On features of hyperonic interactions in neutron stars

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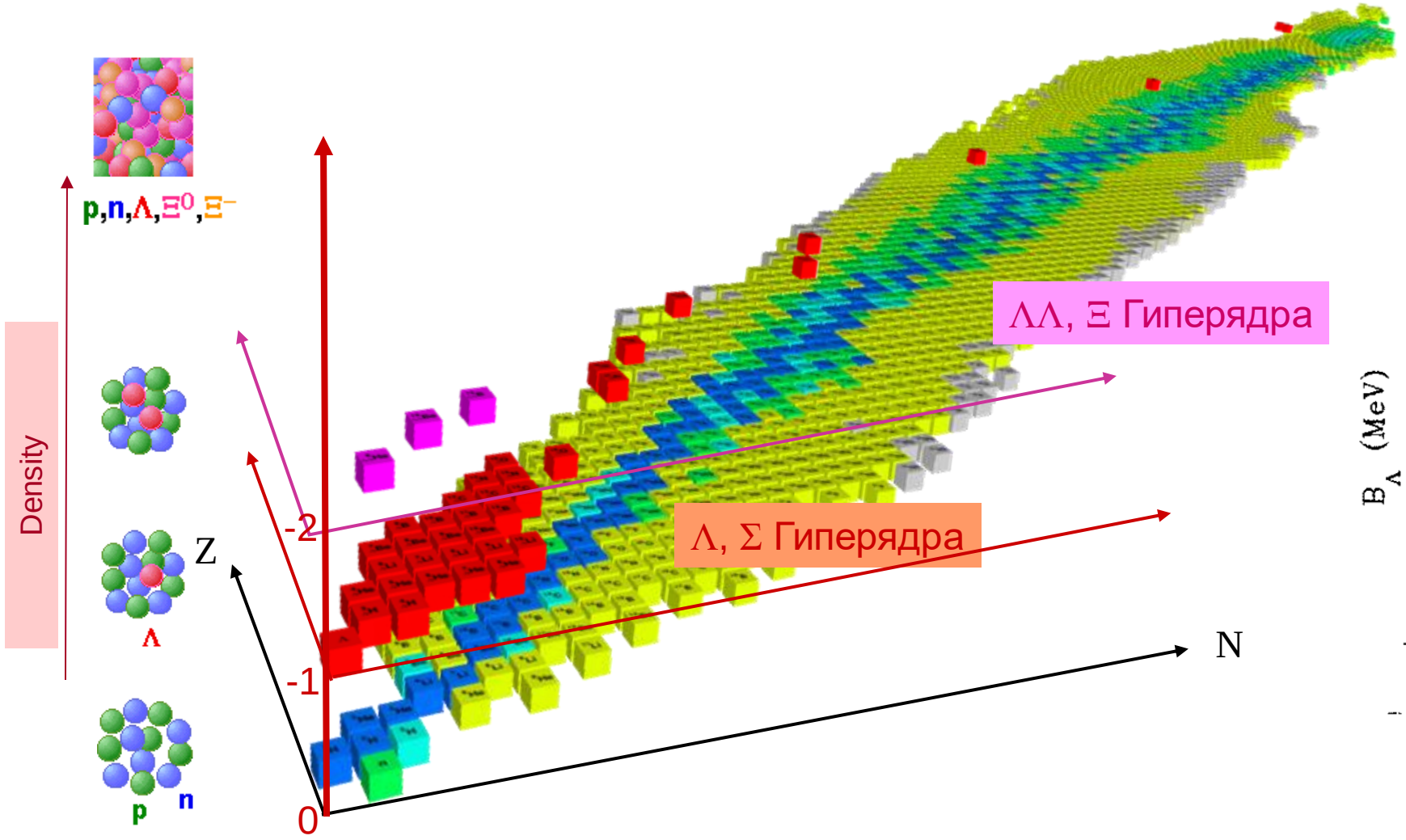
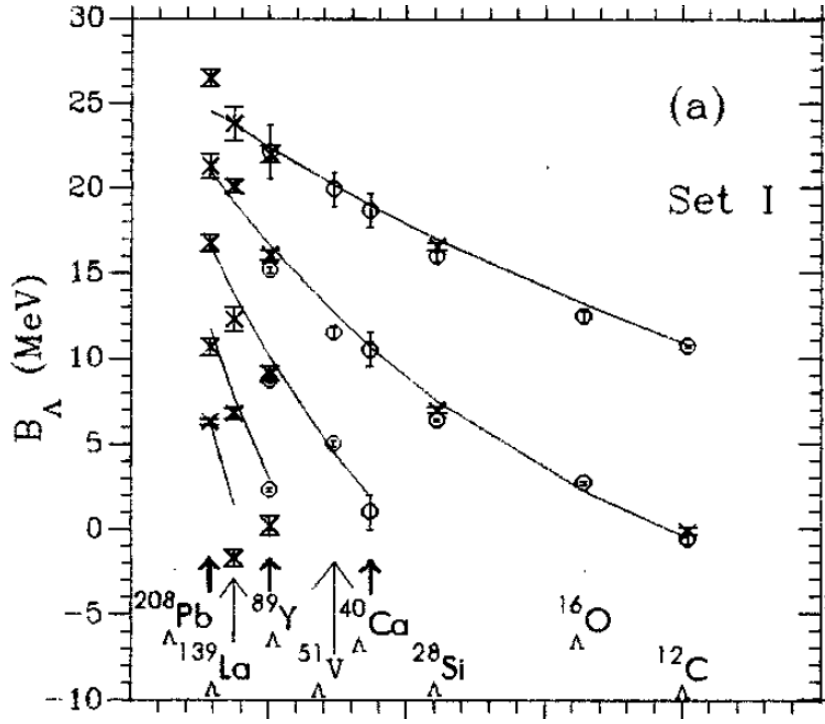
Hypernuclei and hyperonic interactions



