

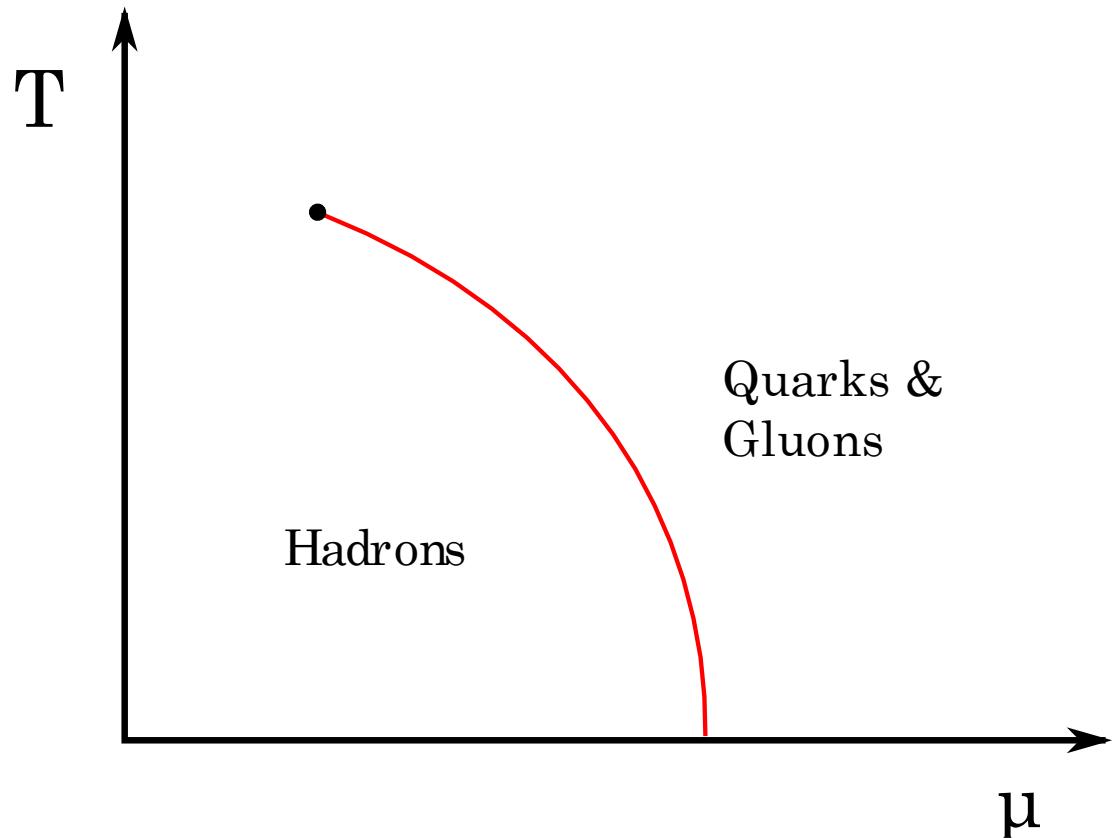
# Strange quark matter from a baryonic approach

Savvas Pitsinigkos

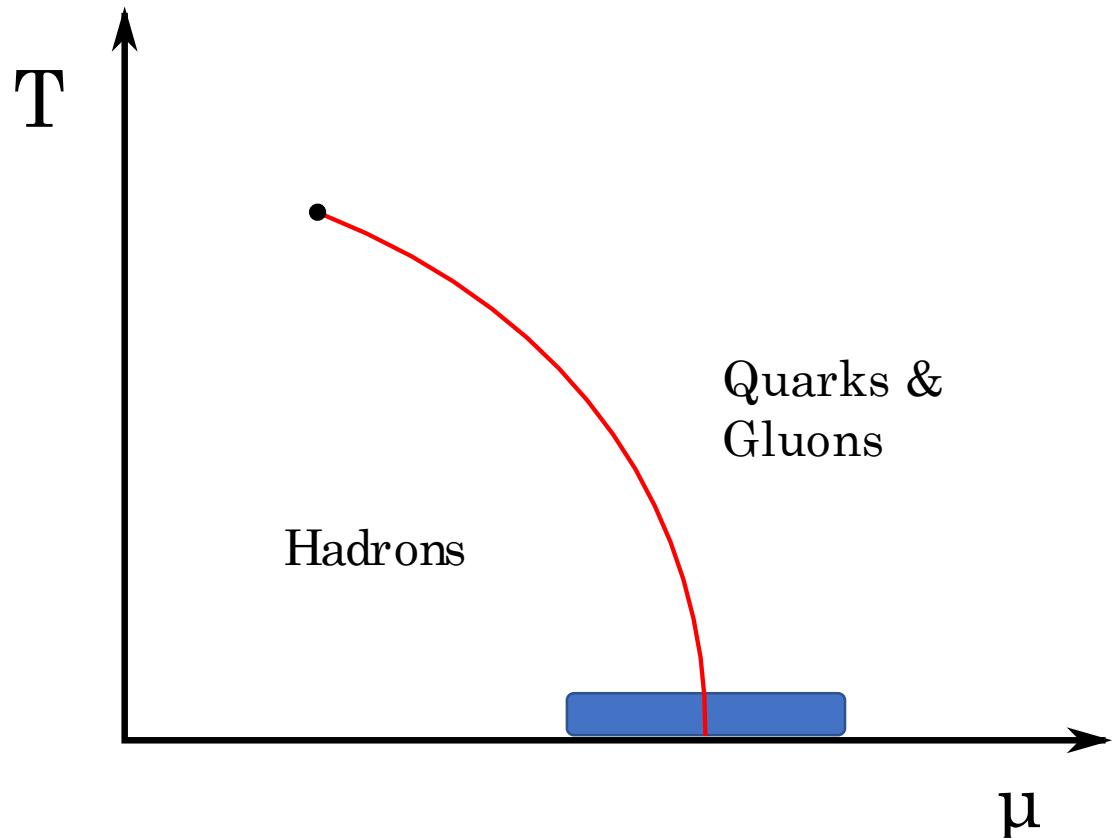
XV<sup>th</sup> “Quark confinement and the Hadron spectrum” conference, Stavanger, August 2022

E. S. Fraga, R. da Mata, S. Pitsinigkos, A. Schmitt, (2206.09219)

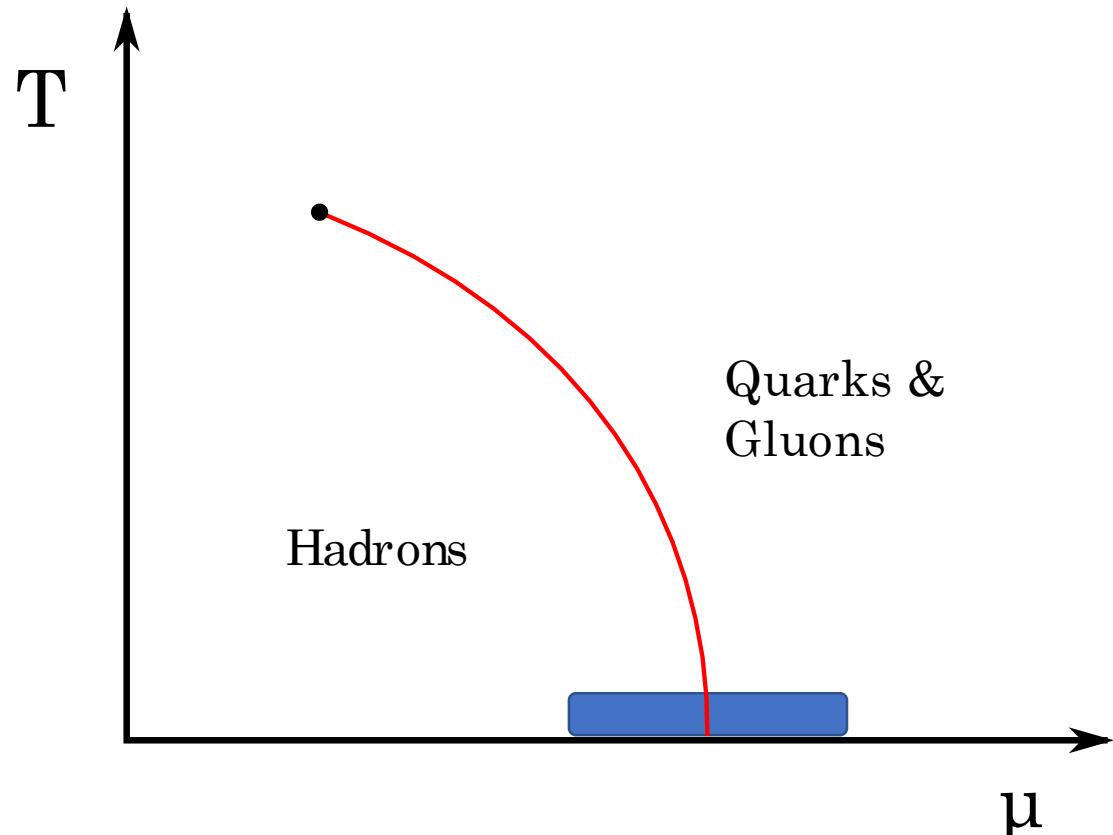
# Cold and dense matter



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- What is the critical  $\mu$  for the phase transition?
- What is the order of the phase transition?
- Can we find inhomogeneous phases in the vicinity?
- What can we learn about neutron stars?

# Two options

Use one model for each phase,  
then stitch models together.

Build a single model that  
describes both phases.

