

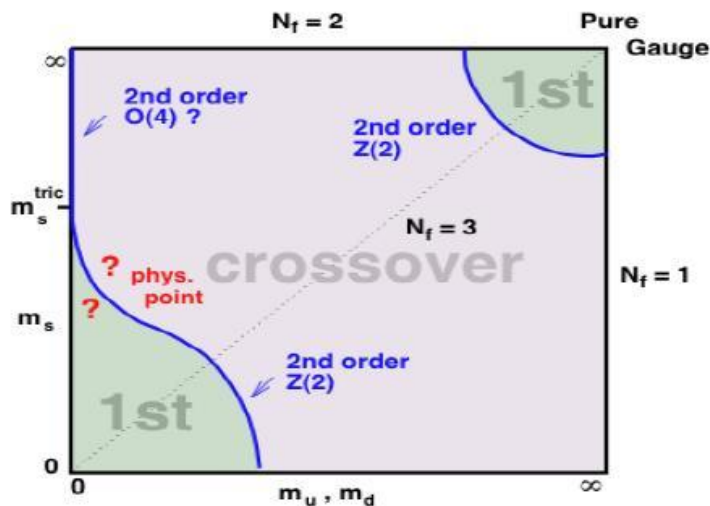
Strangeness in the QGP Phase transition

전남대 이강석

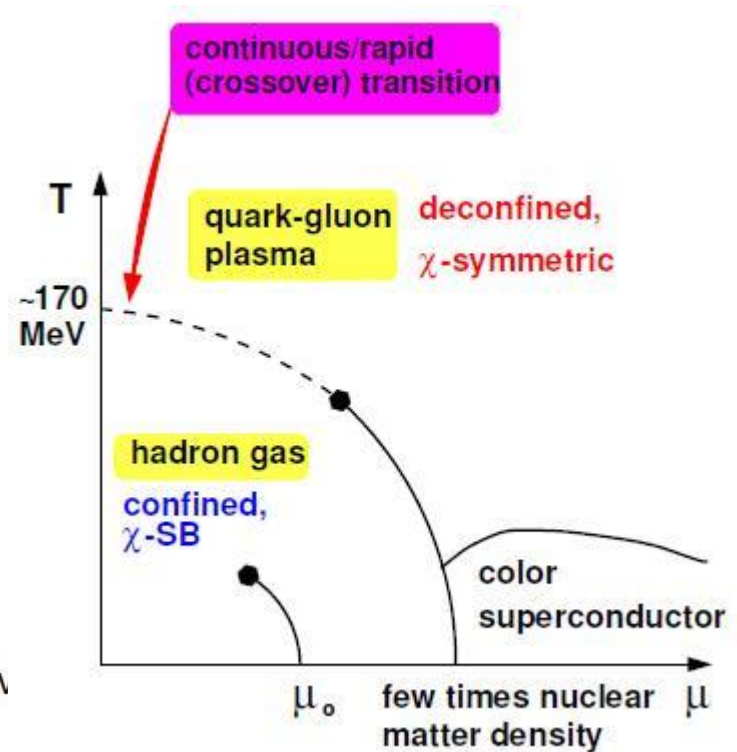
- Phase Transition including strangeness
- Strange Distillation, Strangelet formation
- Effects on Neutron stars
- Phase Diagram with finite strangeness
- Strange Matter Lumps in the early Universe
- Summary

Strangeness enhancement as a signature of QGP formation. Koch, Muller, Rafelski

The order of the phase transition depends on the mass of strange quark.



