KING'S College LONDON

Shaping the Vacuum: The Criticality Paradigm

MITP Youngst@rs

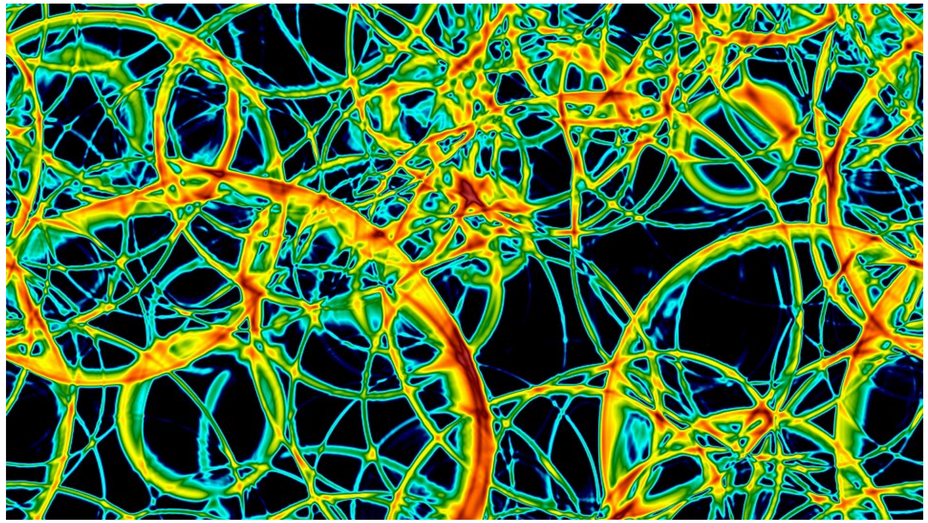
Shaping the Universe: Framework and Footprints of Cosmological Phase Transitions

Maximilian Detering, 27 January 2026

What is shaping the Higgs potential?

Disclaimer

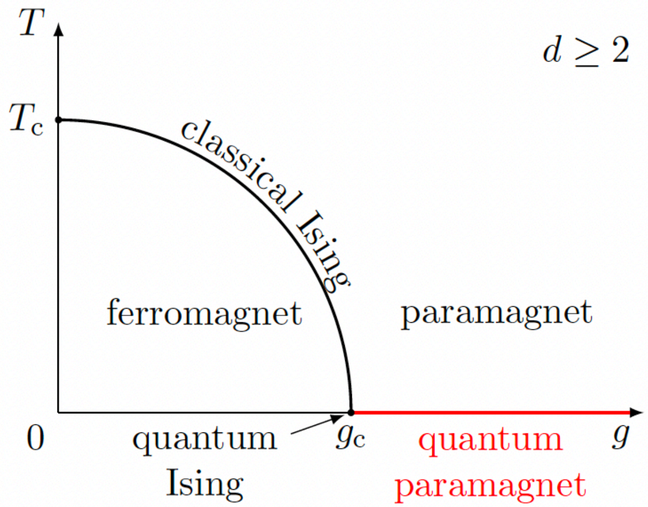
Typically:



Classical (thermal) phase transitions

Thermodynamical parameters varied

This talk:



Quantum phase transitions

Theory parameters varied
(transitions for T=0)

