Non-relativistic bound states across a thermal medium

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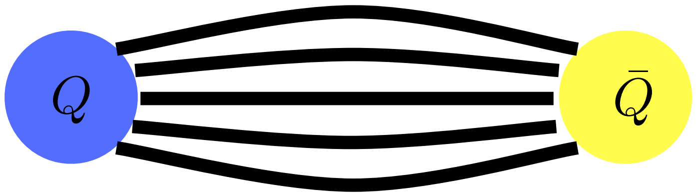
In collaboration with M.A.Escobedo and J. Soto, **Phys.Rev. D84 (2011) 016008**

Outline

- Heavy quarkonia as a thermometer
- Dissociation processes:
  Debye screening vs. Landau damping
- Moving bound state
- Velocity dependent EFT
- Conclusions

Dissociation of heavy quarkonia

In vacuum, the static chromo-electric field leads to the formation of a heavy quark bound state. Very similar to (muonic) hydrogen.



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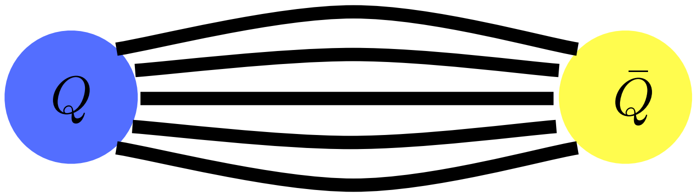

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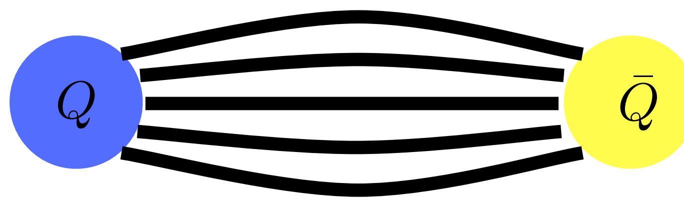

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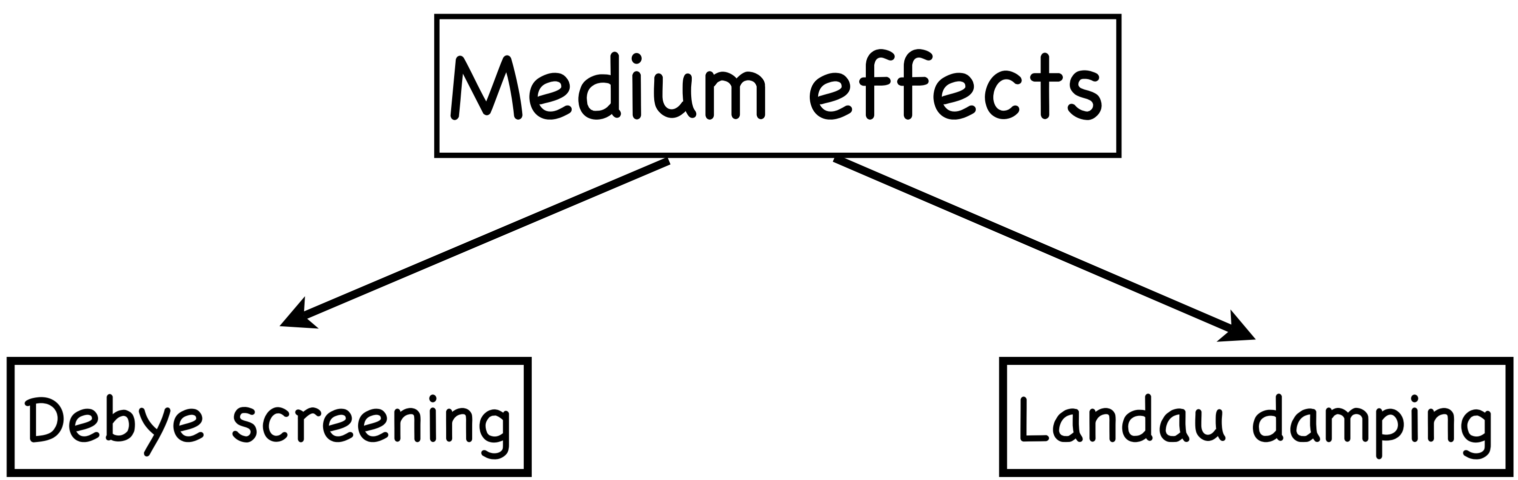
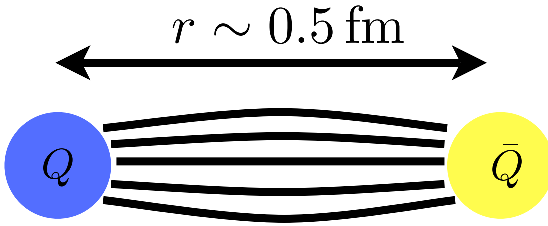


Debye Screening



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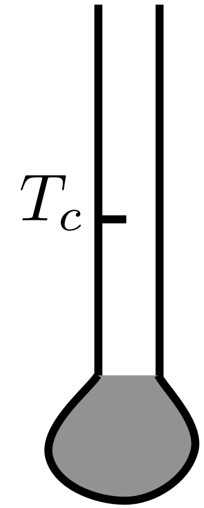