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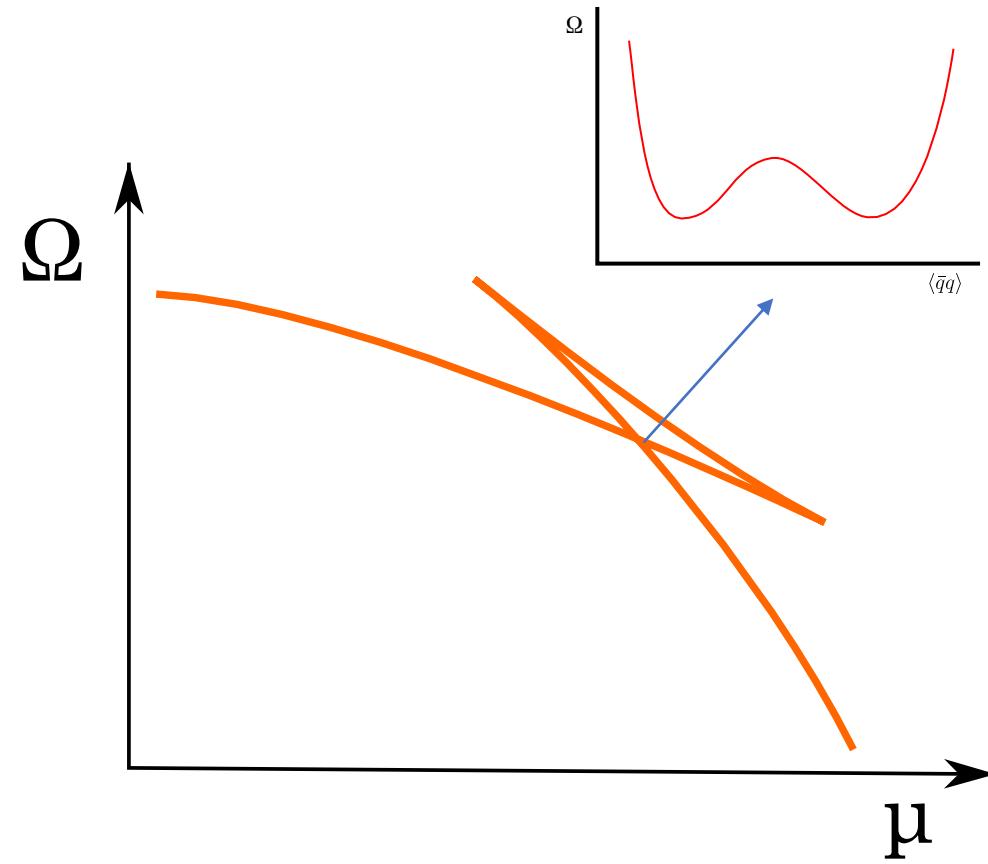
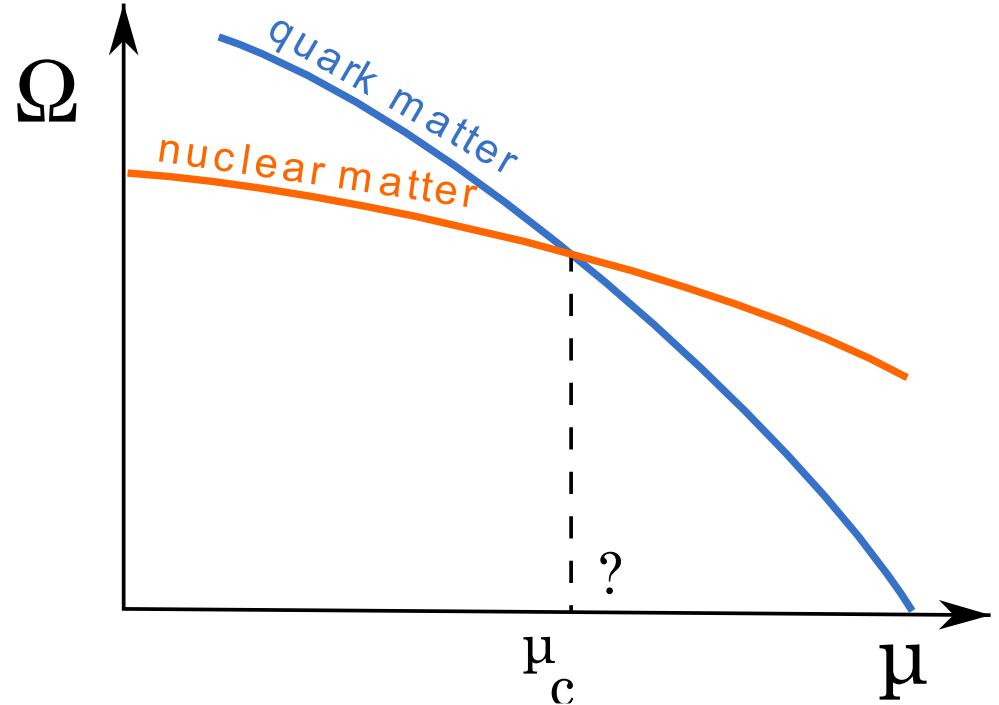
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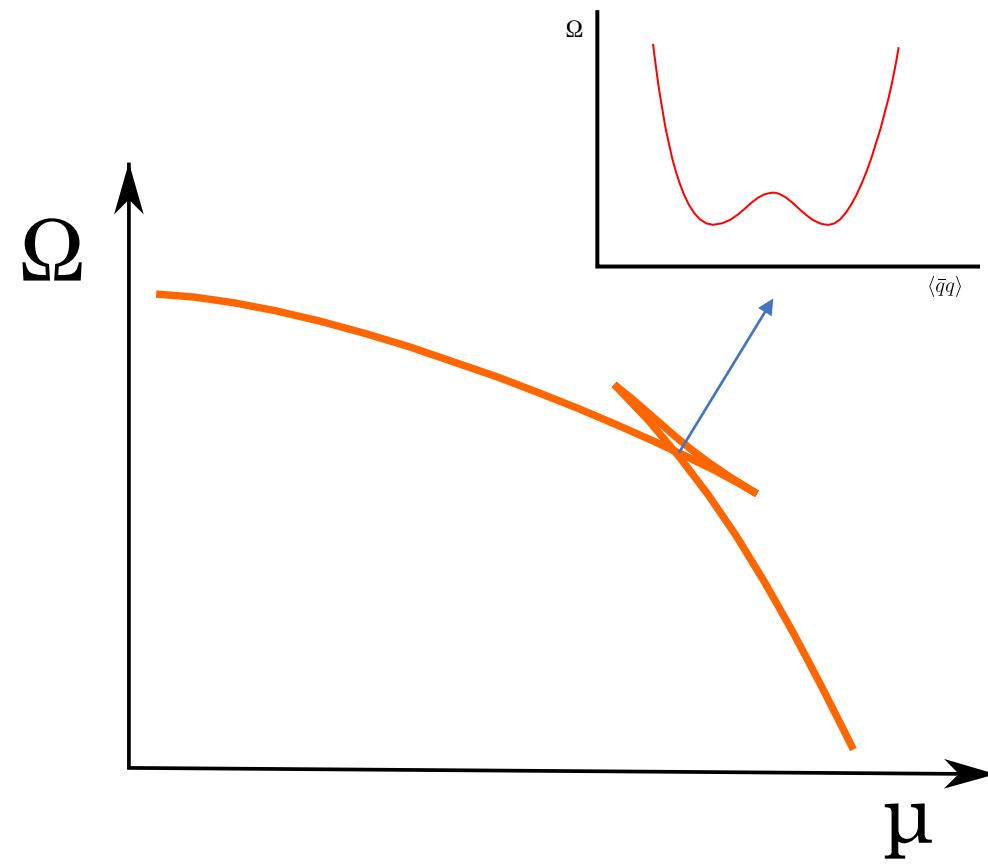
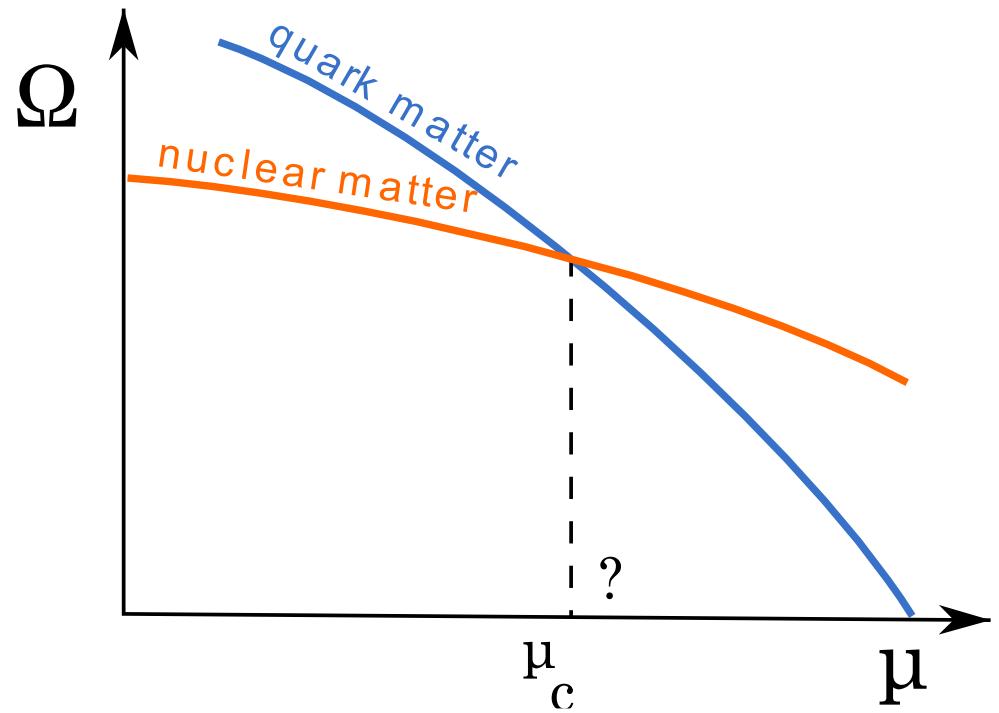
Build a baryon-meson model with spontaneous chiral symmetry restoration  
at high densities. Use chirally restored phase to describe quark matter.  
No quark degrees of freedom!

# Two models vs single model



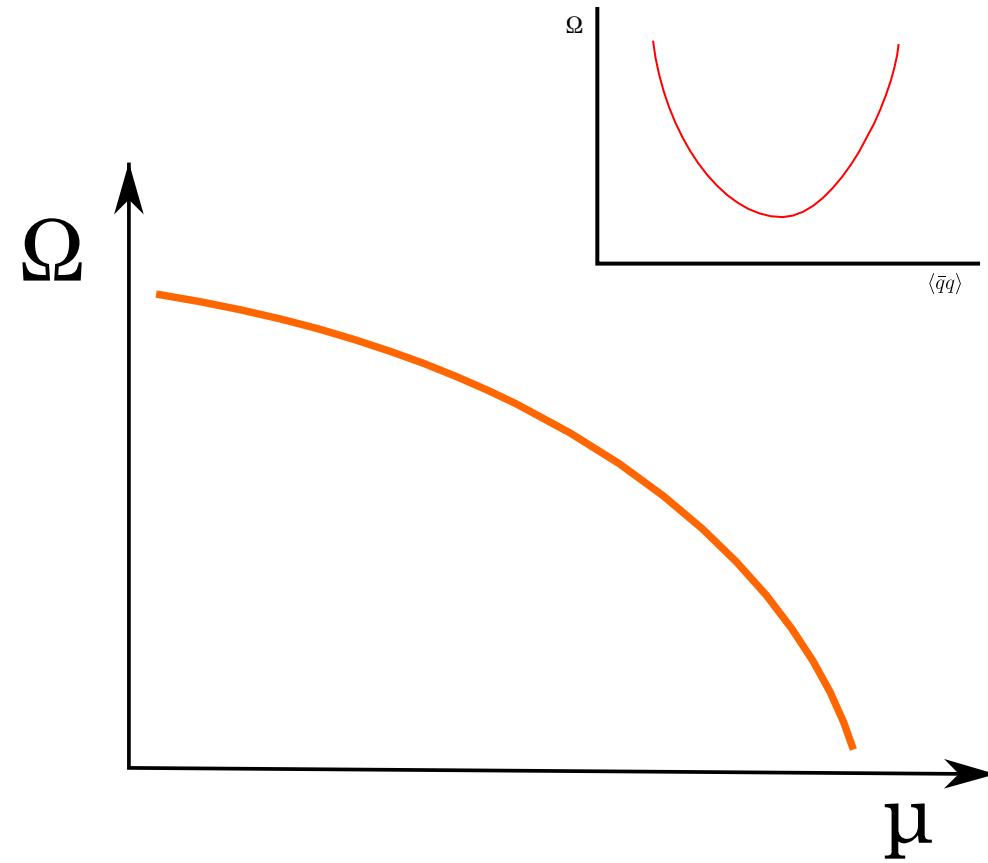
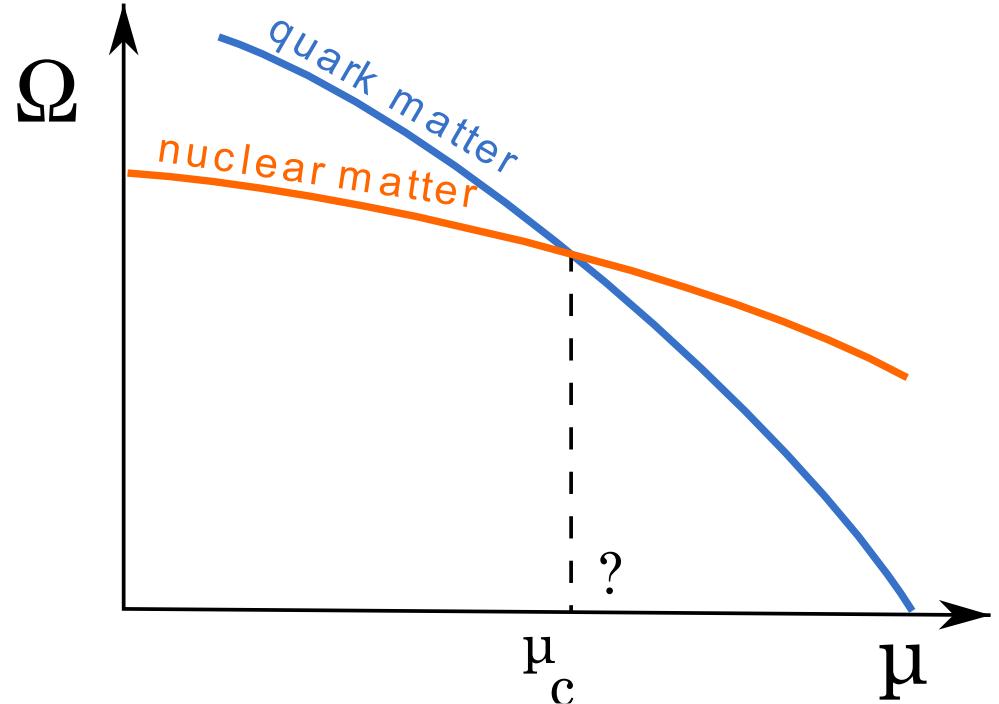
Critical chemical potential  $\mu_c$  is calculated dynamically.

# Two models vs single model



Spinodal region size varies.

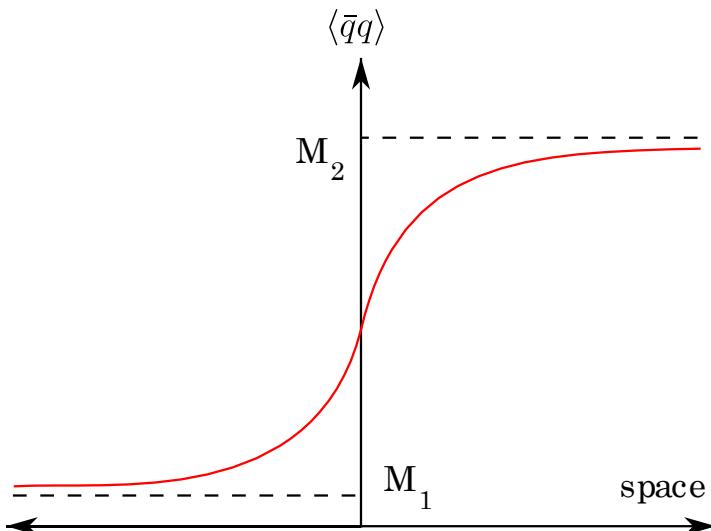
# Two models vs single model



Crossover is also an option.

