Medium modification of SU(3) baryon properties in nuclear matter

NAMYONG KIM, INHA University

IN COLLABORATION WITH HYUN-CHUL KIM,
U. T. YAKHSHIEV AND GHIL-SEOK YANG.

OUTLINE

- Motivation
- Chiral quark-soliton model
- Nuclear matter
- Results
- Summary

MOTIVATION

- Properties of the nucleon in nuclear matter are important for understanding the properties of baryonic matter, in particular, under the extreme condition existing in neutron stars.
- However, the in-medium properties of the nucleon are not well understood.
- But we know the properties of nuclear matter at the saturation density.
- In-medium properties of SU(3) baryons are also not well known. Some intensive studies are made in SU(2) framework[1].
- Consequently, we extend ideas from the approach in Ref.[1] to SU(3) case using the chiral quark-soliton model.

[1]U. T. Yakhshiev, Phys. Rev. C 88, 034318(2013)

Chiral Quark-Soliton Model

- Chiral Quark-Soliton Model

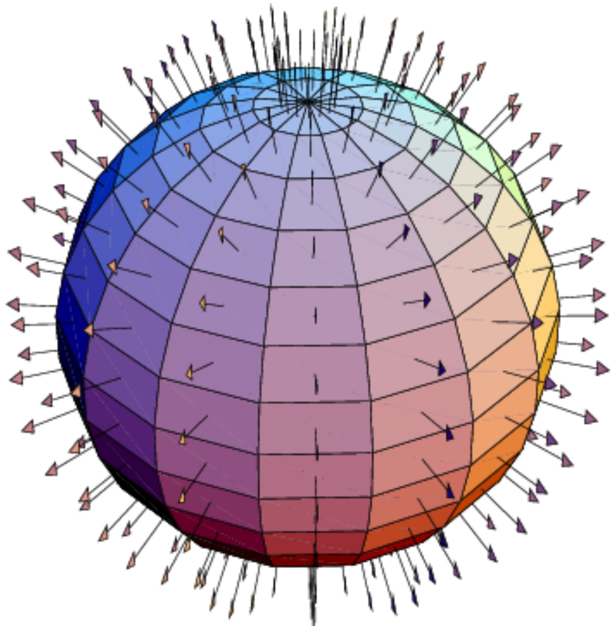
  : Effective low energy theory.

  : Nc valence quark bound by mesonic mean-fields

- Hedgehog ansatz

$$U_{SU(2)}(r) = e^{in^a\tau^a P(r)}$$

$$U(r) = \begin{pmatrix} U_{SU(2)}(r) & 0 \\ 0 & 1 \end{pmatrix}$$



Chiral Quark-Soliton Model

- Collective Hamiltonian

$$H = \mathrm{M}_{\mathrm{cl}} + \frac{1}{2}\left(\frac{1}{I_1} - \frac{1}{I_2}\right)\sum_{i=1}^{3}\hat{J}_i\hat{J}_i + \frac{1}{2I_2}\sum_{a=1}^{8}\hat{J}_a\hat{J}_a - \frac{1}{I_2}\hat{J}_8^2$$
$$+\alpha_{\mathrm{SU(3)}}D^{(8)}_{88}(R) + \beta_{\mathrm{SU(3)}}\hat{Y} + \frac{1}{\sqrt{3}}\gamma_{\mathrm{SU(3)}}\sum_{i=1}^{3}D^{(8)}_{8i}(R)\,\hat{J}_i$$
$$+\frac{\sqrt{3}}{2}\alpha_{\mathrm{Iso}}D^{(8)}_{38}(R) + \beta_{\mathrm{Iso}}\hat{T}_3 + \frac{1}{2}\gamma_{\mathrm{Iso}}\sum_{i=1}^{3}D^{(8)}_{3i}(R)\,\hat{J}_i$$

