Catch-Me-If-You-Can: The Overshoot Problem and the Weak/Inflation Hierarchy

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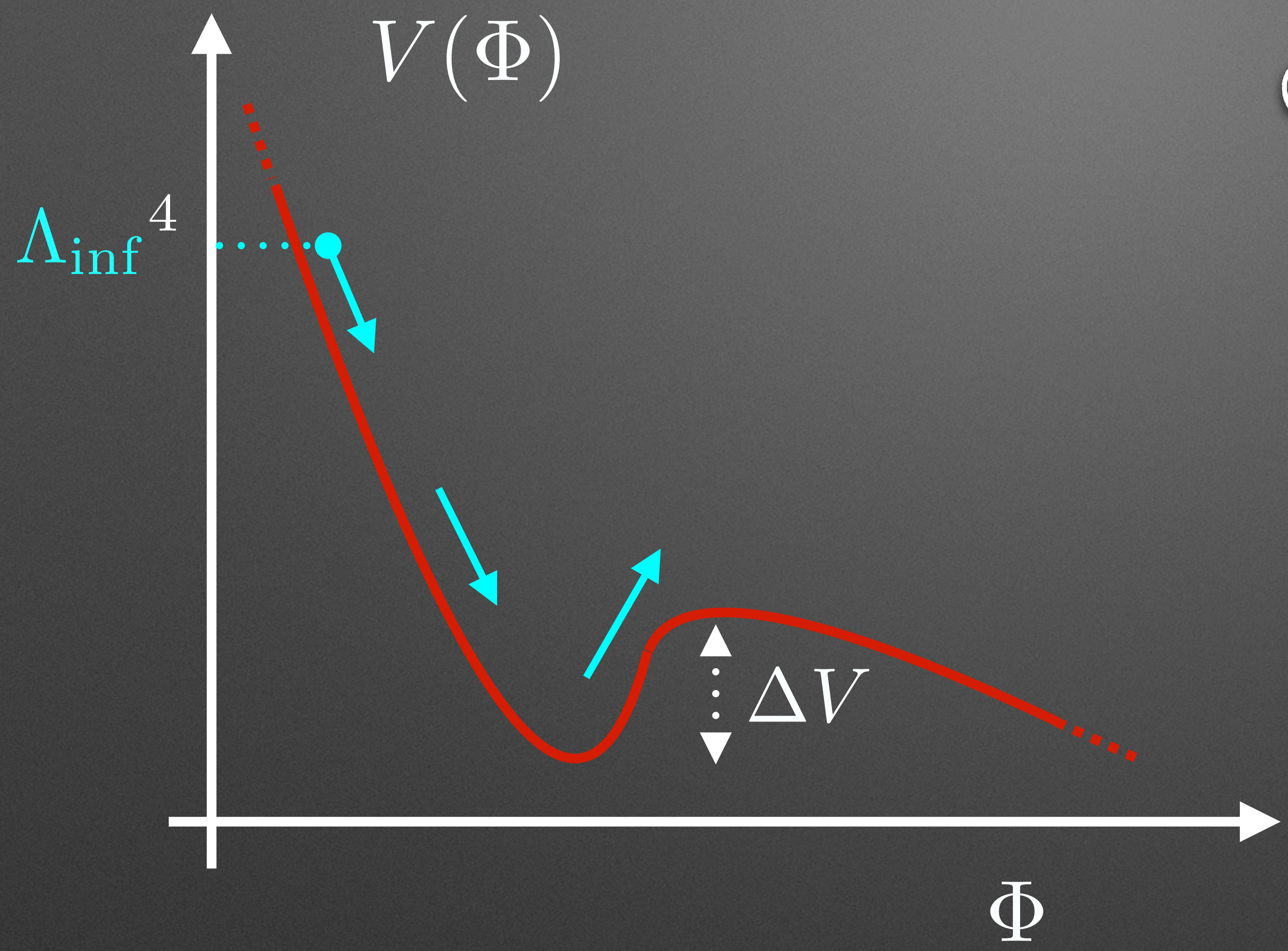
Based on: 2207.00567 [Joseph Conlon, FR]

(See also Joe Conlon's talk)

The overshoot problem

Setting: post-inflationary string cosmology

(See also Fernando Quevedo's talk)



$$\Delta V \sim m_{3/2}{}^2 M_P^2$$

$$(\sim m_{3/2}{}^3 M_P \text{ in LVS})$$

$$\Lambda_{\rm inf} = 10^{15}\,\text{GeV} \rightarrow \frac{\Delta V}{V_{\rm inf}} \sim 10^{-13}$$

Volume kinates and can overshoot

[Brustein, Steinhardt '93]

