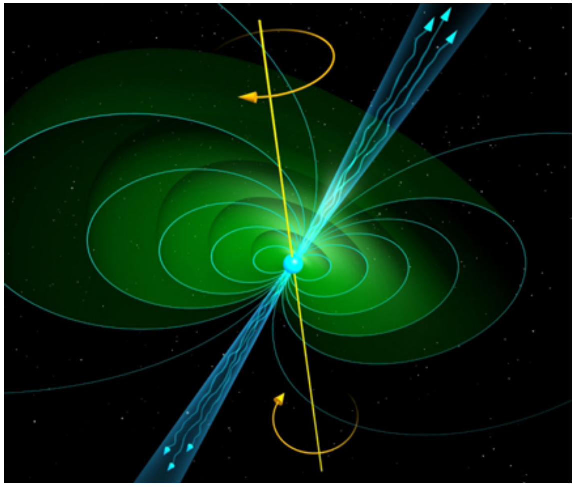
Andreas Schmitt

Institut für Theoretische Physik
Technische Universität Wien
1040 Vienna, Austria

Inverse magnetic catalysis in dense (holographic) matter

F. Preis, A. Rebhan, A. Schmitt, JHEP 1103, 033 (2011); JPG 39, 054006 (2012)



• Magnetic catalysis

K. G. Klimenko, Theor. Math. Phys. 89, 1161-1168 (1992)

V. P. Gusynin, V. A. Miransky, I. A. Shovkovy, PLB 349, 477-483 (1995)

- (massless) fermions in **Nambu-Jona-Lasinio (NJL)** model

$$\mathcal{L}_{\rm NJL} = \bar\psi\, i\gamma^\mu\partial_\mu\psi + G\left[(\bar\psi\psi)^2 + (\bar\psi\, i\gamma^5\psi)^2\right]$$

- mean-field approximation: $\bar\psi\psi = \langle\bar\psi\psi\rangle +$ fluctuations

Zero magnetic field:
dynamical fermion mass

$$M \propto \langle\bar\psi\psi\rangle \neq 0$$

for coupling $g > g_c = 1$

dimensionless coupling $g \equiv G\Lambda^2/\pi^2$

• Magnetic catalysis

K. G. Klimenko, Theor. Math. Phys. 89, 1161-1168 (1992)

V. P. Gusynin, V. A. Miransky, I. A. Shovkovy, PLB 349, 477-483 (1995)

- (massless) fermions in **Nambu-Jona-Lasinio (NJL)** model

$$\mathcal{L}_{\rm NJL} = \bar\psi\, i\gamma^\mu\partial_\mu\psi + G\left[(\bar\psi\psi)^2 + (\bar\psi\, i\gamma^5\psi)^2\right]$$

- mean-field approximation: $\bar\psi\psi = \langle\bar\psi\psi\rangle +$ fluctuations

Nonzero magnetic field:

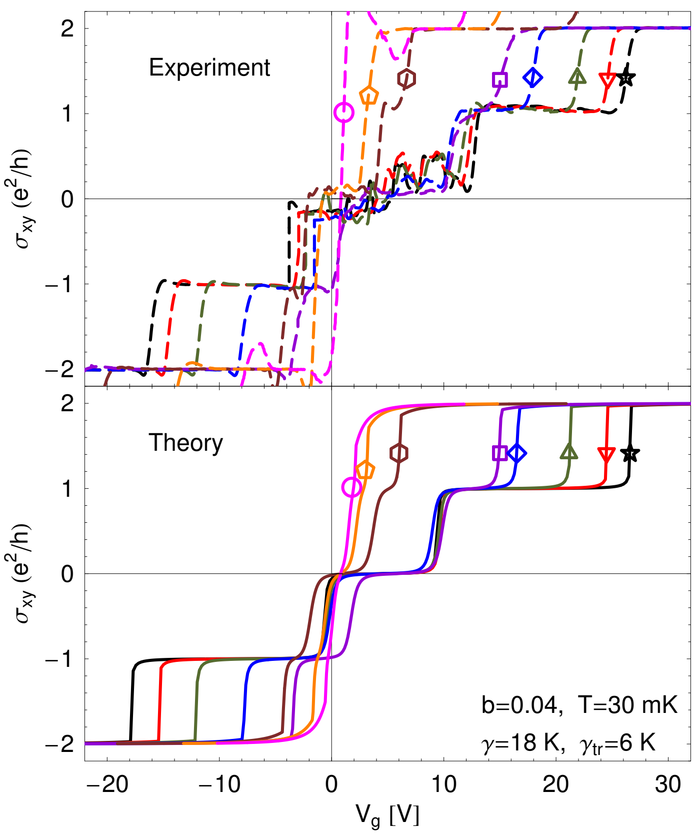
$M \neq 0$ for *arbitrarily small* g,

$$M \propto \sqrt{eB}\, e^{-{\rm const.}/eBg}$$

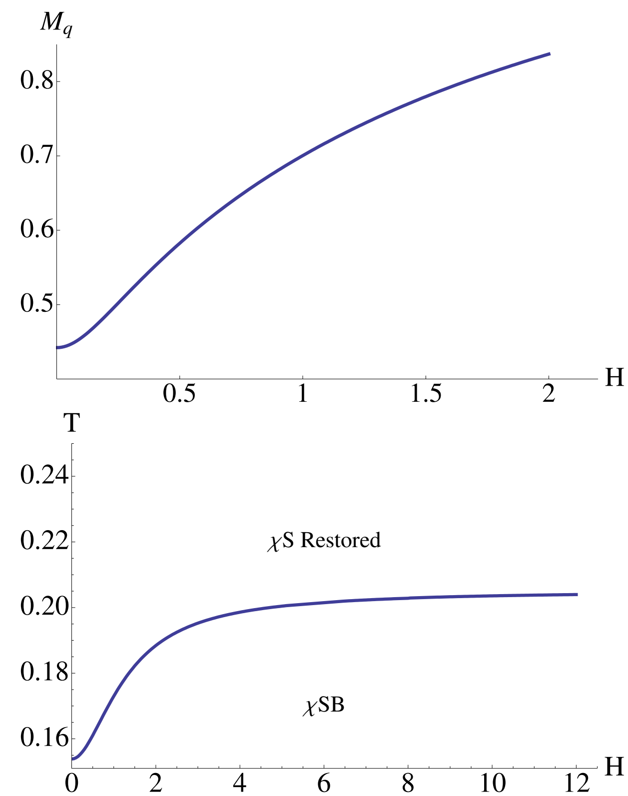
at weak coupling $g \ll 1$

dimensionless coupling $g \equiv G\Lambda^2/\pi^2$

• Magnetic catalysis in the real world and in holography



V.P.Gusynin *et al.*, PRB 74, 195429 (2006)

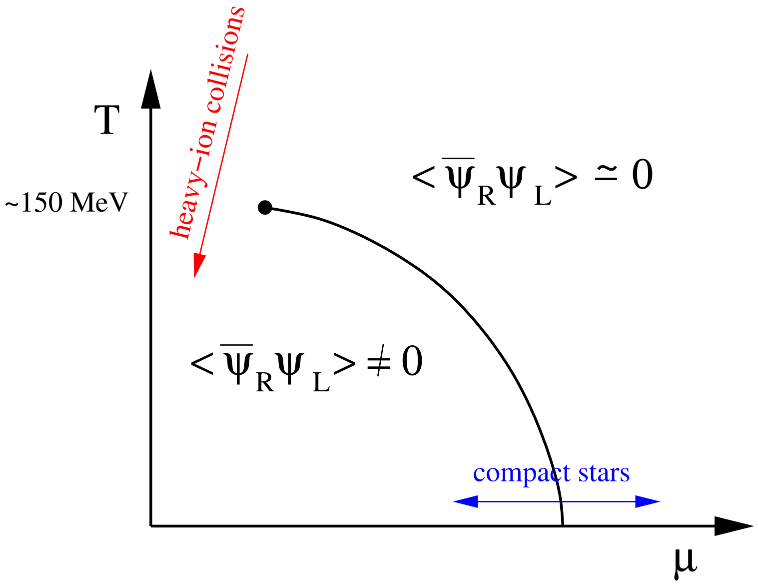


C.V.Johnson, A.Kundu, JHEP 0812, 053 (2008)

