Probing QGP at "mesoscopic scale" through jet-medium interaction

Abstract: we construct a novel model, the extended Israel-Stewart model, IS*, to describe hydro. and non-hydro. response of an expanding QGP to a moving energetic parton in one and the same work. Our model can be employed to explore the properties of QGP at "mesoscopic scale" through jet-medium interaction.

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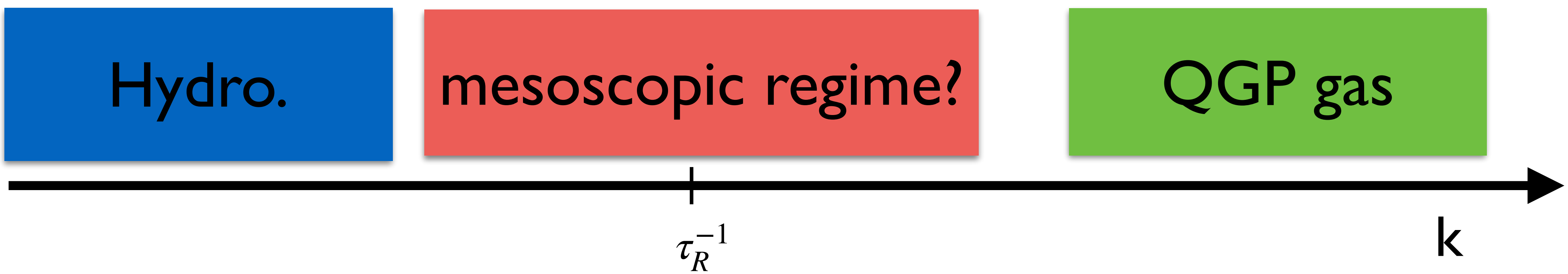
The properties of QGP at mesoscopic scale



Big Question: the "evolution" of QGP as a function of increasing length scale, from an asymptotic free quark-gluon gas to a near-perfect liquid.

Unexplored regime: the properties of QGP at the "mesoscopic scale", where the characteristic length might be too short for a hydrodynamic description, but too long for the applicability of perturbative QCD.

By studying jet-medium interaction, can we explore the properties of QGP at "mescoscopic" scale?

An energetic parton excites density fluctuations at both long and short wavelengths and spends a finite duration in the medium.

How to describe non-hydro. response efficiently?

Jet-medium interaction

This work: studying the stress energy response function for a Bjorken-expanding QGP to the energy/momentum disturbance induced by a moving energetic parton.

$$\delta\epsilon(\tau, x) = \int_{\tau_I}^{\tau} d\tau' \int_{x'} G_{\epsilon\epsilon}(\tau, \tau'; x - x') S_{\epsilon}(\tau', x') + \ldots$$

properties of the medium

Sourced by an moving hard probe

Method: consider a boost-invariant and transversely homogeneous expanding QGP. Then, adding in-homogeneous disturbance. Next, solving linearized kinetic equation under relaxation time approximation to determine Green functions.

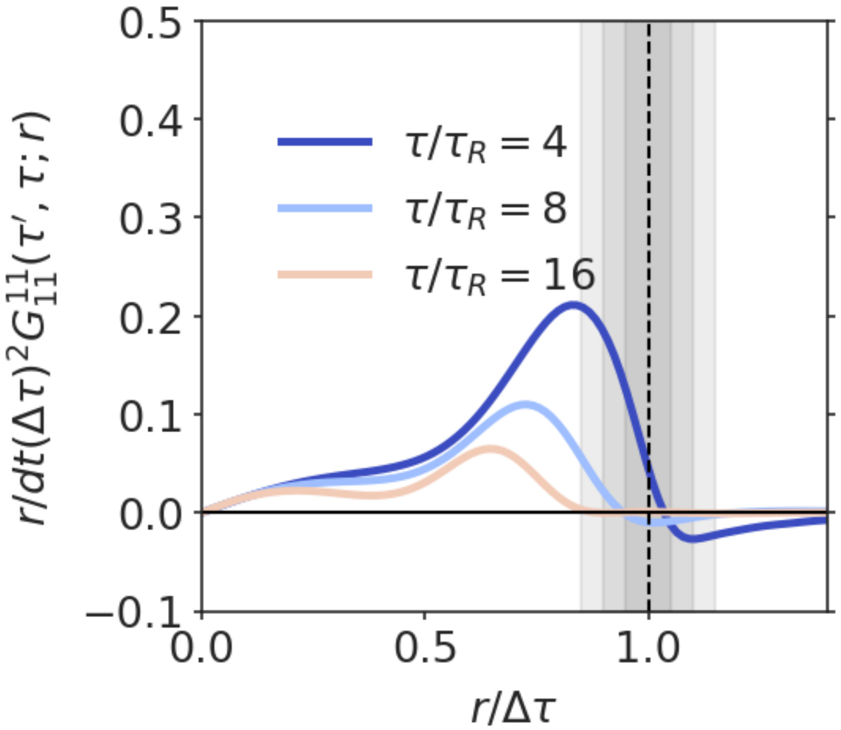
$$\partial_\tau \delta f + i\hat{p}_\perp \vec{k}_\perp \delta f + \frac{p_z}{\tau}\partial_{p_z}\delta f = -\frac{\delta f - \delta f_{\rm eq}}{\tau_R}$$