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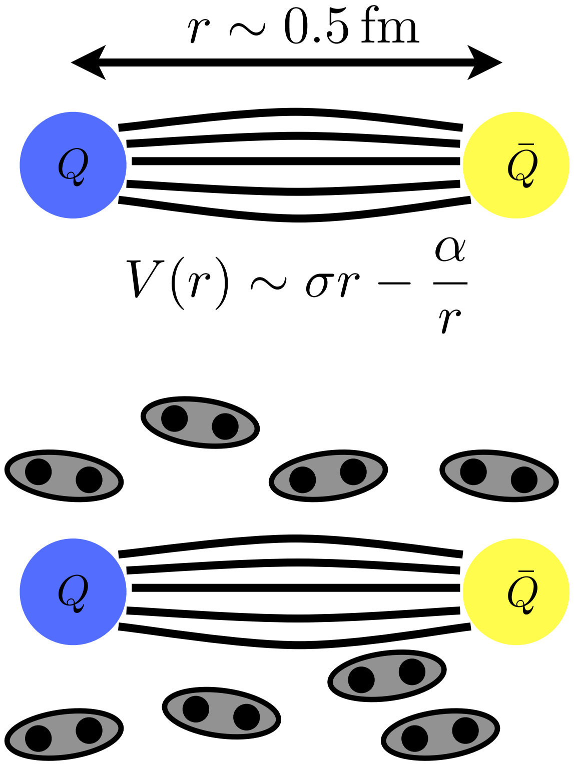

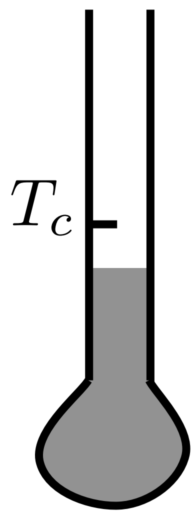

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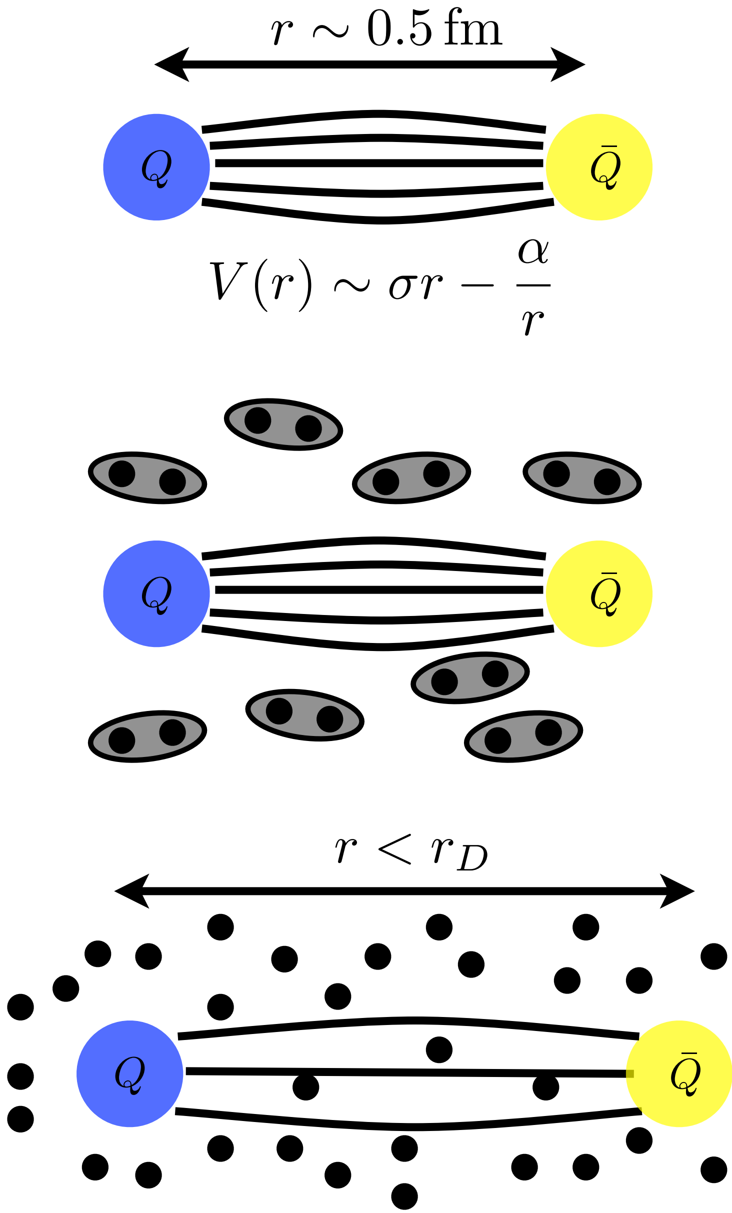

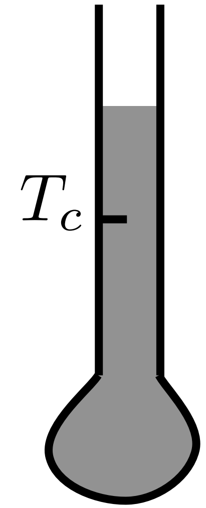

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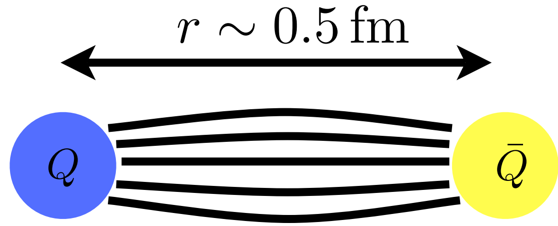

