Comments on the Stability of SUSY Theories

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based on

arXiv:0906.3714 [hep-th] (Tom Banks, JFF),

work in progress (JFF)

Outline

SUSY Breaking vs R-symmetry Breaking

- Spontaneous SUSY breaking in stable states $\rightarrow$ Exact R-symmetry Nelson, Seiberg
  - Unbroken exact R-symmetry $\Rightarrow$ Massless gauginos not compatible with experimental constraints
  - Spontaneously broken exact R-symmetry $\Rightarrow$ Massless R-axion not compatible with experimental constraints

$\Rightarrow$ Need explicit R-symmetry breaking

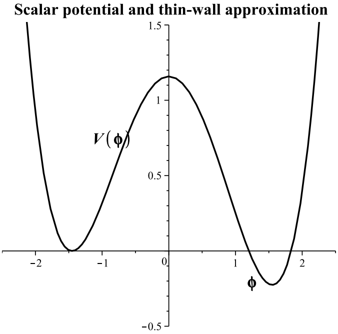
SUSY Breaking vs R-symmetry Breaking

- Spontaneous SUSY breaking in metastable states $\longrightarrow$ Approximate R-symmetry   Intriligator, Seiberg, Shih
  - Approximate R-symmetry $\Rightarrow$ SUSY states far in field space, metastability
  - Unbroken approximate R-symmetry $\Rightarrow$ Massive gauginos from explicit R-symmetry breaking
  - Spontaneously broken approximate R-symmetry $\Rightarrow$ Massive R-axion from explicit R-symmetry breaking
- Metastable SUSY breaking more generic than stable SUSY breaking

$\Rightarrow$ Metastable SUSY breaking with tunneling probability Γ/V compatible with experimental constraints

Faith of the False Vacuum without Gravity

- Tunneling probability $\Gamma/V = Ae^{-[S_E(\phi) - S_E(\phi_F)]}$ Coleman
  - Euclidean action for the instanton solution $S_E(\phi)$
  - Vanishing background Euclidean action $S_E(\phi_F) = 0$



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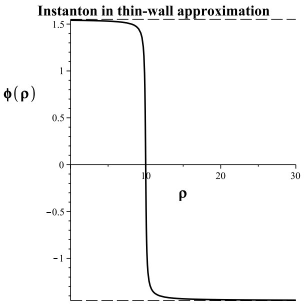
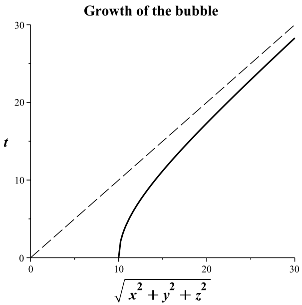
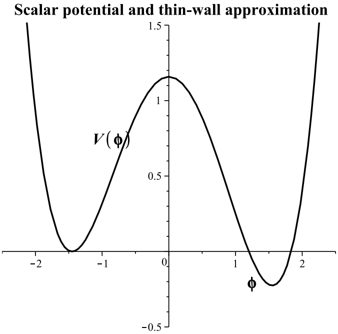




Faith of the False Vacuum with Gravity

- Tunneling probability $\Gamma/V = Ae^{-[S_E(\phi) - S_E(\phi_F)]}$ Coleman, De Luccia
  - Background Euclidean action $S_E^{\mathrm{M}}(\phi_F) = 0$ and $S_E^{\mathrm{dS}}(\phi_F) < 0$
  - Actual "decay" of metastable Minkowski space to AdS space $\Rightarrow$ Gravitational collapse (Big Crunch)
  - Stability of seemingly metastable Minkowski space in thin-wall approximation

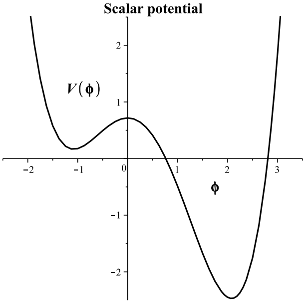


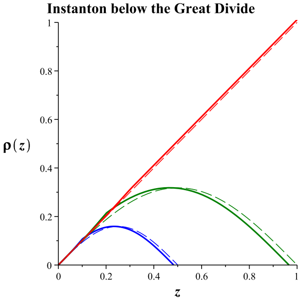
Faith of the False Vacuum with Gravity

Space of potentials partitioned in the $V_F \to 0$ limit $\left(\epsilon \approx \frac{|\Delta\phi|}{M_P}\right)$

