Gravitational shockwave collisions in Anti-de Sitter spaces

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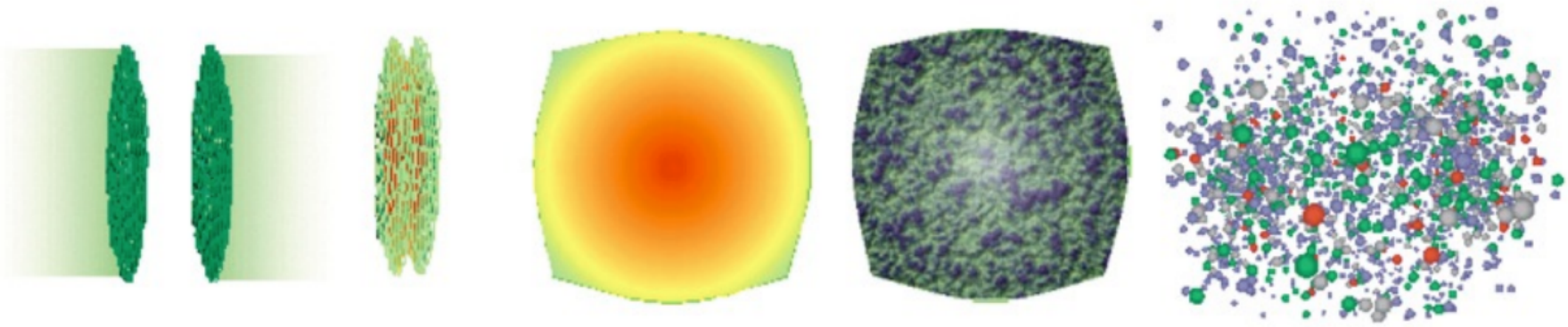
Contents

Outline

Ultra-relativistic heavy-ion collisions

two nuclei approach, collide, form a QGP, the QGP expands and hadronizes, finally hadrons rescatter and freeze out



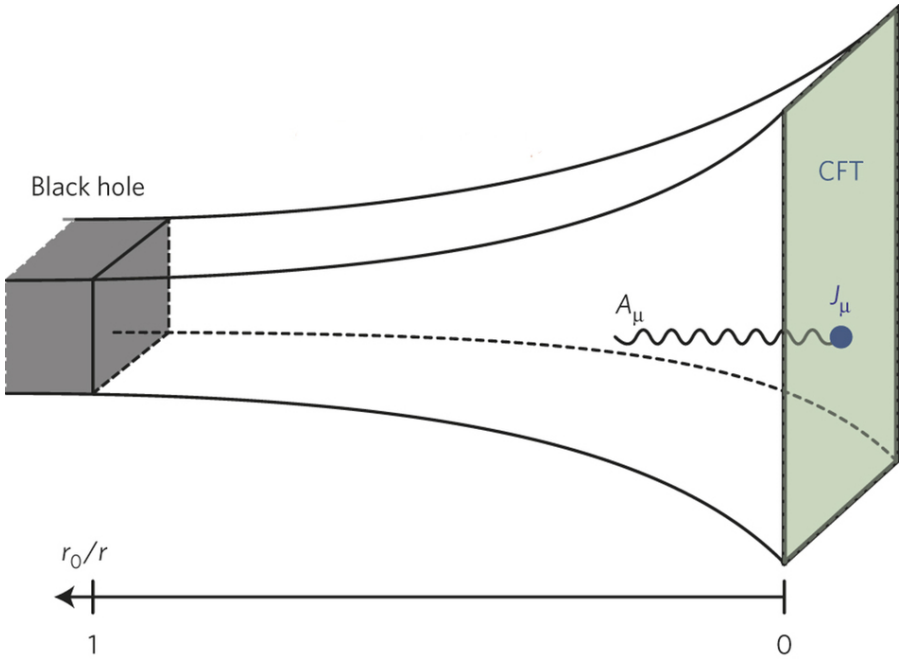
Can we describe all stages in a single framework?