The Higgs Potential

Most of the problems of the Standard Model originate from the Higgs interactions

$$\mathcal{L}_{\text{int}} = (y_{ij}\bar{\Psi}_i\psi_j H + \text{h.c.}) - V(H)$$

Flavour puzzle

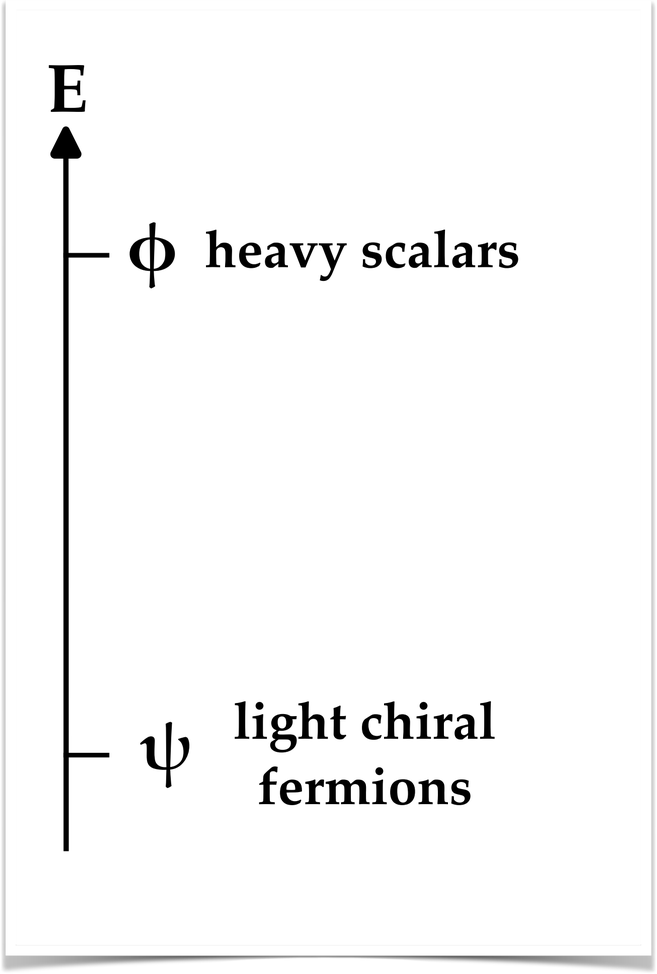
Cosmological constant problem

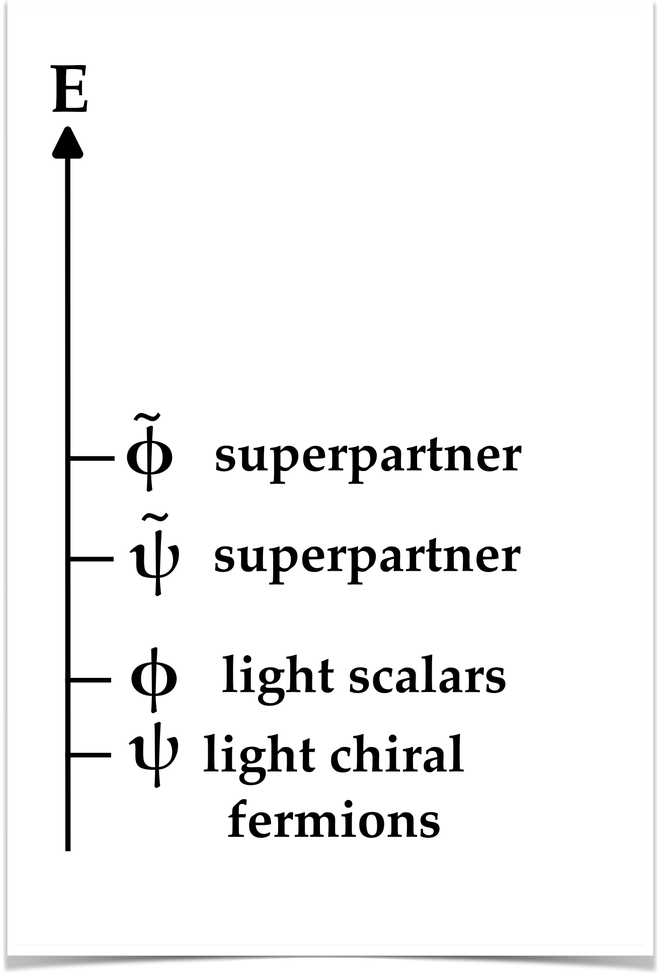
$$V(H) = \Lambda_{CC}^4 - m^2|H|^2 + \lambda|H|^4$$

