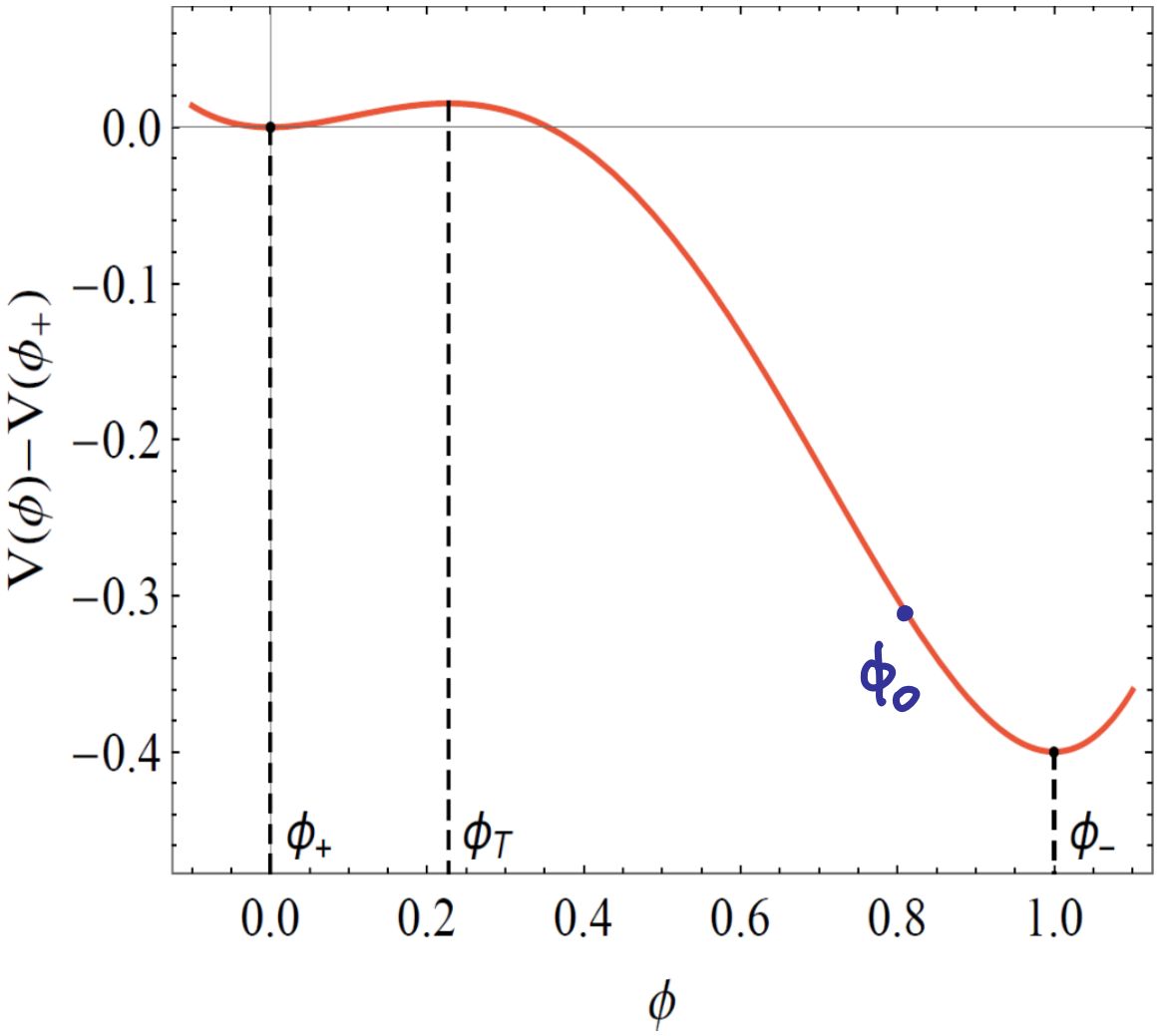
SURPRISES IN VACUUM DECAY

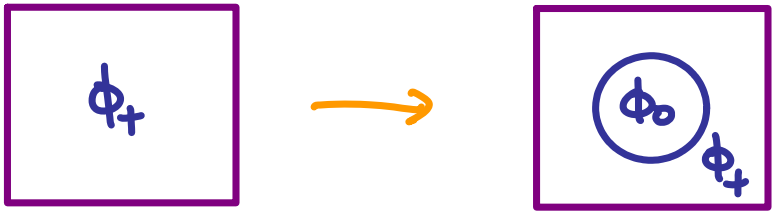
Scalars 2025
Warsaw
23/9/2025

J.R.Espinosa

Instituto de Física Teórica
UAM-CSIC

THE PROBLEM





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

EUCLIDEAN FORMALISM

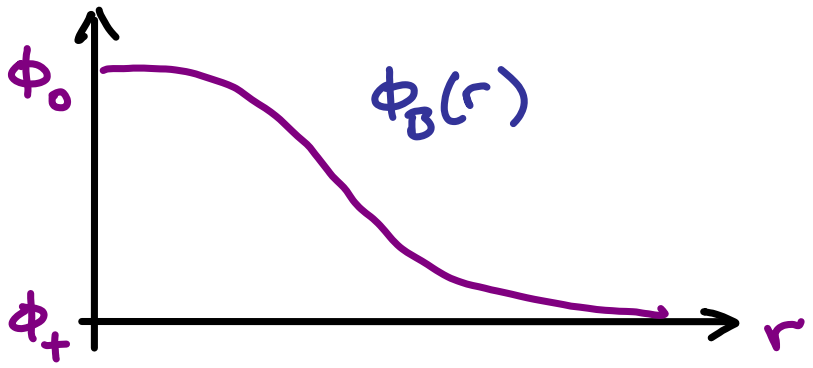
Coleman '77

Euclidean bounce $\phi_B(r)$, $O(4)$-sym, extremizes

$$S_E = 2\pi^2 \int_0^\infty dr\, r^3 \left[\frac{1}{2}\dot{\phi}^2 + V(\phi) \right]$$

$$\Rightarrow \quad \ddot{\phi} + \frac{3}{r}\dot{\phi} = \frac{\partial V}{\partial \phi}$$

with $\phi(0) = \phi_0 \quad \dot{\phi}(0) = 0 \quad \phi(\infty) = \phi_+$



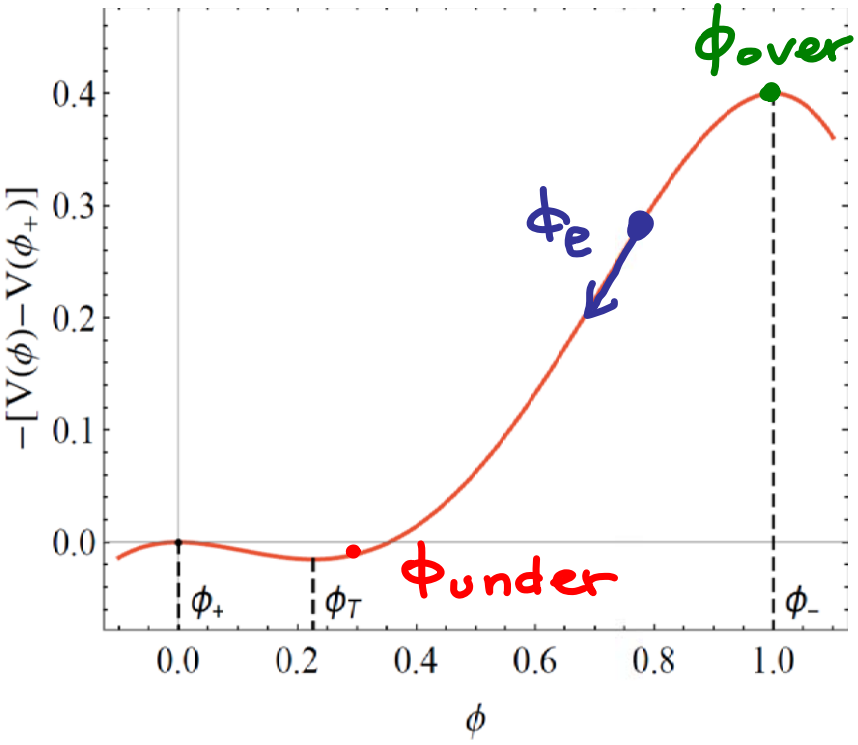
$$S = \Delta S_E \equiv S_E[\phi_B] - S_E[\phi_+]$$

