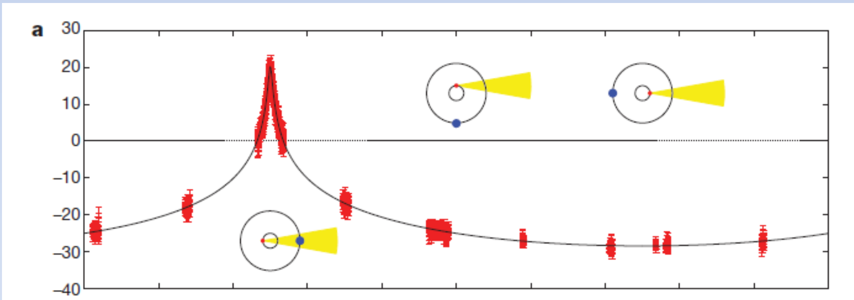
2014/9/25　熱川

ハイペロンパズルとユニバーサル３体斥力

Y. Yamamoto

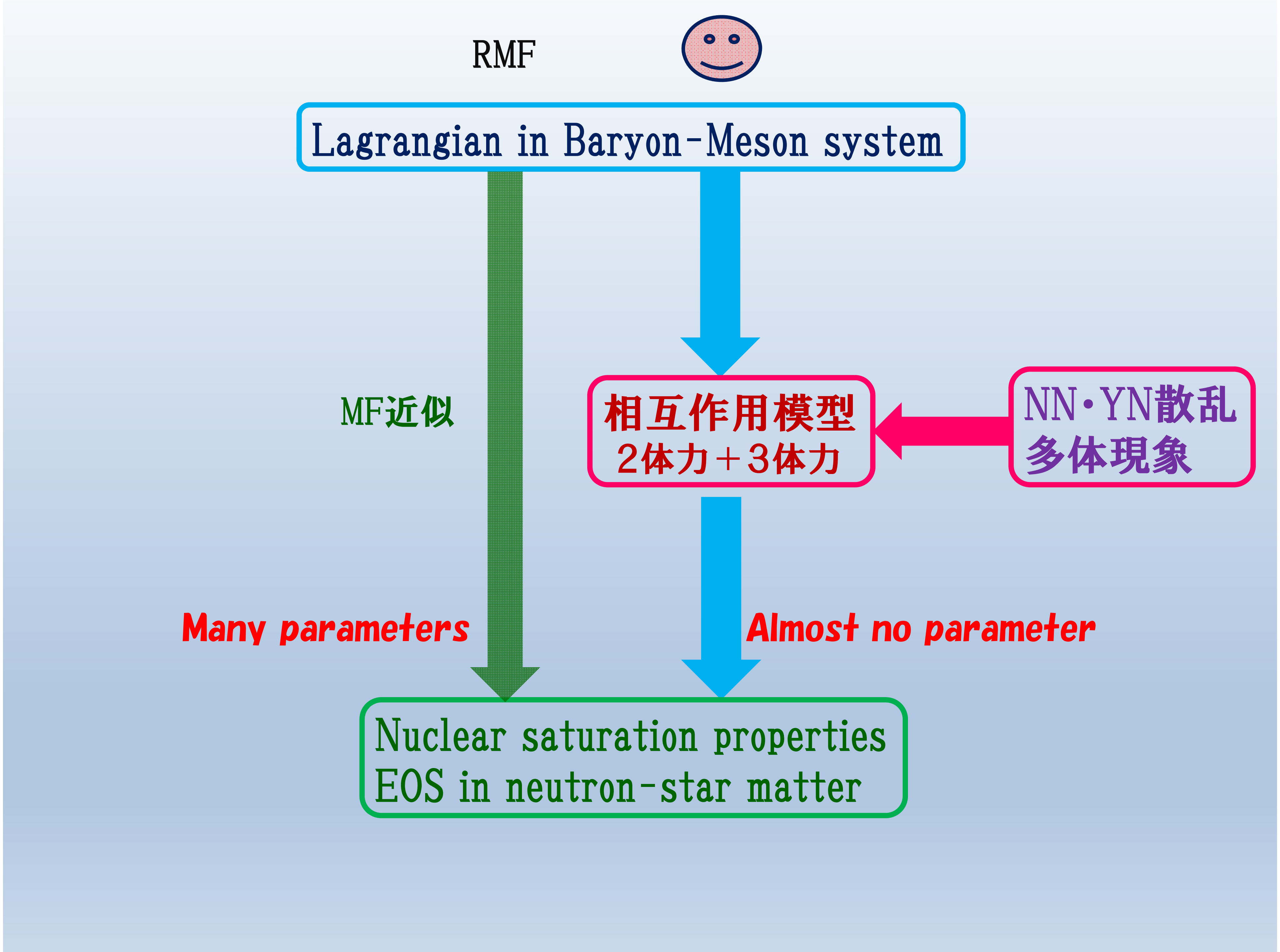
Collaborators:
T. Furumoto
N. Yasutake
Th.A. Rijken

2010　PSR J1614-2230　$(1.97 \pm 0.04) M_{\odot}$



Shapiro delay measurement

2013　PSR J0348-0432　$(2.01 \pm 0.04) M_{\odot}$


RMF
Lagrangian in Baryon-Meson system
MF近似
相互作用模型
2体力＋3体力
NN・YN散乱
多体現象
Many parameters
Almost no parameter
Nuclear saturation properties
EOS in neutron-star matter

核力から核構造

核力は自然認識における重要な結節点である

RMFでHyperon Puzzle は解ける？

2M_{solar}とconsistentなparameter setがあるというだけでパズルが解けたと言えるか？

Our strategy for neutron stars

Neutron-star EOS derived from
Baryon-Baryon interaction model
in relation to **Earth-based experiments**

without ad hoc parameter for stiffness of EOS

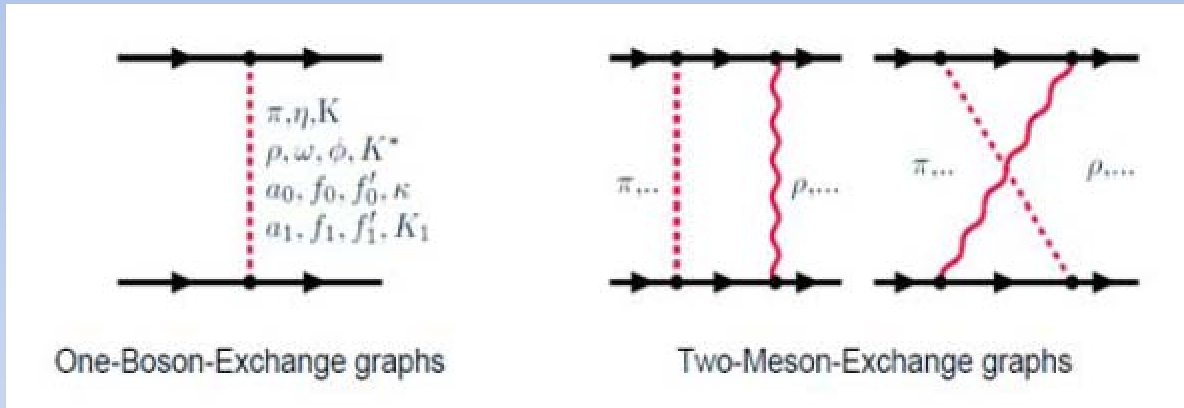
on the basis of G-matrix theory

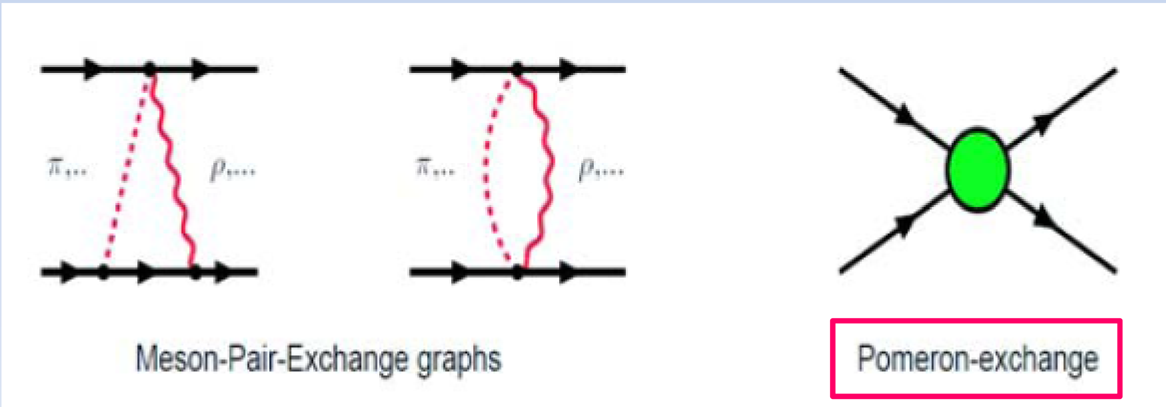
Our story of neutron-star matter
starts from some interaction model

We adopt here Nijmegen ESC model

Extended Soft-Core Model (ESC)

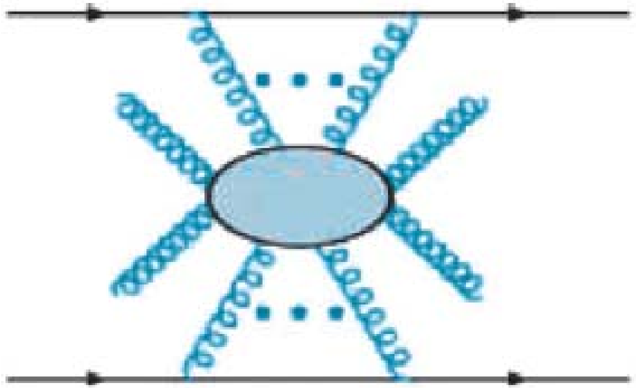
- Two-meson exchange processes are treated explicitly
- Meson-Baryon coupling constants are taken consistently with Quark-Pair Creation model





repulsive cores

What is pomeron?

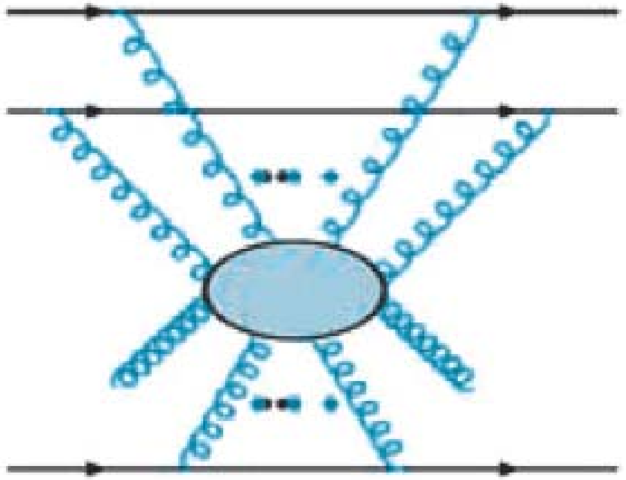


Pomeron-exchange.

g_P

Why pomeron?

SU3 scalar



Triple Pomeron-exchange.

g_{3P}

Pomeron is a model for multi-gluon exchange

ポメロン交換は斥力芯効果に
対する実体論的模型であり
多体斥力効果が自然に導かれる

ざっくり云うと

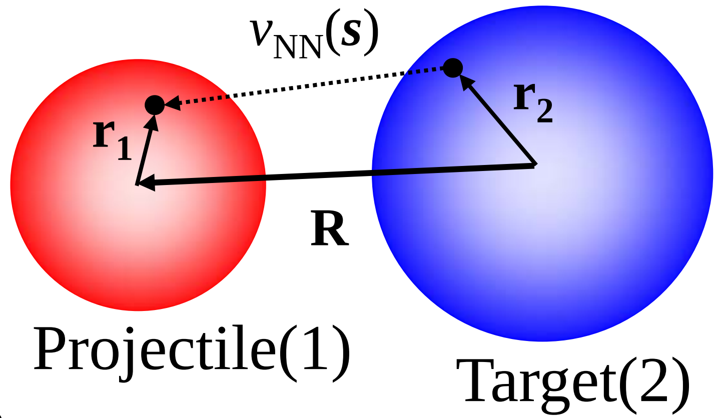
現象論: hard (soft) cores
実体論: ω meson, pomeron, quark Pauli, SJM
本質論: LQCD, ・・・

How to determine coupling constants g_{3P} and g_{4P} ?