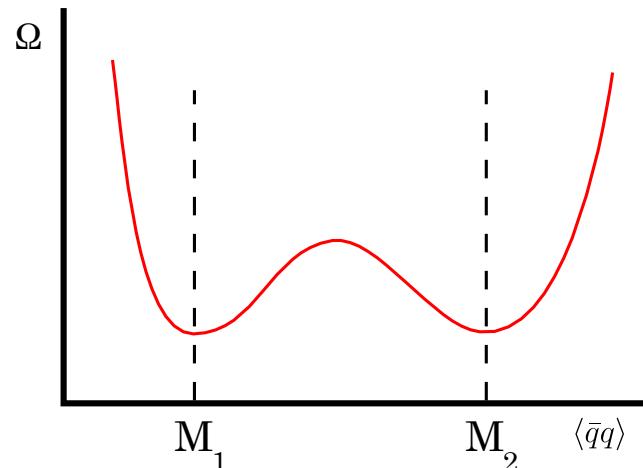
# Inhomogeneous phases

Surface tension E. S. Fraga, M. Hippert, A. Schmitt, PRD 99, 014046 (2019)



Relevant for bubble  
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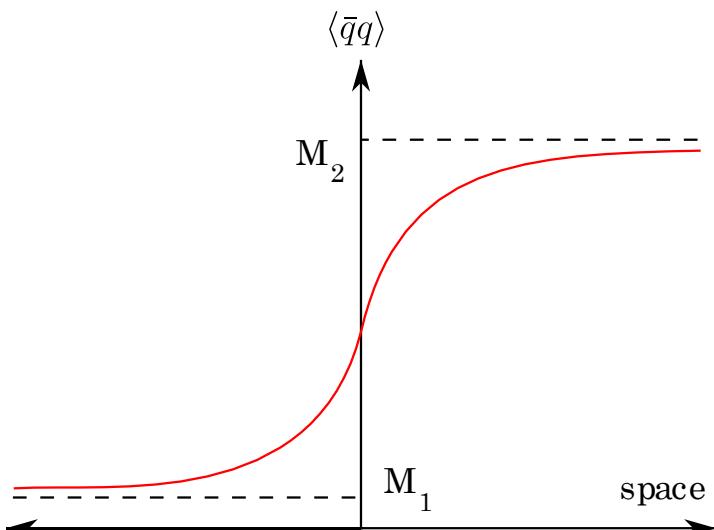
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# Inhomogeneous phases

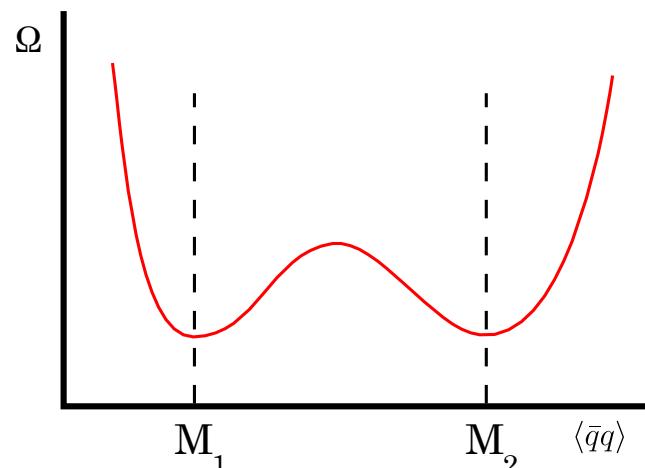
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## Pasta phases

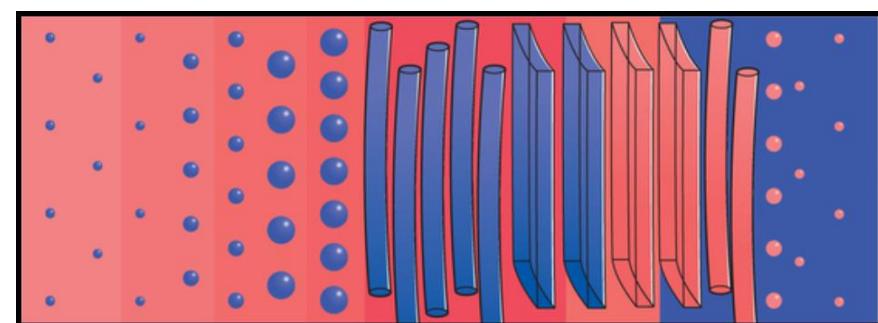
A. Schmitt, PRD 101, 074007 (2020)

Local  $\rightarrow$  Global charge neutrality

+ Coulomb effects

+ Surface tension calculation

Consistently calculate pasta phase free energy.



# The model

M. Drews and W. Weise, Phys. Rev. C91, 035802 (2015)  
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+ hyperons

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- Binding energy:  $E_B = -16.3$  MeV
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# The model

We minimize  $\Omega$  with respect to the condensates:

Approximations:

- Mean field approximation
- Zero temperature limit
- No sea approximation
- Equilibrium phases description

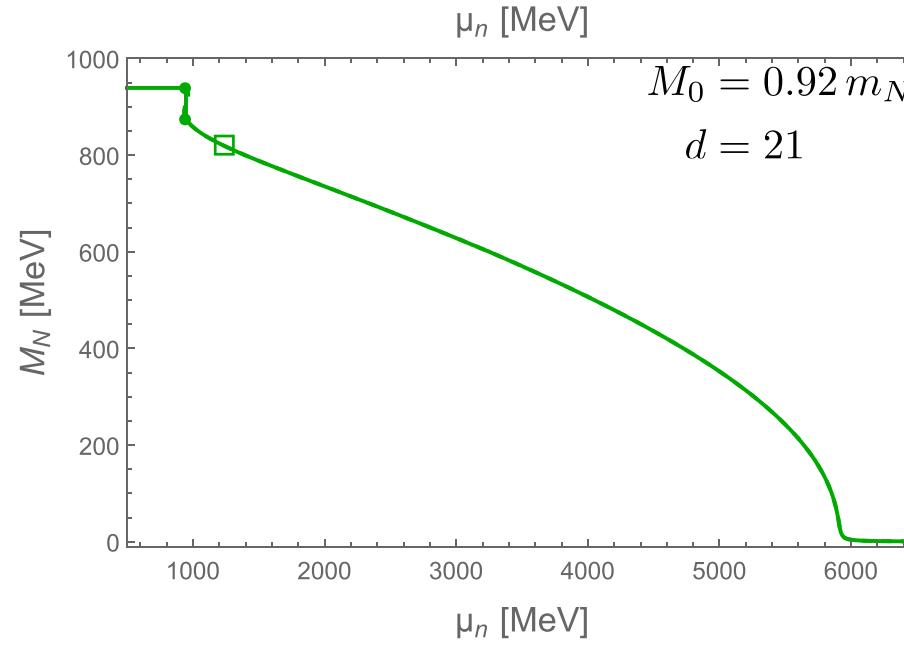
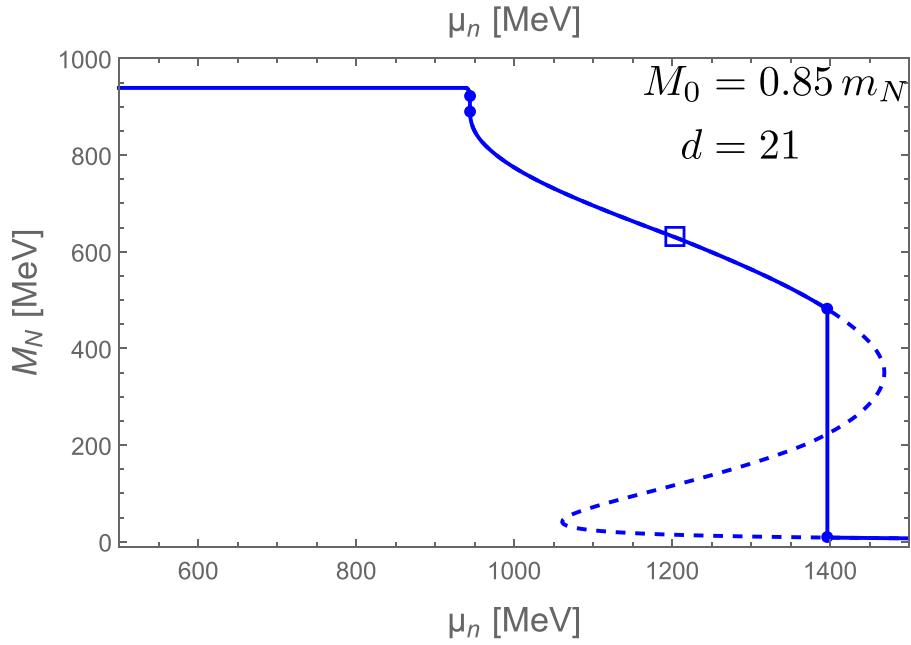
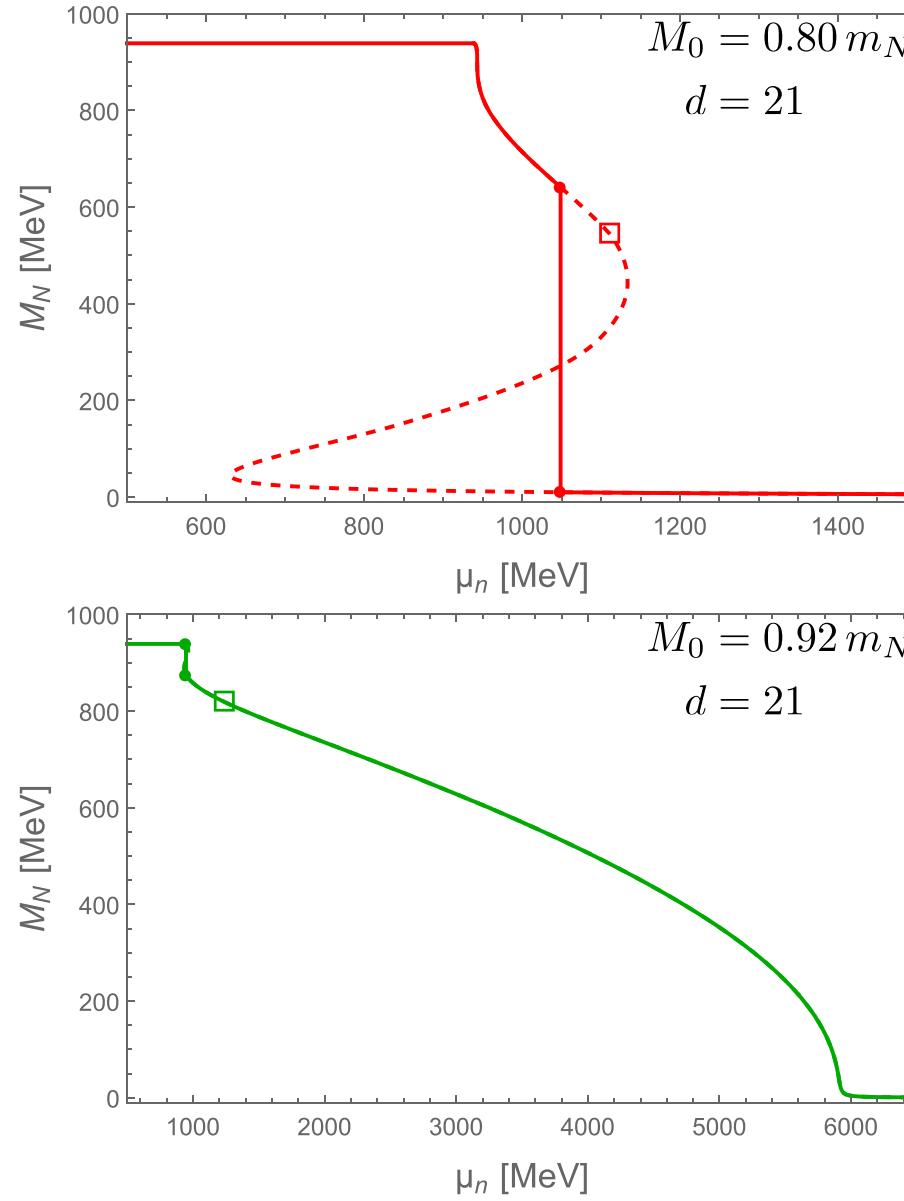
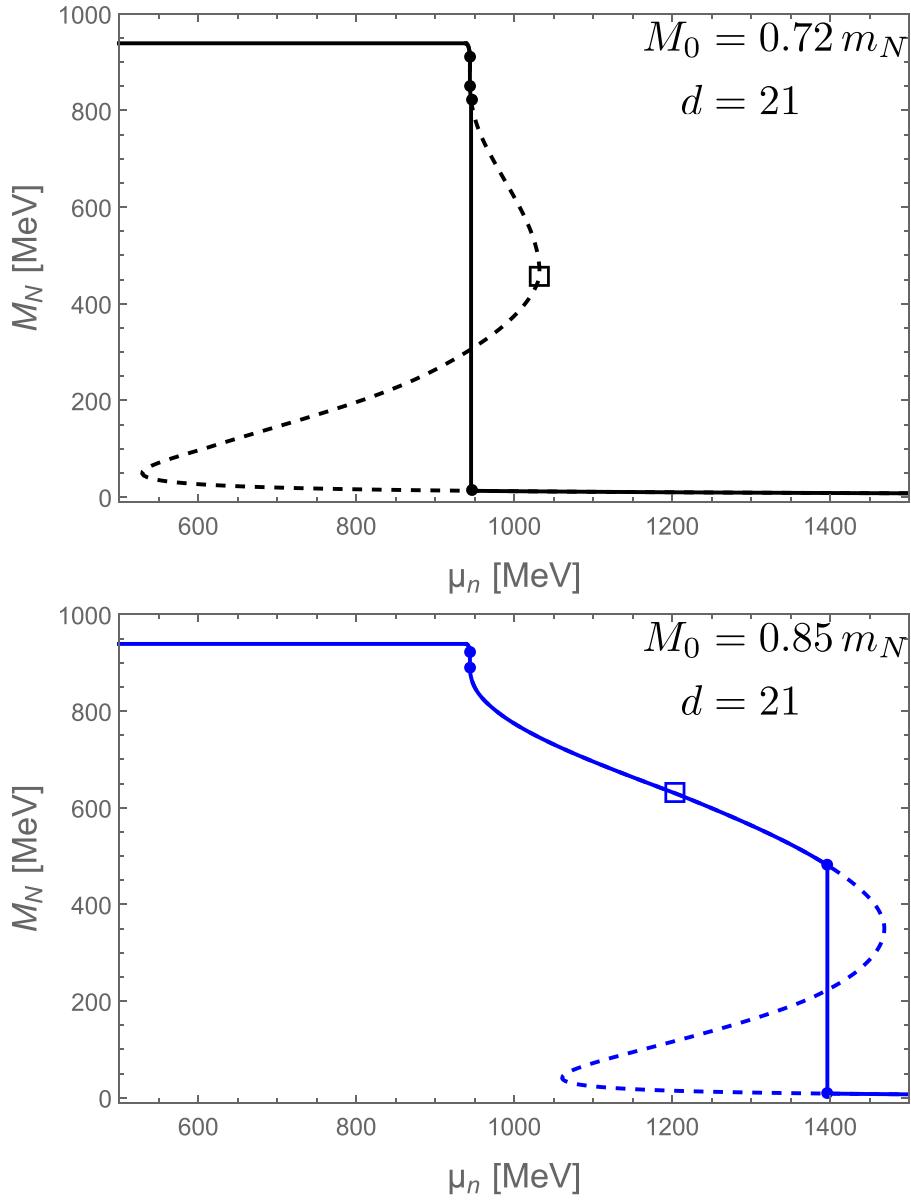
$$-\frac{\partial U}{\partial \sigma} = \sum_i g_{i\sigma} n_{sc,i}$$

$$m_\omega \omega + d \omega (\omega^2 + \rho^2 + \phi^2) = \sum_i g_{i\omega} n_i$$

