# Cosmological Phase Transitions in Composite Higgs Models

**CLHCP 2023**

**Speaker: Yaoduo Wang[1,2]**
based on JHEP09(2023)053
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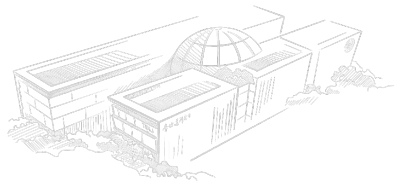
November 19, 2023



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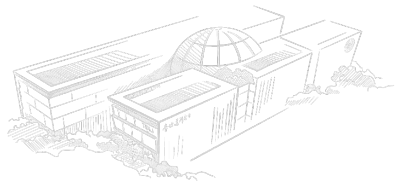
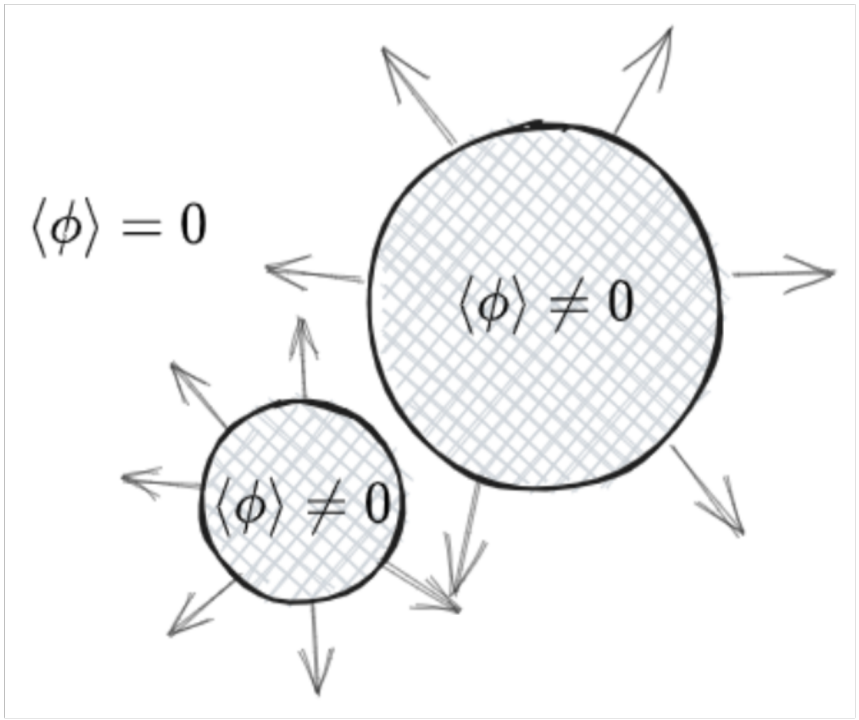


