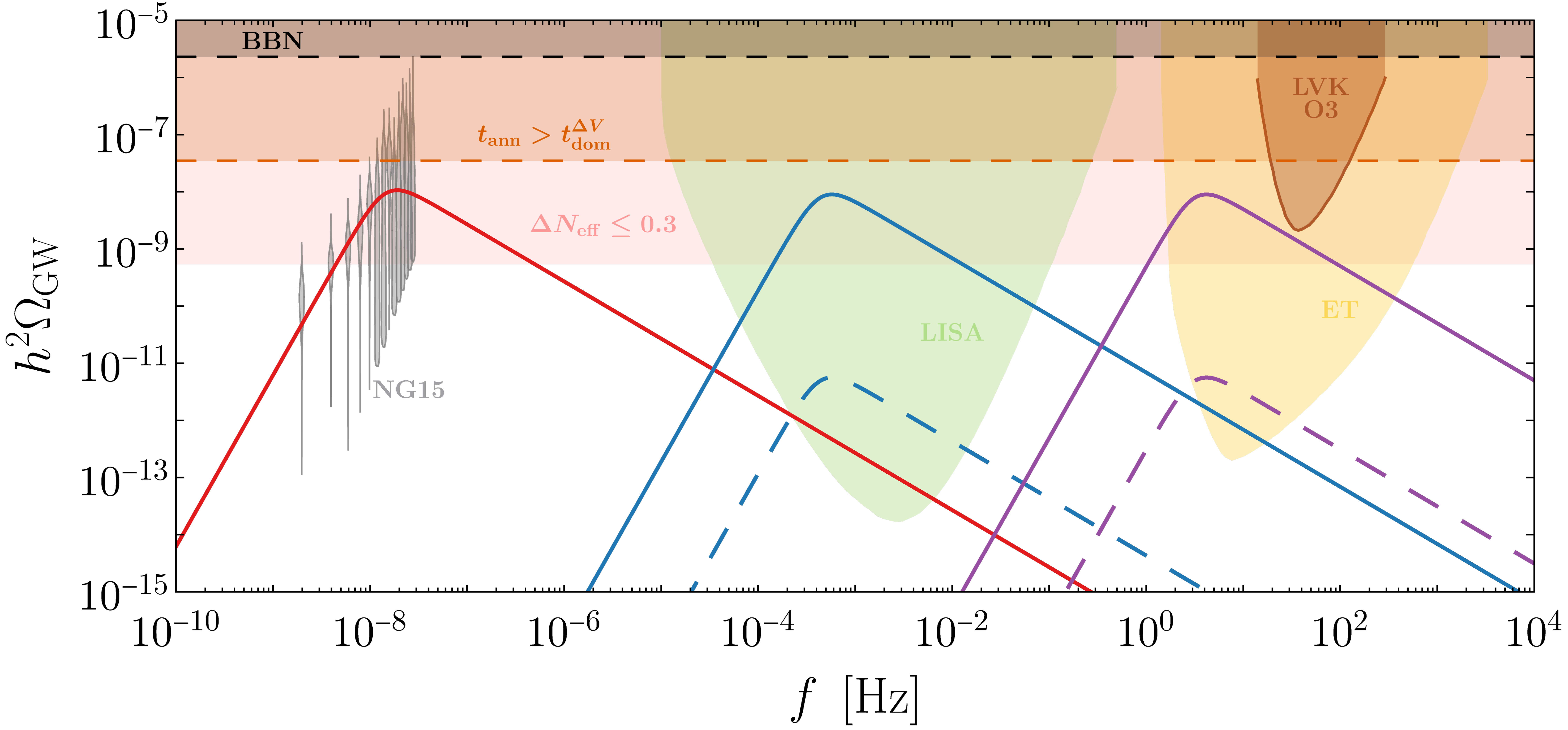
DWs annihilate
and
emit GWs!



