Absolute stability of strange quark matter within confining chiral models

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Can Bodmer-Witten hypothesis on the absolute stability of strange quark matter be realized by using various models of quark dynamics?

- MIT bag model: YES Farhi and Jaffe, 1984
  - Parameters are not well constrained in the model, no chiral dymanics, but there is confinement
- Chiral models without confinement: NO Klaehn and Fischer 2015
  - The low density behaviour forces masses to be too large to satisfy BW
- Chiral models with a «confining» B: maybe Zacchi, Stiele, Schaffner-Bielich 2015
  - IF there is a parameters' space for BW it corresponds to too low densities or it falls back into a MIT-bag scenario in which chiral symmetry plays no role.
- Schwinger-Dyson model with a «confining» B: YES Chen, Wei, Schulze 2016
- What happens in a really confining chiral model?

SU(3) chiral lagrangian

- $U(3) \times U(3)$ invariant quark-mesons theory.
- Using the relativistic mean field approximation (RMFA):

$$\mathcal{L} = m_v^2 \mathrm{Tr}[V^\dagger V] - \lambda_1 \mathrm{Tr}[M^\dagger M]^2 - \lambda_2 \mathrm{Tr}\left[(M^\dagger M)^2\right] - \mu \mathrm{Tr}[M^\dagger M]$$

$$\mathcal{L}_{int} = -\sqrt{2} g_\sigma (\bar{q} M q) - \sqrt{2} g_\omega (q^\dagger V q)$$

$$\mathcal{L}_{break} = \mathrm{Tr}[H(M^\dagger + M)] + \gamma(\mathrm{Det} M^\dagger + \mathrm{Det} M)$$

- RMFA meson matrices:

$$M = \frac{1}{2}\begin{pmatrix} \sqrt{\frac{2}{3}}\sigma_0 + \sigma_3 + \frac{\sigma_8}{\sqrt{3}} & 0 & 0 \\ 0 & \sqrt{\frac{2}{3}}\sigma_0 - \sigma_3 + \frac{\sigma_8}{\sqrt{3}} & 0 \\ 0 & 0 & \sqrt{\frac{2}{3}}\sigma_0 - \frac{2\sigma_8}{\sqrt{3}} \end{pmatrix}$$

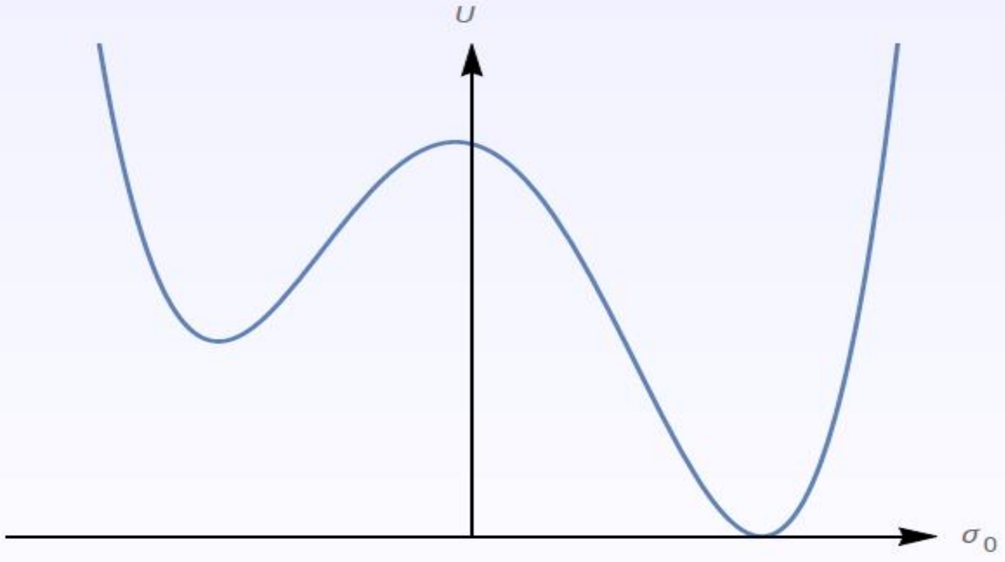
$$V = \frac{1}{2}\begin{pmatrix} \sqrt{\frac{2}{3}}v_0 + v_3 + \frac{v_8}{\sqrt{3}} & 0 & 0 \\ 0 & \sqrt{\frac{2}{3}}v_0 - v_3 + \frac{v_8}{\sqrt{3}} & 0 \\ 0 & 0 & \sqrt{\frac{2}{3}}v_0 - \frac{2v_8}{\sqrt{3}} \end{pmatrix}$$