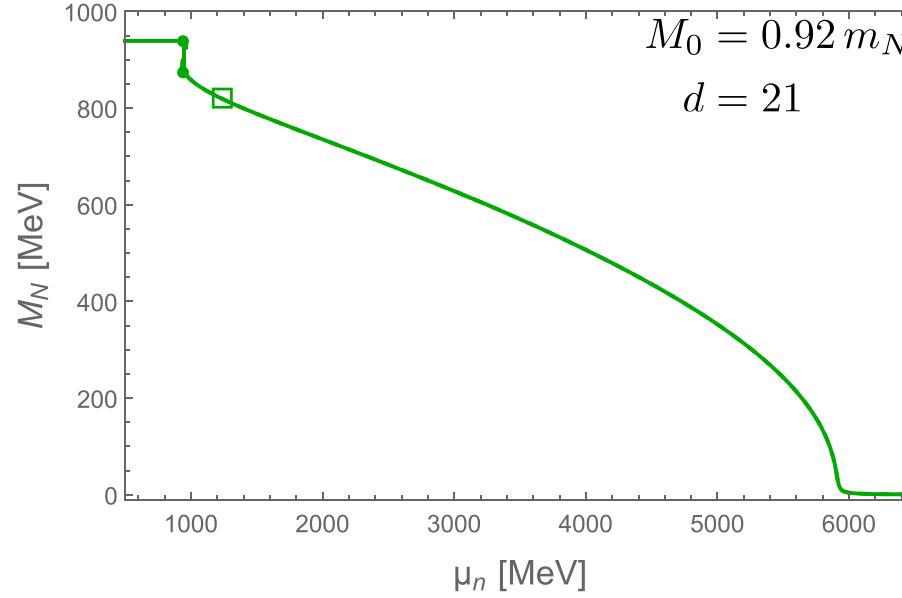
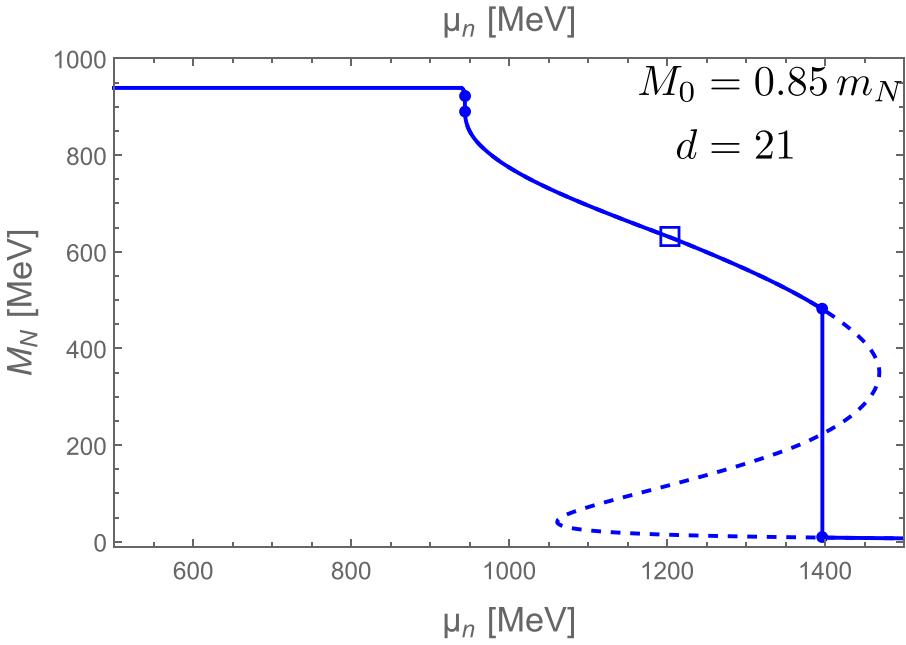
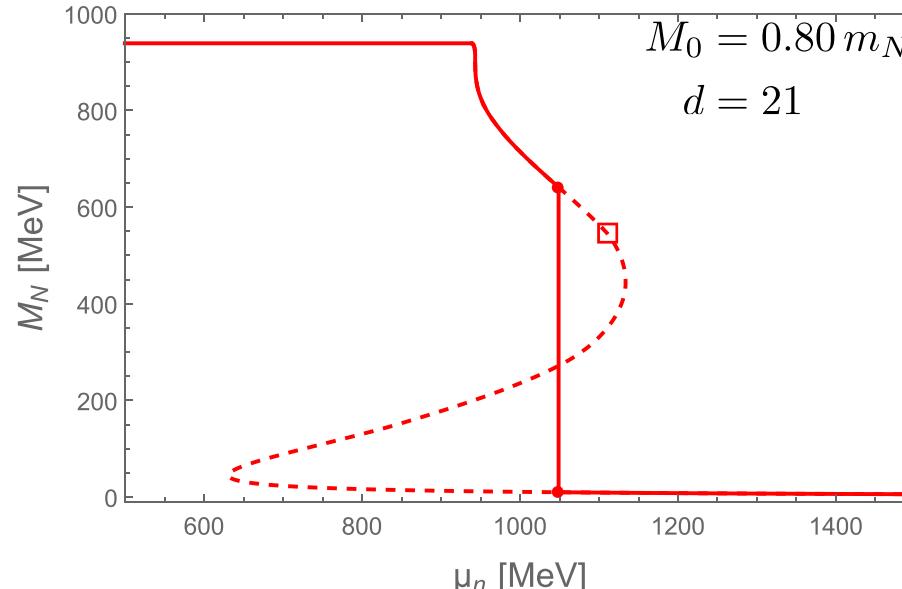
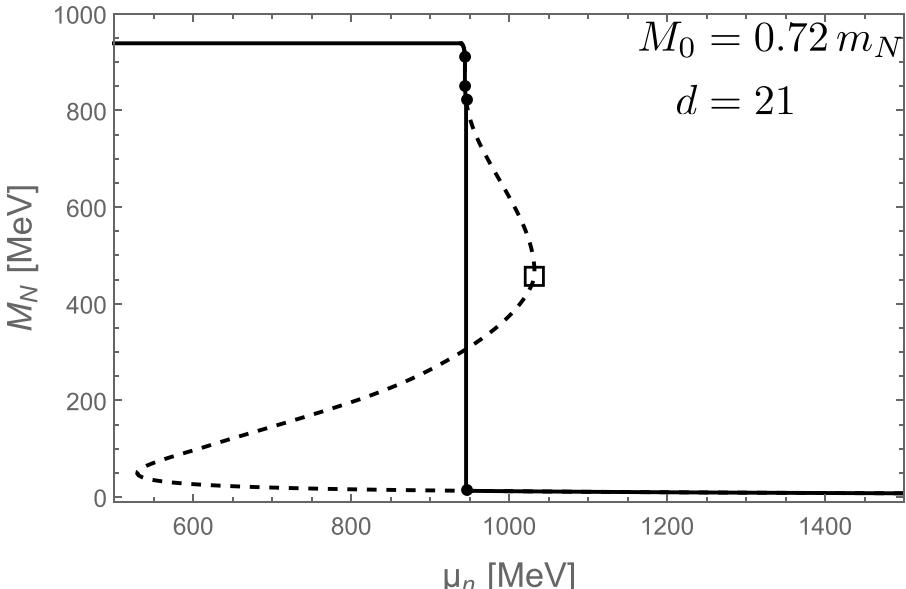
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Beta equilibrium and charge neutrality are imposed, leaving one independent chemical potential.

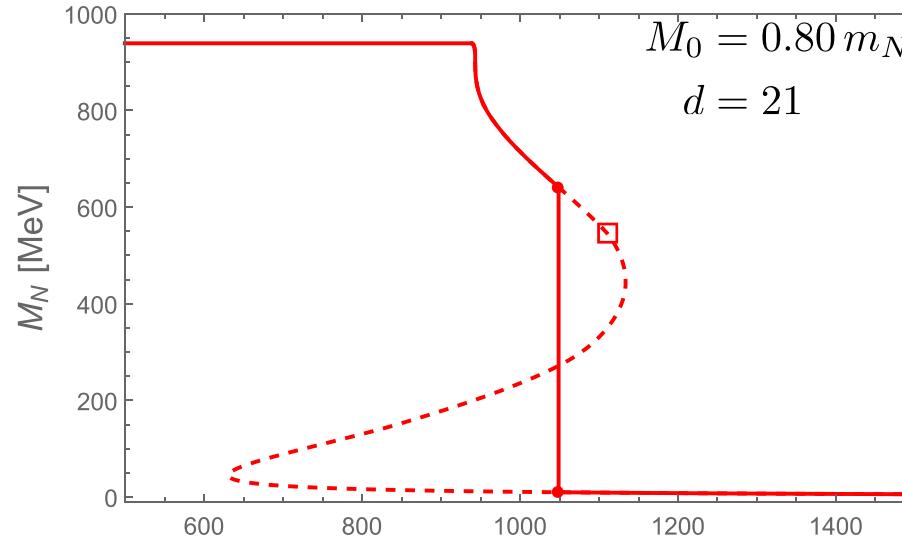
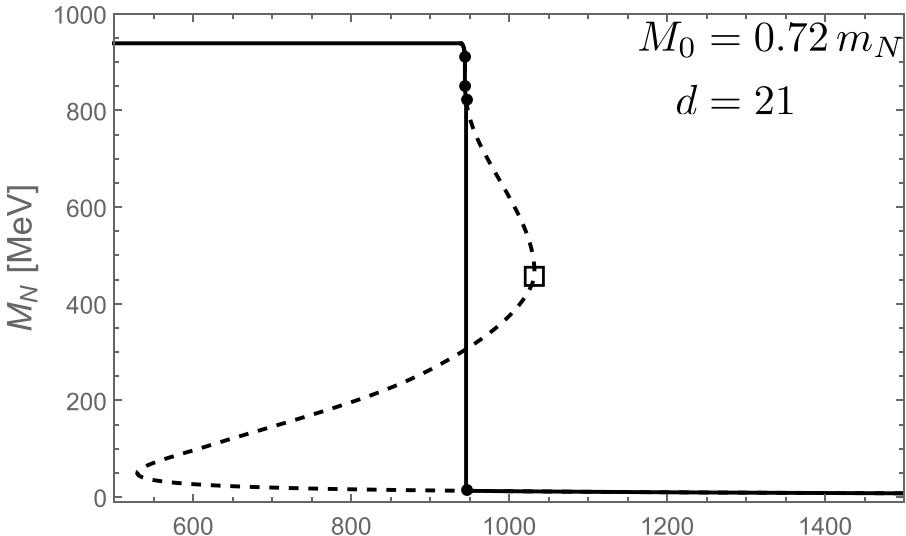