Domain Walls

Gravity Waves



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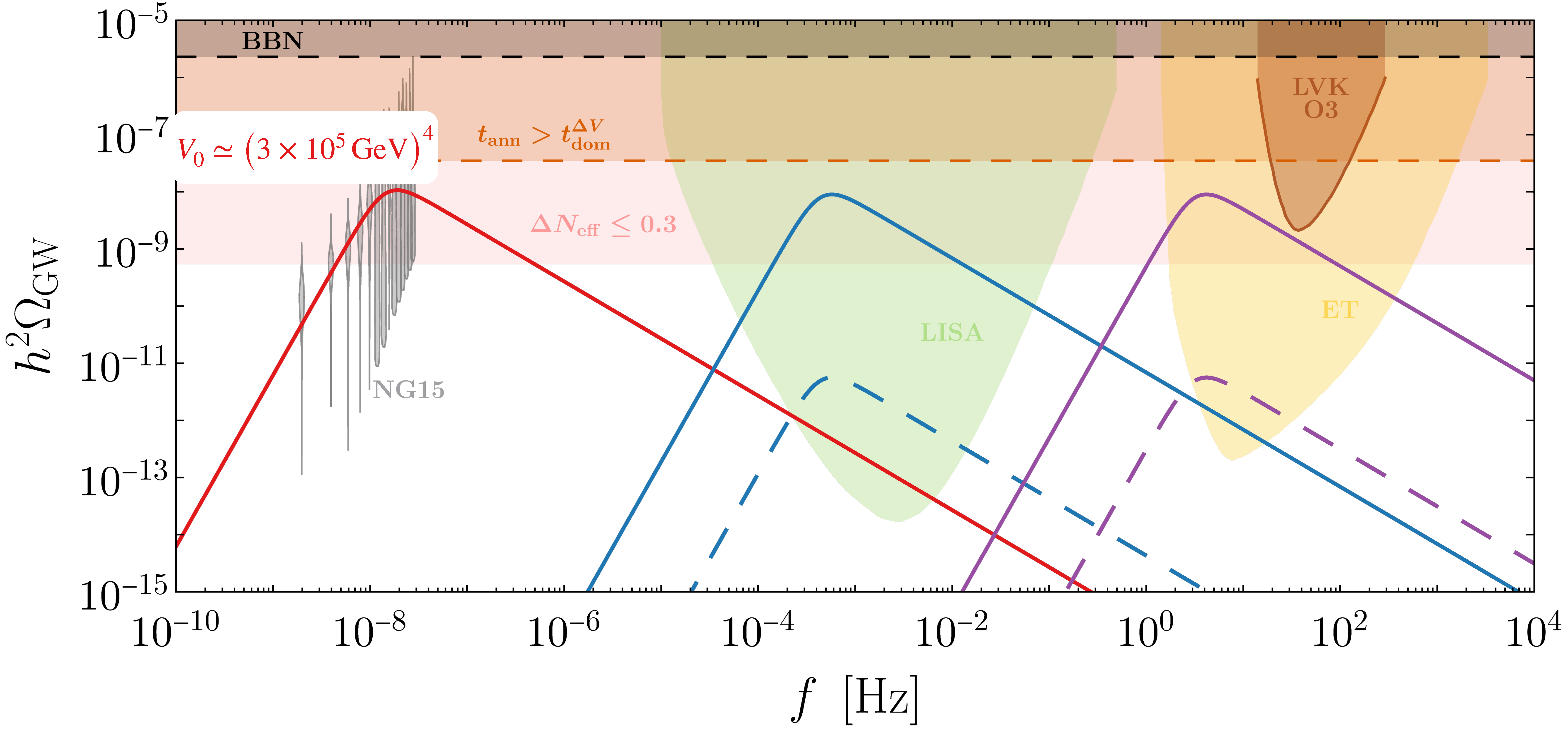
Gravity Waves



