21st November 2023

Walls, Bubbles & Doom

the Cosmology of HEFT.

Coming Soon to arXiv.

Mia West

in collaboration with Rodrigo Alonso, Juan Carlos Criado & Rachel Houtz.

SMEFT

ew symmetry linearly realised

$SU(3)_c \times SU(2)_L \times U(1)_Y$

$H = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi_1 + i\phi_2 \\ \phi_4 + i\phi_3 \end{pmatrix}$ or $\vec{\phi} = \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \\ \phi_4 \end{pmatrix}$

global $O(4)$ custodial symmetry

$\vec{\phi} \to O\vec{\phi}$

V_{SMEFT} is analytic function of $H^\dagger H$

HEFT

ew symmetry non-linearly realised (inclusive)

$SU(3)_c \times U(1)_{em}$

most general EFT parameterisation of low energy physics involving SM DoF.

h and $\vec{\varphi} = \begin{pmatrix} \varphi_1 \\ \varphi_2 \\ \varphi_3 \\ \sqrt{v^2 - \vec{\varphi}\cdot\vec{\varphi}} \end{pmatrix}$

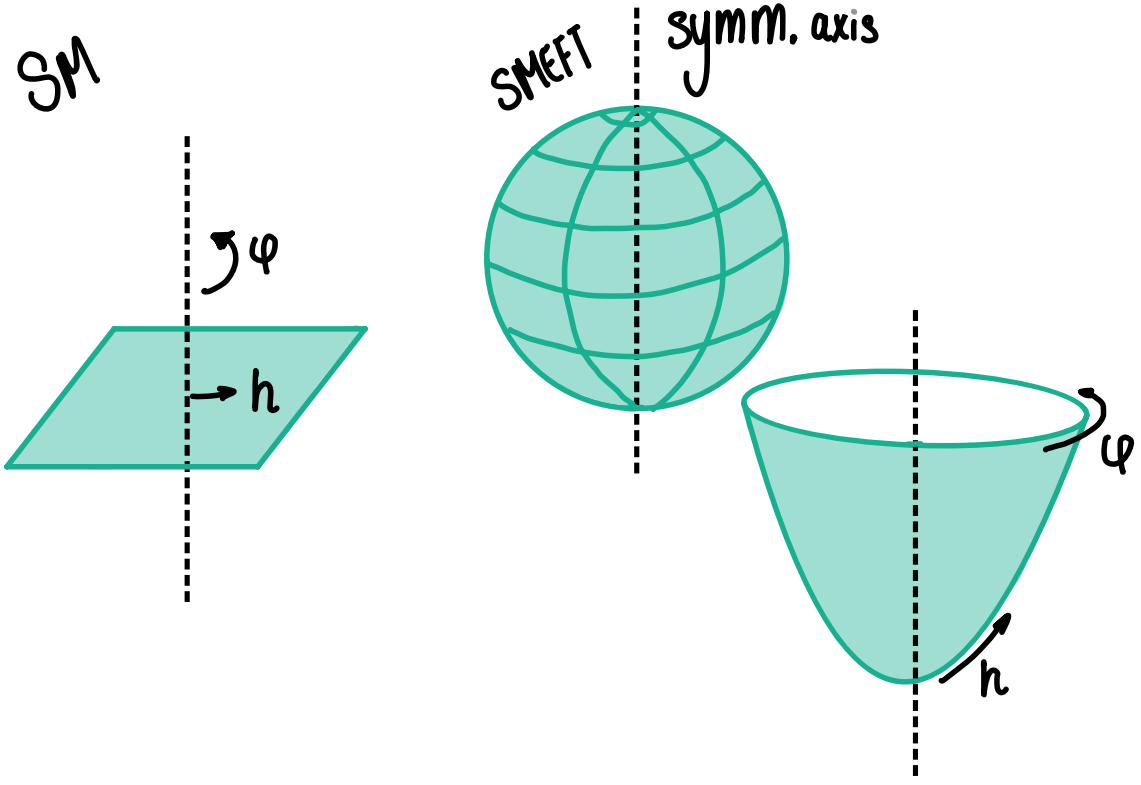
$h \to h$ and $\vec{\varphi} \to O\vec{\varphi}$

$V_{HEFT} = V(h)$

- Represent HEFTs as manifolds.
- Higgs & Goldstone boson fields act as *coordinates*.

