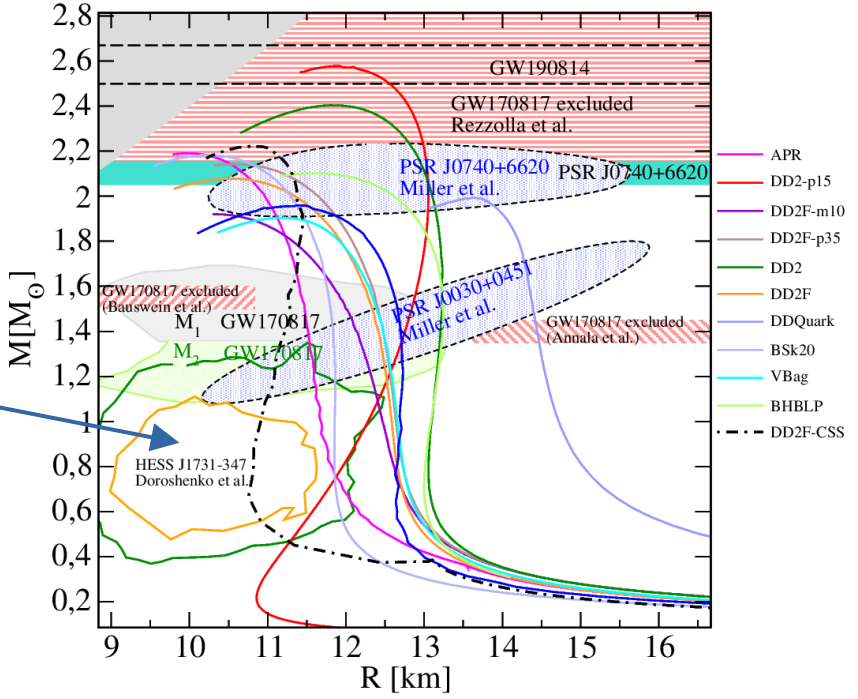
How meson crossing terms reconcile the recent observational data

Sebastian Kubis
Cracow University of Technology
/with W.Wójcik, N.Zabari, D.Alvarez-Castillo/

HESS J1731-347
CCO in SN remnant
the lightest NS !

exotica required ?



Historical perspective

RMF (*J.D.Walecka '74*) :
- scalar mesons → attraction
- vector mesons → repulsion

} saturation of nuclear forces

relativistic Lagrangian with $\sigma, \omega, \vec{\rho}$ coupled to n, p

lightest true mesons:

σ now $f_0(600)$ – very broad resonance

$\omega(782)$

$\rho(780)$

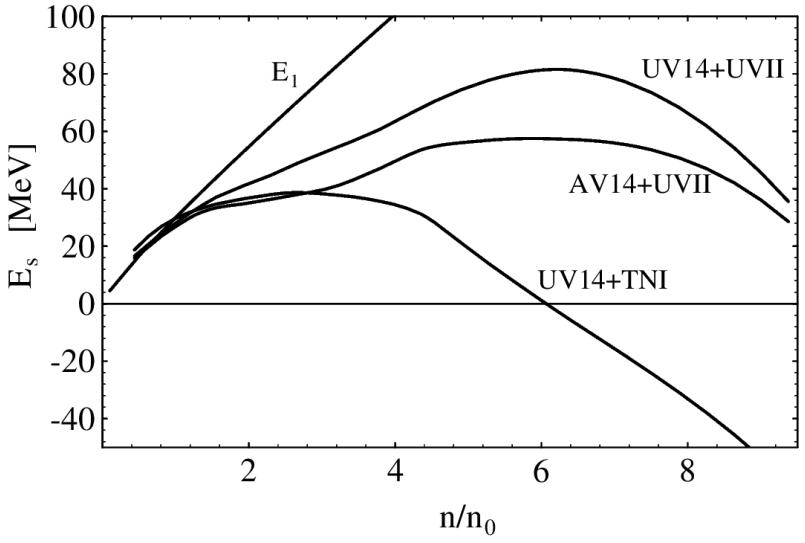
~~experimental coupling constants~~

effective couplings fitted to sat.properties:
(infinite nuclear matter)
binding energy, compressibility
symetry energy…
all at $n_0 = 0.16\ \mathrm{fm}^{-3}$

However!
isospin symmetry ⟶ four nuclear currents: $\bar{\psi}\psi\ ,\ \bar{\psi}\gamma^{\mu}\psi\ ,\ \bar{\psi}\gamma^{\mu}\vec{\tau}\psi\ ,\ \bar{\psi}\vec{\tau}\psi$

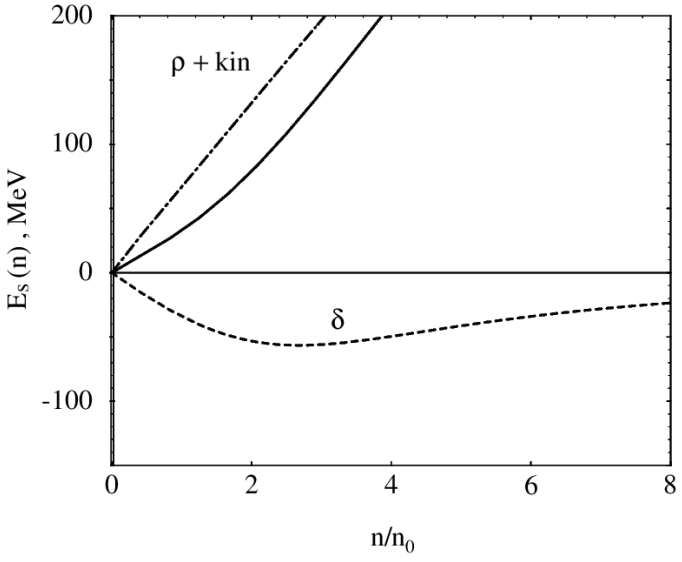
so, the fourth „meson” scalar-isovector ⟶ $\vec{\delta}$ /true $a_0(980)$/ nucleon mass splitting $m_i = m_B - g_\sigma\sigma \pm g_\delta\delta_3$

