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Structure of Light Λ-hypernuclei near Nucleon Drip Lines and Baryonic Interaction

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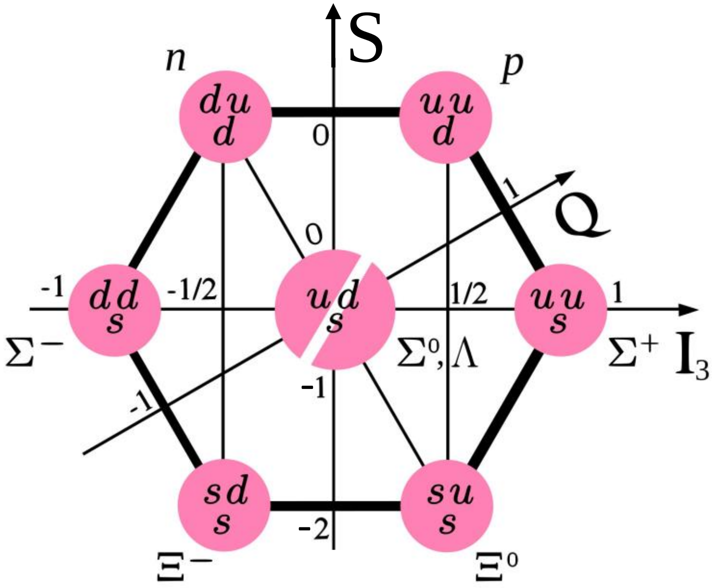
Hypernuclei

Visible baryonic matter as we know it is primarily made of neutrons and protons, made in turn from u- and d- quarks. To study baryonic interaction properties for heavier quarks (such as s-quarks), one may consider synthesizing hypernuclei, a.k.a. nuclei with protons, neutrons and hyperons.



Notation:

${}^{A}_{\Lambda}Z$ is a hypernucleus made of N neutrons, Z protons and 1 Λ-hyperon; mass number $A = N + Z + 1$

${}^{A}_{\Lambda\Lambda}Z$ is a hypernucleus made of N neutrons, Z protons and 2 Λ-hyperons; mass number $A = N + Z + 2$

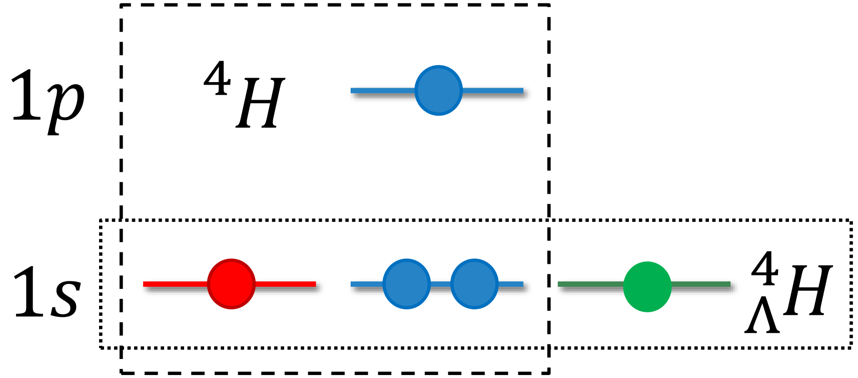
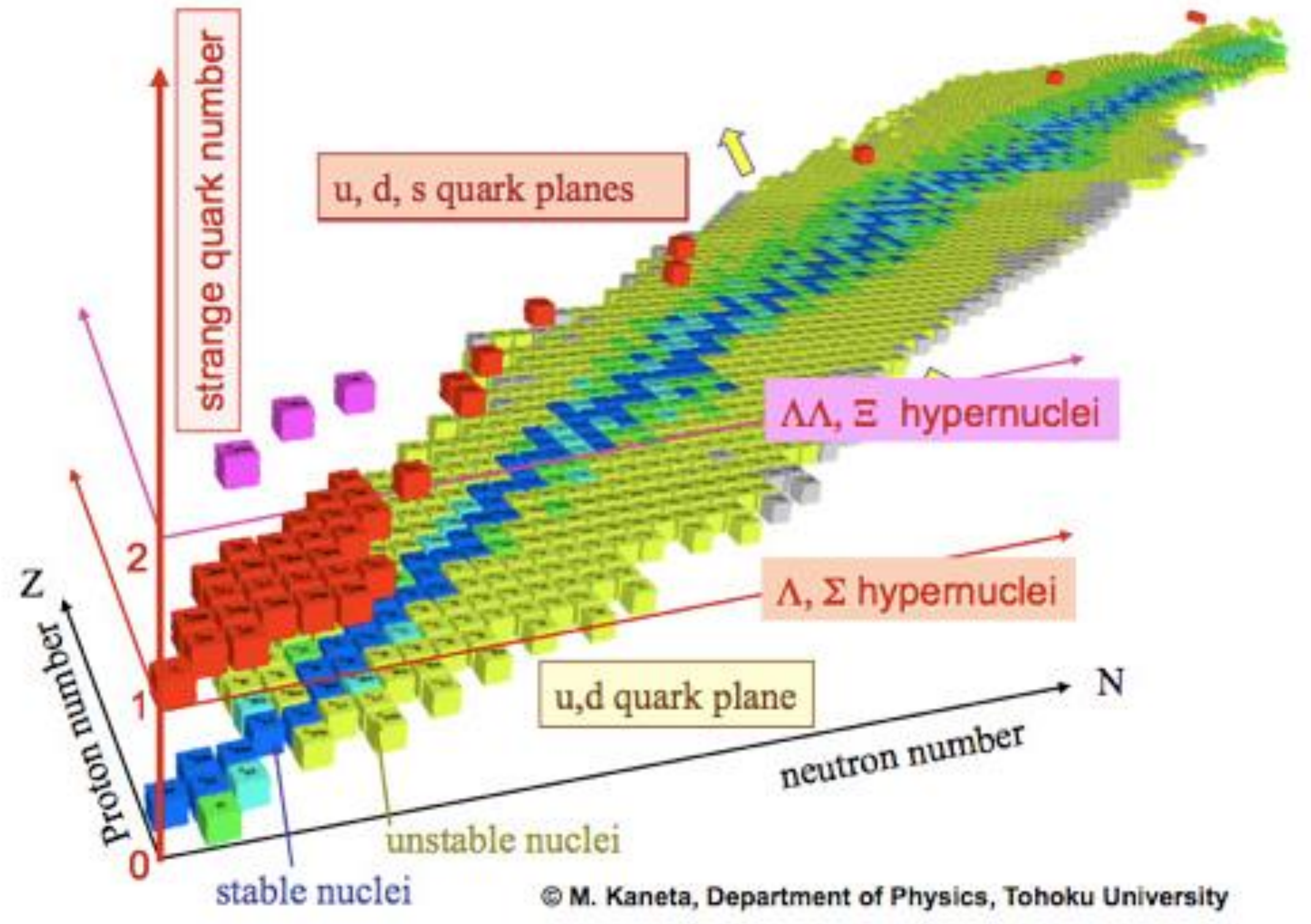