Domain Walls

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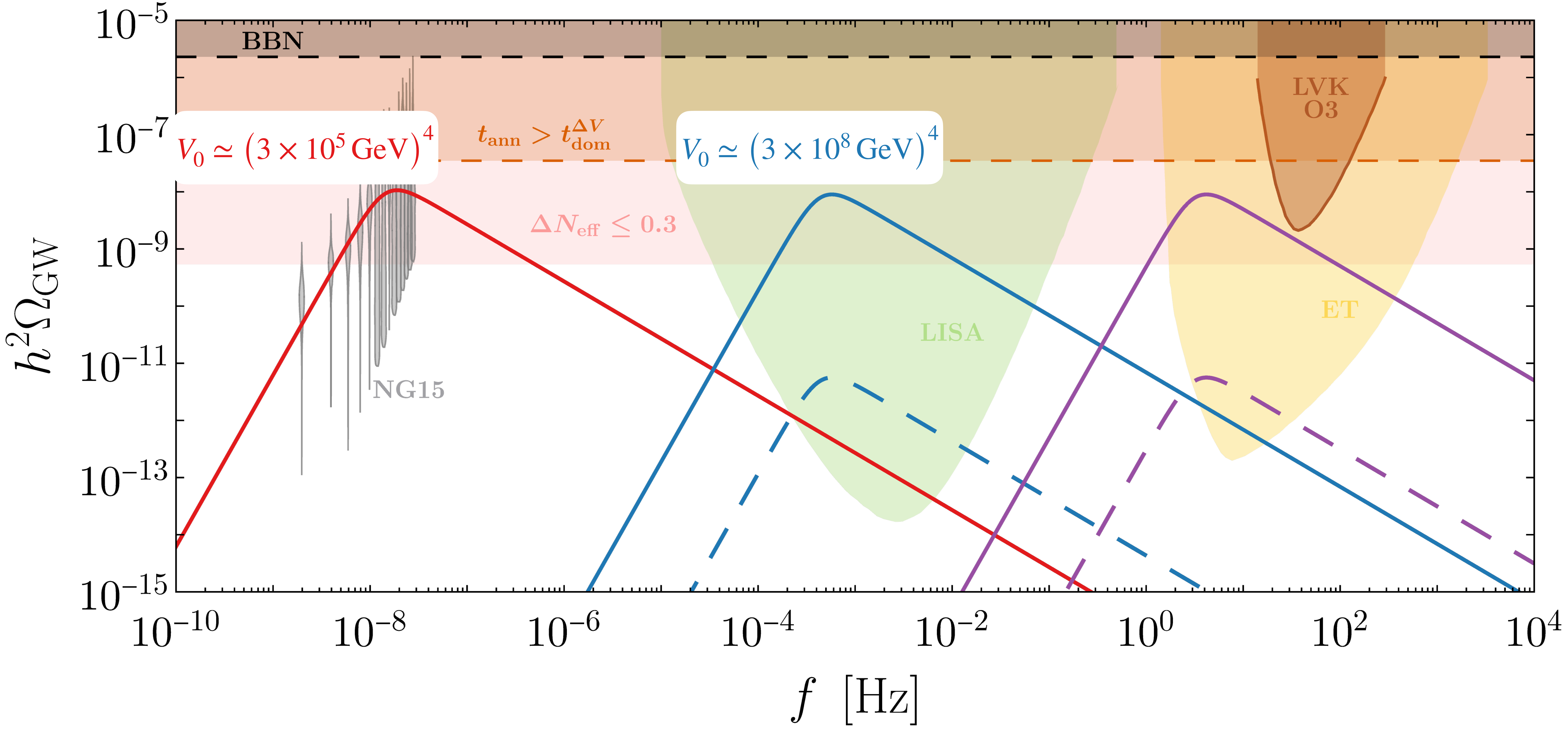
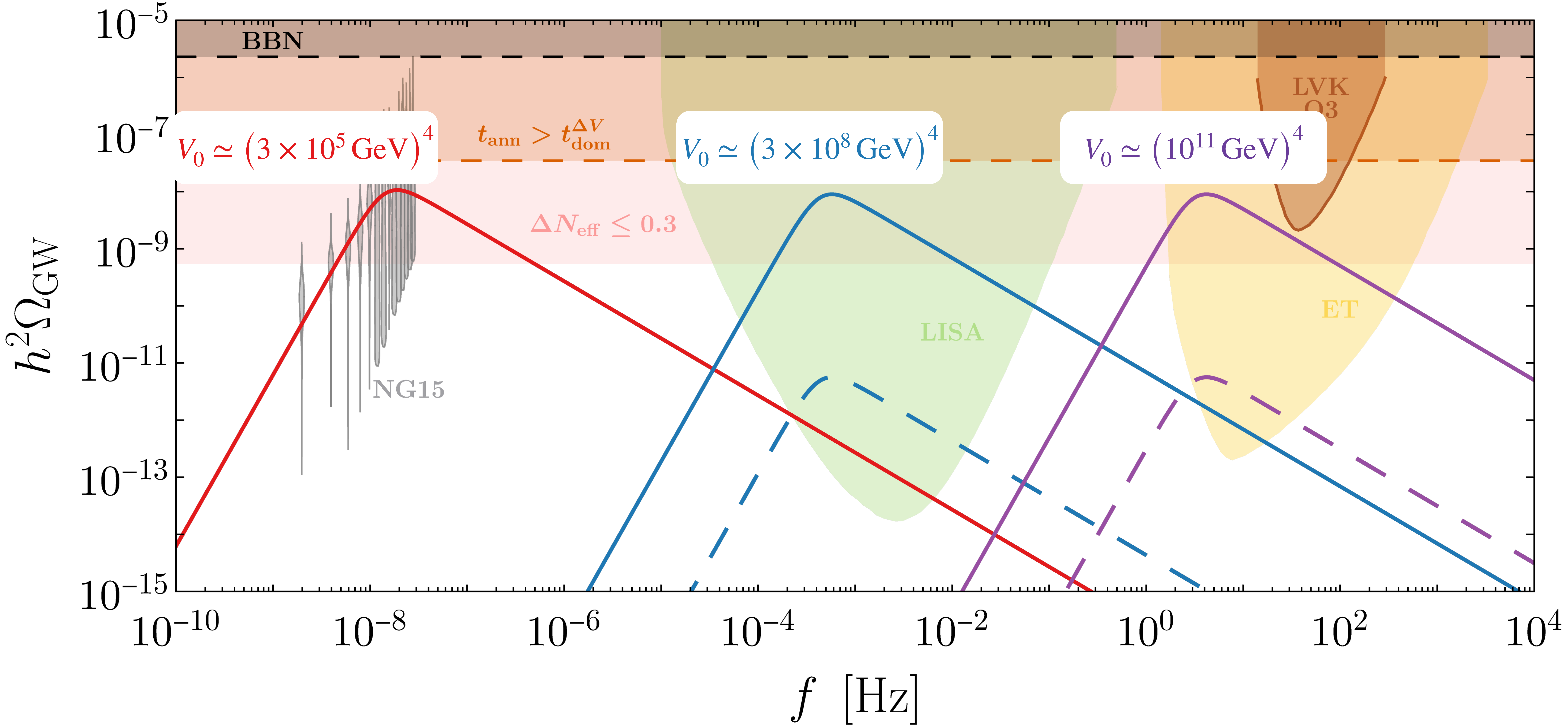