$$m_N \propto \langle \bar{q}q \rangle$$

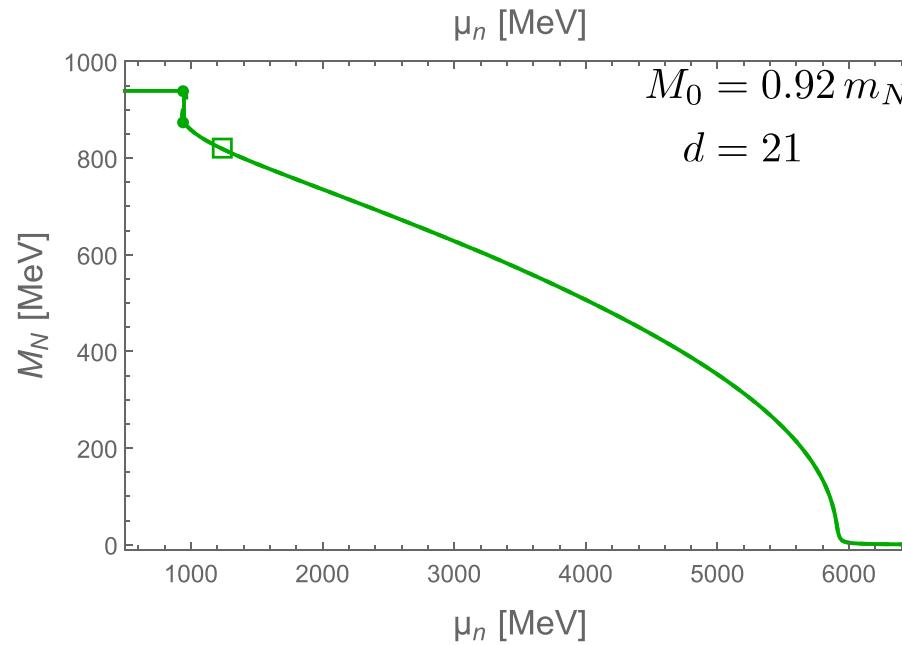
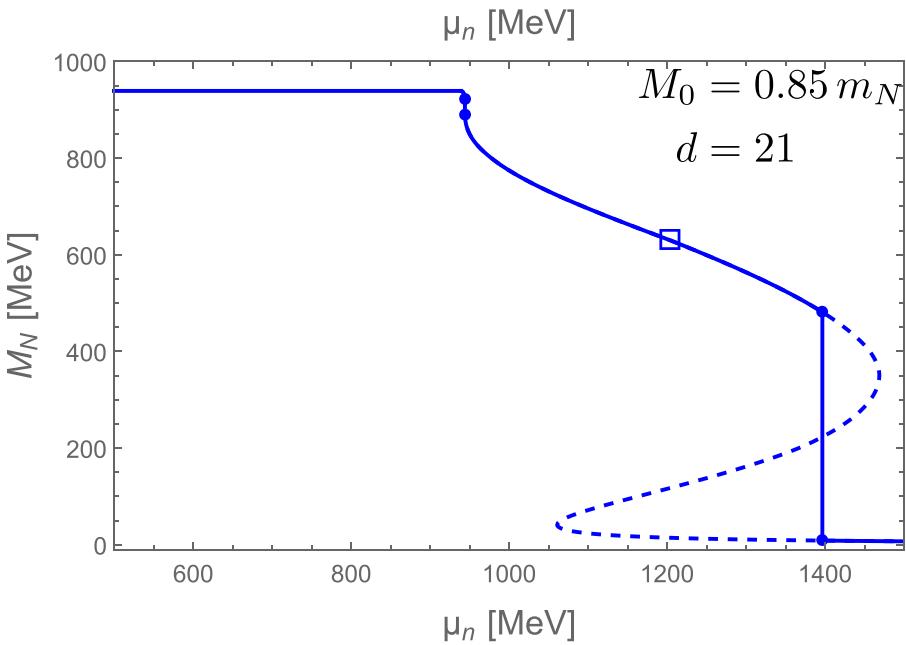


Qualitatively different scenarios for the onset of strangeness.

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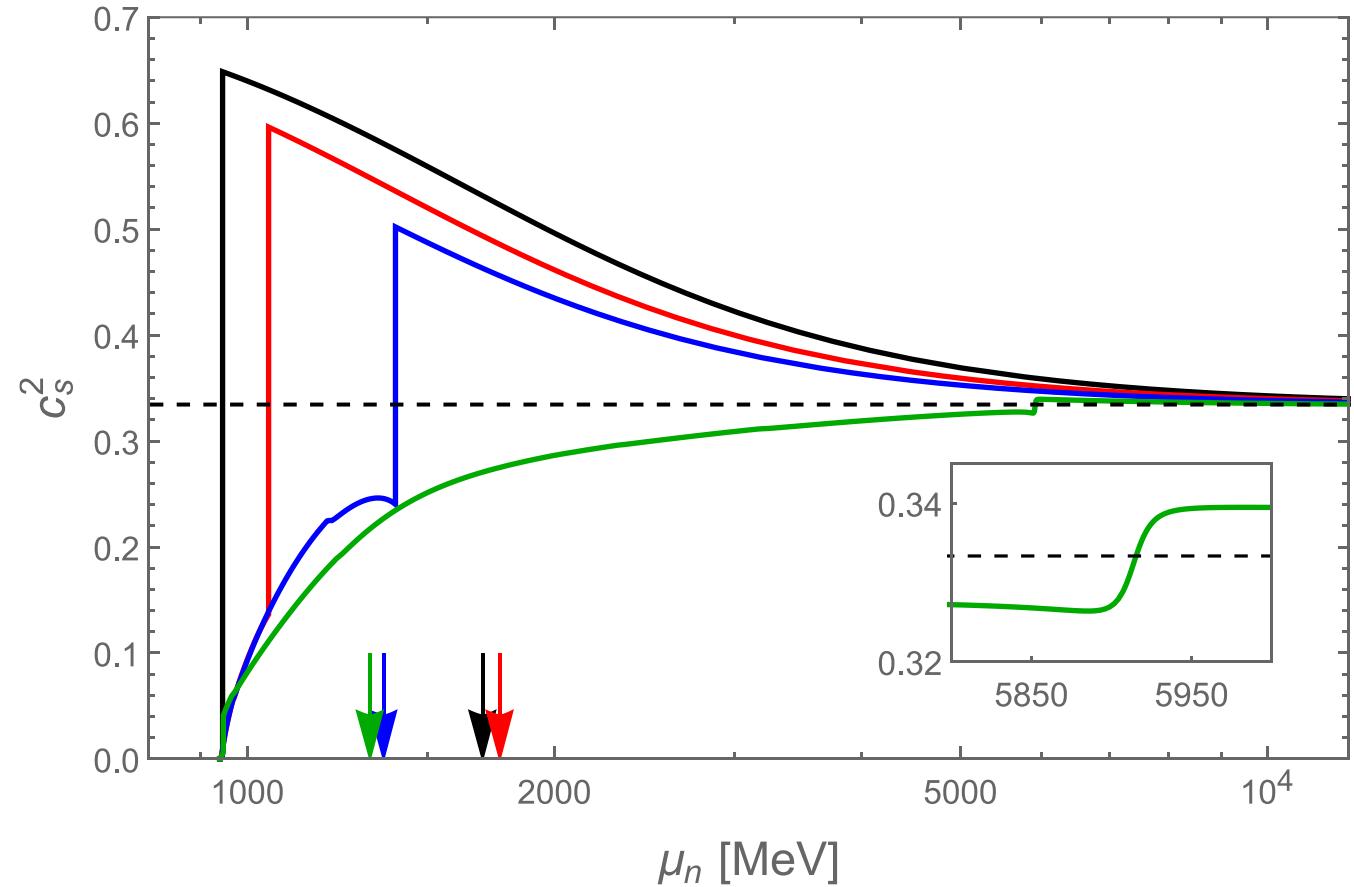


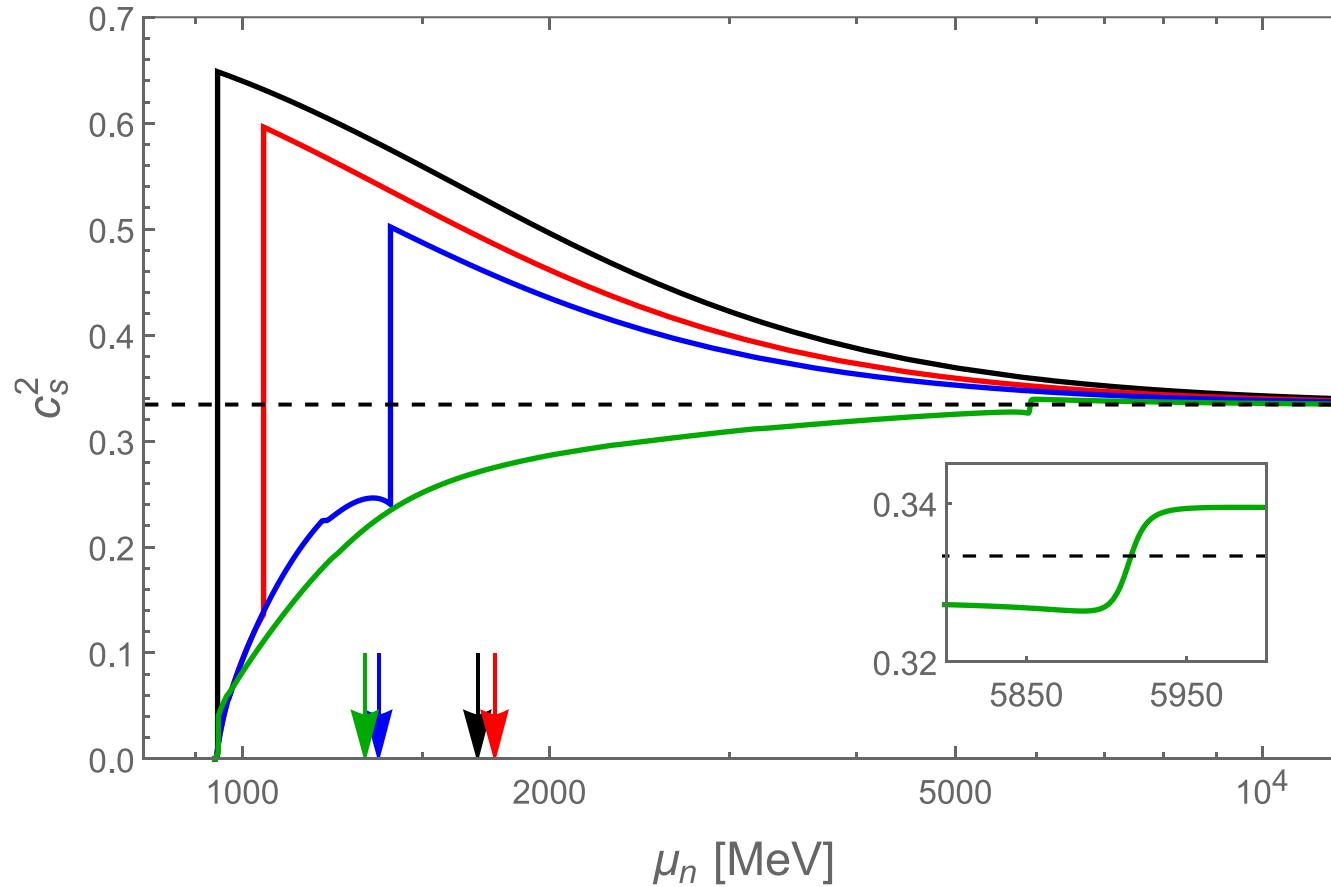
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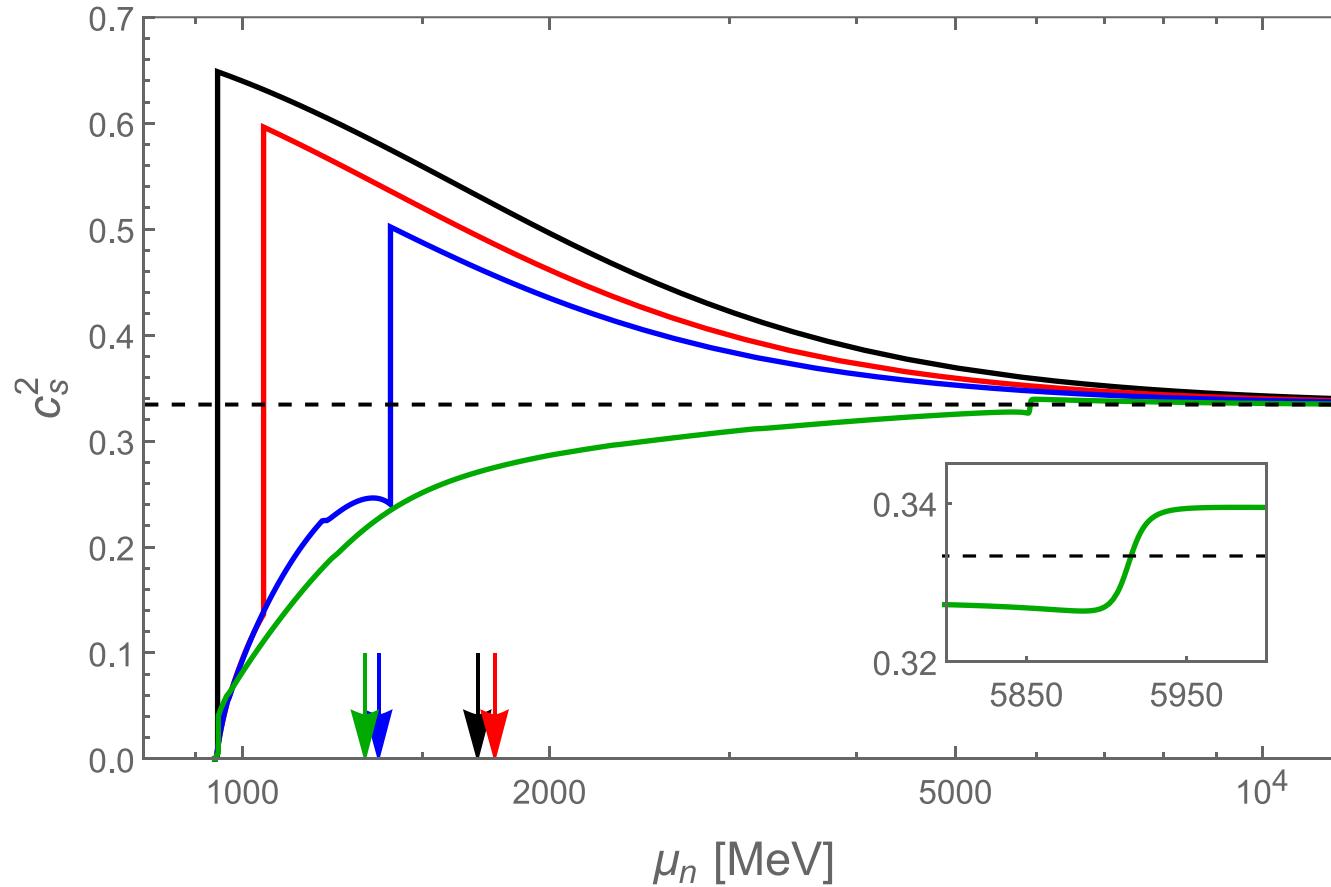
Order of increasing  $M_0$

