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EOSDB: The database for nuclear equations of state*

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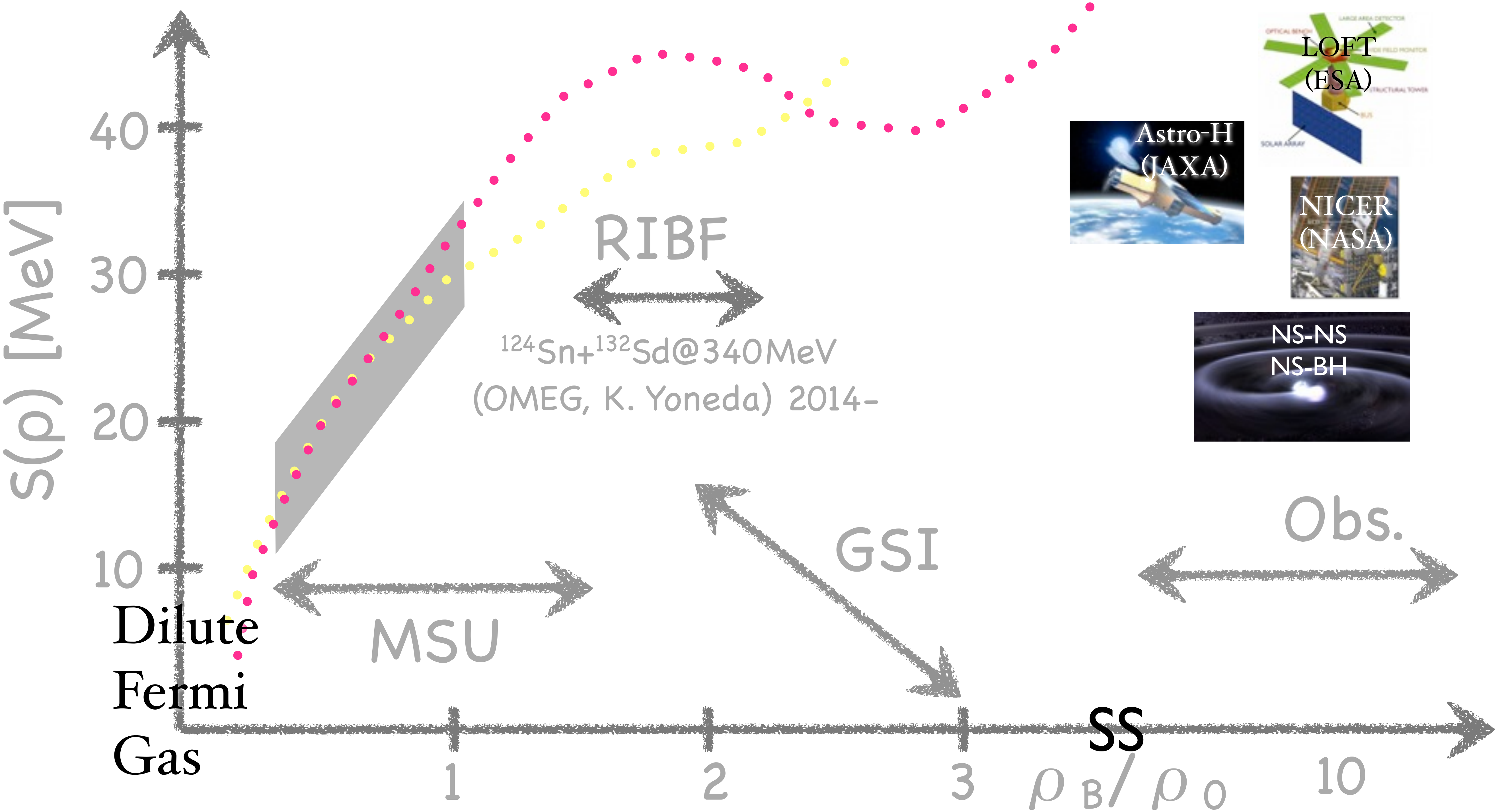
How to constrain nuclear EoSs?



SHARE the information on nuclear EoSs

among various scientific backgrounds

Online-database for nuclear EoSs EOSDB

EOSDB (C. Ishizuka, T. Suda, et al.)
http://aspht1.ph.noda.tus.ac.jp/eos/
collaborating with
CompOSE (S.Typel, M. Dutra, T. Klaen et al.)
http://compose.obspm.fr/

Construction of data table

- Bibliography
- Data attribution (Theo./Expr. analysis/Obs.)
- Constituents (N/Y/α/A/Q/L)
- Method (Model/Approx.)
- Physics constants
- EoS for Sym. nucl. matter (E/P/S)
- EoS for Pure neutron matter(E/P/S)
- Symmetry energy (Esym/L/K)

Primary key ρ_B

36 EoS at T=0 MeV

Data Retrieval System for EOSDB Database

Last update of database:

* not working
** Other options do not work.

Query

	search · example · reset
Graph Options	
Category	Category ▾ (Category / Symmetry Energy / Thermodynamic Variables)
Xaxis	any ▾ From : To : Include ▾ data with upper limit
Yaxis	any ▾ any ▾ From : To : Include ▾ data with upper limit
Criterion +	any ▾ any ▾ From : To : Include ▾ data with upper limit
Optional Criterion	
Bibliographical Criterion	
Author	First author ▾ ex) "Lastname" ◉ strict ○ forward agreement ○ backward agreement ○ fuzzy
Reference	ALL ▾
Publication Year	From To
Retrieval Options	
Display / Page	10 ▾
Order by**	First Author ▾
	search · example · reset

