Can Quarkonia Survive Deconfinement?

Ágnes Mócsy

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

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- what motivated this work
- our approach to determine quarkonium properties
- quarkonia in a gluon plasma
- quarkonia in a quark-gluon plasma
- upper limits on dissociation temperatures

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0706.2183[hep-ph]

Content of This Talk

what motivated this work

Quarkonium properties at high T interesting

- proposed signal of deconfinement Matsui,Satz, PLB 86
- matter thermometer Karsch,Mehr,Satz, ZPhysC 88
- possibility of bound states in deconfined medium Shuryak,Zahed PRD 04

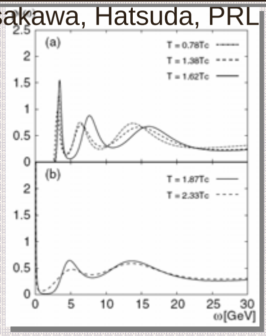
Need to calculate quarkonium spectral function because

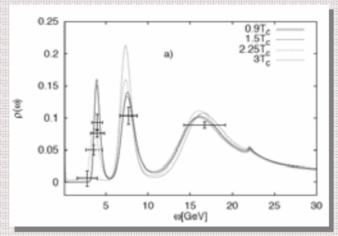
- quarkonium well defined at T=0, but can broaden at finite T
- spectral function contains all information about a given channel: unified treatment of bound states, threshold, continuum
- can be related to experiments

Introduction

Spectral Functions

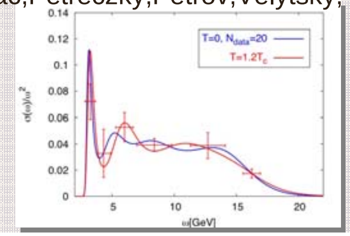
Asakawa, Hatsuda, PRL 04



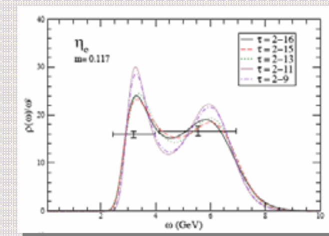


Datta, Karsch, Petreczky, Wetzorke PRD 04

Jakovác,Petreczky,Petrov,Velytsky, PRD 07

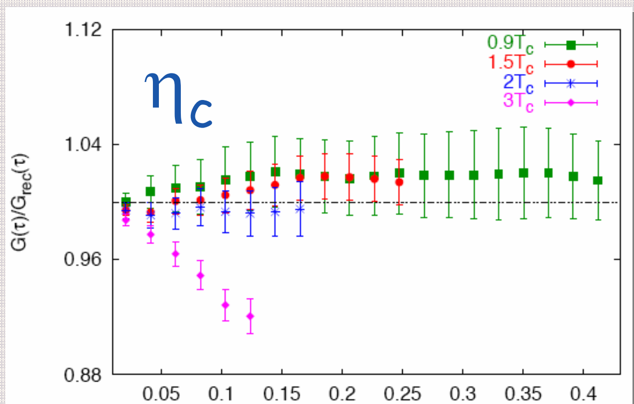


see talk by Péter Petreczky

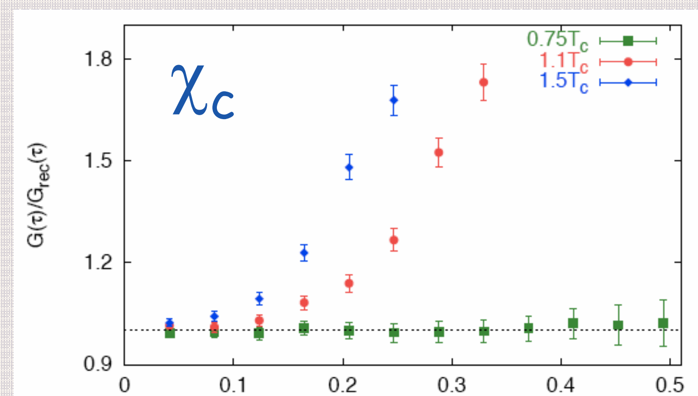


Aarts, Allton, Oktay, Peardon, Skullerud hep-lat/0705.2198

Correlators



Datta et al PRD 04



Datta et al PRD 04

Conclusions drawn from analysis of lattice data:

- J/ψ and η_c survive up to 2 Tc → "quarkonium survival"
- χ_c melts by 1.1 Tc
- χ_b melts by 1.1 Tc →"χ_b puzzle"

based on spectral functions from MEM and (un)modifications of G/G_{rec}

"J/ψ survival" in LQCD

series of potential model studies

with potentials connected to lattice free and internal energy

Shuryak,Zahed PRD 04
Wong, PRC 05
Alberico et al PRD 05
Cabrera, Rapp 06
Alberico et al PRD 07
Wong,Crater PRD 07

Conclusions
- states survive
- dissociation temperatures quoted
- agreement with lattice is claimed

Dissociation temperatures in quenched QCD

States	Spectral analysis	W_1 potential	F_1 potential	U_1 potential
J/ψ, η_c	1.62–$1.70T_c$ [a]	$1.62T_c$	$1.40T_c$	$2.60T_c$
χ_c	Below $1.1T_c$ [b]	Unbound in QGP	Unbound in QGP	$1.18T_c$
ψ', η_c'		Unbound in QGP	Unbound in QGP	$1.23T_c$
Υ, η_b		$4.1T_c$	$3.5T_c$	$\sim 5.0T_c$
χ_b	1.15–$1.54T_c$ [c]	$1.18T_c$	$1.10T_c$	$1.73T_c$
Υ', η_b'		$1.38T_c$	$1.19T_c$	$2.28T_c$