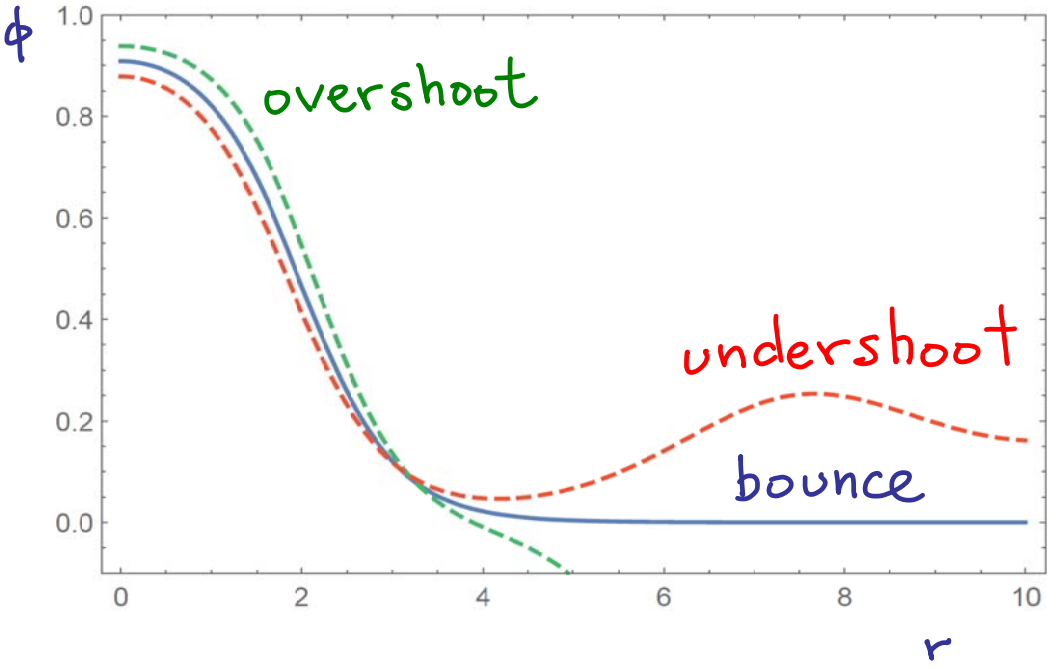
OVER/UNDERSHOOTING

ϕ → particle's position r → time

$$\ddot{\phi} + \frac{3}{r}\dot{\phi} = +V'$$

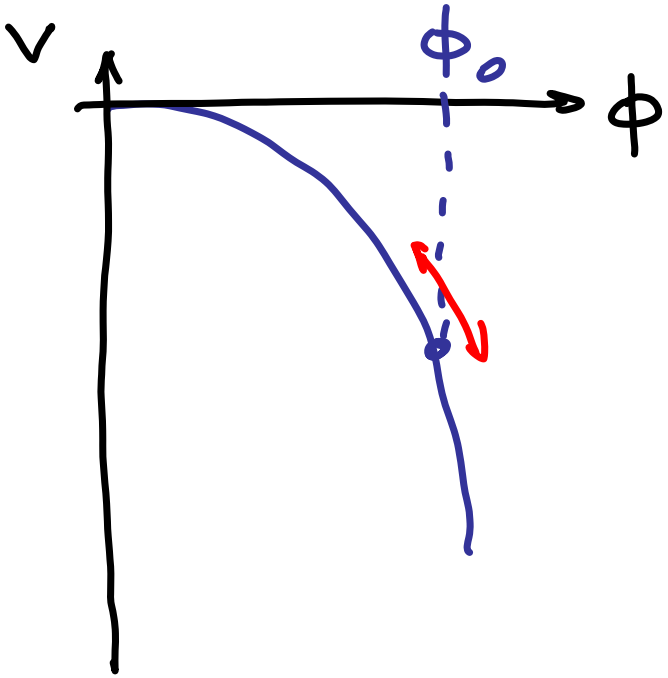
motion on $-V$ with time-dep friction





If undershot, ϕ_e↑. If overshot, ϕ_e↓.

