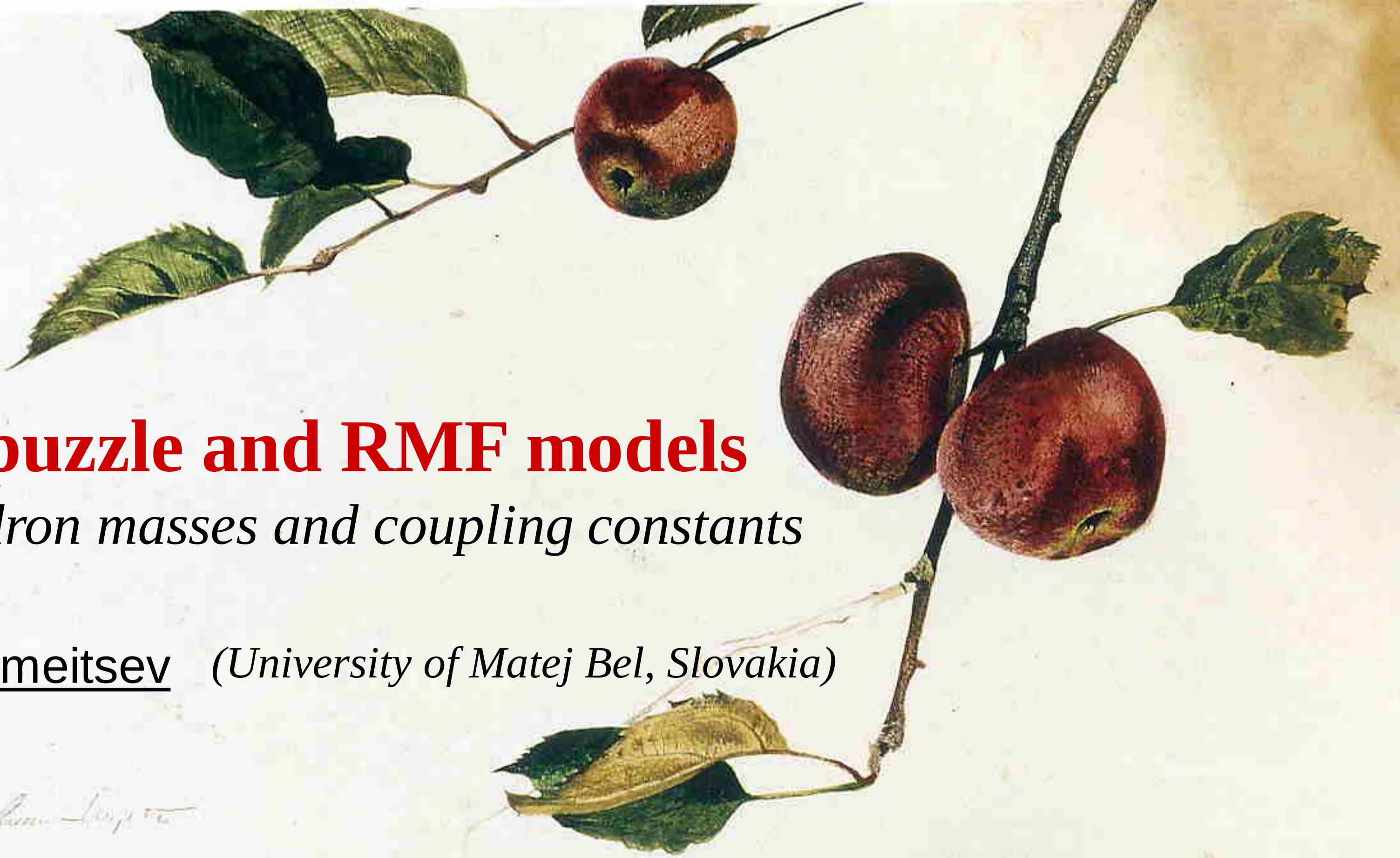

Hyperon puzzle and RMF models

with scaled hadron masses and coupling constants

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K.A. Maslov and D.N. Voskresensky *(MEPhI, Moscow)*

- “Hyperon puzzle” and constraints on the nuclear EoS
  maximum mass of a neutron star
  constraint on pressure from HIC
  constraint from direct Urca (DU) processes
  “hyperon puzzle”

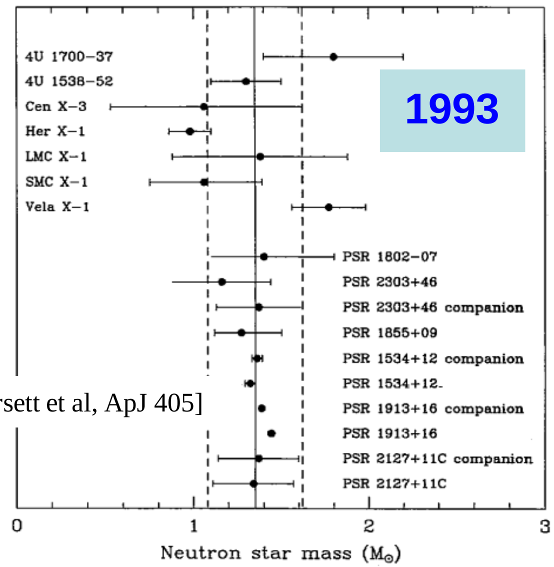
- Cut mechanism for hardening the nucleon EoS.
  Non-linear Walecka model: Play with a scalar-field potential

- Scaling of meson masses and coupling constants

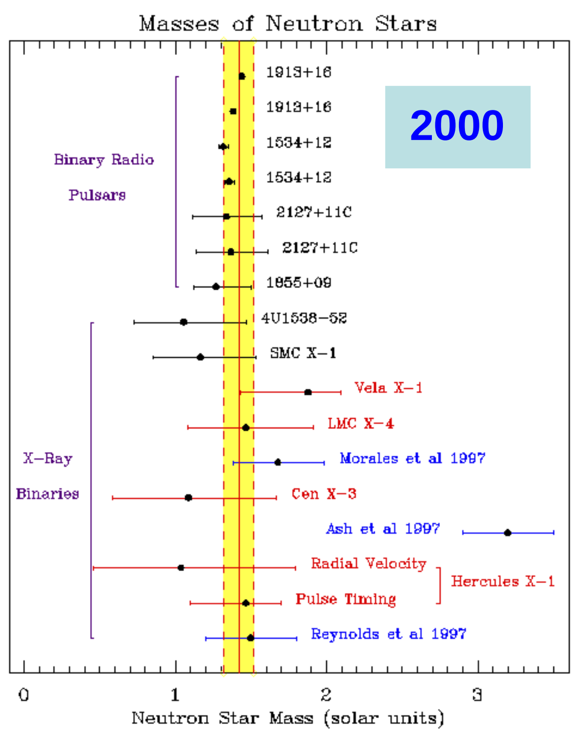
- Solution of the hyperons puzzle in neutron stars

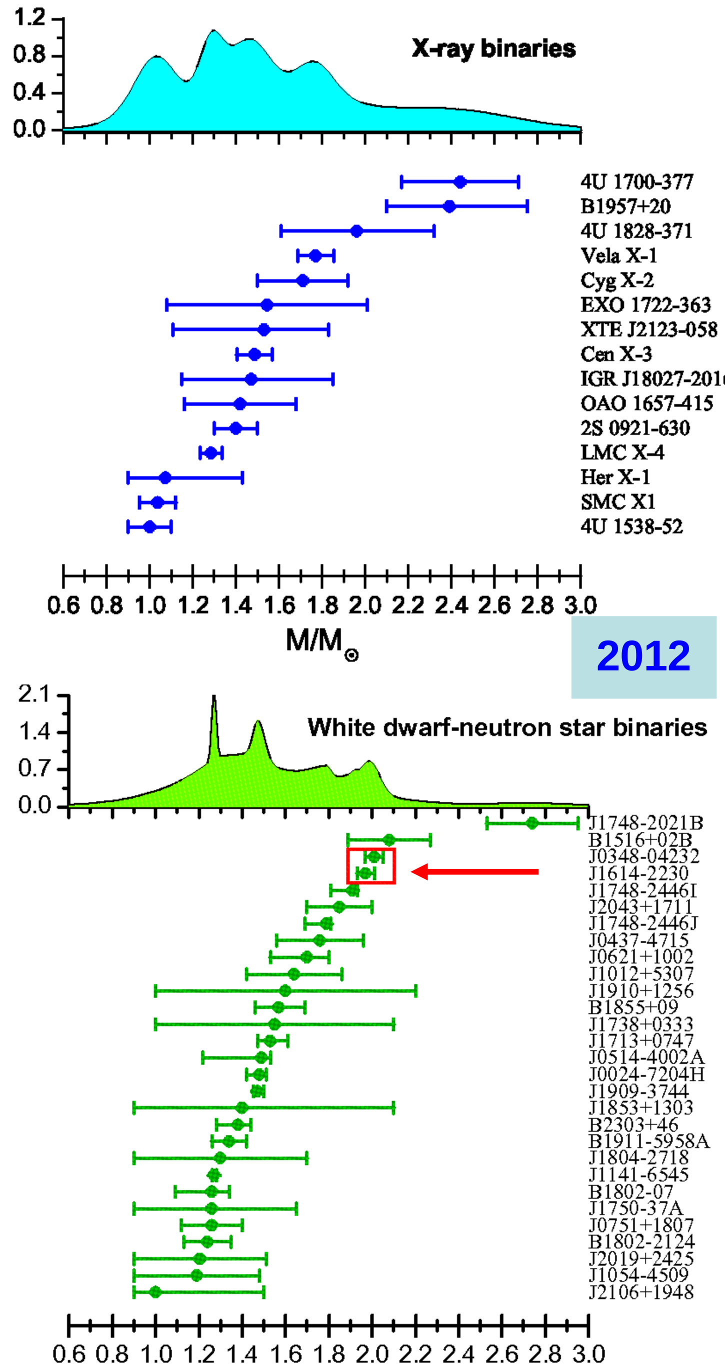
- Δ baryons

Neutron star mass charts



[Thorsett et al, ApJ 405]



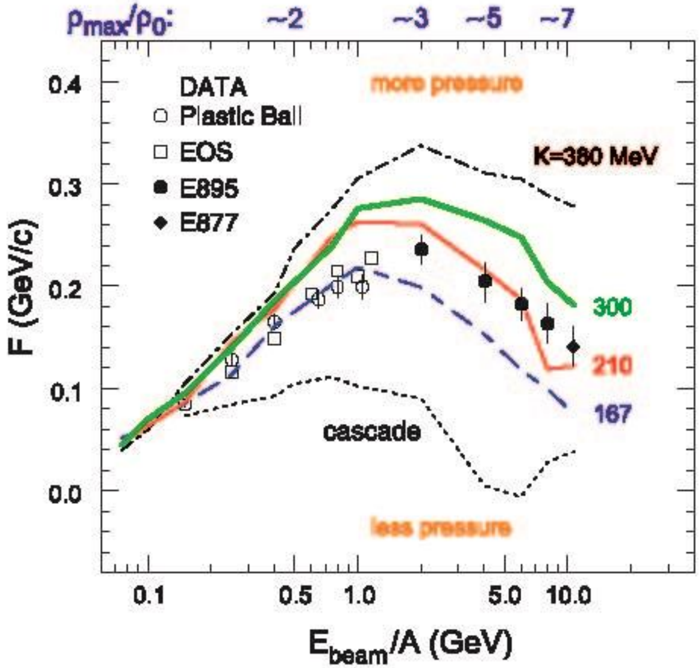


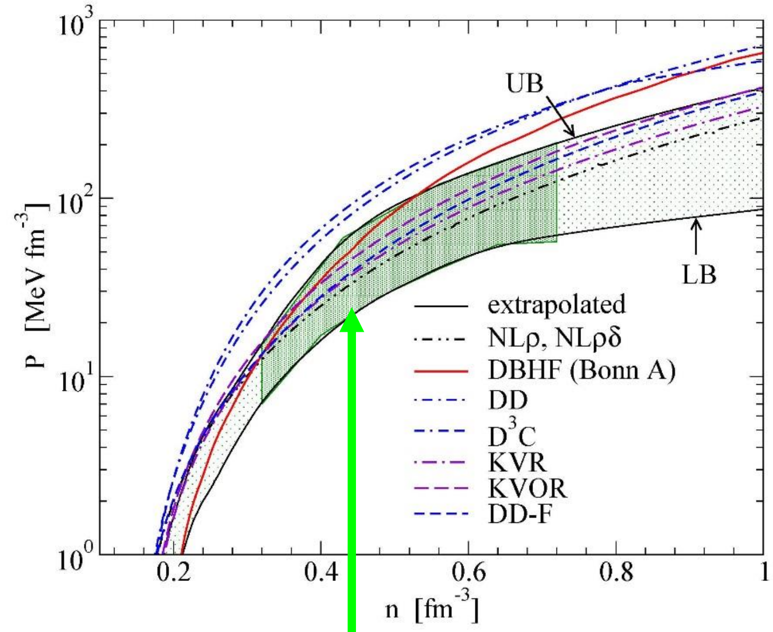
http://www.stellarcollapse.org/

Constraint on the stiffness of nuclear EoS

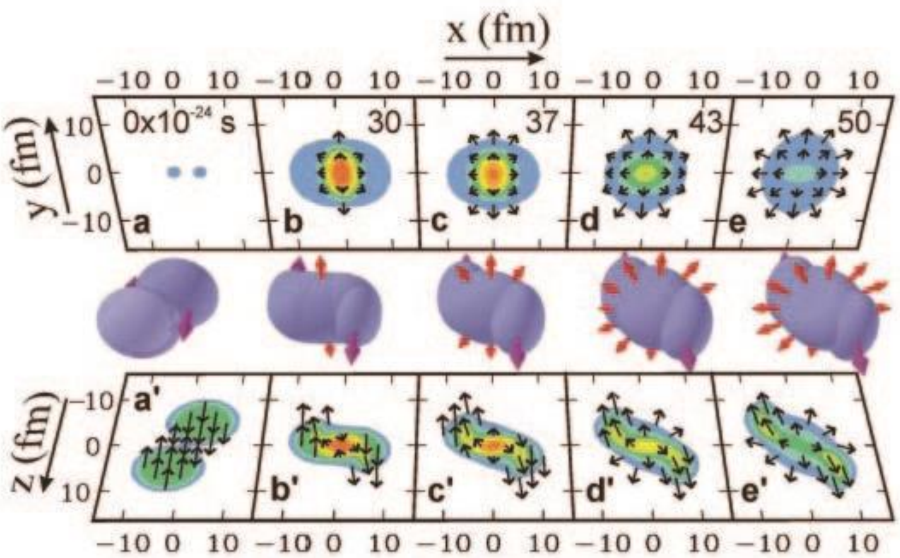
[Danielewicz, Lacey, Lynch, Science 298, 1592 (2002)]

directed and elliptic flow of particles in heavy-ion collisions





range for the pressure of isospin symmetrical matter at T=0



maximum NS mass >1.98 M_{sol} requires stiff EoS restrict the pressure from above!