Hyperon binding energy

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



Skyrme interaction

YN-interaction

$$
\begin{aligned}
V_{YN}(\vec{r_Y},\vec{r_N}) &= u_0(1+\xi_0 P_\sigma)\delta(\vec{r_Y}-\vec{r_N}) \\
&+ \frac{1}{2}u_1(1+\xi_1 P_\sigma)[\vec{P}'^2\delta(\vec{r_Y}-\vec{r_N}) + \delta(\vec{r_Y}-\vec{r_N})\vec{P}^2] \\
&+ u_2\vec{P}'\delta(\vec{r_Y}-\vec{r_N})\vec{P} \\
&+ \frac{3}{8}u_3(1+\xi_3 P_\sigma)\delta(\vec{r_Y}-\vec{r_N})\rho^\gamma(\frac{\vec{r_Y}+\vec{r_N}}{2}) \\
&+ iW_0^\Lambda\vec{P}'\delta(\vec{r_Y}-\vec{r_N})[\vec{\sigma}\times\vec{P}]
\end{aligned}
$$

Parameterization of ΛN-interaction	γ
YBZ6	1
YBZ2	1
SLL4'	1
LYI	1/3
YMR	1/8

ΛΛ-interaction

$$
\begin{aligned}
V_{\Lambda\Lambda}(\vec{r_1},\vec{r_2}) &= \lambda_0\delta(\vec{r_1}-\vec{r_2}) \\
&+ \frac{1}{2}\lambda_1[\vec{P}'^2\delta(\vec{r_1}-\vec{r_2}) + \delta(\vec{r_1}-\vec{r_2})\vec{P}^2]
\end{aligned}
$$

ΛΛ-interaction with density dependence

$$V_{\Lambda\Lambda} = \sum_1^3 (a_i + b_i k_F + c_i k_F^2) e^{-\frac{r^2}{\beta_i^2}}$$

Fermi momentum

$$k_F = (\frac{3\pi^2}{2})^{1/3}\rho_N^{1/3}$$

- **Chemical equilibrium**

$$\begin{cases} \mu_p + \mu_e = \mu_n \\ \mu_\mu = \mu_e \\ \mu_n = \mu_\Lambda \\ 2\mu_n = \mu_p + \mu_\Xi \end{cases}$$

- **Tolman Oppenheimer Volkov equation**

$$\frac{dP}{dr} = \frac{G}{r^2}\frac{[\rho(r) + P(r)/c^2][m(r) + (4\pi r^3 P(r)/c^2)]}{1 - (2Gm(r)/rc^2)}$$

$$\frac{dm}{dr} = 4\pi r^2 \rho(r)$$

- **Tidal deformability coefficient**

$$Q_{ij} = -\lambda \varepsilon_{ij}$$

$$\Lambda = \frac{\lambda}{M^5}$$

- **GW170817**

$$M_{chirp} = 1.186^{+0.001}_{-0.001} \qquad M_{chirp} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

$$\bar{\Lambda} \leq 900 \qquad \bar{\Lambda} = \frac{16}{13}\frac{(m_1 + 12m_2)m_1^4 \Lambda_1 + (m_2 + 12m_1)m_2^4 \Lambda_2}{(m_1 + m_2)^5}$$

$$m_1 = 1.4\mathrm{M}_\odot \rightarrow \Lambda = 70 - 580$$
$$R = 10.5 - 13.3 \text{ км } [1,2,3]$$

[1] B. Abbott et al. (LIGO Scientific and Virgo Collaboration), Phys. Rev. Lett. 119, 161101 (2017)

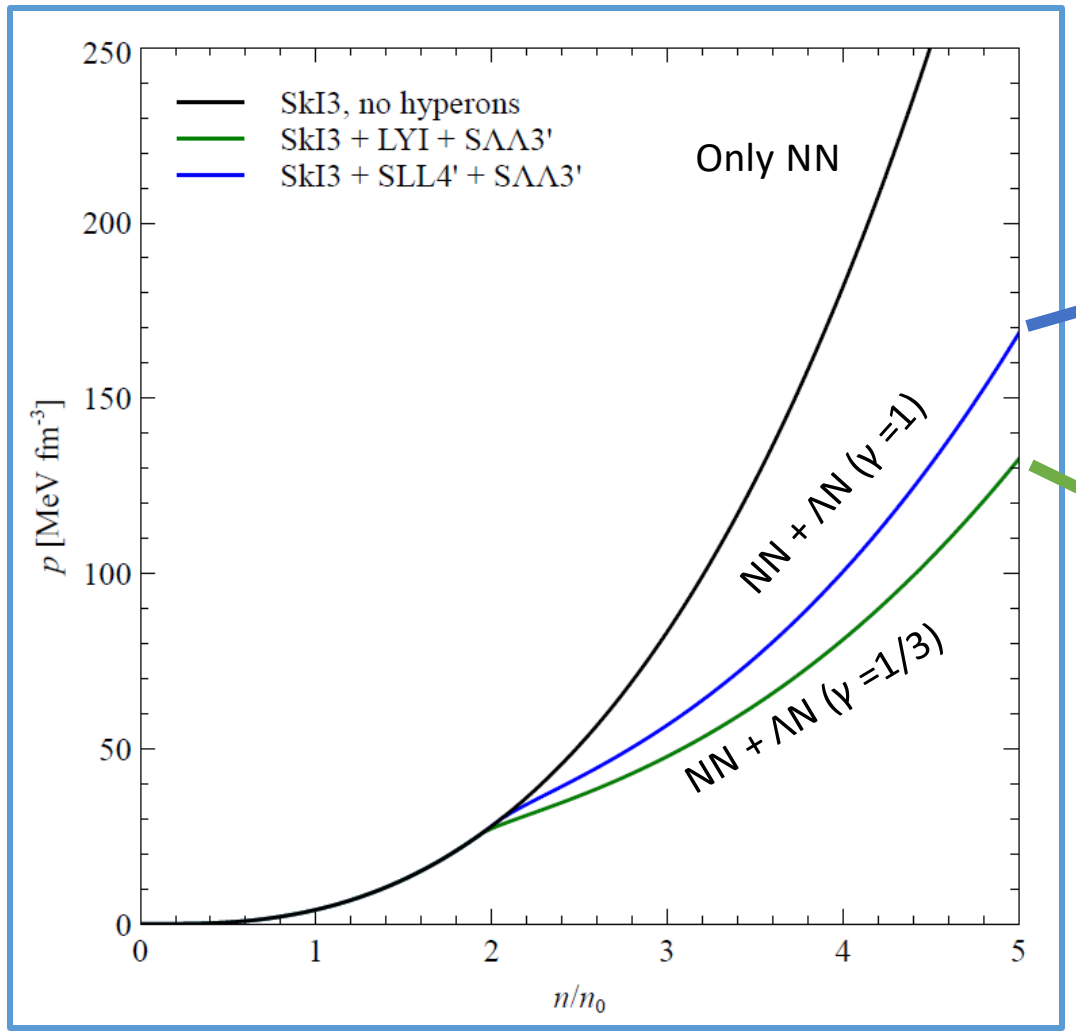
[2] B. Abbott et al. (LIGO Scientific and Virgo Collaboration), Phys. Rev. Lett. 121, 161101 (2018)