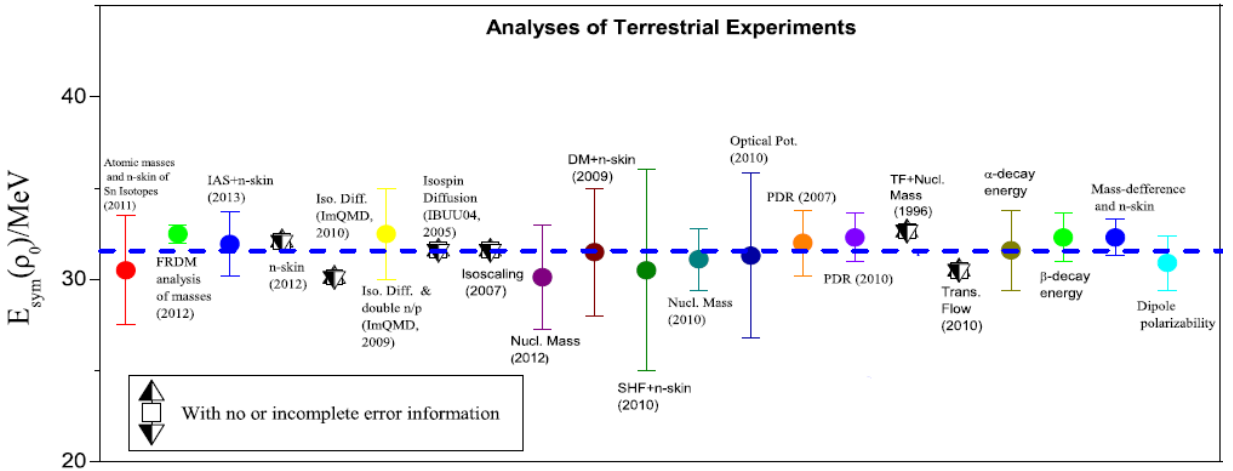
$$E_{\rm sym}(n) = \frac{1}{8}C_\rho^2 n + \frac{k_0^2}{3E_{F,0}} - C_\delta^2 \frac{m_0^2 n}{2E_{F,0}^2(1 - 3C_\delta^2(\frac{n}{E_{F,0}} - \frac{n_s}{m_0}))}$$

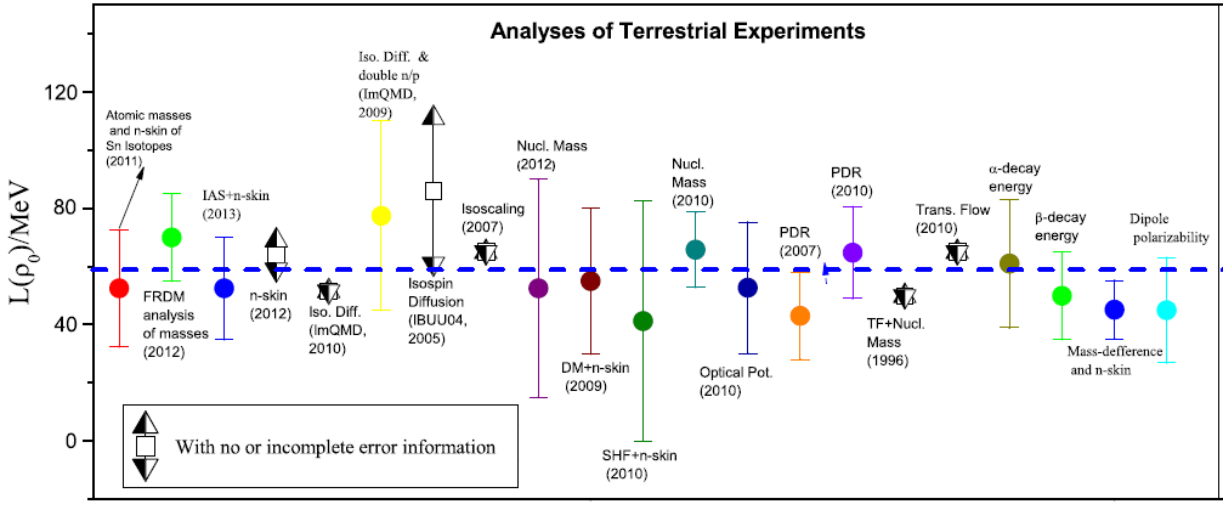


δ - contribution decreases with *n*

Kubis, Kutschera PLB399 (1997)



