Universität Bielefeld

# HEAVY QUARKONIA IN MEDIUM AS OPEN QUANTUM SYSTEM

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## Abstract

According to sequential-suppression picture applied to the dynamics of heavy quarkonia in the hot medium formed in ultrarelativistic nuclear collisions, quark--antiquark pairs created in a given bound or unbound state remain in that same state as the medium evolves. We argue that this scenario implicitly assumes an adiabatic evolution of the quarkonia, and we show that the validity of the adiabaticity assumption is questionable. This suggests that a given quark-antiquark pair is in a constantly changing linear combination of instantaneous energy eigenstates. As a consequence, one should explicitly follow the evolution of the pair in the QGP, using a dynamical microscopic description which seems to be possible by studying quarkonia as open quantum system.

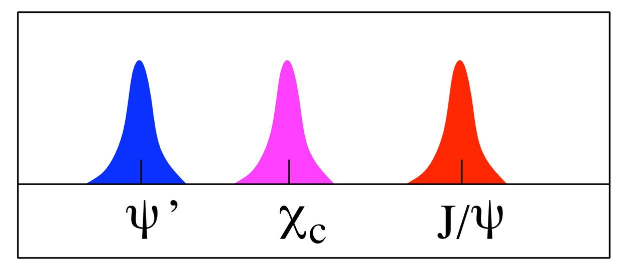

## SEQUENTIAL SUPPRESSION FOR STATIC MEDIUM

1. Potential modeling using lattice QCD and effective theory based on in medium effective potential.

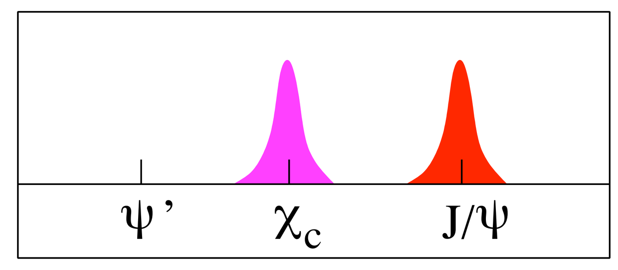
$$V(r) \sim \frac{\frac{4}{3}\alpha_s(T)}{r}\, e^{-A\sqrt{1+N_f/6}\,T g_{2\,\mathrm{loop}}(T)\, r}$$

Some recent studies shows an imaginary part in the potential which indicates finite life time for quarkonium states.

2. Studying spectral function using lattice QCD.




T < $T_c$




T ~ $T_c$

! The prediction of lattice or effective models strictly speaking do not address J/Ψ, Ψ,…or Υ(1S), Υ(2S)…, but the 1S, 2S states of the corresponding potential found at a given temperature. Connecting these to the vacuum quarkonia states then relies on **ADIABATIC APPROXIMATION**.

