ハイブリッドクォーク星

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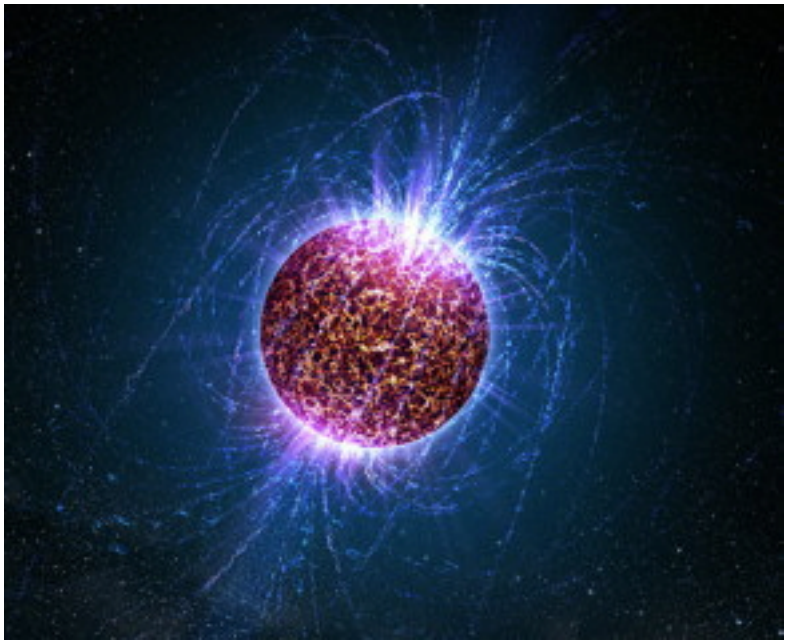
NS - EOS