Neutron star cooling and direct Urca reactions

DU: $n \to p + e^- + \bar{\nu}_e$

$$\epsilon_{\rm DU} = 10^{27} T_9^6 \frac{\rm erg}{\rm cm^3\, s}$$

MU: $n + n \to n + n + e^- + \bar{\nu}_e$

$$\epsilon_{\rm MU} = 10^{22} T_9^8 \frac{\rm erg}{\rm cm^3\, s}$$

standard scenario (MU+pairing)

only "slow" cooling can be described

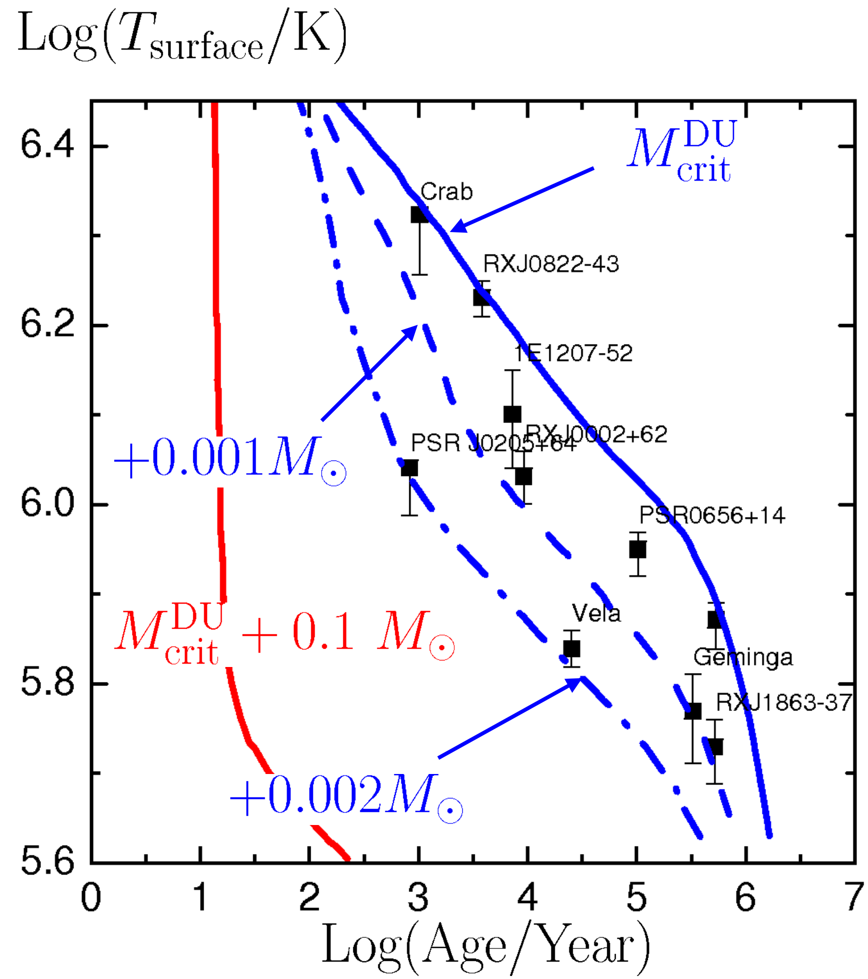
Neutron stars with $M > M_{\rm crit}^{\rm DU}$ will be too cold

DU process schould be „exotics“

(if DU starts it is dificult to stop it)

$M_{\rm crit}^{\rm DU} \gtrsim 1.3\ M_\odot$ weak constraint

$M_{\rm crit}^{\rm DU} \gtrsim 1.5\ M_\odot$ strong constraint



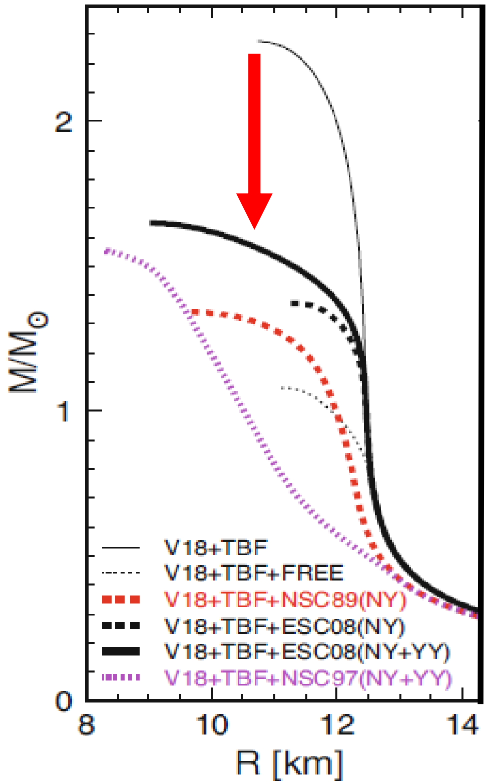
[Blaschke, Grigorian, Voskresensky A&A 424 (2004) 979]

→ constraint on the symmetry energy

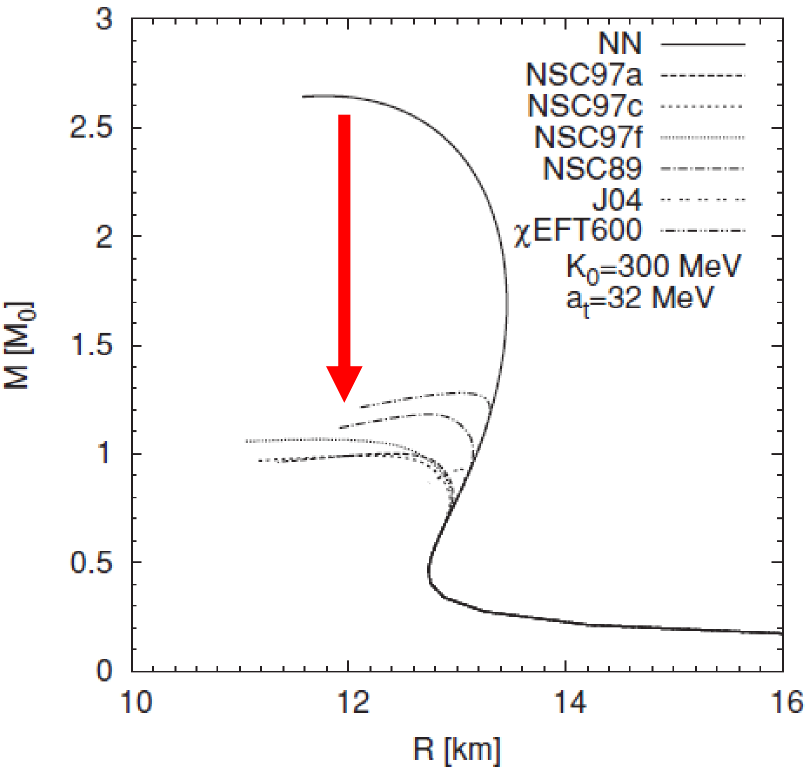
[EEK, Voskresensky NPA759 (2005) 373]

“Hyperon puzzle”

If we allow for a population of new Fermi seas (hyperon, Δ baryons, …)
EoS will be softer and the NS will be smaller



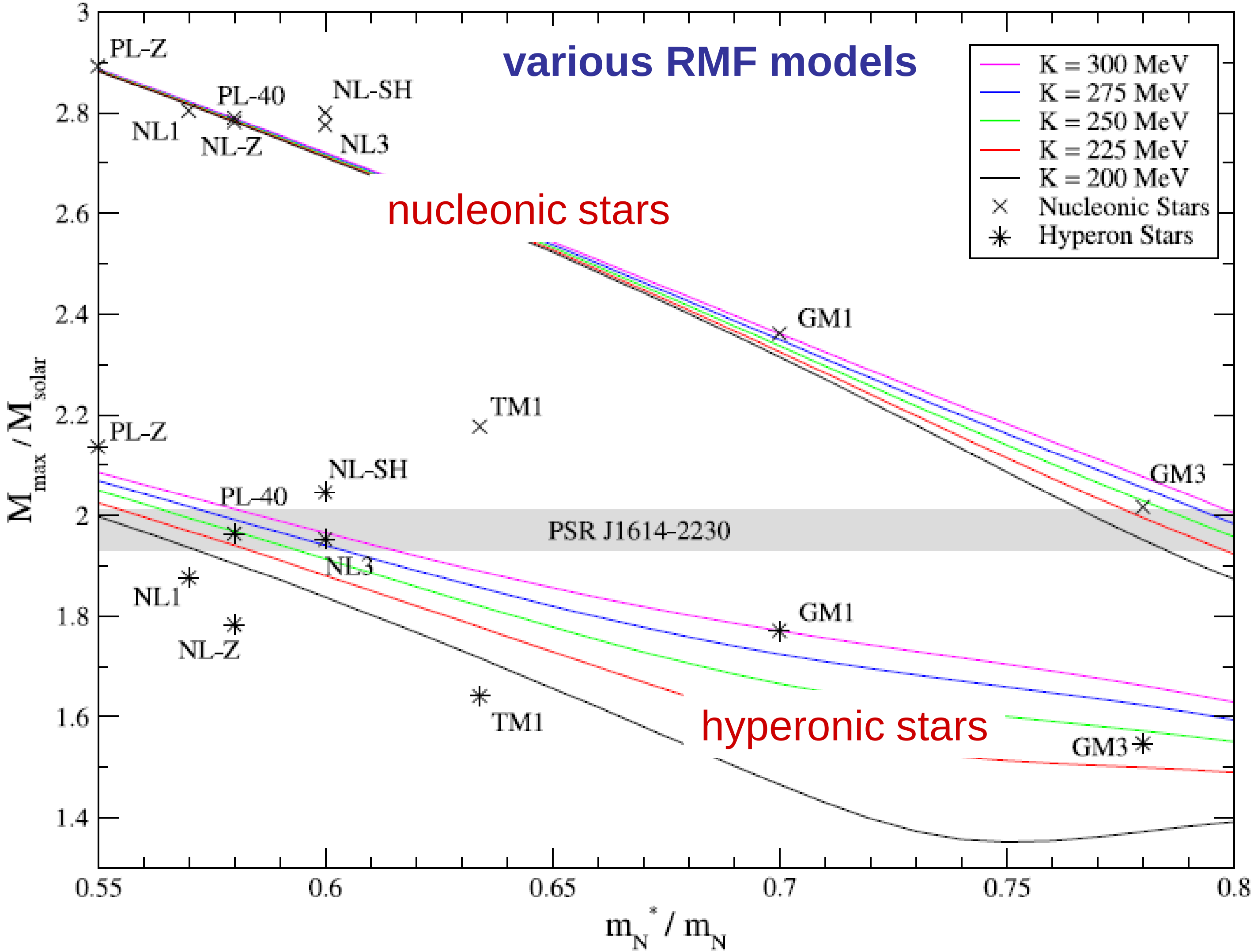
[Rijken, Schulze, EPJA52 (2016) 21]



[Dapo, Schaefer, Wambach PRC 81 (2010) 035803]

Simple solutions: **-- make nuclear EoS as stiff as possible** [flow constraint]
-- suppress hyperon population (increase repulsion/reduce attraction)

against phenomenology of YN,NN,YY interaction in vacuum
+hypernuclear physics



[Weissenborn et al., NPA 881 (2012) 62]

“Cut” mechanism for hardening the nuclear EoS.

Maslov, EEK, Voskresensky, PRD92 (2015) 052801(R)

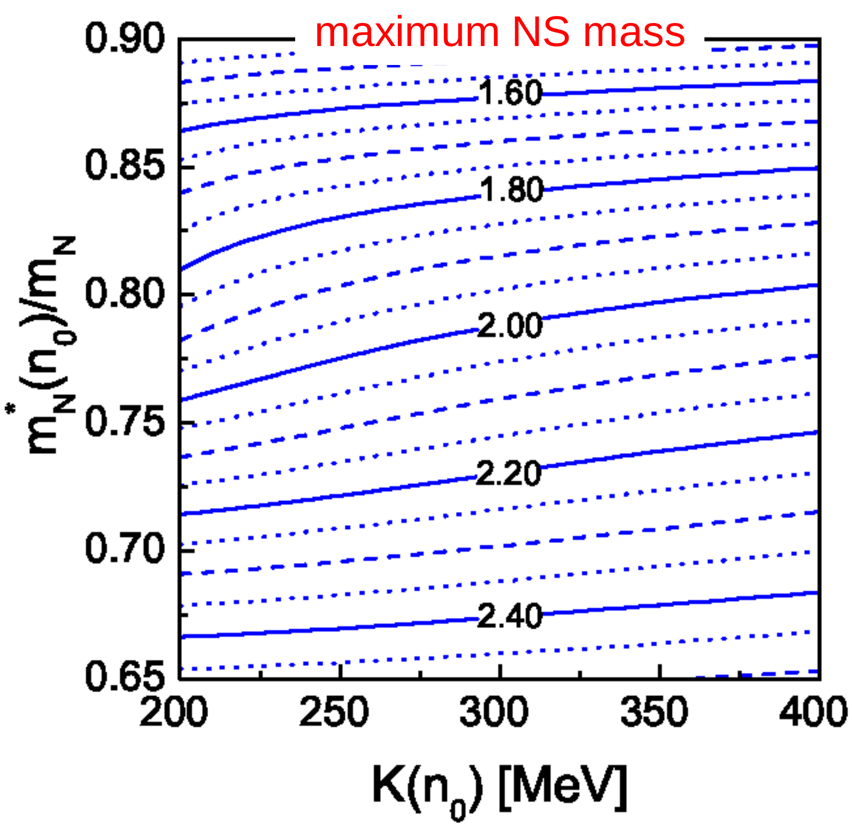
The standard non-linear Walecka (NLW) model

$$\mathcal{L} = \overline{\Psi}_N \left[(i\,\partial_\mu - g_\omega \omega_\mu - g_\rho \boldsymbol{t}\boldsymbol{\rho}_\mu)\,\gamma^\mu - m_N + g_\sigma \sigma \right] \Psi_N$$ *nucleons*

$$+ \tfrac{1}{2}[(\partial_\mu \sigma)^2 - m_\sigma^2 \sigma^2] - U(\sigma)$$ *scalar field*

$$- \tfrac{1}{4}\omega_{\mu\nu}\omega^{\mu\nu} + \tfrac{1}{2} m_\omega^2 \omega_\mu^2 - \tfrac{1}{4}\boldsymbol{\rho}_{\mu\nu}\boldsymbol{\rho}^{\mu\nu} + \tfrac{1}{2} m_\omega^2 (\boldsymbol{\rho}_\mu)^2$$ *vector fields*

$$U(\sigma) = \tfrac{b}{3} m_N (g_{\sigma N}\sigma)^3 + \tfrac{c}{4}(g_{\sigma N}\sigma)^4$$



Input parameters

$$n_0 = 0.16\,\mathrm{fm}^{-3},\ \mathcal{E}_0 = -16\,\mathrm{MeV},\ K = 250\,\mathrm{MeV}$$

$$\mathcal{E}_{\rm sym} = 30\,\mathrm{MeV},\ m_N^*(n_0)/m_N = 0.8$$

$$\Longrightarrow M_{\max} = 1.92\,M_\odot$$

For better description of atomic nuclei one Includes no-linear terms $\omega_\mu^4,\ \omega_\mu^2 \boldsymbol{\rho}_\nu^2$

$\longrightarrow$ softening of EoS and M_{max} reduction

Maximum mass strongly depends on $m^*_N(n_0)$ and weakly on K.

In NLW the scalar field is monotonously increasing function of the density

$$m_\sigma^2 \sigma + U'(\sigma) = g_\sigma \left(n_{\mathrm{S},p} + n_{\mathrm{S},n} \right)$$

$$n_{\mathrm{S},i} = \int_0^{p_{\mathrm{F},i}} \frac{m_N^* p^2 \mathrm{d}p/\pi^2}{(p^2 + m_N^{*2})^{1/2}}$$

dimensionless scalar field $f = g_\sigma \sigma / m_N$

source is the scalar density

$$m_N^* = m_N - g_\sigma \sigma$$

$$m_N^* = m_N(1-f)$$

$$C_\sigma^2 = g_\sigma^2 m_N^2 / m_\sigma^2$$

$$\frac{f}{C_\sigma^2} + \frac{U'(f)}{m_N} = n_{\mathrm{S},p} + n_{\mathrm{S},p}$$

Can we control function f(n)?

$$\frac{\mathrm{d}f}{\mathrm{d}n} = \frac{2\partial(n_{\mathrm{S},p} + n_{\mathrm{S},n})/\partial n}{m_N^3 C_\sigma^{-2} + \widetilde{U}''(f)/m_N - 2\partial(n_{\mathrm{S},p} + n_{\mathrm{S},n})/\partial f}$$

$$\frac{\partial n_{\mathrm{S},i}}{\partial n} = \frac{m_N^*}{2\sqrt{p_{\mathrm{F},i}^2 + m_N^{*2}}}$$

$$-\frac{\partial n_{\mathrm{S},i}}{\partial f} = \int_0^{p_{\mathrm{F},i}} \frac{m_N p^4 \mathrm{d}p/\pi^2}{(p^2 + m_N^{*2})^{3/2}}$$

Observation:

If we modify the scalar potential $\widetilde{U}(\sigma) = U(\sigma) + \Delta U(\sigma)$ so that the $m^*_N(n)$ levels off

NLWcut model $\widetilde{U}(\sigma) = U(\sigma) + \Delta U(\sigma)$

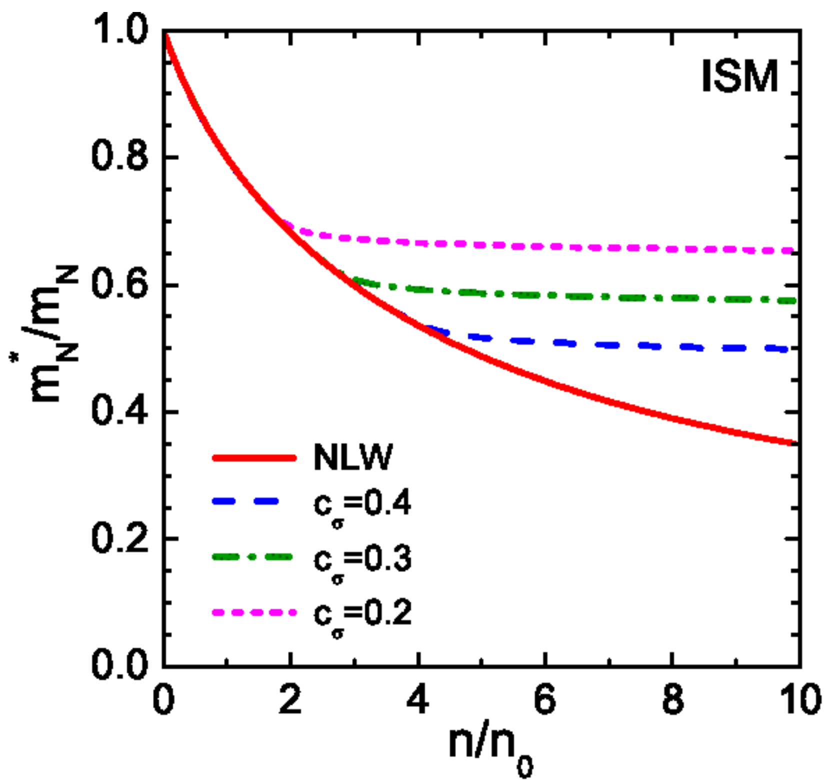
sharpness parameter

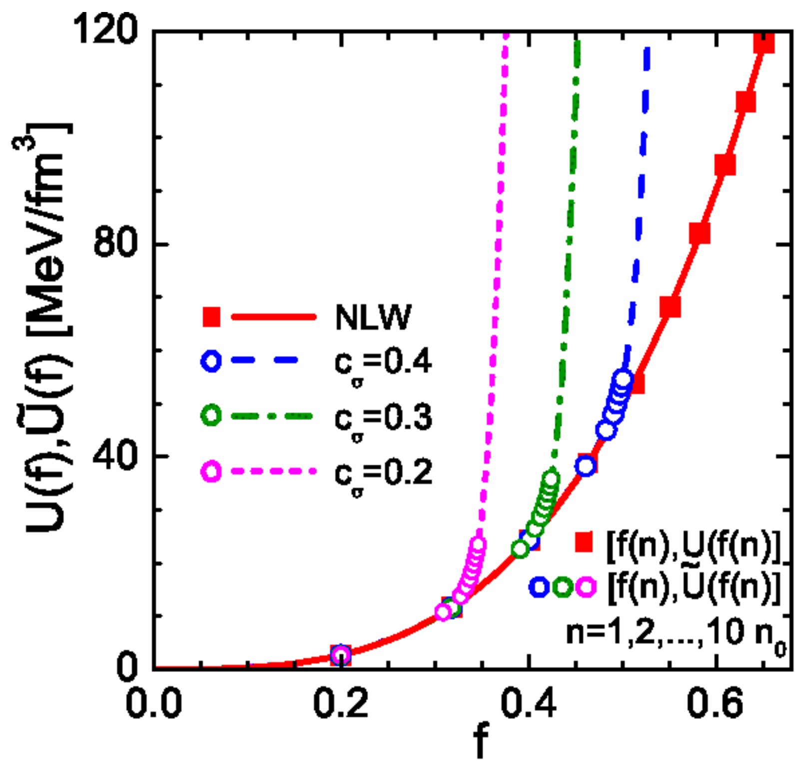
soft core: $\Delta U(f) = \alpha \ln[1 + \exp(\beta(f - f_{\mathrm{s.core}}))]$

