REAL SCALAR PHASE TRANSITIONS: BUBBLE NUCLEATION, NONPERTURBATIVELY

with Oliver Gould & David J. Weir

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(she/her)

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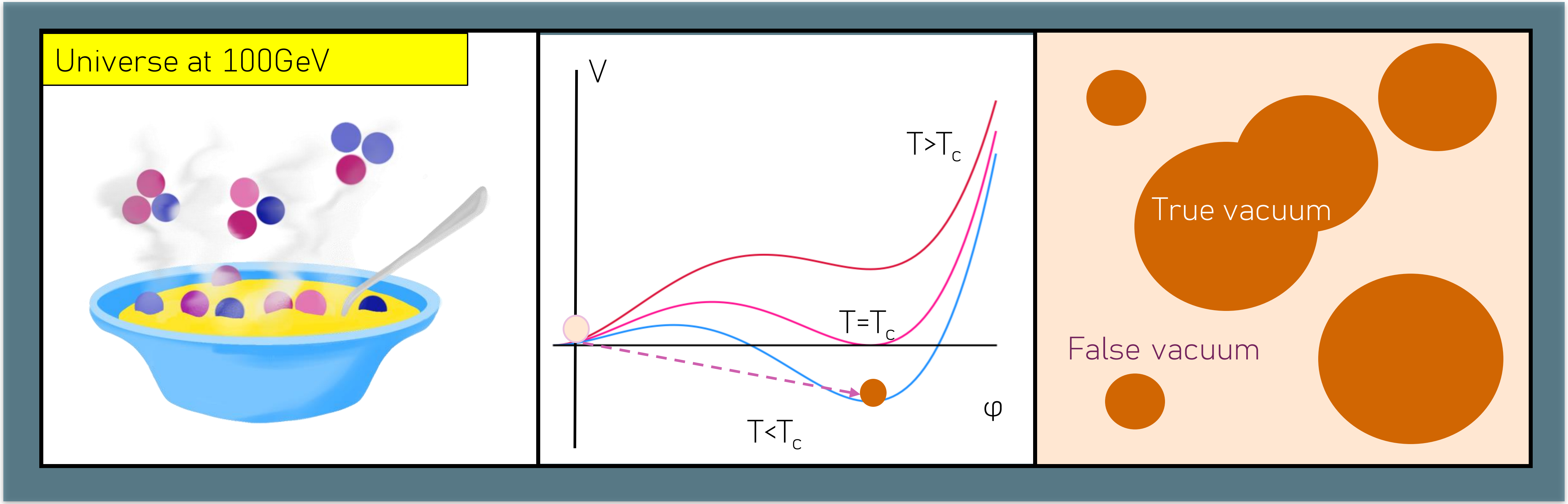
University of Helsinki & Helsinki Institute of Physics



1ST ORDER PHASE TRANSITIONS IN THE EARLY UNIVERSE

FATE OF THE FALSE VACUUM

- Relativistic field theory generalisation Callan & Coleman (Phys. Rev. D 16, 1762 (1977))
- Finite temperature approach introduced later by Affleck & Linde (Phys. Rev. Lett. 46, 388 (1981), Phys. Lett. B 100, 37 (1981))

3D action

Volume averaged nucleation rate

$$\frac{\Gamma}{V} = A\, e^{-S_{3,b}(T)/T}$$

Prefactor

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- Determining the prefactor analytically difficult → perturbation theory

Diffucult!!