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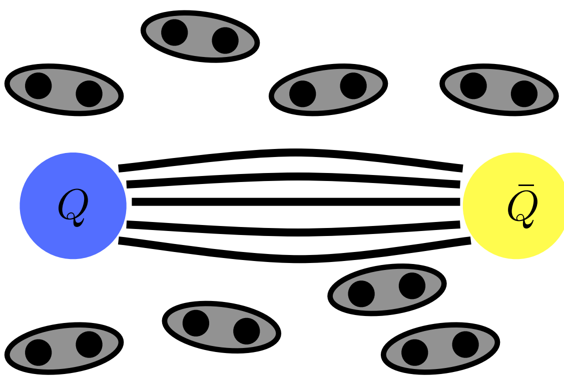
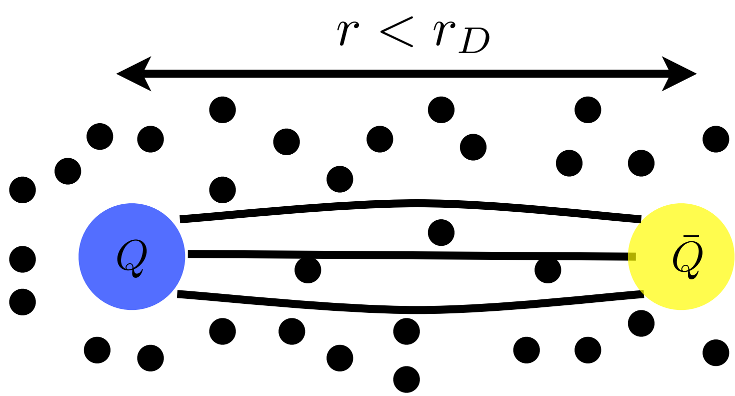
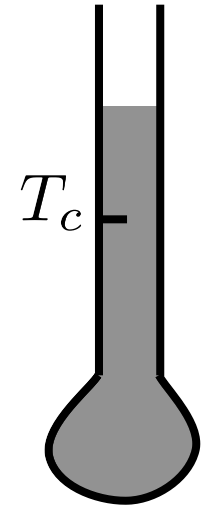




$$V(r) = -\frac{\alpha_{\mathrm{eff}}}{r} e^{-r/r_D}$$



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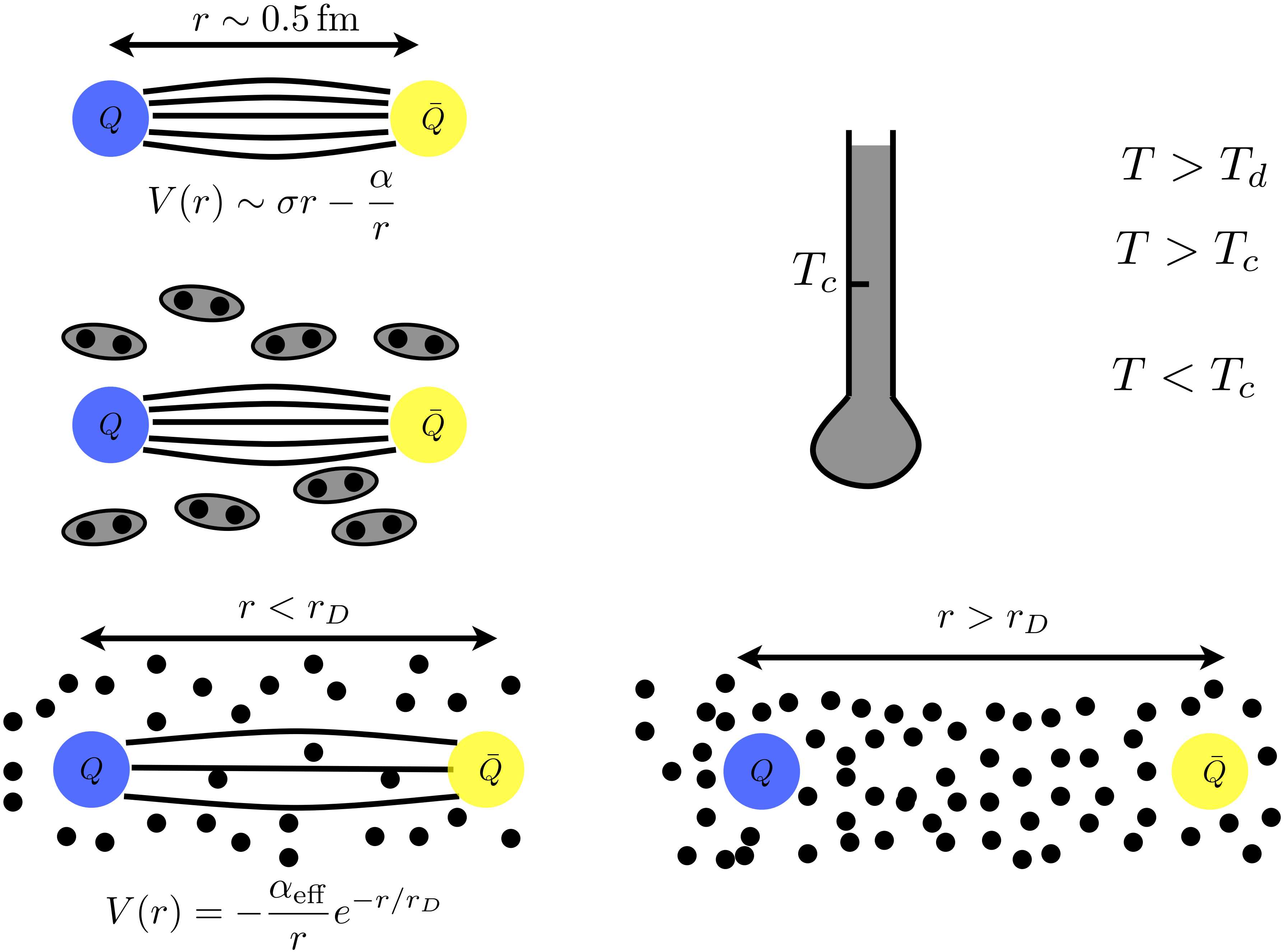