⇒ Nucleus-Nucleus scattering data with G-matrix folding potential

Y. Yamamoto, T. Furumoto, N. Yasutake and Th. A. Rijken: Phys. Rev. C **88** (2013) 022801(R).

Double folding Potential



$$U(\mathbf{R}) = \int \rho_1(\mathbf{r}_1)\rho_2(\mathbf{r}_2)v_D(\mathbf{s};\rho,E)\mathrm{d}\mathbf{r}_1\mathrm{d}\mathbf{r}_2$$

$$+\int \rho_1(\mathbf{r}_1,\mathbf{r}_1-\mathbf{s})\rho_2(\mathbf{r}_2,\mathbf{r}_2+\mathbf{s})v_{EX}(\mathbf{s};\rho,E)\exp\left[i\frac{\mathbf{K}\cdot\mathbf{s}}{M}\right]\mathrm{d}\mathbf{r}_1\mathrm{d}\mathbf{r}_2$$

$$=V_{DFM}(\mathbf{R})+iW_{DFM}(\mathbf{R})$$

Frozen-density approx. (FDA)

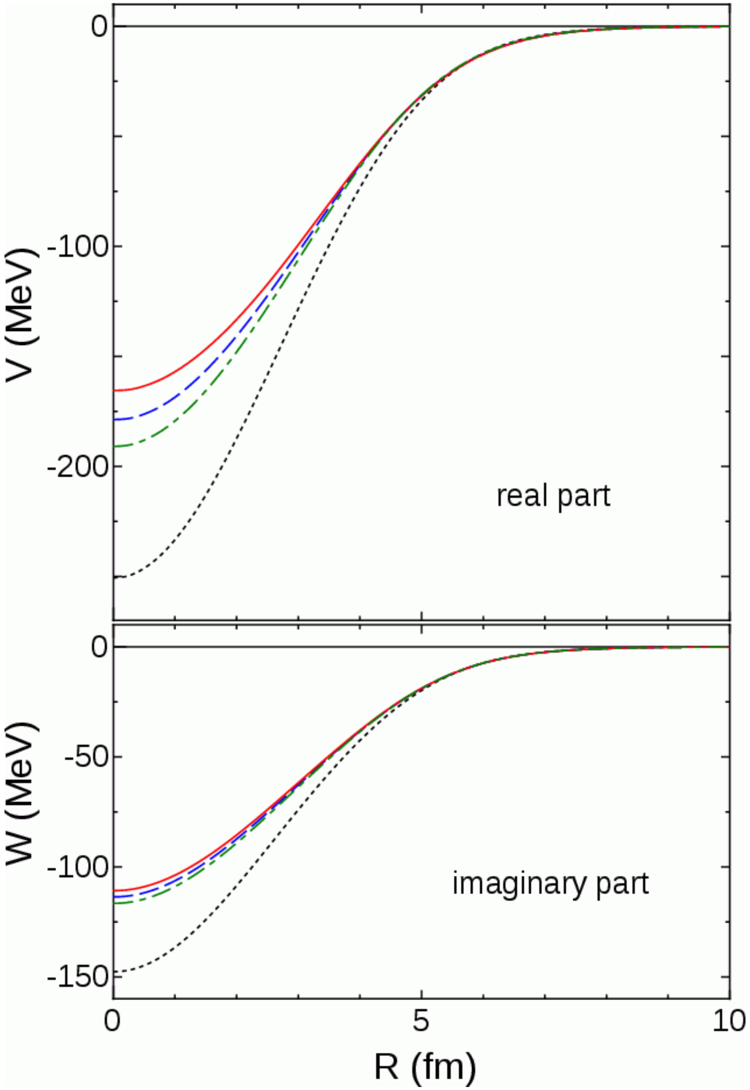
$$\rho = \rho_1 + \rho_2$$

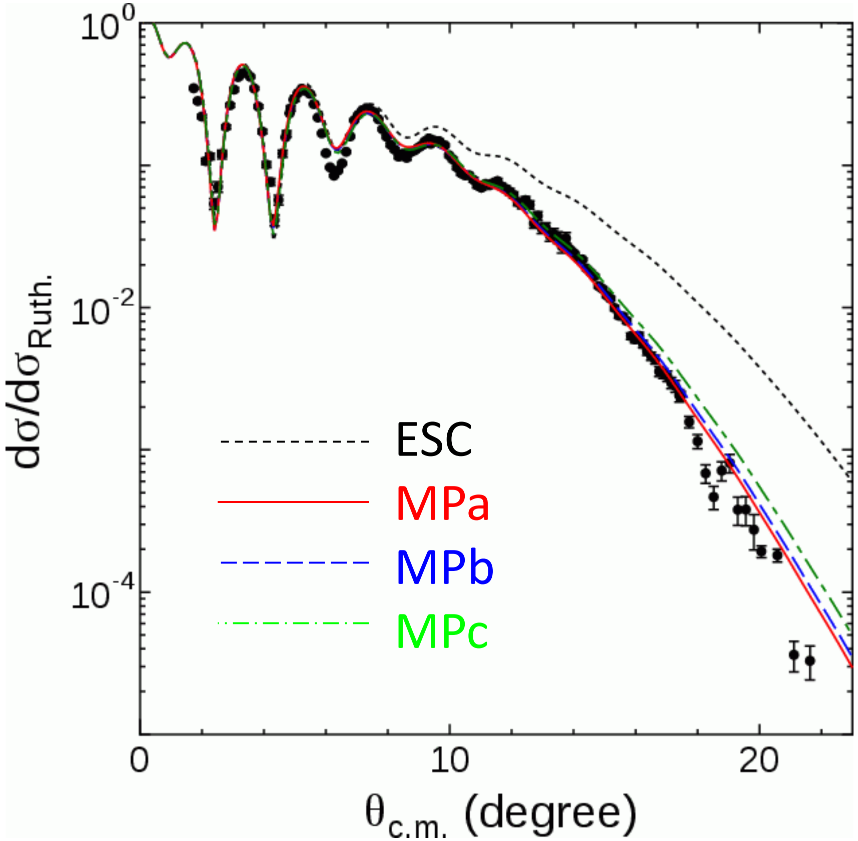
Complex G-matrix interaction (CEG07)

$$v_{D,EX} = v_{D,EX}^{(real)} + iv_{D,EX}^{(imag)}$$

***T. Furumoto**, Y. Sakuragi and Y. Yamamoto, (Phys. Rev. C79 (2009) 011601(R))*
***T. Furumoto**, Y. Sakuragi and Y. Yamamoto, (Phys. Rev. C.80 (2009) 044614)*

$^{16}O + ^{16}O$ elastic scattering cross section at E/A = 70 MeV



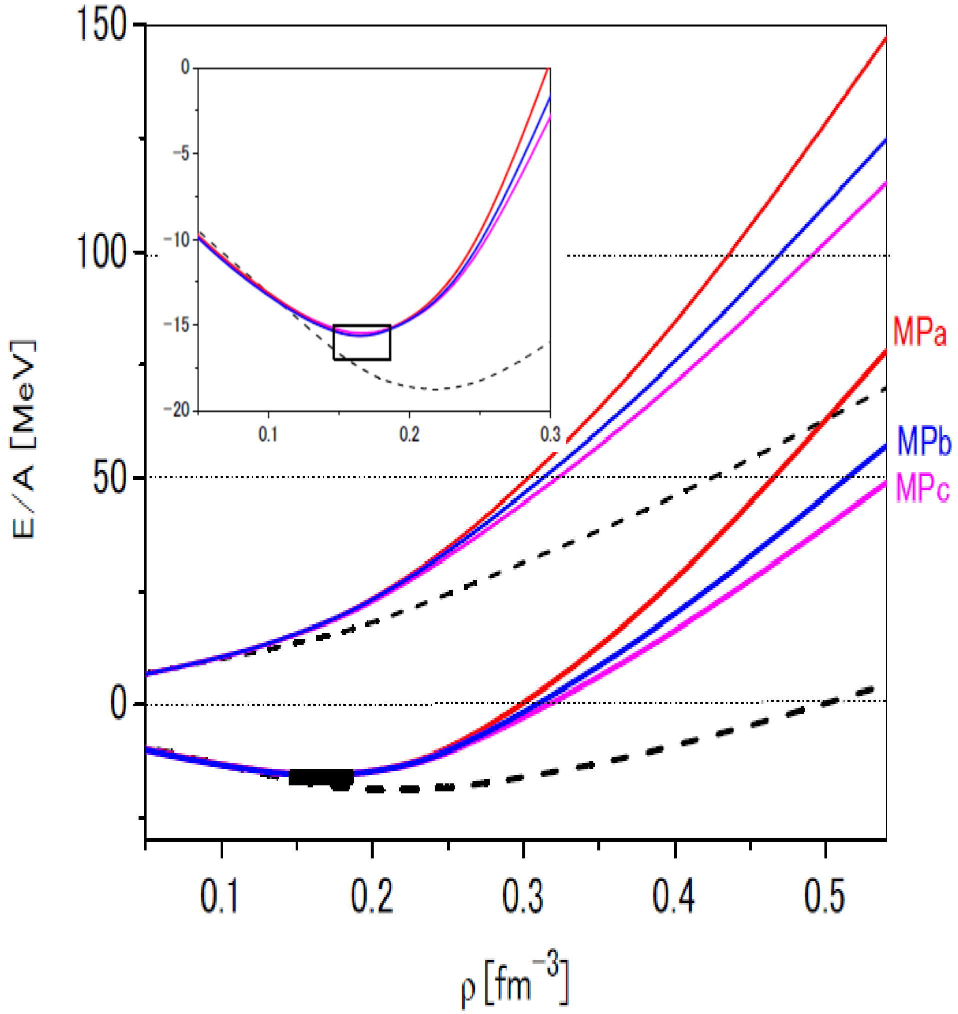


Y. Yamamoto, T. Furumoto, N. Yasutake and Th. A. Rijken, submitted to Phys. Rev. C

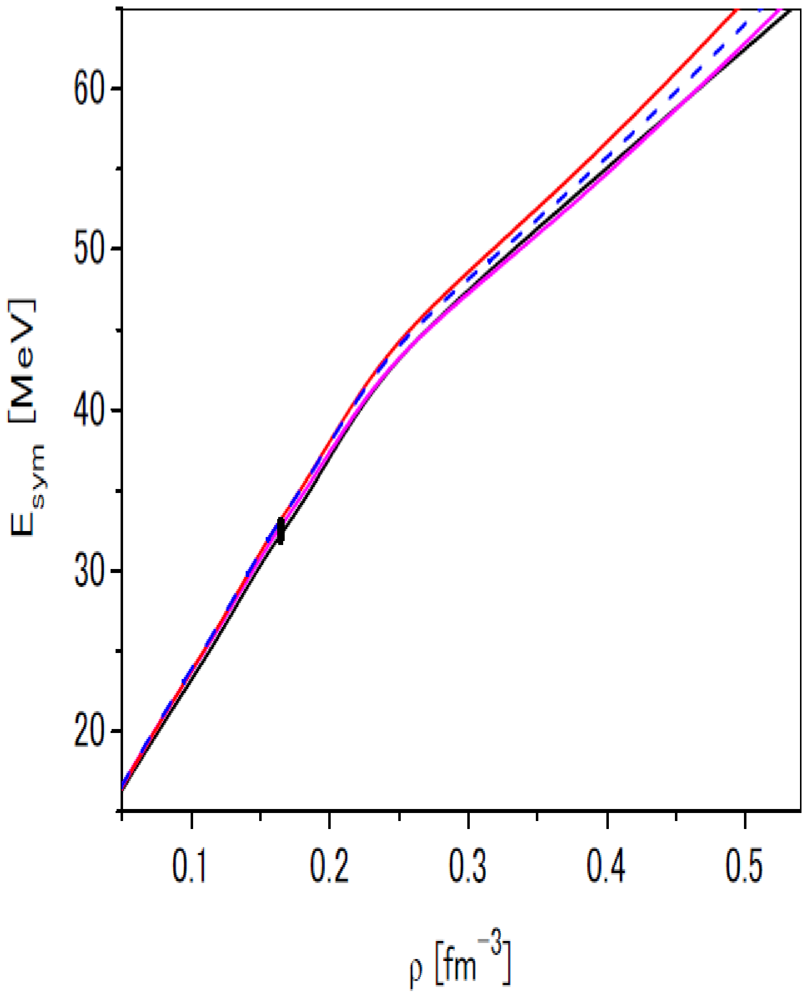
Frozen-Density Approximation
is crucial in our approach！