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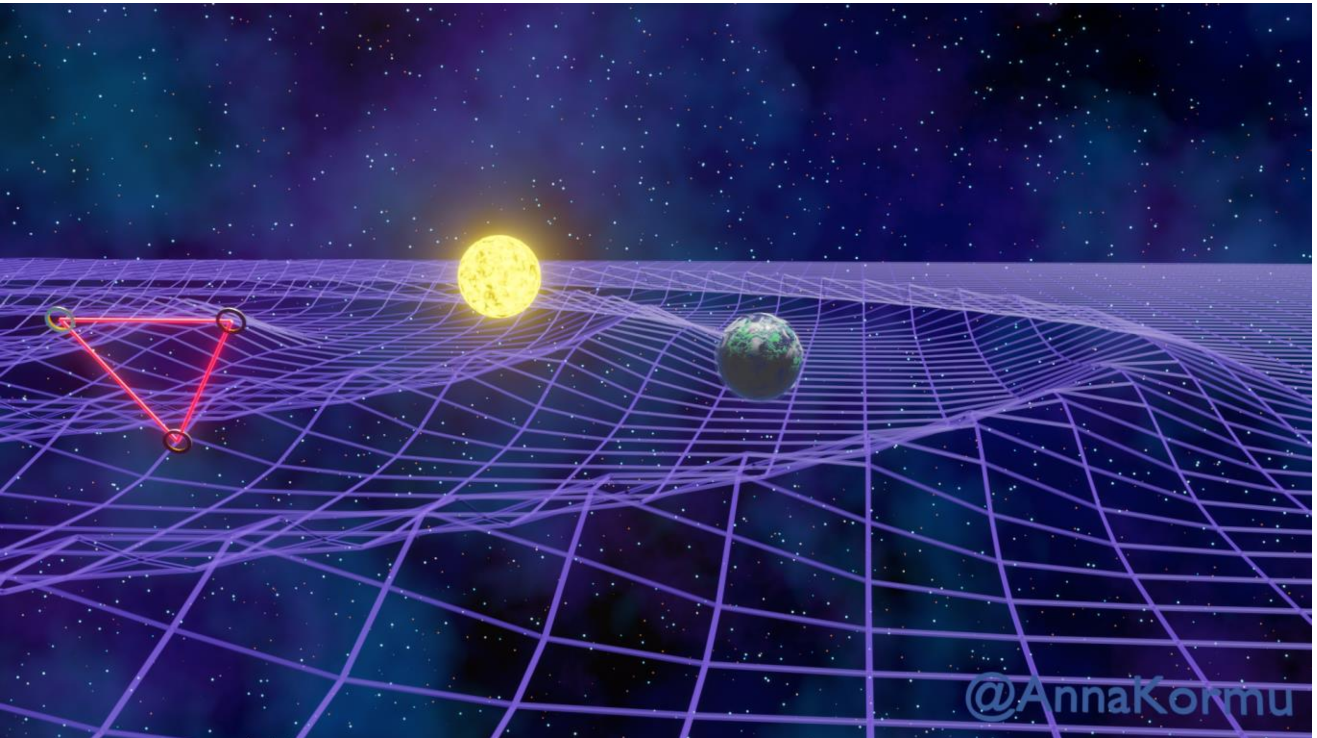
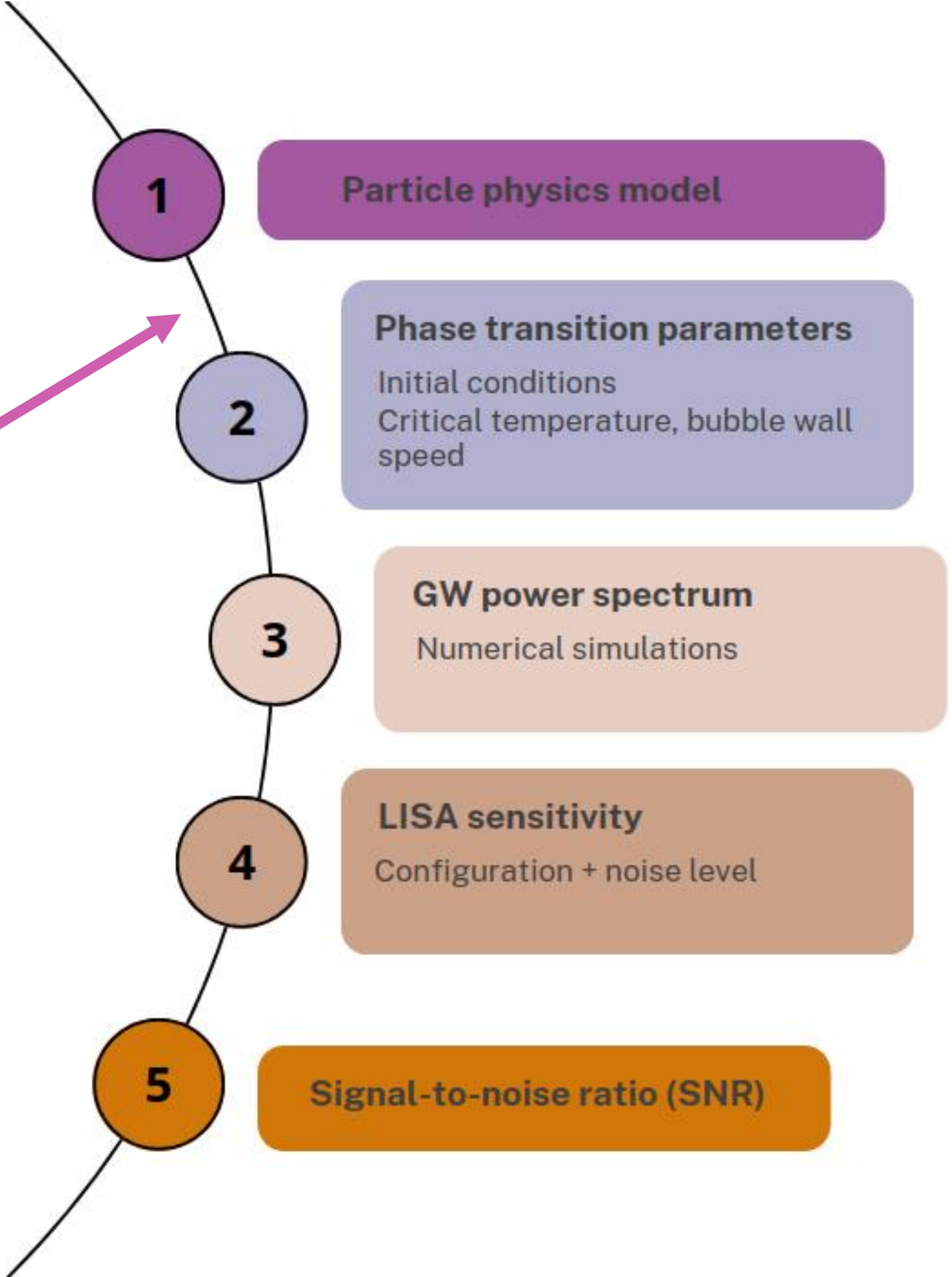
- Moore, Rummukainen & Tranberg introduce a simulation method (hep-lat/0103036, hep-ph/0009132)

