A UNIFIED VIEW OF VACUUM DECAY CHANNELS

22/10/2024
Rencontres de Blois

J.R.Espinosa

Instituto de Física Teórica UAM-CSIC

MOTIVATION & GOALS

- Why QFT vacuum decay?

  BSM/SM pheno, Early universe PhTs, Inflation, String Landscape...

- Tunneling Potential Formalism

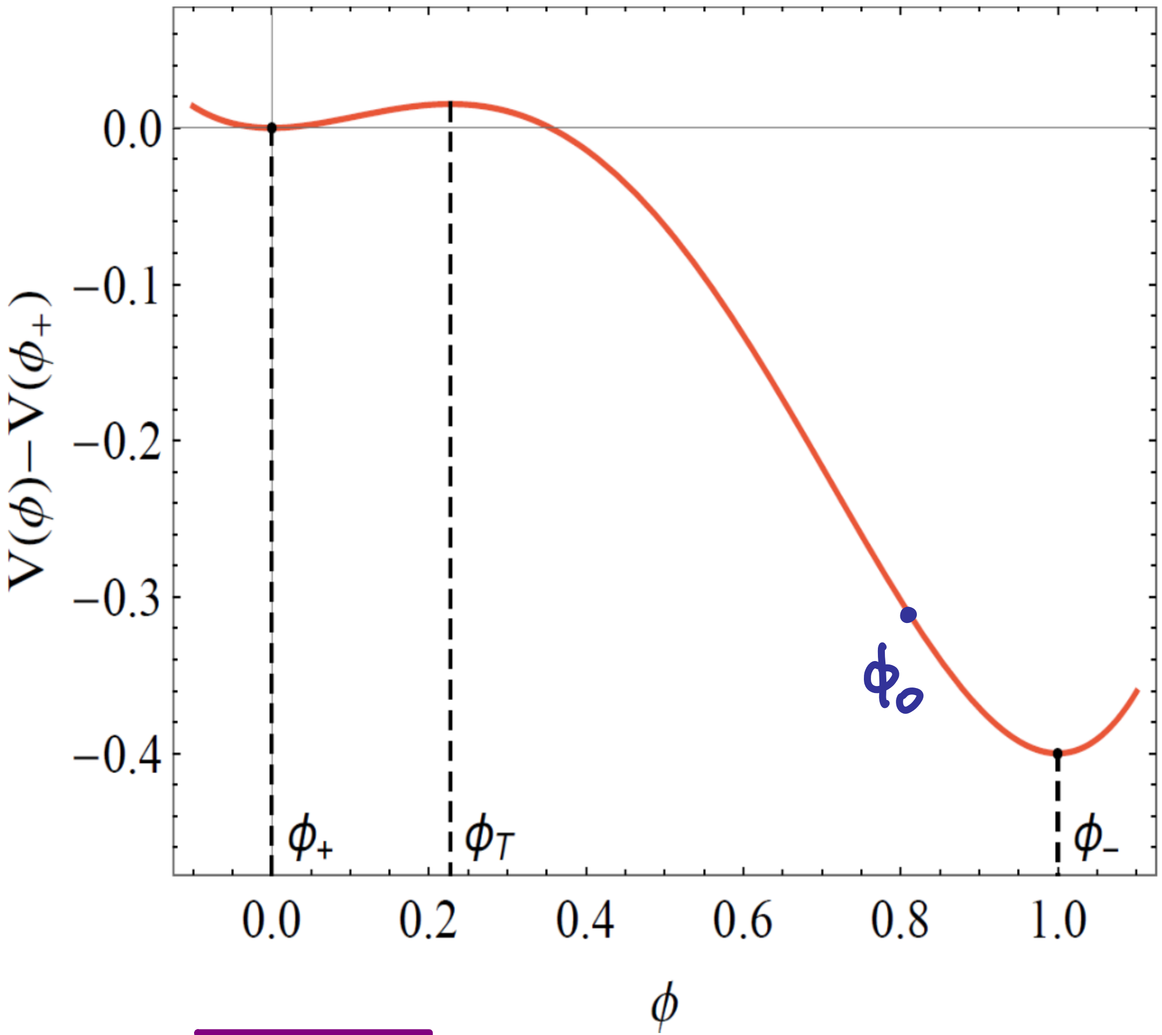
  Alternative to standard Euclidean method (Coleman)

- Unified view of vacuum decay

  Coleman-de Luccia bounces, Hawking-Moss instantons, Bubble of nothing decays, gravitational quenching, domain walls

  ALL RELATED!

DECAY ACTION ~ DECAY PRICE

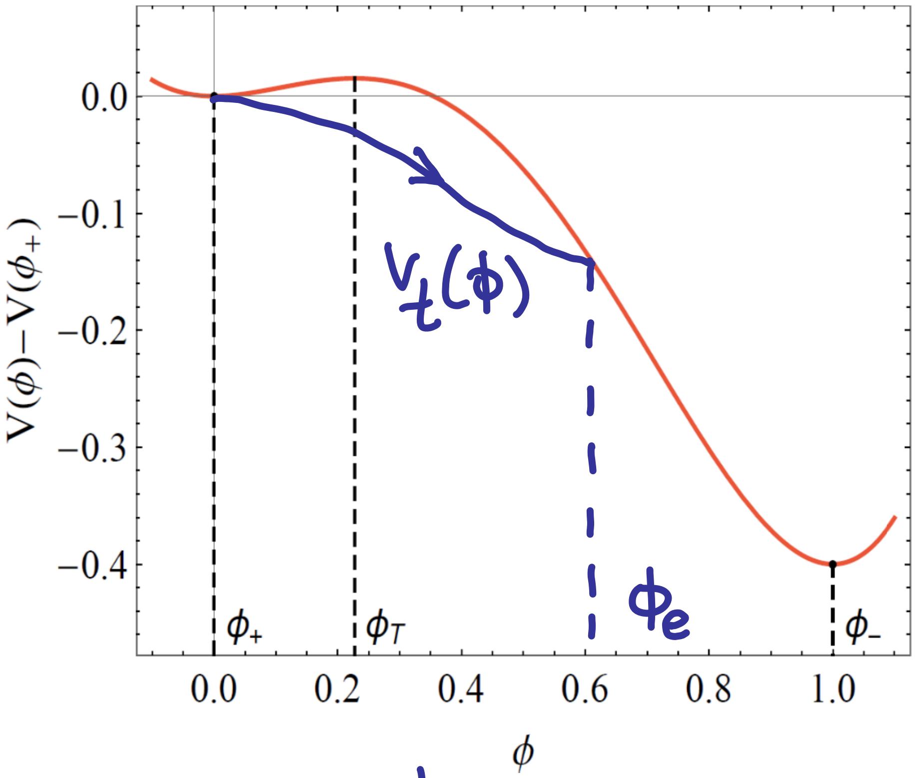


$$\Gamma / V = A e^{-S}$$

calculate this

TUNNELING POTENTIAL FORMALISM

JRE '1805
'1808



$$S[V_t] = \frac{6\pi^2}{\kappa^2}\int_{\phi_+}^{\phi_e} \frac{(D+V_t')^2}{D V_t^2}\, d\phi$$

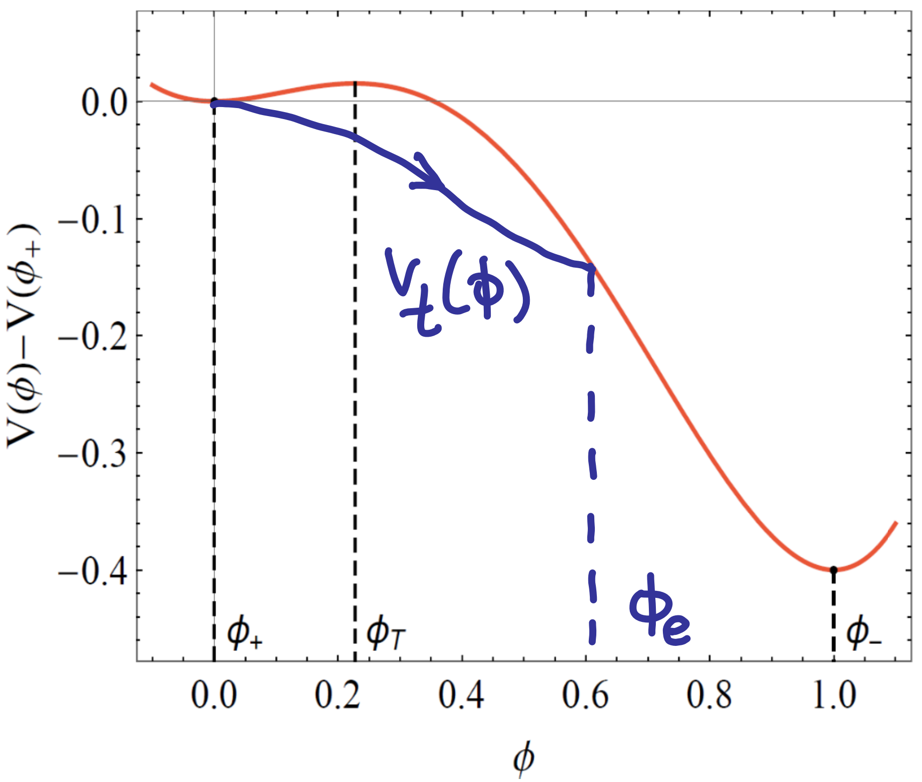
with

$$D = \sqrt{(V_t')^2 + 6\kappa(V-V_t)V_t}$$

$\kappa \equiv 1/m_P^2$

TUNNELING POTENTIAL FORMALISM

JRE '1805
'1808



$$S = \operatorname*{Min}_{V_t} S[V_t]$$

$$\phi_e = \phi(0)$$

Core of Euclidean Coleman-de Luccia (CdL) bounce

NICE PROPERTIES OF V_t-FORM.

