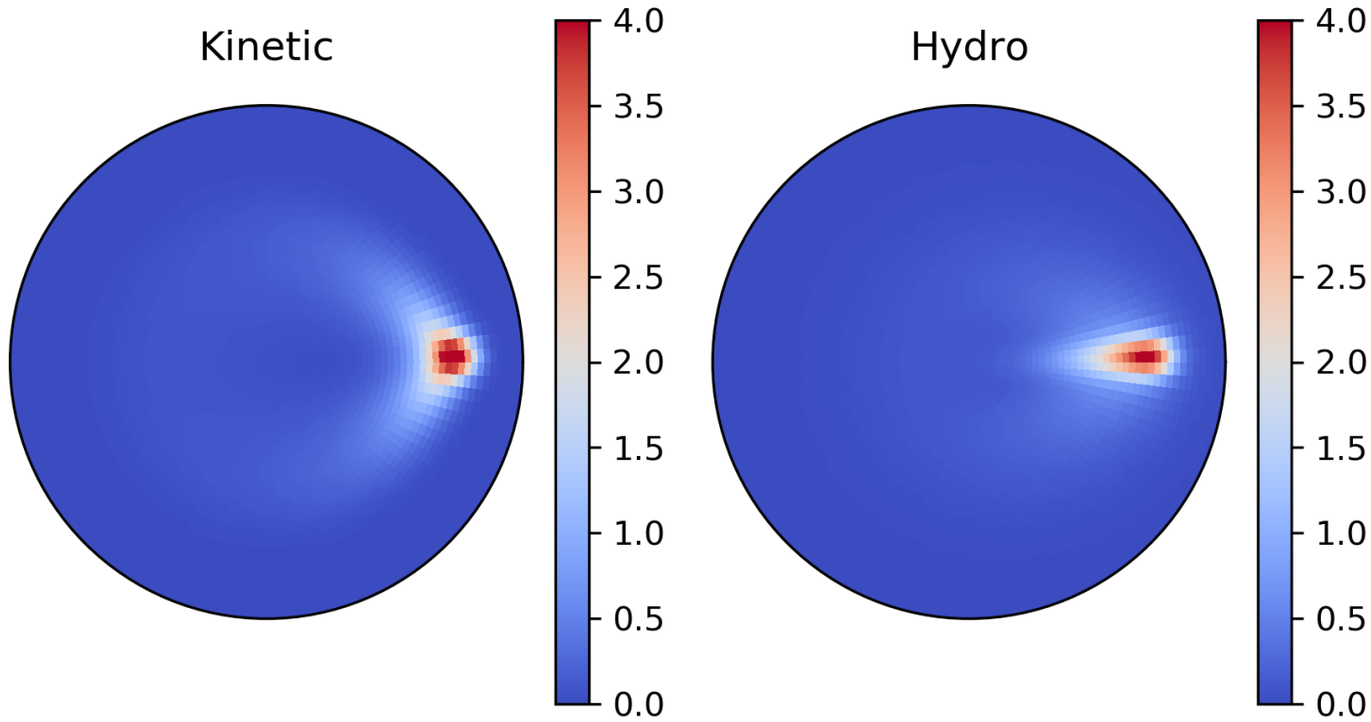
Beyond the wake:

Hydro. and non-hydro. excitations in an expanding QGP

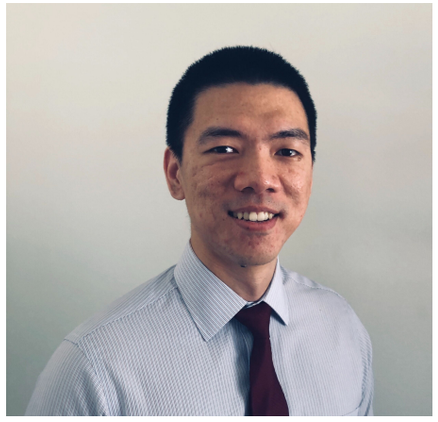


Institute of Modern Physics, Chinese academy of sciences

Yi Yin

Weiyao Ke, YY, in preparation

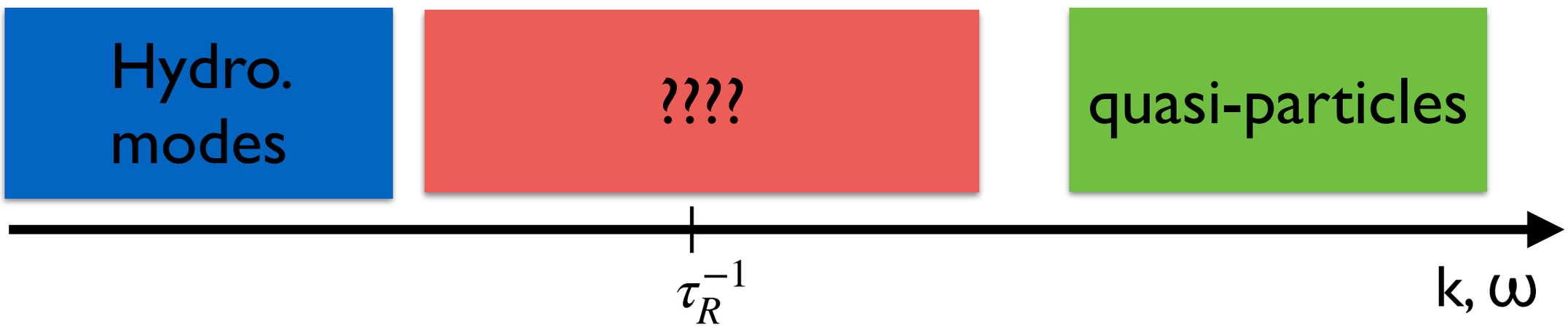
Hard probe, June.4, 2020



Weiyao Ke (@LBNL)

How does the medium excitations of QGP transit from "hydro. modes" to "quasi-particles"?

see also Bin Wu's talk



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

By studying jet-medium interaction, can we explore the excitations of QGP beyond hydro regime?