$f_{\mathrm{s.core}} = f_0 + c_\sigma(1 - f_0)$

hard core: $\Delta U(f) = \alpha\left[\delta f/(f_{\mathrm{h.core}} - f)\right]^{2\beta}$

$m_N^*(n_0) = m_N\,(1 - f_0)$

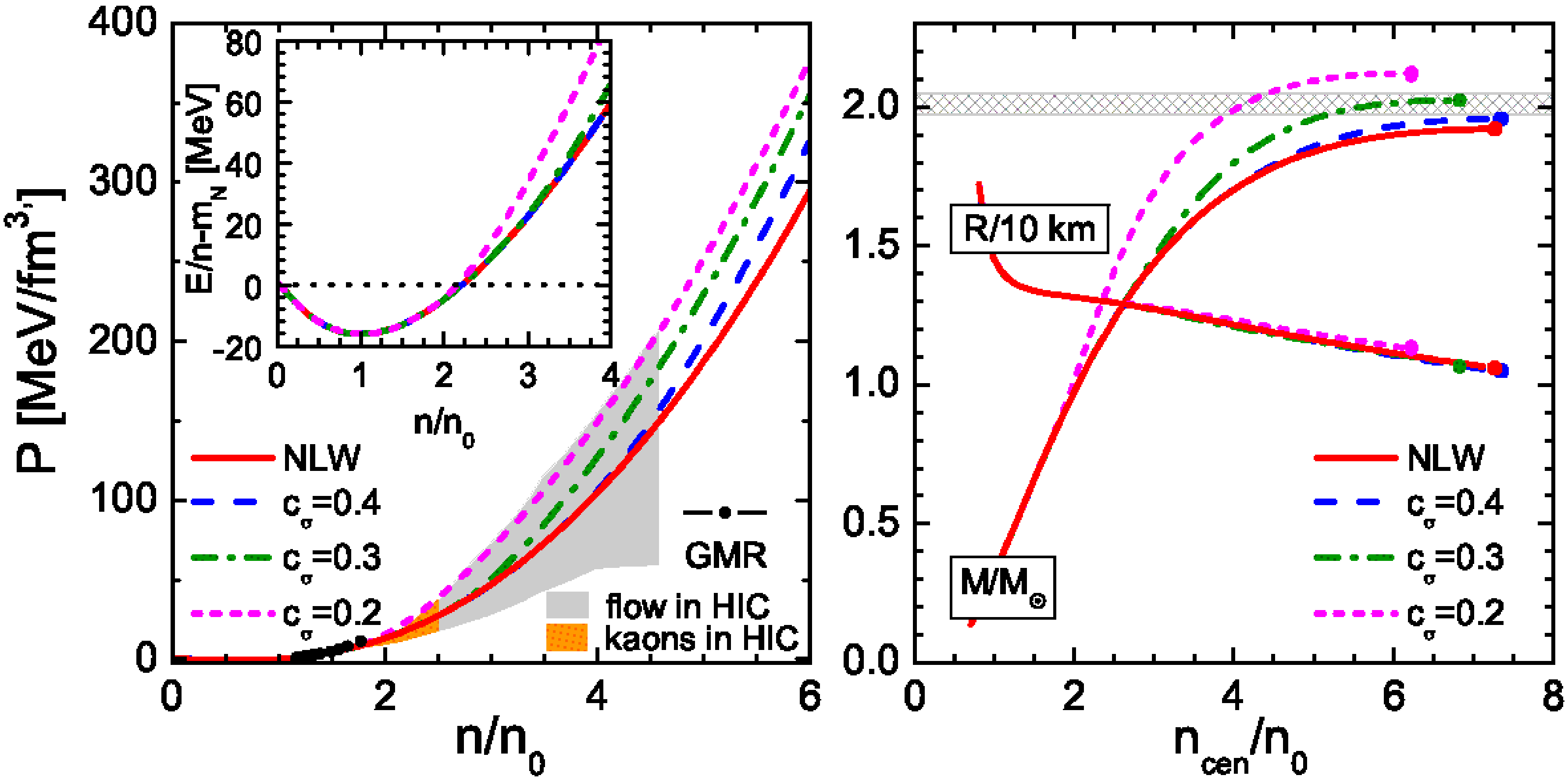




Simulation of excluded volume effect

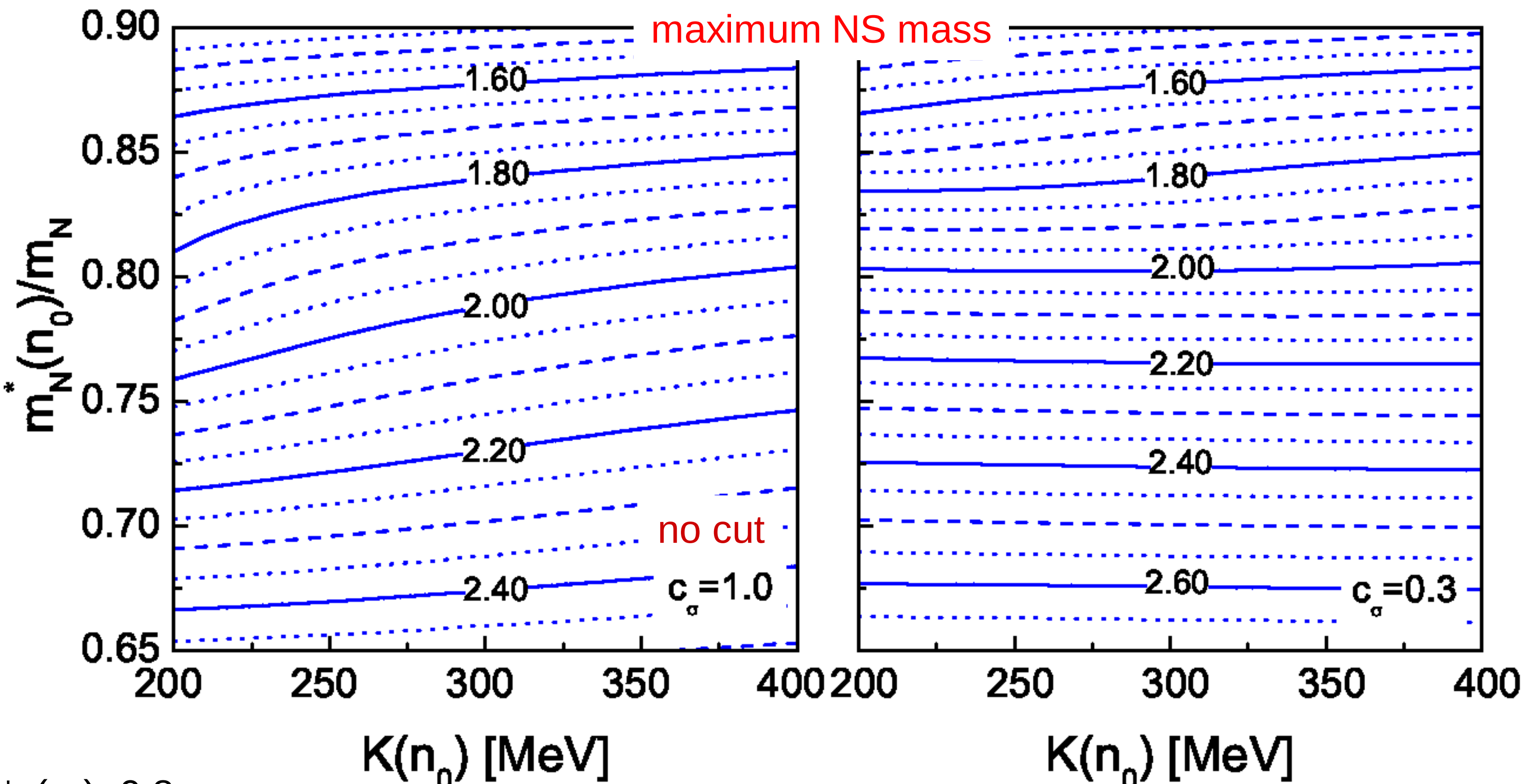
If m*N(n) saturates then the EoS stiffens

$$f_{\mathrm{s.core}} = f_0 + c_\sigma(1 - f_0)$$



P.-G. Reinhard, [Z. Phys. A 329 (1988) 257]
introduced a “switch function”
to get rid off the scalar field fluctuations

$$\mathcal{U}''(\Phi) = m_\infty^2 + \Delta m^2 \cosh^{-2}\left(\frac{\Phi - \Phi_0}{\delta\Phi}\right)$$

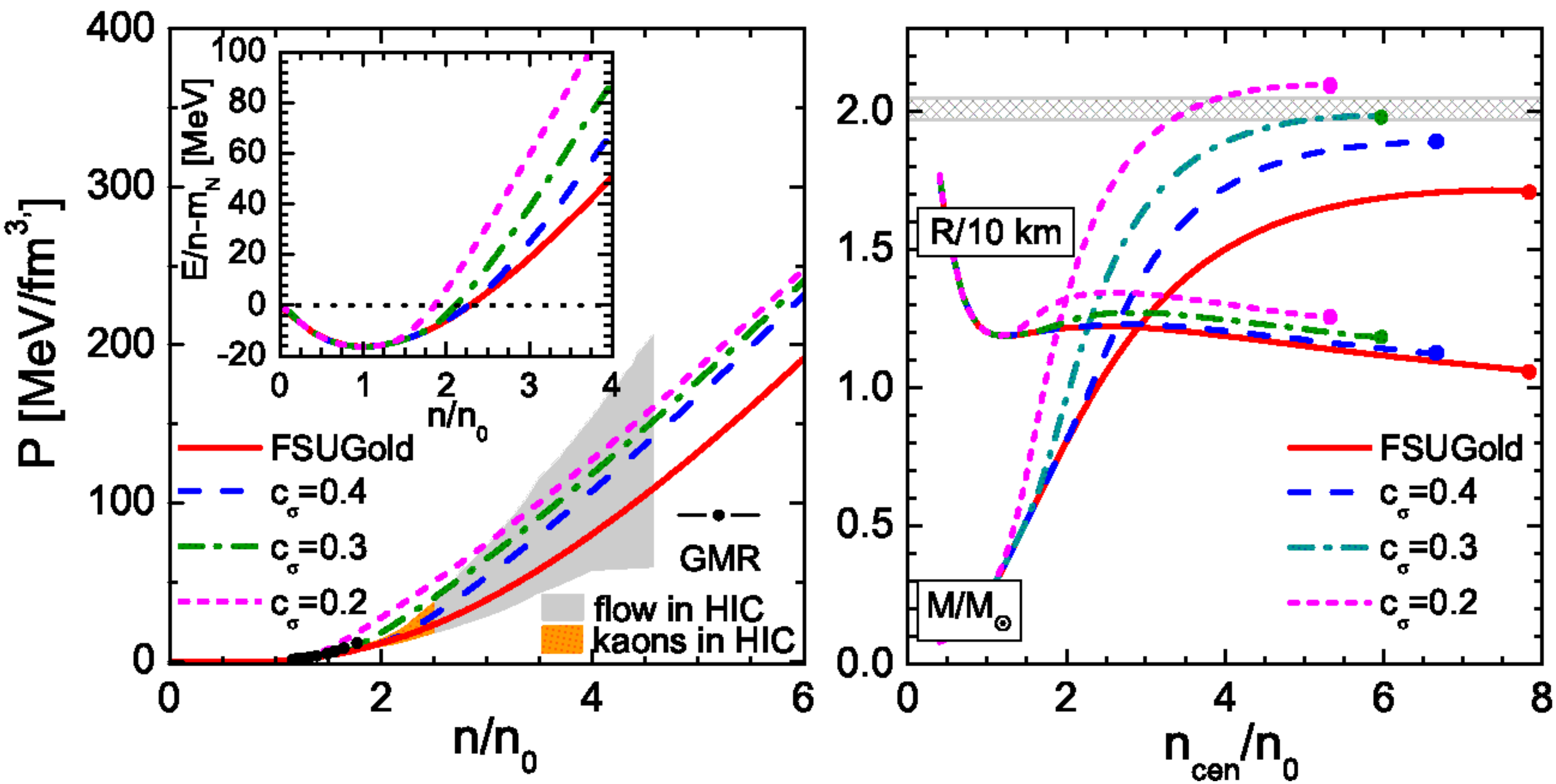


$m^*_N(n_0)=0.8\ m_N$

The effect is more pronounced if the input parameter of the model $m^*_N(n_0)$ is chosen smaller

FSUGold model

Todd-Rutel, Piekarewicz, Phys. Rev. Lett. 95 (2005) 122501



Alternative FSUGold2 model: W.-Ch. Chen, Piekarewicz, Phys. Rev. C 90 (2014) 044305

$$M_{\max} = 2.1\, M_\odot$$

Attempts to solve the hyperon puzzle

play with hyperon coupling constants $x_{mH} = \frac{g_{mH}}{g_{mN}}$

quark counting SU(6) for vector couplings:

$$g_{\omega N} : g_{\omega\Lambda} : g_{\omega\Sigma} : g_{\omega\Xi} = 3 : 2 : 2 : 1$$

$$g_{\rho N} : g_{\rho\Lambda} : g_{\rho\Sigma} : g_{\rho\Xi} = 1 : 0 : 2 : 1$$

scalar couplings:

$$x_{\sigma H} = \frac{x_{\omega H} n_0 C_\omega^2 / m_N^2 - U_H(n_0)}{m_N - m_N^*(n_0)} \longleftarrow \left\{ \begin{array}{l} U_\Lambda(n_0) = -28\,\mathrm{MeV} \\ U_\Sigma(n_0) = +30\,\mathrm{MeV} \\ U_\Xi(n_0) = -15\,\mathrm{MeV} \end{array} \right.$$

extensions

phi meson: HH' repulsion

$$g_{\phi N} : g_{\phi\Lambda} : g_{\phi\Sigma} : g_{\phi\Xi} = 0 : 2 : 2 : 1 \qquad g_{\phi\Lambda} = -\frac{\sqrt{2}}{3} g_{\omega N}$$

[J. Schaffner et al., PRC71 (1993), Ann.Phys. 235 (94),PRC53(1996)]

SU(3) coupling constants: extra parameters to tune.
two effects: $|g_{\omega H}|$ increases; $g_{\phi N}$ non zero

[Weissenborn et al., PRC85 (2012);NPA881 (2012); NPA914(2013)]

alternative

mass of ϕ meson — If we take into account a reduction of the ϕ mass in medium we can increase a HH repulsion

EEK and D.Voskresensky NPA 759 (2005) 373

- in standard RMF model m_σ, m_ω, and m_ρ do not change

Can the in-medium modification (decrease) of meson masses be included in an RMF model??

