Mimicking the Pasta Phase and Robustness of the Third Family Phenomena

Alexander Ayriyan

Department of Computational Physics
Laboratory of Information Technologies
Joint Institute for Nuclear Research

XMatter in HIC and Astrophysics
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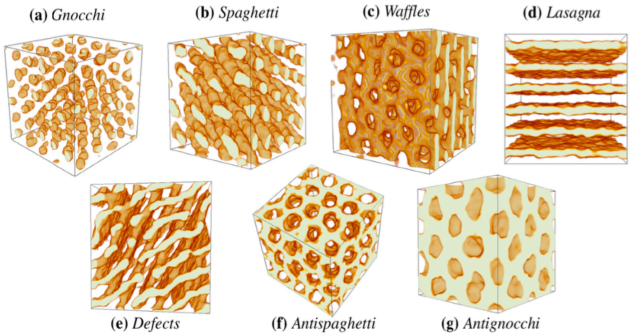
Collaborators

David-Edwin Alvarez-Castillo (JINR)
David Blaschke (JINR & MEPhi & Wroclaw University)
Hovik Grigorian (JINR & YSU)
Konstantin Maslov (MEPhI & JINR)
Dmitry Vosskresensky (MEPhI & JINR)
Nobutoshi Yasutake (Chiba Institute of Technology)
Vahagn Abgaryan (JINR)

Motivation

Simplification of pasta phase calculations

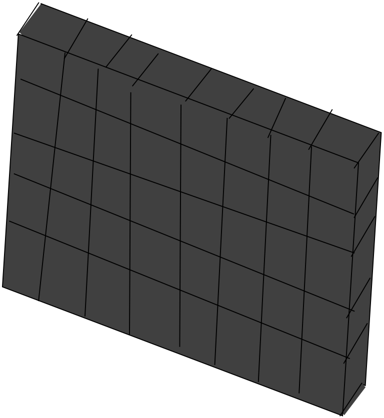


Credit: N. Yasutake

Motivation

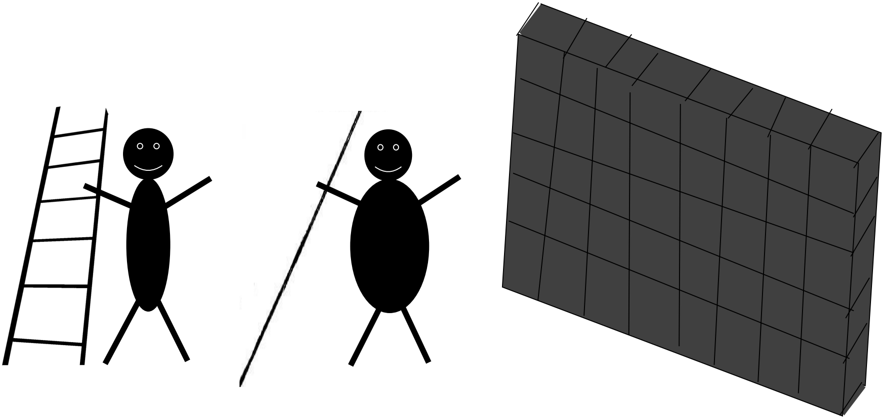
Simplification of pasta phase calculations

Super Yas



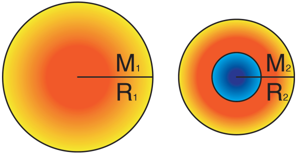
Motivation

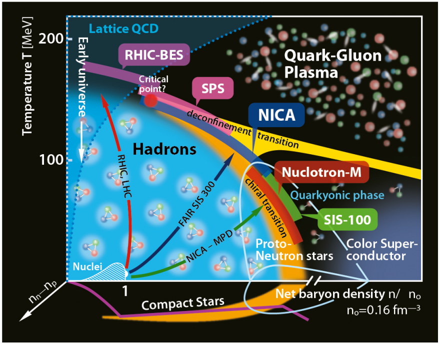
Simplification of pasta phase calculations