[arXiv:1605.03602; R. Alonso, A. Manohar, E. Jenkins]

- HEFT ⊃ SMEFT ⊃ SM



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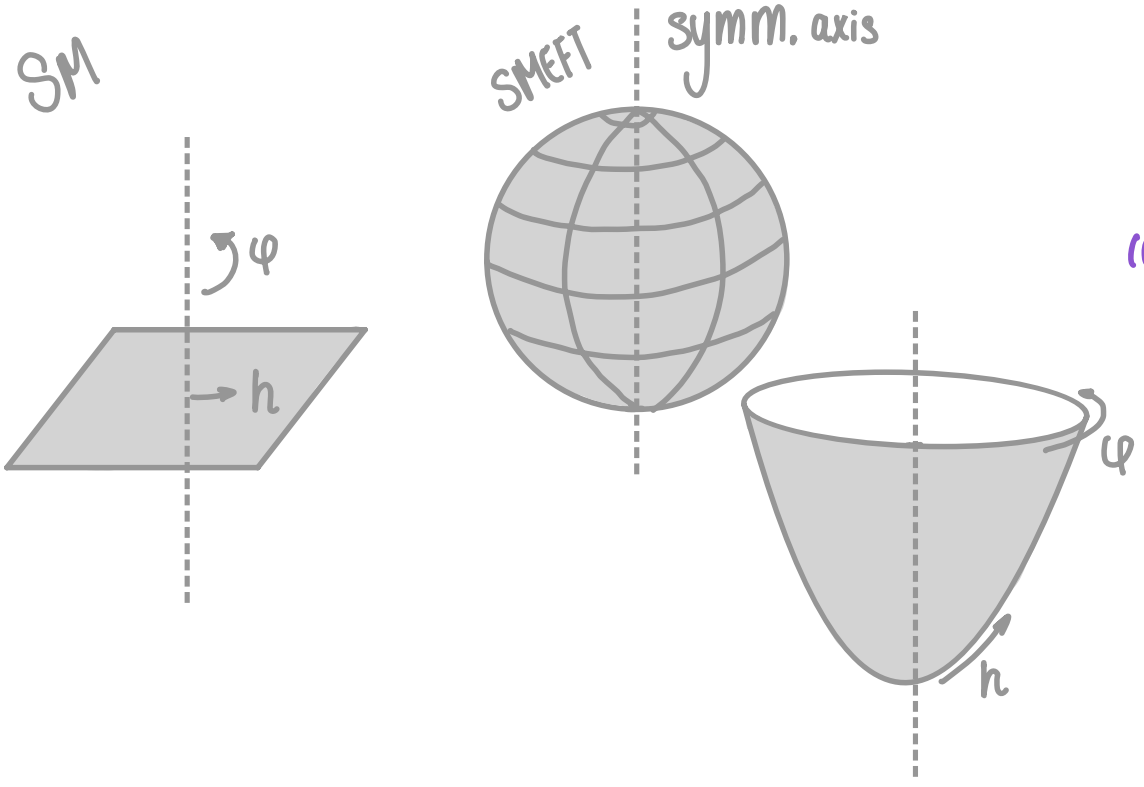
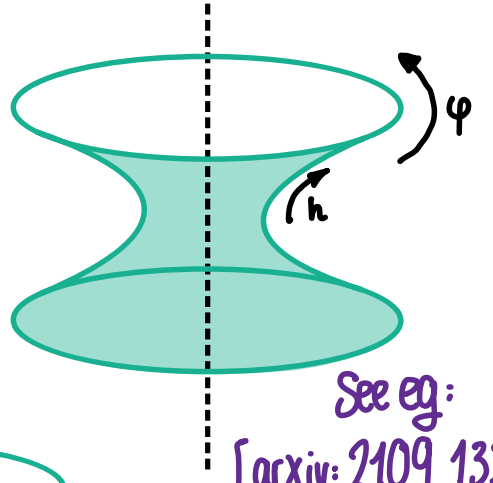
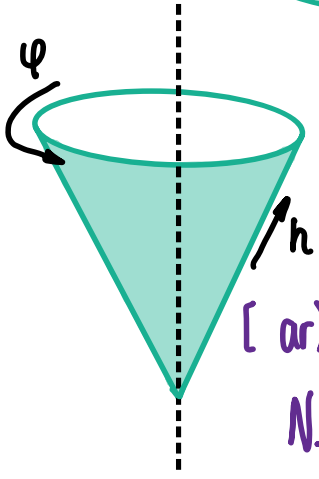


