Charmed (Λ_c) Hypernuclei in the SHF Approach

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- Motivation
- Extended SHF approach
- $N\Lambda_c$ interaction
- Results

Motivation:

- Sufficiently long-lived $\Lambda_c(2286)$ hypernuclei are expected to exist and might provide information on the $\Lambda_c N$ interaction.
- So far no quantitative data and few theoretical studies.
- We perform this study within an extended SHF formalism, including core deformation.
- For this initial investigation we use a scaled ΛN interaction with adjustable strength parameter.

SHF Approach:

- Energy of a hypernucleus:

$$E = \int d^3\boldsymbol{r}\, \epsilon(\boldsymbol{r}) \ , \quad \epsilon = \epsilon_{NN}^{\text{Skyrme}} + \epsilon_{NY} + \epsilon_{\text{em}} \ , \quad Y = \Lambda, \Lambda_c, \Xi, \ldots$$

- SHF Schrödinger equation for the $q = n, p, Y$ wavefunctions:

$$\left[-\nabla \cdot \frac{1}{2m_q^*(r)} \nabla + V_q(r) - i\boldsymbol{W}_q(r) \cdot (\nabla \times \boldsymbol{\sigma}) \right] \phi_q^i(r) = -e_q^i \phi_q^i(r)$$

- SHF mean fields:

$$V_q = V_q^{\text{SHF}} + \frac{\partial \epsilon_{NY}}{\partial \rho_q} + V_{\text{em}}$$

- Coupled equations for eigenvalues e_q^i

- 2D model: quadrupole constraint: $\beta_2 = \sqrt{\frac{\pi}{5}} \frac{\langle 2z^2 - r^2 \rangle}{\langle z^2 + r^2 \rangle}$ fixed

$\Lambda_c N$ Interaction:

- Employ a scaled ΛN interaction (and SLy4 NN force):

$$\epsilon_{N\Lambda_c} = K\,\epsilon_{N\Lambda}$$

- with PRC 90 047301 (2014); PRC 104, L061307 (2021)

$$\epsilon_{NY} = \frac{\tau_Y}{2m_Y} + a_0\rho_Y\rho_N + a_3\rho_Y{\rho_N}^2 - a_2(\rho_Y\Delta\rho_N + \rho_N\Delta\rho_Y)/2 + a_1(\rho_Y\tau_N + \rho_N\tau_Y) + a_4(\nabla\rho_Y\cdot\boldsymbol{J}_N + \nabla\rho_N\cdot\boldsymbol{J}_Y)$$

$$\frac{1}{2m_Y^*} = \frac{1}{2m_Y} + a_1\rho_N\,, \quad m_{Y_c} = 2286.5\,\mathrm{MeV}$$

Parameters: $a_{0,1,2,3} = [-322.0, 15.75, 19.63, 715.0]$

- Mean fields:

$$V_Y = a_0\rho_N + a_3\rho_N^2 + a_1\tau_N - a_2\Delta\rho_N - a_4\nabla\cdot\boldsymbol{J}_N$$

$$V_N^{(Y)} = a_0\rho_Y + 2a_3\rho_N\rho_Y + a_1\tau_Y - a_2\Delta\rho_Y - a_4\nabla\cdot\boldsymbol{J}_Y$$

Choice of scaling factor K:

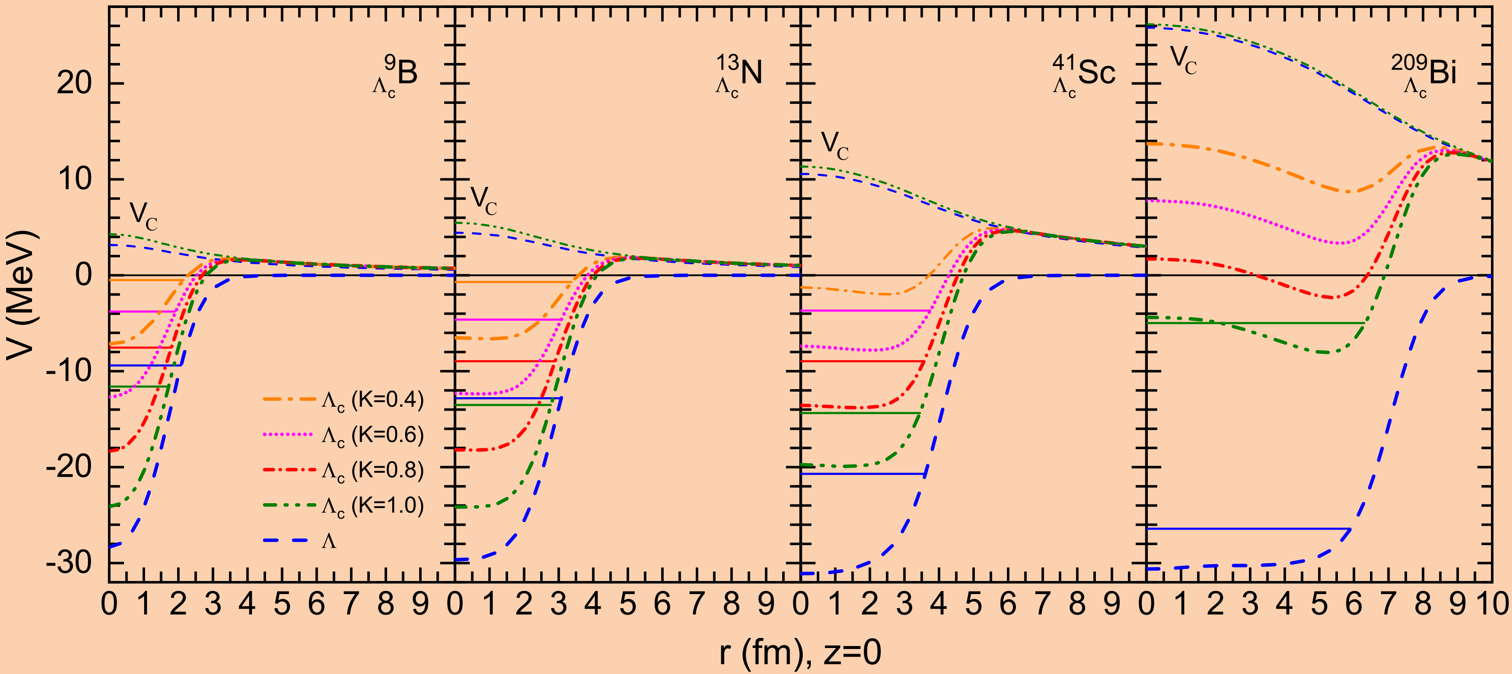
- Theoretical predictions for the Λ_c potential depth $-U_{\Lambda_c}$ in nuclear matter. No Coulomb interaction is included. $\equiv$ indicates 'ad-hoc' values.

Year	Method	Ref.	U_{Λ_c} [MeV]
1978	SU(4) One-boson exchange	N. Cim. A46 313 (1978)	≈ 28
1981	SU(4) One-boson exchange	PRC 24 1816 (1981)	≈ 22
1985	SU(4) One-boson exchange	PTPS 81 197 (1985)	≈ 24.6
1986	SU(4) One-boson exchange	NPA 450 507c (1986)	$\approx 0.8 U_\Lambda$
2004	Relativistic mean field	PRC 70 054306 (2004)	$\equiv 30$
2017	Parity-projected QCD sum rules	PRC 96 055208 (2017)	≈ 23
2018	Lattice QCD ($m_\pi = 410$ MeV)	NPA 971 113 (2018)	$\lesssim 20$
2019	Heavy quark eff. potential	PRC 100 065201 (2019)	$\approx 24-28$
2020	Chiral pert. + Lattice QCD	EPJA 56 195 (2020)	≈ 19
2021	Skyrme-Hartree-Fock	PRC 104 064306 (2021)	$\equiv 0.8 U_\Lambda$

↪ $K \approx 0.8$? We consider K as a free parameter...