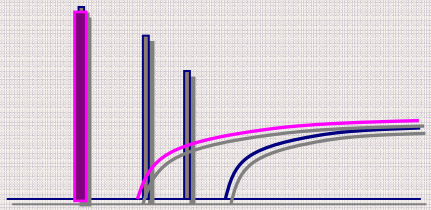
T	0	$1.13T_c$	$1.18T_c$	$1.25T_c$	$1.4T_c$	$1.6T_c$	$1.95T_c$	$2.60T_c$
$C(T)$		0.2962	0.2710	0.2476	0.2218	0.1991	0.1620	0.1094
Bound state energy $\epsilon(T)$		−0.0340	−0.02078	−0.0105	−0.0036	−0.00019	Unbound	Unbound
Mass $M(T)$	3.064	3.082	3.070	3.057	3.038	3.019		

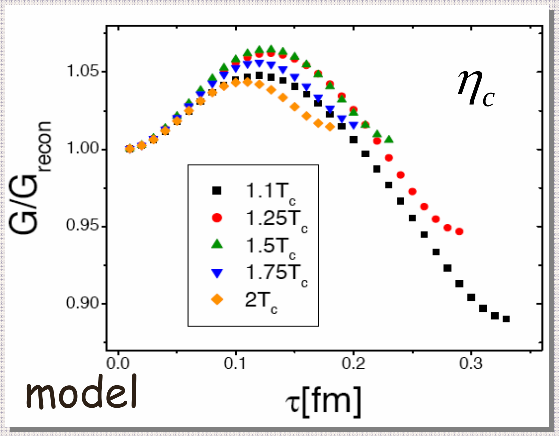
Wong,Crater, PRD 07

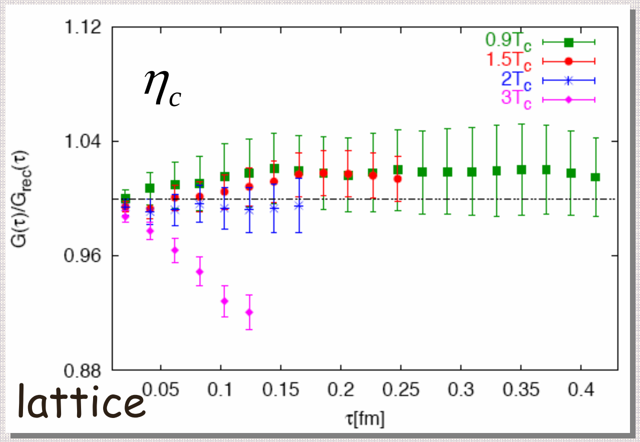
"J/ψ survival" in Potential Models

use a simplified model: discrete bound states + perturbative continuum

Mócsy, Petreczky EJPC 05
PRD 06







correlators calculated in this approach do not agree with lattice

What is the source of these inconsistencies?

validity of potential models?

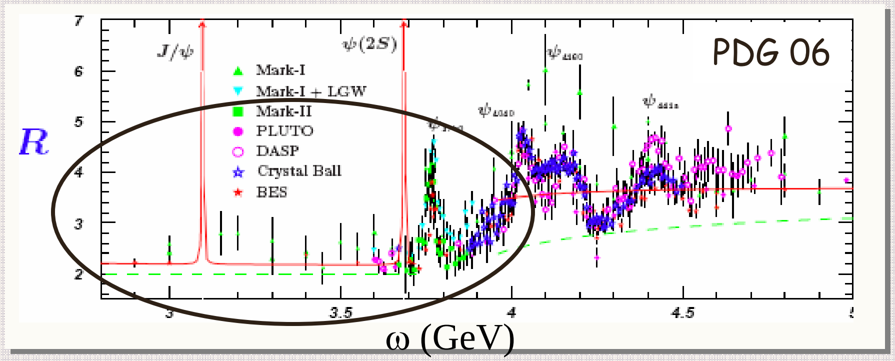
finding the right potential?

relevance of screening for quarkonia dissociation?

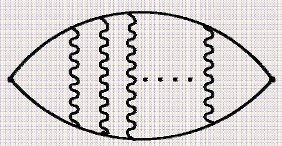
Our Initial Attempt

our recent approach to determine quarkonium properties

- bound states/resonances & - continuum above threshold



$\omega \sim M_{J/\psi}$, s_0 nonrelativistic



medium effects - important near threshold

re-sum ladder diagrams first in vector channel Strassler,Peskin PRD 91

also Casalderrey-Solana,Shuryak 04

$$\sigma(E) = \frac{2N_c}{\pi} \mathrm{Im} G^{NR}(\vec{r},\vec{r}',E)_{\vec{r}=\vec{r}'=0}$$

S-wave

$$\sigma(E) = \frac{2N_c}{\pi}\frac{1}{m^2} \vec{\nabla}\cdot\vec{\nabla}' \mathrm{Im} G^{NR}(\vec{r},\vec{r}',E)_{\vec{r}=\vec{r}'=0}$$

P-wave

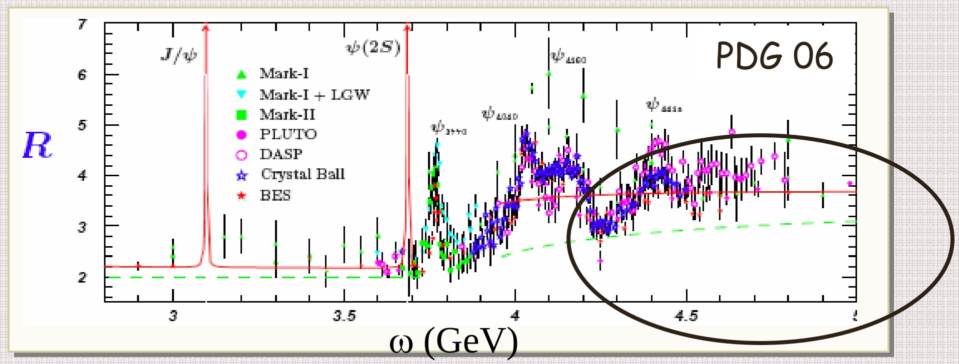
$$\left[-\frac{1}{m}\nabla^2 + V(\vec{r}) + E\right] G^{NR}(\vec{r},\vec{r}',E) = \delta^3(\vec{r}-\vec{r}')$$

nonrelativistic Green's function

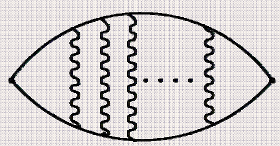
S-wave also Cabrera,Rapp 07

Spectral Function

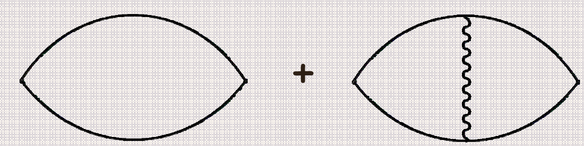
- bound states/resonances & - continuum above threshold