for static QGP: see Hong-Teaney; Hong-Teaney-Chesler 2011; Romatschke 2016.

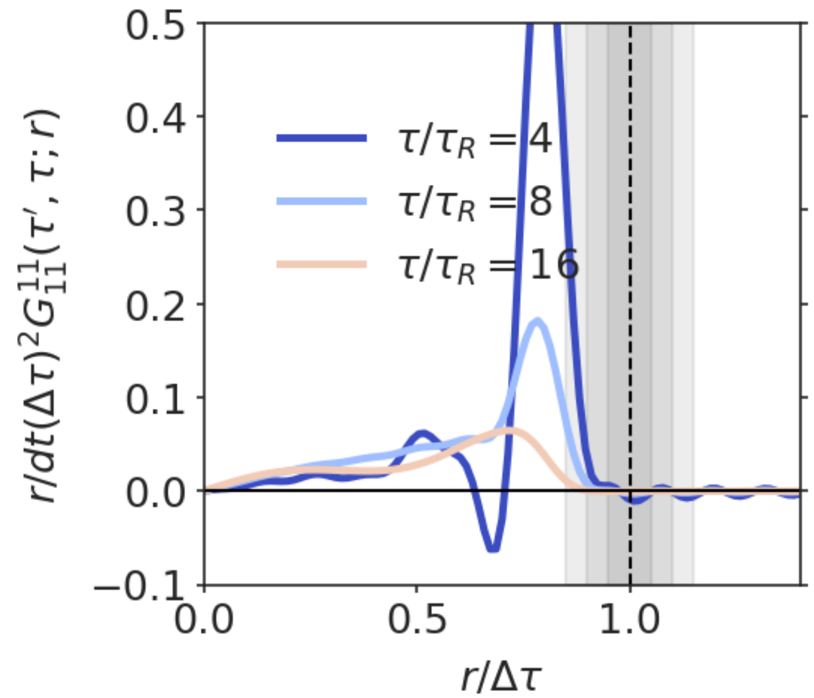
Let us first compare kinetic response functions with hydro. (and/or Isareal-Stewart theory) response functions.

The result of the comparison: (extrapolated) hydro and IS do not describe non-hydro. response properly.

The response function vs effective group velocity



Kinetic theory



IS theory

We observable sizable non-hydro. responses .

Effective group velocity v_{eff} from kinetic theory transits from speed of light (quasi-particle excitation) to sound velocity from early time to late time. However, the deviation of v_{eff} from c_s^2 is significant even for $\tau = 8\tau_R$.

IS theory introduces spurious wave oscillations.

Describing hydro. and non-hydro. response in one and the same framework.

We propose an extended version of IS theory, IS*, to describe non-hydro. response. (inspired by Hydro+). NB: (IS*=IS when $\eta_+ = 0$).

$$T^{\mu\nu} = T^{\mu\nu}_{\text{ideal}} + \tilde{\pi}^{\mu\nu} + \eta_+ \partial^{<\mu} u^{\nu>} \qquad \eta = \Delta\eta + \eta_+$$

$$u^\mu \partial_\mu \tilde{\pi}^{\mu\nu} = -\tau_\pi^{-1} \left(\tilde{\pi}^{\mu\nu} - \Delta\eta\, \partial^{<\mu} u^{\nu>} \right)$$

In hydro. limit $k \ll \tau_R^{-1} \sim \tau_\pi^{-1}$, IS* approaches usual viscous hydro.

In non-hydro. regime $k \gg \tau_R^{-1}$, IS* mimics the feature of kinetic response with suitable choice of two addition model parameters η_+ and τ_π

η_+ controls the dissipative rate in non-hydrodynamic regime.

The combination $c_s^2 + \dfrac{4\Delta\eta}{3w\tau_\pi}$ determines effective group velocity.

