2nd June 2023

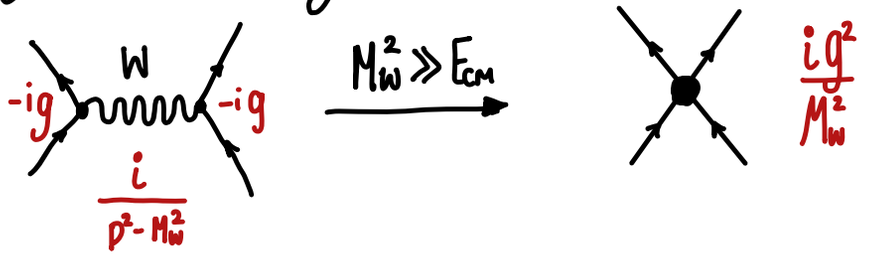
Cosmological History of the Higgs Effective Field Theory (HEFT)

Mia West

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

What is Effective Field Theory?

Top Down: four fermi theory



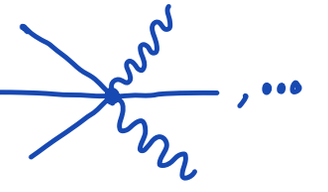
Bottom Up: Standard Model EFT (SMEFT)

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_{i=1}^{n_d} \frac{C_i^{(d)}}{\Lambda^d} Q_i^{(d)} \quad \text{for } d \geq 4.$$

$C_i^{(d)}$: Wilson Coefficients

Λ: Scale of new physics

$Q_i^{(d)}$: Operators of SM fields obey $SU(3)_c \times SU(2)_L \times U(1)_Y$

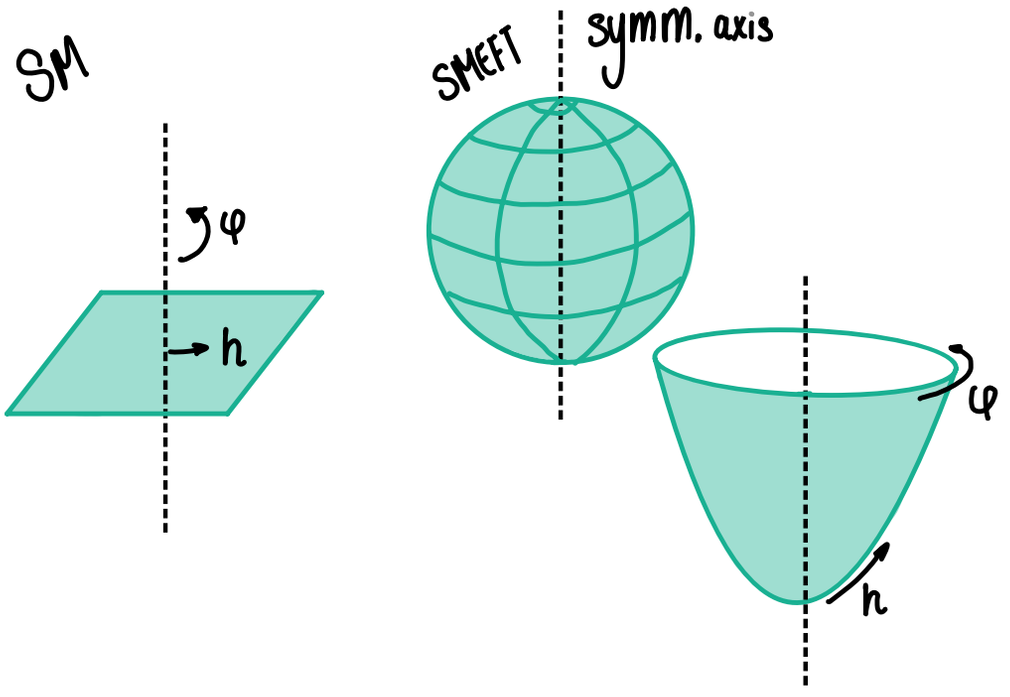


What is Higgs Effective Field Theory (HEFT)?