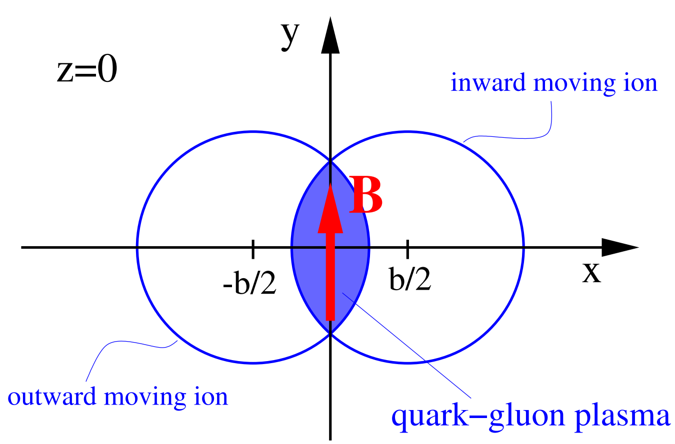
- **graphene**: appearance of additional plateaus in strong magnetic fields [$B = 9\,\mathrm{T}$ (pink), $B = 45\,\mathrm{T}$ (black)]

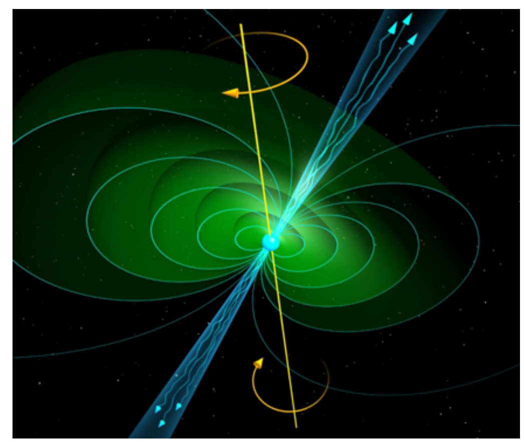
- **holography**: magnetic field enhances dynamical mass M_q and critical temperature T_c

• (Chiral) magnetic catalysis in QCD?



- chiral transition probed in heavy-ion collisions and compact stars
- in both instances huge magnetic fields are present!





heavy-ion collisions: temporarily $B \sim 10^{18}\,\mathrm{G}$	magnetars: at surface $B \sim 10^{15}\,\mathrm{G}$

• Chiral transition in the Sakai-Sugimoto model

- original AdS/CFT correspondence

  J. M. Maldacena, Adv. Theor. Math. Phys. 2, 231 (1998)

(supergravity limit of) string theory on $AdS_5 \times S^5$	$\Leftrightarrow$	(strong coupling limit of) $\mathcal{N} = 4$ SYM theory on $\mathbb{R}^{3,1}$