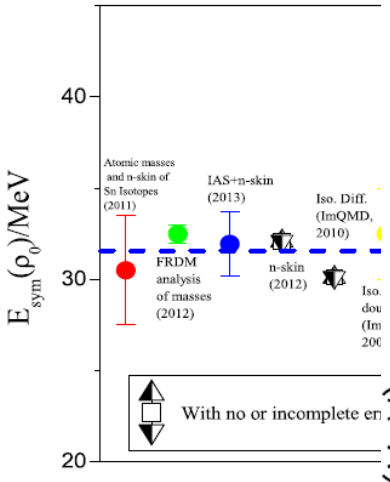


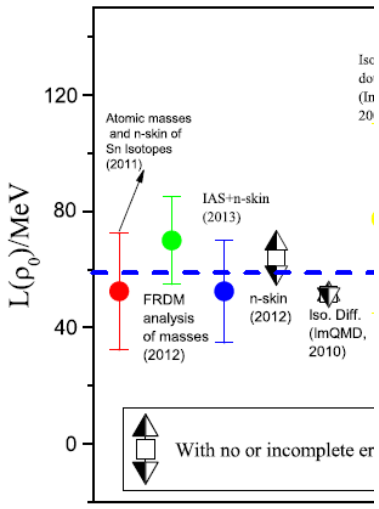


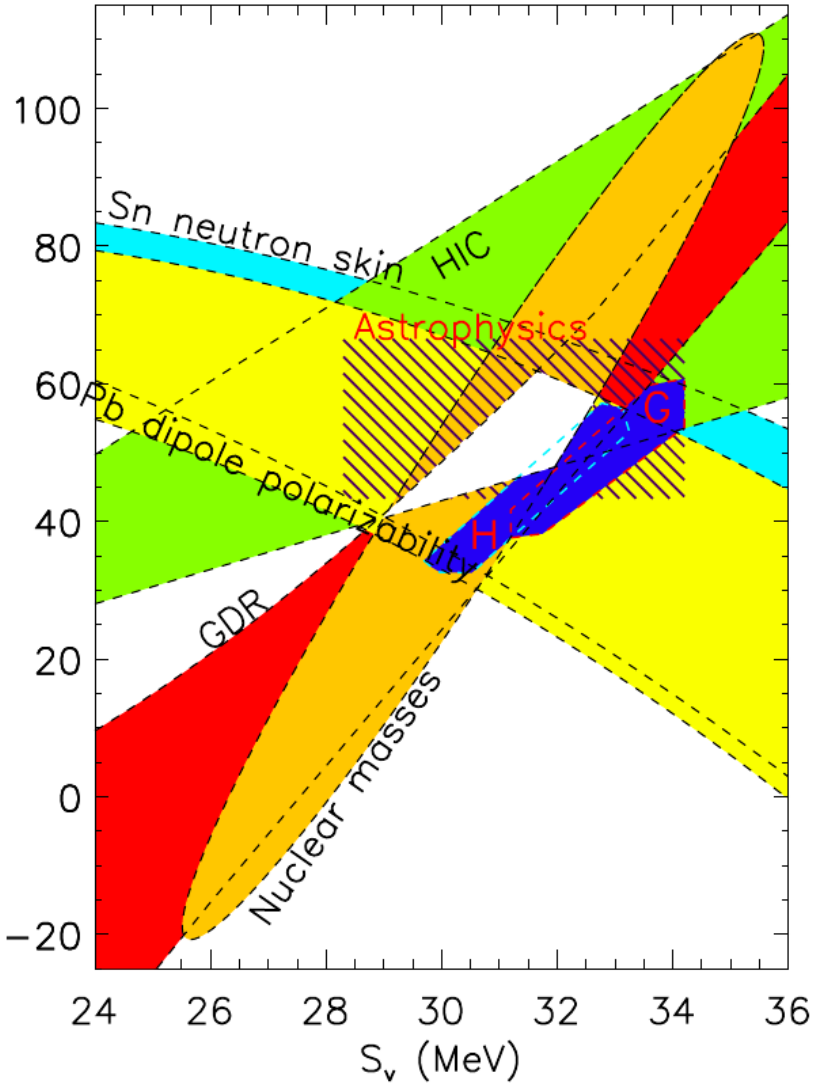
Li, Han, PLB727 (2013)

$$E_s = 30 - 32 \text{ MeV}$$

$$L = 20 - 100 \text{ MeV}$$







Li, Han, PLB727 (2013)

$$E_s = 30 - 32 \text{ MeV}$$

$$L \approx 50 \text{ MeV}$$

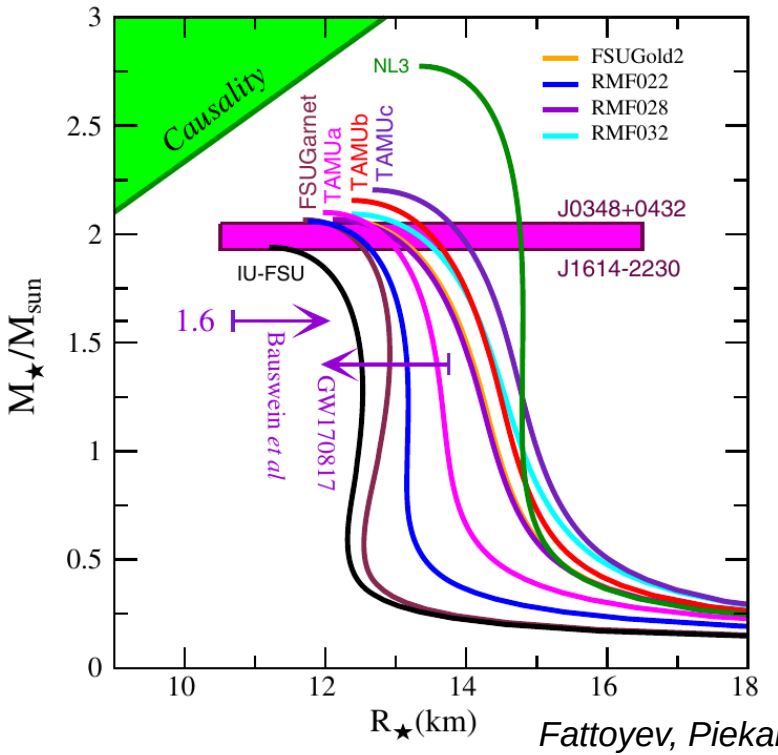
standard RMF : $L > 90$ MeV ?