Two classes of solutions

- Structural: Lower the scale of inflation [German,Ross, Sarkar '01 +…]

  or raise the barrier to decompactification [Kallosh, Linde '04]

This Talk

- Dynamical:

$$\rho_{\rm kin} \sim a^{-6} \quad \text{vs} \quad \overbrace{\rho_{\rm mat} \sim a^{-3} \qquad \rho_{\rm rad}}^{\text{will take over}} \sim a^{-4}$$

$$H^2 = \frac{1}{3M_P^2}\left(\rho_{\rm extra} + \frac{1}{2}\dot{\Phi}^2 + V(\Phi)\right)$$

Hubble Friction halts evolution & 'traps' volume modulus

[Conlon,Kallosh,Linde,Quevedo '08]

Rolling down the slope

Scalar rolling down a steep potential: 'kination'

$$\ddot{\phi} + 3H\dot{\phi} = -\frac{\partial V}{\partial \phi},$$

$$H^2 = \frac{1}{3M_P^2}\left(V(\phi) + \frac{\dot{\phi}^2}{2}\right)$$

$$\phi = \phi_0 + \sqrt{\frac{2}{3}} M_P \ln\left(\frac{t}{t_0}\right) \qquad \rho_{\rm kin}(t) \sim \frac{1}{a(t)^6}$$

stringy realisation

$\Delta\Phi \gtrsim 1$: What about the distance conjecture? [Ooguri, Vafa '08; Ooguri,Palti,Shiu,Vafa '19]

Decompactification limit under control (KK modes as usual)

The Large Volume Scenario (LVS)

LVS: Type IIB flux compactification, with all moduli stabilised

[Balasubramanian,Berglund,Conlon,Quevedo '05] [Conlon,Quevedo,Suruliz '05]

$$V = V_0 e^{-\lambda\Phi/M_P}\left(-\left(\frac{\Phi}{M_P}\right)^{3/2} + A\right) \qquad \Phi = \sqrt{\frac{2}{3}}\ln\mathcal{V}$$

$$\lambda = \sqrt{\frac{27}{2}}$$

canonically normalised volume modulus

Minimum for an exponentially large volume $\mathcal{V} \sim e^{1/g_s}$

Generates Hierarchies: $m_s \sim \frac{M_P}{\sqrt{\mathcal{V}}}$ $\qquad m_{3/2} \sim \frac{M_P}{\mathcal{V}}$

The tracker solution

$$\begin{cases} H^2 = \frac{1}{3M_P^2}\left(\rho_\gamma + \frac{1}{2}\dot{\Phi}^2 + V(\Phi)\right) \\ \dot{H} = -\frac{1}{2M_P^2}\left(\rho_\gamma + P_\gamma + \dot{\Phi}^2\right) = -\frac{1}{2M_P^2}\left(\gamma\rho_\gamma + \dot{\Phi}^2\right) \end{cases}$$

Friedmann Equations

$+$

$$\dot{\rho}_\gamma = -3H\left(\rho_\gamma + P_\gamma\right) = -3H\gamma\rho_\gamma$$

Energy conservation

Attractor solution

$$V = V_0 e^{-\frac{\lambda\Phi}{M_P}}$$

$$\Omega_{\rm kin} = \frac{3}{2}\frac{\gamma^2}{\lambda^2} \qquad \Omega_{\rm pot} = \frac{3(2-\gamma)\gamma}{2\lambda^2} \qquad \Omega_\gamma = 1 - \Omega_{\rm kin} - \Omega_{\rm pot} = 1 - \frac{3\gamma}{\lambda^2}$$

[Wetterich '88; Copeland,Liddle,Wands '98; Ferreira,Joyce '98]

Catch me if you can

radiation must catch up before the minimum:

$$\mathcal{V}_{\rm min} \gtrsim \mathcal{V}_{\rm c} = \mathcal{V}_0\, \Omega_{\gamma,0}{}^{-3/2}$$

How?

- More radiation: higher inflation scale as $\Omega_{\gamma,0} \sim \left(\frac{H_{\rm inf}}{M_P}\right)^n$ for generic source
- More space to roll: smaller initial volume, larger final one

LVS only

Minimum at large volume ↔ Low electroweak scale


dicaprio
hanks
Kinating volume
Radiation
A STEVEN SPIELBERG FILM
catch me if you can
The true story of a real fake. modulus
Catch them in Cinemas
www.dreamworks.com/catchthem
uip.co.uk
alamy
Image ID: T0KB5B

Sources of radiation (I)