- phase diagram dependence on number of flavor quark masses



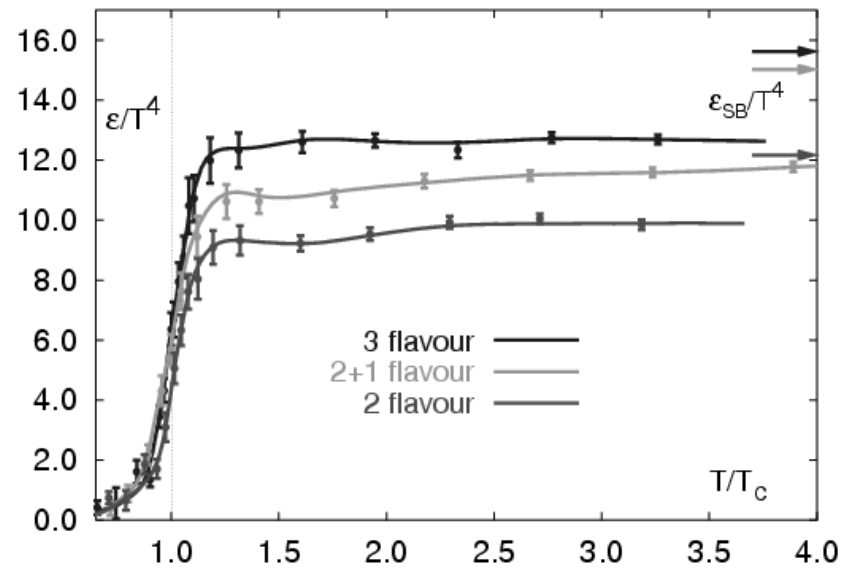


FIG. 2: Scaled energy density ϵ/T^4 for thermal lattice-QCD with two and three light quark flavors and for two light and one heavier flavor (from Karsch [43]).

Phase Diagram including strangeness

QGP phase

$$P_{QGP} = \frac{37}{90} \pi^2 T^4 + \mu_q^2 T^2 + \frac{1}{2\pi^2} \mu_q^4 + \frac{1}{\pi^2} \int_{m_s}^{\infty} de (e^2 - m_s)^{3/2} \\ \times \left(\frac{1}{e^{\beta(e - \mu_q - \mu_s)/T} + 1} + \frac{1}{e^{\beta(e + \mu_q + \mu_s)/T} + 1} \right) - B$$

Hadron phase

$$P_{Had} = \frac{1}{1 + E^{pt} / 4B} \sum_i \frac{d_i}{6\pi^2} \int_{m_i}^{\infty} de (e^2 - m_s)^{3/2} \frac{(e^2 - m_i)^{3/2}}{e^{\beta(e - \mu_i)/T} \pm 1}$$

with $\mu_i = (n_i^q - \bar{n}_i^q) \mu_q + (n_i^s - \bar{n}_i^s) \mu_s$

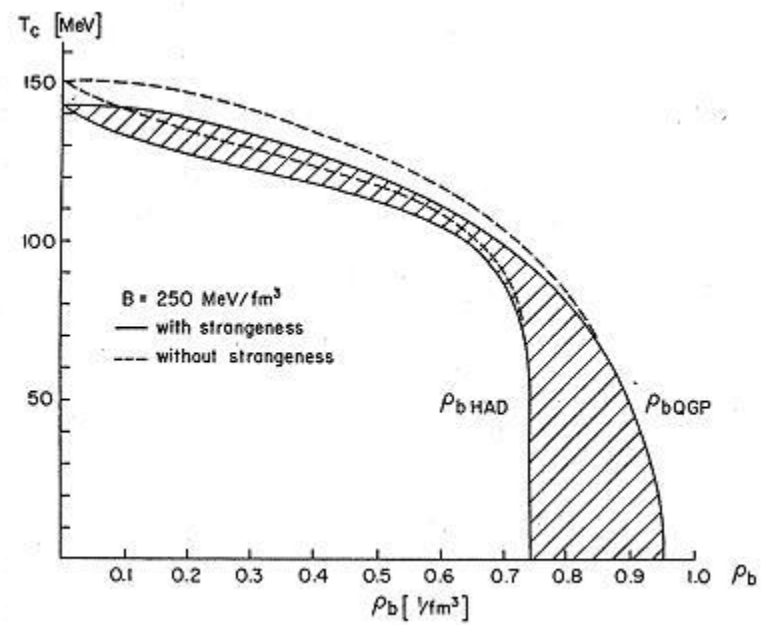
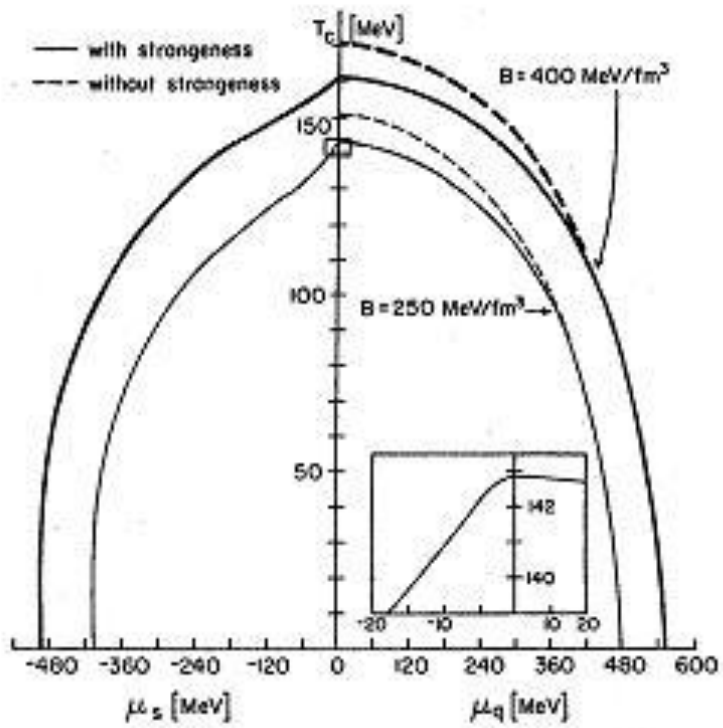
Condition for two
phase equilibrium

