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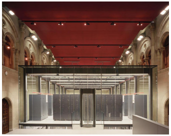

MARIE CURIE ACTIONS

Excitation and saturation of the spinodal instability

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arXiv:1703.09681

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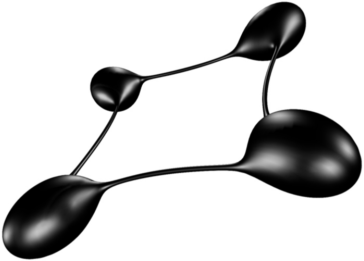
CPOD 2017

Motivations

Phase transition:

melting water out of ice

Gregory-Laflamme Instability:



Black ring pinching off

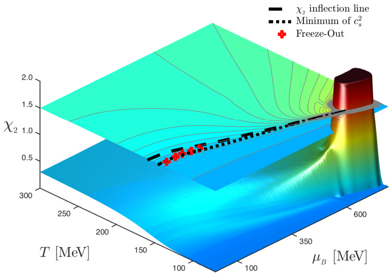
gauge/gravity correspondence:
bridge between physical phenomena in gauge theories and gravity.

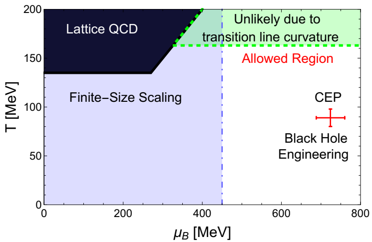
Outline

Excitation and saturation of the spinodal instability

- Introduction gauge/gravity phase diagram
- Introduction Gregory-Laflamme instability
- Introduction gauge gravity duality
- Non-conformal General Relativity setup
- Non-conformal thermodynamics
- Spinodal instability
- Inhomogeneous horizon
- Hydrostatic + Hydrodynamic evolution
- Phase separation

Black-hole engineered critical point w QCD lattice match [Critelli, Noronha, Noronha-Hostler, Portillo, Ratti, Rougemont 2017]

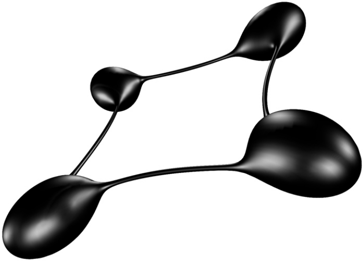




Baryon susceptibility χ_2 extended in the full $T - \mu_B$ plane and critical point located at $T_{CEP} = 89$ MeV and $\mu_B^{CEP} = 724$ MeV

Initial thin black ring:

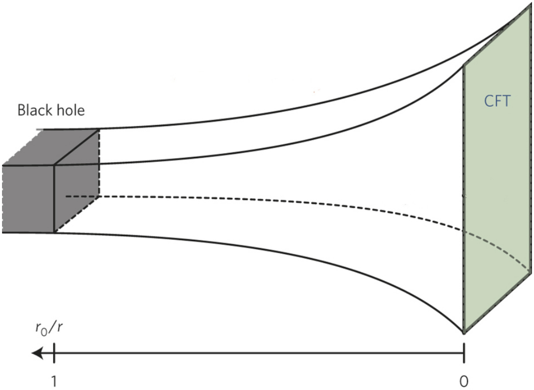
Evolved series of blackholes:



Classical instability affecting black holes in higher dimensions gives rise to a series of bulges connected by strings that become thinner over time. [Gregory, Laflamme 1993; Emparan, Reall 2002; Figueras, Kunesch, Tunyasuvunakool 2015]

Singularities form without being hidden behind a black hole horizon. Numerical general relativity simulation thanks to advanced parallelized mesh confined code GRChombo.

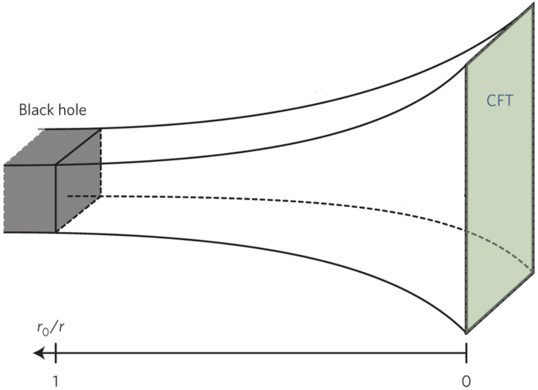
Quantum gravity in $d+1$ dimension AdS $\leftrightarrow$ QFT in d dimension



