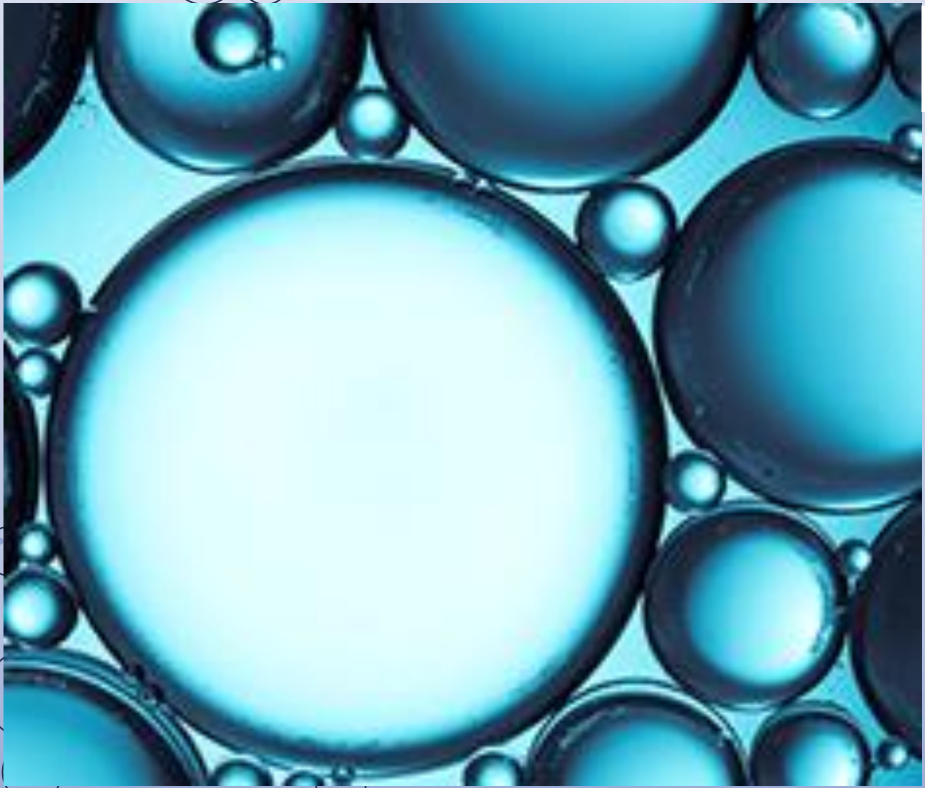


PASCOS PARTICLES STRINGS COSMOLOGY
25-29 JULY 2022 - MPIK - HEIDELBERG - GERMANY

Imperial College London

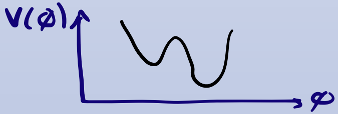
Phase transitions in the early universe: quantum corrections

Mariana Carrillo González

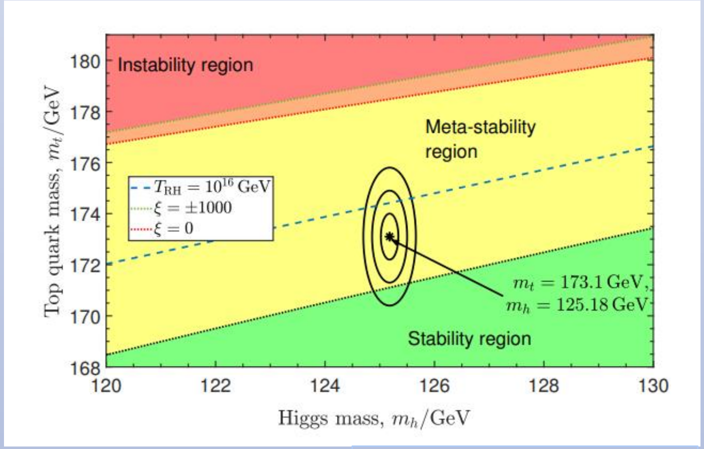
Based on: arXiv:2204.03480 with J.E. Camargo Molina and A. Rajantie

Phase transitions ➡ Bubble nucleation

- Arise in the presence of metastable vacuum

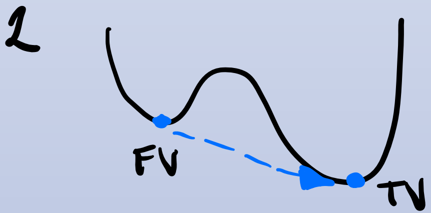


  - Spontaneous symmetry breaking
  - Beyond Standard Model Physics
  - Current measurements: SM Higgs metastable state