massive NS

information about the high density region

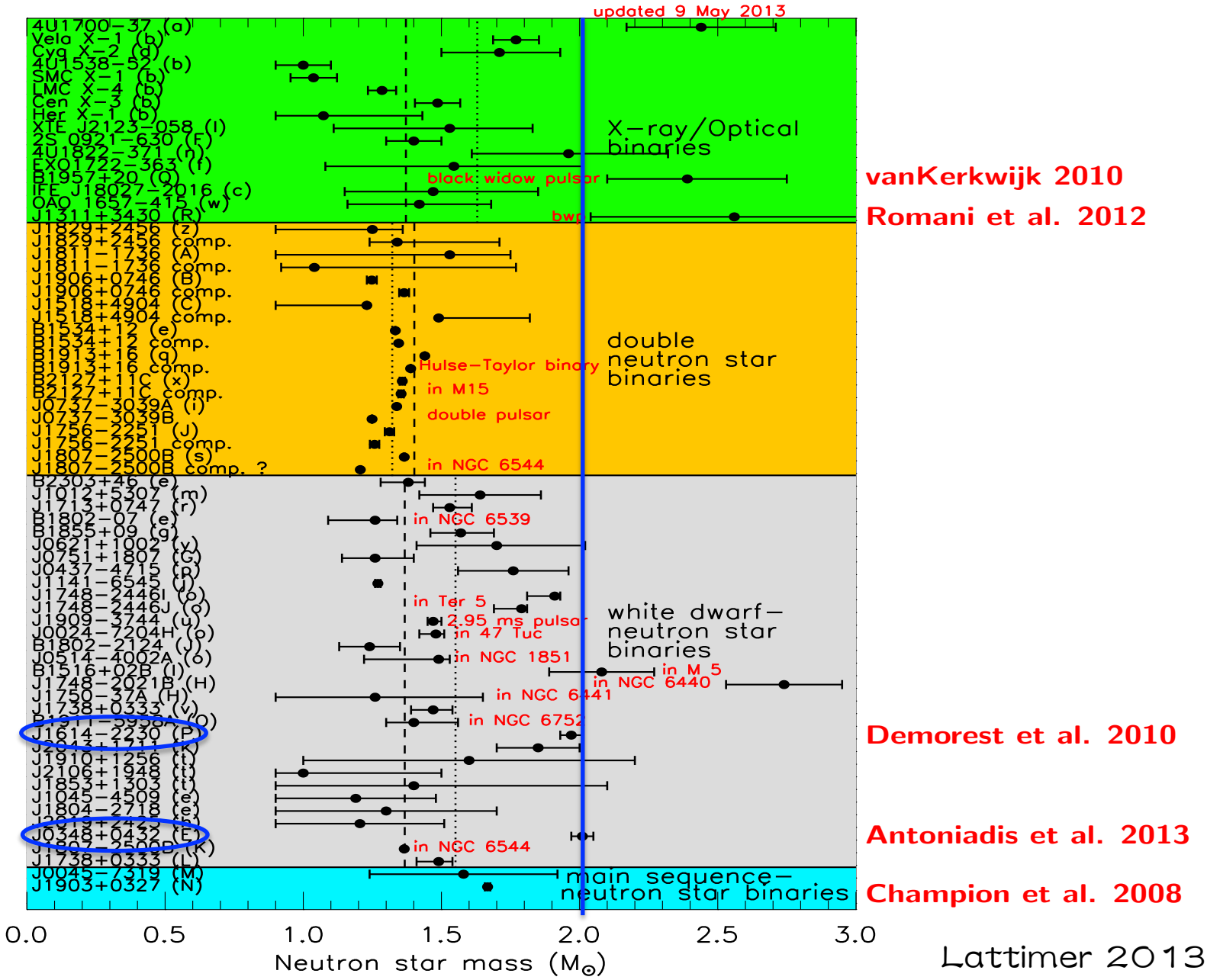
(1) TOV equation

(2) equation of state (EOS)
- model
- nuclear interaction
- composition

constraints from the terrestrial nuclear experiments

''

