In medium properties and effects of vector mesons from effective field theories: recent advances

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Overview

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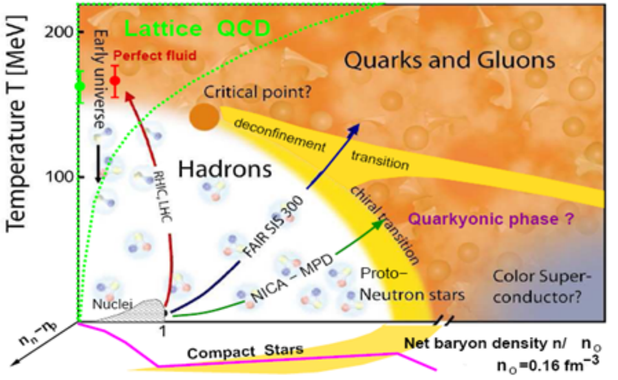
3. (Axial)vector curvature masses
   T-dependence of the masses
4. N_c scaling
   Phase boundary
5. Hybrid star $M - R$ curves
   Hadron-quark crossover
6. Conclusion

Envisaged phase diagram of QCD



Important details of the phase diagram is still unknown (mainly at large baryon density)

Properties of the phase diagram especially at finite baryon densities/baryochemical potential can be well investigated with the help of effective field theories of QCD $\longrightarrow$ e.g. details of the phase boundary like existence and location of the CEP, in medium dependence of meson masses, or properties of compact stars etc.

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The ePQM model

Lagrangian of the ePQM

$\mathcal{L}$ constructed based on linearly realized global $U(3)_L \times U(3)_R$ symmetry and its explicit breaking

$$\begin{aligned}\mathcal{L} &= \mathrm{Tr}[(D_\mu\Phi)^\dagger(D_\mu\Phi)] - m_0^2\mathrm{Tr}(\Phi^\dagger\Phi) - \lambda_1[\mathrm{Tr}(\Phi^\dagger\Phi)]^2 - \lambda_2\mathrm{Tr}(\Phi^\dagger\Phi)^2 \\ &+ c_1(\det\Phi + \det\Phi^\dagger) + \mathrm{Tr}[H(\Phi+\Phi^\dagger)] - \frac{1}{4}\mathrm{Tr}(L_{\mu\nu}^2 + R_{\mu\nu}^2) \\ &+ \mathrm{Tr}\left[\left(\frac{m_1^2}{2}\mathbb{1} + \Delta\right)(L_\mu^2 + R_\mu^2)\right] + i\frac{g_2}{2}(\mathrm{Tr}\{L_{\mu\nu}[L^\mu, L^\nu]\} + \mathrm{Tr}\{R_{\mu\nu}[R^\mu, R^\nu]\}) \\ &+ \frac{h_1}{2}\mathrm{Tr}(\Phi^\dagger\Phi)\mathrm{Tr}(L_\mu^2 + R_\mu^2) + h_2\mathrm{Tr}[(L_\mu\Phi)^2 + (\Phi R_\mu)^2] + 2h_3\mathrm{Tr}(L_\mu\Phi R^\mu\Phi^\dagger) \\ &+ \bar\Psi\left(i\gamma^\mu D_\mu - g_F(S - i\gamma_5 P)\right)\Psi - g_V\bar\Psi\left(\gamma^\mu(V_\mu + \gamma_5 A_\mu)\right)\Psi,\end{aligned}$$

$$\begin{aligned}\Phi &= S + iP \equiv \sum_{a=0}^{8}(S_a\lambda_a + iP_a\lambda_a) \\ D^\mu\Phi &= \partial^\mu\Phi - ig_1(L^\mu\Phi - \Phi R^\mu) - ieA_e^\mu[T_3, \Phi], \\ L^{\mu\nu} &= \partial^\mu L^\nu - ieA_e^\mu[T_3, L^\nu] - \left\{\partial^\nu L^\mu - ieA_e^\nu[T_3, L^\mu]\right\}, \\ R^{\mu\nu} &= \partial^\mu R^\nu - ieA_e^\mu[T_3, R^\nu] - \left\{\partial^\nu R^\mu - ieA_e^\nu[T_3, R^\mu]\right\}, \\ D^\mu\Psi &= \partial^\mu\Psi - iG^\mu\Psi, \quad \text{with} \quad G^\mu = g_s G_a^\mu T_a.\end{aligned}$$

+ Polyakov loop potential (for $T > 0$)

Particle content

- Vector and Axial-vector meson nonets

$$V^\mu = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\omega_N+\rho^0}{\sqrt{2}} & \rho^+ & K^{\star +} \\ \rho^- & \frac{\omega_N-\rho^0}{\sqrt{2}} & K^{\star 0} \\ K^{\star -} & \bar{K}^{\star 0} & \omega_S \end{pmatrix}^\mu \quad A^\mu = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{f_{1N}+a_1^0}{\sqrt{2}} & a_1^+ & K_1^+ \\ a_1^- & \frac{f_{1N}-a_1^0}{\sqrt{2}} & K_1^0 \\ K_1^- & \bar{K}_1^0 & f_{1S} \end{pmatrix}^\mu$$

$\rho \to \rho(770), K^\star \to K^\star(894)$
$\omega_N \to \omega(782), \omega_S \to \phi(1020)$

$a_1 \to a_1(1230), K_1 \to K_1(1270)$
$f_{1N} \to f_1(1280), f_{1S} \to f_1(1426)$

