Quarkonium Suppression in Strongly Coupled Plasmas

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Bruno Scheihing Hitschfeld
based on 2304.03298, 2306.13127, 2310.09325

UC SANTA BARBARA
Kavli Institute for Theoretical Physics

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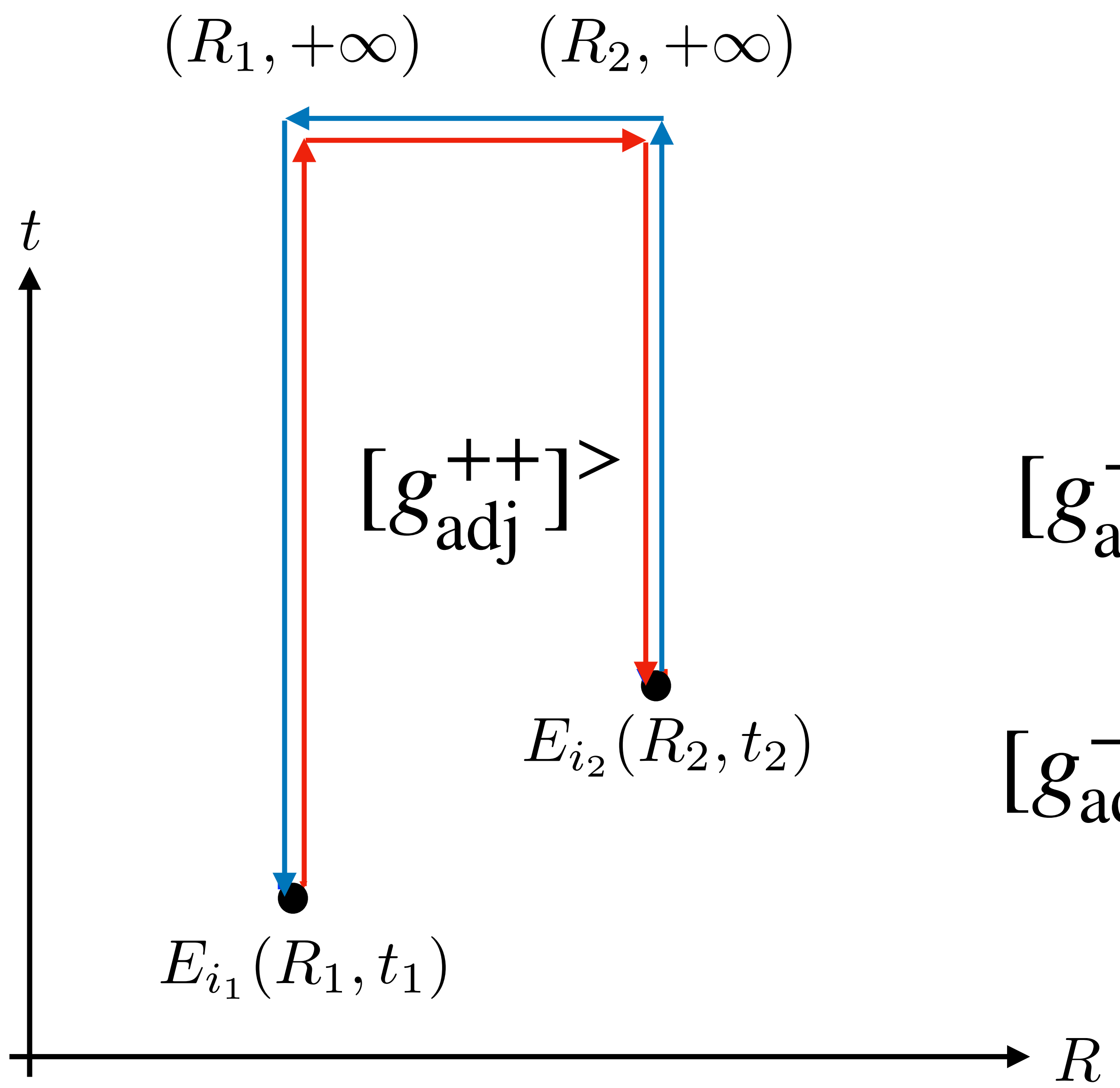
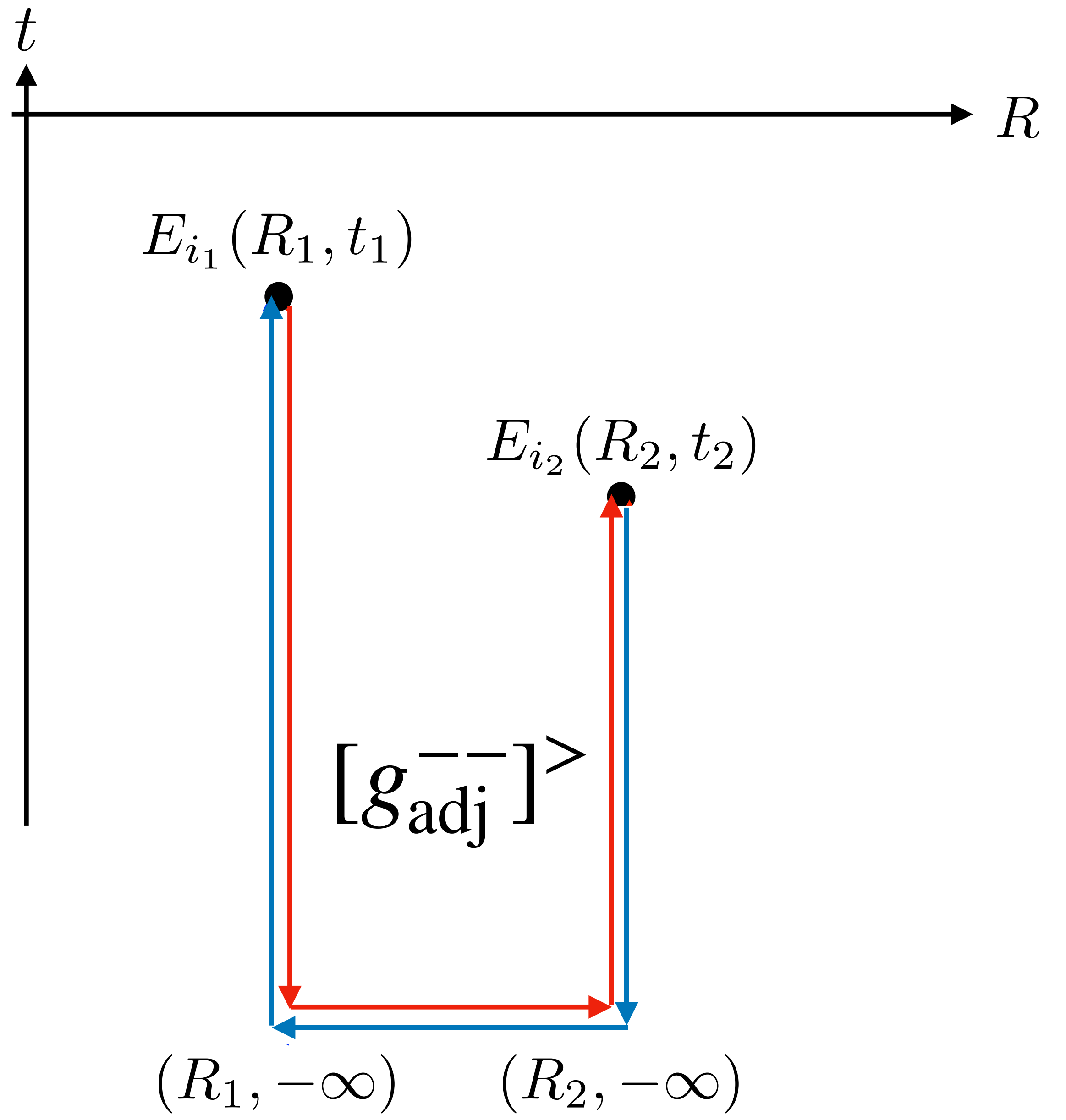