Chiral symmetry breaking

- Chiral simmetry braking pattern:

$$U(3)_L \times U(3)_R \rightarrow SU(3)_L \times SU(3)_R \times U(1)_V \rightarrow SU(3)_V \times U(1)_V$$

- Spontaneous breaking in the meson sector:



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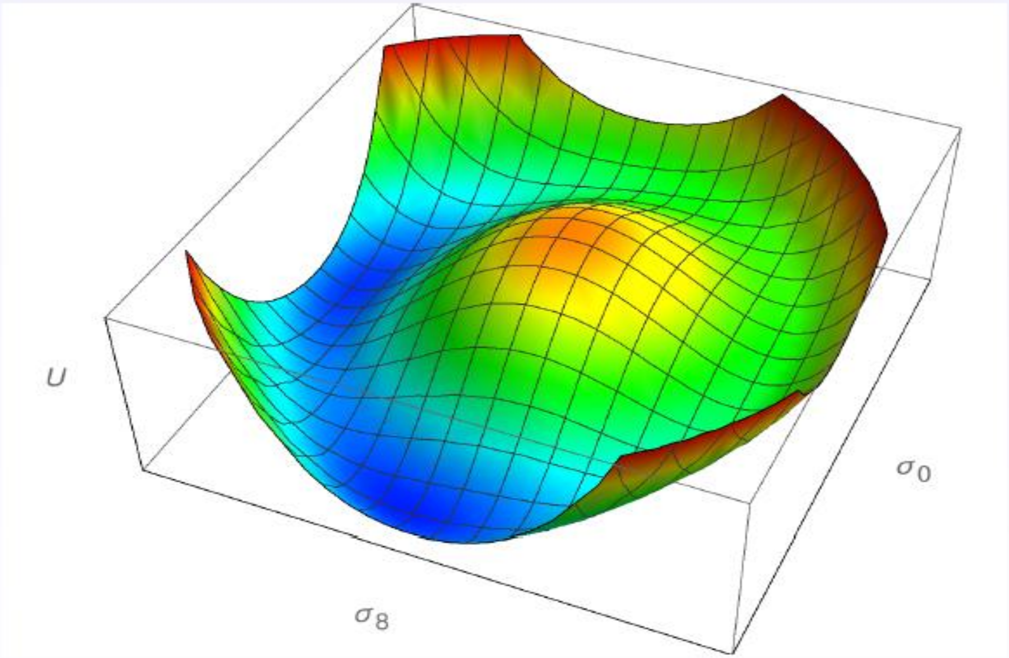
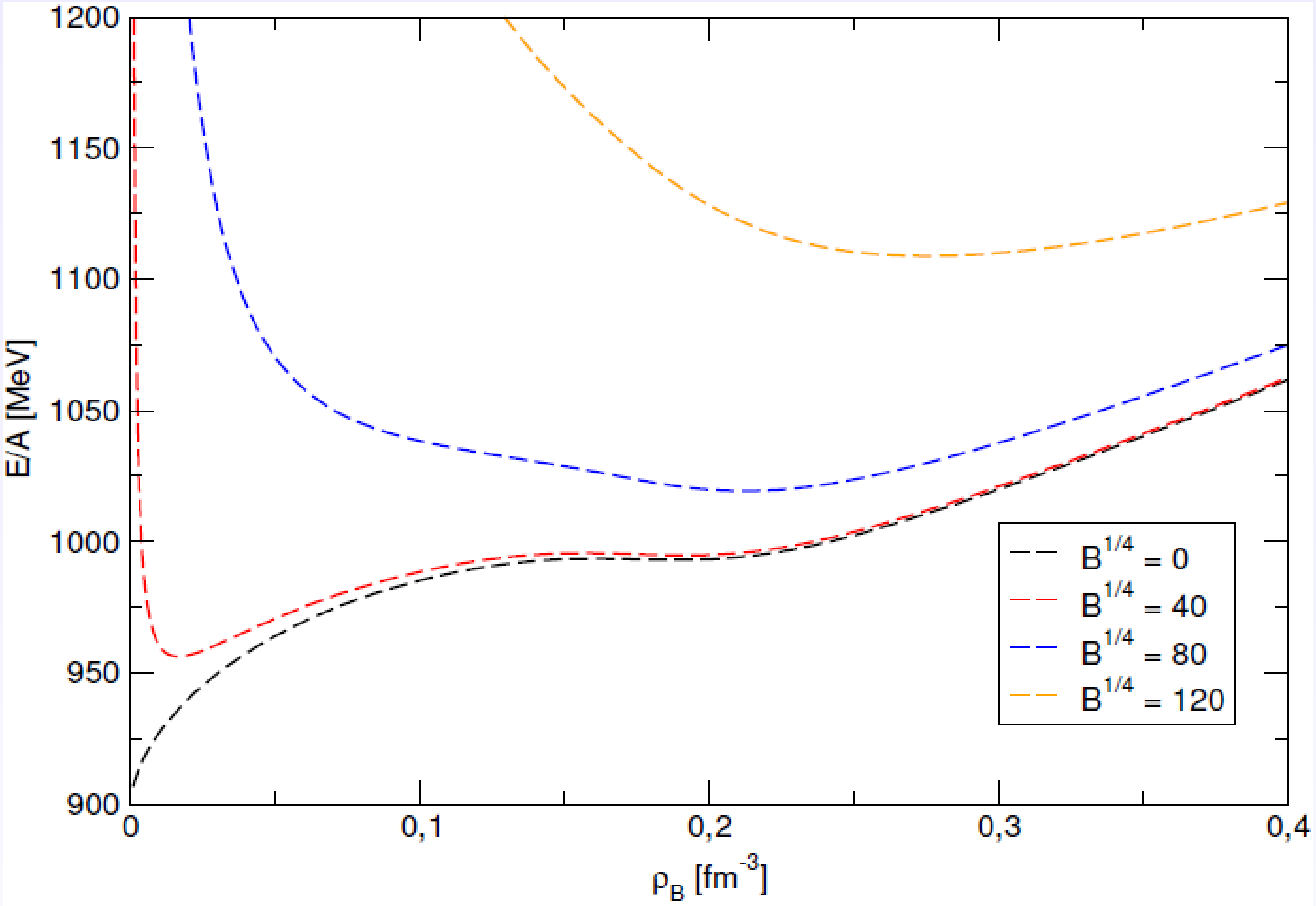


