Hyperon-mixed Neutron-star matter in Dirac-Brueckner-Hartree-Fock approach

Department of Physics, Faculty of Science and Technology
Tokyo University of Science
Tetsuya Katayama

J-PARC hadron physics in 2014,
Nov. 30 – Dec. 2, 2014 Ibaraki Quantum Beam Research Center

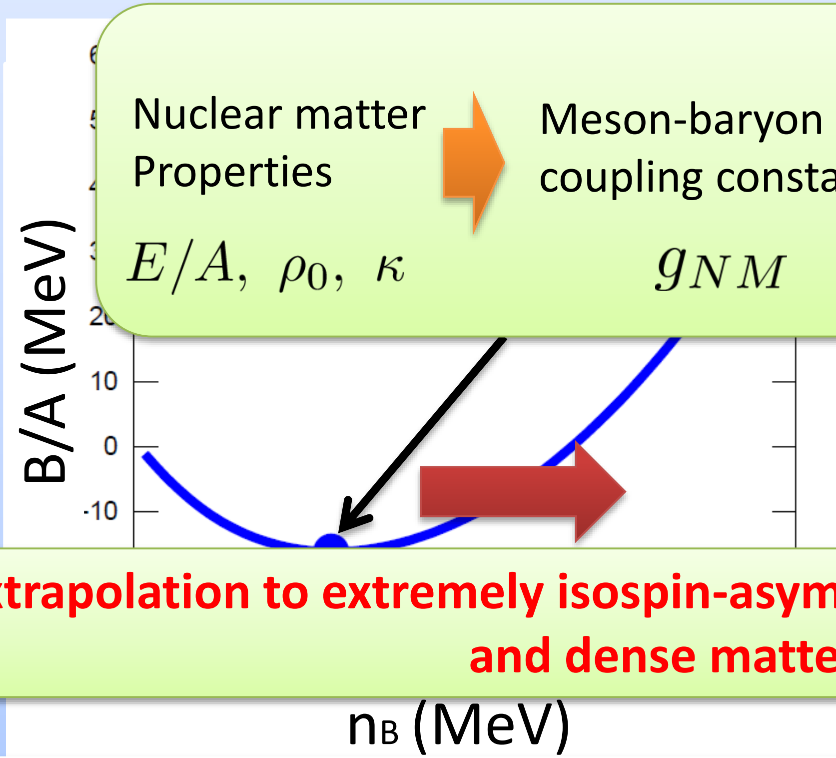
Table of Contents

Models for isospin-asymmetric , dense matter

MFT