- Scalar ($\sim \bar{q}_i q_j$) and pseudoscalar ($\sim \bar{q}_i \gamma_5 q_j$) meson nonets

$$S = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\sigma_N+a_0^0}{\sqrt{2}} & a_0^+ & K_0^{\star +} \\ a_0^- & \frac{\sigma_N-a_0^0}{\sqrt{2}} & K_0^{\star 0} \\ K_0^{\star -} & \bar{K}_0^{\star 0} & \sigma_S \end{pmatrix} \quad P = \frac{1}{\sqrt{2}} \begin{pmatrix} \frac{\eta_N+\pi^0}{\sqrt{2}} & \pi^+ & K^+ \\ \pi^- & \frac{\eta_N-\pi^0}{\sqrt{2}} & K^0 \\ K^- & \bar{K}^0 & \eta_S \end{pmatrix}$$

multiple possible assignments
mixing in the $\sigma_N - \sigma_S$ sector

$\pi \to \pi(138), K \to K(495)$
mixing: $\eta_N, \eta_S \to \eta(548),\ \eta'(958)$

Spontaneous symmetry breaking: $\sigma_{N/S}$ acquire nonzero expectation values $\phi_{N/S}$
fields shifted by their expectation value: $\sigma_{N/S} \to \sigma_{N/S} + \phi_{N/S}$

In case of compact stars, also vector condensates (see later)

Determination of the parameters

14 unknown parameters $(m_0, \lambda_1, \lambda_2, c_1, m_1, g_1, g_2, h_1, h_2, h_3, \delta_S, \Phi_N, \Phi_S, g_F) \longrightarrow$ determined by the min. of χ^2:

$$\chi^2(x_1,\dots,x_N) = \sum_{i=1}^{M}\left[\frac{Q_i(x_1,\dots,x_N) - Q_i^{\exp}}{\delta Q_i}\right]^2,$$

$(x_1,\dots,x_N) = (m_0, \lambda_1, \lambda_2, \dots)$, $Q_i(x_1,\dots,x_N) \longrightarrow$ from the model, $Q_i^{\exp} \longrightarrow$ PDG value, $\delta Q_i = \max\{5\%, \text{PDG value}\}$

multiparametric minimalization $\longrightarrow$ MINUIT

- PCAC $\rightarrow$ 2 physical quantities: f_π, f_K
- Curvature masses $\rightarrow$ 16 physical quantities: $m_{u/d}, m_s, m_\pi, m_\eta, m_{\eta'}, m_K, m_\rho, m_\Phi, m_{K^\star}, m_{a_1}, m_{f_1^H}, m_{K_1}, m_{a_0}, m_{K_s}, m_{f_0^L}, m_{f_0^H}$
- Decay widths $\rightarrow$ 12 physical quantities: $\Gamma_{\rho\to\pi\pi}, \Gamma_{\Phi\to KK}, \Gamma_{K^\star\to K\pi}, \Gamma_{a_1\to\pi\gamma}, \Gamma_{a_1\to\rho\pi}, \Gamma_{f_1\to KK^\star}, \Gamma_{a_0}, \Gamma_{K_S\to K\pi},$ $\Gamma_{f_0^L\to\pi\pi}, \Gamma_{f_0^L\to KK}, \Gamma_{f_0^H\to\pi\pi}, \Gamma_{f_0^H\to KK}$
- Pseudocritical temperature T_c at $\mu_B = 0$

Field equation

Four coupled field equations are obtained by extremizing the grand potential

$$\Omega(T,\mu_q) = U_{\text{meson}}^{\text{tree}}(\langle M\rangle) + \Omega_{\bar{q}q}^{(0)\text{vac}} + \Omega_{\bar{q}q}^{(0)T}(T,\mu_q) + \mathcal{U}_{\log}(\Phi,\bar{\Phi})$$

using $\frac{\partial\Omega}{\partial\phi_N} = \frac{\partial\Omega}{\partial\phi_S} = \frac{\partial\Omega}{\partial\Phi} = \frac{\partial\Omega}{\partial\bar{\Phi}} = 0$ $\quad E_f^{\pm}(p) = E_f(p)\mp\mu_q, \quad E_f^2(p) = p^2 + m_f^2$

1) $$-\frac{1}{T^4}\frac{d\,U(\Phi,\bar{\Phi})}{d\Phi} + \frac{6}{T^3}\sum_{f=u,d,s}\int\frac{d^3p}{(2\pi)^3}\left(\frac{e^{-\beta E_f^-(p)}}{g_f^-(p)} + \frac{e^{-2\beta E_f^+(p)}}{g_f^+(p)}\right) = 0$$

2) $$-\frac{1}{T^4}\frac{dU(\Phi,\bar{\Phi})}{d\bar{\Phi}} + \frac{6}{T^3}\sum_{f=u,d,s}\int\frac{d^3p}{(2\pi)^3}\left(\frac{e^{-\beta E_f^+(p)}}{g_f^+(p)} + \frac{e^{-2\beta E_f^-(p)}}{g_f^-(p)}\right) = 0$$

3) $$m_0^2\phi_N + \left(\lambda_1 + \frac{\lambda_2}{2}\right)\phi_N^3 + \lambda_1\phi_N\phi_S^2 - \frac{c_1}{\sqrt{2}}\phi_N\phi_S - h_{0N} + \frac{3}{2}g_F\left(\langle\bar{q}_u q_u\rangle_T + \langle\bar{q}_d q_d\rangle_T\right) = 0$$

