Low viscosity from pQCD

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- Hot Quarks • De Krim • September 2018 -

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Quark gluon plasma?

why is quark gluon plasma a plasma. and is it realy hot i just want to know

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Answers

Relevance

Best Answer: very hot, according to http://en.wikipedia.org/wiki/Quark-gluon...

Andrew · 1 decade ago

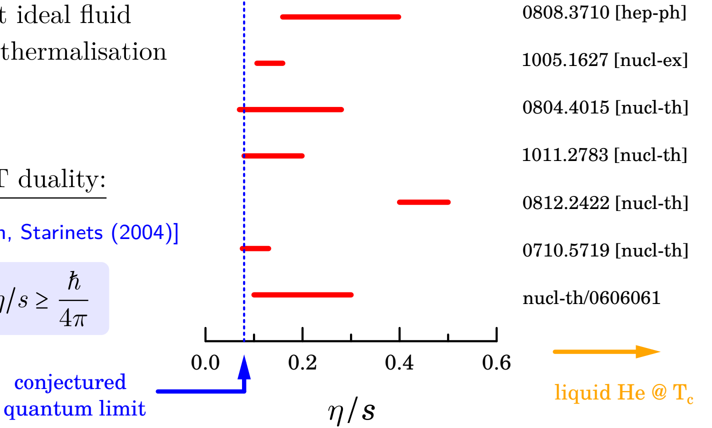
0 · 0 · Comment

Asker's rating ★★★☆☆

LOW shear viscosity

the QGP
@ RHIC/LHC :

- 'strongly' coupled
- almost ideal fluid
- rapid thermalisation

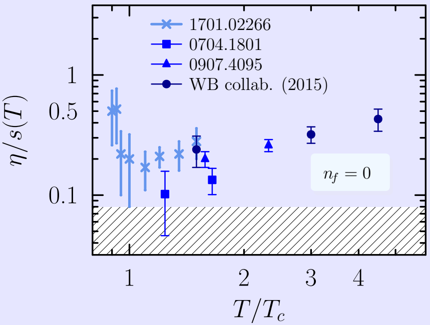


AdS/CFT duality:

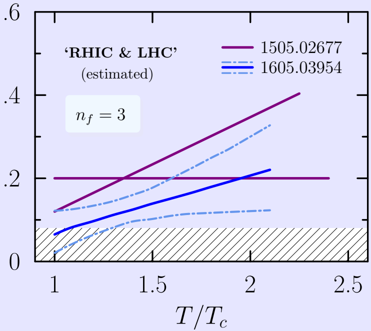
[Kovtun, Son, Starinets (2004)]

$$\eta/s \geq \frac{\hbar}{4\pi}$$

lattice QCD

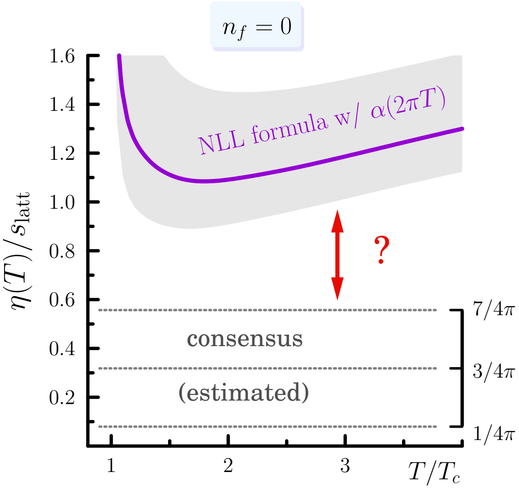


hydrodynamics



Do we *understand* $\eta/s \lesssim 0.5$?

FAKE NEWS* : cannot *explain* $\eta/s < 1$ from pQCD



Next-to-Leading-Log

$$\eta_{\rm NLL} = \frac{\boldsymbol{b}\, T^3}{\alpha^2 \log(\boldsymbol{c}/\alpha)}$$

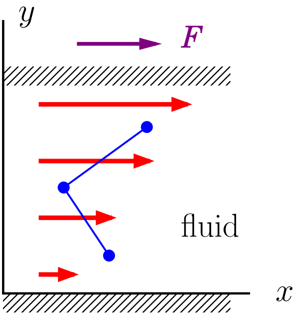
[Arnold, Moore, Yaffe (2001)]

∗ To be questioned...