Nuclear matter Properties → Meson-baryon coupling constants

$E/A,\ \rho_0,\ \kappa$ → g_{NM}

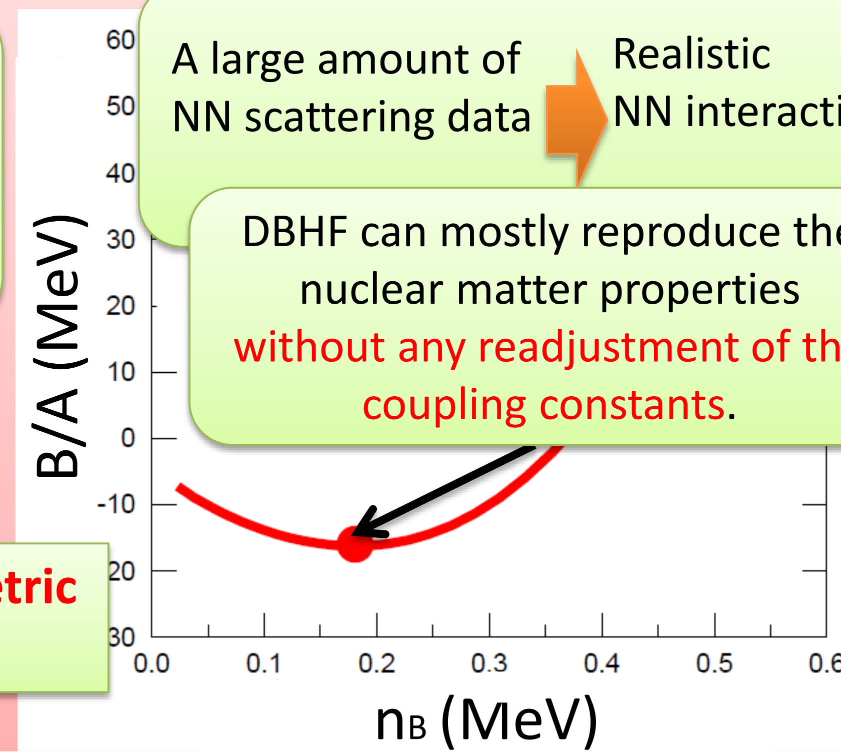


Extrapolation to extremely isospin-asymmetric and dense matter

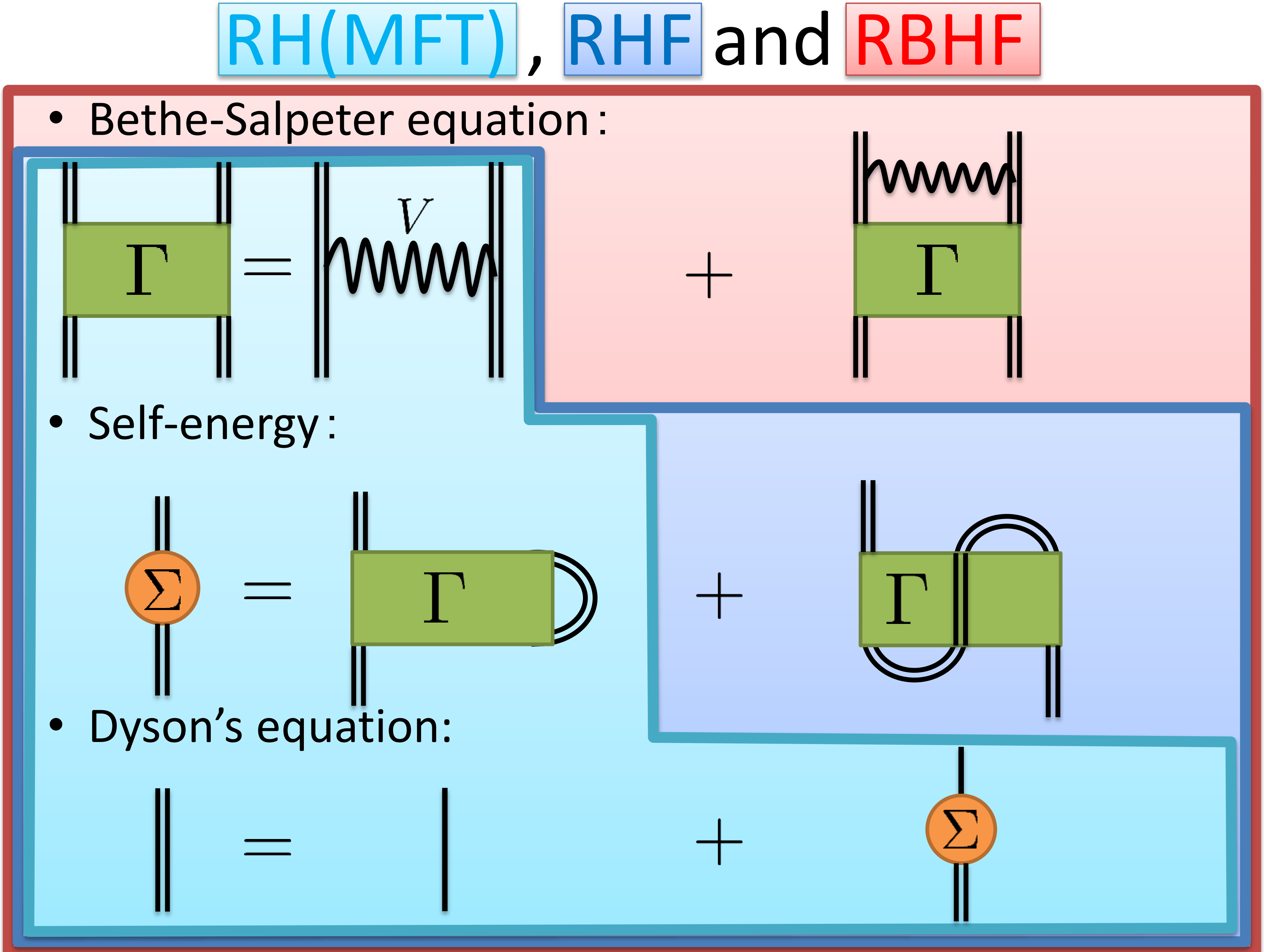
DBHF

A large amount of NN scattering data → Realistic NN interactions

DBHF can mostly reproduce the nuclear matter properties **without any readjustment of the coupling constants**.