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

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

- HEFT ⊃ SMEFT ⊃ SM

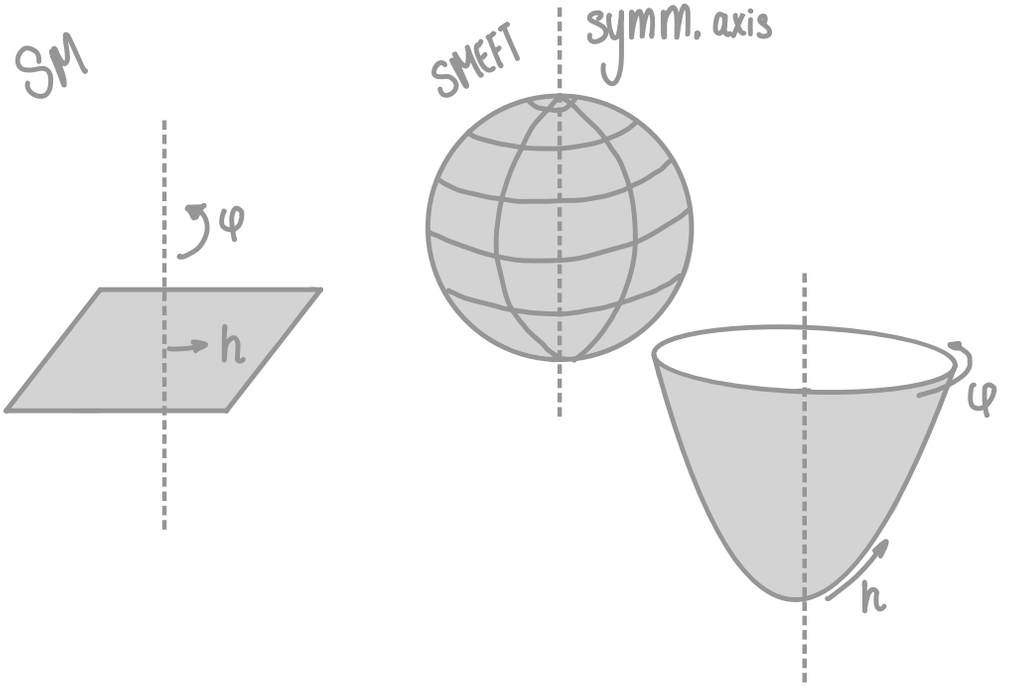


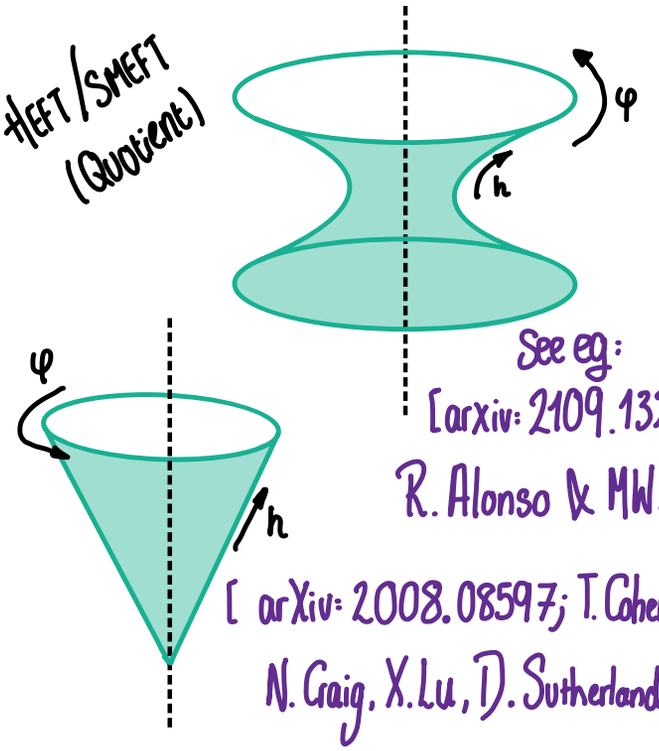
What is Higgs Effective Field Theory (HEFT)?

