Phase Transitions and the Perfectness of Fluids

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Shear viscosity measures

how “perfect” a fluid is!

- Kovtun, Son, and Starinets ('05)

  Conjecture: Shear viscosity / entropy density

$$\frac{\eta}{s} \geq \frac{1}{4\pi}$$

- Motivated by AdS/CFT

$$\frac{\eta}{s} \geq \frac{1}{4\pi}$$

- "QGP" ("quark gluon plasma," quotation marks added after Nu Xu's talk) almost saturates the bound @ just above Tc (Teaney; Romatschke, Romatschke; Song, Heinz)
- LQCD, gluon pasma (Karsch, Wyld; Nakamura, Sakai; Meyer)

⇨ QGP near Tc, a perfect fluid, SQGP

- PQGP: Asakawa, Bass, Müller; Xu, Greiner

QCD Phase Diagram

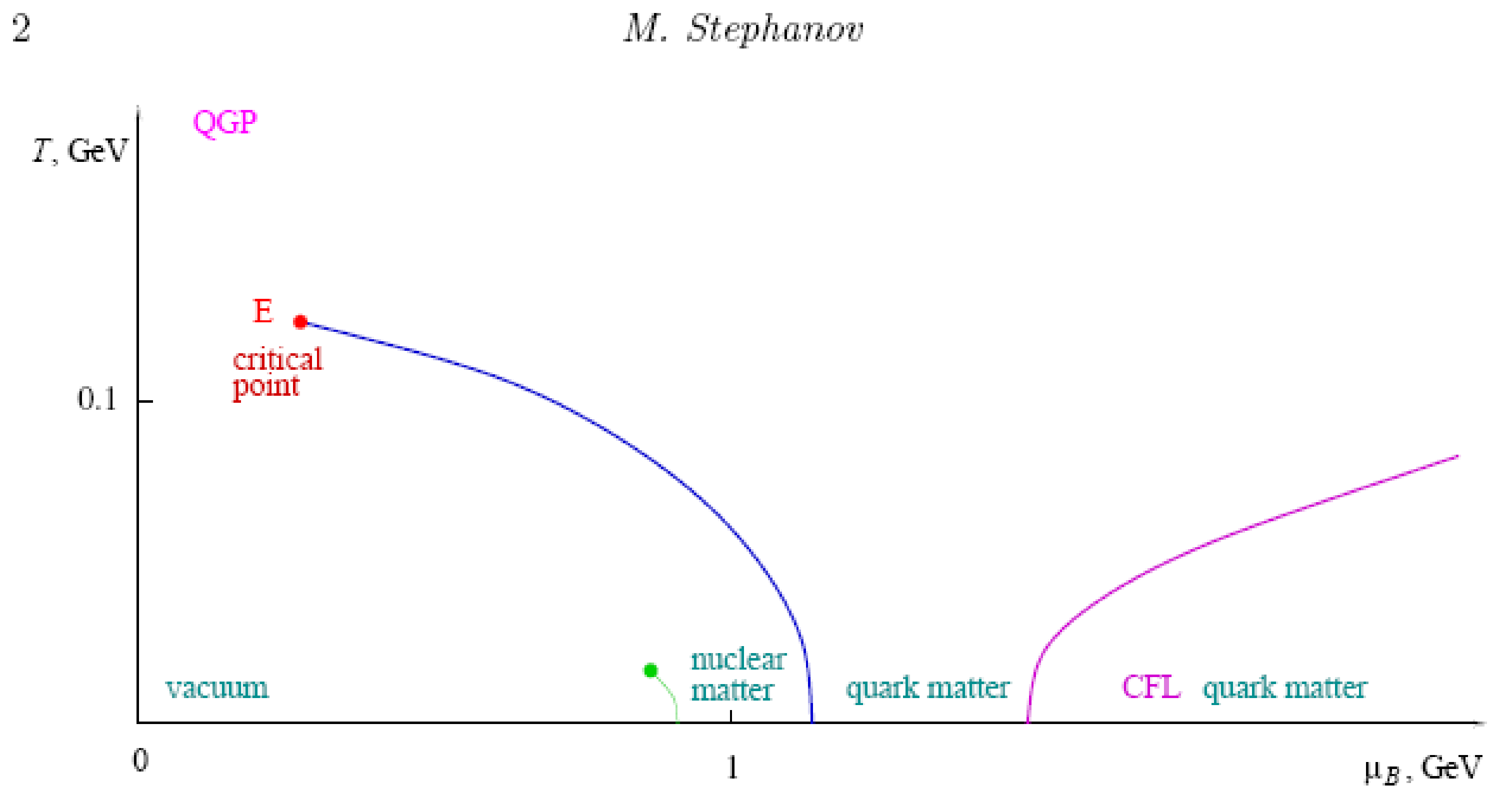


Fig. 1. QCD phase diagram

η/s of QCD below T_c

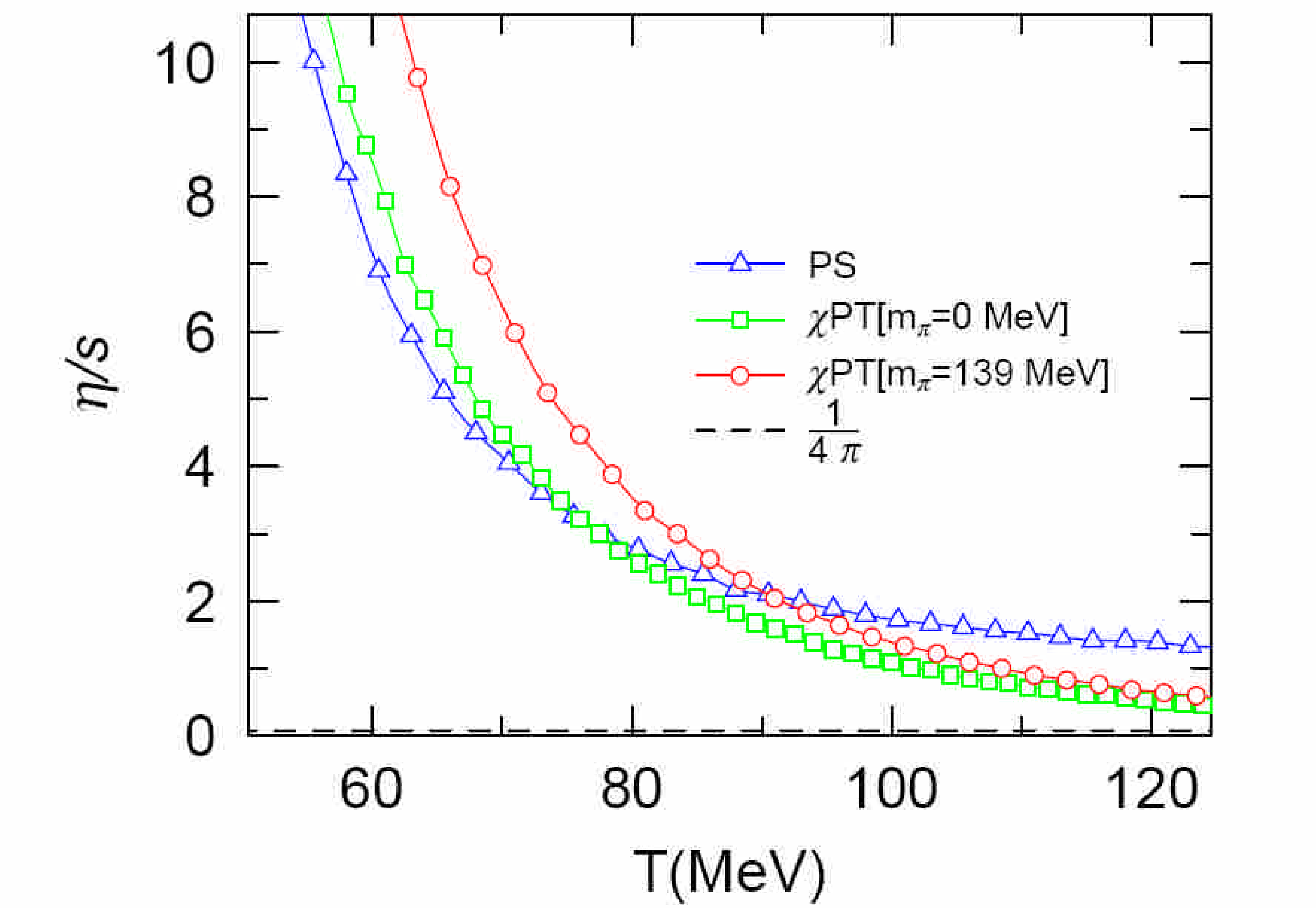
- Pion gas ⇨ ChPT (chiral perturbation theory)
- Non-perturbative in coupling

  ⇨ Boltzman equation

Earlier work: Prakash, Prakash, Venugopalan, Welke;

