

# Warped Hybrid Inflation

R. Sundrum and CMW

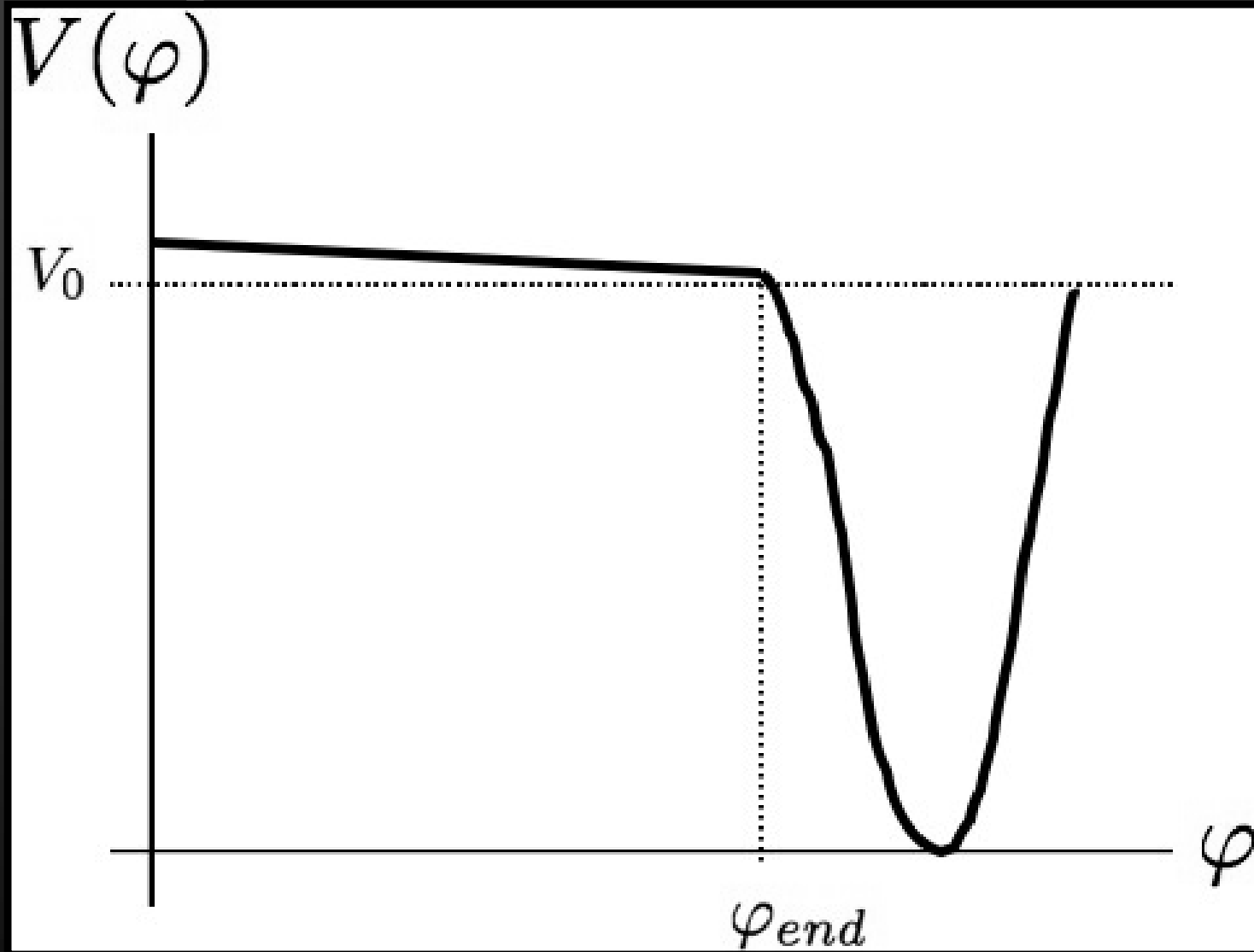
arXiv:0909.3254

JHU HEP Seminar 11/24/2009

# Outline

- Obligatory Remarks
- Why Inflation is Hard
  - Classically
  - Q. M.
- Compositeness
- 5D Dual
  - Specific model
  - 4D EFT
  - Slow-Roll Phenomenology
  - A Slight Wrinkle
- Future Work
- Summary