Answer in Xiaojun Yao's talk (14:50 Wed):

$$[g_{\text{adj}}^{++}]^{>}_{i_2 i_1}(t_2, t_1, \mathbf{R}_2, \mathbf{R}_1) = \Big\langle \big(E_{i_2}(\mathbf{R}_2, t_2)\mathscr{W}_2\big)^a \big(\mathscr{W}_1 E_{i_1}(\mathbf{R}_1, t_1)\big)^a \Big\rangle_T$$

$$[g_{\text{adj}}^{--}]^{>}_{i_2 i_1}(t_2, t_1, \mathbf{R}_2, \mathbf{R}_1) = \Big\langle \big(\mathscr{W}_{2'} E_{i_2}(\mathbf{R}_2, t_2)\big)^a \big(E_{i_1}(\mathbf{R}_1, t_1)\mathscr{W}_{1'}\big)^a \Big\rangle_T$$



Transport descriptions of quarkonia

connecting first-principles theory with physical phenomena

- So far, transport descriptions that incorporate these correlators explicitly make simplifying assumptions that make the dynamics of quarkonium "Markovian" (no memory effects). For example:
  - The Quantum Brownian motion limit assumes $T \gg |\Delta E|$, with ΔE the energy gap between different quarkonium states. In this way, it is assumed that QGP relaxes quickly back to local equilibrium relative to the time scales of quarkonium.

    $$\frac{d\rho}{dt} = \mathscr{L}[\rho(t)]$$

  - The Quantum Optical limit assumes a semiclassical description where QGP is made of quasiparticles. In this way, transitions at different times become decorrelated.

    $$\frac{Df}{dt} = \mathscr{C}[f(t)]$$

- Do these assumptions capture the physics of QGP in HICs?