- Song, Brown, Min, Rho (1997) $m^*_\sigma/m_\sigma \approx m^*_\omega/m_\omega \approx m^*_\rho/m_\rho = \Phi(n)$

Lattice QCD (SC-QCD): common drop of meson masses
[Ohnishi Miura Kawamoto Mod.Phys.Lett A23, 2459]

- decreasing functions of σ: $m^*_\omega(\sigma)$, $m^*_\rho(\sigma) \longleftarrow$ self-consistent σ field

  results in *increase* of ρ an ω masses

- σ field dependent masses and couplings constant

Generalized RMF Model

Nucleon and meson Lagrangian

$$
\begin{aligned}
\mathcal{L} &= \mathcal{L}_N + \mathcal{L}_M \\
\mathcal{L}_N &= a_N \bar{\Psi}_N \big(i \ D \cdot \gamma \big) \Psi_N - m_N \phi_N \bar{\Psi}_N \bar{\Psi}_N \\
& \quad D_\mu = \partial_\mu + i g_\omega \tilde{\chi}_\omega \omega_\mu + \frac{i}{2} g_\rho \tilde{\chi}_\rho \boldsymbol{\rho}_\mu \boldsymbol{\tau} \\
\mathcal{L}_M &= a_\sigma \frac{\partial^\mu \sigma \partial_\mu \sigma}{2} - \phi_\sigma^2 \frac{m_\sigma^2 \sigma^2}{2} - \tilde{U}(\sigma) \\
& \quad - a_\omega \frac{\omega_{\mu\nu} \omega^{\mu\nu}}{4} + \phi_\omega^2 \frac{m_\omega^2 \omega_\mu \omega^\mu}{2} - a_\rho \frac{\boldsymbol{\rho}_{\mu\nu} \boldsymbol{\rho}^{\mu\nu}}{4} + \phi_\rho^2 \frac{m_\rho^2 \boldsymbol{\rho}_\mu \boldsymbol{\rho}^\mu}{2}
\end{aligned}
$$

All scaling functions $a_i, \ \tilde{\chi}_i, \ \phi_i$ depend on $g_\sigma \tilde{\chi}_\sigma \sigma$

Field redefinition

$$\Psi_N \to \Psi_N/\sqrt{a_N}\ ,\ \sigma \to \sigma/\sqrt{a_\sigma}\ ,\ \omega_\mu \to \omega_\mu/\sqrt{a_\omega}, \rho_\mu \to \rho_\mu/\sqrt{a_\rho}$$

$$\begin{aligned}
\mathcal{L}_N &= \bar{\Psi}_N\big(i\ D\cdot\gamma\big)\Psi_N - m_N\Phi_N\bar{\Psi}_N\bar{\Psi}_N, \\
& D_\mu = \partial_\mu + ig_\omega\chi_\omega\omega_\mu + \frac{i}{2}g_\rho\chi_\rho\boldsymbol{\rho}_\mu\boldsymbol{\tau} \\
\mathcal{L}_M &= \frac{\partial^\mu\sigma\partial_\mu\sigma}{2} - \Phi_\sigma^2\frac{m_\sigma^2\sigma^2}{2} - U(\sigma) \\
& -\frac{\omega_{\mu\nu}\omega^{\mu\nu}}{4} + \Phi_\omega^2\frac{m_\omega^2\omega_\mu\omega^\mu}{2} - \frac{\boldsymbol{\rho}_{\mu\nu}\boldsymbol{\rho}^{\mu\nu}}{4} + \Phi_\rho^2\frac{m_\rho^2\boldsymbol{\rho}_\mu\boldsymbol{\rho}^\mu}{2}
\end{aligned}$$

where

$m_i^*/m_i = \phi_i(\chi_\sigma\sigma)/\sqrt{a_i(\chi_\sigma\sigma)} = \Phi_i(\chi_\sigma\sigma)$ *mass scaling function*

$\chi_i = \tilde{\chi}_i(\chi_\sigma\sigma)/\sqrt{a_i(\chi_\sigma\sigma)}$ *coupling-constant scaling function*

Energy-density functional for infinite matter

minimized with respect to ω and ρ fields

$$C_i = \frac{g_{iN} m_N}{m_i}\,, \; i = \sigma, \omega, \rho$$

$$E_N[\rho_n, \rho_p; f] = \frac{m_N^4 f^2}{2C_\sigma^2}\eta_\sigma(f) + U(f) + \frac{C_\omega^2(\rho_n+\rho_p)^2}{2m_N^2\eta_\omega(f)} + \frac{C_\rho^2(\rho_n-\rho_p)^2}{8m_N^2\eta_\rho(f)} + \left(\int_0^{P_{F,n}} + \int_0^{P_{F,p}}\right)\frac{p^2\,dp}{\pi^2}\sqrt{m_N^2\Phi_N^2(f) + p^2}$$

scalar field: $f = g_{\sigma N}\chi_\sigma\sigma_0$

nuclear effective masses: $m_N^*/m_N = \Phi_N(f)$

scaling functions: $\eta_i(f) = \dfrac{\Phi_i^2(f)}{\chi_i^2(f)} \qquad i = \sigma, \omega, \rho$

σ-field potential can be included in the scaling functions

$$\eta_\sigma(f) \to \tilde{\eta}_\sigma(f) = \eta_\sigma(f) - \frac{2\,C_\sigma^2}{m_N^4 f^2}U(f)$$

Equivalence of RMF models

12 scaling functions $a_{N,\sigma,\omega,\rho}$, $\tilde{\chi}_{\sigma,\omega,\rho}$, $\phi_{\sigma,\omega,\rho}$ and $\tilde{U}(\sigma)$

$\longrightarrow$

3 independent scaling functions $\eta_{\omega,\rho}(f)$ and $U(f)$ or η_σ

Choice of scaling functions:

- control of EoS stiffness in ISM and BEM
- monotonous increase of the scalar field as a function of density f(n)
- absence of several solutions for f(n) and jumps among them

KVOR model [EEK,Voskresensky NPA759, 373 (2005)]

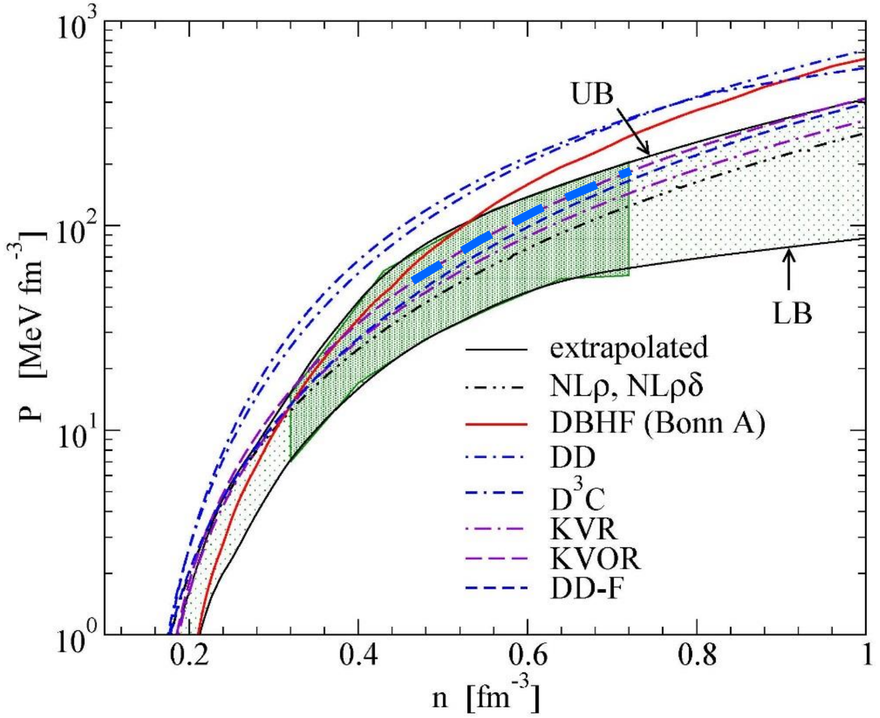
$$\eta_\sigma^{\rm KVOR} = 1 + 2\frac{C_\sigma^2}{f^2}\left(\frac{b}{3}f^3 + \frac{c}{4}f^4\right) \qquad \eta_\omega^{\rm KVOR} = \left[\frac{1+z\bar{f}_0}{1+zf}\right]^\alpha \qquad \bar{f}_0 = f(n_0)$$

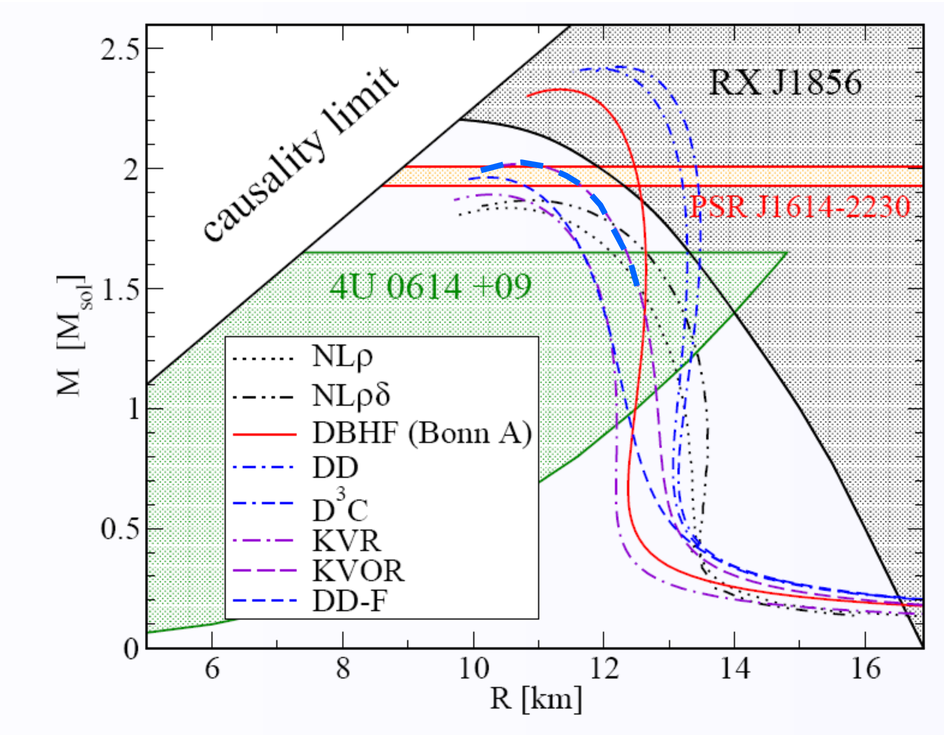
$$\eta_\rho^{\rm KVOR} = \left[1 + 4\frac{C_\omega^2}{C_\rho^2}\left(1 - [\eta_\omega^{\rm KVOR}(f)]^{-1}\right)\right]^{-1} \qquad \alpha = 1 \quad z = 0.65$$

EoS	$\mathcal{E}_0$	n_0	K	$m_N^*(n_0)$	$\tilde{J}_0$	L	K'	$K_{\rm sym}$
	[MeV]	[fm^{-3}]	[MeV]	[m_N]	[MeV]	[MeV]	[MeV]	[MeV]
KVOR	-16	0.16	275	0.805	32	71	423	-85

input

Comparison by Th. Klahn et al., PRC74, 035802 (2006)





KVOR EoS successfully tested

Extended to finite temperature:
Khvorostukhin, Toneev, Voskresensky, NPA791, 180 (2007);NPA813, 313 (2008)

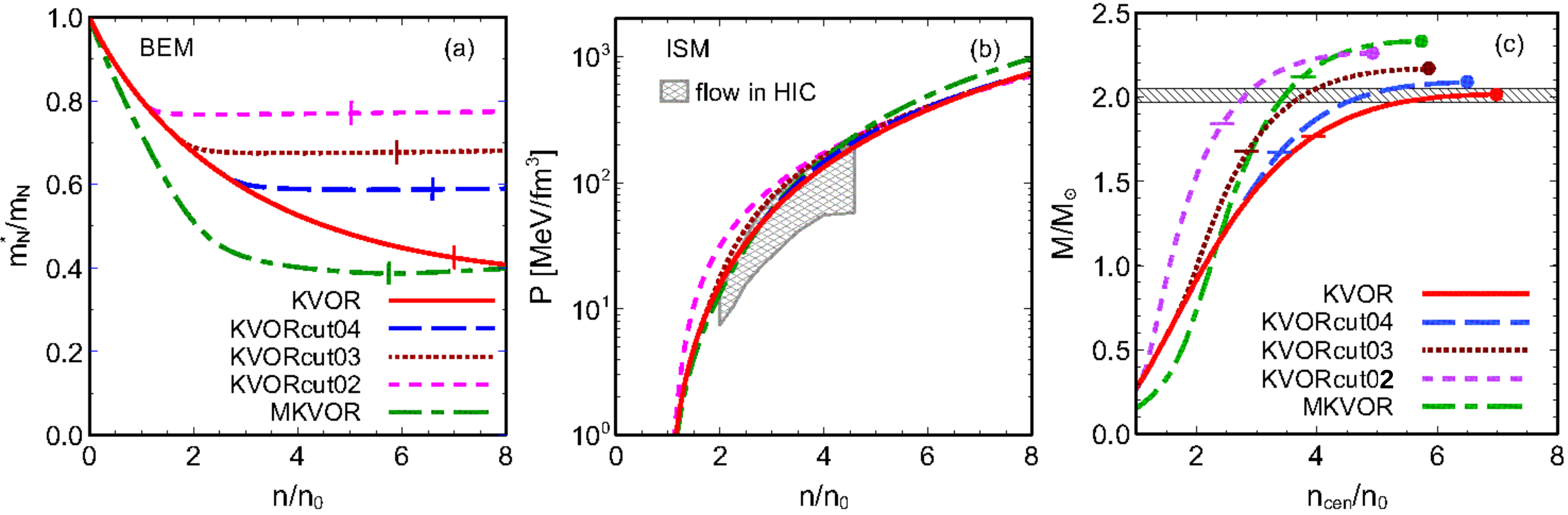
Aim: Construct a better parameterization which satisfies new constraints on the nuclear EoS
Inclusion of hyperons. "Hyperon puzzle".
Increase of hyperon-hyperon repulsion due to phi-meson exchange (phi-mass reduction)

KVORcut model

[Maslov, EEK Voskresensky, JPConfSer668,012064 (2016); NPA950,64(2016)]

Apply cut-scheme to η_ω function

$$\eta_\omega^{\mathrm{KVOR}}(f) \to \eta_\omega^{\mathrm{KVOR}}(f) + \frac{a_\omega}{2}\left[1 + \tanh(b_\omega(f - f_{\mathrm{cut},\omega}))\right]$$



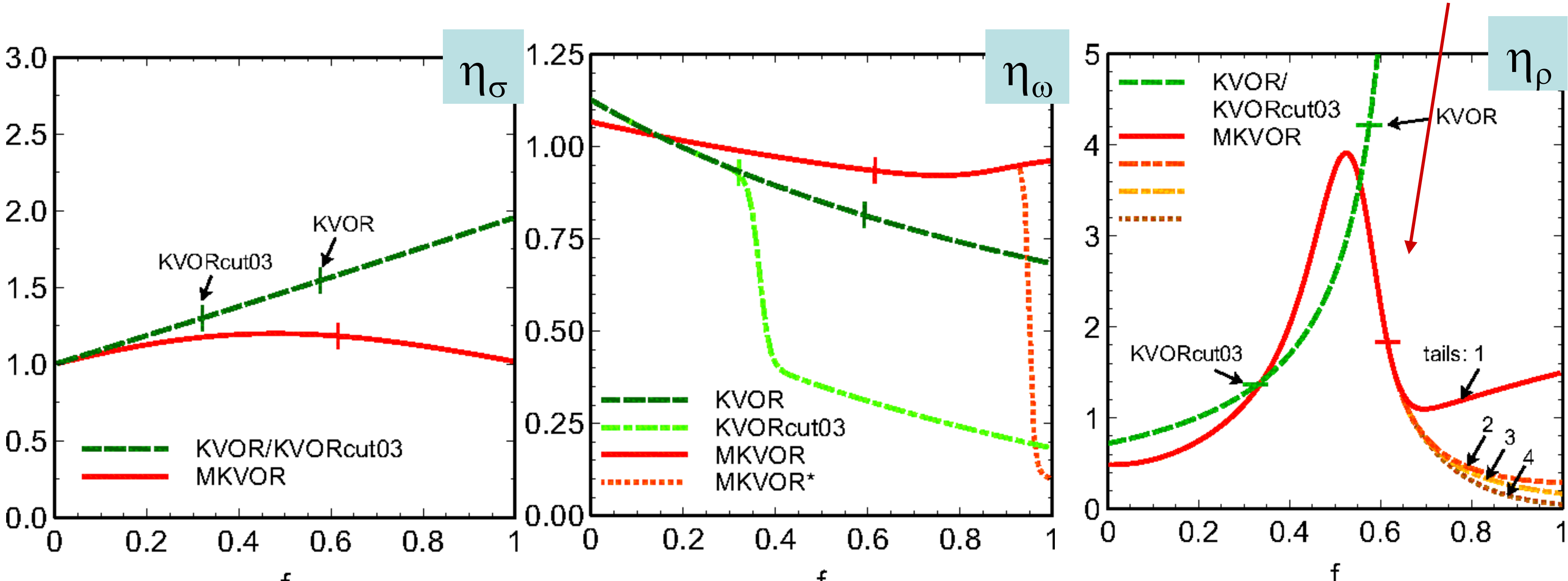
MKVOR model

[Maslov, EEK Voskresensky, PLB748,369 (2015); NPA950,64(2016)]

