Bubble-nucleation in cosmological first-order phase transitions

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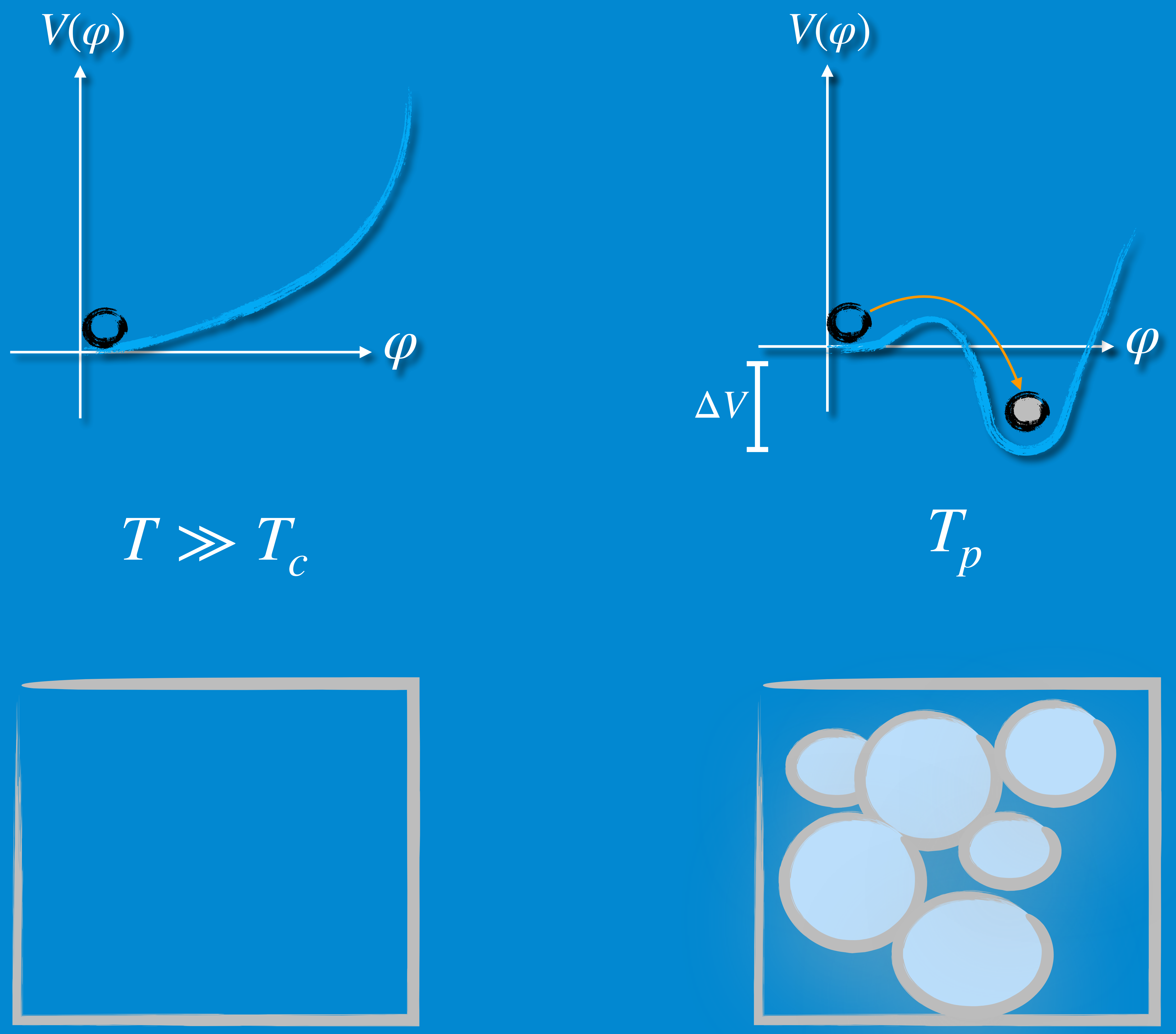
About myself

- PhD at University of Warsaw, Poland
- PhD supervisors: Zygmunt Lalak, Bogumiła Świeżewska
- Now: postdoc at Uppsala, working with R. Enberg
- Scientific interests: cosmological phase transitions

