Heavy-quark diffusion coefficient in out-of-equilibrium plasmas

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Introduction

Transport coefficients contain information about the microscopic properties of the medium. We study the **heavy quark** (HQ) **momentum diffusion coefficient** κ **out of equilibrium** by using classical Yang-Mills (CYM) simulations in the **self-similar regime**. With this setup we aim to **mimic the medium consisting of overoccupied gluon fields** created **at the initial stages of an ultrarelativistic heavy ion collision**.

Diffusion in the Langevin picture [1]

In the Langevin approach the EOM for HQ is given by

$$\frac{\mathrm{d}p_i}{\mathrm{d}t} = -\eta_D p_i + \xi_i(t)\,. \tag{1}$$

Identify the Lorentz force as the stochastic force

$$\langle \xi_i(t)\,\xi_j(t')\rangle = \kappa\delta_{ij}\delta(t-t'). \tag{2}$$

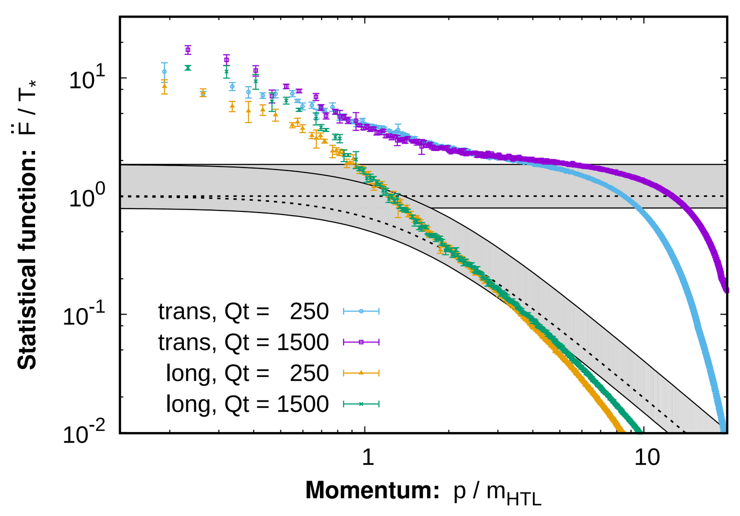
Extracting κ, 3 methods

CYM Measure the force-force correlation , $A^0 = 0$.

$$\kappa(t,\tilde{t}) = \int_0^{\tilde{t}} \mathrm{d}\Delta t\; \kappa(t,\Delta t) \tag{3}$$

$$= \frac{g^2}{3VN_c}\int_0^{\tilde{t}} \mathrm{d}\Delta t \int \mathrm{d}^3x \sum_{i=1}^{3}\left\langle E_i(\boldsymbol{x},t+\Delta t)\,E_i(\boldsymbol{x},t)\right\rangle$$

HTL Use results from LO HTL perturbation theory to estimate $\ddot{F}(t,t+\Delta t) \approx \langle E(t)E(t+\Delta t)\rangle$. Include our data [2] on the quasiparticle damping rate and $\ddot{F}$.



Measured $\ddot{F}(t,t)$. Gray bands: HTL expectation.

KT Kinetic theory [1]. Extract $f(k)$ from lattice, compute:

$$\kappa_{\mathrm{KT}}^{\tilde{t}\to\infty} = \frac{1}{6M}\int \frac{\mathrm{d}^3\boldsymbol{k}\,\mathrm{d}^3\boldsymbol{k}'\,\mathrm{d}^3\boldsymbol{p}'}{(2\pi)^9\, 8k^0k'^0 M}(2\pi)^3$$
$$\times\, \delta^3(\boldsymbol{p}+\boldsymbol{k}'-\boldsymbol{p}'-\boldsymbol{k})\, 2\pi\delta(k'-k)\,\boldsymbol{q}^2$$
$$\times\, |\mathscr{M}|^2_{\text{gluon}}\, f(k)\, f(k')\,, \tag{4}$$