$$P_{QGP}(T, \mu_q, \mu_s) = P_{HAD}(T, \mu_q, \mu_s)$$

$$\rho_s^Q = 0, \rho_s^H = 0$$

Non-equilibrium of weak
interaction ???

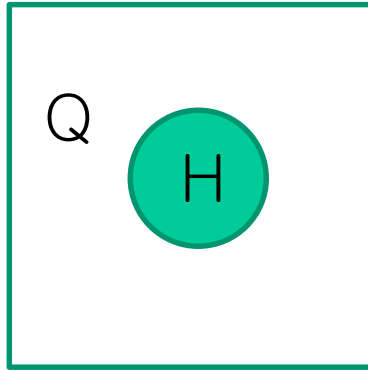
$$\mu_s^Q \neq \mu_s^H$$



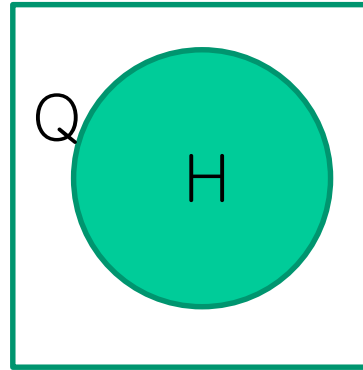
QGP volume fraction $f = \frac{V_Q}{V_Q + V_H}$

Lukas, Zimanyi, Balazs, PLB183 (1987)27

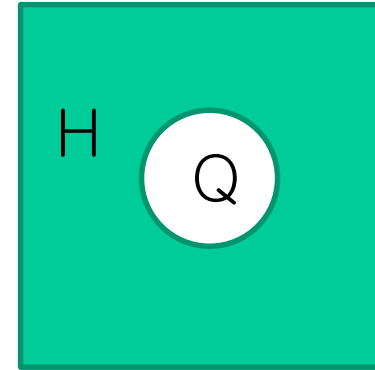
$f \approx 1$



$f \approx 0.5$



$f \approx 0$



$$P_Q^{f \approx 1} = P_H^{f \approx 1}$$

$$P_Q^{f \approx 0.5} = P_H^{f \approx 0.5}$$

$$P_Q^{f \approx 0} = P_H^{f \approx 0}$$

$$\rho_s = 0 = f \rho_s^Q + (1-f) \rho_s^H$$

$$\mu_{Q,s}^{f \approx 1} = \mu_{H,s}^{f \approx 1} \neq \mu_{Q,s}^{f \approx 0} = \mu_{H,s}^{f \approx 0}$$