properties around the saturation density



vanKerkwijk 2010

Romani et al. 2012

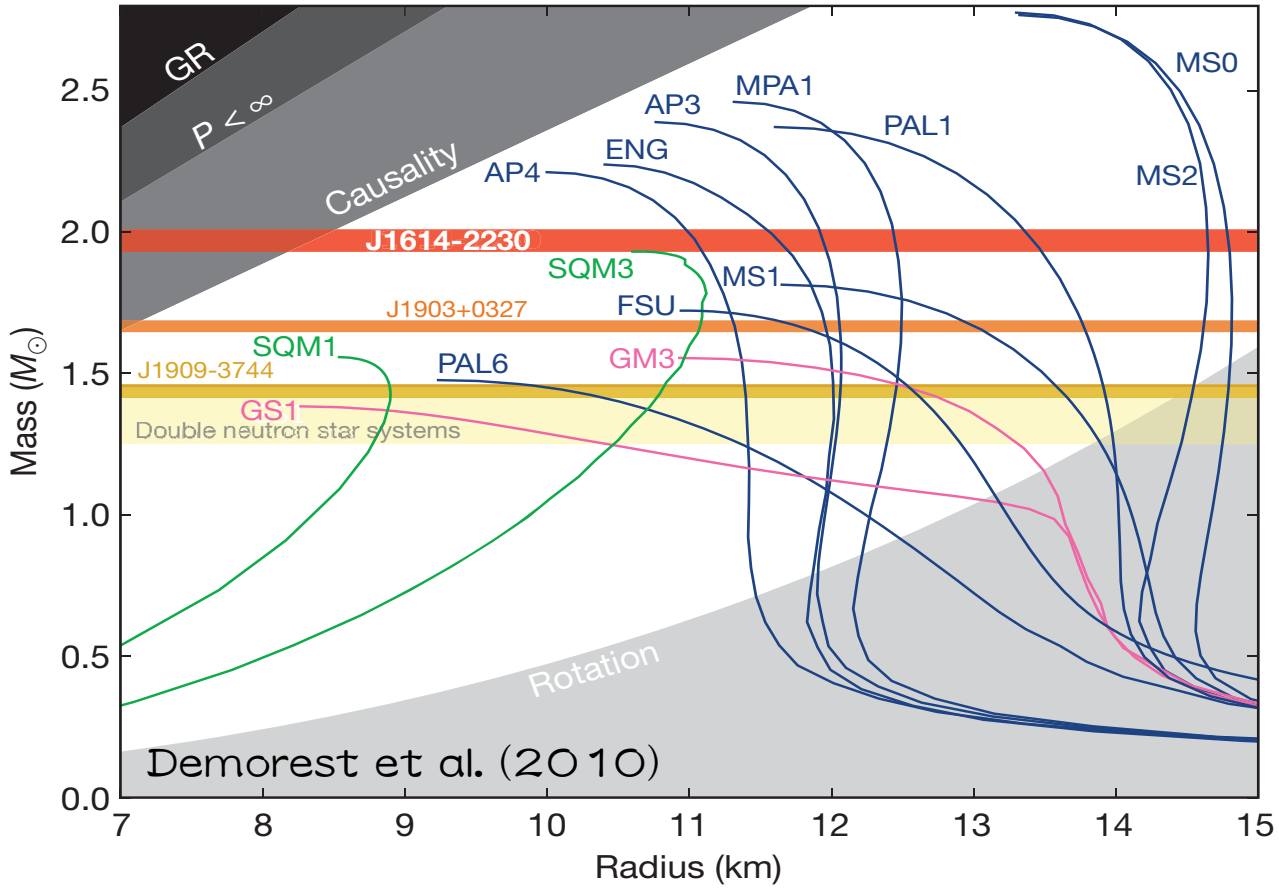
Demorest et al. 2010

Antoniadis et al. 2013

Champion et al. 2008

Lattimer 2013

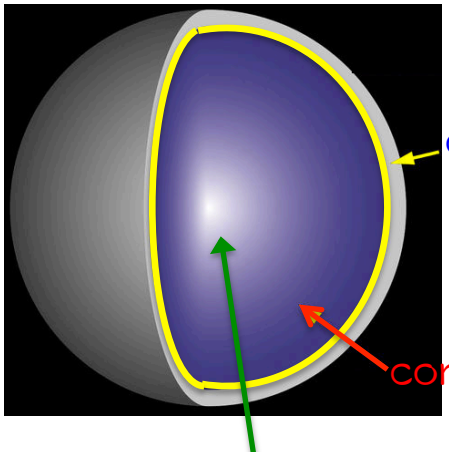
constraint on EOS via massive NSs

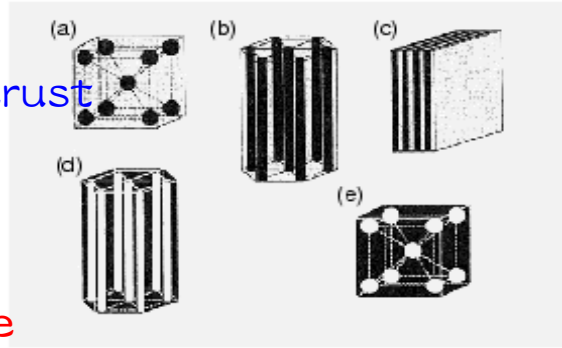


- maximum mass of neutron star should be larger than $2M_\odot$

neutron stars

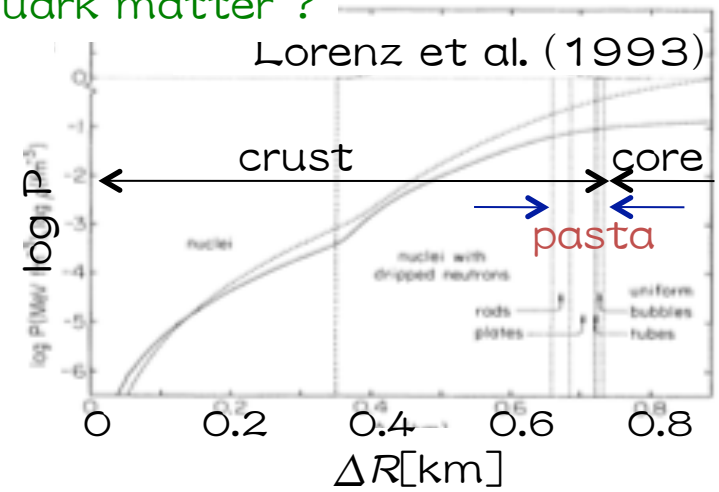
- Structure of NS
  - solid layer (crust)
  - nonuniform structure (pasta)
  - fluid core (uniform matter)
- Crust thickness ≲ 1km
- Determination of EOS for high density (core) region could be quite difficult on Earth
- Possibility of the appearance of quark matter inside the star
  - "hybrid star"
  - mass of hybrid star is generally small
  - quark region is quite small