Search Result

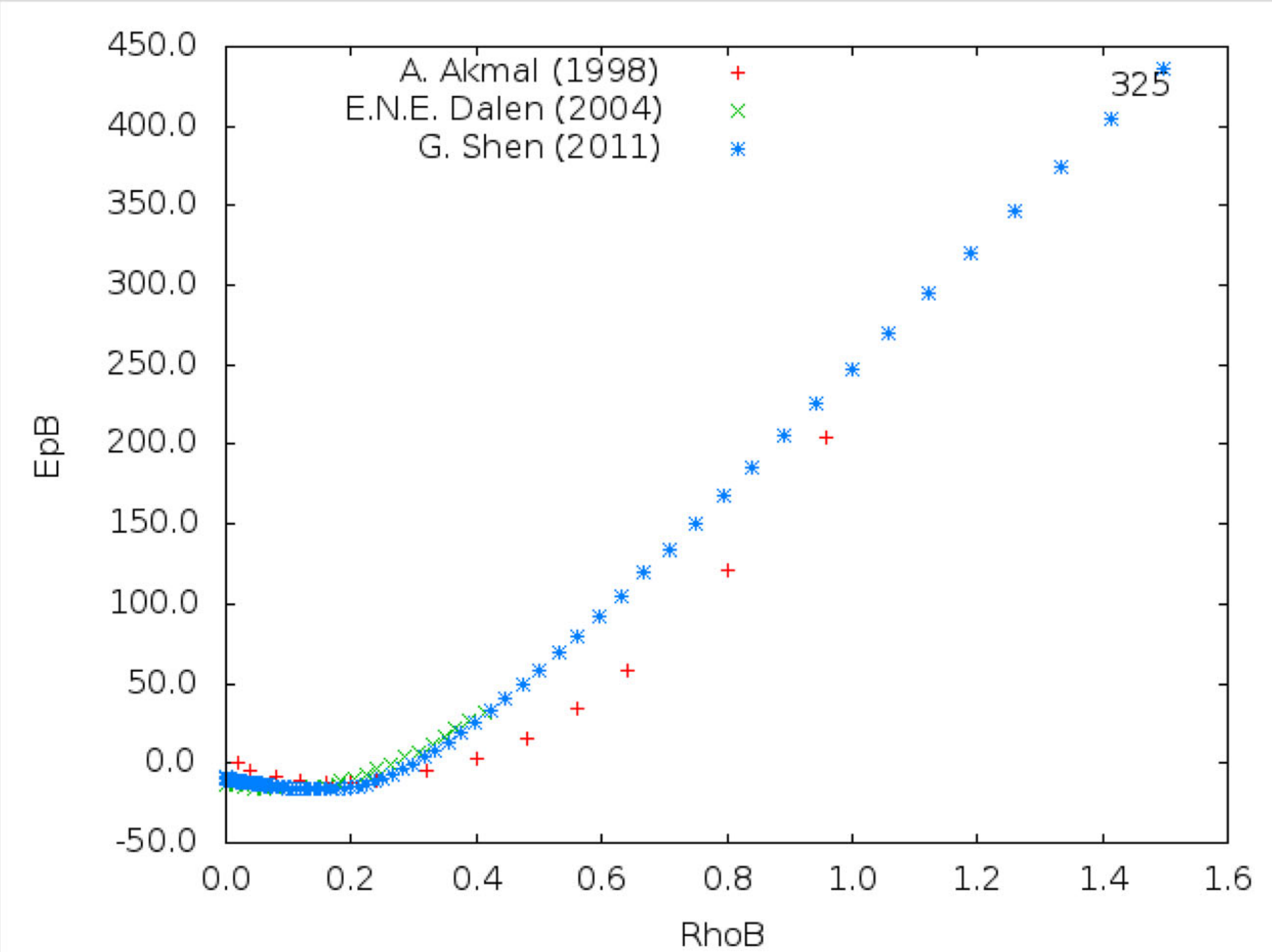
plot | restart | reset | plot_all

Results : 25

#	○	Reference	Min. RhoB	Max. RhoB	Min. EpB	Max. EpB
1	☐	AkmalPRC1998_AV18	0.02	0.96	-18.13	56.51
2	☐	AkmalPRC1998_AV18_3BF	0.02	0.96	-11.85	313.46
3	☐	AkmalPRC1998_AV18_Boost	0.02	0.96	-13.69	82.63
4	☐	AkmalPRC1998_AV18_3BF_Boost	0.02	0.96	-12.21	204.02
5	☐	BotvinaNPA2010	1.5E-09	0.0474	-12.2	-8.338
6	☐	IshizukaJPG2008_SR30	0	1.512692	-8.537953	598.6558
7	☐	vanDalenNPA2004	0	0.4929	-16.17	31.55
8	☐	TimmesAPJS1999	0	0	0	0
9	☐	GShenPRC2011_FSUgold2.1	1.000003E-08	1.49624	-16.22081	435.6136
10	☐	KanzawaPTP2009	0	0	-16.15	28.41
11	☐	HShenNPA1998	7.581421E-11	1.512692	-16.2359	442.3408

Plot

* not working



plot reset

Title

LEGEND

- (•) Left Top
- ( ) Right Top
- ( ) Left Bottom
- ( ) Right Bottom
- ( ) No Key
- ( ) Outside

LABEL

X : RhoB

Y : EpB

SCALE

X : (•) Linear ( ) Logscale

Y : (•) Linear ( ) Logscale

Range

X Low : * High : *

Y Low : * High : *

☑ or < />xupper * ☑ yupper

plot reset Delete all restart

Data		Legend	Size	Type*	Del*
1 :	☑	A. Akmal (1998)	1	1	☐
2 :	☑	E.N.E. Dalen (2004)	1	2	☐
3 :	☑	G. Shen (2011)	1	3	☐