Domain Walls

Gravity Waves



Conclusions

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- Large representations $\Longrightarrow$ tree-level **massless scalars**

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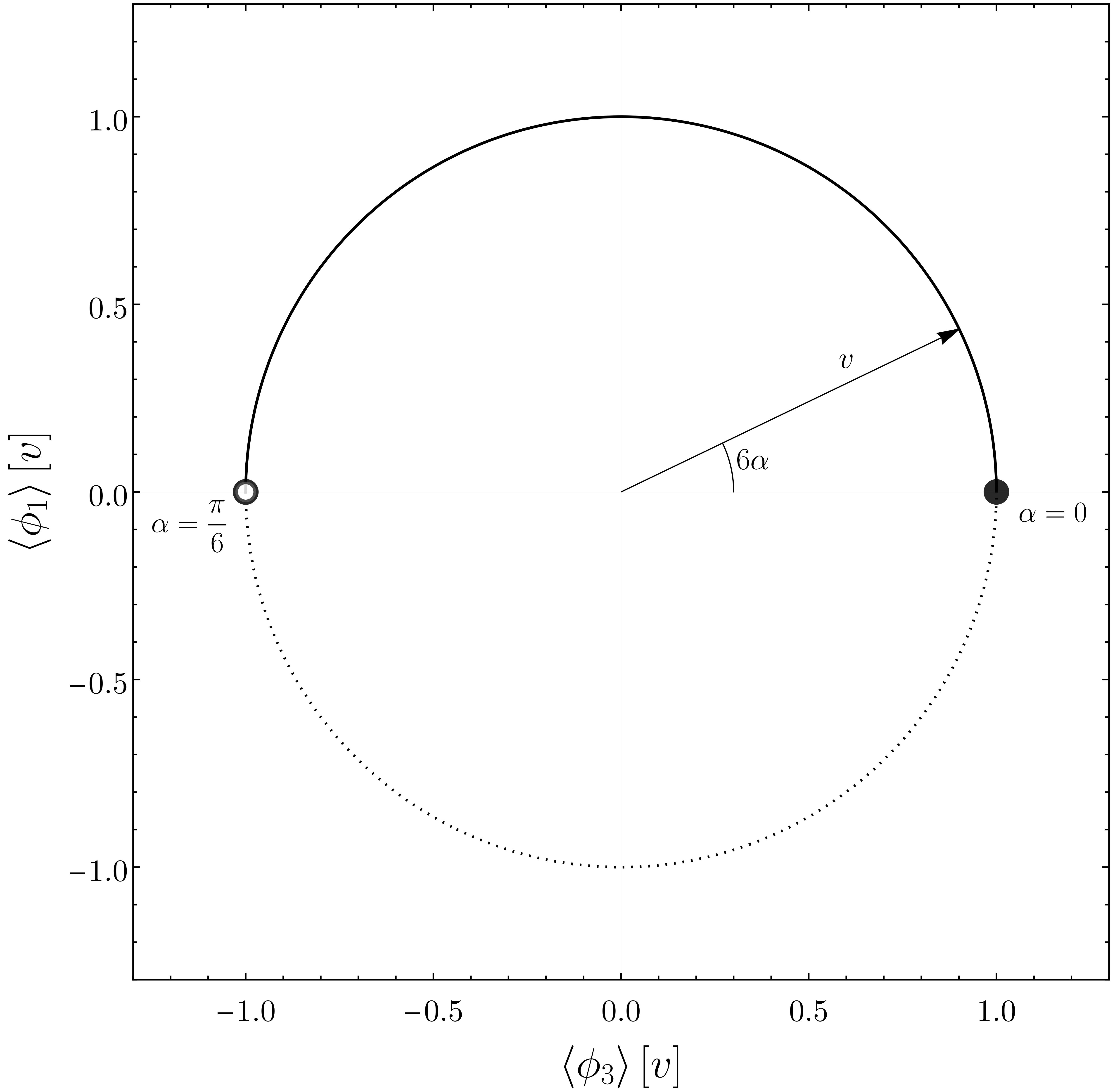
    - **GWs** from DWs
    - **GWs** from **Tachyonic Preheating**

Thank you for your attention!

