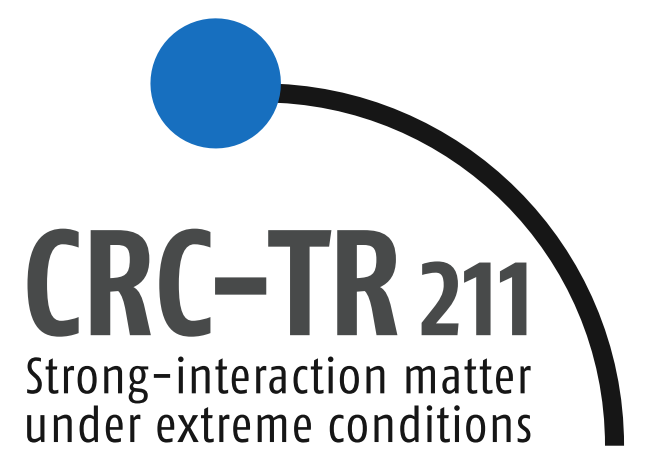


Universality of the Energy-Momentum Response in Kinetic Theories & Applicability of Hydrodynamics [arXiv: [2306.09094](#)]

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Motivation

Quantum many body systems, e.g. heavy ion collisions, are well described by effective theories like kinetic theory and hydrodynamics.

Kinetic theories describe pre-equilibrium phase of QGP with smooth transition to the hydrodynamic phase [1].

In the long time and long wavelength limit hydrodynamics emerge as a universal theory, but under what conditions?

Kinetic Theory

We calculate Green's functions of the energy-momentum tensor via linear response in the sound channel.

$$G_{00}^{00}(\bar{k}, \bar{t}) = \frac{\delta T^{00}(\bar{k}, \bar{t})}{\delta T^{00}(\bar{k}, 0)}$$

We analyze the differences between various kinetic theories, namely the Relaxation Time Approximation (RTA), Scalar ϕ^4 theory, SU(3) Yang-Mills (YM) and QCD kinetic theory (QCD).

We analyze within viscosity independent variables to study on a universal scale that is also found in first order hydrodynamics.

$$\bar{\omega} = \omega \frac{\eta}{sT} \quad \bar{k} = k \frac{\eta}{sT}$$

Green's functions of different kinetic theories exhibit universal behavior, extending into non-hydrodynamic regime with large gradients.

Hydrodynamic and Non-Hydrodynamic Modes

Can kinetic theory be described by one pair of hydrodynamic and one pair of non-hydrodynamic modes?

$$G_{00}^{00}(\bar{k}, \bar{t}) = Z_s(\bar{k}) \text{Re}(e^{-i\bar{\omega}_s(\bar{k})\bar{t} + i\phi_s}) + Z_n(\bar{k}) \text{Re}(e^{-i\bar{\omega}_n(\bar{k})\bar{t} + i\phi_n})$$

In reality, non-hydrodynamic response is far more complicated than two isolated poles [2,3] but it is conceivable that one pair of modes can be an effective description of this behavior.

Extract the complex frequencies from real time data.