- Holography says: Yes! (up to last one)

AdS/CFT

$\mathcal{N} = 4$ super-Yang-Mills is dual to IIB string theory on $AdS_5 \times S_5$

[Maldacena, Witten '98]



- We can learn about strongly coupled phenomena through gravity computations

AdS/CFT

$\mathcal{N} = 4$ SYM

- conformally invariant
- no confinement
- supersymmetric

QCD

- non-conformal
- confinement
- not supersymmetric

Outline

Einstein-Scalar

$$R_{\mu\nu} - \frac{R}{2} g_{\mu\nu} = 8\pi T_{\mu\nu} \,,$$
$$\Box\phi = \frac{\partial V}{\partial \phi} \,,$$

where

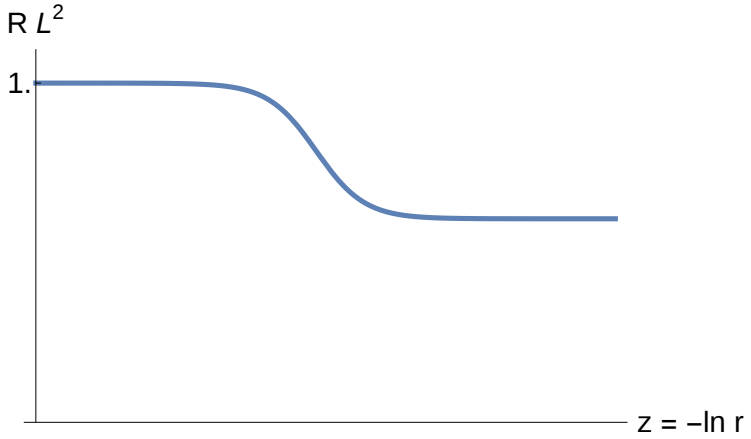
$$8\pi T_{\mu\nu} = 2\partial_\mu\phi\partial_\nu\phi - g_{\mu\nu}\left(g^{\alpha\beta}\partial_\alpha\phi\partial_\beta\phi + 2V(\phi)\right) \,,$$
$$V(\phi) = -3 - \frac{3}{2}\phi^2 - \frac{1}{3}\phi^4 + \left(\frac{1}{2\phi_{\rm M}^4} + \frac{1}{3\phi_{\rm M}^2}\right)\phi^6 - \frac{1}{12\phi_{\rm M}^4}\phi^8 \,,$$