JRE'1805

★ V_t on same footing as V

(Bounce) field can be a distraction.

★ $S[V_t]$ minimized ($\phi_B(r)$ saddle-point)

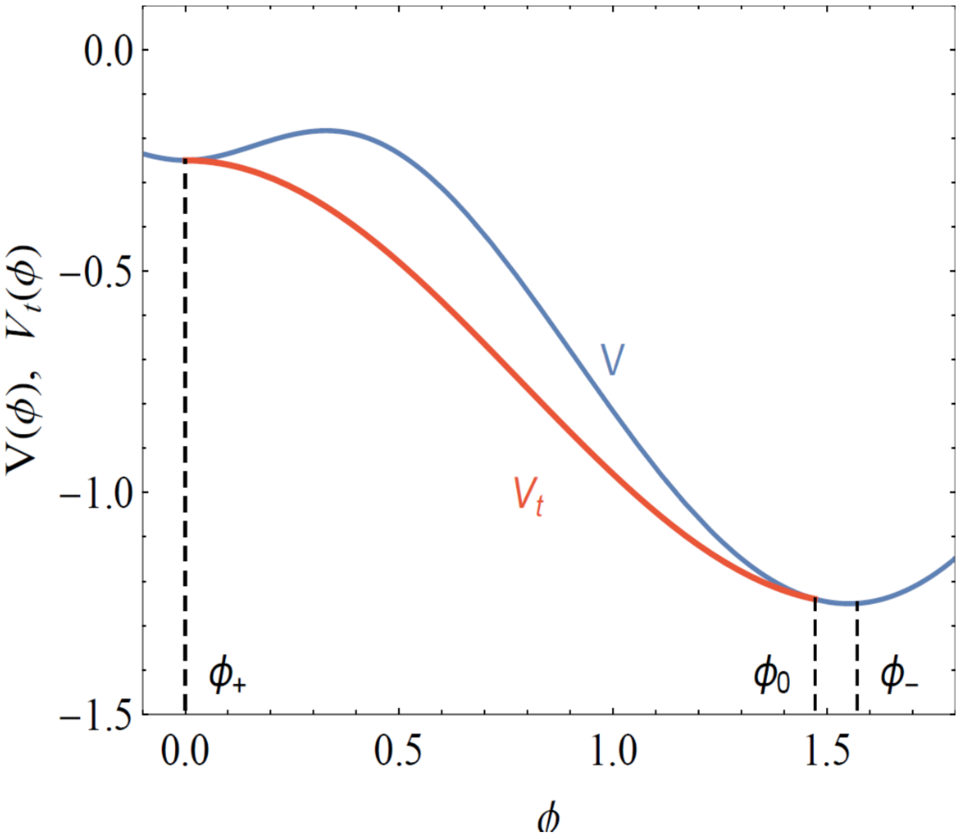
⇨ Good for numerics

⇨ Useful for multi-field case JRE, Konstandin'1811

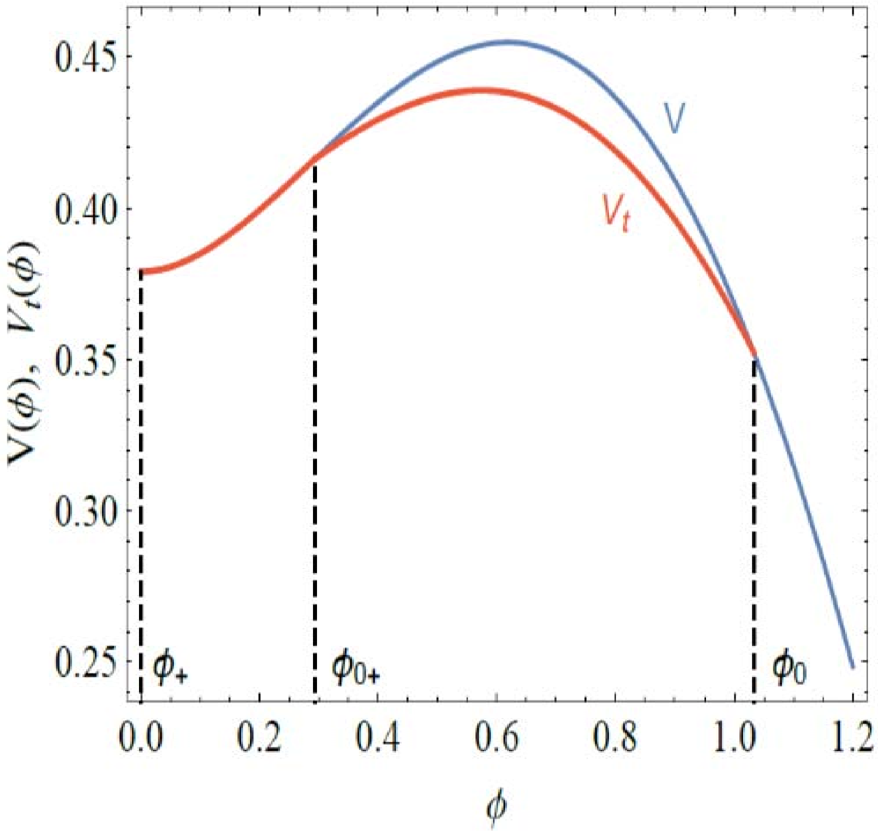
★ $S[V_t]$ is universal

$S[V_t]$ is UNIVERSAL

Valid for AdS, Minkowski or dS false vacua



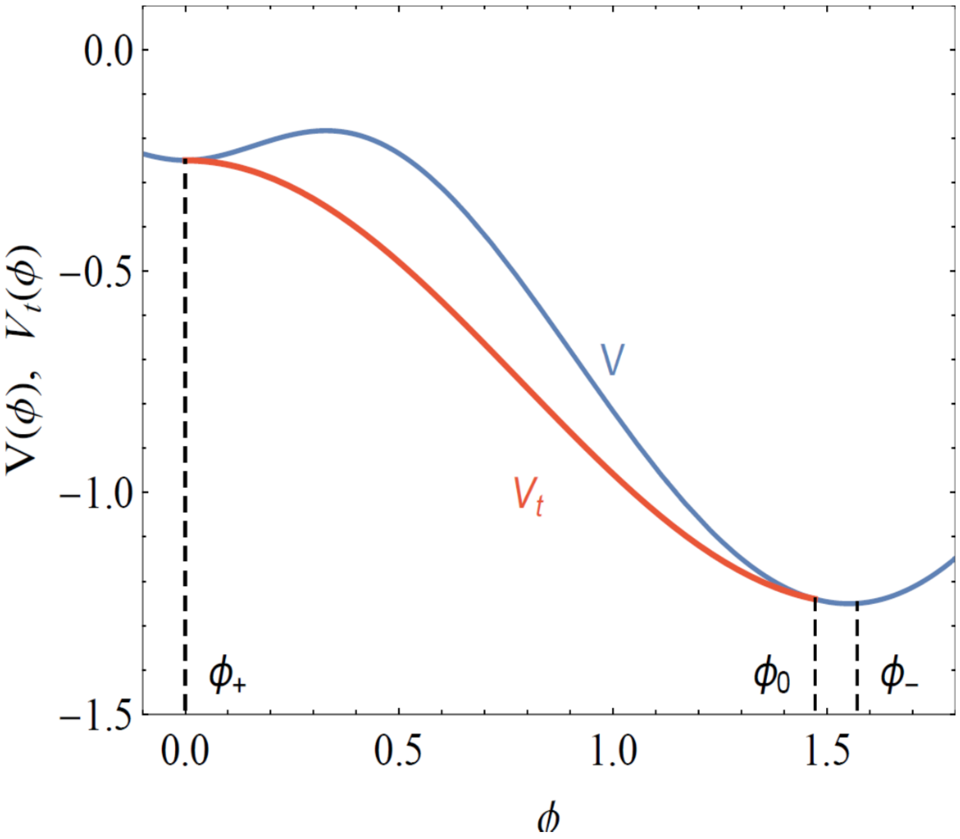
Minkowski or AdS



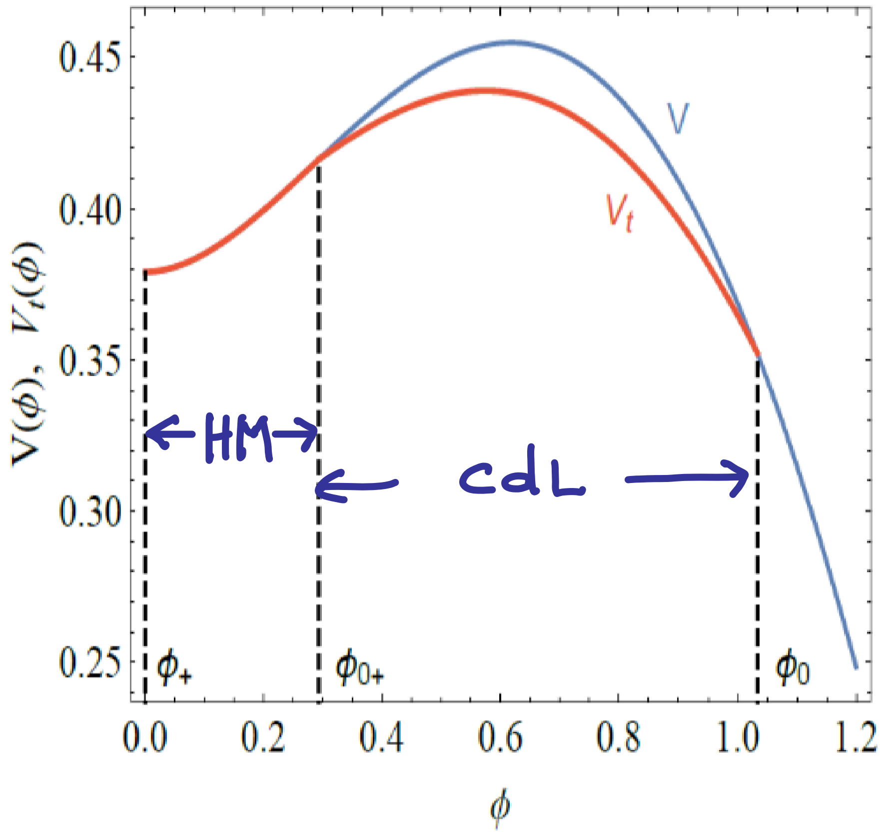
dS

$S[V_t]$ is UNIVERSAL

