# Non-hydrodynamic modes from linear response in effective kinetic theory

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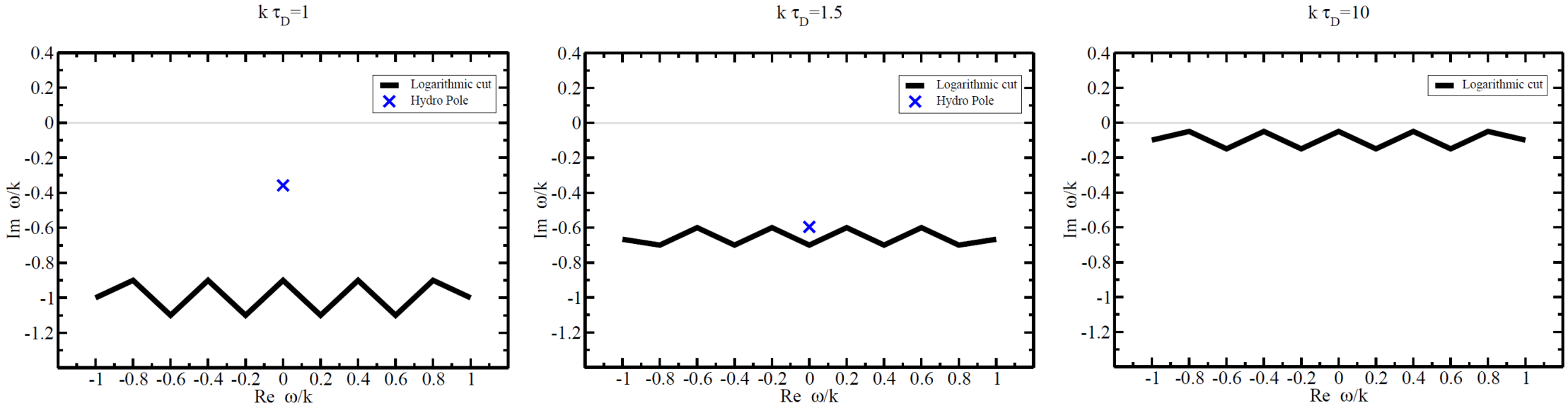
- Quark-Gluon-Plasma created in Heavy-Ion Collisions well described by Hydrodynamics at late times
- On what time and length scales does Hydro apply?
- Hydro modes vanish in the long wavelength limit ($\omega \to 0$ , $k \to 0$)
- Non-Hydro modes are every modes that are not hydro
- Study excitations of equilibrium system in kinetic theory to find modes



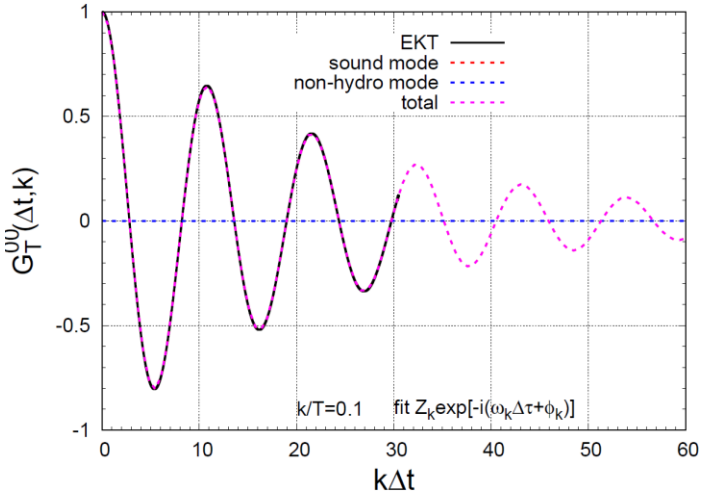

Relaxation Time Approximation [Romatschke, EPJ C(2016)]

- Calculate real time Green's functions and go into complex frequency space
- Numerical Laplace transform breaks down for multiple non-analytic regions
- Develop different methods than brute Laplace transform