$$V(\phi) = -\frac{\lambda}{4}\phi^4$$



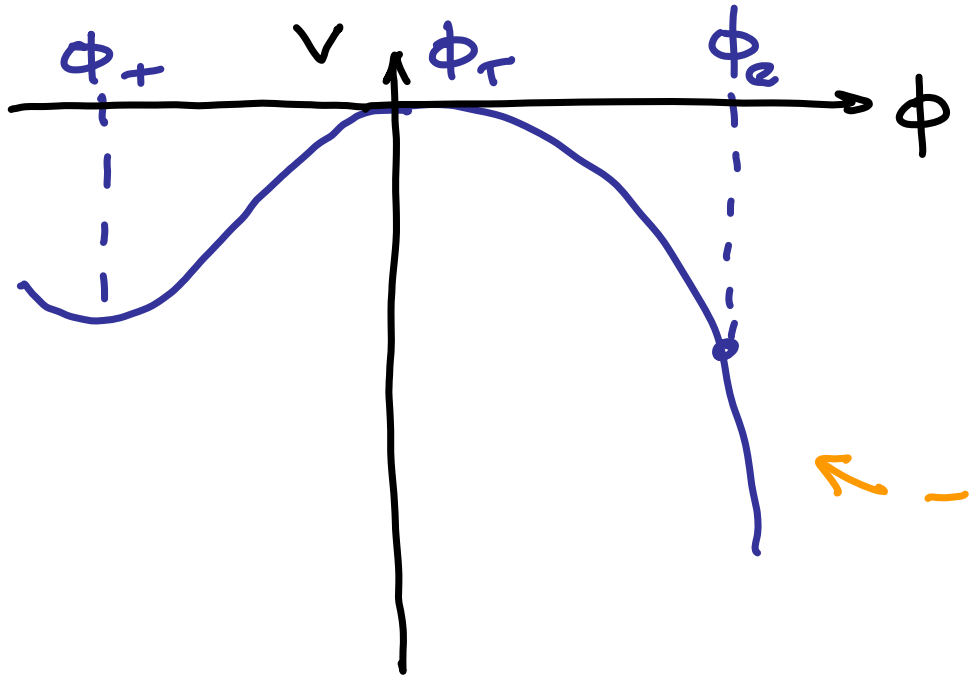
$\Rightarrow$ ϕ_0 arbitrary

scale invariance of V

$$S[\phi_B] = \frac{8\pi^2}{3\lambda}$$

$\Rightarrow$ ϕ_0 - independent

No Bounce



$\nwarrow -\frac{\lambda}{4}\phi^4$ piece

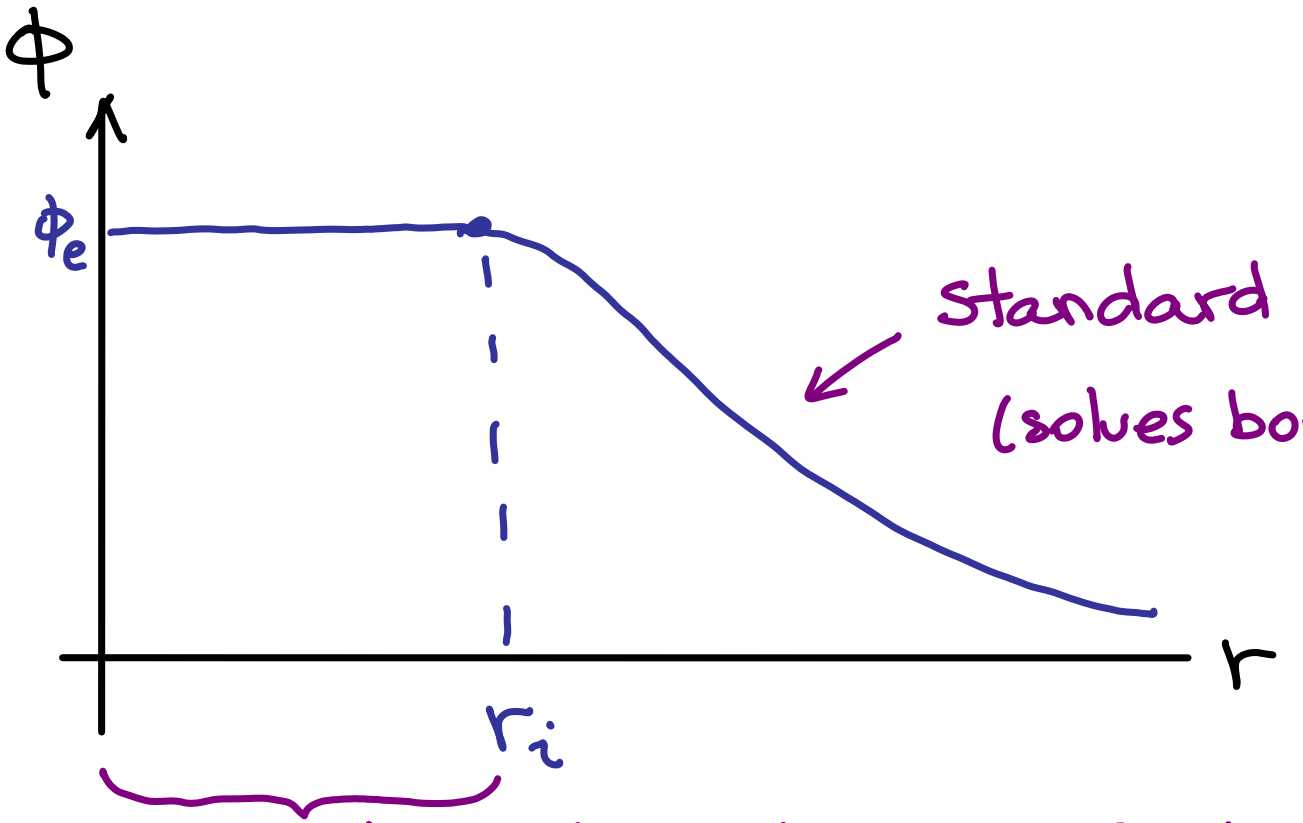
For any $\phi_e \rightarrow \phi(\infty) = \phi_T$ not ϕ_+ (all undershots)

$\Rightarrow$ No bounce ! ~~No decay~~

Decay via pseudo-bounces

JRE '1908

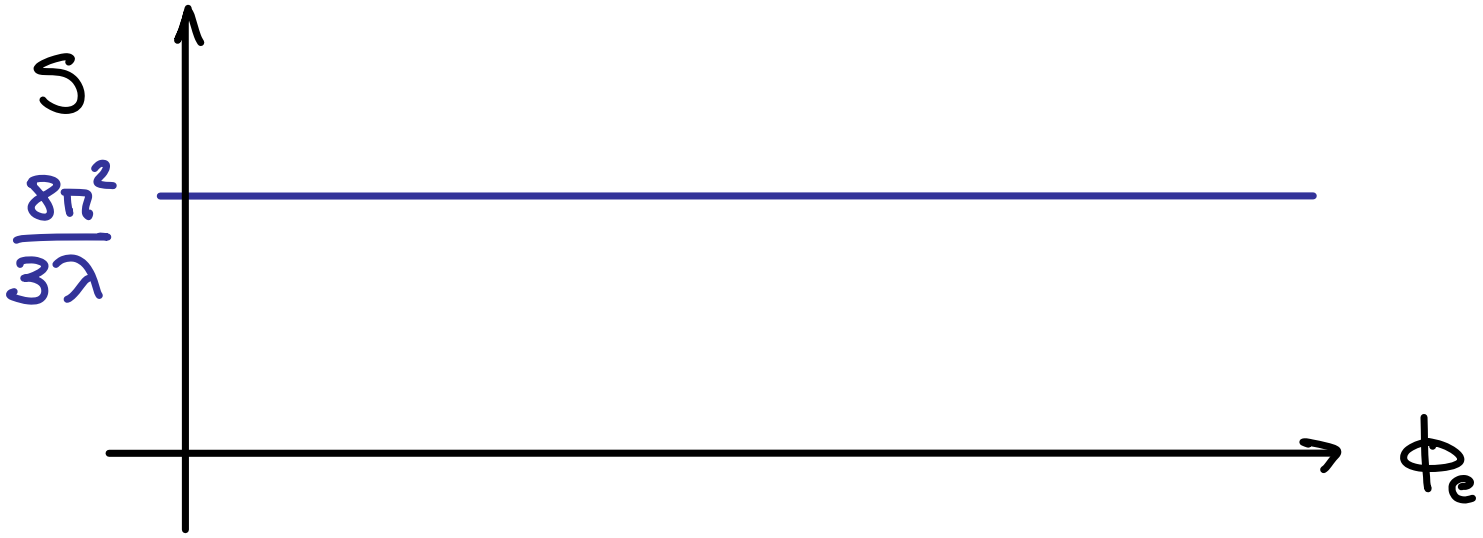
PSEUDOBOUNCE PROFILE



Waiting "time" to decrease friction & avoid undershot. Tuned to give $\phi(\infty) = \phi_+$