Motivation

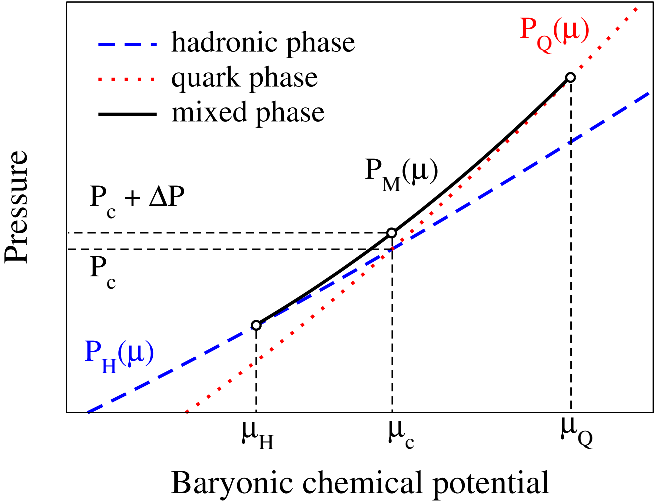
What if we have twins





- Does hybrid neutron star exist?
- Does NS twin exist?
- Does CEP exist on QCD phase diagram?
- etc.

The idea



Schematic representation of the interpolation function $P_M(\mu)$, it has to go though three points: $P_H(\mu_H)$, $P_c + \Delta P$ and $P_Q(\mu_Q)$.

The Grigorian construction

$$P_M(\mu) = \sum_{q=1}^{N} \alpha_q (\mu - \mu_c)^q + (1 + \Delta_P) P_c$$

where Δ_P is a free parameter representing additional pressure of the mixed phase at μ_c.

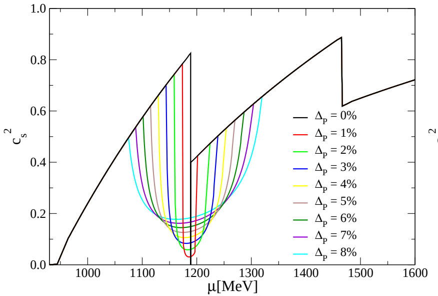
$$P_H(\mu_H) = P_M(\mu_H) \qquad P_Q(\mu_Q) = P_M(\mu_Q)$$

$$\frac{\partial^q}{\partial \mu^q} P_H(\mu_H) = \frac{\partial^q}{\partial \mu^q} P_M(\mu_H) \qquad \frac{\partial^q}{\partial \mu^q} P_Q(\mu_Q) = \frac{\partial^q}{\partial \mu^q} P_M(\mu_Q)$$

where $q = 1, 2, \ldots, k$. All $N + 2$ parameters (μ_H, μ_Q and α_q, for $q = 1, \ldots, N$) can be found by solving the above system of equations, leaving one parameter (ΔP) as a free one.

A. Ayriyan and H. Grigorian, *EPJ Web Conf.* **2018**, 173, 03003
A. Ayriyan et al. *Phys. Rev. C* **2018**, 97(4), 045802

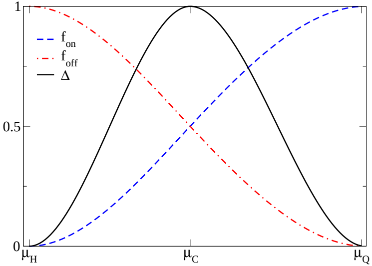
The Grigorian construction



The squared speed vs chemical potential for the Grigorian construction with $k = 2$ (left panel) and $k = 3$ (right panel).

V. Abgaryan, D. Alvarez-Castillo, A. Ayriyan, D. Blaschke, H. Grigorian, Universe (submitted), arXiv:1807.08034

The Blaschke construction



$$f_{>,L} = \alpha_L \left(\frac{\mu - \mu_H}{\mu_Q - \mu_H}\right)^2 + \beta_L \left(\frac{\mu - \mu_H}{\mu_Q - \mu_H}\right)^3$$

$$f_{<,R} = \alpha_R \left(\frac{\mu_Q - \mu}{\mu_Q - \mu_H}\right)^2 + \beta_R \left(\frac{\mu_Q - \mu}{\mu_Q - \mu_H}\right)^3$$

D. Alvarez-Castillo and D. Blaschke, EPJA (submitted), arXiv:1807.03258

V. Abgaryan, D. Alvarez-Castillo, A. Ayriyan, D. Blaschke, H. Grigorian, Universe (submitted), arXiv:1807.08034

The Blaschke construction

$$\Delta(\mu) = \begin{cases} 0 & \mu < \mu_H \\ g_L(\mu) & \mu_H \le \mu \le \mu_C \\ g_R(\mu) & \mu_C \le \mu \le \mu_Q \\ 0 & \mu > \mu_Q \end{cases}$$

$$g_L = \delta_L \left(\frac{\mu - \mu_H}{\mu_C - \mu_H} \right)^2 + \gamma_L \left(\frac{\mu - \mu_H}{\mu_C - \mu_H} \right)^3$$

$$g_R = \delta_R \left(\frac{\mu_Q - \mu}{\mu_Q - \mu_C} \right)^2 + \gamma_R \left(\frac{\mu_Q - \mu}{\mu_Q - \mu_C} \right)^3$$