A first step: drawing qualitative lesson based on a simple model study for an expanding QGP.

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

Green functions and medium excitations

Viewing a moving parton as a source which deposits energy/ momentum.

Propagating the deposited energy/momentum via Green functions (related to the Green functions of $T^{\mu\nu}$):

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

(from energy-momentum Green functions)

properties of the medium

Sourced by an moving hard probe

This talk: computing Green functions and the evolution of the induced energy-momentum density using the kinetic equation for an expanding QGP.

Watching the transitions in the behavior of Green functions with varying distance $\Delta r = |\vec{x} - \vec{x}'|$ and duration $\Delta\tau = \tau - \tau'$.

The model set-up

Bulk background: a boost-invariant and transversely homogeneous expanding QGP.

Then, adding in-homogeneous disturbance.

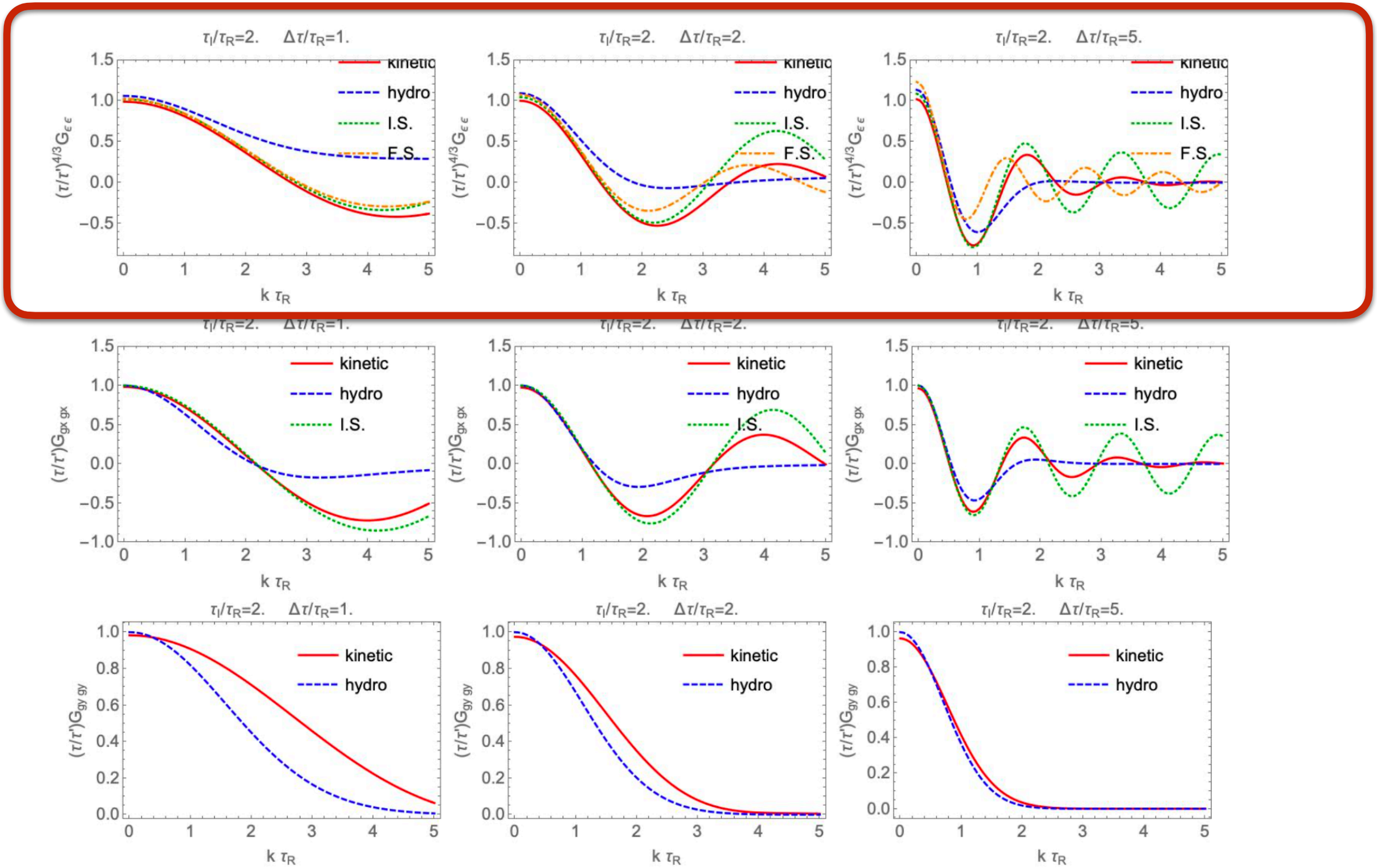
Next, solving linearized kinetic equation under relaxation time approximation to determine Green functions.

$$\partial_\tau \delta f + i\hat{p}_\perp \overrightarrow{k}_\perp \delta f + \frac{p_z}{\tau}\partial_{p_z}\delta f = -\frac{\delta f - \delta f_{\rm eq}}{\tau_R} \Rightarrow \quad G_{\epsilon\epsilon}(\tau, \tau'; k)$$

Assuming disturbance is boost-invariant, Green functions in Fourier space depend on $k \equiv |k_\perp|$, τ' and the duration of the propagation $\Delta\tau = \tau - \tau'$

Focus on the near equilibrium QGP: $\tau'/\tau_R \geq 1$.