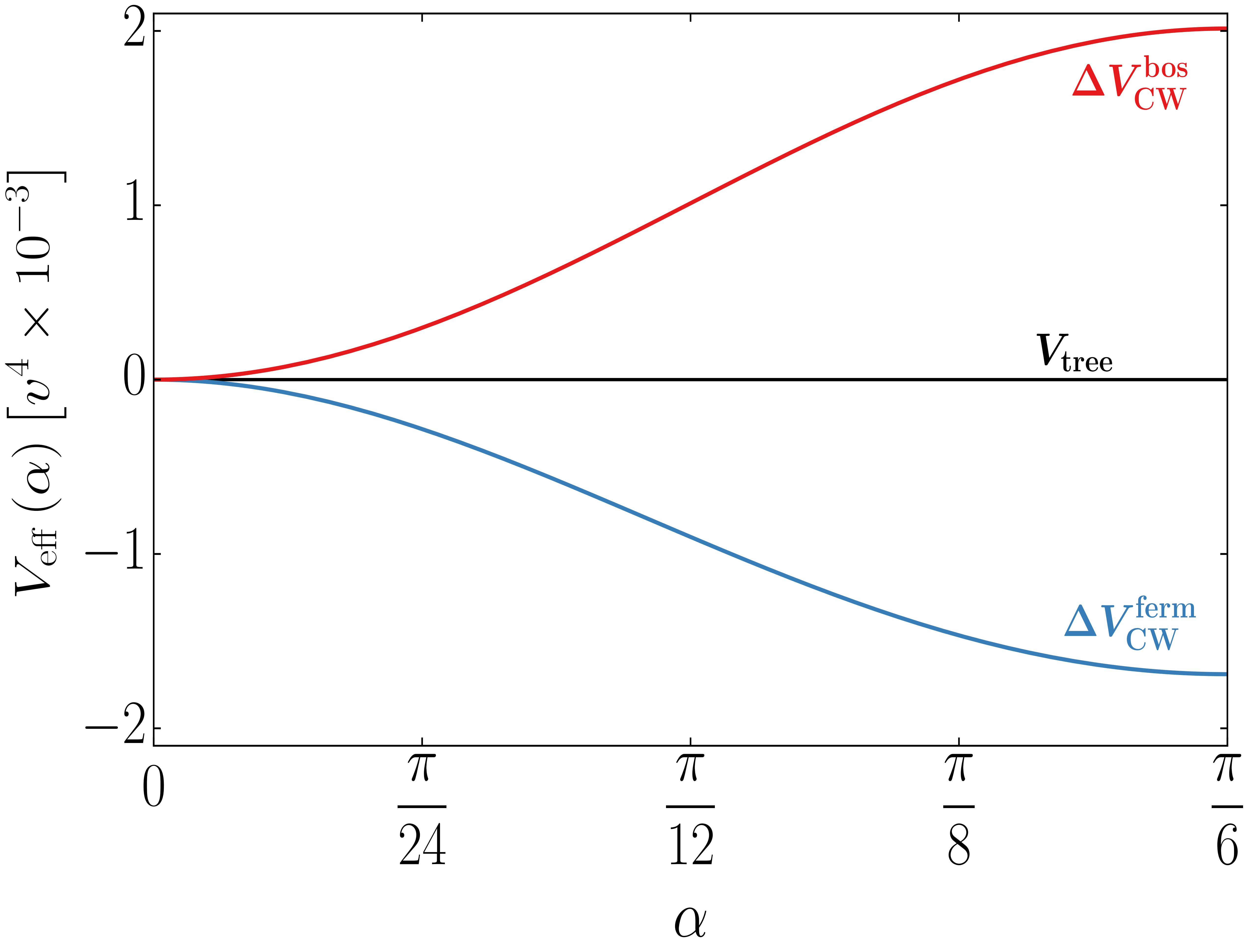
Backup Slides

Vacuum Manifold



Effective Potential

$$\Delta V_{\rm CW}(\alpha) = \frac{1}{64\pi^2}\,{\rm Str}\left(\mathscr{M}(\alpha)^4 \log\frac{\mathscr{M}(\alpha)^2}{\Lambda^2}\right)$$