The reason for the great success of DBHF is the <u>density dependence</u> mainly caused by many-body effects, the Pauli exclusion principle and the short-range NN correlations.



RH(MFT) , RHF and RBHF
• Bethe-Salpeter equation :
Γ
=
V
+
Γ
• Self-energy :
Σ
=
Γ
+
Γ
• Dyson's equation:
=
+
Σ

Conventional DBHF vs Our DBHF

The conventional DBHF approach requires **two assumptions**:

Conventional DBHF approach

1. The space components of the in-medium baryon self-energy, Σ^V, is ignored.
2. The relationship between the in-medium T-matrix for NN scattering and the in-medium nucleon self-energies is not clear.

Our DBHF approach

1. We fully consider the Σ^V.
2. We also include the negative-energy states of baryon in the Bethe-Salpeter amplitude.

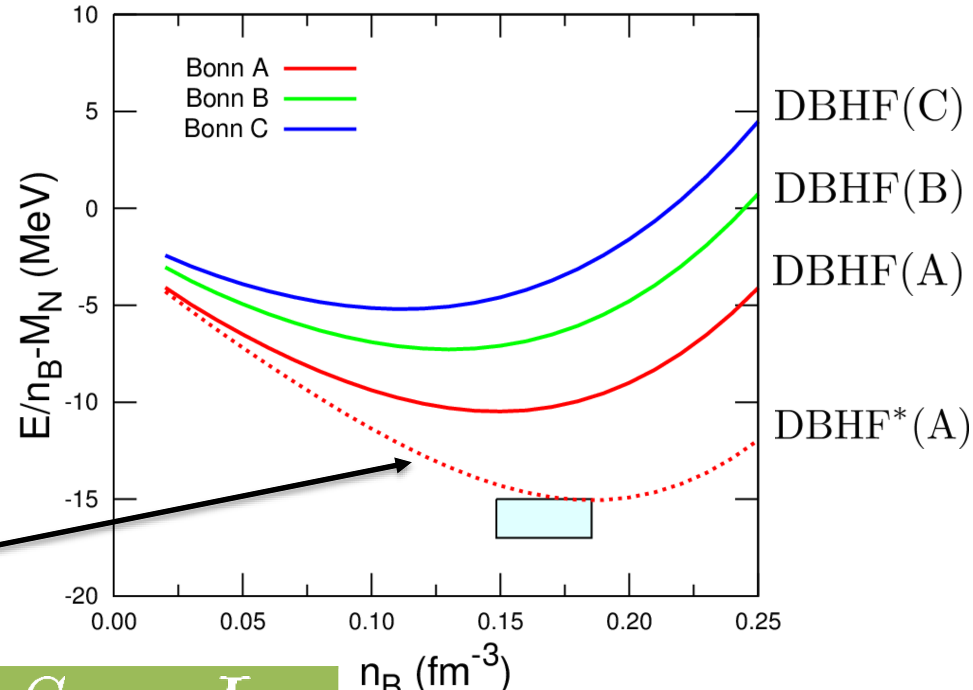
Numerical results

Binding energy per particle in symmetric nuclear matter

Bonn A, B and C potentials

NN potential is generated by the exchanges of $\sigma,\ \omega,\ \rho,\ \pi,\ \delta$ and η mesons.

with $g^{*}_{NN\sigma} = g_{NN\sigma}\left(1 - \beta\frac{\Sigma^S_N}{M_N}\right)$



Case	n_B^0 (fm^{-3})	E/A (MeV)	K (MeV)	S (MeV)	L (MeV)
DBHF (A)	0.149	-10.5	204	28.8	78.6
DBHF (B)	0.130	-7.3	133	22.7	58.2
DBHF (C)	0.112	-5.2	87	18.0	42.2
DBHF *(A)	0.186	-15.1	402	36.8	117.0