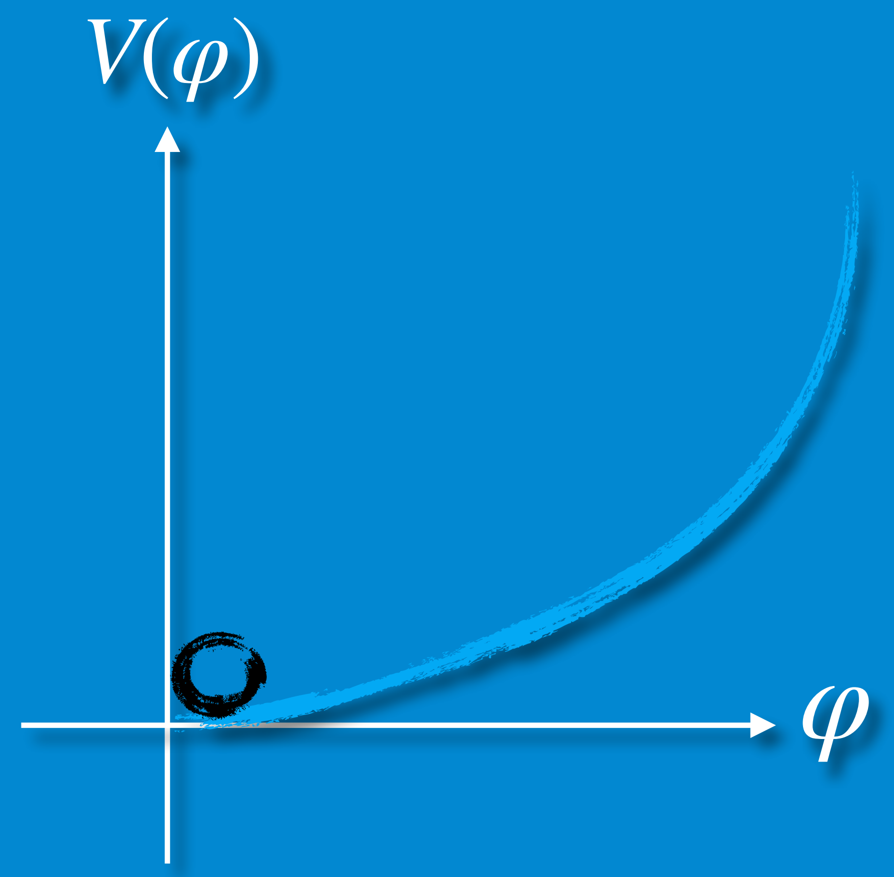
“Soap Bubbles”, Thomas Couture

Field theory picture

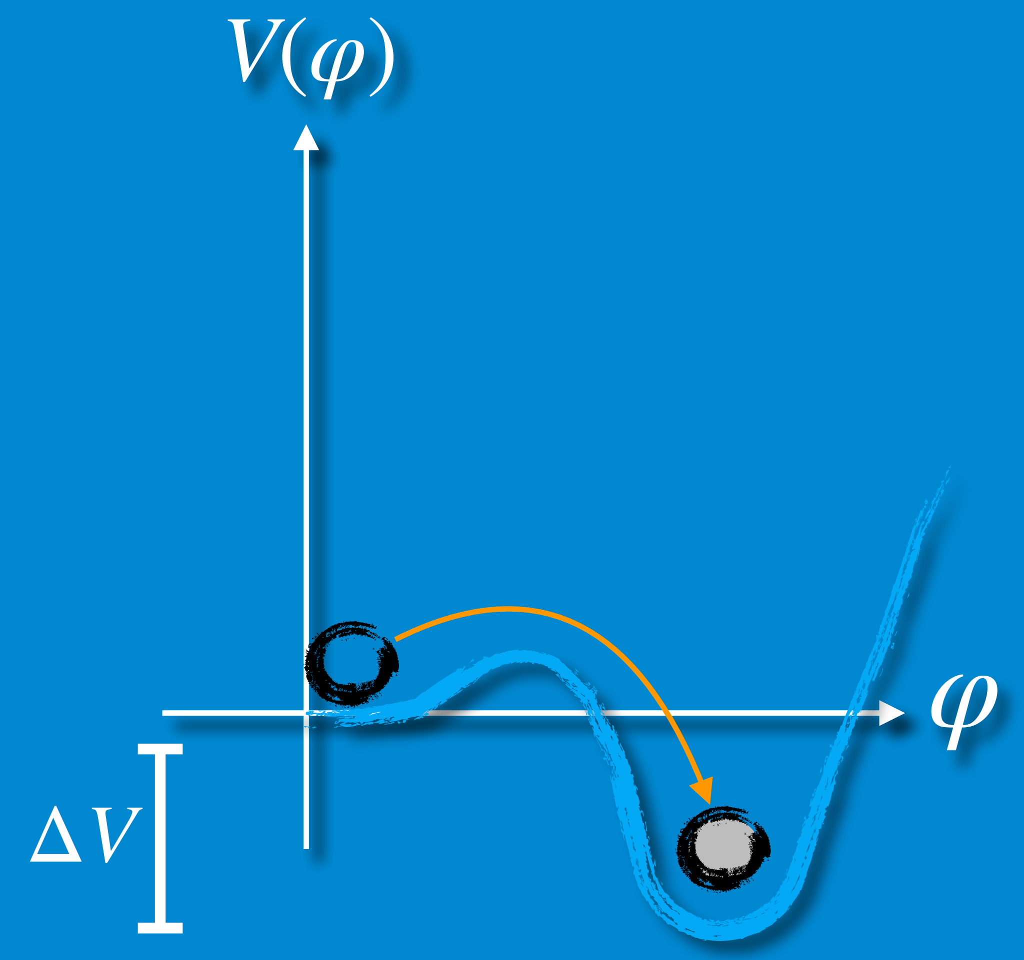
Cosmology picture



Field theory picture

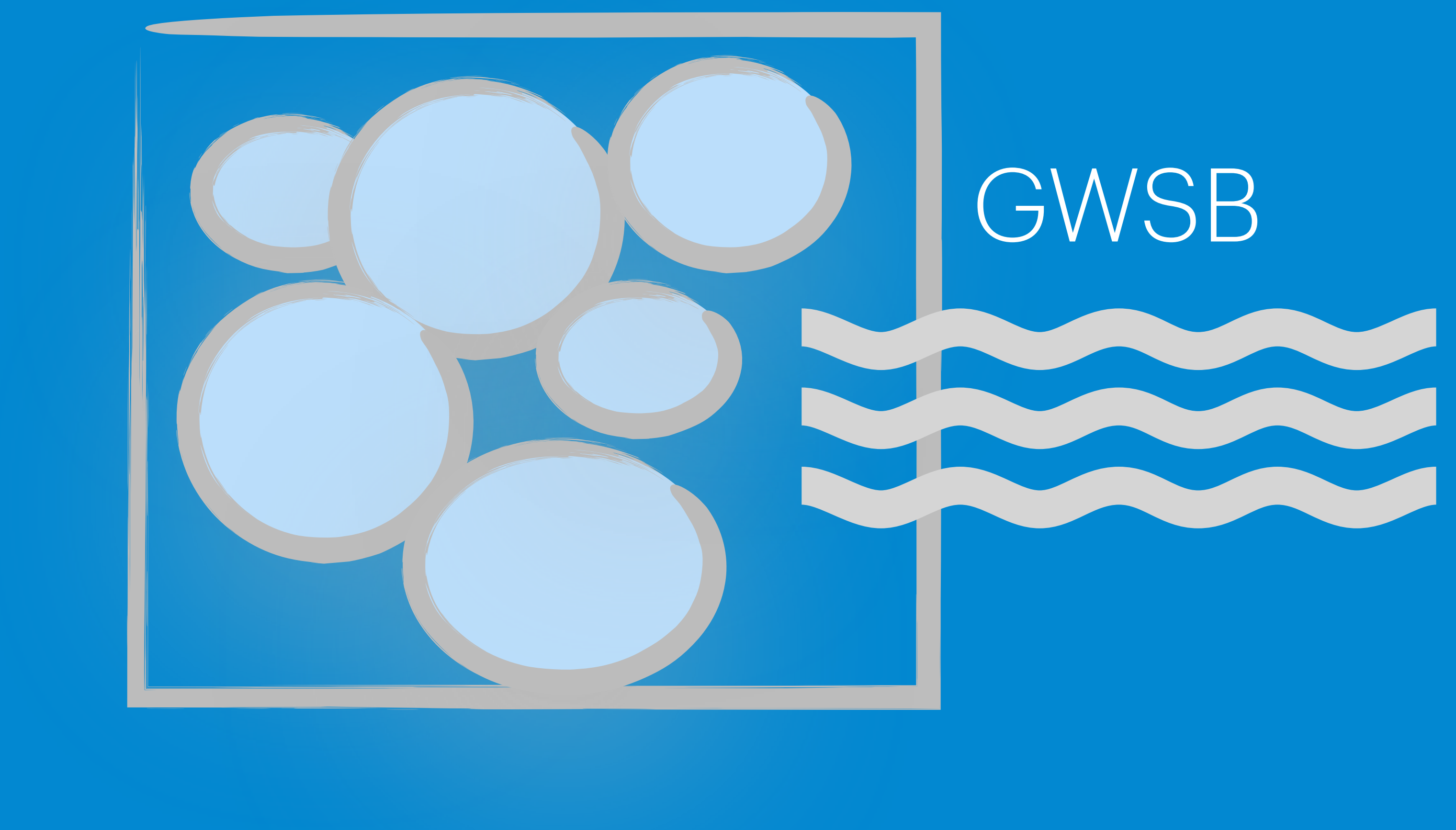


$T \gg T_c$



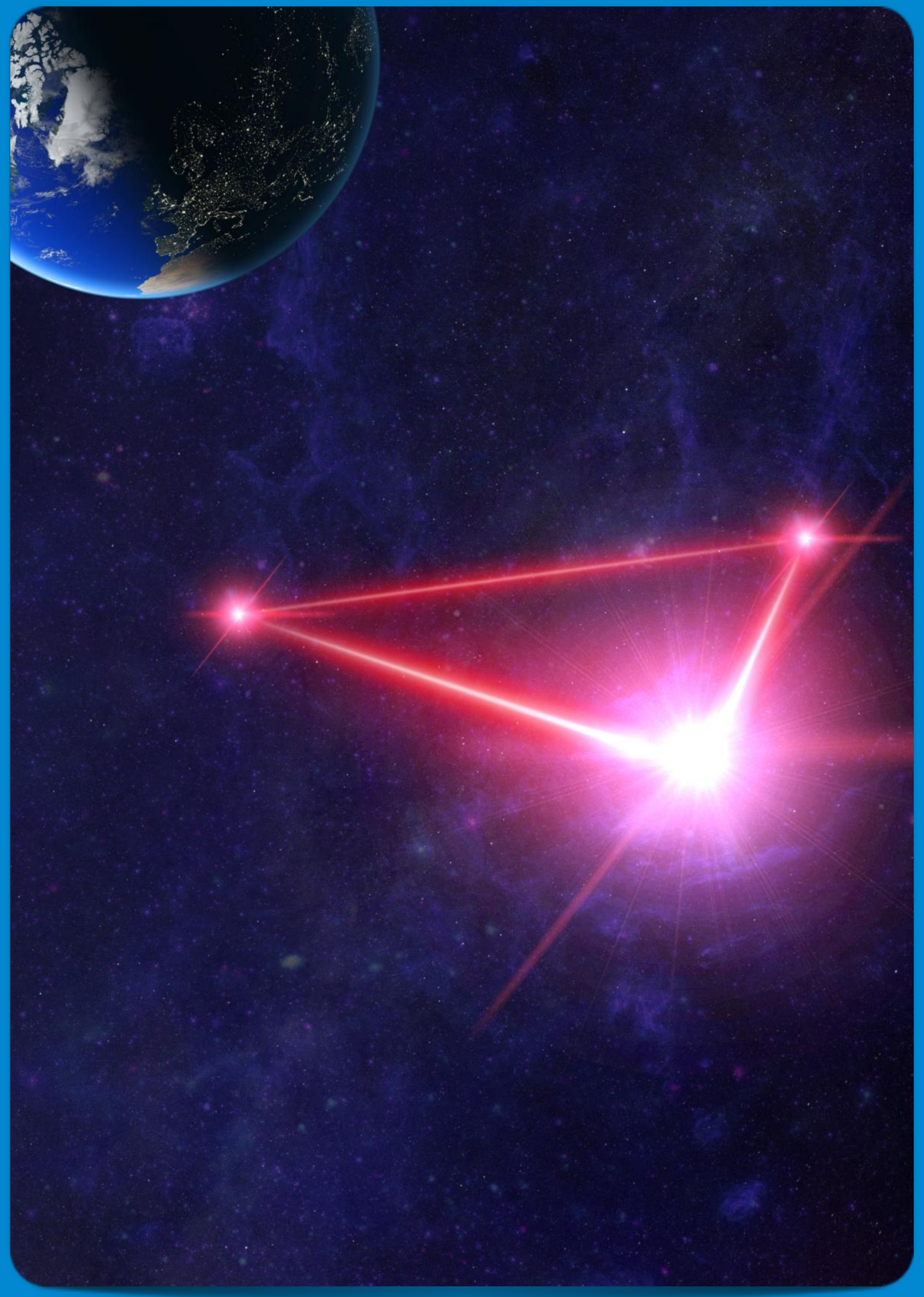
T_p

Cosmology picture



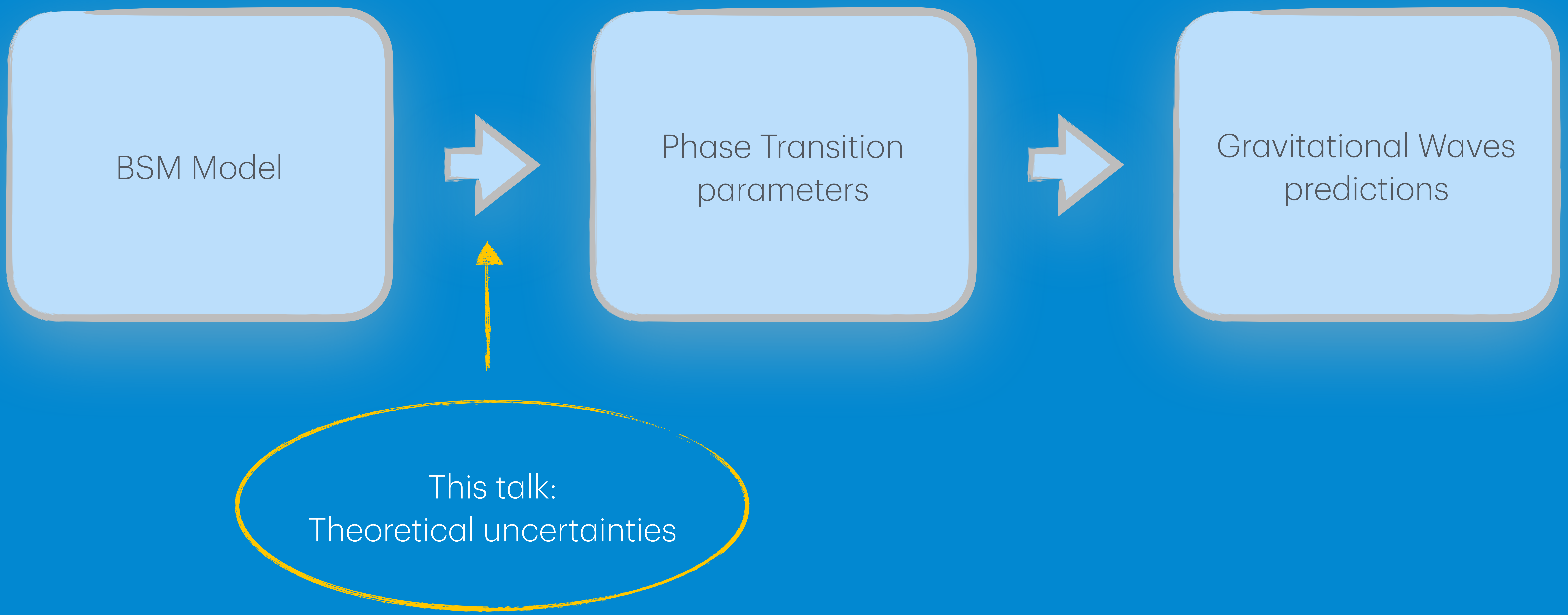
Motivation

- LISA detector will start collecting data in late 2030's
- LISA will be sensitive to the frequencies coming from the first-order electroweak transition
- Detection of such signal is a "smoking gun" for new physics!
- There could be associated phenomena e.g. dark matter, primordial black holes, production, baryogenesis