Dobado, Llanes-Estrada; Csernai, Kapusta , McLerran

η/s of QCD below T_c



JWC, Nakano

QCD Phase Diagram

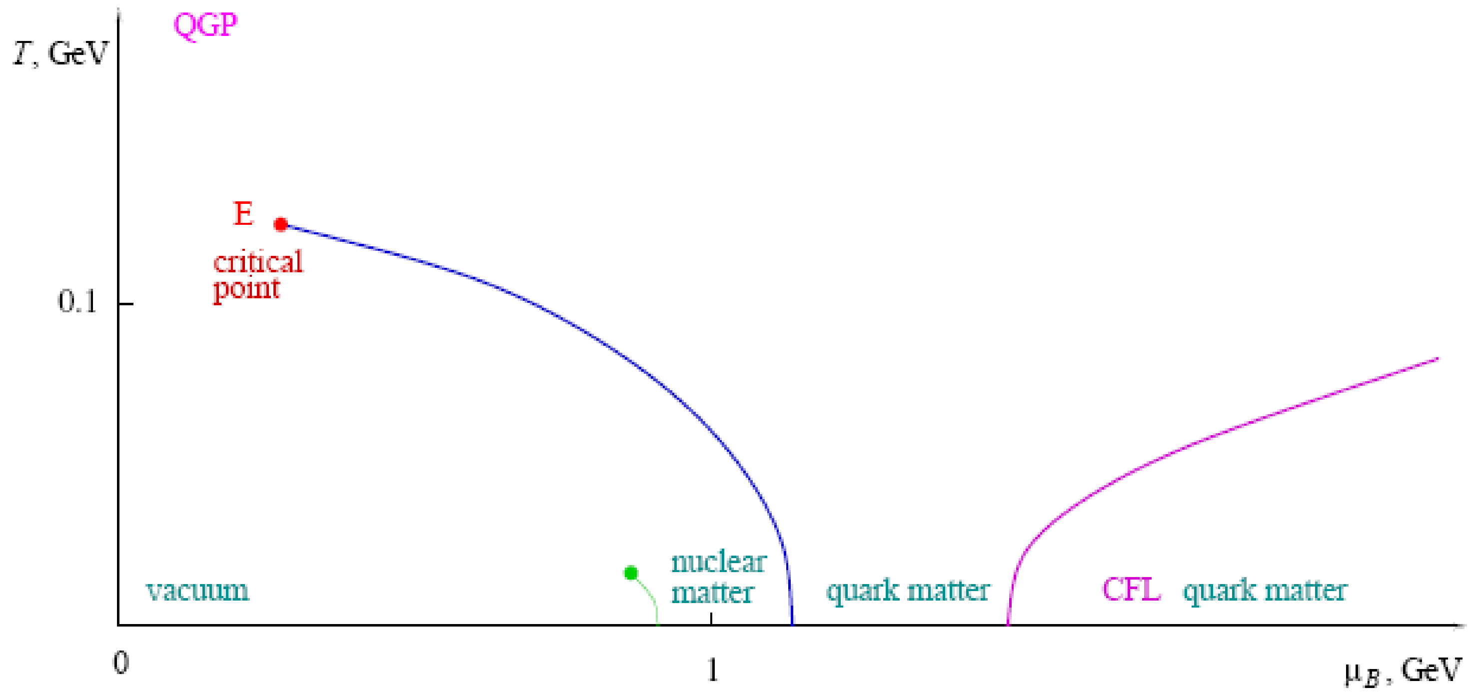
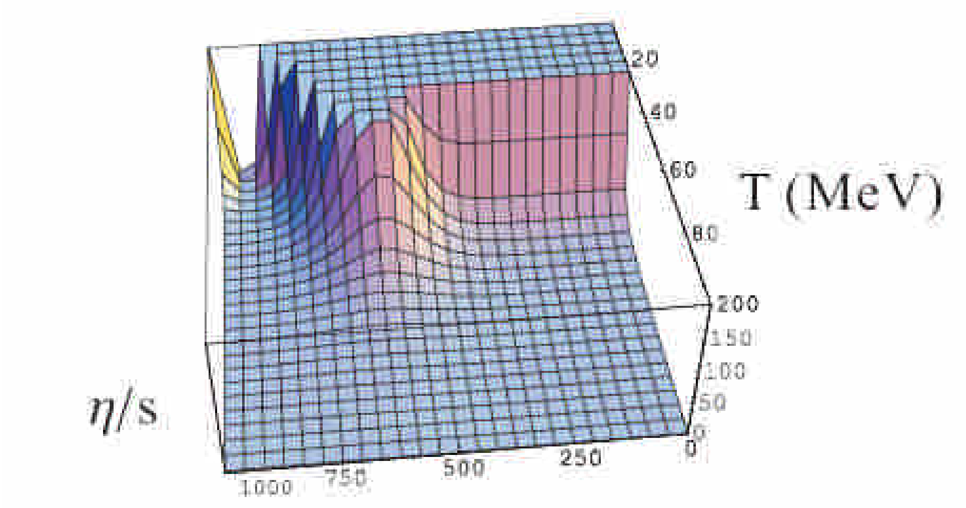
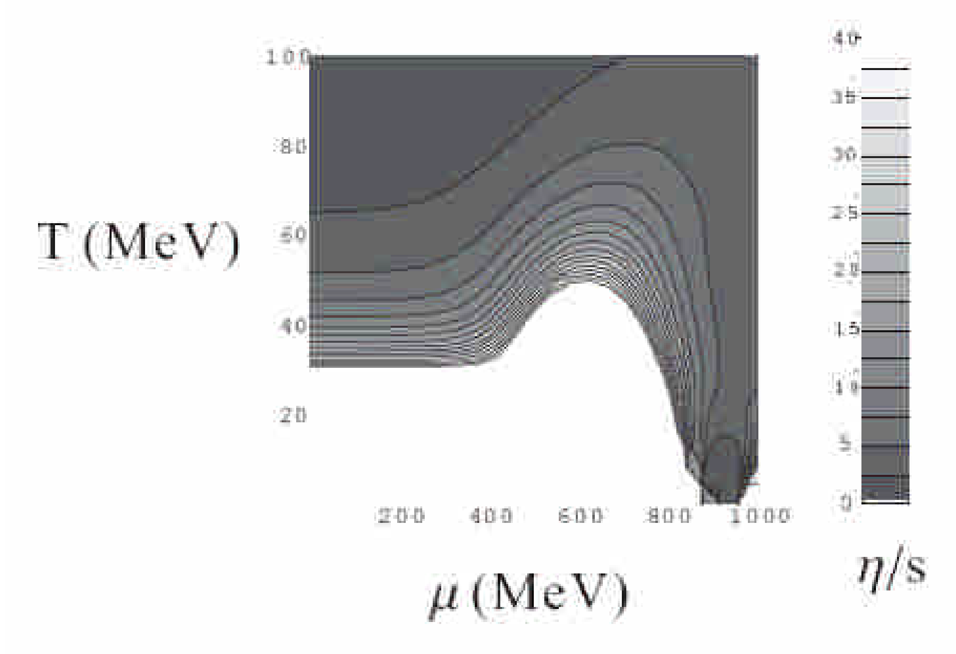


Fig. 1. QCD phase diagram

The η/s "Landscape"