EoS	$\mathcal{E}_0$ [MeV]	n_0 [fm^{-3}]	K [MeV]	$m_N^*(n_0)$ [m_N]	$\widetilde{J}_0$ [MeV]	L [MeV]	K' [MeV]	$K_{\rm sym}$ [MeV]
MKVOR	-16	0.16	240	0.73	30	41	557	-159

scaling functions for coupling constants vs scalar field:

saturate f growth

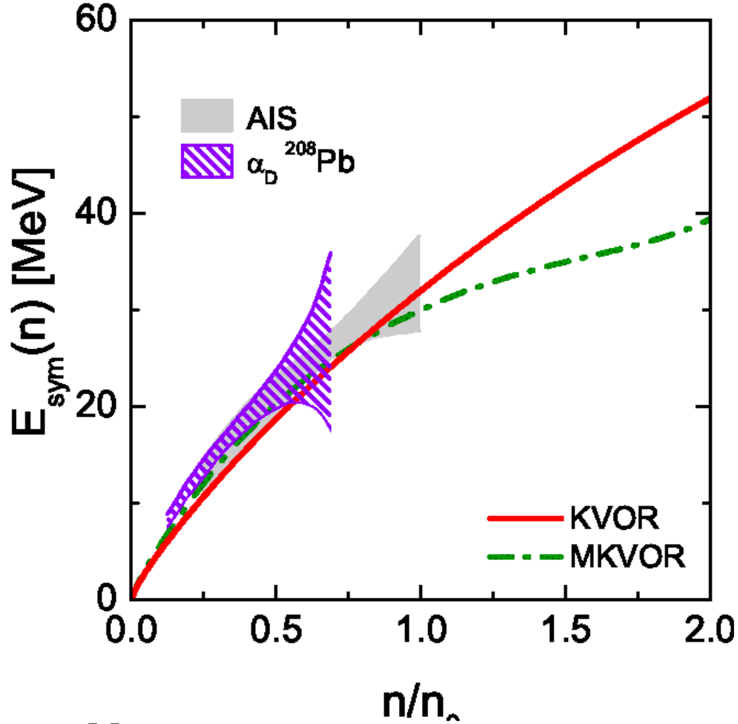


ticks – max. values of f reached in neutron star

increase ω repulsion to stiffen EoS

suppress symmetry energy DU constraint

Neutron matter EoS



empirical constraints on symmetry energy

-- (AIS) analog isobar states

[Danielewicz, Lee NPA 922 (2014) 1]

-- α_D electric dipole polarizability ^{208}Pb

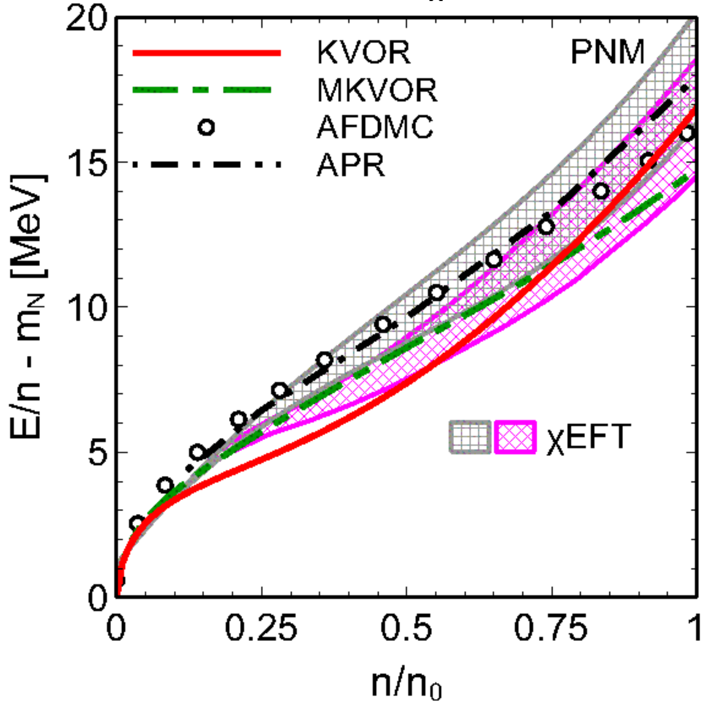
[Zhang, Chen 1504.01077]

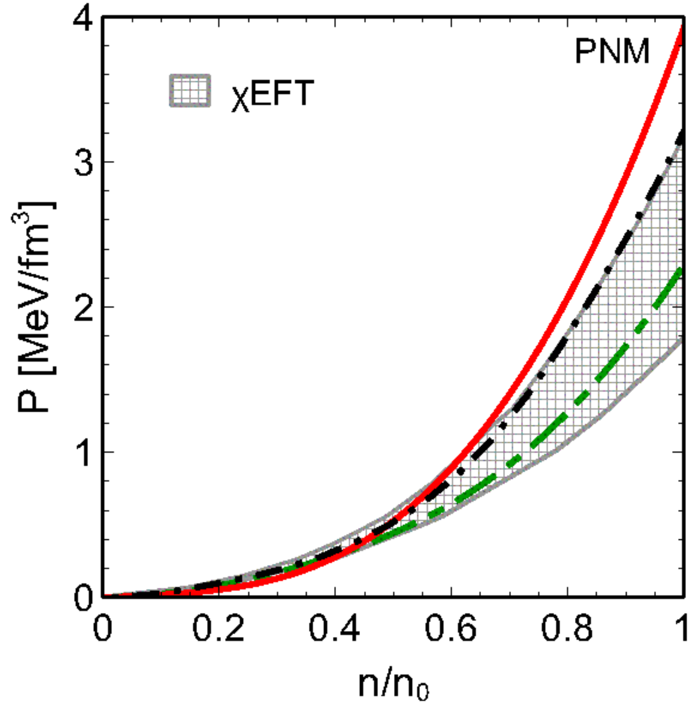
microscopic calculations

-- (APR) Akmal, Pandharipande, Ravenhall

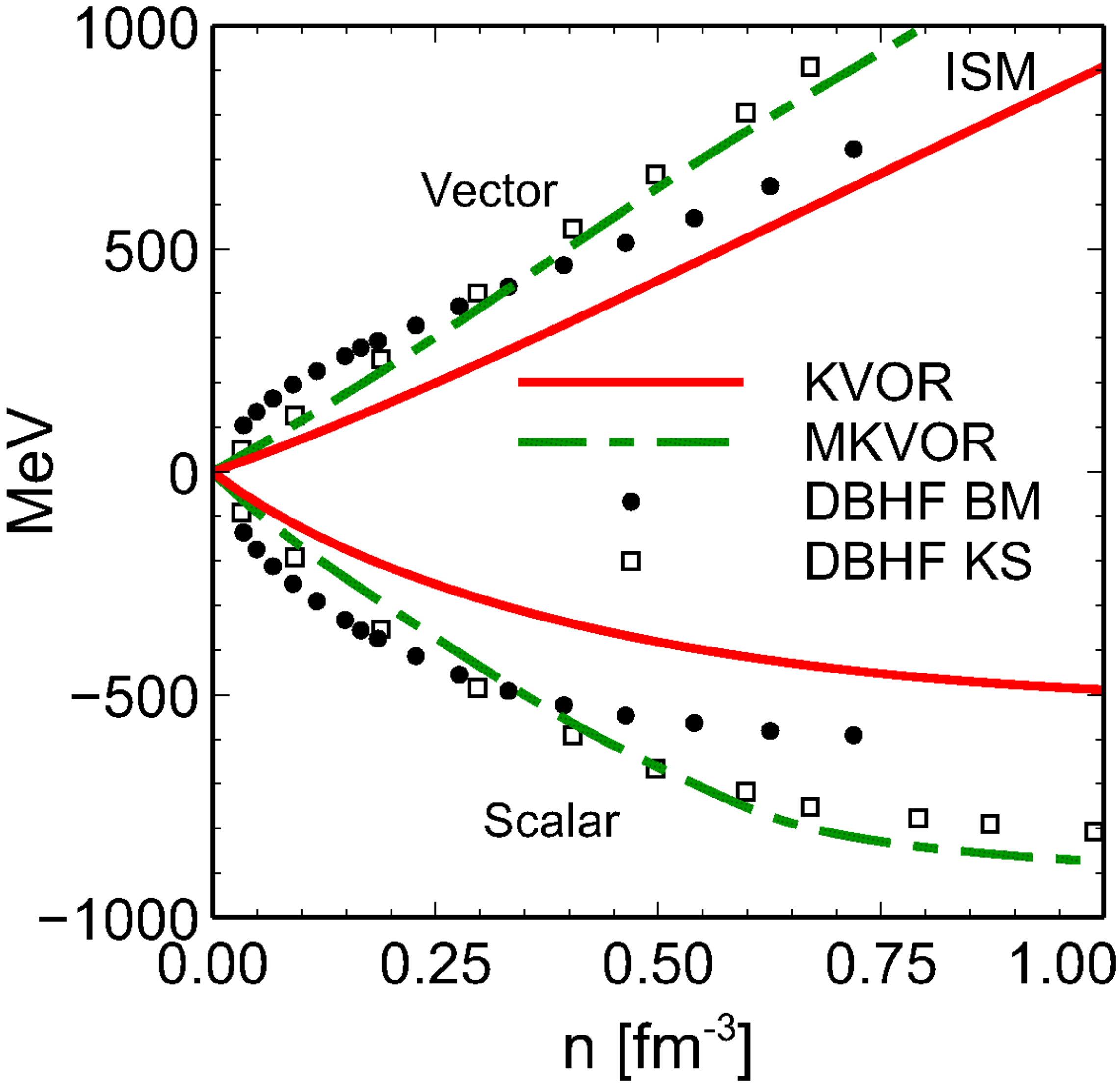
-- (AFDMC) Gandolfi et al.MNRAS 404 (2010) L35

--(χEFT) Hebeler, Schwenk EPJA 50 (2014) 11





Scalar and vector potentials in KVOR and MKVOR models vs. DBHF calculations

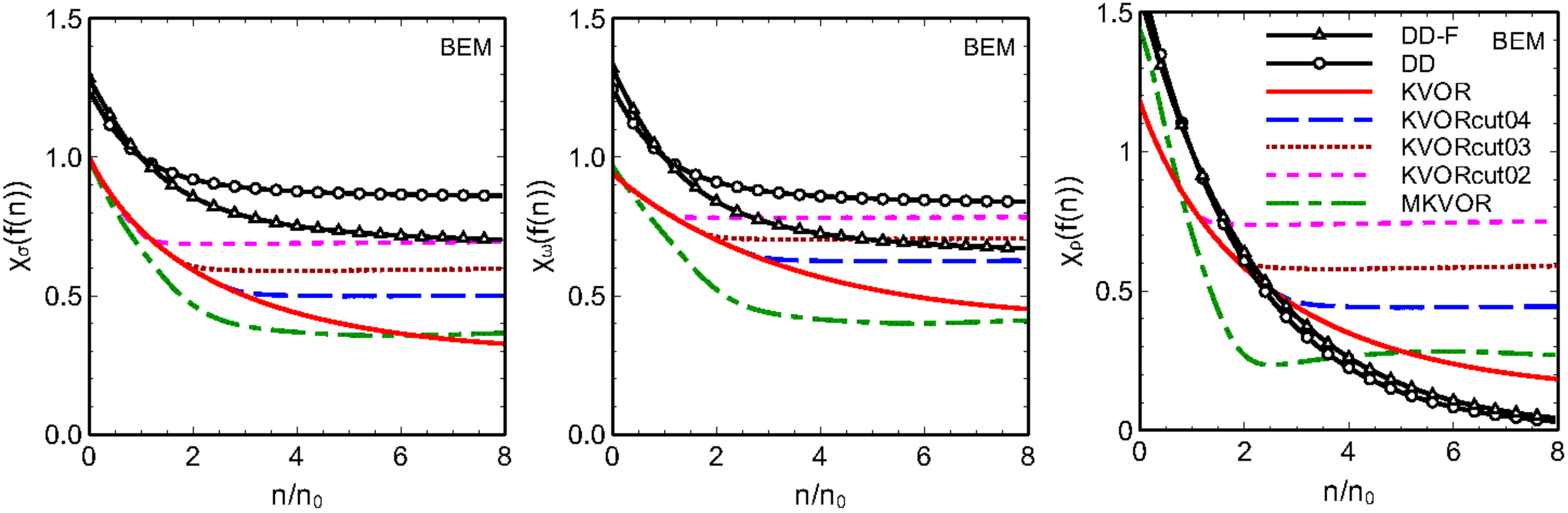


BM: Brockmann – Machleidt
PRC42 (1990)

KS: Katayama-Saito
PRC88 (2013)

Scaling functions for coupling constants

Assuming $\Phi_\sigma(f) \approx \Phi_\omega(f) \approx \Phi_\rho(f) \approx \Phi_N(f) = 1 - f$ we can recover $\chi_m(f(n))$



Compare with scaling functions from DD-F,DD models [Typel,PRC71,064301(2005)]

Nuclear optical potential

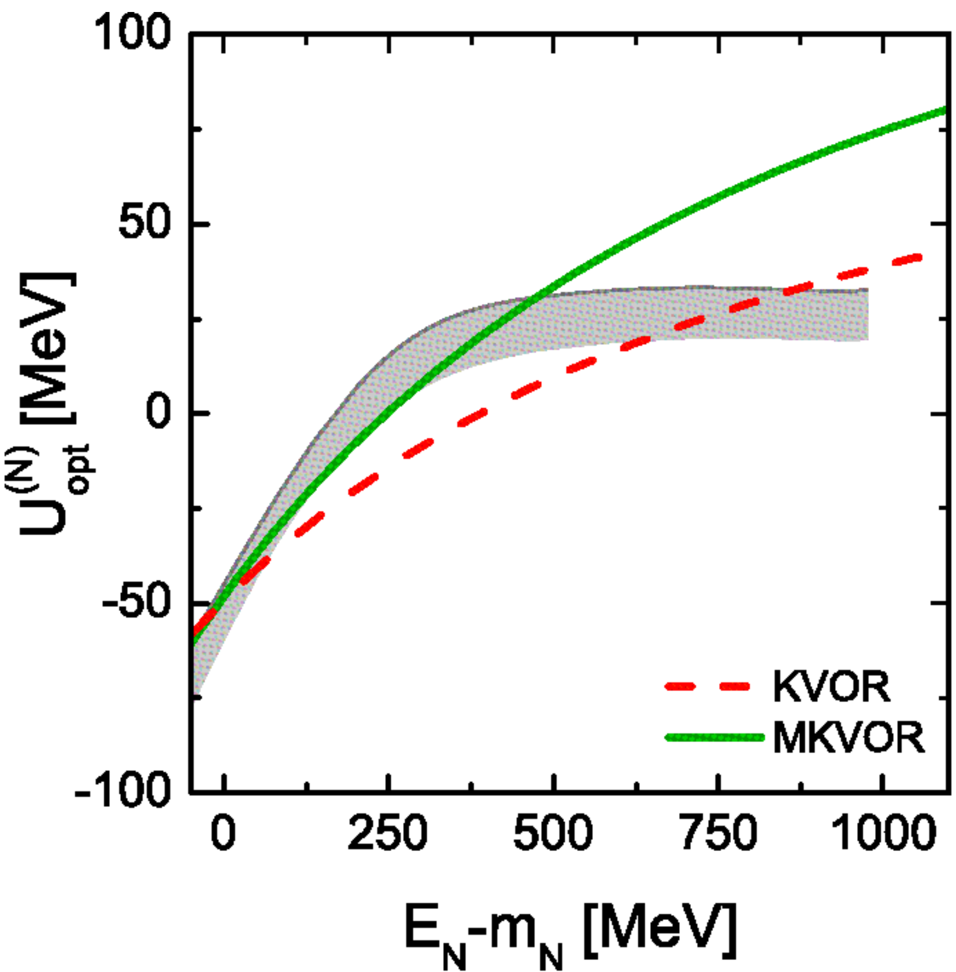
$$U^{(b)}_{\rm opt}(\varepsilon) = \varepsilon - \sqrt{(\varepsilon - V_b)^2 - S_b\,(2\,m_b + S_b)}$$

$$S_b = m_b \Phi_b(x_{\sigma b}\frac{m_N}{m_b} f) - m_b$$

[Feldmeier, Lindner ZPA341 (1991) 83]

$$V_b = x_{\omega b}\frac{C_\omega^2\, n}{m_N^2 \eta_\omega(f)}$$

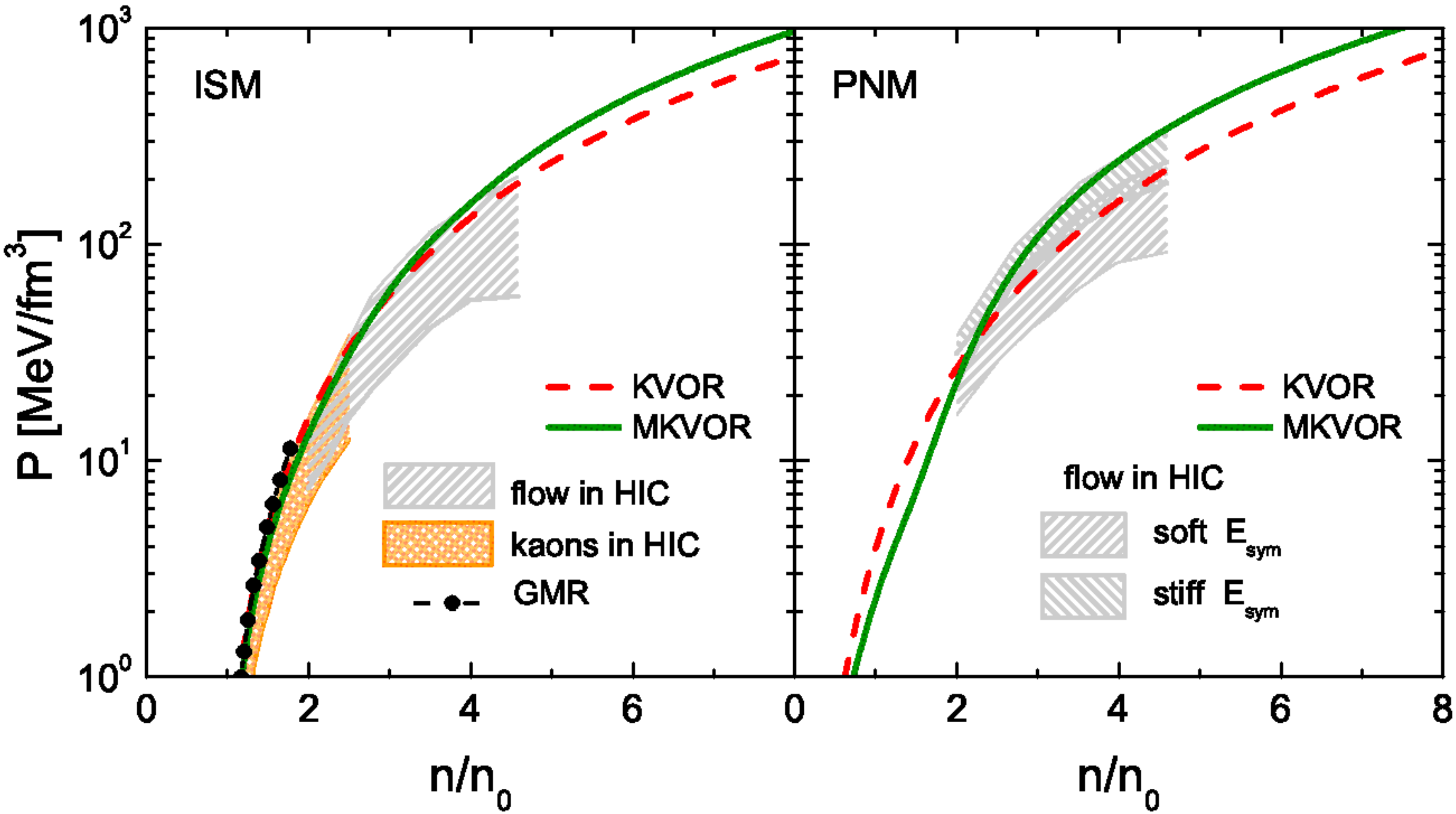
Data: Hama, Clark et al., Phys. Rev. C 41 (1990) 2737