[3] B. Abbott et al. (LIGO Scientific and Virgo Collaboration), Phys. Rev. X 9(1) 011001 (2019).

- **Hyperon puzzle**

PSR J0740+6620, M = 2.08 ± 0.07 M⊙
PSR J0952-0607, M = 2.35 ± 0.17 M⊙

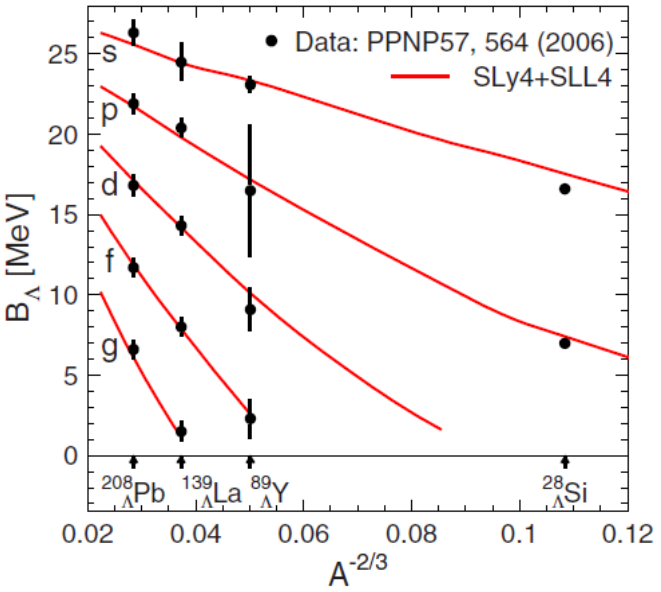
Equation of state of neutron star matter



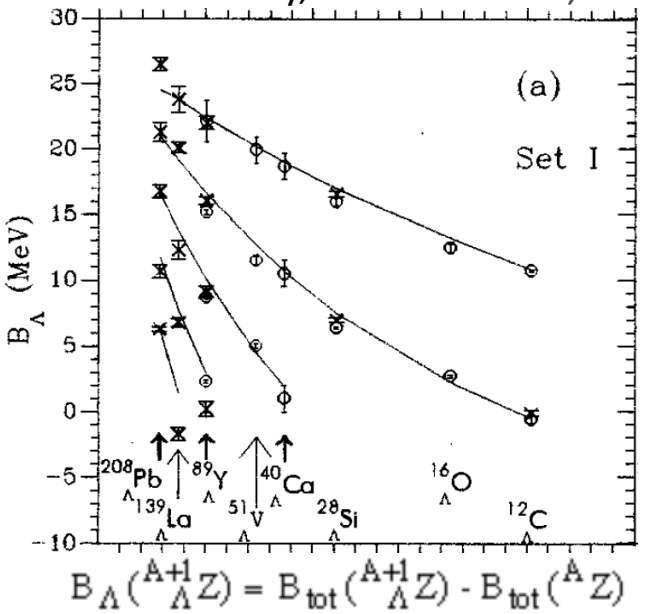
SLL4'