PSEUDOBOUNCES AND DECAY VALLEYS

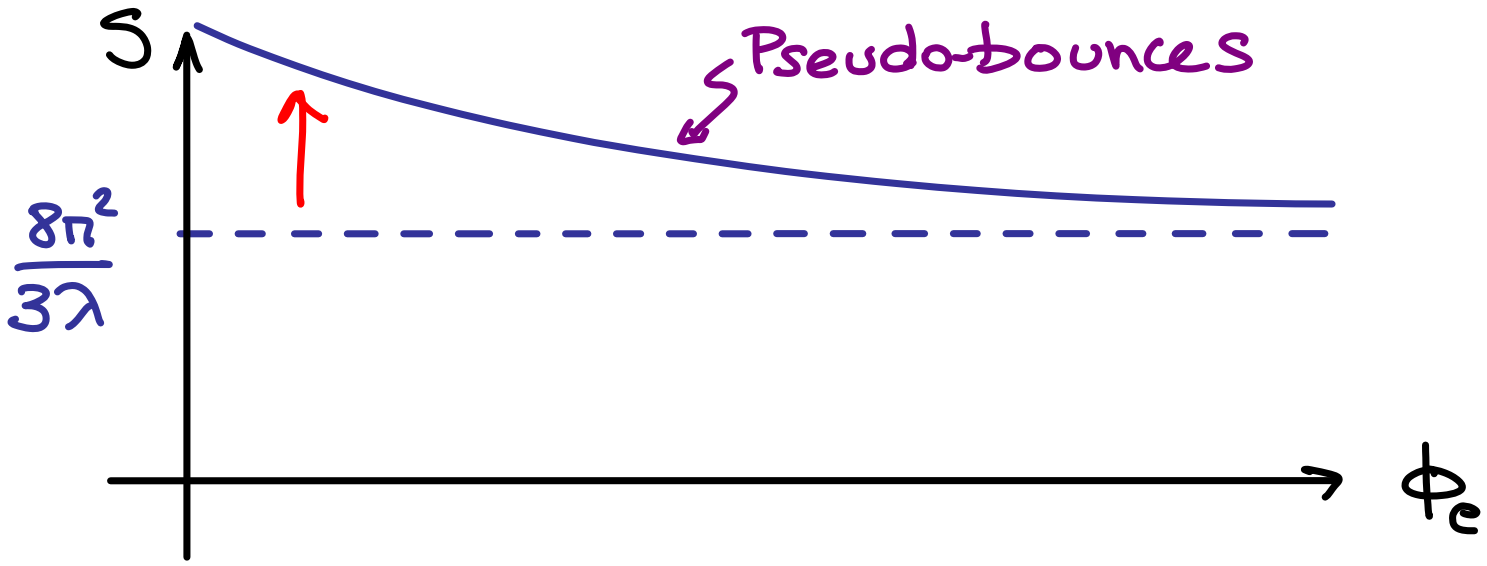
For $V = -\frac{\lambda}{4}\phi^4$



Flat direction of $S[\phi]$ in config. space

PSEUDOBOUNCES AND DECAY VALLEYS

For $V = -\frac{\lambda}{4}\phi^4 + \frac{1}{2}m^2\phi^2$



Flat direction of $S[\phi]$ in config. space

lifted to a sloping valley

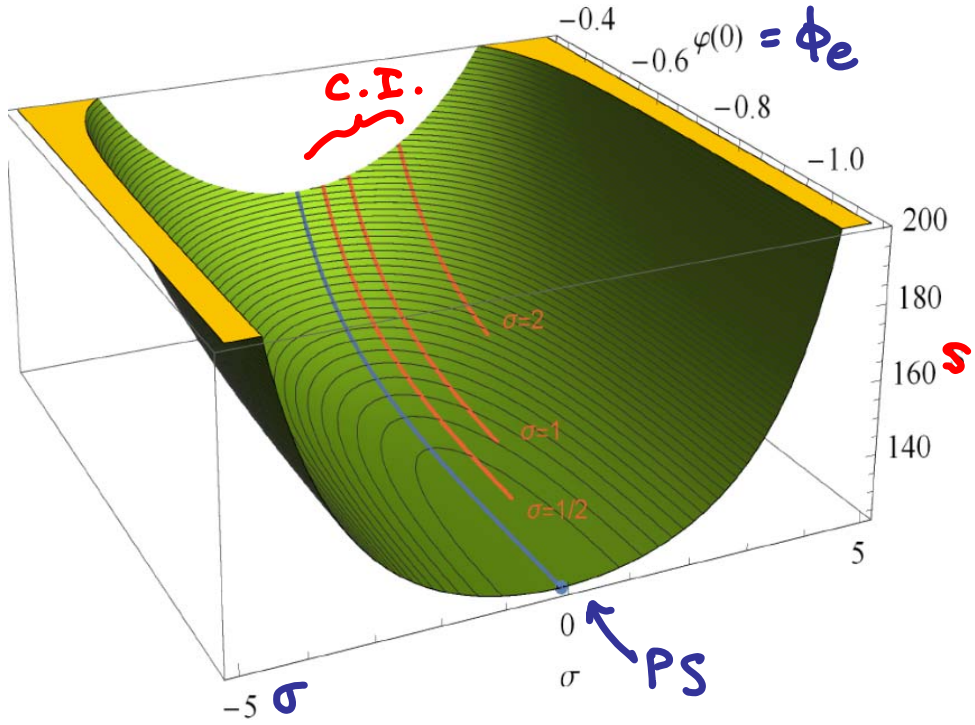
→ Bounce is pushed to $\phi_e \to \infty$

PSEUDOBOUNCES TRACK DECAY VALLEYS

Pseudobounces = O(4) Field configurations $\phi(r)$ that minimize S for fixed $\phi(0)$

➡ "constrained bounces"

Example:



JRE, Huertas '2106
vs
Mukhanov et al.
'2009

PSEUDOBOUNCE PROPERTIES

- Not solutions of bounce eq.

  ➡ Not extremals of $S[\phi]$

  PS sit on a sloping valley ✓

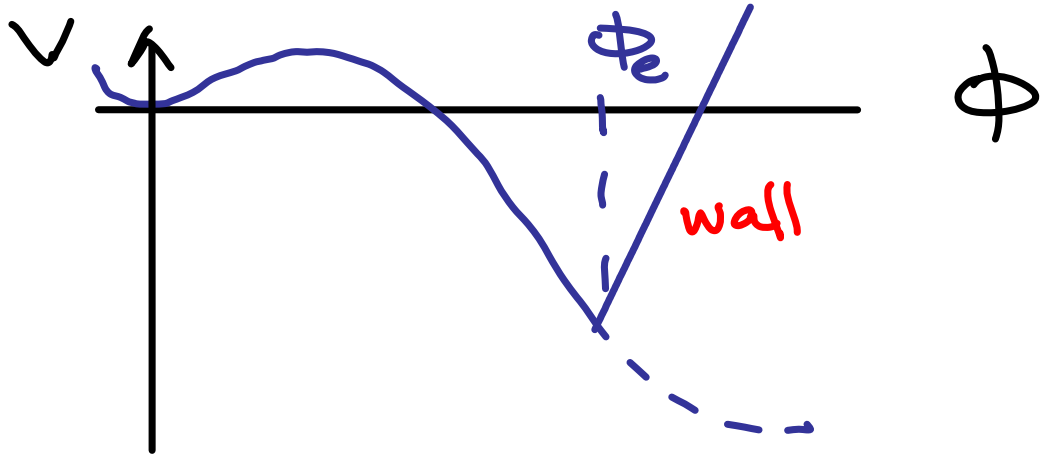
$$\frac{dS}{d\phi_e} = \frac{\pi^2}{2} r_i^4 V'(\phi_e)$$

- Their $\varepsilon = 0$ slice (nucleated bubble) has $\epsilon = 0$ ✓

  Proper final state for decay

PSEUDOBOUNCE PROPERTIES

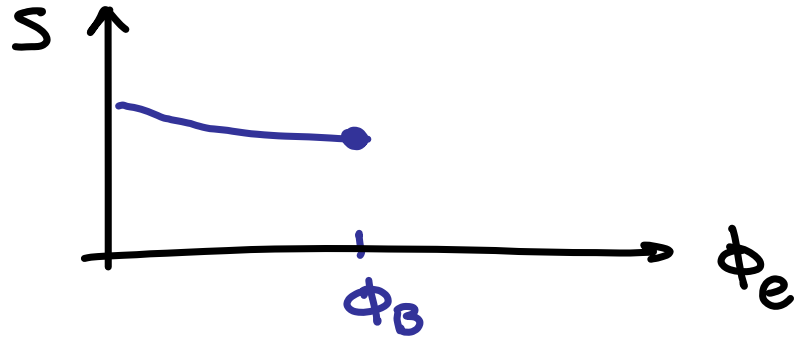
- Origin of their good properties
  - They would be proper bounces for



USES OF PSEUDOBOUNCES

- No bounce cases
- They exist even if there is a bounce !