Lattimer,Lim ApJ771 (2013)

Crossing terms come into play

FSUGold model: $(\omega_\mu \omega^\mu)^2$ ⟶ EoS stiffness , max mass of NS *Todd-Rutel,Piekarewicz PRL95*

$\omega_\mu \omega^\mu \vec{\rho}_\mu \cdot \vec{\rho}^\mu$ ⟶ symmetry energy behaviour



fitted to ground state properties of nuclei

FSUGold „families” - different parametrization

L = 45 – 108 MeV

Fattoyev, Piekarewicz PRL120 (2018)

two scalars crossing term

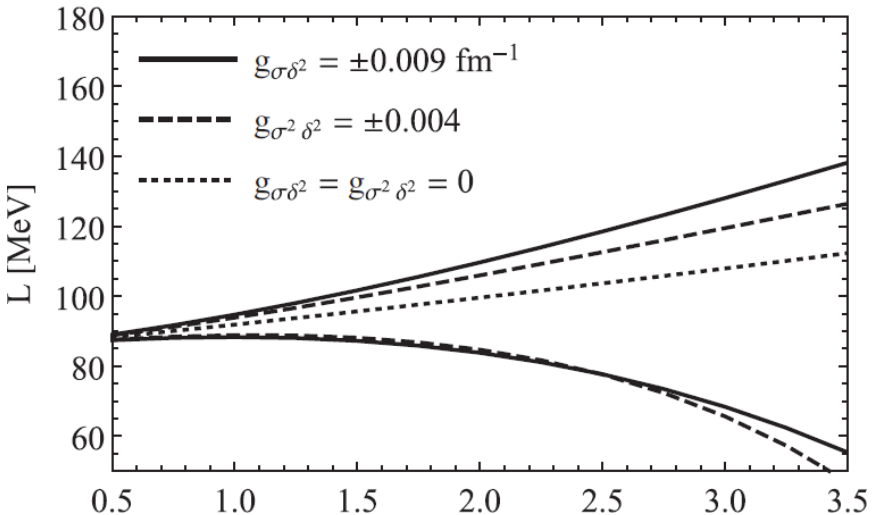
why not scalars? work well at low energy - ChiralPT

$\sigma^n(\vec{\delta}\cdot\vec{\delta})^m$ justified by isospin symmetry

$\sigma\vec{\delta}\cdot\vec{\delta}$ „linear"

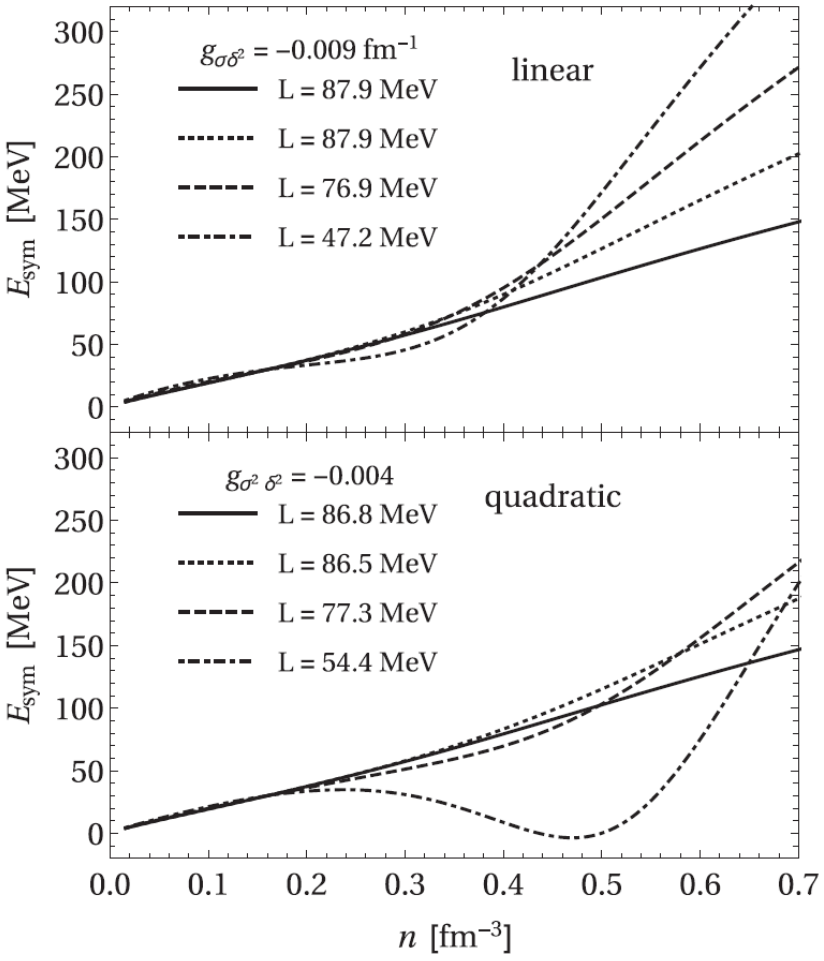
$\sigma^2\vec{\delta}\cdot\vec{\delta}$ „quadratic"

strategy:
keep fixed coupling for crossing term
and vary delta-nucleon coupling



$$g_\delta\bar{\psi}\vec{\delta}\cdot\vec{\tau}\psi \longrightarrow C_\delta^2 = \frac{g_\delta}{m_\delta}$$

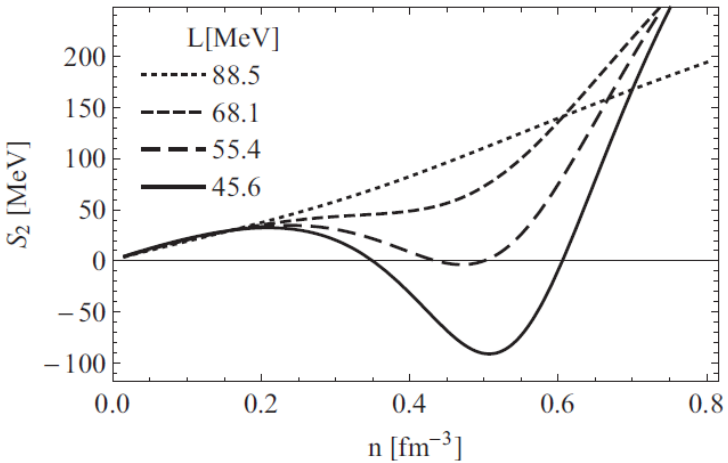
Zabari,Kubis, PRC99 (2018)