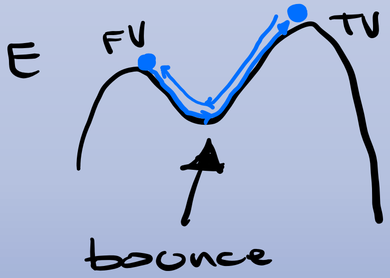
Markkanen, Rajantie, Stopyra; 2018

Decay rates in flat space



$$\Gamma = -2\,\mathrm{Im}\,E = 2\,\mathrm{Im}\left(\lim_{T\to\infty} \frac{\ln Z}{T}\right)$$

Saddle-point approximation:



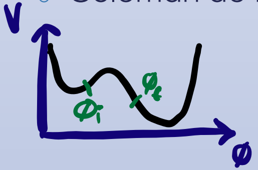
$$\frac{\Gamma}{V} = \left(\frac{B}{2\pi}\right)^2 \left|\frac{\det' S_b''}{\det S_{fv}''}\right|^{-\frac{1}{2}} e^{-B}$$

$$B \equiv S_b - S_{fv}$$

Decay rates in de Sitter

Saddle-point approximation

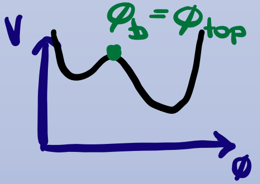
- Coleman de Lucia



similar to flat space bounce

dif. boundary conditions

- Hawking-Moss



No flat space analog.

(thermal transition)

Stochastic Formalism

Starobinski, Yokoyama

- Describes dynamics of long-wavelength modes accounting for short-wavelength modes as noise through Fokker-Planck eq:

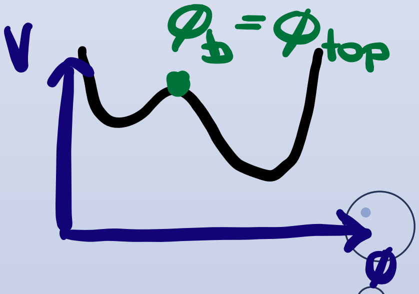
$$\frac{\partial P}{\partial t} = \frac{3H^3}{8\pi^2}\left(\partial_\phi^2 - \frac{4\pi^2}{3H^4}\left(V'(\phi)^2 - V''(\phi)\right)\right)P(t;\phi)$$

$V(\phi)$ potential

Probability distribution of ϕ at time t

- The lowest non-zero eigenvalue gives the decay rate.

Early Universe: large curvature



- Dominated by Hawking-Moss
  - one negative eigenvalue for:

$$H > \sqrt{|V''_{top}|}/2$$

$$\Gamma \sim e^{-B}$$

- Assume fixed dS background:

$$V_{top} - V_{fv} \ll V_{fv}$$

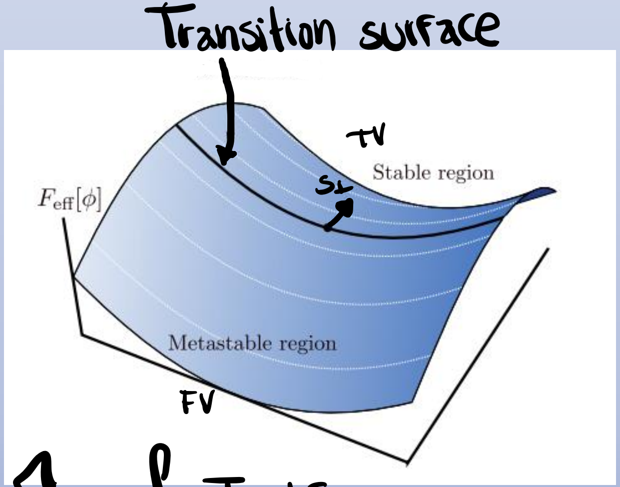
$$B = S_{HM} - S_{FV} = \frac{8\pi^2 \Delta V}{3H^4}$$

- At smaller curvatures, expect transition to Coleman de Lucia dominated decay rates.

$$B = \beta \Delta E = \left(\frac{2\pi}{H}\right)\left(\frac{4\pi}{3}\frac{1}{H^3}\right)\Delta V$$