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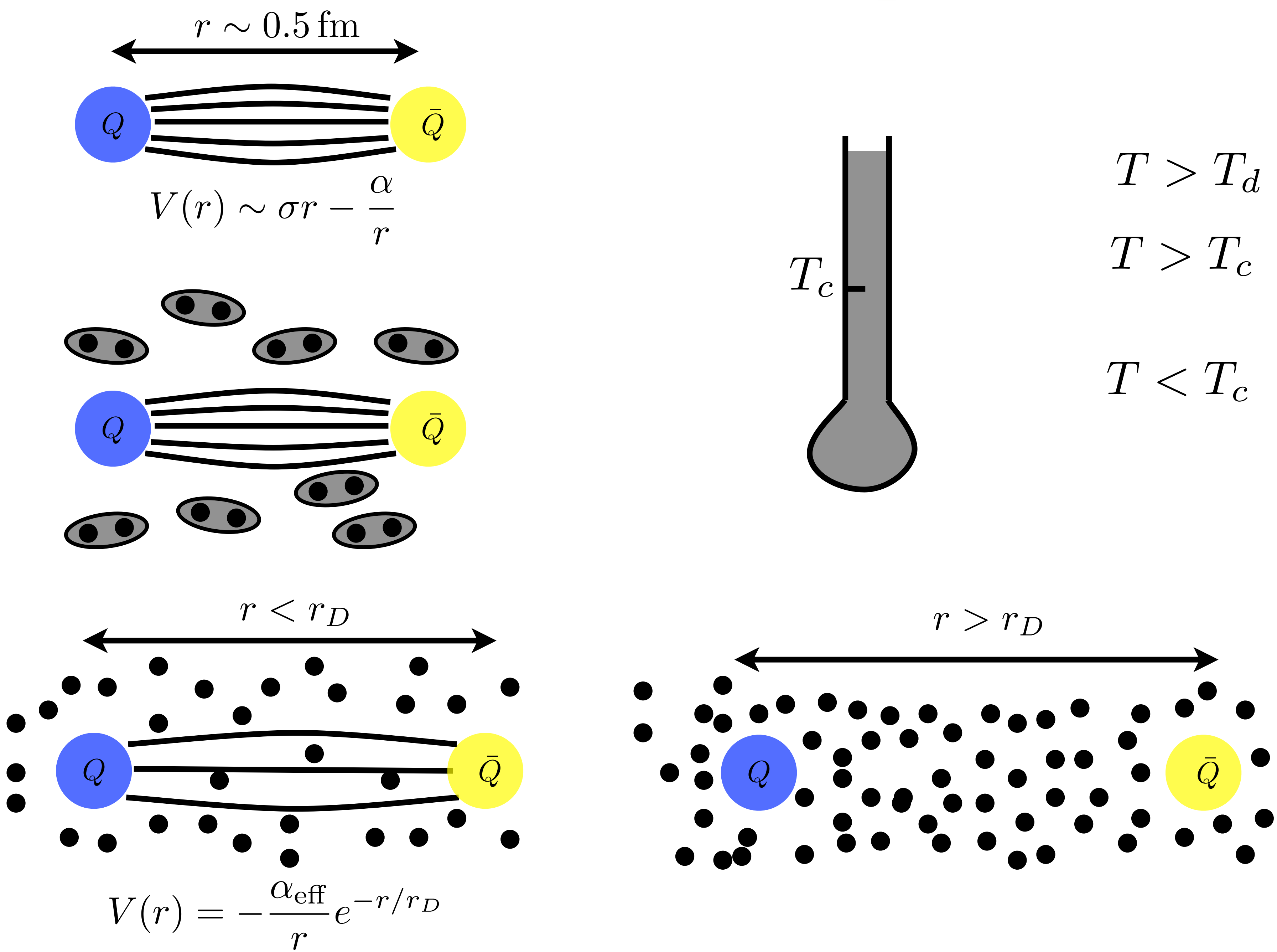