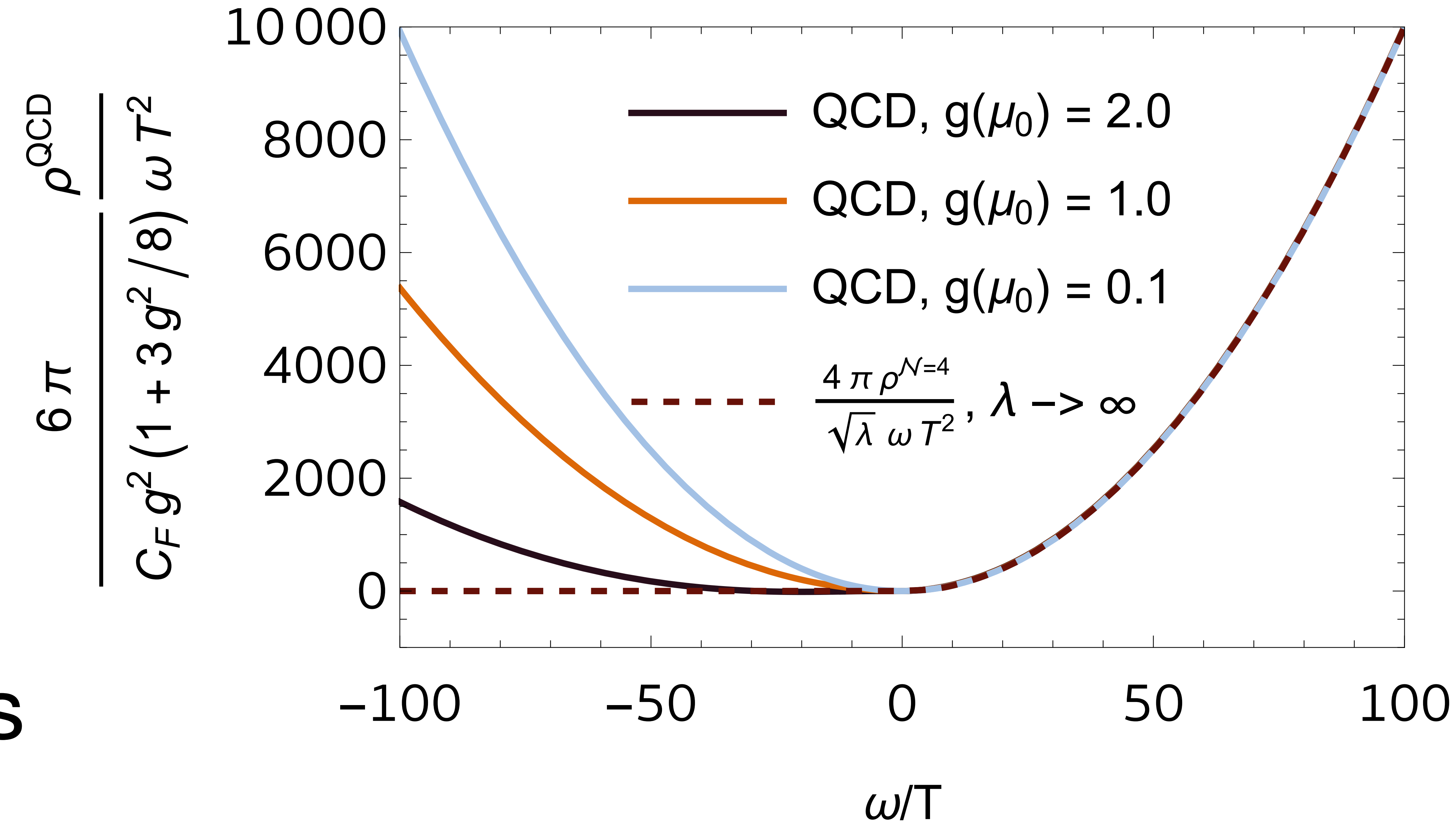
Comparing with a strongly coupled case

how doing calculations in $\mathcal{N} = 4$ SYM helps

- Calculating real time correlation functions in QCD at strong coupling is challenging. A lattice QCD calculation will help! [2306.13127 w/ X. Yao]

- We can gain intuition for what *can* happen by exploring other theories in which calculations are easier. For example, in $\mathcal{N} = 4$ SYM.

- With G. Nijs and X. Yao [2304.03298, 2310.09325] we did this calculation and showed that:
  - The results are qualitatively consistent with an extrapolation from weakly coupled QCD, and
  - the strongly coupled result directly challenges the assumptions of the previously mentioned transport descriptions.