$$\rho_Q^{f \approx 0} \gg 0$$

Strangeness enrichment in Q phase near

$f=0$ – strangeness distillation

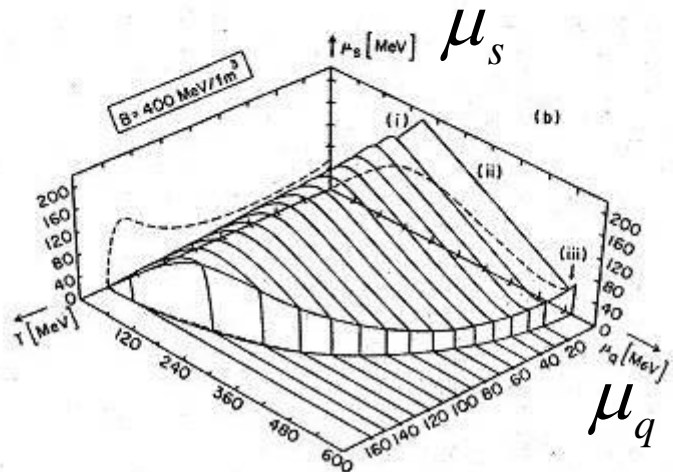
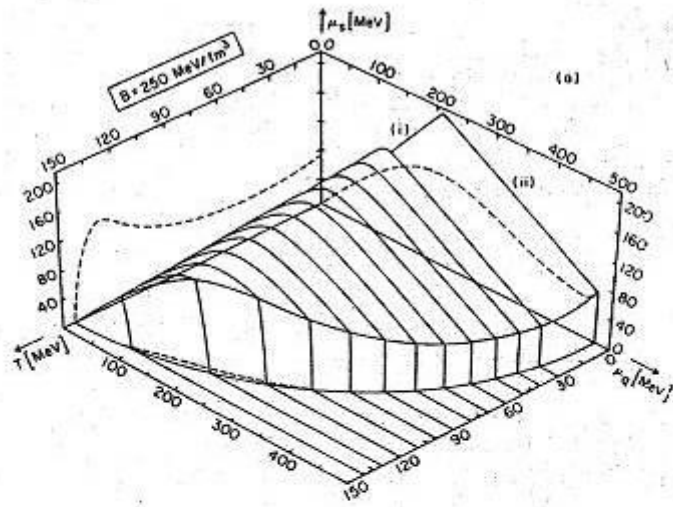
Heinz, KS Lee, Rhoades-Brown, Mod. Phys. Lett. A, 2(1987)153

Strangelet formation by C. Greiner

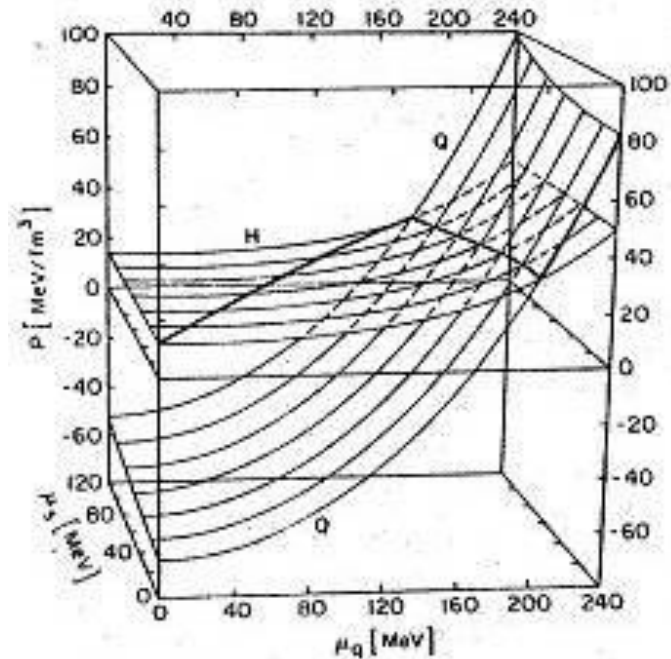
prl58(1987)1825

Phase diagram including strangeness

Heinz, KS Lee, Rhoades-Brown, Mod. Phys. Lett. A, 2(1987)153



P



μ_q

Pressure increases slowly but continuously in the mixed phase.

Neutron star

Inclusion of strangeness is favored since they lower the Fermi energy.