For Green functions in thermalization stage, see KOMPOST et al

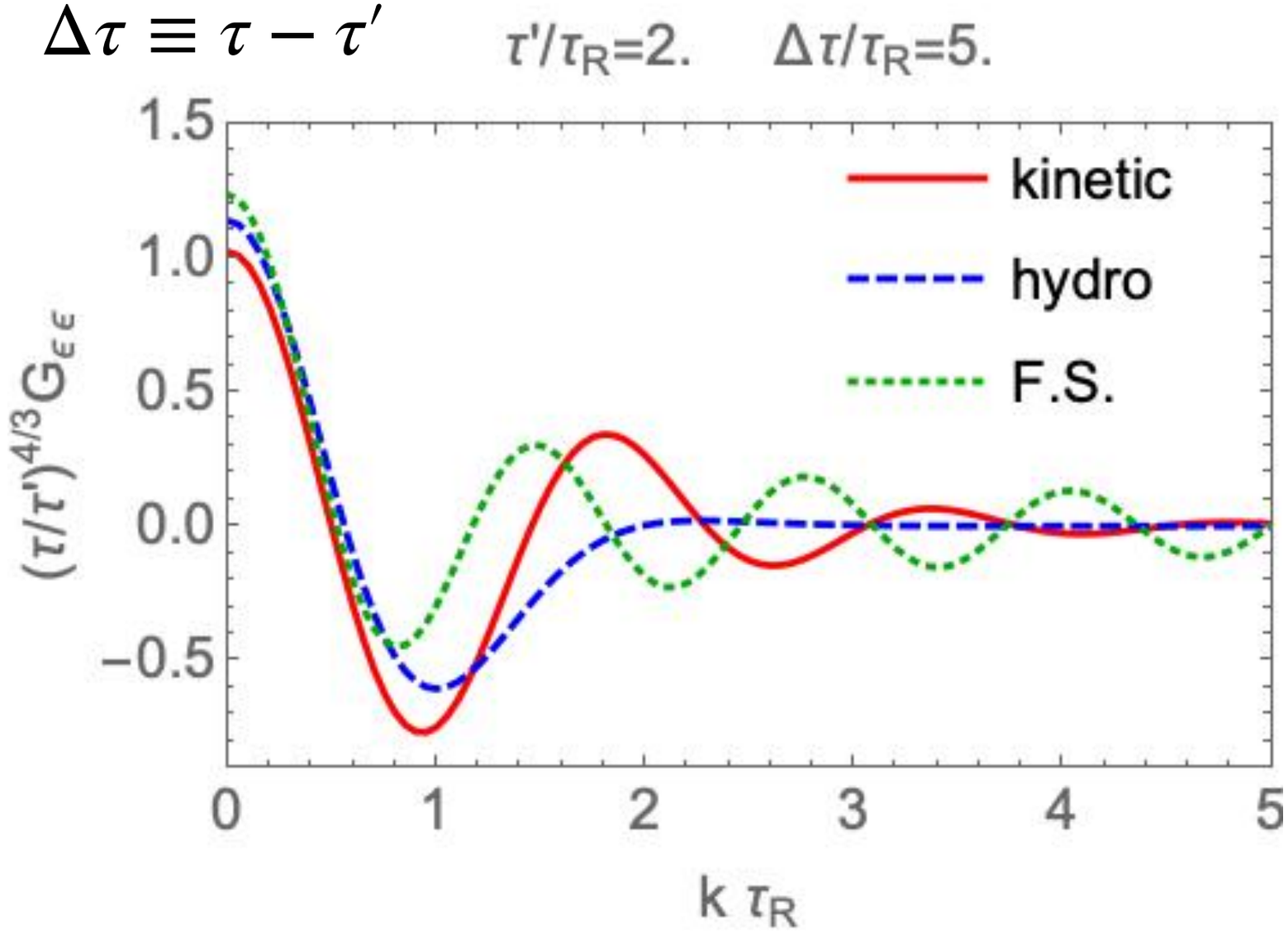


There are several independent Green functions.

Focus on energy-energy Green function from now on.