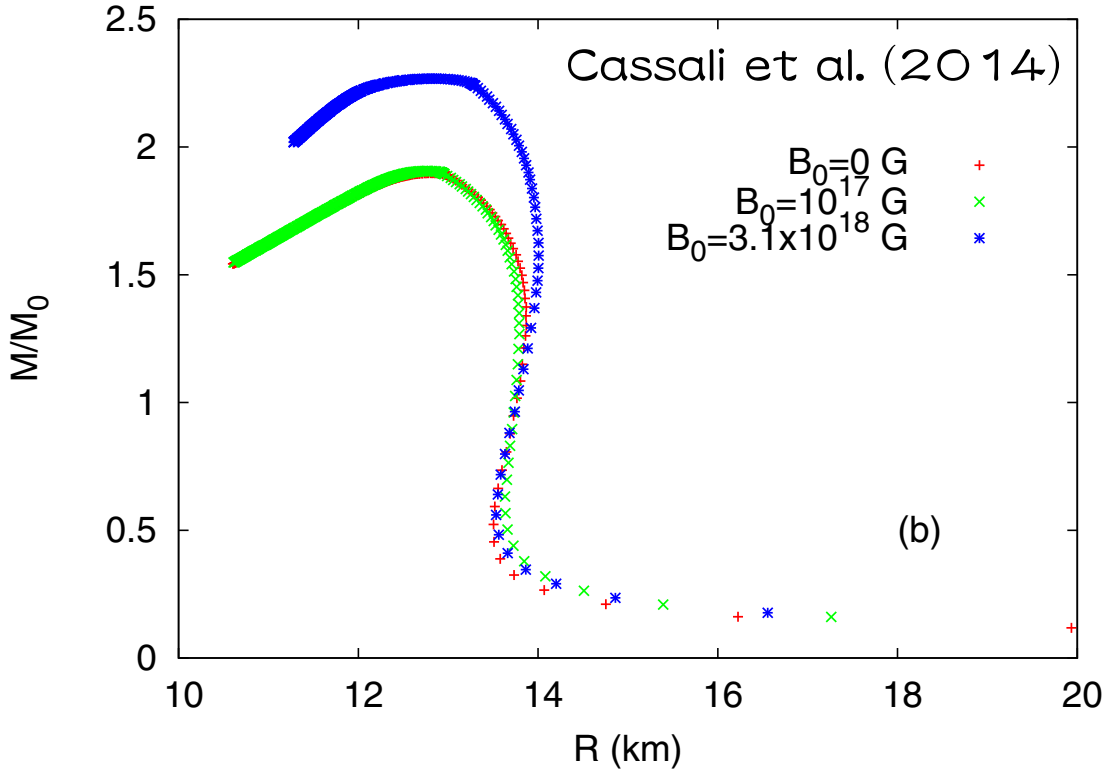
Oyamatsu (1993)

Lorenz et al. (1993)



can we construct the massive hybrid star, having large quark core??

example for MR relations

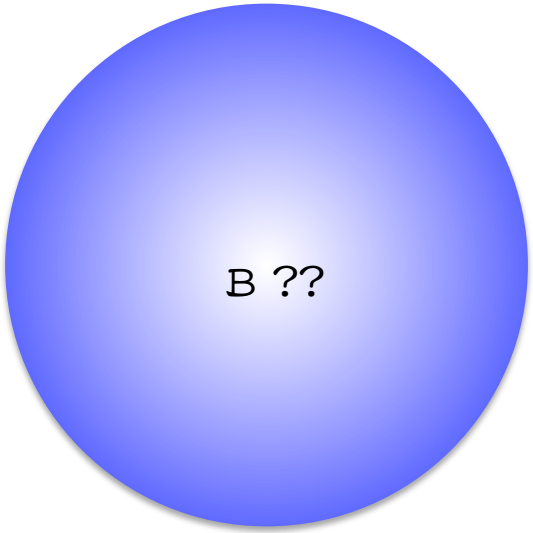


$$B\left(\frac{\rho}{\rho_0}\right) = B_{\rm surf} + B_0\left\{1 - \exp\left[-\beta\left(\frac{\rho}{\rho_0}\right)^{\gamma}\right]\right\}$$

magnetic field of NS

- magnetic field strength @stellar surface
  - B ~ $10^{12\text{-}13}$ Gauss for standard NS
  - B ~ $10^{14\text{-}16}$ Gauss for magnetar
- inside the star, |B| & magnetic configuration are still unknown