Download Figures

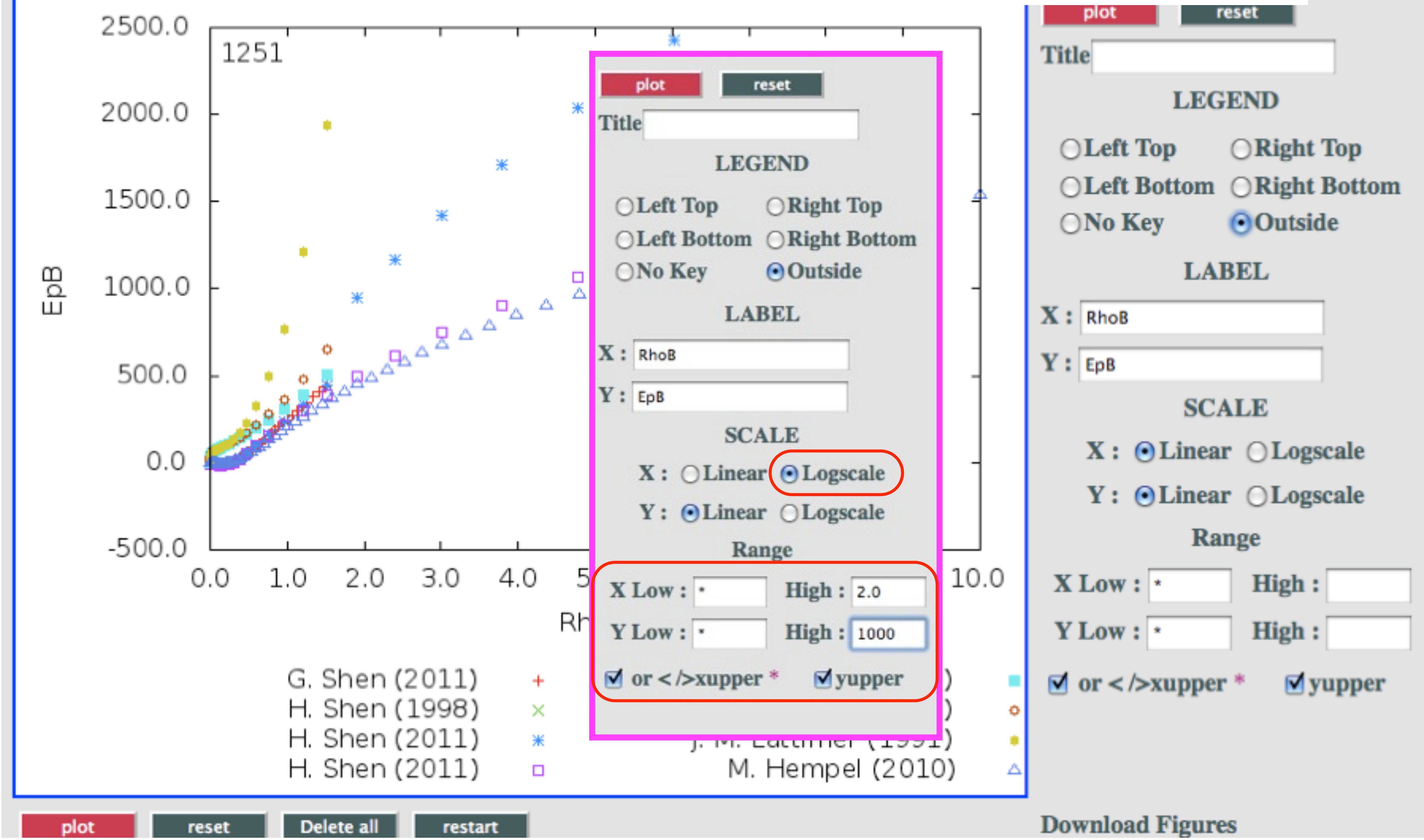
☑ Color Figures

png ps eps pdf

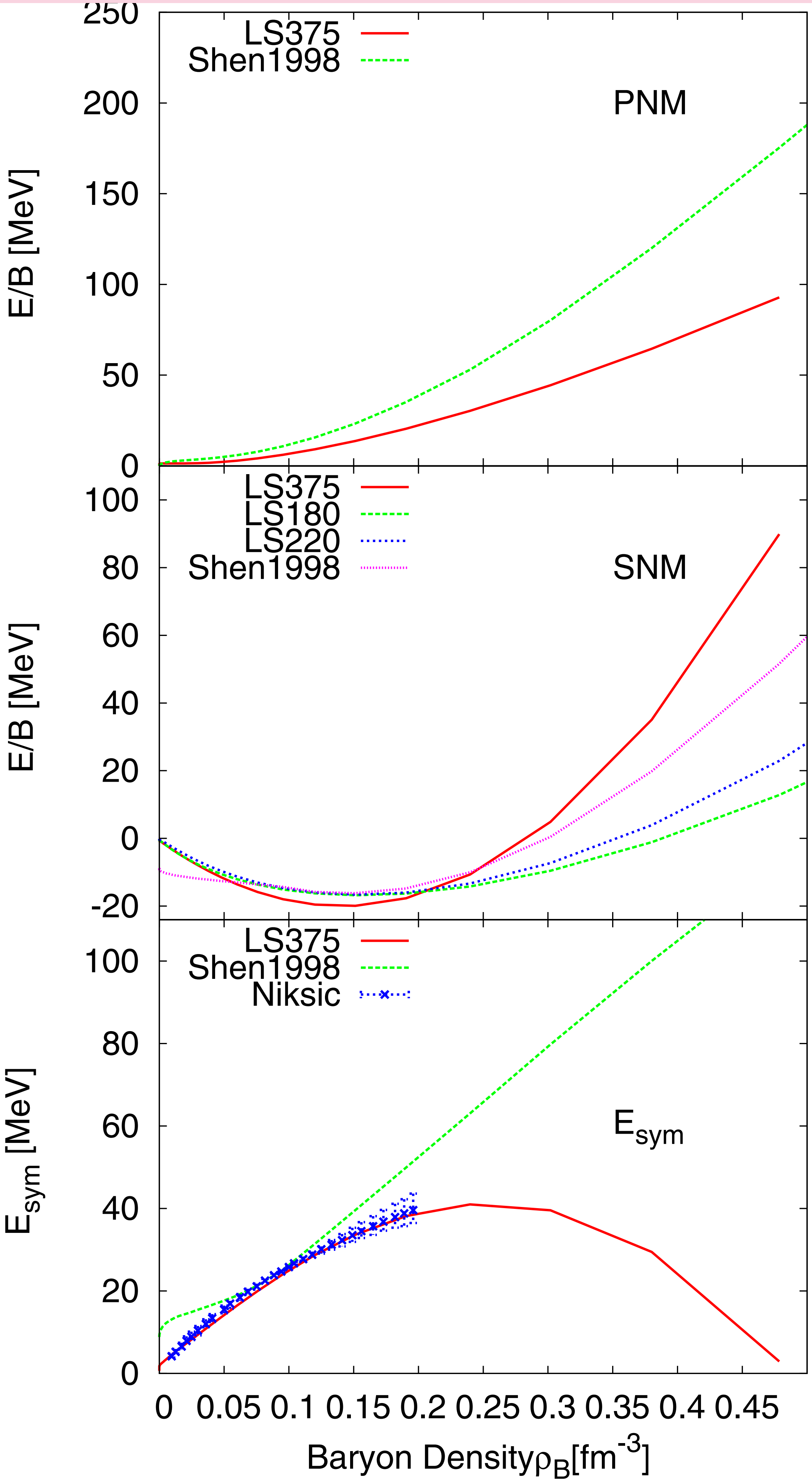
Download Data

download

Can you see that the position of labels changed from previous image to the “Outside” of the figure? Then next, we’ll show you the way to change the plot range. As shown in pink box, you can arrange it at the right bottom “Range” panels.
Now put “2.0” as “X High” and “1000” as “1000” for example.
We change the “SCALE” from “X:Linear” to “X: Log-scale” as well. Then what happens?



Application & Discussion



Standard EoS for Astro. Use

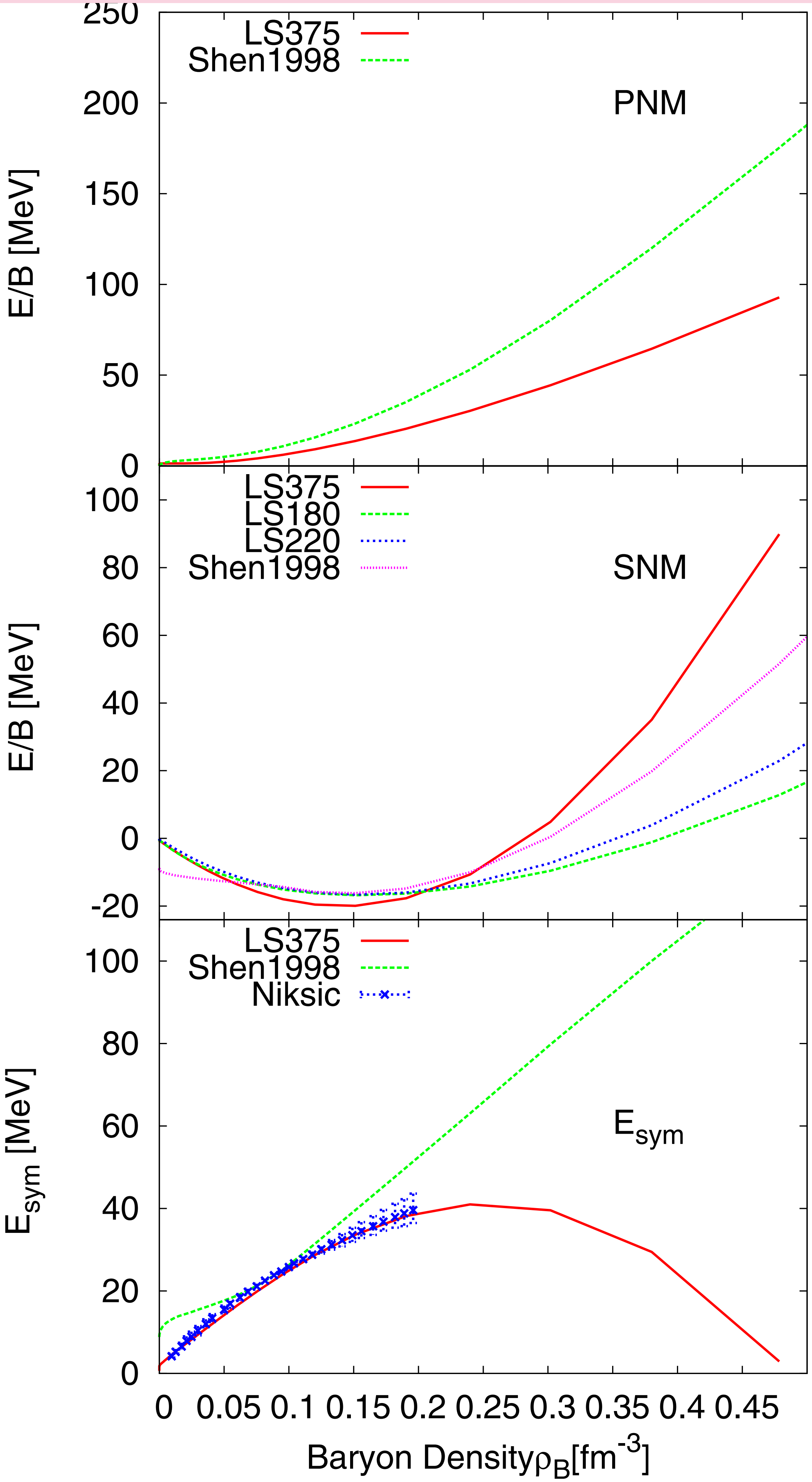
Lattimer&Swesty (LS)