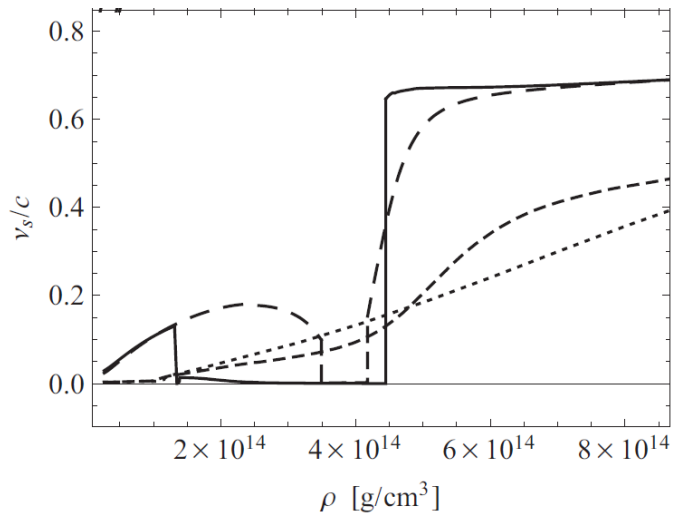


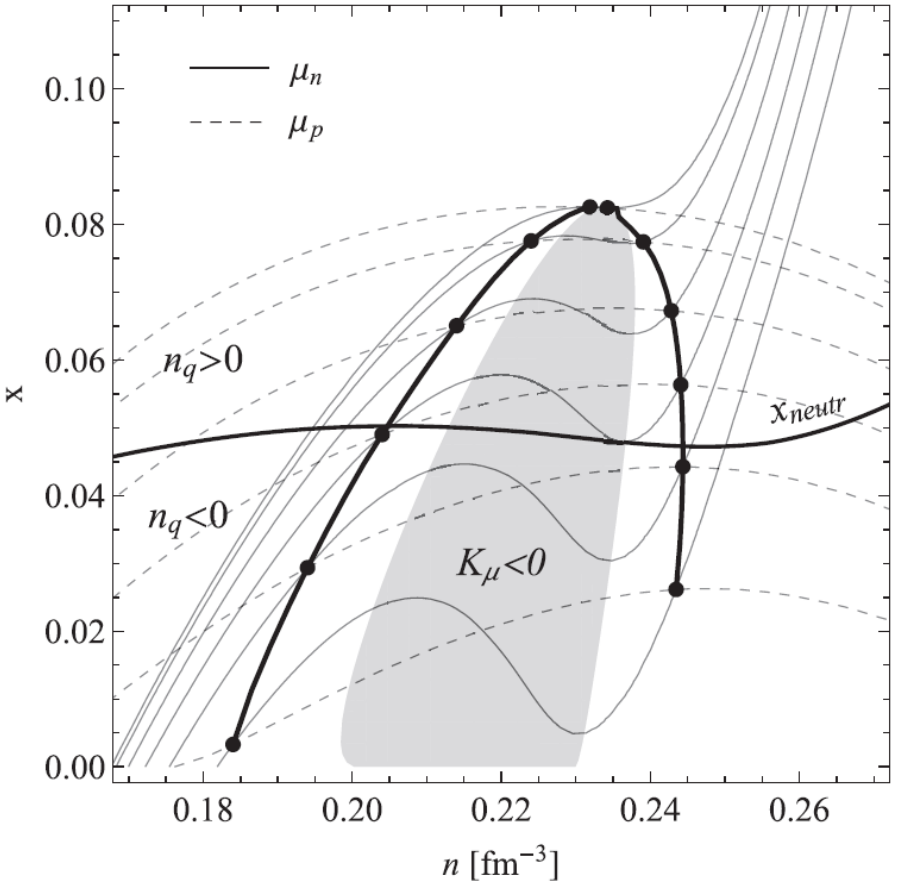
low L → symm. energy bending
phase transition