Two Fermi-spheres separated in momentum space can overlap in coordinate space without disturbance of Pauli principle

E/A curve



Symmetry energy



ESC08c + MPP + TNA

repulsive (MPP) attractive (TNA)

MPP and TNA parts are determined to reproduce
* $^{16}O+^{16}O$ scattering data (E/A=70 MeV)
* nuclear saturation property

$$V_{TNA}(r;\rho) = V_0\ \rho \exp(-\eta\rho) \exp(-(r/2.0)^2)\,(1+P_r)/2$$

phenomenological

V_0 and η are determined so as to reproduce saturation density/energy

	MPP	TNA	
MPa	$(g_P^{(3)}, g_P^{(4)}) = (2.34,\ 30.)$	$V_0 = -32.8$	$\eta = 3.5$
MPb	$(g_P^{(3)}, g_P^{(4)}) = (2.94,\ 0.0)$	$V_0 = -45.0$	$\eta = 5.4$
MPc	$(g_P^{(3)}, g_P^{(4)}) = (2.34,\ 0.0)$	$V_0 = -43.0$	$\eta = 7.3$

Ratio g_{4P}/g_{3P} is not determined in our analysis ---→ three versions MPa/b/c

$$E_{sym}(\rho) = \frac{E}{A}(\rho, \beta = 1) - \frac{E}{A}(\rho, \beta = 0)$$

$$L = 3\rho_0 \left[\frac{\partial E_{sym}(\rho)}{\partial \rho} \right]_{\rho=\rho_0}$$

$$K = 9\rho_0^2 \left[\frac{d^2}{d\rho^2} \frac{E}{A}(\rho, \beta = 0) \right]_{\rho=\rho_0}$$

$$\beta = \frac{\rho_n - \rho_p}{\rho_n + \rho_p}$$

$E/A(\rho_0) = -15.8$ (MPa/b), -15.5 (MPc) MeV at $\rho_0 = 0.16\ \mathrm{fm}^{-3}$

$E_{sym}(\rho_0) = 33.1$ MeV $L(\rho_0) = 70.4$ MeV $K = 310$ MeV for MPa

$E_{sym}(\rho_0) = 33.1$ MeV $L(\rho_0) = 69.2$ MeV $K = 280$ MeV for MPb

$E_{sym}(\rho_0) = 32.7$ MeV $L(\rho_0) = 67.1$ MeV $K = 260$ MeV for MPc

AV8' +UIX : E_{sym}=35.1 MeV L=63.6 MeV (Gandolfi et al.)

Medium effect in high density region probed by nucleus-nucleus elastic scattering

T. Furumoto,[1,*] Y. Sakuragi,[2] and Y. Yamamoto[3]

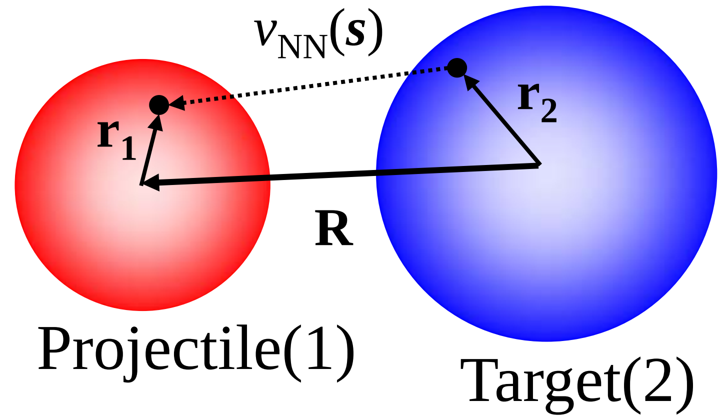
PRC (R) accepted

The paper contains some warnings about the use of others widely accepted folding-like methods like JLM. It is important and timely for the community to start a discussion on this subject.

by the referee

crucial role of the TBF effect up to $k_F = 1.6$ fm^{-1}

Double folding Potential



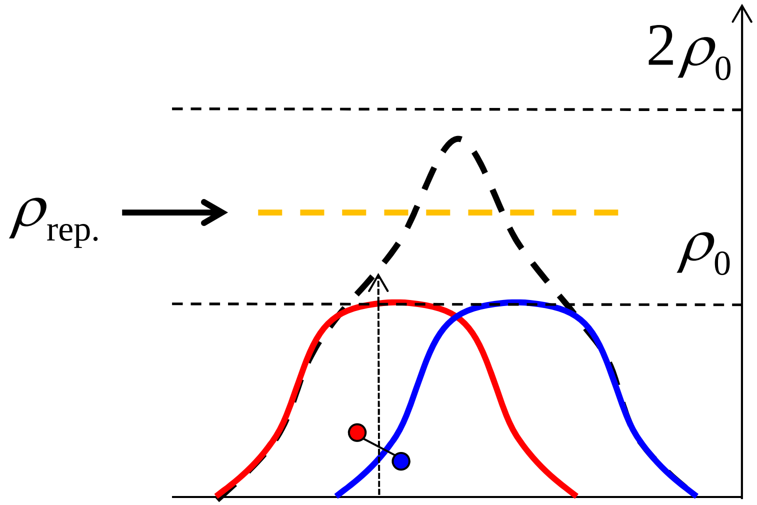
$$U_{DFM}(\mathbf{R}) = V_{DFM}(\mathbf{R}) + iW_{DFM}(\mathbf{R})$$

$$U(\mathbf{R}) = \int \rho_1(\mathbf{r}_1)\rho_2(\mathbf{r}_2) v_{NN}^{(D)}(\mathbf{s};\rho,E)\mathrm{d}\mathbf{r}_1\mathrm{d}\mathbf{r}_2$$

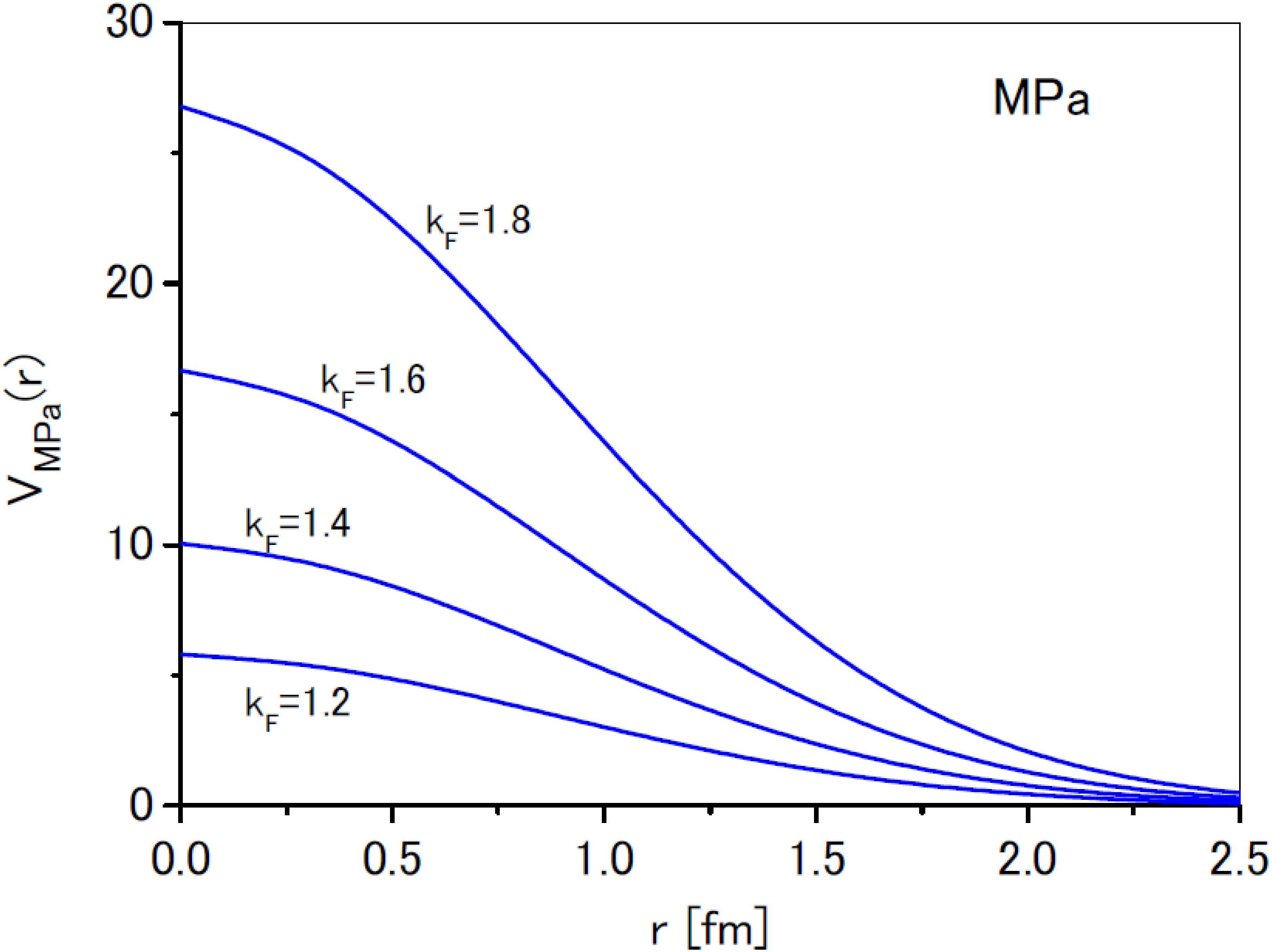
$$+\int \rho_1(\mathbf{r}_1,\mathbf{r}_1-\mathbf{s})\rho_2(\mathbf{r}_2,\mathbf{r}_2+\mathbf{s}) v_{NN}^{(EX)}(\mathbf{s};\rho,E)\exp\left[i\frac{\mathbf{K}\cdot\mathbf{s}}{M}\right]\mathrm{d}\mathbf{r}_1\mathrm{d}\mathbf{r}_2$$

replace the interaction

$$v = \begin{cases} \text{MPa} \ \ (\rho = \rho_1 + \rho_2 \le \rho_{\text{rep.}}) \\ \text{ESC} \ \ (\rho = \rho_1 + \rho_2 > \rho_{\text{rep.}}) \end{cases}$$