$\phi_{\rm M}$ is a free parameter

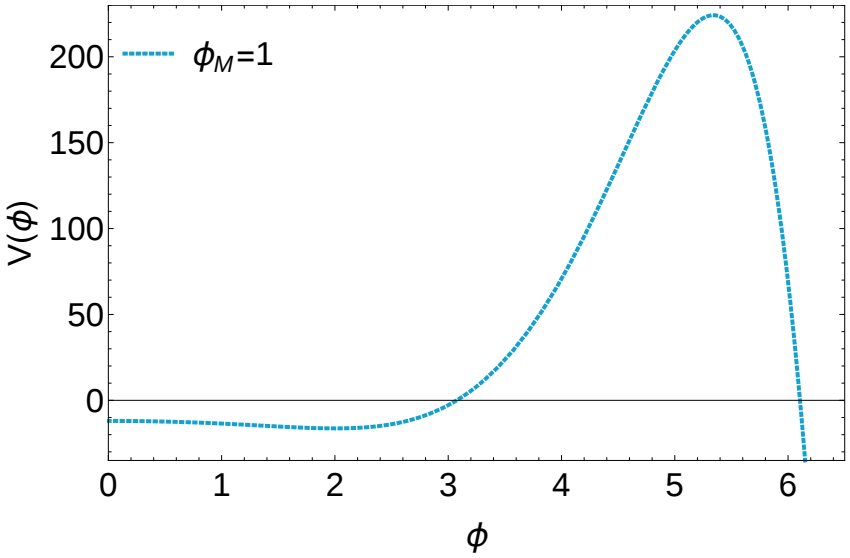
Scalar field

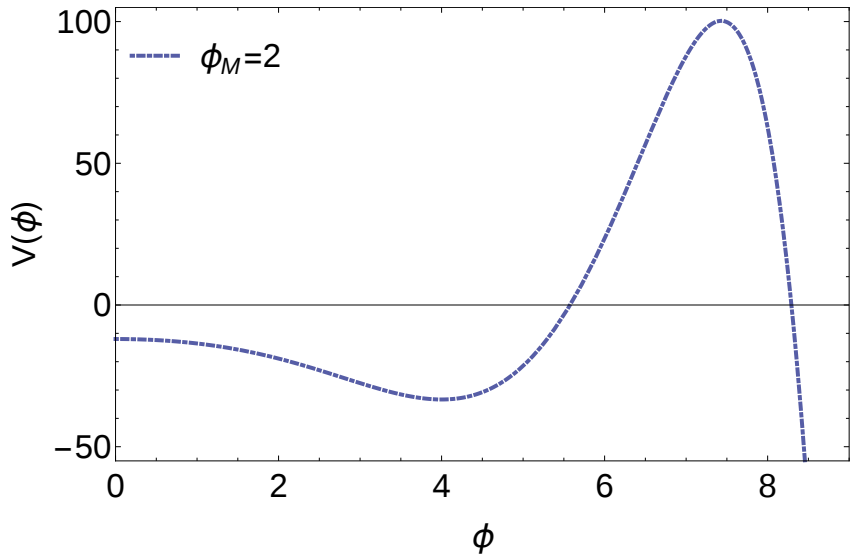
Deforming $\mathcal{N} = 4$ Super Yang-Mills with a dimension 3 operator $\mathcal{O}$ dual to the scalar field ϕ

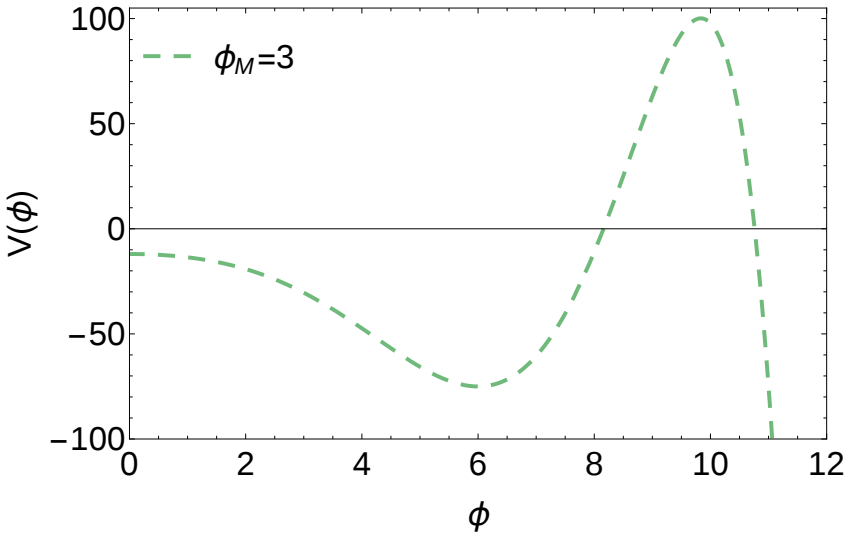
We choose V to interpolate between two AdS spaces:

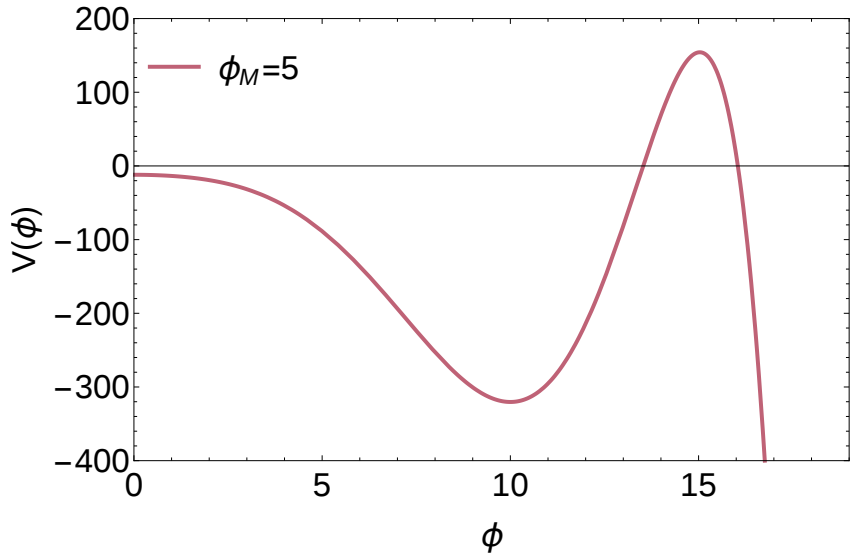


Potential shapes









with varying ϕ_M parameter

Characteristic formulation

$D = 5$ metric in Eddington-Finkelstein coordinates

$$ds^2 = -A dt^2 + \Sigma^2 \left(e^B dx_\perp^2 + e^{-2B} dz^2 \right) + 2dt(dr + F dz) \,,$$

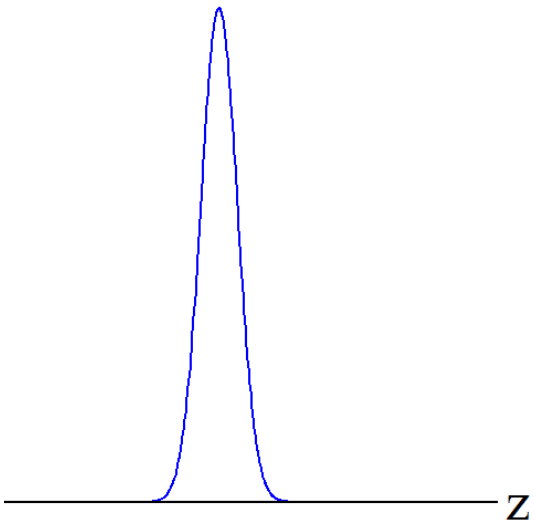
Schematic evolution equations:

$$\partial_r S = H_S(S, B)$$
$$\partial_t \partial_r B = H_B(B, S, \partial_t B)$$

Advantages of characteristic evolution

- Initial data is free (no elliptic constraints on the data);
- No second time derivatives (therefore smaller number of basic variables);
- Equations have convenient hierarchical structure in which variables are integrated in turn in terms of characteristic data from prior members of the hierarchy.

Initial data



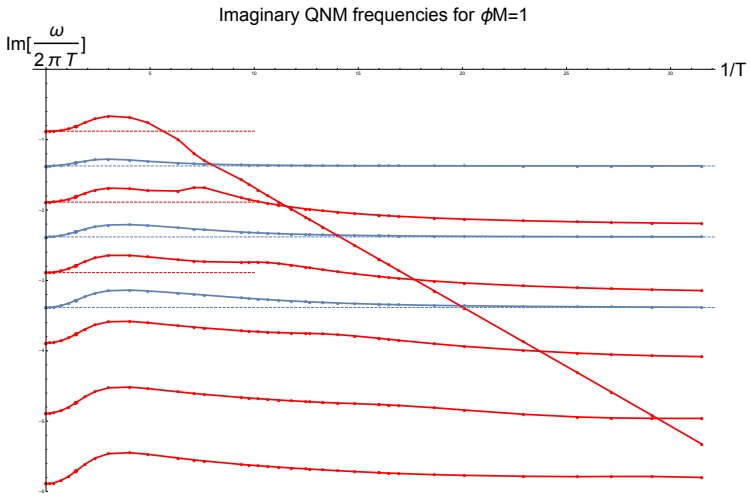
$$ds^2 = dr^2 + f(r)h(x_\perp)dx_+^2 - e^{2A(r)}dx_+dx_- + e^{2A(r)}dx_\perp^2$$