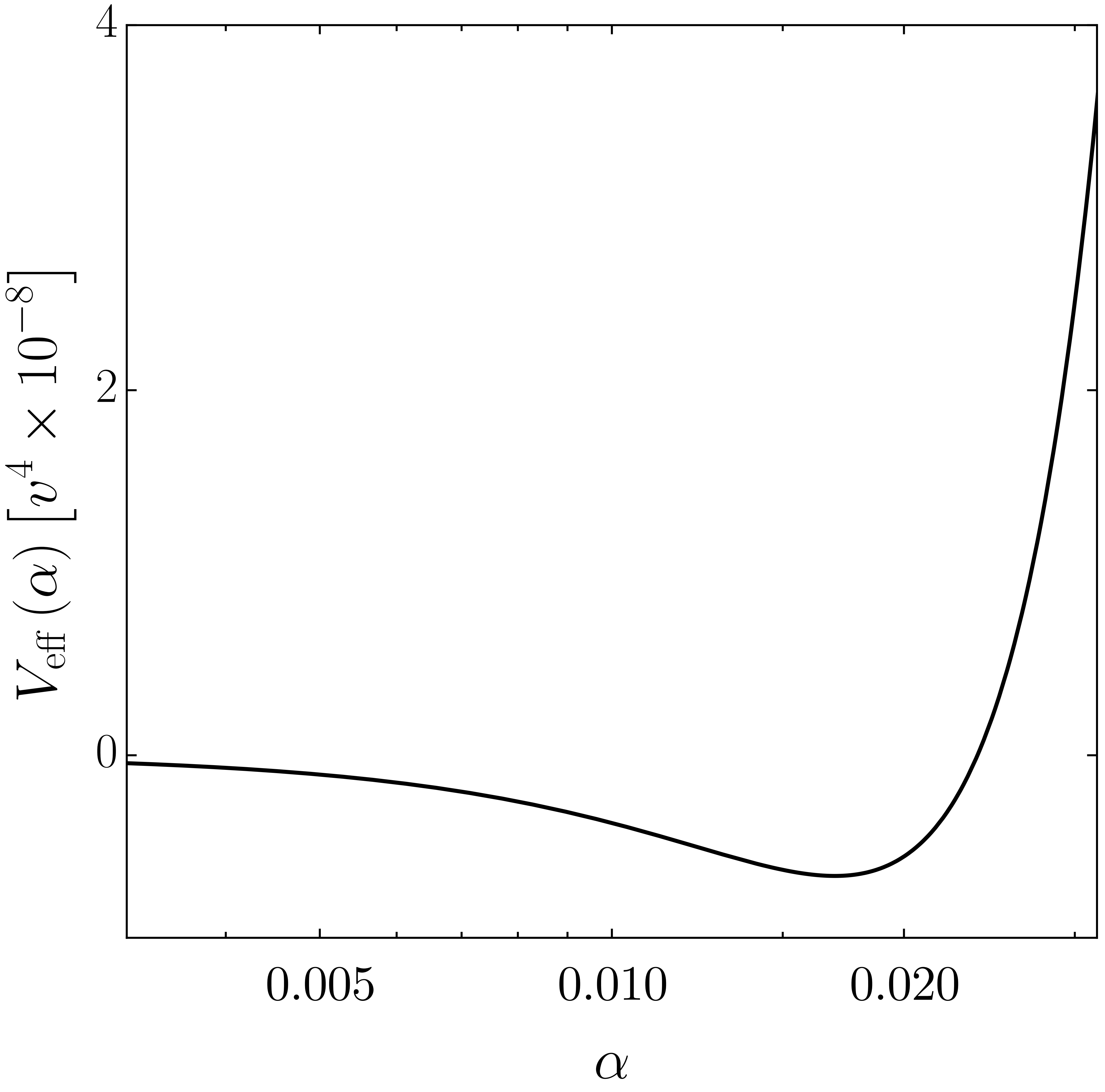


Fermions: $\psi \sim \mathbf{3}_{+1/2}\,, \quad \xi \sim \mathbf{3}_{-1/2}$

$$\mathscr{L} \supset y\left(\psi^T\phi\psi + \chi^T\phi^*\chi\right) + M\psi^T\chi + \mathrm{h.c.}$$

Possible Applications

Abelian Higgs



$$V_{\rm eff}\,(\alpha) \simeq c_1 \cos\left(6\,\alpha\right) + c_2 \cos\left(12\,\alpha\right)$$

↓

Tuning c_1 against c_2:

breaking of $\mathrm{U}(1)'$ at a scale $v' \ll v$

We can identify the accident with the Abelian Higgs

Possible Applications

Dark Matter

Higgs-portal annihilation

$\lambda_{H\phi}\left(HH^{\dagger}\right)\left(\phi\phi^{\dagger}\right)$

Direct detection constraints

$m_{\rm DM} \gtrsim 2 - 3~\text{TeV}$

or

$m_{\rm DM} \simeq m_h/2$

U(1)′-photon annihilation

Ellipticity constraint

$g_D^2 \simeq 4.6 \times 10^{-5}\,(m_{\rm DM}/\text{GeV})$

and

$m_{\rm DM} \gtrsim 100~\text{GeV}$

The SU(3) ten-plet

$$V = -\mu^2 S + \frac{1}{2}(\lambda S^2 + \delta A^a A^a) \longrightarrow$$ Invariant ONLY under $\mathrm{SU}(3)\times\mathrm{U}(1)$

- ESP: $\mathrm{SU}(3)\times\mathrm{U}(1) \longrightarrow \mathrm{U}(1)_3\times\mathrm{U}(1)_8$ & 6 accidents
- Generic point: $\mathrm{SU}(3)\times\mathrm{U}(1) \longrightarrow \emptyset$ & 2 accidents