$$\boxed{\begin{aligned}\alpha_{\mathrm{SU(3)}} &= (m_s-\hat{m})\left(-\frac{2}{3}\frac{1}{m_u+m_d}\Sigma_{\pi N} + \frac{K_2}{I_2}\right),\ \beta_{\mathrm{SU(3)}} = (m_s-\hat{m})\left(-\frac{K_2}{I_2}\right),\ \gamma_{\mathrm{SU(3)}} = (m_s-\hat{m})\left(\frac{K_1}{I_1}-\frac{K_2}{I_2}\right)\\ \alpha_{\mathrm{Iso}} &= (m_d-m_u)\left(-\frac{2}{3}\frac{1}{m_u+m_d}\Sigma_{\pi N} + \frac{K_2}{I_2}\right),\quad \beta_{\mathrm{Iso}} = (m_d-m_u)\left(-\frac{K_2}{I_2}\right),\quad \gamma_{\mathrm{Iso}} = (m_d-m_u)\left(\frac{K_1}{I_1}-\frac{K_2}{I_2}\right)\end{aligned}}$$

The I_1 and I_2 denote the soliton's moment of inertia.

Nuclear matter

- Binding energy per baryon

$$\begin{aligned}\varepsilon &= \frac{Zm_p^* + Nm_n^* + Sm_s^*}{A} - \frac{Zm_p + Nm_n + Sm_s}{A} \\ &= m_N^* - m_N + \frac{\delta}{2}\left(\Delta m_{np}^* - \Delta m_{np}\right) + \delta_s\left(m_s^* - m_s\right)\end{aligned}$$

The Z, N and S denote the number of the proton, neutron and strange baryon.

The m_S is the center of mass of the strange baryons in the baryon octet.

The asterisks indicate in-medium modified quantity.

$$\boxed{\delta = \frac{N-Z}{A}, \ \delta_s = \frac{S}{A}}$$

Nuclear matter

- The volume energy.

$$\varepsilon_V\left(\lambda\right) = m_N^*(\lambda, 0, 0) - m_N$$

- Stability condition.

$$\left.\frac{\partial \varepsilon_V\left(\lambda\right)}{\partial \lambda}\right|_{\lambda=1} = \left.\frac{\partial m_N^*\left(\lambda, 0, 0\right)}{\partial \lambda}\right|_{\lambda=1} = 0$$

- Compressibility

$$K_0 = 9 \left.\frac{\partial^2 \varepsilon_V(\lambda)}{\partial \lambda^2}\right|_{\lambda=1} = 9 \left.\frac{\partial^2 m_N^*(\lambda)}{\partial \lambda^2}\right|_{\lambda=1}$$

$$\boxed{\lambda = \frac{\rho}{\rho_0}}$$

ρ_0 is the saturation density.

Nuclear matter

- Medium modification functions

$$
\begin{aligned}
\mathrm{M}^*_{\mathrm{cl}}(\lambda) &= (1 + C_{\mathrm{cl}}\lambda)\,\mathrm{M}_{\mathrm{cl}},\\
I^*_1(\lambda) &= (1 + C_1\lambda) I_1,\\
I^*_2(\lambda) &= (1 + C_2\lambda) I_2
\end{aligned}
$$

- We fit these three parameters to in-medium properties of the nucleon at the saturation density.

Nuclear matter

- Symmetry energy

$$\varepsilon_S(\lambda) = \frac{1}{2}\frac{\partial^2 \varepsilon\left(\lambda,\delta,0\right)}{\partial \delta^2}\bigg|_{\delta=0} = \frac{1}{2}\frac{\partial}{\partial\delta}\Delta m^*_{np}(\lambda,\delta,0)\bigg|_{\delta=0}$$

- Slope of symmetry energy

$$L_S = 3\frac{\partial \varepsilon_S(\lambda)}{\partial\lambda}\bigg|_{\lambda=1} = \frac{3}{2}\frac{\partial^2\Delta m^*_{np}\left(\lambda,\delta,0\right)}{\partial\lambda\partial\delta}\bigg|_{\lambda=1,\delta=0}$$

- These properties are related to Isospin asymmetry

Nuclear matter

- Medium modification function

$$\frac{K_1^{I*}}{I_1} = \frac{K_1^{I}}{I_1}\{1 + f_I(\lambda)\delta\}, \quad \frac{K_2^{I*}}{I_2} = \frac{K_2^{I}}{I_2}\{1 + f_I(\lambda)\delta\}$$

$$f_I = \frac{C_n^I \lambda}{1 + C_d^I \lambda}$$

- We determine these two parameters by using the symmetry energy and slope of the symmetry energy.