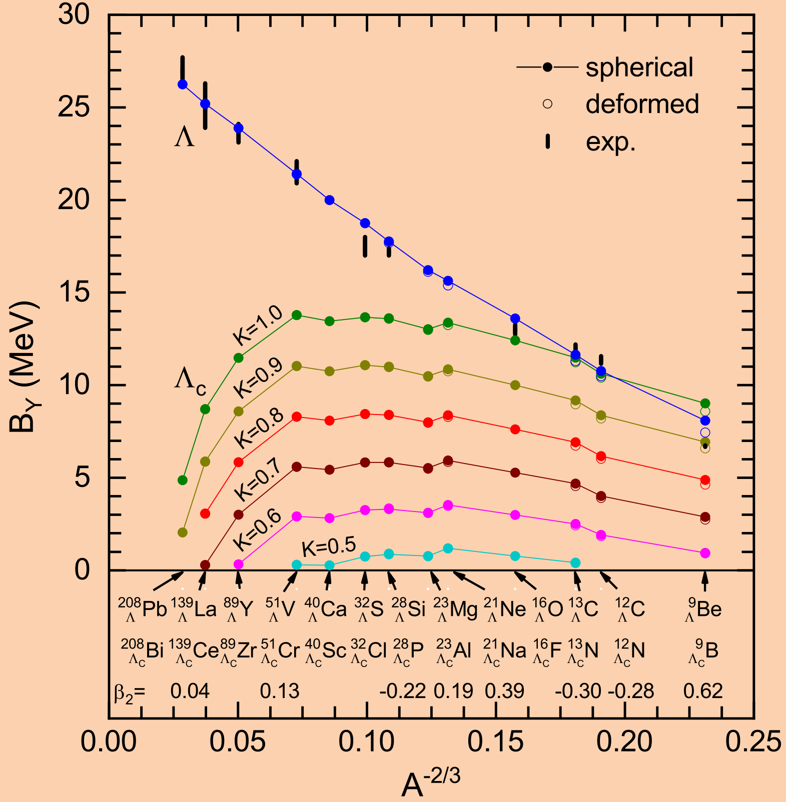
Results:

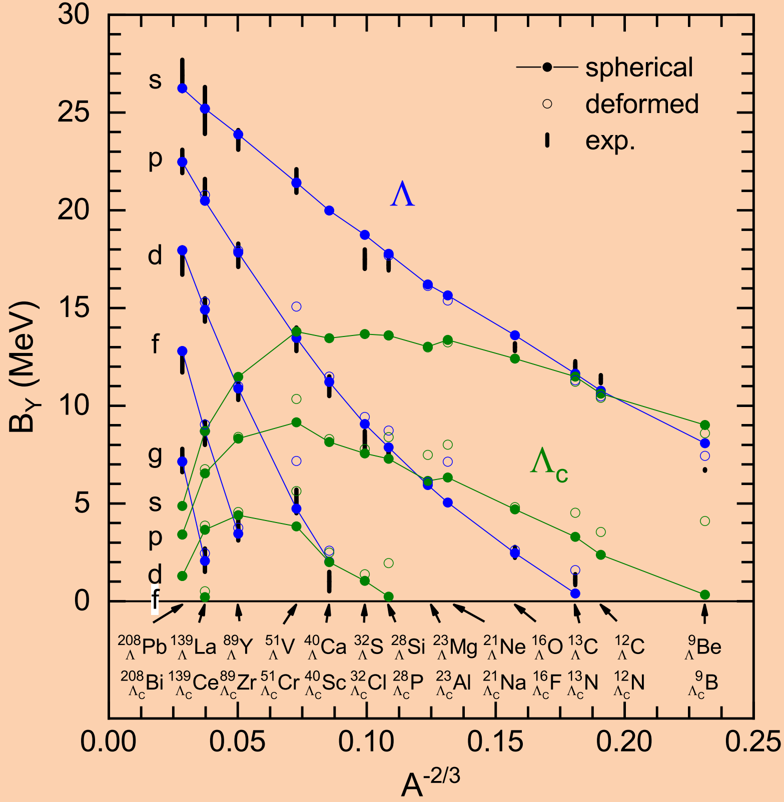
- Hyperon mean fields with varying interaction strength:



↪ $\Lambda_c(K = 1)$ more bound than Λ in light nuclei in spite of Coulomb repulsion: large mass, small E_{kin}

Removal energies with varying interaction strength:



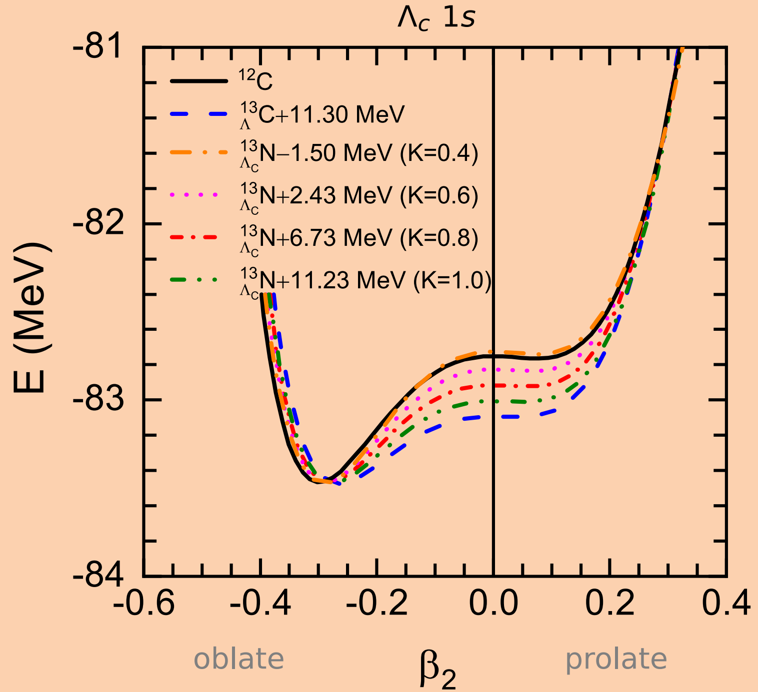


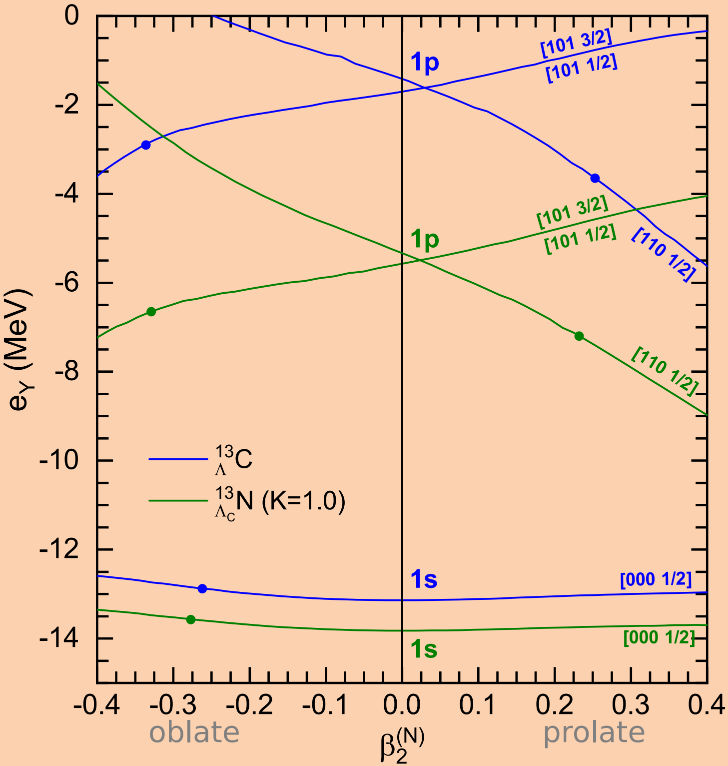
➥ Heavy Λ_c hypernuclei destabilized by Coulomb repulsion

Medium Λ_c hypernuclei are bound down to $K \approx 0.5$

Deformation affects p etc. states...