D. Alvarez-Castillo and D. Blaschke, EPJA (submitted), arXiv:1807.03258

V. Abgaryan, D. Alvarez-Castillo, A. Ayriyan, D. Blaschke, H. Grigorian, Universe (submitted), arXiv:1807.08034

The Blaschke construction

$$f_{\lesseqgtr,L}(\mu)\Big|_{\mu=\mu_c} = f_{\lesseqgtr,R}(\mu)\Big|_{\mu=\mu_c} = 1/2$$

$$\frac{\partial f_{\lesseqgtr,L}(\mu)}{\partial\mu}\Big|_{\mu=\mu_c} = \frac{\partial f_{\lesseqgtr,R(\mu)}}{\partial\mu}\Big|_{\mu=\mu_c}$$

$$\frac{\partial^2 f_{\lesseqgtr,L}(\mu)}{\partial\mu^2}\Big|_{\mu=\mu_c} = \frac{\partial^2 f_{\lesseqgtr,R(\mu)}}{\partial\mu^2}\Big|_{\mu=\mu_c}$$

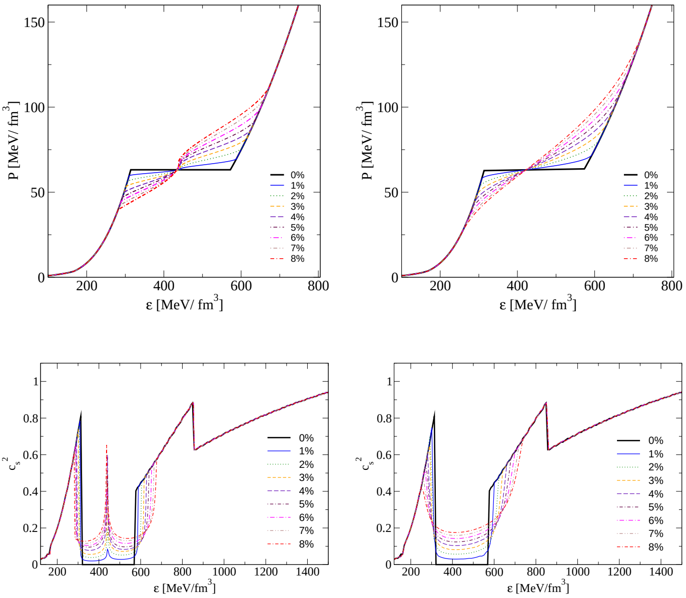
$$g_L(\mu)\Big|_{\mu=\mu_C} = g_R(\mu)\Big|_{\mu=\mu_C} = 1$$

$$\frac{\partial g_L(\mu)}{\partial\mu}\Big|_{\mu=\mu_C} = \frac{\partial g_R(\mu)}{\partial\mu}\Big|_{\mu=\mu_C} = 0 \ .$$

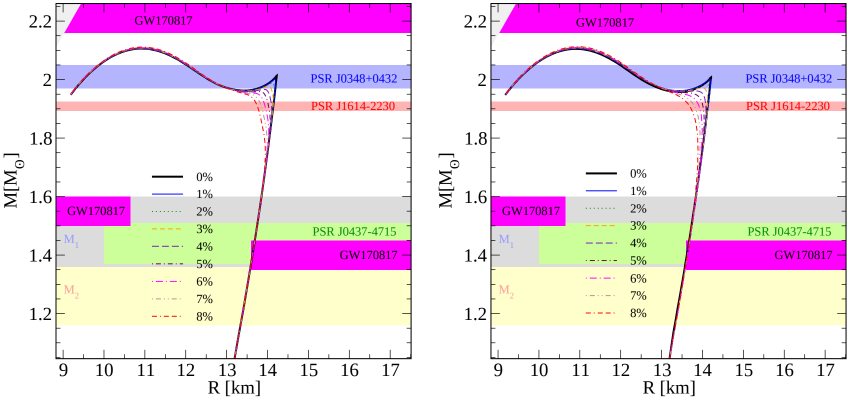
$$\frac{\partial^2 P}{\partial\mu^2}\Big|_{\mu=\mu_H} = \frac{\partial^2 P_H}{\partial\mu^2}\Big|_{\mu=\mu_H}$$

$$\frac{\partial^2 P}{\partial\mu^2}\Big|_{\mu=\mu_Q} = \frac{\partial^2 P_Q}{\partial\mu^2}\Big|_{\mu=\mu_Q} \ .$$