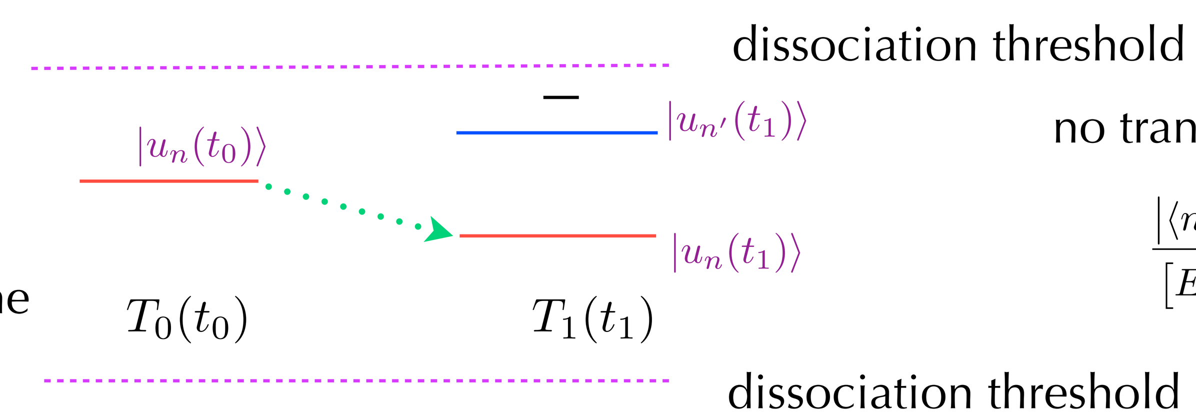
## EVOLVING MEDIUM

*At $t = t_0$ $n-th$ energy eigen state of $q\bar{q}$ pair corresponding to the potential $V(T_0)$ is in the medium. What will be the new state at $t = t_1$ when the medium evolves to a temperature $T_1$?*

**Two possibilities !**

1. Slow Evolution : The pair could constantly adapt and is in n-th eigenstate corresponding to the potential $V(T_1)$.

2. Rapid Evolution : The state of the pair then overlaps with more than one eigenstate of the corresponding potential.




no transition from n to $n'$ if

$$\frac{|\langle n'(t)|\dot{V}(t)|n(t)\rangle|}{[E_n(t)-E_{n'}(t)]^2} \ll 1,$$

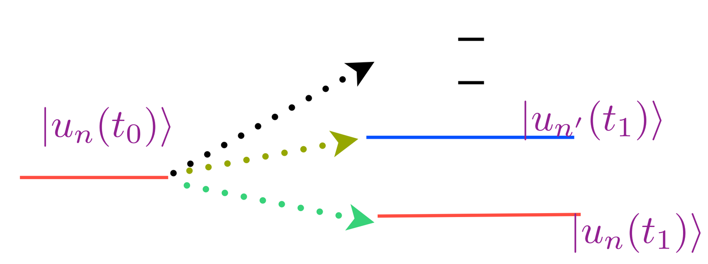
In Heavy Ion Collision $\dot{T} \approx 30\ MeV/\mathrm{fm}$

$$\dot{T}\,\frac{|\langle n'(t)|\frac{dV}{dT}|n(t)\rangle|}{[E_n(t)-E_{n'}(t)]^2}$$

$\approx 200-500$ MeV· fm

$\approx (80-160\ MeV)^2$

In some channel the ratio is very large (even more than 1.)