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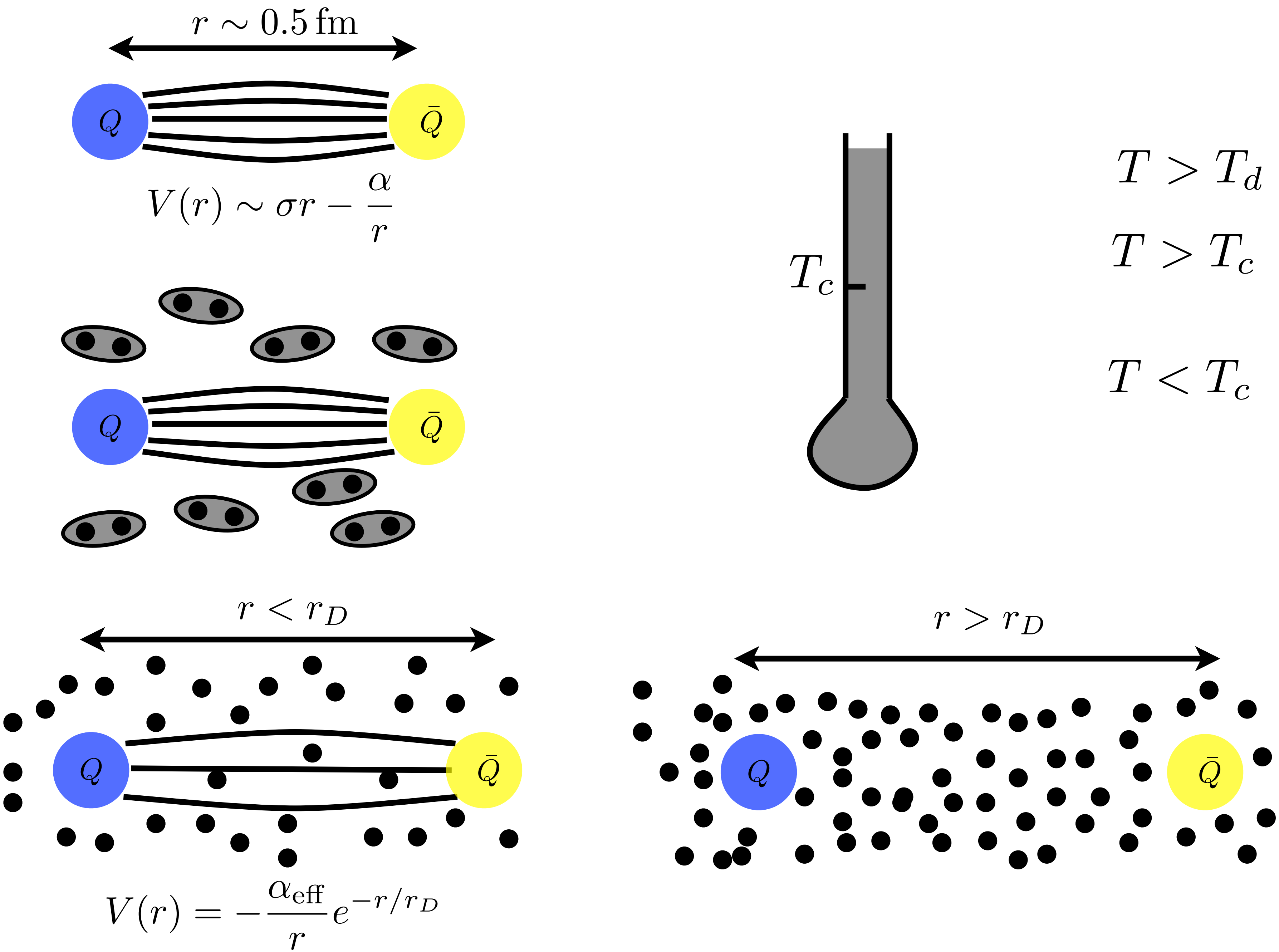

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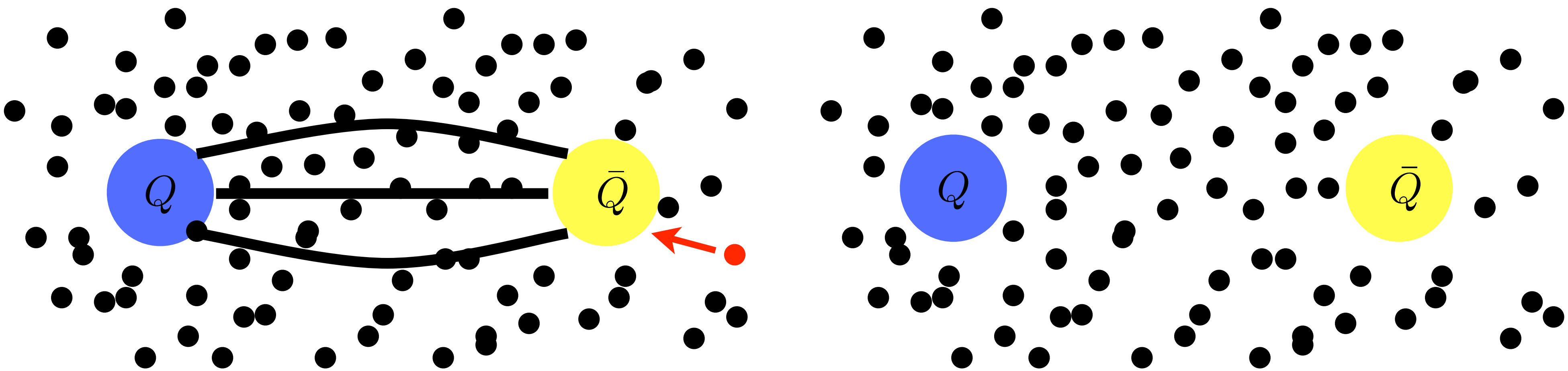
Landau damping

In a thermal medium, no strictly stationary bound state exists.
Interactions with the particles of the medium lead to a finite lifetime for all states.



