# Symmetry energy of dense matter in holographic QCD

Yunseok Seo

CQUeST

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Based on
arXive:1011.0868 : Youngman Kim, YS, Ik Jae Shin, Sang-Jin Sin
JHEP 0804:010, 2008: YS, Sang-Jin Sin
JHEP 1003:074, 2010: Youngman Kim, YS, Sang-Jin Sin

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# Motivation

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- One of main research project in KoRIA(Korea Rare Isotope Accelerator).
- QCD phenomena at finite density is hard to understand.
- AdS/CFT may give clues to understand non-perturbative phenomema.

# AdS/CFT correspondence

- String theory

| Open Strings | $\parallel$ | Closed Strings |
| --- | --- | --- |

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- There is Open-Closed string duality

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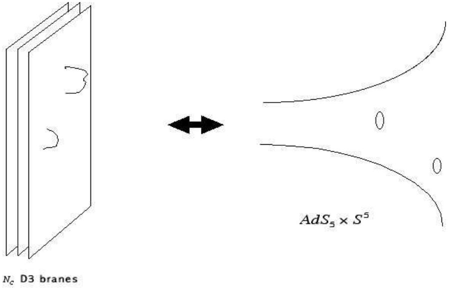


- Weak coupling limit ($\lambda << 1$): $\mathcal{N} = 4$, $D = 4$, $SU(N_C)$ SYM
- Strong coupling limit ($\lambda >> 1$): Classical gravity in $AdS_5 \times S^5$
- From calculating classical gravity, we can obtain some quantities in gauge theory with strong coupling.

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- But it is too far from realistic QCD !!
  - SUSY, zero temperature, no fundamental field ...

# AdS/CFT correspondence

- Toward to QCD
  - Break SUSY
    - D4 brane background with circle compactification

$$ds^2 = \left(\frac{U}{R}\right)^{3/2}\left(-dt^2 + d\vec{x}^2 + dx_4^2\right) + \left(\frac{R}{U}\right)^{3/2}\left(dU^2 + r^2 d\Omega_4^2\right)$$

$$e^{\phi} = g_s\left(\frac{U}{R}\right)^{3/4}, \quad F_4 = \frac{2\pi N_c}{\Omega_4}\epsilon_4, \quad R^3 = \pi g_s N_c l_s^3$$

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      $f(U) = 1 - \left(\frac{U_h}{U}\right)^3, \ T \sim U_h$
  - Confining phase
    - Double Wick rotation

      $t \leftrightarrow ix_4, \ x_4 \leftrightarrow i\tau$

      $ds^2 = \left(\frac{U}{R}\right)^{3/2}(-d\tau^2 + d\vec{x}^2 + f(U)dx_4^2) + \left(\frac{R}{U}\right)^{3/2}\left(\frac{dU^2}{f(U)} + U^2 d\Omega_4^2\right)$

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  - Source of gauge field
    - endpoint of fundamental strings
    - baryon vertex (spherical D-brane with $N_c$ fundamental strings)

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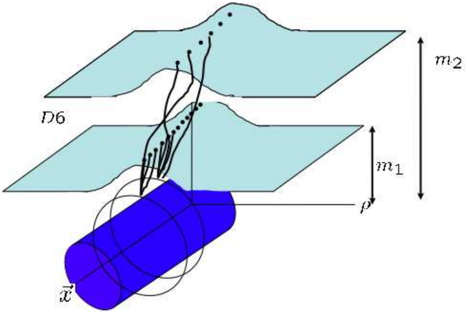

# (A)symmetric dense matter

- DBI action
  - D4 brane(baryon vertex)

$$S_{D4} = -\mu_4 \int e^{-\phi} \sqrt{\det(g + 2\pi\alpha' F)} + \mu_4 \int A_{(1)} \wedge G_{(4)}$$

  - D6 brane(flavor brane)

$$S_{D6} = \int dt \mathcal{L}_{D6} = -\mu_6 \int e^{-\phi} \sqrt{\det(g + 2\pi\alpha' F)}$$

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- Legendre transformed 'Hamiltonian'
  - D4 brane(baryon vertex)

$$\mathcal{H}_{D4} = \tau_4 \int d\theta \sqrt{\omega_+^{4/3}(\xi^2 + \xi'^2)} \sqrt{D(\theta)^2 + \sin^6\theta}$$

  - D6 brane(flavor brane)

$$\mathcal{H}_{D6} = \tau_6 \int d\rho \sqrt{\omega_+^{4/3}\left(\tilde{Q}^2 + \rho^4 \omega_+^{8/3}\right)} \sqrt{1 + \dot{y}^2}$$

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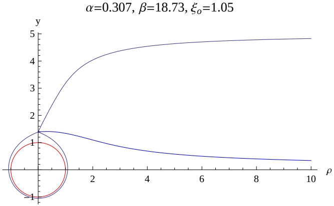


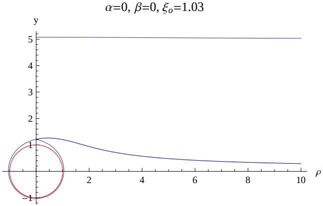

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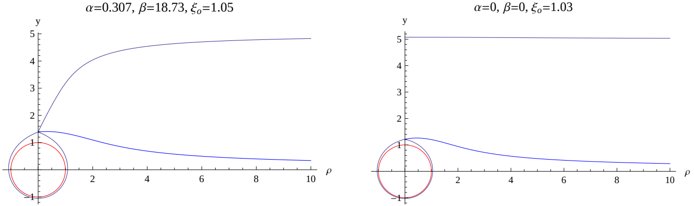