$\omega \sim M_{J/\psi}, s_0$ nonrelativistic



$\omega >> s_0$ perturbative



$$\sigma_{pert} \cong \omega^2 \frac{3}{8\pi}\left(1+\frac{11}{3\pi}\alpha_s\right)$$

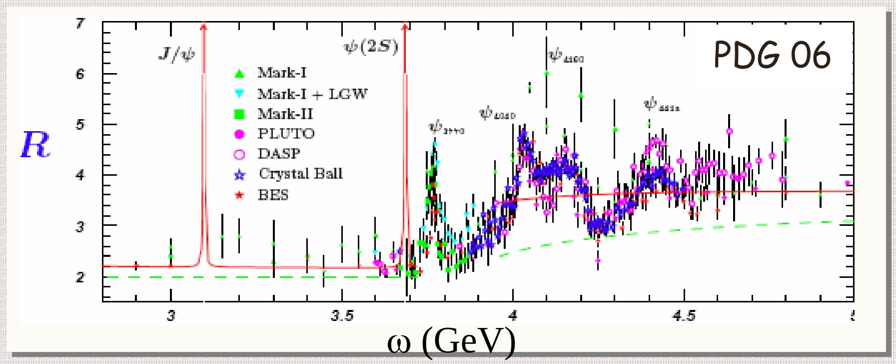
nonrelativistic Green's function

$$\left[-\frac{1}{m}\nabla^2 + V(\vec{r}) + E\right] G^{NR}(\vec{r},\vec{r}\,',E) = \delta^3(\vec{r}-\vec{r}\,')$$

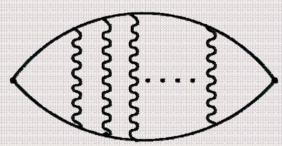
$$\sigma \propto \frac{1}{\pi}\mathrm{Im}G^{NR}$$

Spectral Function

- bound states/resonances & - continuum above threshold

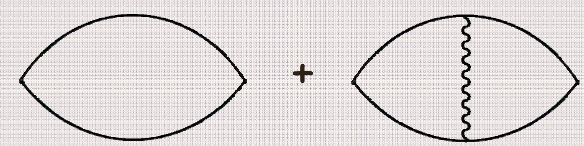


$\omega \sim M_{J/\psi}$, s_0 nonrelativistic $\omega >> s_0$ perturbative



smooth matching

details do not influence the result



$$\left[-\frac{1}{m}\nabla^2 + V(\vec{r}) - E\right] G^{NR}(\vec{r},\vec{r}',E) = \delta^3(\vec{r}-\vec{r}')$$

nonrelativistic Green's function + pQCD

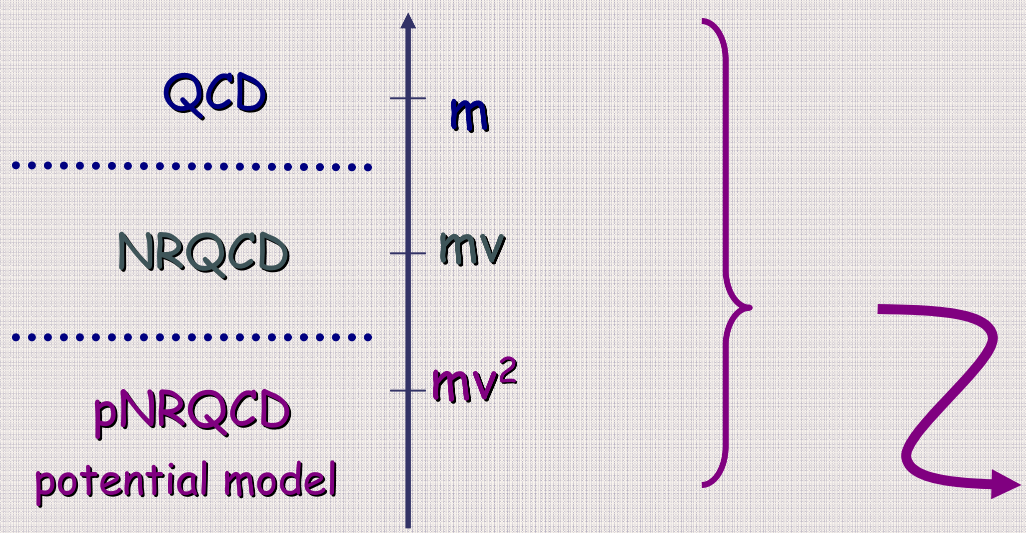
Unified treatment: bound- and scattering states, threshold effects together with relativistic perturbative continuum

Spectral Function

T=0 potential can be derived

Brambilla et al, CERN Yellow Report 05

T=0 hierarchy of energy scales



Cornell potential

$$V(r) = -\frac{a}{r} + \sigma r$$

- describes quarkonium spectra
- confirmed on lattice

Potential at T=0

T>0 potential is unknown: use a phenomenological potential constrained by lattice data