Hierarchy problem

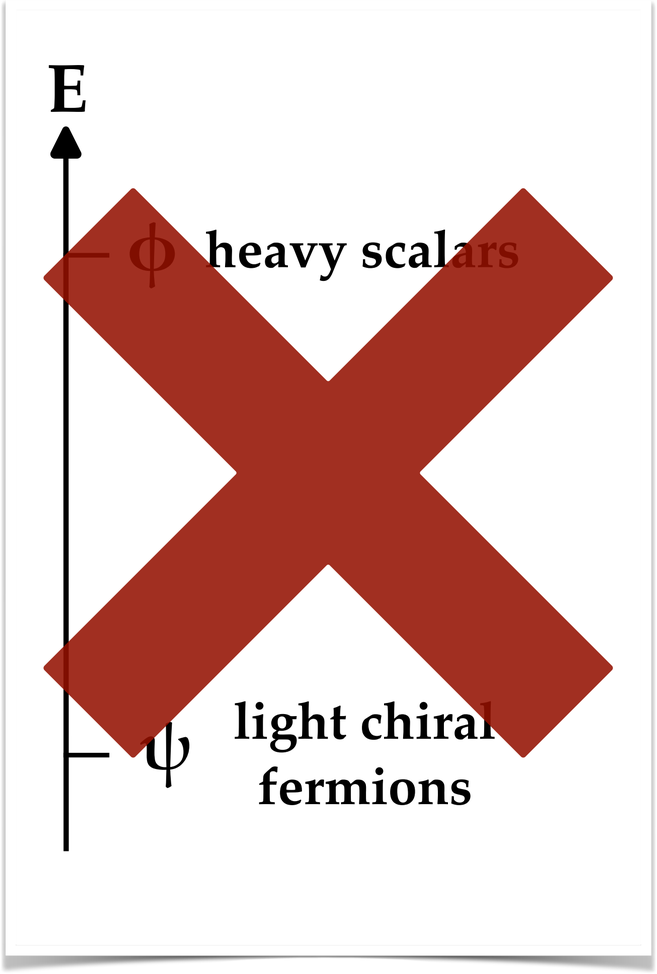
Stability of the potential

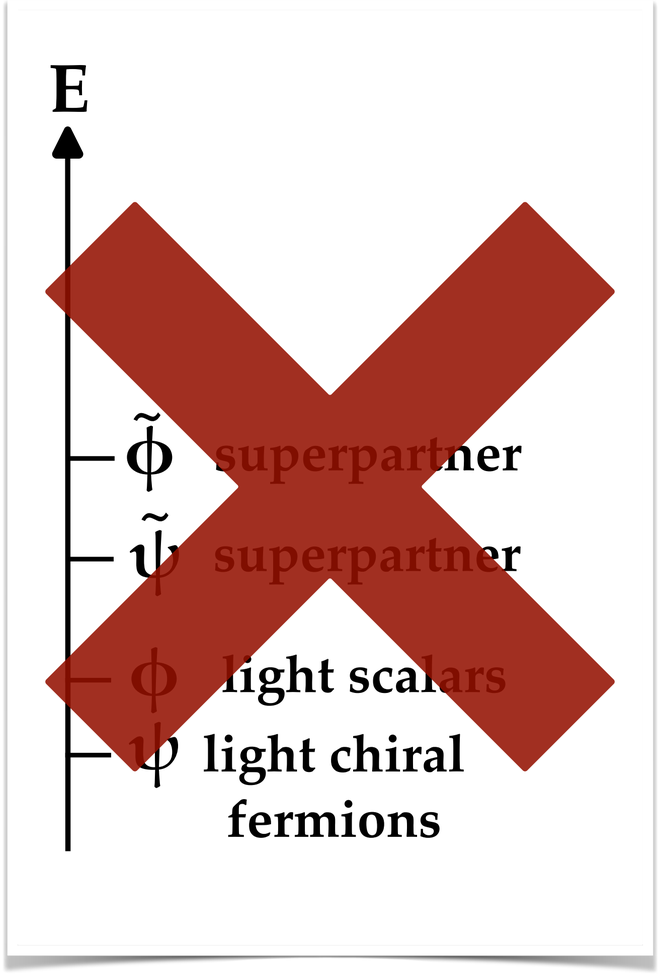
The Natural Spectrum

