Holographic approach of the spinodal instability to criticality

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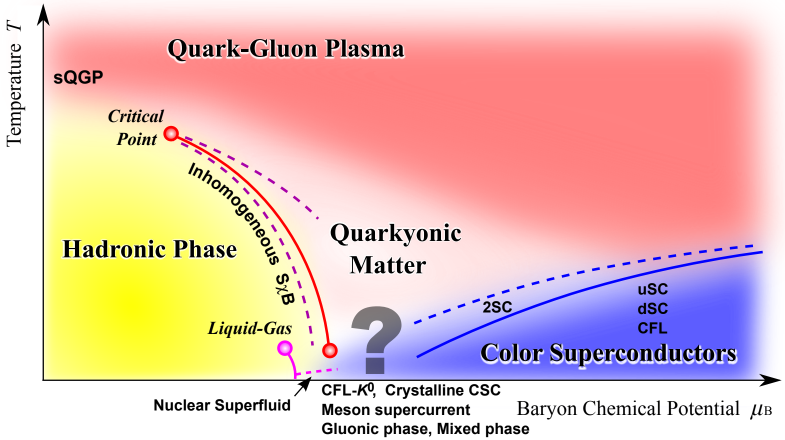
A Virtual Tribute to Quark Confinement
and the Hadron Spectrum 2021

Motivation - QCD phase diagram

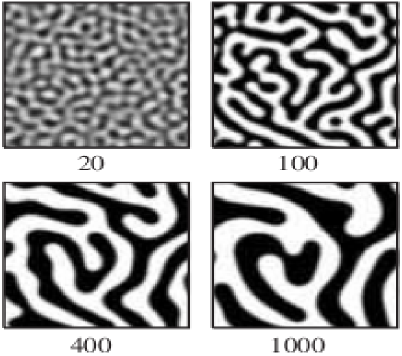
The critical point (CP) is the endpoint of the 1st order phase transition between the Quark-Gluon Plasma and the hadrons:



Assumed theoretical QCD phase diagram [Fukushima, Hatsudo 2010]

Spinodal instability is key signature of 1st-order phase transition:

spinodal instability:



spinodal decomposition in a two phase system

[Onuki 1987]

Gregory-Laflamme instability:

thin black ring pinching off

[Figueras, Kunesch, Tunyasuvunakool 2015]

gauge/gravity correspondence:

bridge between physical phenomena in gauge theories and gravity.

Holographic setup

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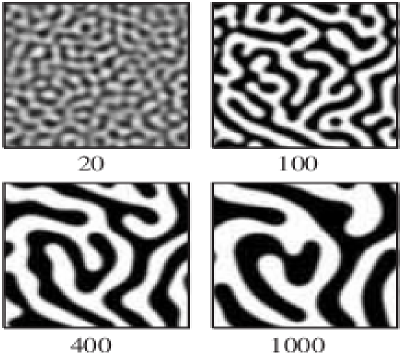

spinodal decomposition in a two phase system

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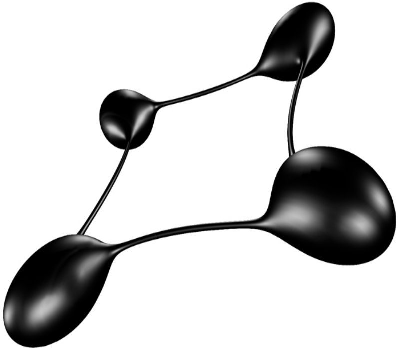

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[Figueras, Kunesch, Tunyasuvunakool 2015]

gauge/gravity correspondence:

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Holographic bottom-up model: setup

Dual field theory: 'mimics'a deformation of N=4 SYM with a dimension 3 operator O and source Λ as 'mass'

$$S_{\text{GaugeTheory}} = S_{\text{conformal}} + \int d^4x \Lambda O$$

Einstein-Hilbert action coupled to a scalar with non-trivial potential in five-dimensional bottom-up model:

$$S = \frac{2}{\kappa_5^2} \int d^5x \sqrt{-g} \left[\frac{1}{4}\mathcal{R} - \frac{1}{2} (\nabla\phi)^2 - V(\phi) \right]$$

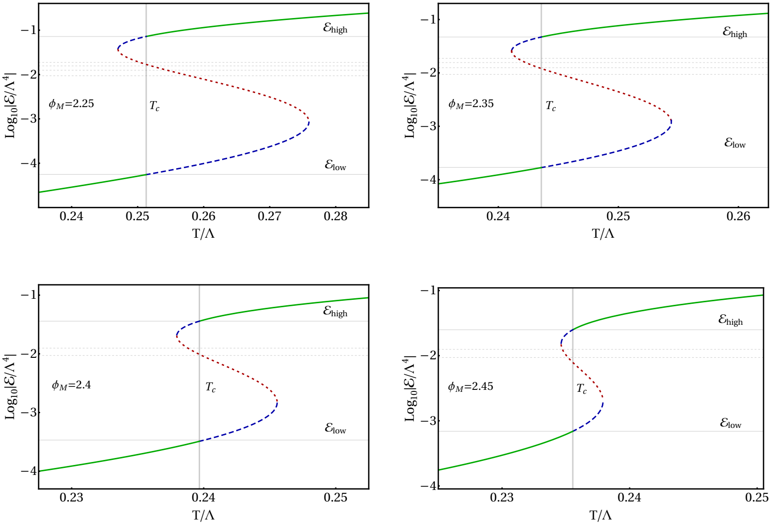
We derive the potential from the superpotential [Bianchi, Freedman, Skenderis 2002]: $V(\phi) = -\frac{4}{3} W(\phi)^2 + \frac{1}{2} W'(\phi)^2$