Valid for AdS, Minkowski or dS false vacua



Minkowski or AdS



dS

EULER-LAGRANGE

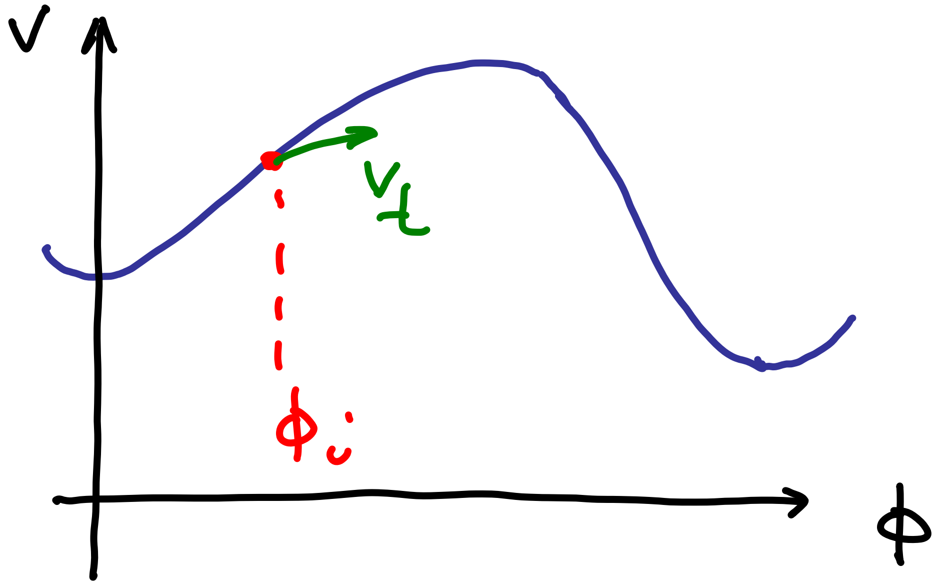
$$\frac{\delta S[V_t]}{\delta V_t} = 0$$

$\Downarrow$ EoM for V_t

$$0 = (4V_t' - 3V')\,V_t' + 6(V - V_t)\left[V_t'' + \kappa\,(3V - 2V_t)\right]$$

BEYOND CdL (dS)

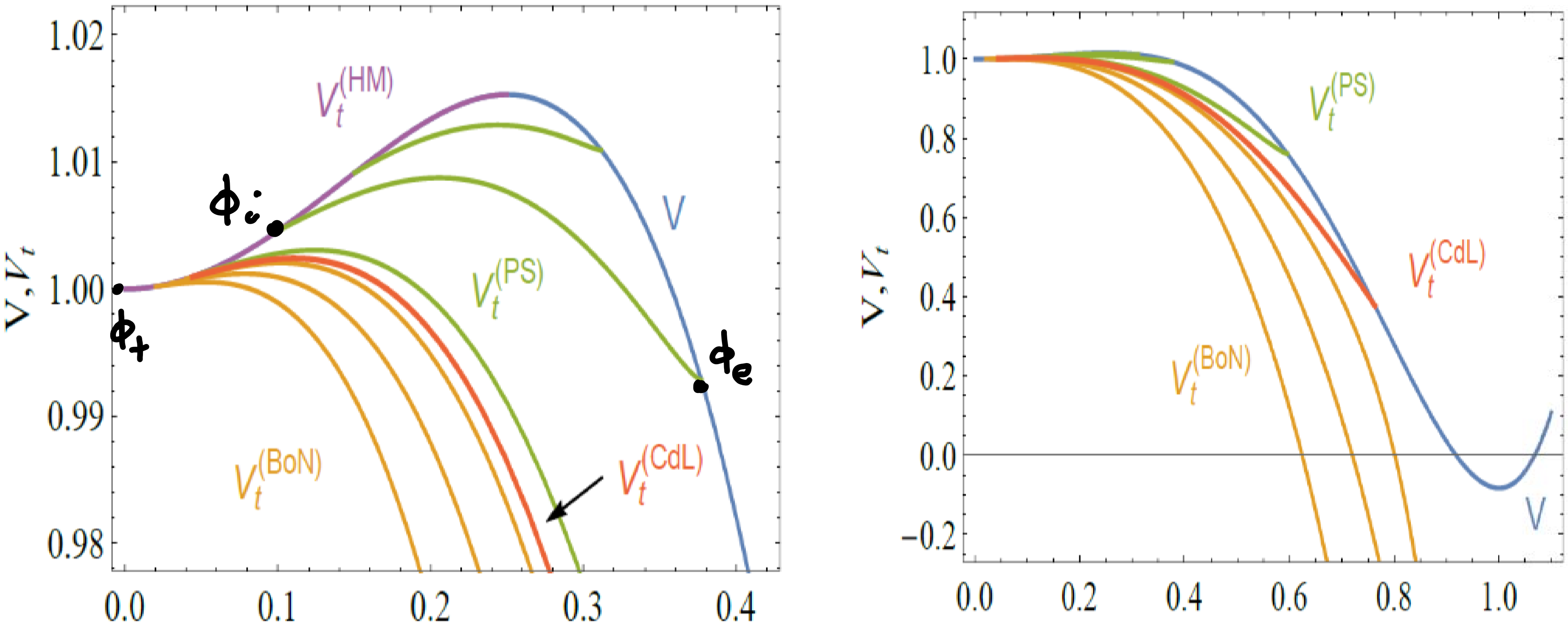
Family of solutions $V_t(\phi_i;\phi)$ of EoM for V_t



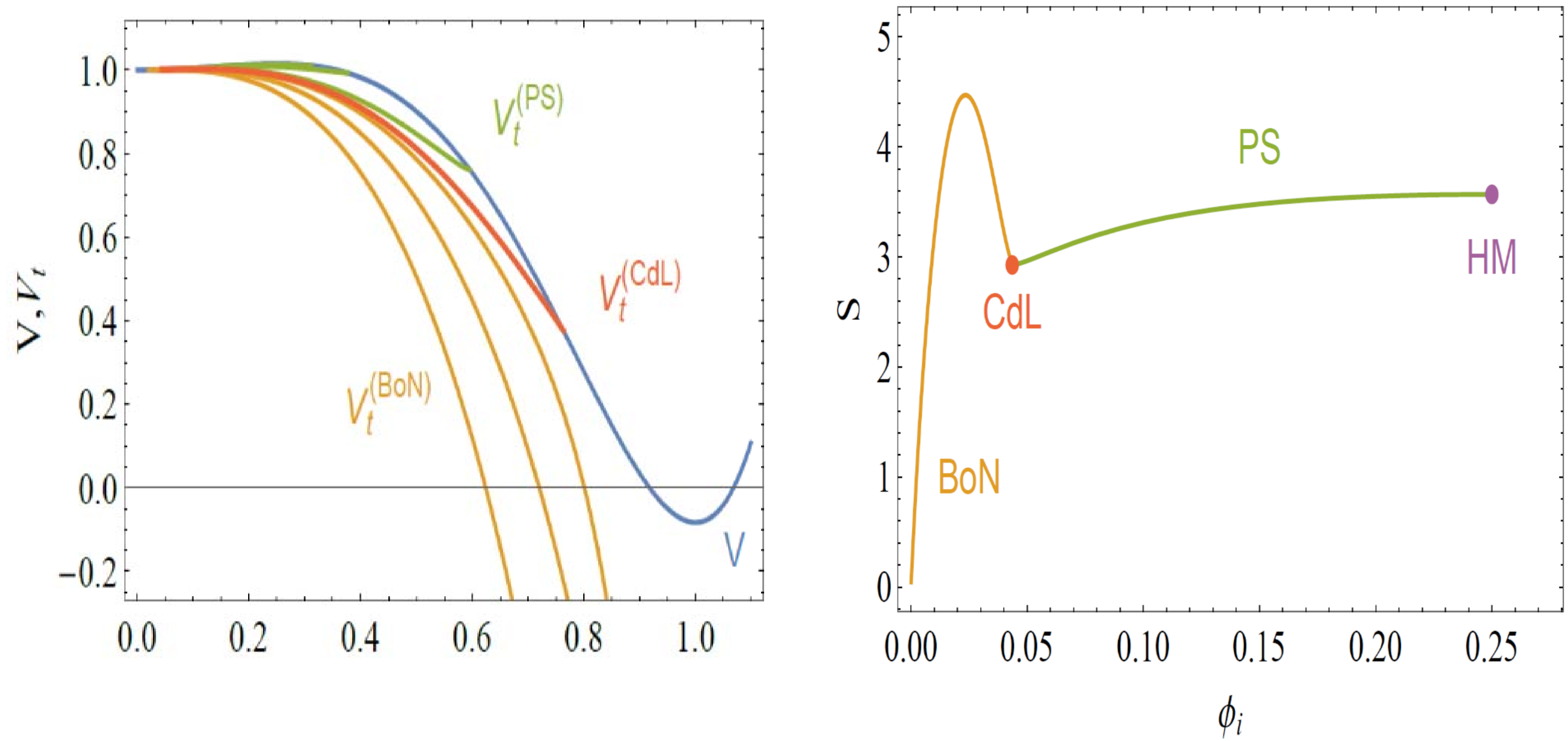
BCs $V_t(\phi_i) = V(\phi_i)$ $V_t'(\phi_i) = \frac{3}{4} V'(\phi_i)$