E_{sym} for LS 180/220/375@ρ_0 = 29.3MeV
LS 375 (K=375MeV) Best consistency with Niksic2002

Basic interaction: SKI (Vautherin+1970)
16O, 40,48Ca, 90Zr and 208Pb
Modification: Adding Three-body int. to SKI

Adjusting K with TBI
It changes EoS itself
Property of Finite Nuclei?

SHF
Various finite nuclei at low E
E/B < 50MeV to reproduce both Pb and Sn
(J.R. Stone+2003)



Standard EoS for Astro. Use

H.Shen EoS (TM1)

E_{sym} for TM1@ρ_0 = 36.9MeV, stiffer than Niksic2002
K=281MeV

Basic interaction: TM1(Sugahara&Toki)
Fitting with major nuclei and unstable nuclei (p-rich/n-rich)

Spurious shell closures
at Z=58 and 92
in Major RMF models
Fock term(TBI or Tensor)?
Rotation of deformed nuclei?

L. S. Geng+ Chin. Phys. Lett 23 (2006) 1139

RMF
Good explanation of p-induced reaction even at high E
For light nuclei, it is difficult to produce B.E. r_{ch}, etc.

The other parameter sets of SHF and RMF models

M. Dutra + 2012, P. D. Stevenson + 2012
Only **16**/240 **Skyrme HF** models satisfy nuclear experimental constraints.
These **16** can NOT commonly reproduce finite nuclei,
(1) B.E. of Even-Even Doubly -(Semi)-Magic Nuclei
(^{16}O, ^{34}Si, ^{40}Ca, ^{48}Ca, ^{48}Ni, ^{56}Ni, ^{68}Ni, ^{78}Ni, ^{80}Zr, ^{90}Zr, ^{100}Sn, ^{114}Sn, ^{146}Gd, and ^{208}Pb)
(2) Fission Barriers in heavy nuclei
(3) Isotope shift

M. Dutra +2013
Only **9**/147 **RMF** models (linear, non-linear $\sigma^3+\sigma^4$, $\sigma^3+\sigma^4+\omega^4$, σ and ω-mixing, density-dependent, point coupling) satisfy nuclear experimental constraints.
BSR, DD-F, FSUGold, TW99
Geng + 2006
RMF models (TMA, NL3, PKDD, DD-ME2) have spurious shell closures at Z=58 and 92.
The above 9 models may have the same property.

J.R. Stone & M. Dutra plan to provide these 240+147=387 EoSs for CompOSE/EOSDB after NuSYM'15.

Please note MNR & RNS ambiguity listed in C. Ishizuka et al., PASJ 67 (2015) 13, ArXiv: 1408.6230v2

Table 5. Table for classification of phenomenological theoretical models.

Phenomenological					
Rel. / Non-rel.	Method	Interaction	Reference	Data ID	Comment
Rel.	RMF	TM1(Only N)	HShenNPA1998	E0002	Thomas-Fermi apprx. for inhomo. phase. $(M_{NS}^{Max}, R) = (2.18M_{\odot}, 12.5$ [km]).
Rel.	RMF	TM1(Only N)	HShenAPJS2011_ N	E0003	Different from E0002 at $(T, Y_p) = (0,0)$. $(M_{NS}^{Max}, R) = (2.18M_{\odot}, 12.5$ [km]).
Rel.	RMF	TM1(Only N)	FurusawaApJ2011	E0011	NSE for inhomo. phase
Rel.	RMF	TM1(Only N)	BotvinaNPA2010	E0010	NSE for inhomo. phase
Rel.	RMF	TM1(with Y)	HShenAPJS2011_Y	E0004	Only Λ included as hyperons. $M_{NS}^{Max} = 1.75M_{\odot}$.
Rel.	RMF	TM1(with Y)	IshizukaJPG2008_SR30	E0012	Full Baryon Octet. $(M_{NS}^{Max}, R) = 1.63M_{\odot}, 13.26$ [km]).
Rel.	RMF	TMA	HempelNPA2010_TMA	E0008	NSE for infomo. phase $(M_{NS}^{Max}, R) = (2.04M_{\odot}, 12.43$ [km])
Rel.	RMF(RHF+QMC)	—	MiyatsuPLB2012	E0009	Full Baryon Octet. $M_{NS}^{Max} = 1.95M_{\odot}$.
Rel.	DD RMF	DD-TW	TypelNPA1999	E0023	$(M_{NS}^{Max}, R) = (2.2M_{\odot}, 11.2$ [km]).
Rel.	DD RMF	DD-ME1	NiksicPRC2002	E0024	$(M_{NS}^{Max} = 2.47M_{\odot}, 11.9$ [km]).
Rel.	DD RMF	FSUgold + Polytrope	GShenPRC2011_FSUgold2.1	E0001	Adjusted to support $2.1M_{\odot}$ NS. $(M_{NS}^{Max}, R) = (2.1M_{\odot}, 12.2$ [km])

Please note MNR & RNS ambiguity listed in C. Ishizuka et al., PASJ 67 (2015) 13, ArXiv: 1408.6230v2

Table 5. Table for classification of phenomenological theoretical models.

Phenomenological					
Rel. / Non-rel.	Method	Interaction	Reference	Data ID	Comment
[illegible]	[illegible]	[illegible]	[illegible]	E0002	Thomas-Fermi apprx.
					for inhomo. phase.
					$(M_{NS}^{Max}, R) = (2.18M_{\odot}, 12.5$ [km]).
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]03	Different from E0002 at $(T, Y_p) = (0,0)$.
					$(M_{NS}^{Max}, R) = (2.18M_{\odot}, 12.5$ [km]).
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]11	NSE for inhomo. phase
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]010	NSE for inhomo. phase
Rel.	RMF	TM1(with Y)	HShenAPJS2011_Y	E0004	Only Λ included as hyperons.
					$M_{NS}^{Max} = 1.75M_{\odot}$.
Rel.	RMF	TM1(with Y)	IshizukaJPG2008_SR30	E0012	Full Baryon Octet.
					$(M_{NS}^{Max}, R) = 1.63M_{\odot}, 13.26$ [km]).
Rel.	RMF	TMA	HempelNPA2010_TMA	E0008	NSE for infomo. phase
					$(M_{NS}^{Max}, R) = (2.04M_{\odot}, 12.43$ [km])
Rel.	RMF(RHF+QMC)	—	MiyatsuPLB2012	E0009	Full Baryon Octet. $M_{NS}^{Max} = 1.95M_{\odot}$.
Rel.	DD RMF	DD-TW	TypelNPA1999	E0023	$(M_{NS}^{Max}, R) = (2.2M_{\odot}, 11.2$ [km]).
Rel.	DD RMF	DD-ME1	NiksicPRC2002	E0024	$(M_{NS}^{Max} = 2.47M_{\odot}, 11.9$ [km]).
Rel.	DD RMF	FSUgold	GShenPRC2011_FSUgold2.1	E0001	Adjusted to support $2.1M_{\odot}$ NS.
		+ Polytrope			$(M_{NS}^{Max}, R) = (2.1M_{\odot}, 12.2$ [km])

$(M_{NS}^{MAX}, R) = (2.18Mo, 12.5km)$

26

Please note MNR & RNS ambiguity listed in C. Ishizuka et al., PASJ 67 (2015) 13, ArXiv: 1408.6230v2

(M_{NS}^{MAX}, R)=(2.18Mo, 12.5km)

Table 5. Table for classification of phenomenological theoretical models.