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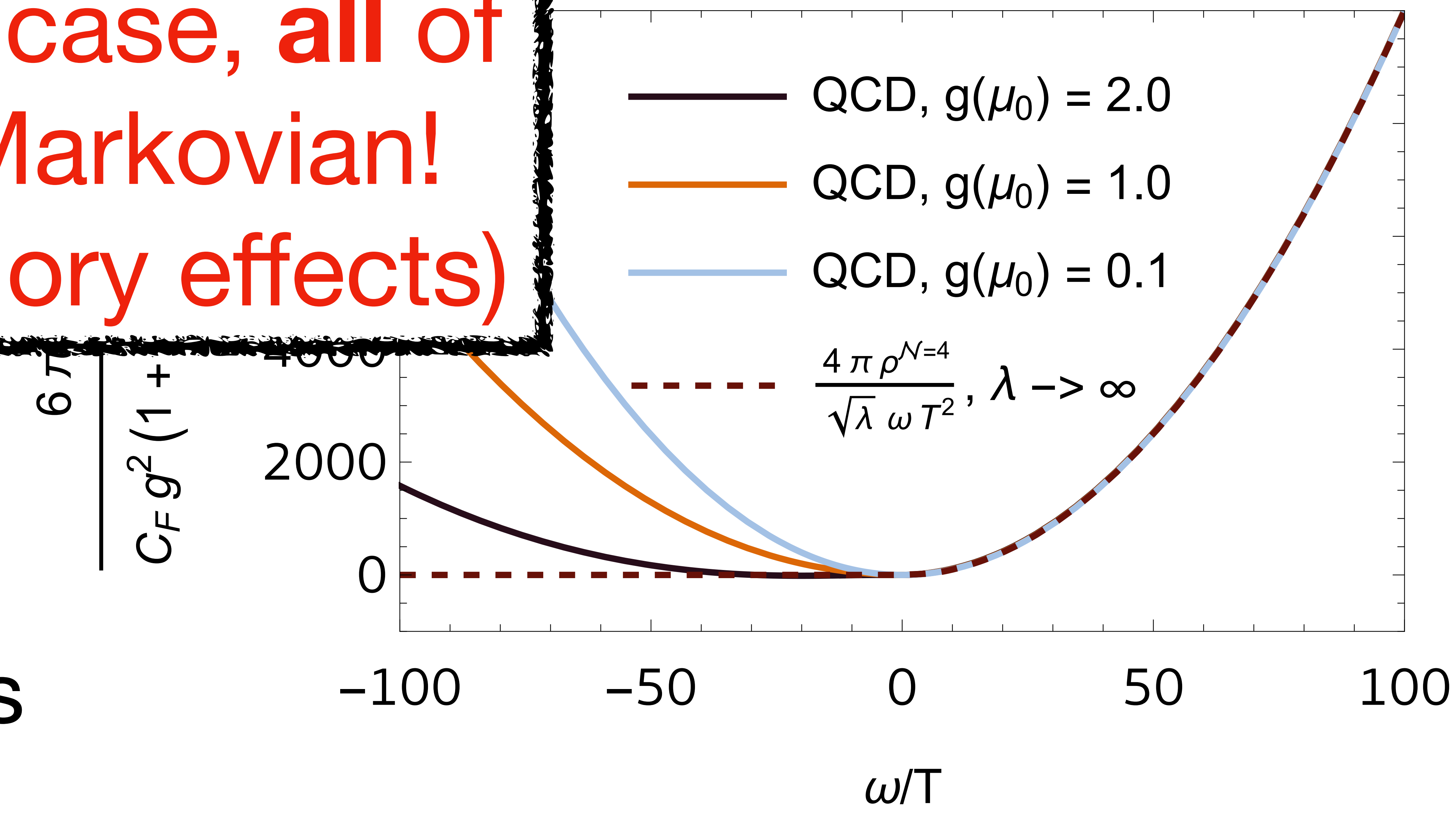
In the strongly coupled case, **all** of the dynamics is non-Markovian!
(i.e., it is driven by memory effects)



Comparing weakly and strongly coupled picture

how our theoretical expectation changes

- A comparison using the existing transport formalisms is impossible, as they completely ignore memory effects.
- In absence of a fully developed transport formalism, back to open quantum systems basics:

$$\rho_{Q\bar{Q}}(t) = \mathrm{Tr}_{\mathrm{QGP}}\left[U(t)\rho_{\mathrm{tot}}(t=0)U^{\dagger}(t)\right].$$

- From here, in time-dependent perturbation theory:

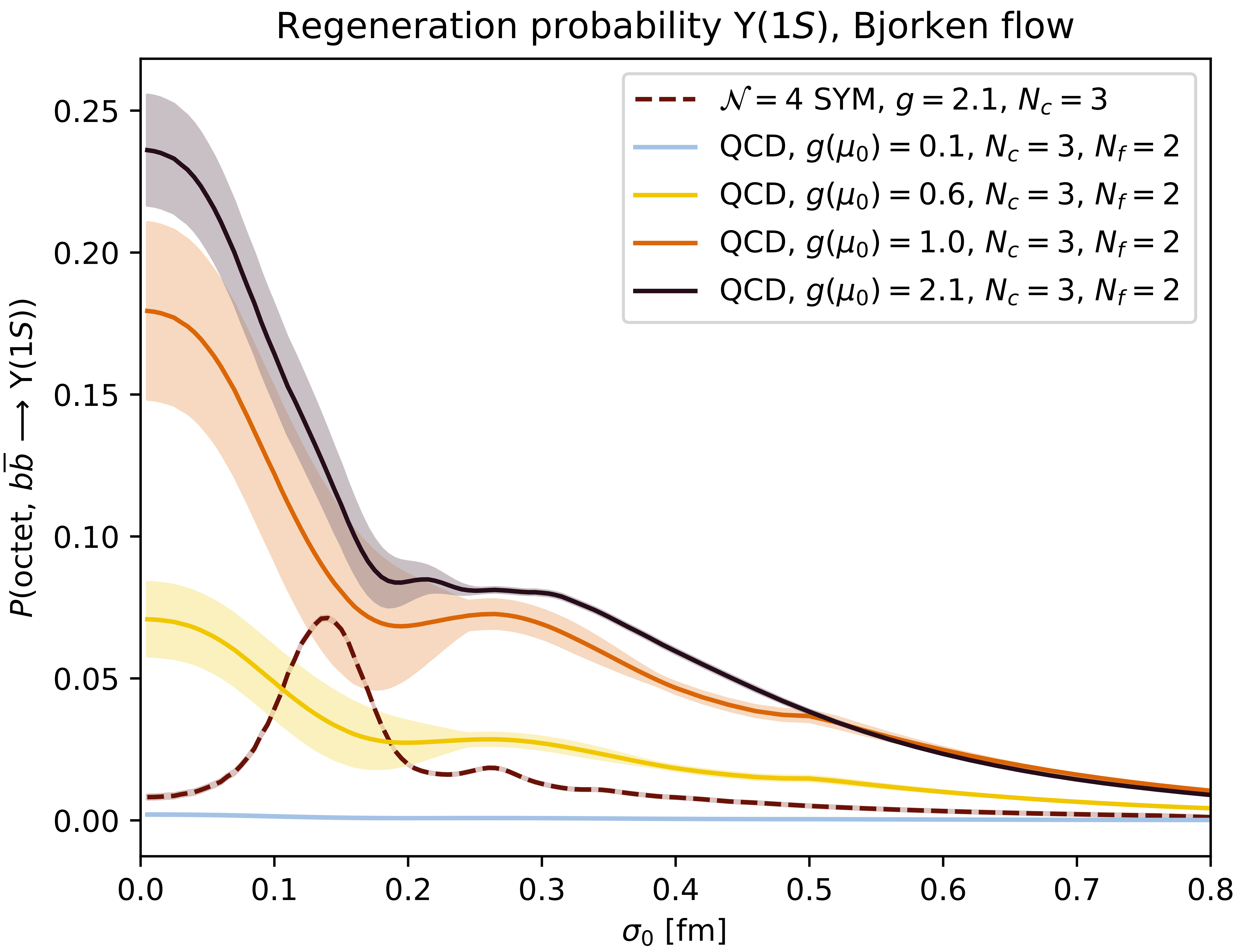
$$\langle nl\,|\,\rho_{Q\bar{Q}}(t_f)\,|\,nl\rangle = \int_{t_i}^{t_f} dt_1 \int_{t_i}^{t_f} dt_2\, [g_{\mathrm{adj}}^{--}]^{>}(t_2, t_1)\, \langle nl\,|\,U_{[t_f,t_1]}^{\mathrm{singlet}} r_i U_{[t_1,t_i]}^{\mathrm{octet}}\,|\,\psi_0\rangle \big(\langle nl\,|\,U_{[t_f,t_2]}^{\mathrm{singlet}} r_i U_{[t_2,t_i]}^{\mathrm{octet}}\,|\,\psi_0\rangle\big)^{\dagger}$$

Quarkonium regeneration

weak vs strong coupling

- Big difference in the magnitude of quarkonium regeneration in the two cases!

$\Longrightarrow$ To interpret data in terms of QCD properties, assumptions about transport need to be relaxed.



Outlook

the road ahead

- A lattice QCD calculation of

$$G_{\text{adj}}(\tau) = \frac{T_F g^2}{3N_c} \left\langle E_i^a(\tau) \mathscr{W}^{ab}(\tau,0) E_i^b(0) \right\rangle_T$$

can help enormously to determine whether Markovian or non-Markovian effects give the dominant contribution to regeneration/dissociation.

- For the most likely case, where things will be somewhere in between:
    - A transport description that incorporates non-Markovian effects is needed to interpret data in terms of microscopic descriptions.

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Stay tuned!