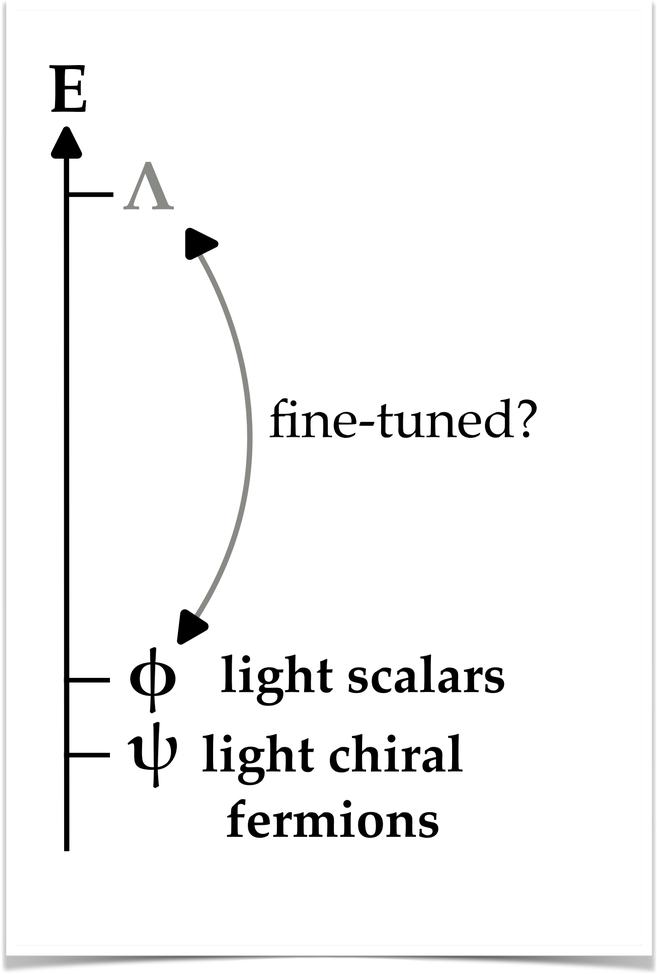




The Natural Spectrum



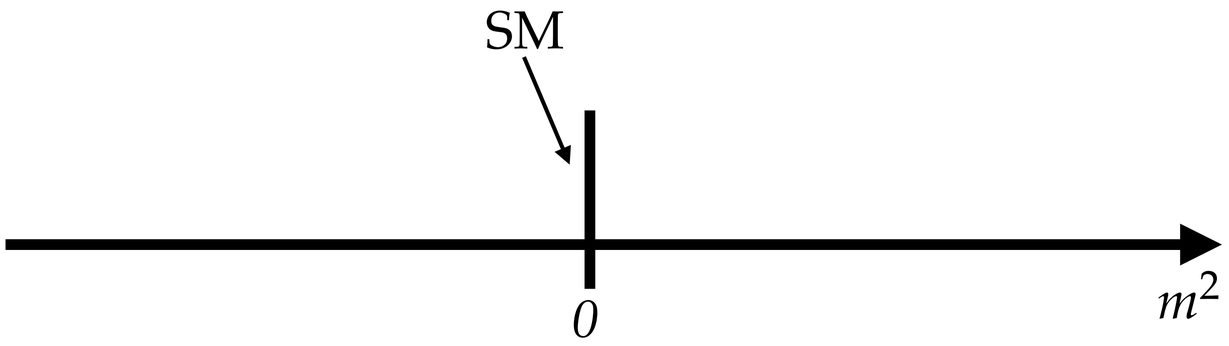




Criticality — A New Paradigm?