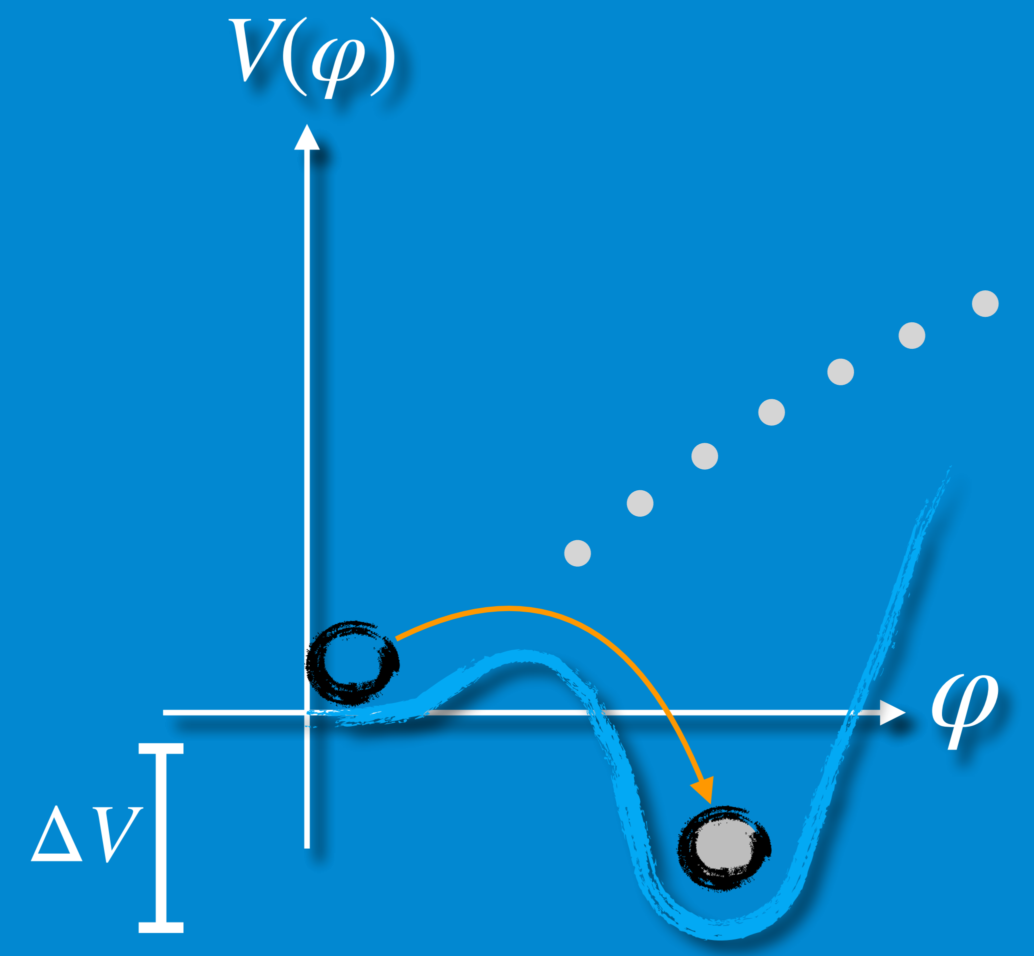
FOPT pipeline

FOPT pipeline



Key quantity

Field theory

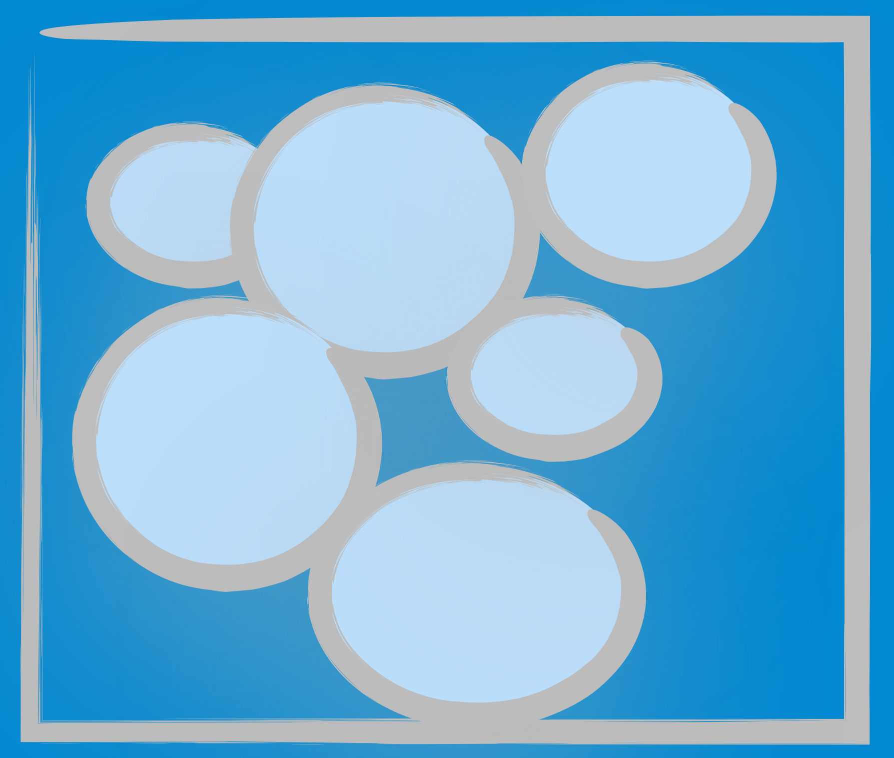


T_p

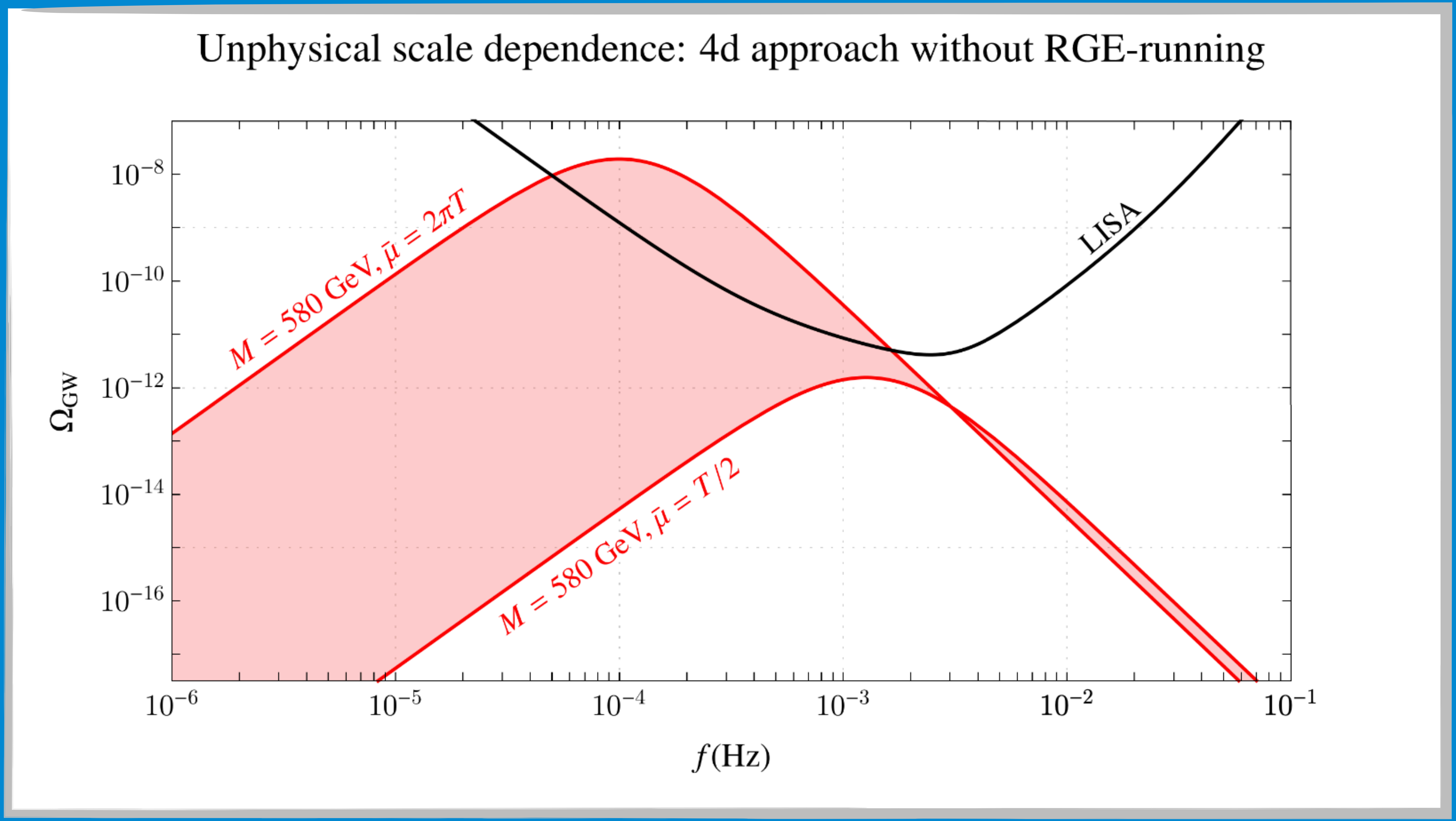
Bubble nucleation rate

$$\frac{\Gamma_T}{H^4}$$

Cosmology



Challenges



[Figure from: D. Croon, O. Gould, P. Schicho, T. Tenkanen, G. White, JHEP 04 (2021) 055]

Daisy resummation

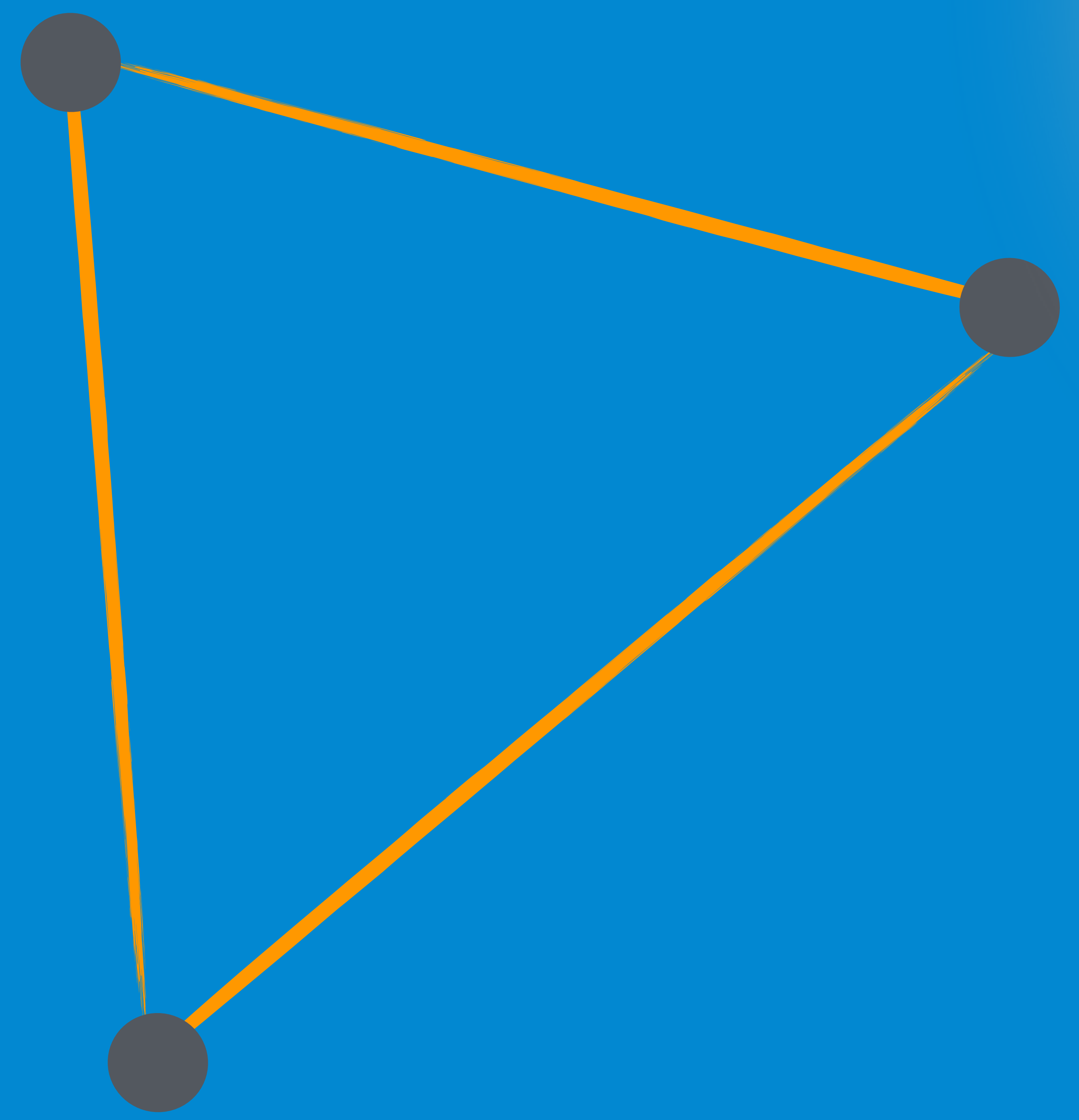
- Captures the "general" behaviour, but:
- Large RG-scale dependence
- Contains imaginary parts in the effective potential
- Gauge-dependent predictions
- Double counting of dofs

VS

Dimensional Reduction

- Captures *everything* at a given $\mathcal{O}(g)$
- Reduced RG-scale dependence
- No imaginary parts in the effective potential
- Gauge-invariant predictions
- One can increase precision consistently, order by order
- Can reproduce lattice very well