Phenomenological					
Rel. / Non-rel.	Method	Interaction	Reference	Data ID	Comment
Rel.	RMF	TM1(Only N)	HShenNPA1998	E0002	Thomas-Fermi apprx.
					for inhomo. phase.
					$(M_{NS}^{Max}$, R) = $(2.18M_\odot$, 12.5 [km]).
[illegible]	[illegible]	[illegible]	[illegible]	…03	Different from E0002 at $(T, Y_p) = (0,0)$.
					$(M_{NS}^{Max}$, R) = $(2.18M_\odot$, 12.5 [km]).
[illegible]	[illegible]	[illegible]	[illegible]	…11	NSE for inhomo. phase
[illegible]	[illegible]	[illegible]	[illegible]	…010	NSE for inhomo. phase
Rel.	RMF	TM1(with Y)	HShenAPJS2011_Y	E0004	Only Λ included as hyperons.
					$M_{NS}^{Max} = 1.75M_\odot$.
Rel.	RMF	TM1(with Y)	IshizukaJPG2008_SR30	E0012	Full Baryon Octet.
					$(M_{NS}^{Max}$, R) = $1.63M_\odot$, 13.26 [km]).
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					$(M_{NS}^{Max}$, R) = $(2.04M_\odot$, 12.43 [km])
Rel.	RMF(RHF+QMC)	—	MiyatsuPLB2012	E0009	Full Baryon Octet. $M_{NS}^{Max} = 1.95M_\odot$.
Rel.	DD RMF	DD-TW	TypelNPA1999	E0023	$(M_{NS}^{Max}$, R) = $(2.2M_\odot$, 11.2 [km]).
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Rel.	DD RMF	FSUgold	GShenPRC2011_FSUgold2.1	E0001	Adjusted to support $2.1M_\odot$ NS.
		+ Polytrope			$(M_{NS}^{Max}$, R) = $(2.1M_\odot$, 12.2 [km])

26

Please note MNR & RNS ambiguity listed in C. Ishizuka et al., PASJ 67 (2015) 13, ArXiv: 1408.6230v2

Table 5. Table for classification of phenomenological theoretical models.

Phenomenological					
Rel. / Non-rel.	Method	Interaction	Reference	Data ID	Comment
Rel.	RMF			E0002	Thomas-Fermi apprx. for inhomo. phase. $(M_{NS}^{Max}, R) = (2.18M_{\odot}, 12.5$ [km]).
				…03	Different from E0002 at $(T, Y_p) = (0,0)$. $(M_{NS}^{Max}, R) = (2.18M_{\odot}, 12.5$ [km]).
				…11	NSE for inhomo. phase
				…010	NSE for inhomo. phase
Rel.	RMF	TM1(with Y)	HShenAPJS2011_Y	E0004	Only Λ included as hyperons. $M^{Max} = 1.75M_{\odot}$ …
Rel.	RMF	TM1(with Y)			…]).
Rel.	RMF	TMA			…m])
Rel.	RMF(RHF+QMC)	—			…$M_{\odot}$.
Rel.	DD RMF	DD-TW			…).
Rel.	DD RMF	DD-ME1			
Rel.	DD RMF	FSUgold + Polytrope			$(M_{NS}^{Max}, R) = (2.1M_{\odot}, 12.2$ [km])

$(M_{NS}^{MAX}, R) = (2.18M_{\odot}, 12.5km)$

R=12.5km ± 0.5km @1.4Msolar

[Ref] C.Ishizuka et al., PoS (NIC XIII) 2015 in print

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Summary

Online Database for nuclear EoSs, EOSDB

http://aspht1.ph.noda.tus.ac.jp/eos/

Basic Structure:
EOSDB following SAGA database (Suda + 2008, 2011) :MySQL/CSV
Search&Plot system: Perl/CGI/Java

Aim:
Sharing Basic EoS Properties with all scientists
Development of a "Feel & Think" system
for various models and interactions used to derive nuclear EoSs

Strong Point:
Useful to assess the validity of each EoS
Including used assumptions and approximations in each EoS

Application suggestion:
Checking the correlation among E_{sym}, L, K and so on.
∵)E/P/S/Es_{ym}/L are compiled as a function of ρ_B
Checking the NS properties

Appendix

Open EoSs for NS core and crust

Crust EoS	Core EoS
MYN[2] $\rho_B < \rho_0$	RHF(MYN)[2]
BBP[5] $\rho_B < 0.8\rho_0$	RMF(TM1)[3]
NGB[6] $\rho_B < 0.5\rho_0$	Ab initio (FPS)[4]
HZ[7] $\rho_B < 0.1\rho_0$	Skyrme HF (SLy) [4]

[1] C. Ishizuka et al. PoS2 015 in press
[2] T. Miyatsu et al., ApJ 777, 4 (2013)
[3] Y. Sugahara & H. Toki, NPA 579, 557 (1994)
[4] SLy and FPS are from the formula given in P. Haensel & A. Y. Potekin, A&A 428, 191(2004)
[5] G. Baym et al., NPA 175, 225 (1971)
[6] W. G. Newton et al., ApJS 204, 9 (2013)
[7] P. Haensel & J. L. Zdunik, A&A 480,459 (2008)
[8] H. Sotani et al., MNRAS 434, 2060 (2013)