Confining chiral models

- Bag-like confinement: $\mathcal{E} \rightarrow \mathcal{E} + B$, with MIT bag constant $[B] = MeV^4$ (It is **not** really a confining model!)

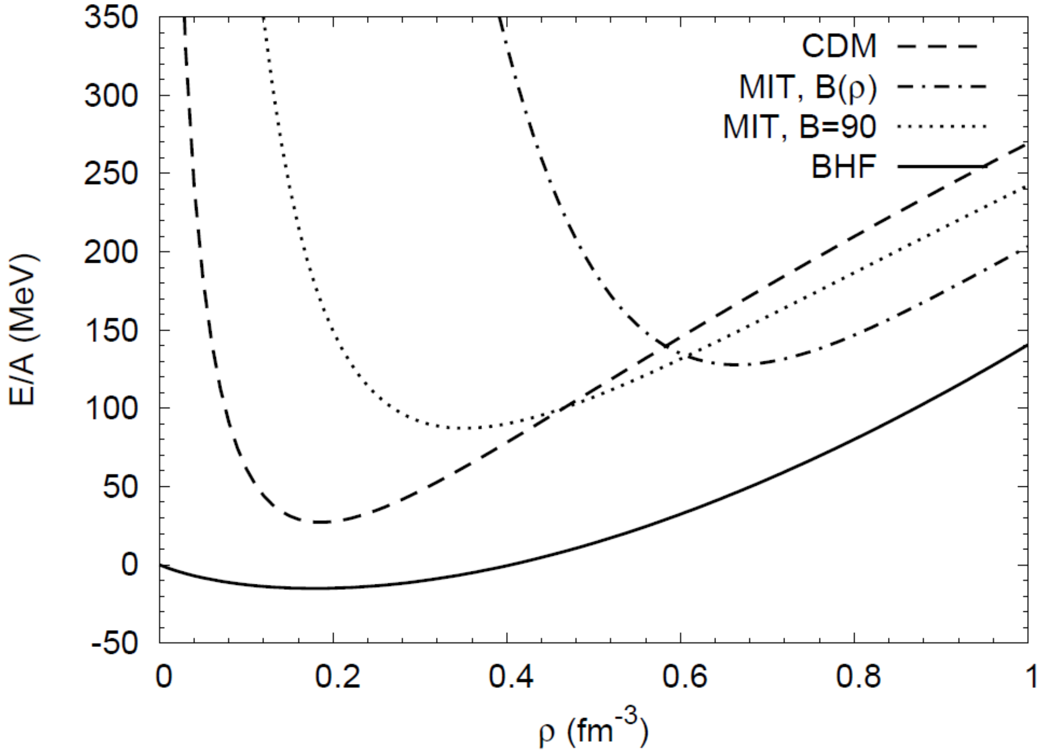


Color dielectric (or chromo-dielectric) model

- Introduced in the 80s by Pirner, Chanfray, Nachtmann…
- Used by Thomas, Schuh, Mathiot, Birse…
- Applied to study:
  - Hadron spectroscopy
  - Nucleon form factors
  - Nucleon structure functions
  - Nucleon-nucleon potential
  - Quark matter and compact stars
  - …
- Quark confinement is obtained by introducing a scalar field (the dielectric field) which modifies the masses of the quarks as $m \rightarrow m/\chi$. Masses diverge at low densities, because χ scales as $\rho^{1/3}$.
- The CDM model was derived from the scaling properties of lattice QCD.

Chiral CDM model

$$\mathcal{L}_\chi = \frac{1}{2}(\partial_\mu \chi)^2 - \frac{1}{2}M_\chi^2\chi^2 \qquad \mathcal{L}_{int} = -\frac{\sqrt{2}\,g_\sigma}{\chi}(\bar{q}Sq)$$



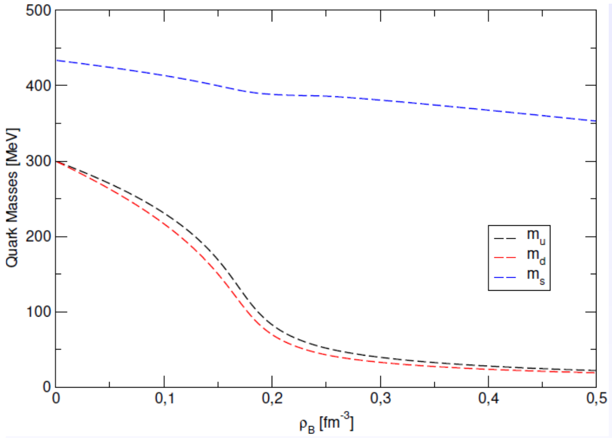
Low density behaviour:

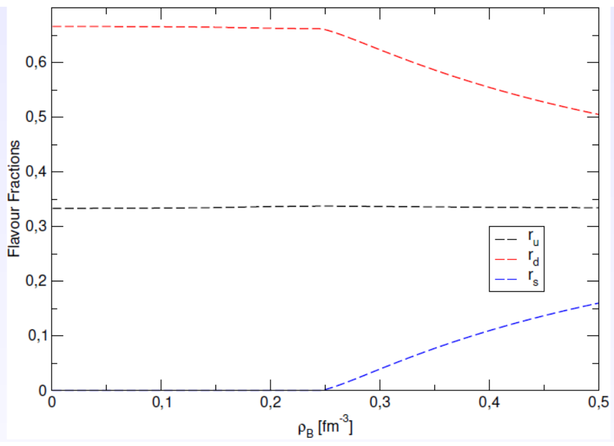
- In the CDM E/A scales as $\rho^{-1/3}$ in agreement with a linear confining potential
- In the MIT bag-like model E/A scales as ρ^{-1}