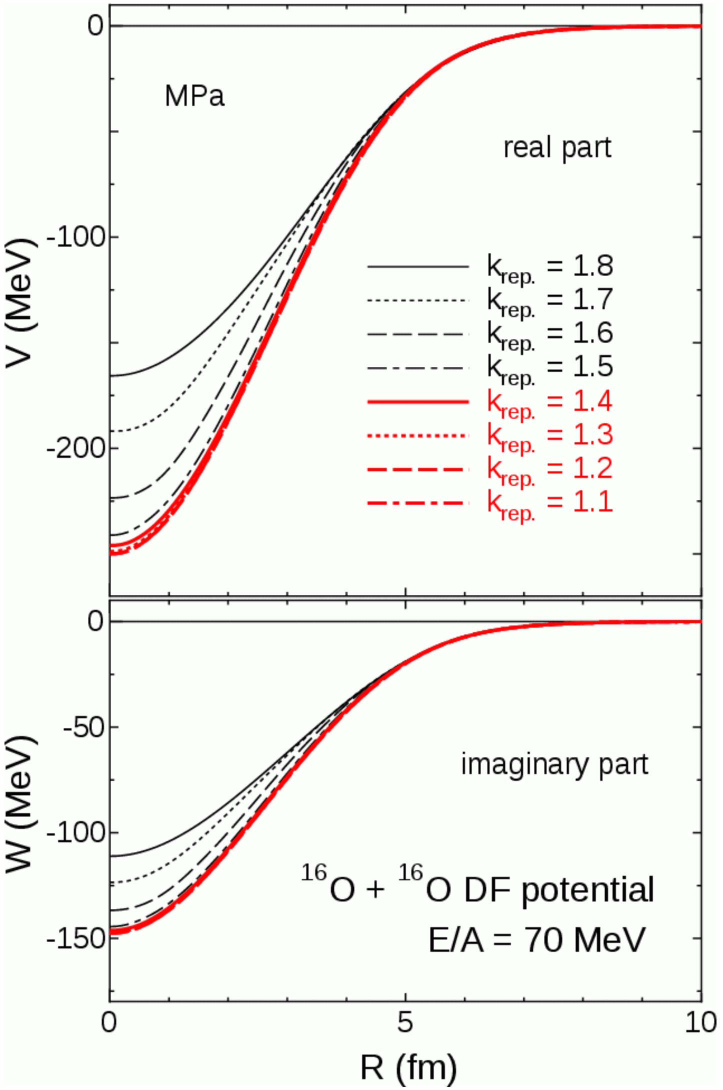


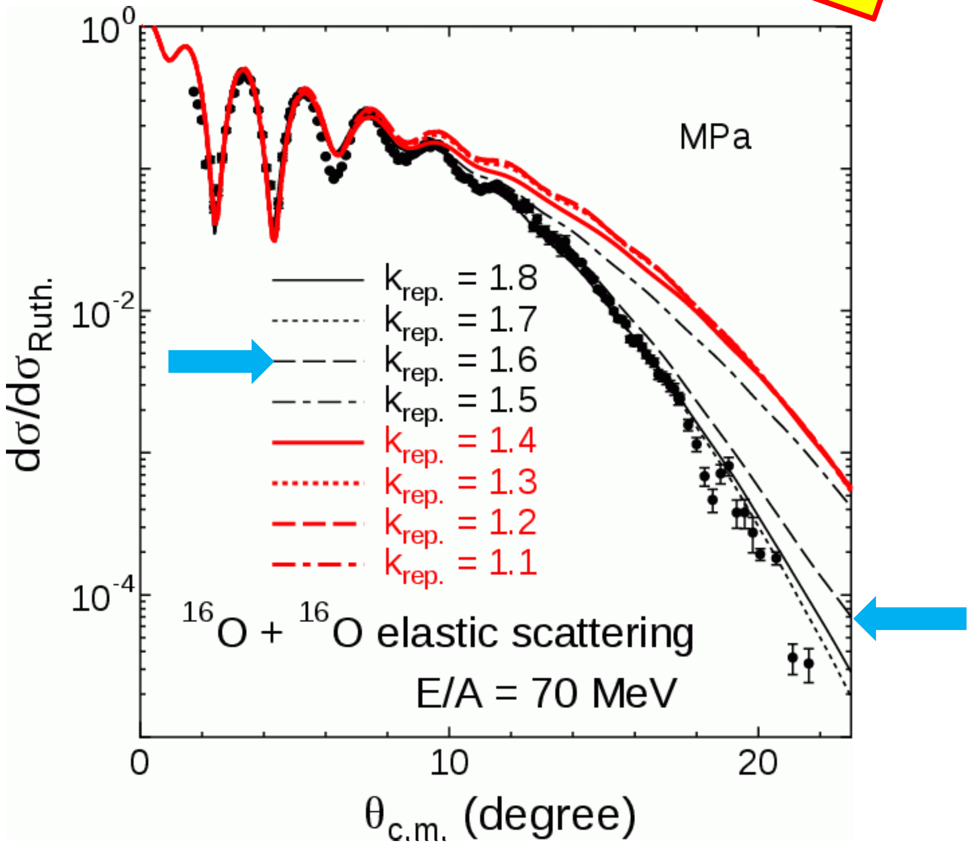
Effective two-body potential derived from MPP



$^{16}O + ^{16}O$ elastic scattering cross section at E/A = 70 MeV

MPa





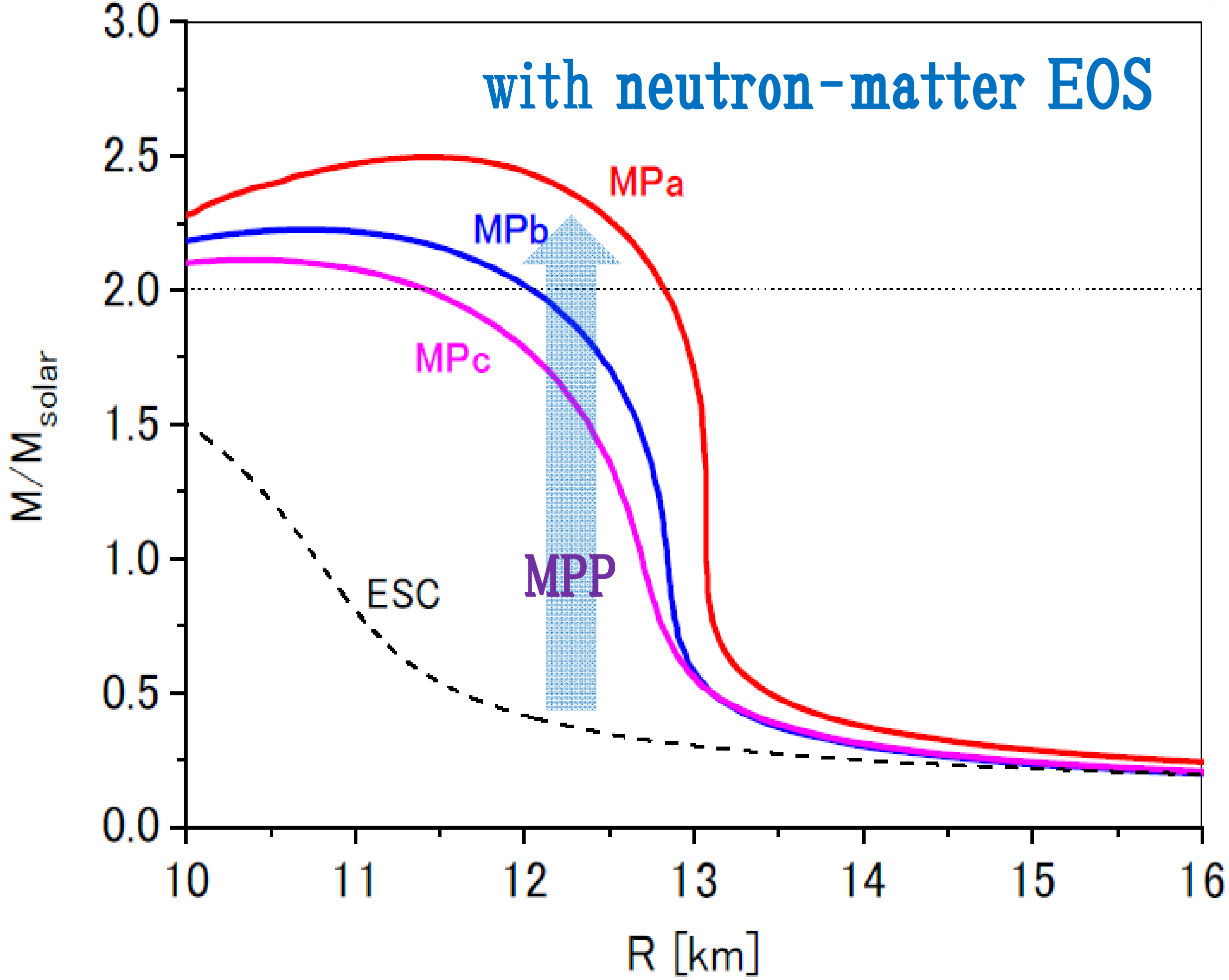
T. Furumoto, Y. Sakuragi and Y. Yamamoto, accepted as Rapid Com. in Phys. Rev. C

Medium effect including TBF effect **in high density region**

- needs up to k_F = 1.6-1.7 fm^{-1} for heavy-ion elastic scattering

Path to high-density EOS

by solving TOV eq.



No ad hoc parameter to adjust stiffness of EOS

MPa : K=310 MeV
MPb : K=280 MeV
MPc : K=260 MeV

^{16}O-^{16}O scattering data

Hyperon-Mixed Neutron-Star Matter

ESC08c	defined in S=0,-1,-2 channels
MPP	universal in all BB channels
TNA	TBA ???

(ESC08c+MPP+TBA) model should be tested in hypernuclei

hyperonic sector

Massive ($2M_{\odot}$) neutron stars

Softening of EOS by hyperon mixing

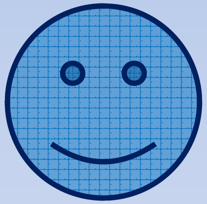
Hyperon puzzle !

An idea is Universal Three-Baryon Repulsion (TBR)
by Takatsuka

Modeling of TBR in ESC = Multi-Pomeron exchange Potential hypernuclei ↔ ? ↔ neutron star

YN interactions based on hypernuclear study

→ Hyperon mixing in neutron-star matter



Λ & Σ states based on
ESC08c + MPP + TBA

↑

TNA

Y-nucleus folding potential derived from YN G-matrix interaction $G(r; k_F)$

$$
\begin{aligned}
U_Y(\mathbf{r},\mathbf{r}') &= U_{dr} + U_{ex} \\
U_{dr} &= \delta(\mathbf{r}-\mathbf{r}') \int d\mathbf{r}'' \rho(\mathbf{r}'') V_{dr}(|\mathbf{r}-\mathbf{r}''|; \langle k_F \rangle) \\
U_{ex} &= \rho(\mathbf{r},\mathbf{r}') V_{ex}(|\mathbf{r}-\mathbf{r}'|; \langle k_F \rangle) \\
V_{dr} &= \frac{1}{2(2t_Y+1)(2s_Y+1)} \sum_{TS} (2T+1)(2S+1)[G_{TS}^{(+)} + G_{TS}^{(-)}] \\
V_{ex} &= \frac{1}{2(2t_Y+1)(2s_Y+1)} \sum_{TS} (2T+1)(2S+1)[G_{TS}^{(+)} - G_{TS}^{(-)}]
\end{aligned}
$$