Chart of nuclei and hypernuclei



Motivation

- Study of the properties of baryonic interactions beyond nucleon-nucleon interactions
- Predictions for bound hypernuclei with an unbound nucleon core
- Research in neutron star structure

Hartree-Fock approach for hypernuclei

- Energy density functional:

$$E = \langle g.s.|T + V_{12}|g.s\rangle = \int H(\rho,\tau,J)dr, \quad |g.s.\rangle = \frac{1}{\sqrt{A!}}\det\left|\phi_i(\boldsymbol{r_j})\right|$$

- Hartree-Fock single particle states:

$$\frac{\delta}{\delta\phi_i}\left(E - \sum_i e_i \int |\phi_i(\boldsymbol{r})|^2 dr\right) = 0$$

- Hartree-Fock equations:

$$\frac{\hbar^2}{2m^*_{q,\Lambda}(r)}\left[-R''_\alpha(r) + \frac{l_\alpha(l_\alpha+1)}{r^2}R_\alpha(r)\right] - \left(\frac{\hbar^2}{2m^*_{q,\Lambda}(r)}\right)' R'_\alpha(r) + U_{q,\Lambda}(r)R_\alpha(r) = e_\alpha R_\alpha(r)$$

Skyrme interaction for hypernuclei

- Nucleon-nucleon Skyrme potential:

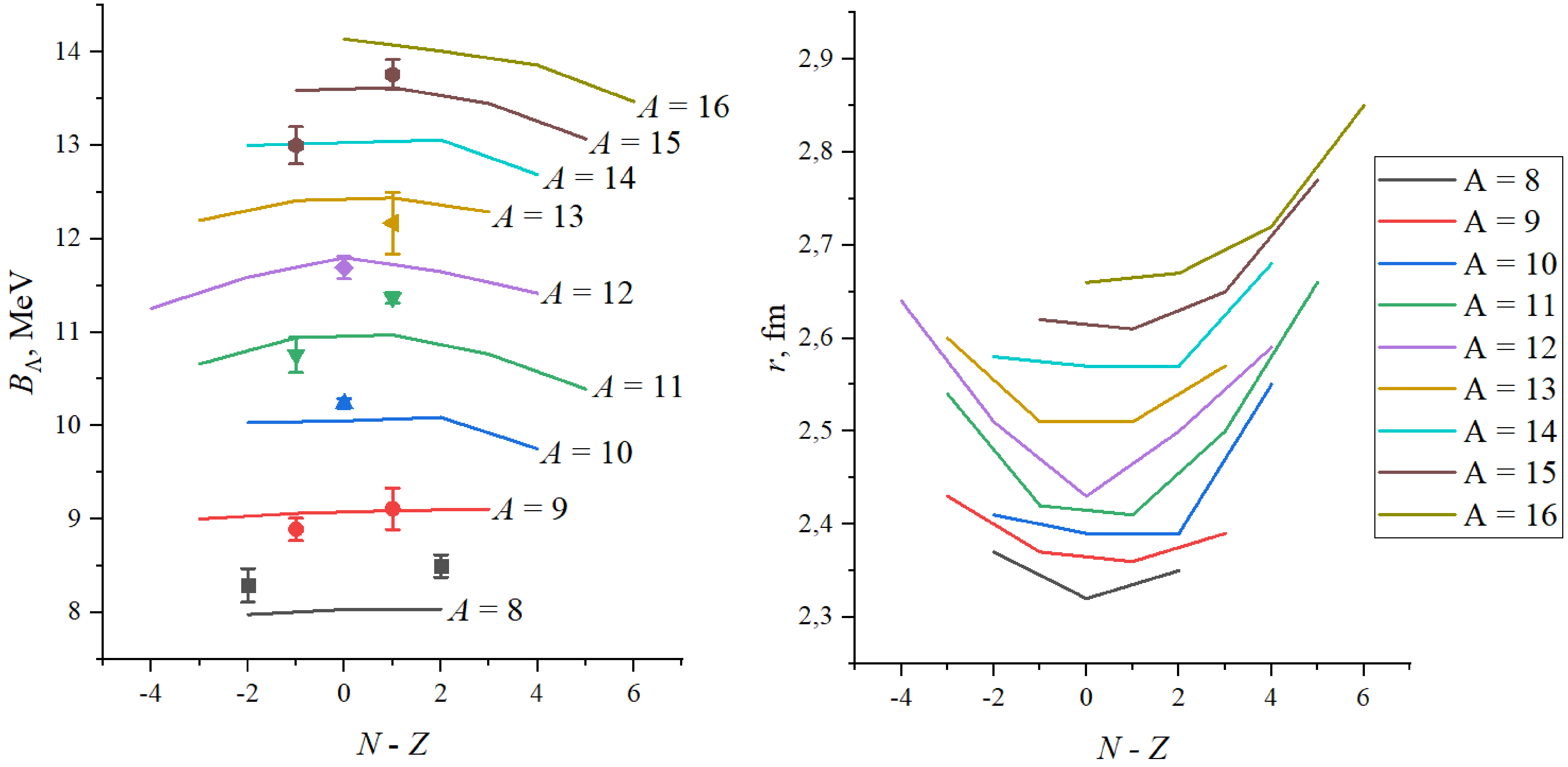
$$V_{NN}(\boldsymbol{r_1},\boldsymbol{r_2}) = t_0(1+x_0P_\sigma)\delta(\boldsymbol{r_{12}}) + \frac{1}{2}t_1(1+x_1P_\sigma)(\boldsymbol{k}^2\delta(\boldsymbol{r_{12}}) + \delta(\boldsymbol{r_{12}})\boldsymbol{k}'^2)$$
$$+t_2(1+x_2P_\sigma)\boldsymbol{k}'\delta(\boldsymbol{r_{12}})\boldsymbol{k} + \frac{1}{6}t_3\rho^\alpha(\boldsymbol{R})(1+x_3P_\sigma)\delta(\boldsymbol{r_{12}}) + iW(\sigma_1+\sigma_2)[\boldsymbol{k}'\times\delta(\boldsymbol{r})\boldsymbol{k}]$$