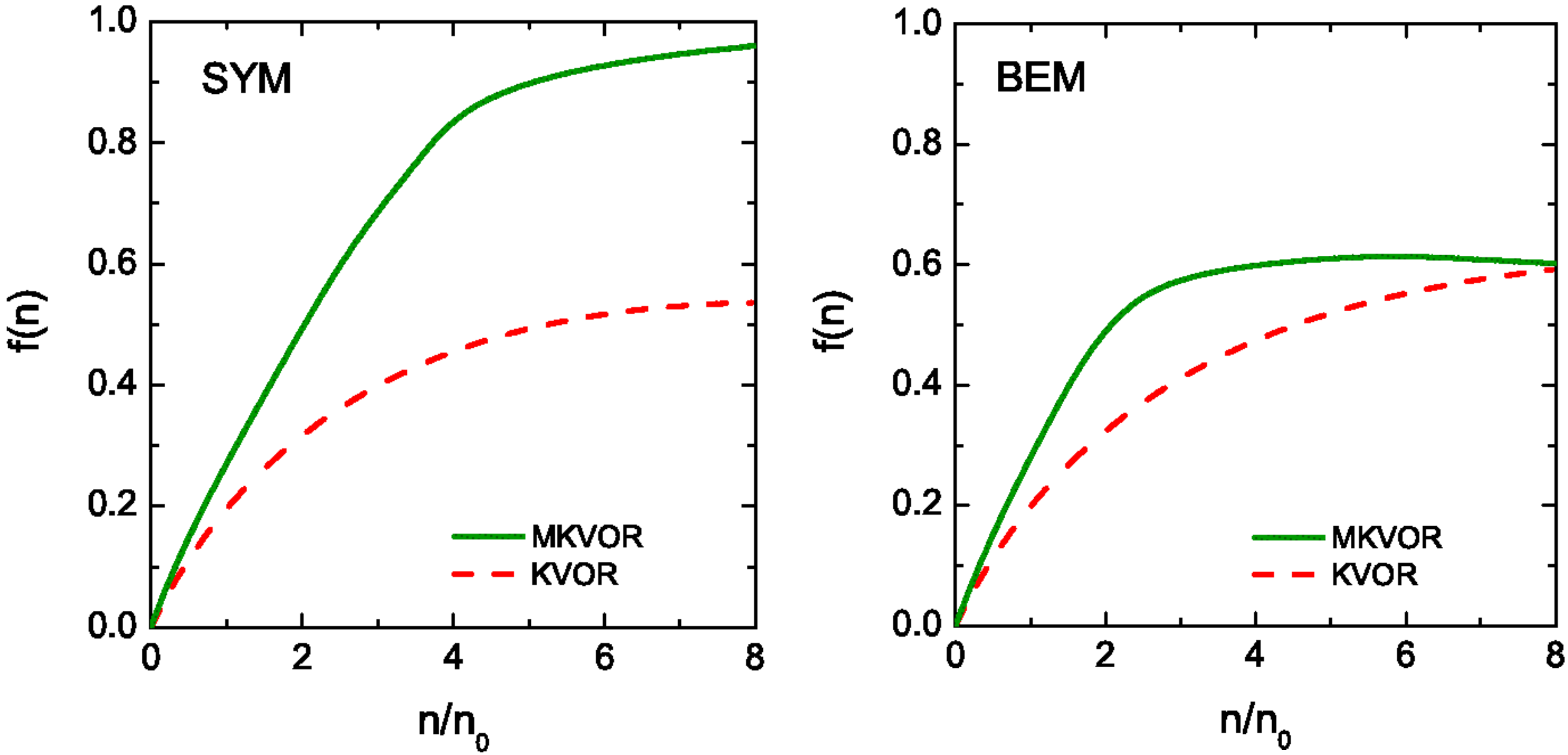
Constraints on EoS from HICs

Particle flow: Danielewicz, Lacey and Lynch, Science 298 (2002) 1592

Kaon production: Fuchs, Prog. Part. Nucl. Phys. 56 (2006) 1



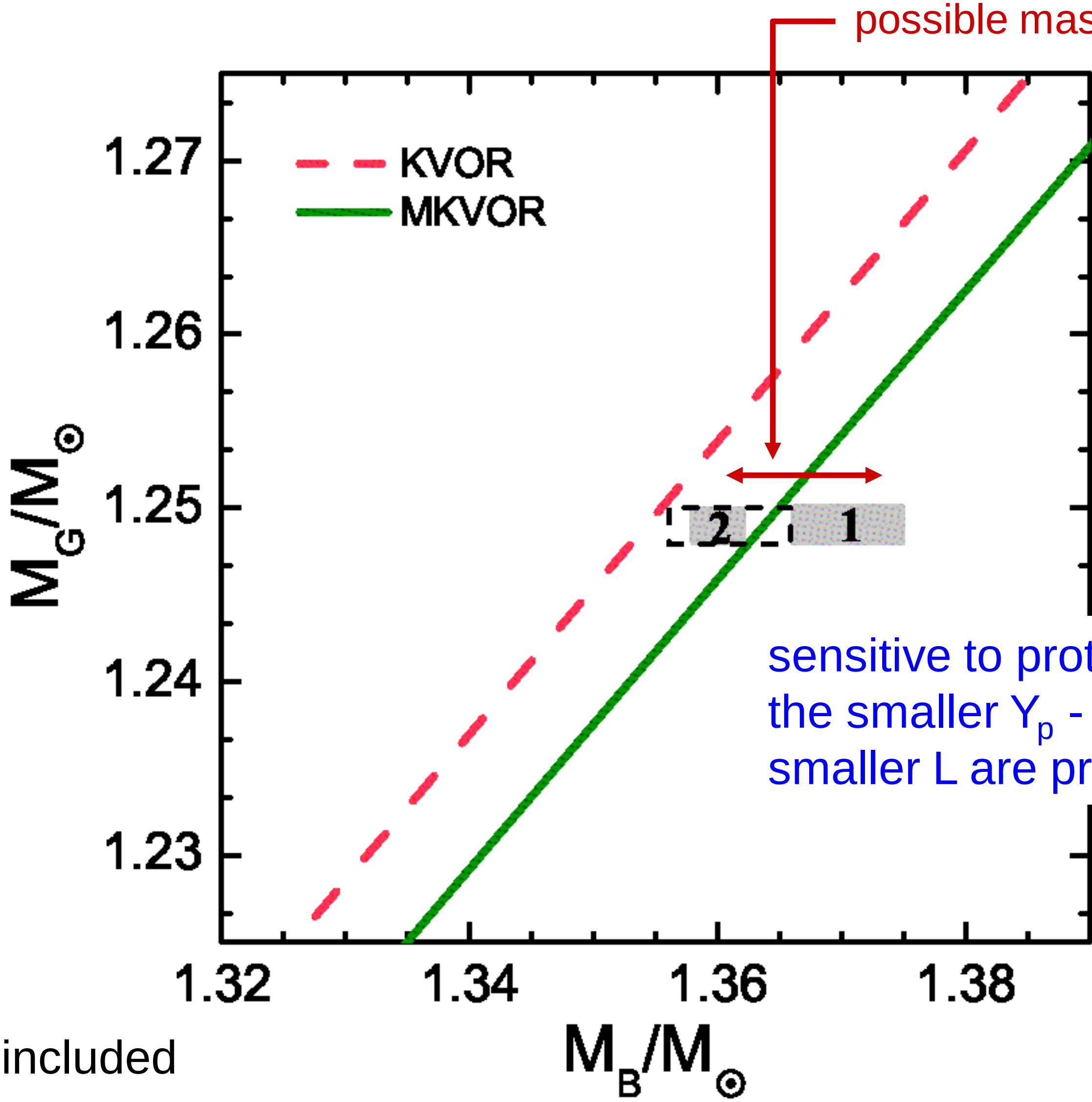
Scalar field in dense matter



Gravitational vs baryon mass of PSR J0737-3039(B)

PSR J0737-3039(B): double pulsar system

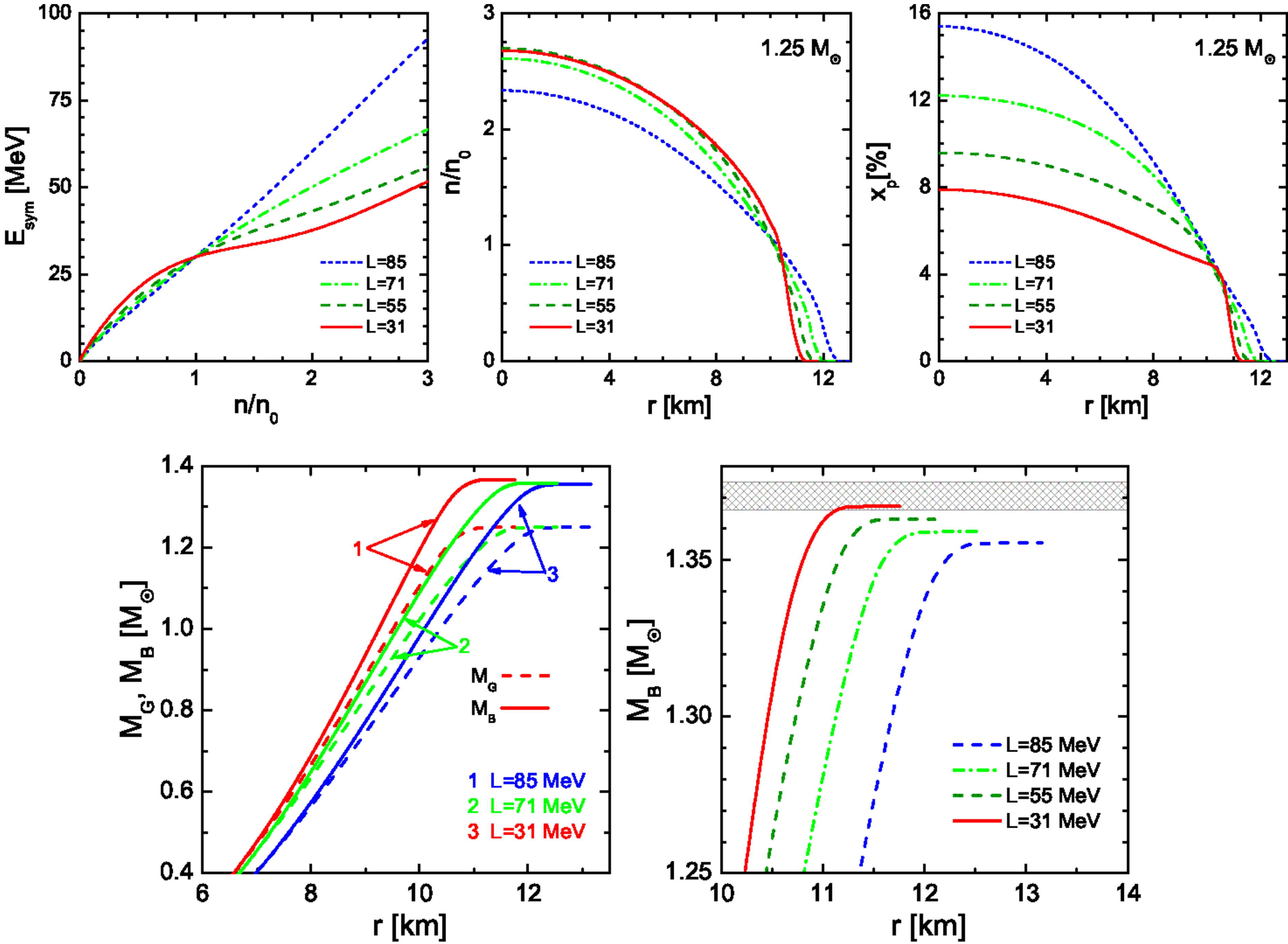
1. Podsiadlowski et al., MNRAS 361 (2005) 1243
2. Kitaura et al., A&A 450 (2006) 345



sensitive to proton concentration Y_p
the smaller Y_p - the better;
smaller L are preferred.

L_{KVOR} =71 MeV
L_{MKVOR}=41 MeV

BPS crust is included



E_sym [MeV]
n/n_0
L=85
L=71
L=55
L=31
1.25 M_⊙
r [km]
x_p [%]
M_G, M_B [M_⊙]
M_G
M_B
1 L=85 MeV
2 L=71 MeV
3 L=31 MeV
M_B [M_⊙]
L=85 MeV
L=71 MeV
L=55 MeV
L=31 MeV

Inclusion of hyperons: energy-density functional

$B \in \mathrm{SU}(3)$ ground state multiplet

scalar field $f = g_\sigma \, \chi_\sigma \, \sigma / m_N$

$$E[f, \{n_{\mathrm{B}}\}] = \sum_B E_{\mathrm{kin}}\big(p_{\mathrm{F},B}, m_B \Phi_B(f)\big) + \sum_{l=e,\mu} E_{\mathrm{kin}}(p_{\mathrm{F},l}, m_l)$$

$$+ \frac{m_N^4 f^2}{2C_\sigma^2} \eta_\sigma(f) + \frac{1}{2m_N^2}\left[\frac{C_\omega^2 \widetilde{n}_B^2}{\eta_\omega(f)} + \frac{C_\rho^2 \widetilde{n}_I^2}{\eta_\rho(f)} + \frac{C_\phi^2 \widetilde{n}_S^2}{\eta_\phi(f)}\right],$$

$C_i = \frac{g_{iN} m_N}{m_i}$, $i = \sigma, \omega, \rho$ $\quad C_\phi = m_\omega C_\omega / m_\phi$

effective densities: $\widetilde{n}_B = \sum_B x_{\omega B} n_B \quad \widetilde{n}_I = \sum_B x_{\rho B} t_{3B} n_B \quad \widetilde{n}_S = \sum_H x_{\phi H} n_H$

with coupling constant ratios $\quad x_{\omega(\rho)B} = \frac{g_{\omega(\rho)B}}{g_{\omega(\rho)N}} \quad x_{\phi H} = \frac{g_{\phi H}}{g_{\omega N}}$

mass scaling:

$$\Phi_m(f) \approx \Phi_N(f) = 1 - f$$

$$\Phi_H(f) = 1 - x_{\sigma H} \frac{m_N}{m_H} \xi_{\sigma H} f$$

scaling functions

$$\eta_i(f) = \frac{\Phi_i^2(f)}{\chi_i^2(f)}, \quad i = \sigma\,,\, \omega\,,\, \rho$$

The standard sigma potential can be introduced as $\eta_\sigma(f) = 1 + \frac{2\,C_\sigma^2}{m_N^4 f^2} U(f)$