# Why Inflation is Hard: Classically



$$V(\varphi) = \sum_n \#_n \frac{\varphi^n}{M^{n-4}} ?$$

# Why Inflation is Hard: Classically

$$V(\varphi) \propto \varphi^{2,3,4^*} ?$$

Slow - Roll:

$$\langle \varphi \rangle \gtrsim M_{Pl} !?$$

\*n = 4 is excluded at 95% c.l. by WMAP.

# Why Inflation Is Hard: Q.M.

- Need:

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are needed to see this picture.

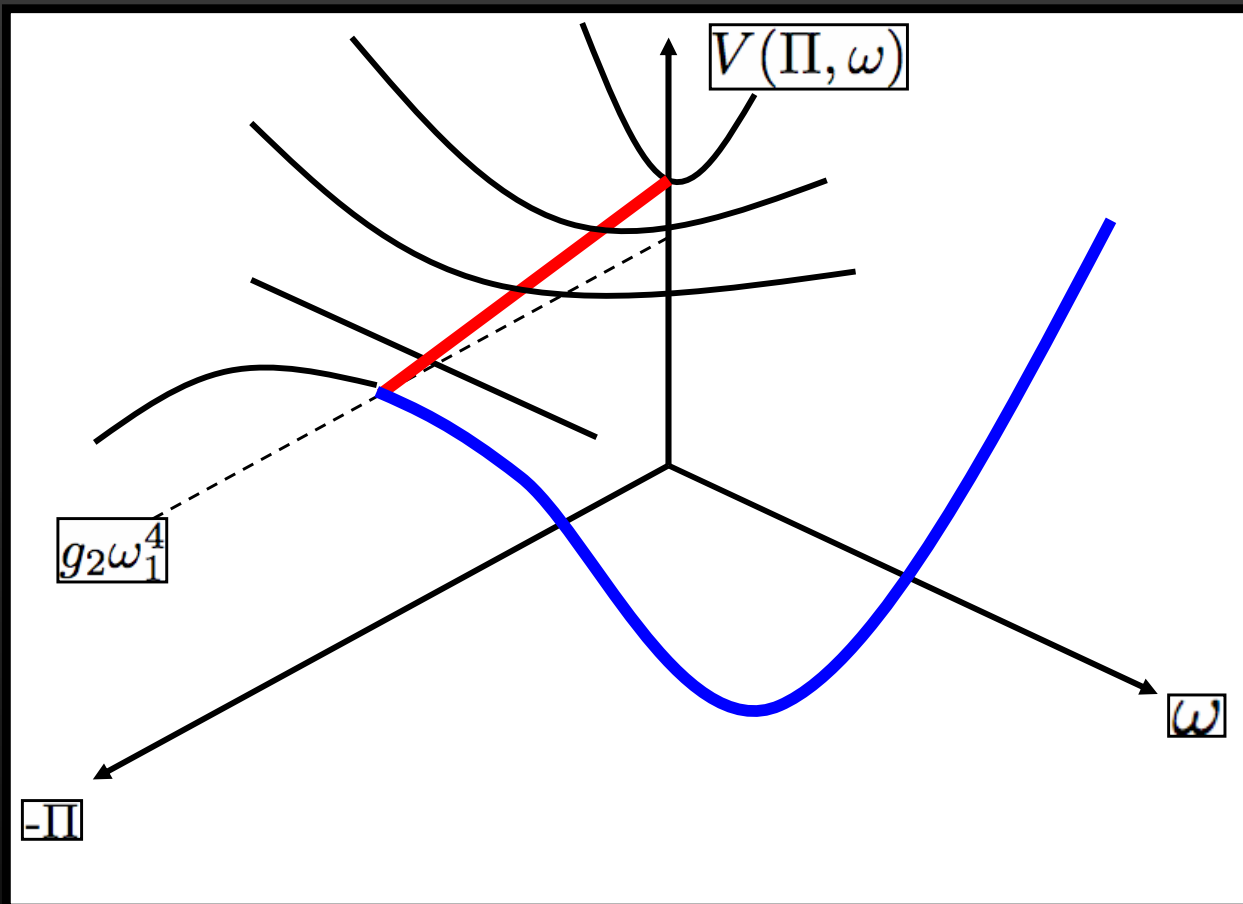
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- Without Special Structure:

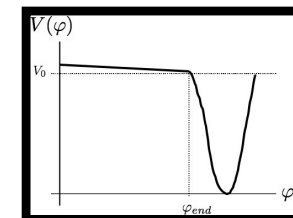
$$\eta > 1$$

# Hybrid Inflation: Classical Shape

$$V(\omega, \Pi) = \frac{m_{\Pi}^2}{2} \Pi^2 + (g_1 \Pi^2 - 2g_2 \omega_1^2) \omega^2 + g_2 \omega^4 + g_2 \omega_1^4$$

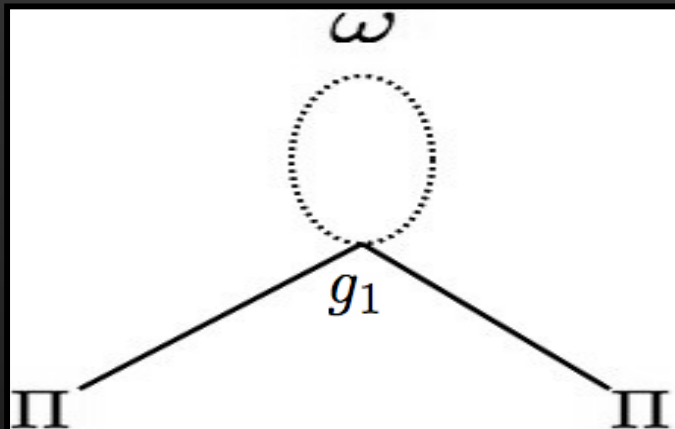


$$V_{Inflation} = \text{red line} + \text{blue curve}$$



# Hybrid Inflation: Corrections

$$V(\omega, \Pi) = \frac{m_{\Pi}^2}{2} \Pi^2 + (g_1 \Pi^2 - 2g_2 \omega_1^2) \omega^2 + g_2 \omega^4 + g_2 \omega_1^4$$