  Flattish valleys



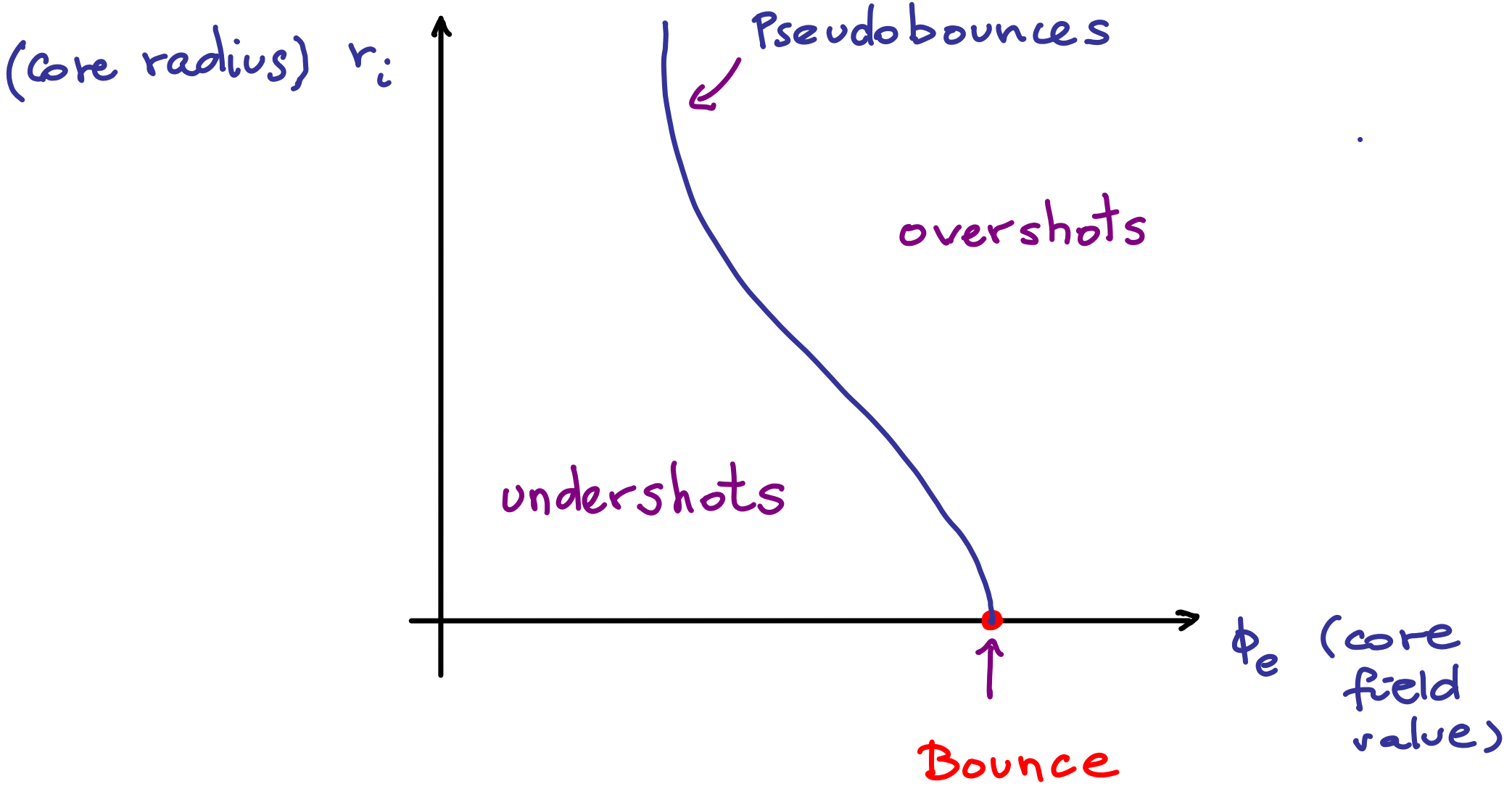
- Get upper bound on S_{Bounce}

  Mirbabayi, Villadoro '2506

- Tool to study general decay structure ➡

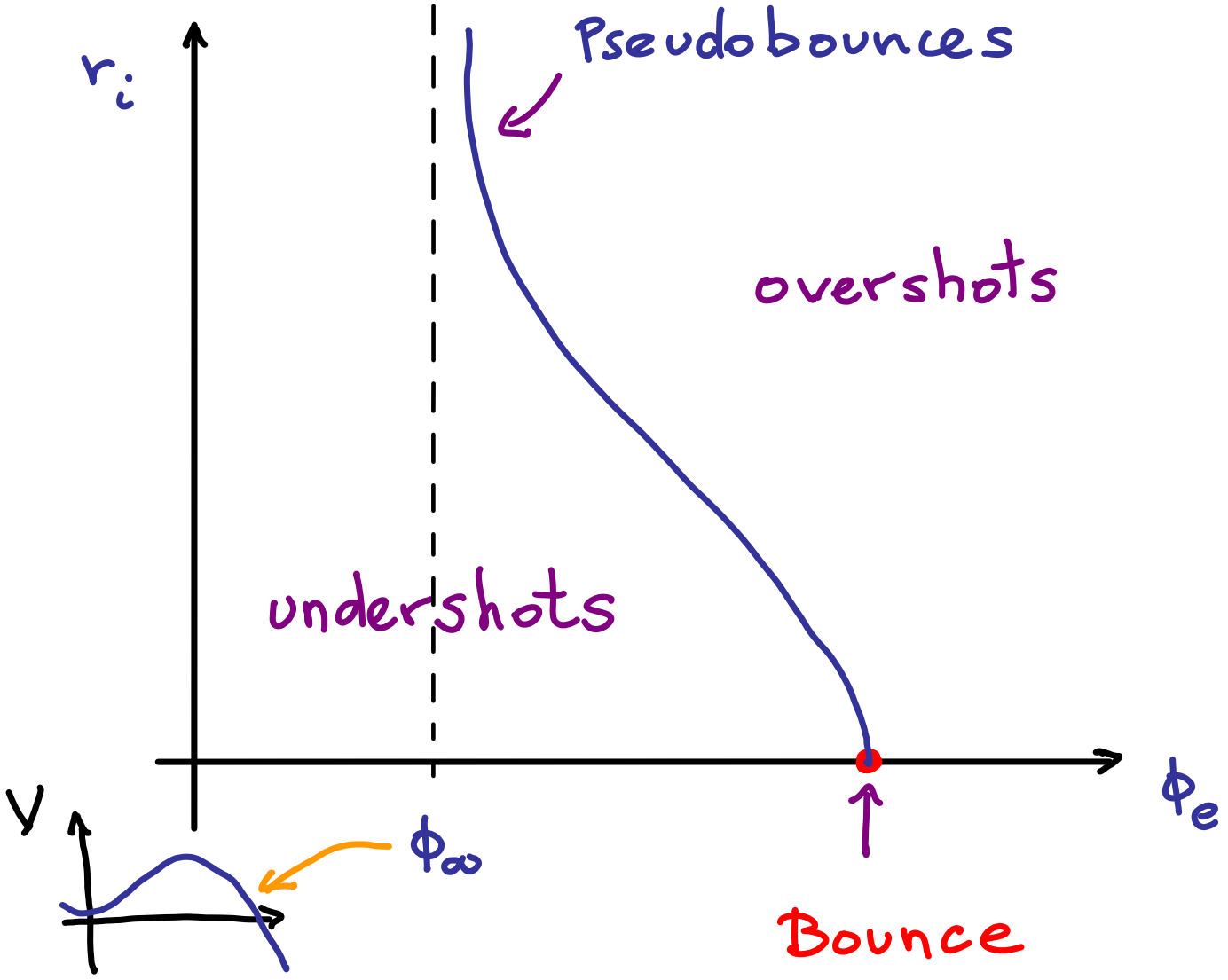
STANDARD CASE

Pseudobounces in (ϕ_e, r_i) plane :



STANDARD CASE

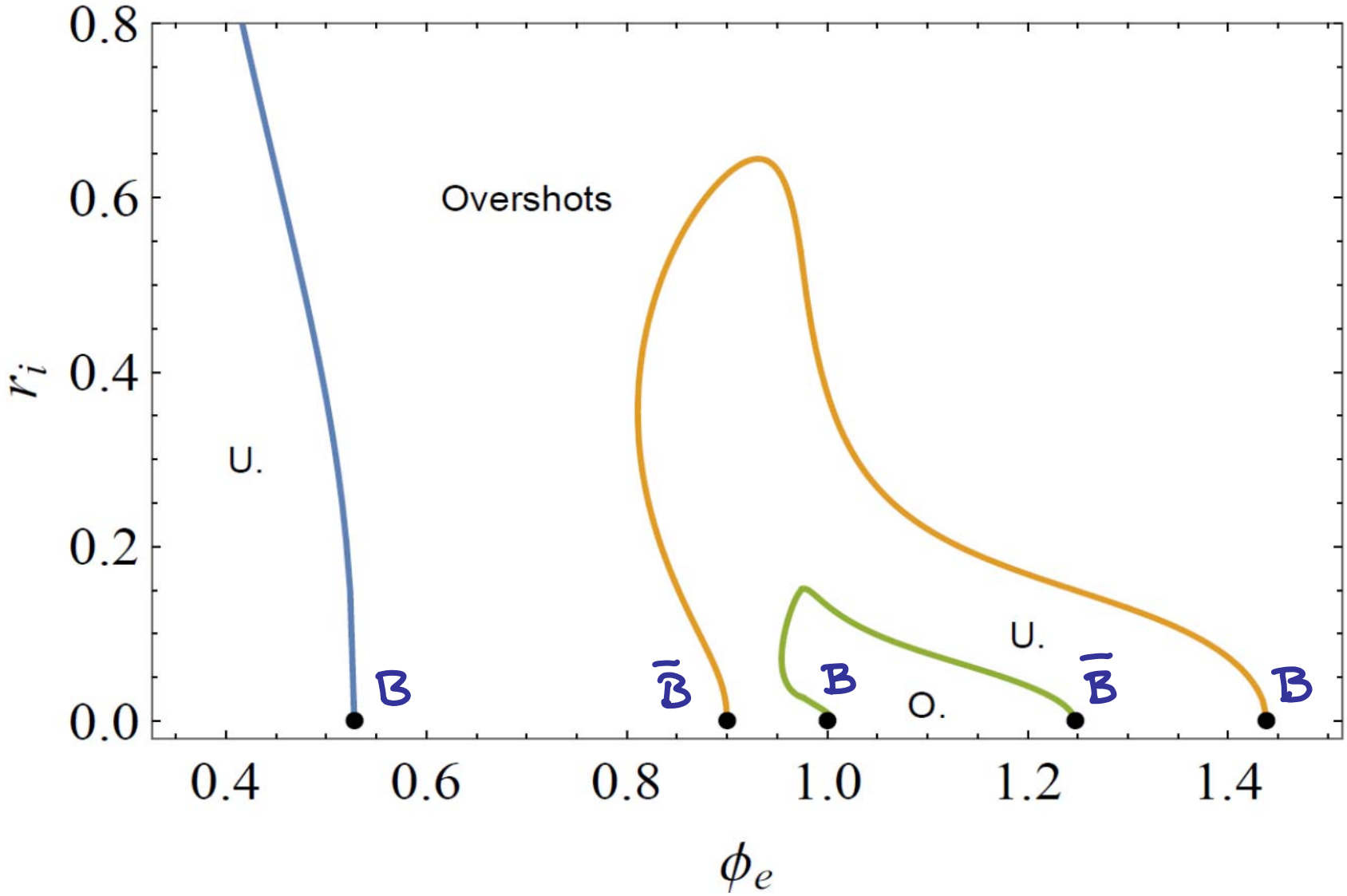
Pseudobounces in (ϕ_e, r_i) plane :