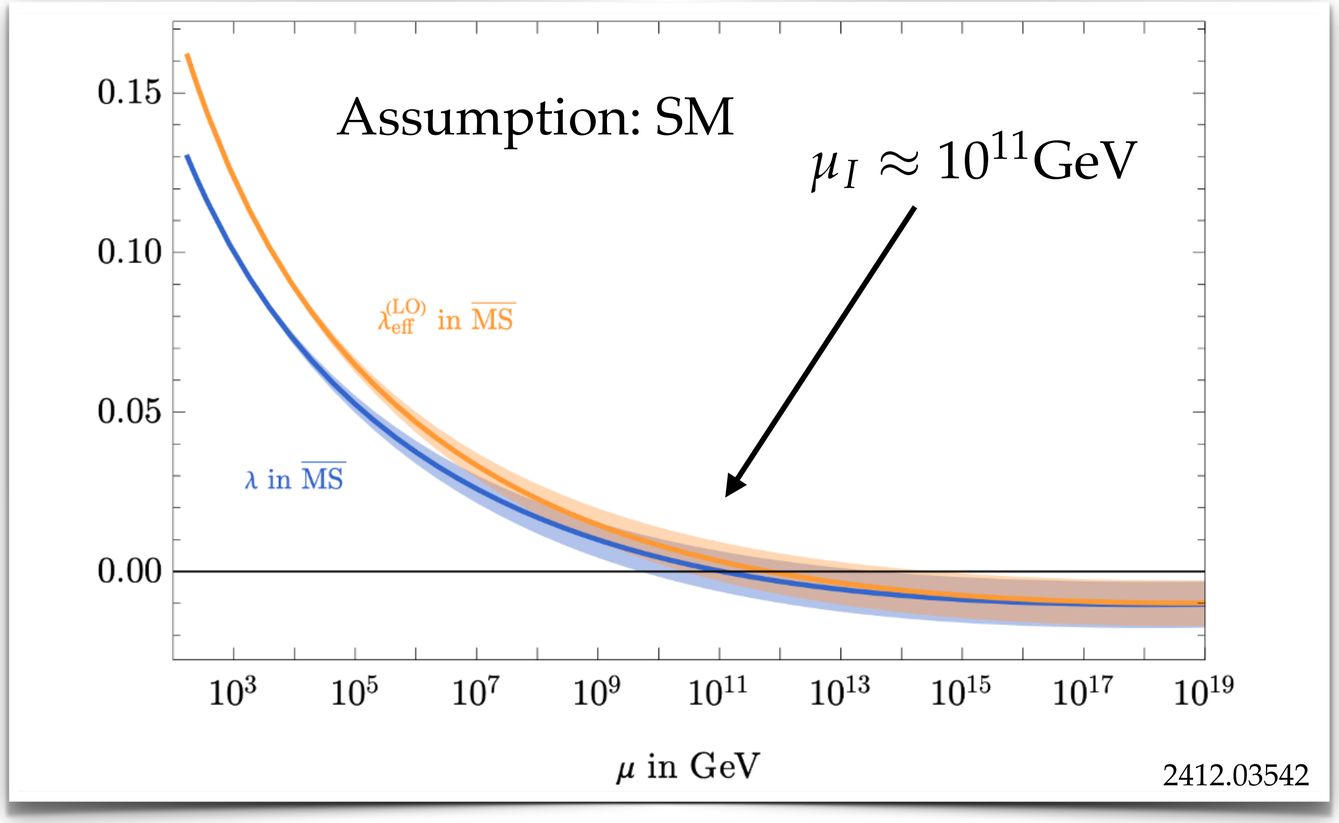
'06 Giudice, Rattazzi
'15 Giudice

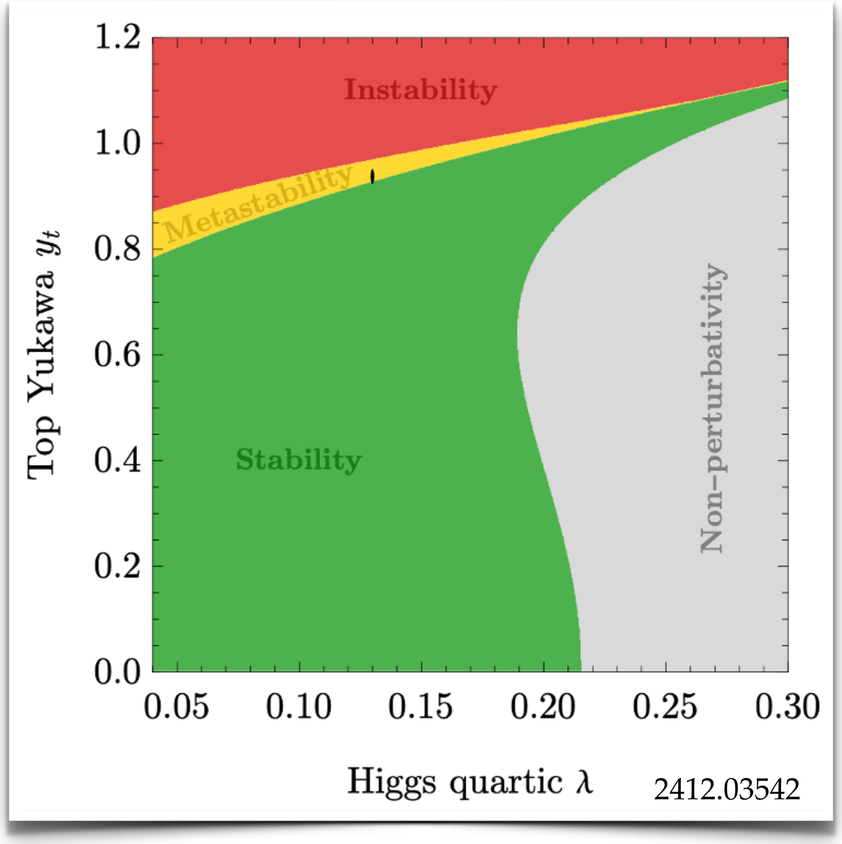
Characterising the "fine-tuning" as a *criticality condition*



Stability of the Higgs potential

'13 Buttazzo, Degrassi, Giardino, Guidice
'12 Degrassi, Di Vita, Elias-Miro, Espinosa, Giudice





Criticality

Why does the Universe appear to be critical?

Could these tunings be related?

An indication for an underlying phenomenon?

Possible Explanations — Mechanisms

Self-organised localisation

['21 Guidice, McCullough, You]

- Higgs mass promoted to effective parameter depending on background scalar field
  $m^2H^2 \to (m^2 + g\phi)H^2$
- statistical evolution during inflation localises effective Higgs mass at near-critical values

Landscape Transition Dynamics

['19 Khoury, Parrikar]

- Transition dynamics on string landscape
- preferential selection of metastable vacua

Higgs-driven crunching

['25 Benevedes,, Ismail, Steingasser]

- landscape where the Higgs mass is scanned across different patches of the universe
- patches with a large, natural value of the Higgs mass "crunch" and disappear
- patches with small enough Higss mass develop metastable EW vacuum