Conclusions

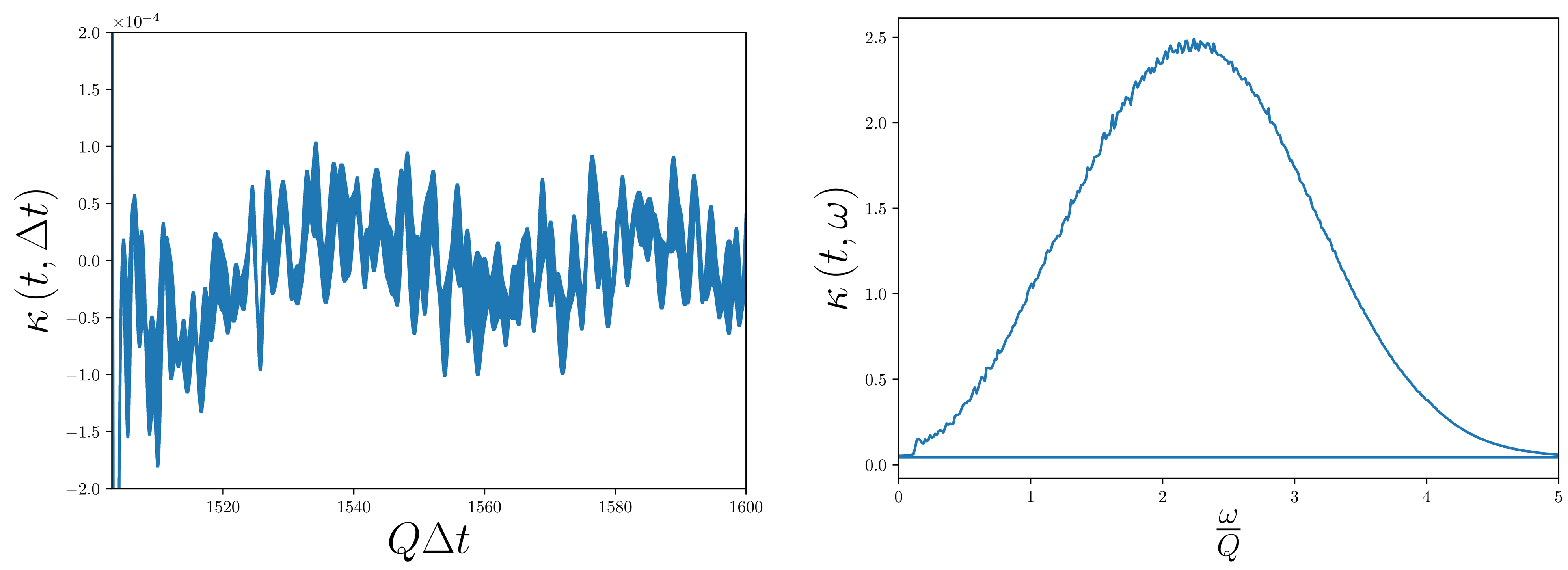
- We measure the heavy quark momentum diffusion coefficient κ far from equilibrium. κ follows an approximate $t^{-1/2}$ power law (preliminary). This is consistent with HTL ($t^{-5/7}\times$ logarithmic correction). Including the IR enhancement improves the agreement with the transient time behavior.
- We find that the IR enhancement of the *gauge-fixed* $\ddot{F}$ leads to an observable modification of the *gauge-invariant* signal in $\kappa(t,\tilde{t})$. Oscillations in finite $\tilde{t}$ have a similar frequency as the plasmon frequency.

References

[1] G. D. Moore, D. Teaney, Phys.Rev. C71 (2005) 064904
[2] K. Boguslavski, A. Kurkela, T. Lappi, J. Peuron, Phys.Rev. D98 (2018) no.1, 014006