Transition from hydro to quasi-particle excitations with increasing gradient

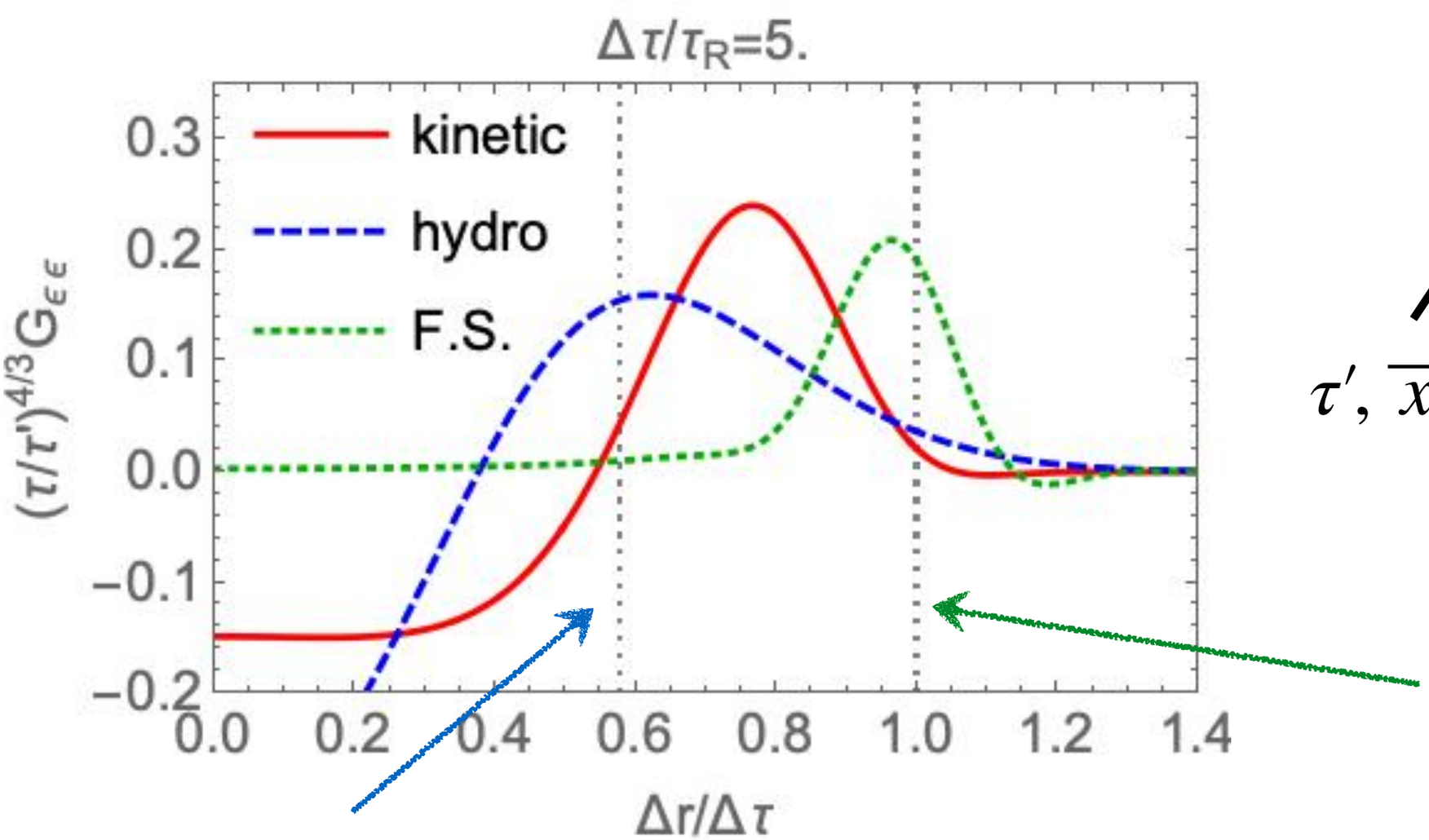
$$\Delta\tau \equiv \tau - \tau'$$



The propagation of hydro. modes which are damped by viscosity.

The dispersal of quasi-particles.

The propagation of hydro. and non-hydro excitations



$\tau, \vec{x}$

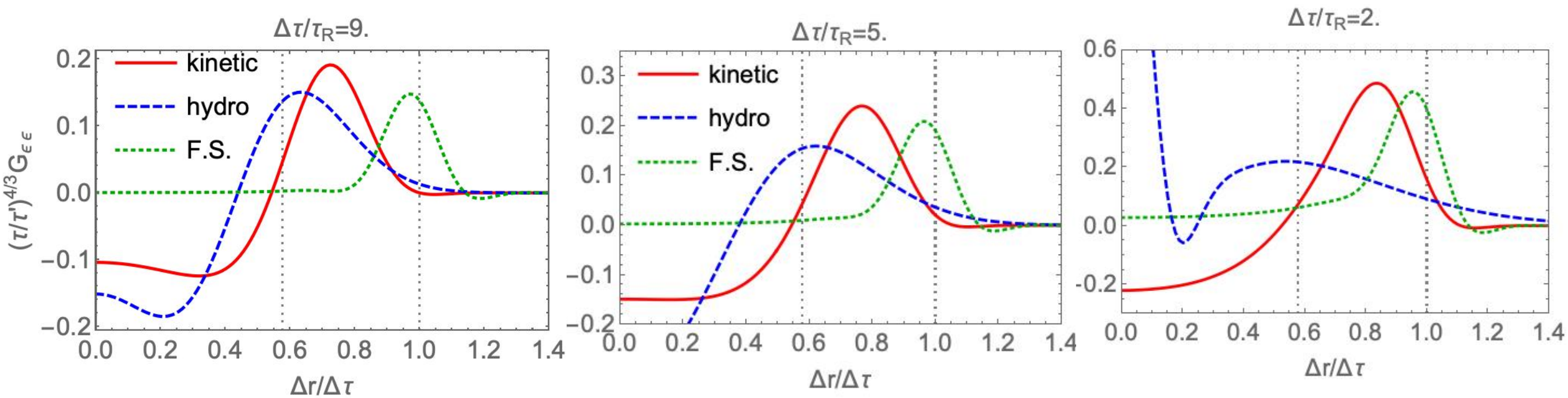
$\tau', \vec{x}'$

$\Delta r = |\vec{x} - \vec{x}'|$

"We see the lightning before we hear the thunder".

Imagine there is an observer in the fireball, will he/she "see" or "hear" the signal sent by a moving hard probe?

shorter duration, more "non-hydro"



shorter duration $\Delta\tau$

Implication: selecting jet events which happen closer to the surface of the fireball to enhance the chance of seeing non-hydro. excitations.

