Cold quarks stars from hot lattice QCD

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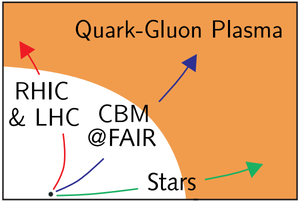
1. hot lattice QCD and quasiparticles
2. quasiparticle model: going to $\mu > 0$
3. cold quark stars



Effective QPM

- quasiparticle model:

$$s = \sum_i s_i \qquad i = g, u, d, s$$

$$s_i \sim \int_{\mathrm{d}^4 k} \frac{\partial\, n_{\mathrm{B/F}}}{\partial T} \Theta\left(-\omega^2 + k^2 + m_\infty^2(\mu, T, G^2(\mu, T)\right)$$

(derived from 1-loop QCD)

Blaizot, Iancu, Rebhan: PRD'01
RS, Bluhm, Kämpfer: JPPNP'09

- running/effective coupling

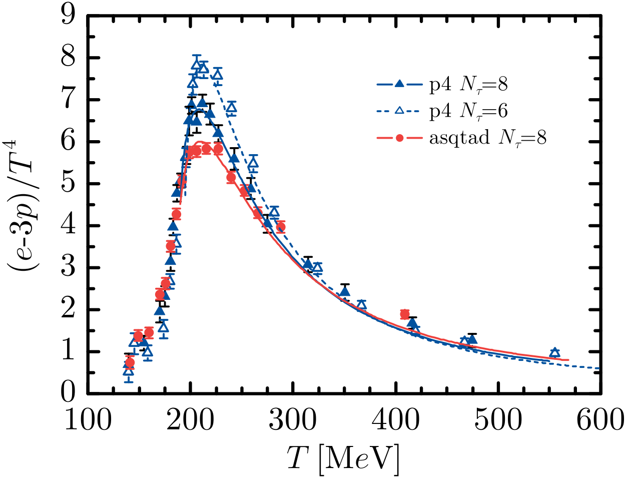
$$G^2(x^2) = \frac{16\pi^2}{\beta_0 \ln(x^2)} \quad \overset{\mu=0}{\longrightarrow} \quad x = \frac{\bar{\mu}}{\Lambda_{\mathrm{QCD}}} \to \frac{T\text{-}T_s}{\lambda}$$

Bluhm, Kämpfer, RS, Seipt: EPJC'07

- fit to e-$3p$ with fixed $p(T_c)$: T_s, λ, p_0

At $\mu=0$

- quasiparticle model (QPM) fit to lattice results



Bazavov et al.: PRD '09

state variables s, n, p, $(e\text{-}3p)$, ...

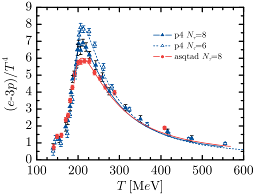
↑

effective coupling G^2

↗ ↖

@ $\mu = 0$:

@ $\mu \neq 0$:



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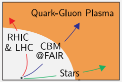
Into the T-μ-plane



- $\mu > 0$: stationary potential, self-consistent model
  $\longrightarrow$ impose Maxwell's relation

$$\frac{\partial s}{\partial \mu} = \frac{\partial n}{\partial T} \qquad \longrightarrow \qquad a_T \frac{\partial G^2}{\partial T} + a_\mu \frac{\partial G^2}{\partial \mu} = b$$

Peshier, Kämpfer, Soff: PRC'00, PRD'02

- quasilinear PDE for $G^2(T, \mu \neq 0)$:
  $\longrightarrow$ T-μ-plane accessible

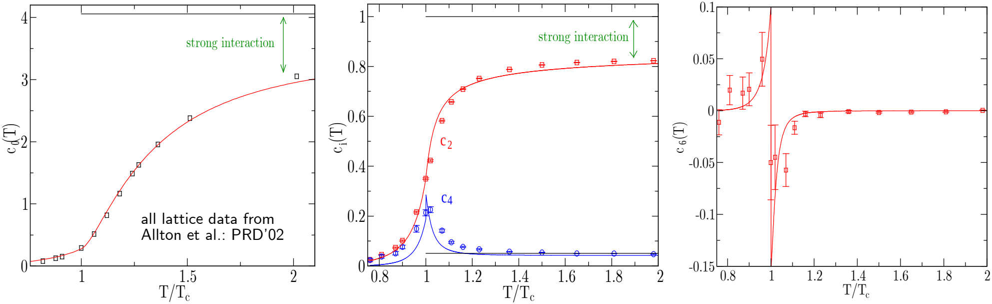
caveat: for perfect solution collective excitations
and damping terms necessary