Free energy - contains negative entropy contribution

- provides a lower limit for the potential

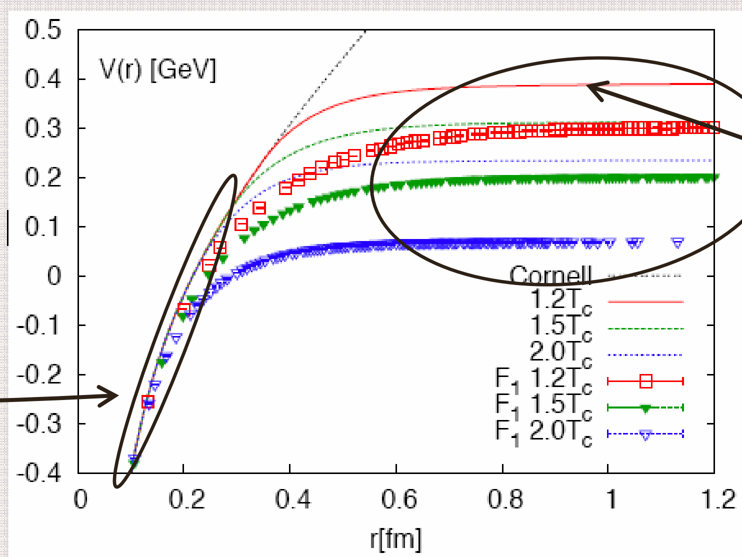
see talk by Péter Petreczky

Potential assumed to share general features with the free energy

$r < r_{med}$

no temperature effects

$$V(r,T) = -\frac{\alpha}{r} + r\sigma$$



$r > r_{med}$

strong screening effects

$$V(r,T) = V_\infty(T) - \frac{\alpha_1(T)}{r} e^{-\mu(T) r}$$

$$V_\infty(T) = r_{med}(T)\sigma > F_1^\infty(T)$$

subtract entropy

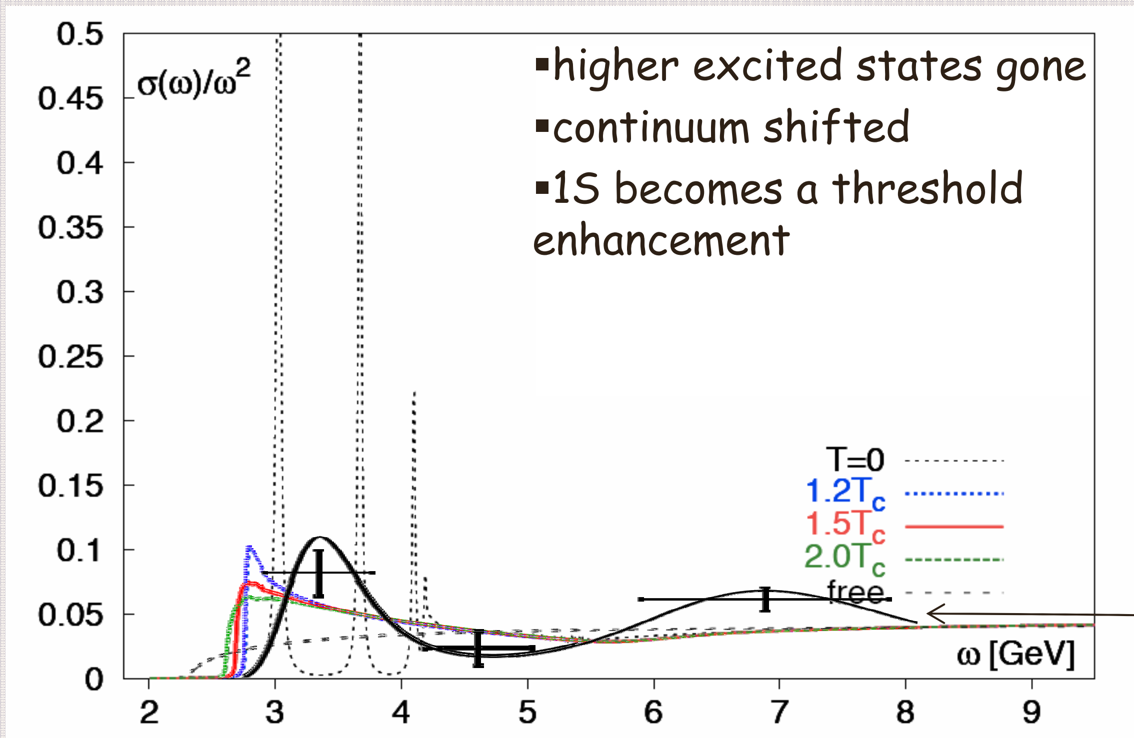
also motivated by Megías,Arriola,Salcedo PRD07