$\sigma^2 \vec{\delta} \cdot \vec{\delta}$

spinodal region, Gibbs conditions

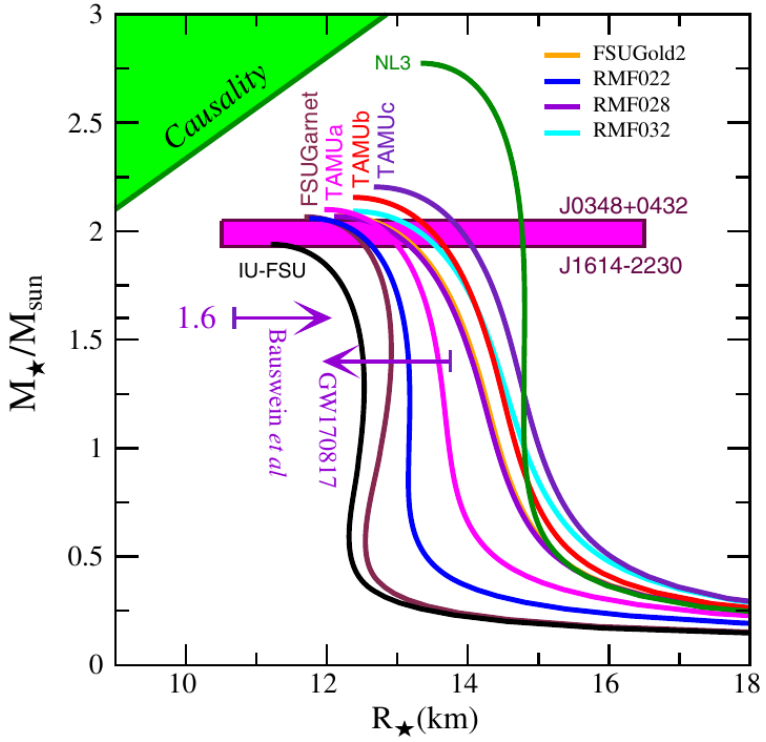




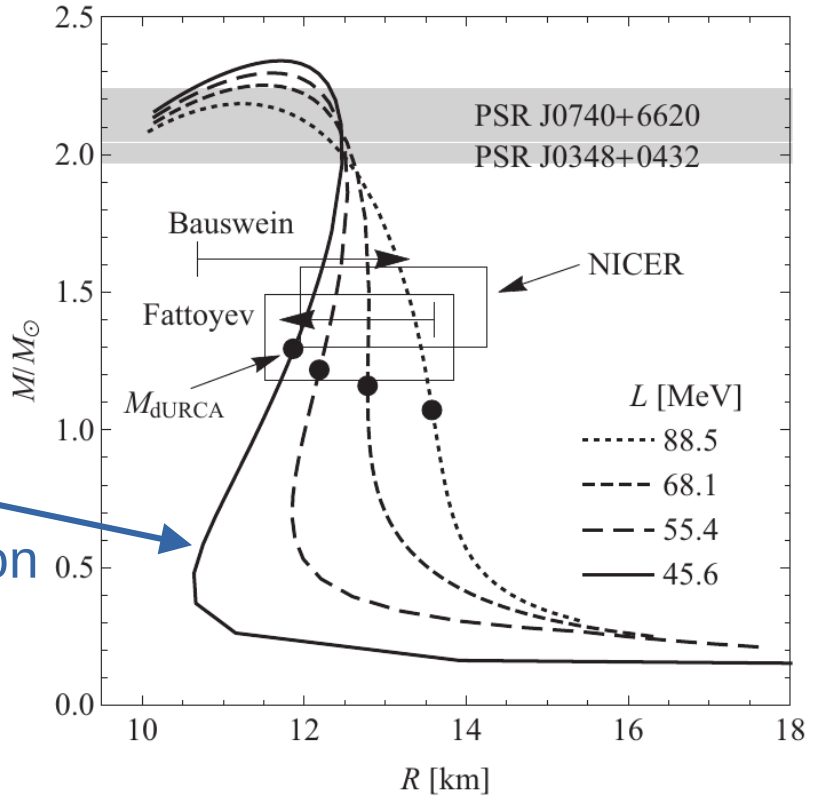


symmetry energy and NS radius

larger L → larger R



Kubis,Wójcik, PRC102 (2018)



„Z-like” MR relation

scalar „works” at lower densities!

symmetry energy and NS radius

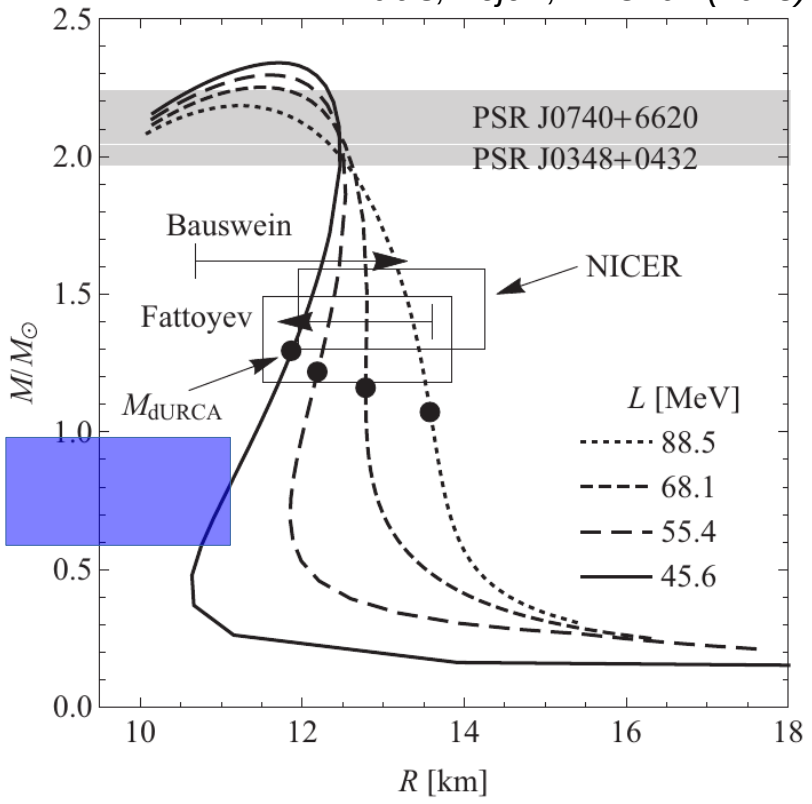
HESS 1731-347
CCO in supernova remnant

$$R = 10.4^{+0.86}_{-0.78}\ \mathrm{km}$$

$$M = 0.77^{+0.20}_{-0.17} M_\odot$$

Doroshenko et.al. Nature Astr. 6 (2022)

Kubis,Wójcik, PRC102 (2018)

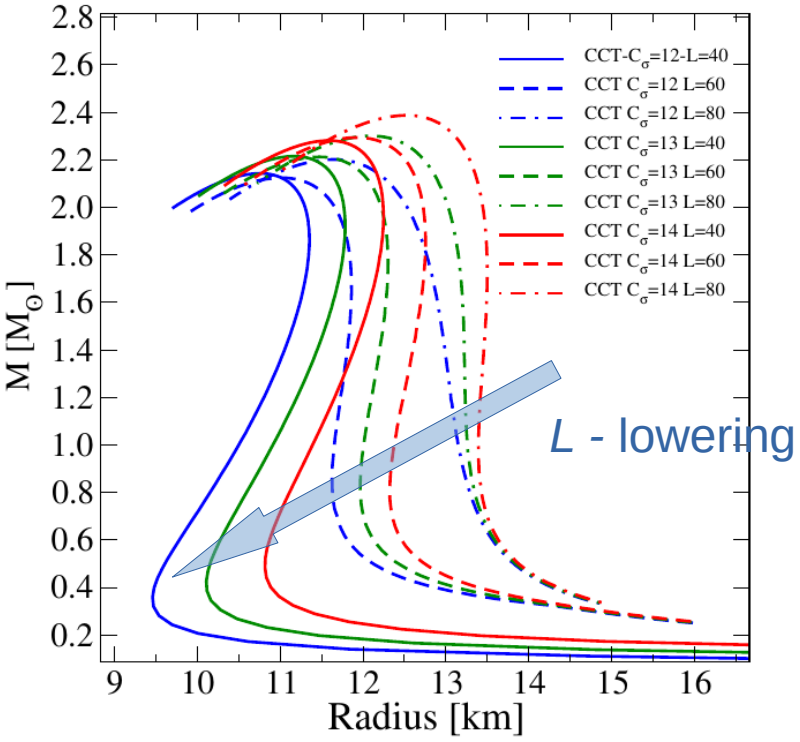


can't be L < 40 ??