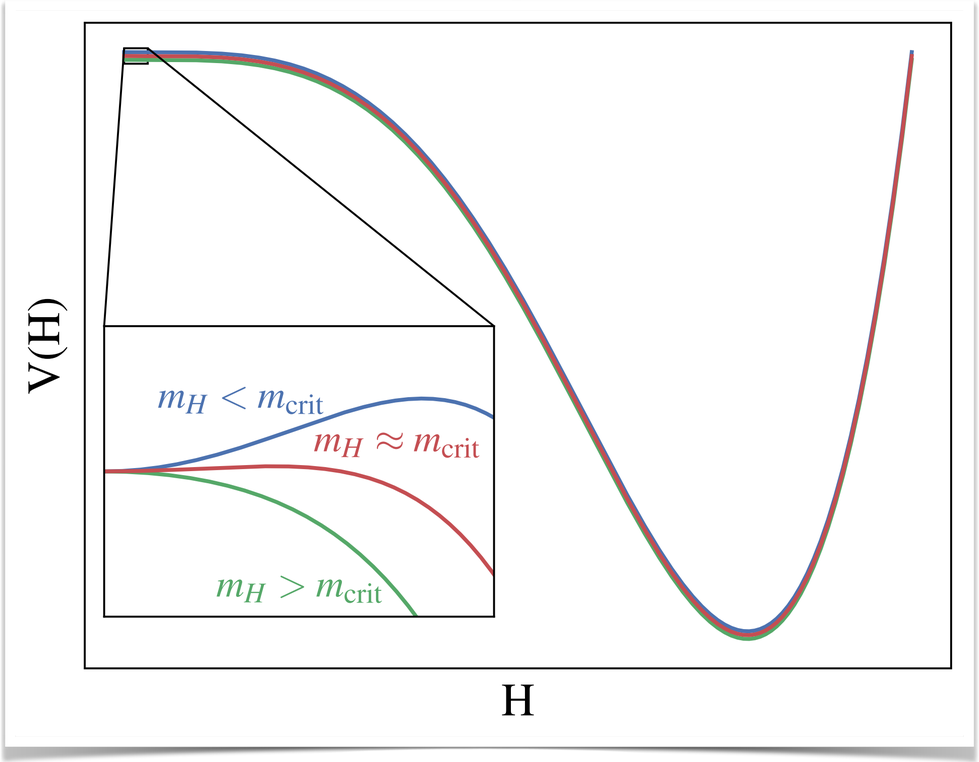
Higgs Criticality

’23 Kaiser, Steingasser
’24 Steingasser
’25 Detering, Enguita, Gavela, Steingasser, You
…

mechanisms relevant for first-order (quantum) phase transitions

Unfortunately, both tunings may not be related in the SM …

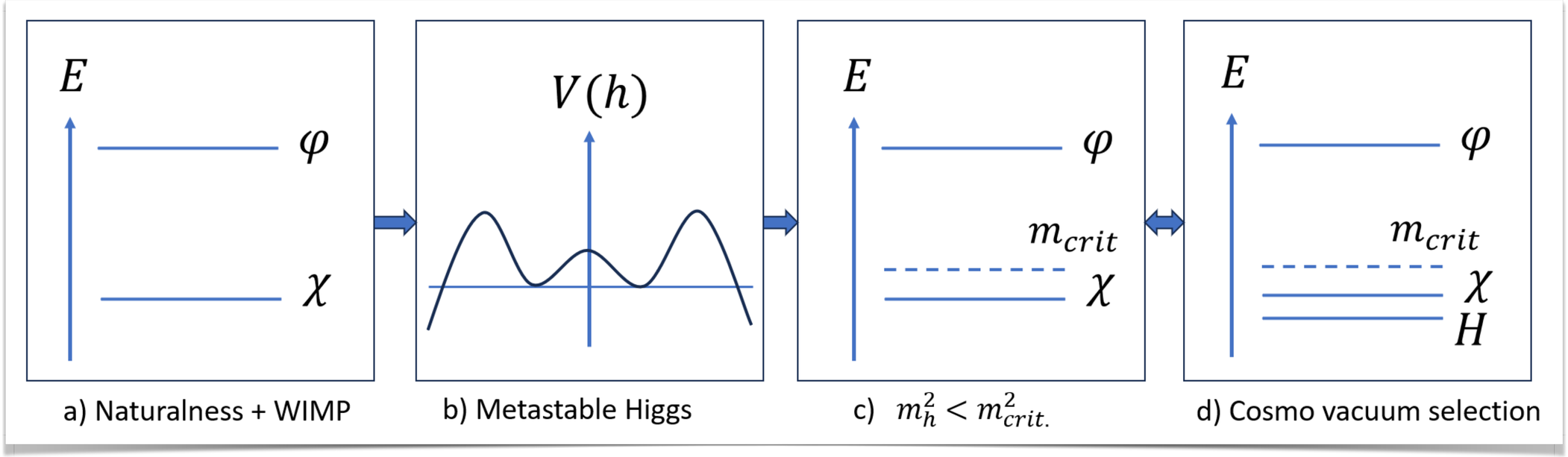
… but in extensions thereof!



universal metastability bound: $m_h^2 \lesssim |\beta_\lambda(\mu_I)|\mu_I^2$

Criticality — A Natural Expectation?