NON UNIQUENESS OF THE BOUNCE

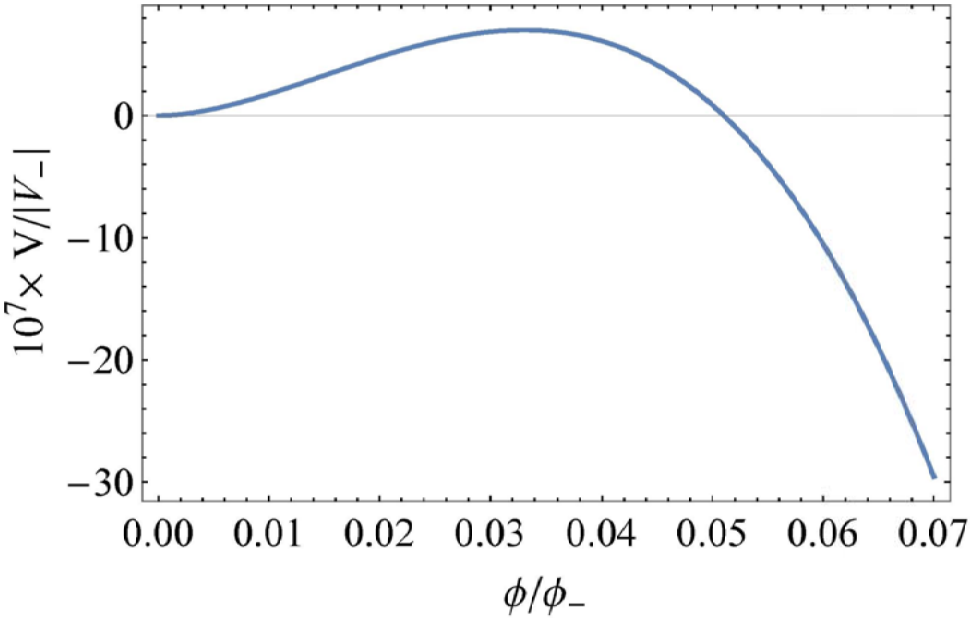
JRE, Konstandin '2506

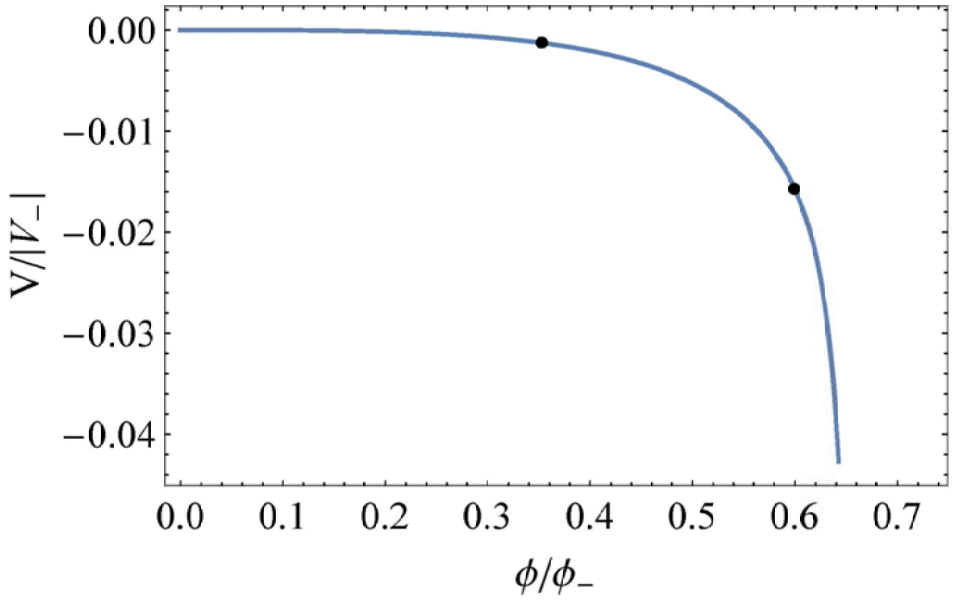
Some potentials have a richer decay structure :

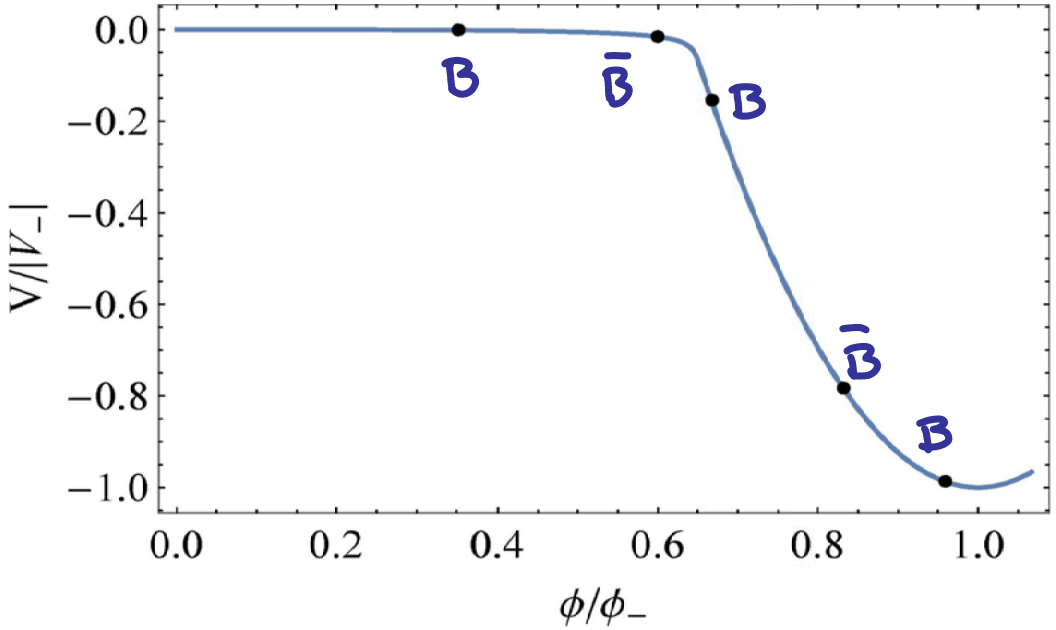


THE POTENTIAL

JRE, Konstandin '2312 '2506



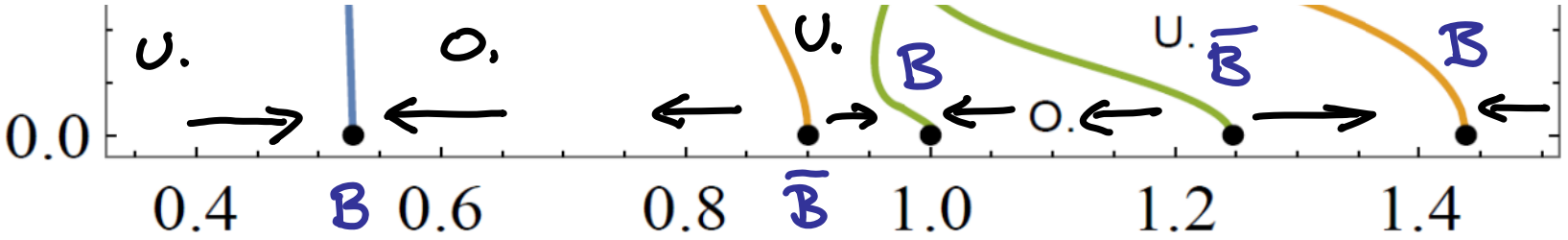




ANTI BOUNCES

- Antibounces missed in standard searches

Mühlleitner et al '2404



How are they possible ??