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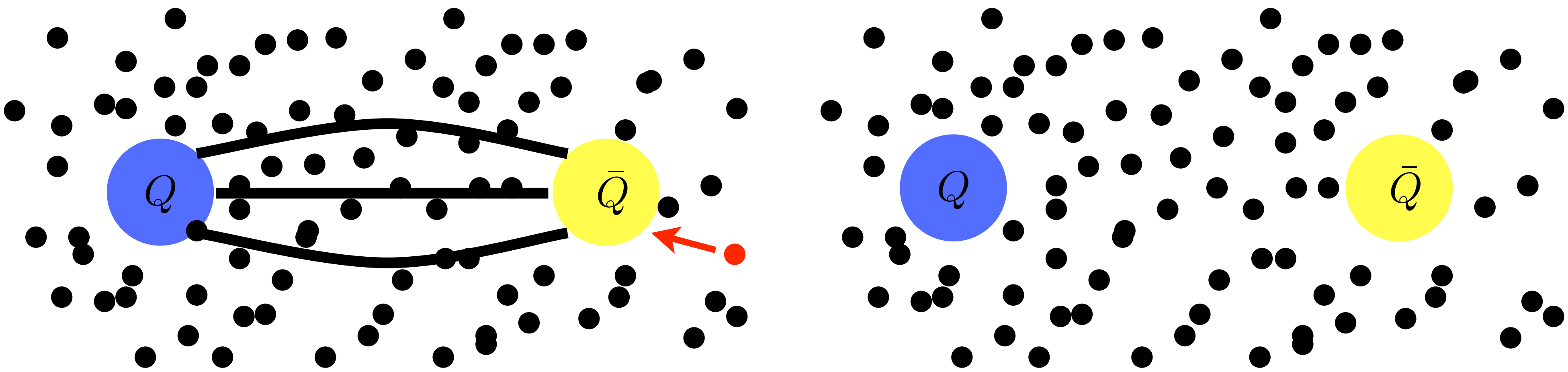

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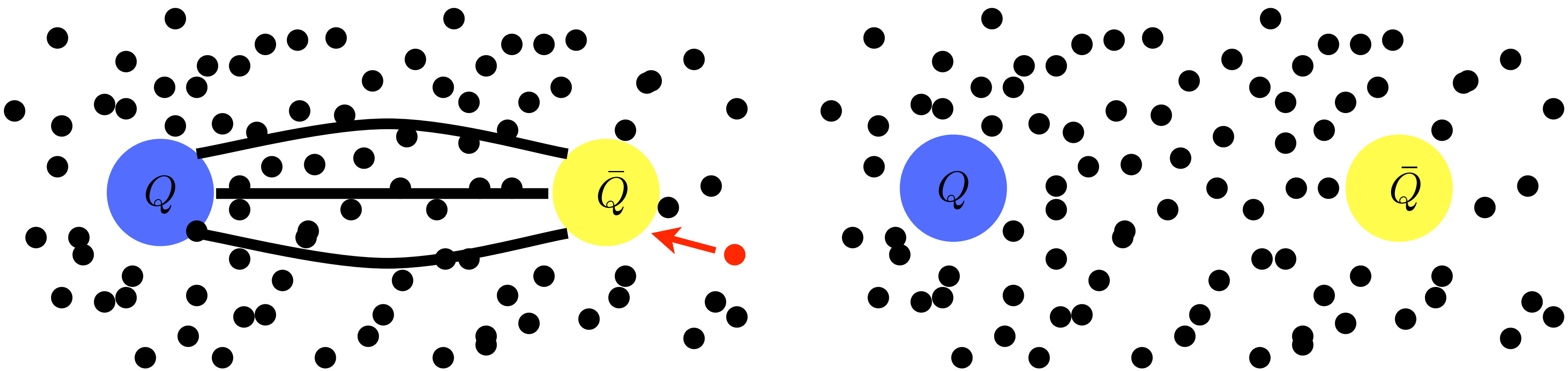

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Analogous to photodissociation of molecules like

$$O_2 + \gamma \to 2O$$

in a heat bath.

Dissociation in a static thermal bath

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Radius of a bound state	$r_B \sim \frac{1}{m_Q \alpha_{\rm eff}}$	dissociation $r_D = 1.2\, r_B$
Debye screening length	$r_D = \frac{1}{m_D}$	$T_d \sim m_Q \frac{\alpha_{\rm eff}}{g}$

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Imaginary potential

The real part of the potential is smaller than the imaginary part for

$$1/r \sim k > g^{2/3} T$$

The imaginary part dominates for $g^{2/3} T > m_D$

and leads to dissociation for $T \gg m_Q C_F g^2 / 16\pi$

Laine et al.
hep-ph/0611300

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Plasma (or black-body radiation) in thermal equilibrium at a temperature T and moving with a velocity v with respect to the bound state.