Loop Correction

$$\Delta m_{\Pi}^2 \sim \frac{g_1}{16\pi^2} \Lambda^2$$

+ 'Waterfall' Effect

$$g_1 \Pi_0^2 > 2g_2 \omega_1^2 \simeq \frac{M_{Pl}^2}{\omega_1^2} H^2$$

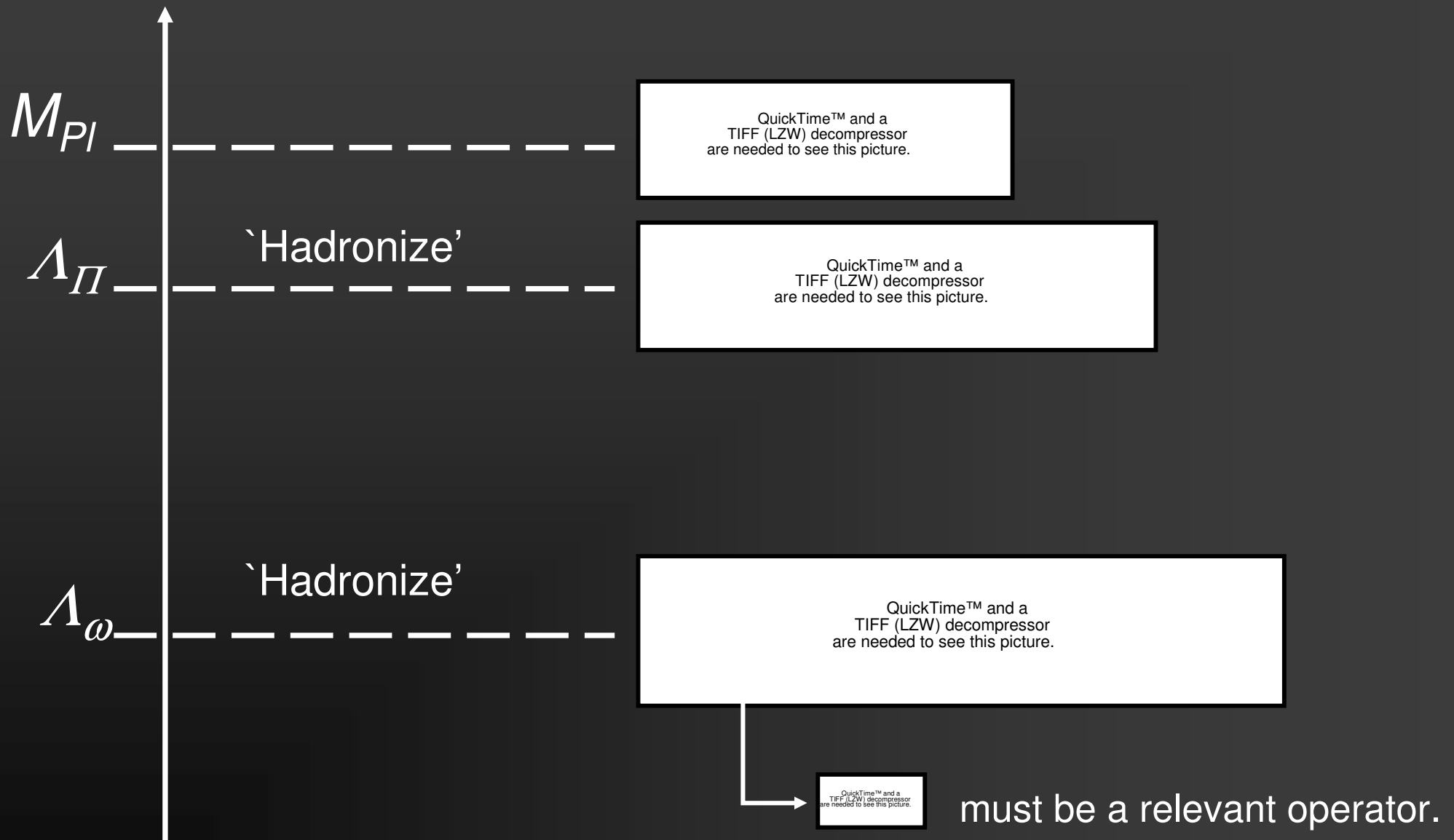
+ **Natural** Slow - Roll

$$H^2 \gg m_{\Pi}^2 \gtrsim \Delta m_{\Pi}^2$$

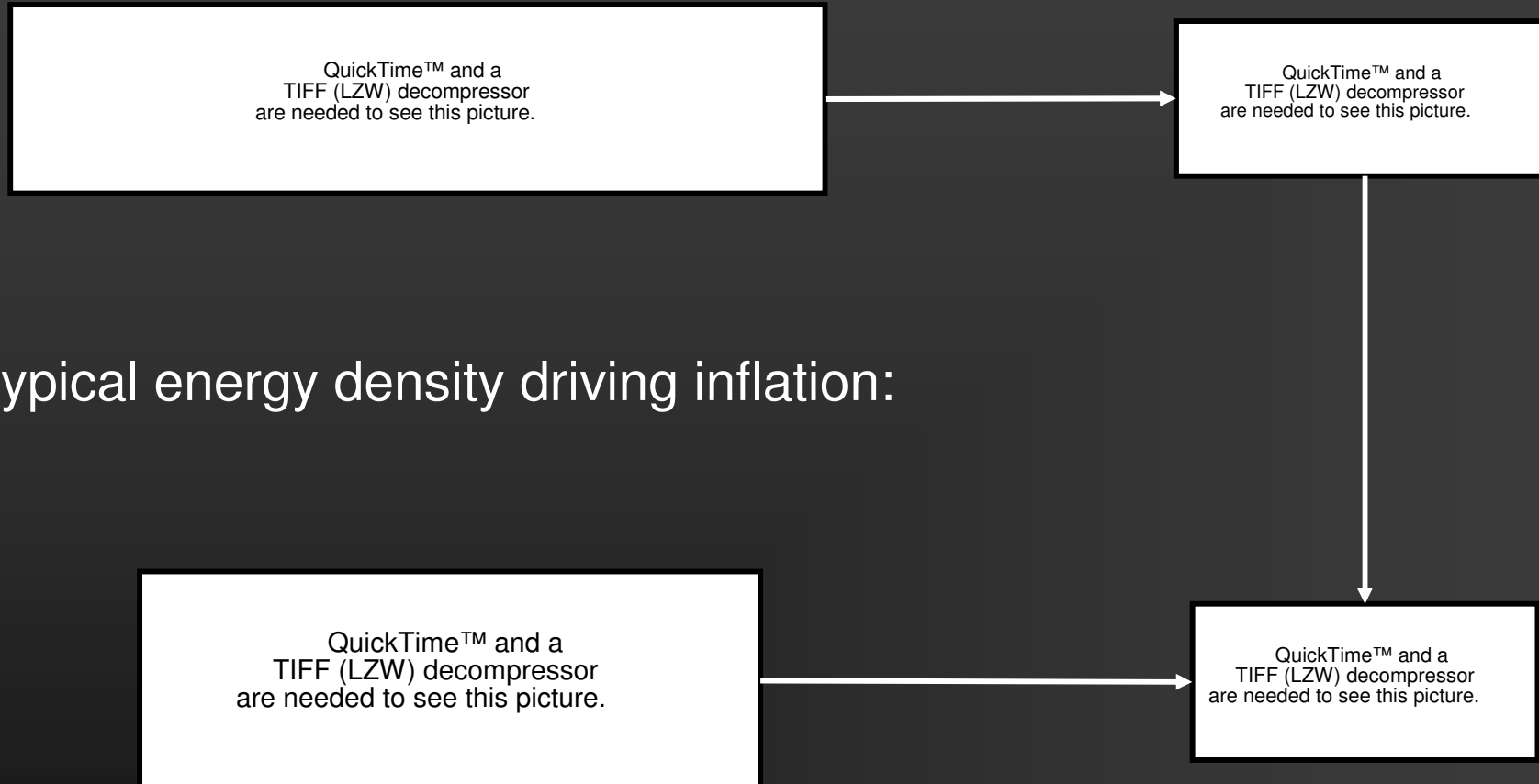
= You have left EFT.