Scalar one-loop corrections $\longrightarrow$ The ESP is stabilised

"Accidental" Inflation

"Real" Model

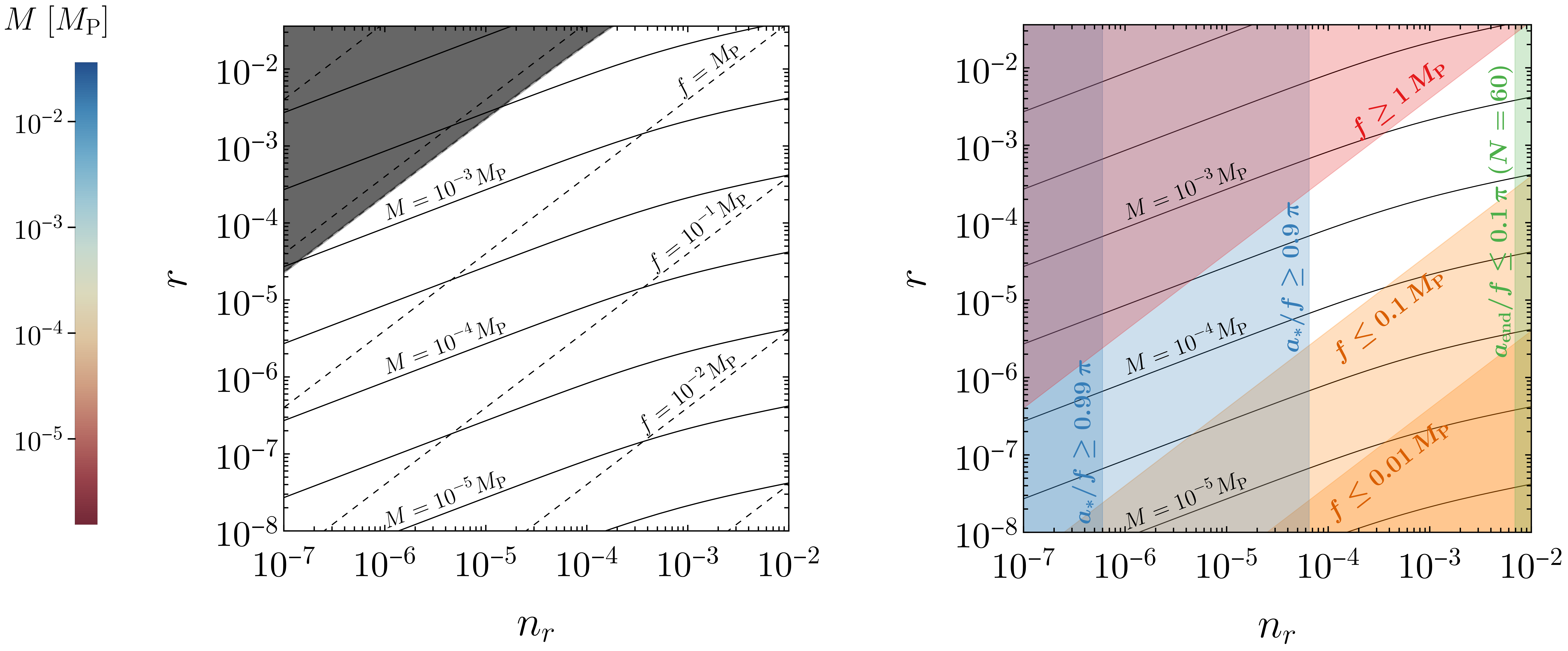
$\phi \sim \mathbf{5}\,, \quad \chi \sim \mathbf{3}$

$G = \mathrm{SO}(3) \times \mathbb{Z}_2^{(\phi)}$

$$V = -\frac{1}{2}\mu_\phi^2\phi^2 - \frac{1}{2}\mu_\chi^2\chi^2 + \frac{\lambda_\phi}{4}(\phi^2)^2 + \frac{\lambda_\chi}{4}(\chi^2)^2 + \frac{\varepsilon}{4}\phi^2\chi^2 + \frac{\zeta}{4}T^a_{AC}T^b_{CB}\phi_A\phi_B\chi^a\chi^b$$