LISA PIPELINE

This work: from particle physics model to PT params





SINGLET SCALAR THEORY

Gould, arXiv:2101.05528

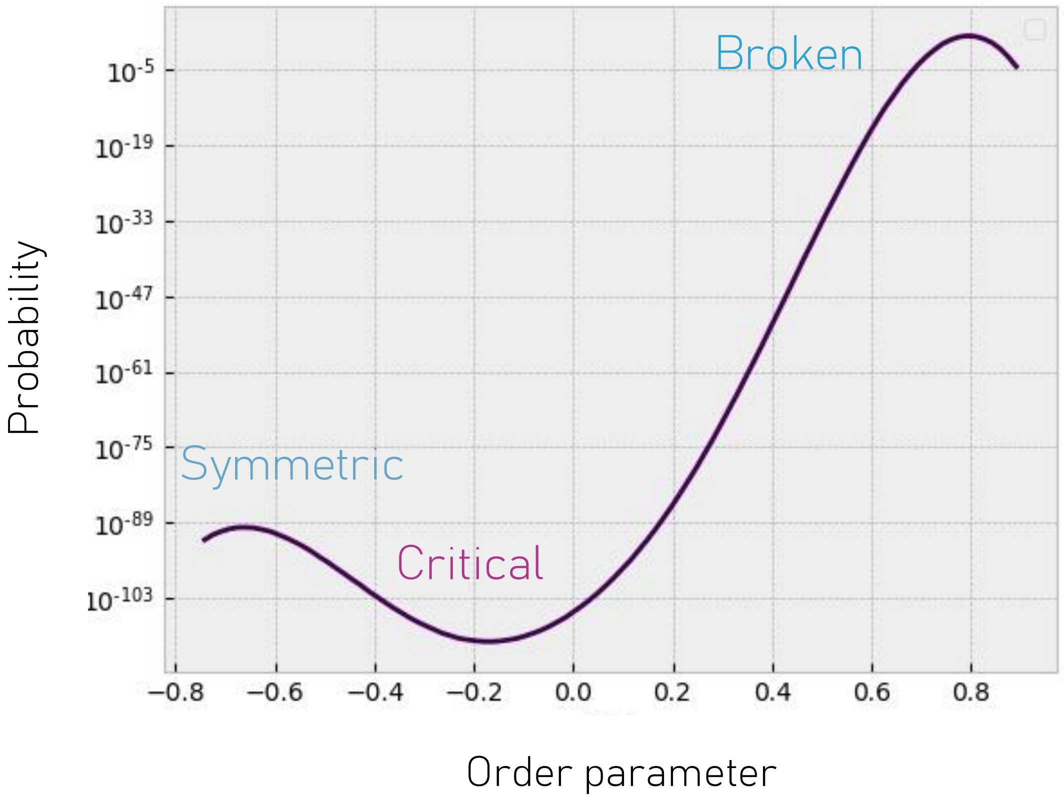
- Toy model possessing key features of BSM models
  - Potential has a tree-level barrier
  - Strong phase transition
- Dimensional reduction 4D cont → 3D cont → 3D lattice (imaginary time, high temp)

$$S_{\text{lat}} = \sum_x a^3 \left[-\frac{1}{2} Z_\phi \phi_x (\nabla^2_{\text{lat}} \phi)_x + \sigma_{\text{lat}} \phi_x + \frac{1}{2} Z_\phi Z_m m^2_{\text{lat}} \phi_x^2 + \frac{1}{3!} g_{\text{lat}} \phi_x^3 + \frac{1}{4!} Z_\phi^2 \lambda_{\text{lat}} \phi_x^4 \right]$$

NONPERTURBATIVELY

1. Pick an order parameter that behaves differently in the two phases
2. Simulate the probability of being in the critical bubble configuration
3. Perform real time evolution to determine whether the critical bubble tunnels or not
4. Calculate the total nucleation rate, dynamical prefactor × probability info

NONPERTURBATIVELY



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Perform real time evolution to determine whether the critical bubble tunnels or not