HEFT \ SMEFT (non-linear) ↑ (exclusive)



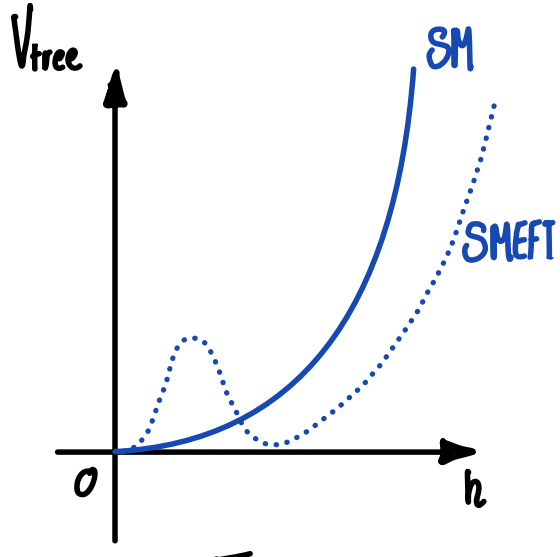
See eg: [arXiv: 2109.13290; R. Alonso & MW]



[arXiv: 2008.08597; T. Cohen, N. Craig, X. Lu, D. Sutherland]

HEFT Effective Potential

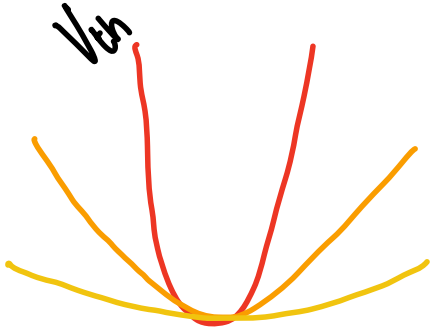
V_{EFF} =

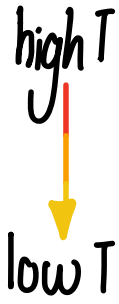


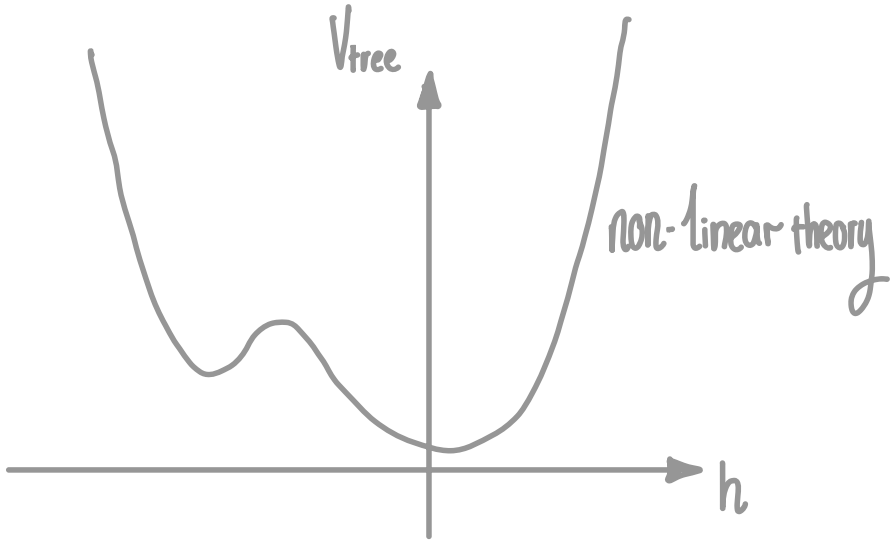
TREE

+

THERMAL







(+ loops &
higher-order terms &
resummations...) 5

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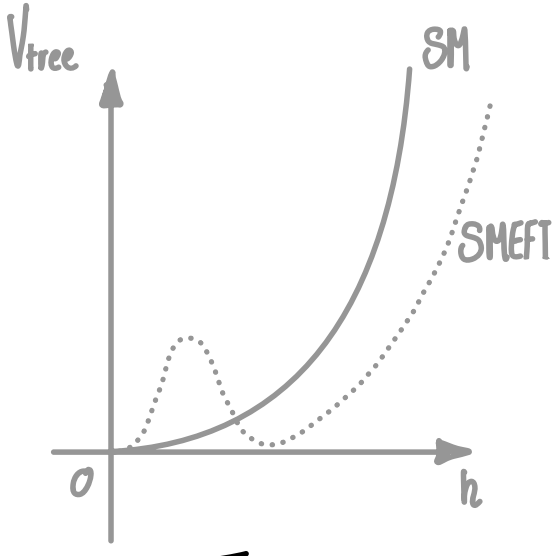

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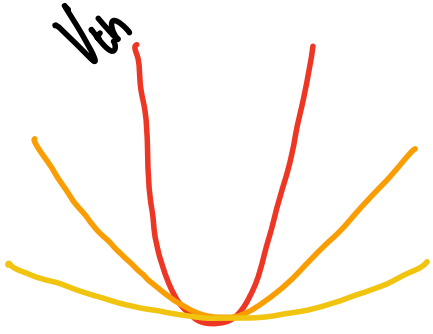
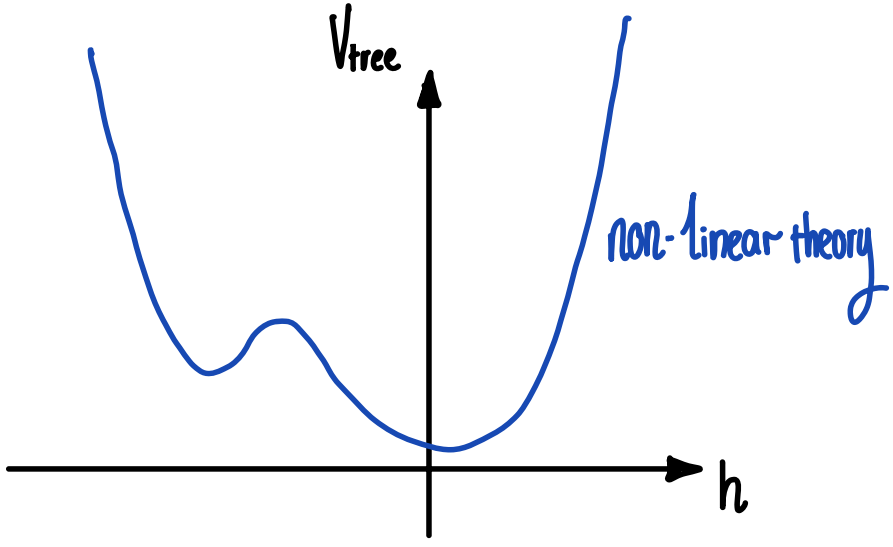