No Topological Defect Production

Parameter Space



Accidental Inflation

GWs from Tachyonic Preheating

End of inflation: $m^2_{\chi^3} < 0$

↓

Tachyonic Preheating

G. N. Felder et al. *Phys. Rev. Lett. 87, 011601 (2001)*

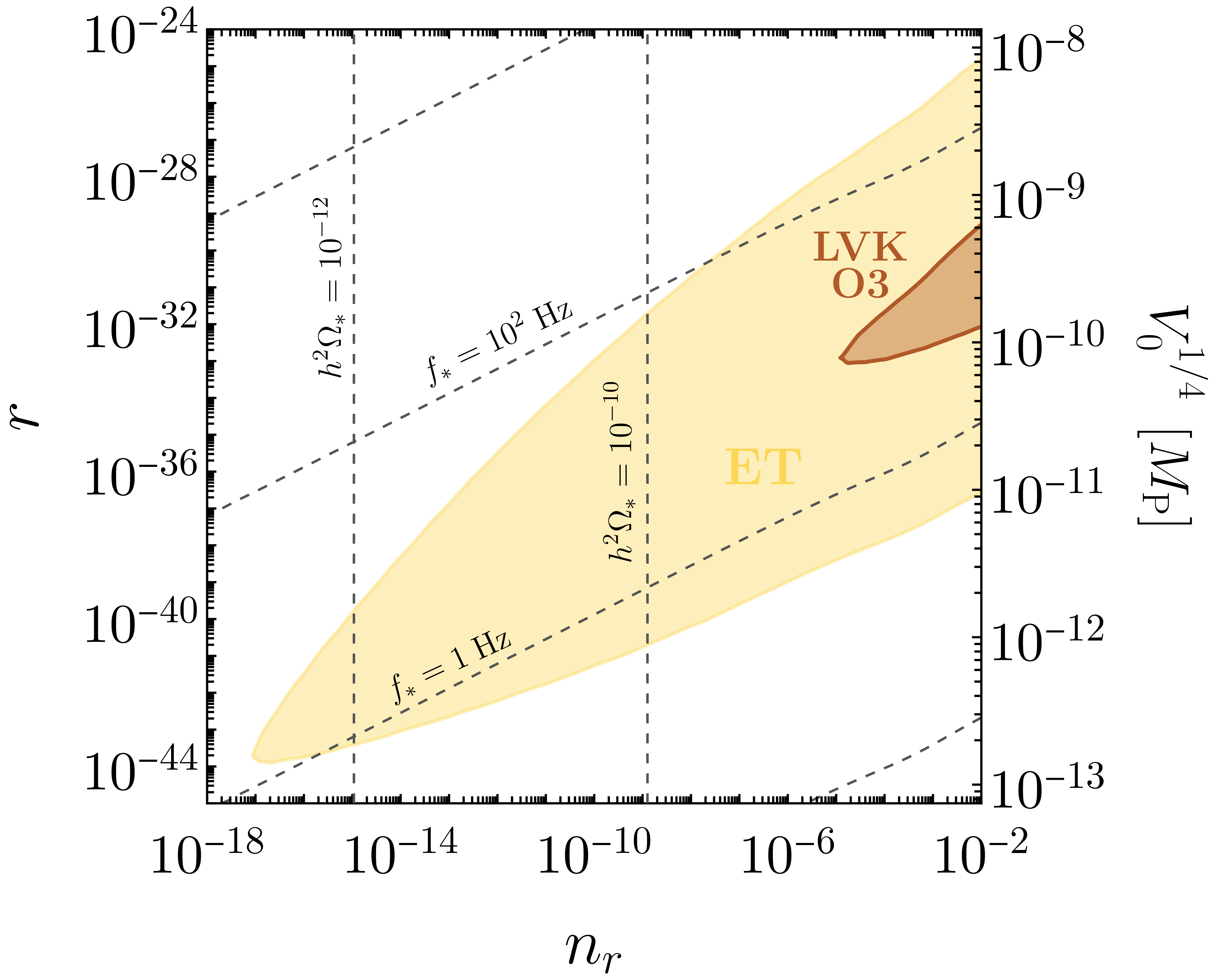
G. N. Felder et al. *Phys. Rev. D 64, 123517 (2001)*

Large "bubbly" inhomogeneities: $R_* \sim \dfrac{1}{k_*}$

$\Downarrow$

J. F. Dufaux et al.
Phys. Rev. D, vol. 76, p. 123517, 2007.

GWs:
$$\begin{cases} \nu_* \simeq 4 \times 10^{10}\ \mathrm{Hz} \dfrac{k_*}{\rho_{\rm inf}^{1/4}} \\ h^2\Omega_* \simeq 10^{-6} \left(\dfrac{H_{\rm inf}}{k_*}\right)^2 \end{cases}$$



Cosmic Strings

Accidental $\mathrm{U}(1)_\chi$ broken by $\begin{cases} \langle \phi \rangle = 0 \\ \langle \chi \rangle = v_\chi \end{cases}$ $\Longrightarrow$ Stable Local Cosmic Strings

$$\mu = 2\pi v_\chi^2$$

$$(G\mu)^{\mathrm{CMB}} \lesssim 10^{-7} \Longrightarrow V_0 \lesssim \text{few} \times 10^{14}\,\mathrm{GeV}$$

Domain Walls

$$V = -\frac{1}{2}\mu_\phi^2\phi^2 + \frac{\lambda_\phi}{4}(\phi^2)^2 - \mu_\chi^2\chi^*\chi + \lambda_\chi\left(\chi^*\chi\right)^2 + \delta\chi^{*2}\chi^2 + \frac{1}{2}\left(\kappa\chi^2\chi^2 + \mathrm{h.c.}\right) + \frac{\varepsilon}{2}\phi^2\left(\chi^*\chi\right) + \frac{\zeta}{2}T^a_{AC}T^b_{CB}\phi_A\phi_B\chi^{a^*}\chi^b$$

$$f_p \simeq 1.6 \times 10^{-7}\ \mathrm{Hz}\left(\frac{g_*(T_{\rm ann})}{100}\right)^{1/6}\frac{T_{\rm ann}}{\rm GeV}$$

$$h^2\Omega_{\rm GW}\left(f_p\right) \simeq 1.6 \times 10^{-5}\left(\frac{100}{g_*(T_{\rm ann})}\right)^{1/3}\frac{3}{32\pi}\,\tilde{\epsilon}\,\alpha_{\rm ann}^2\,\mathcal{S}(f/f_p)$$

$$\alpha_{\rm ann} \equiv \frac{\rho_{\rm DW}(t_{\rm ann})}{\rho_r(t_{\rm ann})} \simeq \frac{4}{3}C_d\,\mathcal{A}^2\frac{\sigma^2}{M_P^2\,\Delta V}$$

$$T_{\rm ann} = \left[\frac{45}{2\pi^2}\,\frac{g_*(T_{\rm ann})^{-1}}{C_d^2\,\mathcal{A}^2}\,\frac{M_{\rm P}^2\Delta V^2}{\sigma^2}\right]^{1/4}$$