Inclusion of hyperons: coupling constants

1) standard. extension: **H**

Vector coupling constants from SU(6) symmetry:

$$g_{\omega\Lambda} = g_{\omega\Sigma} = 2g_{\omega\Xi} = \tfrac{2}{3} g_{\omega N}\,, \quad g_{\rho\Sigma} = 2g_{\rho\Xi} = 2g_{\rho N}\,,$$
$$2g_{\phi\Lambda} = 2g_{\phi\Sigma} = g_{\phi\Xi} = -\tfrac{2\sqrt{2}}{3} g_{\omega N}\,, \quad g_{\rho\Lambda} = g_{\phi N} = 0\,.$$

data on hypernuclei

Scalar coupling constants from hyperon binding energies

$$U_\Lambda(n_0) = -28\,\mathrm{MeV}$$
$$U_\Sigma(n_0) = +30\,\mathrm{MeV}$$
$$U_\Xi(n_0) = -15\,\mathrm{MeV}$$

$$U_H(n_0) = C_\omega^2 m_N^{-2} x_{\omega H} n_0 - (m_N - m_N^*(n_0)) x_{\sigma H}$$

$$x_{\omega(\rho)B} = g_{\omega(\rho)B} / g_{\omega(\rho)N}$$

2) +phi mesons. extension: **Hϕ**

$$\Phi_\phi = 1 - f, \quad \chi_{\phi H} = 1 \qquad \eta_\phi = \frac{\Phi_\phi^2}{\chi_\phi^2} = (1-f)^2$$

Phi meson mediated repulsion among hyperons is enhanced

3) + hyperon-sigma couplings reduced. extension: **Hϕσ**

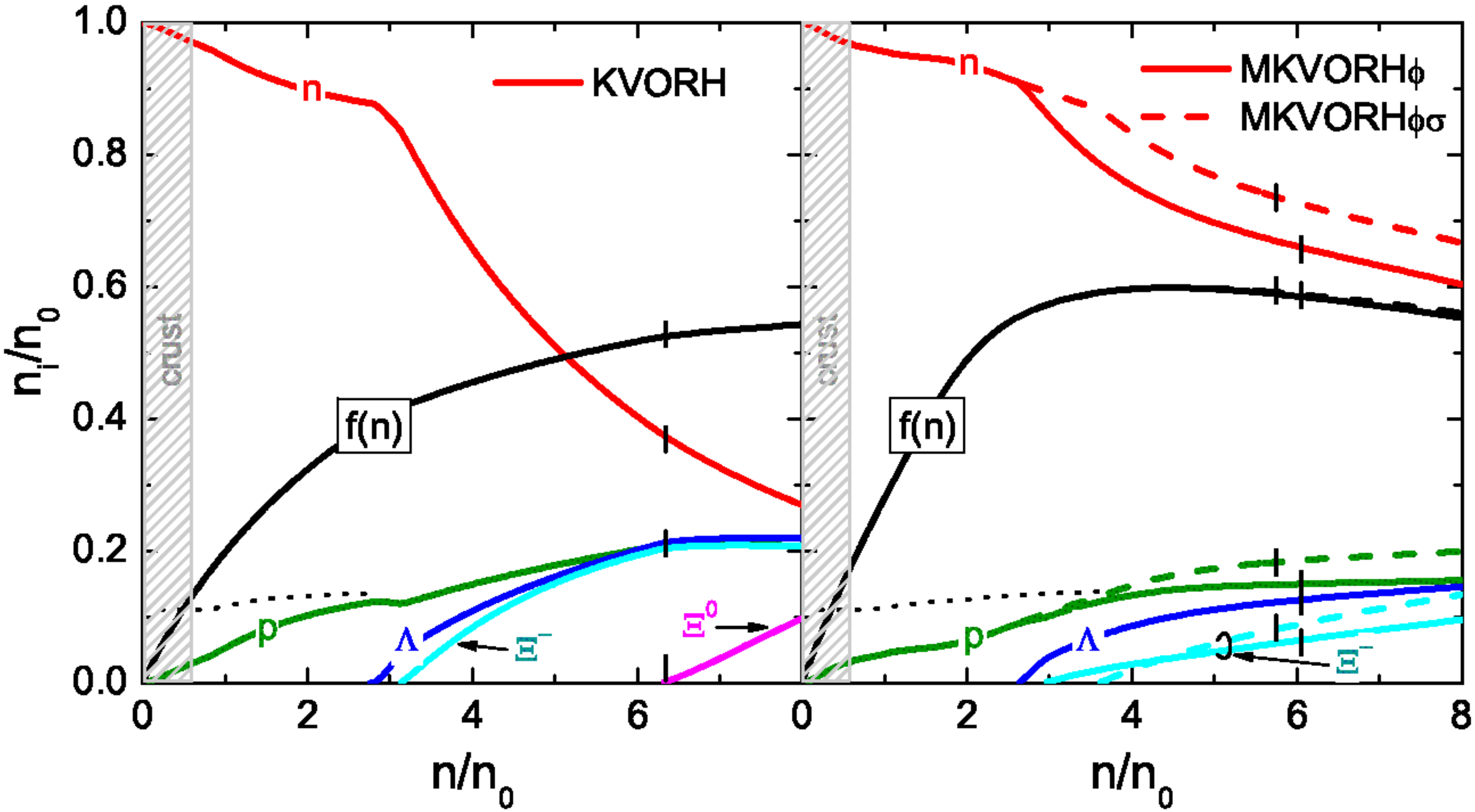
$$\Phi_H(f) = 1 - x_{\sigma H} \frac{m_N}{m_H} \xi_{\sigma H} f$$

$\xi_{\sigma H}(n \le n_0) = 1$ but $\xi_{\sigma H}(n \gtrsim n_\Lambda) \to 0$

QMC model: Guichon, Thomas

hyperon-nucleon mass gap grows with density

Strangeness concentration



KVORH: $n_\Lambda=2.81n_0$, $M_\Lambda=1.37M_{sol}$,
$n_\Xi=3.13n_0$ $M_\Xi=1.48\ M_{sol}$

KVOR: $n_{DU}=3.96$ $M_{DU}=1.77\ M_{sol}$

MKVORHϕ: $n_\Lambda=2.63n_0$, $M_\Lambda=1.43M_{sol}$,
$n_\Xi=2.93n_0$, $M_\Xi=1.65M_{sol}$

MKVORHϕσ: $n_\Xi=3.61n_0$, $M_\Xi=2.07M_{sol}$

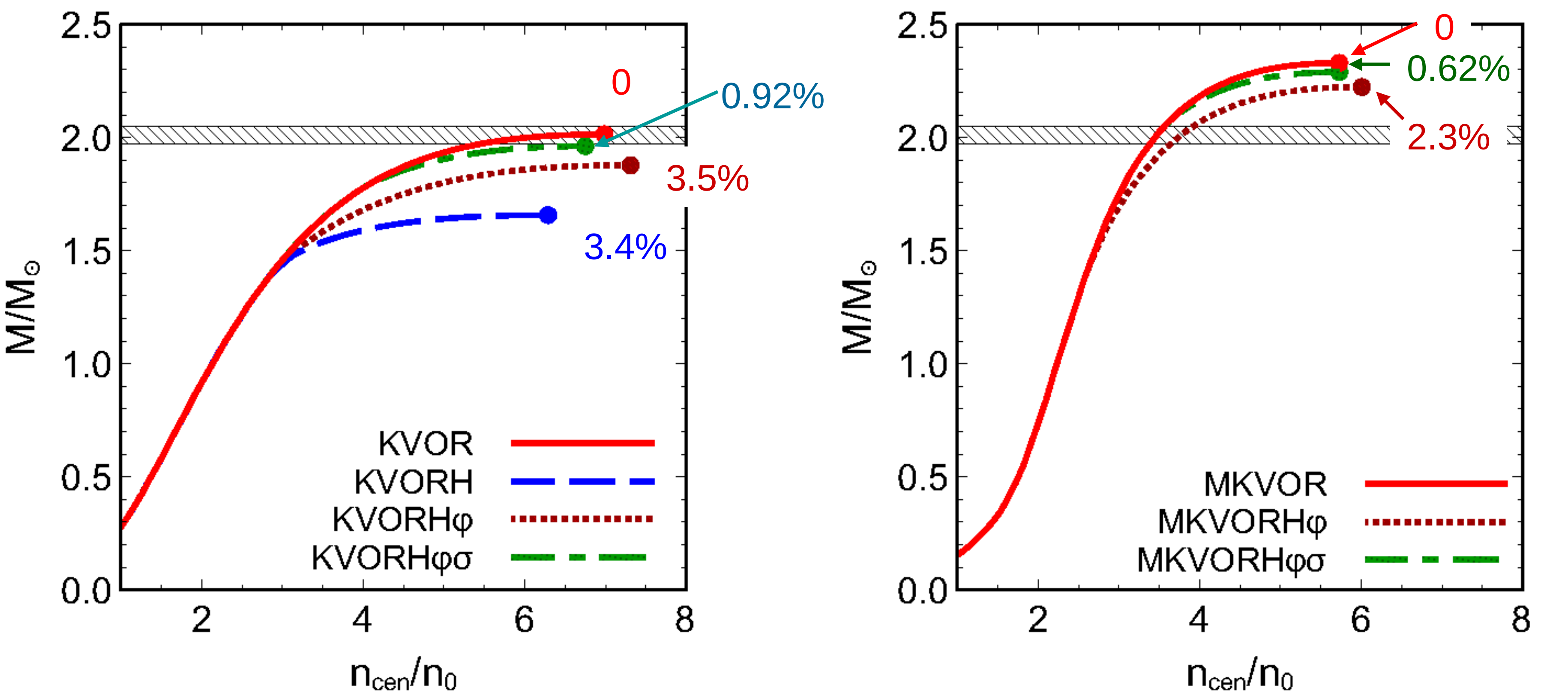
fulfill DU constraint

no Lambdas!

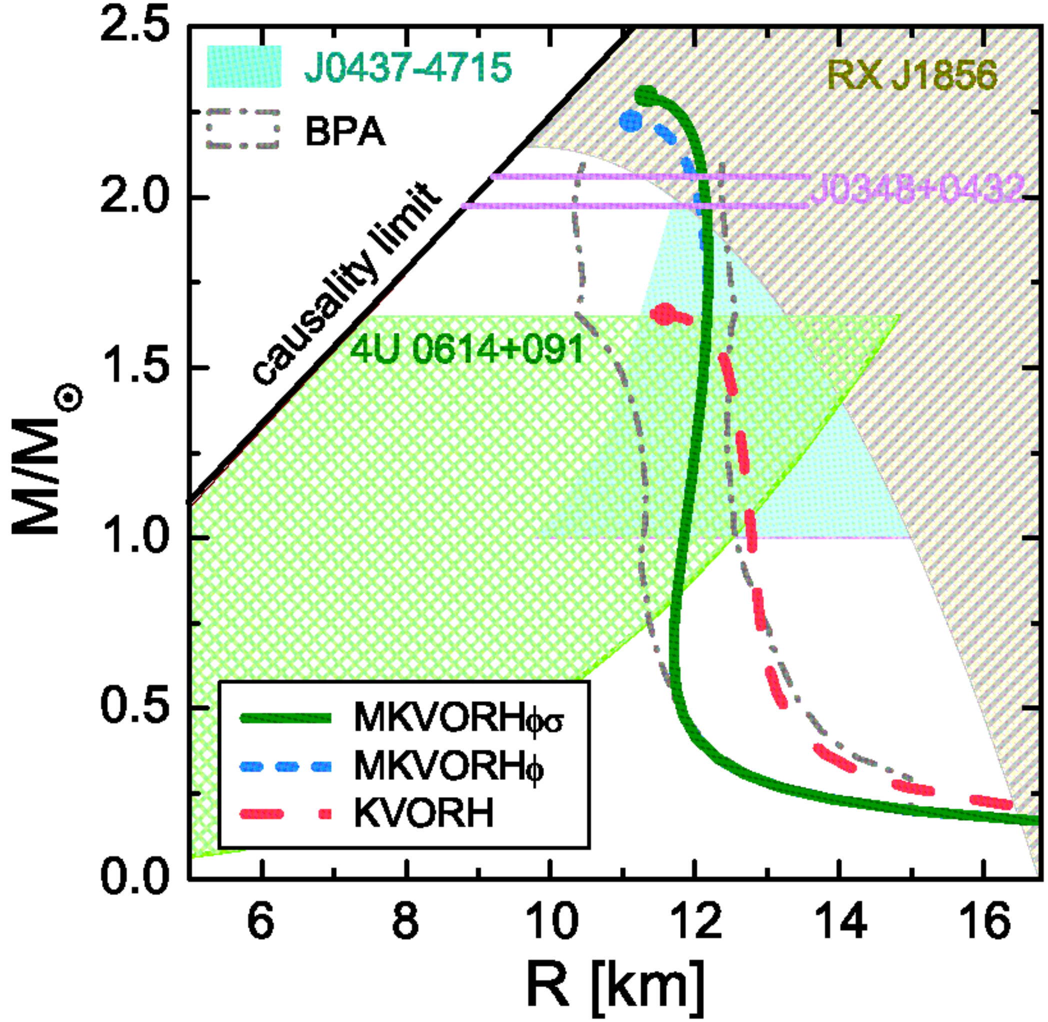
Maximum NS mass and the strangeness concentration

f_S –# strange quarks / # all quarks

Weissenborn, Chatterjee Schafner-Bielich



Mass-radius constraints



BPA: Bayesian probability analysis [Lattimer,Steiner …]

msp PSRJ0437-4715: 3σ confidence Bogdanov ApJ 762, 96 (2013)

Inclusion of Δ(1232) baryons

vector meson couplings
quark counting SU(6)

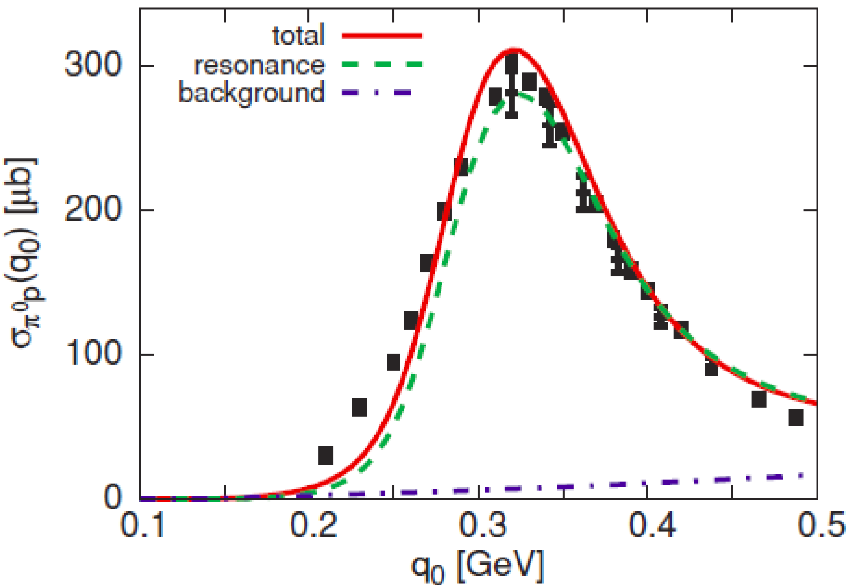
$$g_{\omega\Delta} = g_{\omega N}\,, \quad g_{\rho\Delta} = g_{\rho N}\,, \quad g_{\phi\Delta} = 0$$

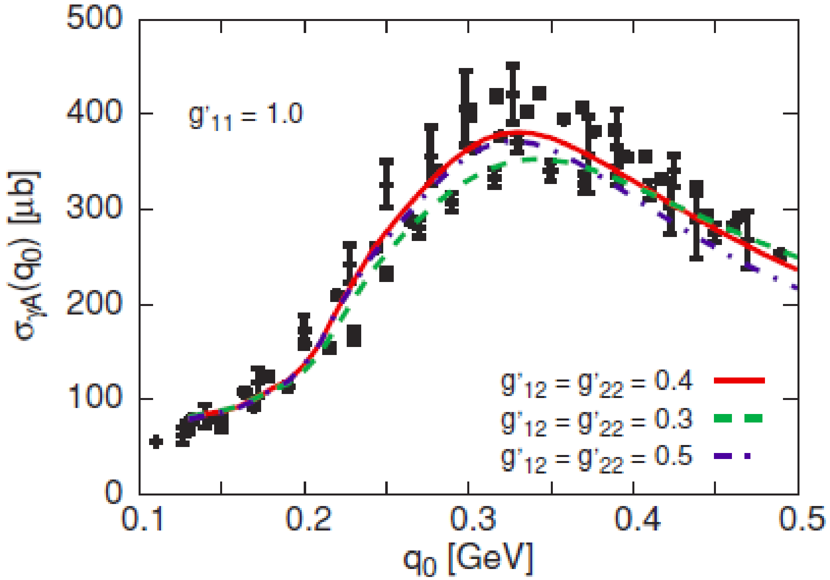
scalar couplings:

$$x_{\sigma\Delta} = \frac{x_{\omega\Delta} C_\omega^2 n_0/m_N^2 - U_\Delta(n_0)}{m_N - m_N^*(n_0)} \qquad x_{m\Delta} = \frac{g_{m\Delta}}{g_{mN}}$$

Photoabsorption off nuclei with self-consistent vertex corrections: $U_\Delta(n_0) \simeq -50\,\mathrm{MeV}$

[Riek,Lutz and Korpa, PRC 80, 024902 (2009)]