- Hyperon star –N.S with hyperons in the core
- N star with kaon condensate in the core [chlee](#)
- hybrid star –neutron star with QGP core
- hybrid star –neutron star with mixed phase
[Glendenning, prd46,1274\(1992\)](#)
[Heiselber,pethick, Staubo, prl70,1355\(1993\)](#)
- mixed phase in N–star: rod and pastas
[Baym, Glendenning](#)

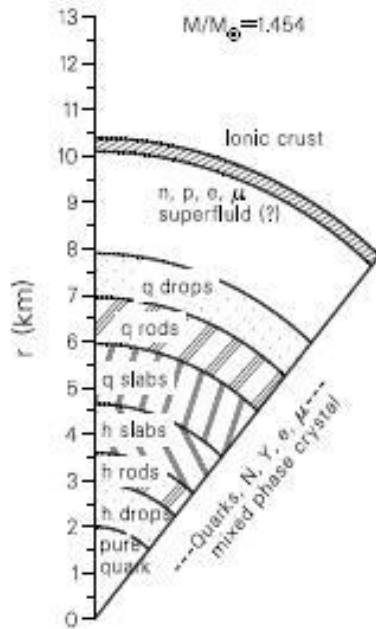


Figure 7: Showing the quark gas core, surrounding crystalline region, hyperon liquid and thin nuclear crust. Geometric phases are denoted a q(uark) drops, etc. [1] Reprinted with permission of Springer-Verlag New York; copyright 1997.

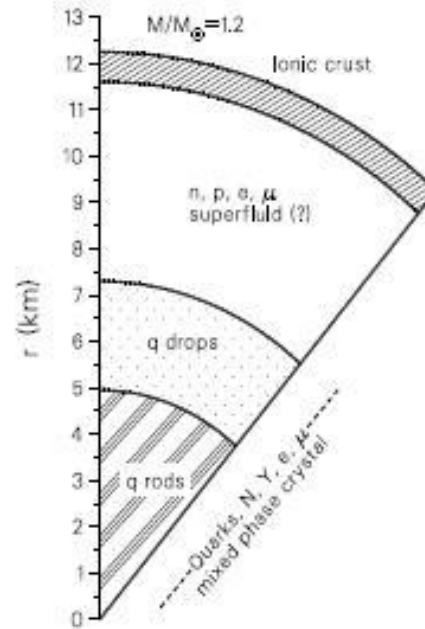


Figure 8: For a slightly less massive star than depicted in Fig. [1] the interior structure is vastly different. The Coulomb lattice extends to the center, but only several geometrical phases are present [1] Reprinted with permission of Springer-Verlag New York; copyright 1997.

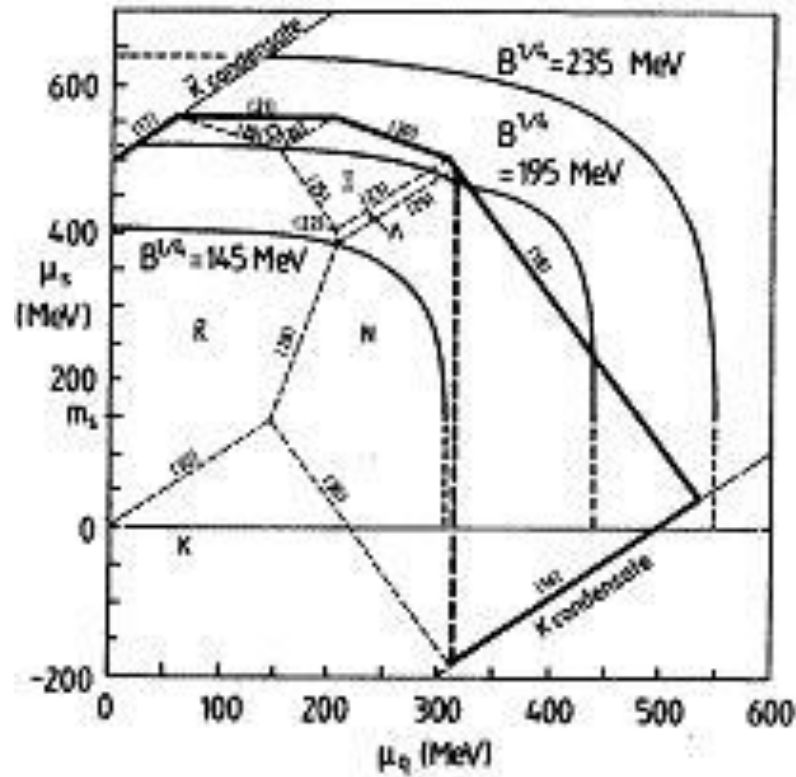
Glendenning, Compact Stars,
Springer 1997

Quark star

- Quark star [Jaffe](#)
- Strange quark star [Witten, PRD30,272\(1984\)](#)
- Strange matter lump in the early universe [S.J.Cho, KSLee, Heinz, PRD50,4771\(1994\)](#)