$$\frac{M_{Pl} \Lambda}{\omega_1 \Pi_0} < 1$$

# Dual Compositeness: Waterfall Coupling



# Dual Compositeness: Slow - Roll Correction

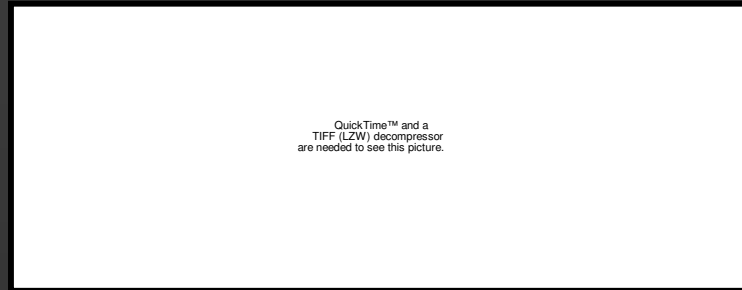


Typical energy density driving inflation:

~~Slow - Roll~~

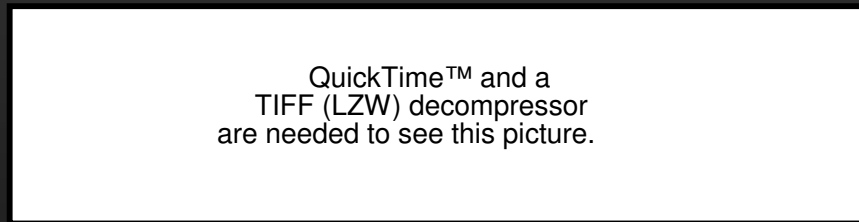
# Dual Compositeness: Dilaton Waterfall

What are we missing?