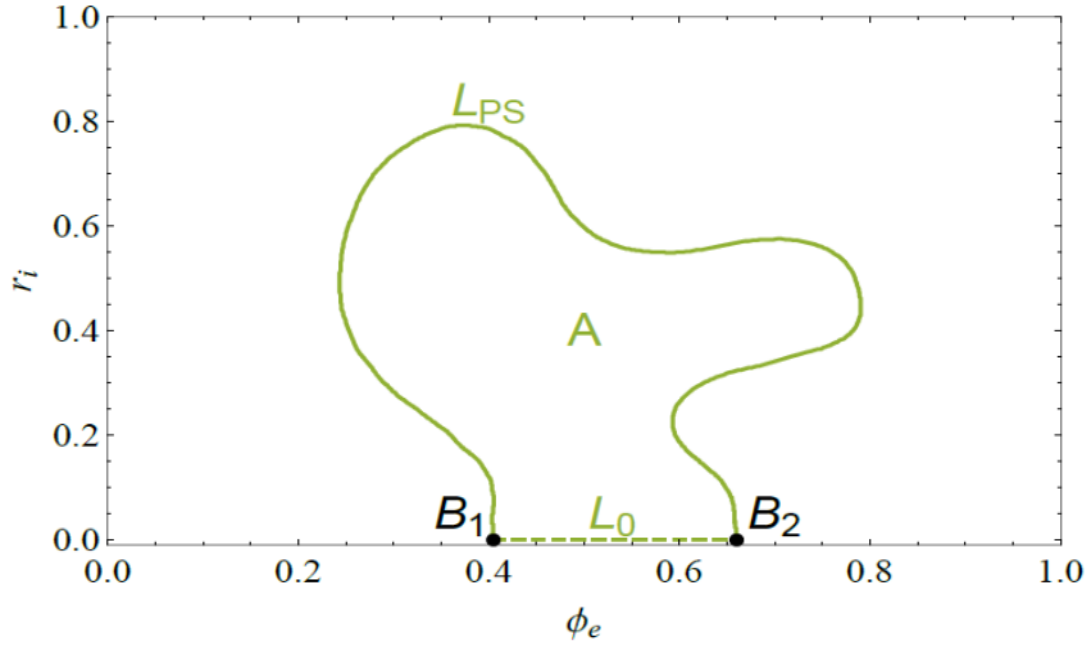
U: $\phi_e \to \phi_e + \Delta\phi$ ⇨ ϕ_e reached at higher r

⇨ less friction $\sim \dot{\phi}/r$

Higher $\dot{\phi}$ compensates r ⇨ Steep V required

GENERAL STRUCTURE

- $2n+1$ bounces, with n $B\bar{B}$ pairs joined by pseudobounce lines



Using $\frac{dS}{d\phi_e} = \frac{\pi^2}{2} r_i^4 V'(\phi_e)$ and Stoke's theorem

$$S_{B_2} < S_{B_1}$$

GENERAL STRUCTURE

JRE, Konstandin '2506

- For disconnected B_i, B_j no general proof $S_i \gtrless S_j$

  Typically S lower for higher ϕ_e

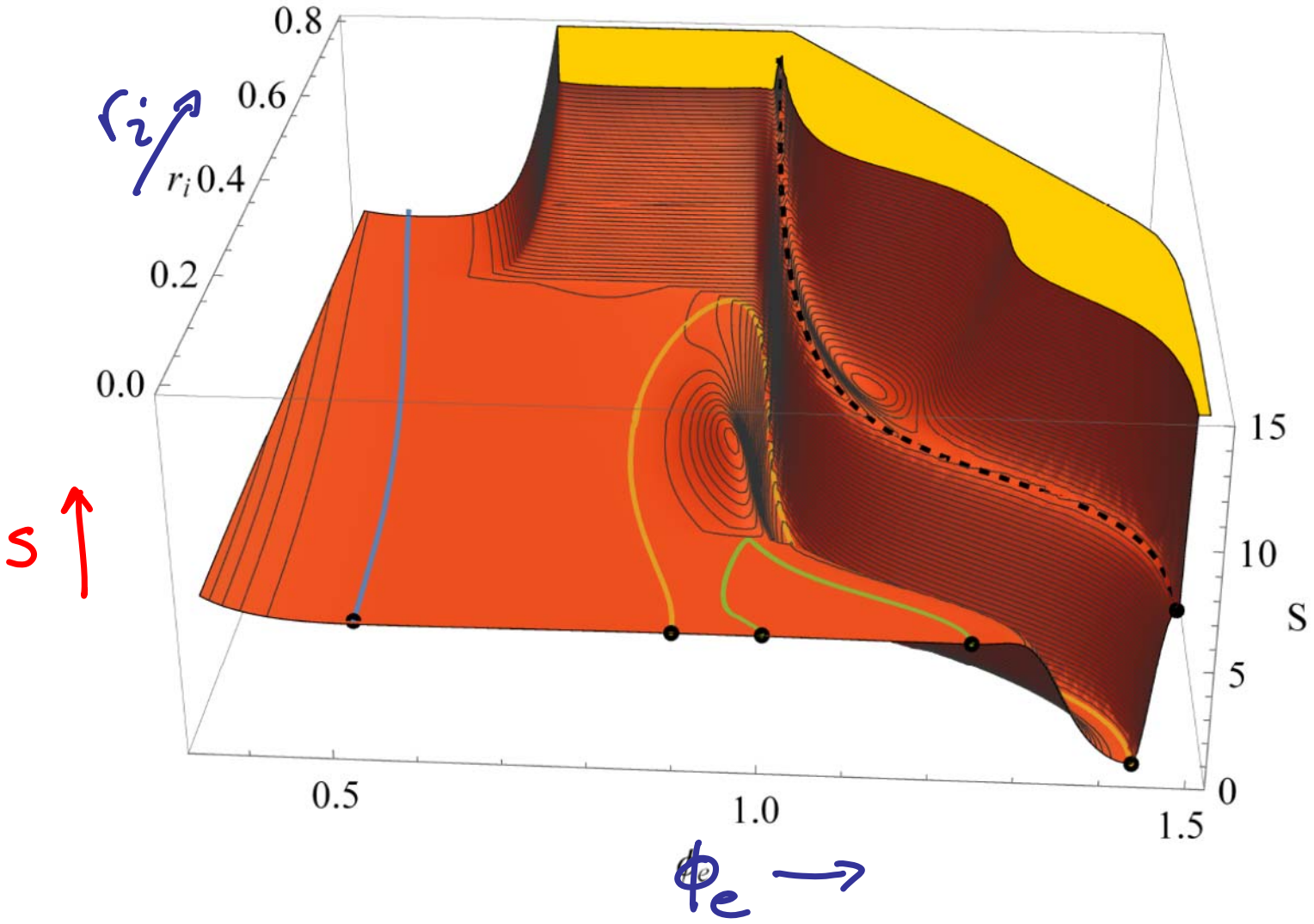
  Highest ϕ_e solution always a bounce

⇨ Lowest action for bounce closer to minimum

  Exceptions ?