The results of pasta mimicking



The results of pasta mimicking

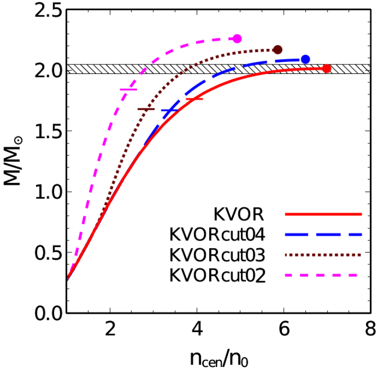


Third family robust against additional pressure up to around $\Delta_P = 5\%$!

Realistic hadronic matter

For the hadronic pase the well known KVOR equation of state [Kolomeitsev & Voskresensky, Nuc. Phys. A 759 (2005)] with modification of stiffness is taken.

[K.A. Maslov, E.E. Kolomeitsev, D.N. Voskresensky, Nucl.Phys. A950 (2016)]

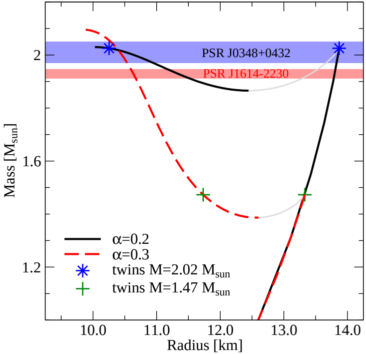


Realistic quark matter

For the quark phase the density functional for quark matter model is used with available volume fraction parameter α (varied in the range [0.1..0.3]).

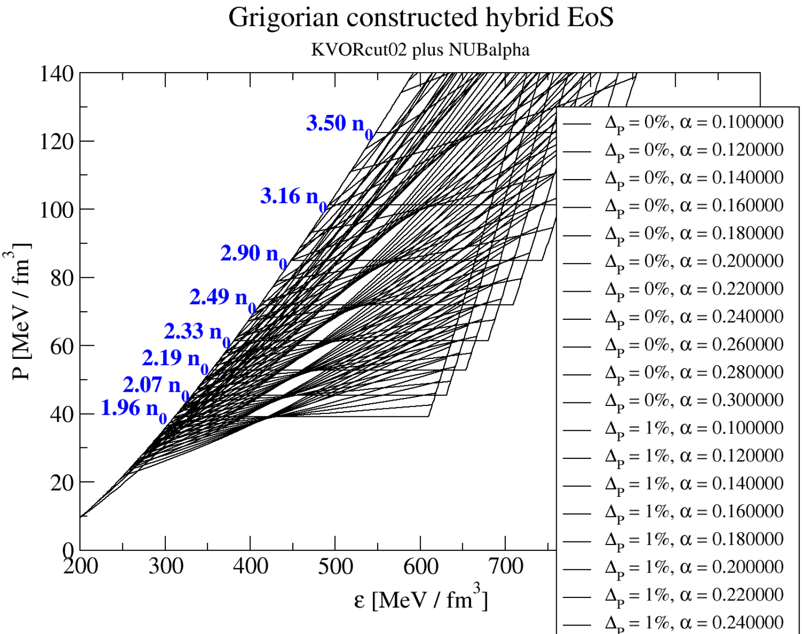
$$\Phi(n_\mathrm{B}) = \begin{cases} 1, & \text{if } n_\mathrm{B} < n_0 \\ e^{-\alpha(n_\mathrm{B}-n_0)^2}, & \text{if } n_\mathrm{B} > n_0 \end{cases},$$

