SUPPRESSION OF HYPERONIZATION OF DENSE NUCLEAR MATTER BY WEAKLY INTERACTING LIGHT BOSONS

F. Simkovic (Dubna, JINR & Bratislava, Uni)

M.I. Krivoruchenko, F.S., Amand Faessler, PRD79 (2009) 125023

1. Motivation to search for WILBs
2. Neutrons stars & physics beyond the Standard m
3. Low masses of hyperon stars and solutions inclu

Dense Baryonic Matter in the Cosmos and the Laboratory
Tubingen, 11 October 2012

MOTIVATION TO SEARCH FOR WILBS

1). To check Newton law:

The deviations are usually parametrized in the form

$$V(r) = -\frac{Gm_1m_2}{r}(1 + \alpha_G e^{-r/\lambda}).$$

The second Yukawa term is attributed to WILBs

$$Gm^2\alpha_G = \pm\frac{g^2}{4\pi}, \qquad \lambda = 1/\mu,$$

where +/- stands for scalar/vector bosons, m is the pro

2). Schemes with extra dimensions

suggest modifications of gravity below λ_D and WILE

Expanding Universe at accelerating rate is attributed t energy density

$$\rho_D \approx 3.8 \text{ keV/cm}^3$$

may correspond to a fundamental macroscopic scale

$$\lambda_D = \rho_D^{-1/4} \approx 0.1 \text{ mm}$$

3). Beyond the Standard model:

new particles appear, such as neutralino. Typically, particles are expected with masses above several hur or even higher.

However,

light particles may exist also,

such as a neutral very weakly coupled spin-1 gauge U (P. Fayet, 1980)

that can provide annihilation of light dark matter to e^+e and be responsible for the 511 keV line observed from the galactic bulge.

4). Low masses of hyperon stars:

Hyperonisation softens EoS of nuclear matter and decreases the maximum mass of neutron stars below the observed value of mass of PSR J1614-2230

$$M = 1.97 +/- 0.04 \ M^{J}$$

reported by

P. B. Demorest, T. Pennucci, S. M. Ransom, M. S. E. Roberts, and J. W. T. Hessels, Nature 467

NEUTRON STARS & PHYSICS BEYOND THE STANDARD MODEL

WILBs modify nuclear matter EOS & neutron stars.

The effect depends on the ratio g^2/μ^2 only

Even when its baryon couplings are extraordinary small
WILB may influence the structure of neutron stars.

The effect of a vector boson on the energy density of nuclear matter can be evaluated by averaging the Yukawa potential:

$$E_I = \frac{1}{2}\int d\boldsymbol{x}_1 d\boldsymbol{x}_2 \rho(\boldsymbol{x}_1) \frac{g^2}{4\pi r} e^{-\mu r} \rho(\boldsymbol{x}_2)$$

where $\rho(\boldsymbol{x}_1) = \rho(\boldsymbol{x}_2) = \rho$ is the number density,

$r = |\boldsymbol{x}_1 - \boldsymbol{x}_2|$,

g is the coupling constant with baryons, and

$\boldsymbol{\mu}$ is the boson mass.

The integration gives

$$E_I = V\frac{g^2\rho^2}{2\mu^2},$$

where V is the normalization volume.

The contribution to the energy density of nuclear matter from vector WILBs should be compared to that from the ordinary ω-meson:

$$\frac{g^2}{\mu^2} \approx \frac{g_\omega^2}{\mu_\omega^2} \approx 200\,\mathrm{GeV}^{-2}.$$

A similar reasoning applies to scalar WILBs which have to compete with the standard σ-meson exchange:

$$\frac{g^2}{\mu^2} \approx \frac{g_\sigma^2}{\mu_\sigma^2} \approx 300\,\mathrm{GeV}^{-2}.$$

Effect of scalar WILBs:

An increase of g (a decrease of μ) of scalar WILBs increases the negative contribution to pressure, makes EOS of nuclear matter softer, makes neutron stars less stable against gravitational compression.