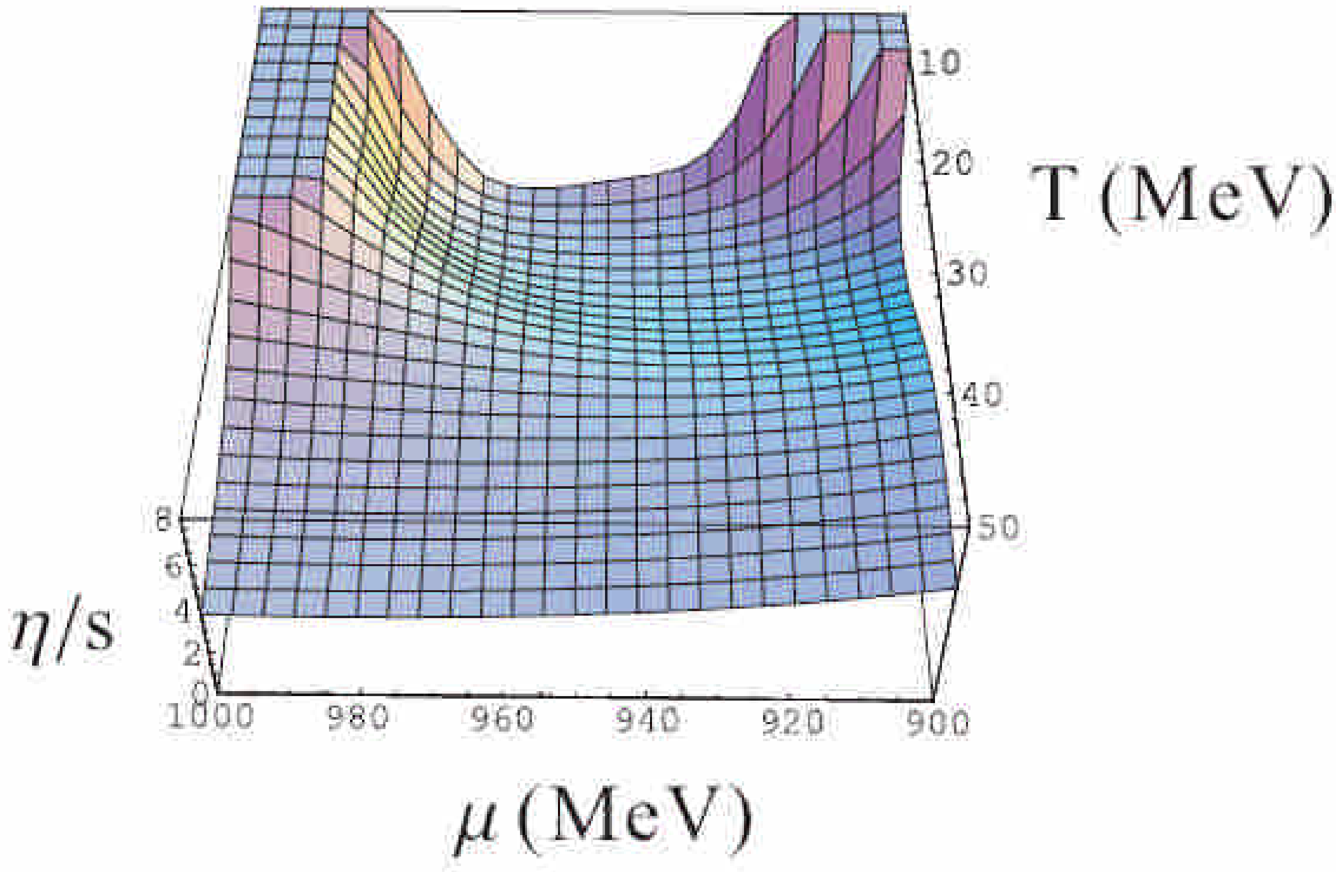


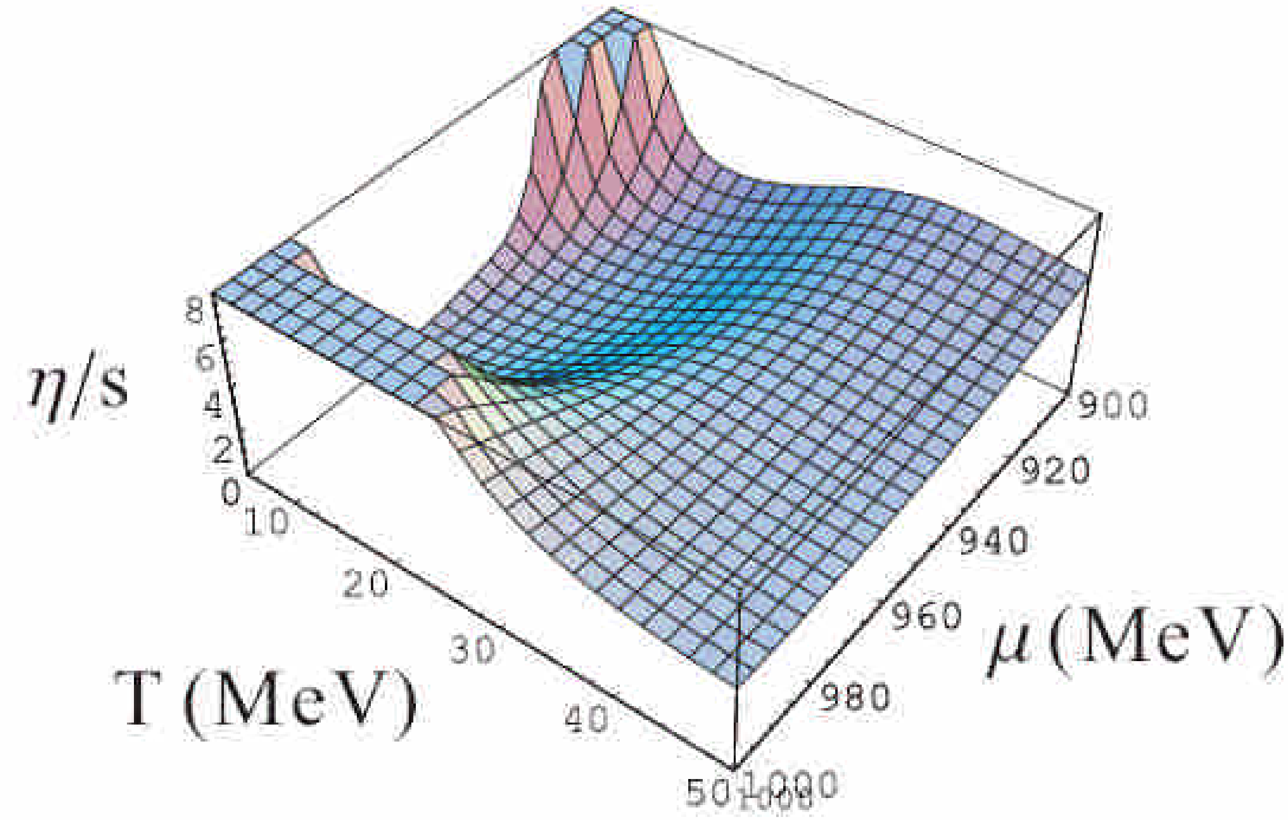


JWC, Li, Liu, Nakano; Itakura , Morimatsu, Otomo

The η/s "Landscape"

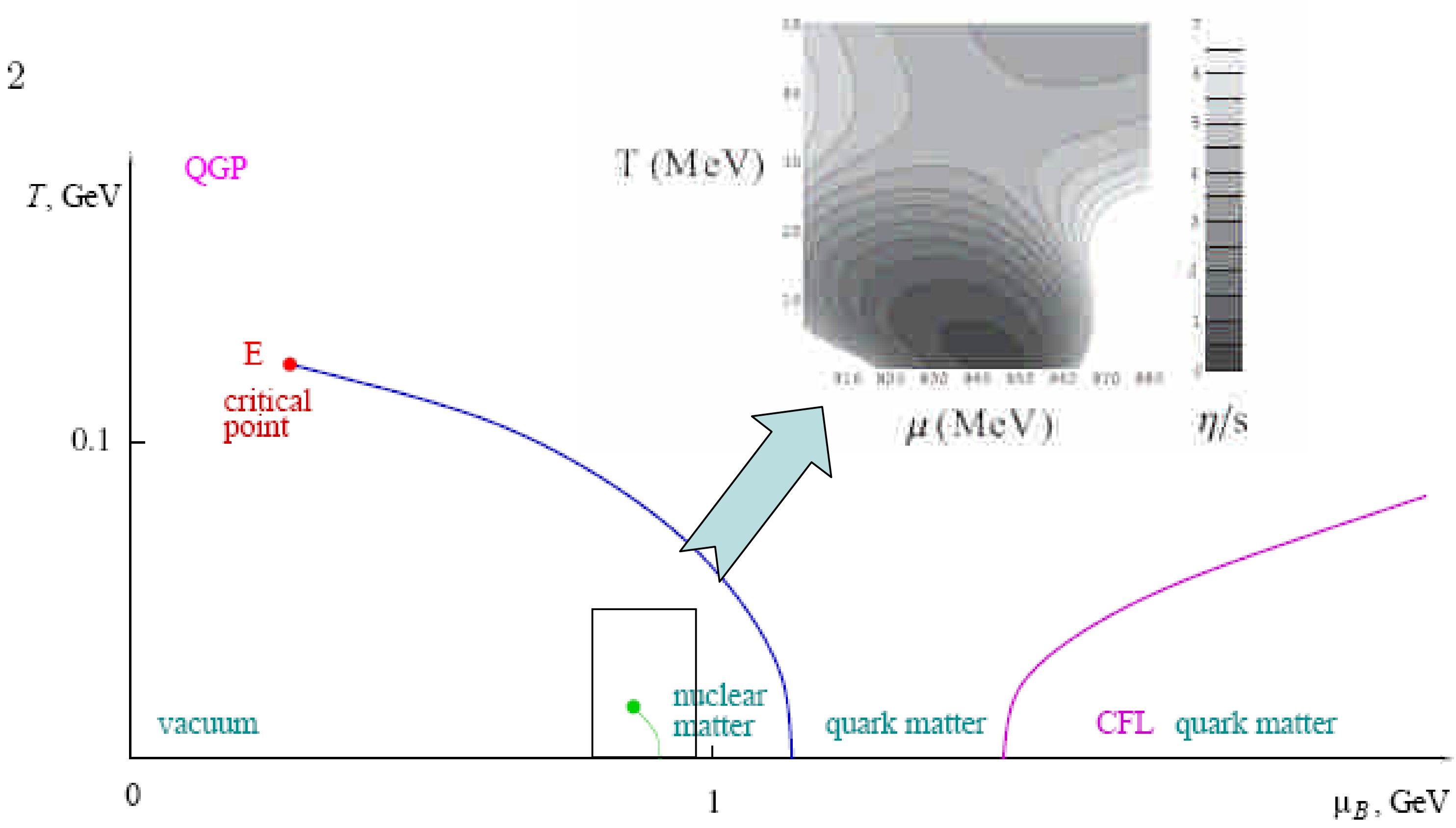
JWC, Li, Liu, Nakano





η/s
8
6
4
2
0
10
20
30
40
50
T (MeV)
900
920
940
960
980
1000
μ (MeV)