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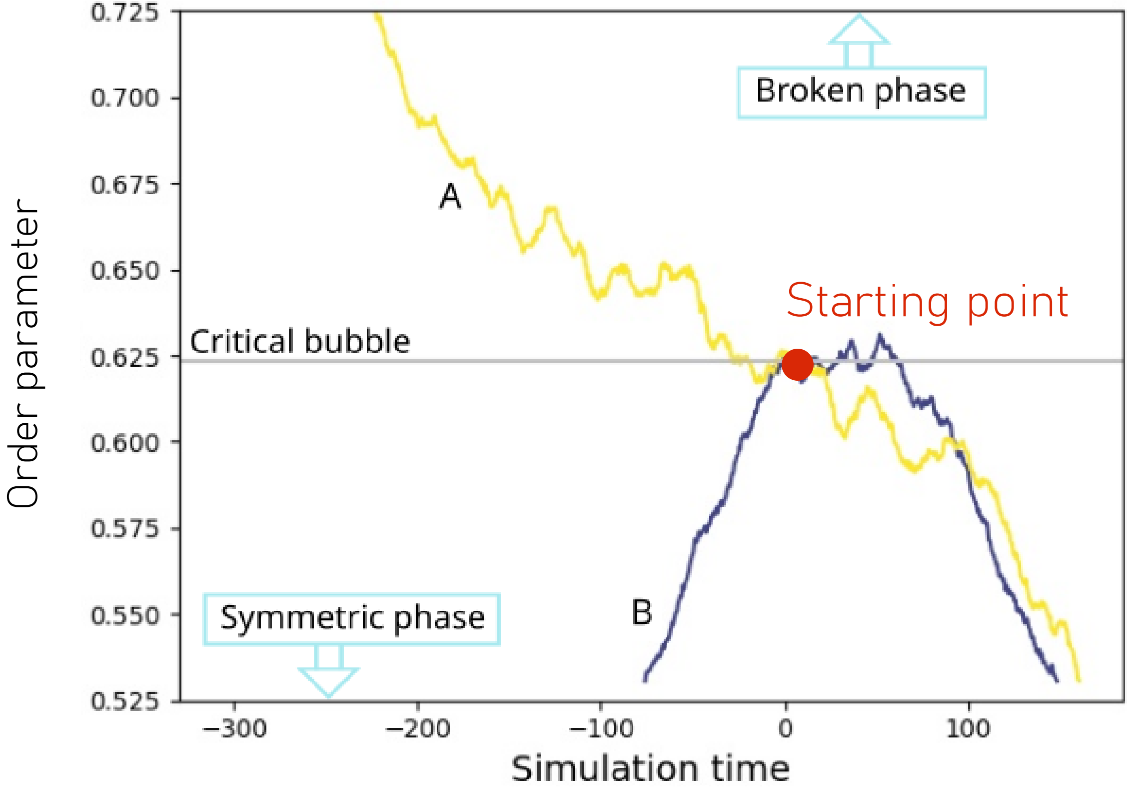

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NONPERTURBATIVELY

1

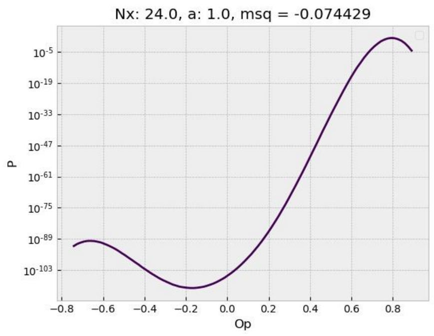
Pick an order parameter that behaves differently in the two phases

$$\Gamma V = \frac{1}{2} P_C^{\epsilon} \left\langle \left| \frac{\Delta\theta(\alpha)}{\Delta t} \right| \times \mathbf{d}^{\alpha} \right\rangle$$

4

Calculate the total nucleation rate, dynamical prefactor × probability info

NONPERTURBATIVELY



Flux, rate of change of op

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1

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Calculate the total nucleation rate, dynamical

r ×

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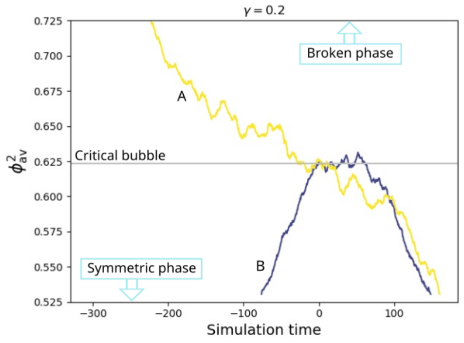
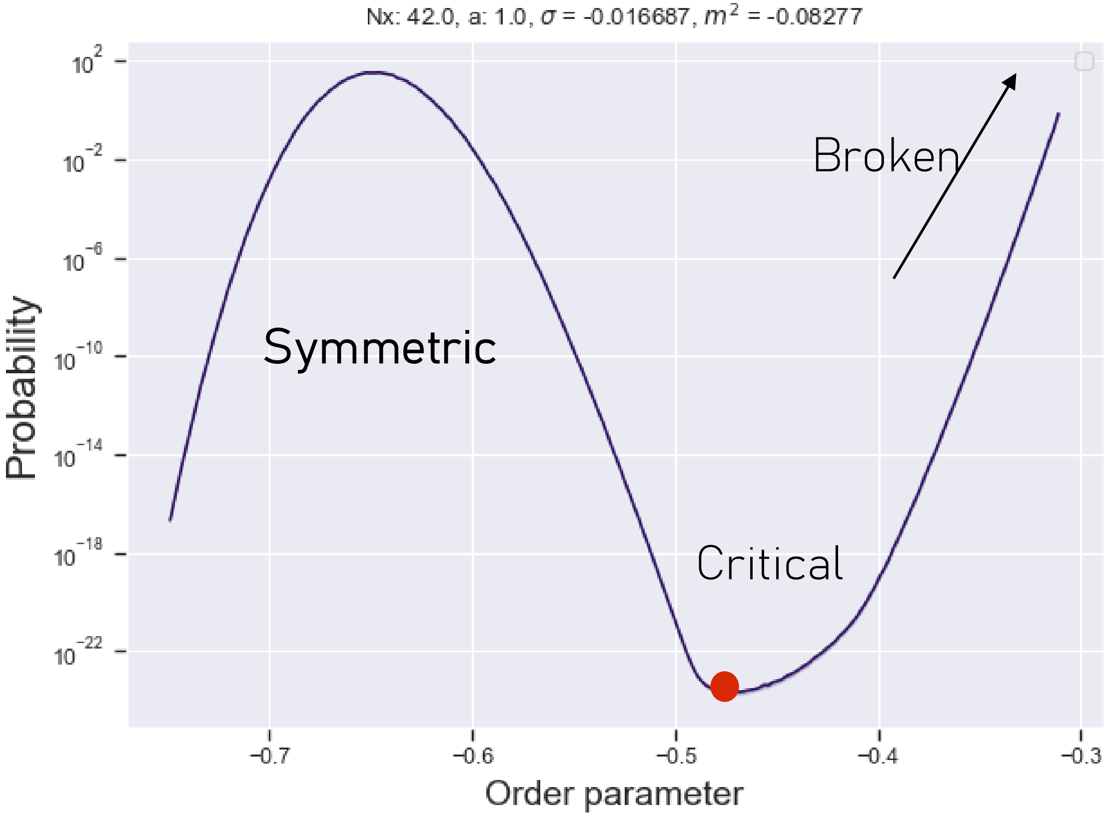