IIB string theory on $\mathrm{AdS}_5 \times \mathrm{S}_5 \leftrightarrow \mathcal{N} = 4$ Super-Yang-Mills
[Maldacena 1998, Witten 1998]

shear viscosity over entropy density ratio $\frac{\eta}{s} = \frac{1}{4\pi} \approx 0.08$
[Policastro, Son, Starinets 2001]

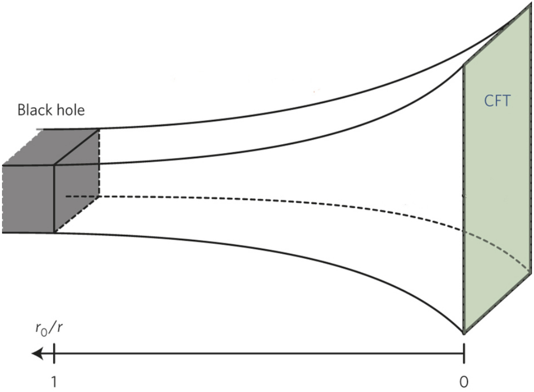
Quantum gravity in $d+1$ dimension AdS $\leftrightarrow$ QFT in d dimension

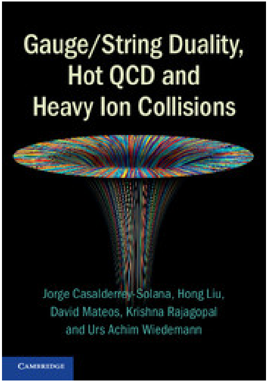


Holographic dictionary relates:

Black hole	$\Longleftrightarrow$	Equilibrium state with temperature
$g_{\mu\nu}$		$T_{\mu\nu}$

Quantum gravity in $d+1$ dimension AdS $\leftrightarrow$ QFT in d dimension





Use of the duality:

To solve complicated dynamical problems in non-abelian theories.

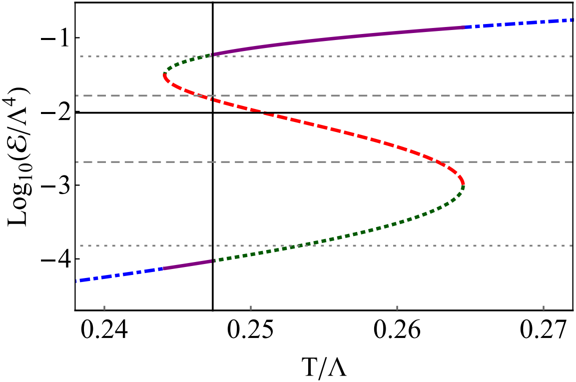
As a source of new modeling ideas for strongly coupled QGP.

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

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

Small IR modification of the model leads to rich phase structure

First order phase transition



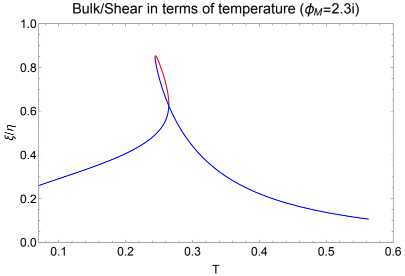
Non-conformal thermodynamics

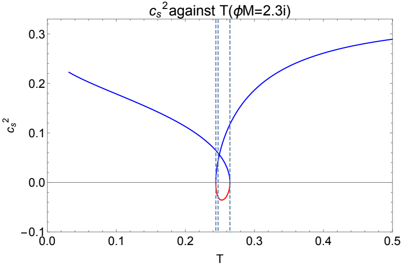
Einstein-Hilbert action coupled to a scalar with non-trivial potential (single parameter ϕ_M) in five-dimensional bottom-up model:

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

Holographic renormalization [Bianchi, Freedman, Skenderis 2002]

$$V(\phi) = -\frac{1}{12\phi_M^4}\phi^8 + \left(\frac{1}{2\phi_M^4} \mp \frac{1}{3\phi_M^2} \right) \phi^6 - \frac{1}{3}\phi^4 - \frac{3}{2}\phi^2 - 3$$

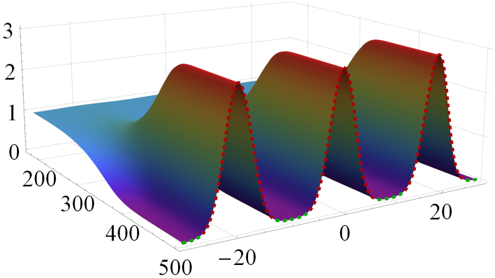




Deconfined strong non-conformality with 1st order phase transition

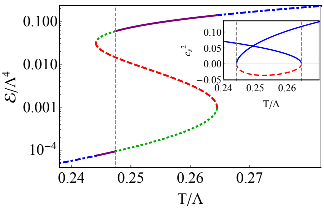
Spinodal instability

Quasi-adiabatic energy density evolution of black branes afflicted by the Gregory-Laflamme instability:



The excited unstable mode grow until non-linear saturation.