The ratio g^2/μ^2 cannot be increased significantly above 200 GeV^{-2}, since the maximum mass of the neutron star sequence cannot be moved below masses of the observed pulsars.

Effect of vector WILBs:

An increase of g (a decrease of μ) of vector WILBs, conversely, increases the positive contribution to pressure, makes EOS of nuclear matter stiffer, makes neutron stars more stable against gravitational compression and drives the maximum mass of neutron stars up.

In case of vector bosons, it is less obvious what kind of the observables confronts to high g^2/μ^2.

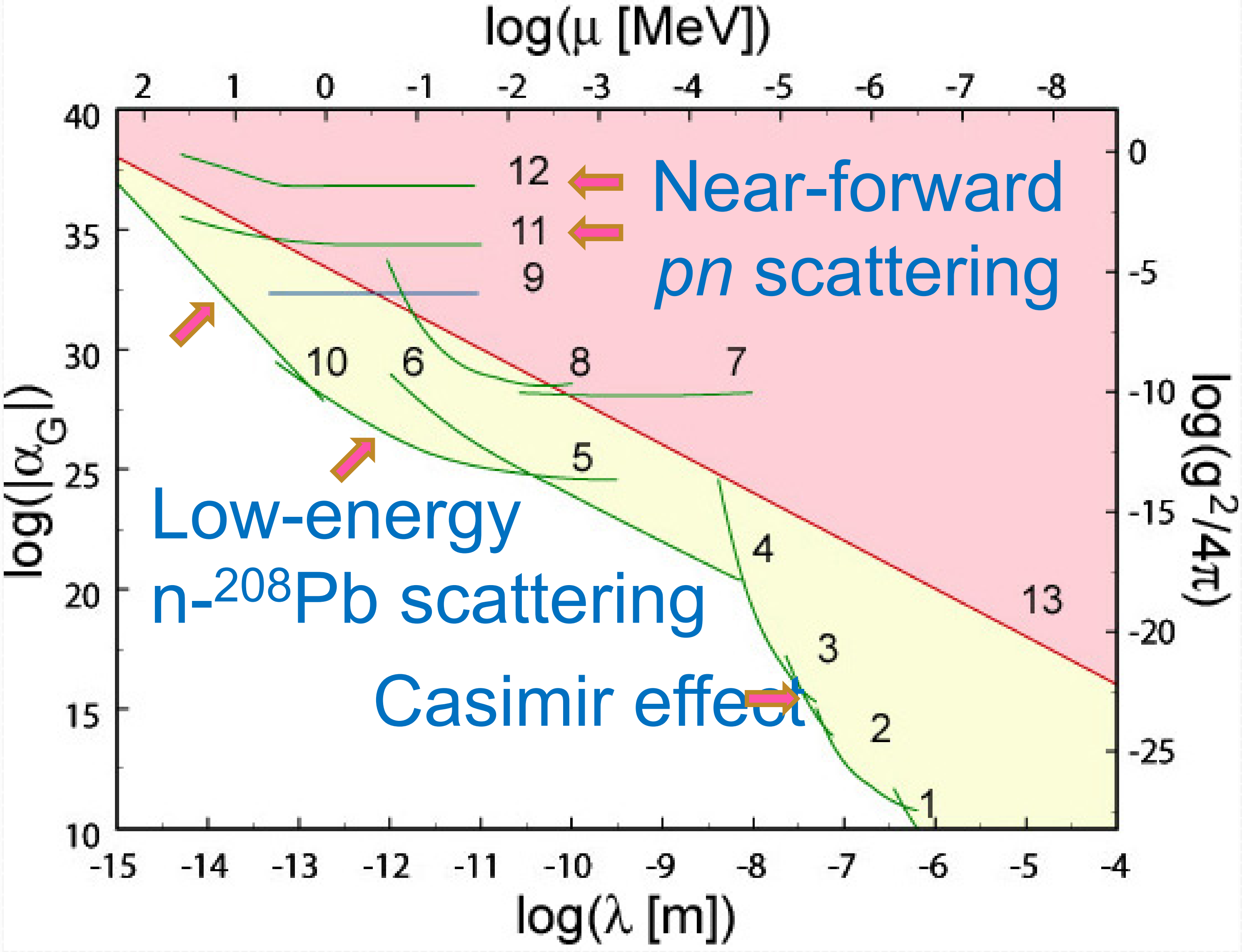
What is known about WILBs from experiments at labs.?