Constructing the Potential at $T>T_c$

quarkonia in a gluon plasma

Mócsy, Petre□czky hep-ph/0705.2559

η_c



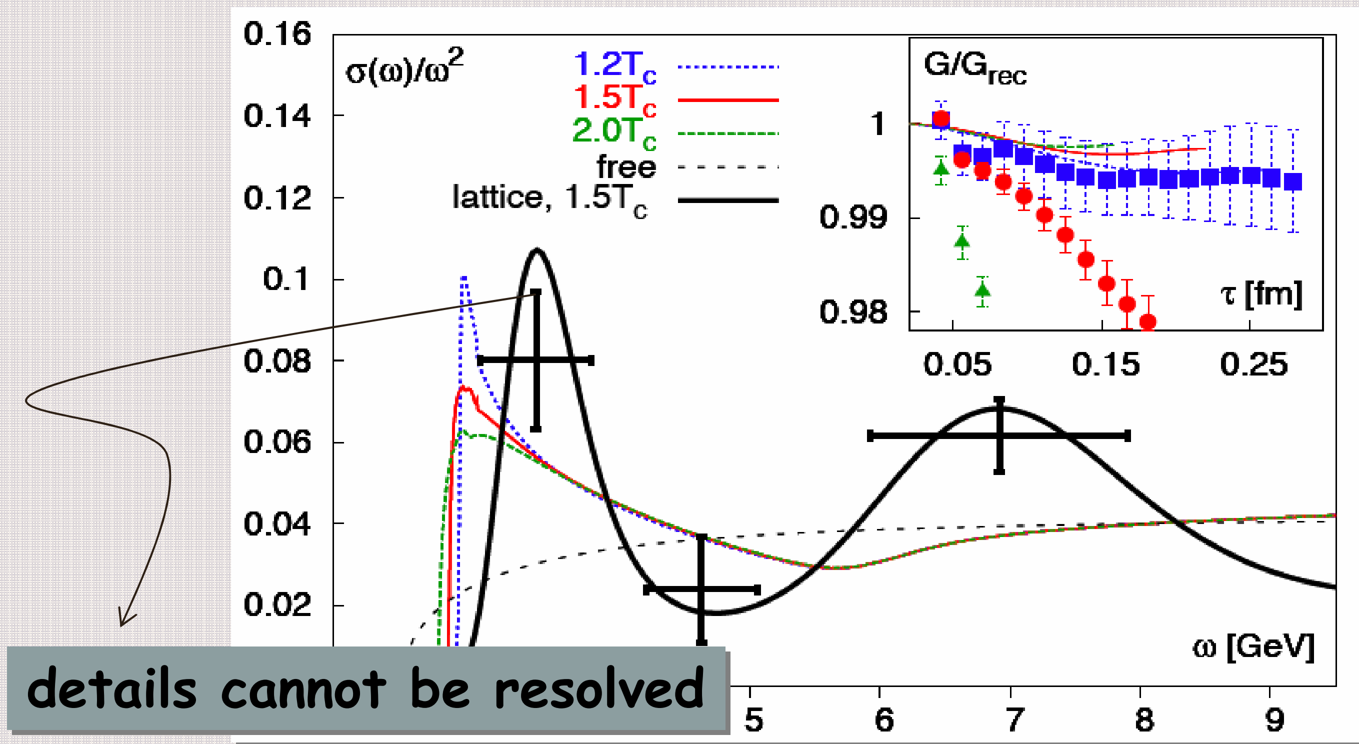
lattice

Jakovác,Petreczky, Petrov,Velytsky, PRD07

- resonance-like structures disappear already by 1.2Tc
- strong threshold enhancement
- contradicts previous claims

S-wave Charmonium in Gluon Plasma

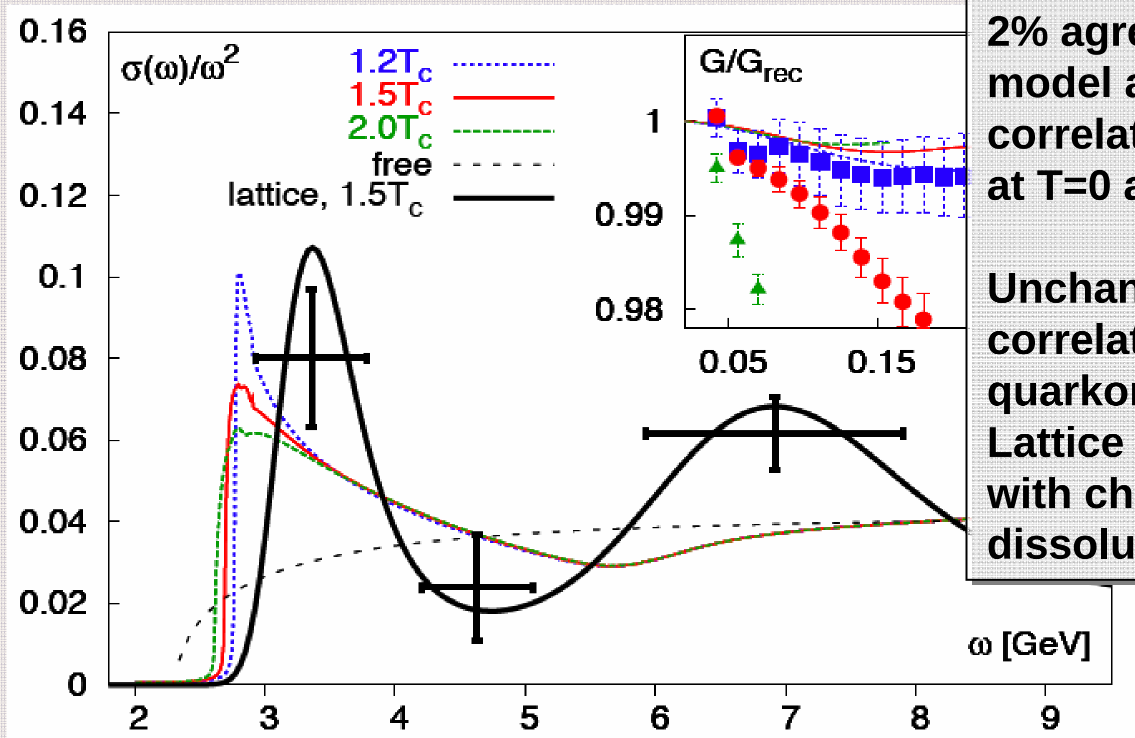
Mócsy, Petre□czky hep-ph/0705.2559



- resonance-like structures disappear already by $1.2T_c$
- strong threshold enhancement above free case indication of correlation
- height of bump in lattice and model are similar

S-wave Charmonium in Gluon Plasma

Mócsy, Petre□czky hep-ph/0705.2559



N.B.: 1st time 2% agreement between model and lattice correlators for all states at T=0 and T>T_c

Unchanged LQCD correlators do not imply quarkonia survival: Lattice data consistent with charmonium dissolution just above T_c