$$\ell^2 W(\phi) = -\frac{3}{2} - \frac{\phi^2}{2} - \frac{\phi^4}{4\phi_M^2}$$

using a single parameter with critical value $\phi_M = 2.521$

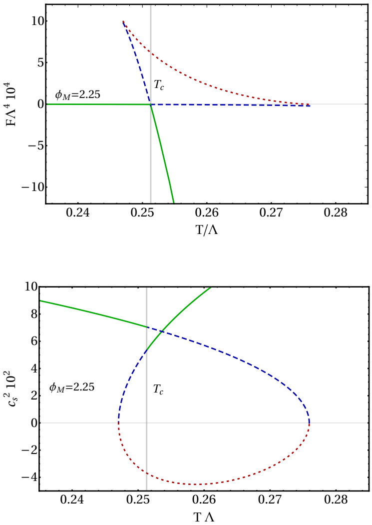
$$\ell^2 V(\phi) = -3 - \frac{3\phi^2}{2} - \frac{\phi^4}{3} - \frac{\phi^6}{3\phi_M^2} + \frac{\phi^6}{2\phi_M^4} - \frac{\phi^8}{12\phi_M^4}$$

Holographic bottom-up model: tuning criticality



Equation of states with stronger or softer first-order phase transition with $\phi M = \{2.25, 2.3, 2.35, 2.4, 2.45\}$.

Holographic bottom-up model: tuning criticality II



free energy F and the speed of sound squared cs^2 over temperature for the theories with different criticality

Spinodal instability - stages

four generic stages:

1. linear stage
2. reshaping
3. merger
4. final:
   static + phase-separated

endstate:
phase-separated configuration

conjecture:
all static, non-phase separated configurations are dynamically unstable

inhomogeneous structures: 1 phase separated, 2 phase mixed

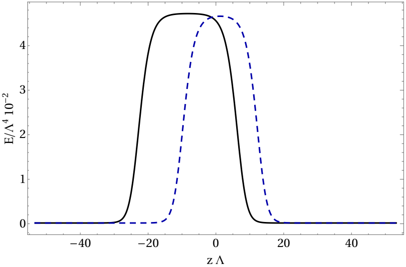
maxima:

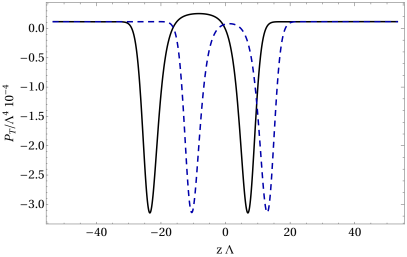
1. plateaux
2. peak

minima:

1. valley
2. gorge

New transverse pressure $P_T \geq 0.8 P_c$ criterium for distinction:





Longitudinal profiles $\mathcal{E}$, P_T of a plateau and a peak

Spinodal instability - formation time

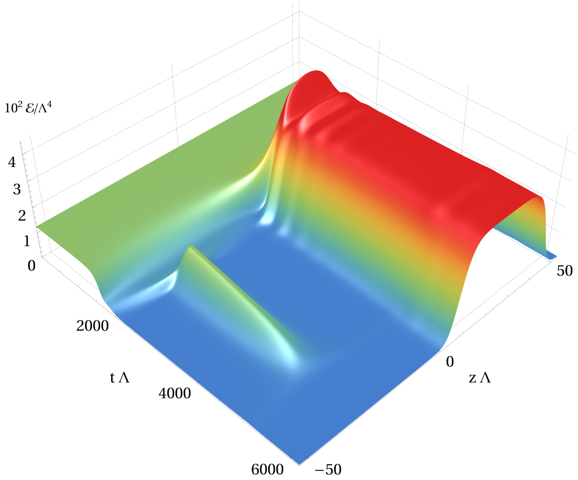
Formation time of the spinodal instability with varying criticality:

ϕ_{M}	2.25	2.35	2.4	2.45
$t_{\mathrm{formation}}\Lambda$	880	1380	1725	2660

The time until $\mathcal{E}_{\mathsf{high}}$ is reached heavily depends on criticality.

Spinodal instability dissipation

Dissipation of a peak into a plateau:



First simulations where the rigid interface disappear for different criticality.

Main lessons from holographic studies of criticality

- Fast spinodal instability away from CP
- distinction of the inhomogeneous structures of a spinodal instability via new criterium:
  peaks versus domains; valleys versus gorges
- classification of the dynamics of a spinodal instability:
  quasi-linear regime, reshaping, merger, preferred final state
- new dissipation with spinodal instabilites
- More studies on the way..