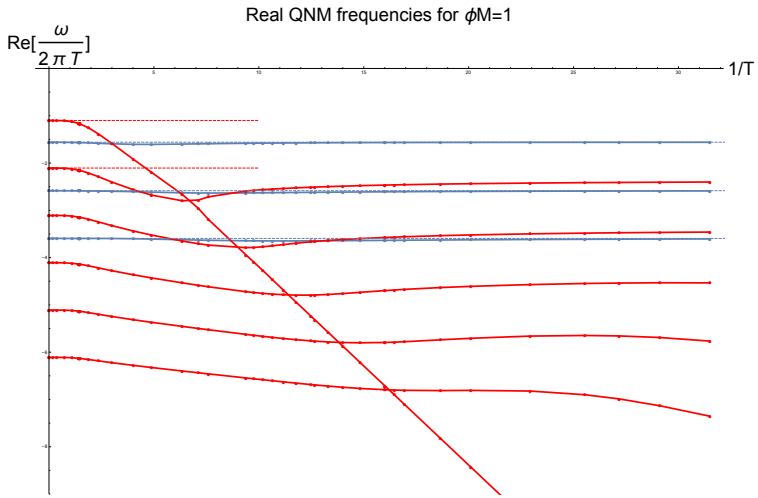
Using the Gaussian profile (h height, ω width):