Effects of core deformation:





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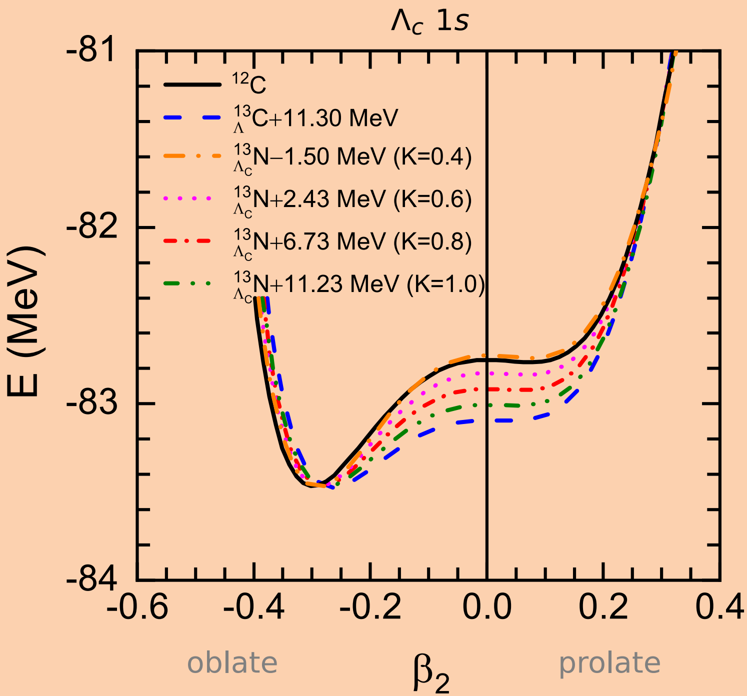
