TECHNISCHE UNIVERSITÄT WIEN

Towards understanding hybrid strong/weak thermalisation of the QGP

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∫dkΠ Doktoratskolleg Particles and Interactions

INSTITUTE FOR THEORETICAL PHYSICS

Outline

- Motivation
- Semiholography in heavy ion collisions
- Kinetic theory/hydrodynamics
- Some results

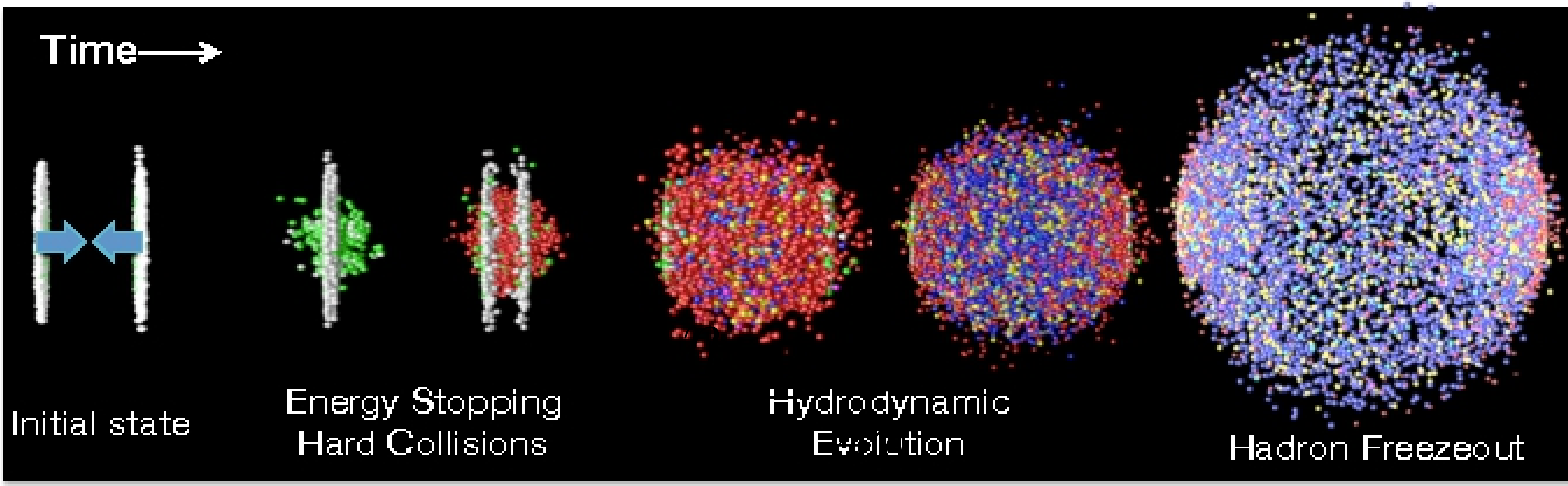
Motivation

Challenge: To develop a consistent framework which combines weak and strong degrees of freedom

To understand the evolution of Quark-Gluon Plasma (QGP), need weak and strong degrees of freedom interacting at various energy scales

How does this interplay affect thermalization?

Heavy Ion Collisions



Competing descriptions:

- pQCD – good for hard momentum scales
- Gauge/gravity duality – good for fluid description

$$\frac{\eta}{s} = \frac{1}{4\pi}$$

Picture from: NAYAK T. Heavy ions: Results from the Large Hadron Collider. Pramana. 2012;79(4):719-735. doi:10.1007/s12043-012-0373-7.

Semiholographic models

Original proposal by Iancu and Mukhopadhyay[1]
Refined by Mukhopadhyay, Rebhan, Preis, Stricker[2]

Dynamical boundary theory coupled to a strongly coupled conformal sector with a gravity dual

UV theory: captured by classical YM theory for overoccupied gluon modes at Q_s

IR theory: described by N=4 Super Yang-Mills theory for effective theory of strongly coupled soft gluon modes

