Precarious Naturalness

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A. Strumia and D. Teresi,

The top way to relax the Higgs mass and its vacuum energy,

arXiv:2002.02463 [hep-ph]

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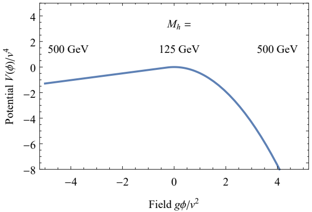
Post-naturalness

- very long story short:
  hierarchy problems of the Higgs mass and cosmological constant are still there
- today more than yesterday
- approaches based on symmetries at the weak scale predict “symmetric partners”, which have not been seen
- **post-naturalness**: the problem is still there, but qualitatively new paradigms:

  unnatural values special points of cosmological dynamics,
  selected either dynamically, anthropically or environmentally

Light Higgs on top

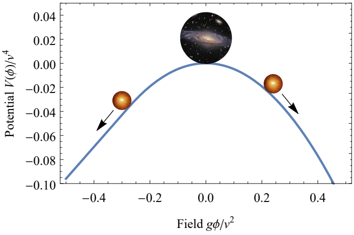
- New physics at M that gives Higgs hierarchy problem: $\dfrac{M^2}{16\pi^2} \gg M_h^2$
- only new ingredient: scalar $\phi \simeq$ shift-symmetric, broken at Λ by coupling $g \lesssim H_0$
- EFT at weak scale: $V_{\rm eff}(H,\phi) = V_0 - \dfrac{M_h^2(\phi)}{2}|H|^2 + \lambda|H|^4 + V_\phi^{\rm heavy}(\phi)$
- Taylor-expanding: $M_h^2(\phi) \simeq M_{h0}^2(\phi) + g\phi, \quad V_\phi^{\rm heavy}(\phi) \simeq \mathcal{S} g\phi$
- separation of scales
  $\rightarrow \phi$ evolves cosmologically, H at its minimum
- EFT for ϕ:
  $$V_{\rm eff}(\phi) = V_0 - \frac{M_h^4(\phi)}{16\lambda}\theta(M_h^2(\phi)) + V_\phi^{\rm heavy}(\phi)$$
- assume $\langle NP \rangle = 0 \Longrightarrow \mathcal{S}$ loop-suppressed:
  $\mathcal{S} \sim \dfrac{M^2}{(16\pi^2)^2}$ (more later)
- maximum at $M_h^2 = 8\lambda\mathcal{S} \ll M^2$



Living at the top

- light Higgs $\sim$ top of the potential $\longrightarrow$ special point of dynamics
- people [Cheung, Saraswat, '18] add wiggles to create minima around the top, that could inflate most if $H_{\rm infl} \sim v$ [Geller, Hochberg, Kuflik, '18]
- other people don't like wiggles + slope, small $H_{\rm infl}$, measure problems, ...
- we propose that **we do actually live on top!**

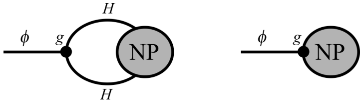
- inflation (of whatever else) populates patches
- inflation does inflation's job $\longrightarrow \phi$ equal everywhere inside horizon
- at the top slope arbitrarily tuned to zero $\longrightarrow$ long-lived patch
- away from the top patches crunch quickly in $\Delta t \ll 1/H_0$ if $\Delta V > \Delta V_{\rm max} \sim \mathcal{O}(\,{\rm meV}^4)$



light Higgs selected both environmentally and anthropically

Loops, finally

- intuitively, loops give tadpole corrections for ϕ:



- more precisely, consider shift-symmetry at $\mu = \Lambda \gtrsim M$
- best case: broken mainly by coupling to H: $M_h^2(\phi)|H|^2 \approx g\phi|H|^2$
- toy new physics: $\lambda_{HS} S^2 |H|^2$
- run down from Λ to M: $\dfrac{dM_h^2(\phi)}{d\ln\mu} = -\dfrac{4\lambda_{HS}^2 M^2}{(4\pi)^2}, \qquad \dfrac{dV_\phi}{d\ln\mu} = \dfrac{M_h^4(\phi)}{2(4\pi)^2} + \cdots$
- contribution to the EFT at v:

$$V_\phi^{\text{heavy}}(\phi) \simeq \frac{M^2 M_h^2(\phi)}{(16\pi^2)^2}\, 2\lambda_{HS}^2 \ln^2\frac{\Lambda}{M} \; + \; \mathcal{O}(M^4/(16\pi^2)^3) \; + \; \mathcal{O}(M_h^4/(16\pi^2))$$

- to retro-fit $M_h = 125\,\text{GeV}$ at the top $\Longrightarrow \Lambda \sim 20\,\text{TeV}$
- if, instead, ϕ couples to S: $\Lambda \sim 1.5\,\text{TeV}$

Getting quantitative

- around the top $V = -\frac{m^2}{2}\phi^2$ with $m = g/\sqrt{8\lambda}$

- the patch does not crunch at times $\ll 1/H_0$ if

$$\Delta V \lesssim \Delta V_{\max} \sim \text{meV}^4 \sim H_0^2 M_{\text{Pl}}^2$$

