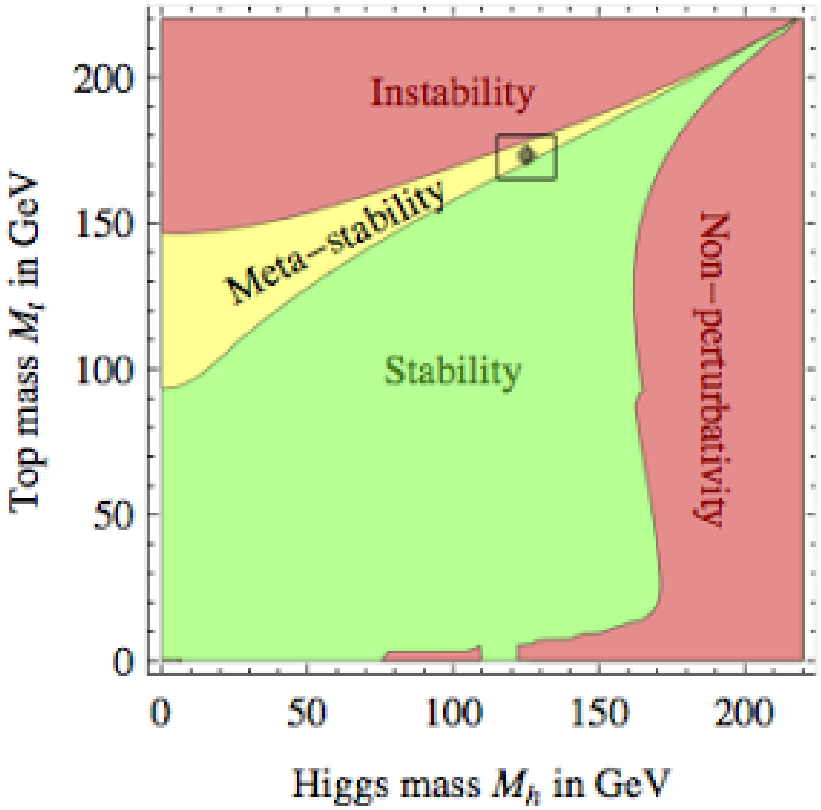
Spacetime Dynamics of the Higgs Instability and the Fate of the Early Universe

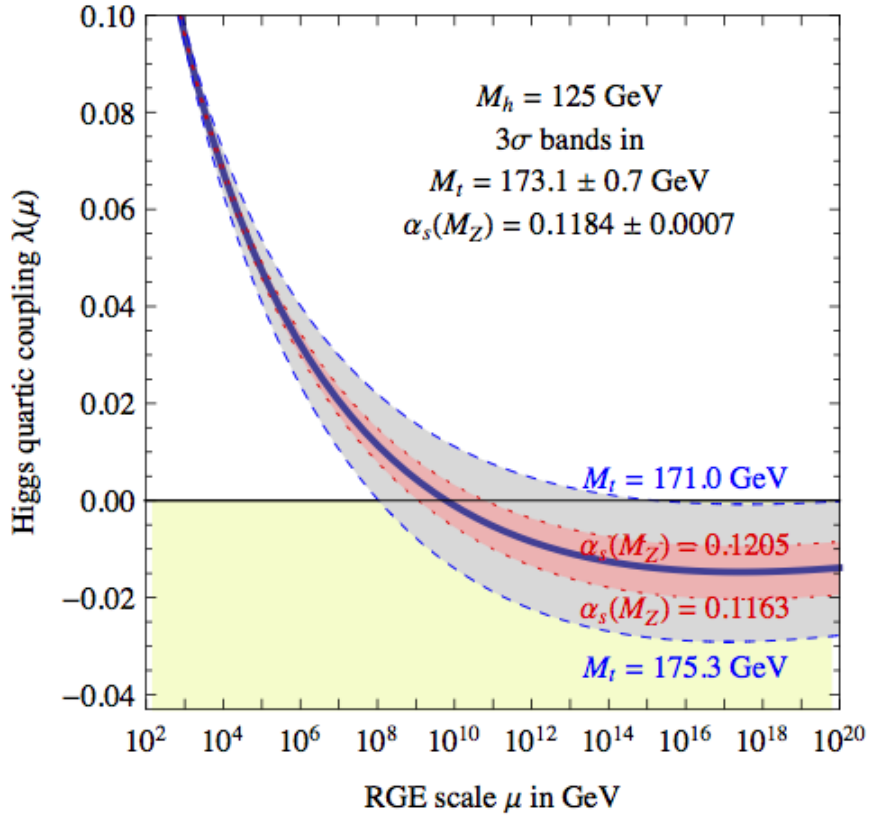
William East
KIPAC/Stanford University

July 14, 2016 / GR21

WE, J. Kearney, B. Shakya, H. Yoo, & K. Zurek
arXiv:1607.00381

Unstable Higgs





Degrassi et al. (2012)