[1]JHEP06(2015)003

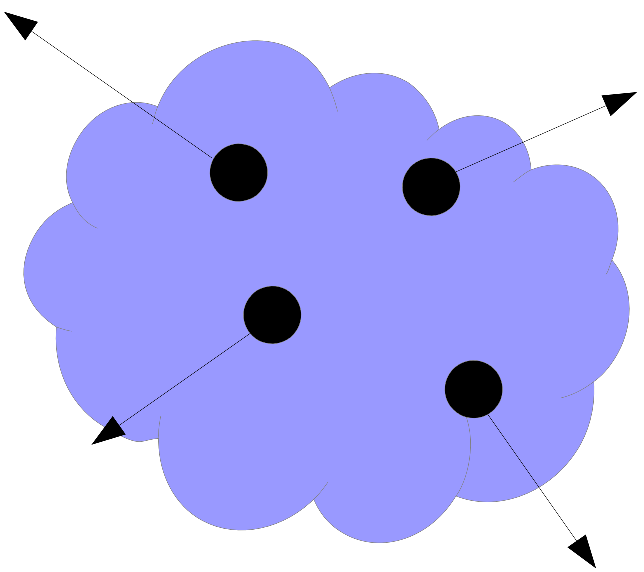
[2]JHEP05(2016)141

Semiholography at late times

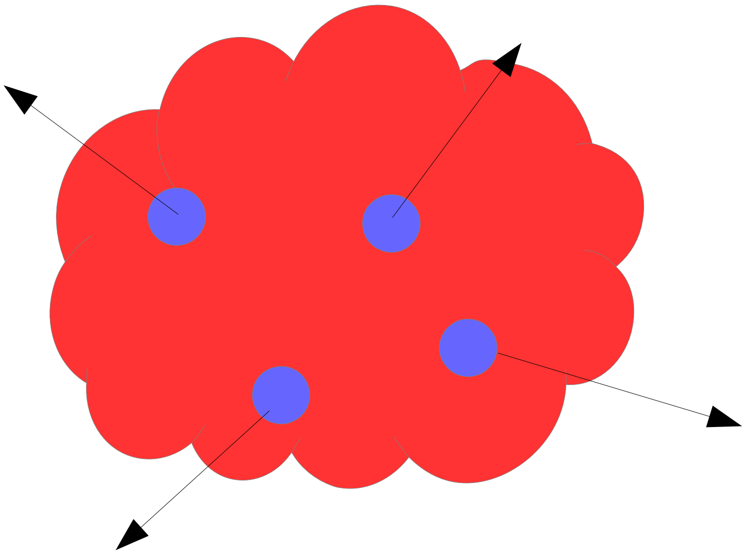
- At late times, gluons are not in an overoccupied state

  → Classical YM description of glasma fails

  → Use kinetic theory instead
- Soft radiation seems to undergo hydrodynamization



The model



Nearly free streaming limit:

- Hard partons (UV) described by kinetic theory
- Soft radiation (IR) described via hydrodynamics (approximation due to fluid/gravity correspondence)

Coupling

The two theories know about each other through the metric deformation

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{\gamma}{Q_s^4} t_{\mu\nu}\sqrt{-g}$$

$$g_{\mu\nu} = \eta_{\mu\nu} + \frac{\gamma}{Q_s^4} \mathfrak{t}_{\mu\nu}\sqrt{-g}$$

Both sectors have a respective conservation law

$$\nabla_\mu \mathfrak{t}^\mu{}_\nu = 0 \qquad \nabla_\mu t^\mu{}_\nu = 0$$

Equations

Kinetic sector (UV)

$$t^{\mu}{}_{\nu} = \int \frac{\mathrm{d}^3 p}{\sqrt{-g} p^0} p^{\mu} p_{\nu} f(x^{\mu}, p_j)$$

$$\left[p^{\mu}\partial_{\mu} + \Gamma^{\mu}{}_{\nu\rho} p^{\nu} p_{\mu}\right] f(x^{\mu}, p_j) = C(f, f)$$

Hydrodynamic sector (IR)

$$\mathfrak{t}^{\mu}{}_{\nu} = (\epsilon + \mathfrak{P})\mathfrak{u}^{\mu}\mathfrak{u}_{\nu} + \mathfrak{P}\delta^{\mu}_{\nu} - \eta\sigma^{\mu}{}_{\nu}$$

$$\nabla_{\mu}\mathfrak{t}^{\mu}{}_{\nu} = 0$$

Total energy-momentum tensor

Can construct a stress tensor of full system:

$$T^{\mu}{}_{\nu} = t^{\mu}{}_{\nu}\sqrt{-g} + t^{\mu}{}_{\nu}\sqrt{-g} - \frac{\gamma}{Q_s^4} t^{\alpha}{}_{\beta}\sqrt{-g}\, t^{\beta}{}_{\alpha}\sqrt{-g}\,\delta^{\mu}_{\nu}$$

This is conserved in the flat background!

$$\partial_{\mu} T^{\mu}{}_{\nu} = 0$$

Linear response

The linear response of both the UV and IR theories is known.