high T

low T



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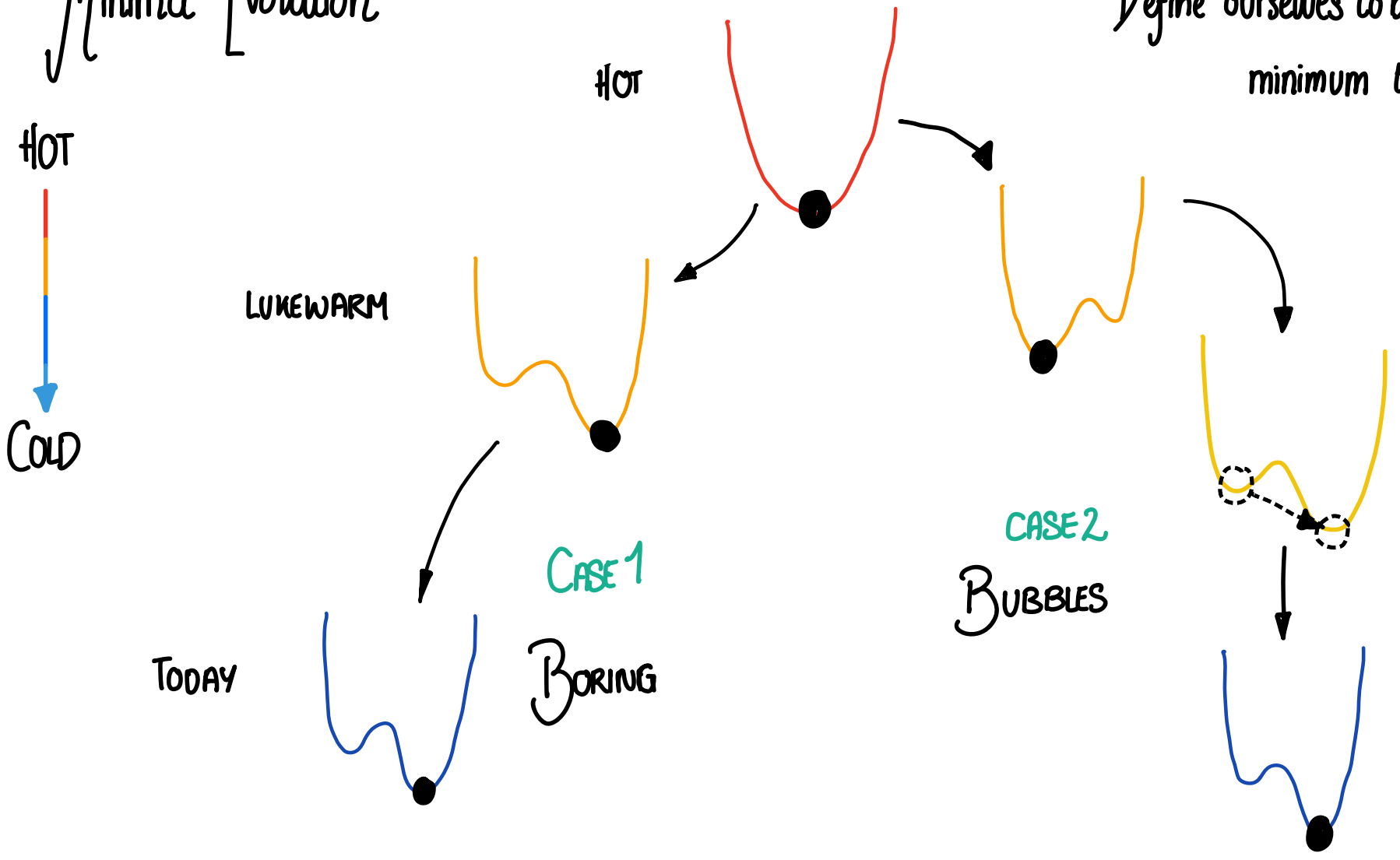
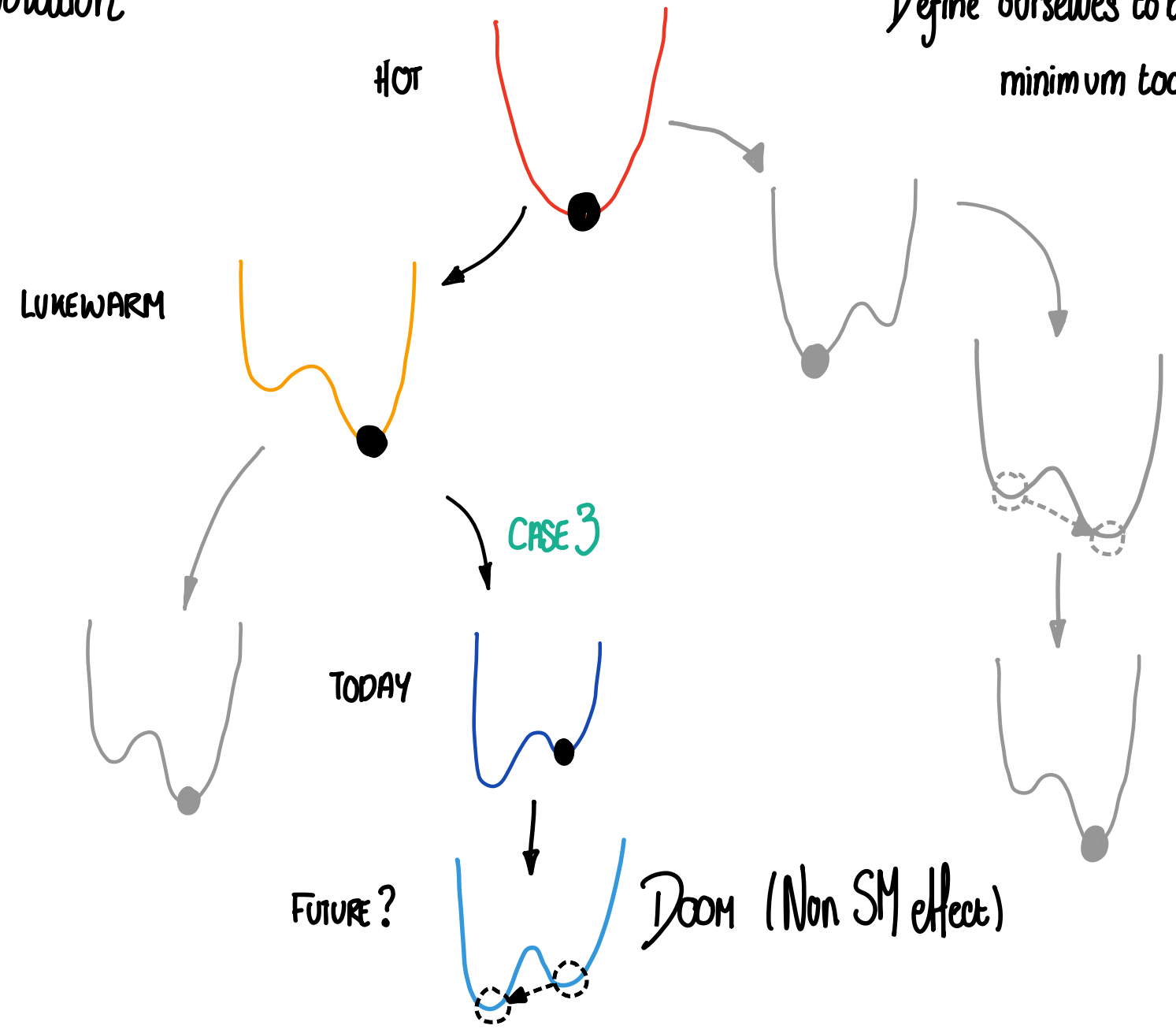
Minima Evolution