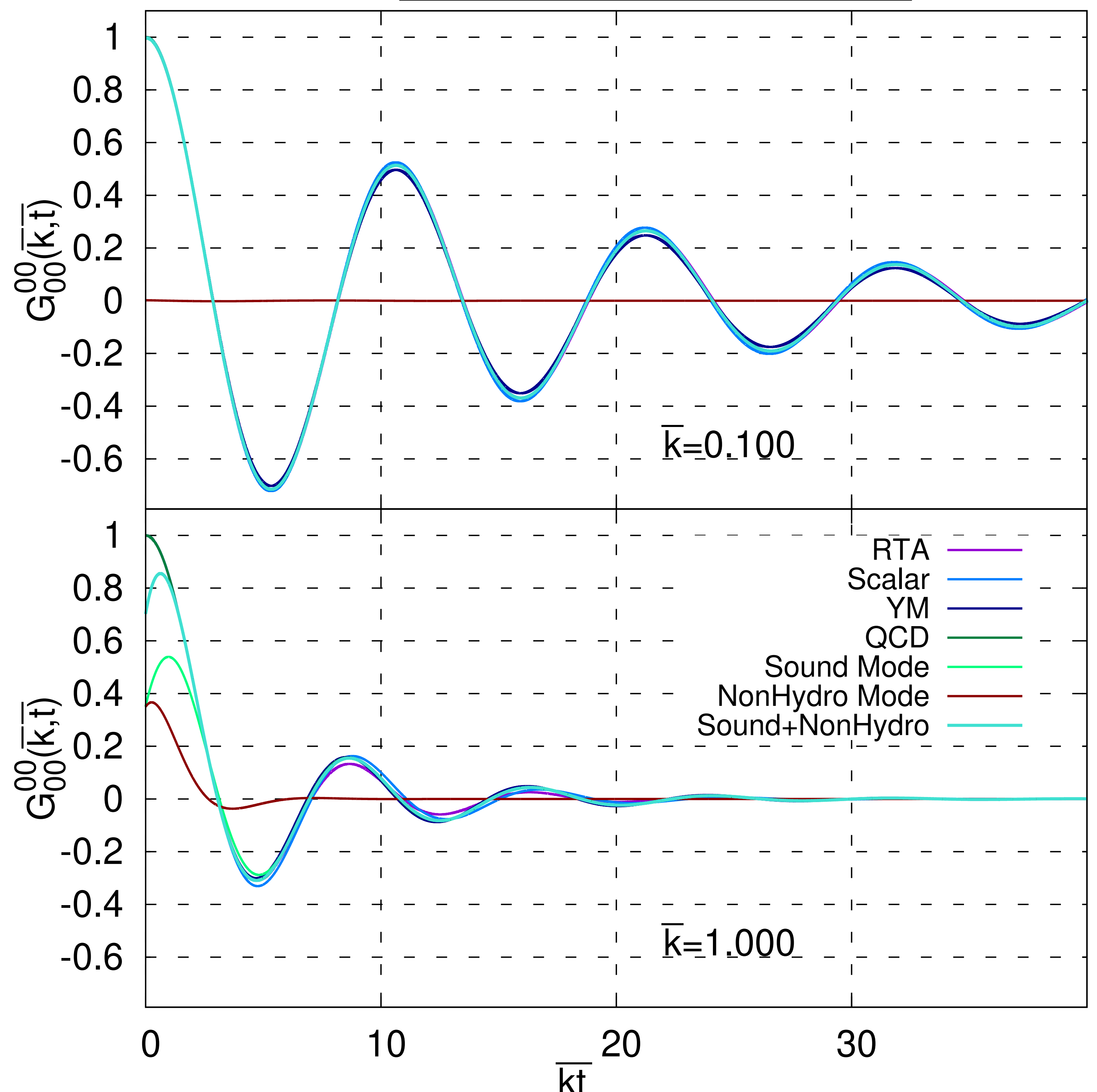
One Effective Sound Mode to Rule Them All

The extracted sound mode properties can be parametrized as smooth functions of the gradient via Padé approximation.

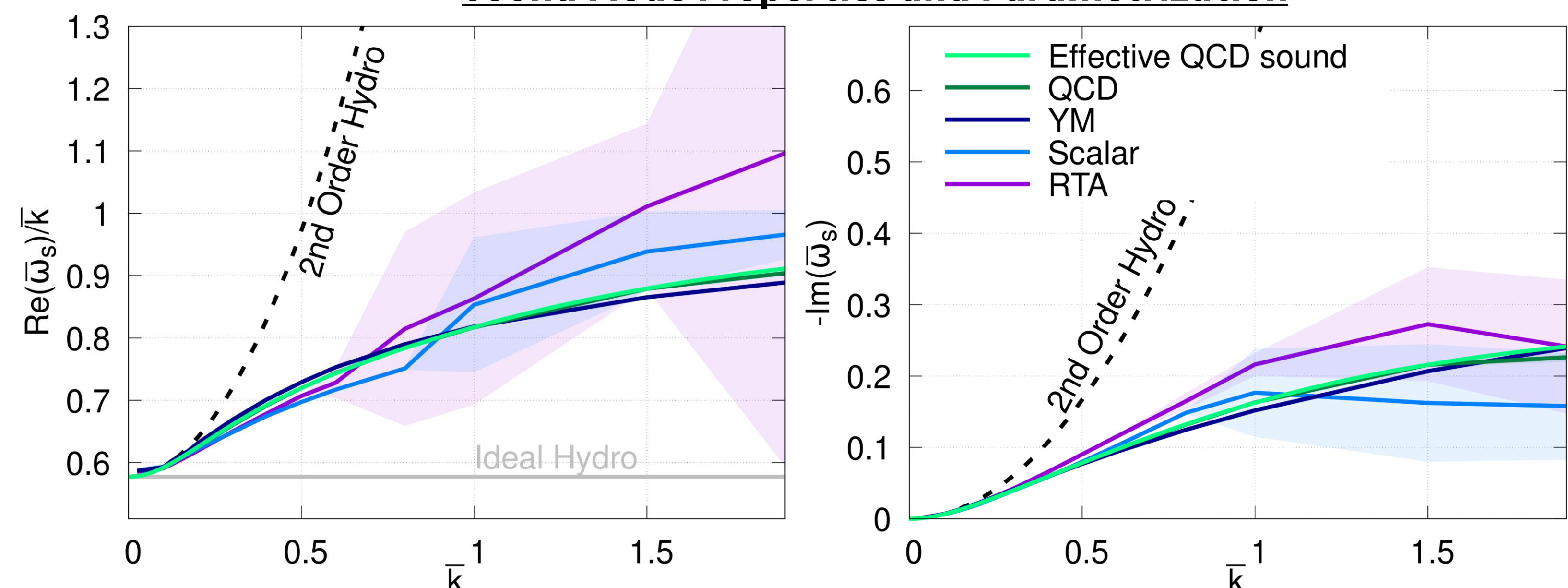
Construct Green's function from parametrized effective sound mode and analyze position space.