RESULTS

- **Parameter set and Input data**

	Input data
$\varepsilon_V\,(\lambda = 1)$	-16 MeV
$\mathrm{P}(\lambda = 1)$	0
K_0	240 MeV
$\varepsilon_S\,(\lambda = 1)$	32 MeV
L_S	60 MeV

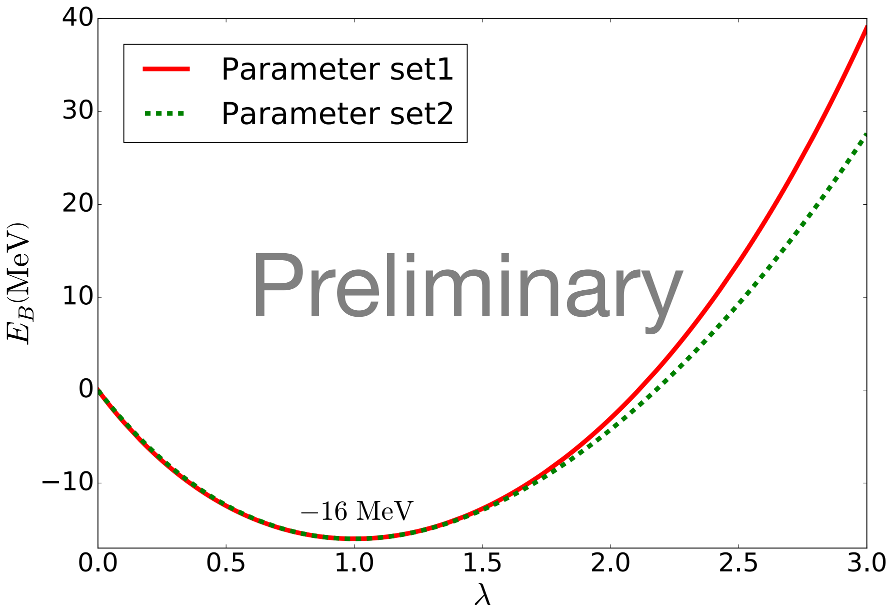
Properties of nuclear matter at the saturation density

	Parameter set 1	Parameter set 2
C_{cl}	-0.0540	0.0603
C_1	0.6266	-0.1381
C_2	-0.1217	0.2552
C_n^I	72.547	72.547
C_d^I	0.6	0.6