- Sakai-Sugimoto model

  E. Witten, Adv. Theor. Math. Phys. 2, 505 (1998)

  T. Sakai, S. Sugimoto, Prog. Theor. Phys. 113, 843-882 (2005)

  – breaks supersymmetry completely

  – accounts for confinement and chiral symmetry breaking

  – reproduces meson/hadron spectra surprisingly well

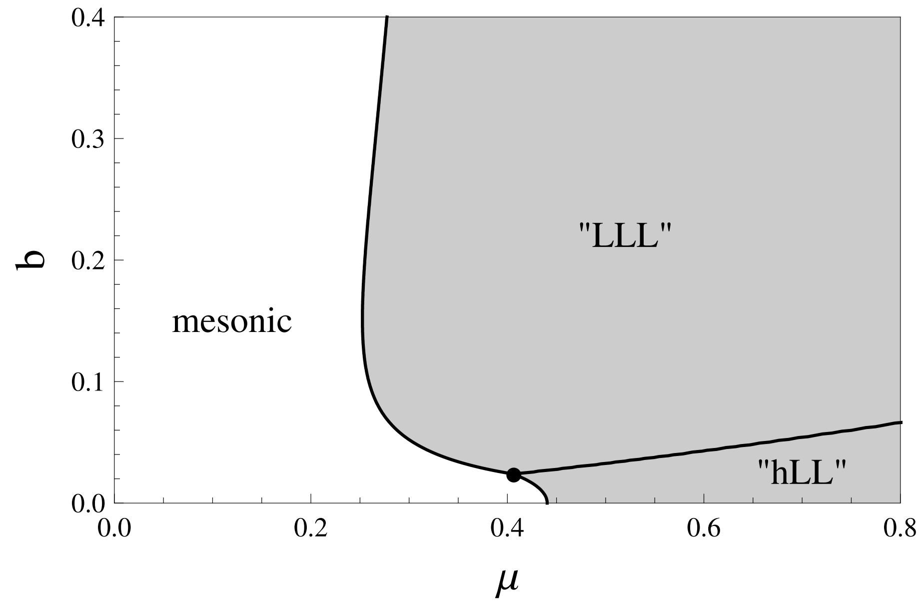
- here: "NJL limit" (as opposed to large-N_c QCD limit)

  – small separation of flavor branes

  – deconfined phase

  – chiral transition sensitive to μ, B

• $T = 0$ phase diagram



- apparent Landau level transition

  G. Lifschytz, M. Lippert, PRD 80, 066007 (2009)

  (charge density exactly like in LLL for free fermions)

- non-monotonic behavior of critical μ

  (in apparent contrast to magnetic catalysis)

- **Inverse magnetic catalysis**

Why does B *restore* chiral symmetry for certain μ?

- free energy *gain* from $\bar{\psi}-\psi$ pairing increases with B (magnetic catalysis)
- μ induces free energy *cost* for pairing; this cost depends on B!

weak coupling (NJL):

E. V. Gorbar *et al.*, PRC 80, 032801 (2009)

$$\Delta\Omega \propto B[\mu^2 - M(B)^2/2]$$

just like Clogston limit $\delta\mu = \frac{\Delta}{\sqrt{2}}$

in superconductivity

A. Clogston, PRL 9, 266 (1962)

B. Chandrasekhar, APL 1, 7 (1962)

Sakai-Sugimoto:

large B:

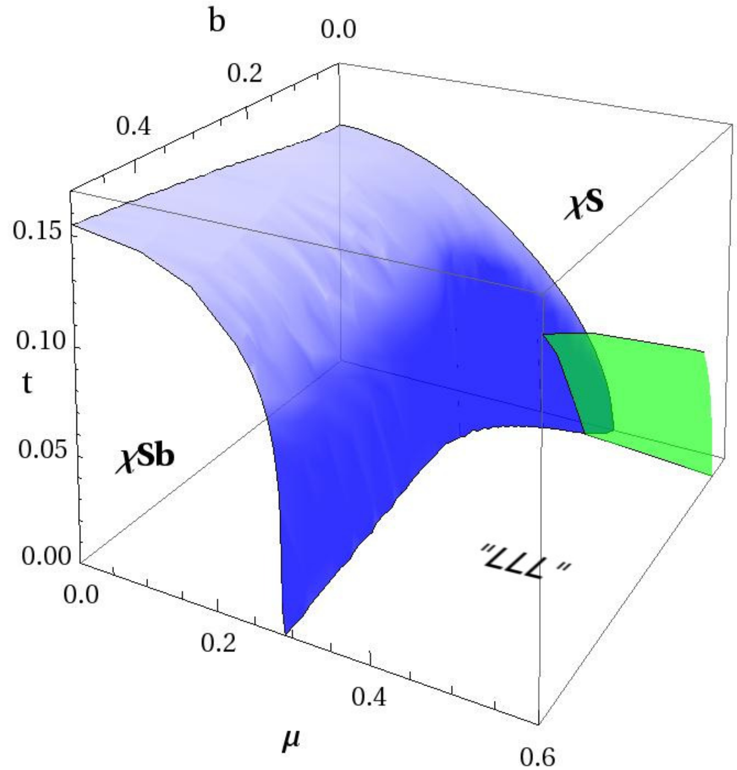
$$\Delta\Omega \propto B[\mu^2 - 0.12\, M(B)^2]$$

small B:

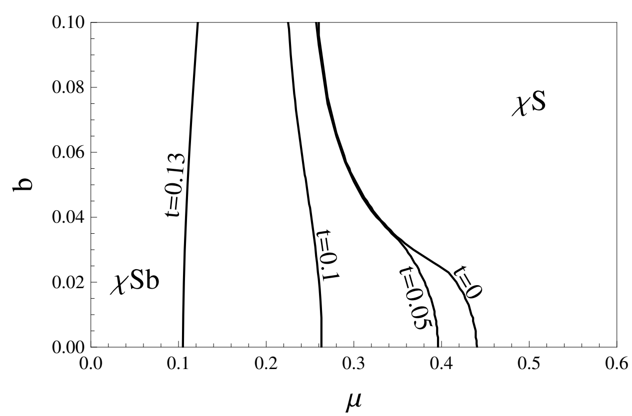
$$\Delta\Omega \propto \mu^2 B - \text{const} \times M(B)^{7/2}$$

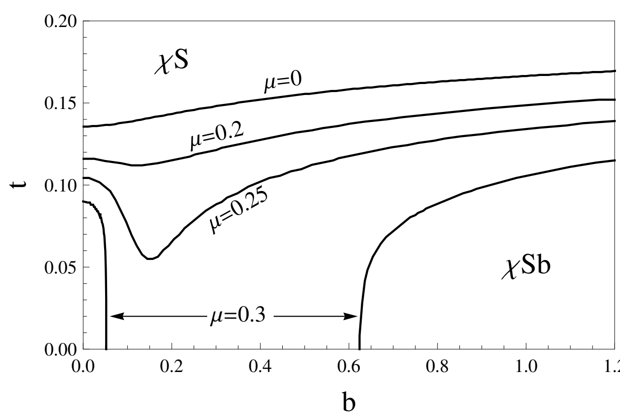
"Inverse magnetic catalysis"

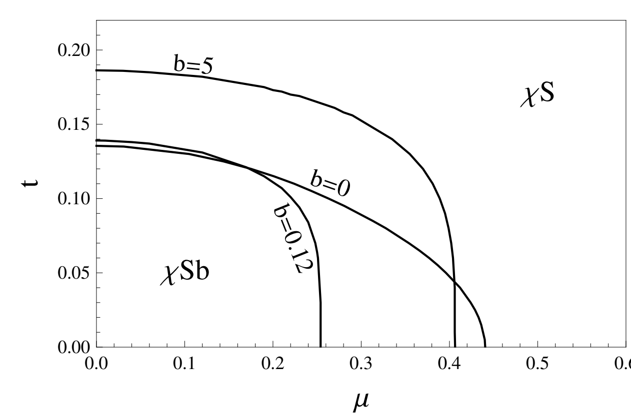
• Phase structure at nonzero temperature