Define ourselves to be in RHS minimum today.

Minima Evolution



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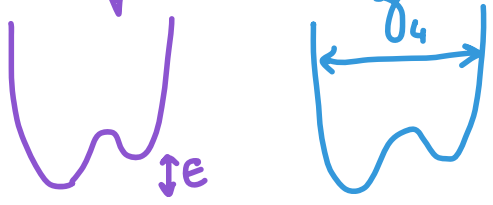
An Example Non-Linear Theory Scenario

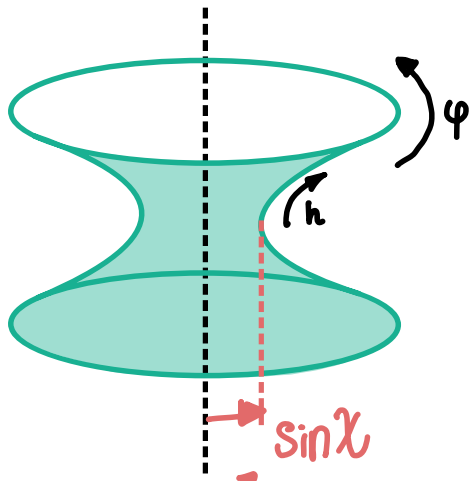
$$\mathcal{L}_{HEFT} = \frac{v^2}{4}F(h)^2\,\mathrm{Tr}\left[\partial_\mu U(\varphi)\,\partial^\mu U(\varphi)\right] + \frac{1}{2}\partial_\mu h\,\partial^\mu h$$

$$+ \frac{v^2}{8}F(h)^2\left[2g^2 W^+_\mu W^-_\mu + (g^2+g'^2)\,Z_\mu Z^\mu\right]$$

$$V_{tree}$$

$$+ \frac{m_h^2}{2}h^2 + \frac{m_h\sqrt{\lambda}}{2}\gamma_4(1-\epsilon)h^3 + \frac{\lambda}{8}\gamma_4^2 h^4 + \dots$$