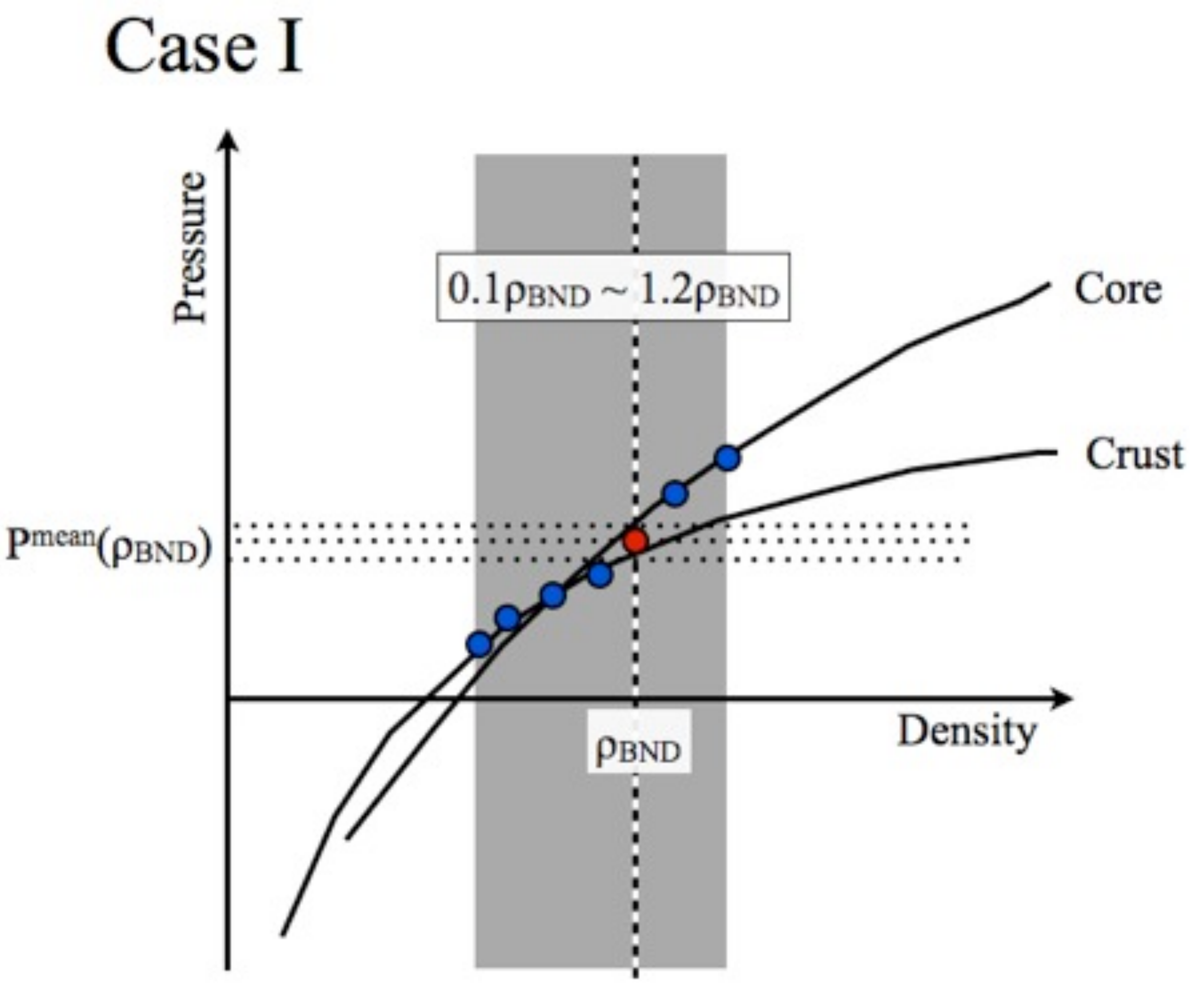
Data from EOSDB
http://aspht1.ph.noda.tus.ac.jp/eos/index.html
C. Ishizuka et al., PASJ 67 (2015) 13

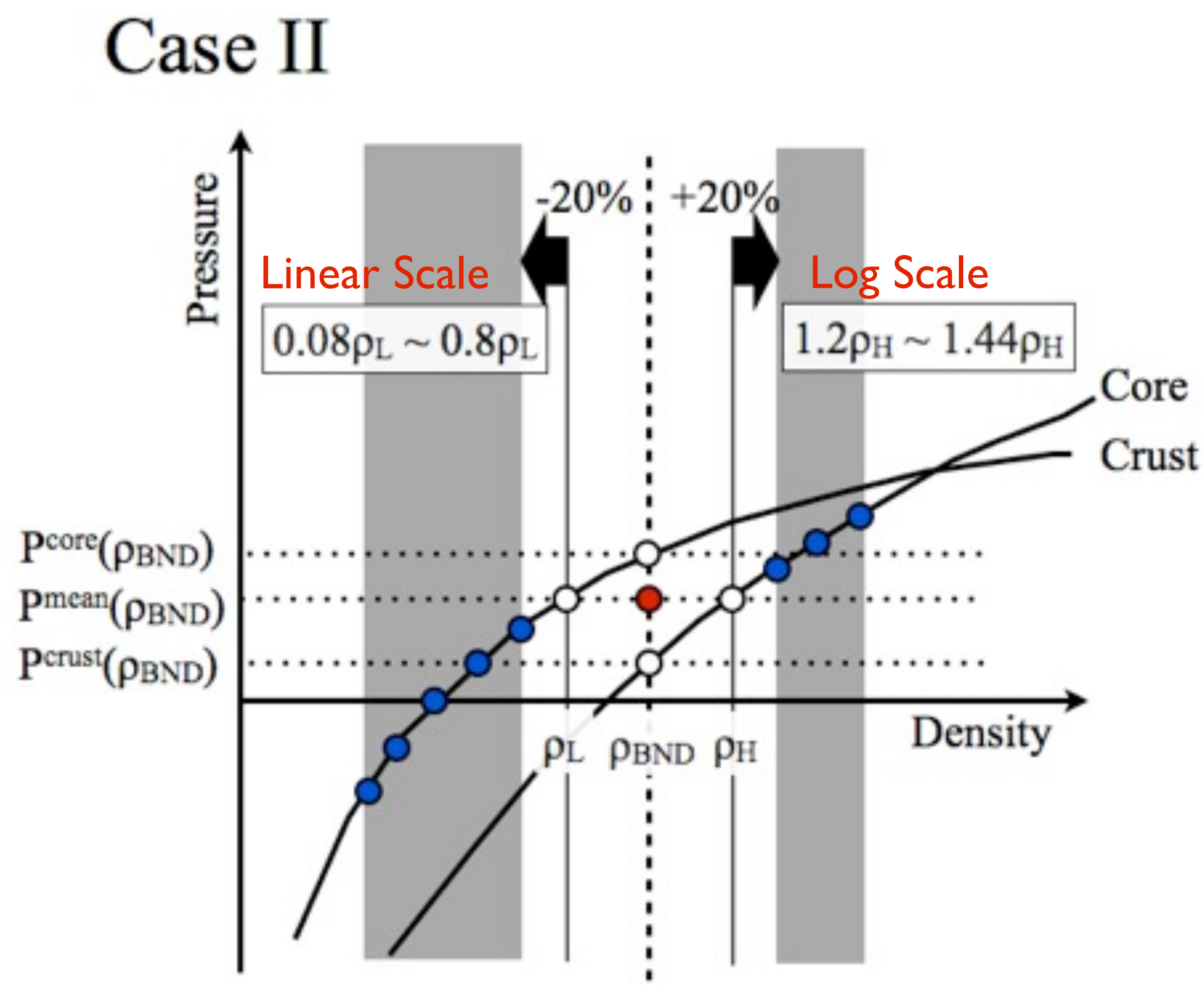
M_{NS} and R_{NS} can be obtained from the TOV equation

$$\frac{dP(r)}{dr} = -\frac{G}{r^2}\left(\rho(r) + \frac{P(r)}{c^2}\right)\left(M(r) + 4\pi r^3\frac{P(r)}{c^2}\right)\left(1 - \frac{2GM(r)}{cr^2}\right)^{-1}$$