LYI

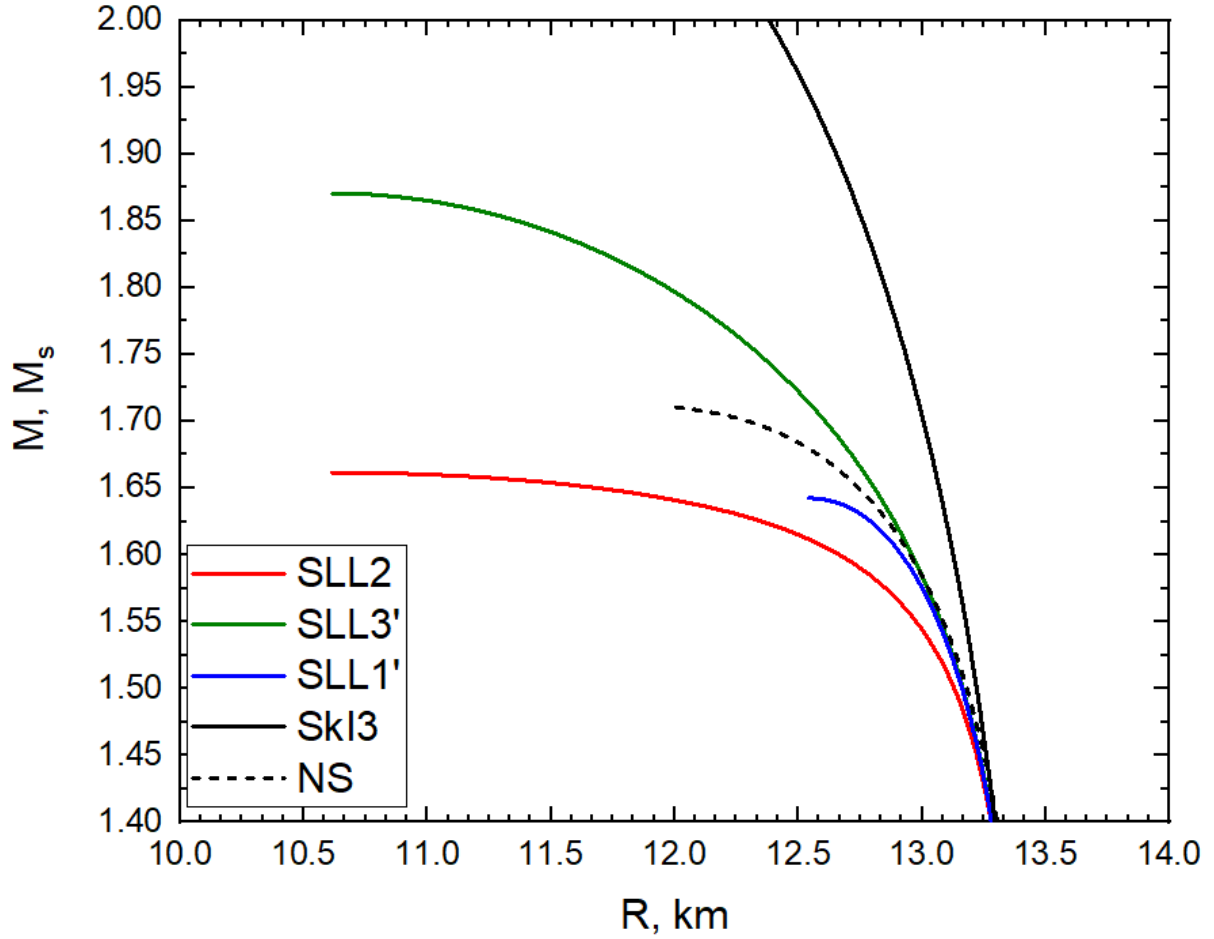
H.-J. Schulze, E. Hiyama, 2014



D. E. Lanskoy, Y. Yamamoto, 1997



ΛΛ-interaction

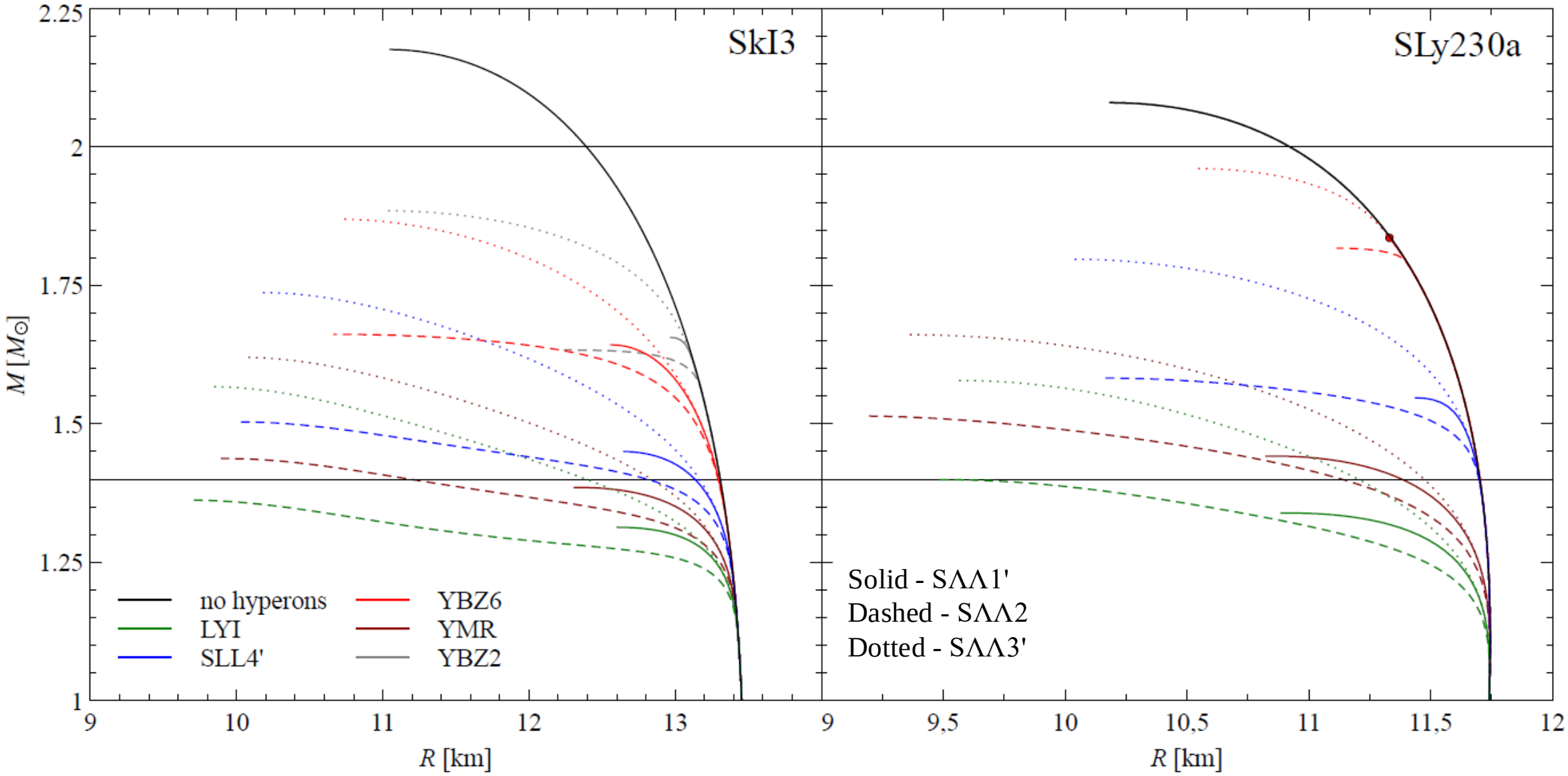


ΛΛ-interaction	Radius of interaction
SΛΛ1'	Small
SΛΛ2	Medium
SΛΛ3'	Large

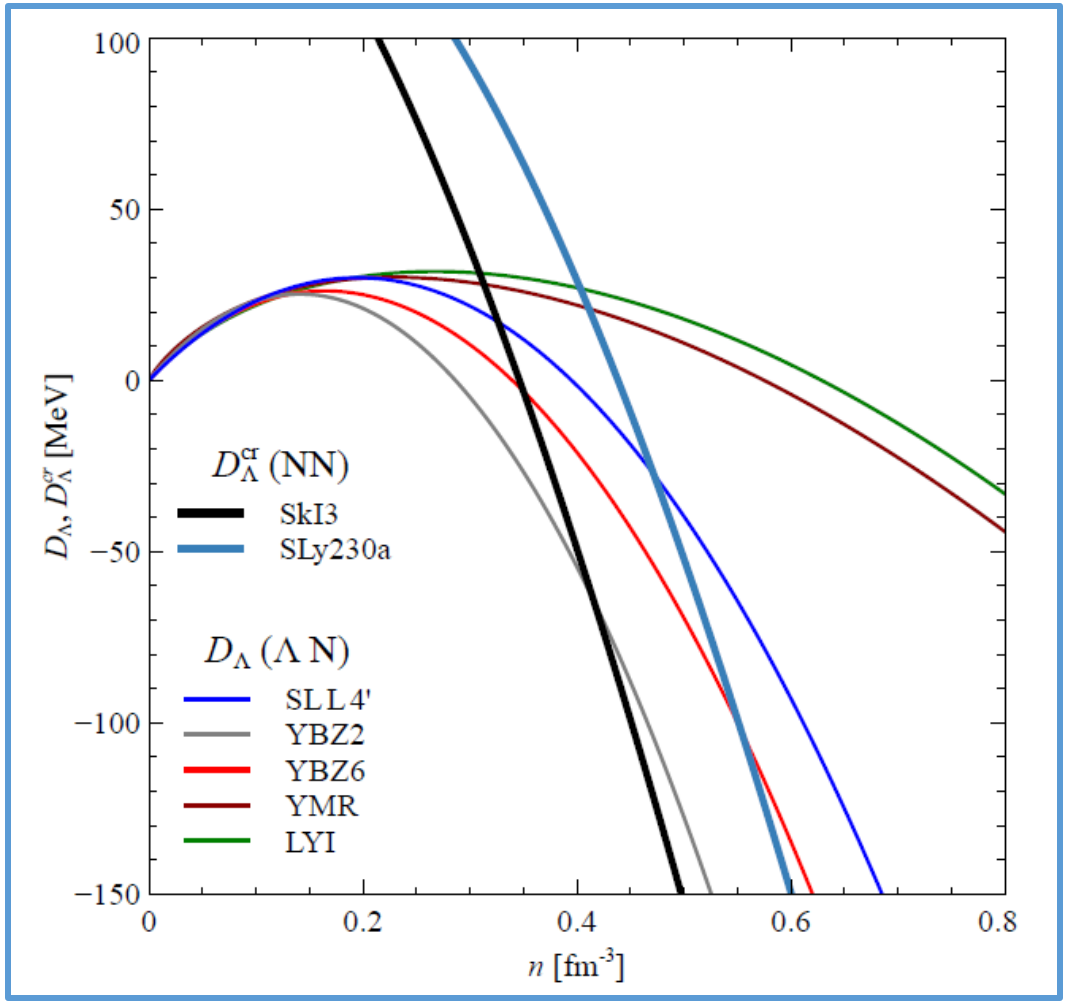
NS – density dependent ΛΛ-interaction

D. E. Lanskoy, 1998
Minato F., 2011