4) $$m_0^2\phi_S + (\lambda_1+\lambda_2)\phi_S^3 + \lambda_1\phi_N^2\phi_S - \frac{\sqrt{2}}{4}c_1\phi_N^2 - h_{0S} + \frac{3}{\sqrt{2}}g_F\langle\bar{q}_s q_s\rangle_T = 0$$

renormalized fermion tadpole: $\quad m_{u,d} = \frac{g_F}{2}\phi_N$ and $m_s = \frac{g_F}{\sqrt{2}}\phi_S$

$$\langle\bar{q}_f q_f\rangle_T = 4m_f\left[-\frac{m_f^2}{16\pi^2}\left(\frac{1}{2} + \ln\frac{m_f^2}{M_0^2}\right) + \int\frac{d^3p}{(2\pi)^3}\frac{1}{2E_f(p)}\left(f_f^-(p) + f_f^+(p)\right)\right]$$

Axial(vector) curvature masses

Curvature masses

$$\Delta\hat{m}^{2,(X)}_{ab} \equiv \frac{d^2 U_f(\phi,\xi)}{dX_a dX_b}\bigg|_{\xi=0}, \quad X\in\{S,P\}$$

$$\Delta\hat{M}^{2,(Y)}_{\mu\nu,ab} \equiv -\frac{d^2 U_f(\phi,\xi)}{dY^\mu_a dY^\nu_b}\bigg|_{\xi=0}, \quad Y\in\{V,A\}, \quad \xi\in\{X_a,Y_a\}, \quad \phi\in\{\phi_N,\phi_S,\Phi,\bar{\Phi}\ \ldots\}$$

where U_f is the fermionic contribution to the effective potential,

$$U_f(\phi,\ \xi) = i\mathrm{Tr}_D\int_K \log(i\mathcal{S}^{-1}(K;\xi)\big|_{\xi=0} - \frac{i}{2}\mathrm{Tr}\int_K \log\left(i\mathcal{D}^{-1}_{(\mu\nu),ab}(K) - \Pi_{(\mu\nu),ab}(K)\right)$$

On the other hand: The curvature masses are the one-loop self-energies at vanishing momentum:

$$\Pi^{(V/A)\mu\nu}_{ab}(Q) = i2N_c g_V^2 \int_K \frac{g^{\mu\nu}(\pm\ m_a m_b - K^2 + K\cdot Q) + 2K^\mu K^\nu - K^\mu Q^\nu - Q^\mu K^\nu}{(K^2-m_a^2)((K-Q)^2-m_b^2)} \tag{1}$$

- At $T=0 \rightarrow$ vacuum self-energy $\rightarrow$ renormalization $\rightarrow$ dimensional regularization
- At $T\neq 0 \longrightarrow$ matter part (with statistical function) $\rightarrow$ Wick rotation, Matsubara sum, $\int_K \rightarrow iT\sum_n \int \frac{d^3k}{(2\pi)^3}$

Mode decomposition

Vacuum contribution: $\Pi^{\mu\nu}_{\rm vac}(Q) = \Pi_{{\rm vac},L}(Q) P_L^{\mu\nu} + \Pi_{{\rm vac},T}(Q) P_T^{\mu\nu}$

Thermal contribution: $\Pi^{\mu\nu}(Q) = \sum_{x=l,t,L} \Pi_x(Q) P_x^{\mu\nu} + \Pi_C(Q) C^{\mu\nu}$

Where the 4-long./transv., 3-long./transv. projectors and C are ([1,2])

$$P_L^{\mu\nu} = \frac{Q^\nu Q^\mu}{Q^2},\ P_T^{\mu\nu} = g^{\mu\nu} - P_L^{\mu\nu}$$

$$P_l^{\mu\nu} = \frac{u_T^\mu u_T^\nu}{u_T^2},\ P_t^{\mu\nu} = g^{\mu\nu} - P_L^{\mu\nu} - P_l^{\mu\nu},\ C^{\mu\nu} = \frac{Q^\mu u_T^\nu + Q^\nu u_T^\mu}{\sqrt{(Q\cdot u)^2 - Q^2}},\ u_T^\mu = u^\mu - (Q\cdot u) Q^\mu / Q^2$$

- (Pseudo)scalar curvature masses

$$\begin{array}{ccccc} \text{Tree-level} & & T=0 & & T\neq 0 \\ \hat{m}^2 & \longrightarrow & \hat{M}^2 = \hat{m}^2 + \Pi_{\rm vac}(0) & + & \Pi_{\rm mat}(0) \end{array}$$

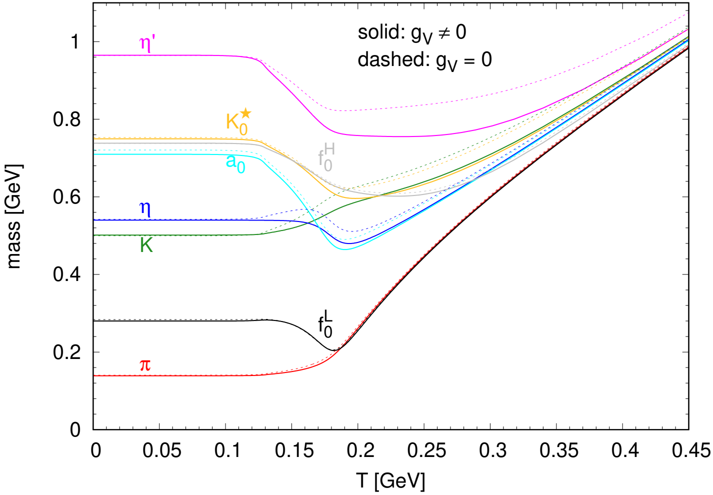
- (Axial) vector curvature masses

$$\begin{array}{ccc} \text{Tree-level} & & \text{Fermion correction} \\ \hat{m}^2 = \hat{m}_L^2 = \hat{m}_T^2 & \xrightarrow{T=0} & \hat{M}^2_{\rm vac} = \hat{M}^2_{{\rm vac},L/T} = \hat{m}^2_{L/T} + \Pi_{{\rm vac},L/T}(0) \\ & \xrightarrow{T\neq 0} & \hat{M}^2_{L/l/t} = \hat{m}^2_{L/l/t} + \Pi_{L/l/t}(0) \end{array}$$