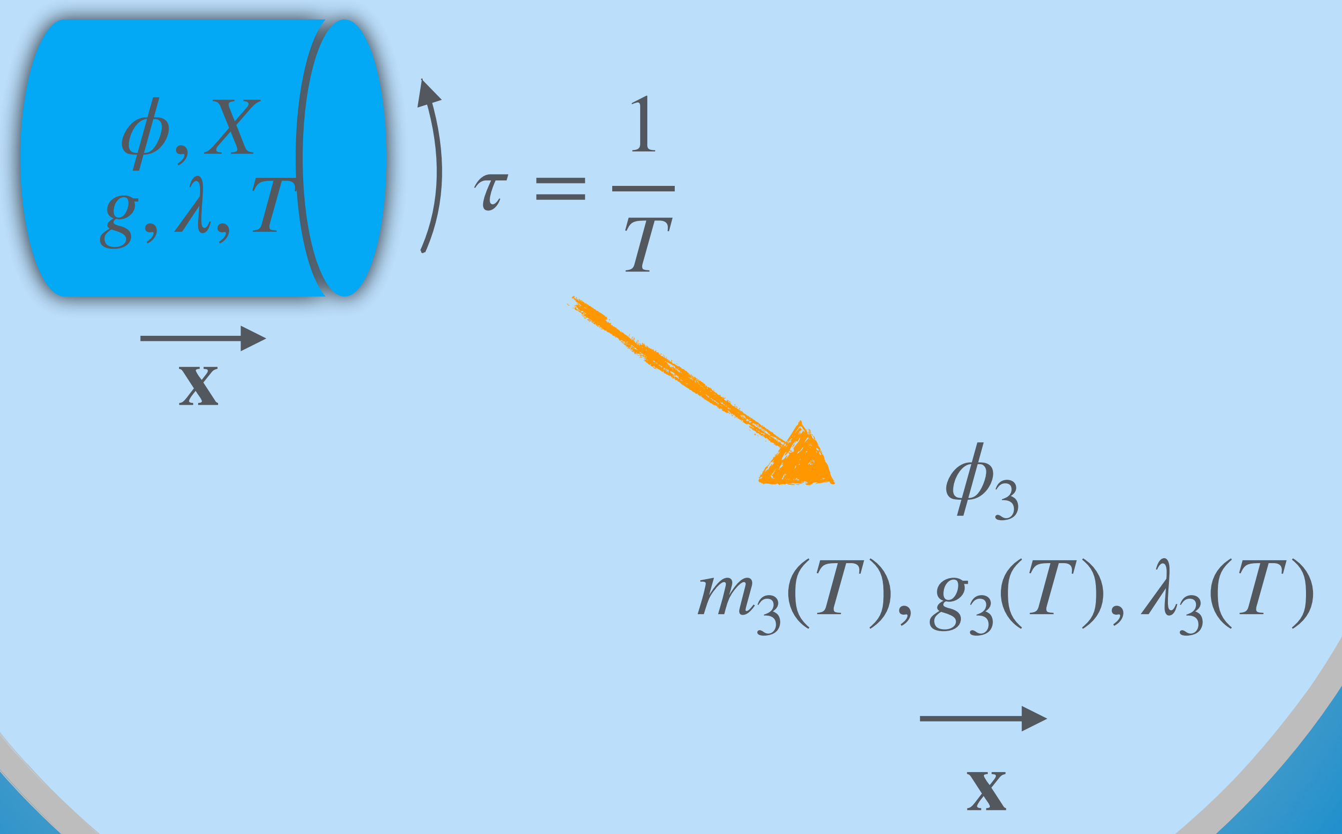
My work so far: applying the DR to strongest PTs



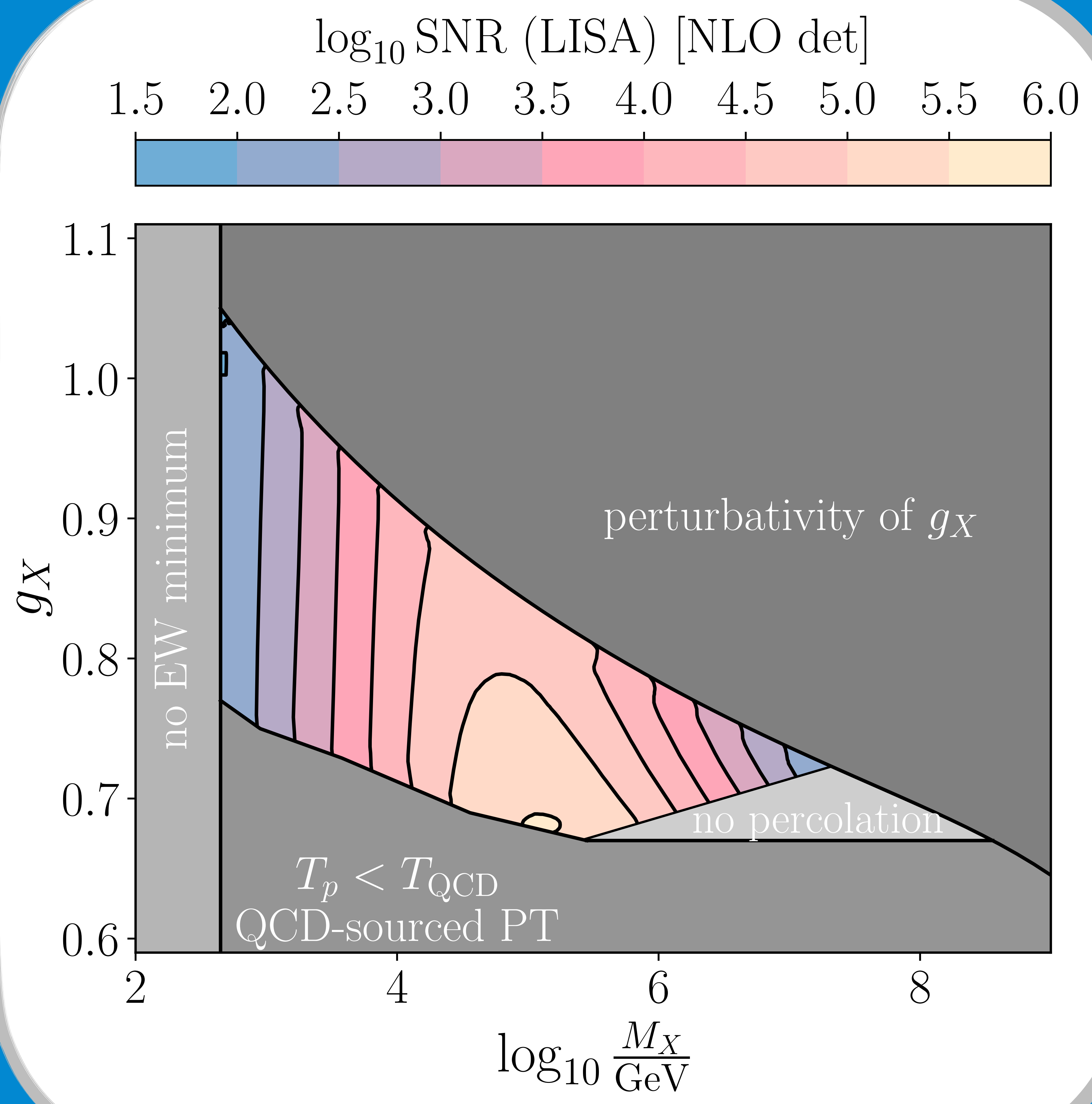
Supercooled PT in a classically scale-invariant model

$$V_0(\phi) = \frac{1}{4}\lambda_1 h^4 + \frac{1}{4}\lambda_2 \phi^2 h^2 + \frac{1}{4}\lambda_3 \phi^4$$