G-matrix interactions

Averaged-k_F Approximation

$$
\langle \rho \rangle = \langle \phi_Y(r) | \rho(r) | \phi_Y(r) \rangle
$$

$$
\langle k_F \rangle = (1.5\pi^2 \langle \rho \rangle)^{1/3}
$$

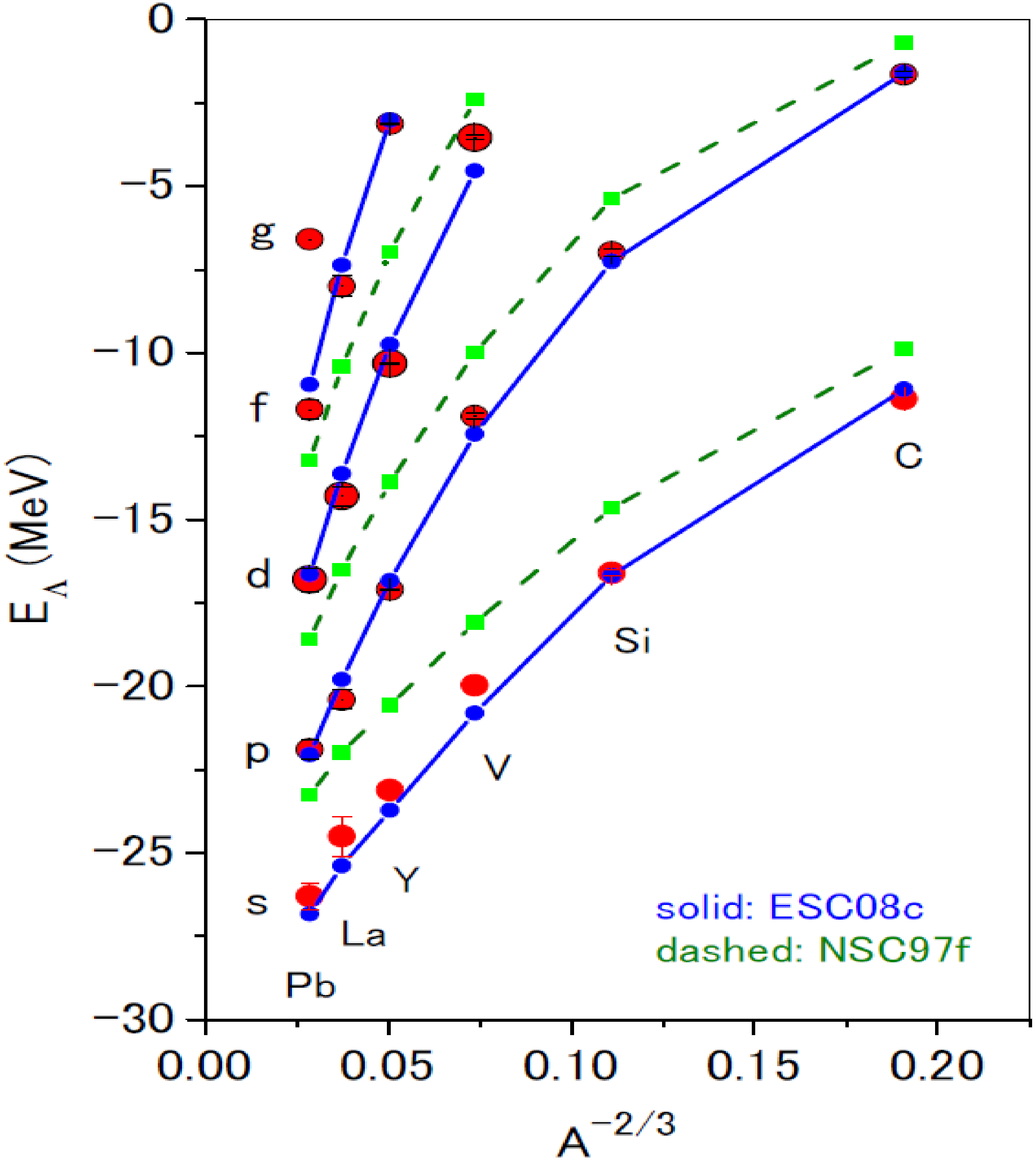
calculated self-consistently

Mixed density $\rho(\mathbf{r}_1,\mathbf{r}_2) = \sum_j \varphi_j^*(\mathbf{r}_1)\varphi_j(\mathbf{r}_2)$ obtained from SkHF w.f.

ESC08cとNSC97fから導かれるG-matrix interactionの比較
（同じnucleon spectraを用いる）

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Λ	$U_{\sigma\sigma}$	m^*_Λ
ESC08c	-13.3	-26.7	2.6	0.2	1.8	-3.2	-1.6	-40.0	1.09	0.73
NSC97f	-14.6	-25.0	2.3	0.4	3.7	-0.8	-1.3	-35.4	1.56	0.67

- ○ 違いはodd statesにある （高密度では大きな差）
- ○ ESC08cはIsakaの計算で用いられたバージョン



同じ条件の下では
ESC08cはNSC98f
より優れている

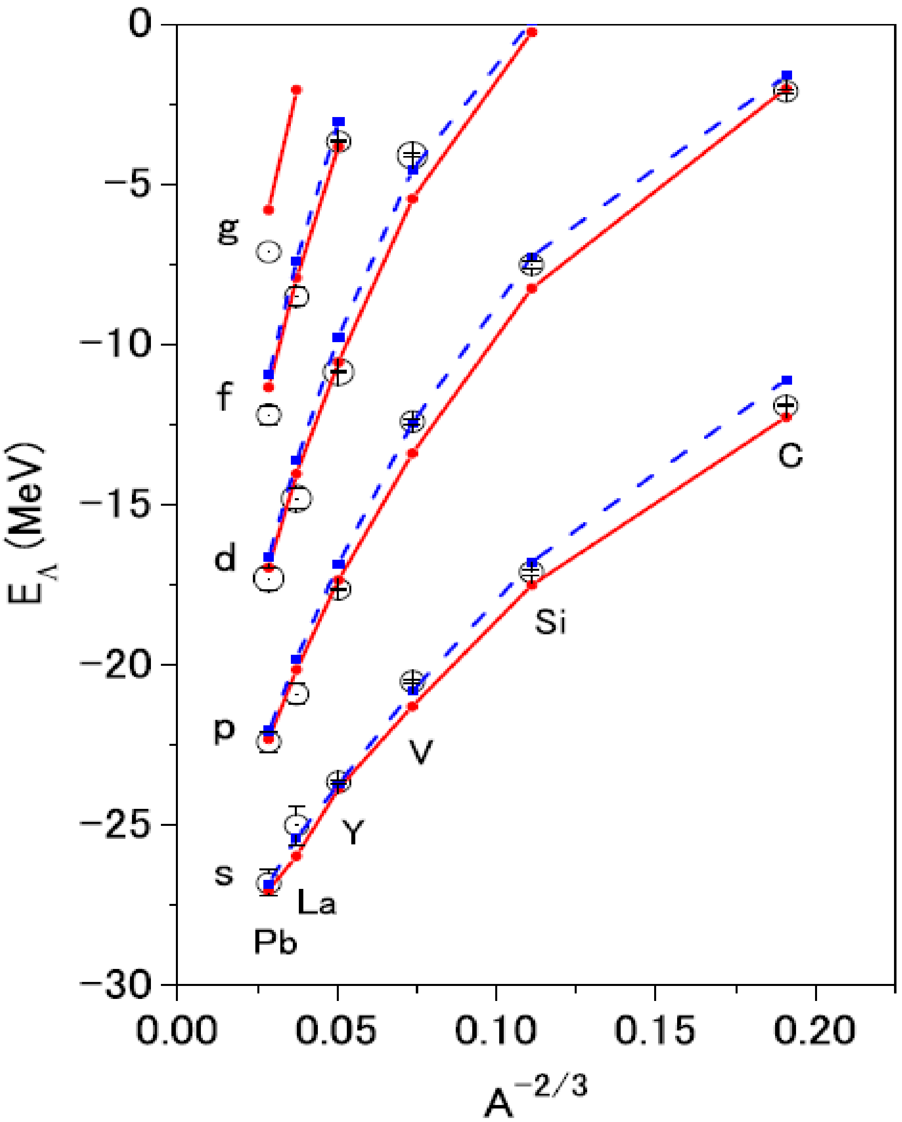
様々なYN相互作用模型(ND/NF, NSC89, NSC97, JA/JB,･･･)

自然な同一条件(nucleon spectrum等)で比較すれば多くはリジェクトされる

相互作用模型の違いは中性子星における onset densityに反映される

従来使われたND、NF、NSC89、NSC97eは
それぞれにまずい点を有している

Our Case



	s	p	d	f
exp	−23.7	−17.6	−10.9	−3.7
MPa	−23.8	−17.4	−10.6	−3.8
ESC	−23.7	−16.8	−9.8	−3.0

	${}^{13}_{\Lambda}$C	${}^{12}_{\Lambda}$B
exp	−11.9	−11.4
MPa	−12.3	−11.6
ESC	−11.1	−10.4

Strong density dependence by (MPP+TBA)

→ mass-dependence of B_Λ

YNN3体力効果を検証するためには
精密で系統的なBΛの実験値と
対応する理論計算が必要である

RMF model におけるhyperon sectorへのinput

$U_{\Lambda}^{(N)} = -30 \text{ MeV}$	-40.0
$U_{\Sigma}^{(N)} = +30 \text{ MeV}$	+15.2
$U_{\Xi}^{(N)} = -18 \text{ MeV}$	-1.2

G-matrix with ESC08c

U_YのみがYN interactionの指標ではない
Density dependence, Effective Mass, etc

Quark-Pauli effect in ESC08 models

ESC core = pomeron + ω

Repulsive cores are similar to each other in all channels

Assuming
"equal parts" of ESC and QM are similar to each other

Almost Pauli-forbidden states in [51] are taken into account by changing the pomeron strengths for the corresponding channels phenomenologically

$$g_P \longrightarrow \text{factor} * g_P$$

by Oka-Shimizu-Yazaki

Table III. $SU(6)_{fs}$-contents of the various potentials on the isospin, spin basis.

(S,I)	$V = aV_{[51]} + bV_{[33]}$
$(0,1)$	$V_{NN} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$(1,0)$	$V_{NN} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$(0,1/2)$	$V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$(1,1/2)$	$V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$(0,1/2)$	$V_{\Sigma\Sigma} = \frac{17}{18}V_{[51]} + \frac{1}{18}V_{[33]}$
$(1,1/2)$	$V_{\Sigma\Sigma} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$(0,3/2)$	$V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$(1,3/2)$	$V_{\Sigma\Sigma} = \frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}$

(S,I)	$V = aV_{[51]} + bV_{[33]}$
$(0,0)$	$V_{\Lambda\Lambda,\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$(0,0)$	$V_{\Xi N,\Xi N} = \frac{1}{3}V_{[51]} + \frac{2}{3}V_{[33]}$
$(0,0)$	$V_{\Sigma\Sigma,\Sigma\Sigma} = \frac{11}{18}V_{[51]} + \frac{7}{18}V_{[33]}$
$(0,1)$	$V_{\Xi N,\Xi N} = \frac{7}{9}V_{[51]} + \frac{2}{9}V_{[33]}$
$(0,0)$	$V_{\Sigma\Lambda,\Sigma\Lambda} = \frac{2}{3}V_{[51]} + \frac{1}{3}V_{[33]}$
$(0,2)$	$V_{\Sigma\Sigma,\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$(1,0)$	$V_{\Xi N,\Xi N} = \frac{5}{9}V_{[51]} + \frac{4}{9}V_{[33]}$
$(1,1)$	$V_{\Xi N,\Xi N} = \frac{17}{27}V_{[51]} + \frac{10}{27}V_{[33]}$
$(1,1)$	$V_{\Sigma\Lambda,\Sigma\Lambda} = \frac{2}{3}V_{[51]} + \frac{1}{3}V_{[33]}$
$(1,1)$	$V_{\Sigma\Sigma,\Sigma\Sigma} = \frac{16}{27}V_{[51]} + \frac{11}{27}V_{[33]}$

Pauli-forbidden state in $V_{[51]}$ → strengthen pomeron coupling

$$V_{BB} = V(\mathrm{pom}) + w_{BB}[51] * V(\mathrm{PB})$$

Table 1: Values of U_Σ at normal density and partial wave contributions for ESC08c models (in MeV).

model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ
ESC08c	1/2	10.9	−21.6	2.4	2.1	−6.0	−1.0	−0.7	
	3/2	−13.5	31.0	−4.7	−1.8	5.9	−1.5	−0.2	+1.2

Pauli-forbidden state in QCM ➔ strong repulsion in T=3/2 $^3S_1$ state

↓

Σ^- in neutron matter

U_{Σ^-} = +15.2 MeV

Events of twin Λ hypernuclei in emulsion

E176 events

Event I (most probable mode) [1]

(A) $\Xi^- + {}^{12}\mathrm{C} \to {}^{9}_{\Lambda}\mathrm{Be} + {}^{4}_{\Lambda}\mathrm{H} \quad (B_{\Xi^-} = 0.82 \pm 0.17\ \mathrm{MeV})$,

(B) $\Xi^- + {}^{12}\mathrm{C} \to {}^{9}_{\Lambda}\mathrm{Be} + {}^{4}_{\Lambda}\mathrm{H}^* \quad (B_{\Xi^-} = -0.23 \pm 0.17\ \mathrm{MeV})$,

Event II (three possibilities) [2]

(A) $\Xi^- + {}^{12}\mathrm{C} \to {}^{9}_{\Lambda}\mathrm{Be} + {}^{4}_{\Lambda}\mathrm{H} \quad (B_{\Xi^-} = 3.89 \pm 0.14\ \mathrm{MeV})$,

(B) $\Xi^- + {}^{12}\mathrm{C} \to {}^{9}_{\Lambda}\mathrm{Be}^* + {}^{4}_{\Lambda}\mathrm{H} \quad (B_{\Xi^-} = 0.82 \pm 0.14\ \mathrm{MeV})$,

(C) $\Xi^- + {}^{12}\mathrm{C} \to {}^{9}_{\Lambda}\mathrm{Be} + {}^{4}_{\Lambda}\mathrm{H}^* \quad (B_{\Xi^-} = 2.84 \pm 0.15\ \mathrm{MeV})$,