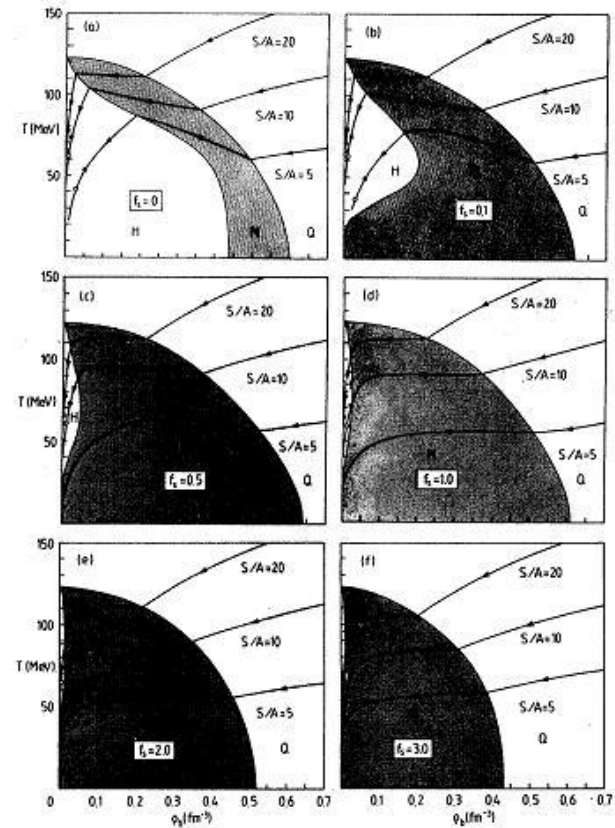
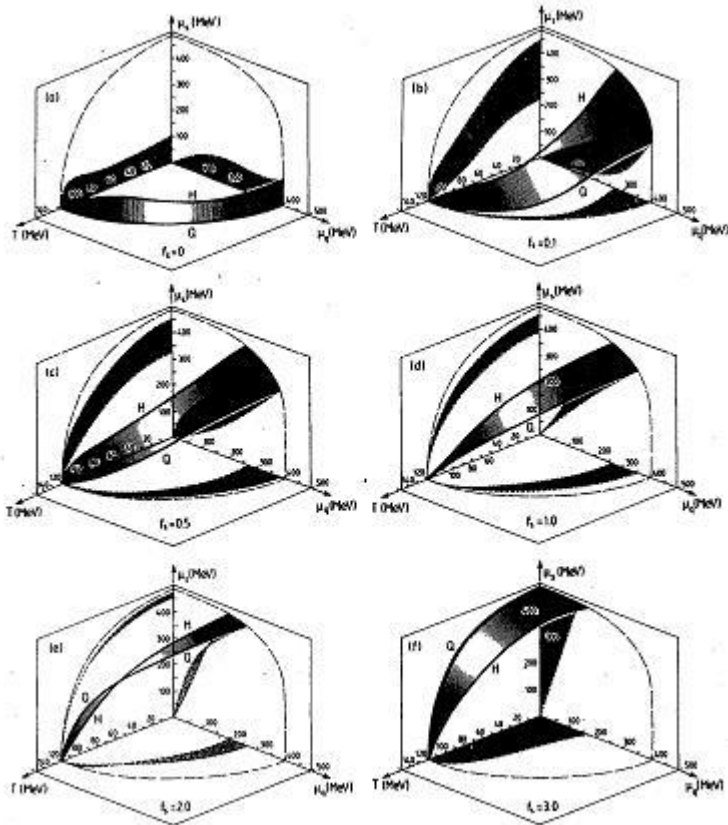
Phase Structure of strange matter

KS Lee, Heinz, PRD47,2068(1993)