Masses and radii of neutron stars for different baryonic interactions



The point of appearance of hyperons



The binding energy of Λ-hyperon in the pure nucleonic matter

$$D_\Lambda = -\mu_\Lambda .$$

The critical energy of Λ-hyperons in the nucleonic matter

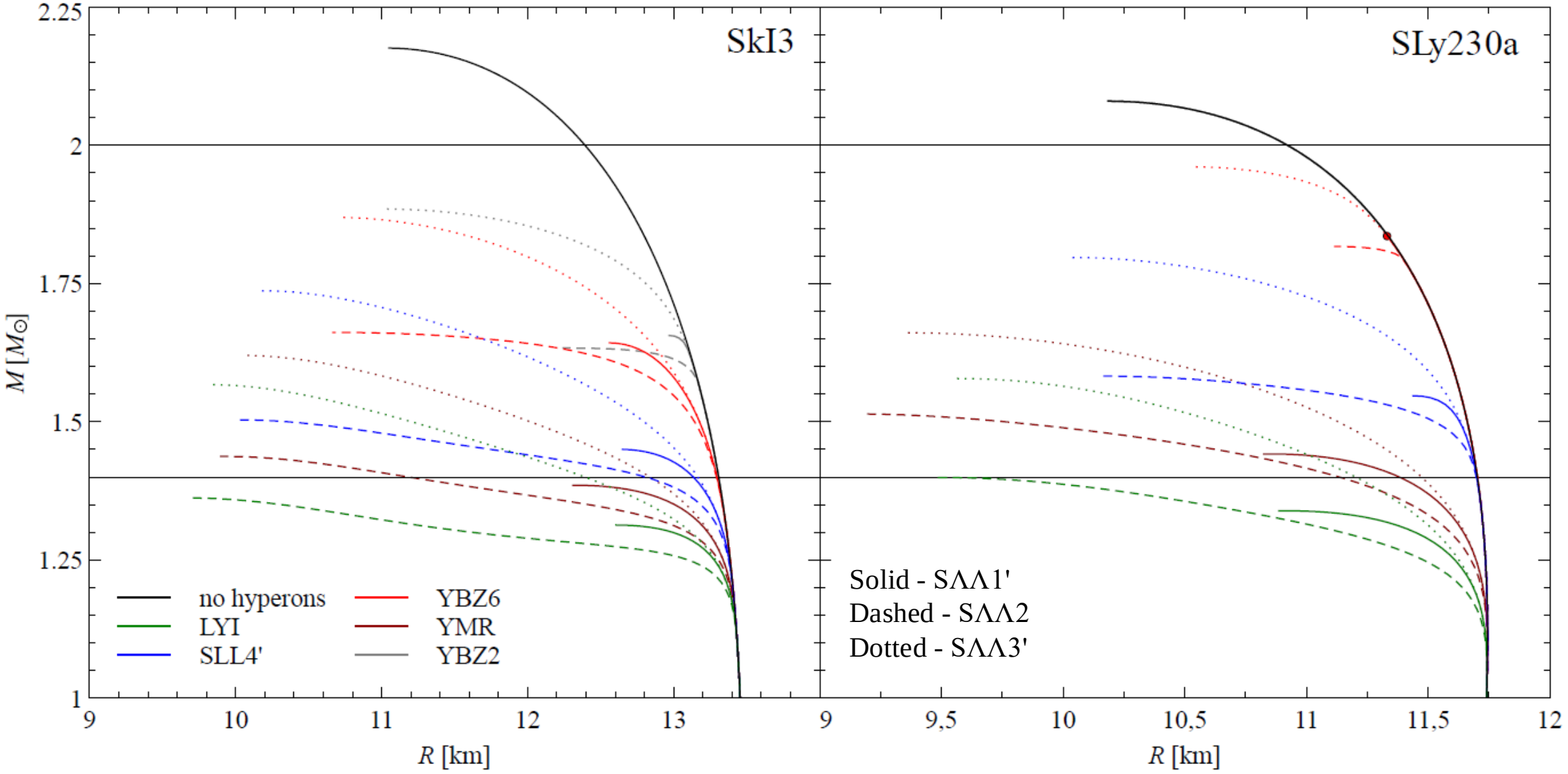
$$D_\Lambda^{cr} = m_\Lambda - m_n - \mu_n .$$