From Maieron, Baldo, Burgio, Schulze 2013
No vector mesons included

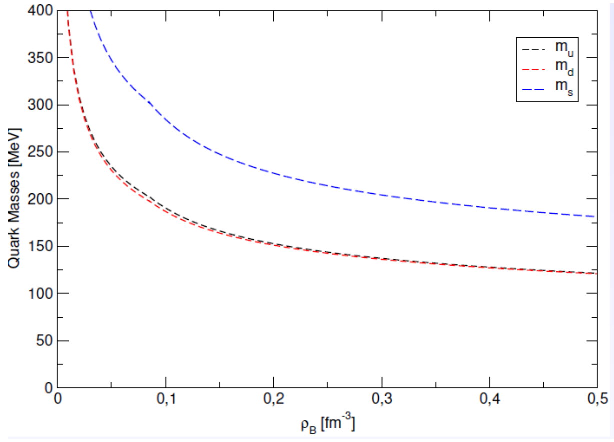
Quark masses and quark fractions

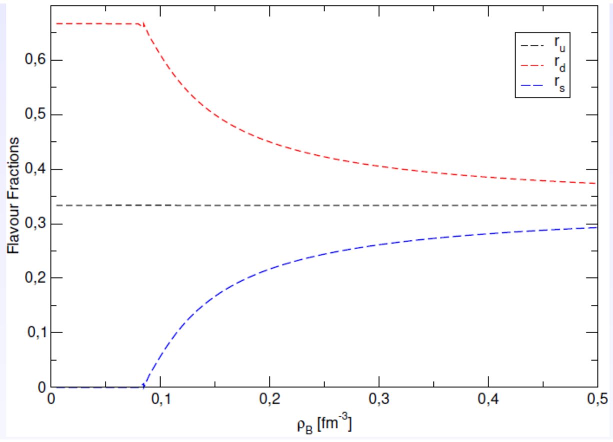
Chiral model without confinement or with B term