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Now turn to systematically constraining the parameter space

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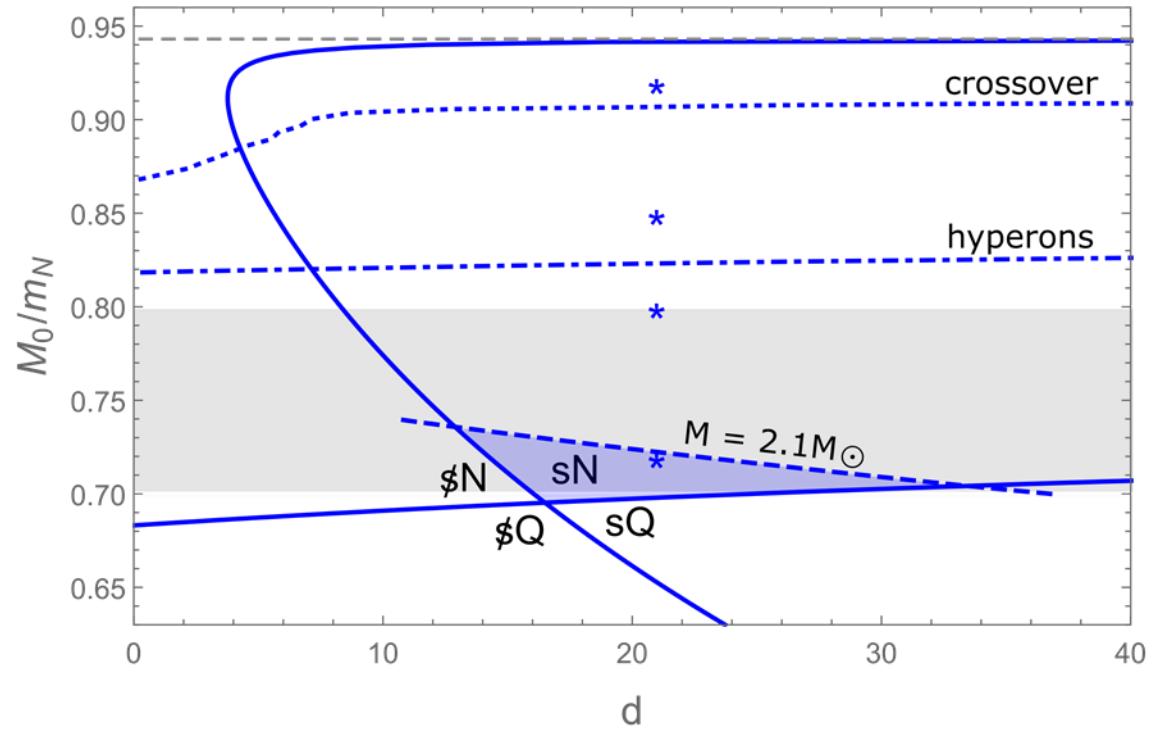
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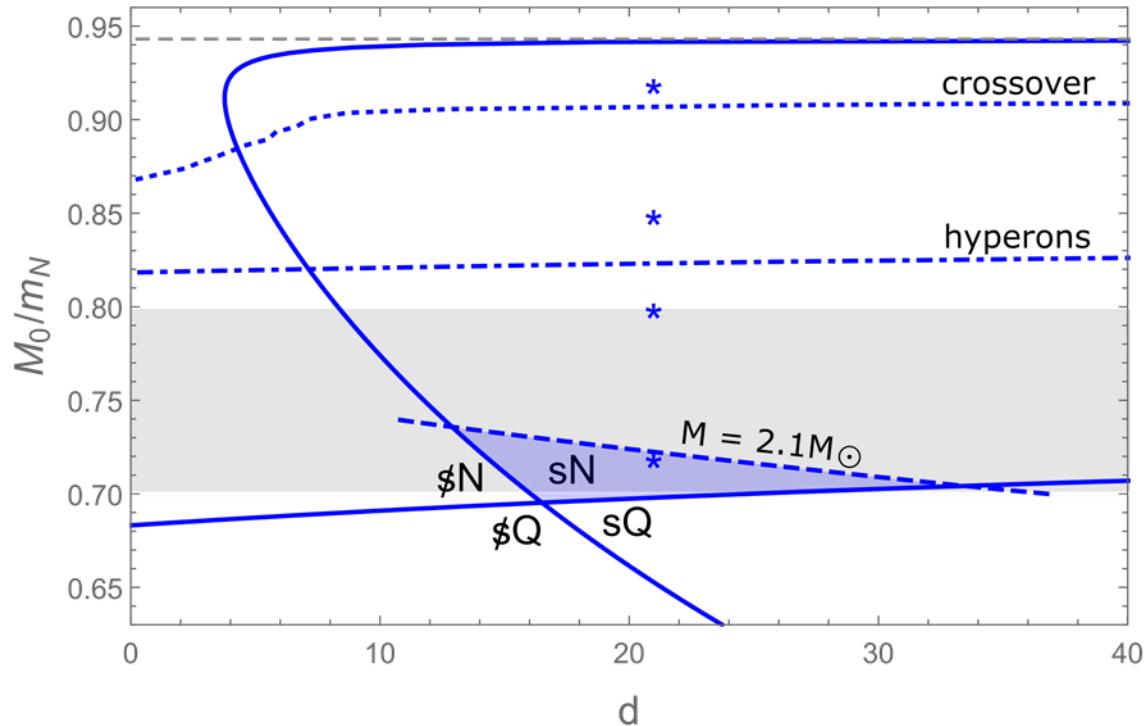
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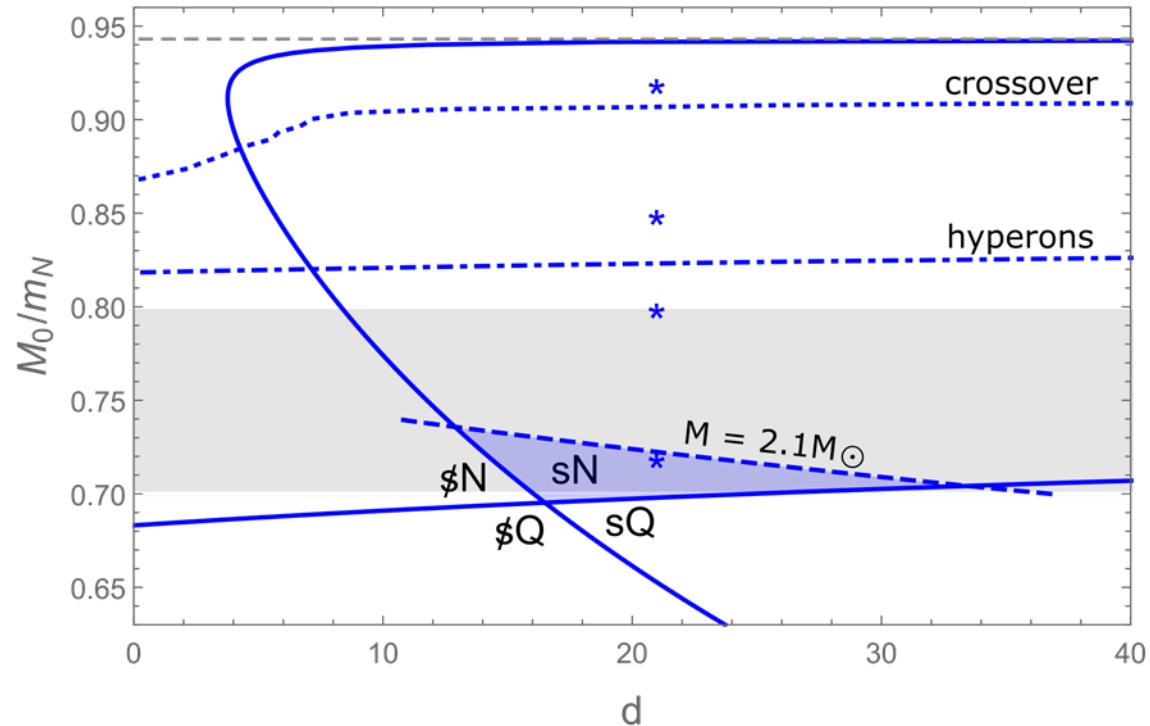
- 3) Sufficiently heavy stars can be constructed.

Observational constraint.

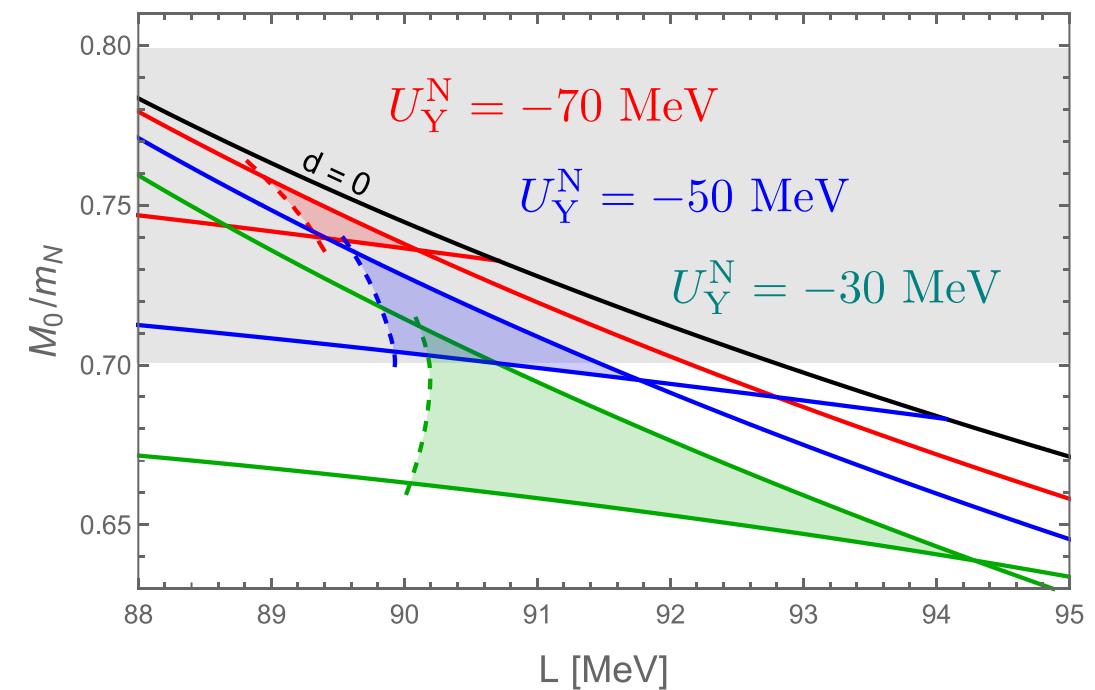


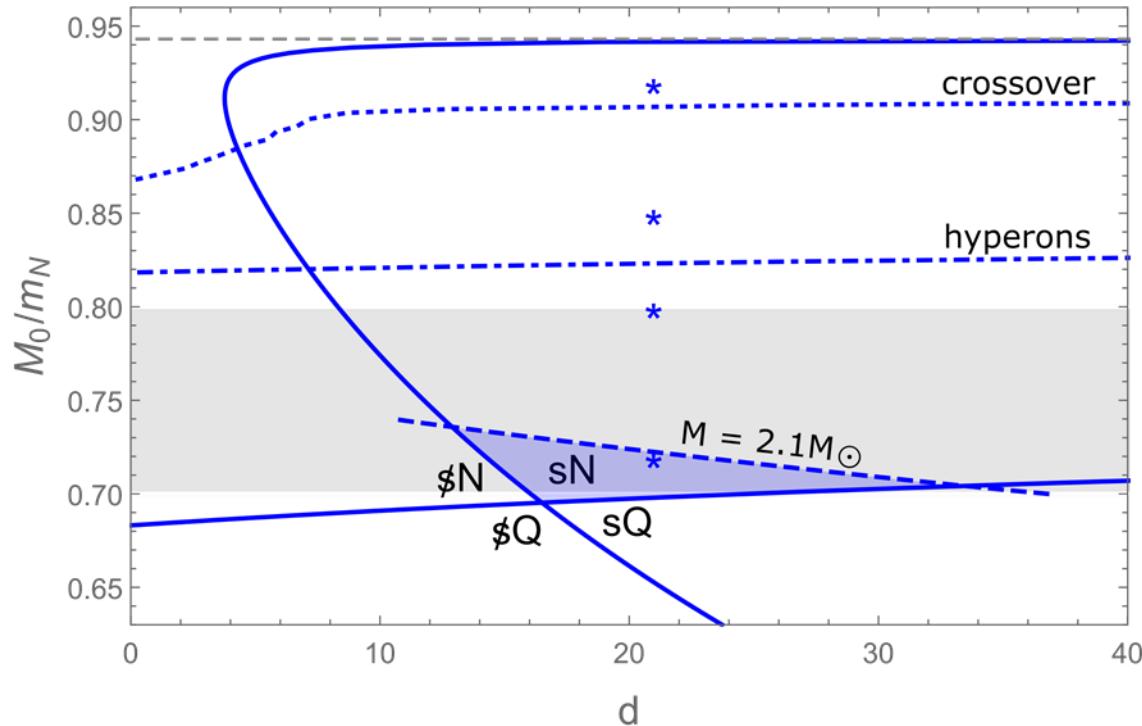


- The crossover scenario is disfavored.
- Hyperons do not appear in stars.
- Heavy stars require an early chiral phase transition.