Thermal spectrum with $$T_{\rm dS} = \frac{H_{\rm inf}}{2\pi}$$

$$\Omega^0_{\rm th} = g^* \frac{\pi^2}{30} \left(\frac{H_{\rm inf}}{2\pi} \right)^4 \frac{1}{3H^2_{\rm inf} M_P^2} = \frac{g^*}{270 \times 16\pi^2} \left(\frac{\Lambda_{\rm inf}}{M_P} \right)^4$$

	$\Lambda_{\rm inf}$(GeV)	$3 \cdot 10^{16}$	$3 \cdot 10^{15}$	$3 \cdot 10^{14}$
$g^* = 10^2$	$\mathcal{V}_{\rm min}$	$8.0 \cdot 10^{17}$	$1.7 \cdot 10^{25}$	$3.7 \cdot 10^{32}$
$g^* = 10^4$	$\mathcal{V}_{\rm min}$	$8.0 \cdot 10^{14}$	$1.7 \cdot 10^{22}$	$3.7 \cdot 10^{29}$
$g^* = M_P^2/\Lambda^2_{\rm inf}$	$\mathcal{V}_{\rm min}$	$1.6 \cdot 10^{15}$	$3.3 \cdot 10^{19}$	$7.2 \cdot 10^{23}$

semi- realistic

$$\mathcal{V}_{\rm min} \gtrsim 8.0 \times 10^{17} \left(\frac{g^*}{100} \right)^{-3/2} \left(\frac{V_0}{M_P^4} \right)^{1/3} \left(\frac{\Lambda_{\rm inf}}{3 \cdot 10^{16}\,{\rm GeV}} \right)^{-22/3}$$

Sources of radiation (2)

Perturbative decays to i.e. axions

same scaling

$$\Omega^0_{\rm dec} = \frac{3\sqrt{3}}{2}\sum_i \alpha_i \left(\frac{\lambda^3}{16\pi}\right)\frac{H^2}{M_P^2} = \frac{9\sqrt{3}}{2} g_{\rm dec}\left(\frac{\lambda^3}{16\pi}\right)\left(\frac{\Lambda_{\rm inf}}{M_P}\right)^4$$

Enhanced coefficient

	$\Lambda_{\rm inf}(\text{GeV})$	$3\cdot 10^{16}$	$3\cdot 10^{15}$	$3\cdot 10^{14}$	$3\cdot 10^{13}$
$g_{\rm dec}=1$	$\mathcal{V}_{\rm min}$	$4.1\cdot 10^{12}$	$8.9\cdot 10^{19}$	$1.9\cdot 10^{27}$	$4.1\cdot 10^{34}$
$g_{\rm dec}=10^2$	$\mathcal{V}_{\rm min}$	$4.1\cdot 10^{9}$	$8.9\cdot 10^{16}$	$1.9\cdot 10^{24}$	$4.1\cdot 10^{31}$
$g_{\rm dec}=10^4$	$\mathcal{V}_{\rm min}$	$4.1\cdot 10^{6}$	$8.9\cdot 10^{13}$	$1.9\cdot 10^{21}$	$4.1\cdot 10^{28}$

realistic

$$\mathcal{V} \gtrsim 4.2\times 10^9 \left(\frac{g_{\rm dec}}{100}\right)^{-3/2}\left(\frac{V_0}{M_P^4}\right)^{1/3}\left(\frac{\Lambda_{\rm inf}}{3\cdot 10^{16}\,\text{GeV}}\right)^{-22/3}$$

Cosmic fundamental strings?

Cosmic strings after brane inflation

[Dvali,Tye ' 99; Sarangi Tye ' 02]

[Kachru,Kallosh,Linde,Maldacena, McAllister, Trivedi '03; Baumann,Dymarsky, Klebanov,McAllister '07 + …]

scaling regime $\rho_{\rm string} \sim \mu H^2$ parametrically better scaling with H!

Constraints

Today $G\mu \lesssim 10^{-7}$ (CMB) but $\mu \sim m_s^2 \sim \frac{M_P^2}{\mathcal{V}}$

string scale after inflation <u>can be high</u>

$10^{12}{\rm GeV} \lesssim m_s \lesssim 10^{16}{\rm GeV}$ ⟷ $10^{-11} \lesssim G\mu \lesssim 10^{-7}$

Decay to GWs ⟶ GW dominated epoch?

Conclusions and outlook

- Lots of interest on scenarios with $\Delta\Phi \gtrsim 1$, e.g. large field inflation. What about early phase of kination?

Overshoot problem in LVS:

solved by a hierarchy between EW and inflation scales

- Not just qualitative but quantitatively accounts for EW hc

Open questions/future work

- Non perturbative particle production
- Fundamental cosmic string network [Motivation to study brane inflation in LVS]
- Graviation epoch?

Thank you for your attention!