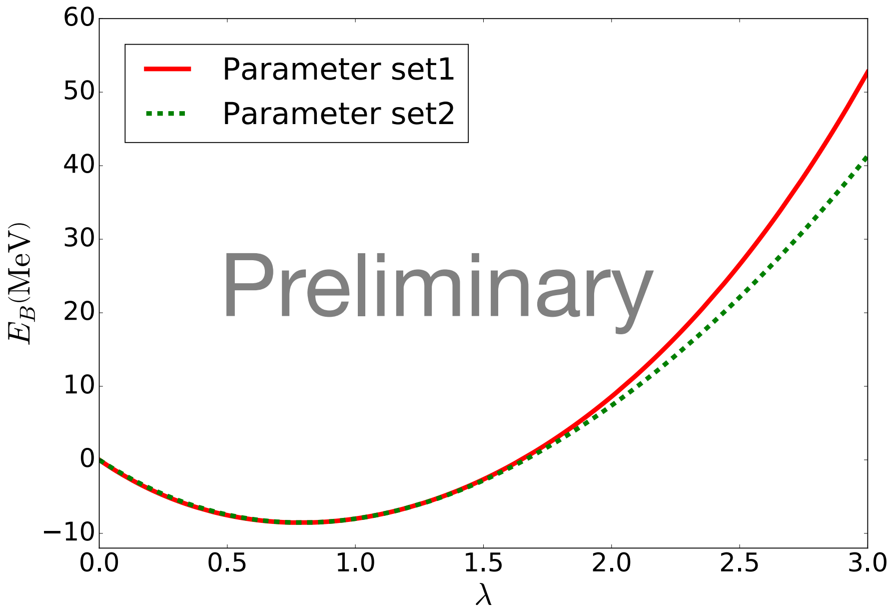
Medium modification parameters

RESULTS

- **EoS for nuclear matter**

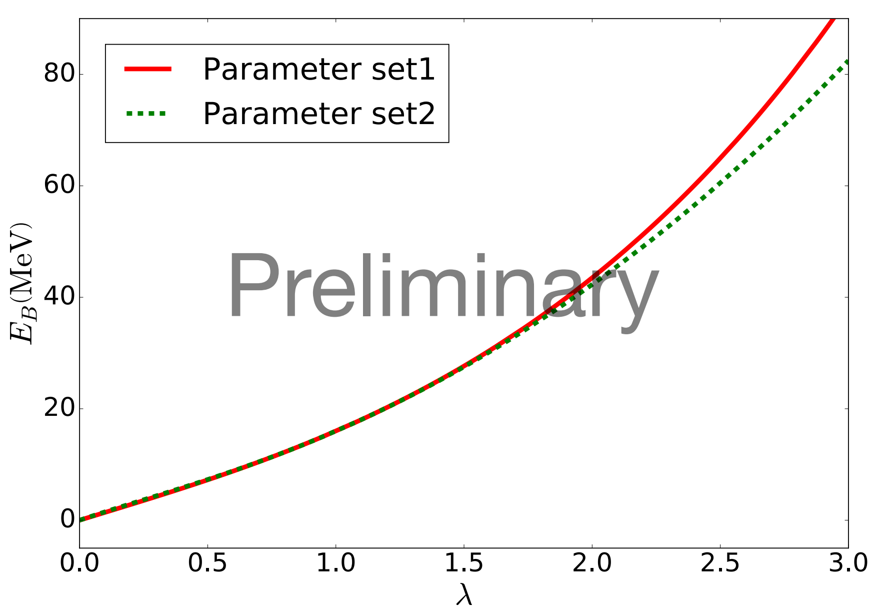


Isospin symmetric nuclear matter