Higgs goes unstable during inflation

- Current lifetime much longer than age of Universe.
- However, during inflation quantum fluctuations may destabilize Higgs (Espinosa et al. 2007): de-Sitter space $T_{GH} = H_I/2\pi$.
- Goal: Put constraints on H_I and/or beyond SM physics. Measurement of r by CMB experiments could imply new physics.
- Two parts to problem: Stochastic (quantum) development of unstable Higgs fluctuation and (classical) spacetime dynamics of true vacuum regions

See also Espinosa+ 2007,2015; Lebedev+ 2012; Kobakhidze+ 2013; Enqvist+ 2013; Hook+ 2014; others.

Spacetime dynamics

- GR question: What happens when an fluctuation regions true vacuum? “Benign" crunch? Disaster? Dominates the volume or not?
- Initially addressed using thin-wall solutions (spherical bubble of AdS inside dS) (Espinosa et al. 2015)
- However important features that come from studying as dynamical process in GR.
- Negative energy density can break the “usual rules" of GR: BH topology, cosmic censorship, Hoop conjecture

Classical evolution of unstable Higgs fluctuations: setup

- Einstein equations: $R_{ab} - \frac{1}{2} R g_{ab} = T_{ab}$
- Coupled to Higgs field: $\Box h = V'(h)$ with

$$V(h) = \Lambda_{\rm Infl} - \frac{\lambda}{4} h^4 + \frac{\lambda_6}{6 M_p^2} h^6$$

- Spacetime is initially (very nearly) de Sitter
- Consider an unstable Higgs fluctuation, e.g.:

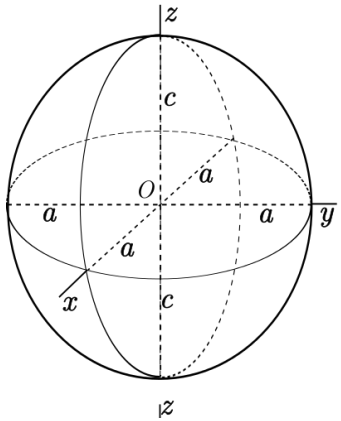
$$h(r) = h_{in} \exp(-r^2/2R^2)$$

Higgs field

Expansion

Beyond spherical: Cosmic censorship vs. Hoop Conjecture

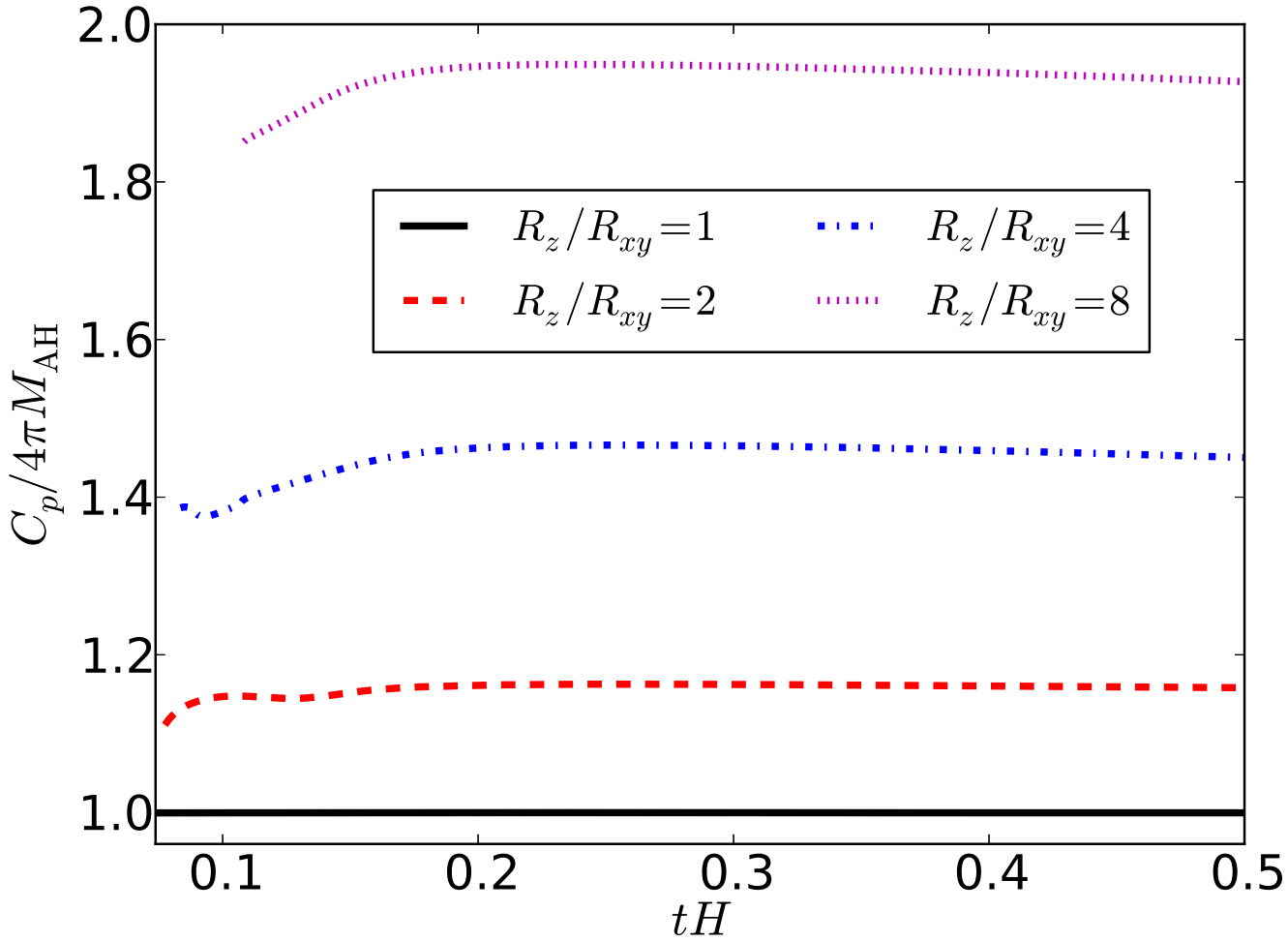
No reason for stochastically formed unstable Higgs fluctuations to be spherical, so consider a series of elongated fluctuations: $R_z/R_{xy} > 1$.



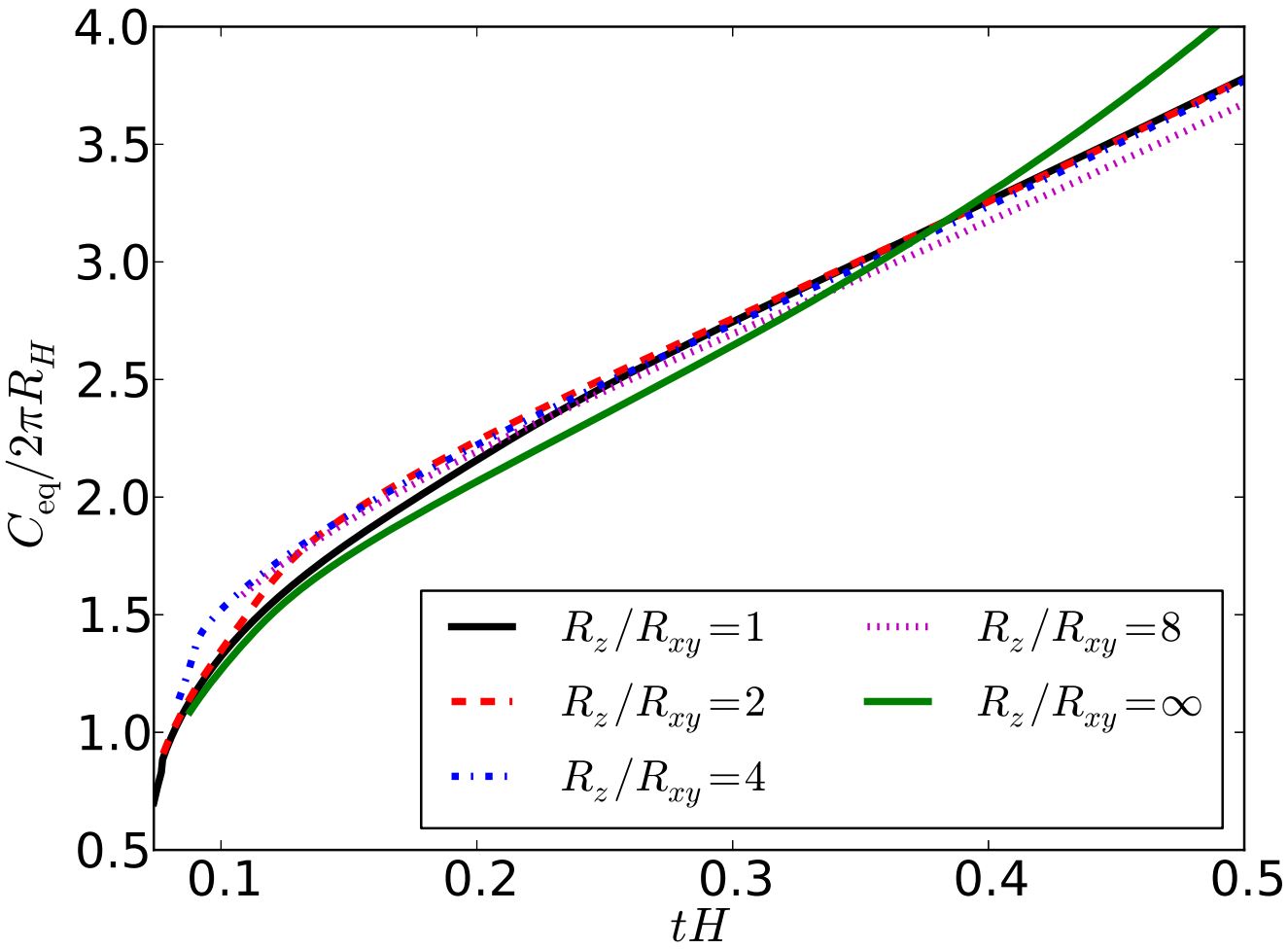
Cosmic censorship: Spacetime singularities should be hidden behind horizons.