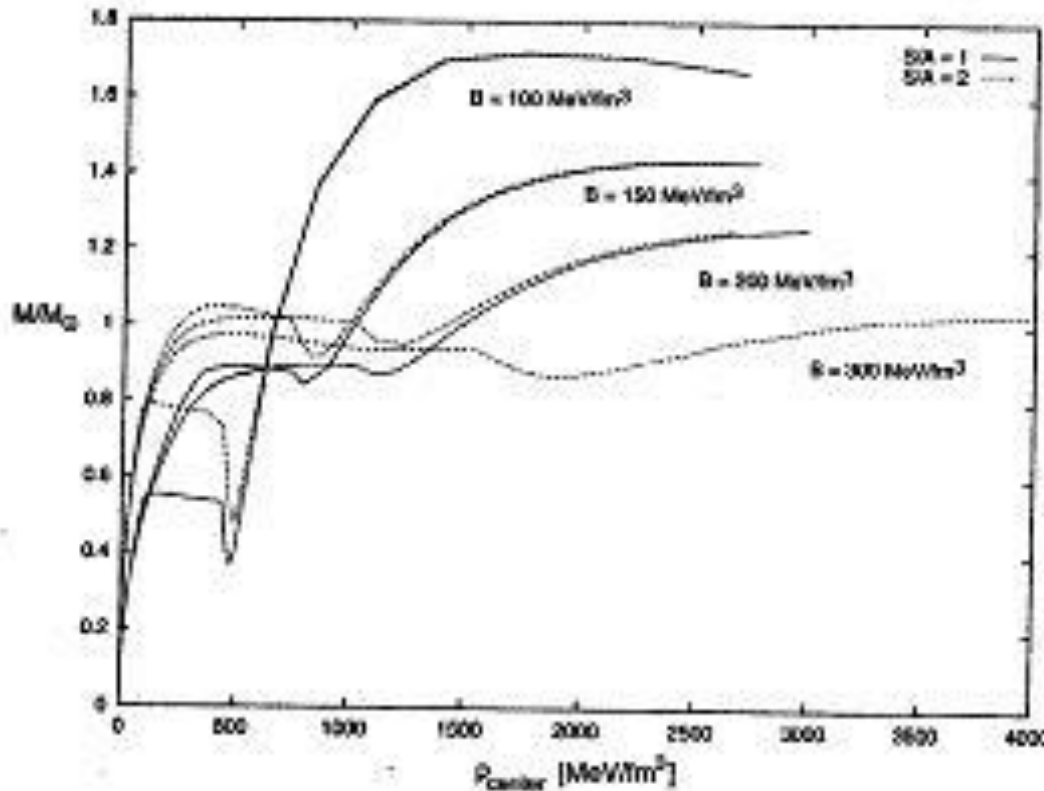
$$\rho_s \neq 0$$

Phase diagram with different strangeness



Strange matter lump with hadronic crust in the early universe

S.J.Cho,KSLee,Heinz,
PRD50,4771(1994)

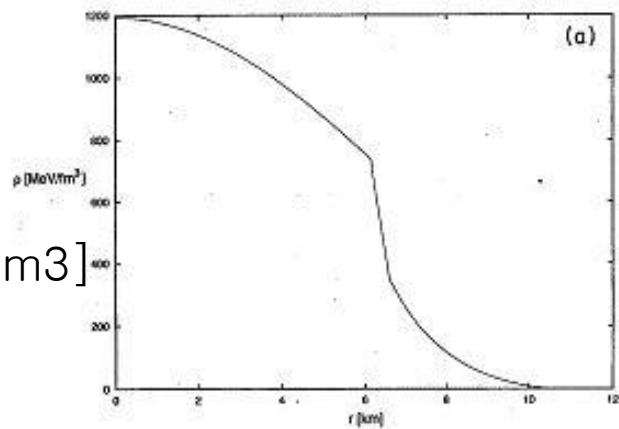


Strange matter lumps
are stable only in the
region of positive
slope.

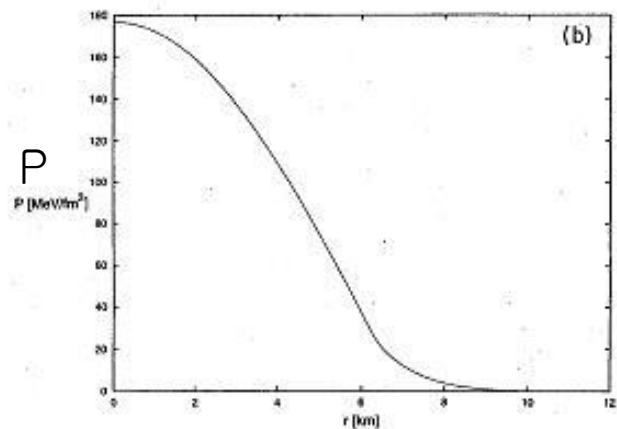
[MeV/fm³]