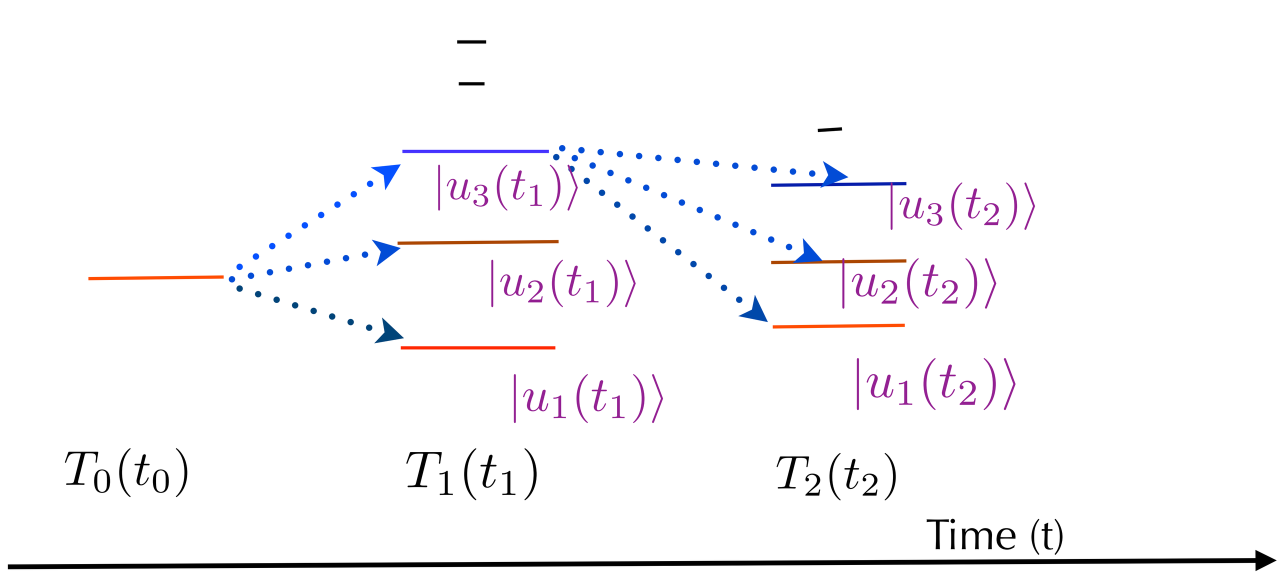


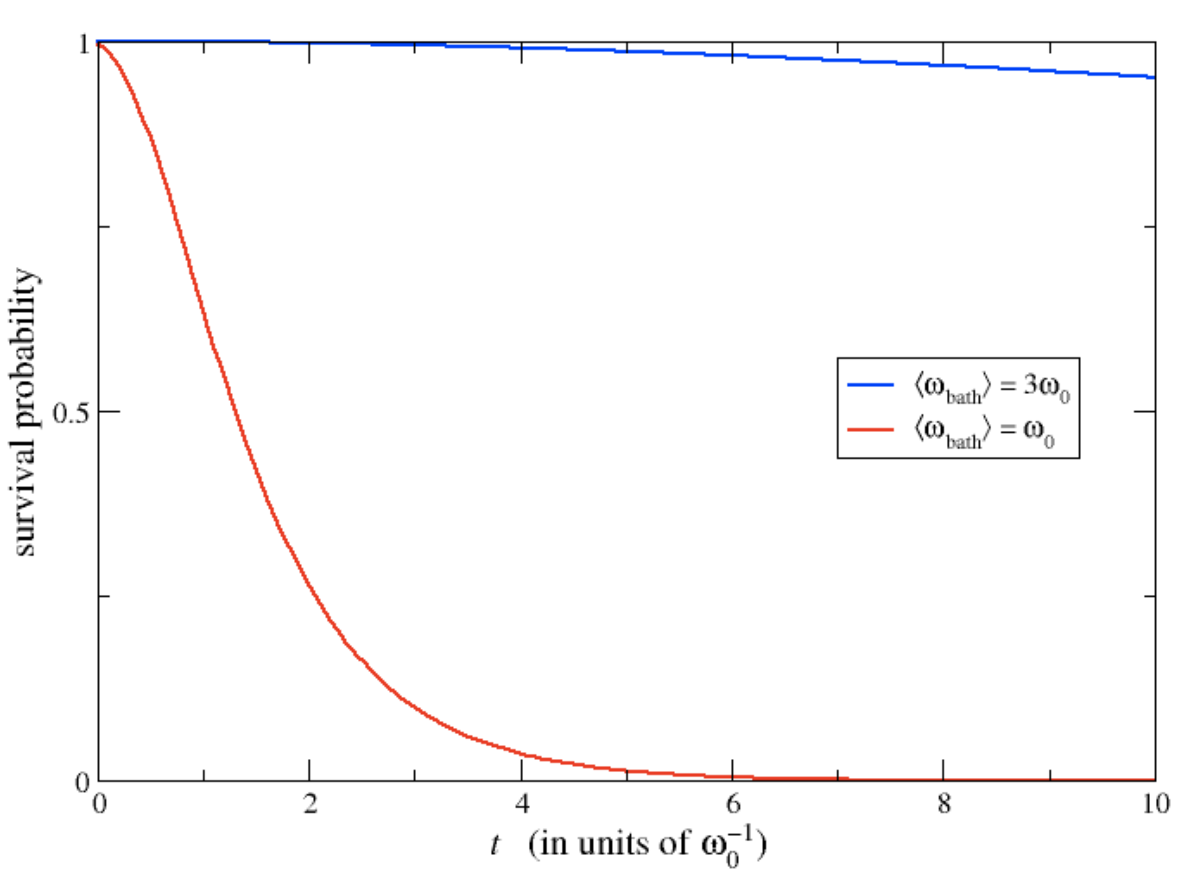

"Reshuffling"

See more on arXiv:1206.2149v1[nucl-th]

!In a rapidly evolving medium thermal effective potential might not be usefull to describe quarkonium states. Therefore a dynamical picture is needed.