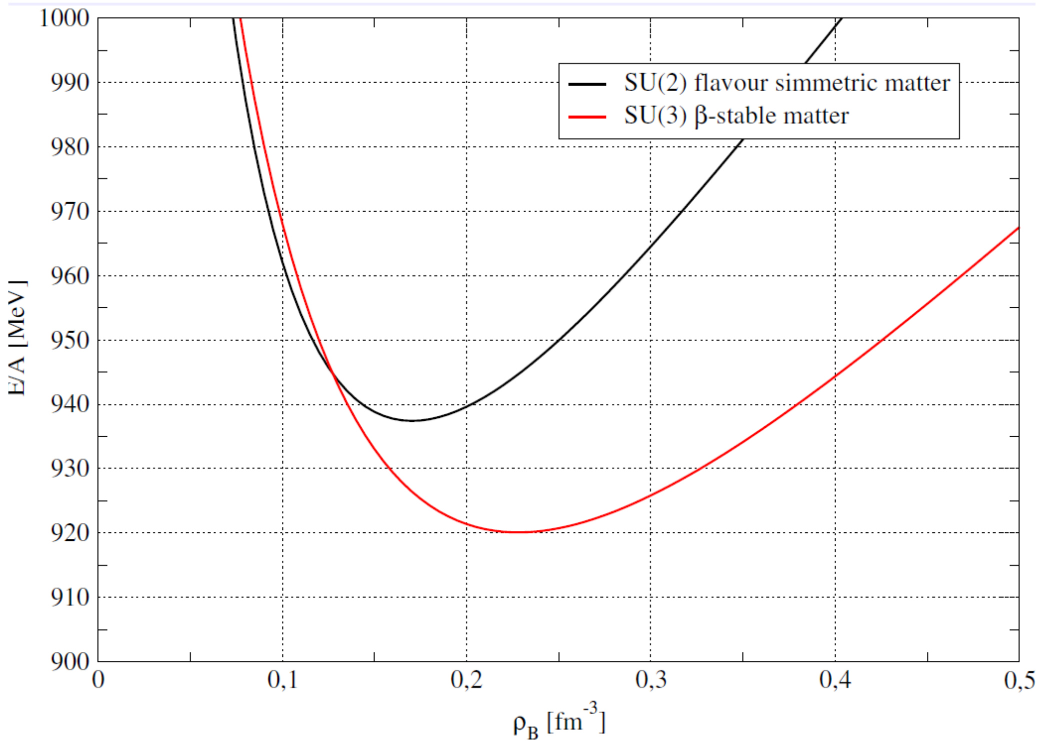


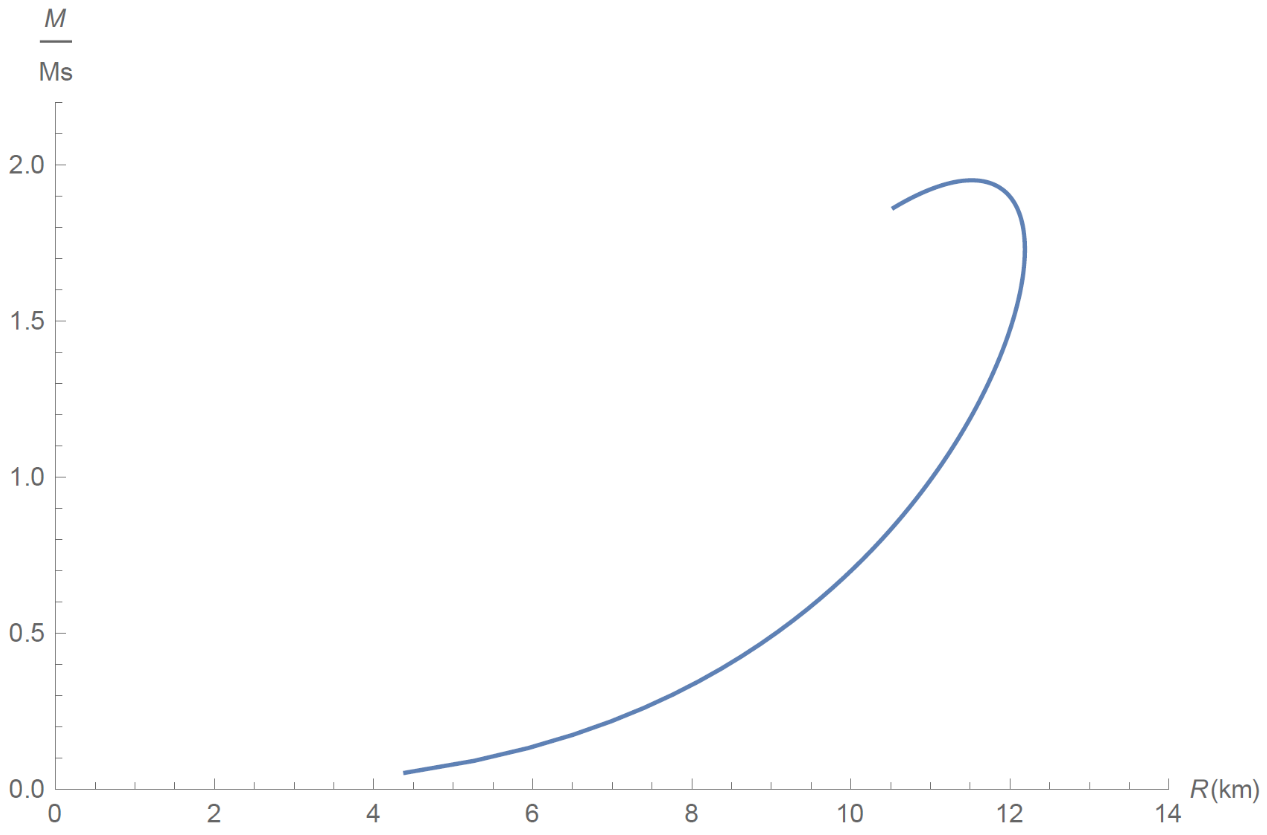
Chiral chromo-dielectric model





Results within the Chiral CDM by using the RMFA



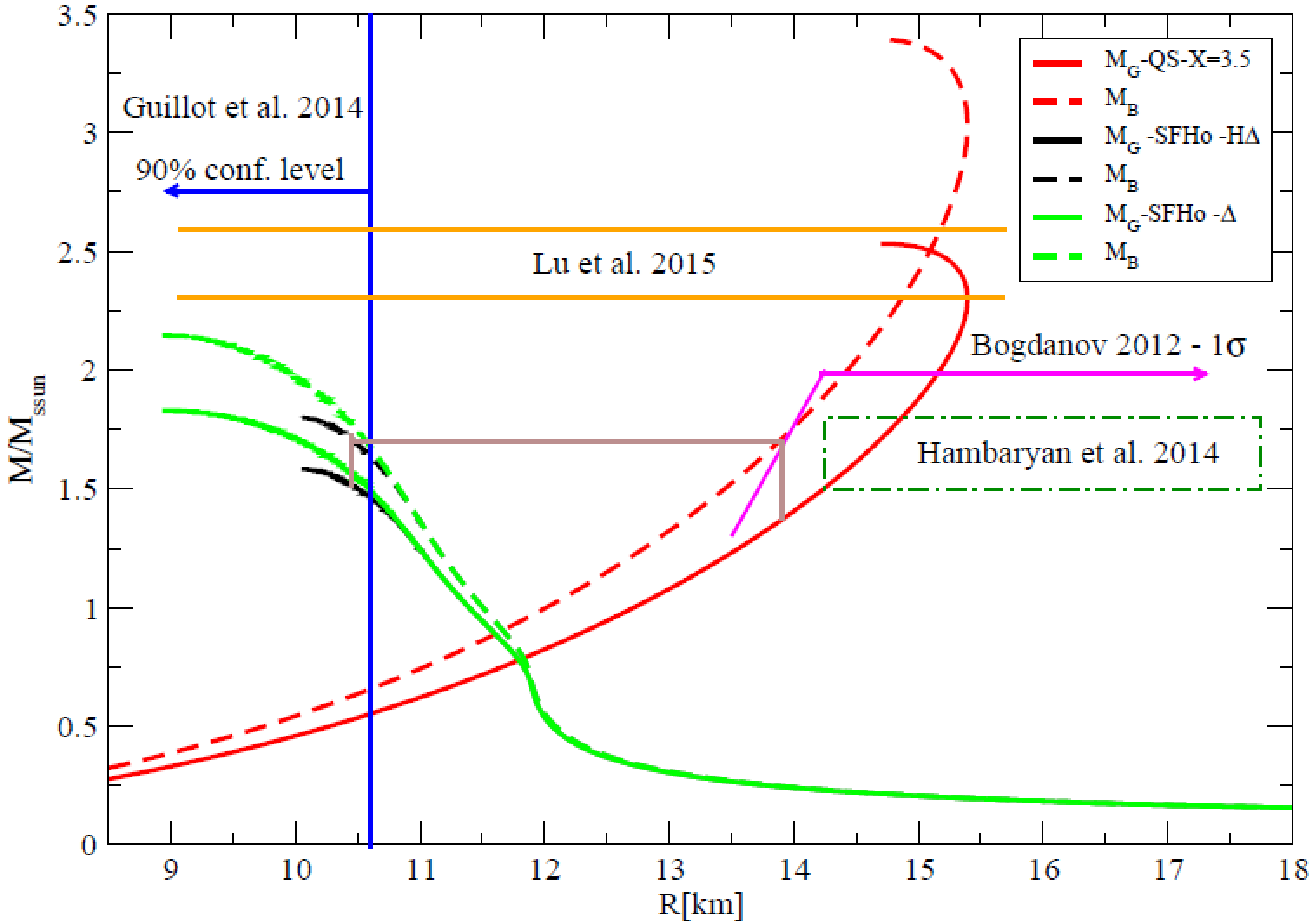


The minimum of E/A always contains strange quarks

The EOS has been computed using the RMFA, including the Hartree but not the Fock term. The inclusion of the Fock term Will increase the mass and the radius by about 10-15 percent, Allowing to get M_{max}~ 2.2-2.3 Ms with radii of about 13-14 km

The possibility of having very massive quark stars is a crucial condition for the validity of the two-families scenario

- Radii (NICER, LOFT)
- Anomalous mass distribution (SKA)
- Moment of inertia (SKA)
- GW signal in NS-NS merger (LIGO & VIRGO)



Conclusions

- The dynamics associated with confinement, as described within the chiral CDM, reduces the masses of quarks for all flavors, favouring the production of strange quarks at lower densities.
- The minimum of E/A for beta-stable quark matter is located at a density for which strange quarks are present.
- It is possible to find a window of parameters for which the Bodmer-Witten hypothesis is satisfied. This window is compatible with the values used to study hadronic physics within the CDM.
- Within chiral models the number of free parameters is very limited and it can be associated with the value of a few observables. This opens the possibility of suggesting lab experiments which will put more stringent constrains on the validation of the BW hypothesis.