Central energy density

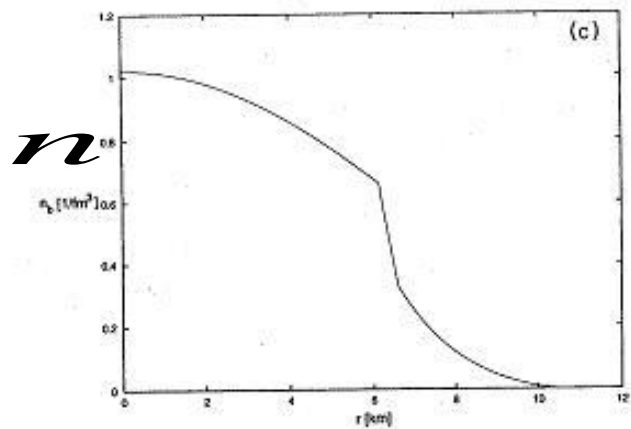
[MeV/fm³]



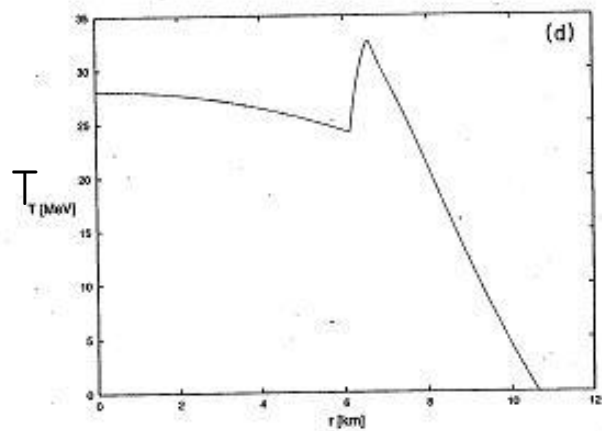
R [km]



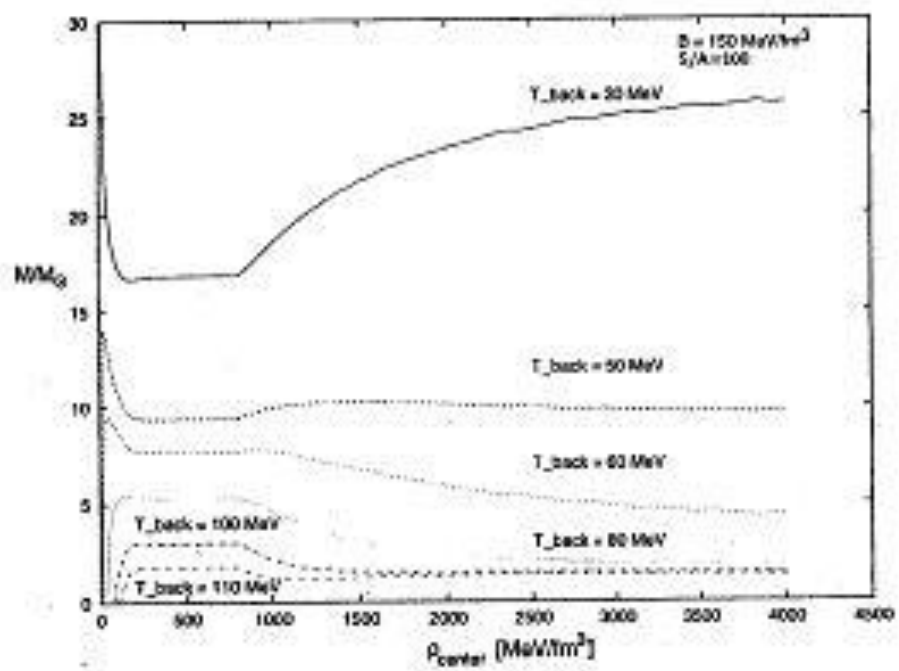
R [km]



R [km]



R [km]



Summary

- Enhancement of strangeness in QGP.
- Inclusion of strangeness in the Q–H phase transition needs careful study, especially when the phase transition is of the 1st order.
- Strange quark star, strange matter lump in the early universe, hybrid star