- Akin to thermal transition $T = \frac{H}{2\pi}$

Thermal interpretation and semi-classical approximation



$$\Gamma = \int_{TS} J \cdot dS_\perp$$

- At high temperature (curvature) physics is driven by long-wavelength modes:
  - Semi–classical approximation
- Dynamics governed by Langevin eq.

$$(\partial_t^2 - \bar{\nabla}^2)\phi + \frac{\partial V}{\partial \phi} + 3H\dot{\phi} = \xi$$

noise encoding thermal fluctuations

- Use flux-over-population method
  - Escape rate (Kramers; 1940 Langer;1969)
  - Thermal Field theory (Berrera, Mabillard, Mintz, Ramos; 2019, Gould, Hirvonen; 2021)

Hawking-Moss decay rate at 1-loop

deviation from thermal eq.

$$\Gamma = \int_{TS} J\cdot dS_\perp = \frac{1}{Z_{FV}}\int D\pi\, D\phi\; e^{-S[\phi]}\,\sigma\,\delta(c_-)$$

negative eigenmode coef.

growth rate of φ_-

$$\underset{S.P.}{=} \frac{\kappa}{2\pi}\left|\frac{\det S''_{top}}{\det S''_{FV}}\right|^{-1/2} e^{-B}$$

Match to S.F.

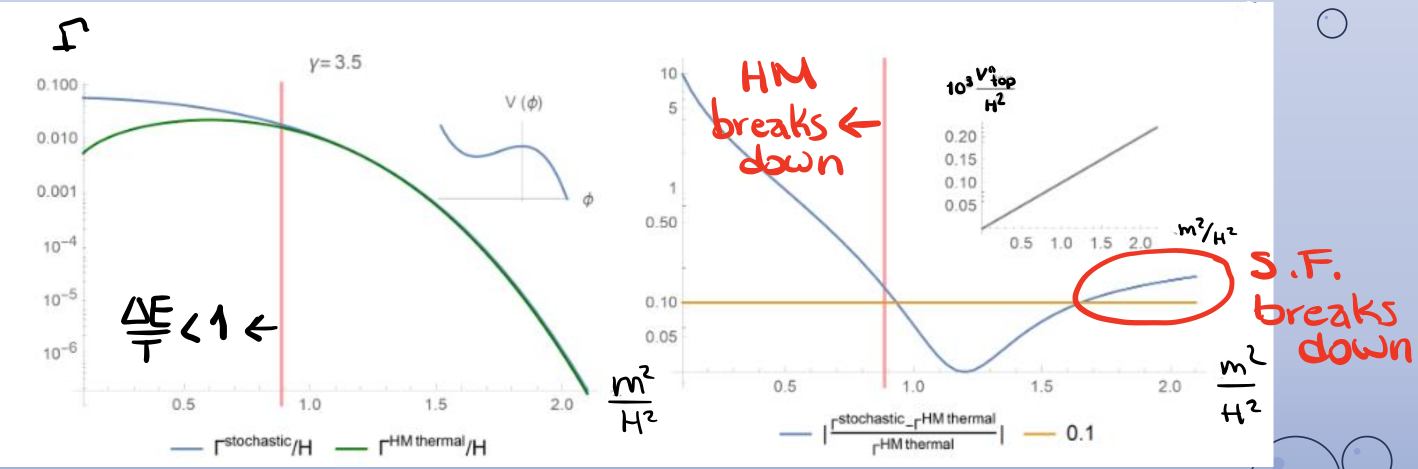
$T^2 \gg V''_{top}$

$$\frac{|V''_{FV}V''_{top}|^{1/2}}{2\pi}\, e^{-\frac{8\pi^2}{3H^4}\Delta U_{1\text{-loop}}}$$

Constraint effective potential

Comparison: HM thermal vs Stochastic F.

$$\underset{1\,\text{loop}}{U(\phi)} = 3H^2M_{pl}^2 - \frac{1}{2}m^2\phi^2 - \frac{\gamma}{3!}H\phi^3$$



Conclusions

- At large Hubble rates, **thermal** interpretation of **Hawking-Moss** instanton allows us to compute **higher order corrections**.
- **Matching** when saddle-point approx. is valid tells us that **quantum corrections** can be captured by **stochastic formalism** using **constraint effective potential.**

Complementary approaches:

Hawking-Moss

Breaks down when perturbation theory is not valid and thermal fluctuations are large

Stochastic Formalism

Breaks down for large masses due to overdamped approximation.