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

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

- HEFT ⊃ SMEFT ⊃ SM



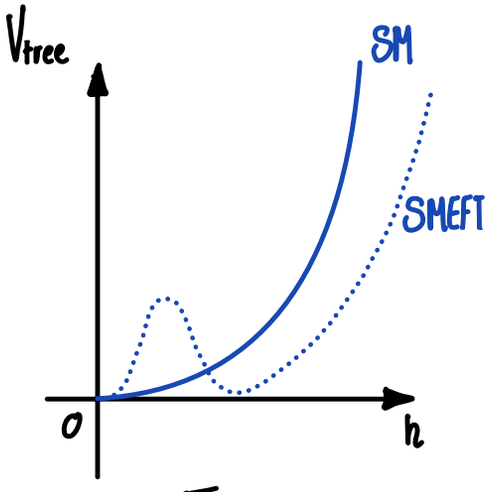


See eg:
[arXiv: 2109.13290; R. Alonso & MW]

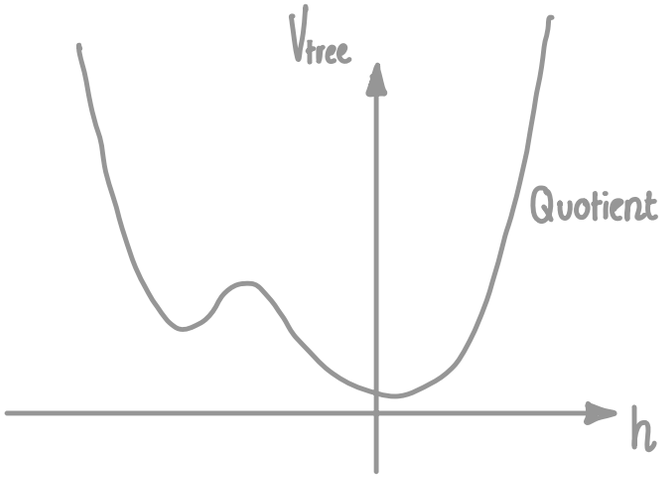
[arXiv: 2008.08597; T. Cohen, N. Craig, X. Lu, D. Sutherland]

HEFT Effective Potential

$V_{EFF} =$

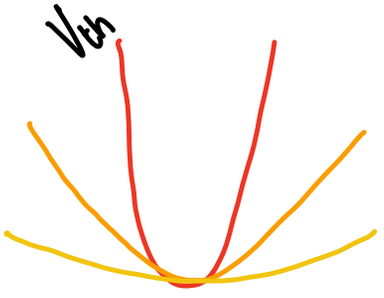


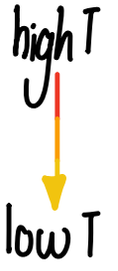
TREE



$+$

THERMAL

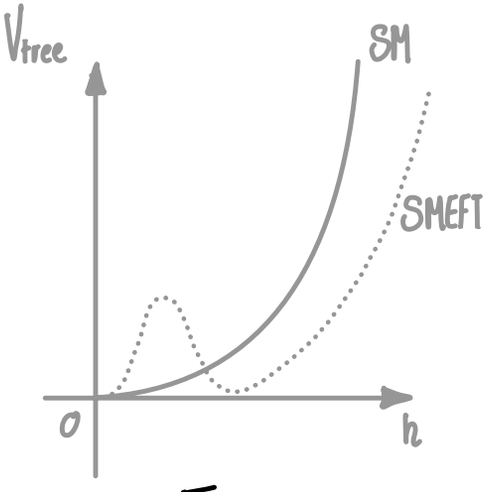




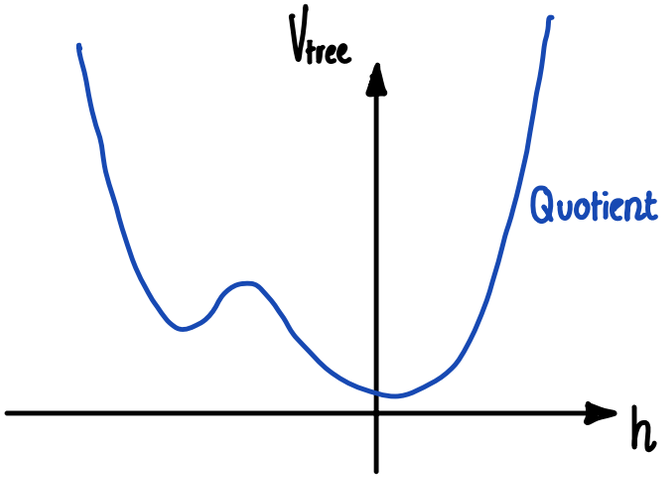
(+ loops &
higher-order terms &
resummations...)