Vary ϕ_i and see what other solutions appear

BEYOND CdL (dS)



BEYOND CdL (dS)



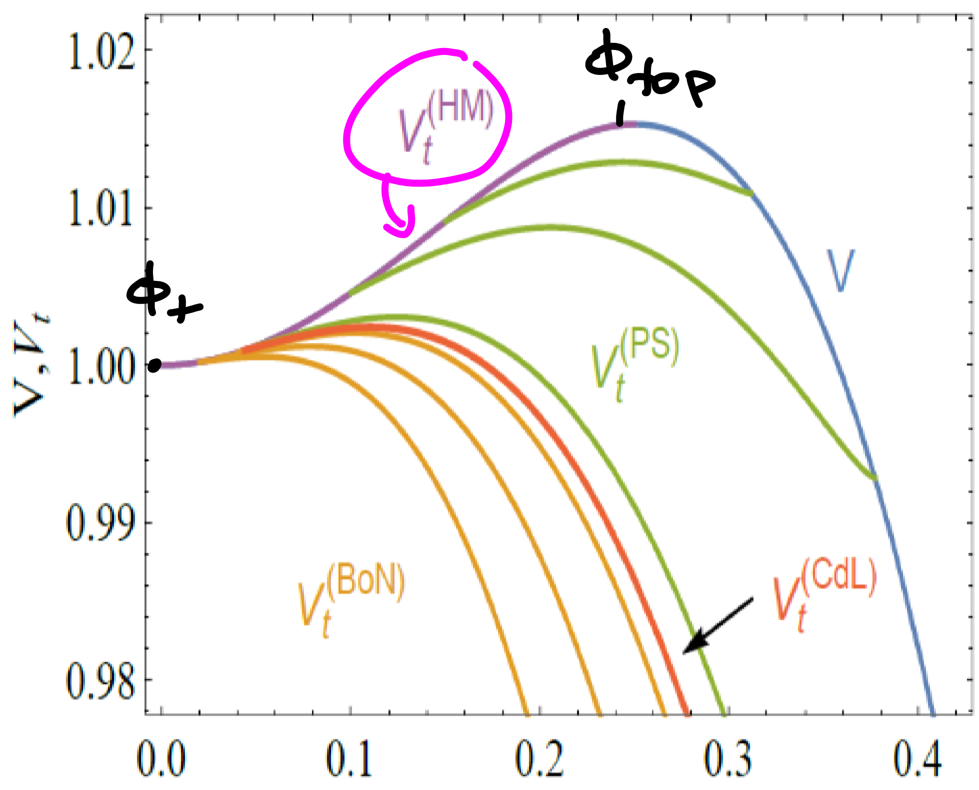
Finite action

HAWKING-MOSS '82

Hawking-Moss decay with tunneling action

$$S_{HM} = \frac{24\pi^2}{\kappa^2}\left(\frac{1}{V_+} - \frac{1}{V_{top}}\right)$$

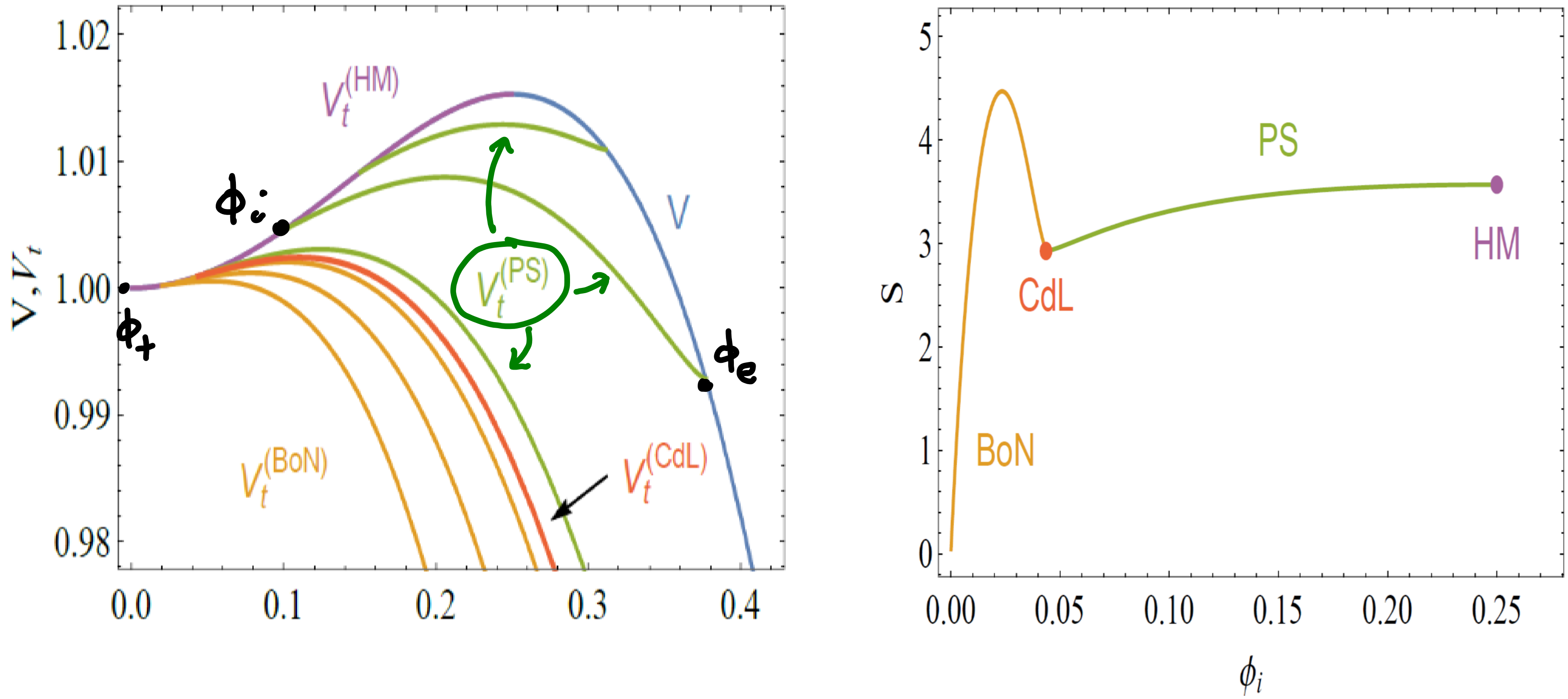
$S[V_t]$ reproduces this ✓



For $V_+ \uparrow$ $\Rightarrow$ no CdL bounce, only HM

PSEUDOBOUNCES

JRE '1908



★ Minimize $S[V_t]$ if ϕ_e held fixed

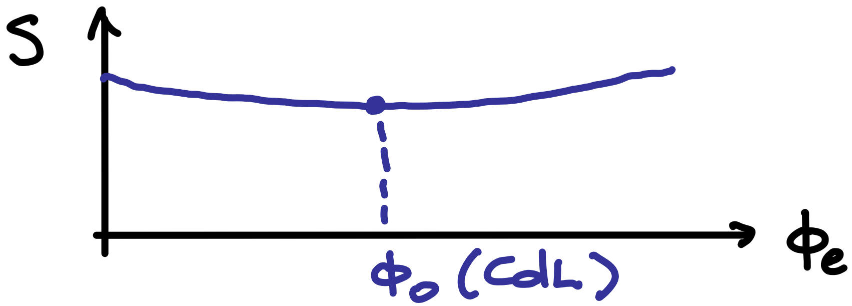
⇨ Not true extremals $dS/d\phi_e \neq 0$