# Cosmological PTs and bubble formation




First Order PTs

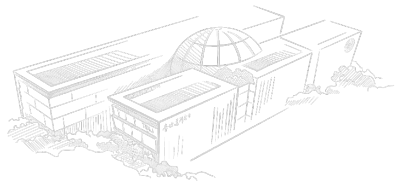
↓

Bubble Formation

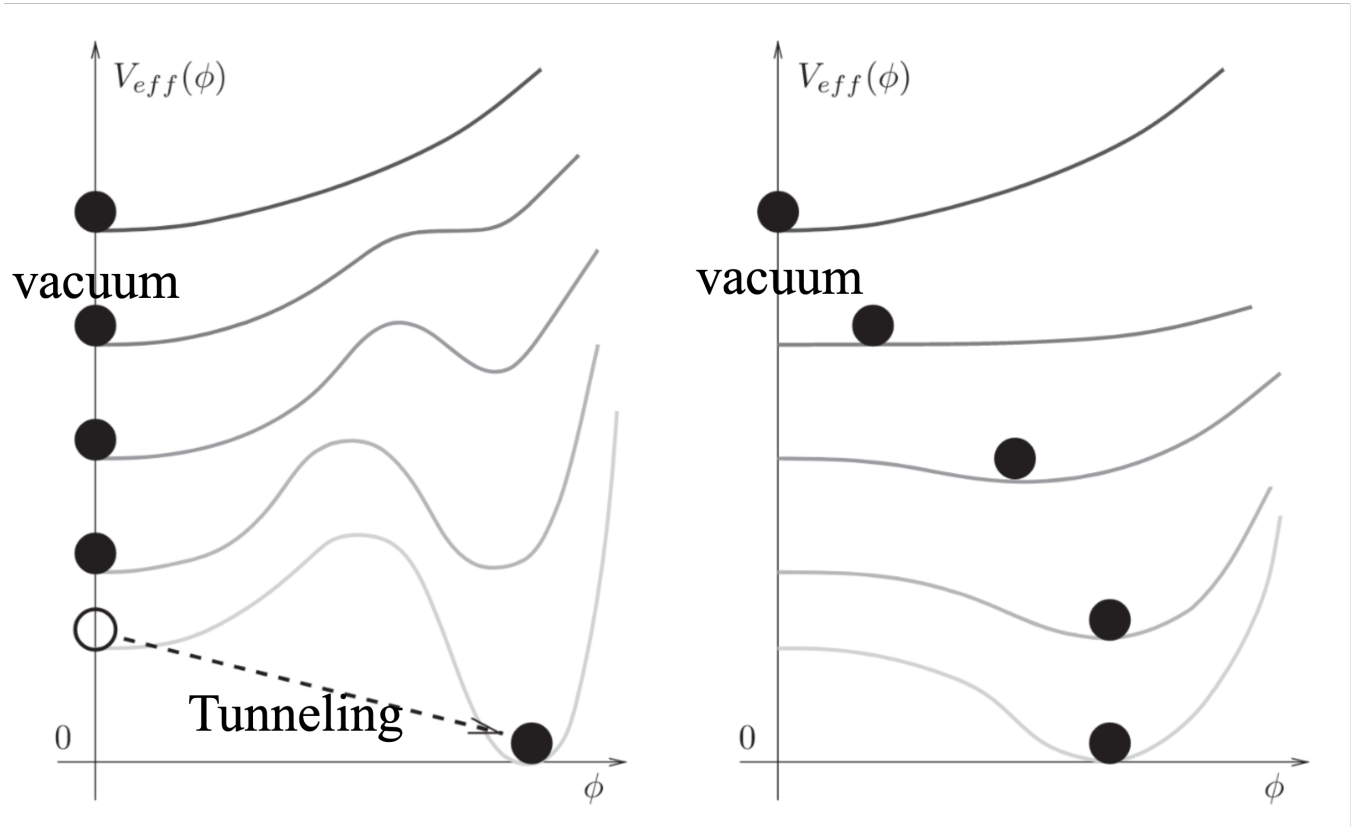
↓

GW, DM,

primordial BH...

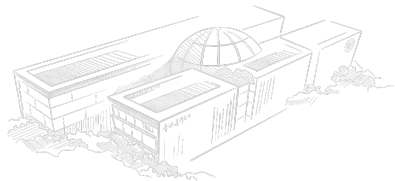


# How to determine the order of PTs?




First Order PT Second Order PT

Potential Barrier?



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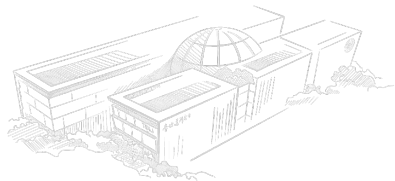