Spontaneously broken CFT:

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Drives  $\omega \rightarrow 0$ .

Protects  $m_\Pi$  (low cutoff).

A relevant caveat:

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Assign  $O_\Pi$  and  $O_\omega$  discrete charge.

# 5D Dual Theory: Dictionary

4D

PNGB

Dilaton

Dual Comp. w/ Gravity

Slow - Roll Potential

Waterfall Potential

Cross - Coupling

Relevant Operator

5D

$A_5$  Wilson Line

Warped Throat Radion

Two throats

Shared Planck Brane

$(A_5)$  Charged Matter

Bulk Matter (Radion)

Planck Brane Mix. Mass

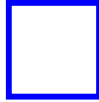
Warped Tachyon

# 5D Schematic

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# Inflaton Throat



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$$W(x) = e^{i2\pi L g_5 A_5(x)} \equiv e^{i\Pi(x)/f_\pi}$$

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# The Waterfall Throat

$$S_{water} = S_{gravity} + S_{stab} + S_{tension}$$

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$$\omega \equiv e^{-ky_{water}}$$

$$\frac{m_{GW}^2}{k^2} = \gamma(4 + \gamma)$$

# The Cross - Coupling

$$S_{cross} = S_{tachyons} + S_{inflation} + S_{water} + S_{midbrane}$$



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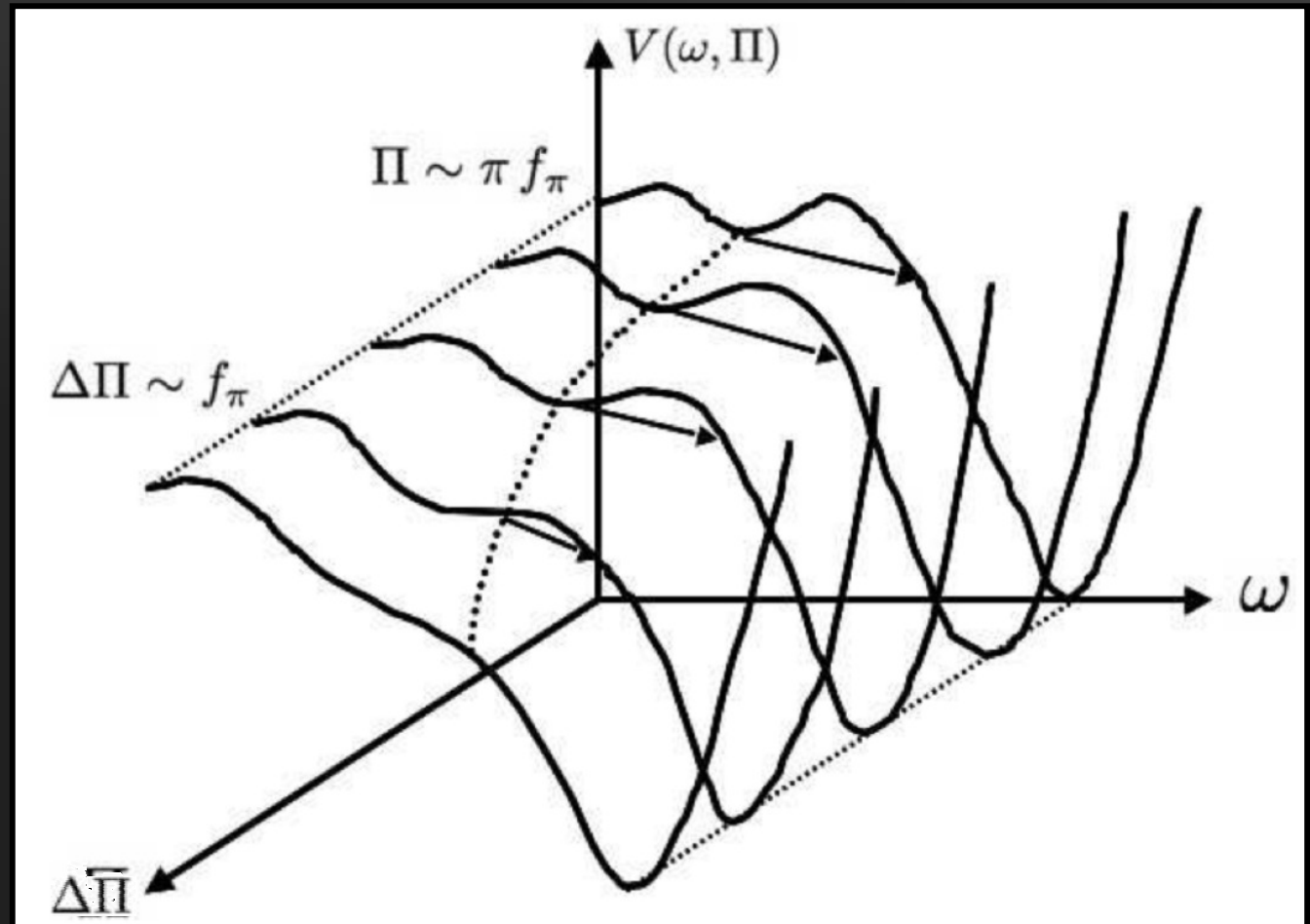
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# Two Field EFT