- Hyperon-nucleon Skyrme potential:

$$V_{\Lambda N}(\boldsymbol{r_\Lambda},\boldsymbol{r_q}) = t_0^\Lambda(1+x_0^\Lambda P_\sigma)\delta(\boldsymbol{r_{\Lambda q}}) + \frac{1}{2}t_1^\Lambda(\boldsymbol{k}^2\delta(\boldsymbol{r_{\Lambda q}}) + \delta(\boldsymbol{r_{\Lambda q}})\boldsymbol{k}'^2)$$
$$+t_2^\Lambda\boldsymbol{k}'\delta(\boldsymbol{r_{\Lambda q}})\boldsymbol{k} + \frac{1}{6}t_3^\Lambda\rho^\alpha(\boldsymbol{R})\delta(\boldsymbol{r_{\Lambda q}})$$

- NN: SLy4
- ΛN: SLL4’, YBZ1, YBZ5, LY1, YMR, SkSH1

Hyperon binding energies and radii of nuclear cores in ${}^{A+1}_{\Lambda}Z$



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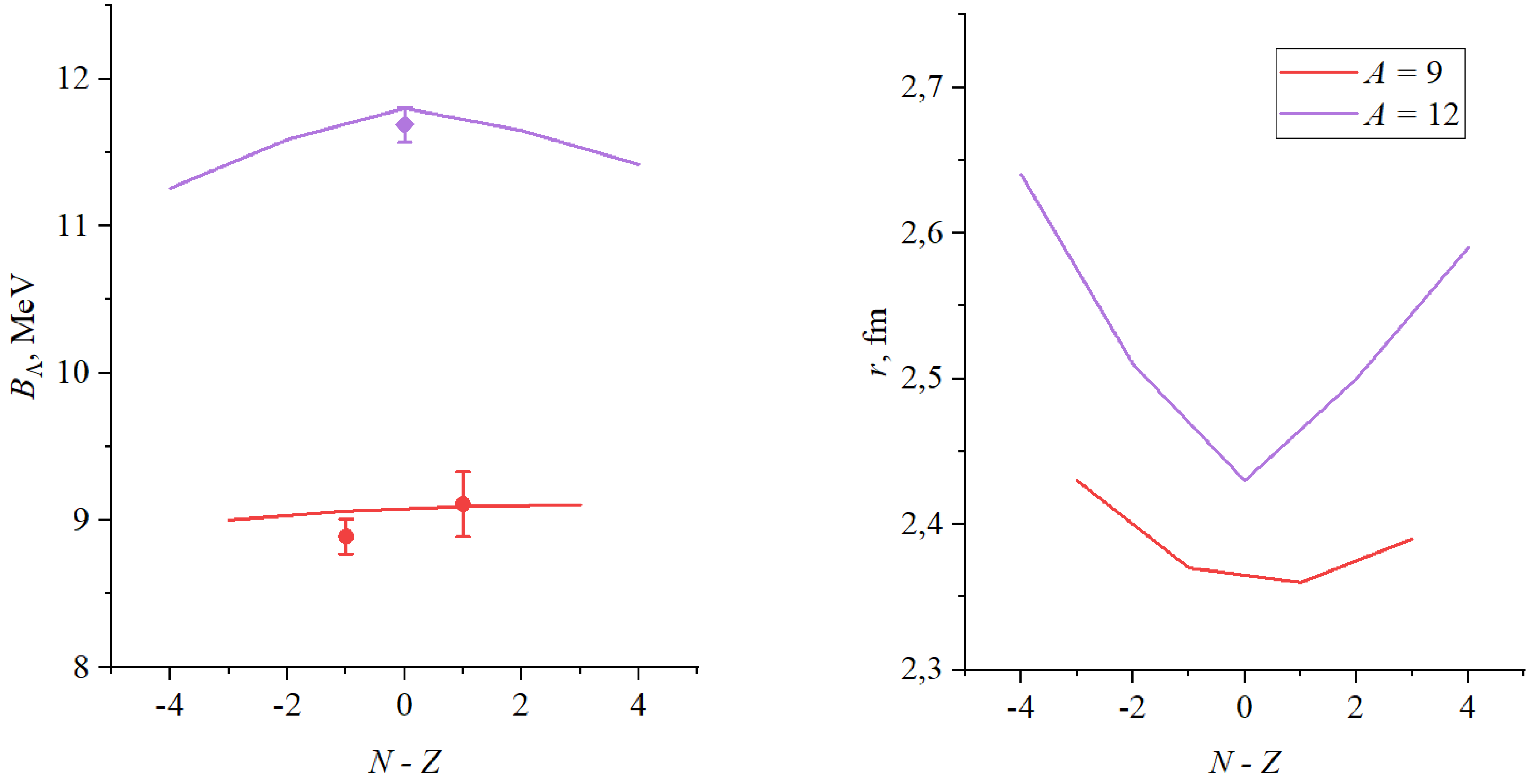