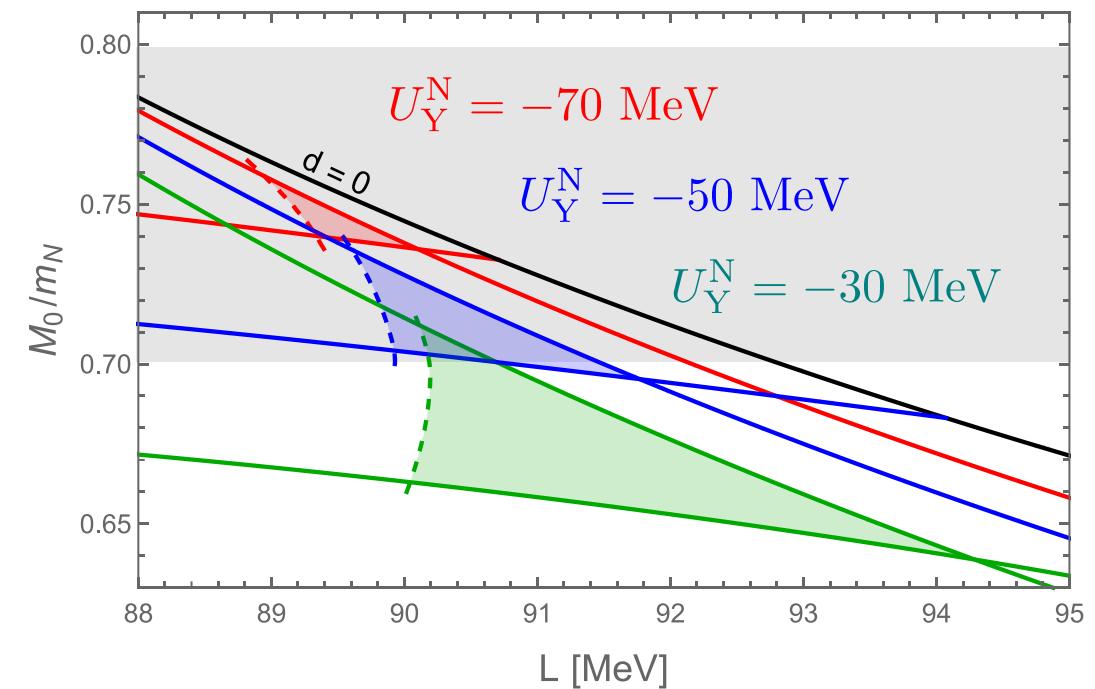
- The crossover scenario is disfavored.
- Hyperons do not appear in stars.
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- The slope parameter is significantly constrained:  $L \approx (88 - 92)$  MeV.
- The hyperon potential depths  $U_Y^N$  do not significantly influence the predicted range of the slope parameter  $L$ .

- The crossover scenario is disfavored.
- Hyperons do not appear in stars.
- Heavy stars require an early chiral phase transition.



# Summary

- We built a phenomenological model (incorporating strangeness) that describes a chirally broken and a chirally restored phase.
- Interpreting the latter as “quark matter”, we explored the quark-hadron transition.
- The quark-hadron crossover scenario is disfavored.
- An early chiral phase transition prevents hyperons from appearing in heavy stars, suggesting a resolution to the hyperon puzzle.
- The slope parameter of the symmetry energy is significantly constrained:

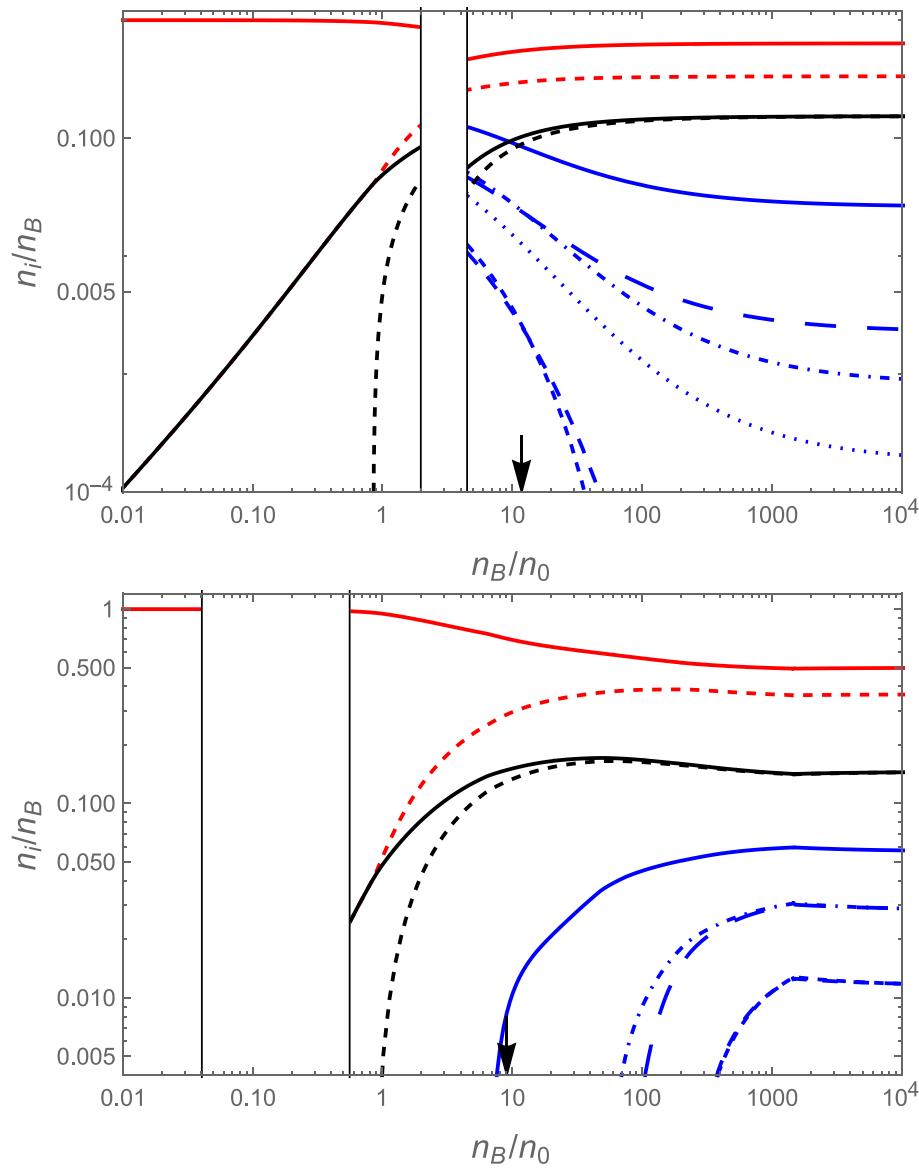
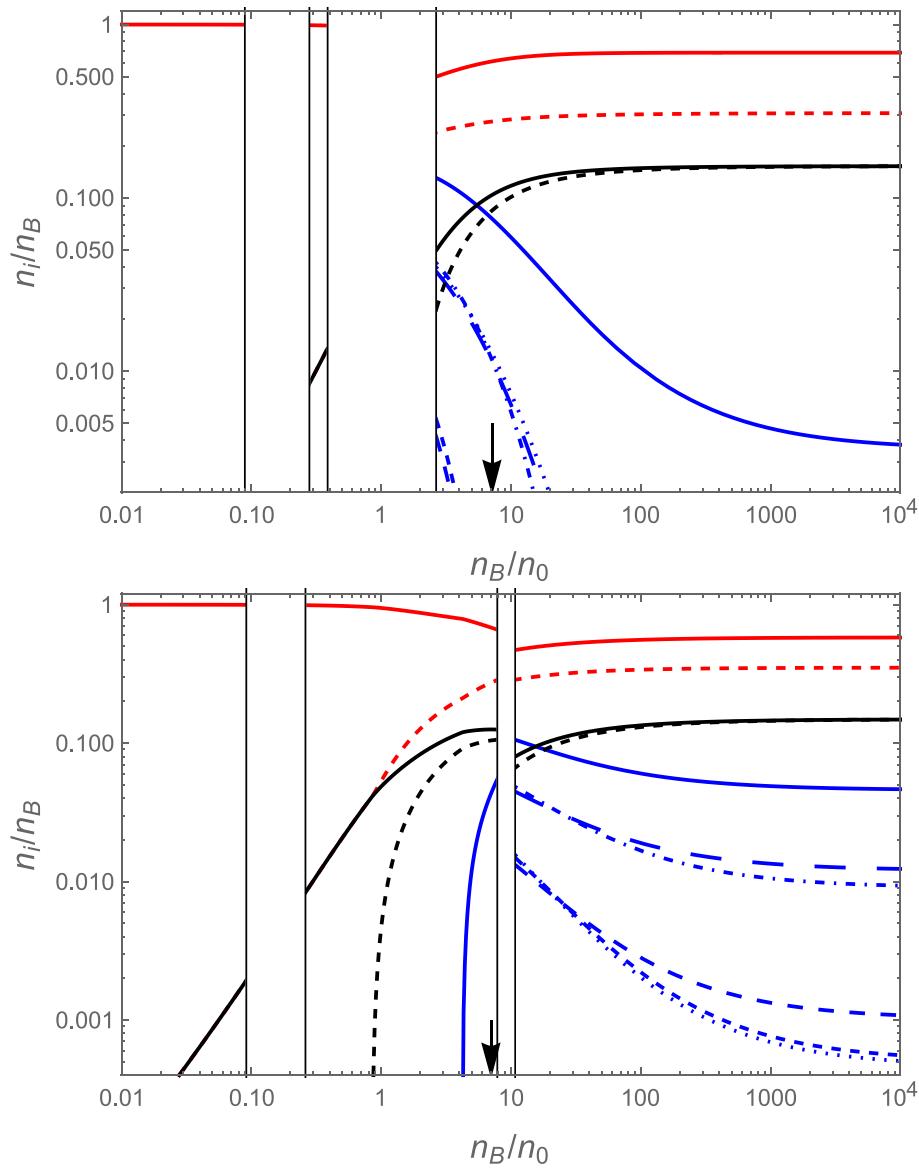
$$L \approx (88 - 92) \text{ MeV}$$

# Outlook

- Compute the surface tension and pasta phases.
- Chiral density wave and interplay with pasta phases.
- Include the strange condensate  $\langle \bar{s}s \rangle$ .
- Include pairing (both phases).
- Extend to finite temperature (mergers).
- Go beyond mean field.