[1] M. Le Bellac, *Thermal Field Theory*, (1996) Cambridge University Press

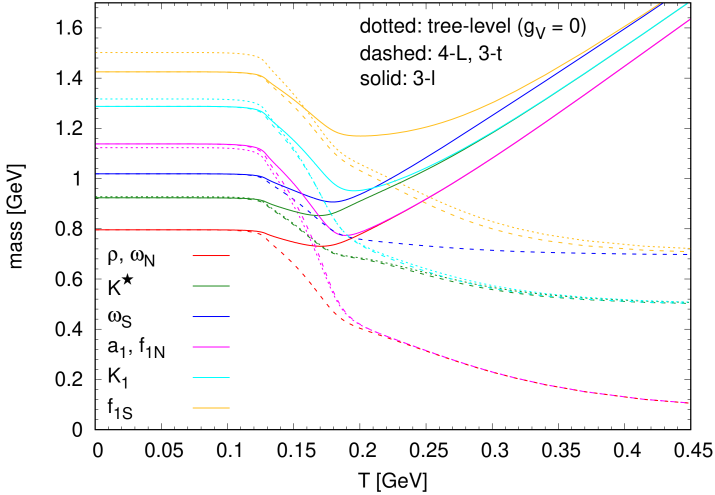
[2] Buchmuller *et al* Nucl. Phys. B **407**, 387-411 (1993)

T dependence of (pseudo)scalar masses



From the χ^2 fit the vector coupling: $g_v \approx 5$

T dependence of (axial)vector masses



From the χ^2 fit the vector coupling: $g_v \approx 5$

Large N_c thermodynamics

Some properties of mesons and baryons for Large N_c

- $g_{QCD} \sim \frac{1}{\sqrt{N_c}}$
- quark loops are $1/N_c$ suppressed
- leading diagrams are palanar diagrams with minimum number of quark loops
- mesons are free, stable, and non-interacting
- mesons are pure $q\bar{q}$ for Large N_c
- meson masses $\sim N_c^0$
- meson decay amplitudes $\sim 1/\sqrt{N_c}$
- for one meson creation: $< 0|J|m > \sim \sqrt{N_c}$
- k meson vertex $\sim N_c^{1-k/2}$. Specifically, the three- and four-meson vertices are $\sim 1/\sqrt{N_c}$ and $\sim 1/N_c$, respectively
- baryon masses $\sim N_c$. Consequently constituent quark masses $\sim N_c^0$

G. 't Hooft. (1974), Nucl. Phys. B 72:461
G. 't Hooft. (1974), Nucl. Phys. B 75:461–470
E. Witten. (1979), Nucl. Phys. B 160:57–115

N_c scaling of the Lagrange parameters

The parameters are: $m_0, \lambda_1, \lambda_2, c_1, m_1, g_1, g_2, h_1, h_2, h_3, \delta_S,\ \Phi_N, \Phi_S, g_F,\ h_N,\ h_S$

- $m_0^2,\ m_1^2,\ \delta_s \sim N_c^0$, because terms of tree level meson masses
- $g_1,\ g_2 \sim \frac{1}{\sqrt{N_c}}$, three couplings
- $\lambda_2,\ h_2,\ h_3 \sim \frac{1}{N_c}$, four couplings
- $\lambda_1,\ h_1 \sim \frac{1}{N_c^2}$, four couplings with different trace structure
- $c_1 \sim \frac{1}{N_c^{3/2}}$ $U_A(1)$ anomaly term has extra $1/N_c$ suppression
- $\Phi_{N/S} \sim \sqrt{N_c},\ \Phi_N = Z_\pi f_\pi,\ f_\pi \sim \sqrt{N_c}$
- $h_{N/S} \sim \sqrt{N_c}$, Goldstone-theorem: $m_\pi^2 \Phi_N = Z_\pi^2 h_N$
- $g_F \sim \frac{1}{\sqrt{N_c}},\ m_{u/d} = g_F \Phi_N$

practically: $g_1 \longrightarrow g_1\sqrt{\frac{3}{N_c}},\ \Phi_{N/S} \longrightarrow \Phi_{N/S}\sqrt{\frac{N_c}{3}} \ldots$ *etc.*

Parameter sets

For lower $m_\sigma = 600$ MeV

Φ_N	0.092
Φ_S	0.095
m_0^2	-0.036
m_1^2	0.395
λ_1	-17.01
λ_2	82.47
h_1	-9.0
h_2	11.659
h_3	4.703
δ_S	0.153
c_1	0.0
g_1	-5.894
g_2	-2.996
g_F	6.494

For higher $m_\sigma = 1300$ MeV

Φ_N	0.162
Φ_S	0.124
m_0^2	-0.754
m_1^2	0.395
λ_1	0.0
λ_2	65.322
h_1	0.0
h_2	11.659
h_3	4.703
δ_S	0.153
c_1	1.121
g_1	-5.894
g_2	-2.996
g_F	4.943

Field equations, masses in Large N_c

Field equations:

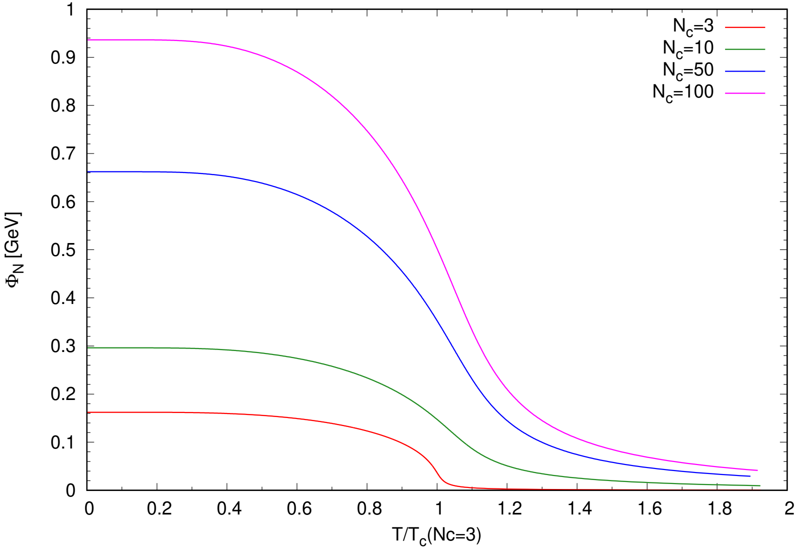
$$m_0^2\Phi_N\sqrt{\frac{N_c}{3}}+\left(\lambda_1\frac{3}{N_c}+\frac{\lambda_2}{2}\right)\Phi_N^3\sqrt{\frac{N_c}{3}}+\lambda_1\Phi_N\Phi_S^2\sqrt{\frac{3}{N_c}}-\frac{1}{\sqrt{2}}c_1\sqrt{\frac{3}{N_c}}\Phi_N\Phi_S$$
$$-h_N\sqrt{\frac{N_c}{3}}+\frac{3}{2}g_F(\mathrm{Tad}_u+\mathrm{Tad}_d)=0$$

$$m_0^2\Phi_S\sqrt{\frac{N_c}{3}}+\left(\lambda_1\frac{3}{N_c}+\lambda_2\right)\Phi_S^3\sqrt{\frac{N_c}{3}}+\lambda_1\Phi_N^2\Phi_S\sqrt{\frac{3}{N_c}}-\frac{1}{2\sqrt{2}}c_1\sqrt{\frac{3}{N_c}}\Phi_N^2$$
$$-h_S\sqrt{\frac{N_c}{3}}+\frac{3}{\sqrt{2}}g_F\mathrm{Tad}_s=0$$

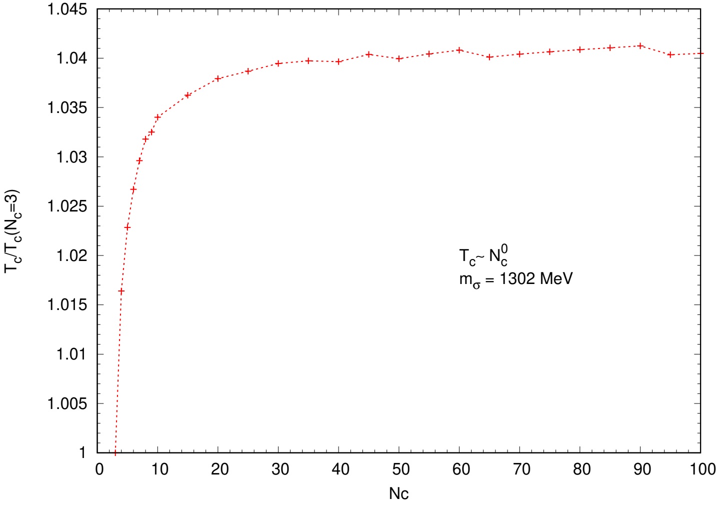
Pion three-level mass:

$$m_\pi^2=Z_\pi^2\left(m_0^2+\left(\lambda_1\frac{3}{N_c}+\frac{\lambda_2}{2}\right)\Phi_N^2+\lambda_1\frac{3}{N_c}\Phi_S^2-c_1\frac{3}{N_c}\frac{\Phi_S}{\sqrt{2}}\right)$$

$\phi_N(T)$ at diff. N_c values ($\mu_B = 0$, $m_\sigma = 1300$ MeV)

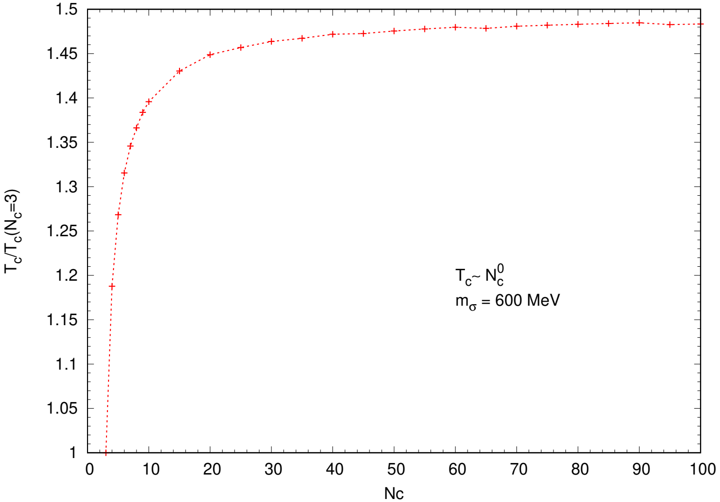


N_c scaling of the pseudocrit. T_c ($m_\sigma = 1300$ MeV)