IS: Describing hydro. and non-hydro. response in one and the same framework.*

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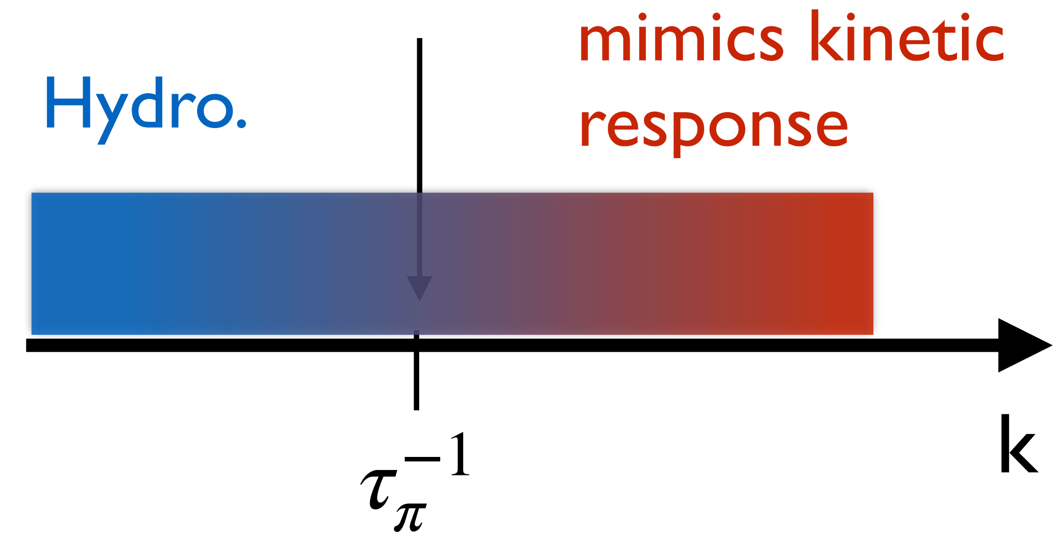