Hoop conjecture: A black hole forms if and only if a mass M fits within a hoop of circumference $C \lesssim 4\pi M$

Violating Hoop Conjecture Criterion



Elongated Horizons



Equatorial circumference of black holes and black string.

But the universe is here...

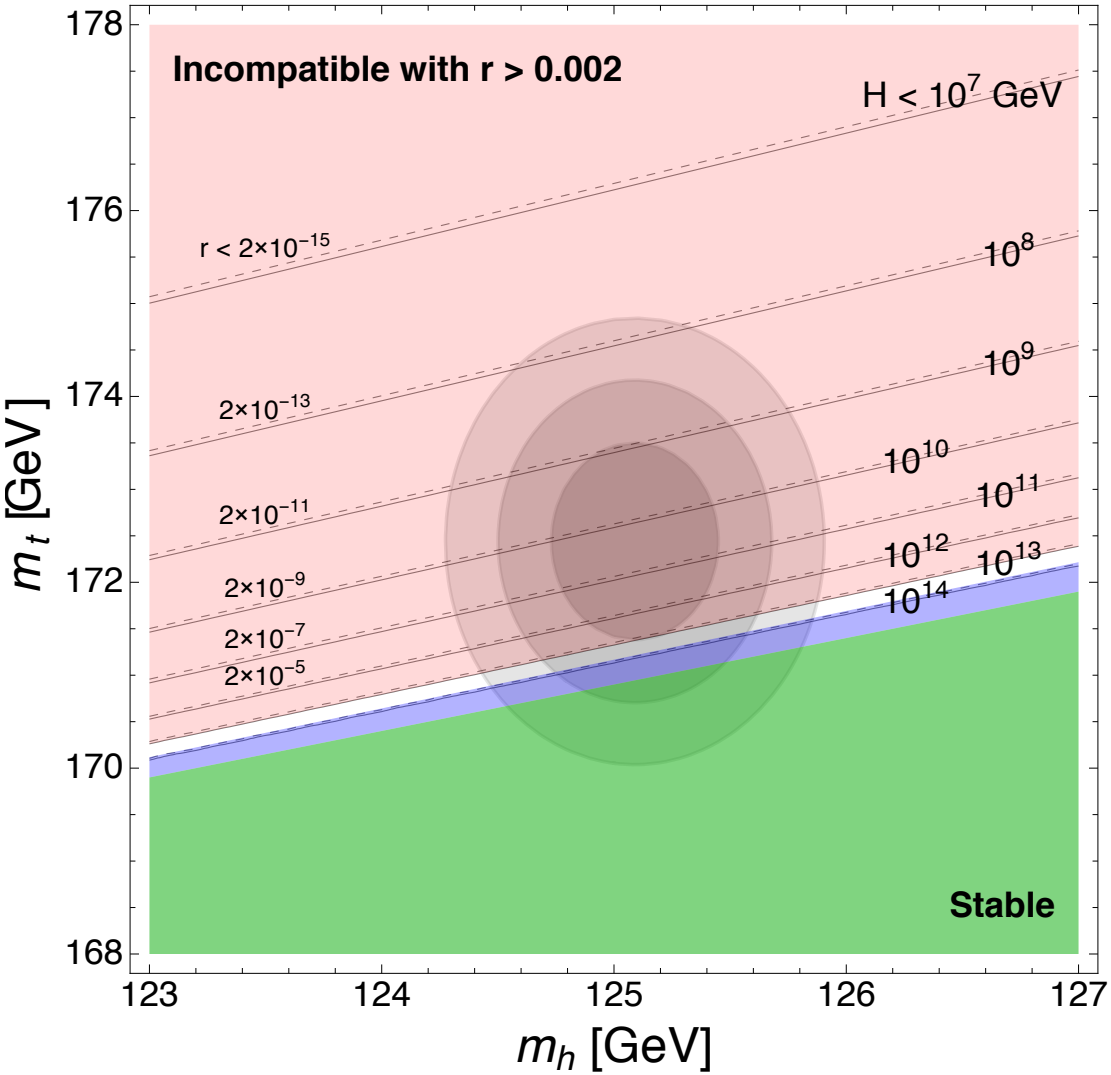
- A region of true vacuum can persist/expand through the end inflation, at which point it can engulf all the electroweak vacuum roughly at speed of light
- Since we don't see this, want to find conditions such that we don't expect any true vacuum regions in our past light cone are created during inflation
- Find number of e-folds for single patch to reach true vacuum:

$$P(|h| > h_{S/R}, N_{\max}) = e^{-3N_{\max}}$$

- Solve Fokker-Planck equation, incorporate new features (running of coupling, non-Gaussian tails, etc.) with help of some numerical tricks.

Evolution of Higgs distribution

Limits on inflation/instability scale of Higgs

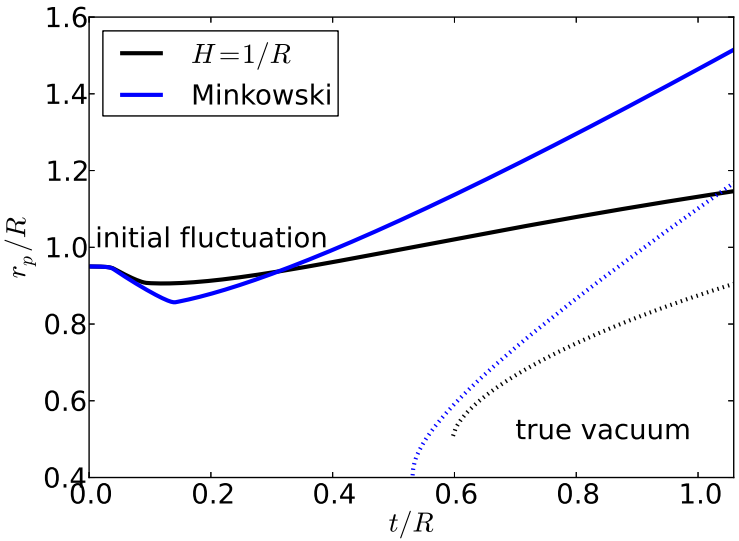


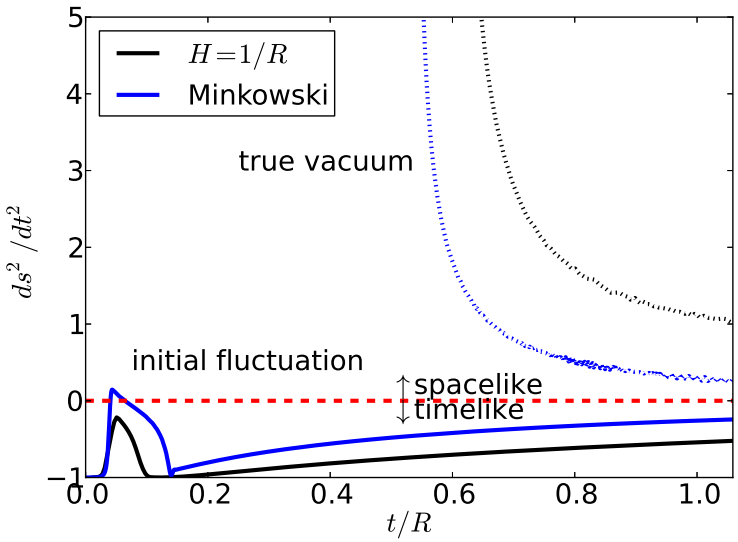
Limits on H_I in GeV for various values of Higgs and top quark mass.