QCD Phase Diagram



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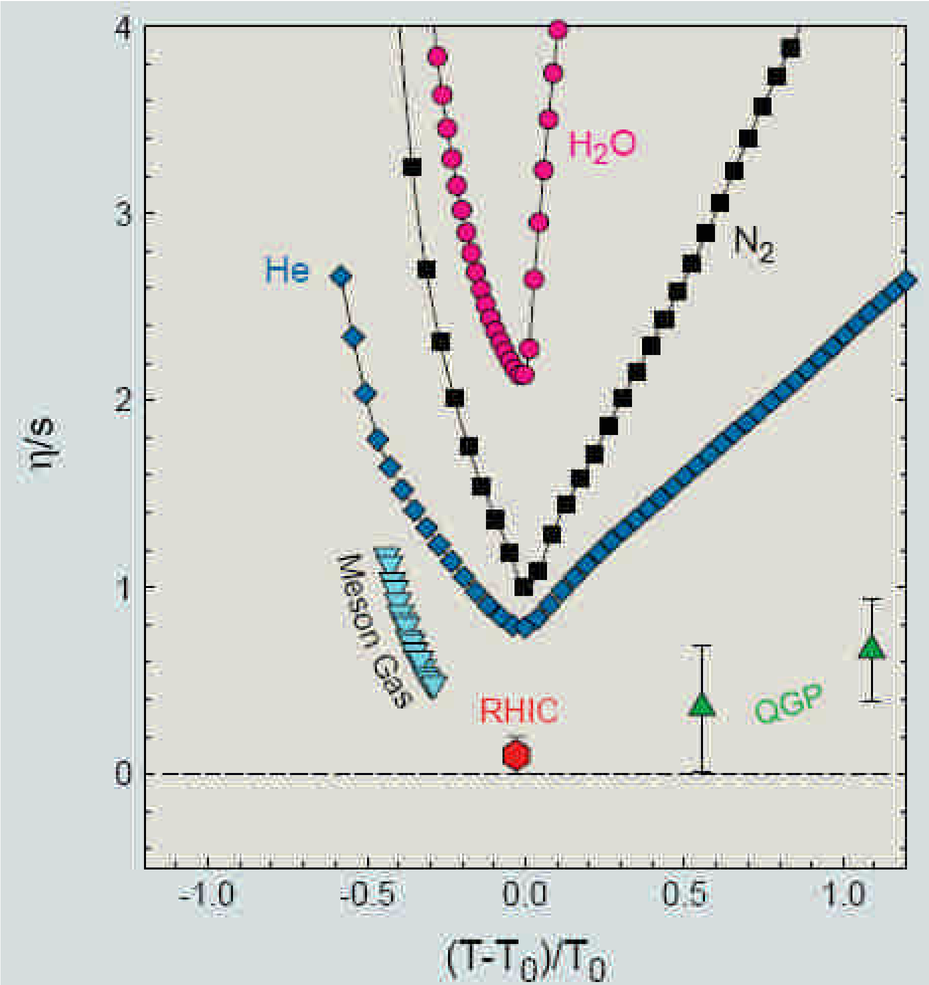
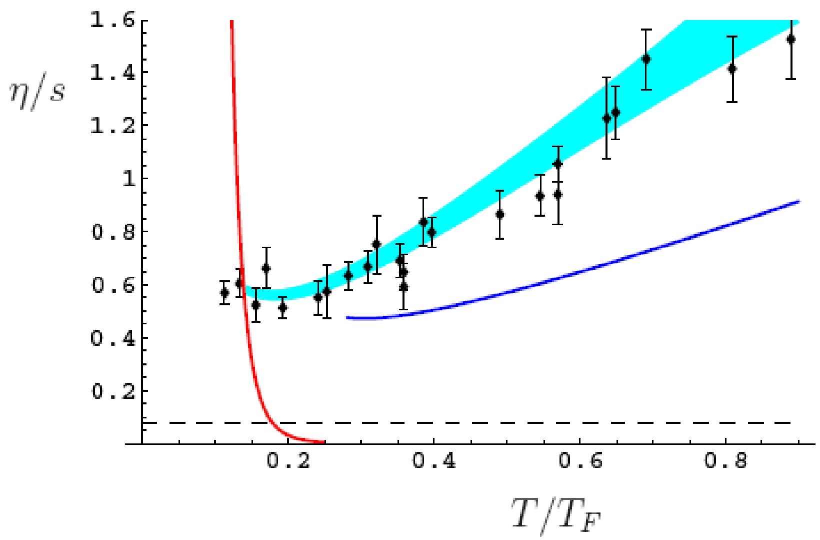
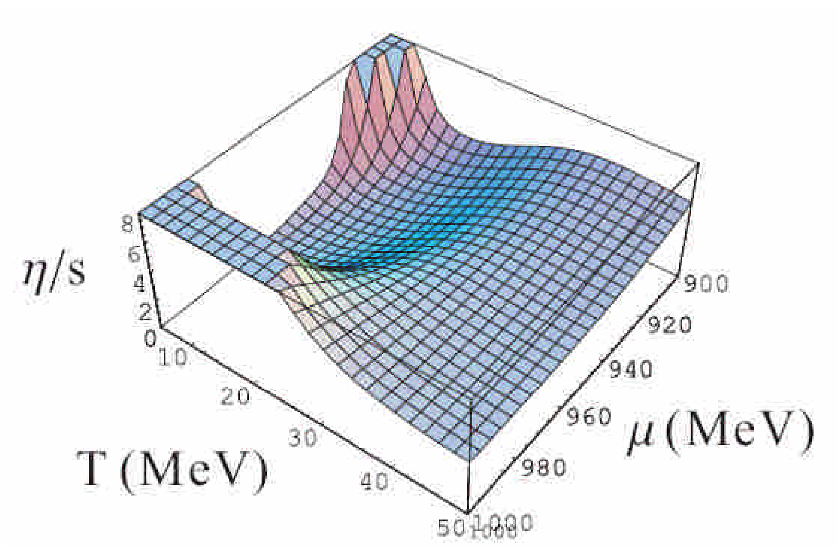