Signal from real time lattice

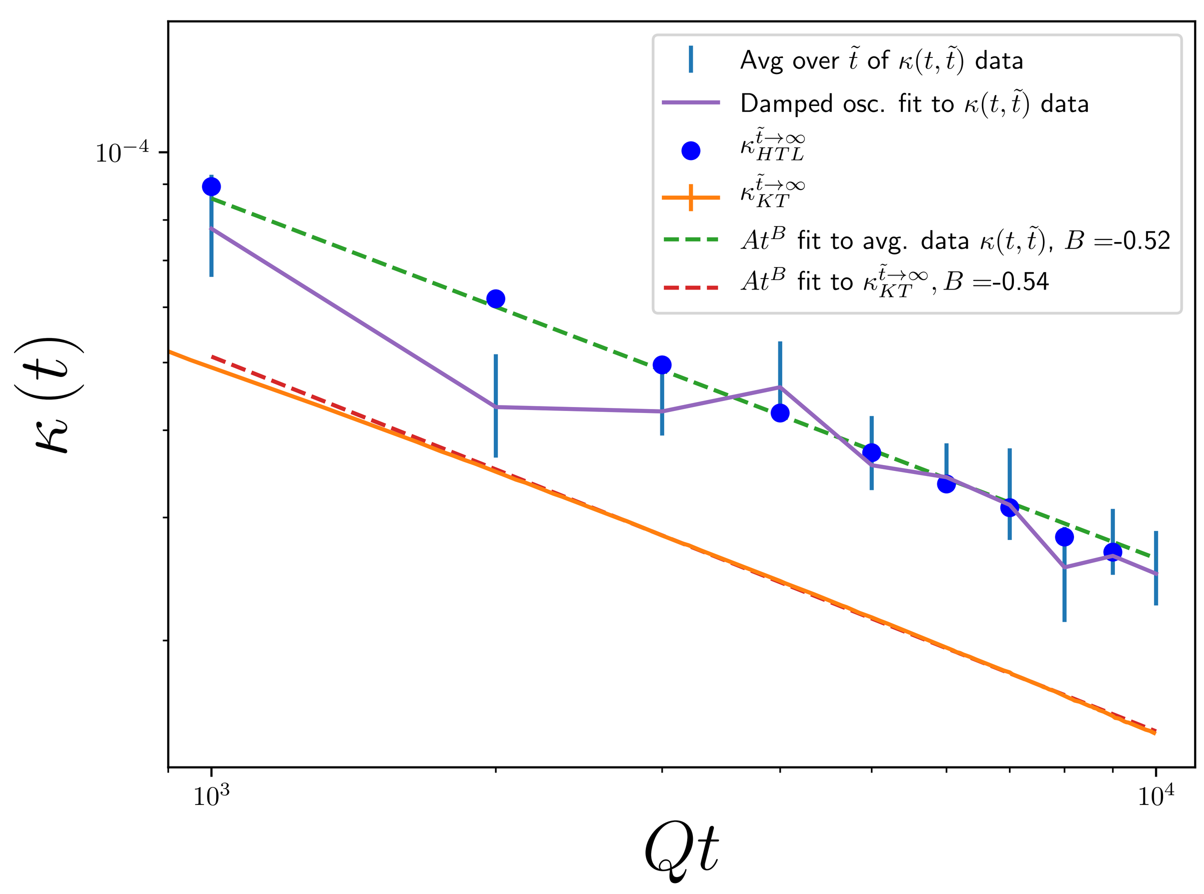
Extracted signal in time and frequency domains



- Left: The signal $\kappa(t,\Delta t)$ in the t-domain, initially large, fast oscillations not shown.
- Right: The signal in the frequency domain. The diffusion coefficient is $\kappa = \kappa(t,\omega=0)$.