# PTs in the viewpoint of RG flow

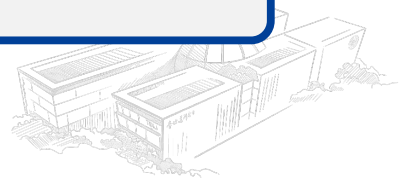


## Problem: Strongly-coupled system

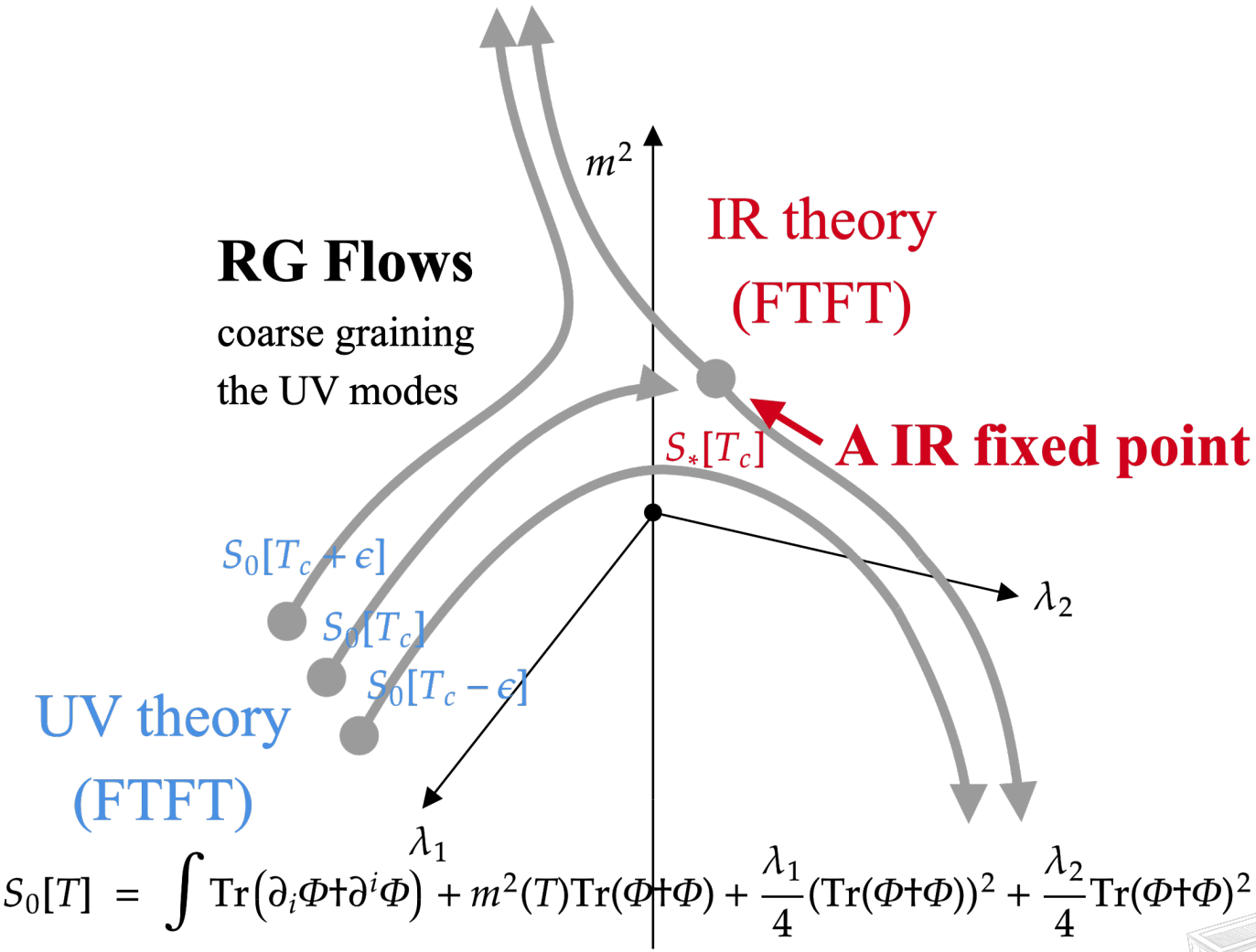
During PTs, the system is strongly-coupled(the coupling constants $\lambda(T_c)$ divergent), and perturbative $V_{\text{eff}}$ is no longer reliable.