Cold Unitary Atoms

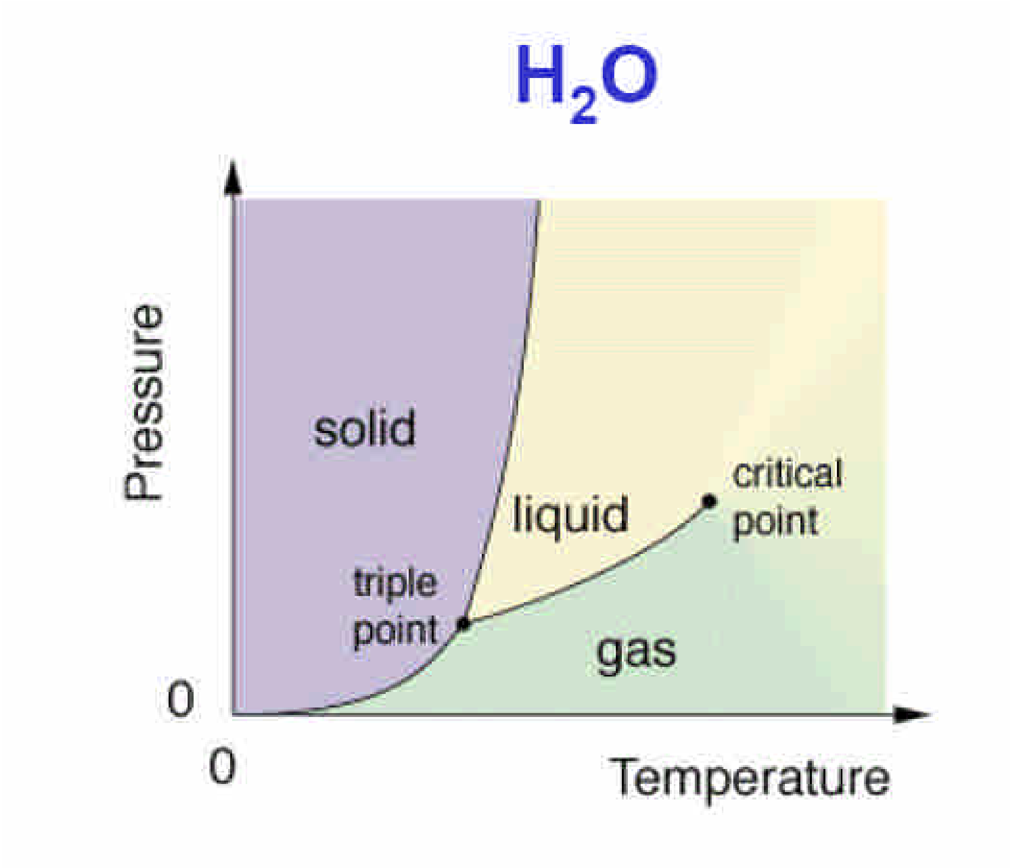
Rupak & Schafer 2007

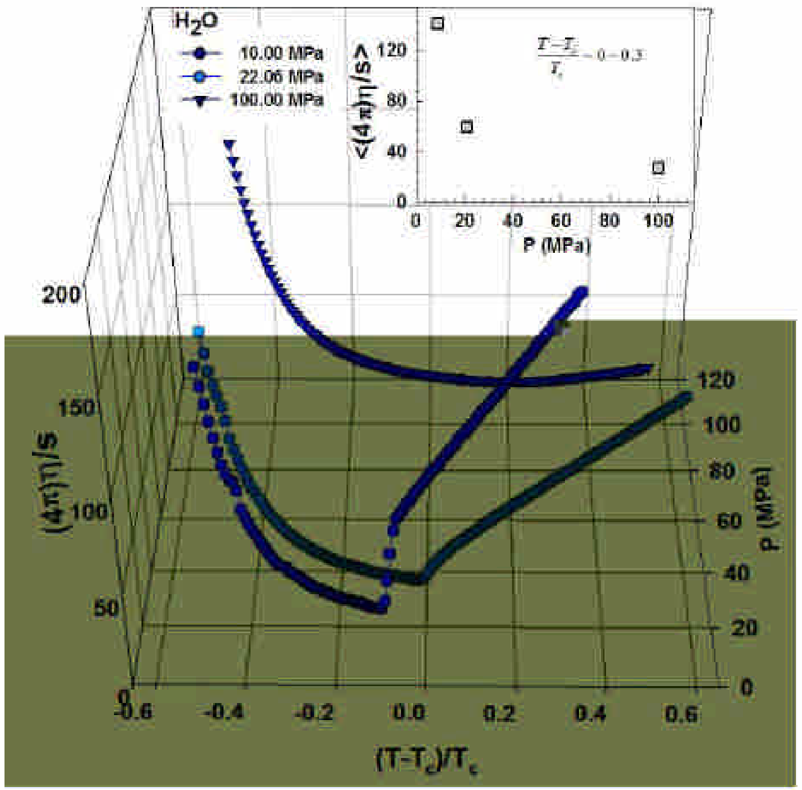




Lacey et al., PRL 98:092301,2007; 2007 US Nuclear Science Long Range Plan

η/s of Water

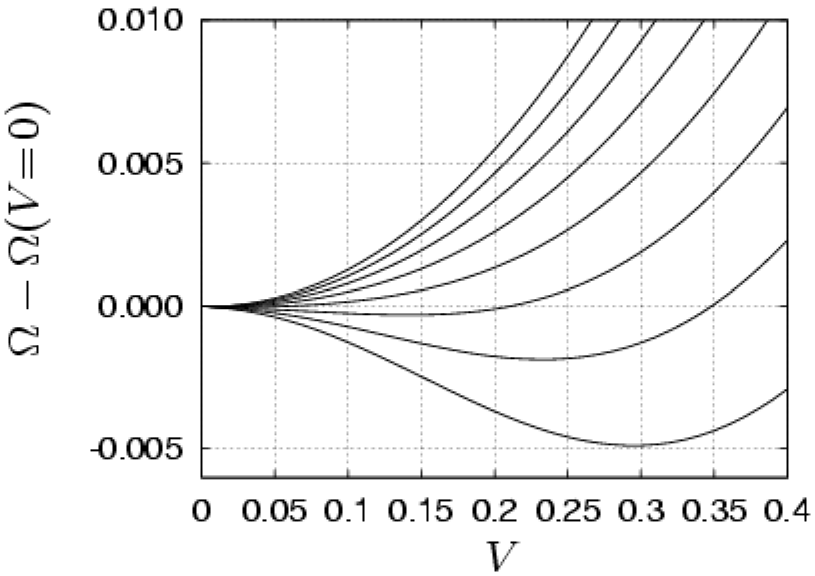


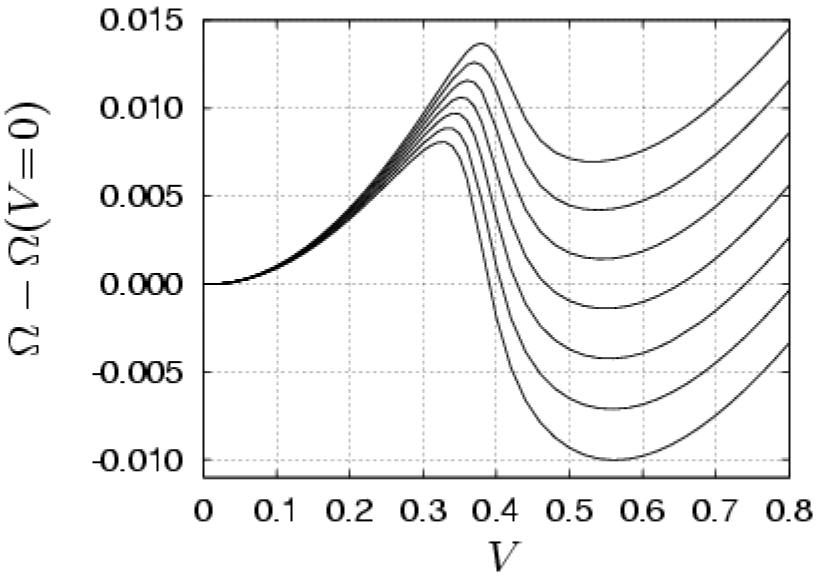


(Lacey et al.)

$$\mathcal{L} = \frac{1}{2}(\partial_\mu \phi)^2 - \frac{1}{2}a\phi^2 - \frac{1}{4}b\phi^4 - \frac{1}{6}c\phi^6$$

(JWC, M. Huang, Y.H. Li, E. Nakana, D.L. Yang)



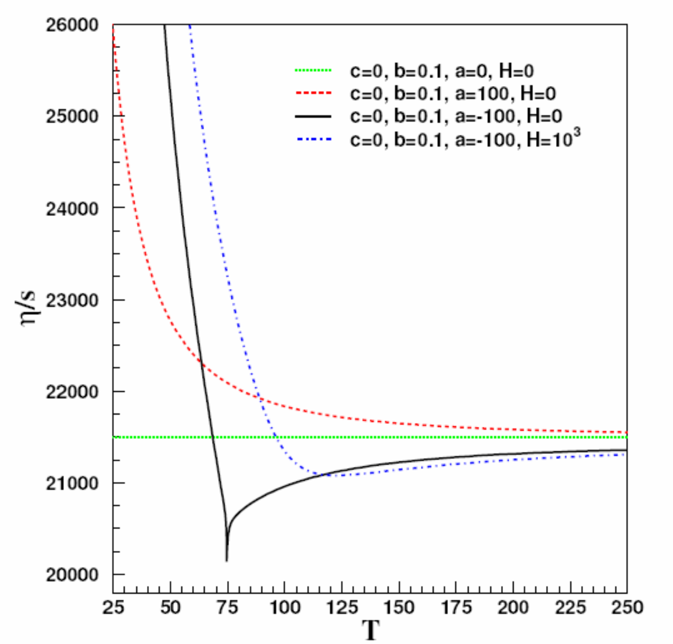


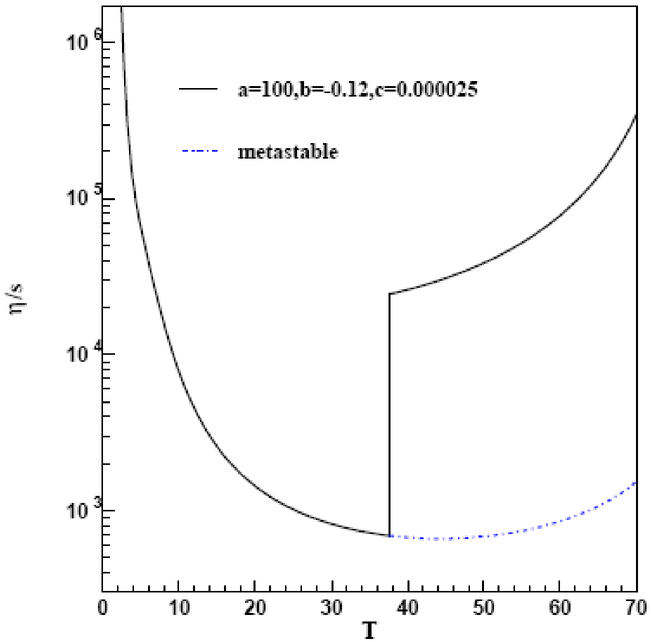
2nd-order p.t.:
a < 0, b > 0, c = 0
crossover: + $\delta\mathcal{L} = H\phi$
No p.t.: a > 0, b > 0, c = 0