blue: chiral phase transition
green: "LLL" transition



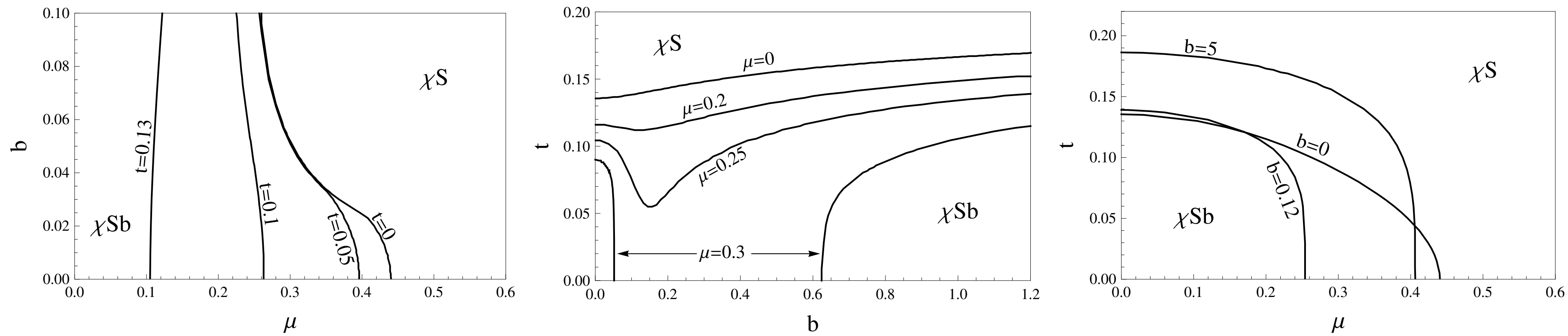




• Agreement with NJL calculation

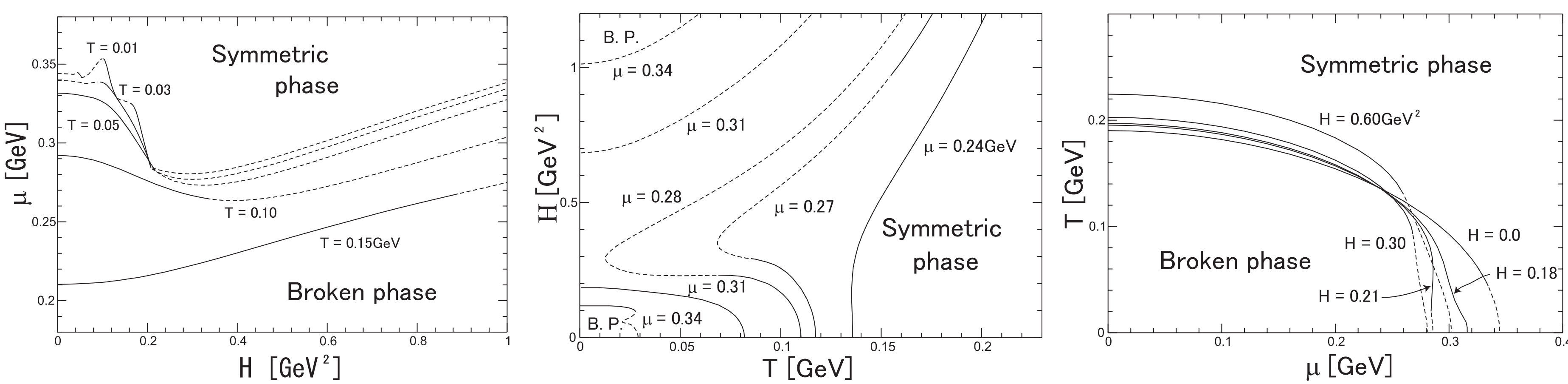
Sakai-Sugimoto:

F. Preis, A. Rebhan and A. Schmitt, JHEP 1103, 033 (2011)



NJL:

T. Inagaki, D. Kimura, T. Murata, Prog. Theor. Phys. 111, 371-386 (2004)



(IMC also in quark-meson model J. O. Andersen and A. Tranberg, arXiv:1204.3360 [hep-ph])