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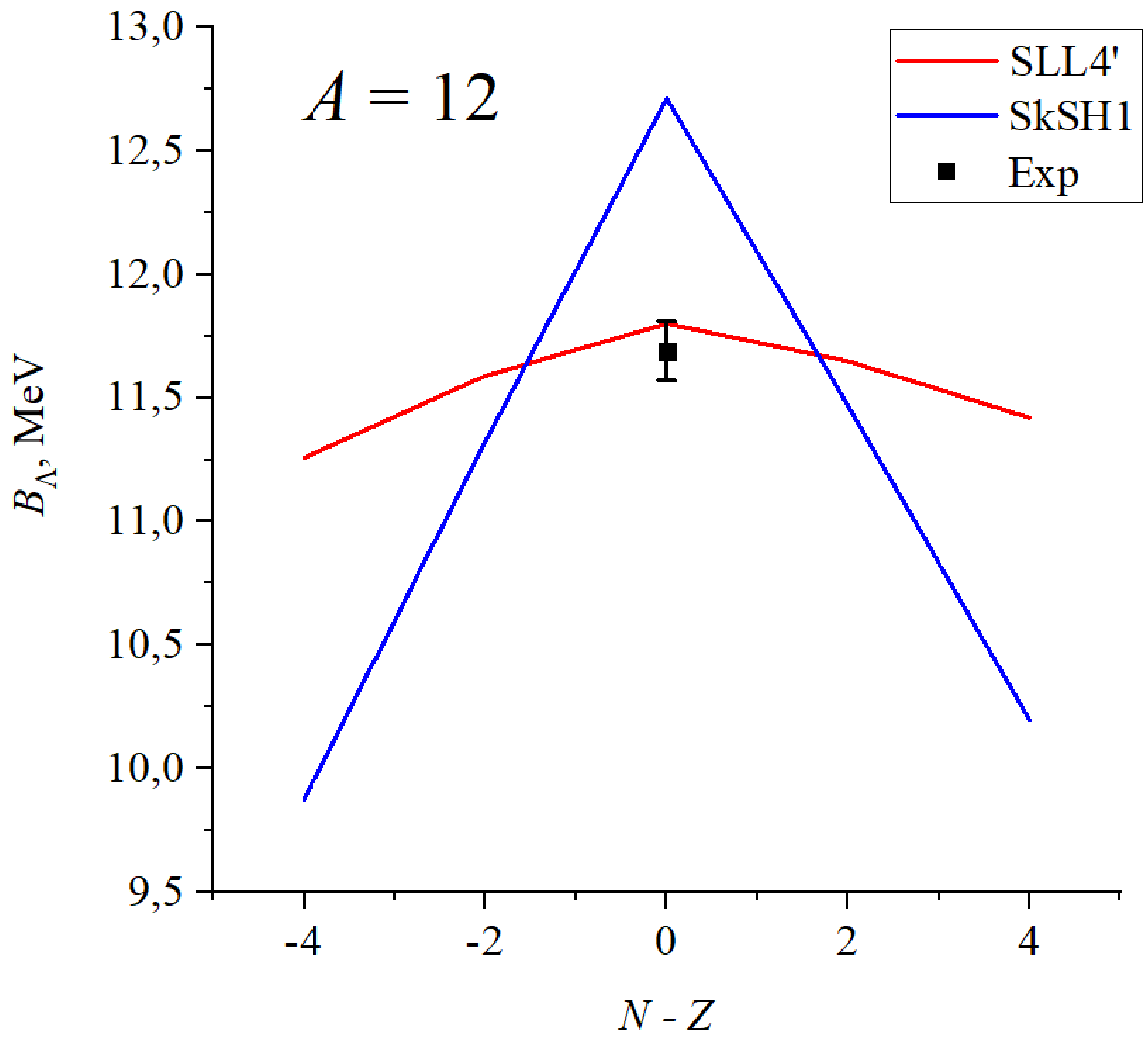