HEFT Effective Potential

V_{EFF} =

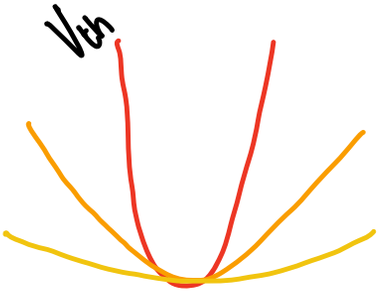


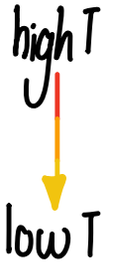
TREE



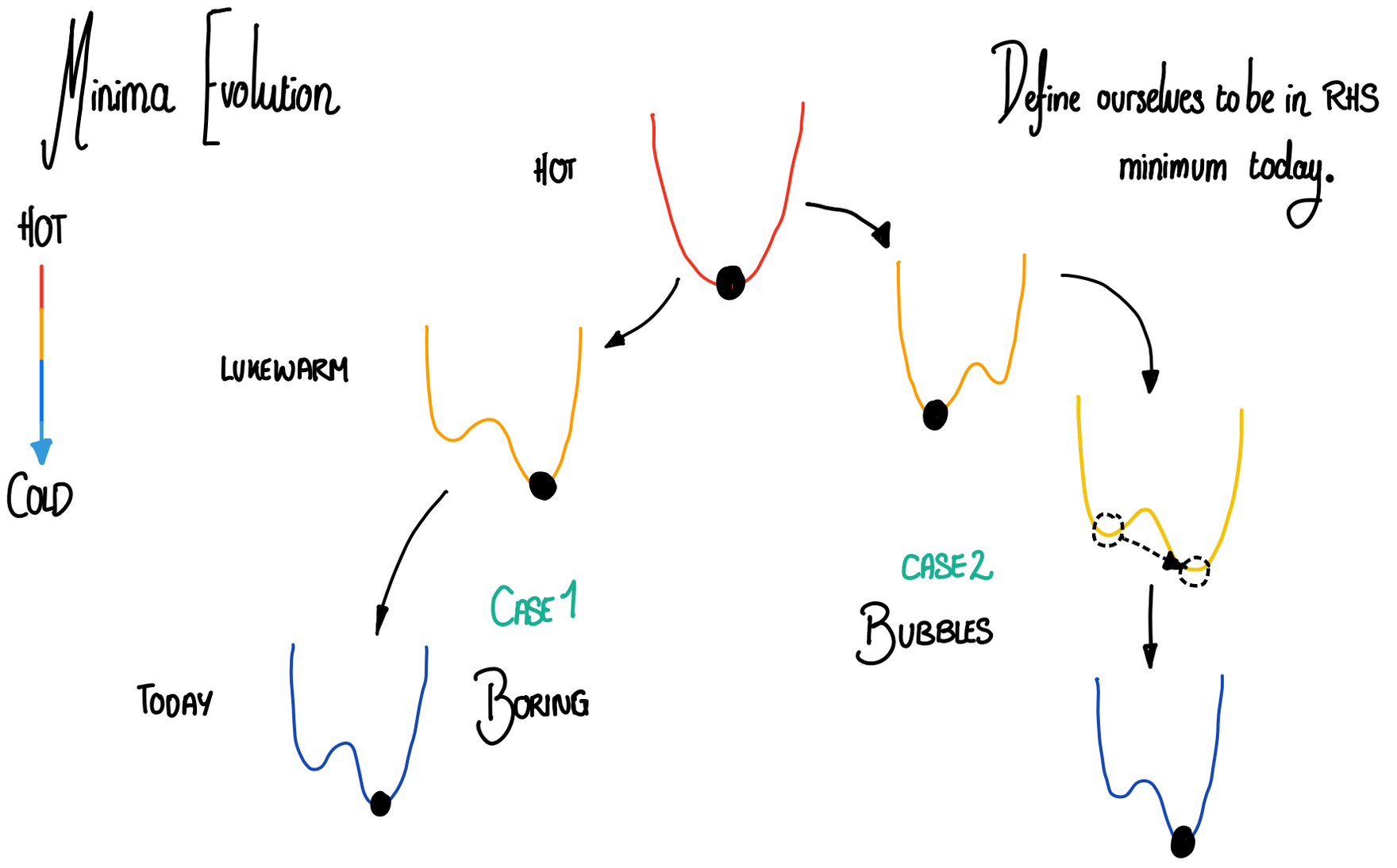
+

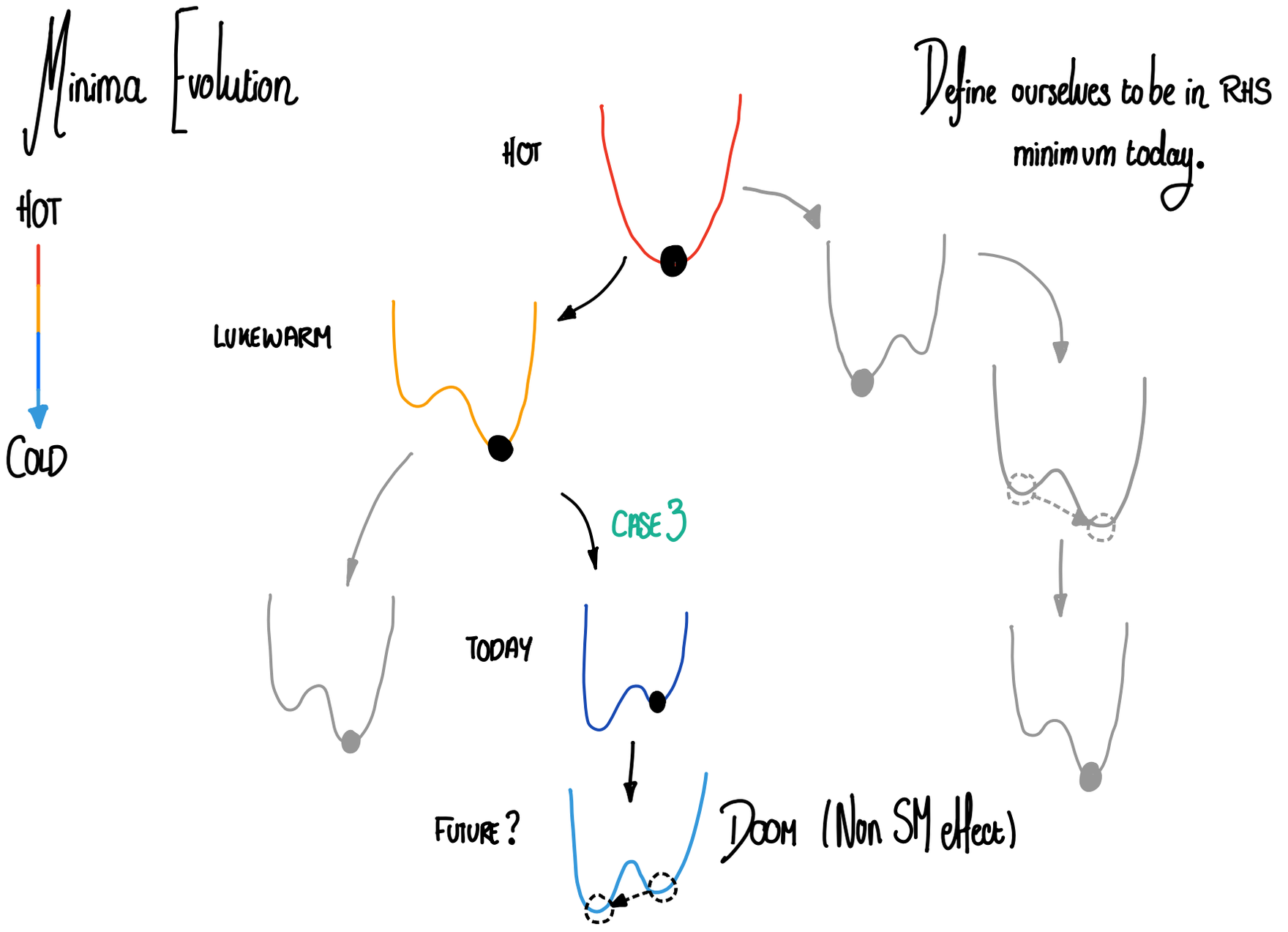
THERMAL





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


Minima Evolution
HOT
COLD
HOT
LUKEWARM
TODAY
CASE 1
BORING
CASE 2
BUBBLES