LQCD measures correlators

$$G(\tau,T)=\int\sigma(\omega,T)K(\tau,\omega,T)d\omega \qquad G_{rec}(\tau,T)=\int d\omega\sigma(\omega,T=0)K(\omega,\tau,T)$$

$$\frac{G(\tau,T)}{G_{rec}(\tau,T)}=1$$

spectral function unchanged across deconfinement

or… integrated area under spectral function unchanged

S-wave Charmonium in Gluon Plasma

constant contribution in the correlator at finite T

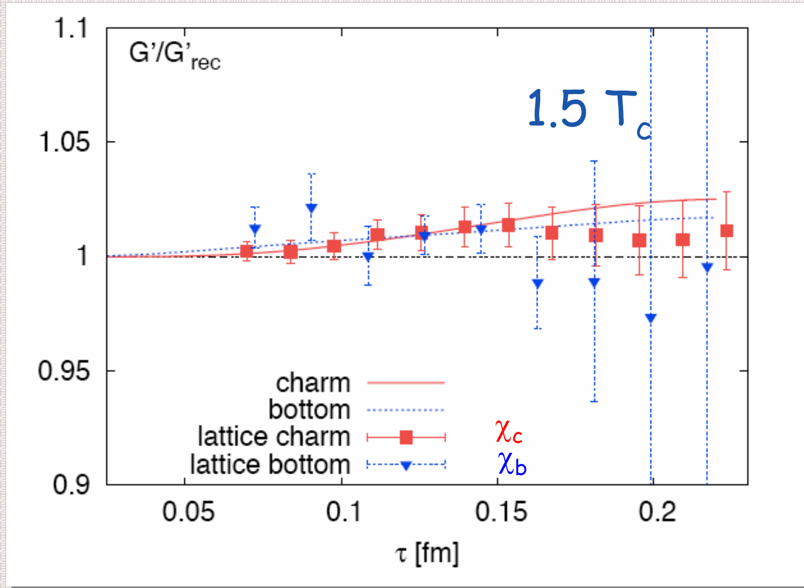
$$\sigma_i(\omega,T) = \sigma_i^{high}(\omega,T) + \chi_i^s(T)\omega\delta(\omega)$$

so look at the derivative

following Umeda 07

$$G_i^{low}(T) = T\chi_i^s(T)$$

quark number susceptibility

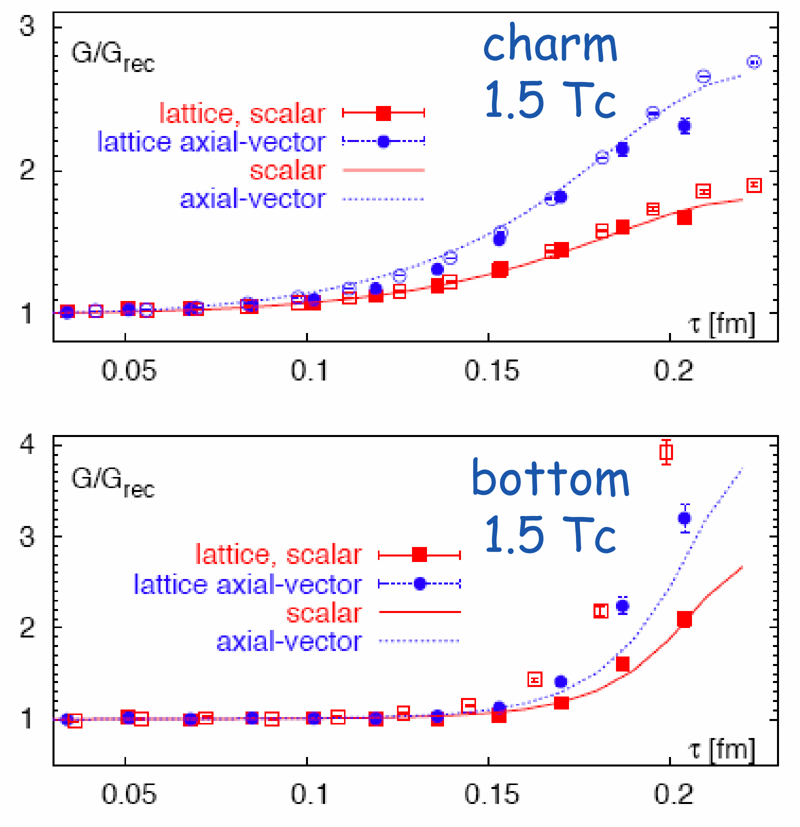


Threshold enhancement of spf compensates for dissolution of states

Agreement with lattice data for scalar charmonium and bottomonium

$\rightarrow \chi_b$ *"puzzle" resolved*

Agreement for P-wave as well



$$G_i^{low}(T) = T\chi_i^s(T)$$

$$\chi_{sc}^s(T) = \frac{6m_{c,b}^2}{\pi^2}\int_0^\infty dp p^2 \frac{1}{E_p^2}\left(-\frac{\partial n_F}{\partial E_p}\right)$$