THE PROBLEM WITH LINEAR ORDER PARAMETER

$$\varphi_{op} = \frac{1}{V}\sum_i \phi_i$$



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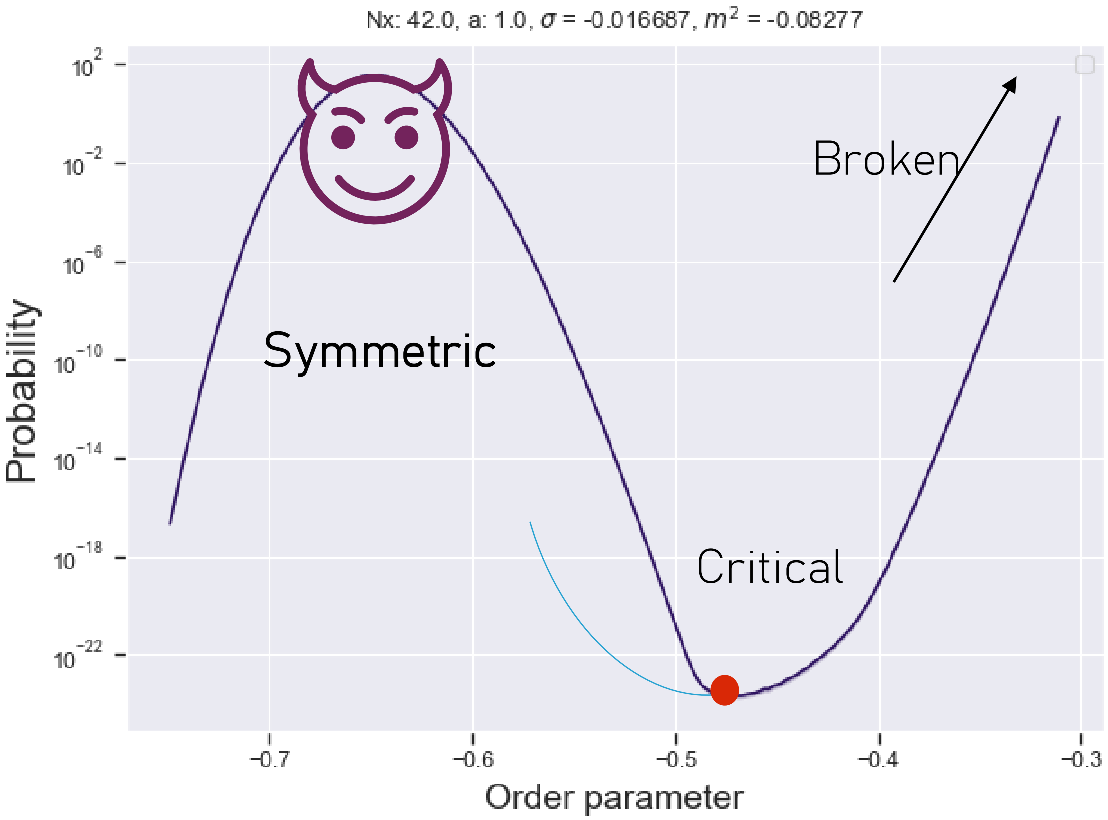
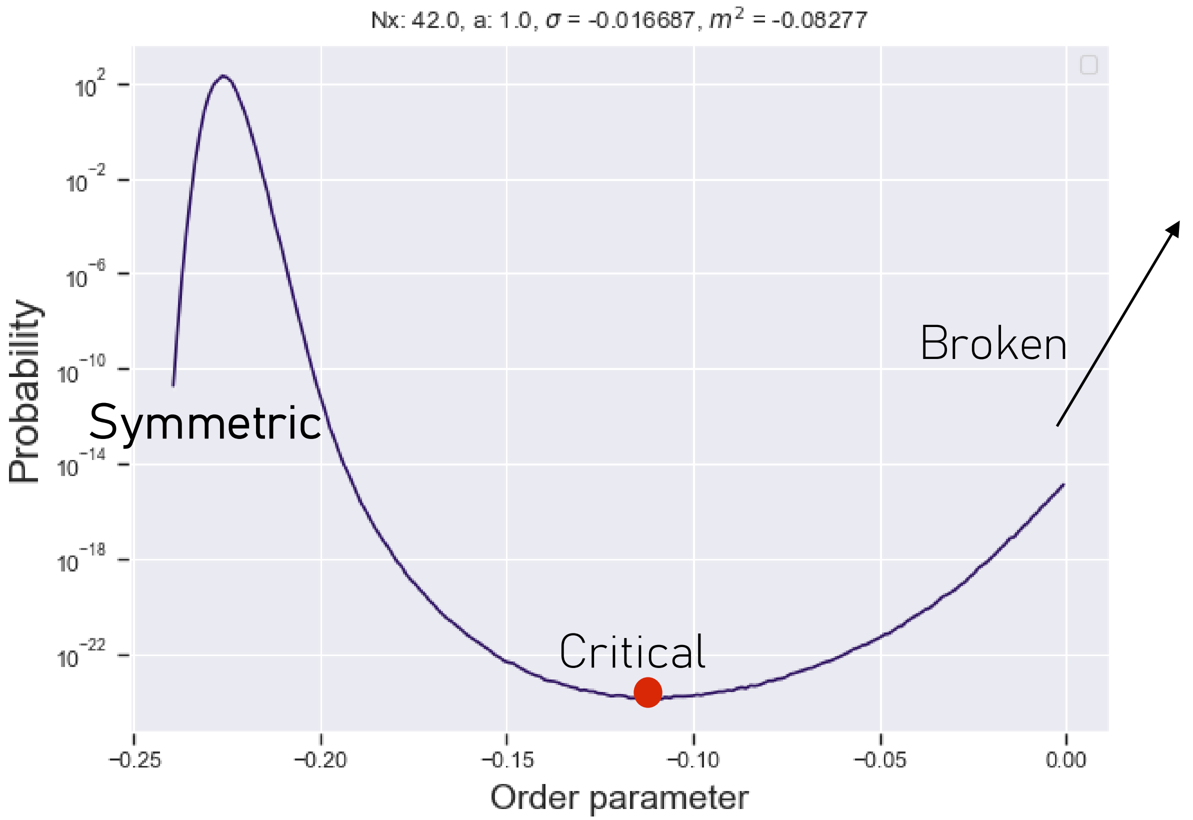
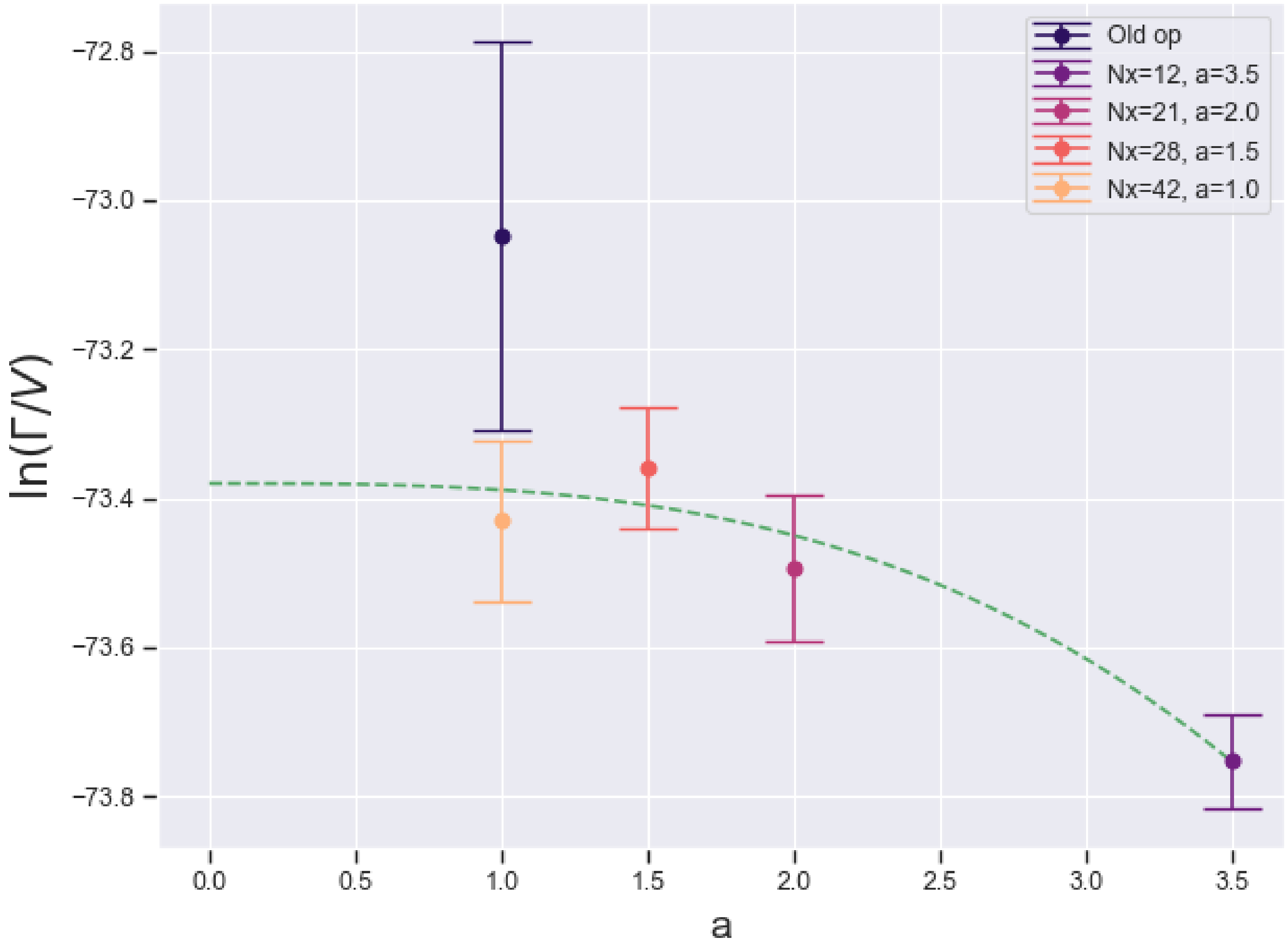