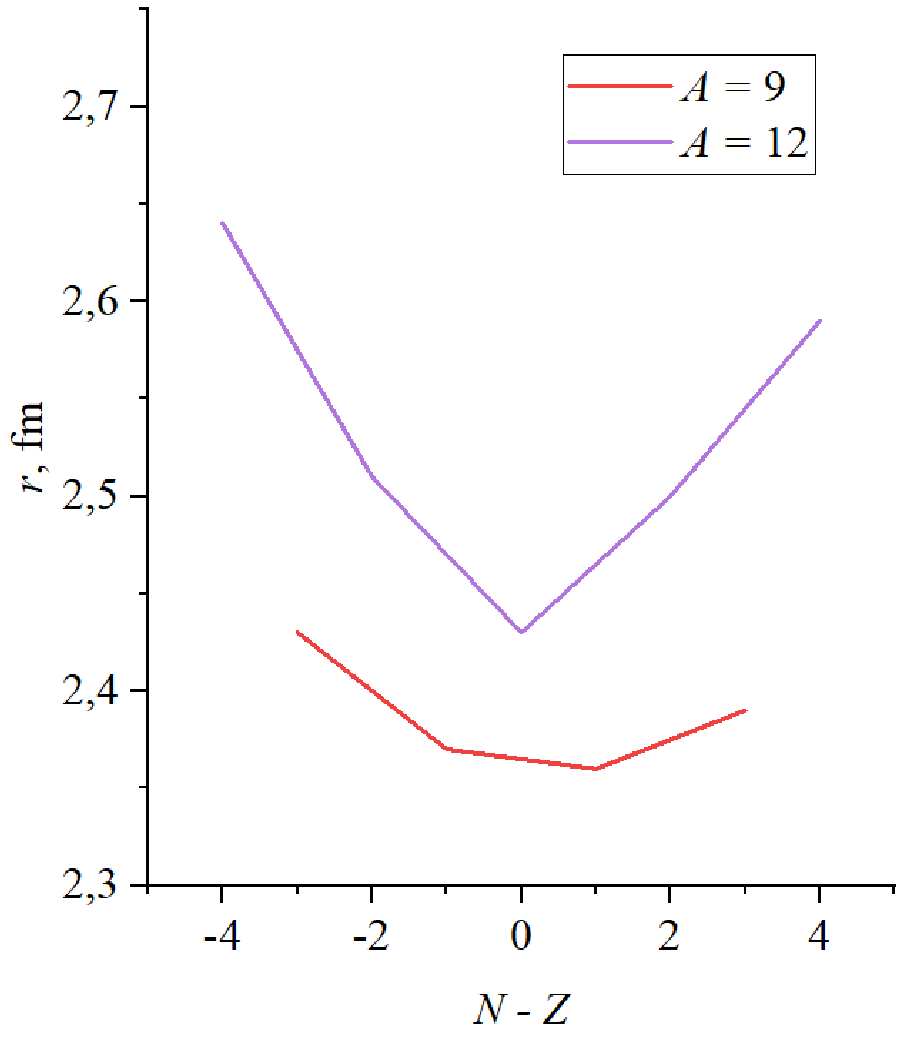