## MORE REALISTIC PICTURE : an attempt




Harmonic oscillator as an exploratory model

### OPEN SYSTEM

The medium interacts with quarkonia and exchanges energy and momentum.

$$L = L_{Q\bar{Q}} + L_M + L_I$$

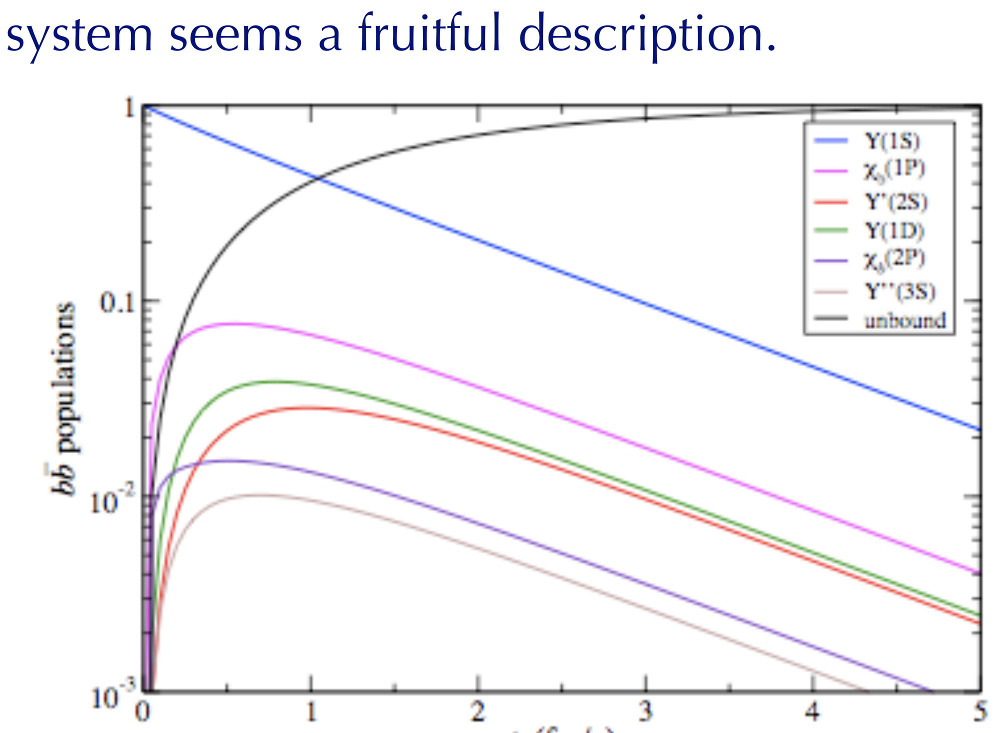
The realistic way to see quarkonia as an open system interacting with the medium.

$$P_{n,m} = \int \Psi_n(Q'_t)\Psi_n^\star(Q_t)\exp[i(S_0(Q)-S_0(Q'))]F(Q,Q')\Psi_m^\star(Q_\tau)\Psi_m(Q'_\tau)dQ_\tau dQ_\tau dQ_t dQ'_t \mathcal{D}Q\mathcal{D}Q'$$

$F(Q,Q')$ quantifies the influence of the medium to the quarkonium

### CONCLUSION

1. A possible scenario " partial reshuffling of $q\bar{q}$ states" due to the rapid evolution of the medium.
2. A dynamical picture is needed to address the problem.
3. Analogy with the open quantum system seems a fruitful description.




Evolution of different bottomonium states

Log Plot for 5 $T_c$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