Hubble Selection of the Weak Scale

possibility from QCD quantum phase transition

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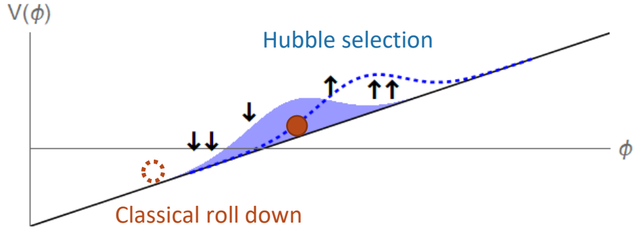
arXiv:2107.02801, work with Sunghoon Jung

Hubble selection: Introduction & concept

- Inflationary fluctuations of quantum field can "kick" the field value toward higher potentials, against the classical rolling.
- Having higher Hubble rates in higher potentials, a global distribution of field can behave radically different from local field values, during inflation.
  We call this "Hubble selection".
- We first analyze Hubble selection and then show the possibility from QCD that the weak scale might be Hubble-selected.



Hubble selection: Analysis & analogy

- The distribution of patch-by-patch field values among different Hubble patches follows the modified Fokker Planck equation

$$\frac{\partial \rho(\phi,t)}{\partial t} = \frac{\partial}{\partial \phi}\left(\frac{V'}{3H}\rho\right) + \frac{1}{8\pi^2}\frac{\partial^2(H^3\rho)}{\partial \phi^2} + 3\Delta H(\phi)\rho$$

- $3\Delta H(\phi)\rho$ accounts for greater expansion rates for higher potentials. This makes the global distribution to climb up the potential, against the classical motion which rolls down.
- It has an analogy with the natural selection; see the table below.

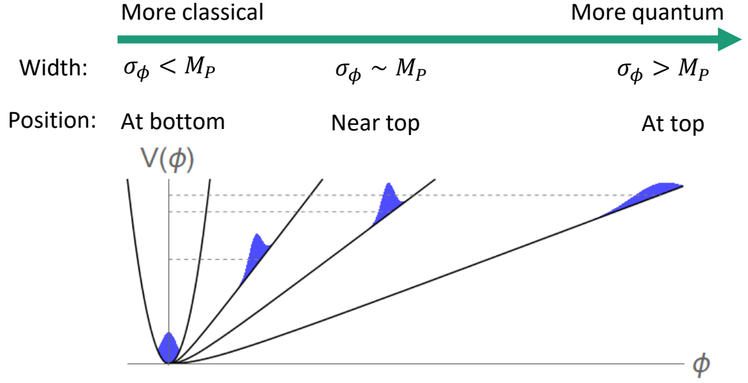
	Natural selection	Hubble selection
Applied to	Biological organisms	Hubble patches
"Offspring" production	Reproduction	Hubble expansion
rate differs by	Adaptation to environment	$\Delta H(\phi) = \Delta V(\phi)/6M_P^2 H_0$
Diversity	Genetic variation (mutation)	Quantum fluctuation
Result: Dominance	Genotypes with higher reproduction rate	Hubble patches at higher potentials, higher Hubble rates

Hubble selection: Conditions

- Selection needs diversity. If all the Hubble patches have the same field value, Hubble selection does not occur, and only classical rolling is in effect.
- The distribution starts to climb up the potential when $\sigma_\phi \gtrsim M_P$.
- Also, the time required to develop such super Planckian width already saturates the de Sitter entropy bound for non eternal inflation.
- Thus, super Planckian field range and eternal inflation are necessary.