- E/A : binding energy
- K : incompressibility
- S : symmetry energy
- L : slope parameter

Neutron stars without hyperons

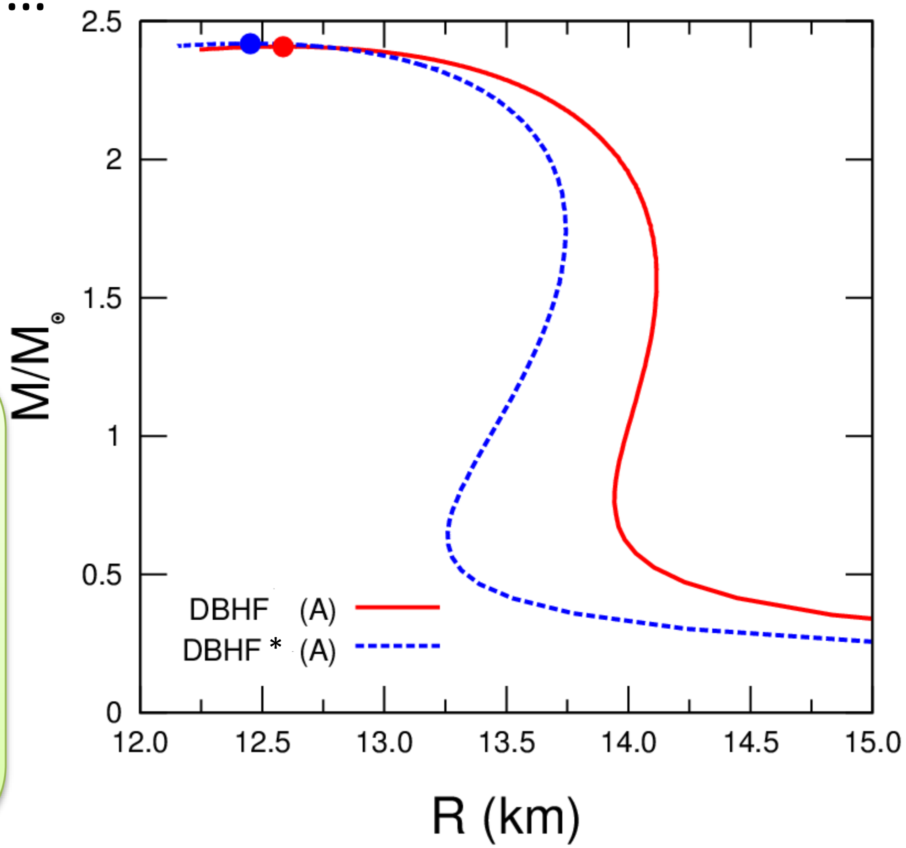
We assume that
neutron-star matter is composed of …