Define ourselves to be in RHS minimum today.


Minima Evolution
HOT
COLD
HOT
LUKEWARM
CASE 3
TODAY
FUTURE?
DOOM (Non SM effect)
Define ourselves to be in RHS minimum today.

An Example Quotient Scenario

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

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

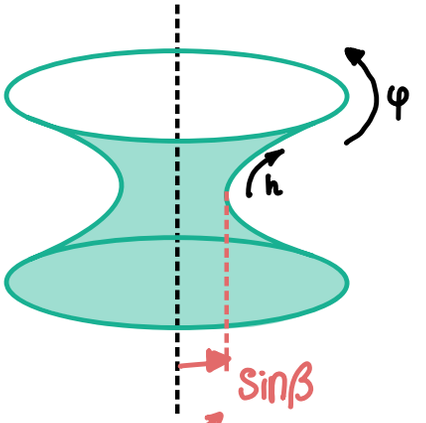
$$V_{\text{tree}}$$

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

ϵ

γ_4

+ higher order derivatives & potential terms



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

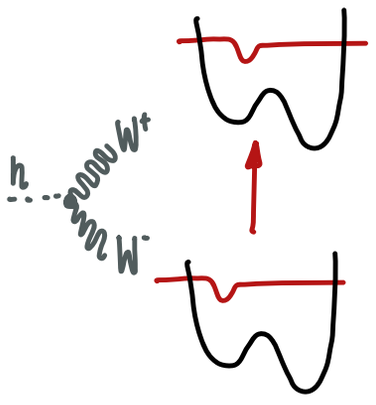
γ_a

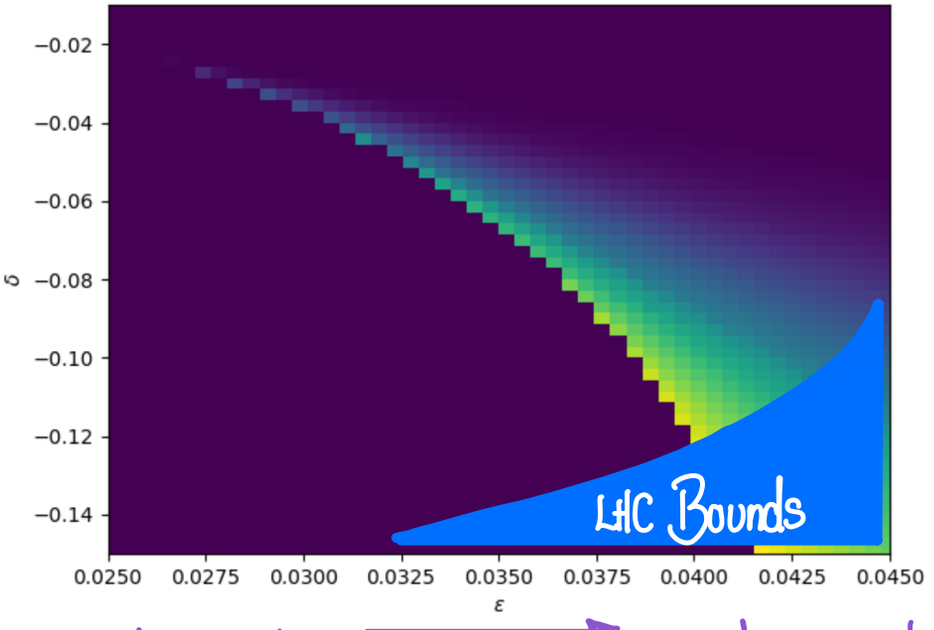
shifts thermal corrections

Gravitational Wave Phenomenology in Case 2 - Bubbles!