- Total free energy
  $E_{tot} = \frac{Q}{N_C}\mathcal{H}_{D4} + \mathcal{H}_{D6}((1-\alpha)Q) + \mathcal{H}_{D6}(\alpha Q)$

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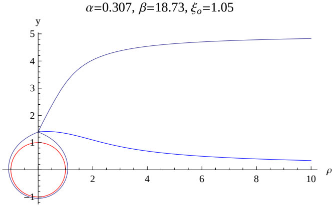


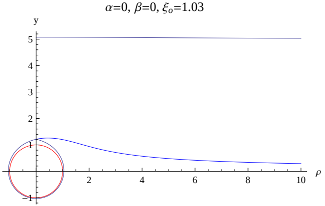


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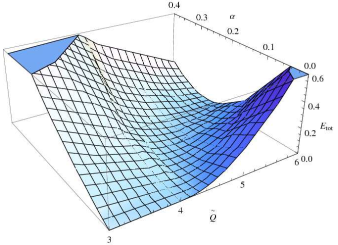

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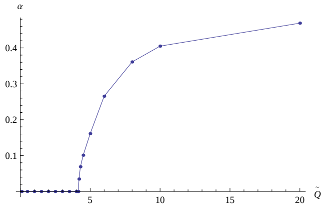

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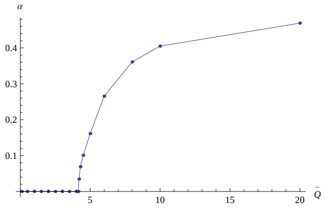


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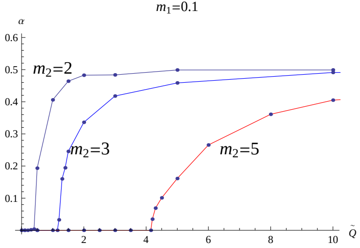

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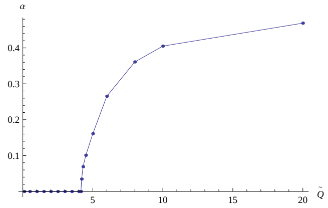


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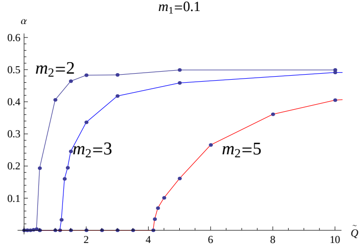


- $m_2/m_1 = 1$, physical system is $\alpha = 0.5$ for any density $\rightarrow$ symmetric matter

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$$E(\rho, \tilde{\alpha}) \sim E(\rho, 0) + S_2(\rho)\tilde{\alpha}^2$$

$$\tilde{\alpha} \equiv (N - Z)/A = 1 - 2\alpha$$

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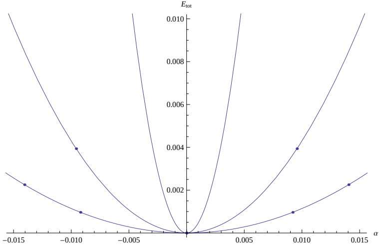

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$$E_1 = 0$$

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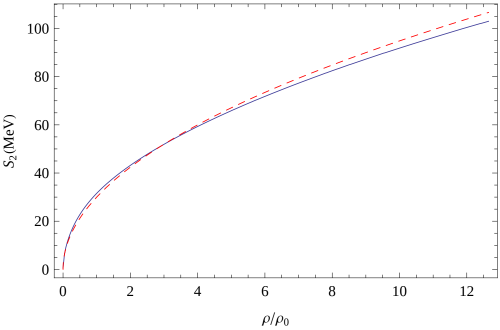

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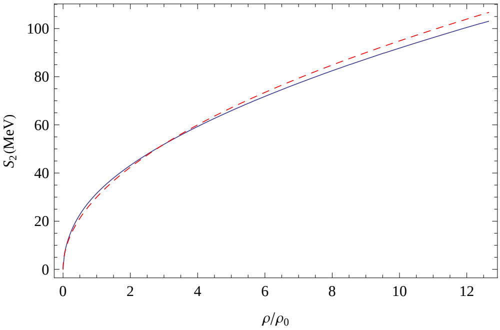


- Analytic calculation($m_q >> 1,\ \tilde{Q} << 1$)

$$E_2 = \left(\Gamma\left(\frac{5}{4}\right)\right)^2 \sqrt{\frac{\lambda\rho_0}{2M_{KK}}}\sqrt{\frac{\rho}{\rho_0}}$$

- Physical quantities

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\begin{aligned}
M_q &= \frac{m_\infty \lambda M_{KK}}{9\pi} \\
\rho &\equiv \frac{N_b}{V_3} = \frac{Q}{N_c V_3} \\
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- From $m_{\eta'} \sim 390\mathrm{MeV}$ and $M_q = 7\mathrm{MeV}$,

$$M_{KK} \sim 1.039 \text{ GeV}, \ \lambda \sim 1.905$$

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$$E_2 \sim 31 \left(\frac{\rho}{\rho_0}\right)^{0.48} \mathrm{MeV}$$

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- We are calculating (a)symmetry energy for large mass ratio.

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Thank you !!!