scalar-scalar OK , why not vector-scalar ?

$$\mathcal{L}_{\rm CCT} = \tfrac{1}{2} g_{\sigma\delta}\, \sigma^2 \vec{\delta}^2 + \tfrac{1}{2} g_{\omega\delta}\, \omega_\mu \omega^\mu \vec{\delta}^2$$

Cracow Crossing Terms model



submitted to PRC

6 model parameters fitted to sat.point properties

two free parametrs:

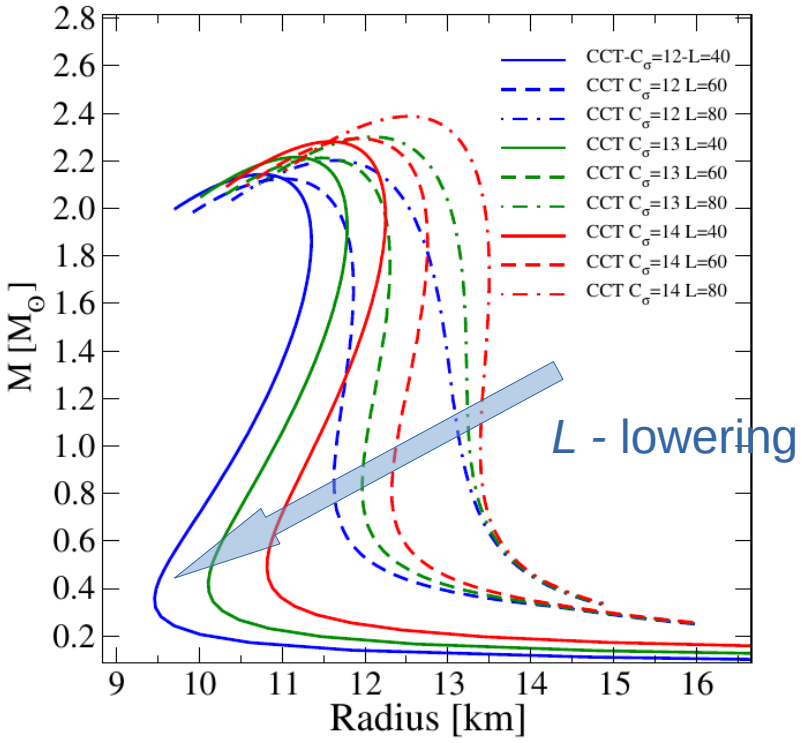
$C_\sigma^2 = 12 - 14 \ \ \mathrm{fm}^2$ EoS stiffnes

C_δ controls $L = 40 - 80$ MeV

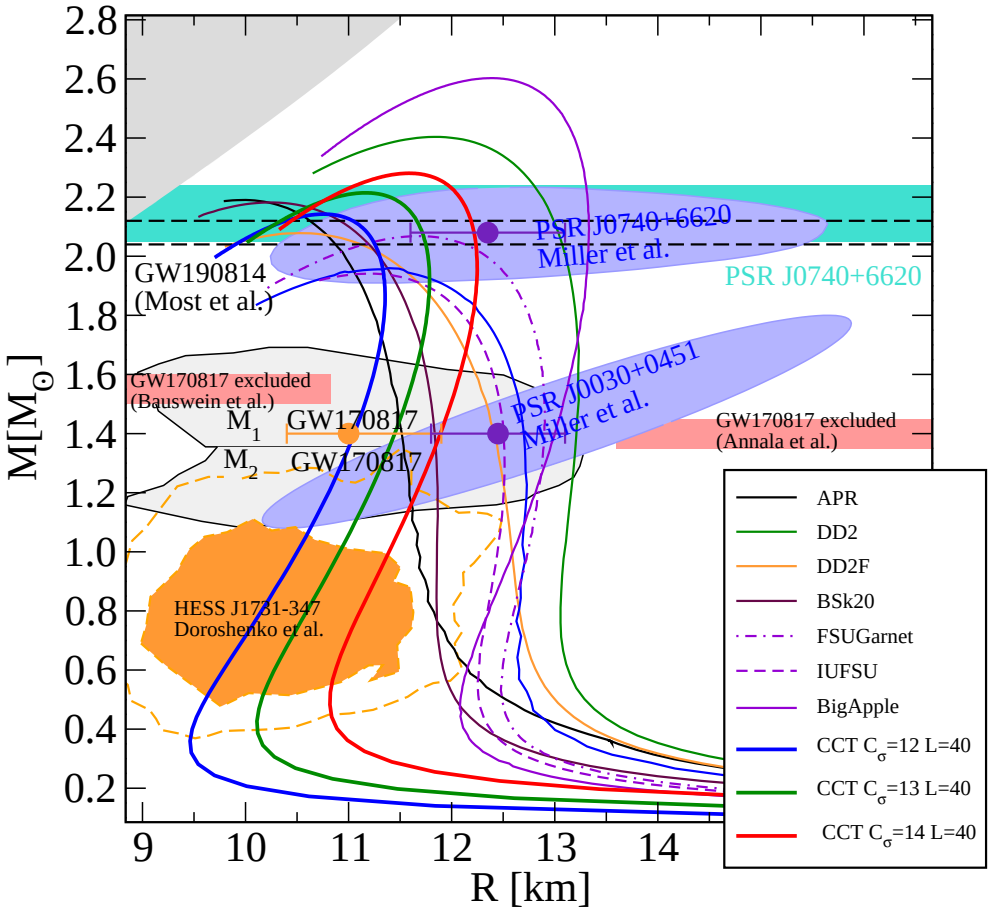
phase transition occurs for *L<50* MeV

scalar-scalar OK , why not vector-scalar ?