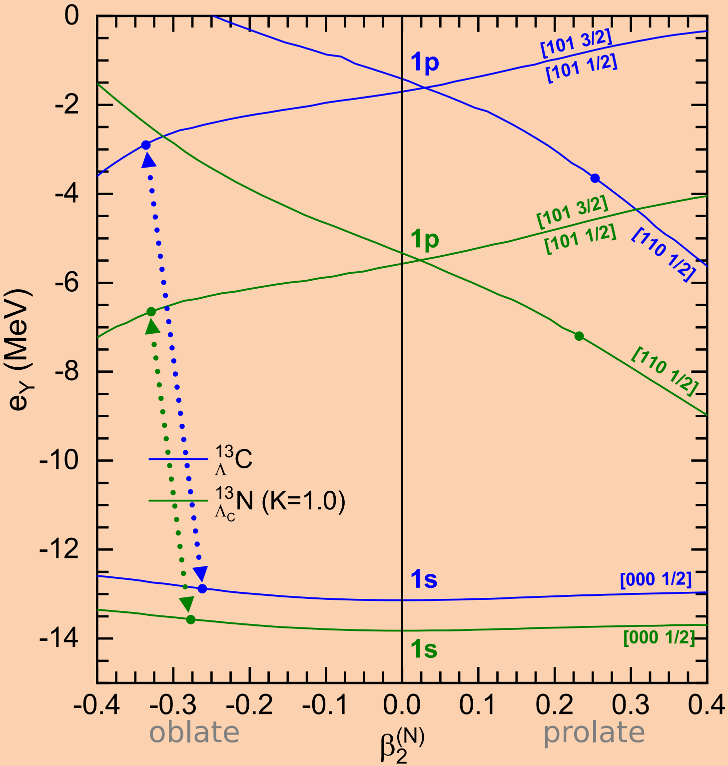
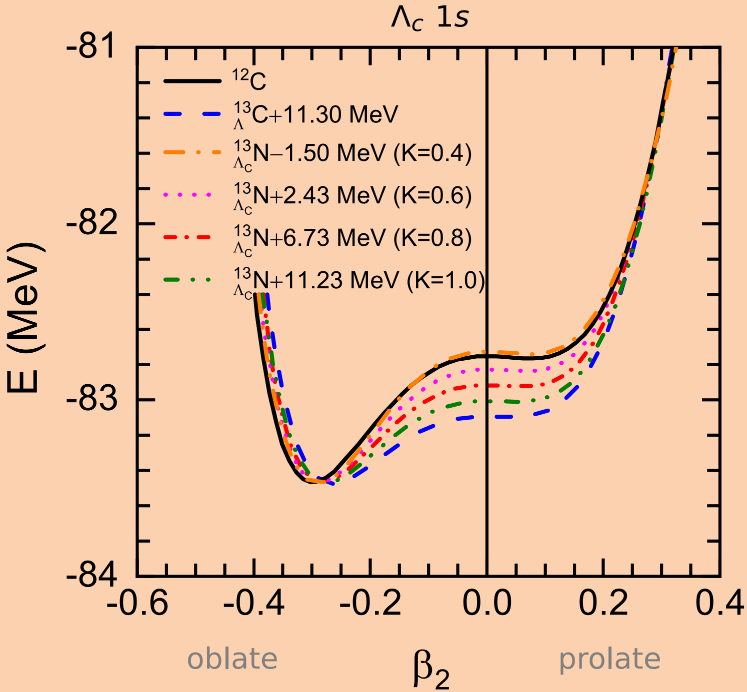
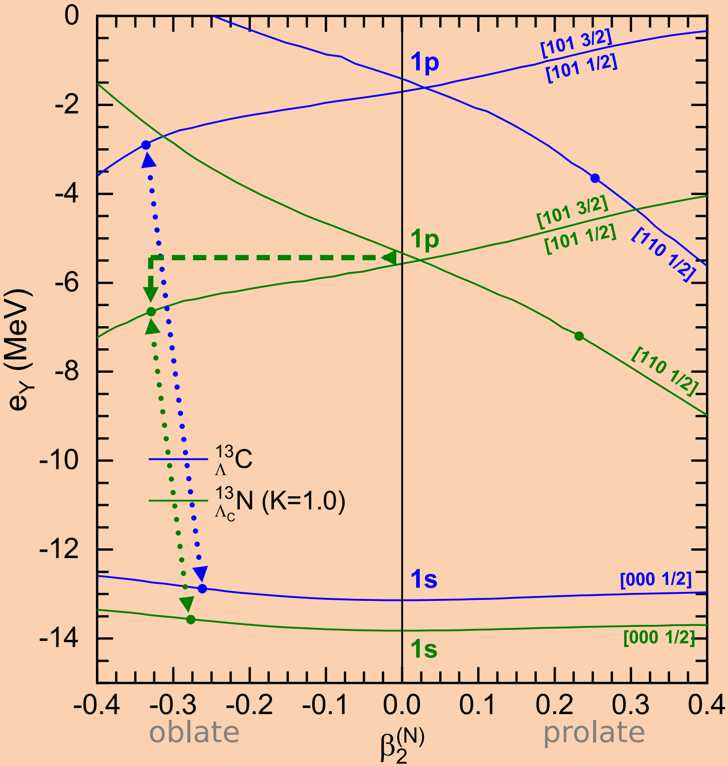