Linear response for the complete theory?

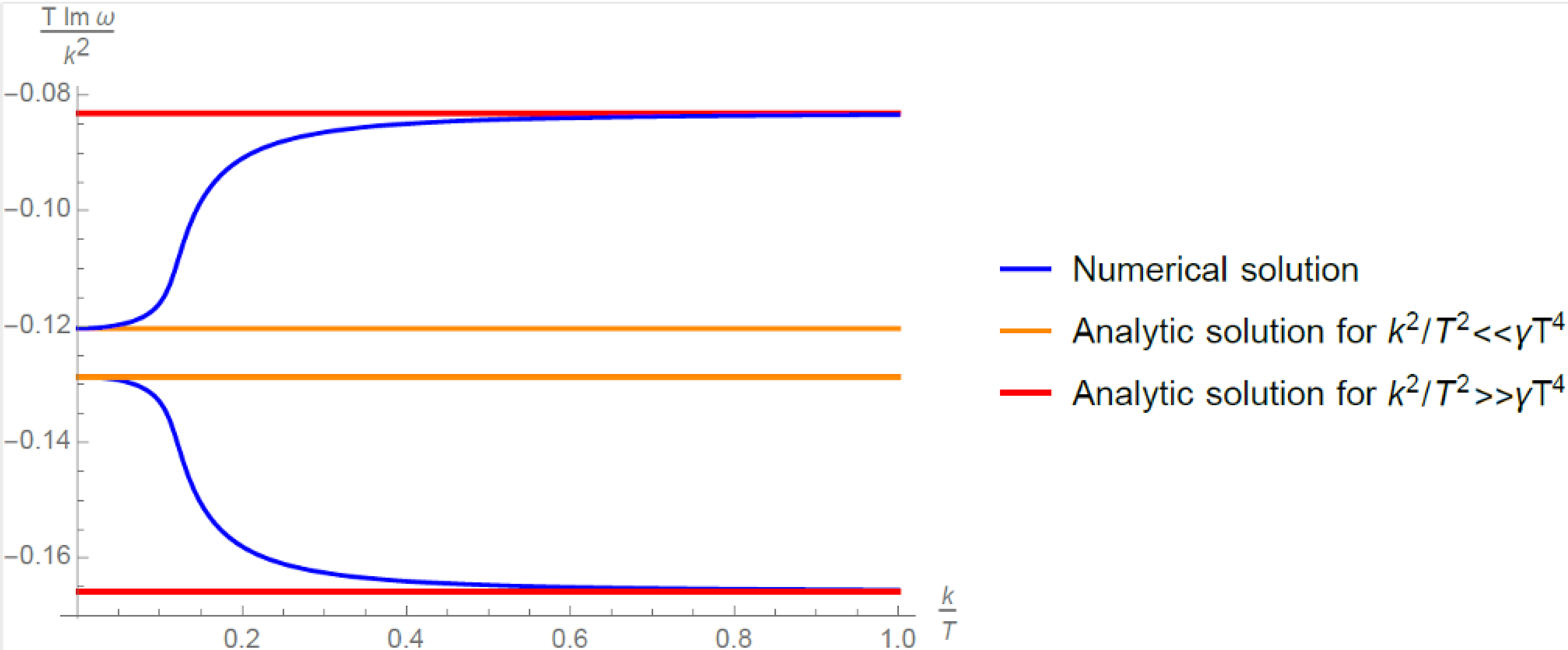
We find that the shear viscosity is additive

$$\eta = \eta(1 + \gamma \frac{\varepsilon}{2}) + \eta(1 + \gamma \frac{\varepsilon}{2})$$

Bi-hydro

- Look at the effective change of the hydrodynamic degrees of freedom in both sectors
- Study eigenmodes of the complete system
- Find the total system has a hydro mode, which is just the sum of the eigenmodes of the two sectors

Shear viscosity



Outlook

- Understanding the thermodynamics of the complete system
- Moving away from conformal limit (e.g. adding bulk viscosity)
- Moving from linearization to numerics
- Dependence on initial conditions?