PSEUDOBOUNCES

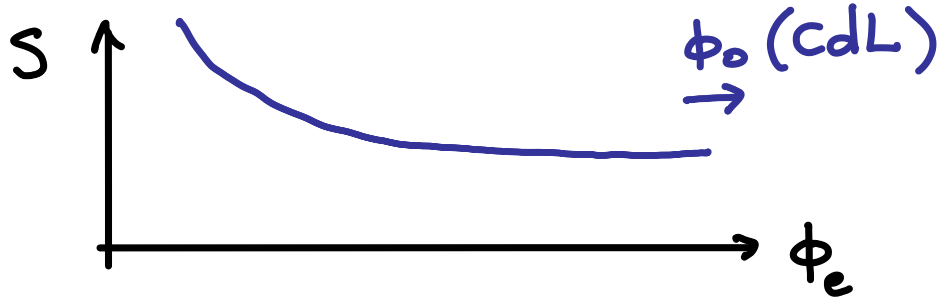
JRE '1908

Relevant if

- $dS/d\phi_e$ small

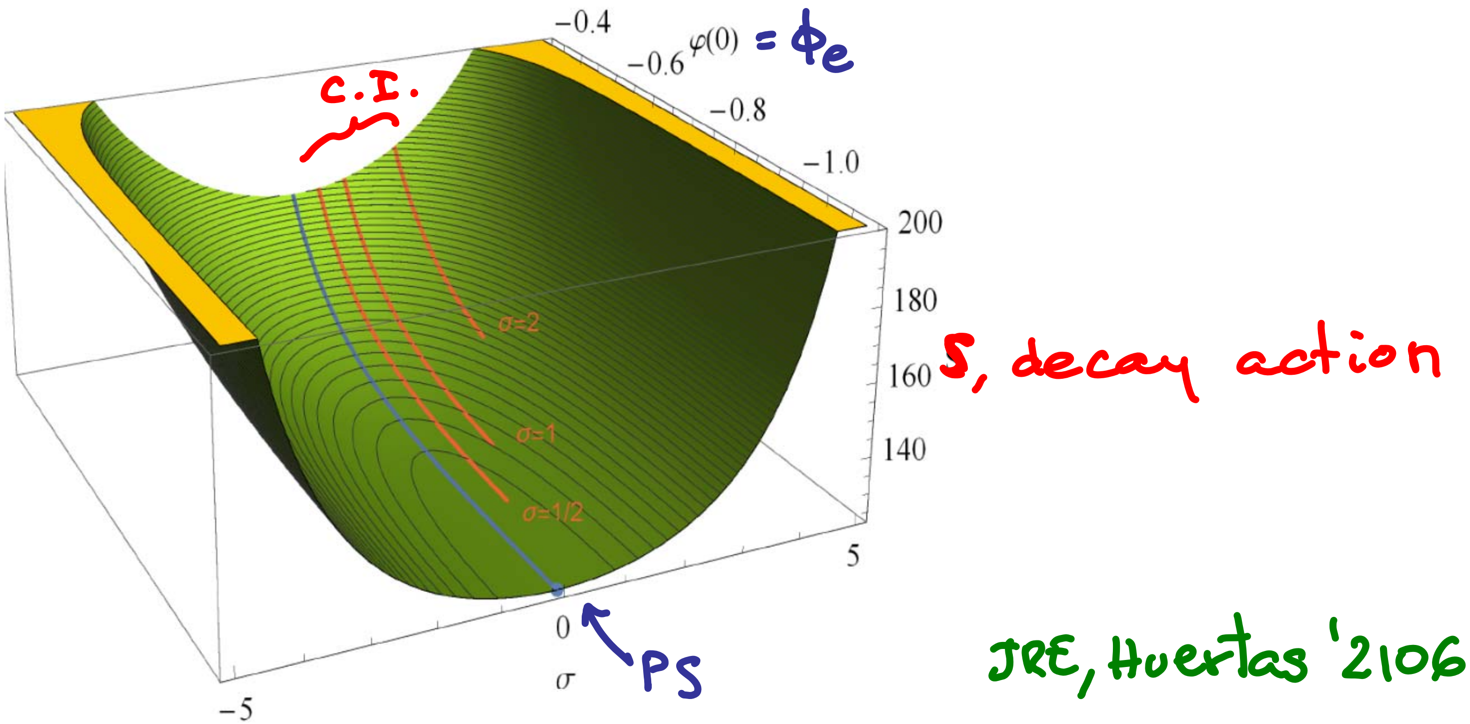


- $\phi_0 \to \infty$ (no bounce)



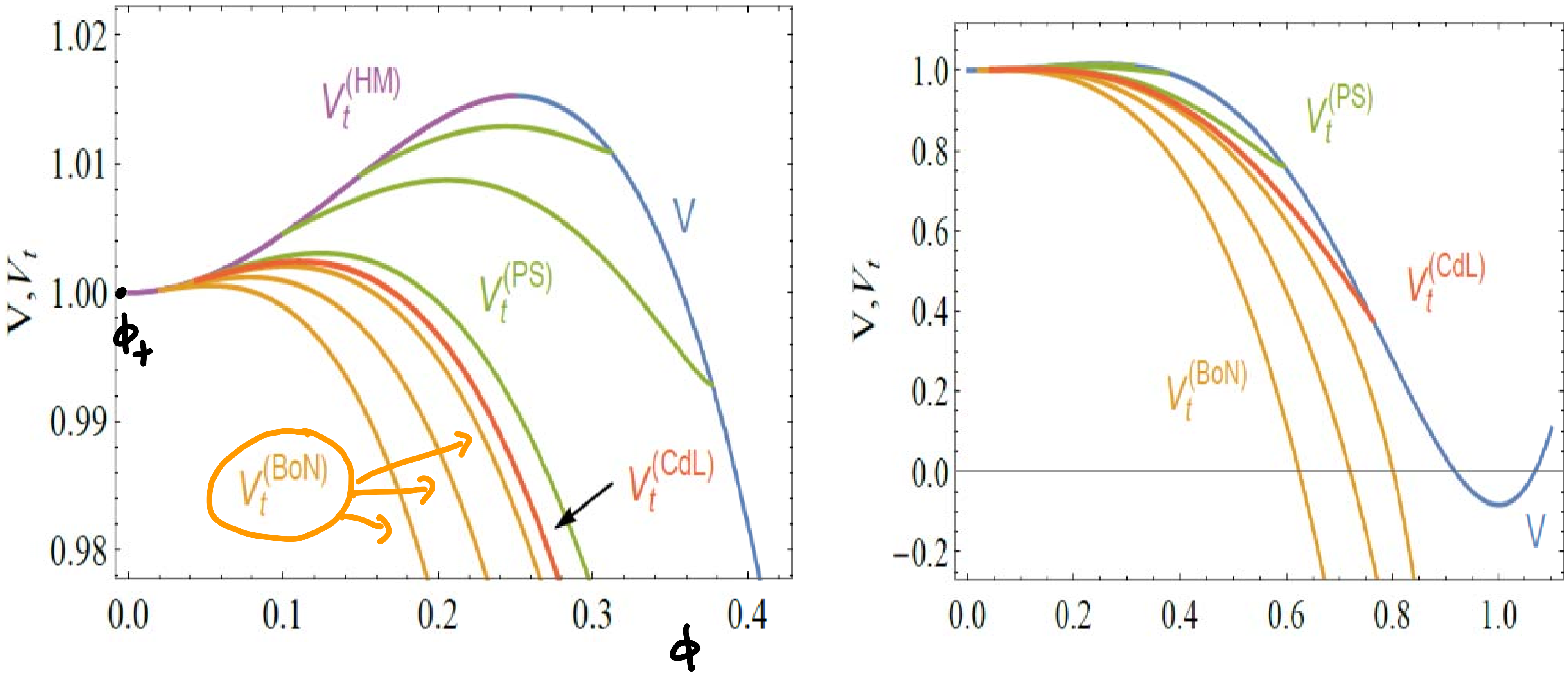
No bounce example :

(ϕ_e, σ) slice



JRE, Huertas '2106

BUBBLE OF NOTHING DECAYS



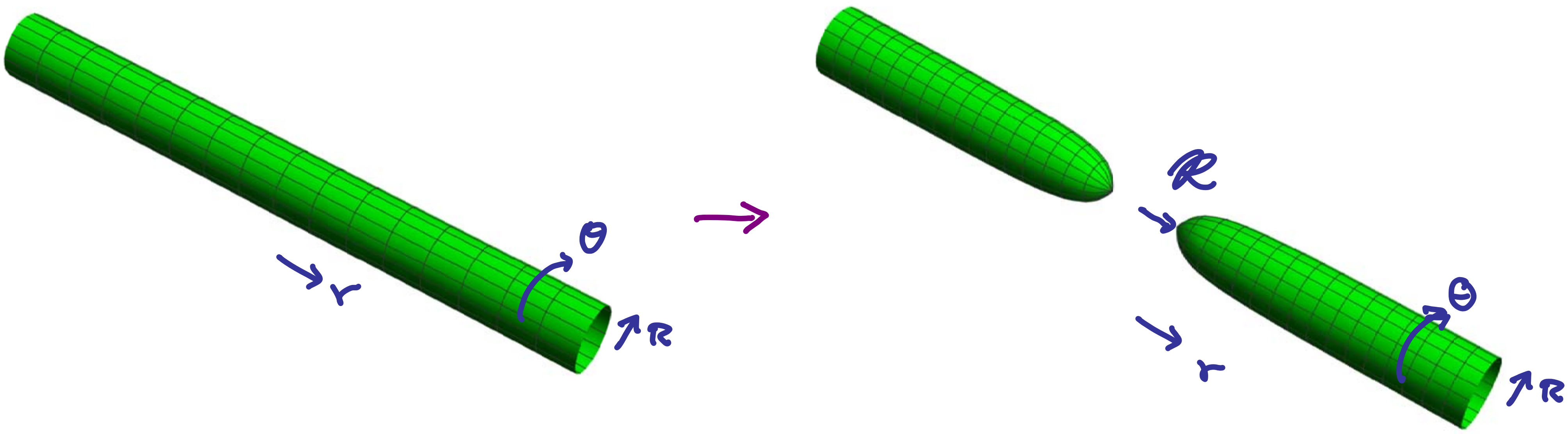
Relevant if ϕ is a size modulus.

BUBBLE OF NOTHING DECAYS

Decays of spacetimes with compactified dim. like

5d KK ($M^4 \times S^1$)