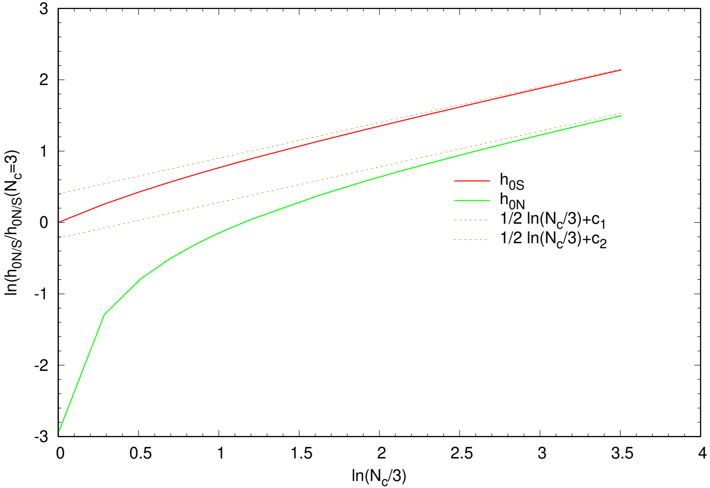
From $N_c = 3$ to $N_c = 100$: T_c changes $\approx 4\%$

N_c scaling of the pseudocrit. T_c ($m_\sigma = 600$ MeV)



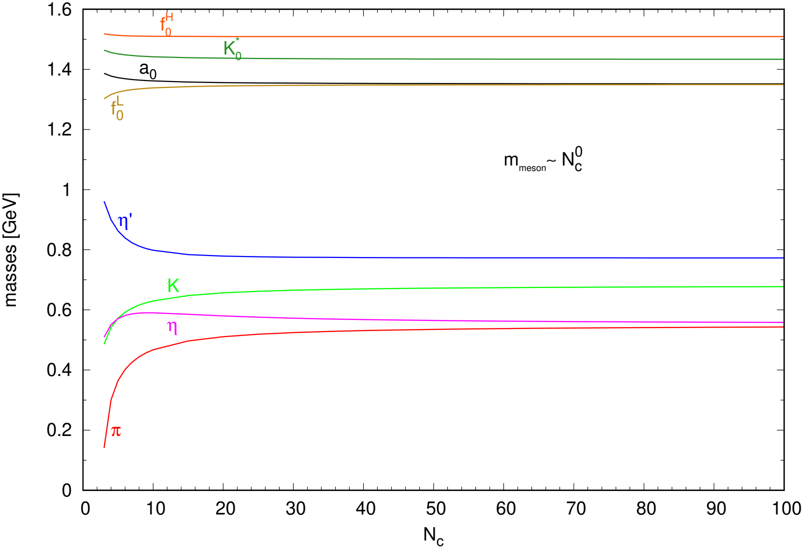
From $N_c = 3$ to $N_c = 100$: T_c changes $\approx 50\%$. In both cases $T_c \sim N_c^0$ as expected

N_c scaling of $h_{N/S}$ ($m_\sigma = 1300$ MeV)

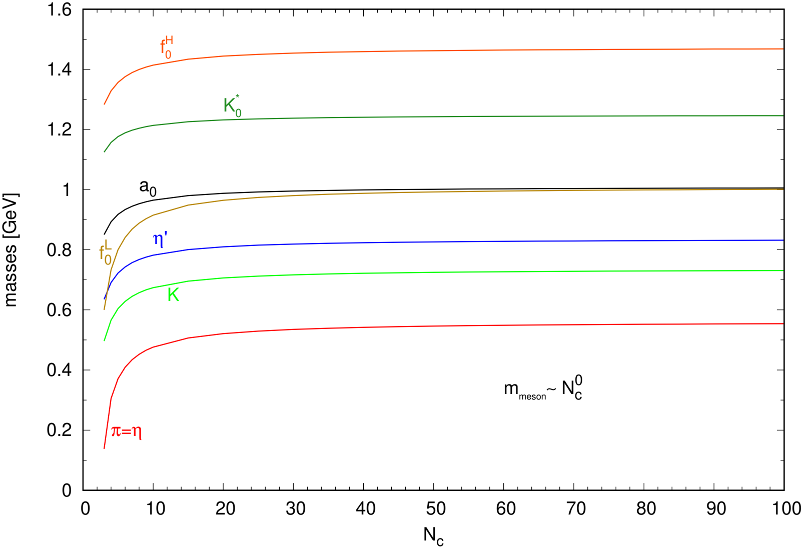


The expected N_c scaling ($h_{N/S} \sim \sqrt{N_c}$ are calculated from the field equations at $T = \mu_B = 0$)

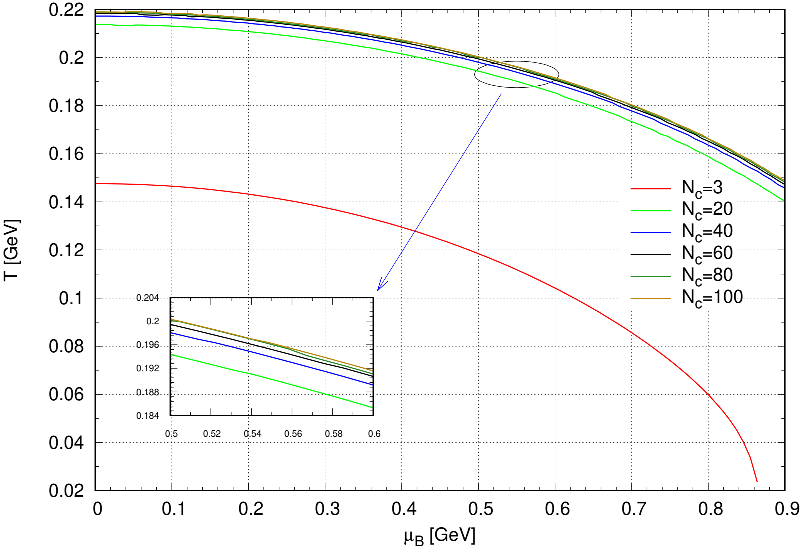
N_c scaling of meson masses ($m_\sigma = 1300$ MeV)