'25 Detering, Steingasser, You



Critical Footprints

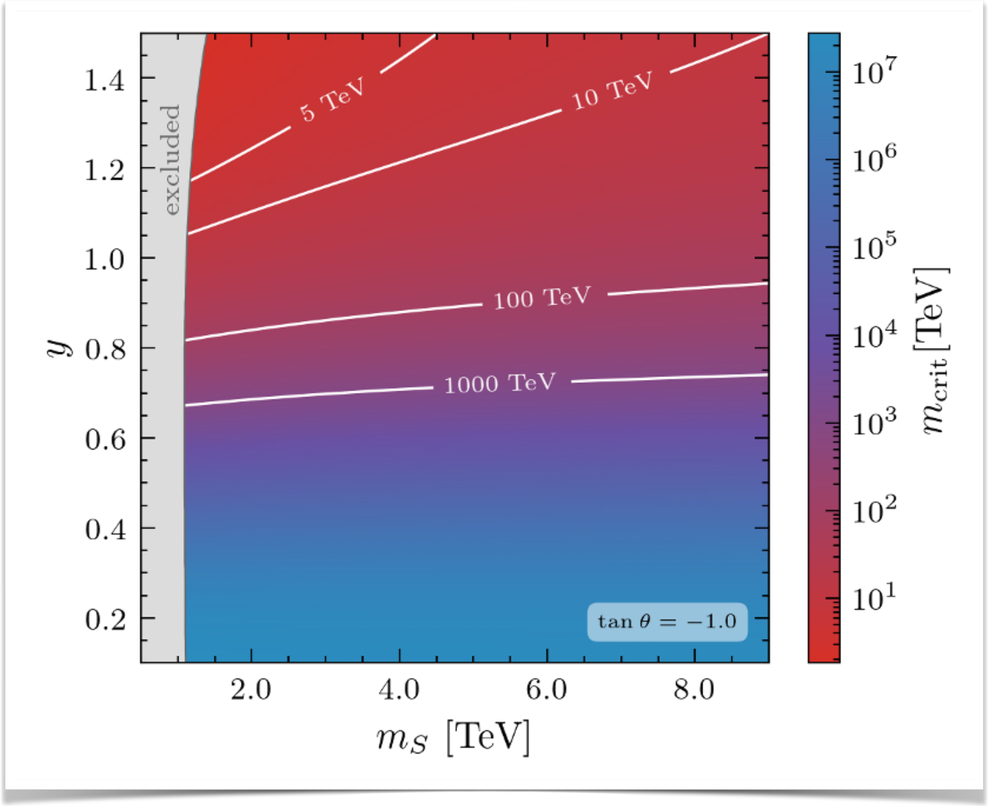
Dark Matter — An Example: The Singlet-Doublet Model

Consider SU(2) singlet and vector-like doublet

$$\mathscr{L}_{int} = -m_S \psi^c \psi - m_D \chi_d \cdot \chi_u - y_1 \chi_u H^\dagger \psi - y_2 \chi_d \cdot H \psi + \text{h.c.}$$

⇒ can give rise to dark matter
within the celebrated WIMP miracle

⇒ requires a small Higgs mass for
existence of EW symmetry broken in IR



Critical Footprints

Dark Matter — An Example: The Singlet-Doublet Mo

Many other models, see e.g.

ALPs [2412.03542]
Majoron [2503.03825]
RHN [2408.10297]