THE PROBLEM WITH LINEAR ORDER PARAMETER

Linear op → Quadratic op

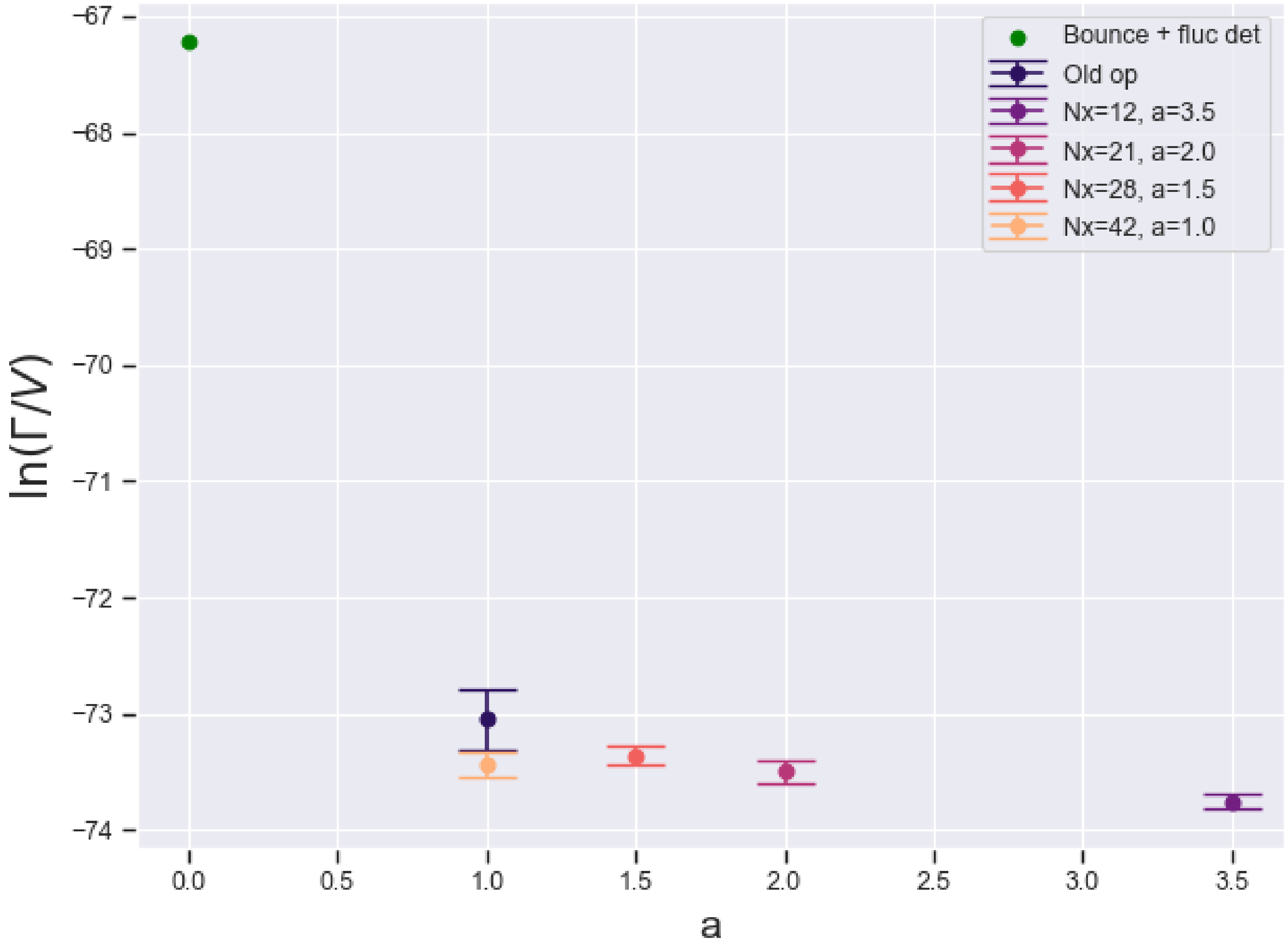
$$\frac{1}{V}\sum_i \phi_i \rightarrow \frac{1}{V}\sum_i (\phi_i^2 - \phi\phi_{sym})$$