## Hint: IR fixed points control the critical behavior

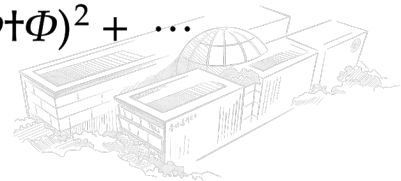
Stable IR fixed point
(who controls the PT dynamics)
$\downarrow$
Information of the barrier formation
(who controls the PT order)



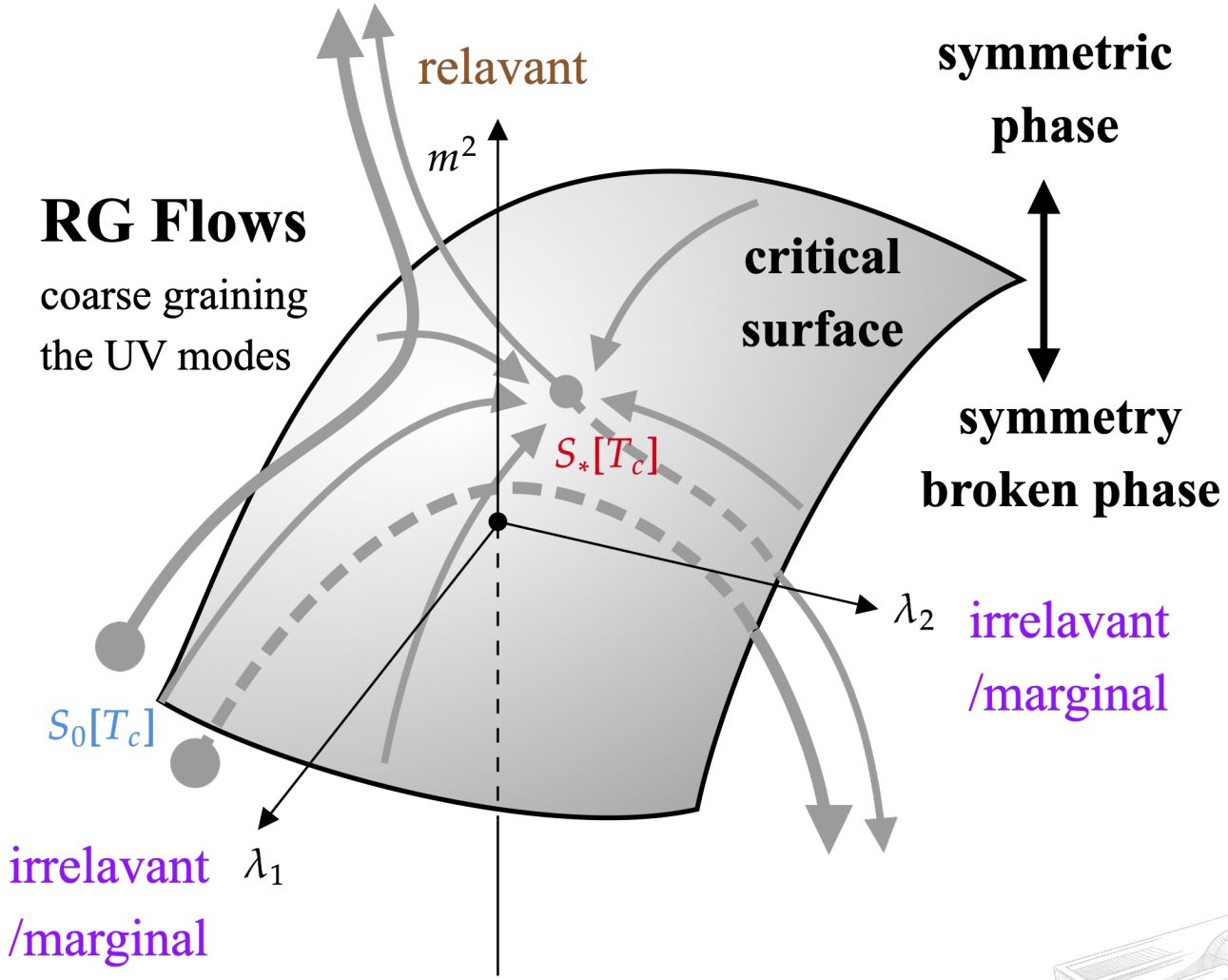
# RG flow depicted in terms of couplings