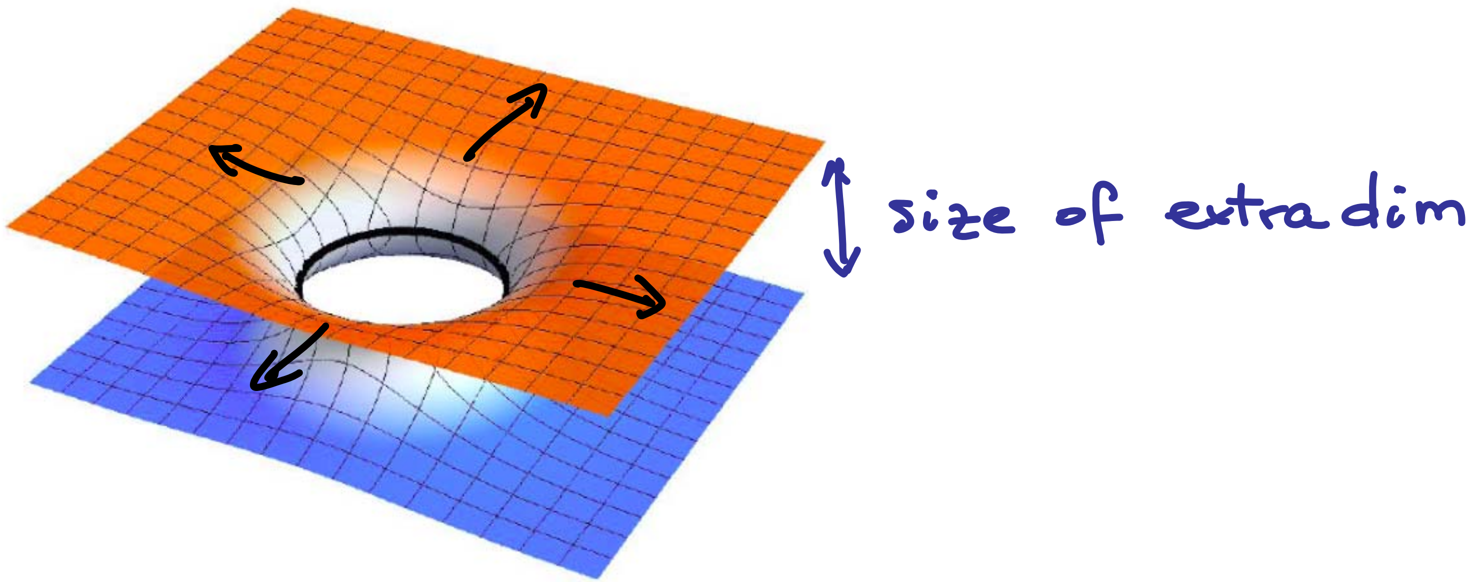
Witten' 82



with $S = (\pi R m_p)^2$

BUBBLE OF NOTHING DECAYS

End-product of tunneling process is a hole in space-time



It's smooth, w/o singularities, curvature not large

But it grows, eating the whole space

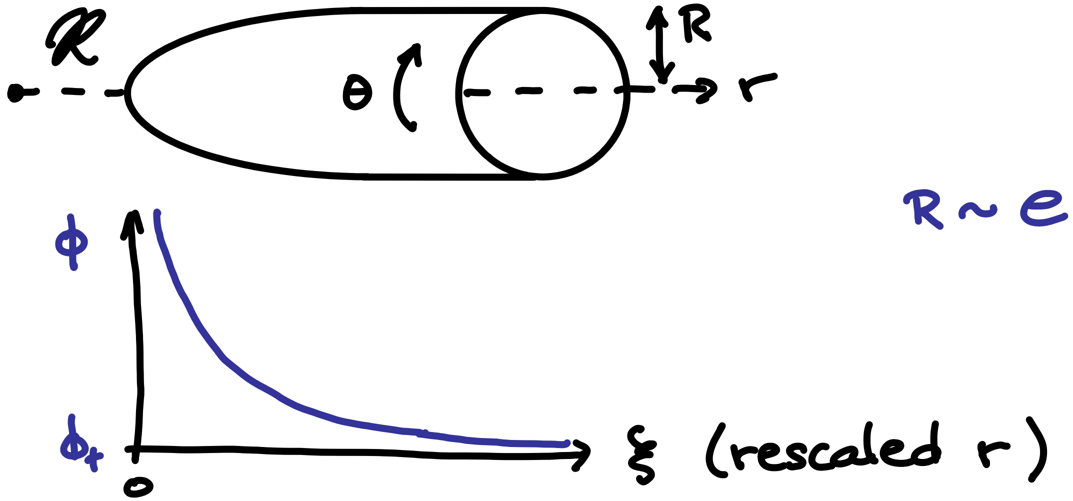
4d VIEW

Dine, Fox, Gorbatov '0405

5d $\to$ 4d + Scalar ϕ (geometric modulus)

5d:

4d:



$R \sim e^{-\#\phi/m_p}$

BoN $\sim$ CdL problem $\phi(0)=\infty$, $\dot{\phi}(0)=-\infty$, $\phi(\infty)=\phi_+=0$

5d Action reproduced (adding special boundary terms)

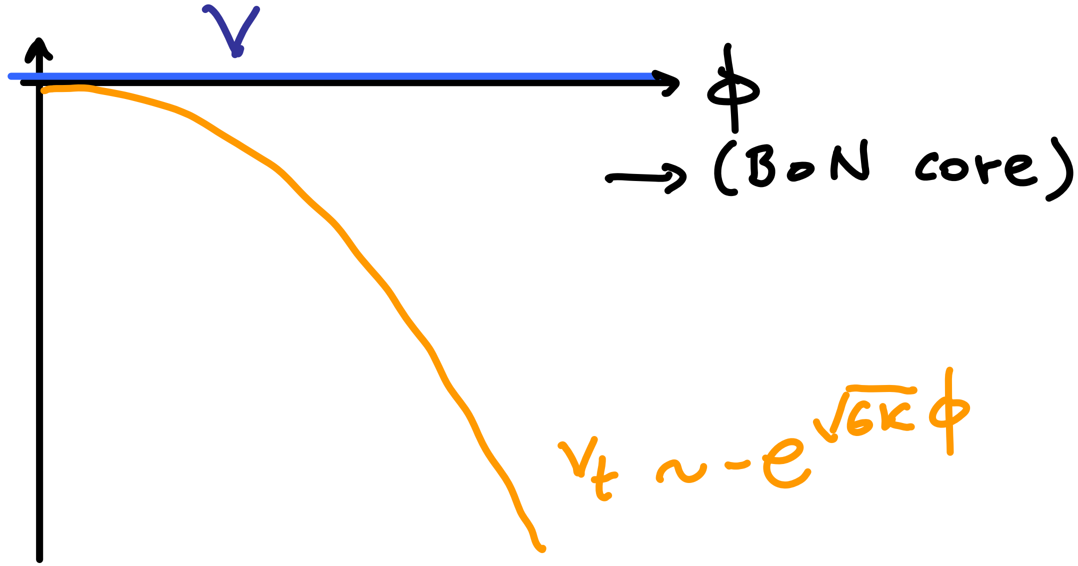
Useful to study which $V(\phi)$ have BoN decays

Draper, García-García, Lillard '2105 (Euclidean)

V_t FOR BONS

Blanco-Pillado, JRE, Huertas, Sousa '2312

Witten's BoN, $V=0$



$$V_t = -\frac{6 m_p^2}{R^2} \sinh^3\left(\sqrt{2\kappa/3}\,\phi\right)$$

BoN ~ tunneling to $-\infty$ AdS

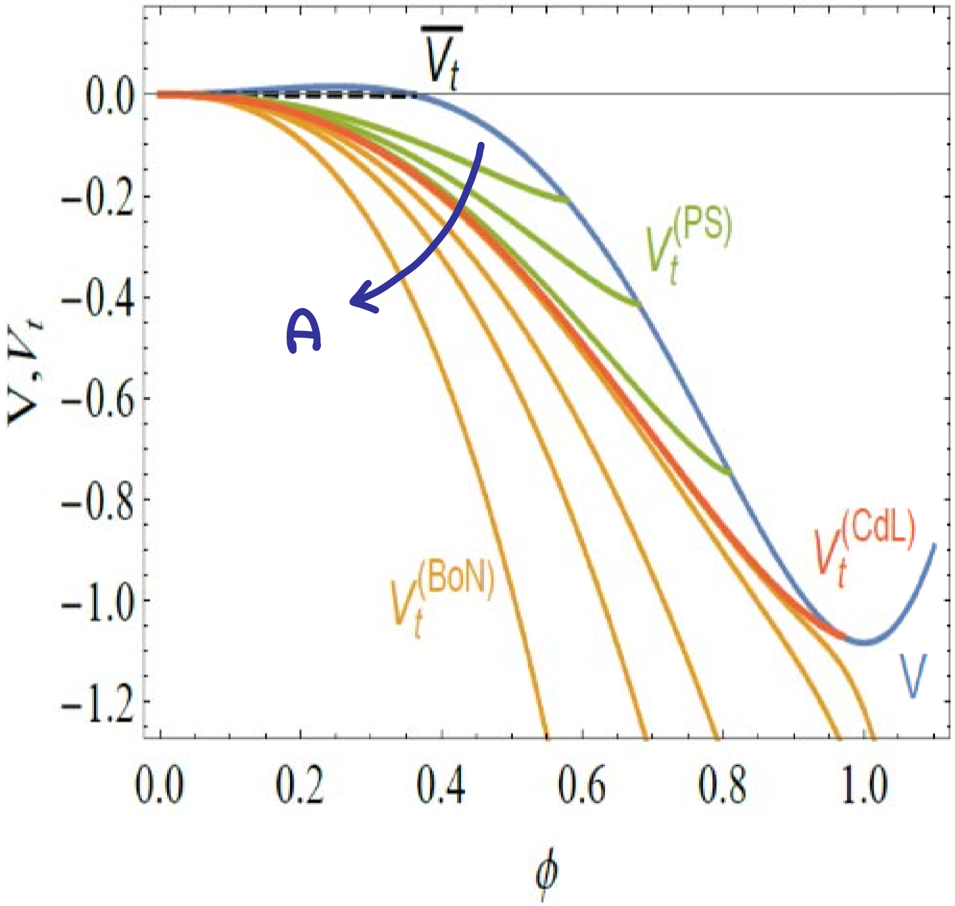
★ $S[V_t]$ ✓ without additional boundary terms