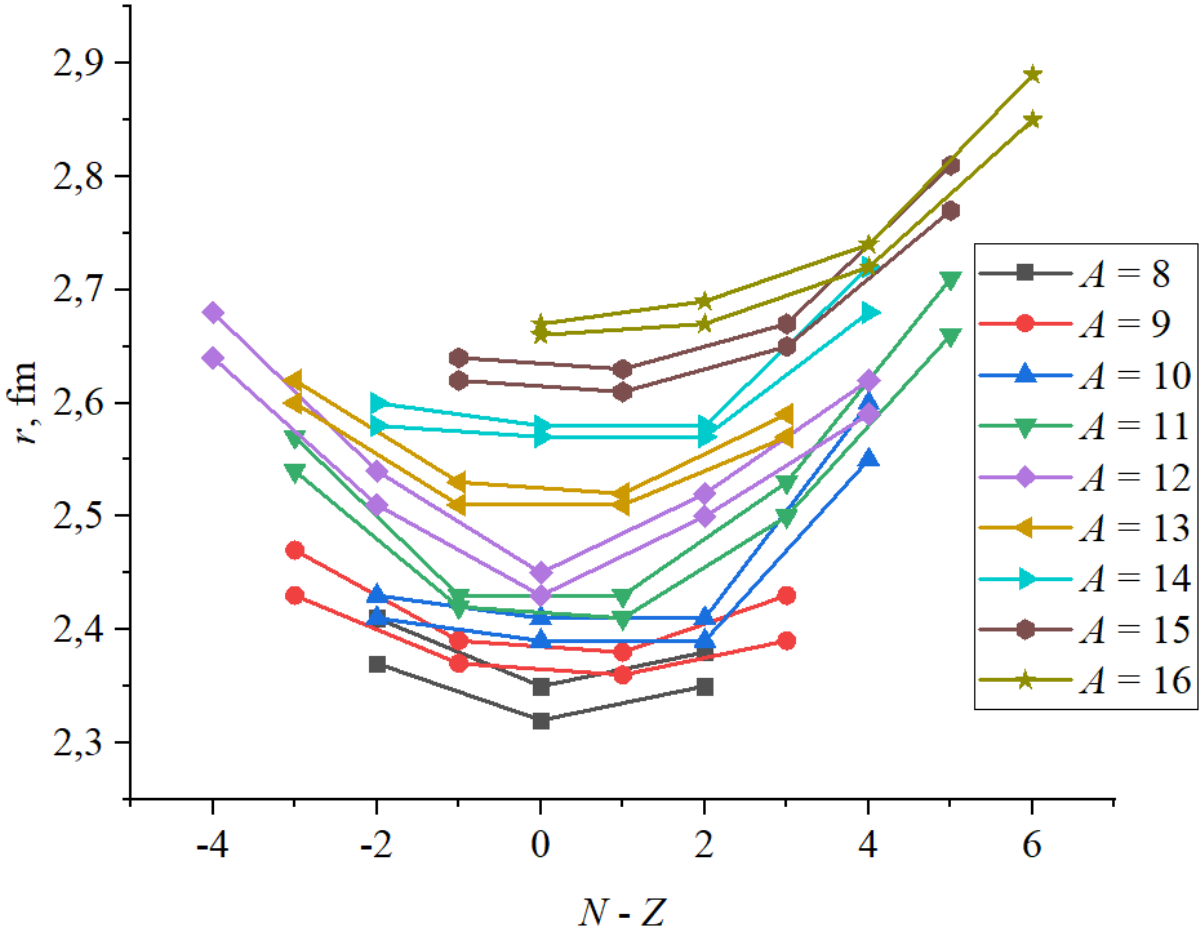
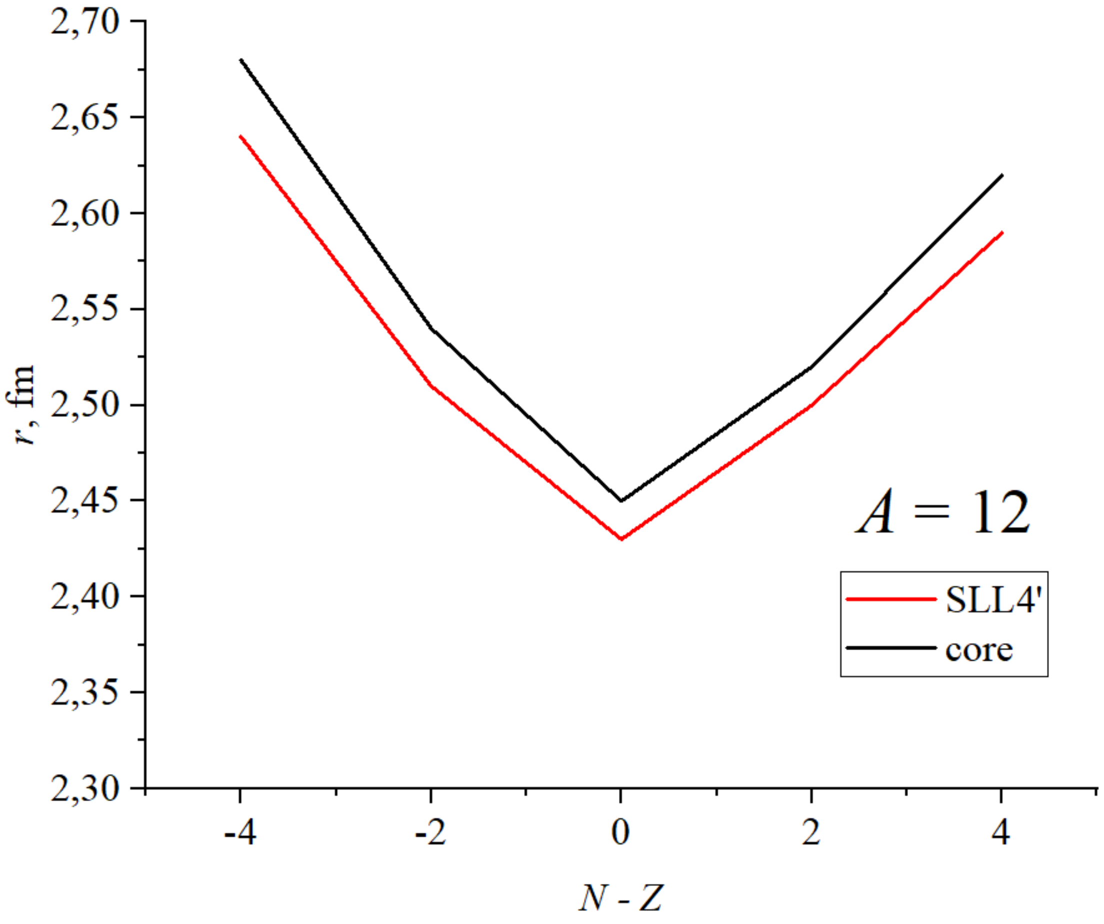