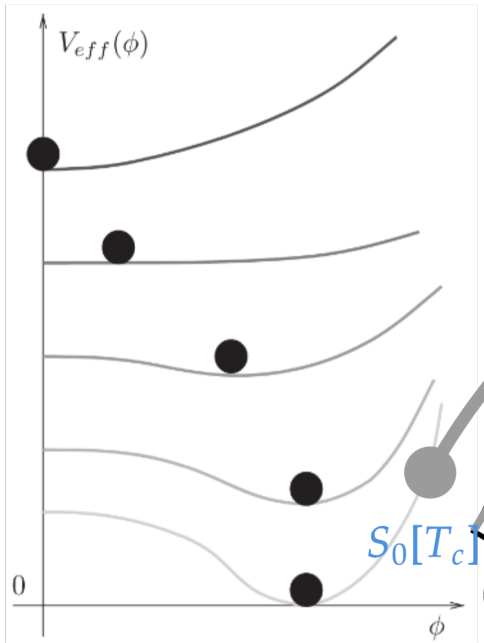

$$S_0[T] = \int \mathrm{Tr}\left(\partial_i \Phi^\dagger \partial^i \Phi\right) + m^2(T)\mathrm{Tr}(\Phi^\dagger\Phi) + \frac{\lambda_1}{4}(\mathrm{Tr}(\Phi^\dagger\Phi))^2 + \frac{\lambda_2}{4}\mathrm{Tr}(\Phi^\dagger\Phi)^2 + \cdots$$



# Critical surface and phases



# Classicification of stable IR fixed points




**Second order PT**

(with scaling invariance)

relavant parameters

**Unstable region**

(can form barrier)

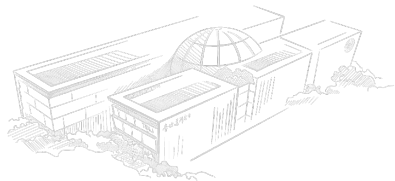
$S_*[T_c]$

$S_0[T_c]$

**critical surface**

**Stable region**

(cannot form barrier)