Constraints are available from:

1. Casimir effect
2. Low-energy n-^{208}Pb scattering
3. Spectroscopy of antiproton atoms
4. Near-forward *pn* scattering

and some others.

Constraints on the coupling strength with nucleons $g^2/(4\pi)$ and the mass μ (α_G and λ):

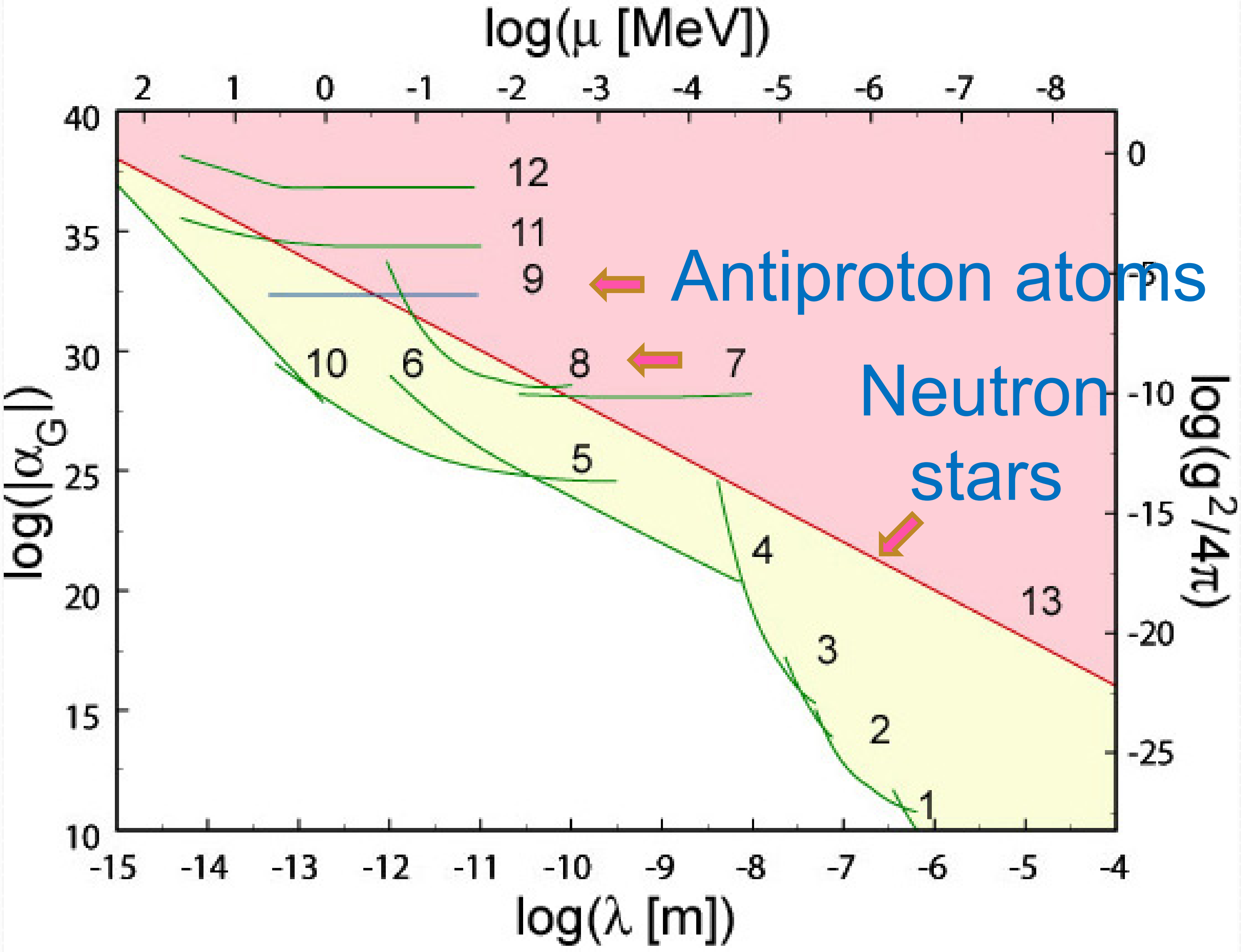


Near-forward *pn* scattering

Low-energy n-^{208}Pb scattering

Casimir effect

Constraints on the coupling strength with nucleons $g^2/(4\pi)$ and the mass μ (α_G and λ):



Antiproton atoms

Neutron stars

The axes are in the $\log_{10}$ scale.

The internal structure of neutron stars is not modified provided the boson coupling strengths and masses lie at

$$g^2/\mu^2 < 200\ \mathrm{GeV}^{-2}$$

beneath the highlighted area 13.

1 - S. K. Lamoreaux, Phys. Rev. Lett. 78, 5 (1997).
2 - R. S. Decca et al., Phys. Rev. Lett. 94, 240401 (2005).
3 - V. M. Mostepanenko et al., J. Phys. A41, 164054 (2008)
[Casimir effect].
4 - M. Bordag et al., Phys. Lett. A187, 35 (1994).
5 and 10 - Yu. N. Pokotilovski, Phys. Atom. Nucl. 69, 924 (2006), R. Barbieri, T. E. O. Ericson, Phys. Lett. B57, 270 (1975)
[low-energy n-^{208}Pb scattering].
6 - V. V. Nesvizhevsky, G. Pignol, K. V. Protasov, Phys. Rev. D77, 034020 (2008).

7 – V. V. Nesvizhevsky and K.V. Protasov, Class. Quantum Grav. 21, 4557 (2004).