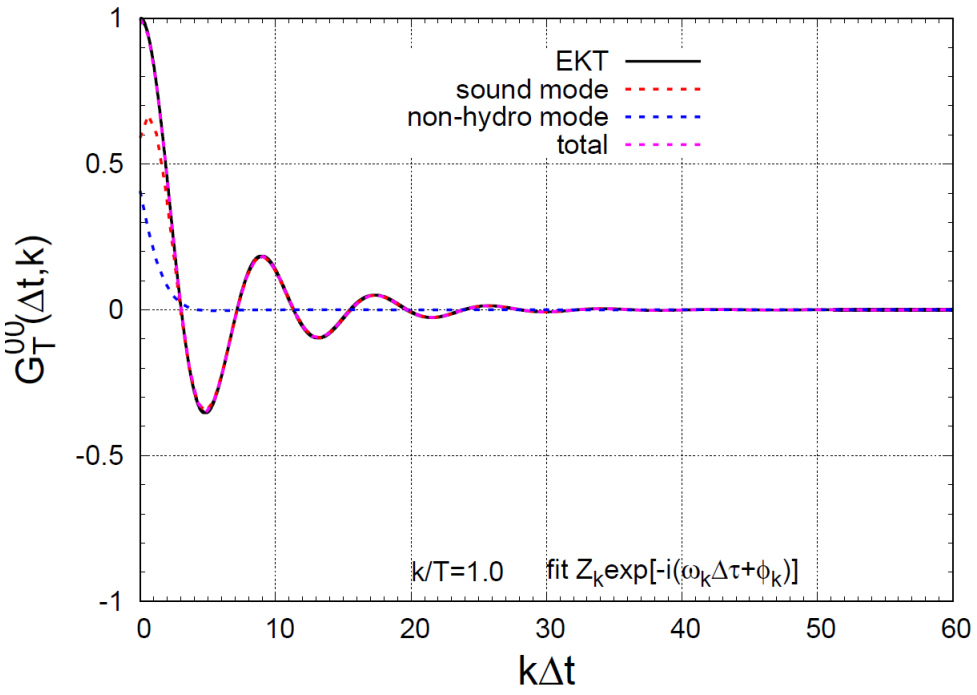
Approach: Fit Green's Function

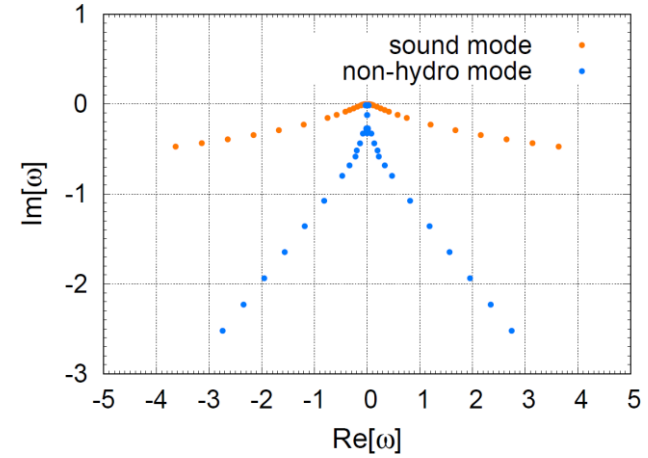
$$f(t) = Z_k \cos(\omega_1 t) e^{-w_2 t}$$

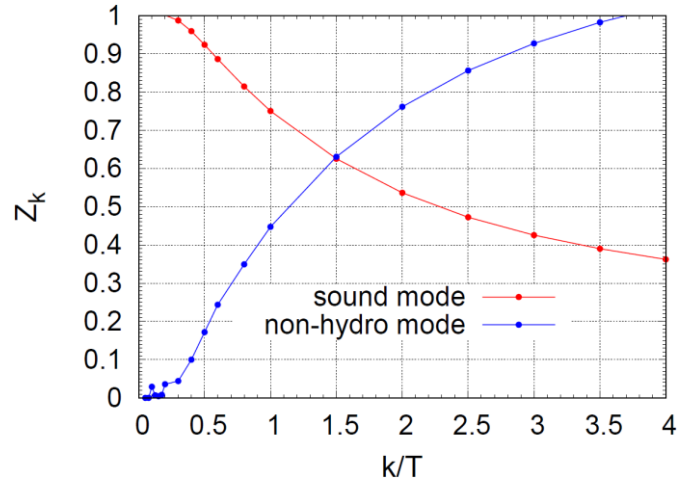
$$\Rightarrow \omega = \pm\omega_1 - i\omega_2$$