(D) $\Xi^- + {}^{12}\mathrm{C} \to {}^{9}_{\Lambda}\mathrm{Be}^* + {}^{4}_{\Lambda}\mathrm{H}^* \quad (B_{\Xi^-} = -0.19 \pm 0.15\ \mathrm{MeV})$,

木曽イベント

$$\Xi^- + {}^{14}\mathrm{N} \to {}^{10}_{\Lambda}\mathrm{Be} + {}^{5}_{\Lambda}\mathrm{He}$$

(A) ${}^{10}_{\Lambda}\mathrm{Be}$ in ground state $(B_{\Xi^-} = 3.82 \pm 0.18\mathrm{MeV})$,

(B) ${}^{10}_{\Lambda}\mathrm{Be}$ in excitation of 2.68MeV $(B_{\Xi^-} = 1.14 \pm 0.18\mathrm{MeV})$

G-matrix folding model

$\Xi^- + {}^{12}C$

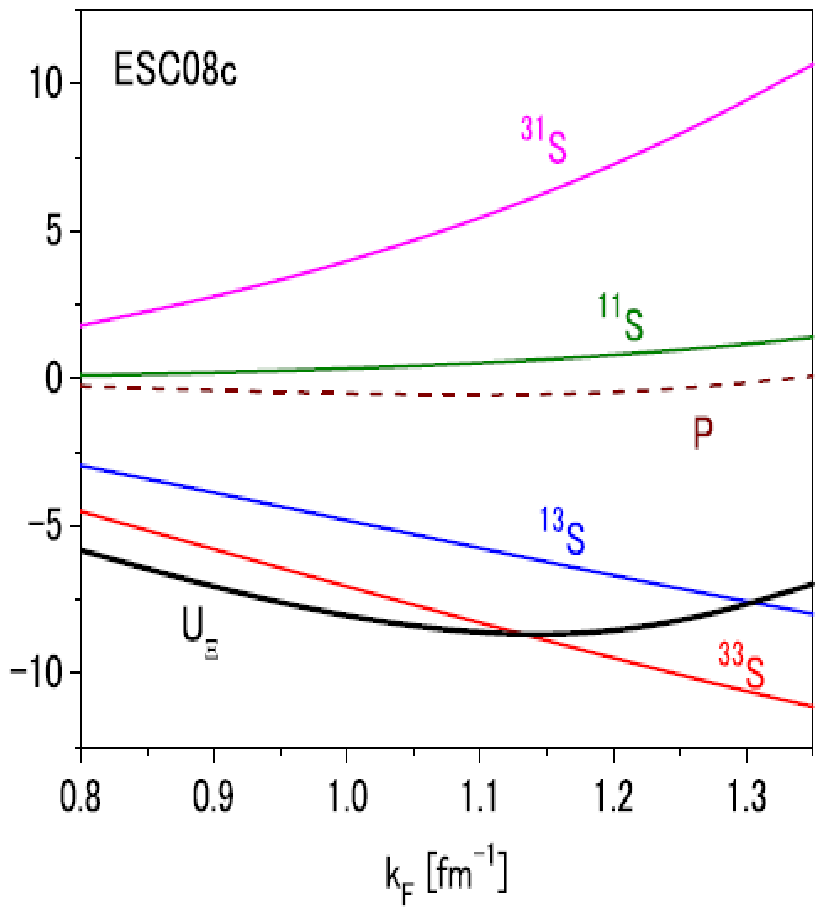
		ESC08c	Ehime	exp
$1S$	B_{Ξ^-}	3.83	5.10	
	Γ_{Ξ^-}	1.49	0.21	
	$\sqrt{\langle r^2 \rangle}$	3.34	3.18	
	$\bar{k}_F$	1.16	1.22	
$2P$	B_{Ξ^-}	0.68	0.82	0.82 ± 0.17
	Γ_{Ξ^-}	0.44	0.13	
	$\sqrt{\langle r^2 \rangle}$	7.54	6.92	
	$\bar{k}_F$	0.84	0.75	

$\Xi^- + {}^{14}N$

		ESC08c	Ehime	exp
$1S$	B_{Ξ^-}	4.82	5.45	
	Γ_{Ξ^-}	1.87	0.25	
	$\sqrt{\langle r^2 \rangle}$	3.18	3.18	
	$\bar{k}_F$	1.19	1.25	
$2P$	B_{Ξ^-}	1.22	1.17	1.14 ± 0.18
	Γ_{Ξ^-}	0.77	0.17	
	$\sqrt{\langle r^2 \rangle}$	5.66	6.17	
	$\bar{k}_F$	0.93	0.80	

Table 1: $U_\Xi(\rho_0)$ and partial wave contributions for ESC08c calculated with the CON choice. Γ^c_Ξ denotes ΞN-$\Lambda\Lambda$ conversion width. all entries are in MeV.

T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ^c_Ξ
0	1.4	−8.0	−0.3	1.8	1.4	−2.1		
1	10.7	−11.1	1.1	0.7	−2.6	−0.0	−7.0	4.5



U_{Ξ^-} = −1.2 MeV
in neutron matter

Hyperon-mixed Neutron-Star matter with universal TBR (MPP)

EoS of $n+p+\Lambda+\Sigma+e+\mu$ system

ESC08c(YN) + MPP(YNN) +TBA(YNN)

Hyperon-mixed neutron matter

Starting from single particle potentials calculated with the G-matrix theory:

$$U_B(k) = \sum_{B'} U_B^{(B')}(k) \quad \text{with} \quad B, B' = n, p, \Lambda, \Sigma^-$$

$U_B^{(B')}$ means a single particle potential of B particle in B' matter

$$\begin{aligned}
\varepsilon &= \varepsilon_{mass} + \varepsilon_{kin} + \varepsilon_{pot} \\
&= 2\sum_B \int_0^{k_F^B} \frac{d^3k}{(2\pi)^3} \left[M_B - M_n + \frac{\hbar^2 k^2}{2M_B} + \frac{1}{2} U_B(k) \right]
\end{aligned}$$

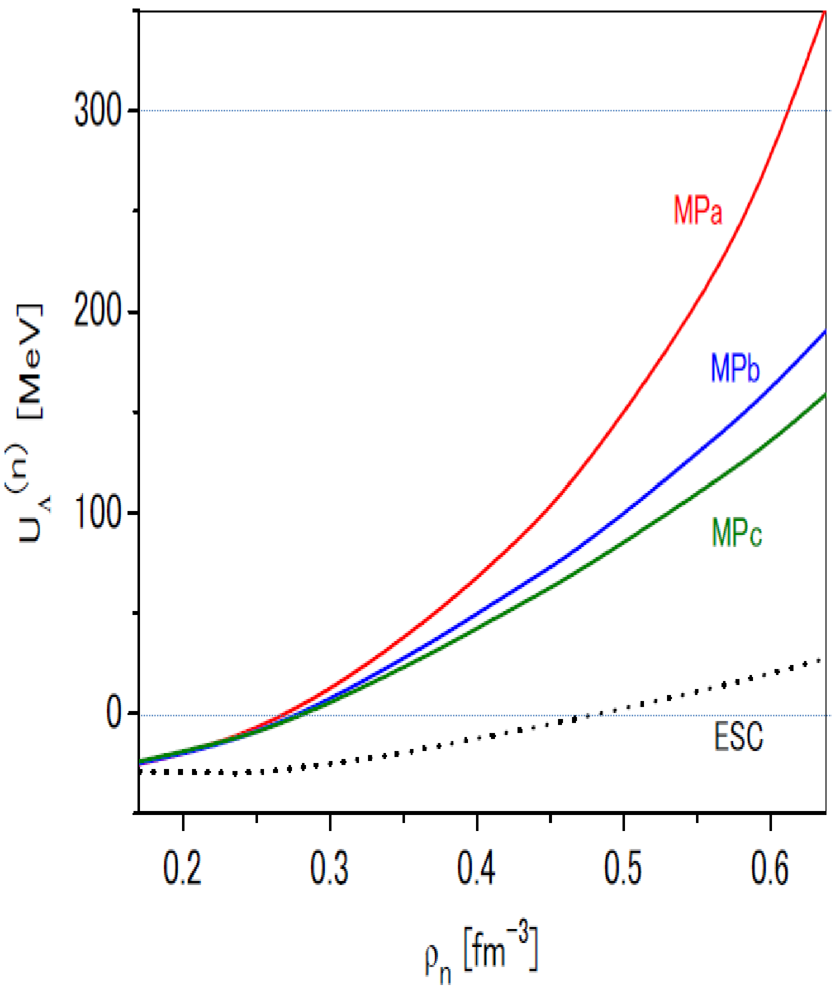
$$\varepsilon_{mass} = \sum_B (M_B - M_n)\rho_B$$

$$\varepsilon_{kin} = \sum_B \frac{3}{5} \frac{\hbar^2 (k_F^B)^2}{2M_B} \rho_B = \sum_B \frac{3}{5} \frac{\hbar^2}{2M_B} (3\pi^2)^{2/3} (\rho_B)^{5/3}$$

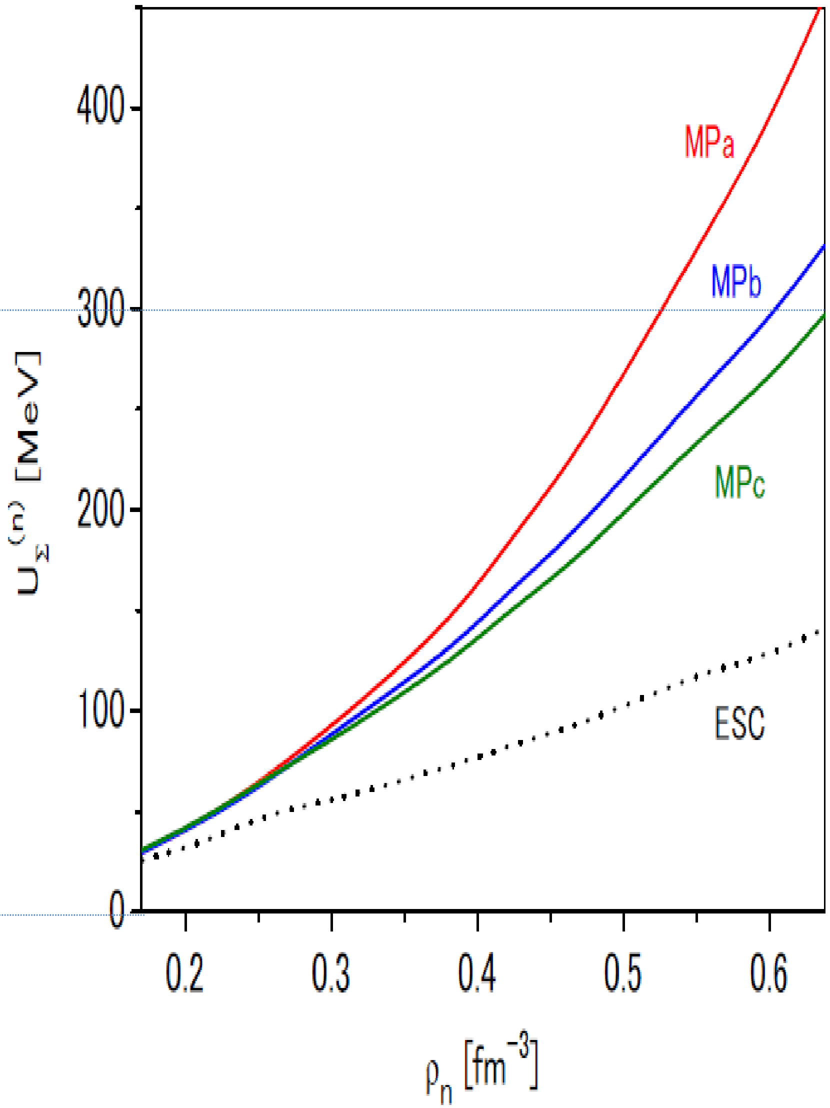
$$\varepsilon_{pot} = 2\sum_B \int_0^{k_F^B} \frac{d^3k}{(2\pi)^3} \frac{1}{2} U_B(k) = \frac{1}{2} \sum_B \int_0^{k_F^B} \frac{k^2 dk}{\pi^2} U_B(k)$$