• (Homogeneous) baryonic matter in Sakai-Sugimoto

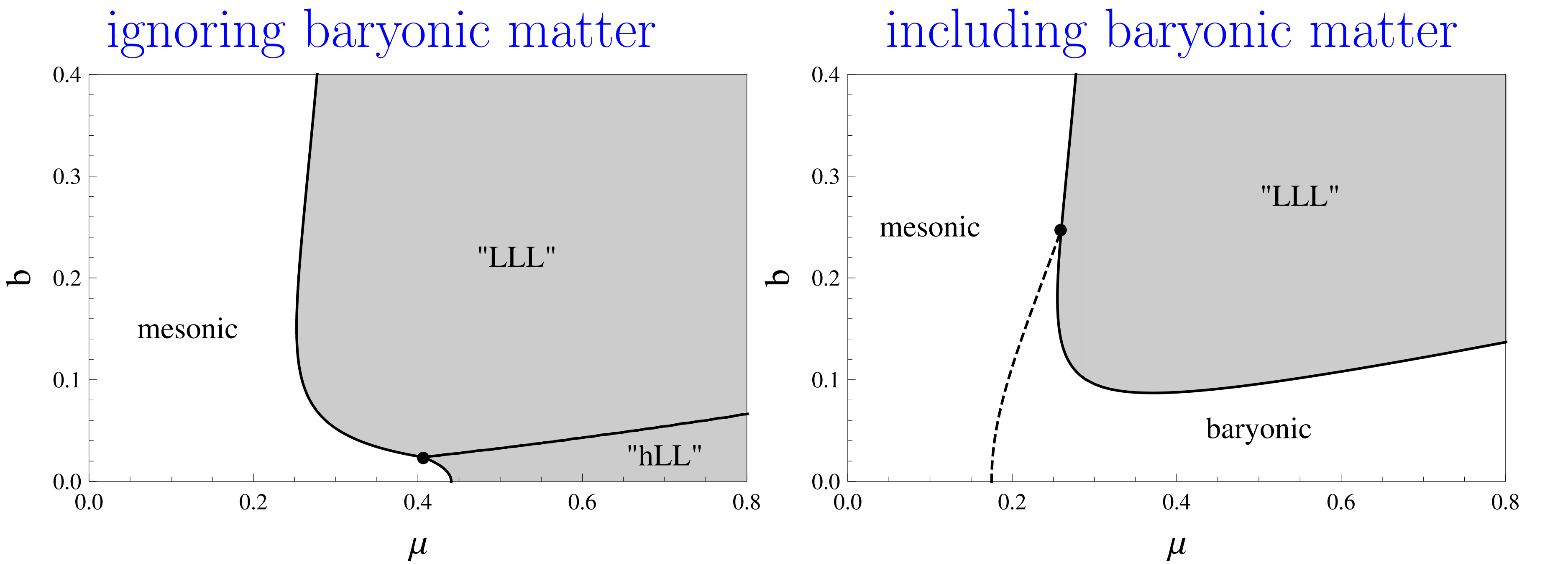
- baryons in AdS/CFT: wrapped D-branes with N_c strings
  E. Witten, JHEP 9807, 006 (1998); D. J. Gross, H. Ooguri, PRD 58, 106002 (1998)

- baryons in Sakai-Sugimoto:
  - D4-branes wrapped on S^4
  - equivalently: instantons on D8-branes ($\rightarrow$ skyrmions)

  T. Sakai, S. Sugimoto, Prog. Theor. Phys. 113, 843-882 (2005)
  H. Hata, T. Sakai, S. Sugimoto, S. Yamato, Prog. Theor. Phys. 117, 1157 (2007)

- pointlike approximation for $N_f = 1$
  O. Bergman, G. Lifschytz, M. Lippert, JHEP 0711, 056 (2007)

• Effect of baryons on $T = 0$ phase diagram



- small b: baryonic matter prevents the system from restoring chiral symmetry
- baryon onset (2nd order!) intersects chiral phase transition $\rightarrow$ large b: mesonic matter superseded by quark matter
- with baryonic matter, IMC plays an even more prominent role in the phase diagram

• Summary

- dense matter in the "NJL limit" of the Sakai-Sugimoto model...
  ... shows a transition reminiscent of LLL
  ... shows a chiral phase transition with
  MC at large B and IMC at small B

- baryonic matter changes the phase diagram
  dramatically for small B

- agreement with NJL calculations
  only before including baryonic matter

• Outlook

- Sakai-Sugimoto calculation:
  - understand chiral non-restauration with baryons
    $\to$ extend to $N_f = 2$
  - more general: problem of large N_c vs. $N_c = 3$!

- inverse catalysis in QCD and NJL models
  - how is IMC affected by the "chiral shift"?
    E. V. Gorbar, V. A. Miransky and I. A. Shovkovy, PRC 80, 032801 (2009)
    F. Preis, A. Rebhan, A. Schmitt, work in progress
  - are recent lattice results for $T_c(B)$ related to IMC?
    G. S. Bali *et al.*, JHEP 1202, 044 (2012)