High-temperature dimensional reduction



Conformal models will be testable in LISA



Vector-Goldstone determinant in derivative expansion

$\boxed{\frac{m_3}{m_X} \ll 1}$

$\delta Z = -\frac{11}{16\pi}\frac{g_3}{\phi_b}$

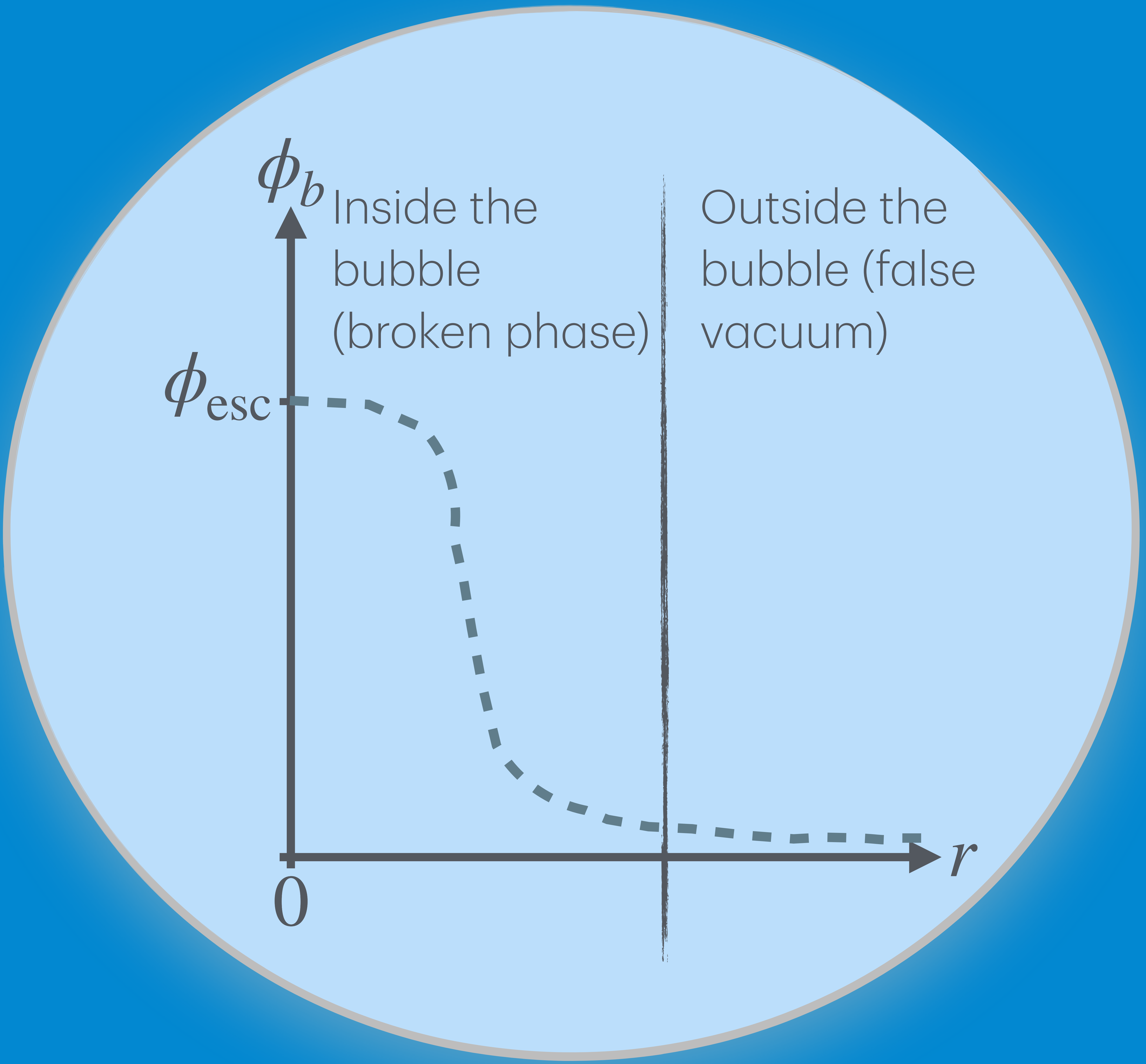
$$-\log \mathrm{Det}_{VG} \simeq \underbrace{\int_x \frac{-3}{48\pi} g^3 \phi_b^3}_{\mathcal{O}(g^3)\ \mathrm{LO}} + \underbrace{\int_x \frac{1}{2}\delta Z[\phi_b](\partial\phi_b)^2}_{\mathcal{O}(g^4)\ \mathrm{NLO}} + \ldots$$