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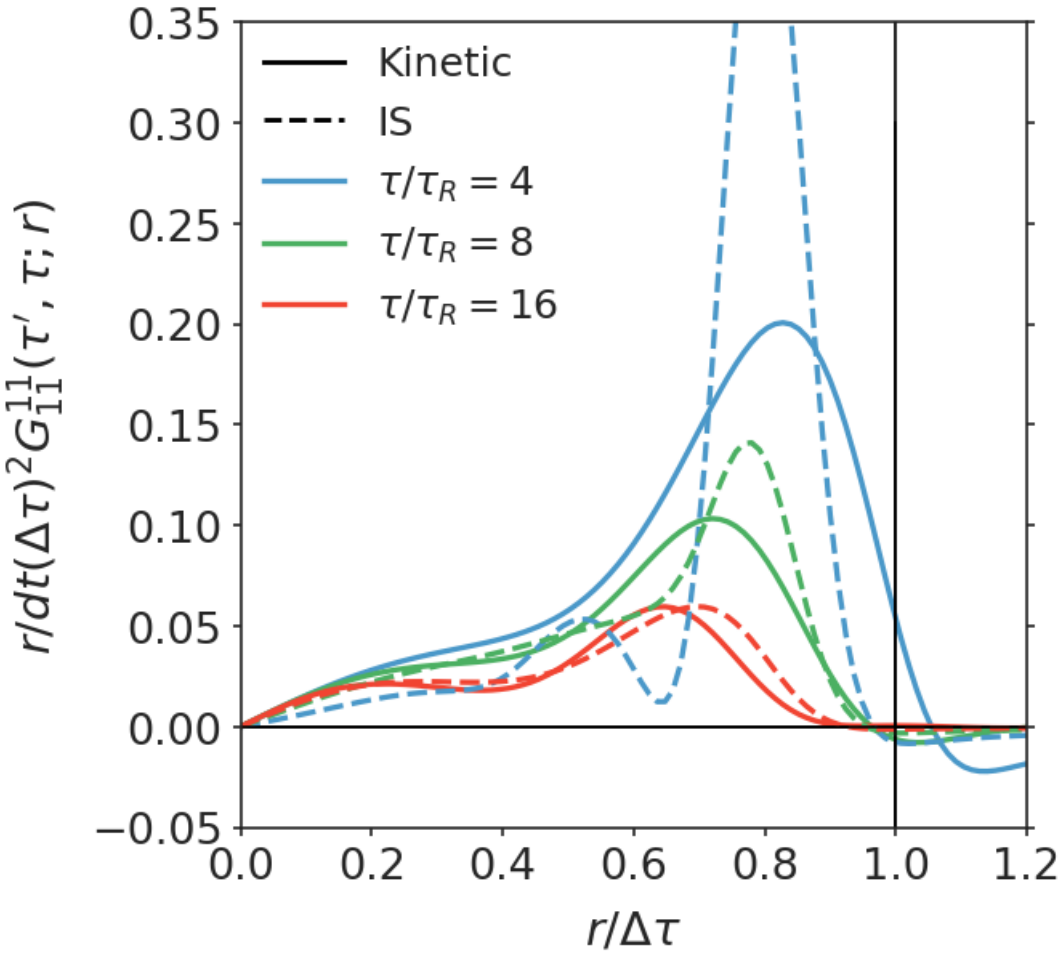
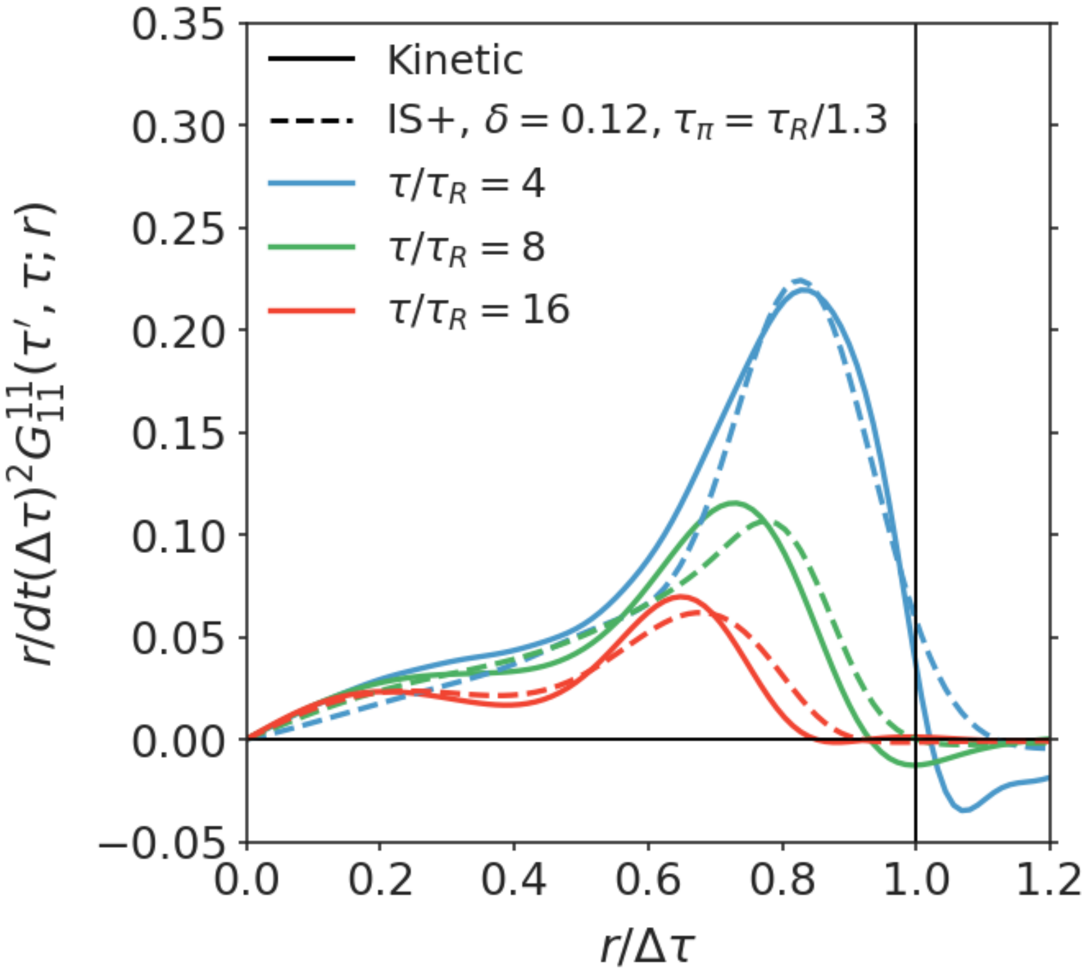
Representative result: momentum-momentum response function