in free theory

$\exp(-m_{c,b}/T)$ >> $\exp(-3m_{c,b}/T)$

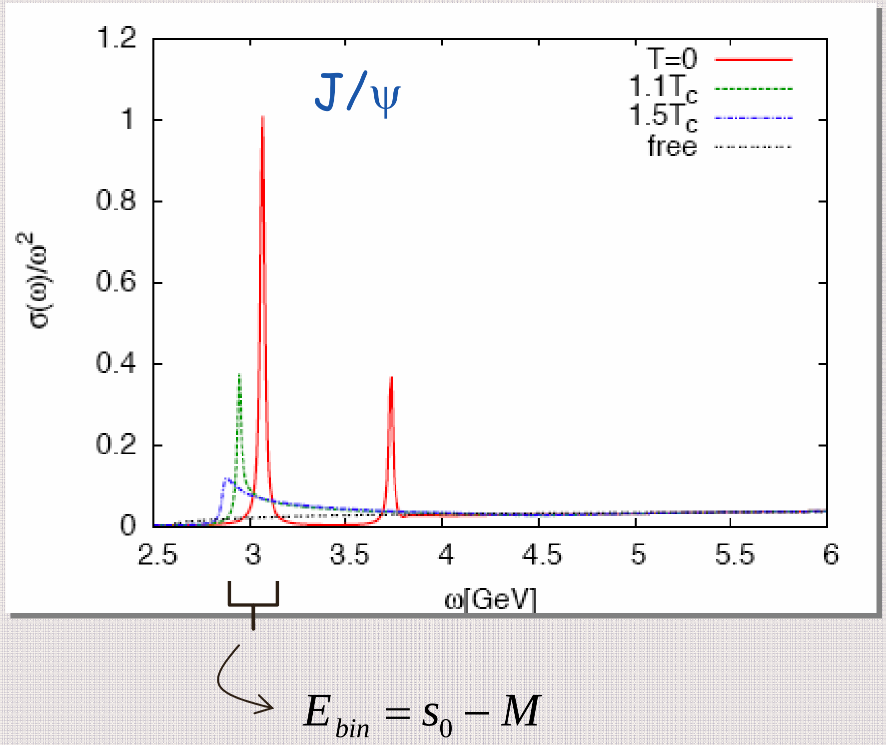
deconfined confined

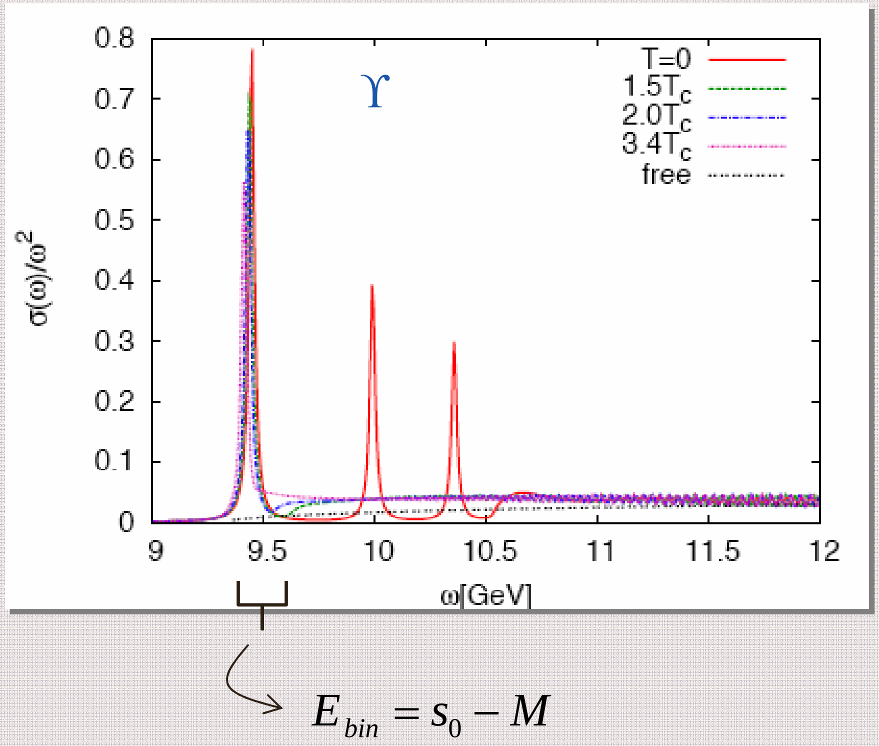
behavior explained using ideal gas expression for susceptibilities:

indicates deconfined heavy quarks carry the quark-number at 1.5 T_c

P-wave

quarkonia in a quark-gluon plasma





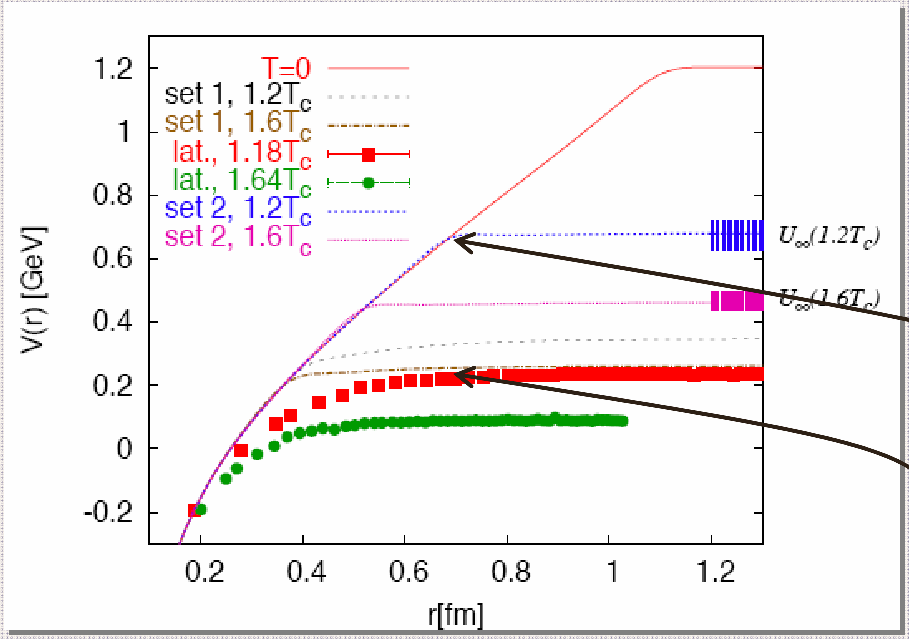
- J/ψ at 1.1T_c is just a threshold enhancement
- ϒ(1S) survives up to ~2T_c with unchanged peak position, but reduced binding energy
- Strong enhancement in threshold region - Q and antiQ remain correlated