Shear viscosity, simplest case

$$\frac{\text{lateral force}}{\text{area}} = \eta \cdot (\perp \text{ gradient of velocity})$$

Example: pattern of horizontal flow v_x, that varies with y ...



$$\Rightarrow \boxed{\eta \simeq n\,\bar{p}\,\ell_{\text{mfp}}}$$

'pocket formula' (dilute gas)

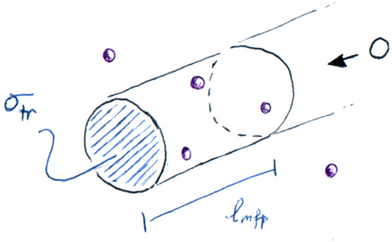
n = # density

$\bar{p}$ = mom. transfer

Momentum transfer,
due to collisions of particles,
from different layers

Mean free path for η?

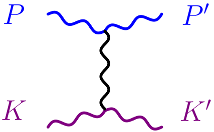
$$\ell_{\mathrm{mfp}} \sim \frac{1}{n\sigma_{\mathrm{tr}}}$$



transport cross section:

$$\sigma_{\mathrm{tr}} = \frac{1}{s}\int_{-s}^{0} \mathrm{d}t \cdot |t| \, \frac{\mathrm{d}\sigma}{\mathrm{d}t}$$

<u>mimic</u> integral by $\displaystyle \frac{1}{s}\int_{-s}^{-\mu^2} \mathrm{d}t \cdot |t| \frac{\alpha^2}{t^2} \sim \frac{\alpha^2}{T^2}\log\left(\alpha^{-1}\right)$ NLL



$$t = (\cos\theta - 1)\frac{s}{2}$$

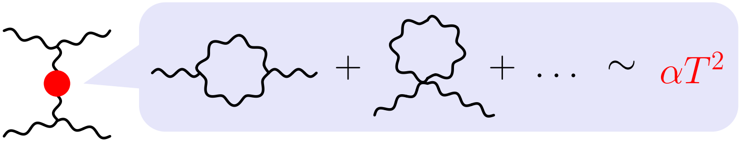
$$s = 4E_{\mathrm{cm}}^2 \sim T^2$$

SCREENING $\mu^2 = \alpha T^2$

pQCD: state-of-the-art

(following [AMY, (2003)] & [Baym, (1990)])

lin. Boltzmann eq + *Hard Thermal Loops*



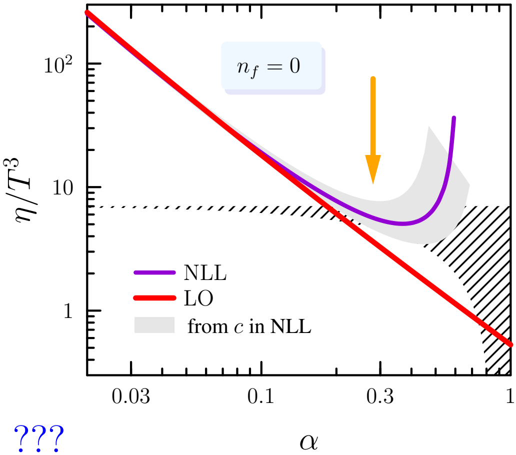
$$\left.\begin{aligned} f &= f_{\text{eq}} + \delta f \\ \delta f &\sim \eta \partial_y u_x \end{aligned}\right\} \text{ ... find constraint } \quad S[f_{\text{eq}}] = \mathcal{C}[\delta f]$$

$$\mathcal{Q}[\delta f] = \langle \delta f | S \rangle - \tfrac{1}{2} \langle \delta f | \mathcal{C} | \delta f \rangle \quad \Rightarrow \quad \boxed{\eta = \frac{2}{15} \text{Max}[\mathcal{Q}]} \quad \text{LO}$$

(in "Hilbert space" of test functions δf)

The full LO result for η is 'well-behaved' NLL → **unphysical**

...maybe pQCD *can* explain $\eta/s < 0.5$



BUT: what is $\alpha(T)$???