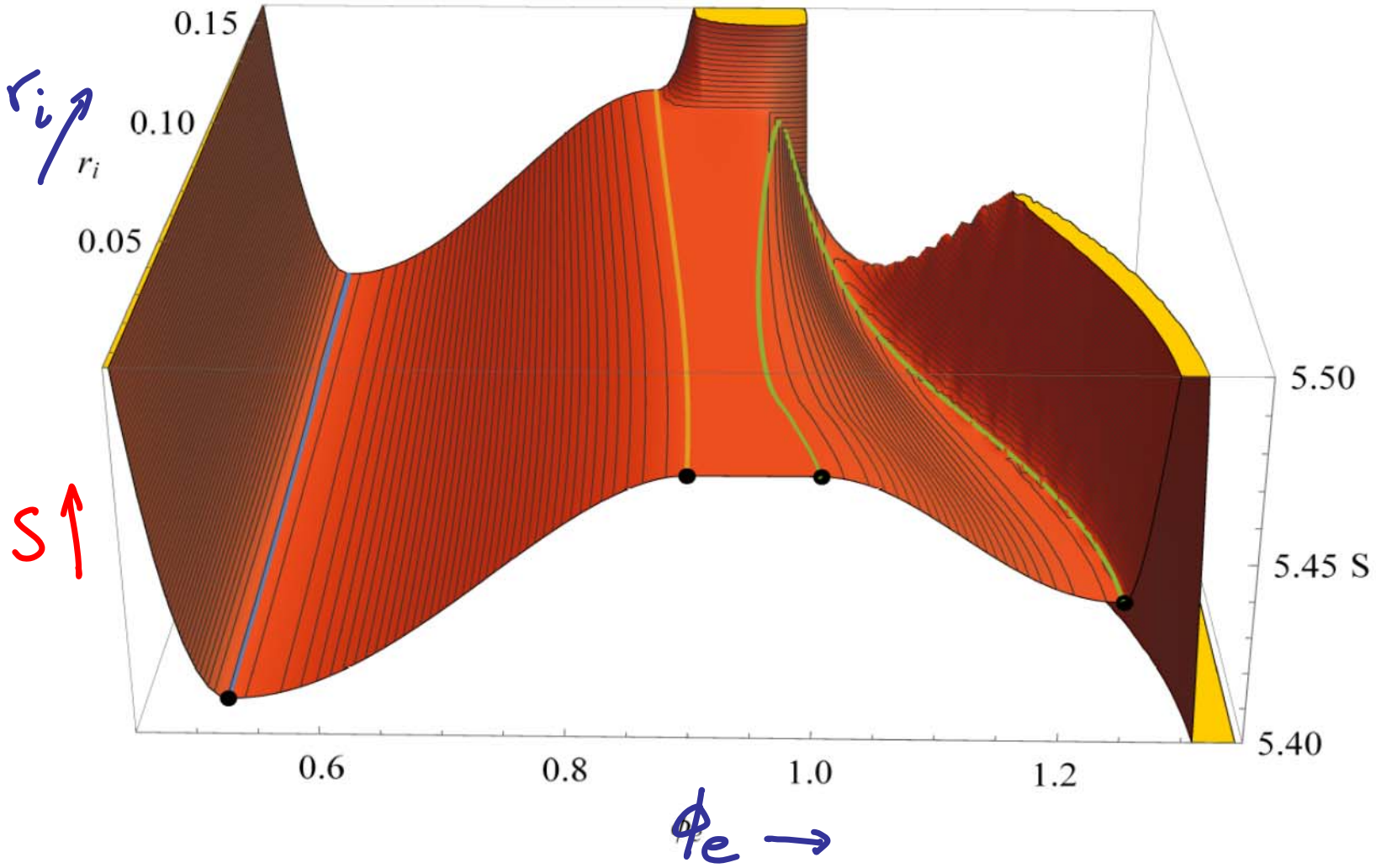
DECAY LANDSCAPE

JRE, Konstandin '2506



DECAY LANDSCAPE

JRE, Konstandin '2506



A UNIFIED VIEW OF VACUUM DECAY

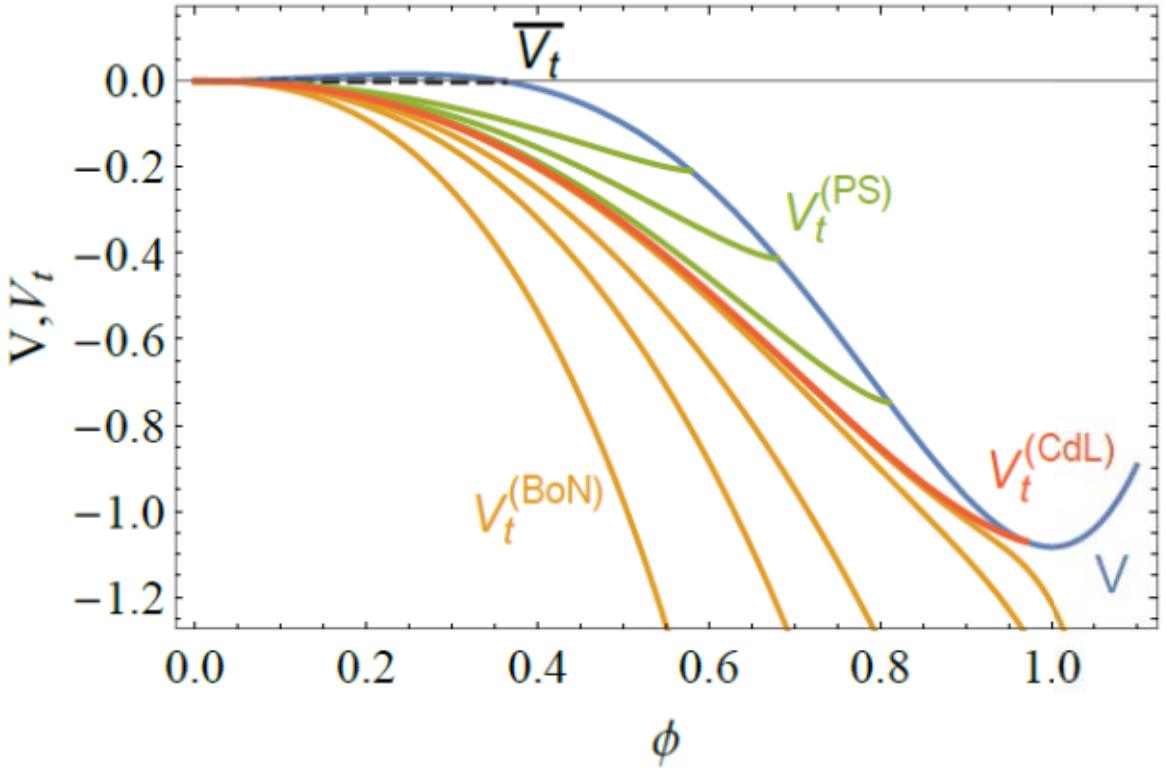
JRE'2501

Natural way to discuss pseudobounces :

Tunneling Potential Formalism JRE'1805

$$S[V_t] = 54\pi^2 \int_{\phi_t}^{\phi_e} \frac{(V - V_t)^2}{(-V_t')^3}\, d\phi$$

$$0 = (4V_t' - 3V')\, V_t' + 6(V - V_t)\, V_t''$$



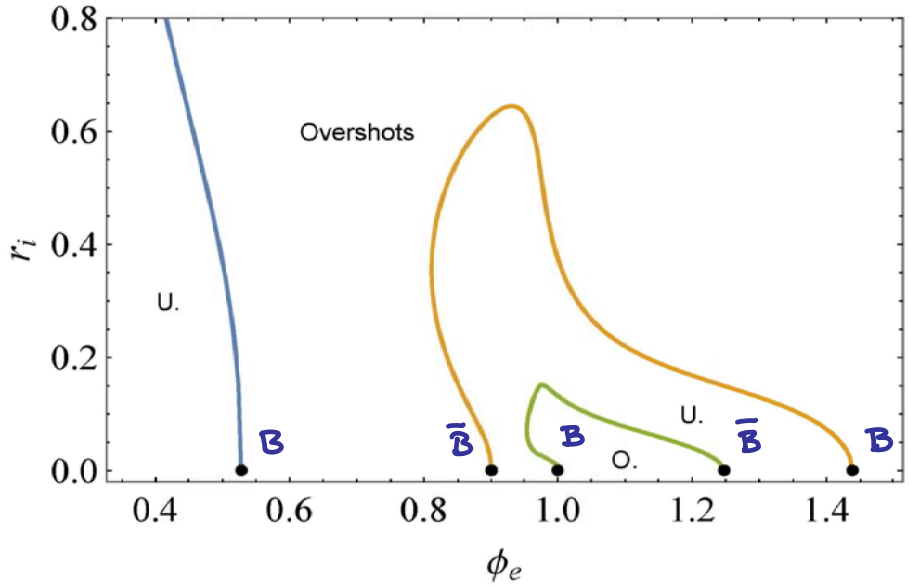
CONCLUSIONS

★ Rich vacuum decay structure is possible

★ Pseudobounces (track valleys) can be relevant even with bounce

★ Most general case

2n+1 bounces



★ Open questions: How steep V should be?

Can antibounces dominate decay? ...

EXPLORING VACUUM DECAY VALLEYS

J.R.Espinosa

Scalars 2025
Warsaw
23/9/2025

ift Instituto de Física Teórica UAM-CSIC

BOUNCES, PSEUDO BOUNCES & ANTI BOUNCES

Scalars 2025
Warsaw
23/9/2025

J.R. Espinosa

Instituto de Física Teórica
UAM-CSIC