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Previous works:

Dynamic Debye screening considered by M.C. Chu and T. Matsui (1989)

Dynamic Landau damping considered by T. Song et al. (2008) and by F.Dominguez and B.Wu (2009)

Thermal medium

Distribution function of particles in the plasma

$$f(\beta^\mu k_\mu) = \frac{1}{e^{|\beta^\mu k_\mu|} \pm 1}$$

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then

$$f(k, T, \theta, v) = \frac{1}{e^{k/T_{\rm eff}(\theta, v)} \pm 1}$$

Effective temperature
(massless particles)

$$T_{\rm eff}(\theta, v) = \frac{T\sqrt{1 - v^2}}{1 - v\cos\theta}$$

relative change of temperature as in the Doppler effect

Light-cone variables

We choose v in the z direction and define

$$k_+ = k_0 + k_3 \qquad \text{and} \qquad k_- = k_0 - k_3$$

Then the distribution function depends on

$$\beta^\mu k_\mu = \frac{1}{2}\left(\frac{k_+}{T_+} + \frac{k_-}{T_-}\right)$$

where $$T_+ = T\sqrt{\frac{1+v}{1-v}} \qquad \text{and} \qquad T_- = T\sqrt{\frac{1-v}{1+v}}$$

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In the construction of the effective theory one has to take into account the existence of these scales. In particular for $v \sim 1$

$$T_- \ll T \ll T_+$$

for more details see Escobedo, MM, Soto **Phys.Rev. D84 (2011) 016008**

Evaluating the potential

Temperature range

$$m_Q \gg T \gg \Lambda_{QCD} \gg m_q$$
$$T \gg 1/r$$

HTL approximation, Coulomb gauge.
The potential is obtained by a Fourier transform of the longitudinal gauge boson propagator

$$\Delta_{11}(k) = \frac{1}{2}[\Delta_R(k) + \Delta_A(k) + \Delta_S(k)]$$

where

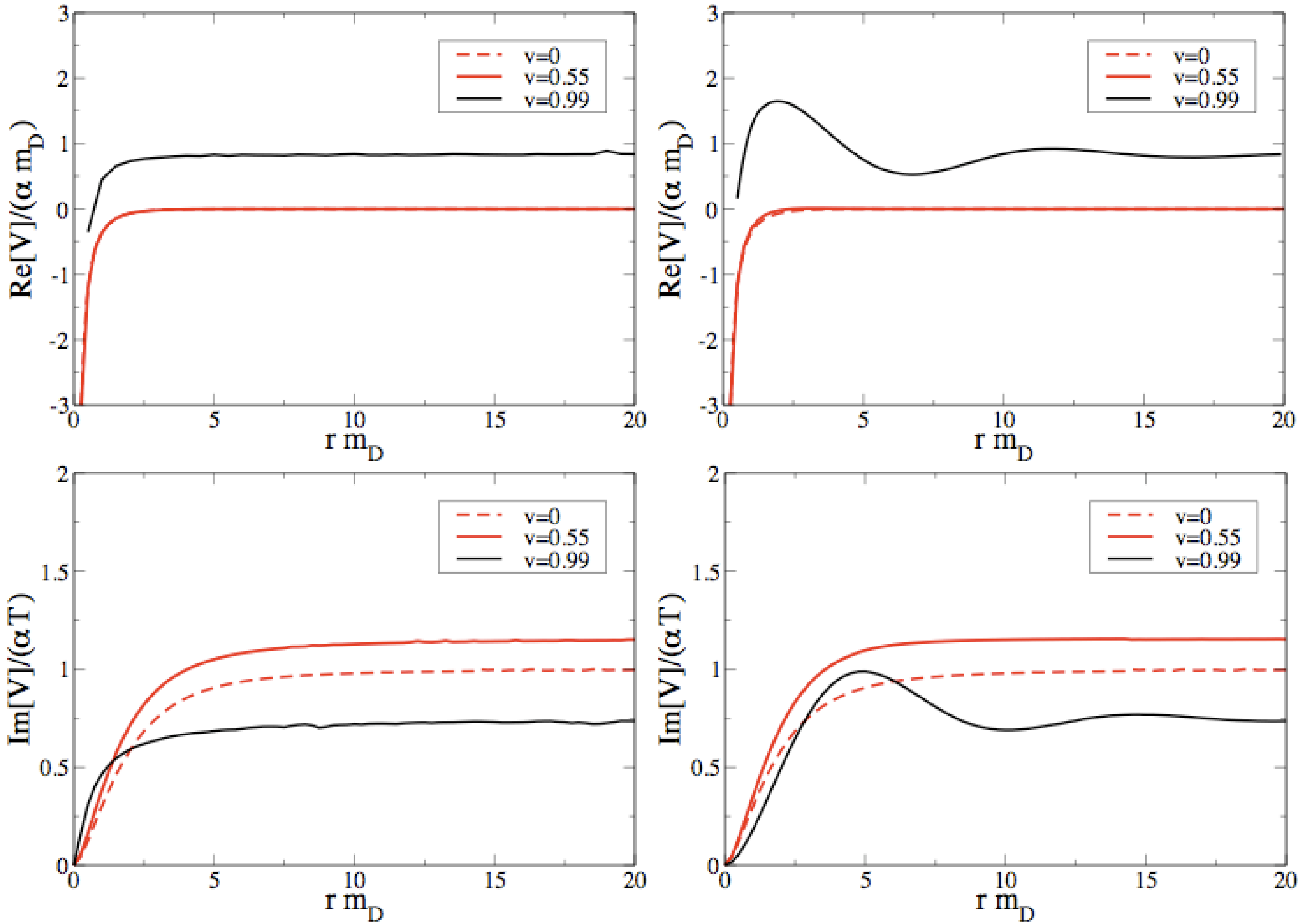
$$\Delta_R^*(k) = \Delta_A(k)$$
$$\Delta_S(k,u) = \frac{\Pi_S(k,u)}{2i\Im\Pi_R(k,u)}(\Delta_R(k,u) - \Delta_A(k,u))$$