The condition of appearance of hyperons

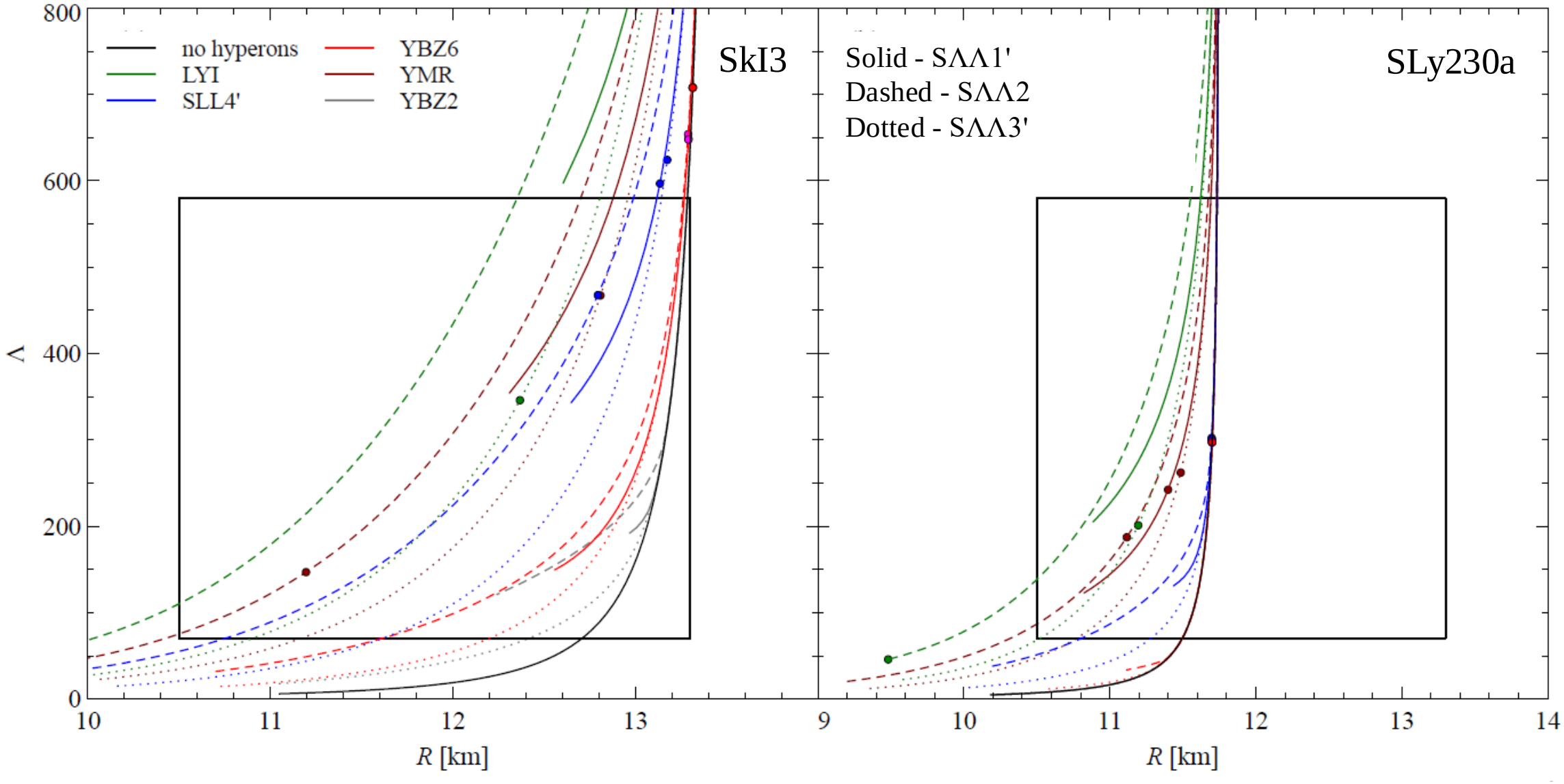
$$D_\Lambda = D_\Lambda^{cr}$$

Л. Т. Имашева, 2019

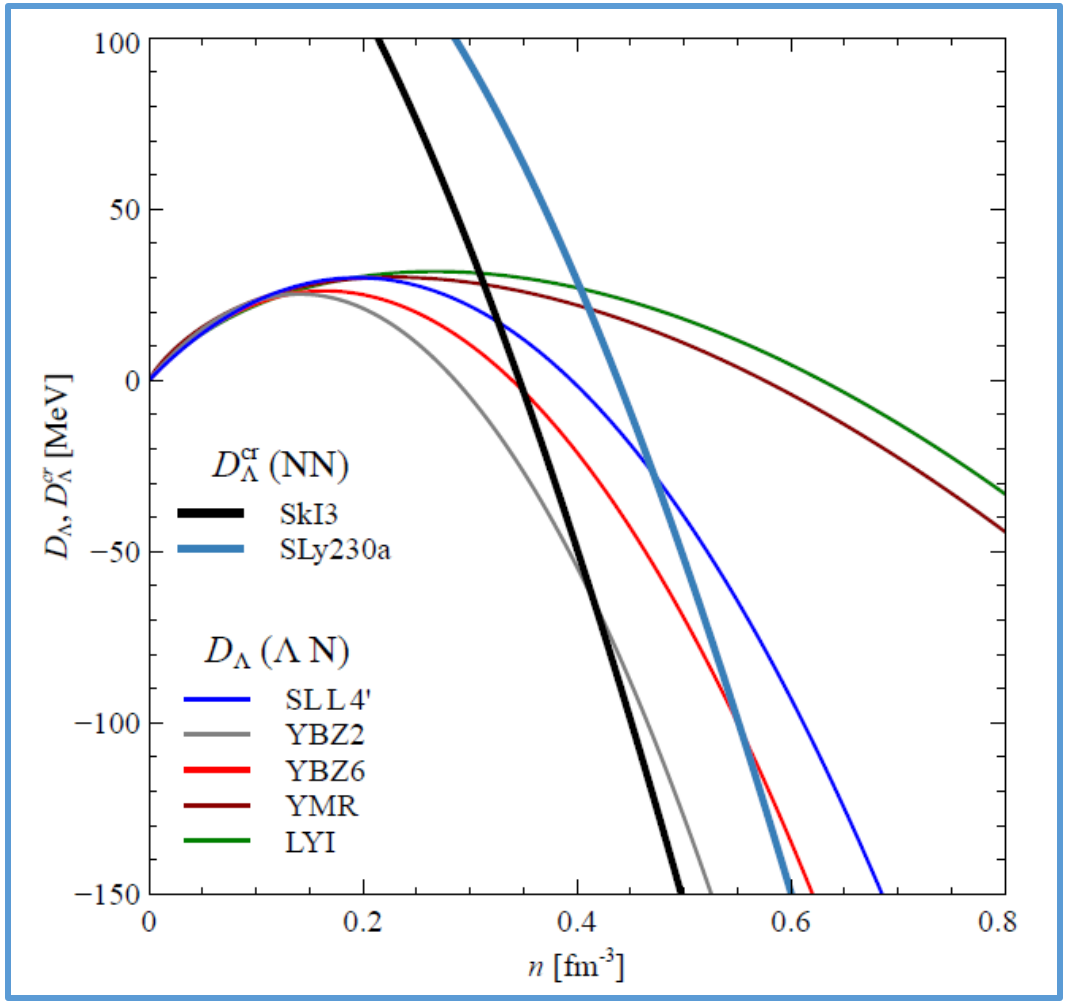
Masses and radii of neutron stars for different baryonic interactions