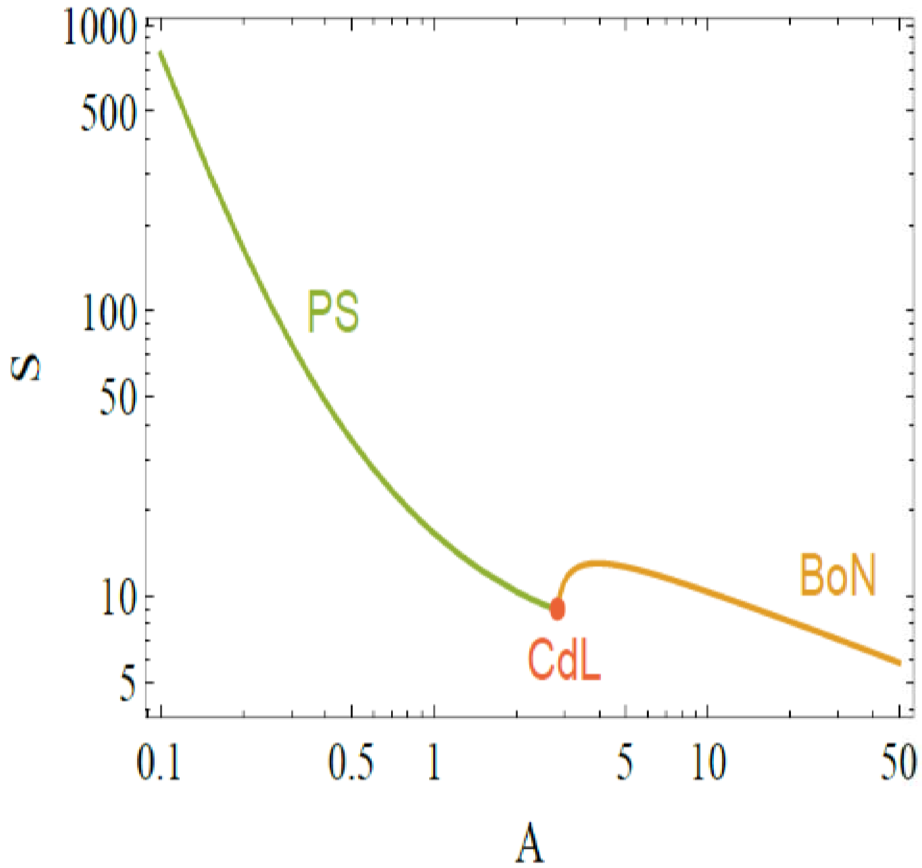
Allows a more efficient study of which $V(\phi)$ have BoN decays

BEYOND CdL (Mink.)

Family of solutions $V_t(A;\phi)$ No H.M.

$\bar{V}_t \geq V_t^{PS} \geq V_t^{CdL}$

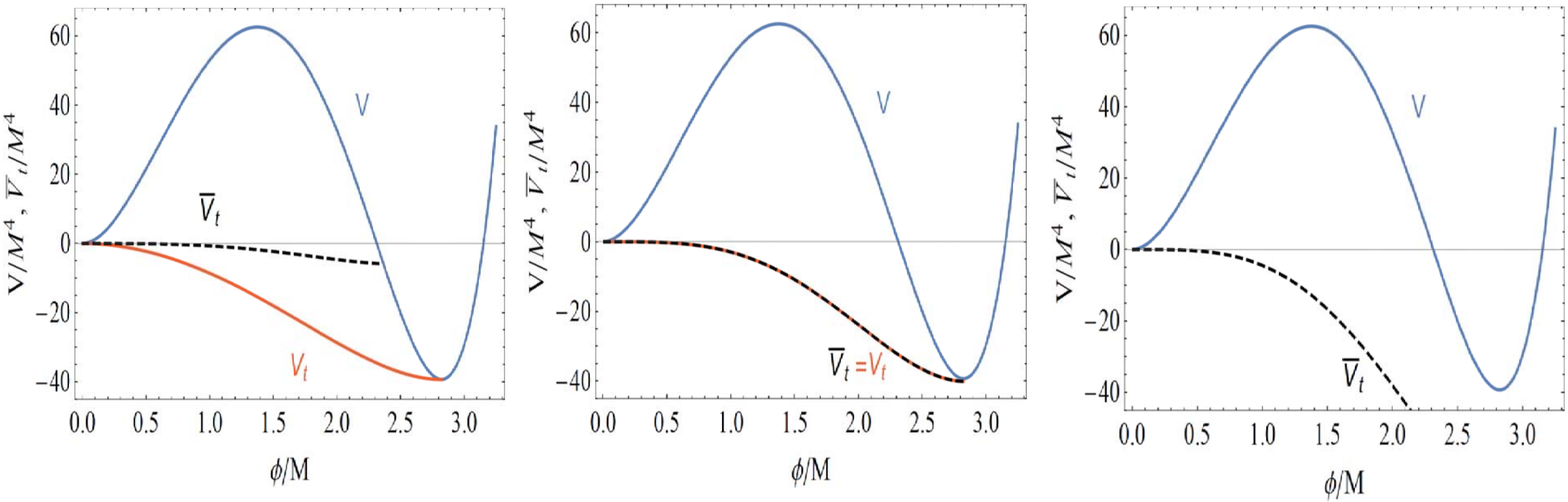




$\bar{V}_t$ solves $D^2 = V_t'^2 + 6\kappa(V - V_t)V_t = 0 \Rightarrow S \to \infty$

BEYOND CdL (Mink.)

$\bar{V}_t$ solves $D^2 = V_t'^2 + 6\kappa(V - V_t)V_t = 0$ and $V_t \leq \bar{V}_t$



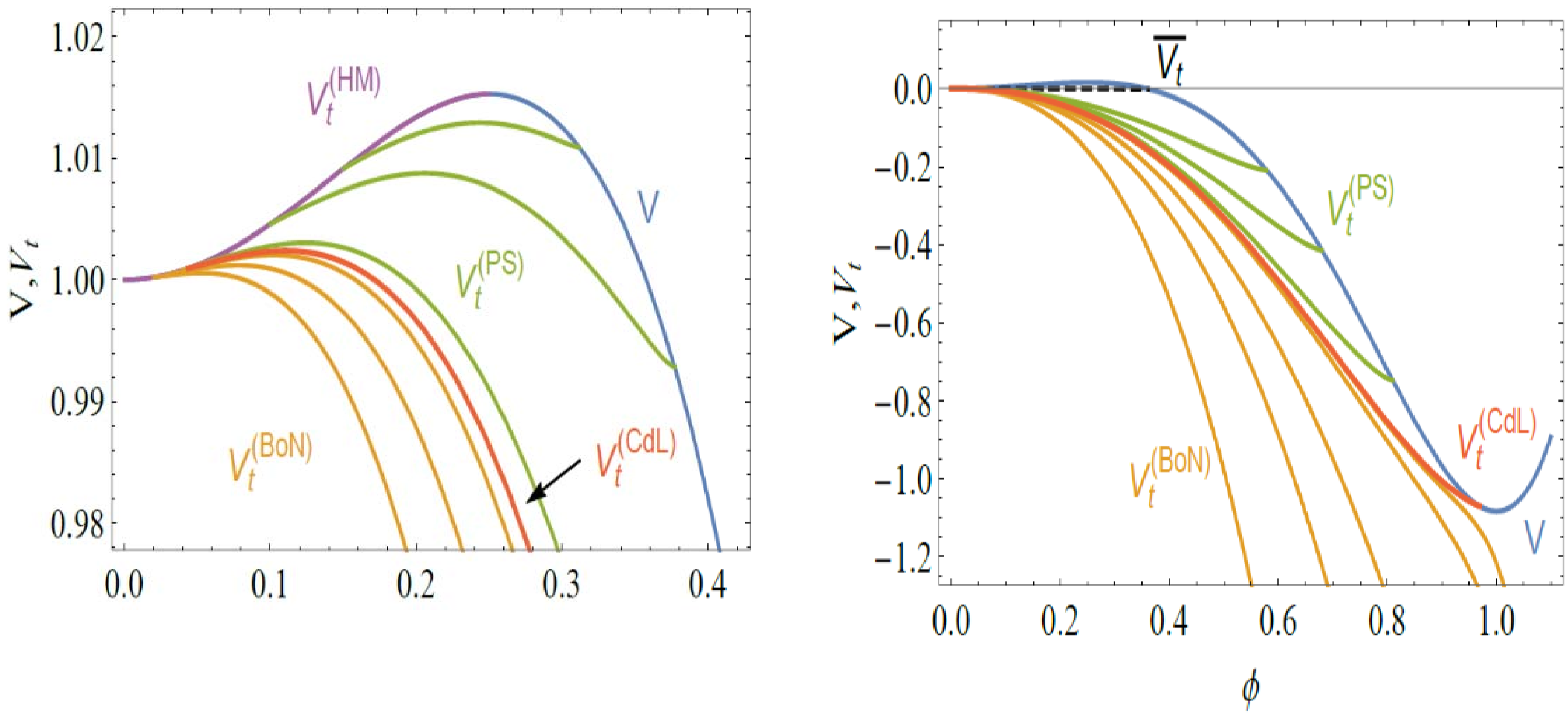
Decay allowed

Domain Wall

Decay forbidden (by gravity)

CONCLUSIONS

★ Tunneling Potential Formalism gives a simple Unified view of vacuum decay channels