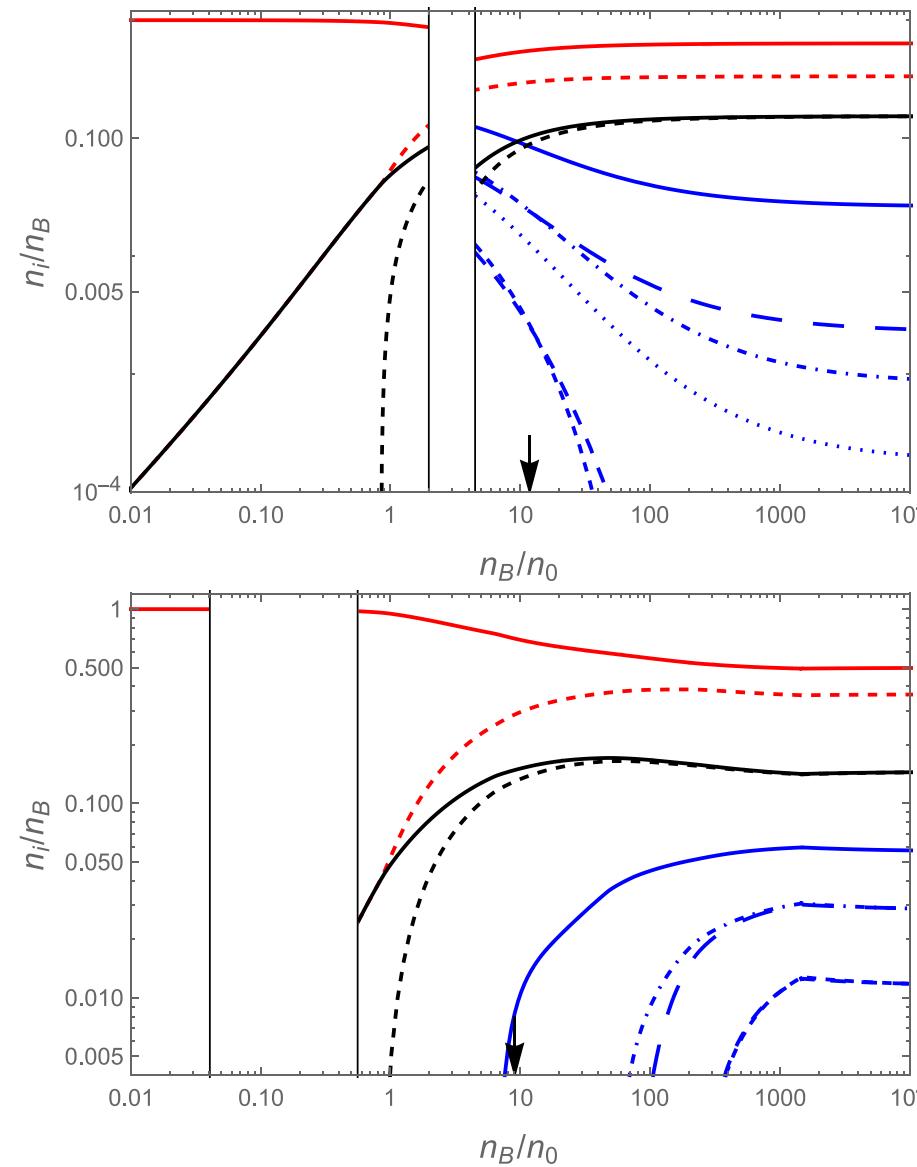
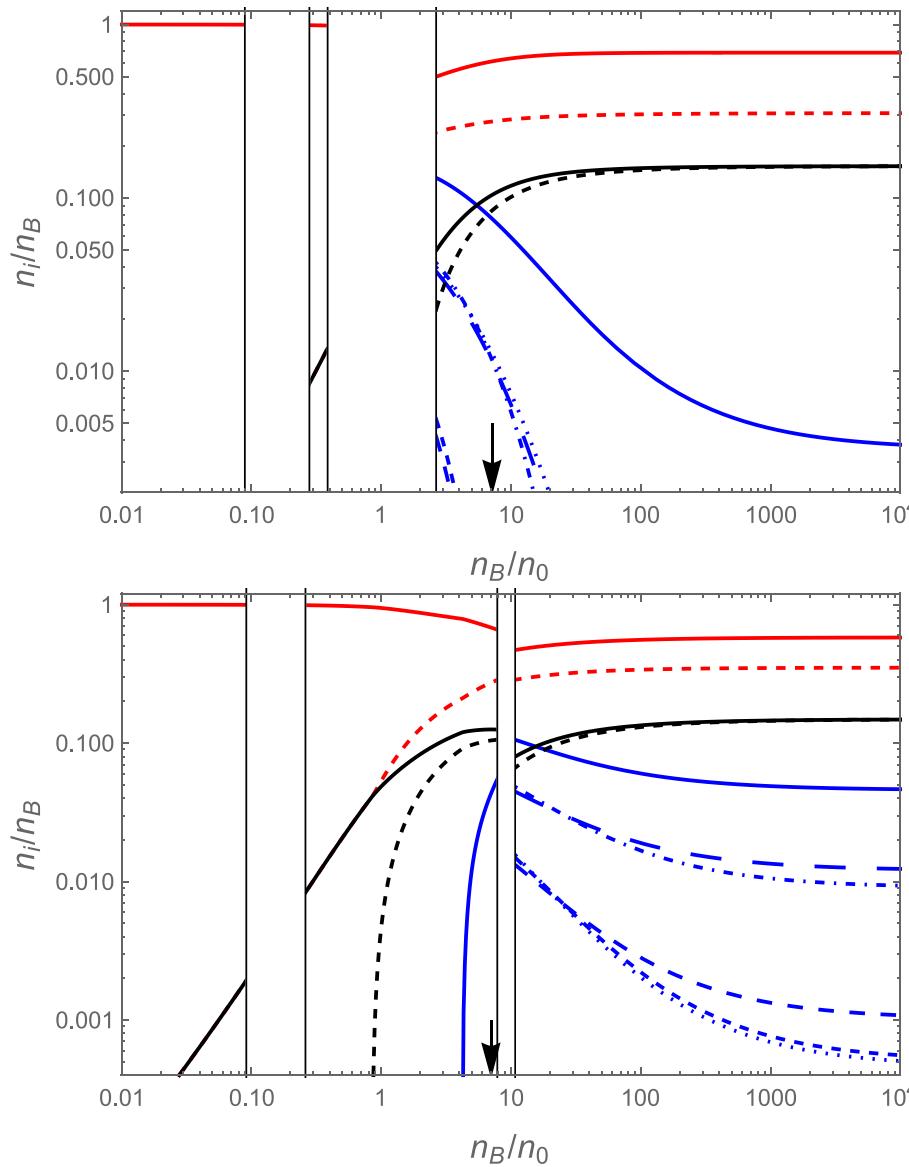
Thank you !

Extra Slide(s)



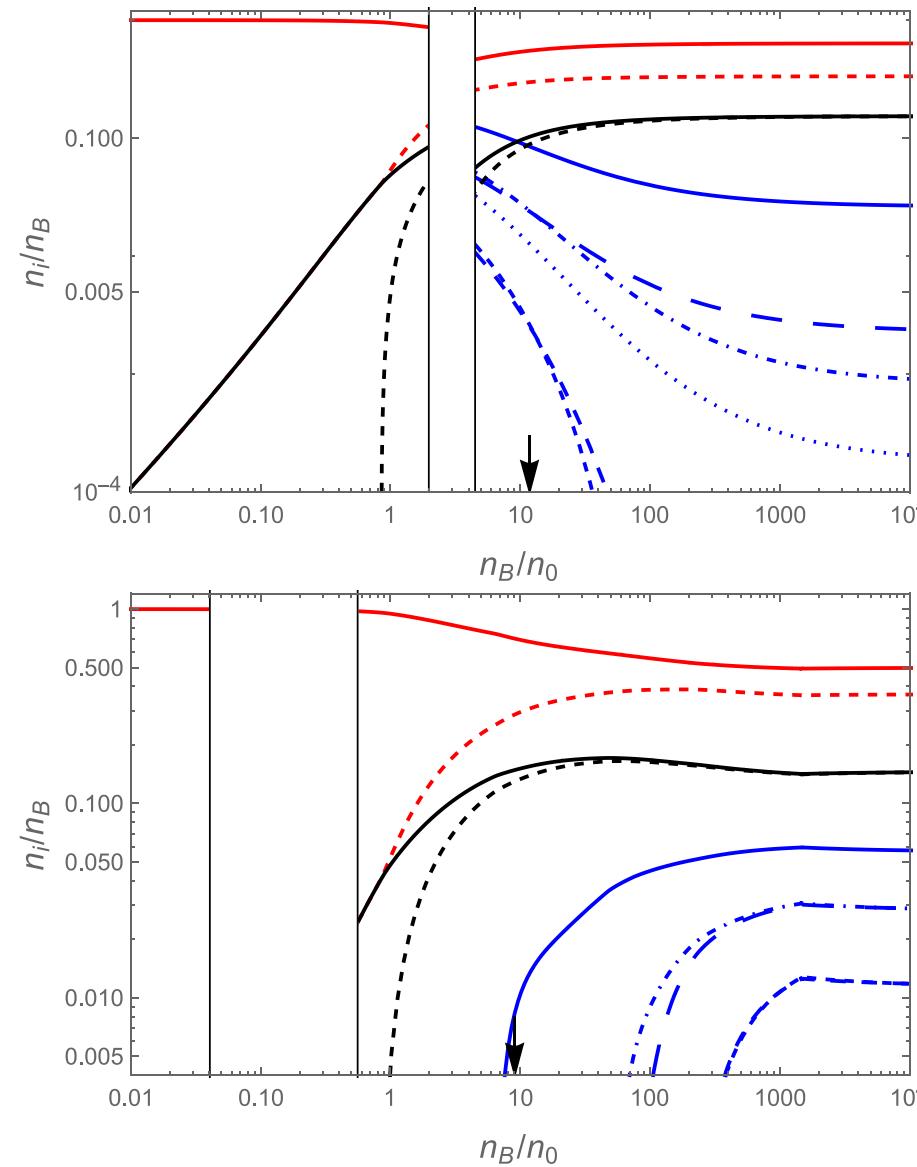
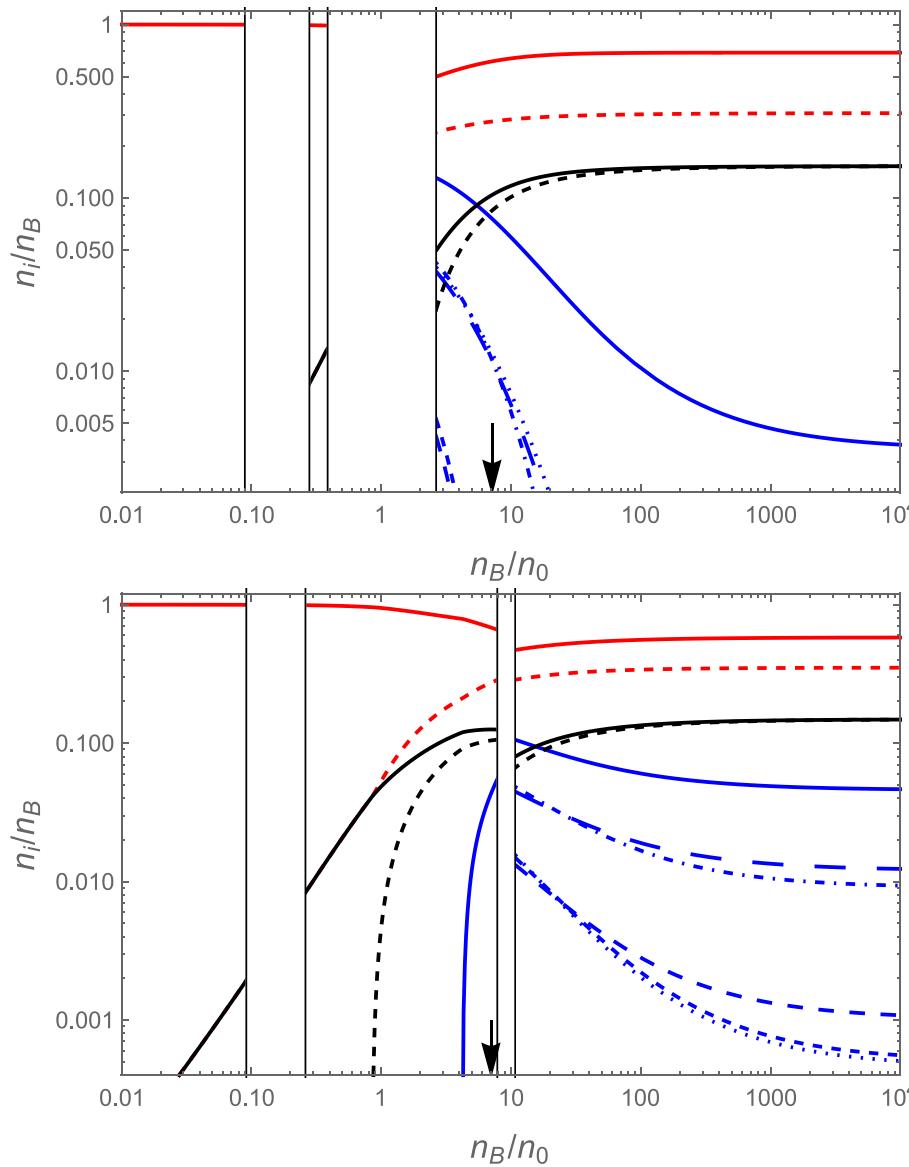
nucleons  
 hyperons  
 leptons

$n$	$n$
$p$	$p$
$\Lambda$	$\Lambda$
$\Sigma^-$	$\Sigma^-$
$\Sigma^+$	$\Sigma^+$
$\Sigma^0$	$\Sigma^0$
$\Xi^-$	$\Xi^-$
$\Xi^0$	$\Xi^0$
$e^-$	$e^-$
$\mu^-$	$\mu^-$



nucleons n (solid red) p (dashed red) $\Lambda$ (dotted blue)	hyperons $\Sigma^-$ (solid blue) $\Sigma^+$ (dashed blue) $\Sigma^0$ (dash-dot blue) $\Xi^-$ (dotted blue) $\Xi^0$ (dash-dot blue)	leptons $e^-$ (solid black) $\mu^-$ (dashed black)
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Strangeness survives asymptotically.



<span style="color: red;">—</span> n <span style="color: red; font-style: dashed;">—</span> p <span style="color: blue; font-style: dotted;">—</span> $\Lambda$ <span style="color: blue;">—</span> $\Sigma^-$ <span style="color: blue; font-style: dashed;">—</span> $\Sigma^+$ <span style="color: blue; font-style: dash-dotted;">—</span> $\Sigma^0$ <span style="color: blue; font-style: dotted;">—</span> $\Xi^-$ <span style="color: blue; font-style: dash-dotted;">—</span> $\Xi^0$ <span style="color: black;">—</span> $e^-$ <span style="color: black; font-style: dashed;">—</span> $\mu^-$	<b>nucleons</b> <b>hyperons</b> <b>leptons</b>
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Strangeness survives asymptotically.

Strangeness fraction does not asymptote to  $\frac{1}{3}$ .