RS, Bluhm, Kämpfer: EPJ ST'08

Small chemical potential

- test with $p(T, \mu \gtrsim 0)$ lattice data

$$p = T^4 \sum_n c_n(T) \left(\frac{\mu}{T}\right)^n \qquad c_n(T) = \frac{1}{n!} \frac{\partial^n (p/T^4)}{\partial(\mu/T)^n}$$



Bluhm, Kämpfer, Soff: PLB'05

- application in hydro @ RHIC successful

Bluhm, Kämpfer, RS, Seipt, Heinz: PRC'07

Isospin asymmetric QPM

- five chemical potentials

$$\mu_u,\ \mu_d,\ \mu_s \quad + \quad \mu_e,\ \mu_\mu$$

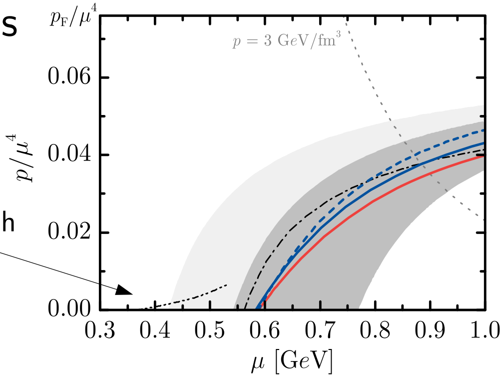
- four side conditions
  - β equilibrium (e.g. $n \leftrightarrow p^+ + e^- + \bar{\nu}_e;\ \mu_d = \mu_u + \mu_e$)
  - equilibrium in strangeness changing decays (e.g. $\Lambda \leftrightarrow p^+ + \pi^-;\ \mu_s = \mu_d$)
  - muon decay (e.g. $\mu^- \leftrightarrow e^- + \bar{\nu}_e + \nu_\mu;\ \mu_\mu = \mu_e$)
  - electric neutrality

$\longrightarrow$ only one independent chemical potential $\mu = \mu_u$

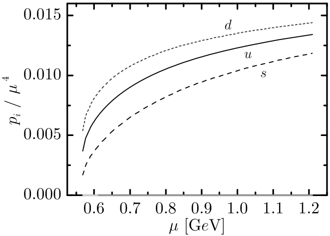
At $T=0$

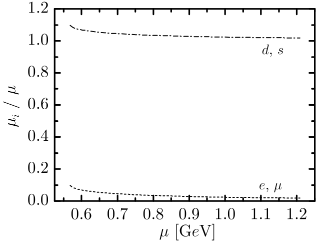
- thermodynamic quantities well within perturbative predictions
  (Andersen, Strickland: PRD'02
  Fraga et al.: NPA'02)

hybrid approach
needed



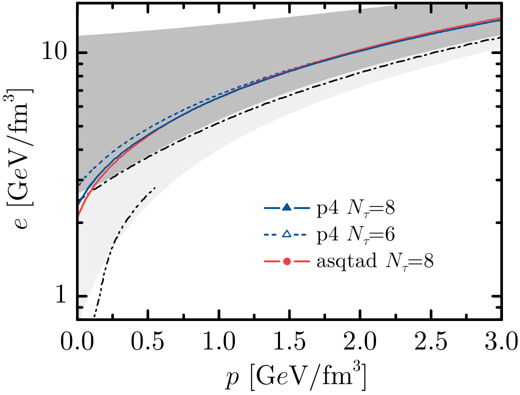
- individual contributions





At T=0

- EOS: narrow range for all actions
  - vacuum energy density dep. on lattice spacing
  - asymptotics governed by lattice action



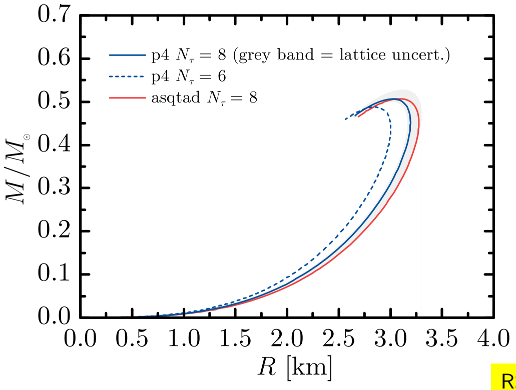
- good approximation

$$e = v_s^{-2} p + e_0$$

$$3.3 - 3.6 \qquad (375 - 395\mathrm{MeV})^4$$

Pure quark stars

- solutions of TOV equations



RS, Kämpfer: arXiv:0912.2827
submitted to PRC

→ rather small and light ($M, R \sim e_0^{-1/2}$)

→ no twin candidates

Summary & Outlook

- ℓQCD results mapped to large μ, even T=0
- EOS for quark stars similar for all actions
- quark stars with rather smaller radii + masses

- outlook: hybrid stars
  full HTL quasiparticle model with
  Landau damping and collective modes
  EOS for FAIR/CBM