Aguirre, Banks, Johnson & Bousso, Freivogel, Lippert

- Below the Great Divide ($\epsilon < \epsilon_c \sim \mathcal{O}(1)$)
  - Non-compact instanton
  - Instanton action scales like and comparable to background action $\Rightarrow$ No "extra" decay suppression





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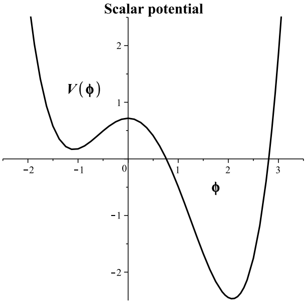
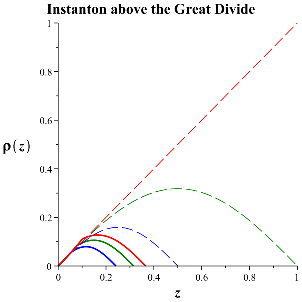
- Above the Great Divide ($\epsilon > \epsilon_c \sim \mathcal{O}(1)$)
  - Compact instanton
  - Instanton action negligible compared to background action $\Rightarrow$ "Extra" decay suppression of order $\mathcal{O}(e^{S_E^{\mathrm{dS}}(\phi_F)})$





Temperature and Entropy of dS Space

- dS temperature $T_{\rm dS} = \frac{1}{2\pi R_{\rm dS}}$ and entropy $\mathcal{S}_{\rm dS} = \pi(R_{\rm dS} M_P)^2$
  Gibbons, Hawking
- $S_E^{\rm dS}(\phi_F) = -\mathcal{S}_{\rm dS}$ thus $\Gamma/V = Ae^{-[S_E(\phi)+\mathcal{S}_{\rm dS}]}$
- Below the Great Divide
  - $\Gamma/V = Ae^{-[S_E(\phi)+\mathcal{S}_{\rm dS}]} \xrightarrow{\Lambda_{\rm dS}\to 0} \text{finite} > 0$
  - Actual "decay" of metastable dS space to AdS space $\Rightarrow$ Gravitational collapse (Big Crunch)
  - No entropic explanation of decay
- Above the Great Divide
  - $\Gamma/V = Ae^{-[S_E(\phi)+\mathcal{S}_{\rm dS}]} \xrightarrow{\Lambda_{\rm dS}\to 0} Ae^{-\mathcal{S}_{\rm dS}} \approx 0$
  - Decay seen as a Poincaré recurrence instead of an instability
  - Entropic explanation of decay

Stable dS space with $\mathcal{N} < \infty$

- Quantum theory of stable dS space $\Rightarrow$ Finite number of quantum states $\mathcal{N} < \infty$ (Assumption) Banks, Fischler

$\Rightarrow$ Theory above the Great Divide

Stable dS space with $\mathcal{N} < \infty$ (Assumption)

- Consequences for models with SUSY breaking in $M_P \to \infty$ limit (e.g. gauge and gravity mediation)
  - Metastable SUSY breaking with SUSY vacua $\Rightarrow$ AdS space theories with $\Lambda_{\mathrm{AdS}} \approx -F^2/M_P^2$
  - $|\Delta\phi| \ll M_P \Rightarrow$ Theory below the Great Divide

$\Rightarrow$ Spontaneous SUSY breaking in stable states !

- Generic with (spontaneously broken) exact R-symmetry
- PNGB R-axion with $m_a \approx (F^3/M_P^2)^{1/4} > 10\,\mathrm{MeV}$ Bagger, Poppitz, Randall
  - Gauge mediation $\Rightarrow \sqrt{F} \gtrsim 10^5\,\mathrm{GeV}$
  - Gravity mediation $\Rightarrow$ Cosmologically safe R-axion with $m_a \approx 10^7\,\mathrm{GeV}$
- Non-generic superpotential $\Rightarrow$ Cosmological SUSY breaking Banks

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Conclusions

- $M_P \to \infty$ limit
  - SUSY breaking and R-symmetry breaking $\Rightarrow$ Spontaneous SUSY breaking in metastable states
    - Massive gauginos
    - Massive R-axion
- $M_P < \infty$
  - Stable dS space with $\mathcal{N} < \infty$ (Assumption) $\Rightarrow$ Spontaneous SUSY breaking in stable states
    - Generic with exact R-symmetry
    - Non-generic superpotential