Nuclear core distortion (polarization) by hyperon





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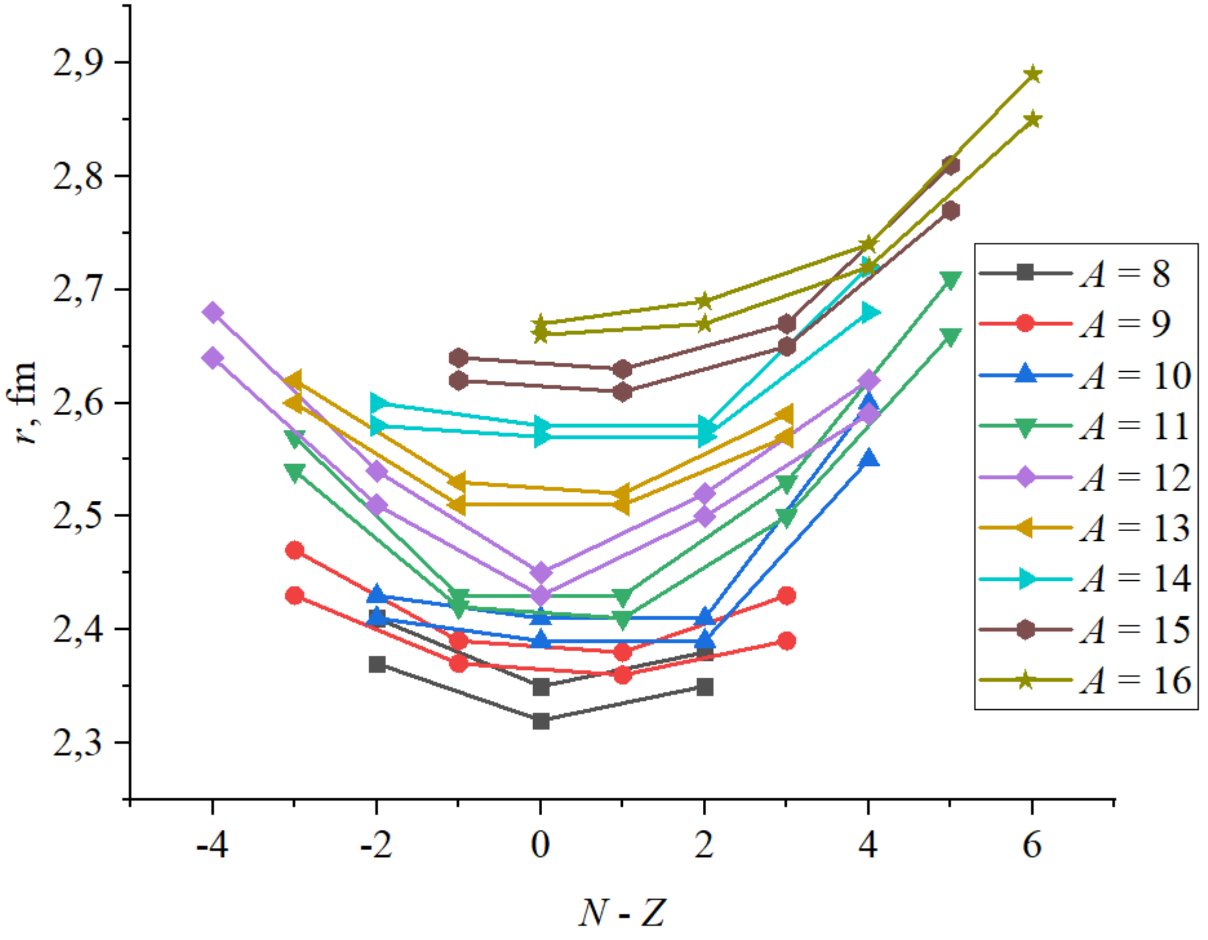
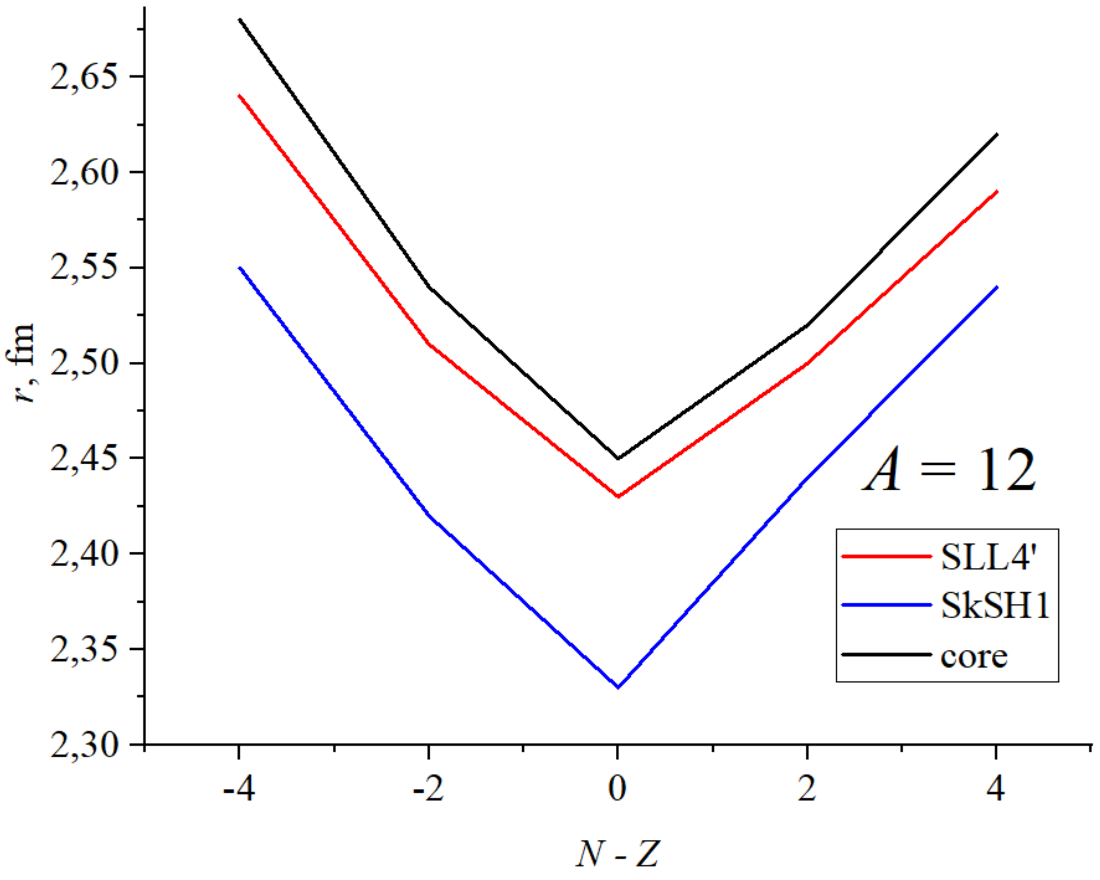




Conclusions

Hypernuclear Hartree-Fock approach was utilized to study the properties of light neutron-rich Λ-hypernuclei.