$$h(x_\perp, z) = he^{-z^2/(2\omega^2)}$$

Outline

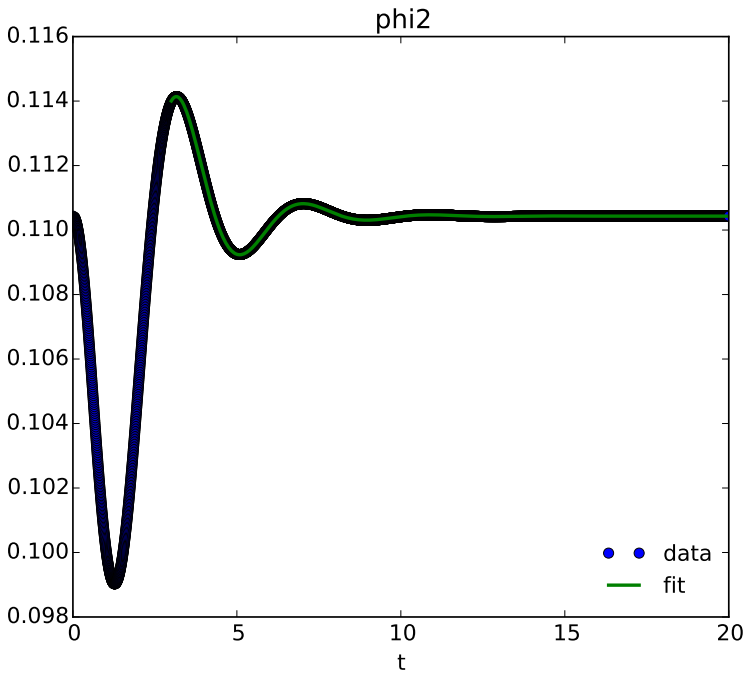
QNMs





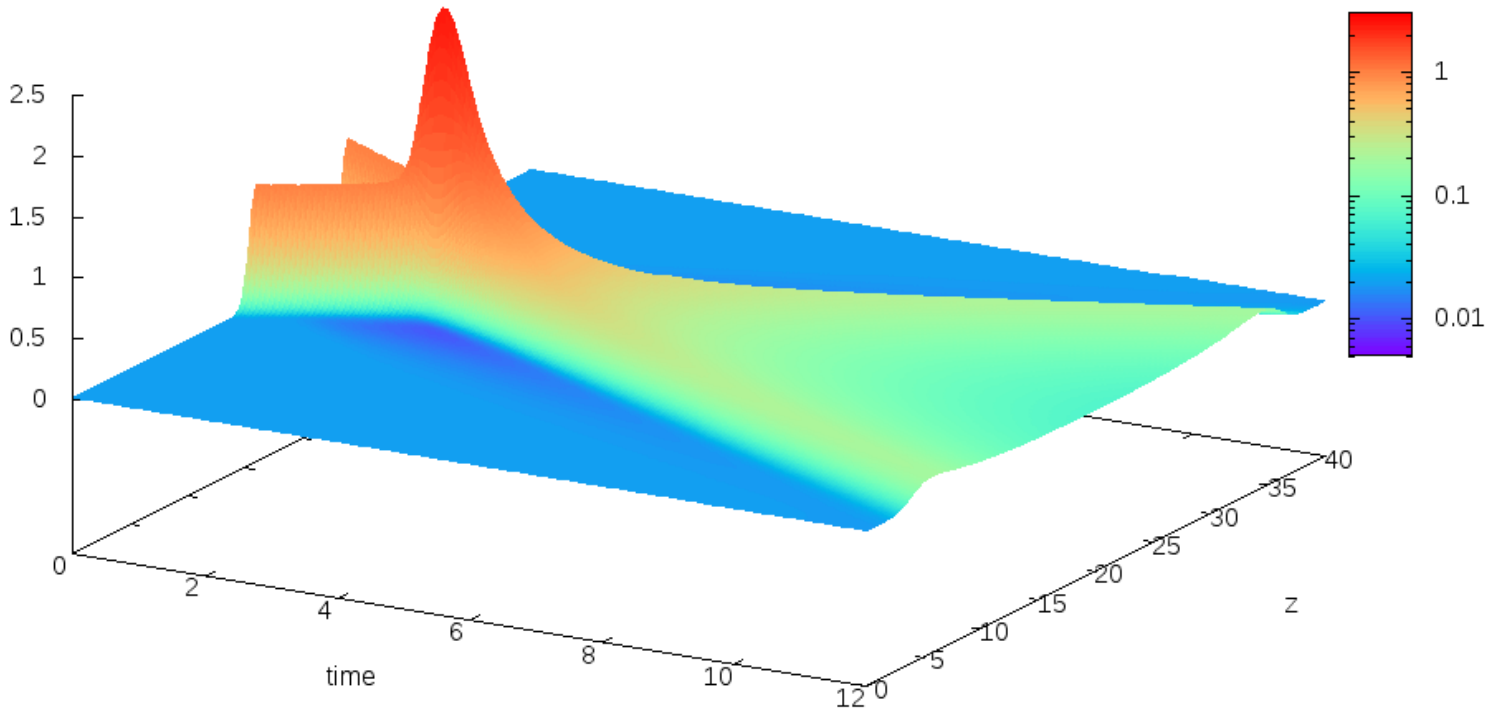
QNM frequencies for $\phi_M = 1$, corresponding to the metric tower and the scalar tower

QNMs



- Results from the code in excellent agreement with perturbative computation

Energy density



Outline

Final Remarks

- Shockwave collisions in AdS spaces provide convenient framework to study heavy-ion collisions
- First simulation of a holographic non-conformal model for heavy ion collisions
- TODO:
  - hydrodynamization time
  - explore parameter space
  - asymmetrical collisions
  - different potentials