Yang Mills

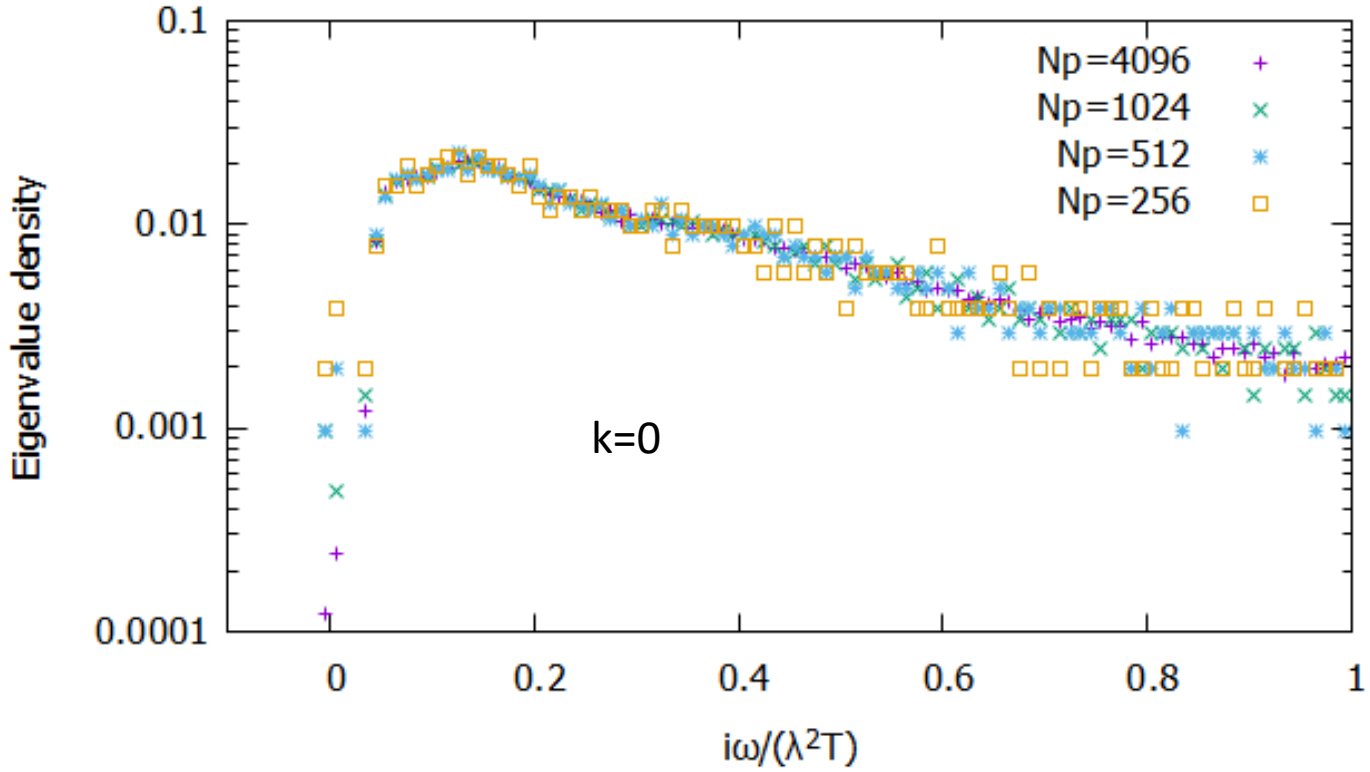


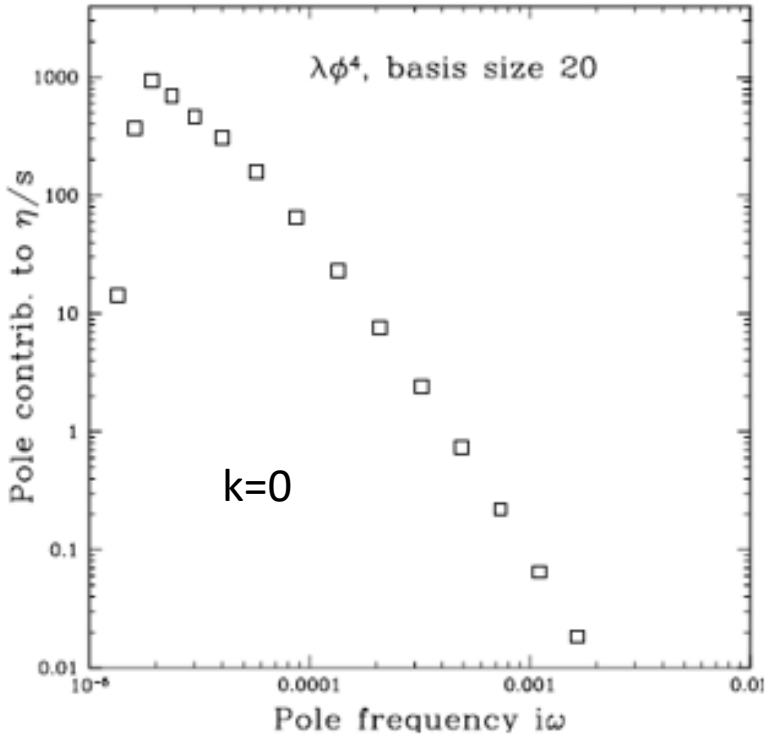



- Scalar $\phi^4$-theory:
- Approach: Eigenvalues of the collision operator
- Continuous spectrum for k=0