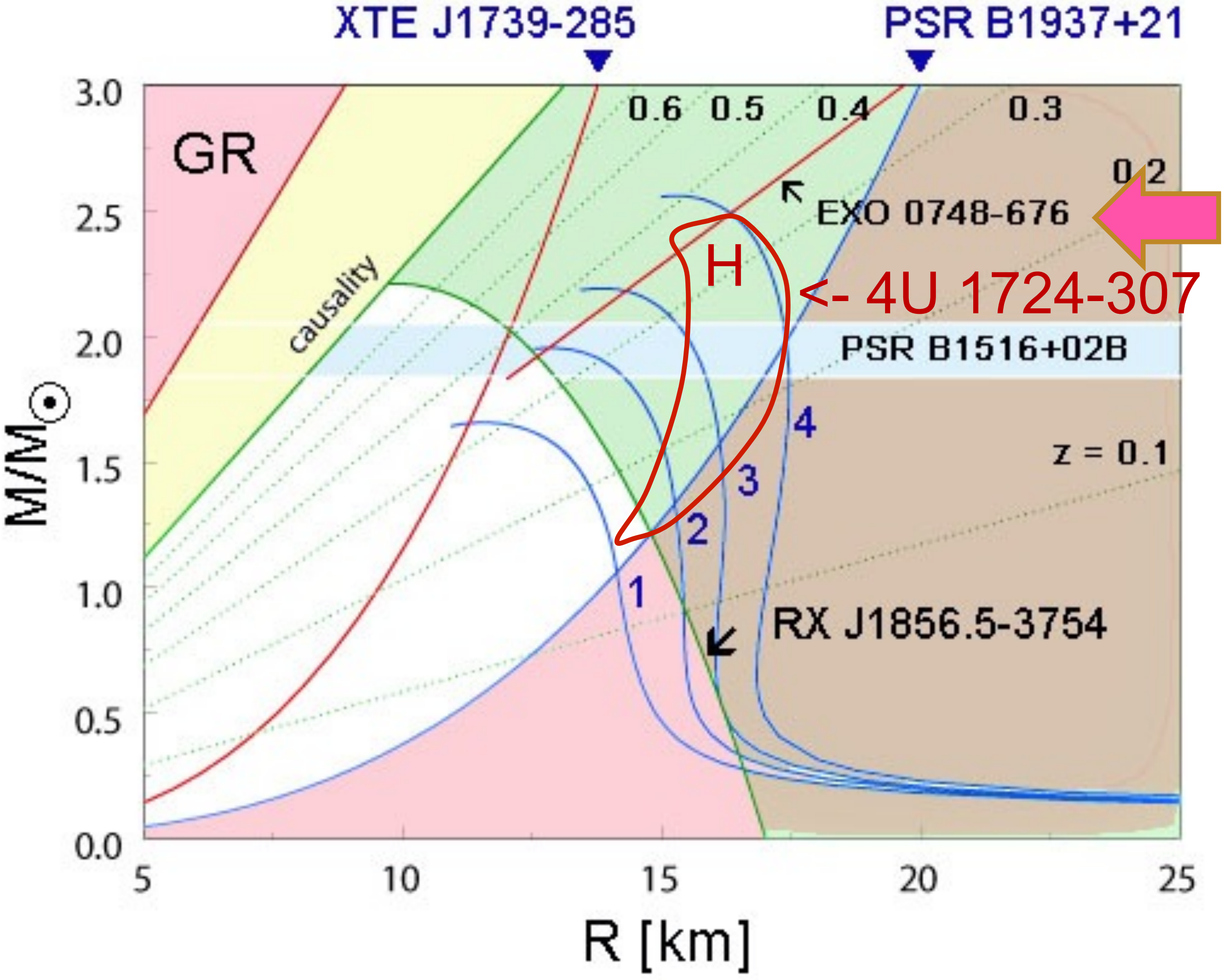
8 and 9 - Yu. N. Pokotilovski, Phys. Atom. Nucl. 69, 924 (2006)

[spectroscopy of antiproton atoms].

11 and 12 - Y. Kamyshkov, J. Tithof and M. Vysotsky, Phys. Rev. D78, 114029 (2008)