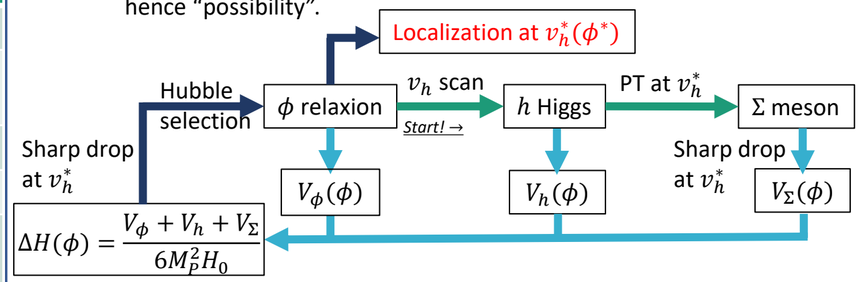
Hubble selection: Equilibrium

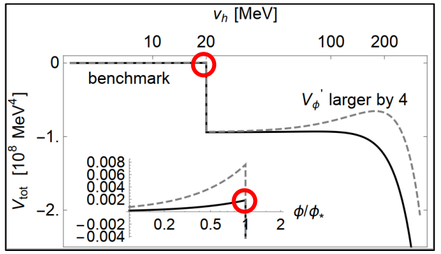
- After climbing up the potential, the distribution localizes near the upper boundary. This gives the equilibrium distribution.
  See ***[Giudice et al. 2021]*** for the full solutions and more discussions.
- Only the equilibrium distribution is the relevant to us, since eternal inflation is assumed.

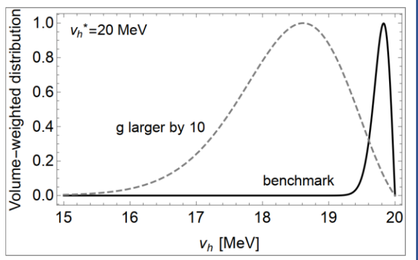


Possibility from QCD: selection of the weak scale

- Can we use Hubble selection for the current weak scale? Hubble selection gives localization near the upper boundary of the potential.
- QCD chiral phase transition could be 1st order, at QCD scale.
  - Sharp drop of potential gives an upper boundary of the potential.
  - Subject to strange quark mass, and also not firmly established yet; hence "possibility".







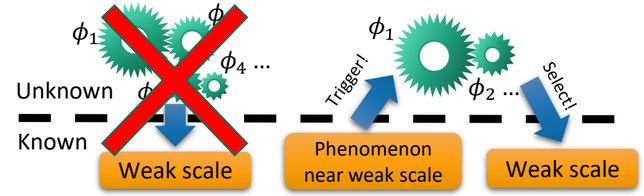
- Successful benchmark for $H = v_h^* \simeq 20$ MeV, $M = 3 \times 10^{-3} M_P$ (h cutoff), $\Lambda_\phi^2 = 10^{-2} H\, M_P$ (ϕ potential), and $g = 10^{-3} H^2/M_P$ ($h-\phi$ coupling).
- Weak scale v_h is well localized near $v_h^* \simeq 20$ MeV!

Possibility from QCD: Discussion

- However, $\Lambda_\phi < M$ is instable due to quantum corrections from Higgs-relaxion coupling. "Tail wagging the dog" is not allowed by the naturalness.
- Several different "translations" of original hierarchy problem were obtained.
- Unsuccessful model building: Should we discard Hubble selection? NO!

Discussion: General viewpoint

- Why Hubble selection is important? Just because "climbing up" is interesting?



- We want models that some known sector physics triggers a minimal hidden sector, by acting as a "brake", to select the current weak scale.
- Also, all known sector fields always roll down; they are sub Planckian fields.
- But a brake can only work for a competing tendency. Rolling down cannot stop another rolling down.
- Thus, Hubble selection is still an attractive mechanism for unknown sector.

Conclusion

- Hubble selection: global field distribution climbs up the potential.
  - Higher Hubble rate in higher potential regimes.
  - Super Planckian field range & eternal inflation are required.
- We saw a possibility that QCD quantum phase transition may have Hubble-selected the current weak scale.
- Model building was not so successful, but Hubble selection is definitely not dead; it provides a competing tendency against classical rolling.

Giudice, G. F., McCullough, M., & You, T. (2021). Self-Organised Localisation. arXiv preprint arXiv:2105.08617.