Dependence of tidal deformability on radius



The point of appearance of hyperons



The binding energy of hyperon in the pure nucleonic matter

$$D_Y = -\mu_Y$$

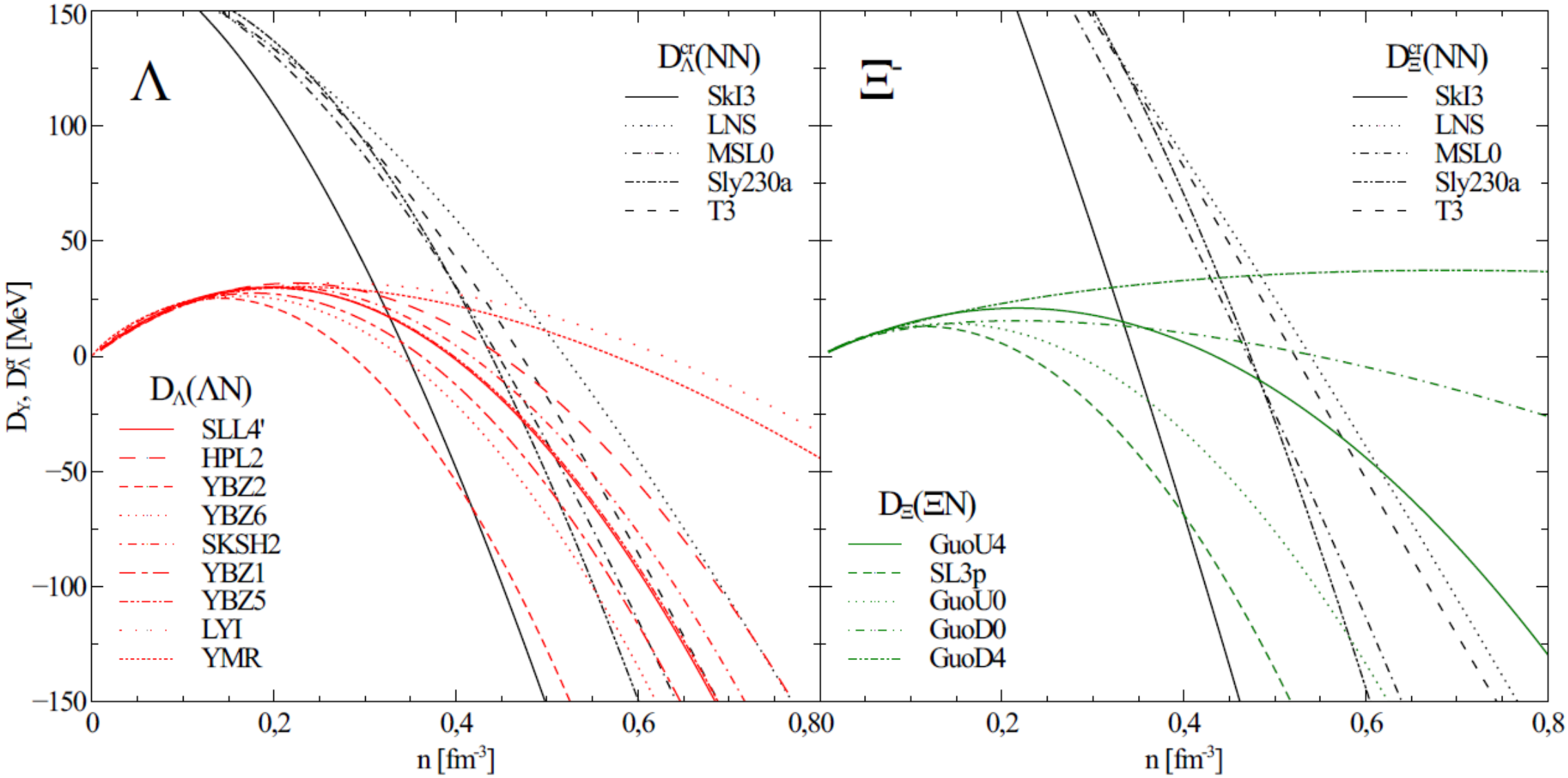
The critical energy of hyperons in the nucleonic matter