→ Λ_c level spacing is narrower than Λ due to larger mass

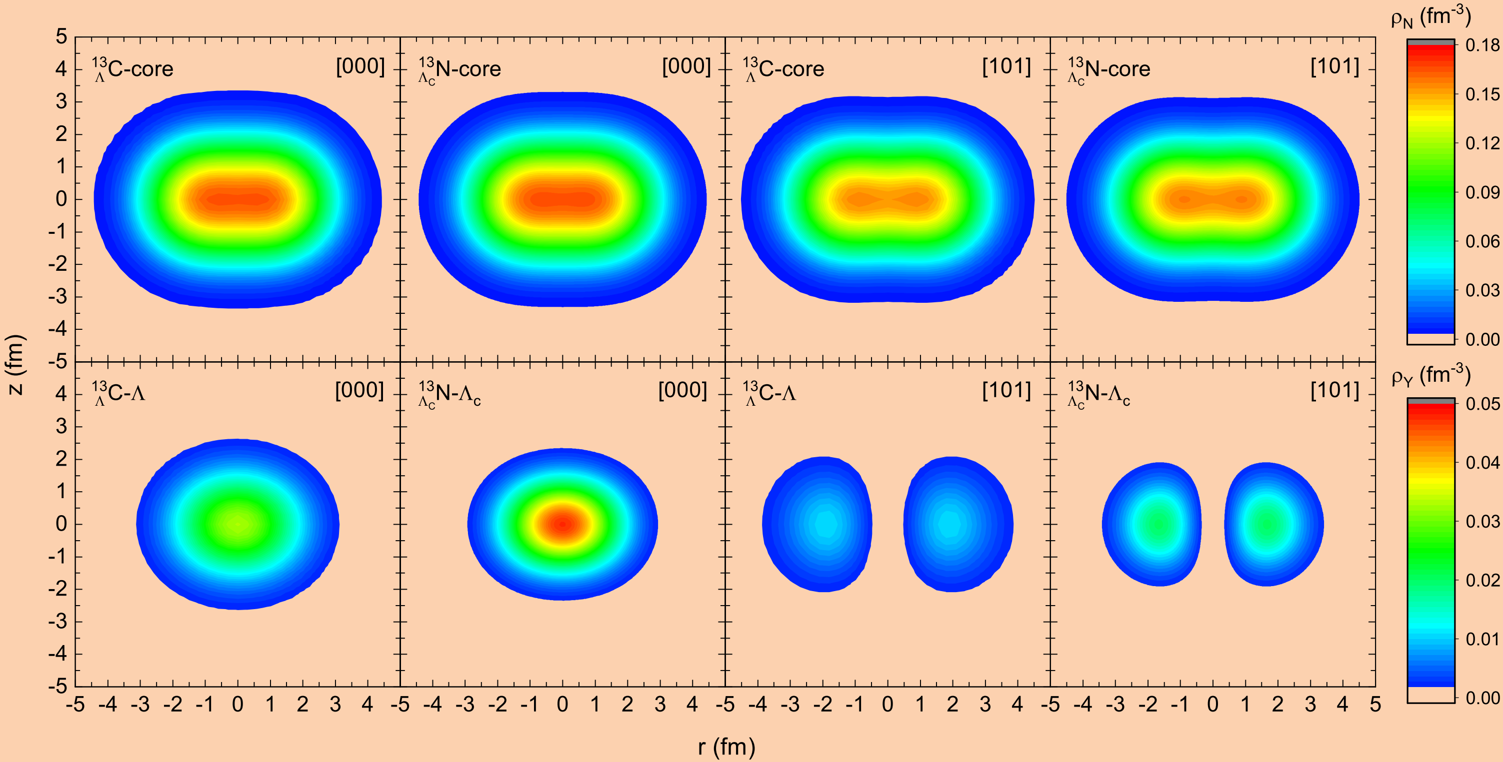
Effects of core deformation:





- Λ_c level spacing is narrower than Λ due to larger mass
- In addition, Λ_c $1p$ substates with same deformation as embedding core are lowered in energy

● Density distributions:



Summary :

- Self-consistent DSHF treatment of hypernuclei
- Λ_c hypernuclei exist for weak interaction strengths
- Λ_c $1p$ states strongly bound due to small level spacing and deformation effect

Open Problems :

- Data needed !
- Beyond-mean-field formalism