Leptons	Mesons	Baryons
e^-, μ^-	σ, δ, ω, ρ, η, π	n, p

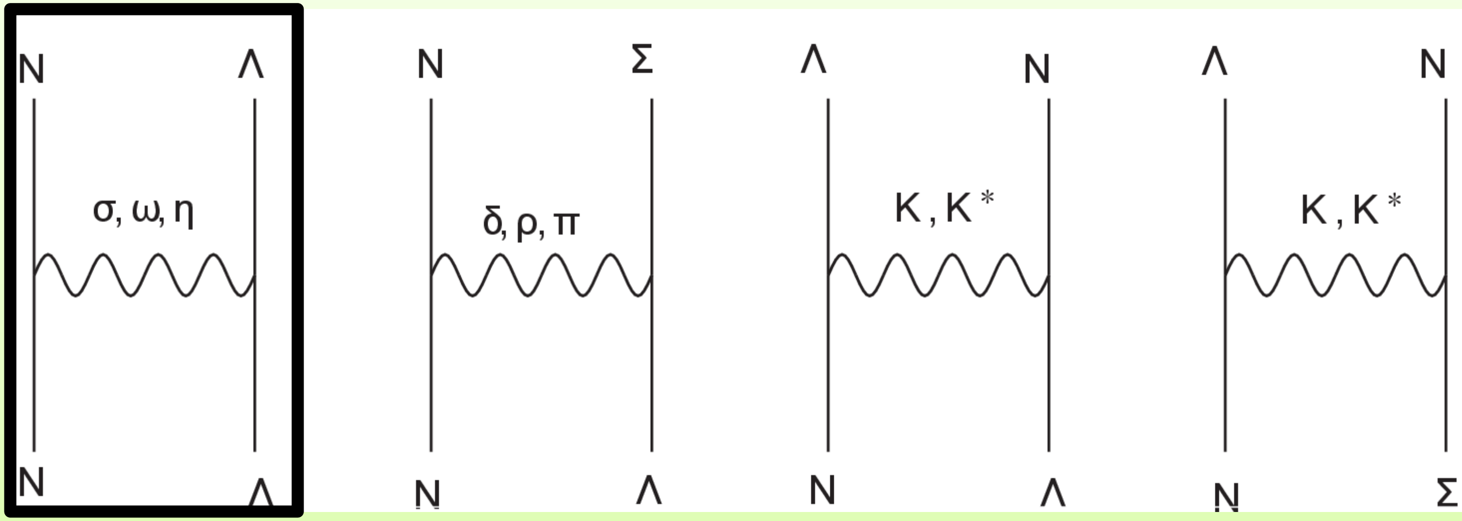
- Charge neutrality:
$$\rho_p - \rho_{e^-} - \rho_{\mu^-} = 0$$
- β-equilibrium in weak interaction:
$$\mu_n = \mu_p + \mu_{e^-}$$
- Baryon number conservation:
$$n_B = \rho_p + \rho_n$$

Tolman-Oppenheimer-Volkoff (TOV) equation

DBHF(A) and DBHF*(A)



Inclusion of hyperons



One-boson-exchange processes for the $N\Lambda$ system.

We assume that neutron-star matter is composed of …

	Leptons	Mesons	Baryons
NlY5	e^-, μ^-	σ, δ, ω, ρ, η, π	n, p, Λ, Σ^-, Ξ^-
NlY8	e^-, μ^-	σ, δ, ω, ρ, η, π	n, p, Λ, Σ^-, Σ^0, Σ^+, Ξ^-, Ξ^0