$\delta = \eta_+/\eta$



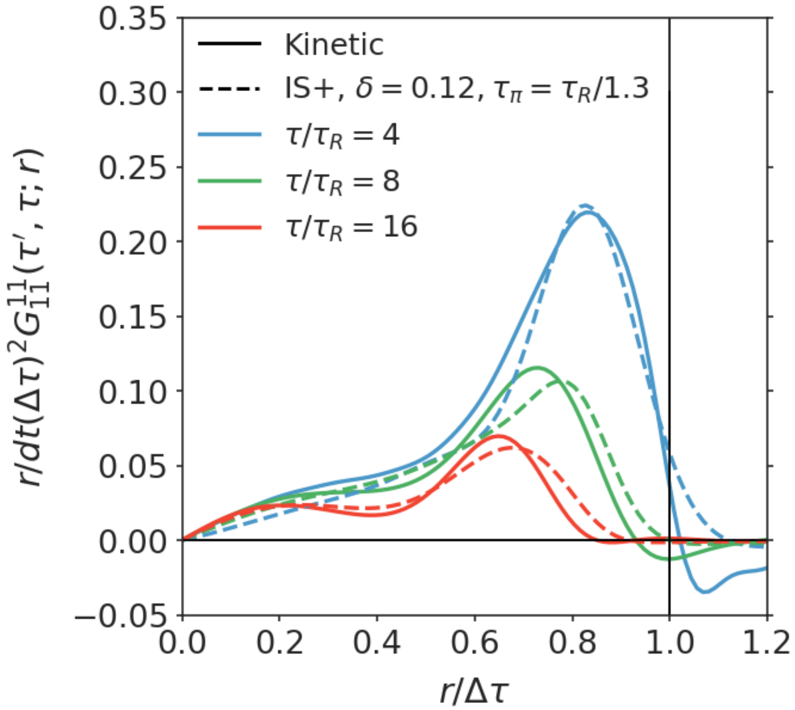
kinetic cf IS

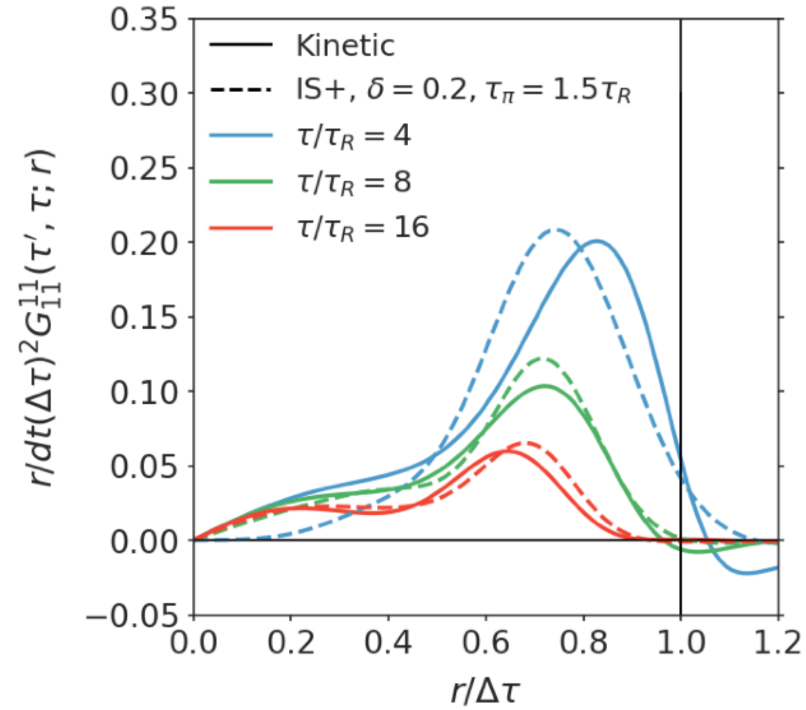


kinetic cf IS*

By tuning two model parameters, IS* can describe the dissipation and propagation in non-hydro. dynamic regimes.

Summary and outlook





We analyze hydro. and non-hydro. response based on RTA kinetic theory.

We construct a novel model, the extended Israel-Stewart theory, IS*, to interpolate hydro. and kinetic response.

⇒ can be implemented in the numerical modeling of jet-medium interaction.

If the results of modeling are sensitive to model parameter, it indicates that non-hydro. regime is probed.

Outlook: towards exploring "mesoscopic regime" of QGP.

Back-up

	Effective group velocity	Effective damping rate
Kinetic theory	<1	grows with k
"extrapolated Hydro"	speed of sound c_s^2	νk^2
Isareal-Stewart	$c_s^2 + \frac{\nu}{\tau_\pi}$	const
IS+	$c_s^2 + \frac{\Delta\nu}{\tau_\pi}$	$\nu_+ k^2$

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"*Extremely small objects and incredibly rapid processes are now being seen in a new light.*"

The announcement of Royal Swedish Academy of Sciences 2018

It would be interesting if the "small objects" and "rapid processes" of QGP being seen.