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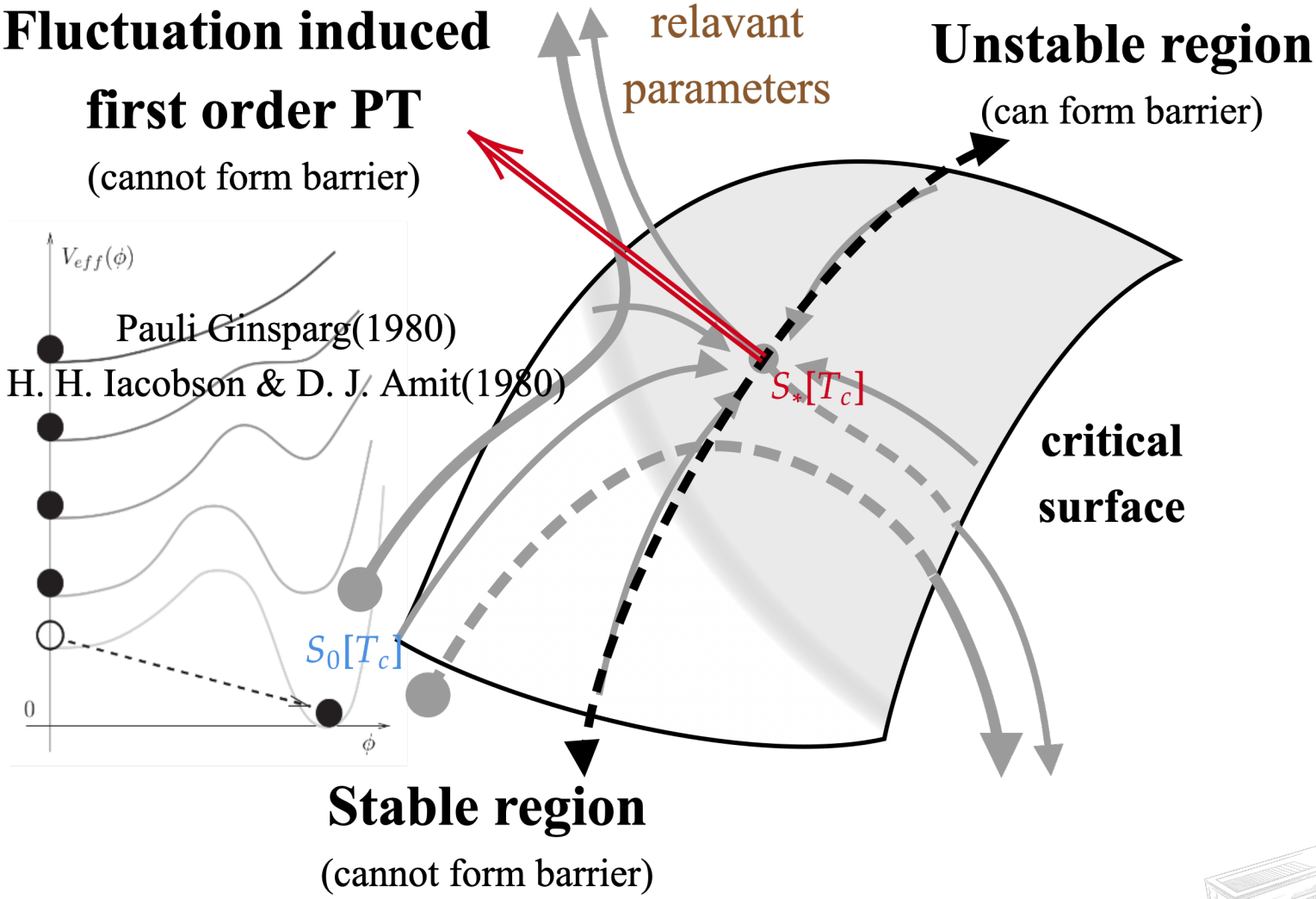