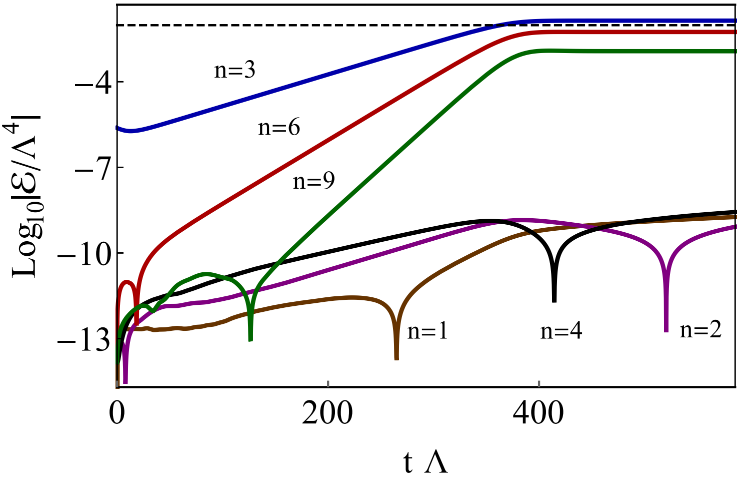
Energy density versus temperature for the gauge theory:



The dashed red curve is locally unstable, the dotted green curve metastable.

Unstable modes

Fourier modes of the local energy density $\mathcal{E}$:



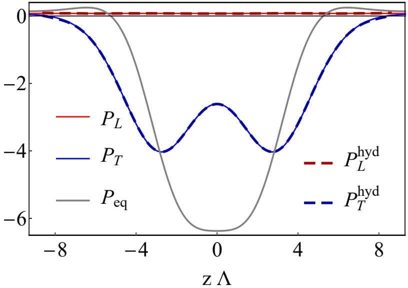
momentum dependent growth rate dictated by the sound dispersion relation $\Gamma(k) \simeq |c_s|\, k - \frac{1}{2T}\left(\frac{4}{3}\frac{\eta}{s} + \frac{\zeta}{s}\right) k^2$

Inhomogeneous horizon

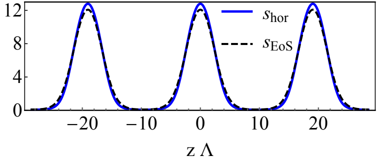
Hydrodynamics description with transport coefficients c_L, f_T:

$$P_{L/T}^{\mathrm{hyd}} = P_{\mathrm{eq}}(\mathcal{E}) + c_{\mathrm{L/T}}(\mathcal{E})(\partial_z\mathcal{E})^2 + f_{\mathrm{L/T}}(\mathcal{E})(\partial_z^2\mathcal{E})$$

Pressure evolution:



Pressures agree with hydrodynamic prediction for a different state

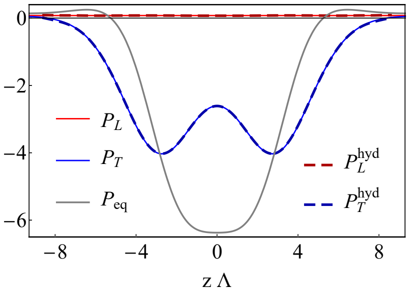


Final entropy density extracted from the area of the horizon and estimated from the equation of state

Hydrostatic + Hydrodynamic evolution

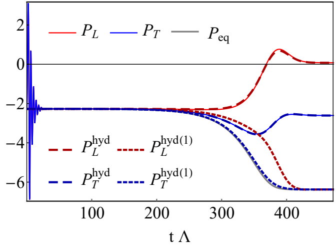
Hydro description $P^{\mathrm{hyd}}_{L/T} = P_{\mathrm{eq}}(\mathcal{E}) + c_{\mathrm{L/T}}(\mathcal{E})(\partial_z\mathcal{E})^2 + f_{\mathrm{L/T}}(\mathcal{E})(\partial_z^2\mathcal{E})$

