The effect of multi-field interactions on false vacuum decay

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ABSTRACT : We study quantum tunneling from false vacuum in multi-field system. Tunneling is often treated by using method of instanton. It was not known whether multi-field instanton exists or not when multi-field interaction is considered, so we study about it. We found multi-field instanton exists in the potential of open inflation model. But, in certain potential there is no instanton. We discuss physical interpretation on this. Method of instanton corresponds to WKB approximation in Quantum Mechanics, so there is a range of application. We have to study when method of instanton can be applied.

Motivations

- Multi-field tunneling occurs on string-landscape
- Method of instanton is often used to describe quantum tunneling
- It was not known whether multi-field instanton exists when multi-field interaction is considered

We study whether multi-field instanton exists.

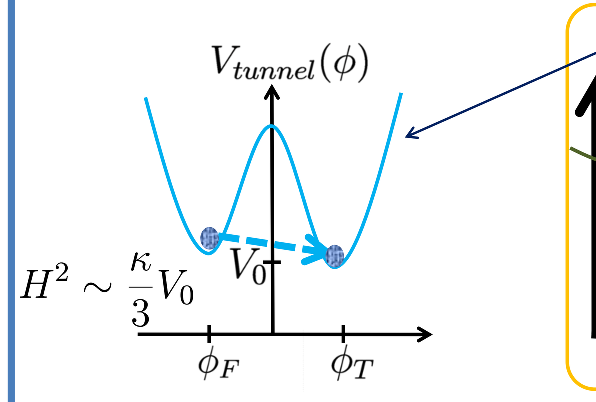
- No instanton does not directly mean tunneling does not occur
- But, in that case, it is necessary to go beyond instanton method

Model & Methods

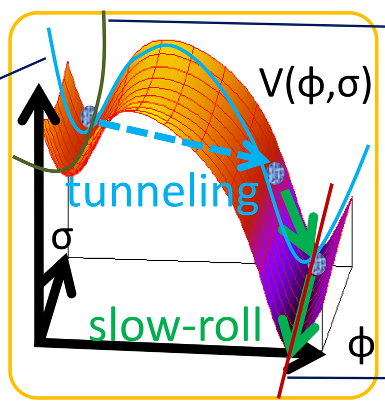
We study quantum tunneling in the potential of **multi-field Open Inflation model** (Linde-Mezhlumian 1995)

tunneling of tunneling field ϕ from false vacuum ⇨ potential which slow-roll field σ feels changes

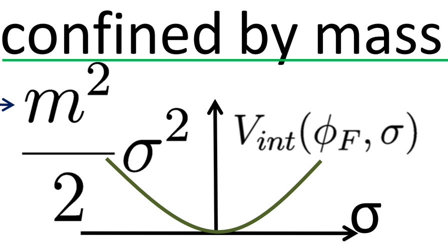
$$V(\phi,\sigma) = V_{tunnel}(\phi) + V_{int}(\phi,\sigma)$$



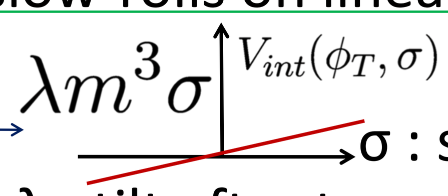
ϕ : tunneling field



confined by mass potential



slow-rolls on linear potential



σ : slow-roll field

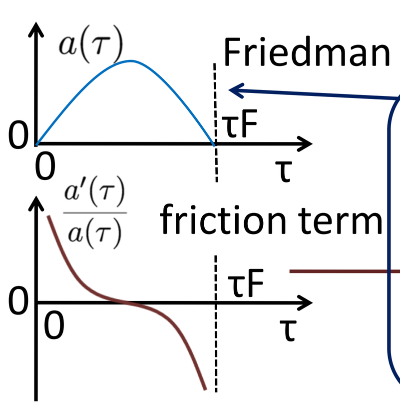
λ : tilt after tunneling

We can treat quantum tunneling by using method of **instanton**

assuming O(4)-symmetry $ds^2 = d\tau^2 + a^2(\tau)d\Omega^2$

Euclidean action $S_E = \int d\tau d^3x a^3\left(\frac{1}{2}\phi'^2 + \frac{1}{2}\sigma'^2 + V(\phi,\sigma)\right) + \frac{3}{\kappa}(a^2a'' + aa'^2 - a)$

instanton is a solution which satisfies following EOM and B.C. (Boundary Condition)



EOM

$$\left(\frac{a'}{a}\right)^2 - \frac{1}{a^2} = \frac{\kappa}{3}\left(\frac{1}{2}\phi'^2 + \frac{1}{2}\sigma'^2 \ominus V\right)$$
$$\phi'' + 3\frac{a'}{a}\phi' \ominus V_\phi(\phi,\sigma) = 0$$
$$\sigma'' + 3\frac{a'}{a}\sigma' \ominus V_\sigma(\phi,\sigma) = 0$$

2-Dim particle mechanics form

B.C.
$$\phi'(0) = \phi'(\tau_f) = 0$$
$$\sigma'(0) = \sigma'(\tau_f) = 0$$

zero velocity at $\tau=0,\tau_F$

Using these eqs., we search for instanton for the above potential numerically (shooting method) and analytically (approximated with $V_{int} \ll V_{tunnel}$)