- this happens in the stability range:

$$|\phi| \lesssim \phi_{\max} \approx M_{\text{Pl}} \begin{cases} H_0^2/m^2 & \text{if } m \lesssim H_0 \\ e^{-m/H_0} H_0/m & \text{if } m \gtrsim H_0 \end{cases}$$

- to solve the hierarchy problem, inside it the Higgs mass should vary $\ll \mathcal{O}(1)$:

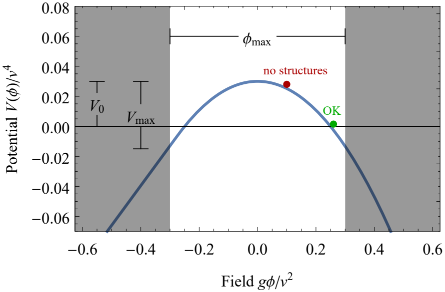
$$m \gtrsim H_0^2 M_{\text{Pl}}/v^2 \sim 10^{-29} H_0$$

Anthropic cosmological constant without a landscape

- if $m \ll H_0$ the potential range in the stability region is $V_{\max} \sim m^2 \phi_{\max}^2$:

$$V_{\max} = \frac{H_0^2}{m^2} \Delta V_{\max} \lesssim v^4$$

- if $m \ll H_0 \quad \Longrightarrow \quad V_{\max} \gg \Delta V_{\max} \sim \; \mathrm{meV}^4$



Precarious Naturalness can also solve the CC problem up to $\mathcal{O}(v^4)$

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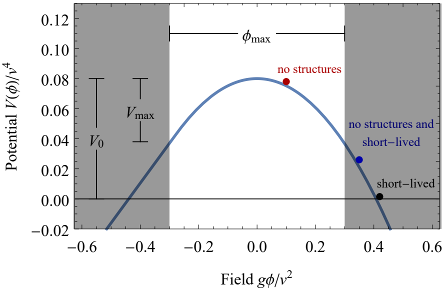


Precarious Naturalness can also solve the CC problem up to $\mathcal{O}(v^4)$

Useless bounds

- quantum fluctuations should not destabilize successful patches
- de Sitter fluctuation $\sim H_0$ should not destabilize successful patches
- thermal slope due to Higgs thermal mass could complicate dynamics
- variation of fundamental constants

long story short: all weaker than next slide (some by $\mathcal{O}(10^{\text{a lot}})$)

The bound that matters: inflationary dynamics

- homogeneous Universe $\longrightarrow$ whatever populates patches has to happen before or during inflation
- $\Longrightarrow$ de Sitter fluctuations during inflation could destabilize the successful patch
- in the observable Universe $\delta\phi \sim \sqrt{N} H_{\rm infl}$
- this must be smaller than $\phi_{\rm max}$, obtaining:

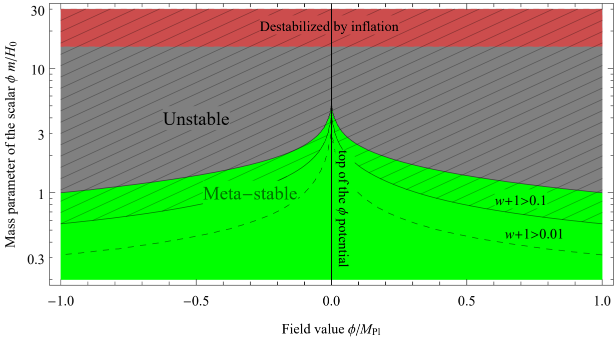
$$m \lesssim H_0 \ln \frac{M_{\rm Pl}}{\sqrt{N} H_{\rm infl}} \sim 15 H_0 \quad \text{for } H_{\rm infl} \sim 10^{10}\,\text{GeV}$$

- unlike other proposals, **Precarious Naturalness** is **compatible with standard** mildly sub-Planckian **inflation**

Precarious Universe

- we expect that in an $\mathcal{O}(1)$ fraction of patches ϕ is **sliding down today**
- observable effects on dark-energy parameter $w = p/\rho$

$$w \approx -\frac{1 - \phi^2/\phi_{\rm max}^2}{1 + \phi^2/\phi_{\rm max}^2}$$



Conclusions

- in the presence of an ultra-light scalar ϕ that couples mainly to the Higgs the hierarchy problem is solved: **Precarious Naturalness**

  only patches with light Higgs are long-lived, the other ones crunch quickly

- if the scalar is ultra-ultra light also the cosmological-constant problem is solved:

  small CC selected anthropically, but without a landscape

- compatible with standard high-scale inflation
  (differently from most existing approaches)

- precarious Universe: natural expectation is that the field is sliding down today

- a natural target for new physics is the **20 TeV scale**

"Our field is presently in a precarious state, given that no new physics was discovered despite significant efforts. Precarious naturalness would guarantee future discoveries, at the price of making the Universe itself precarious."

Real conclusions (not sure if shared among authors)

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Start digging