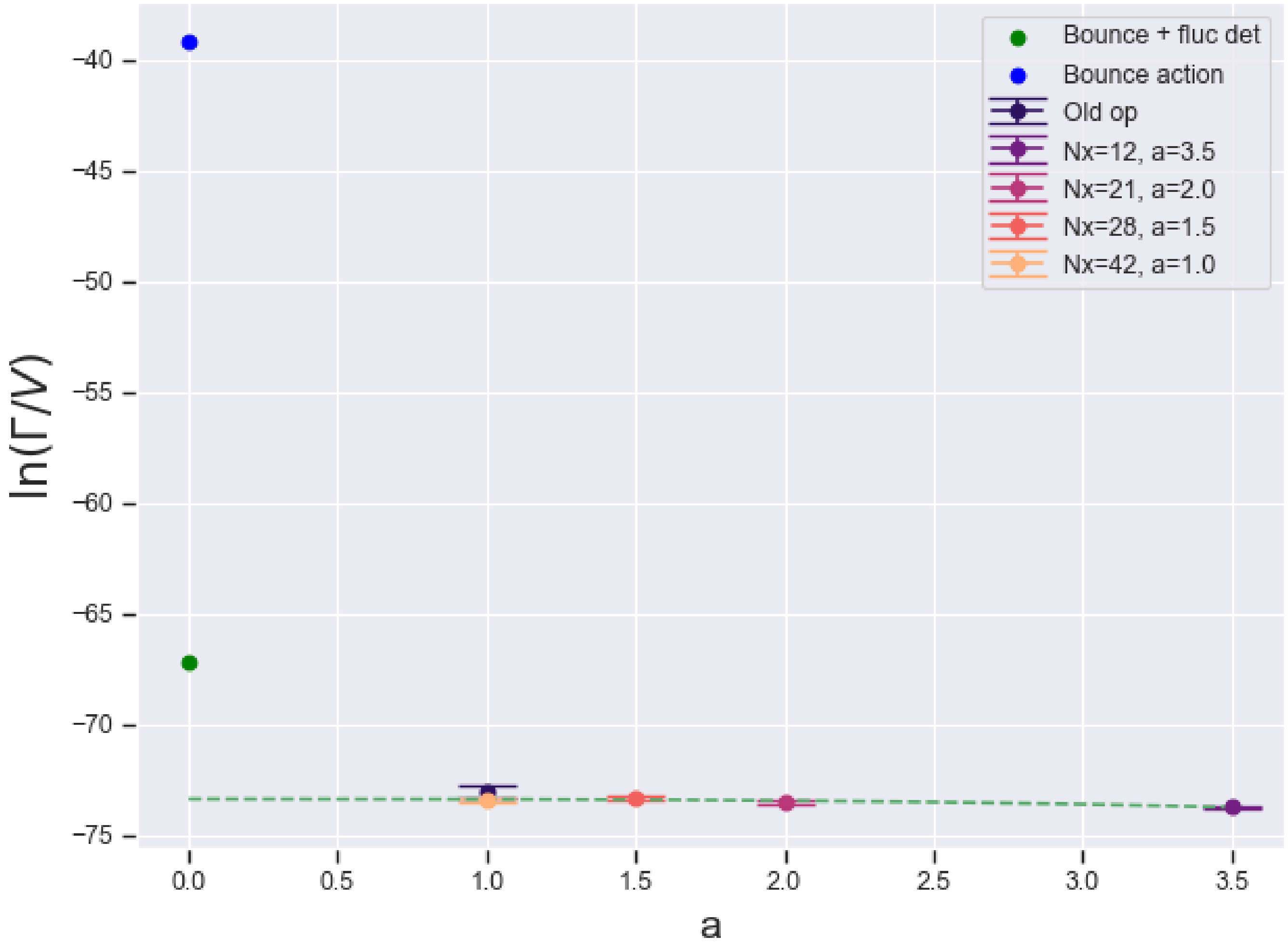
RESULTS

New order parameter runs compared to the old order parameter run



RESULTS

… compared to the bounce action + fluctuation determinant



RESULTS

… and with the bounce action only

CONCLUSIONS

- Allows us to calibrate the uncertainty in PT parameters when obtained from perturbative results
- Our simulations show a substantial suppression of nucleation rate compared to the one loop estimate
- Accurate computations of the nucleation rate are crucial for calculating e.g. the GW power spectrum
- Method and results can be applied to other theories

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One-pumpkin takeaway

There can be large uncertainties in nucleation rates calculated from the bounce action

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Thank you! Questions?

BACKUP

- Volume averaged nucleation rate vs. the perturbative calculation results as a function of temperature T (GeV)

- Lattice spacing fixed, varying physical volume