- In this talk,
  - appearance of quark matter inside the star
  - magnetic effect only on quark matter
  - effect of the Landau level



effect of magnetic field on quark matter

- n-th energy level of quark with flavor f

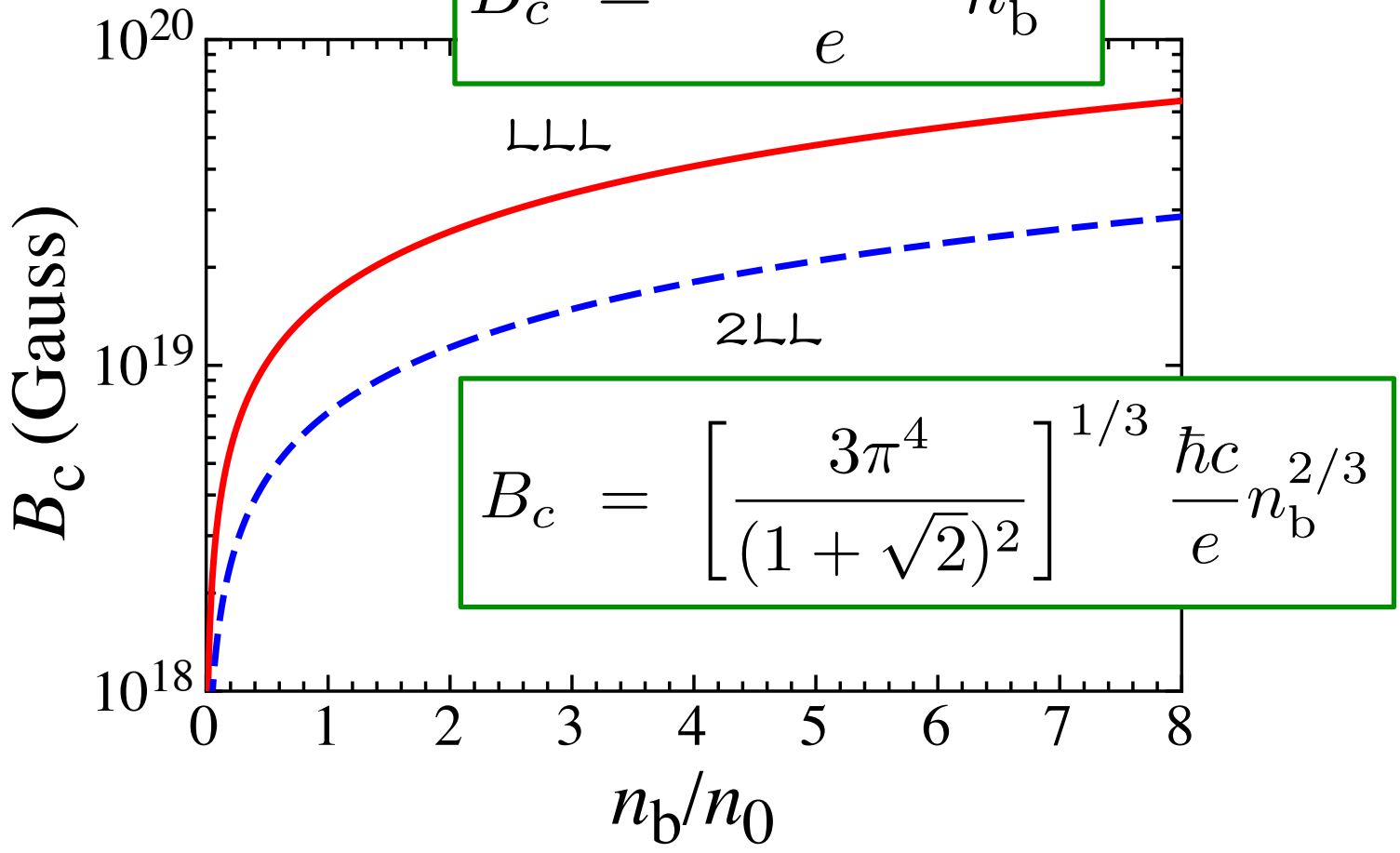
$$E_n^f = \sqrt{c^4 m_f^2 + c^2 p_z^2 + \hbar c |e_f B| [2n + 1 + \mathrm{sgn}(e_f B) s]},$$

  assuming the uniform magnetic field $\mathcal{B}$ locally.