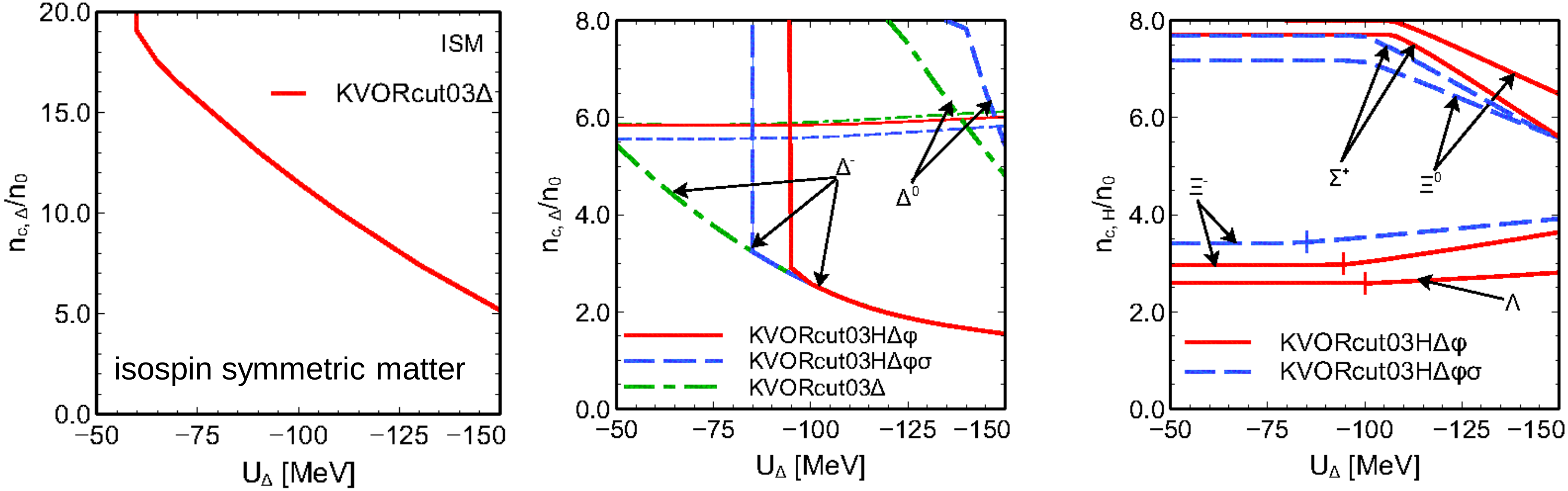
We allow for a variation of parameters $-100\,\mathrm{MeV} \leq U_\Delta \leq -50\,\mathrm{MeV}$

KVORcut model

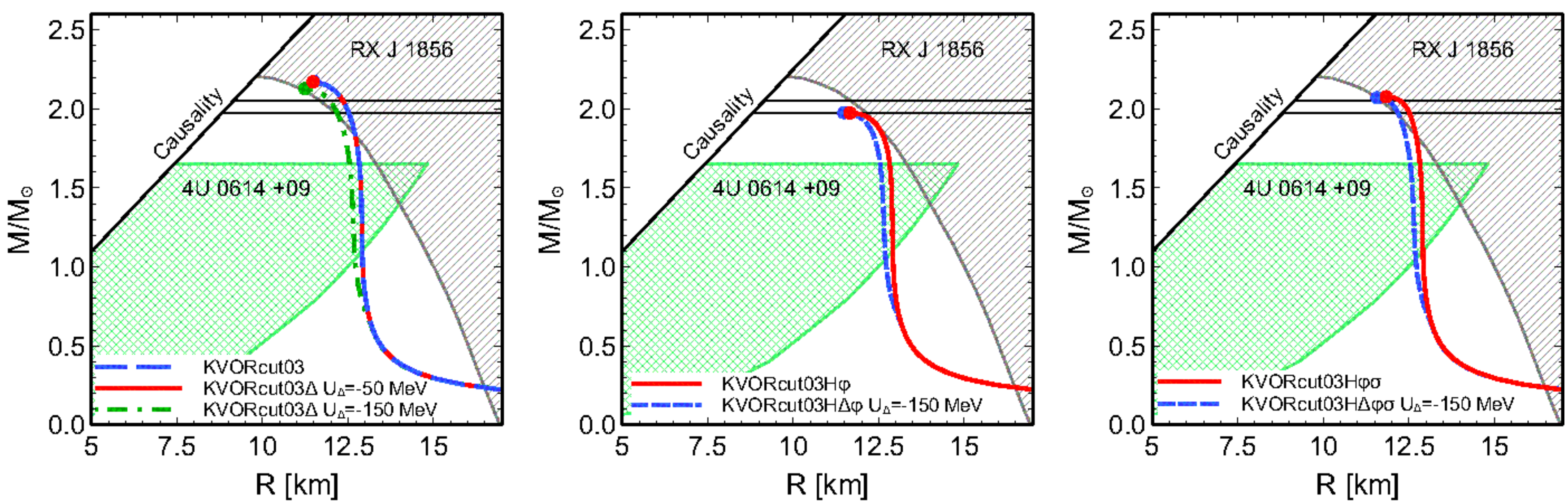
very few Δ baryons, no influence

critical densities for Δ appearance

beta-equilibrium matter



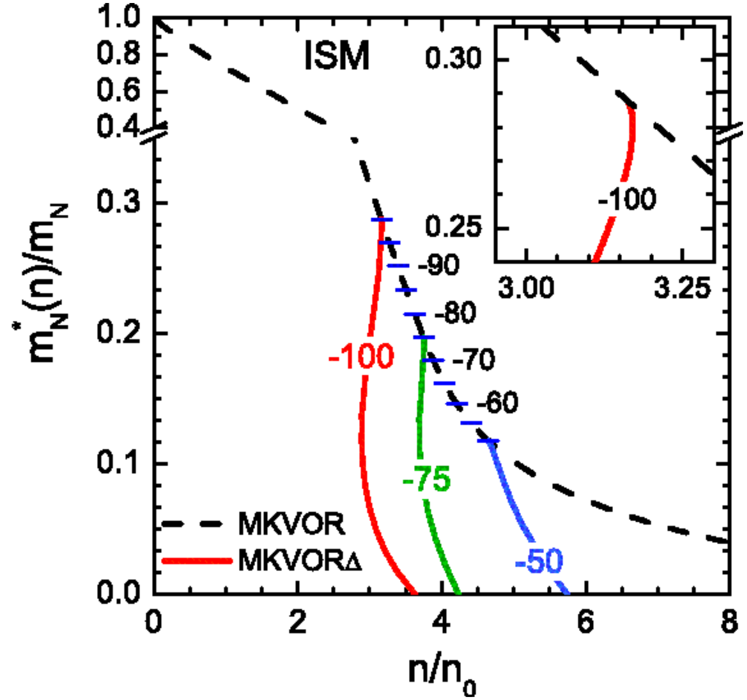
mass-radius relation

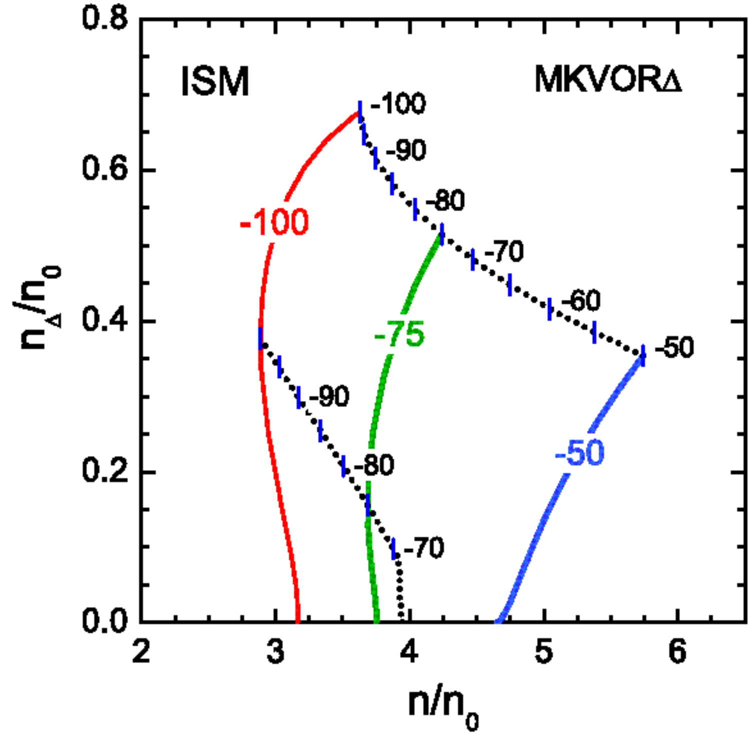


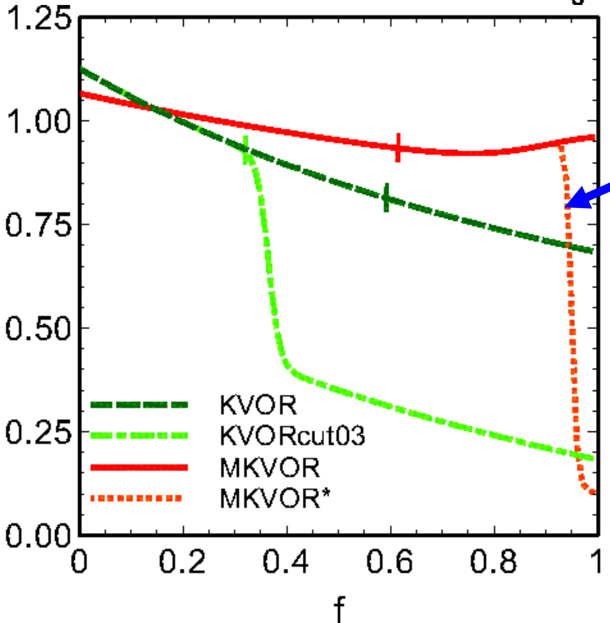
MKVOR model

isospin symmetric matter

nucleon mass can vanish!







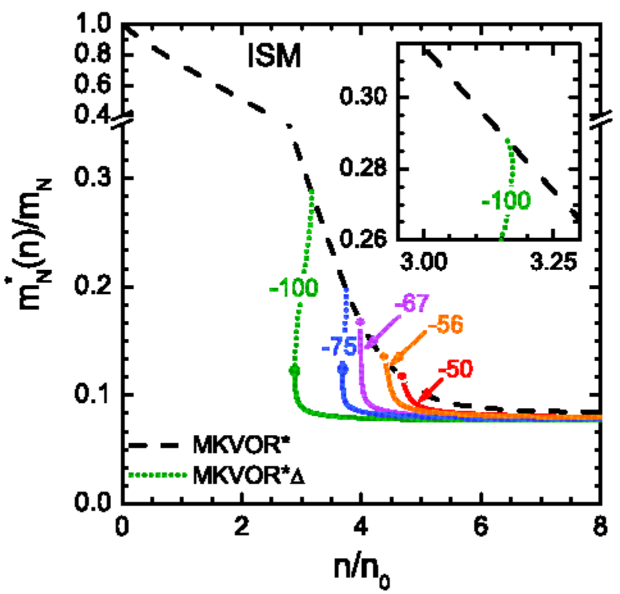
To avoid the vanishing of the effective nucleon mass
We introduce cut-mechanism in the ω-sector of the model

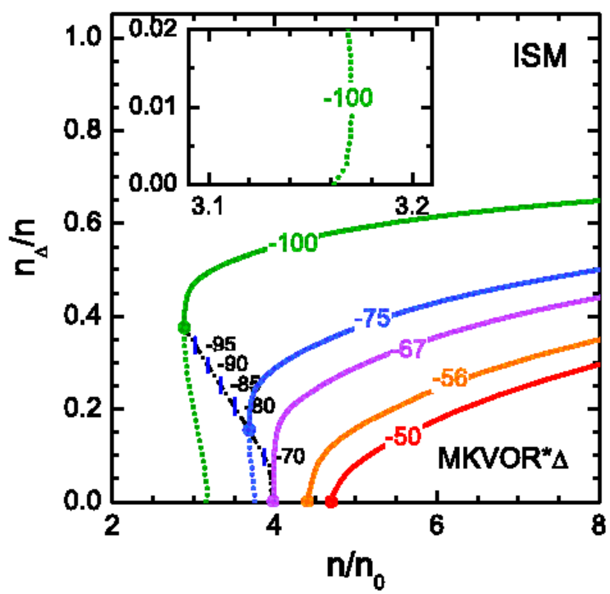
$f_{lim}<f_{cut}$ results for neutron stars do not change!

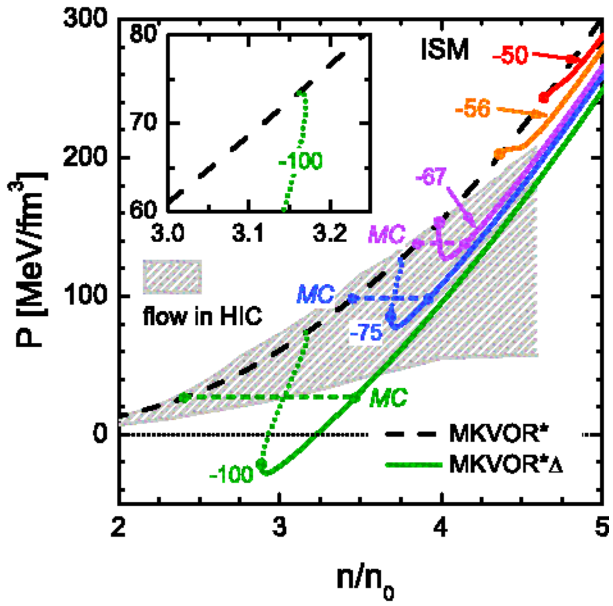
MKVOR $\longrightarrow$ MKVOR*

MKVOR* model

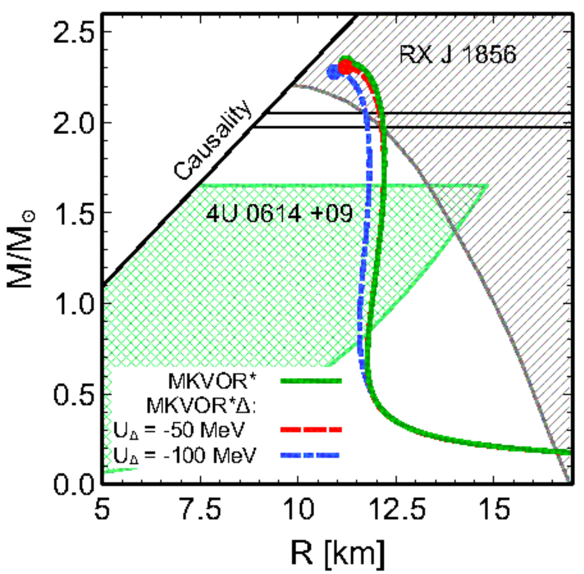
isospin symmetric matter

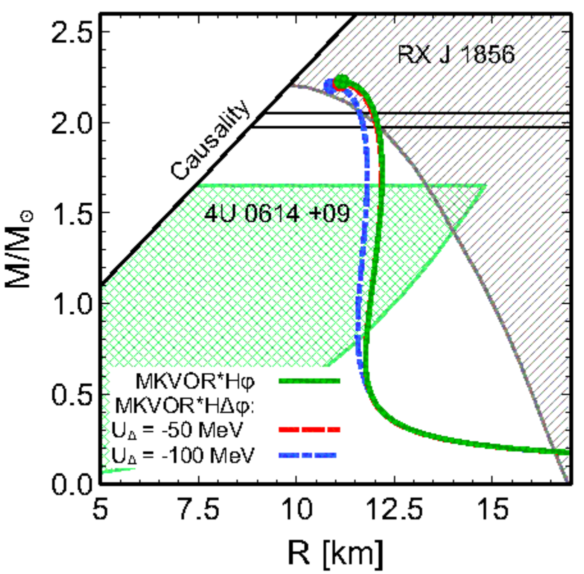


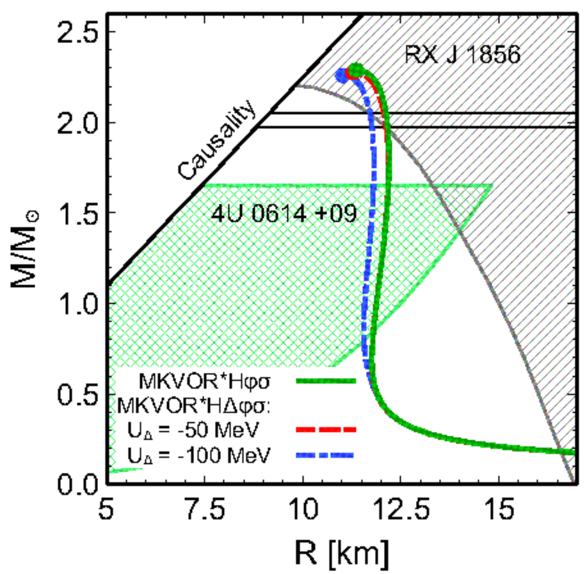




neutron stars







RMF model with scaled meson masses and coupling constants

- ✓ **Universal scaling of hadron masses. Not universal scaling of coupling constants**
- ✓ **The model is flexible enough to satisfy many astrophysical constraints, constraints from HIC and microscopic calculations.**
- ✓ **Hyperon puzzle can be partially resolved if the reduction of phi meson mass is taken into account**
- ✓ **Models are safe against the inclusion of Δ baryons**