Isospin asymmetric nuclear matter

$\delta = 0.5$

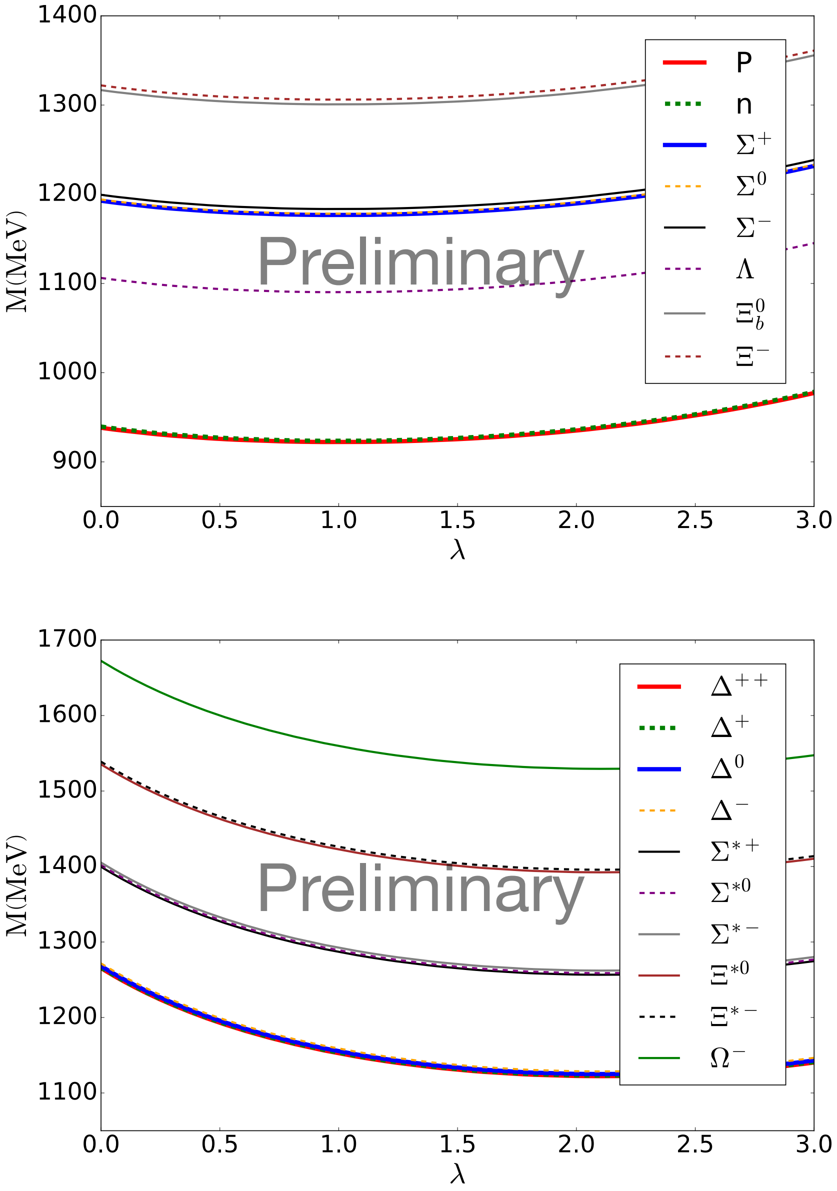


Pure neutron matter

RESULTS

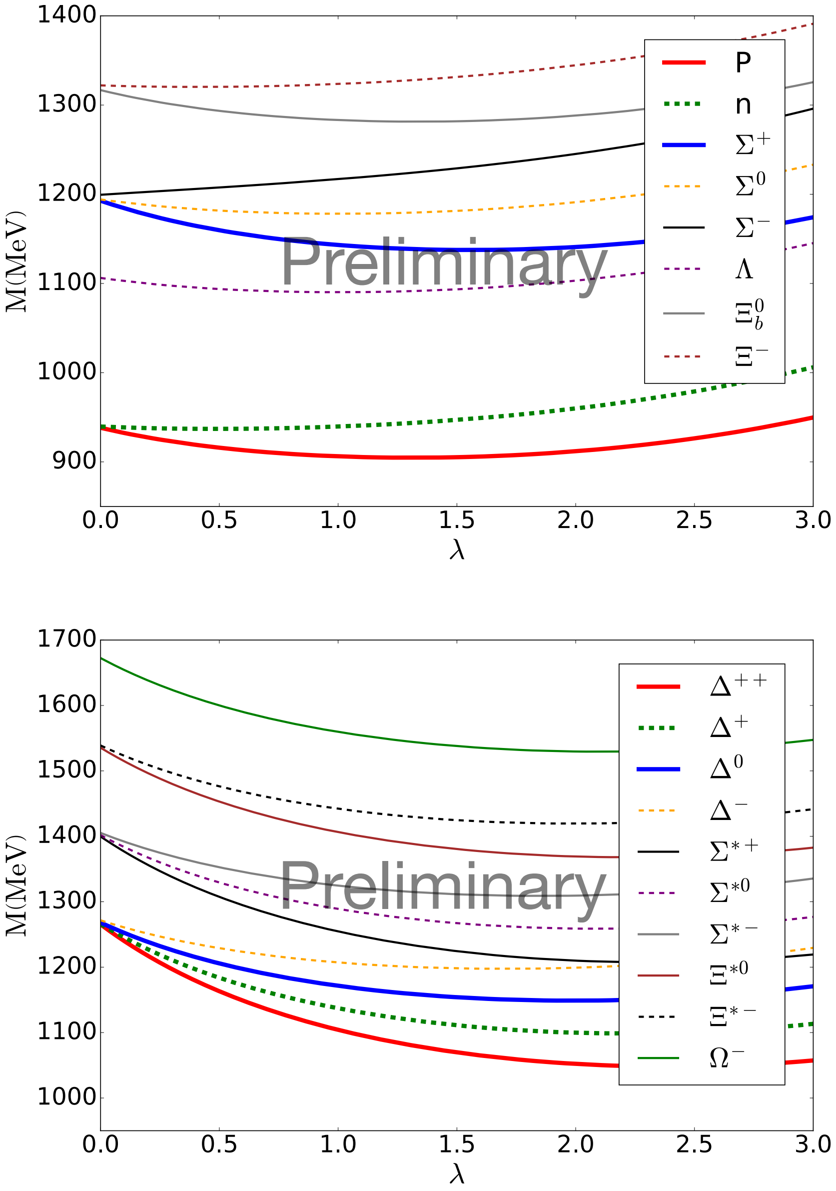
- **Baryon masses in various nuclear matter.**