Connection method between NS core and crust

Interpolation method#1





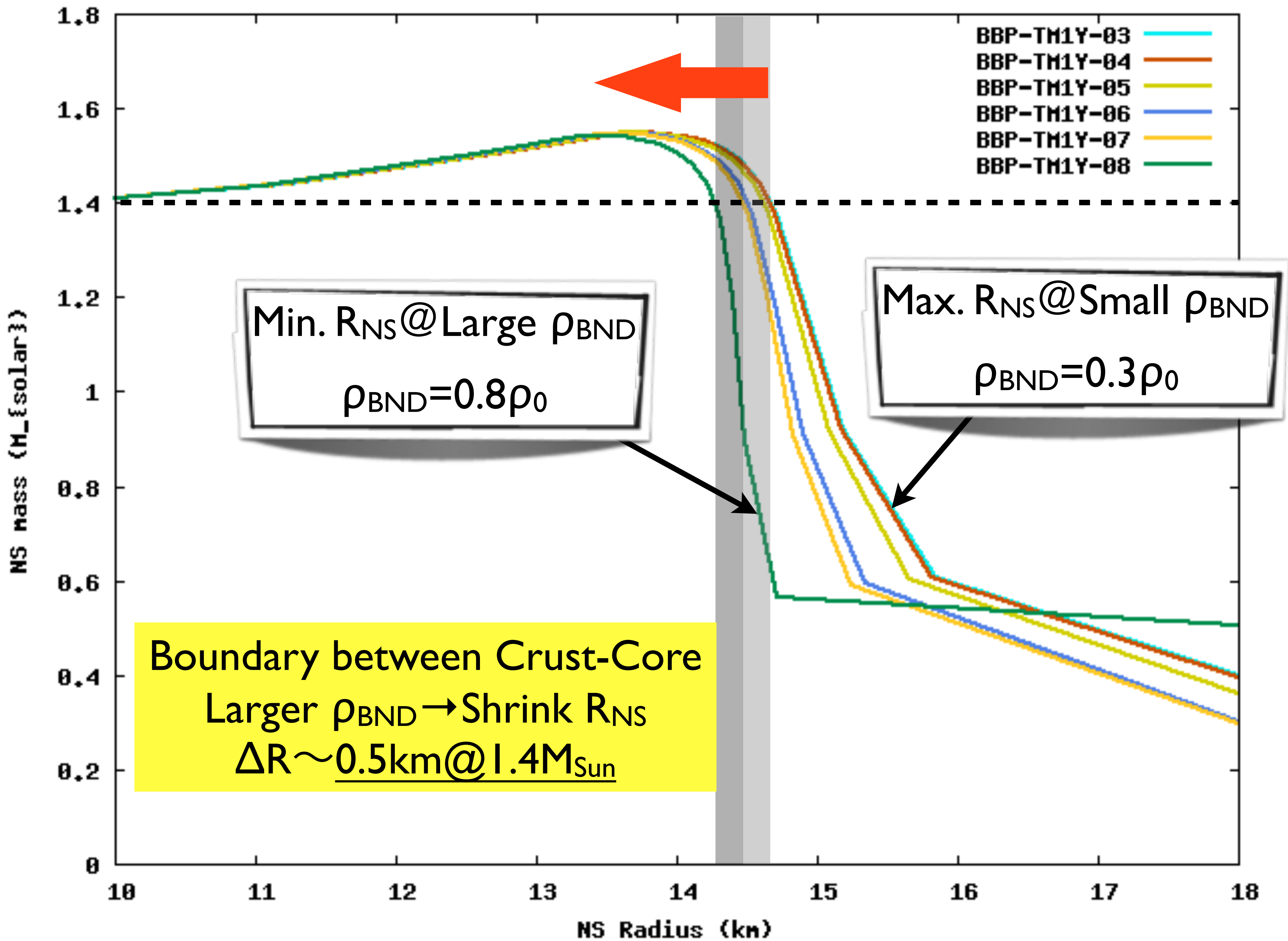
Interpolation method#2

Connecting data smoothly using 10 data points before/behind the boundary
i.e.) Interpolation depending the data-grids

without interpolation

Result #1

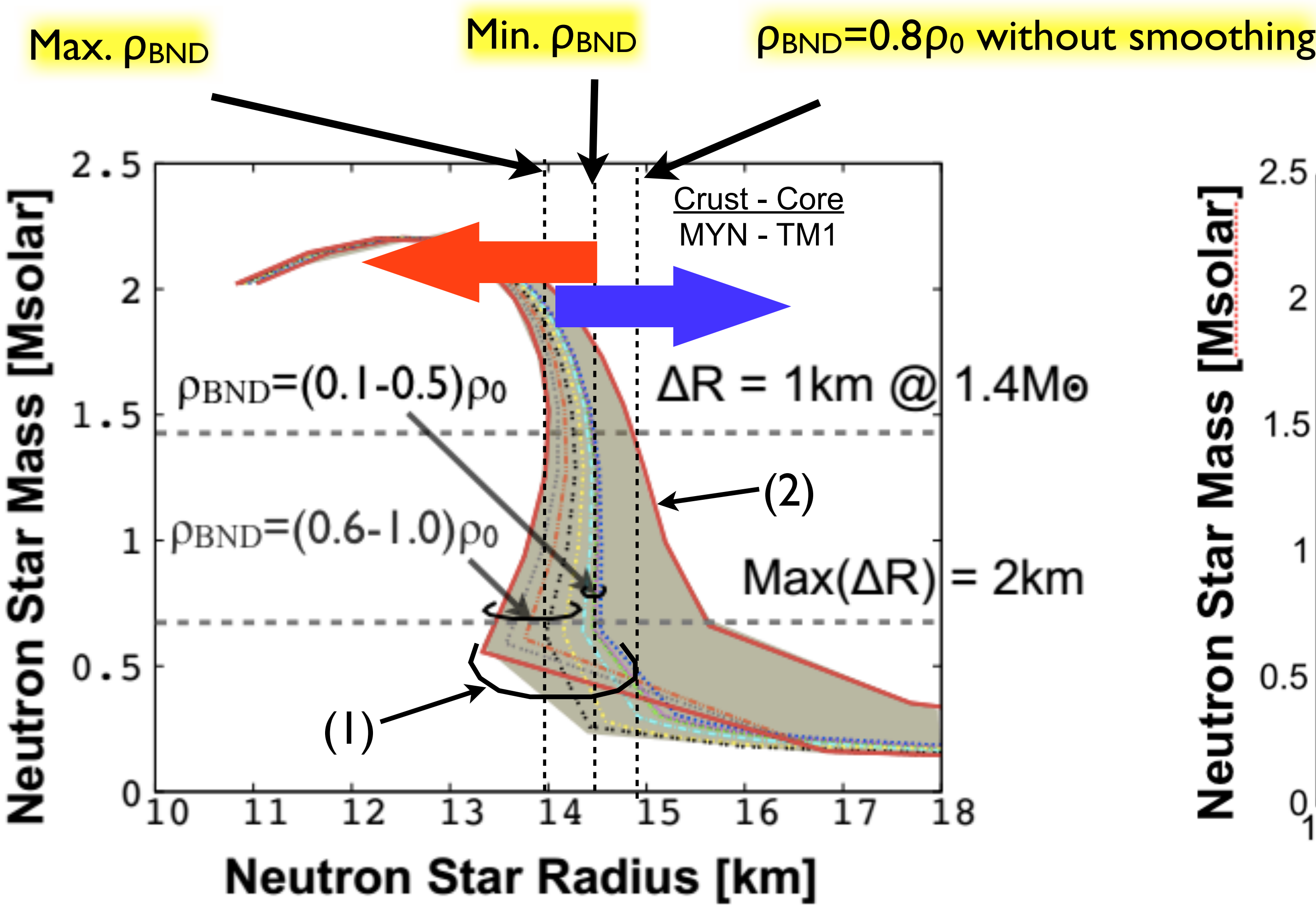
Connection between Core and Crust
with interpolation independent of given data-grids