So far, the Green functions

Now, consider an energetic parton born at τ_I=2 τ_R and is moving along x-direction. (assuming energy loss rate $\propto T^2$)

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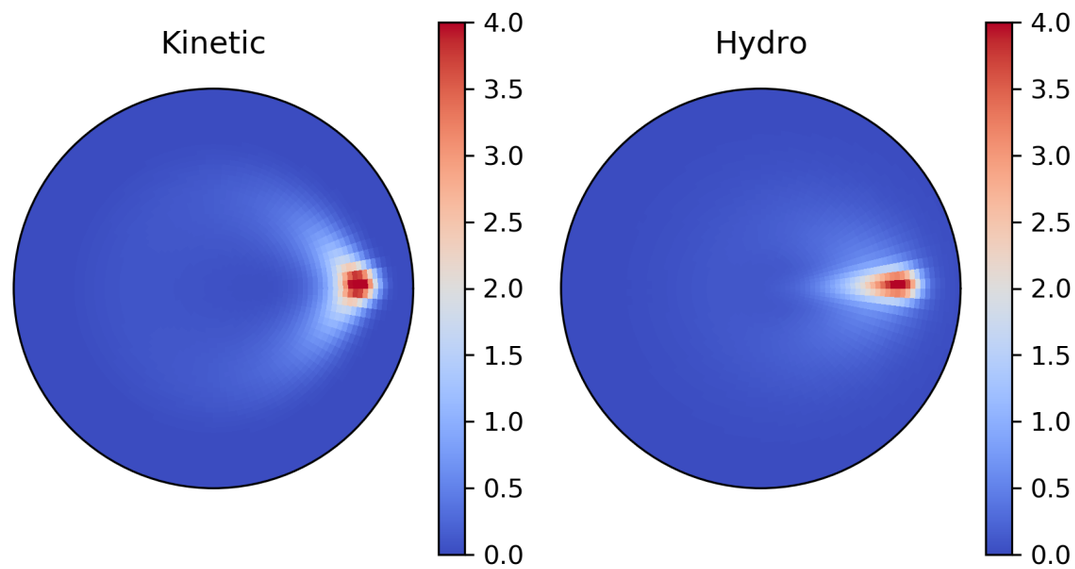
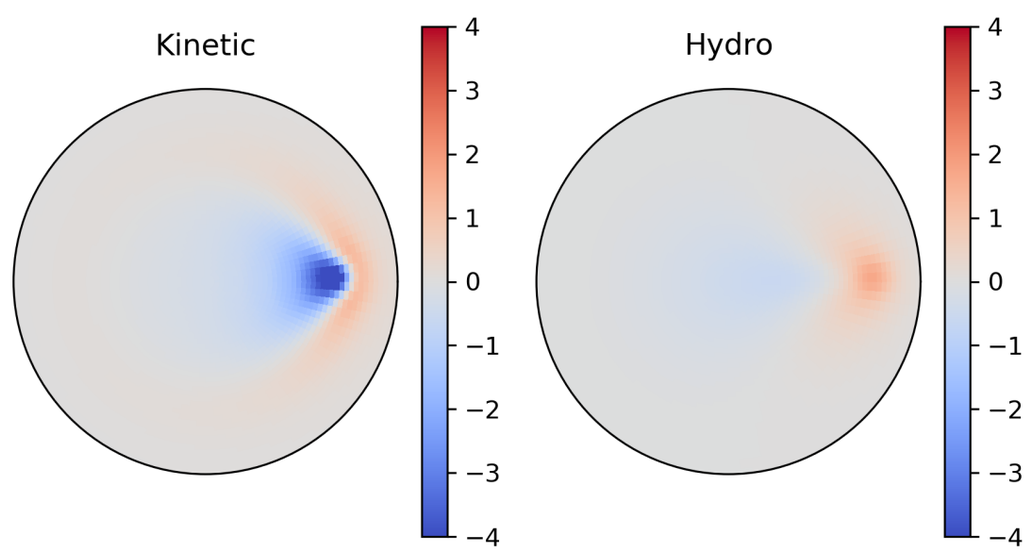
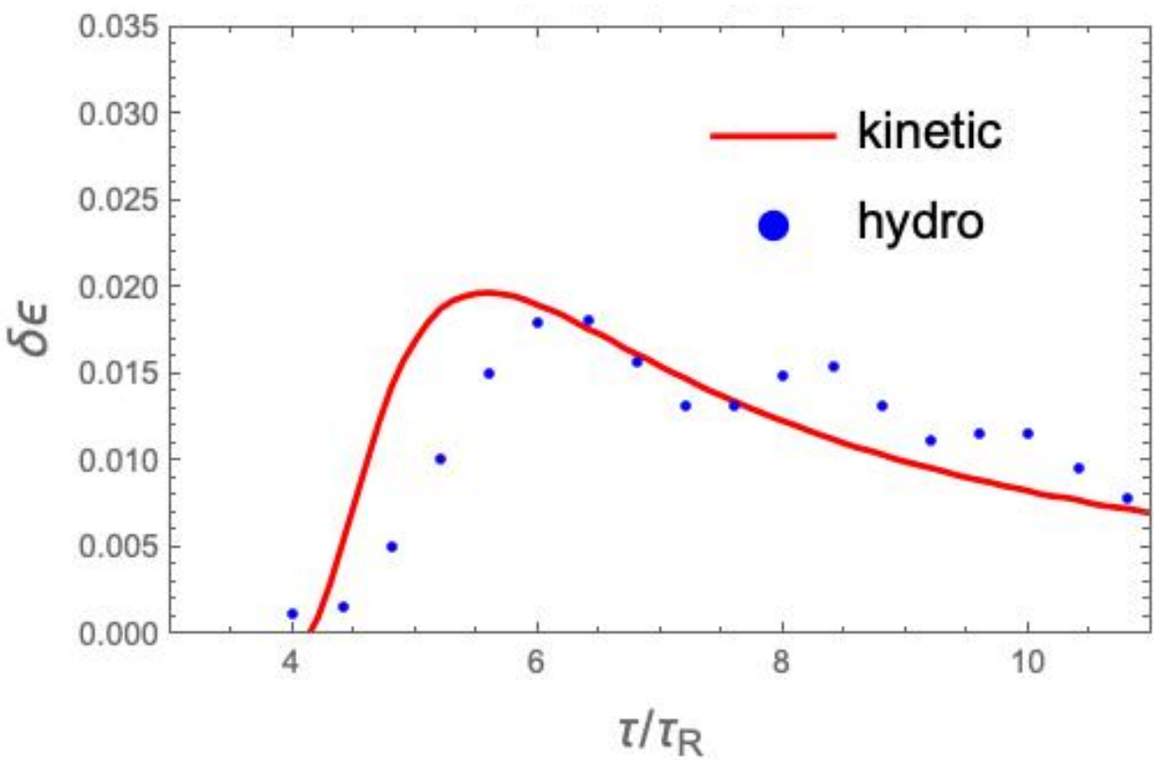