How strong is strong?

renormalised *HTL*

textbook procedure:

1) DROP vacuum part,

$$\alpha \Pi_{\text{vac}} \sim \alpha Q^2 \left(\epsilon^{-1} + \log(Q^2/M^2) \right)$$

2) 'guess' coupling in $\alpha \Pi_{\text{med}} \sim \alpha T^2$

$$\alpha_{\text{fix}} \to \alpha(Q_T), \quad Q_T = 2\pi T$$

vacuum	medium
running coupling $\alpha(\mathbf{Q}^2) = \dfrac{1/\beta_0}{\log(\mathbf{Q}^2/\Lambda^2)}$	*HTL* pert. theory – quasiparticles – Landau damping

renormalised *HTL*

textbook procedure:

1) DROP vacuum part,

$\alpha\Pi_{\text{vac}} \sim \alpha Q^2 (\epsilon^{-1} \ldots M^2))$

WRONG!

2) 'guess' … g in $\alpha\Pi_{\text{med}} \sim \alpha T^2$

$\alpha_{\text{fix}} \to \alpha(Q_T)\,, \quad Q_T = 2\pi T$

vacuum	medium
running coupling $\alpha(\mathbf{Q}^2) = \dfrac{1/\beta_0}{\log(\mathbf{Q}^2/\Lambda^2)}$	*HTL* pert. theory – quasiparticles – Landau damping

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'dressed' propagators: (1-loop, resummed)

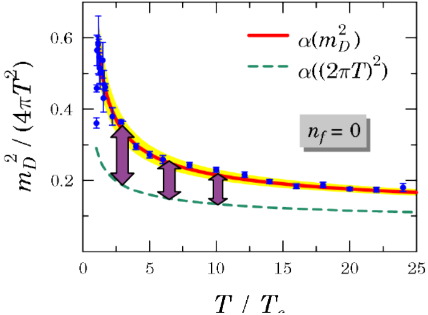
$$\frac{\alpha}{Q^2 - \alpha\,(\Pi_{\text{vac}} + \Pi_{\text{med}})} \xrightarrow{\text{renorm.}} \frac{\alpha(Q^2)}{Q^2 - \alpha(Q^2)\Pi_{\text{med}}}$$

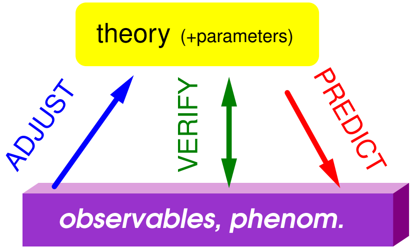
Consistent treatment of loop corrections!

Perturbation theory does not converge

... it can still be useful!!

- in QFT, renormalisation
  = adjusting params.
- validity check crucial
  compare to lattice:





consistent: $m_D^2 = \#\,\alpha(m_D^2)\,T^2$

textbook: $\alpha\big(Q_T = 2\pi T\big)$

using $\mathbf{\Lambda \approx 0.2}$ **GeV**

works quantitatively for $T \approx T_c$

[Peshier, hep-ph/0601119]

Consistent treatment of loop corrections!

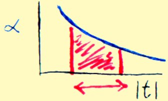
Rethink an old integral:

$$\int_{-s}^{-\mu^2} \mathrm{d}t \cdot |t| \, \frac{\alpha(t)^2}{t^2} \;=\; -\beta_0^{-2} \int_{-s}^{-\mu^2} \frac{\mathrm{d}t}{t \log^2(-t/\Lambda^2)} \;=\; \frac{1}{\beta_0^2 \log(-t/\Lambda^2)}\Bigg|_{-s}^{-\mu^2}$$

$$= \boxed{\alpha(\mu^2)\alpha(s) \log \frac{s}{\mu^2}}$$ instead of $\alpha^2_{\text{fixed}} \times$ (Coulomb log)

$s \sim T^2$ 'hard' $\quad \mu^2 \sim \alpha T^2$ 'soft'