Isospin symmetric matter



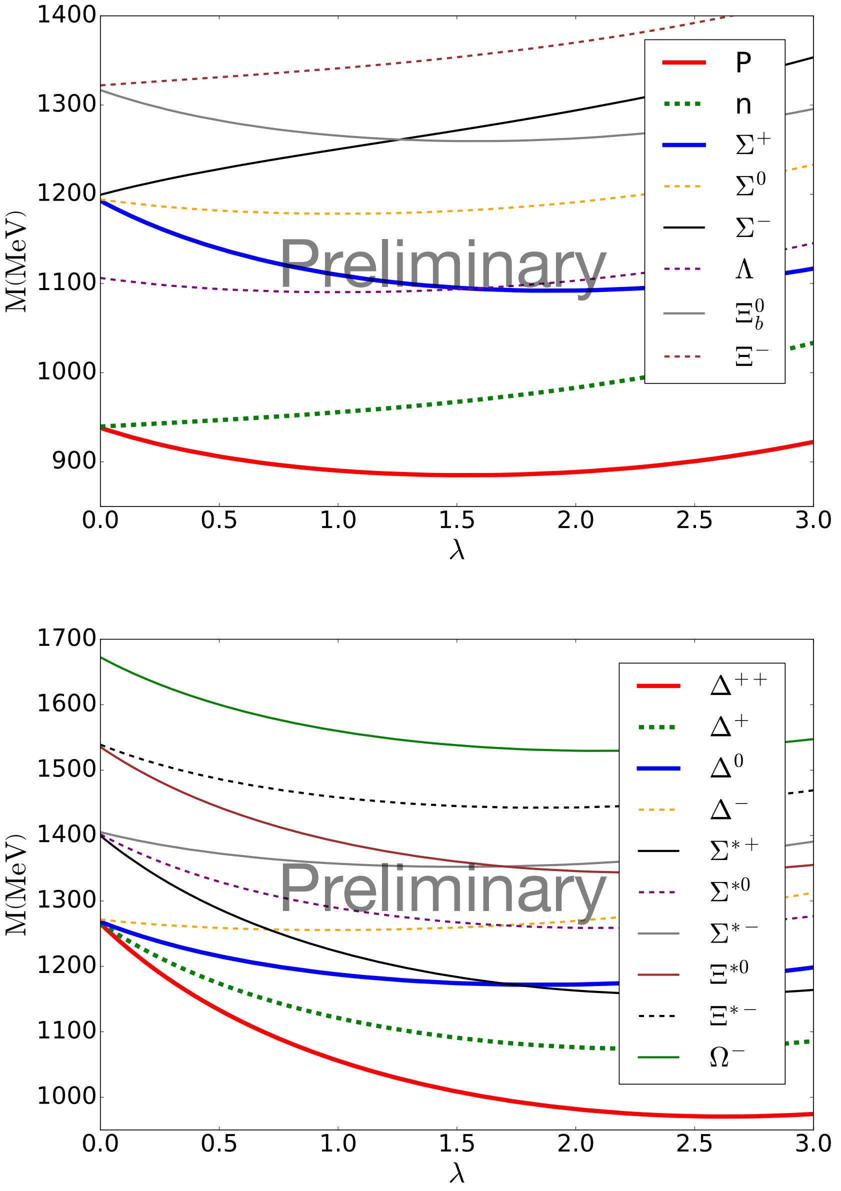
$\delta = 0$

Isospin asymmetric matter



$\delta = 0.5$

Pure neutron matter



$\delta = 1$

SUMMARY

- We discussed how the SU(3) baryon masses undergo changes in nuclear matter within the chiral quark-soliton model.
- Using the empirical data, we determined the in-medium parameters and described the mass changes of the SU(3) baryons in nuclear matter.
- We examined how the masses of the SU(3) baryons are changed in different nuclear environments when isospin asymmetry is considered.
- The tendencies of baryons mass changes are the same each other in the isospin symmetric nuclear matter.
- When isospin symmetry is broken, the masses of the positive charged particles decrease the effects of isospin asymmetry become stronger. However, the masses of the negative and neutral charged particles increase as isospin asymmetry gets stronger.

THANK YOU VERY MUCH