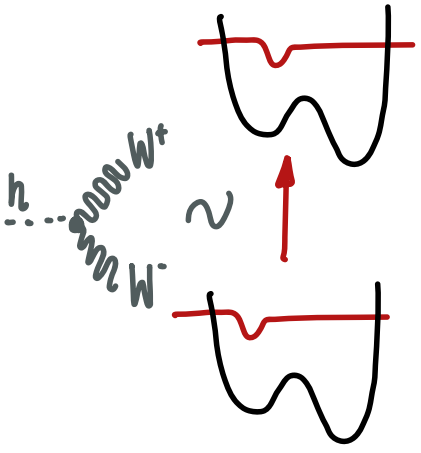
$$F(h) = \sqrt{\sin^2\chi + \cos^2\chi\left(1+\gamma_a\frac{h}{v}\right)^2}$$

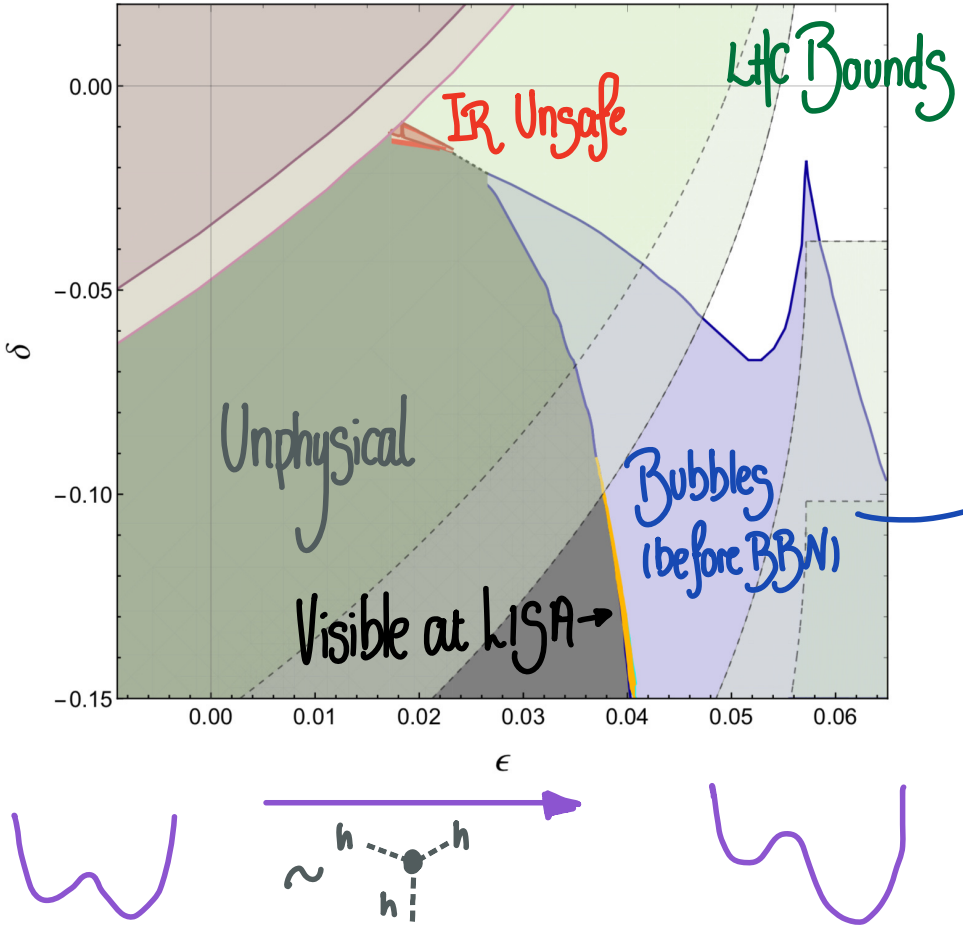
shifts thermal corrections

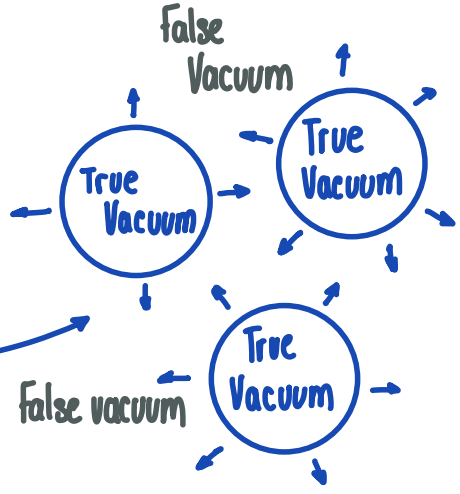
+ higher order derivatives & potential terms

Gravitational Wave Phenomenology in Case 2 - Bubbles!