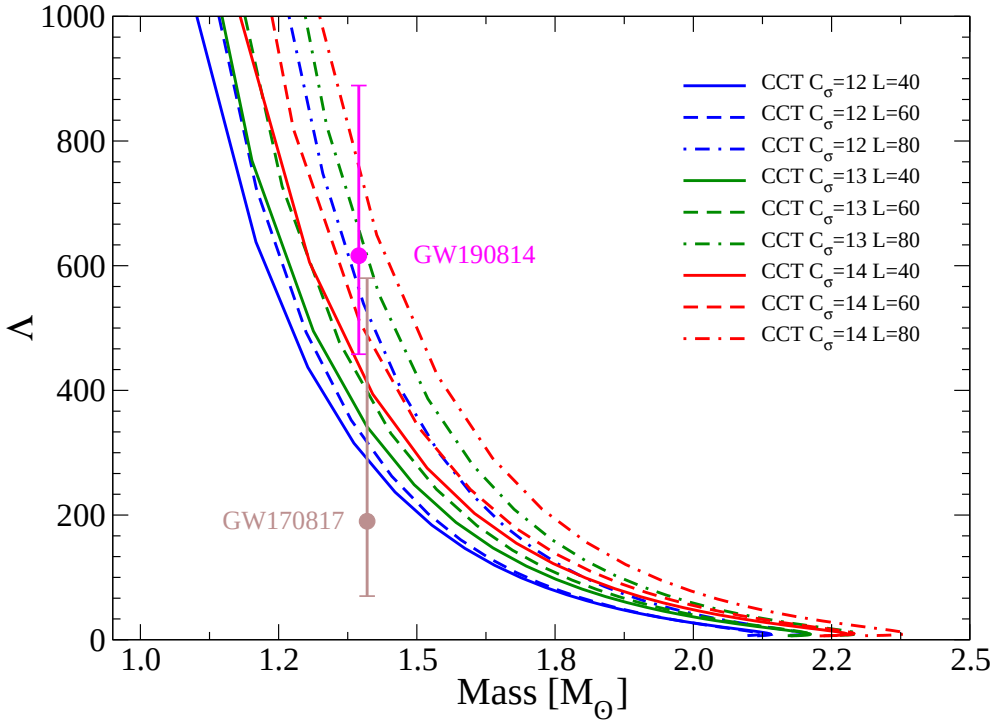
$$\mathcal{L}_{\rm CCT} = \frac{1}{2} g_{\sigma\delta}\, \sigma^2 \vec{\delta}^2 + \frac{1}{2} g_{\omega\delta}\, \omega_\mu \omega^\mu \vec{\delta}^2$$

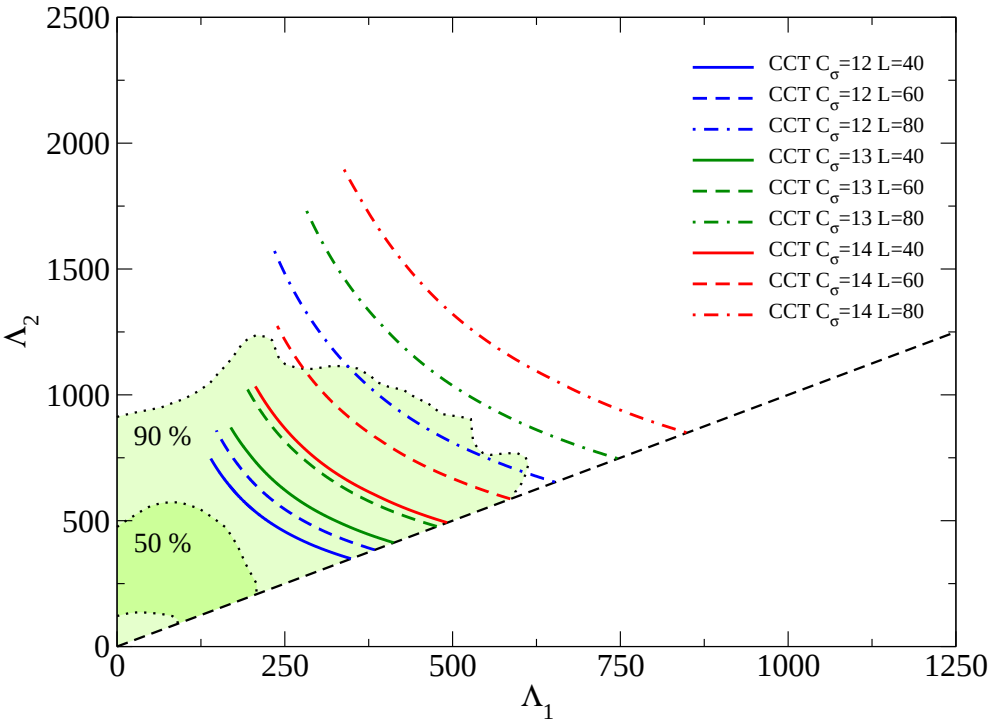


submitted to PRC



tidal deformabilities from GW events





open question:

- at $n \approx 3n_0$ a gap between proton and neutron eff. mass
  → isospin symmetry breaking

for future:

- cooling with dUrca - amplitude dependent on eff. masses

- fit the model to ground-state properties of nuclei

- include vector-vector crossing terms