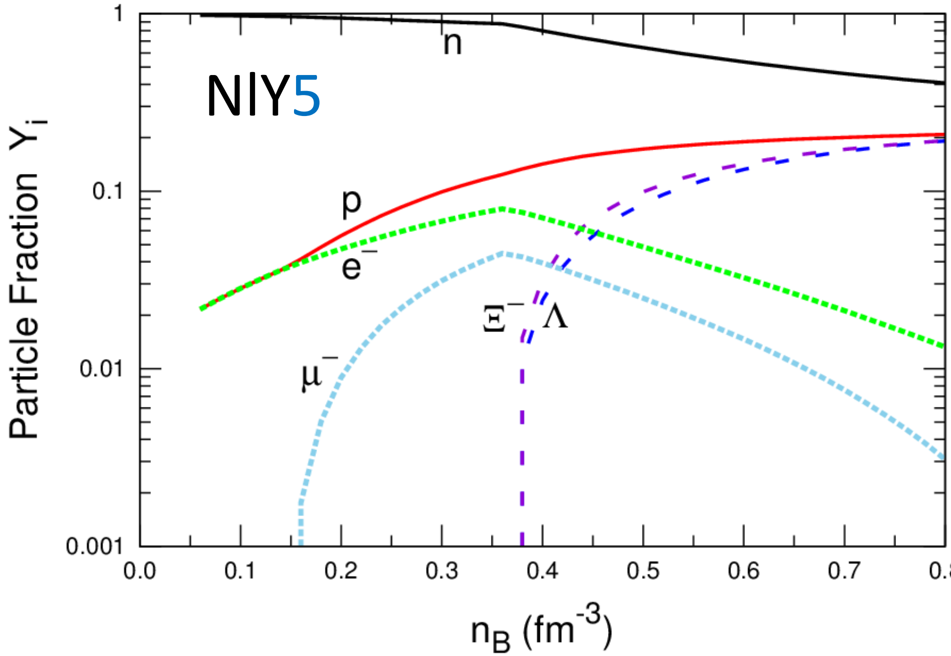
Calculation parameters for hyperons

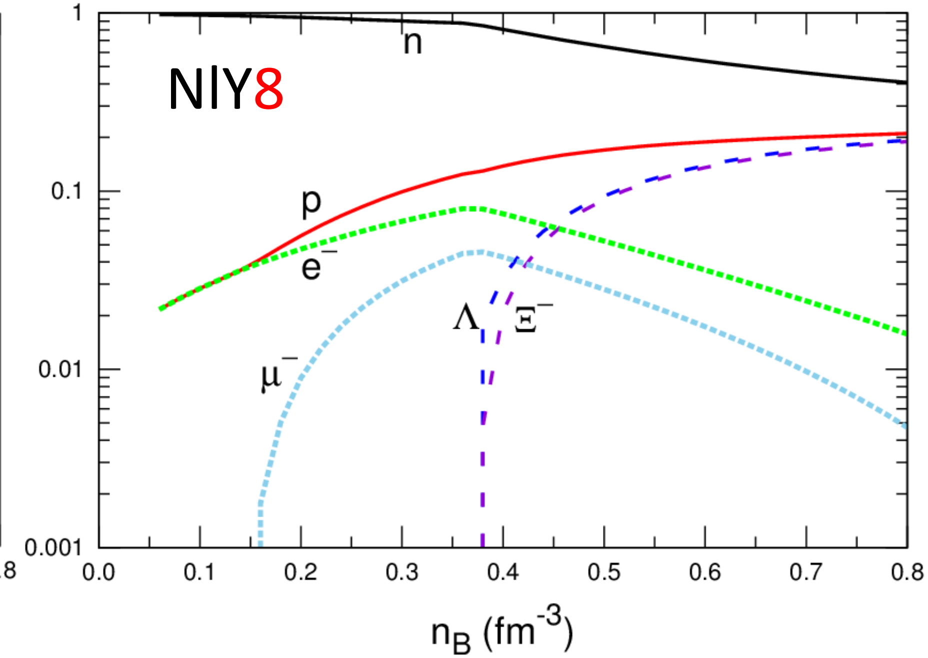
Parameters for hyperons cannot be determined without large ambiguities.

- Baryon-Baryon-meson coupling constants:
  - ⇨ SU(6) symmetry   e.g. $g_{NN\omega} = \frac{3}{2} g_{\Lambda\Lambda\omega} = g_{\Sigma\Sigma\omega} = 3 g_{\Xi\Xi\omega}$
- Baryon-Baryon-sigma coupling constants:
  - ⇨ $U_\Lambda \simeq -27\,\mathrm{MeV} \quad U_{\Sigma^-} \simeq +30\,\mathrm{MeV} \quad U_{\Xi^-} \simeq -15\,\mathrm{MeV}$
- Cutoff parameters in the form factor:
  - ⇨ $\Lambda_{YYM} = \Lambda_{NNM}$