Conclusion

- In absence of beyond SM physics, Higgs instability place bounds on energy scale of inflation.
- Patches of true Higgs vacuum are fatal for the Universe, but very interesting from a strong gravity perspective.
- “Realistic" setting to study AdS-like features of gravity: can terminate inflation, develop black strings (c.f. Lemos 1994)
- Hoop conjecture is violated to save cosmic censorship

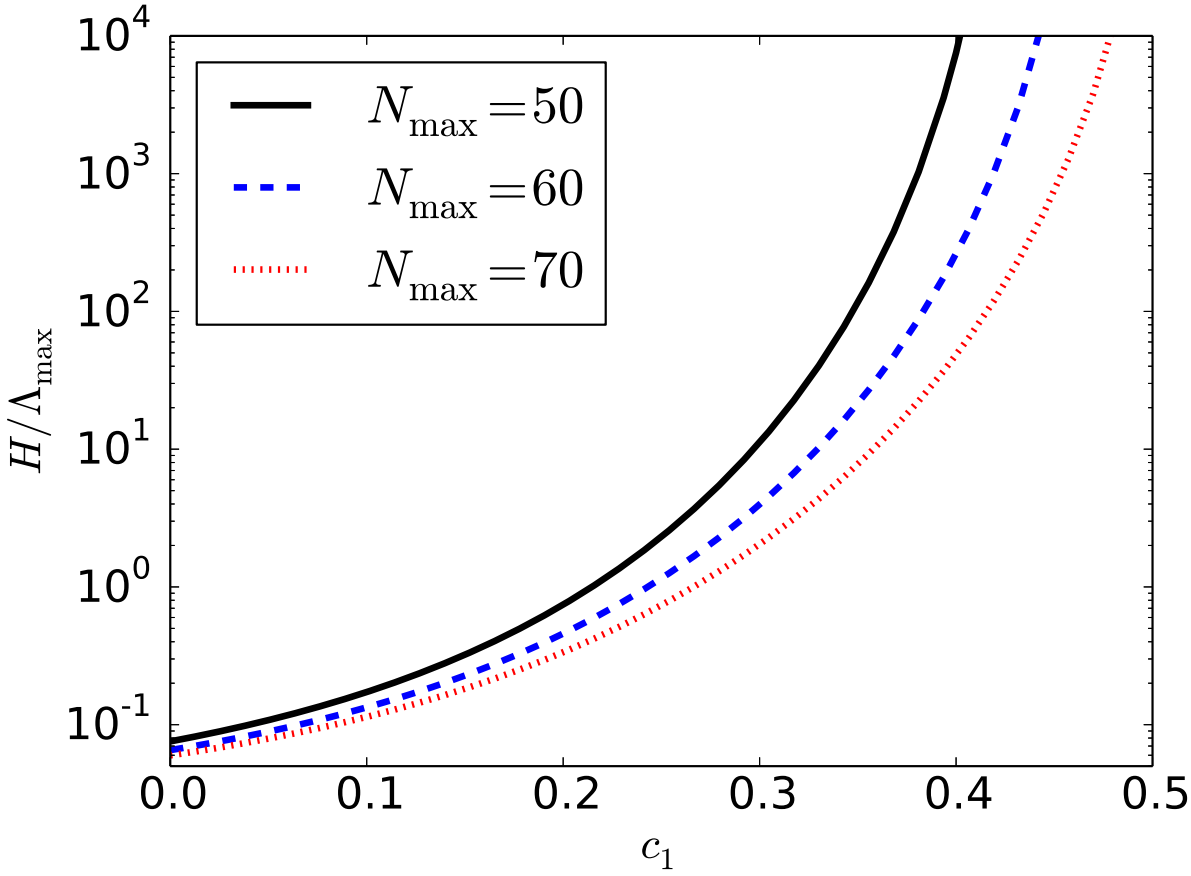
Evolution of true vacuum region





Causally disconnected, hence not sensitive to behavior near minimum of potential.

Beyond SM stabilizing terms



Coupling the Higgs to the inflaton: $V \supset \frac{kV_I h^2}{M_P^2} = c_1 H^2 h^2/2$