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$$+12 \frac{M_5^3}{k} H^2 \omega^2 - \frac{m_\Sigma^2}{8\pi^4 L^2} e^{-2m_\Sigma \pi L} \cos \frac{\Pi}{f_\pi} + \text{constant}$$



# Slow - Roll: Integrate out $\omega$

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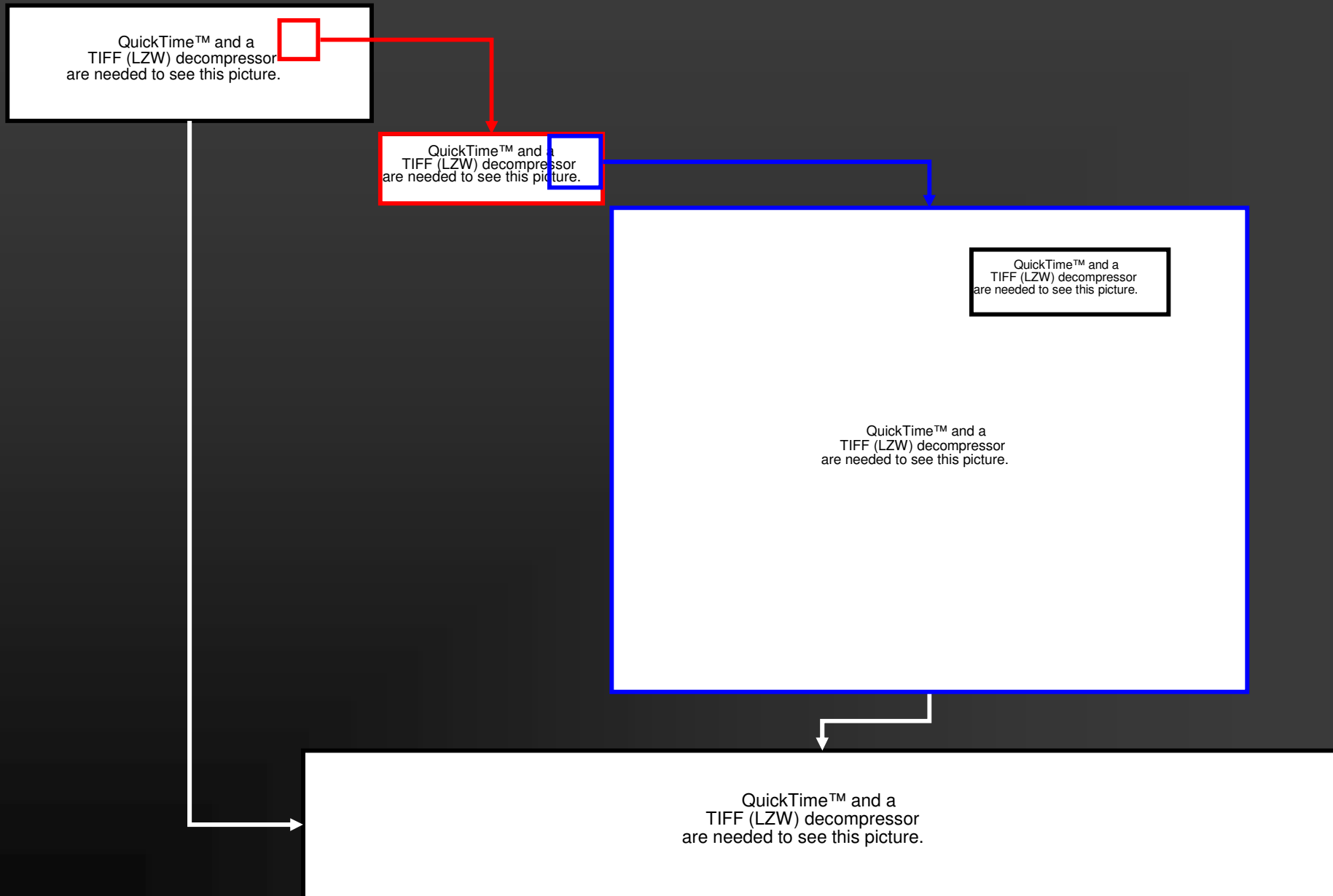
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# Tunneling: Comparing Hybrids