Barrier generating term

Terms with higher powers in derivatives

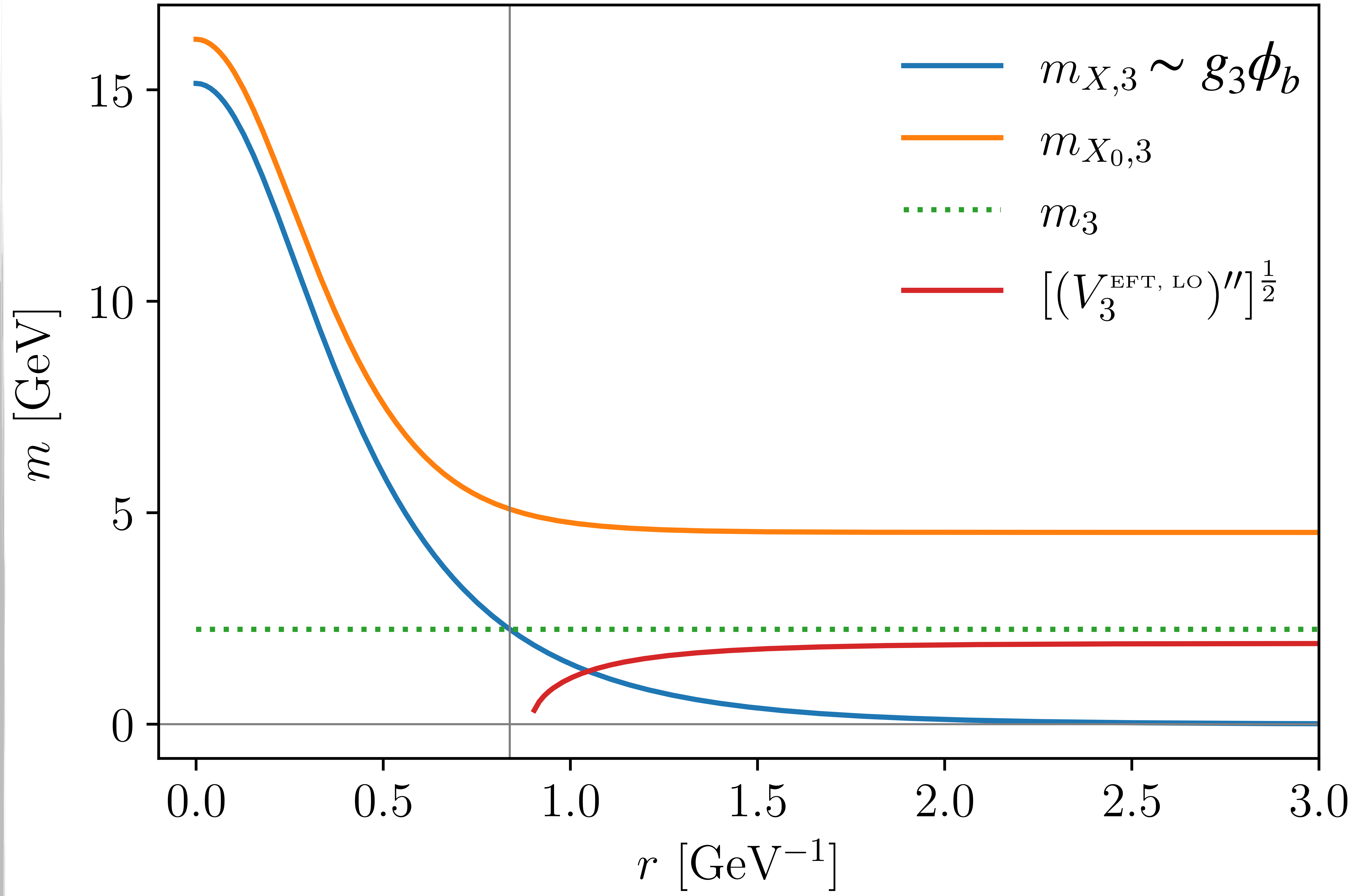
See also: A. Ekstedt, O. Gould, J. Hirvonen, 2308.15652; A. Ekstedt 2104.11804, J. Hirvonen et al 2112.08912, MK, B. Świeżewska, T.V.I Tenkanen, J. van de Vis, 2312.12413

Critical bubble field configuration

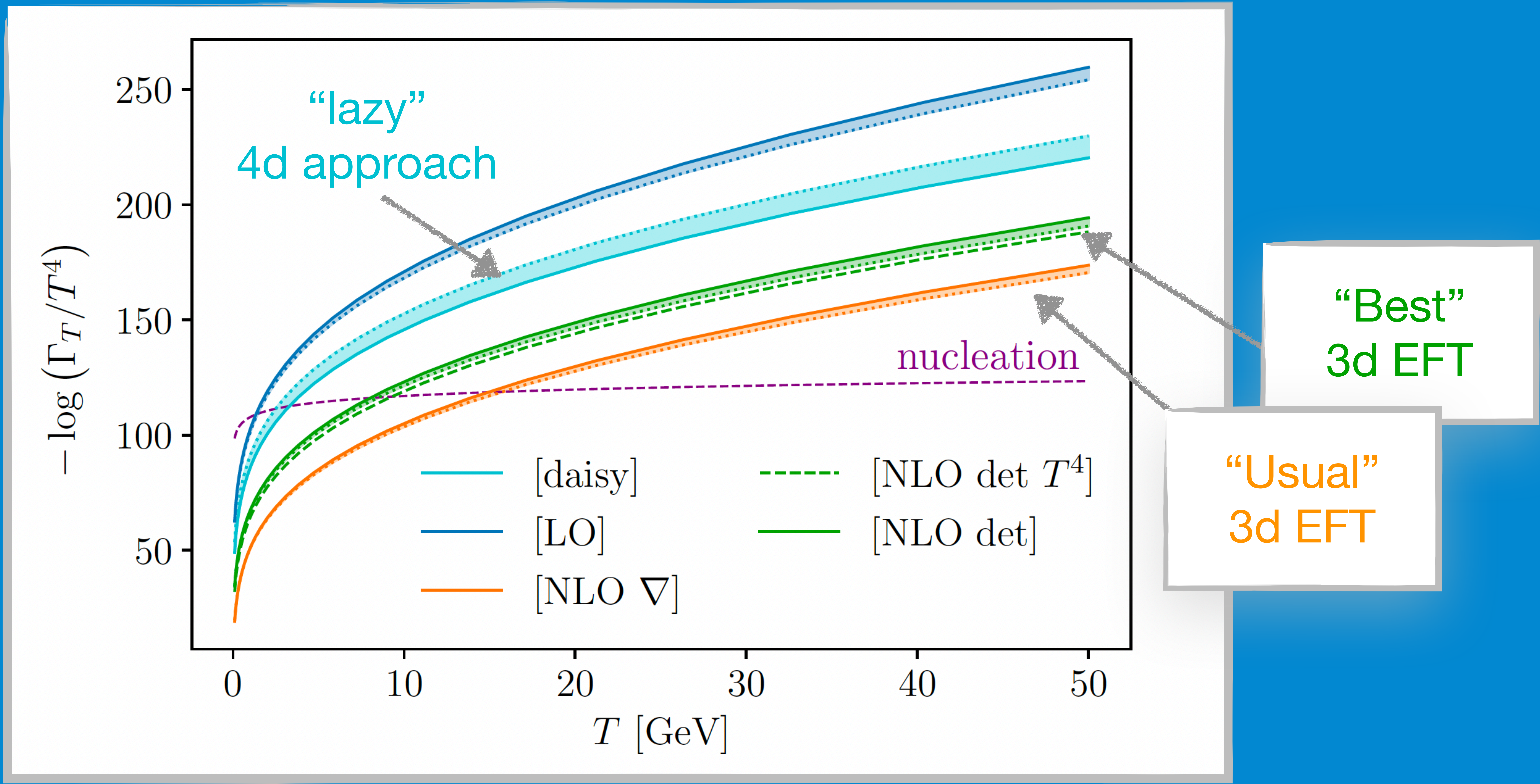


See also: S. Coleman Phys.Rev.D 15 (1977), A. Ekstedt 2201.07331, 2104.11804

Scale-shifters



Nucleation rate from different "recipes"



[2503.13597, with P. Schicho, B. Świeżewska, T.V.I. Tenkanen and J. van de Vis,]

Summary

Derivative expansion for **gauge modes** introduces significant **errors**.

NLO corrections are **mandatory** for reliable pheno predictions

Conformal BSM give strong EW FOPTs

Outlook

It'd be nice to have a comparison to nucl. rate from lattice!

Impact of NLO corrections on model reconstruction from GW

Thank you!

Feel free to ask questions:

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