Charm properties in the quark–gluon plasma

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Outline

Background
  Spectral functions
  QCD with 2 light quarks

Results
  Reconstructed correlators
  MEM systematics
  Temperature dependence

Summary and outlook
Background
Background

- $J/\psi$ suppression — a probe of the quark–gluon plasma?
- Quenched lattice results indicate that S-waves survive well into the plasma phase
- Sequential charmonium suppression + recombination explains experimental results?
- Uncertainty about which potential to use in potential models, how to treat continuum
- How reliable are quenched lattice simulations?
Quenched vs dynamical

Are quenched lattice results reliable?

- \( T_{c}^{N_f=0} = 270 \text{MeV} \), \( T_{c}^{N_f=2} \approx 180 \text{MeV} \), \( T_{c}^{N_f=2+1} \approx 170 \text{MeV} \)
- Light quarks can catalyse \( Q \bar{Q} \) dissociation so it occurs at lower temperature
- Lower \( T_c \), lower \( T_d \) — conspire to give the same \( T_d/T_c \)?
- Potential models indicate little change in \( T_d/T_c \)
Quenched vs dynamical

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- Light quarks can catalyse $Q\bar{Q}$ dissociation so it occurs at lower temperature
- Lower $T_{c}$, lower $T_{d}$ — conspire to give the same $T_{d}/T_{c}$?
- Potential models indicate little change in $T_{d}/T_{c}$
- Only dynamical lattice calculations can give the answer
Dynamical anisotropic lattices

- A large number of points in time direction required
- For $T = 2T_c$, $O(10)$ points $\Rightarrow a_t \sim 0.025$ fm
- Far too expensive with isotropic lattices $a_s = a_t$!
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- Introduces 2 additional parameters
- Non-trivial tuning problem [PRD 74 014505 (2006)]
Spectral functions

- contain information about the fate of hadrons in the medium
  - stable states $\rho(\omega) \sim \delta(\omega - m)$
  - resonances or thermal width $\rho(\omega) \sim$ Lorentzian...
  - continuum above threshold

- can be used to extract transport coefficients
Spectral functions

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- $\rho_\Gamma(\omega, \vec{p})$ related to euclidean correlator $G_\Gamma(\tau, \vec{p})$ according to

\[
G_\Gamma(\tau, \vec{p}) = \int \rho_\Gamma(\omega, \vec{p}) \frac{\cosh[\omega(\tau - 1/2T)]}{\sinh(\omega/2T)} d\omega
\]

- an ill-posed problem — requires a large number of time slices
- use Maximum Entropy Method to determine most likely $\rho(\omega)$
Simulation parameters

[arXiv:0705.2198]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Light quarks</td>
<td>$m_\pi/m_\rho$</td>
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<td>Anisotropy</td>
<td>$\xi$</td>
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<td>Lattice spacing</td>
<td>$a_\tau$</td>
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<td>1/Temperature</td>
<td>$N_\tau$</td>
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Reconstructed correlators

We use $N_{\tau} = 32$ as our reference temperature
Reconstructed correlators

![Graph showing reconstructed correlators](image)

- **$\chi_{c0}$**
- **$\chi_{c1}$**

Parameters:
- $N_t = 33$
- $N_t = 31$
- $N_t = 30$
- $N_t = 29$
- $N_t = 28$
- $N_t = 24$
MEM systematics

\[ \eta_c \]
\[ m = 0.117 \]
MEM systematics

\[ \rho(\omega) \]

\[ \omega \text{ (GeV)} \]

\[ m(\omega) = 0.3\omega^2 \]

\[ m(\omega) = 8.0\omega^2 \]

\[ m(\omega) = 80\omega^2 \]

\[ m(\omega) = 1.0(\omega+\omega^2) \]

\[ m(\omega) = 12.0(\omega+\omega^2) \]

\[ m(\omega) = 0.0064 \]

\[ m(\omega) = 0.248\omega \]
Statistics

\[ \eta_c \]

\[ m = 0.117 \]
Using $m_0 = 16$ — third peak appears for high statistics??
P-wave systematics

\[ \chi_{c1} \]

\[ m = 0.092 \]
Systematics at $N_\tau = 24$

\[ \eta_c \quad m = 0.117 \]
Systematics at $N_\tau = 24$

![Graph showing the correlation functions with different mass terms](image)

- $\eta_c$
  - $m = 0.092$

Graph parameters:
- $m(\omega) = 0.3\omega^2$
- $m(\omega) = 8.0\omega^2$
- $m(\omega) = 80\omega^2$
- $m(\omega) = 2.0(\omega + \omega^2)$
- $m(\omega) = 20(\omega + \omega^2)$
- $m(\omega) = 0.0324$
- $m(\omega) = 0.9564\omega$
S-wave T dependence ($\eta_c$)
S-wave T dependence ($\eta_c$)

\[ \eta_c \]

\[ m = 0.092 \]
S-wave T dependence ($\eta_c$)
S-wave T dependence ($J/\psi$)

$J/\psi$ (S-wave) melts at $T > 400$ MeV or $2T_c$?
S-wave T dependence ($J/\psi$)

$J/\psi$ (S-wave) melts at $T > 400$ MeV or $2T_c$?
P-waves melt at $T < 250 \text{ MeV}$ or $1.2 T_c$?
Outlook
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▶ Charm flow
  → Diffusion constant related to \( \lim_{\omega \to 0} \frac{\rho \nu(\omega)}{\omega} \)
  → Can this be determined using MEM?
  → Use \( m(\omega) = m_0 \omega (b + \omega) \), vary \( b \)
Outlook

- **Charm flow**
  - Diffusion constant related to $\lim_{\omega \to 0} \rho_V(\omega)/\omega$
  - Can this be determined using MEM?
  - Use $m(\omega) = m_0\omega(b + \omega)$, vary $b$

- **Nonzero momentum**
  - Charmonium is produced at nonzero momentum
  - Transverse momentum (and rapidity) distributions important to distinguish between models
  - Momentum dependent binding?
  - Gives an additional window to transport properties
  - Simulations getting underway
Outlook

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  → Diffusion constant related to \( \lim_{\omega \to 0} \rho V(\omega)/\omega \)
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▶ \( D \) and \( B \) mesons

▶ non-zero chemical potential

▶ ....
Summary
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- Charmonium S-waves survive to $T \sim 2T_c$
- P-waves melt at $T < 1.3T_c$
- Consistent with sequential suppression:
  - $60\%$ of $J/\psi$ production is direct, the rest is feed-down from $\psi', \chi_c$
  - Observed suppression at SPS, RHIC is feed-down
  - Direct suppression not yet observed — may be seen at ALICE?
- Charmonium regeneration complicates picture!
- Systematic uncertainties:
  - Dependence on default model?
  - Coarse lattice $\rightarrow$ doubler peak uncomfortably close
  - Cannot distinguish bound state vs threshold
  - Coarse lattice $\rightarrow$ hard to reach high temperatures
- Simulations on finer lattices planned
- Simulations with lighter sea quarks in preparation