$\gamma_4 = 1.6 \; ; \; \chi = \sqrt{0.1}$







See Oliver Gould's talk

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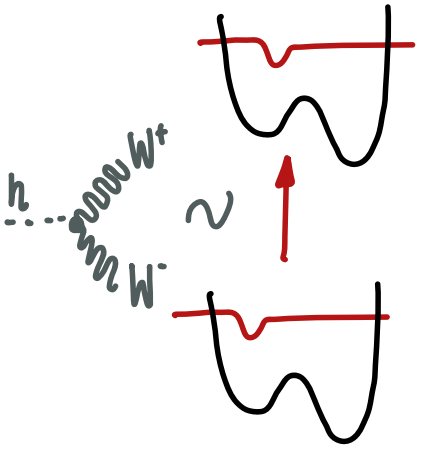

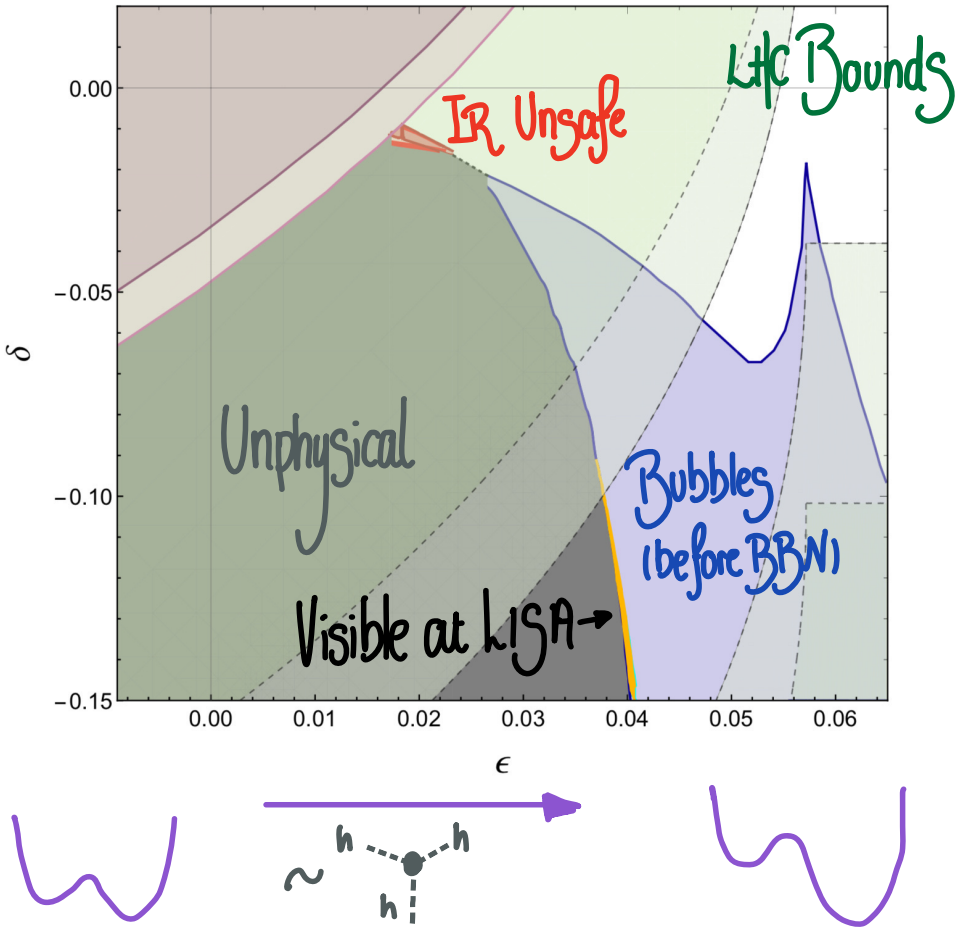

SUMMARY: • lots of interesting physics here (sphalerons, domain walls, SM limits & strange potentials) ↗ or lack thereof?

• and we've only scratched the surface.