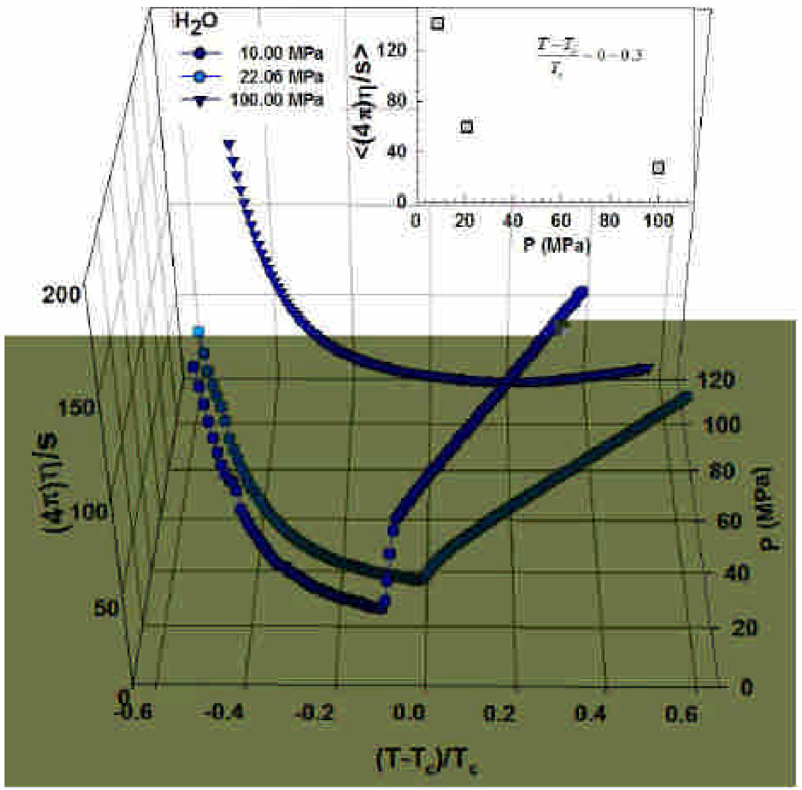
1st-order phase transition
a > 0, b < 0, c > 0

- Weak coupling, Boltzmann eq.
- Mean field calculation
- CJT formulism (Cornwall, Jackiw, Tomboulis)

η/s of Water



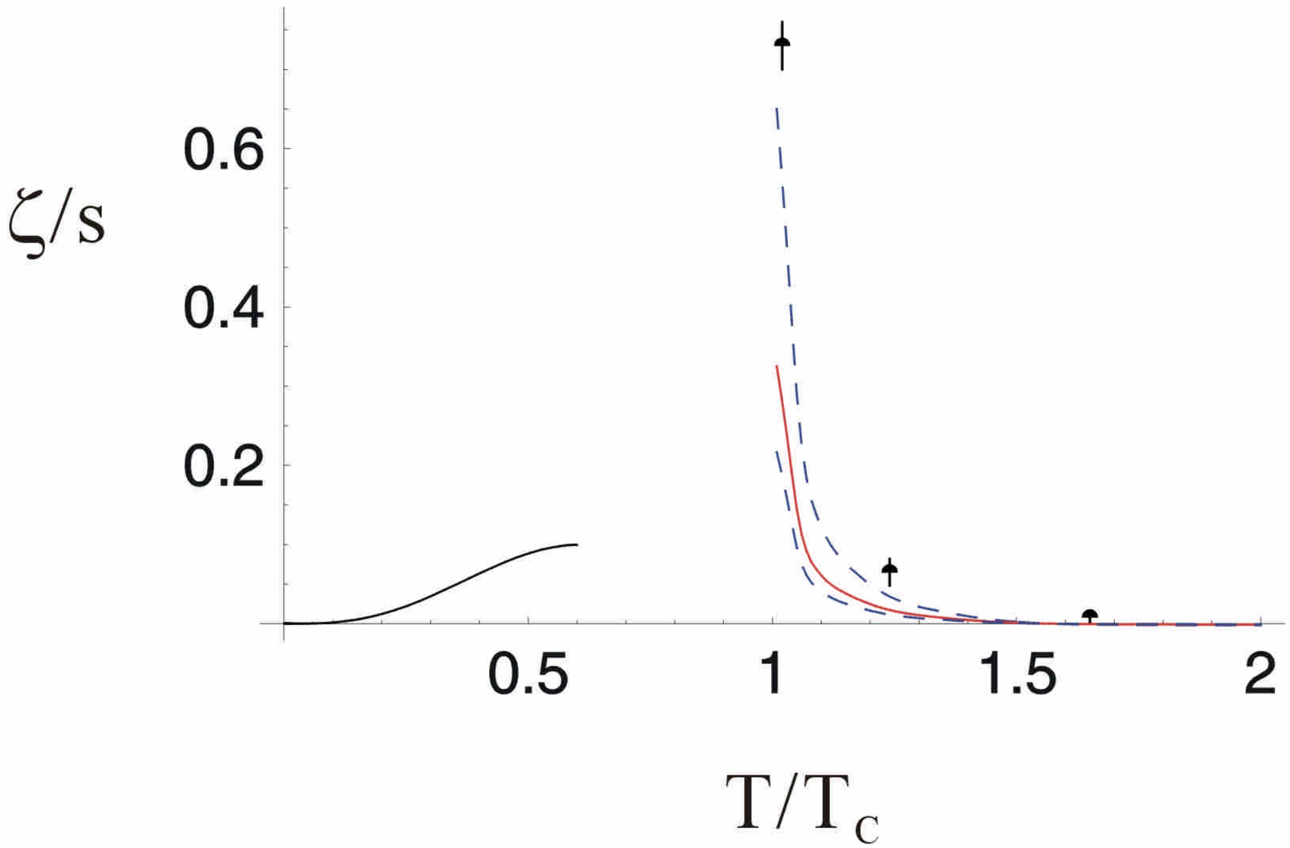




(Lacey et al.)

QCD Bulk Viscosity (Chiral Limit)

Karsch, Kharzeev, Tuchin;
Meyer; JWC, Wang



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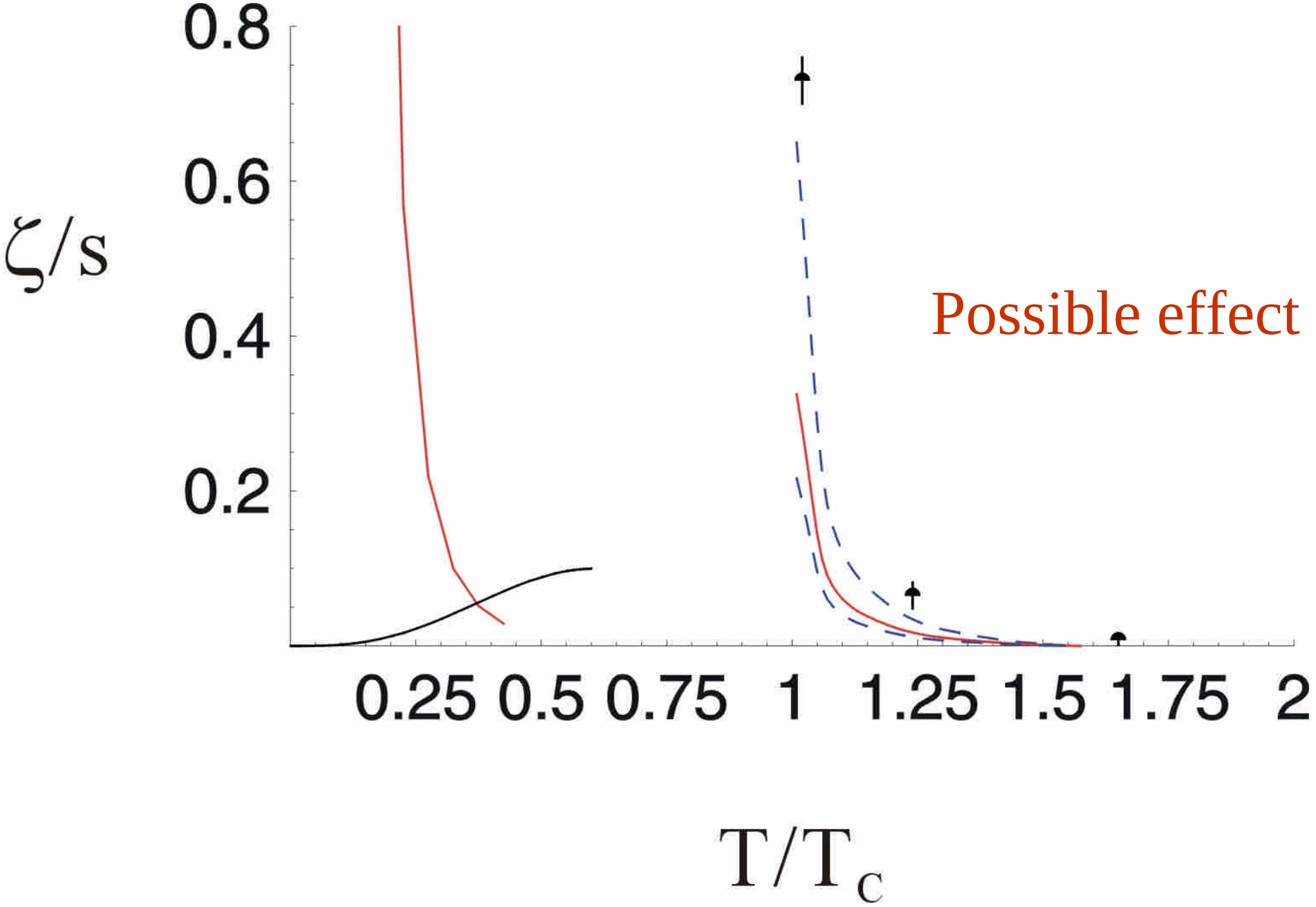
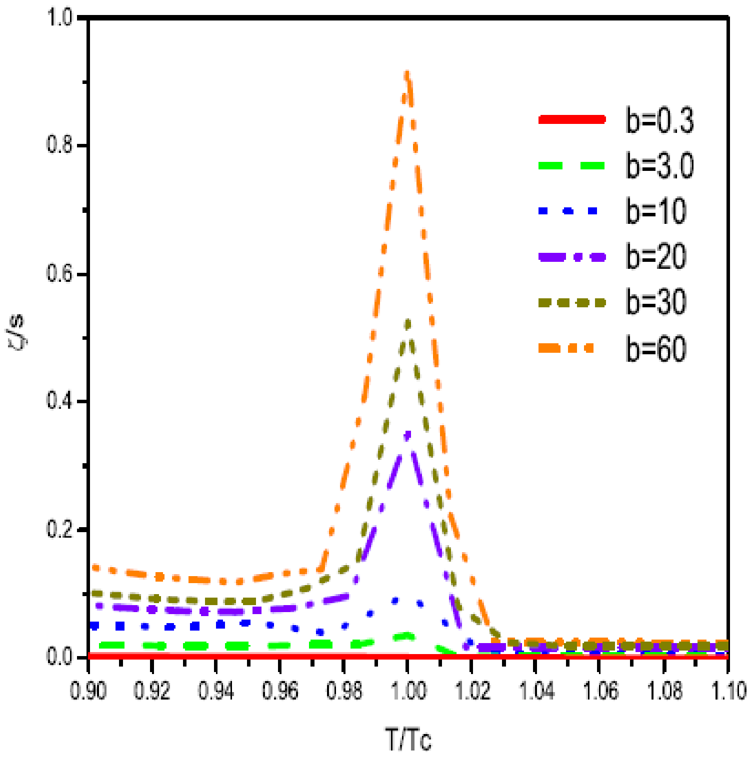
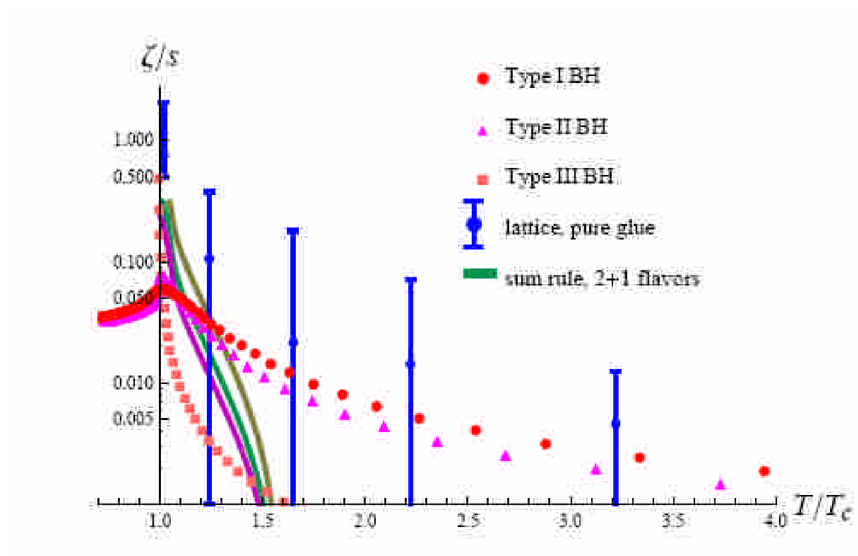