Single effective sound mode captures the physics of the sound channel Green's function well. Only small deviations for early times / large gradients.

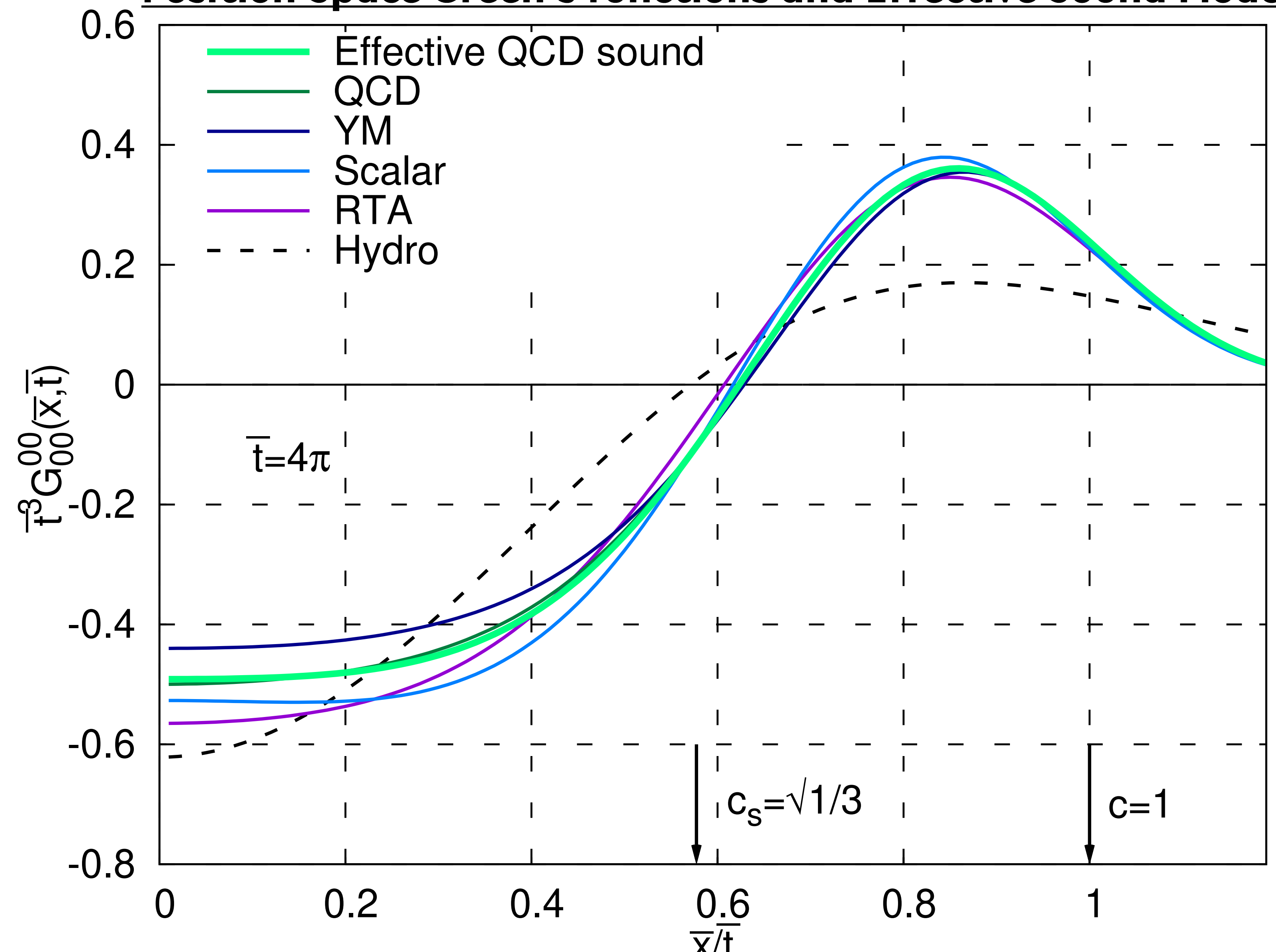
Universality of Kinetic Theories and Deconstruction into Two Modes



Sound Mode Properties and Parametrization



Position Space Green's functions and Effective Sound Mode



References

[1] Romatschke, *Int. J. Mod. Phys. E* 19 (2020)
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[2] Kurkela and Wiedemann, *Eur. Phys. J. C* 79 (2019)
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