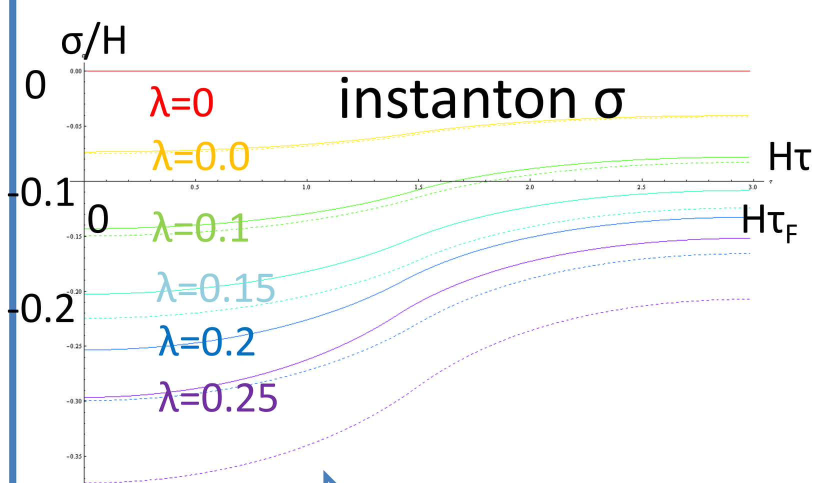
tunneling rate is given using instanton $\bar{a}(\tau), \bar{\phi}(\tau), \bar{\sigma}(\tau)$

$$\Gamma/V \propto \exp\left[-S_E[\bar{a}(\tau),\bar{\phi}(\tau),\bar{\sigma}(\tau)]/\hbar\right]$$

Results

we found multi-field instanton does **exist** in this potential

these are examples of instanton when parameters are $m^2/H^2=1$, $\lambda=0, 0.05, \dots, 0.25$

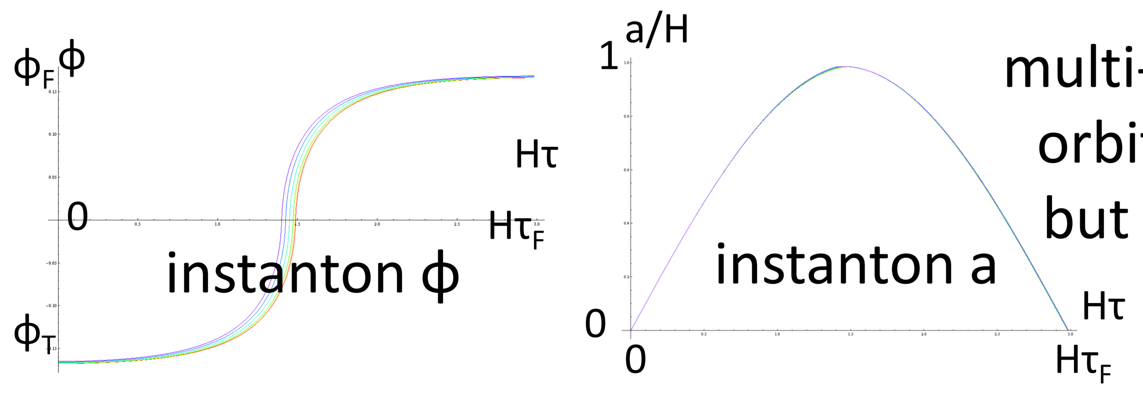


solid : numerical solution (shooting method)

dotted : analytical solution (approximated with $V_{int} \ll V_{tunnel}$)

λ=0 ⇨ σ is not dynamical because of (σ ↔ -σ) symmetry

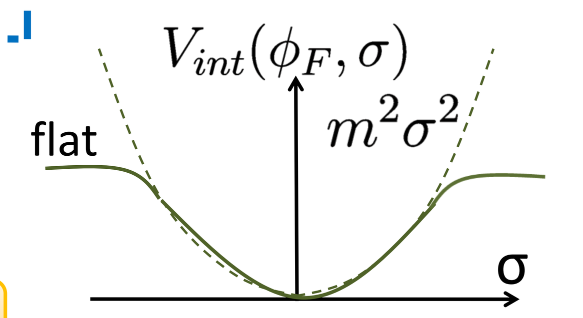
λ↑ ⇨ dynamical range of σ becomes larger



multi-field interaction ditorts orbit of instanton ϕ and a, but the difference is small

Conclusions & Discussions

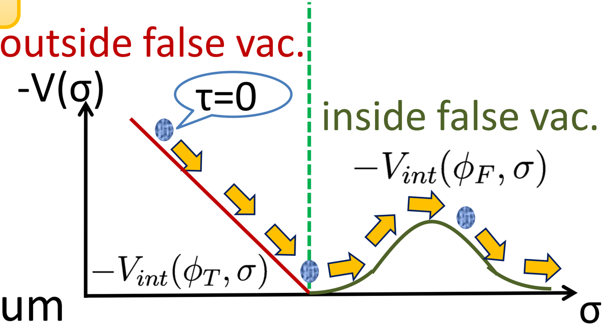
- Multi-field instanton exists when potential for σ is mass potential in false vacuum and linear after tunneling. (potential of multi-field open inflation model)
- In this case, we can naturally extend method of instanton to multi-field tunneling



- But, if potential at false vacuum is like the figure, there may exist no instanton
- We can understand this as follows

EOM and B.C. of instanton is like particle mechanics

τ=0, v=0 ⇨ $0<\tau<\tau_F$ particle moves feeling potential –V and friction a′/a ⇨ $\tau=\tau_F$, v=0



In such potential, potential gradient outside false vacuum can be always greater than potential gradient at false vacuum. Then the particle cannot stop at $\tau=\tau_F$. This means there exists no instanton.

There are some possible physical interpretations on no instanton in this potential

1. Even if instanton does not exist, quantum tunneling may occurs. WKB approximation may be broken. It is necessary to check first WKB order action is by far larger than second WKB order action.
2. In such potential, scalar field σ is not confined at the false vacuum. σ may spread broadly from beginning, because high k-modes don't feel mass potential.

Anyway, we have to study when method of instanton can be applied