Pressure evolution:



Pressures agree with hydrodynamic prediction for a different state

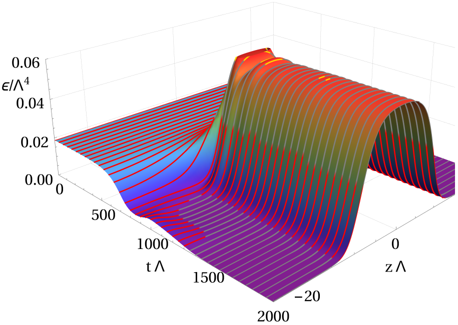
Pressures predicted by hydro match:



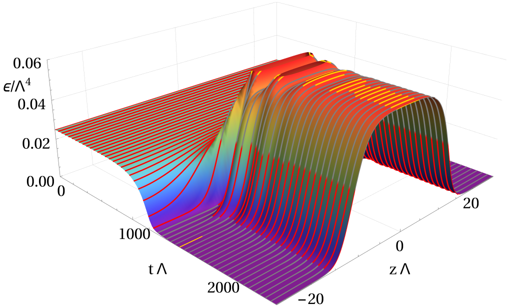
Early time behaviour with exponential decay of quasi-normal modes

Phase separation I

Universal shape of the phase transition across different setups

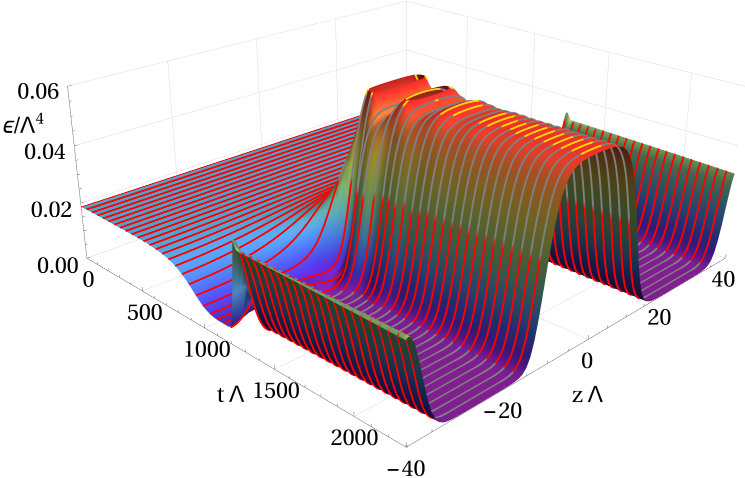


Different quasi-normal mode relaxation in different phases



Plateaus touching both stable phases [Janik, Jankowski, Soltanpanahi 2017]

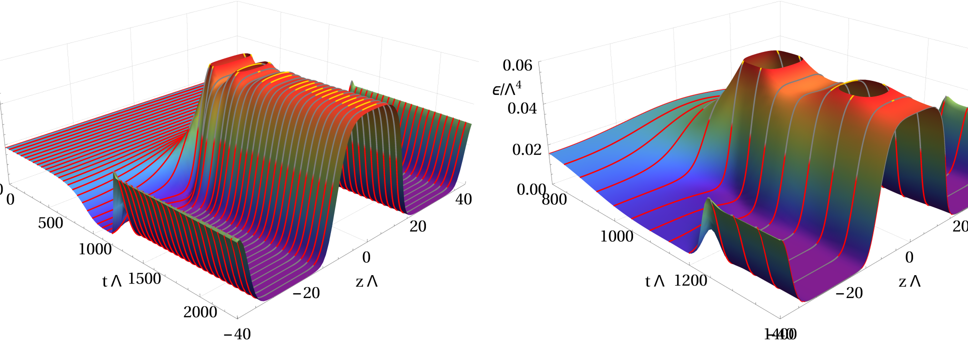
Inhomogeneous double peak (bigger box):



Stable middle peak, 2nd side peak in metastable phase growing out of unstable flat side region.

Phase separation II

Inhomogeneous double peak (bigger box):



Stable middle peak, 2nd side peak in metastable phase growing out of unstable flat side region.

Conclusions

- First simulation of a holographic spinodal instability, now also reaching phase separation
- Excitation of the Gregory-Laflamme instability
- New example of the applicability of hydrodynamics to systems with large gradients in energy densities - even in non-trivial phase structure - both for the time evolution of the spinodal instability and the static final states
- Final set of static inhomogeneous black branes
- Holographic non-conformal shockwaves see talk next session
- More studies are on the way