Chemical potential : $\mu_B = \frac{\partial \varepsilon}{\partial \rho_B}$

$U_Y^{(n)}(\rho_n)$



Λ+neutron matter



Σ^-+neutron matter

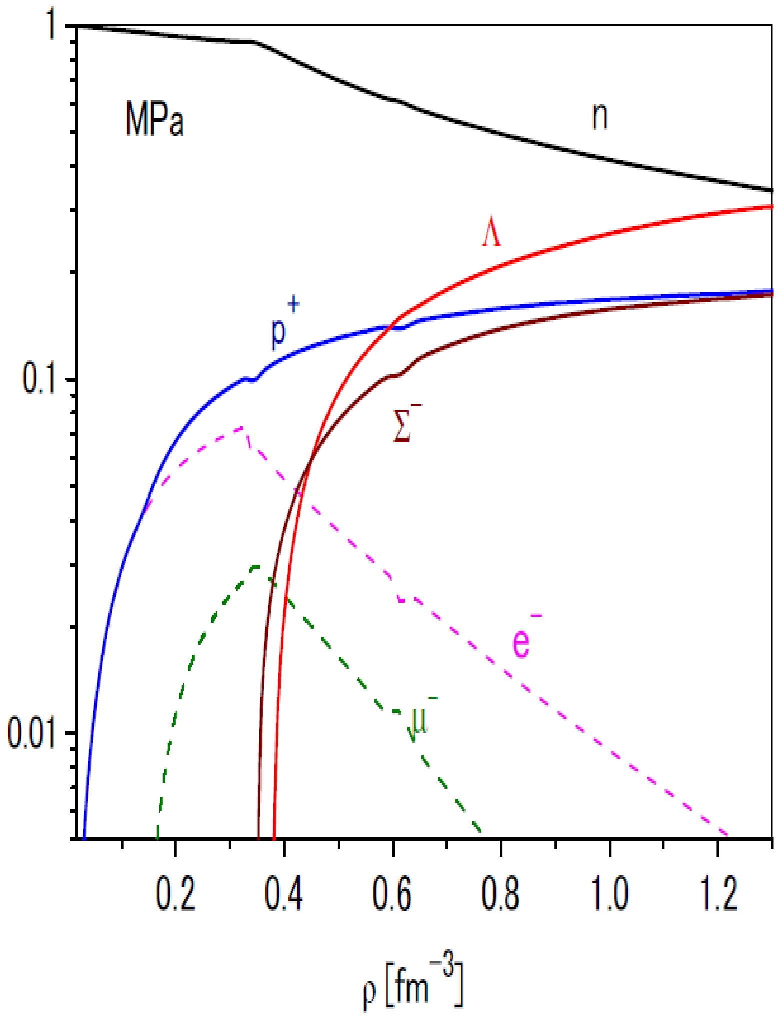
Chemical potential : $\mu_B = \frac{\partial \varepsilon}{\partial \rho_B}$

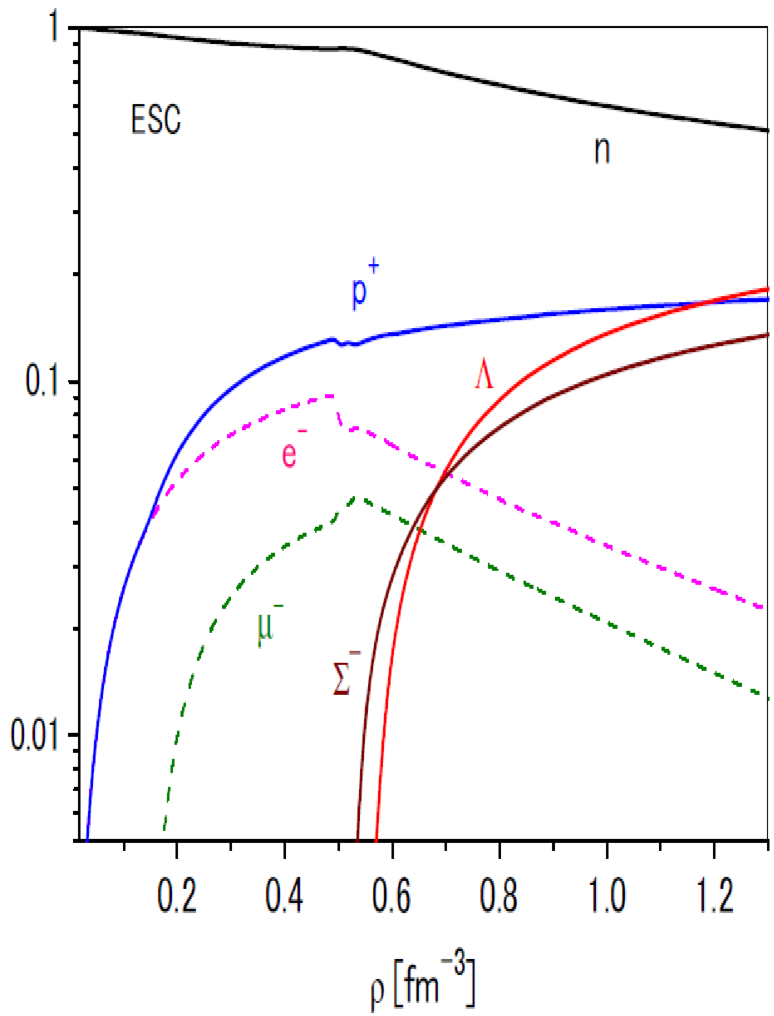
Chemical equilibrium conditions:

$$
\begin{aligned}
\mu_n &= \mu_p + \mu_e \\
\mu_e &= \mu_\mu \\
\mu_{\Sigma^-} &= \mu_n + \mu_e \\
\mu_\Lambda &= \mu_n
\end{aligned}
$$

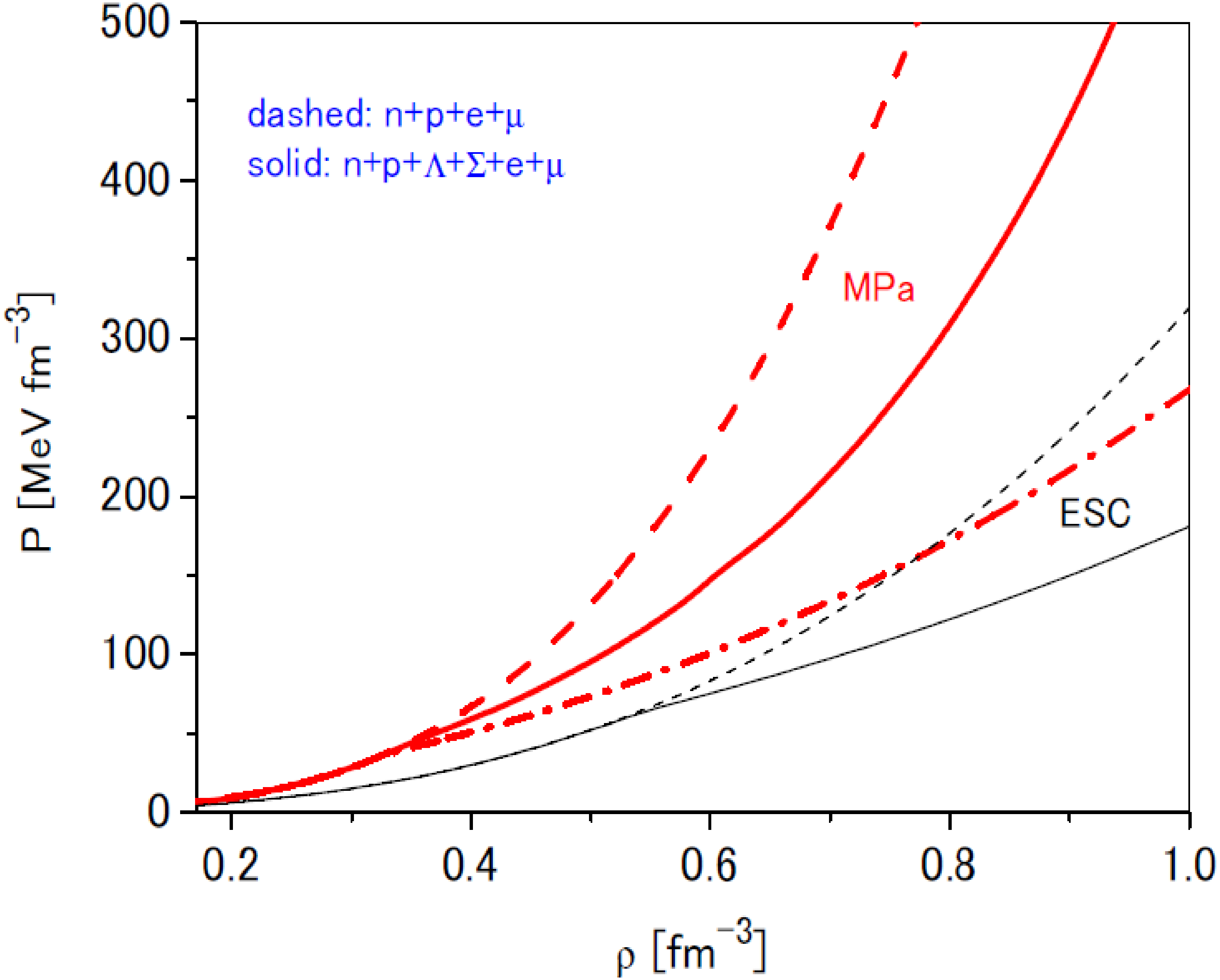
Baryon-number conservation : $y_n + y_p + y_\Lambda + y_{\Sigma^-} = 1$
Charge neutrality : $y_p = y_{\Sigma^-} + y_e + y_\mu$

