(No) Eternal Inflation, and Precision Higgs Physics

(A possibility to tell about the destiny of our Universe at the ILC)

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Outline

• The Universe is Accelerating (Inflating)
• Probably due to the Energy of our Vacuum
• For light Higgs our vacuum can be unstable
• Depending on the mass
  – The Phase of Acceleration will terminate
  – The Phase of Acceleration will last forever
• We have chances to discover this at ILC with precision measurements
From Cosmology:

- The universe is accelerating $a \sim e^{Ht}$
- ~ it seems there is a small Vacuum Energy (this is a remarkable discovery)
The Potential for Every Scalar has a Non-Zero Energy Minimum

Our CC

More likely: no stable positive energy minimum

⇒ False (unstable) vacuum

Absolute (stable) vacuum

\[ a \sim e^{Ht} \]

\[ H \sim V(\phi_{\text{min}})^{1/2} \]
Quantum Mechanical Instability

- Decay rate per unit time and unit volume is very small \( \Gamma \sim e^{-\frac{1}{|\lambda|}} \)

- Every decay produces a true-vacuum bubble that expands in a false-vacuum expanding see

Coleman PRD 15, 1977
Callan and Coleman PRD 16, 1977
Two Qualitative Regimes and a Phase Transition

- Decay rate: \( \Gamma \sim e^{-\frac{1}{|\lambda|}} \)

- Small Decay Rate: expansion of false vacuum wins over expansion of bubbles:
  Bubble do not meet \( \Rightarrow \) Eternal Expansion (Eternal Inflation)

- Large Decay Rate: bubble production is so fast that they eat all the false vacuum
  The acceleration ceases.

- The distinction is sharp (A Phase Transition)

\[
V_{\text{infl}} = V_0 e^{3H_{\Lambda}t} e^{-\Gamma} \hat{\text{Vol}}_4(t) \quad \Rightarrow \quad \frac{\Gamma}{H_{\Lambda}^4} < \frac{9}{4\pi} \quad \text{Sharp!}
\]

A. Guth and E. J. Weinberg

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A. Guth and E. J. Weinberg
This applies to the potential of all the scalar fields we have:

it applies to the Higgs potential
Metastability of the Standard Model

If SM holds up to some very high energy:
A light higgs \( \Rightarrow \) metastability of SM

\[ \Gamma \sim e^{-\frac{1}{|\lambda|}} \]

\[ m_h \sim \lambda(\nu)^{1/2} \nu \]

The Renormalization group running drives the quartic coupling negative

\[ V(\phi) \sim m^2 \phi^2 + \lambda(\phi)\phi^4 \]
A Particle Physics Signature

$V(\phi)$

Heavier higgs

Lighter higgs

$\Gamma \sim e^{-\frac{1}{|\lambda|}}$

- No eternally inflating $\iff \Gamma/H^4_A > 9/(4\pi)$: the standard model channel is fast enough if:

$$m_H(\text{GeV}) < 110.7 + 4.1 \frac{m_t(\text{GeV}) - 173.1}{1.3} - 2.5 \frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\text{th}}$$

This is a sharp number.

- Errors come from the running for many energy scales:
  - $m_t$ from Tevatron
  - $\alpha_s$ from PDG

- Assumption: Standard Model holds up to high energies ($10^{16}$ GeV)
But we should not have already decayed

\[ \Gamma \sim e^{-\frac{1}{|\lambda|}} \]

- Requirement that we have not yet decayed (at 95% C.L.)

\[ m_H(\text{GeV}) > 110.5 + 4.1 \frac{m_t(\text{GeV}) - 173.1}{1.3} - 2.5 \frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\text{th}} \]

This is a not-sharp but reasonable number.

- No eternally inflating:

\[ m_H(\text{GeV}) < 110.7 + 4.1 \frac{m_t(\text{GeV}) - 173.1}{1.3} - 2.5 \frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\text{th}} \]

- A tiny window!: \( \Delta m_H \sim 0.2 \text{ GeV} \)

Kransikov, Maiani, Cabibbo, Parisi, Petronzio, Hung, Linde, Sher, Altarelli, Isidori, Strumia, Casas, Ispinosa, Quiros,....., Giudice, Riotto....

('78-'08)
A tiny window

- Window small: $\Gamma \sim H \sim H_\Lambda$
- If we find only the higgs at LHC, and
- and we find it to be in this tiny window,
- $\implies$ believe the assumption of SM up to high energies
- Learn about destiny of our Universe
- Learn about Quantum Gravity

(scenario theoretically motivated)
Can we do it? Yes we can

- Now: $m_H(\text{GeV}) < 110.7 + 4.1 \frac{m_t(\text{GeV}) - 173.1}{1.3} - 2.5 \frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 3_{\text{th}}$

- After LHC: 
  $m_t(\text{GeV}) > 174.4 + 0.3 \times (m_H(\text{GeV}) - 115) + 0.8 \times \frac{\alpha_s(m_Z) - 0.1176}{0.0020} \pm 1_{\text{th}}$

- Theory:
  - Now: $O(\alpha_s^3), O(\alpha_W^2)$
  - Need: $O(\alpha_s^5), O(\alpha_W^3)$

- Experiment:
  - Now: $\Delta m_h \lesssim ?$, $\Delta m_t \lesssim 1.4 \text{ GeV}$, $\frac{\Delta \alpha_s}{\alpha_s} \lesssim 1.7\%$
  - Need: $\Delta m_h \lesssim 100 \text{ MeV}$, $\Delta m_t \lesssim 70 \text{ MeV}$, $\frac{\Delta \alpha_s}{\alpha_s} \lesssim 0.14\%$

LHC $\rightarrow$ ILC $\rightarrow$ Lattice
ILC, LHC?
All of this was assuming we find only the Higgs at LHC. What if, if we find SUSY?
Metastability of SUSY vacua

- Depending on the size of the soft terms, there are MSSM vacua with energy lower than our vacuum

\[ 3 \lesssim \frac{A_t^2 + 3\mu^2}{m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2} \lesssim 7.5 \quad \Rightarrow \quad \text{No Eternal Inflation condition:} \quad A_t^2 + 3\mu^2 \simeq 7.5 \left( m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 \right) \]

- Good: everything at the TeV scale: no need to assume anything about high energy physics
- Good: can get some evidences from LHC
- ~Bad: couplings are difficult to measure

Kusnko, Langacher, Segre
PRD 54, 2996
Conclusions

• Even in the ‘nightmare scenario’ with only the Higgs at LHC
  • Sharp Phase Transition to Eternal Inflation ⇒
    • A sharp value of the Higgs mass

• If verified:
  • Learn about our Future (and that we will decay soon)
  • Learn about Eternal Inflation and Quantum Gravity

At ILC!

• Possibilities even with Physics BSM
A “No Eternal Inflation” Principle?

If (~ and only if) LHC verifies this scenario:

• No dS Space with Gravity
  • Quantum Gravity $\Rightarrow$ No local Observables: S matrix $\Rightarrow$ No dS space
  • With GR: Coleman de-Luccia minimum rate $e^{-S_{\text{dS}}}$ $\Rightarrow$ Metastable Minimum
  $\Rightarrow$ dS only Metastable
  • Naively Truly Metastable dS is ok with S-matrix
  • Problem with S-matrix with Eternal
  $\Rightarrow$ A “No Eternal Inflation” principle