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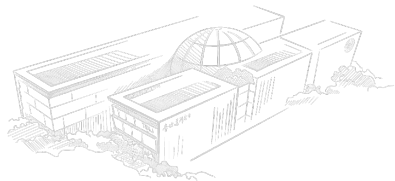
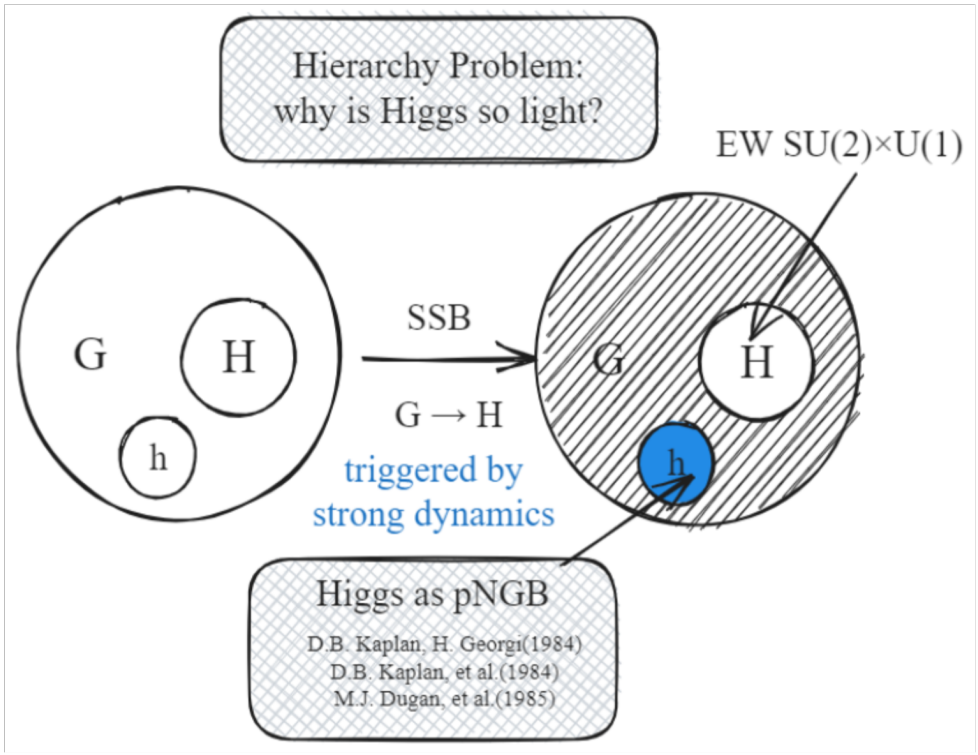
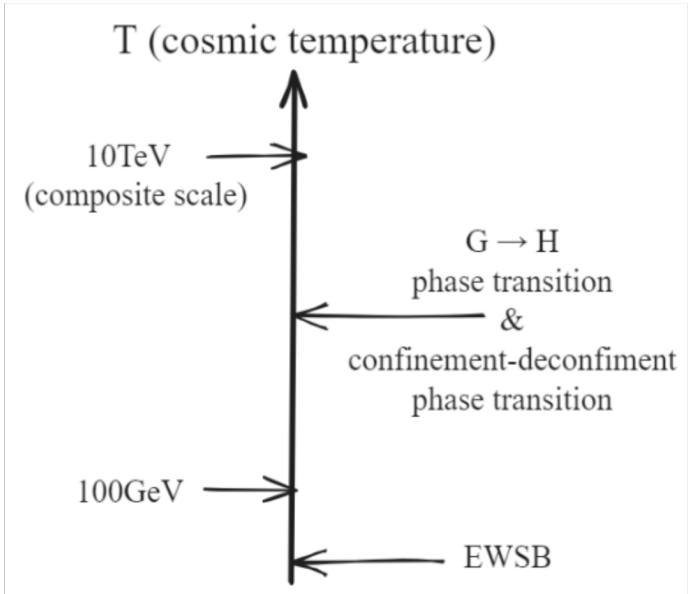
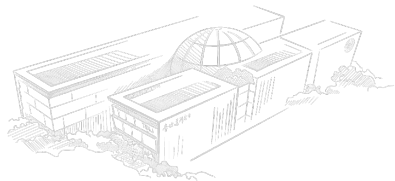