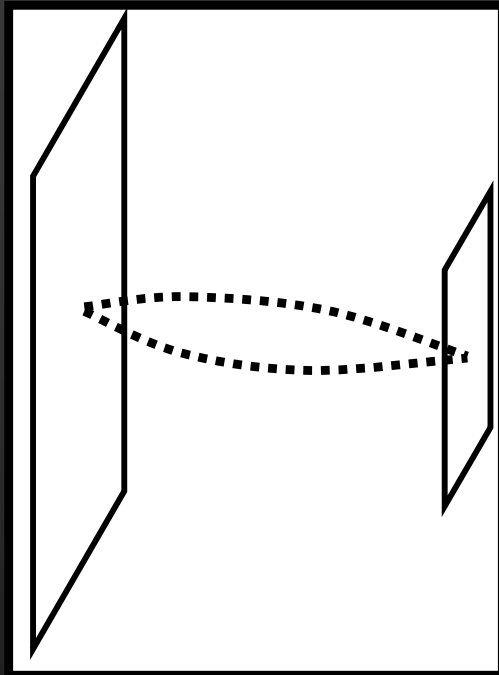
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# Tunneling: Constraint



# (finite) Quantum Correction



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**DEMAND:**

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# Sample Set of 5D Parameters

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**\*\* (Planck Units) \*\***

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# Tunings

One fine tuning (everybody does it): The 4D CC

Tachyon degeneracy:

$$\alpha_1 \approx \alpha_2$$

$\lambda$  is *technically* natural:

$$\lambda \sim \lambda_{Loop} \sim \frac{M_5^4}{16\pi^2}$$

$$T_{RS} = 24M_5^3 k \gg \lambda_{Loop}$$

Totally Avoid Bubbles?

$$N \sim 1?$$

# Future Work

- SUSY
  - Detune IR tension
  - Low - scale inflation
- Bubble Phenomenology
  - Bubble evolution/filling
  - CMB signal

# Summary

- Inflation under EFT control
  - Classical Problems -> Hybrid
  - Quantum Problems -> Dual Composites
- Dual 5D description of CFT
- Matches precision cosmology
- Possible novel signal

# Happy Thanksgiving!

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