V_t - EUCLIDIAN CONNECTION

JRE '1808

$$V_t = V - \frac{1}{2}\dot{\phi}^2$$

$$\dot{\phi} = -\sqrt{2(V - V_t)}$$

$$\rho = \frac{3\sqrt{2(V - V_t)}}{D}$$

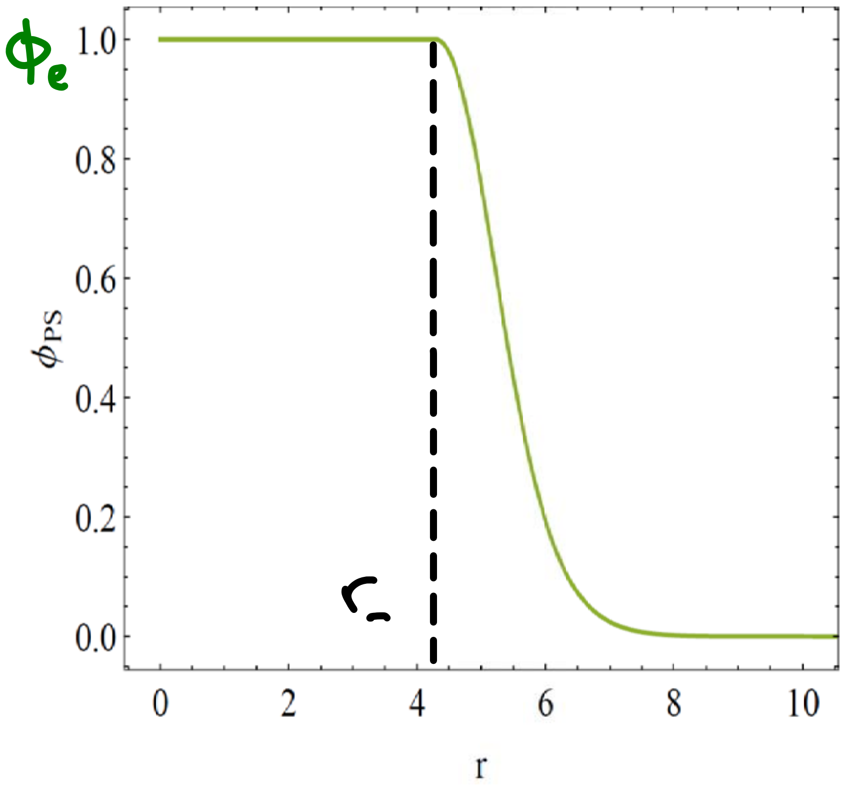
$$\ddot{\phi} = V' - V_t'$$

$$\dot{\rho} = -\frac{V_t'}{D}$$

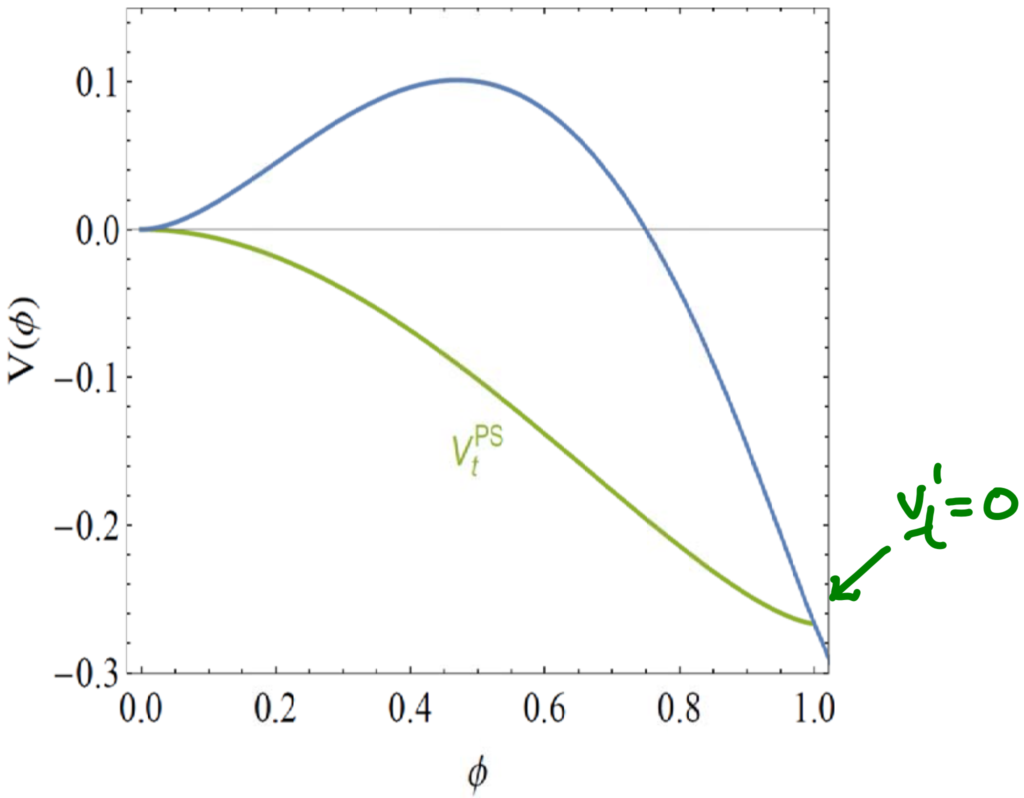
PSEUDOBOUNCE PROFILES

JRE '1908

Euclidean



V_t

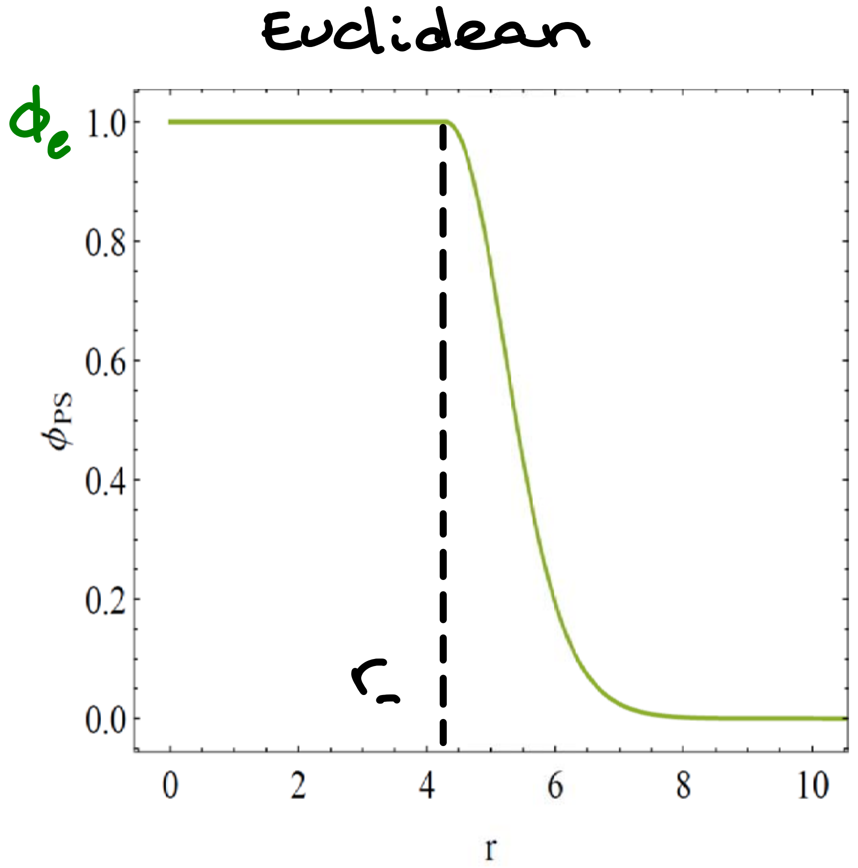


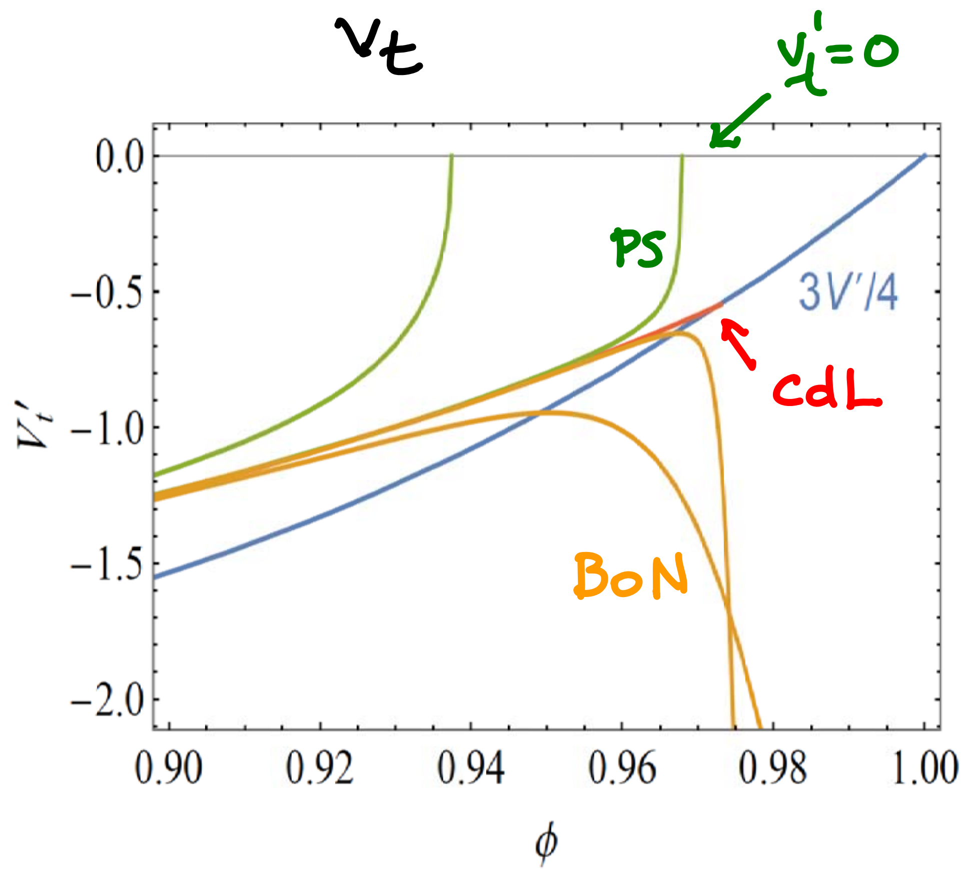
$$\frac{r_-^2}{18} = \left.\frac{V - V_t}{V_t'^2}\right|_{\phi_e}$$

$$\frac{dS}{d\phi_e} = \frac{\pi^2}{2} r_-^4 V'(\phi_e)$$

PSEUDOBOUNCE PROFILES

JRE '1908





$$\frac{r_-^2}{18} = \left.\frac{V-V_t}{V_t'^2}\right|_{\phi_e}$$

$$\frac{dS}{d\phi_e} = \frac{\pi^2}{2} r_-^4 V'(\phi_e)$$