β-stable n+p+Λ+Σ^- matter

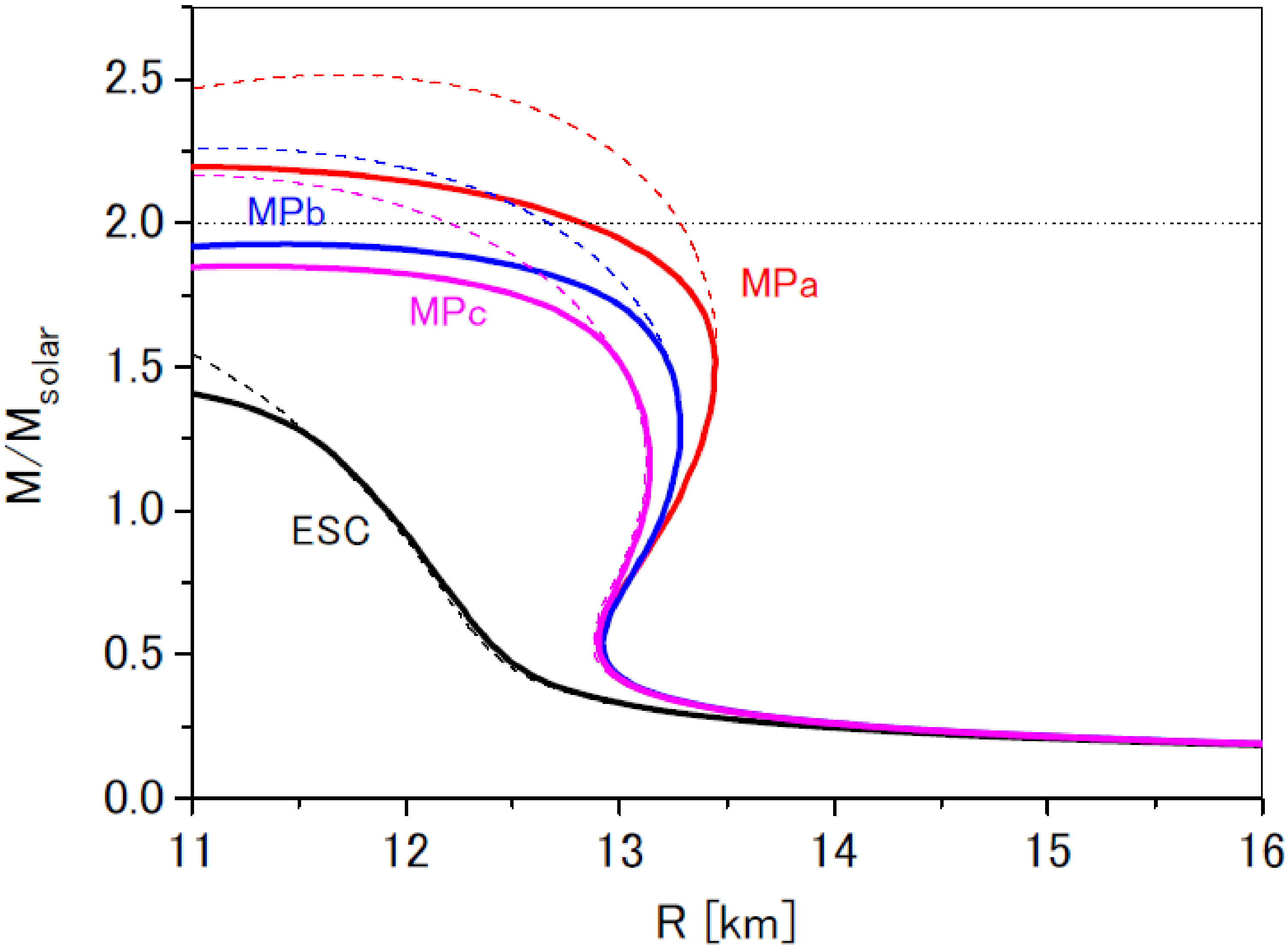




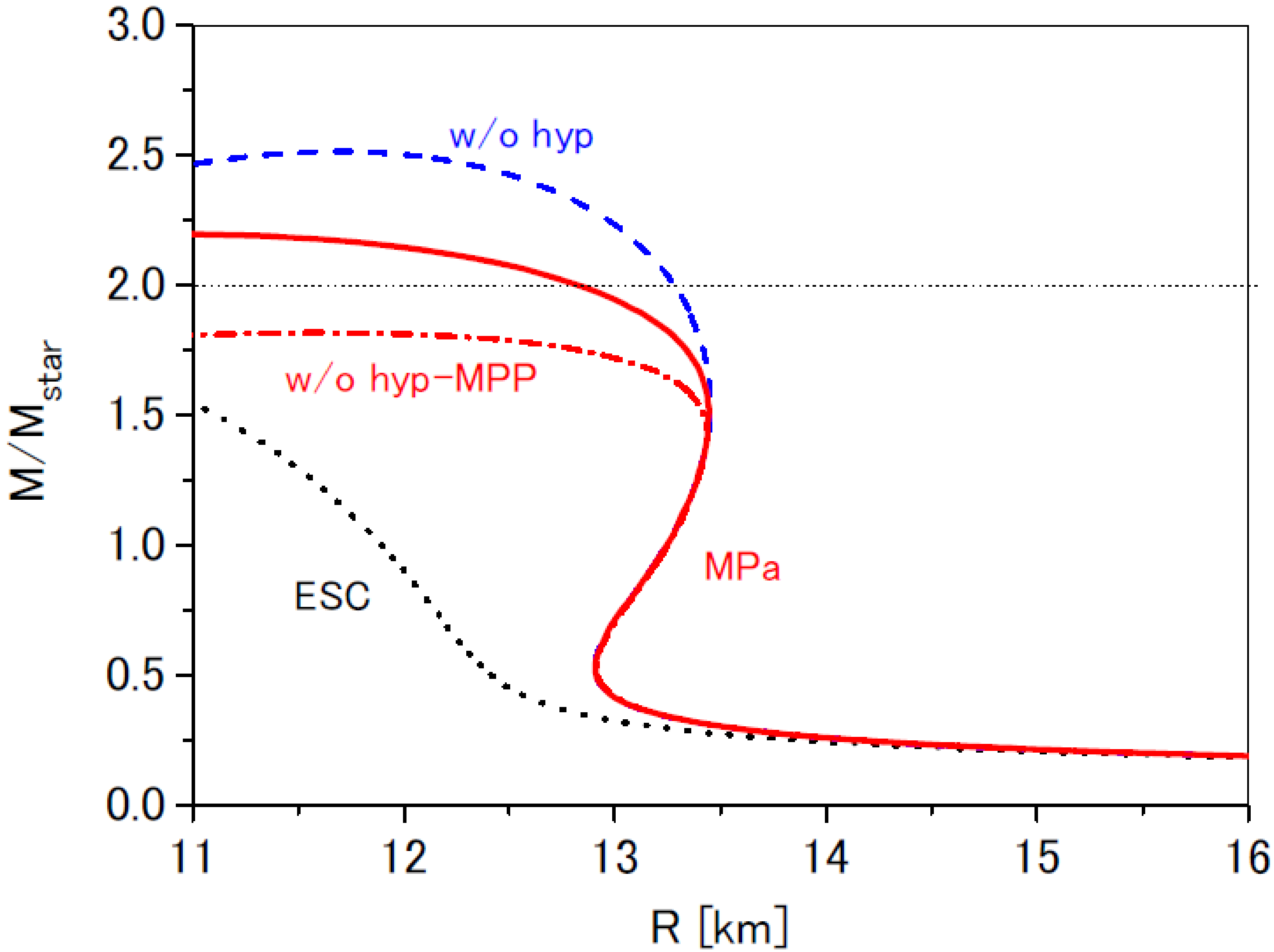
EOS



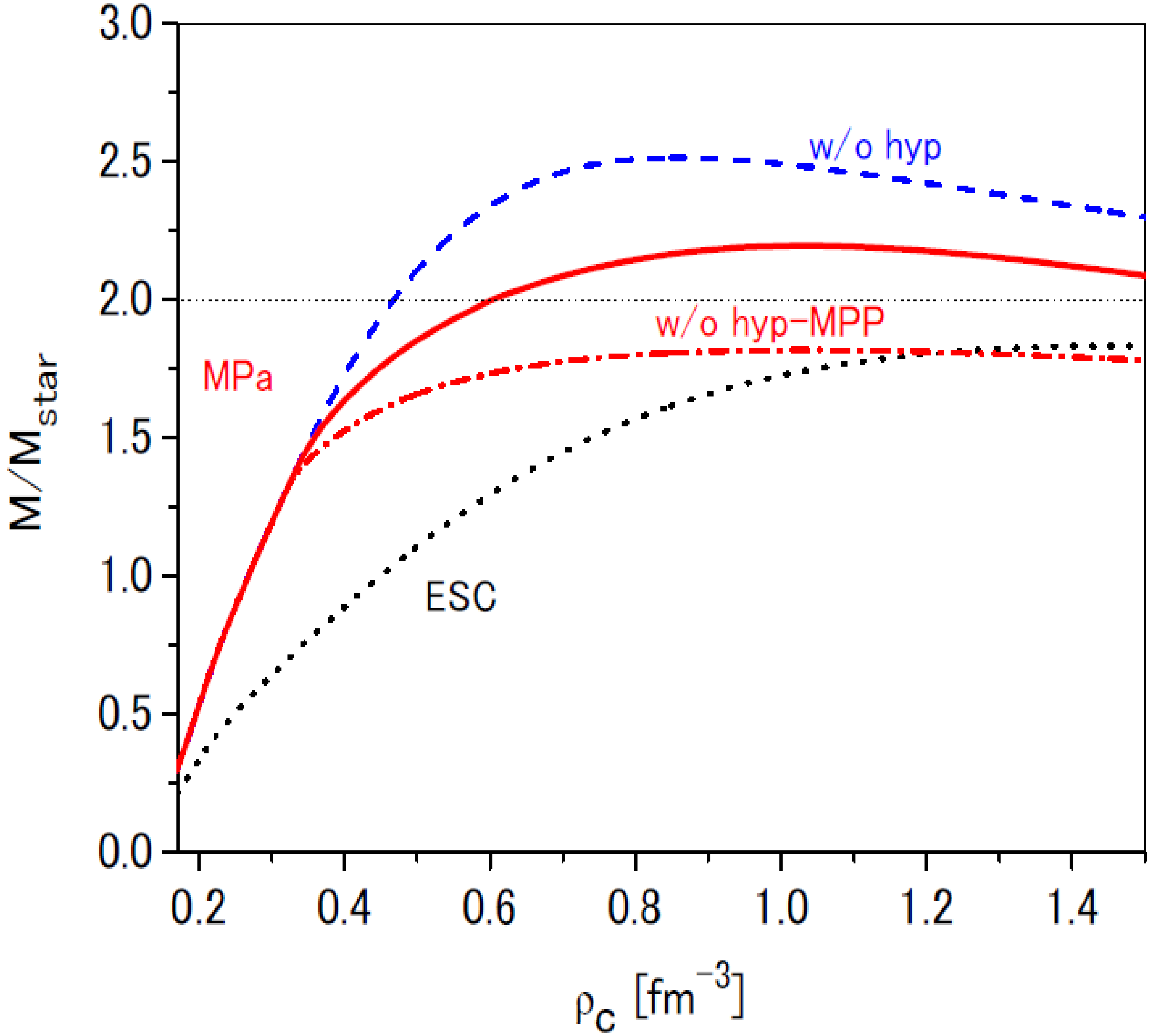
dashed: n+p+e+μ
solid: n+p+Λ+Σ+e+μ
MPa
ESC
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
P [MeV fm^{-3}]
ρ [fm^{-3}]



2.5
2.0
1.5
1.0
0.5
0.0
M/M$_{solar}$
MPb
MPa
MPc
ESC
11
12
13
14
15
16
R [km]



3.0
2.5
2.0
1.5
1.0
0.5
0.0
M/M$_{star}$
w/o hyp
w/o hyp-MPP
MPa
ESC
11
12
13
14
15
16
R [km]



3.0
2.5
2.0
1.5
1.0
0.5
0.0
M/M_star
0.2
0.4
0.6
0.8
1.0
1.2
1.4
ρc [fm^-3]
w/o hyp
w/o hyp-MPP
MPa
ESC

Conclusion

ESC08c+MPP+TBA model

* MPP strength determined by analysis for $^{16}O+^{16}O$ scattering
* TNA adjusted phenomenologically to reproduce
  $E/A(\rho_0) = -15.8$ MeV with $\rho_0 = 0.16$ fm^{-3}
* Consistent with hypernuclear data
* No ad hoc parameter to stiffen EOS

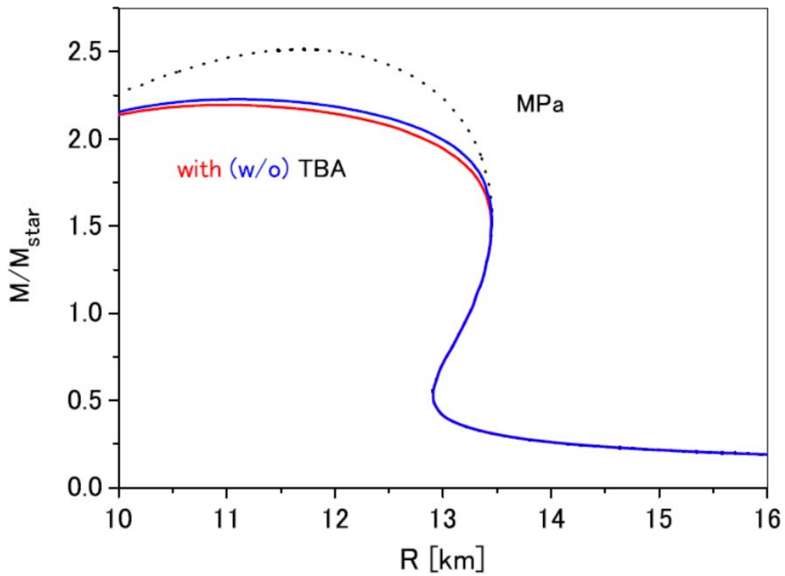
BB interactions based on on-Earth experiments

MPa set including 3- and 4-body repulsions leads to massive neutron stars with $2M_\odot$ in spite of significant softening of EOS by hyperon mixing

MPb/c including 3-body repulsion leads to comparable to or slightly smaller values than $2M_\odot$

Hyperon Puzzleは解けるか？

B_Λで決まるのは(MPP+TBA)
中性子星のMR relationに実際に効くのはMPP



MPP(hyperon sector)のterrestrial experiment困難？
LQCDか？