where $\alpha = v|v|/2$ and v is the excluded volume parameter

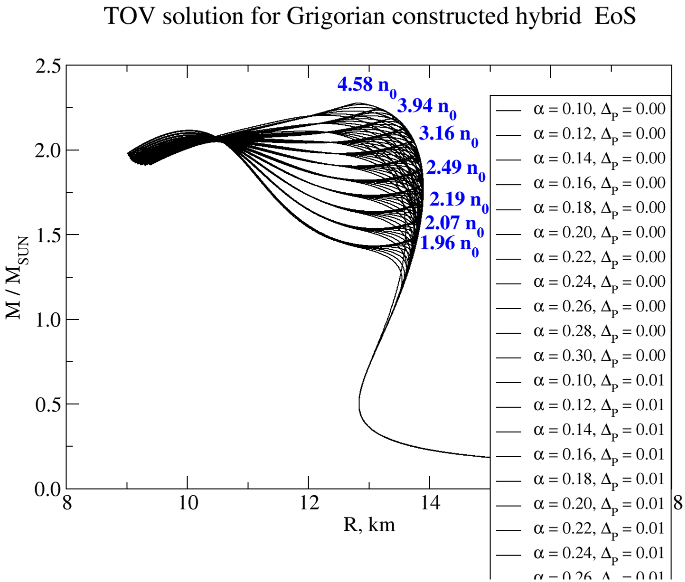


[M. Kaltenborn, N.-U. Bastian, D. Blaschke, Phys. Rev. D 96, 056024 (2017)]

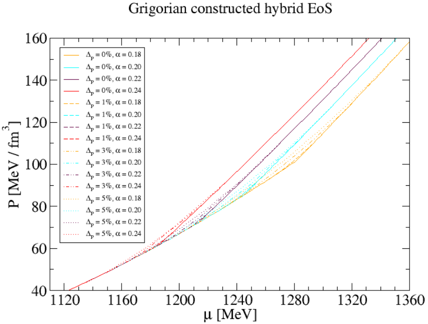
Results of mimicking pasta phase

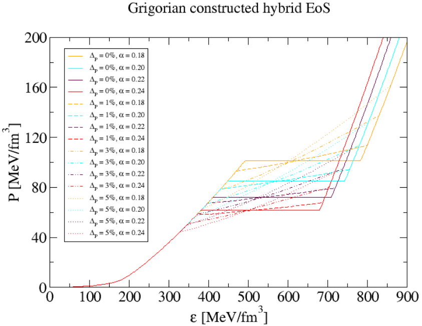


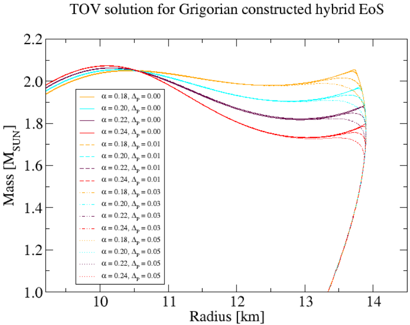
TOV solutions

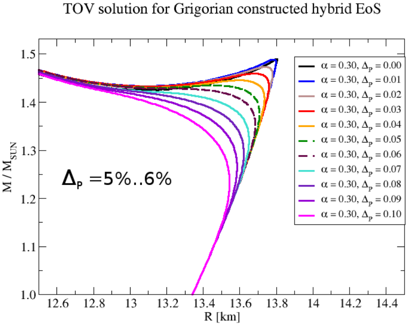


Results of mimicking pasta phase

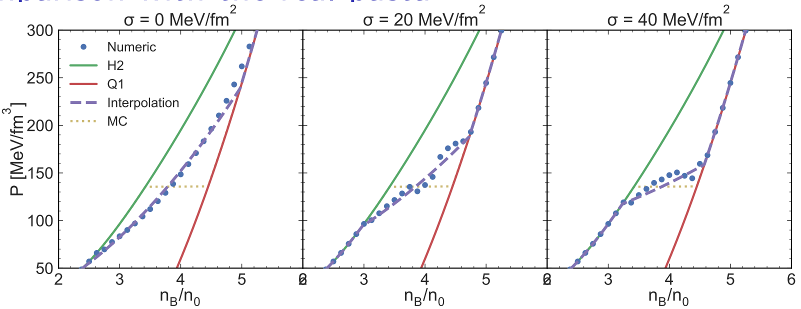




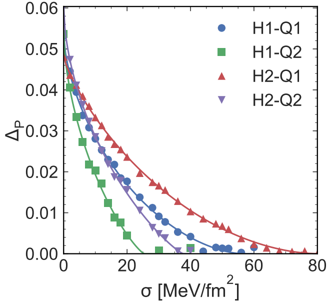




Comparison with the real pasta



Grigorian construction
of the pasta phase
supports third family!



Nobutoshi Yasutake & Konstantin Maslov

Thank you for your attention!