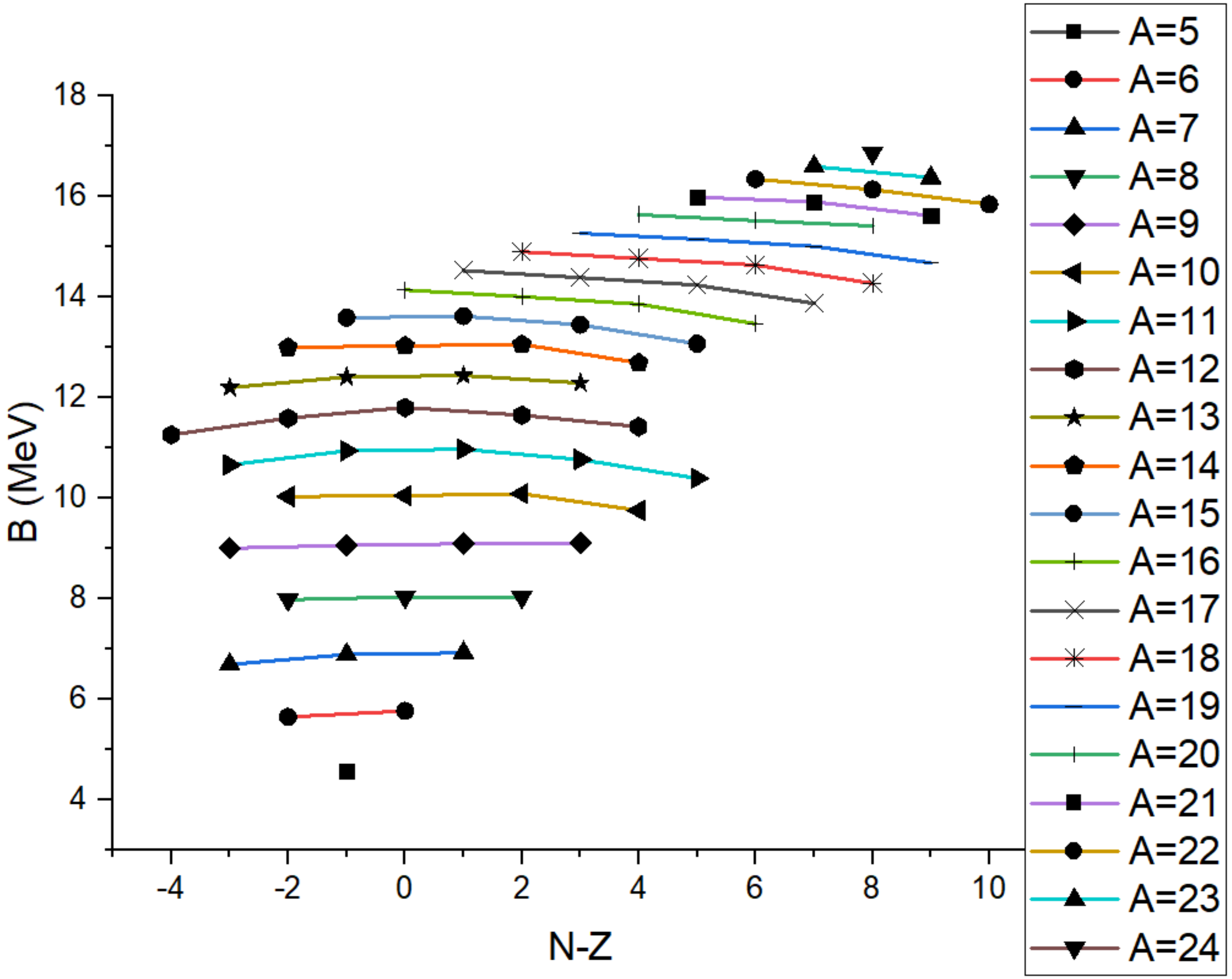
- Hyperon binding energy depends on excess of neutrons or protons in the nucleus (isospin)
- Various choices of ΛN-interaction can lead to significantly different predictions of B_Λ
- Hyperon binding energy vs isospin dependence is more pronounced for the cases with more dramatic density changes, and the corresponding nuclei should be chosen as primary sources of information on ΛN-interaction

It is planned to improve the predictive power of the approach by taking charge symmetry breaking into consideration.

Thank you for your attention

Back-up slides

Hyperon binding energy



$$B_\Lambda\left({}^{A}_{\Lambda}Z\right) = B_{tot}\left({}^{A}_{\Lambda}Z\right) - B_{tot}\left({}^{A-1}Z\right)$$

- The difference in neighboring isobar chains is around 1 MeV for lighter hypernuclei, smaller as A increases
- Symmetric character of B_Λ with respect to isospin $N - Z$
- B_Λ is almost constant for nuclei in the same isobar chain

Hypernuclear radii