Possible effect see Song's talk

Bulk Viscosity





Gubser, Nellore, Pufu, Rocha

Li, Huang

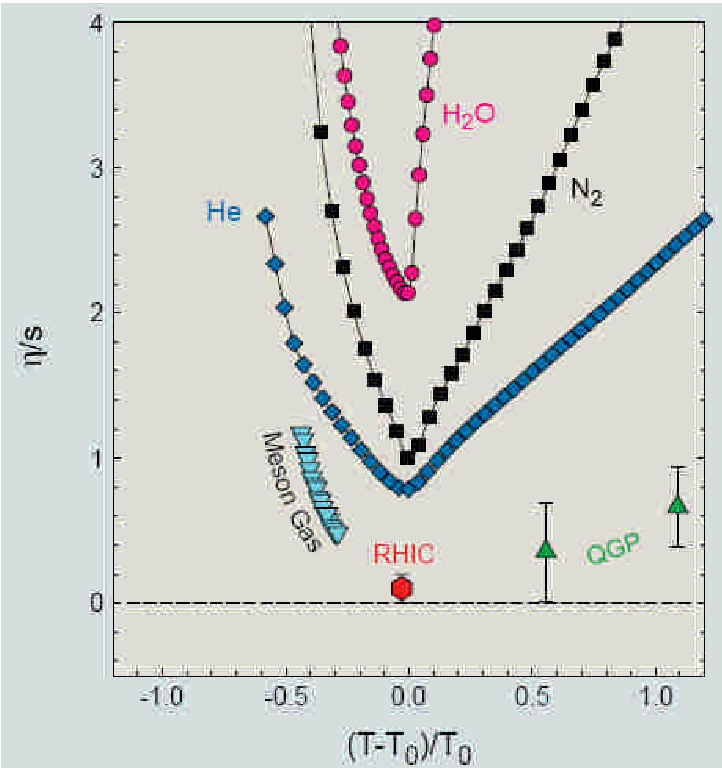
$$\frac{\eta}{s} = \frac{1}{4\pi}$$

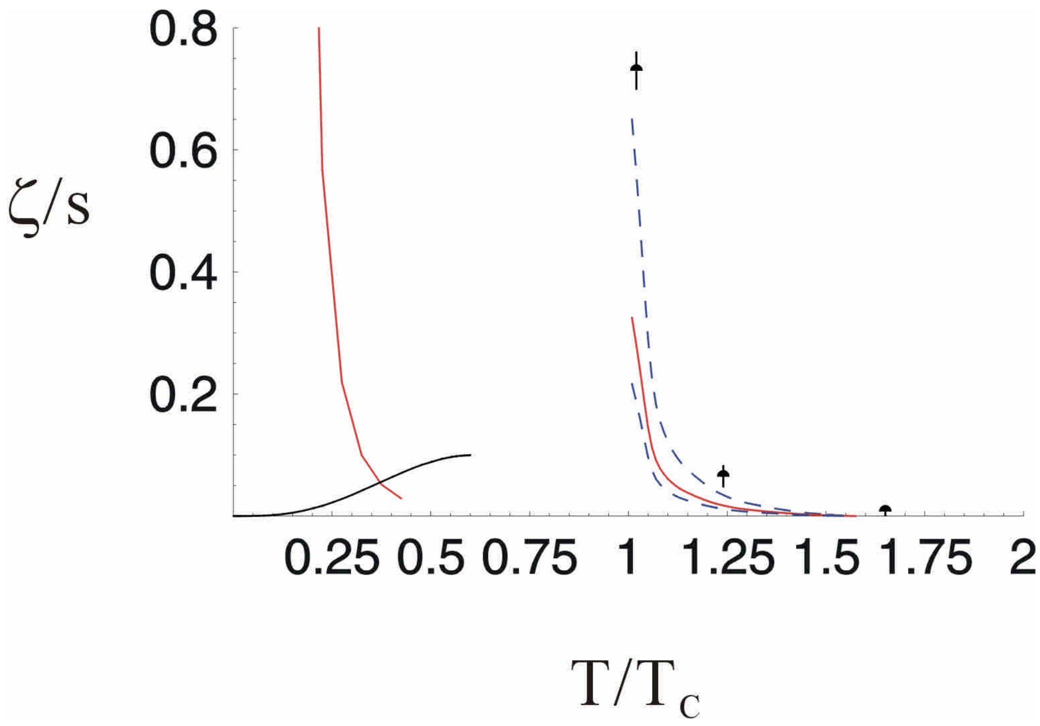
Outlook I: Universality?

Universal η/s and ζ/s behaviors?

(η/s reaches local minimum near p.t.

ζ/s reaches local maximum near p.t.)





Mapping QCD phase diagram by η/s ?