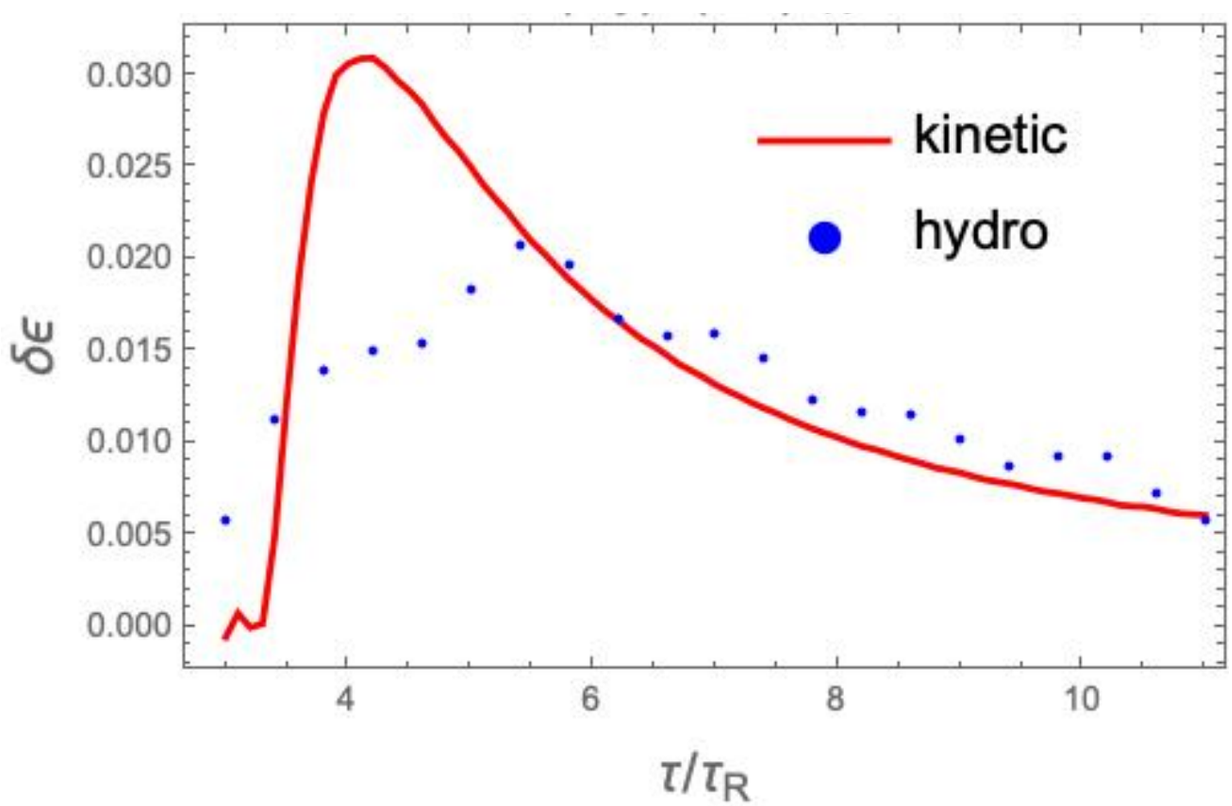
P_x

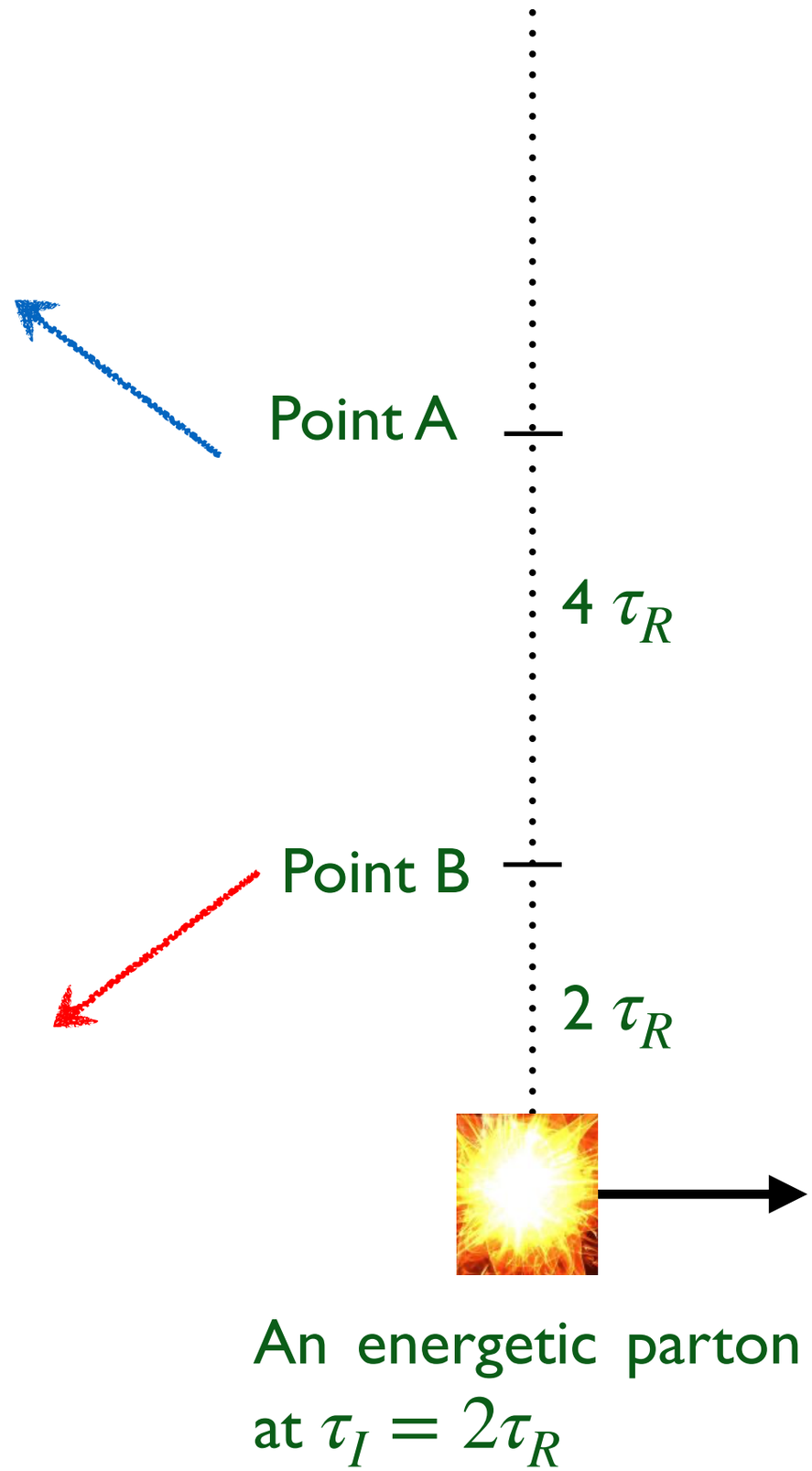


at $\Delta\tau = 3\tau_R$

Energy-density evolution observed at fixed positions.







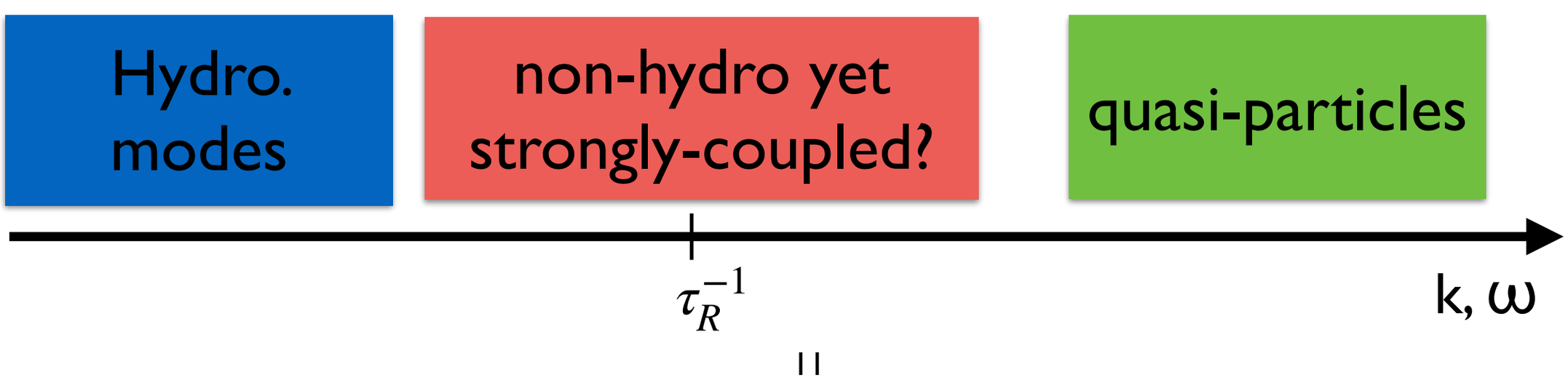
Summary and outlook

We have seen visible difference between hydro. and non-hydro. excitations in both Fourier and real space within RTA kinetic theory.

We are now estimating how such difference will influence observables (paper is coming).

Future: inputing Green functions from QCD kinetic theory to describe the medium-jet interaction.

⇒ Looking for the hints of quasi-particle excitations and exploring non-hydro. yet strongly-coupled regime of QGP.