- considering that the lowest Landau level (LLL) plays a primary role due to the strong magnetic field,
  - number density : $n_f = \dfrac{3|e_f B|}{2\pi^2 \hbar^2 c} p_{f\mathrm{F}}$
  - energy density : $\varepsilon_f = \dfrac{3|e_f B|}{4\pi^2 \hbar^2} p_{f\mathrm{F}}^2$
- total energy density within the MIT bag model : $\boxed{\varepsilon = \dfrac{5\pi^2 \hbar^2 c^2}{2eB} n_{\mathrm{b}}^2 + \mathcal{B}}$
- pressure : $\boxed{P = n_{\mathrm{b}}^2 \dfrac{\partial(\varepsilon/n_{\mathrm{b}})}{\partial n_{\mathrm{b}}} = \dfrac{5\pi^2 \hbar^2 c^2}{2eB} n_{\mathrm{b}}^2 - \mathcal{B}}$ → $\gamma = 2$
- EOS : $\boxed{P = \varepsilon - 2\mathcal{B}}$ - independent of the magnetic field strength!
  - limiting case of a stiff EOS

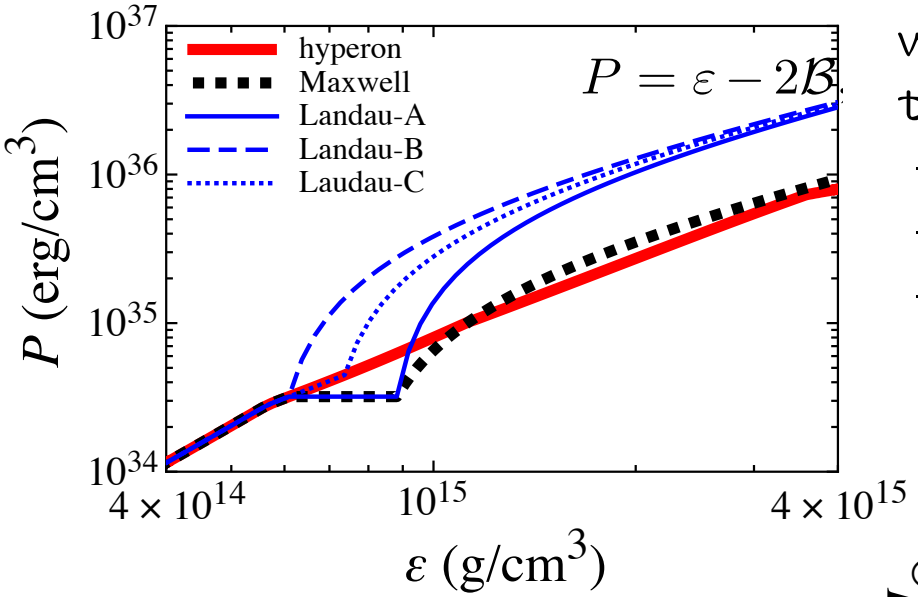
critical magnetic field strength

$$B_c = \frac{\sqrt[3]{6\pi^4}\hbar c}{e} n_{\rm b}^{2/3}$$



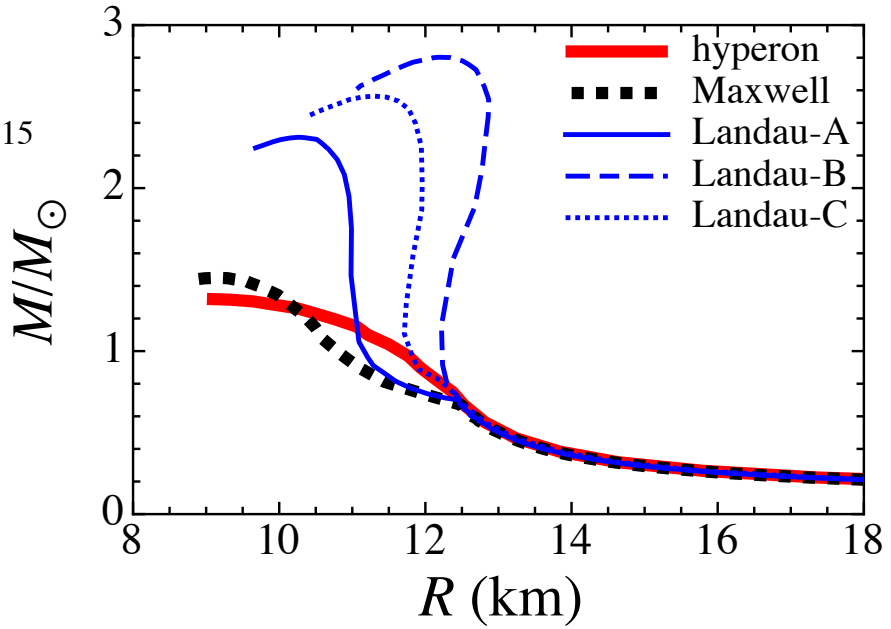
$$B_c = \left[\frac{3\pi^4}{(1+\sqrt{2})^2}\right]^{1/3} \frac{\hbar c}{e} n_{\rm b}^{2/3}$$