Simple parameter set

Particle fractions for NlY5 and NlY8

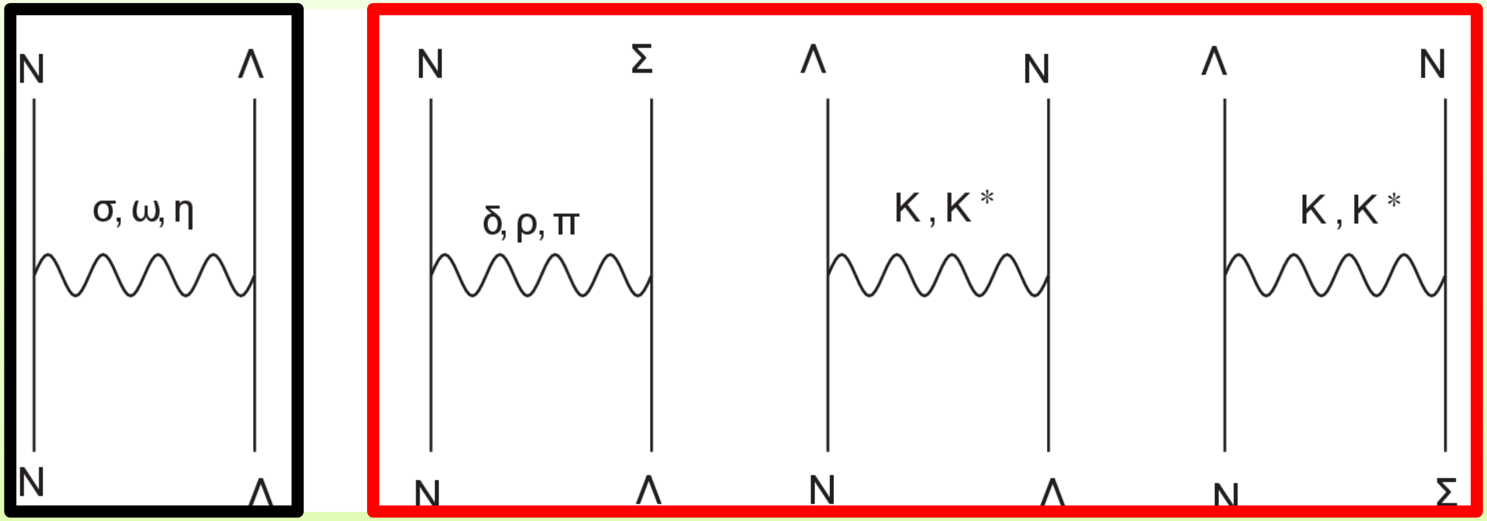




The difference between the result in NlY5 and NlY8 is expected to be very small.

We proceed to the next calculation, where K and K^* mesons are considered.

Baryon-exchange and Baryon-transition processes

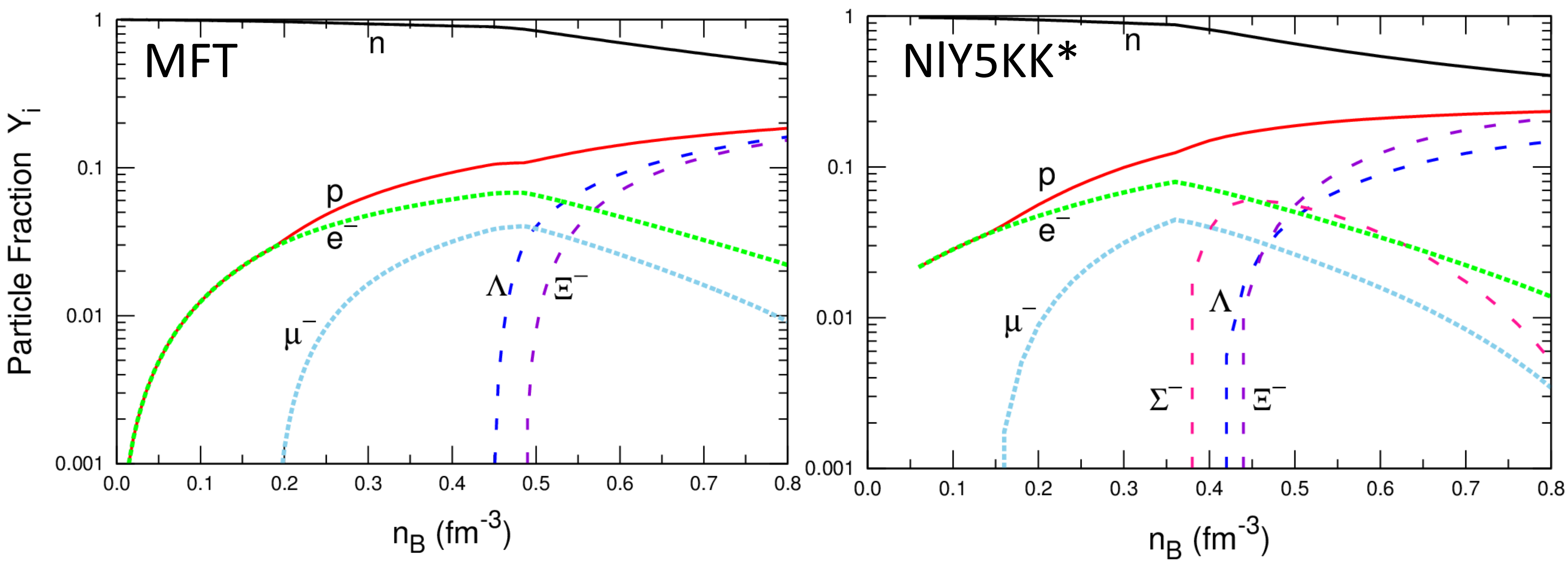


One-boson-exchange processes for the $N\Lambda$ system.