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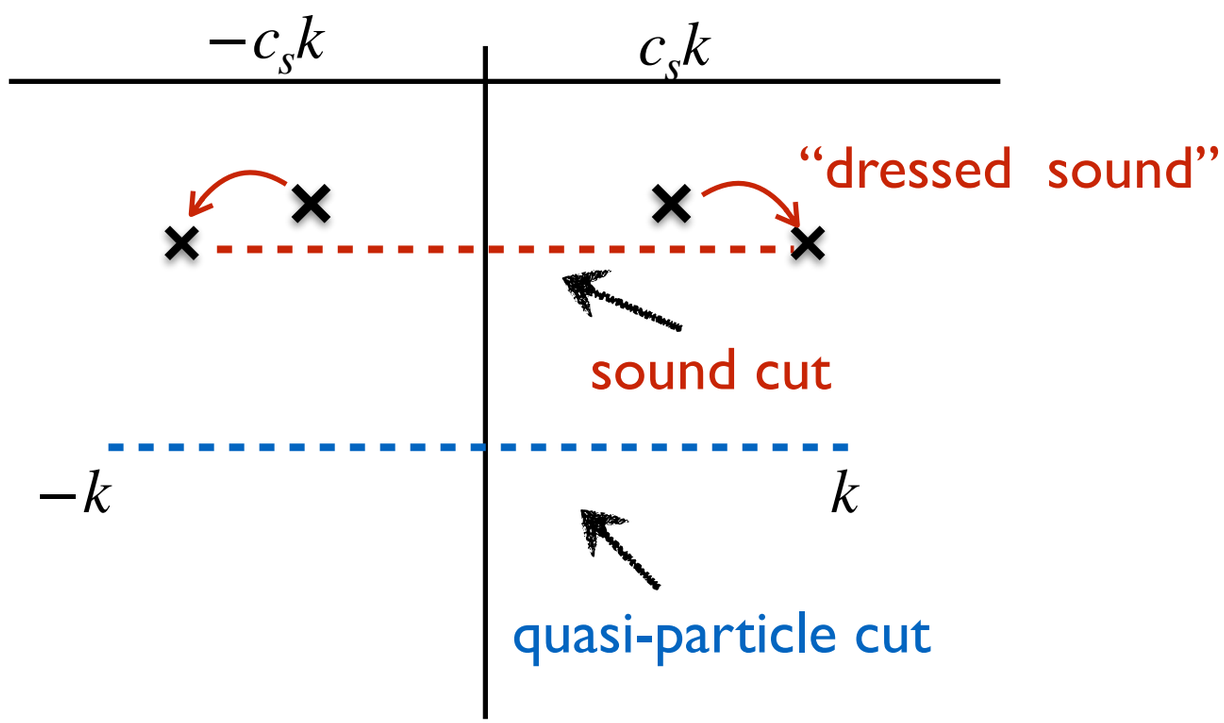
"Extremely small objects and incredibly rapid processes are now being seen in a new light."

The announcement of Royal Swedish Academy of Sciences 2018

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

Back-up

The rich analytic structure of Green function at finite k



Hydro. flucts. leads to distinct non-analytic structure to the medium's response as a function of gradient k.

Chris Lau, Hong Liu, YY, in preparation

Big question: the evolution of QGP (as a function of coarsening scale)

Can we resolve the "parton distribution" in QGP?

e.g. by analyzing the large angle scattering between jet parton and the medium.

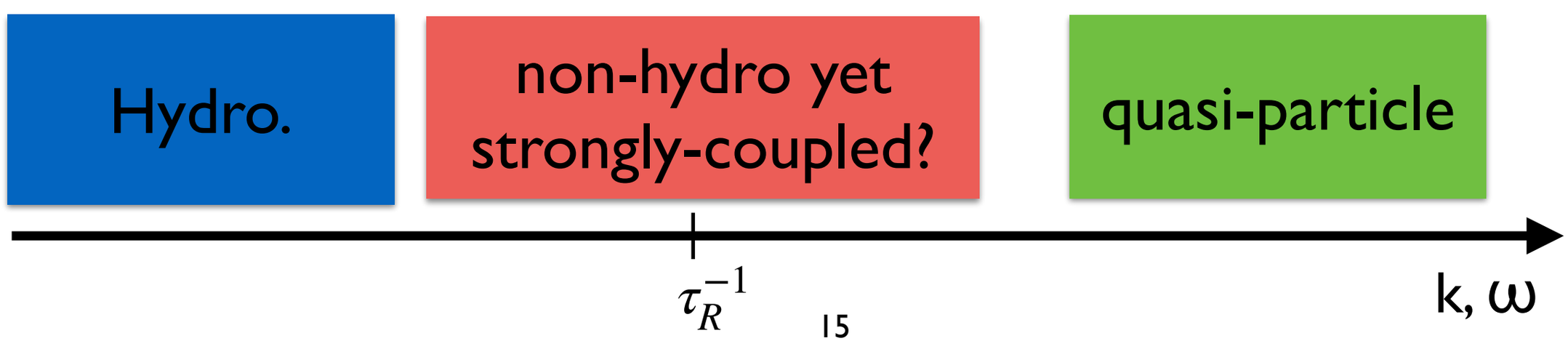
Eramo, Rajagopal and YY, 1808.03250

How does the dynamic properties of QGP evolve from "fluid-like" to "gas-like"?

see also Bin Wu's talk

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

By studying jet-medium interaction, can we extract the properties of QGP in non-hydro yet strongly-coupled regime?



Response function