EOS & MR relation



we simply connect quark matter to hadronic matter

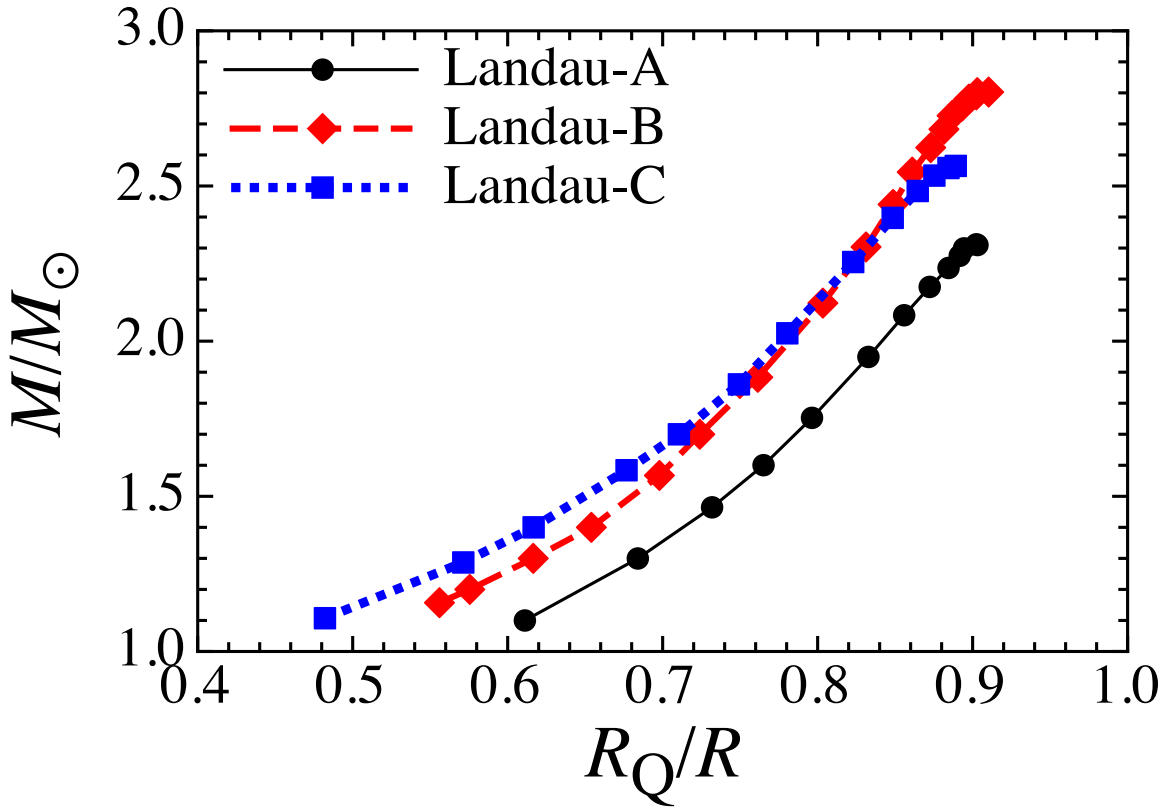
- Landau-A
- Landau-B
- Landau-C



mass of hybrid star can become quite massive!

- more than $2M_\odot$

boundary between quark & hadronic phases



- for star with $2M_\odot$, R_Q can be more than ~80% of R
  - "hybrid quark star"

summary

- we consider the effect of the lowest Landau level on the hybrid NS, due to the existence of strong magnetic field
- the resultant hybrid NS can become quite massive
- quark matter can occupy in large part of NS
  - "hybrid quark star"
  - massive neutron star ~ hybrid quark star ??

- we may also take into account
  - magnetic configuration (& stellar deformation)
  - the magnetic pressure in EOS
  - the effect of magnetic field on hadron phase
  - the hadron-quark mixed phase