$\gamma_4 = 1.4$; $\beta = \sqrt{0.1}$

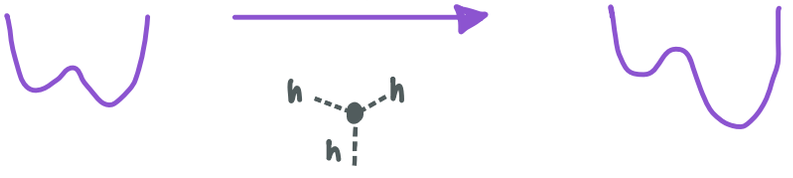
(Preliminary & Schematic)





Latent Heat of phase transition

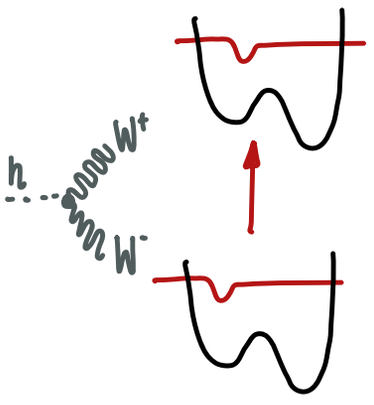
← Bubbles do not nucleate before BBN.

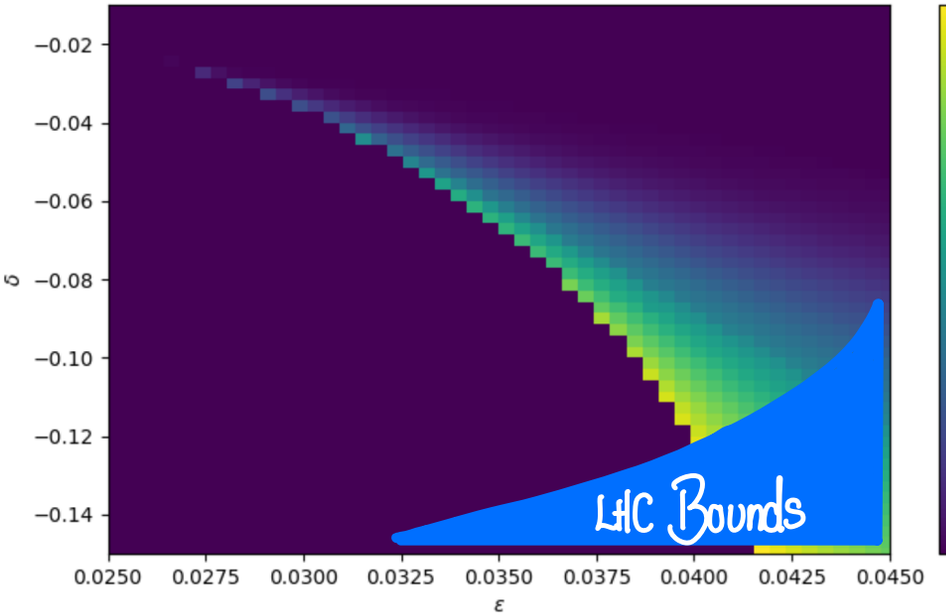


Gravitational Wave Phenomenology in Case 2 - Bubbles!

$\gamma_4 = 1.4$; $\beta = \sqrt{0.1}$

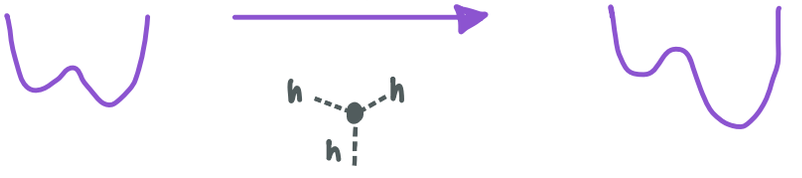
(Preliminary & Schematic)





Latent Heat of phase transition

Bubbles do not nucleate before BBN.



Summary:• We've only scratched the surface of what's possible in HEFT.

- So much more interesting physics: Domain walls, strange potentials,...