S-wave Quarkonium in QGP

upper limits on dissociation temperatures

Find upper limit for binding

need strongest confining effects = largest possible r_{med}



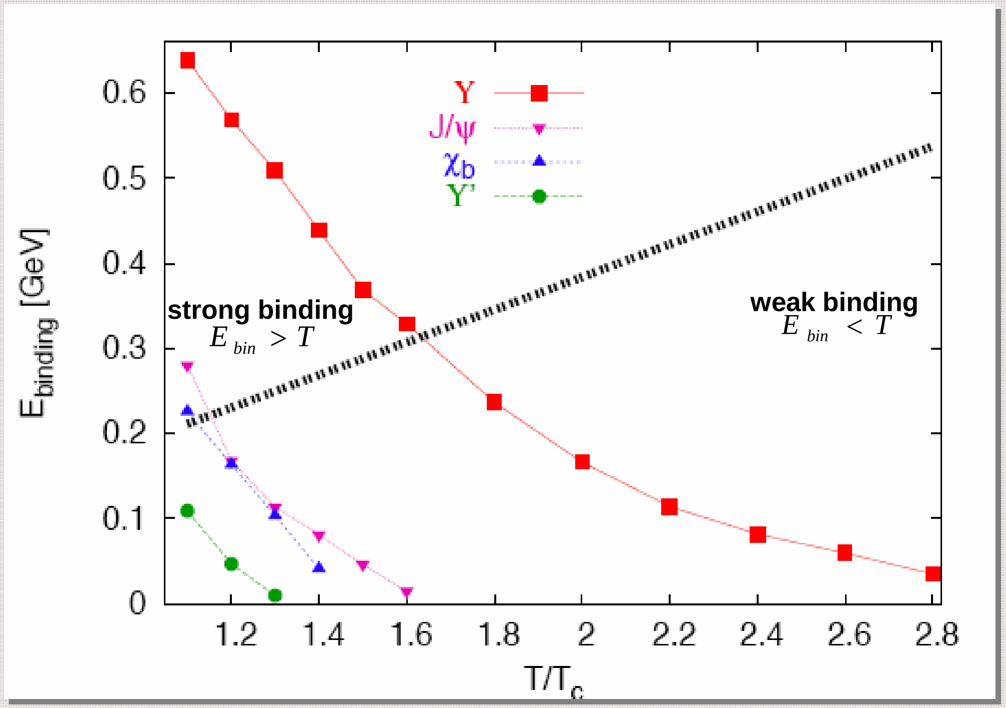
r_{med} = distance where exponential screening sets in

NOTE: uncertainty in potential - have a choice for r_{med} or V_∞
our choices physically motivated
all yield agreement with correlator data

Most Binding Potential

When binding energy drops below T

- state is weakly bound
- thermal fluctuations can destroy the resonance



Upsilon remains strongly bound up to 1.6T_c
Other states are weakly bound above 1.2T_c

Binding Energy Upper Limits

Rate of escape into the continuum due to thermal activation

= thermal width $\Gamma \to$ related to the binding energy

Kharzeev, McLerran, Satz PLB 95

$$E_{bin} = s_0 - M_{Q\bar{Q}}$$

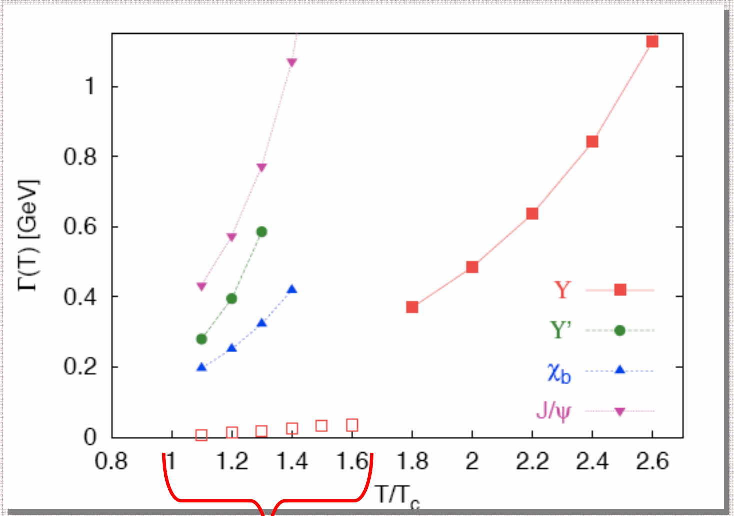
for weak binding: $E_{bin}<T$

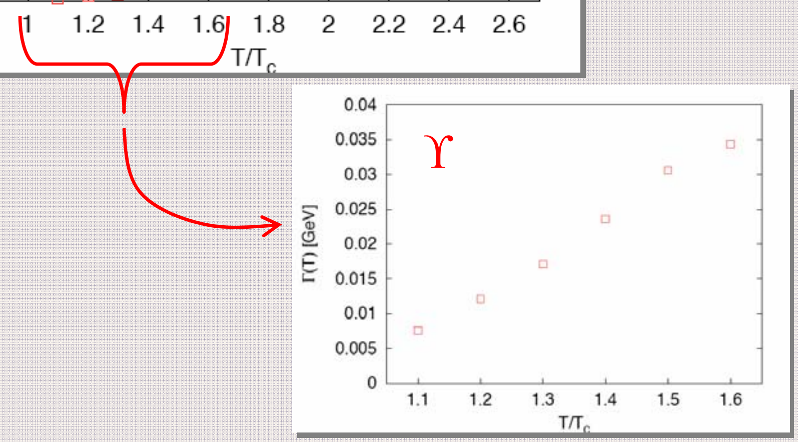
$$\Gamma = \frac{4}{L}\sqrt{\frac{T}{2\pi m}}$$

$$L \approx r_0 - r_{Q\bar{Q}}$$

for strong binding $E_{bin}>T$

$$\Gamma = \frac{(LT)^2 m}{3\pi}\exp\left(-\frac{E_{bin}}{T}\right)$$





Thermal Dissociation Widths

Upper bounds on dissociation temperatures

condition: thermal width > 2x binding energy

$$\Gamma(T) \geq 2E_{bin}(T)$$

state	χ_c	ψ'	J/ψ	Υ'	χ_b	Υ
T_{dis}	$\leq T_c$	$\leq T_c$	$1.2T_c$	$1.2T_c$	$1.3T_c$	$2T_c$

Can Quarkonia Survive?

Quarkonium spectral functions can be calculated within a potential model with screening - reliable description of quarkonium dissociation at high T

Lattice correlators have been explained correctly for the 1st time

Unchanged correlators do not imply quarkonia survival: **lattice data are consistent with charmonium dissolution just above T_c**

Contrary to previous statements, we find that all states except Υ and η_b are dissolved by at most 1.3 T_c

Threshold enhancement found: spectral function enhanced over free propagation =>> correlations between Q-antiQ may remain strong

Outlook

Implications for heavy-ion phenomenology need to be considered

Conclusions

****The END****