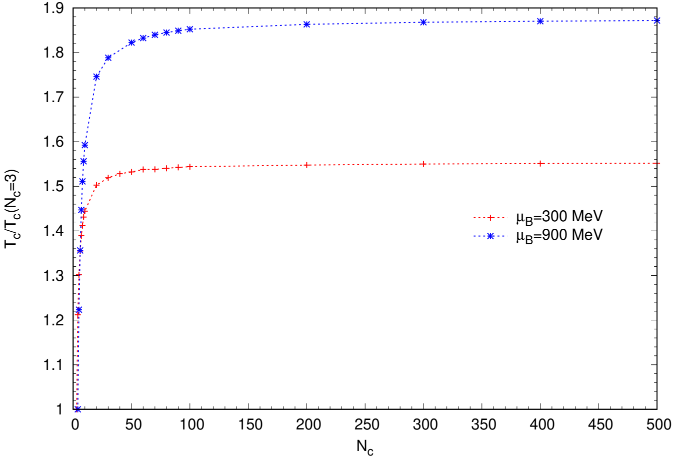
N_c scaling of meson masses ($m_\sigma = 600$ MeV)



Phase boundary at diff. N_c's ($m_\sigma = 600$ MeV)



T_c scaling at different μ_B's



For both low and high μ_B: T_c scales as $\sim N_c^0$. What happens if there is a CEP at large N_c?

$M-R$ curves of hybrid stars

Structure of compact stars

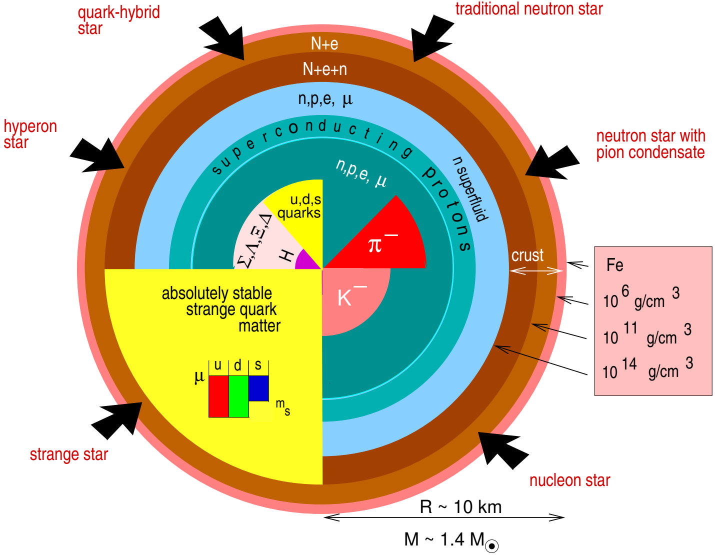
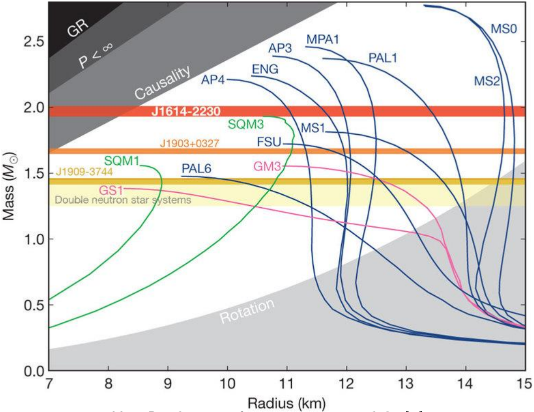


Fig. from *F. Weber, J. Phys. G* **27**, *465 (2001)*

Various $M - R$ curves for different compact star EoS's

- QCD directly unsolvable at finite density
- One can use effective models in the zero temperature finite density region
- Neutron star observations restrict such models [1,2]



$M - R$ relations from various models [1]

[1] *P. Demorest et al. (2010), Nature* **467**, *1081*

[2] *J. Antoniadis et al. (2013), Science* **340**, *6131*

Elements of the quark EOS

For large density e(P)QM model is used, but with additional vector condensates

- non-zero vector condensates: $\langle(\rho^0)^0\rangle = \phi_\rho$, $\langle(\omega)^0\rangle = \phi_\omega$, $\langle(\Phi)^0\rangle = \phi_\Phi$
- free electron gas + β-equilibrium
- modified chemical potentials:

$$\mu_u = \mu_q - \frac{2}{3}\mu_e - \frac{1}{2}g_V(\phi_\omega + \phi_\rho)$$
$$\mu_d = \mu_q + \frac{1}{3}\mu_e - \frac{1}{2}g_V(\phi_\omega - \phi_\rho)$$
$$\mu_s = \mu_q + \frac{1}{3}\mu_e - \frac{1}{\sqrt{2}}g_V\phi_\Phi$$