IR sensitive



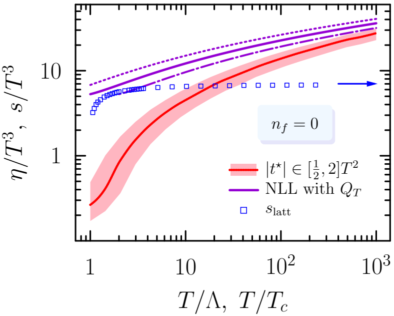
Scale for the running coupling is specified :-)

$\Rightarrow$ enhanced transport Xsection

Details omitted: '*sub-leading*' terms

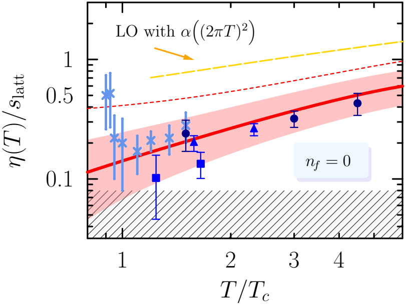
Estimate, extrapolate

(more details in [GJ, Peshier, (2017)])



$(\lambda \approx 0.8) \Rightarrow$

$$\frac{\eta\big(T/(\lambda T_c)\big)}{s_{\rm latt}(T/T_c)} \quad \text{where} \quad \lambda = \Lambda/T_c$$

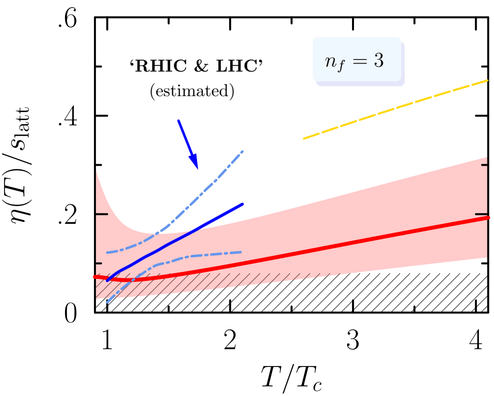


effective (soft) ints. → *higher* interaction rates → lower η

Estimate, extrapolate

(more details in [GJ, Peshier, (2017)])

$(\ \lambda \approx 2.1\ ) \Downarrow$



PREDICTION:

- mild increase with temperature
- little overall difference vs. $n_f = 0$

Bayesian hydro constraints
[Bernhard, *et al* (2016)]

effective (soft) ints. → *higher* interaction rates → lower η

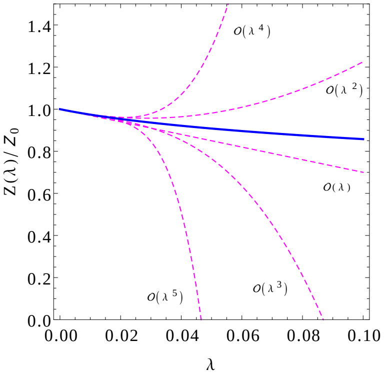
Summary

Arxiv: 1704.06284
1711.02119

- running coupling crucial for a *strongly coupled* QGP
- simple **understanding** of the ‘perfect’ fluid

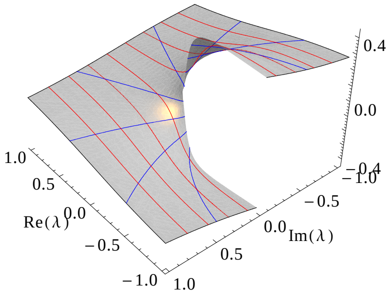
A comment ...

... on asymptoyic series



$$L(\lambda) = \frac{1}{2}x^2 + \lambda x^4$$ **toy "0-dim" QFT**

$$\left[\begin{array}{c}\text{partition}\\ \text{function}\end{array}\right] \to Z(\lambda) = \int \mathrm{d}x \exp[-L(\lambda)]$$

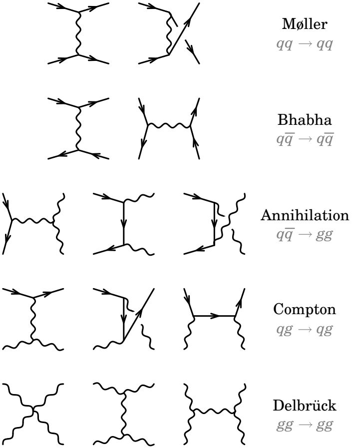


At *LARGE* coupling...

truncate @ $n \sim \lambda^{-1}$

pQCD still useful!