M. E. Carrington et al.
Eur. Phys. J. C 7, 347 (1999)

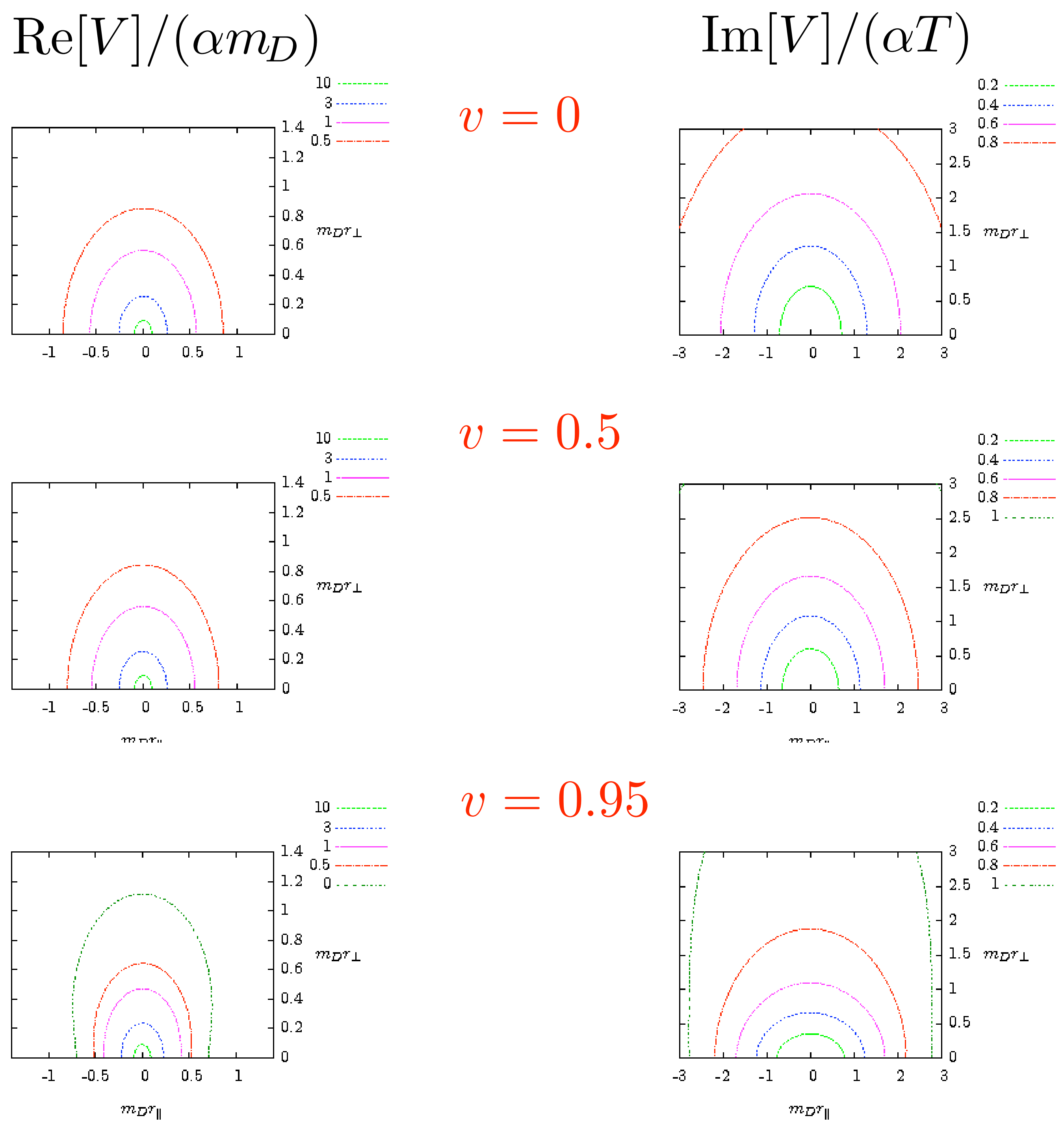
Results

Potential

$\theta = 0$ $\theta = \pi/2$



Contour lines



“critical” velocity

	$v = 0$	$v \neq 0$
m_D	gT	$\sim gT$
$\mathrm{Re}[V] = \mathrm{Im}[V]$	$\bar{k} \simeq g^{2/3} T$	$\bar{k}(v) \simeq g^{2/3} T \sqrt{1 - v^2}$

For $k < \bar{k}(v)$ the real part dominates and if $\bar{k}(v) < m_D$ the dissociation is due to screening

“critical” velocity: $v_{cr} = \sqrt{1 - a g^{2/3}}$

If $v > v_{cr}$ dissociation is due to Debye screening

Summary

- The properties of bound states change in the presence of a thermal medium
- In the HTL approximation for a static bound state, Landau damping dominates
- We find that there should be a "critical" velocity, v_{cr} , such that for $v > v_{cr}$, Debye screening dominates.
- Next step: evaluation of the yield of HQ in a heavy-ion collision