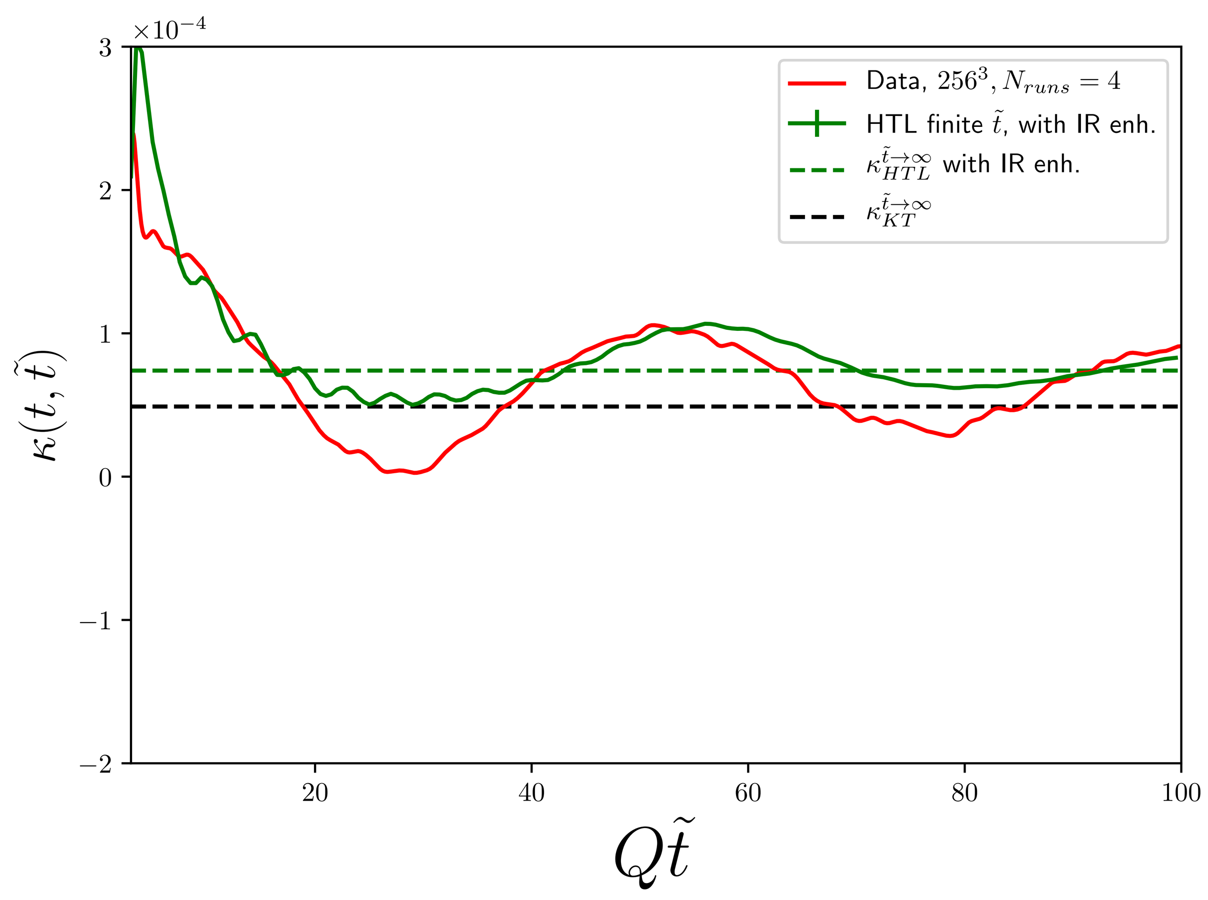
Results: Time dependence and IR enhancement

Dependence on time t of $\kappa(t) = \lim_{\tilde{t}\to\infty}\kappa(t,\tilde{t})$



- At large t our gauge field configuration is that of a universal attractor where the physical scales evolve as powerlaws in t. We extract the powerlaw of κ so that we can compare the exponent and coefficient to other physical scales, such as m_D, T_*, Λ.
- Preliminary: HTL method close to data extractions, KT method is a factor 2 smaller.
- In "At^B fit to avg. $\kappa(t,\tilde{t})$", powerlaw fit to $\tilde{t}$-averaged data for $Qt \geq 3000$. The fit reveals a considerable uncertainty.

Dependence on upper integration limit $\tilde{t}$



- Time-dependent curves (full lines): "Data" corresponds to $\kappa(t,\tilde{t})$ extracted from real time lattice. HTL finite $\tilde{t}$ with IR enh. curve replaces the HTL $\ddot{F}$ with the one extracted from data.
- Time-independent curves (dashed lines): $\kappa_{HTL}^{\tilde{t}\to\infty}$ corresponds to Δt integration up to ∞. KT method uses eq. (4).