Matrix elements, $n_f > 0$



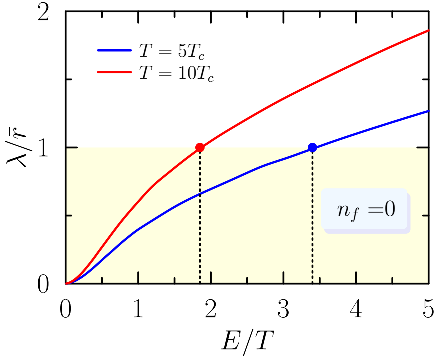
$ab \leftrightarrow cd$	$\left\|\mathcal{M}^{ab}_{cd}\right\|^2 / g^4$
$q_1 q_2 \leftrightarrow q_1 q_2$, $q_1 \bar{q}_2 \leftrightarrow q_1 \bar{q}_2$, $\bar{q}_1 q_2 \leftrightarrow \bar{q}_1 q_2$, $\bar{q}_1 \bar{q}_2 \leftrightarrow \bar{q}_1 \bar{q}_2$	$8 \frac{d_F^2 C_F^2}{d_A} \left(\frac{s^2+u^2}{t^2} \right)$
$q_1 q_1 \leftrightarrow q_1 q_1$, $\bar{q}_1 \bar{q}_1 \leftrightarrow \bar{q}_1 \bar{q}_1$	$8 \frac{d_F^2 C_F^2}{d_A} \left(\frac{s^2+u^2}{t^2} + \frac{s^2+t^2}{u^2} \right) + 16\, d_F C_F \left(C_F - \frac{C_A}{2} \right) \frac{s^2}{tu}$
$q_1 \bar{q}_1 \leftrightarrow q_1 \bar{q}_1$	$8 \frac{d_F^2 C_F^2}{d_A} \left(\frac{s^2+u^2}{t^2} + \frac{t^2+u^2}{s^2} \right) + 16\, d_F C_F \left(C_F - \frac{C_A}{2} \right) \frac{u^2}{st}$
$q_1 \bar{q}_1 \leftrightarrow q_2 \bar{q}_2$	$8 \frac{d_F^2 C_F^2}{d_A} \left(\frac{t^2+u^2}{s^2} \right)$
$q_1 \bar{q}_1 \leftrightarrow g\, g$	$8\, d_F C_F^2 \left(\frac{u}{t} + \frac{t}{u} \right) - 8\, d_F C_F C_A \left(\frac{t^2+u^2}{s^2} \right)$
$q_1\, g \leftrightarrow q_1\, g$, $\bar{q}_1\, g \leftrightarrow \bar{q}_1\, g$	$-8\, d_F C_F^2 \left(\frac{u}{s} + \frac{s}{u} \right) + 8\, d_F C_F C_A \left(\frac{s^2+u^2}{t^2} \right)$
$g\, g \leftrightarrow g\, g$	$16\, d_A C_A^2 \left(3 - \frac{su}{t^2} - \frac{st}{u^2} - \frac{tu}{s^2} \right)$

Kinetic theory: $\lambda \gg m_D^{-1} \gg \bar{r}$

Debye mass is largest when $T = 1.2\,T_c$ but still satisfies $m_D^{-1} \geq \frac{1}{3}\,T^{-1}$

The interparticle distance $\bar{r} \approx \frac{1}{2}\,n^{-1/3}$

Self-consistency check!



$$\lambda^{-1}(E_1) = \frac{1}{6E_1}\int \mathrm{d}\Gamma\, \frac{tu}{s^2}|\mathcal{M}|^2 \frac{f_2\bar{f}_3\bar{f}_4}{\bar{f}_1}$$

What fraction of particles satisfty $\lambda > \bar{r}$?

T	part.
$10\,T_c$	70%
$5\,T_c$	30%