- charge neutrality: $\frac{2}{3}n_u - \frac{1}{3}n_d - \frac{1}{3}n_s - n_e = 0$
- field equations:

$$\frac{\partial\Omega_{tot}}{\partial\phi_N} = \frac{\partial\Omega_{tot}}{\partial\phi_S} = \frac{\partial\Omega_{tot}}{\partial\phi_\rho} = \frac{\partial\Omega_{tot}}{\partial\phi_\omega} = \frac{\partial\Omega_{tot}}{\partial\phi_\Phi} = 0 \quad \to p(\varepsilon)\text{curve}$$

Tolman-Oppenheimer-Volkoff (TOV) equation

Solving the Einstein's equation for spherically symmetric case and homogeneous matter $\longrightarrow$ TOV eqs.:

$$\frac{\mathrm{d}p}{\mathrm{d}r} = -\frac{[p(r)+\varepsilon(r)]\,[M(r)+4\pi r^3 p(r)]}{r[r-2M(r)]} \qquad (2)$$

with

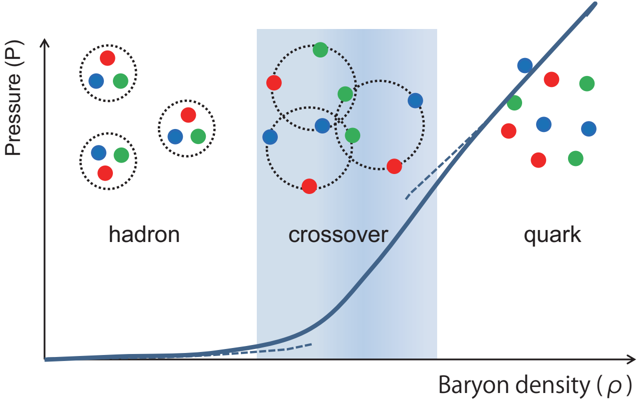
$$\frac{\mathrm{d}M}{\mathrm{d}r} = 4\pi r^2 \varepsilon(r)$$

These are integrated numerically for a specific $p(\varepsilon)$

- For a fixed ε_c central energy density Eq. (2) is integrated until $p = 0$
- Varying ε_c a series of compact stars is obtained (with given M and R)
- Once the maximal mass is reached, the stable series of compact stars ends

Schematic picture of pressure (H-Q crossover)

based on: *K. Masuda et al., PTEP* **2013** *073D01*



In the crossover region hadrons starts to overlap
$\longrightarrow$ both low and high ρ_B models loose their validity.
Gibbs condition (extrapolation from the dashed lines) can be misleading.

Hadron-quark crossover with P-interpolation

Features of the model:

- H-EOS: Relativistic Mean Field (RMF) models: Steiner-Fischer-Hempel (SFHo) [1], density-dependent RMF model (DD2) [2]
- Q-EOS: e(P)QM model with u, d, s quarks and vector interaction
- mean-field approximation

P-interpolation ($\rho = \rho_B$):

$$P(\rho) = P_H(\rho) f_-(\rho) + P_Q(\rho) f_+(\rho), \quad (3)$$

$$f_\pm(\rho) = \frac{1}{2}\left(1 \pm \tanh\left(\frac{\rho - \bar{\rho}}{\Gamma}\right)\right) \quad (4)$$

$$\varepsilon(\rho) = \varepsilon_H(\rho) f_-(\rho) + \varepsilon_Q(\rho) f_+(\rho) + \Delta\varepsilon \quad (5)$$

$$\Delta\varepsilon = \rho \int_{\bar{\rho}}^{\rho} (\varepsilon_H(\rho') - \varepsilon_Q(\rho')) \frac{g(\rho')}{\rho'} d\rho' \quad (6)$$

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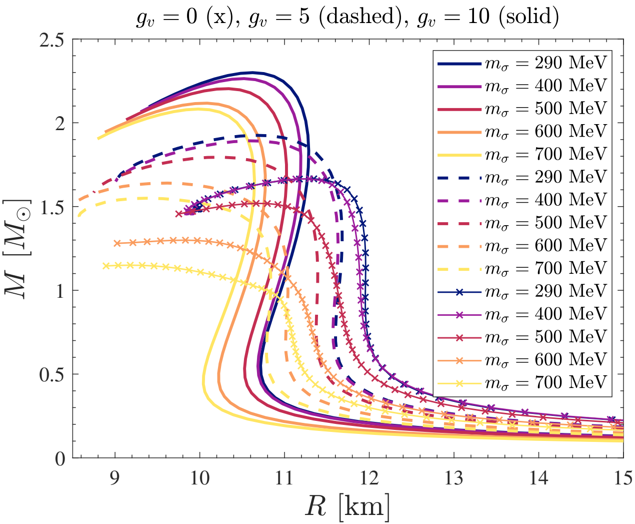
[1] A. W. Steiner *et al.*, Astrophys.J.**774**, 17 (2013)
[2] S. Typel *et al.*, Phys. Rev. C**81**, 015803 (2010)

$M-R$ relations of BPS+SFHo+e(P)QM



$\bar{\rho} = 3\rho_0, \Gamma = \rho_0$, From (axial)vector curvature masses: $g_V \approx 5$

Conclusion

Conclusion

- ePQM model can be used for various in medium investigations
- (Axial)vector meson curvature masses were calculated at one-loop level
- Parameterization determines g_V
- Large N_c scaling was also investigated
- Hybrid star $M-R$ curves were calculated and curves compatible with current observations

Plans

- Solve the model in the Gaussian approximation
- Determine the phase boundary and the CEP
- Investigate the Large N_c scaling of the CEP if it exists
- Beside the $M-R$ curves also calculate tidal deformabilities
- Consequences of the g_V determination on the compact star properties

Thank you for your attention!