$$D_\Lambda^{cr} = m_\Lambda - m_n - \mu_n$$
$$D_{\Xi^-}^{cr} = m_{\Xi^-} - m_n + m_p - \mu_n + \mu_p$$

The condition of appearance of hyperons

$$D_Y = D_Y^{cr}$$

The point of appearance of hyperons

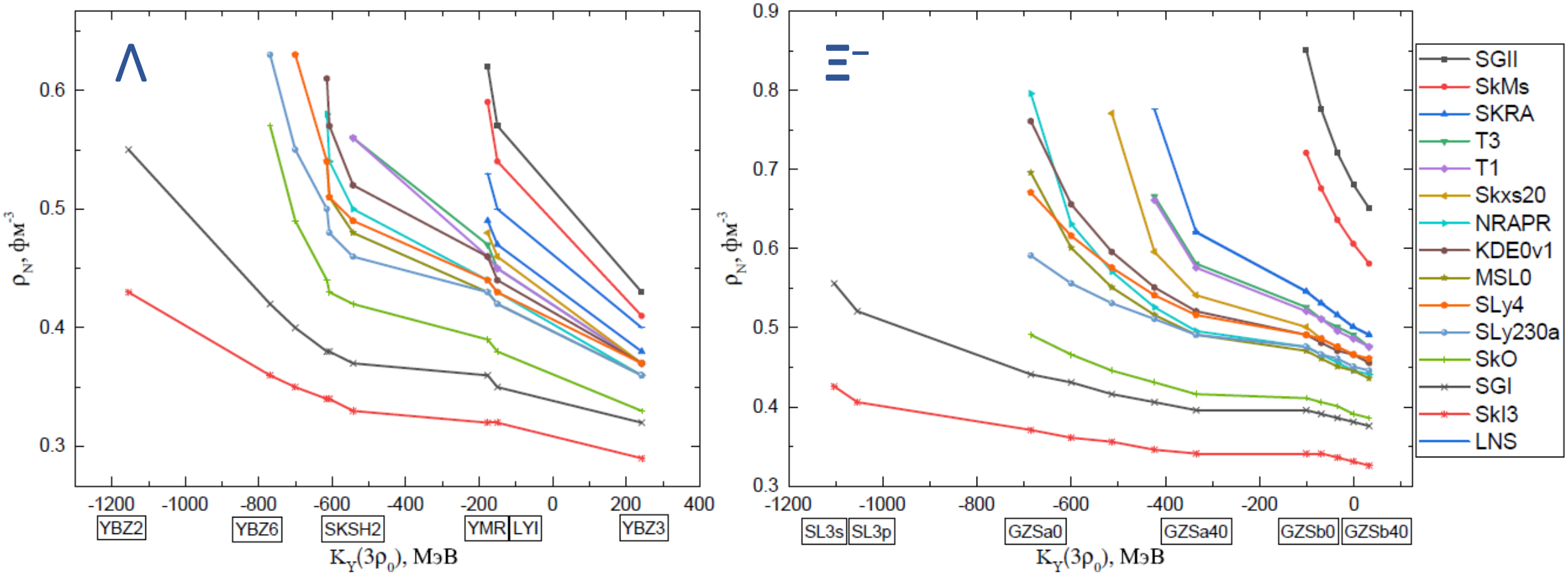


Correlation between density of hyperon appearance and properties of hyperonic interaction

Compression power of YN-interaction

Ланской, Третьякова , ЯФ 1989

$$K_Y = k_F \frac{dD_Y}{dk_F} = 3D_Y - (1 - \frac{m_Y^*}{m_Y})(\frac{6}{5}\frac{\hbar^2}{2m_Y^*}k_0^2) - \frac{9}{8}\gamma u_3 \rho_0^{1+\gamma}$$



Conclusion

- Parameterizations with γ = 1 in the nucleon density dependence in the ΛN interaction are the most suitable for describing neutron stars .
- The point of appearance of hyperons is closely related to the maximum mass of the neutron star and is important for solving the hyperon puzzle.
- There is a strong correlation between the density of appearance of hyperons and the compressive capacity of the hyperon-nucleon interaction

THANK YOU FOR ATTENTION