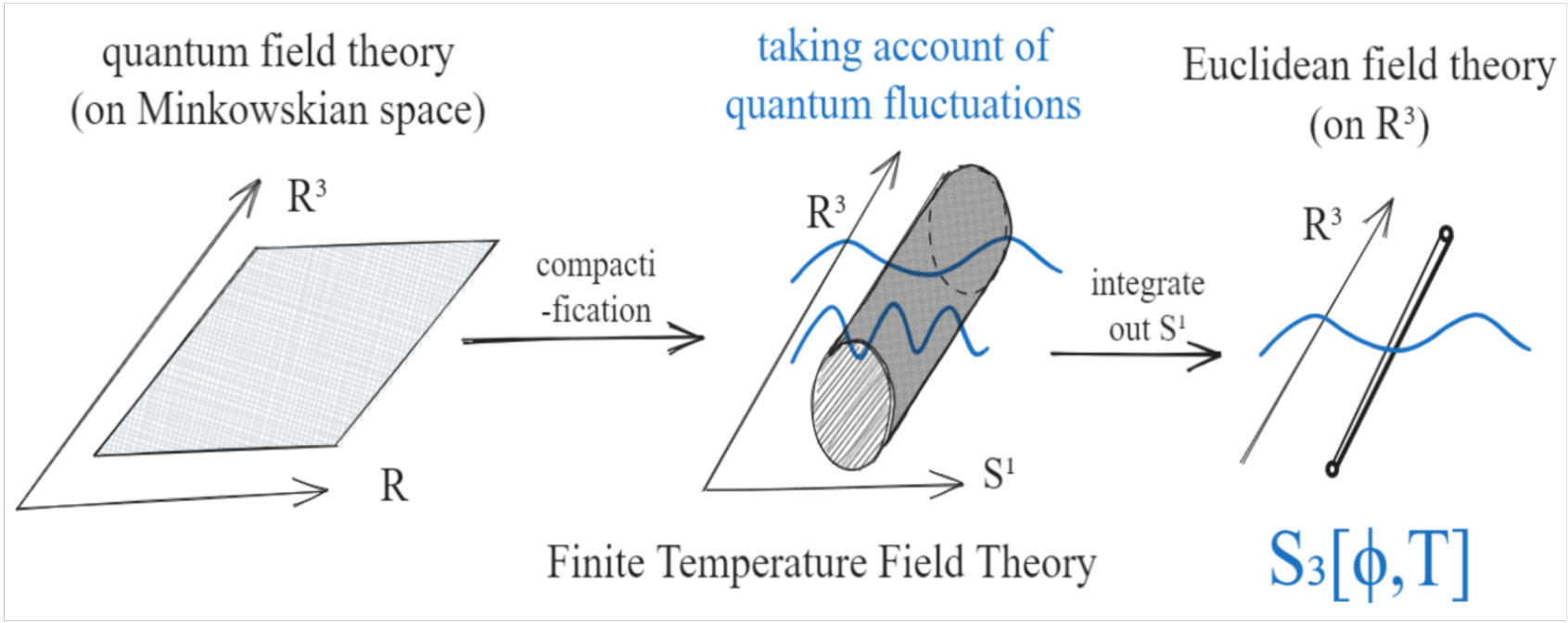
# Composite Higgs models

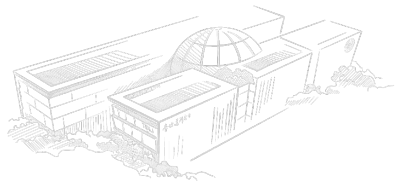


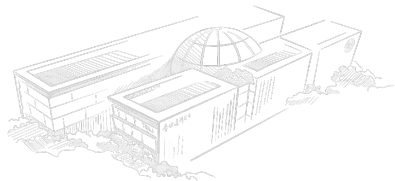
# Finite Temperature Field Theory



# PT orders in Composite Higgs models

| G→H SSB patterns | SO(N)→SO(N-1) | SO(9)→SO(5)×SO(4) | SU(2N)→Sp(2N) U(2N)→Sp(2N) | SU(N)→SO(N) U(N)→SO(N) |
|---|---|---|---|---|
| Composite Higgs Models | N=5: K. Agashe et al.(2005)<br>N=9: E. Beltuzzo et al.(2013) | S. Chang(2013) | N=2: J.Barnald et al.(2014)<br>N=3: E. Katz et al.(2005) | N=5: N. Arkani-Hamed et al.(2005) |



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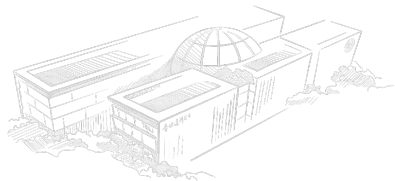
|---|---|---|---|---|
| Composite Higgs Models | N=5: 2nd E. Brezin et al(1973)<br>N=9: 2nd P.H. Ginsparg (1980) | 1st this work | N=2: anomaly J. Wirstam (2000)<br>N=3: 1st J. Wirstam (2000) | N=5: 1st F. Basile et al. (2005) |



# Thanks