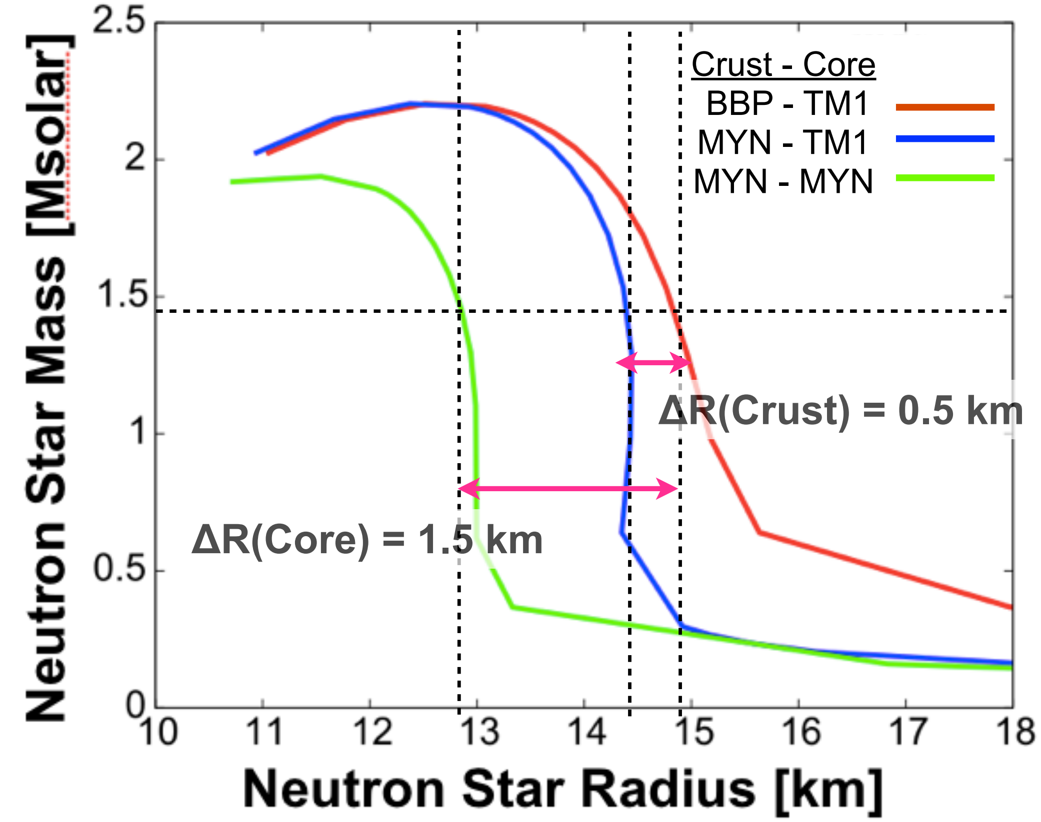


[ref] TM1Y: C. Ishizuka et al., J. Phys G 35 (2008) 08521

Result #2

Interpolation depending the data-grids





(1)The same crust & core with ρ_{BND} = (0.1, 0.2, ..., 0.9, 1.0)xρ_0.
(2)Simply connect crust EoS ($\rho_B<0.8\rho_0$) and core EoS ($\rho_B>\rho_0$)

[Ref] C. Ishizuka et al., PoS 2015 in press

The effect of using different crusts with $\rho_{BND} = 0.5\rho_0$ are shown as well as that of using different cores.

- R_{NS} ambiguity due to the connection method ΔR~1.0 km@1.4M_{Sun}
- ΔRNS between different crust model >> ΔRNS between different core model but not always!

Sumary

[Ref] C.Ishizuka et al., PoS (NIC XIII) 2015 in print

★Systematical Investigation of Ambiguity of R_{NS} due to ρ_{BND} treatment

$0.1\rho_0 \leqq \rho_{BND}$ < (upper limit defined by Crust-EoS data), by $0.1\rho_0$

☆Smooth connection below the upper-limit ρ_B of the given crust (Case-I)

$\Delta R \sim$- 0.5km@$1.4M_{Sun}$

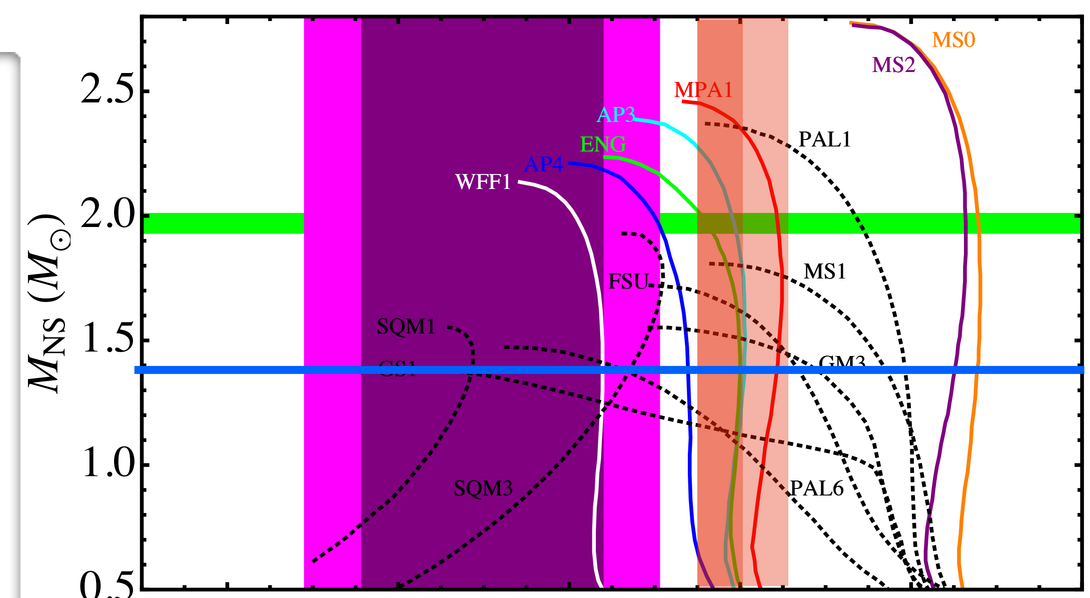
☆Smooth connection above the upper-limit ρ_B of the given crust (Case-II)

ΔR > +0.5km@$1.4M_{Sun}$ depending the upper limit of the crust EoS

☆Connection at $\rho_{BND}=0.8\rho_0$(Spinodal region) without smoothing (Case-III)

Diff. between Case-I and III $\Delta R \sim 1.0$km@$1.4M_{Sun}$

- M_{NS},R_{NS} are determined by high ρ_B EoS
  Non-negligible the ambiguity caused by the treatment of the crust-core boundary ρ_{BND}
- Small ΔR@Large mass NS
- $\Delta R \sim 1.0$km@$1.4M_{Sun}$
- If ρ_{BND} is given by observation,
  We can make ΔR much smaller.
  Possible determination of the boundary using crust oscillation!?



Please note MNR & RNS ambiguity listed in
C. Ishizuka et al., PASJ 67 (2015) 13,
ArXiv: 1408.6230v2
R_{NS} +/-0.5km @$1.4M_{Sun}$