$$\partial_t f(t) = C f(t)$$
$$\Leftrightarrow f(t) = e^{Ct} f(0)$$




[Moore, JHEP(2018)]

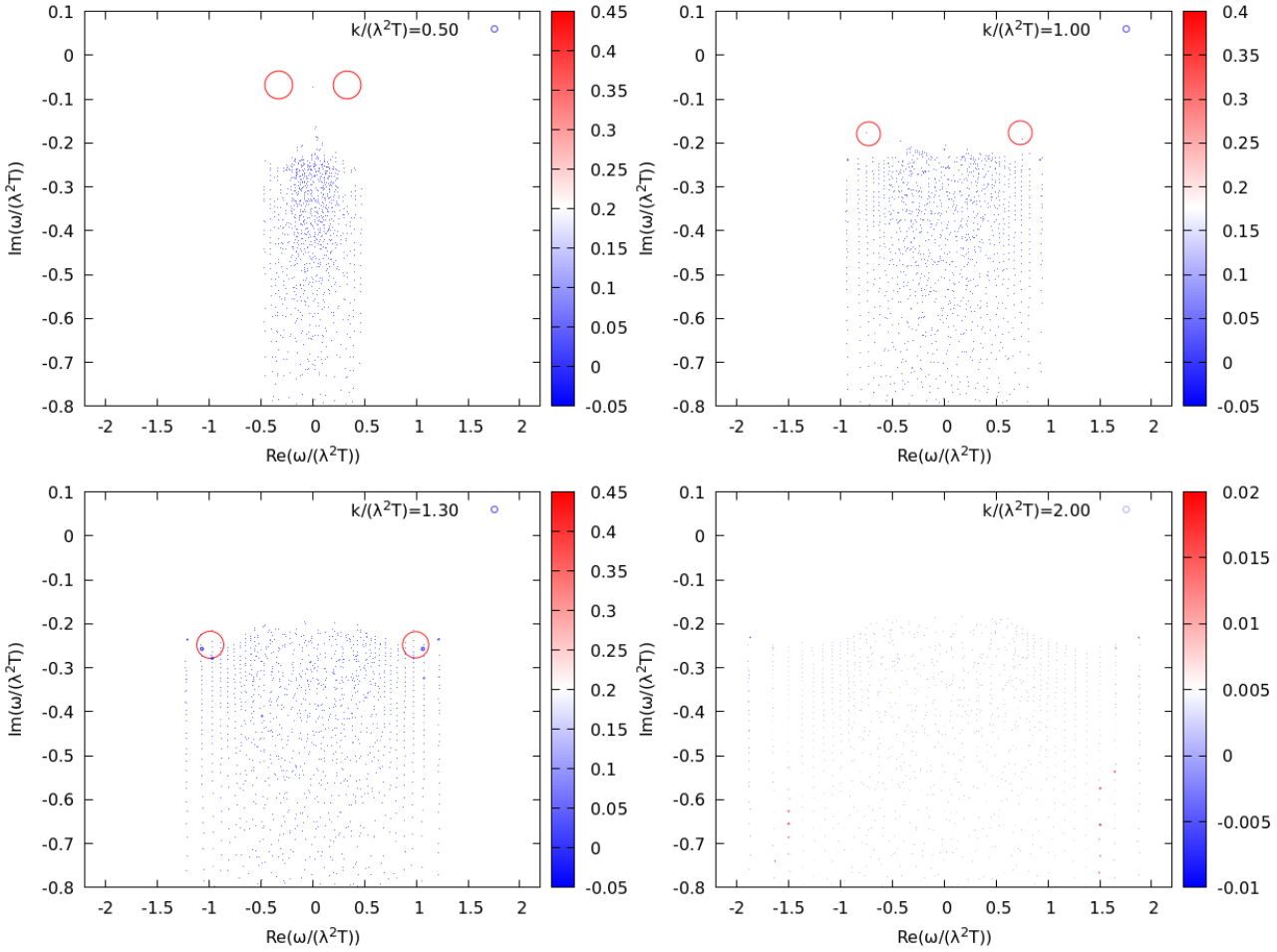


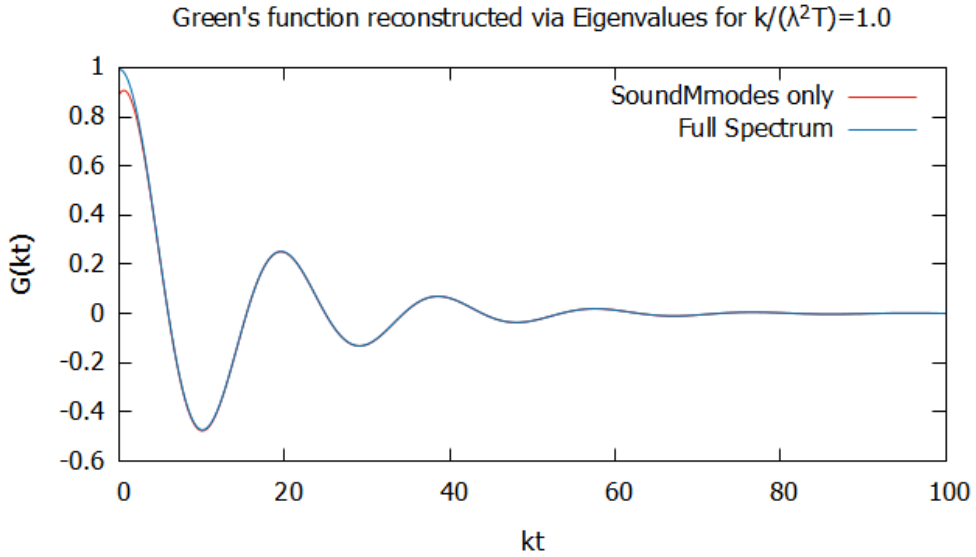
# Non-Hydrodynamic Modes from Linear Response in Kinetic Theory

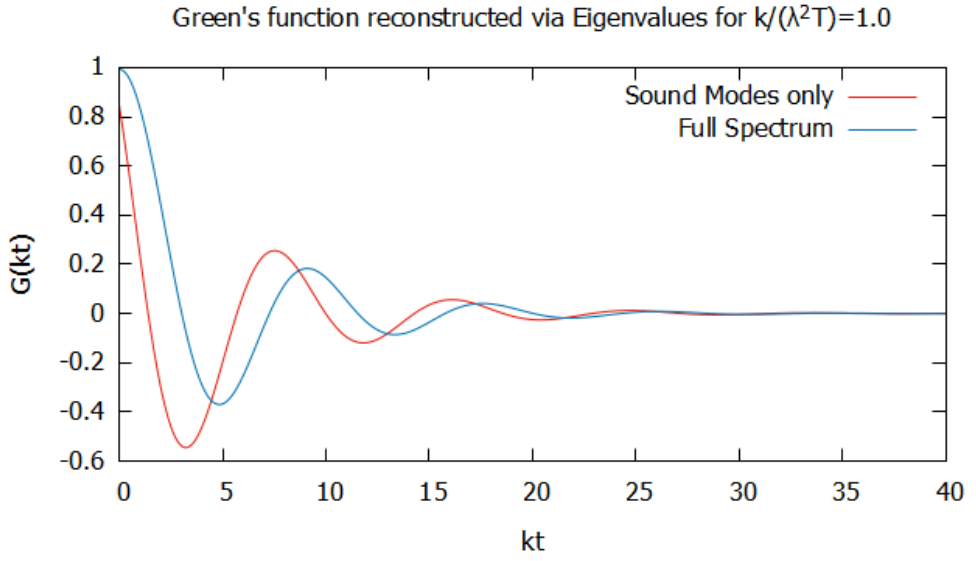
- Sound mode wanders behind non-hydro region for higher k
- Reconstruct Green's function from modes

$$G(t) = \sum e^{\lambda_i t} \langle O|a_i\rangle \langle b_i|I\rangle \qquad G(\omega) = \sum -\frac{\langle O|a_i\rangle \langle b_i|I\rangle}{i\omega + \lambda_i}$$

$\lambda = 100$



- Analytical structure of Green's functions in scalar theory shows signs of more complicated behavior than just poles and cuts
  - Also expected for QCD
- Extract dominant modes and study approach to Hydro
- Extend formalism to QCD kinetic theory