We assume that neutron-star matter is composed of …

	Leptons	Mesons	Baryons
NlY5KK*	e^-, μ^-	σ, δ, ω, ρ, η, π, K, K^*	n, p, Λ, Σ^-, Ξ^-

Particle fractions in cases of MFT and NlY5KK*

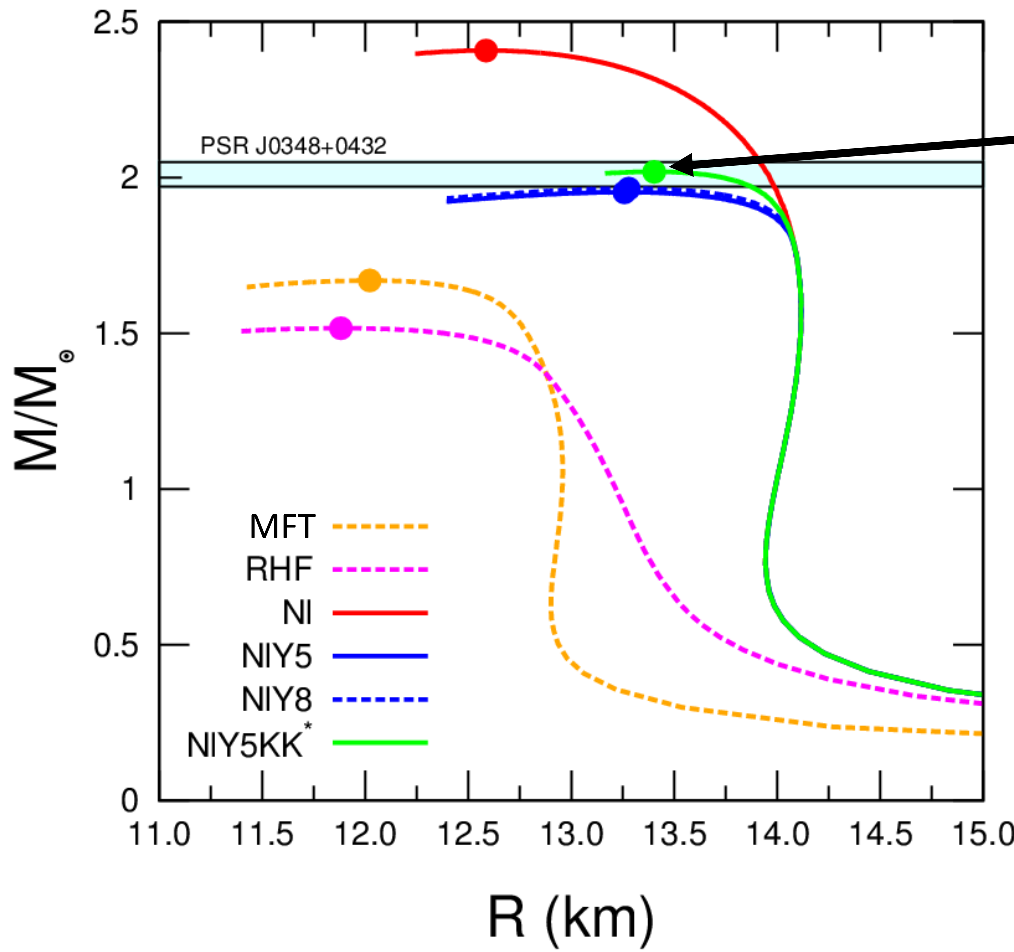


The results are similar to one another, except for the appearance of Σ^- in NlY5KK*.

However

EOSs in two cases make large difference.

Mass-radius relations for neutron stars



2.02M⊙

NIY5KK*

The DBHF calculation involves <u>the strong density dependence</u> of the in-medium baryon-baryon scattering amplitude.

Summary

- Using the improved DBHF approach, we have investigated the nuclear matter properties, and have applied the DBHF approach to neutron stars.
- The hyperon-mixed neutron-star calculation has predicted the maximum neutron-star mass of $2.02M_{\odot}$.

Future works

- More realistic parameter set for hyperons