Consider SU(2) singlet and vector-like doublet

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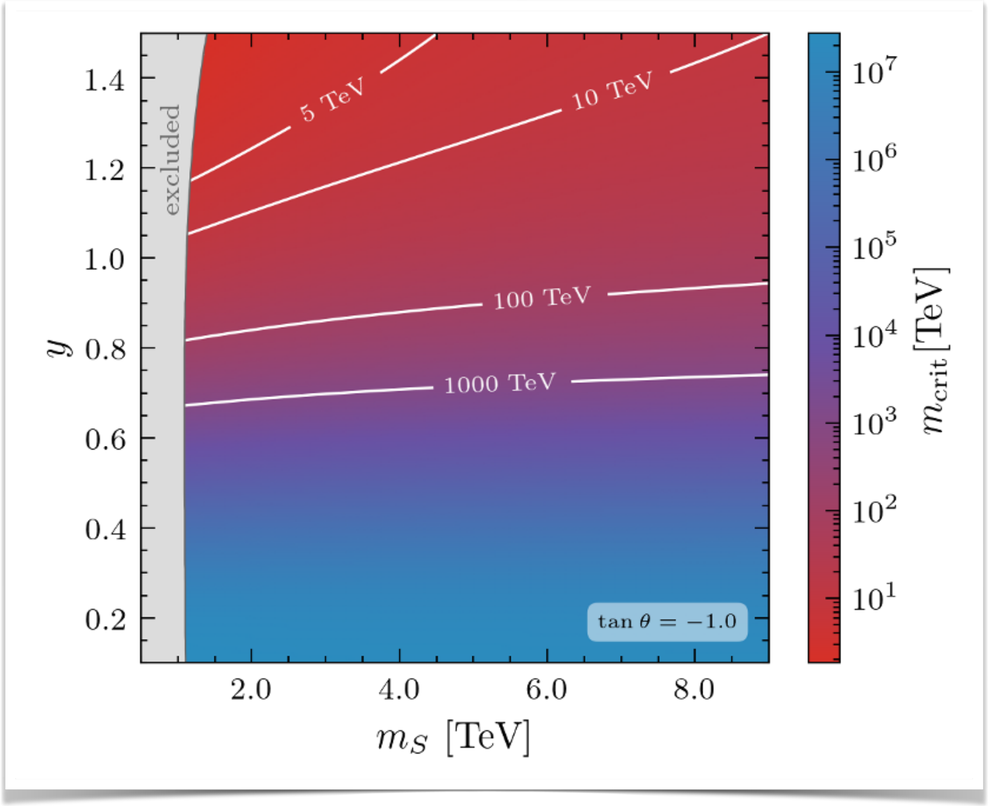


Conclusion

Problem

- Higgs mass unnaturally small
- (Meta-)Stability of Higgs potential determined by Higgs self-coupling

→ What is dictating the phase structure of the Higgs potential?

Mechanisms

- *Self-organised localisation, living dangerously in the multiverse*, or *Higgs crunching*
- placing us close to the critical surface of a quantum phase transition

Concept of Higgs Criticality

- Phase structure allows coexistence of IR and UV vacuum
- Universal implication: Metastability bound $m_h^2 \lesssim |\beta(\mu_I)|\mu_I^2$

Concept of Higgs Criticality

- New Physics required to resolve the hierarchy problem, e.g.
  - fermions with large Yukawas
  - light or heavy scalars

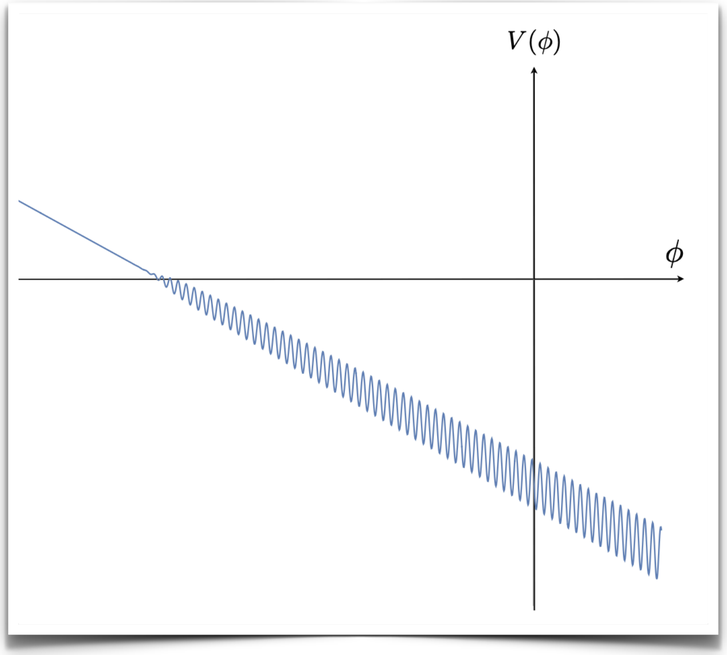
Thanks !

Backups

Dynamical Pathways to the Weak Scale

Other dynamical solutions to the hierarchy problem exist, such as for example the **Relaxion** ['15 Graham, Kaplan, Rajendran]

See e.g.
['20 Arkani-Hamed, D'Agnolo, Kim]
['25 Catinari, D'Agnolo, Sesma]



Common idea: Triggering operator

In the SM: $\mathcal{O}_T = \tilde{G}G$

Beyond the SM,
for example: $\mathcal{O}_T = (m^2 + g\phi)\,|H|^2$