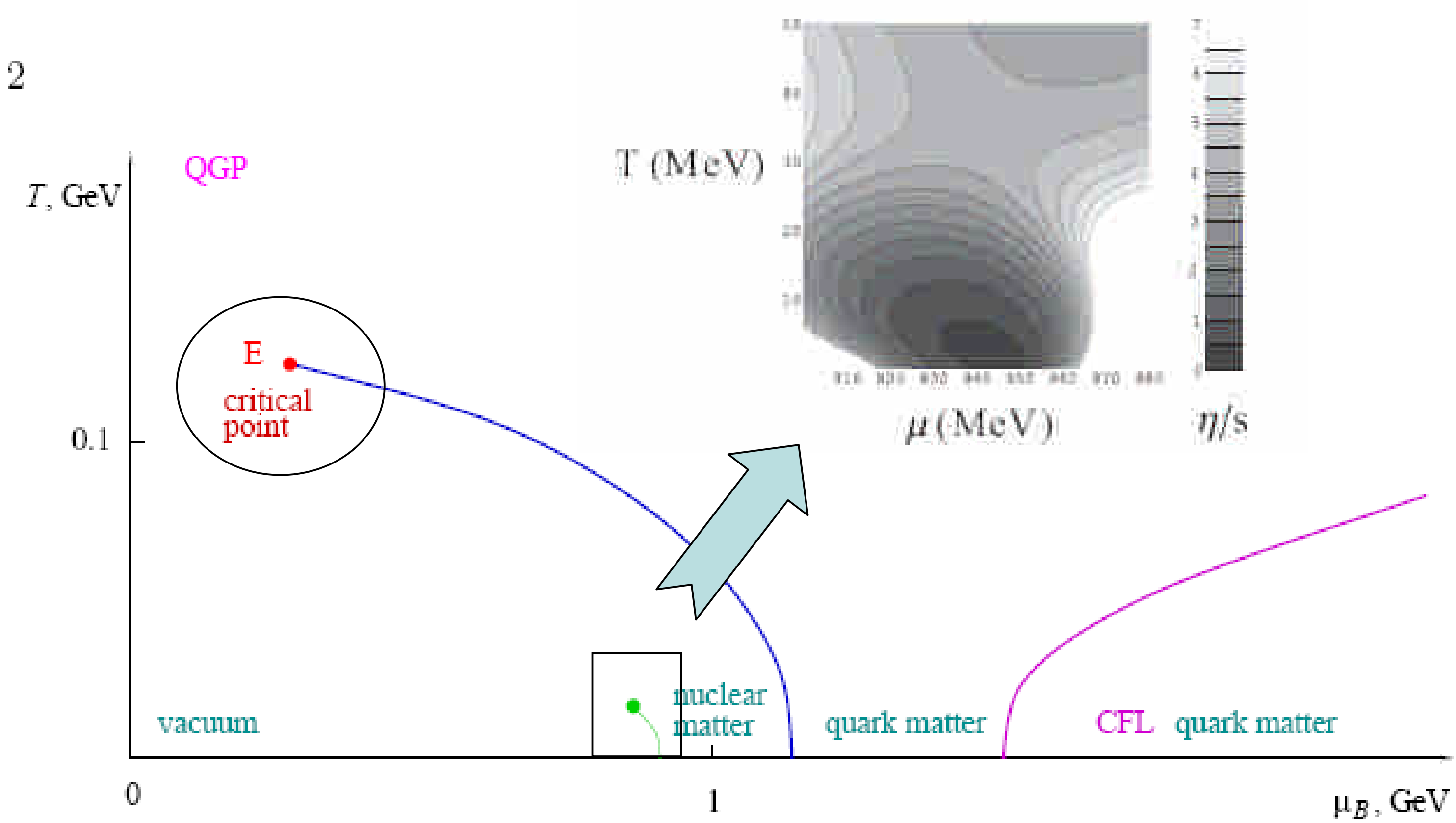


Fig. 1. QCD phase diagram

Locating critical end point (Lacey)

Outlook II: Invading the Bound

Go metastable

(T. Cohen)

$$Q\overline{q}$$

$$\begin{aligned} N_Q &= N, \;\; N_{\overline{q}} = 1 \\ m_Q &\propto N, \;\; N_c \propto N \end{aligned}$$

$$\eta/s \propto 1/\ln N$$

UV complete but metastable

Outlook

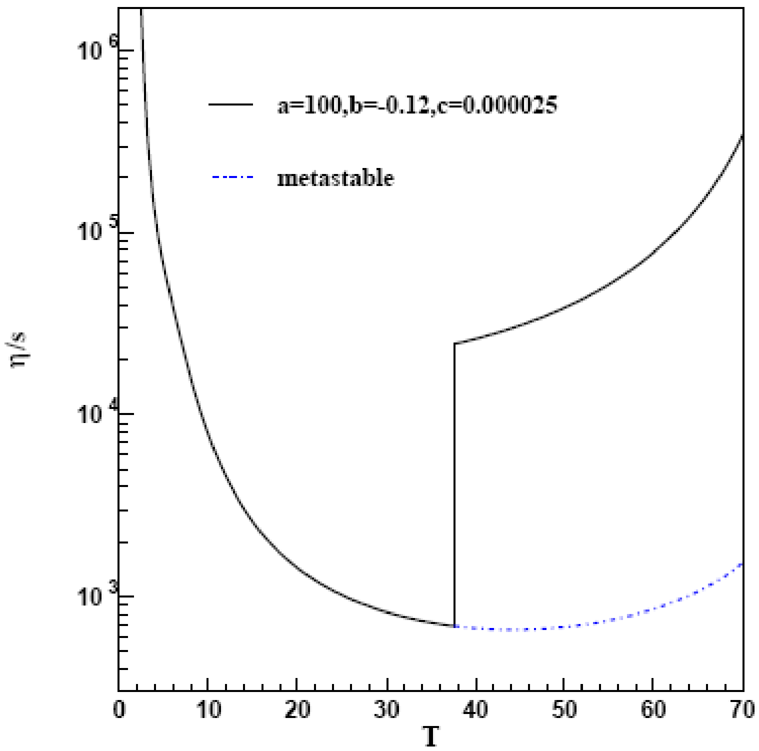
Invading the bound

$$Q\bar{q}$$

$$N_Q$$

$$m_Q$$

$$\eta/s \propto 1/\ln N$$



UV complete but metastable

Go Finite N

- O(1/N) effect, Higher derivative gravity,
  (Brigante, Liu, Myers, Shenker, Yaida; Kats, Petrov)

$$\frac{\eta}{s} \geq \frac{16}{25}\left(\frac{1}{4\pi}\right)$$

Outlook III: Cold Atoms

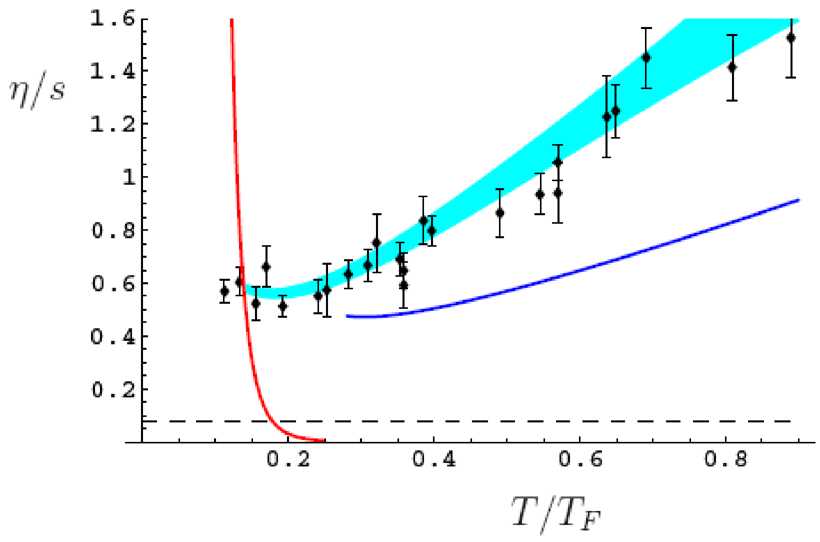
- NR AdS/CFT

Adams, Balasubramanian, McGreevy;
Maldacena, Martelli, Tachikawa;
Herzog, Rangamani, Ross, 2008

d = 2 + 1

$$\frac{\eta}{s} = \frac{1}{4\pi}$$

Cold Unitary Atoms



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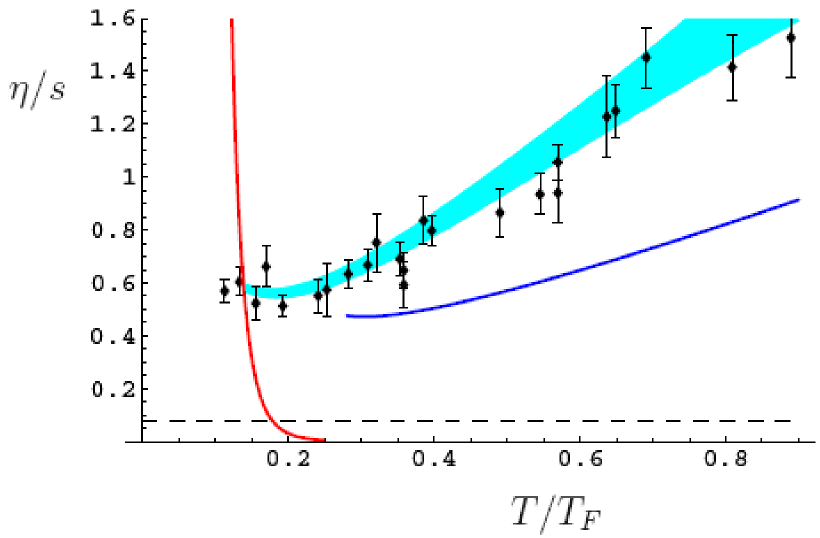

Not for cold atoms at 2+1 d,
where unitary fermi gas is a free gas JWC, Wen, 08

- QCD shear viscosity in the hadronic phase:

  (a) zero density (w/ Eiji Nakano)

  (b) nuclear L-G phase transition

  (w/ Yen-Fu Liu, Yen-Han Li, Eiji Nakano)

- Scalar field theory (w/ Mei Huang, Yen-Han Li, Eiji Nakano, Di-Lun Yang)
- Bulk Viscosity (w/ Juven Wang)