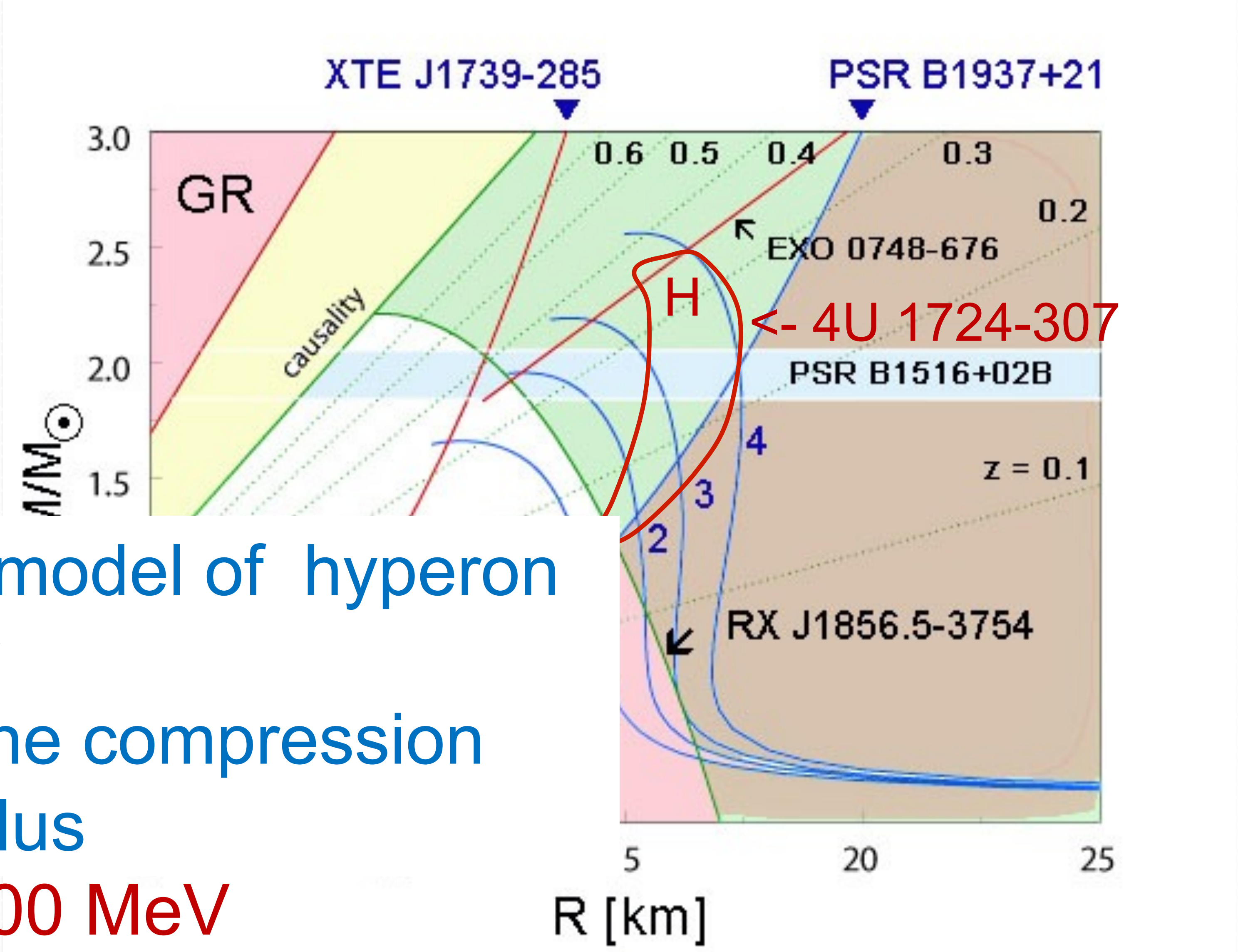
[near-forward *pn* scattering for vector and scalar bosons].

WILBS EFFECT ON MASSES OF NEUTRON STARS



revised

WILBS EFFECT ON MASSES OF NEUTRON STARS



RMF model of hyperon mater
with the compression modulus
K = 300 MeV
from N. Glendenning

	g^2/μ^2 [GeV^{-2}]
1	0
2	25
3	50
4	100

Laboratory constraints do not apply to WILBs coupled to hyperons. A vector WILB coupled to the second generation of the quarks makes hyperon matter EOS stiffer as required.

The high mass of PSR J1614-2230

1.97 +/- 0.04 M^J

can be explained by the existence of a vector WILB

that provides stiff EOS of the *β*-equilibrated

HYPERONS EFFECT ON MASSES OF NEUTRON STARS

At high density the production of hyperons becomes energetically favorable:

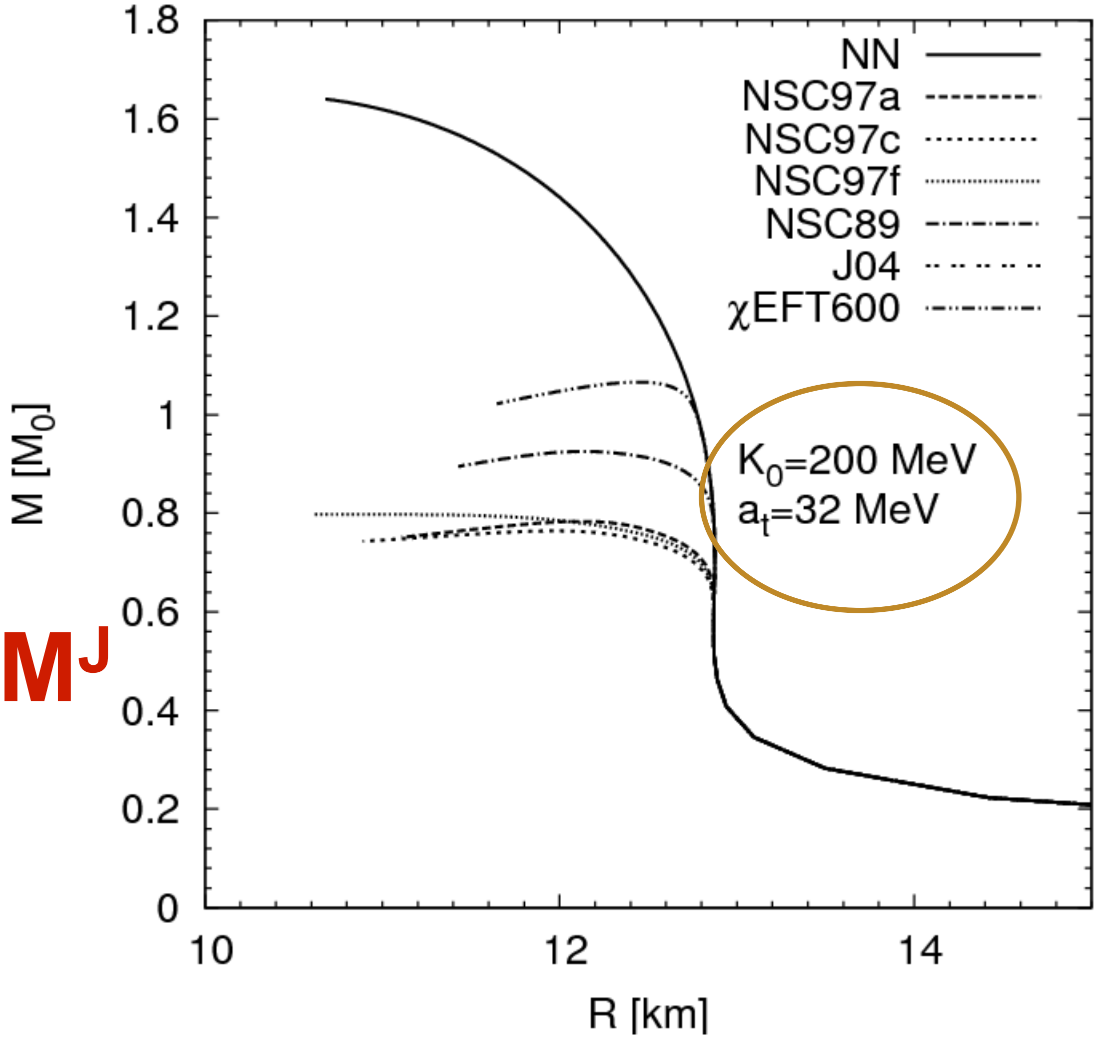
V. A. Ambartsumyan and G. S. Saakyan, Astron. Zh. 37, 193 (1960).

In the EoS based on the Reid soft core model, the inclusion of hyperons drops the maximum mass of neutron stars from 1.6 M^J down to 1.4 M^J.

HF model with hyperons from H. Djapo, B.-J. Schaefer and J. Wambach, Phys. Rev. C81, 035803 (2010)

?!

$\Delta M = 0.8\ M^J$

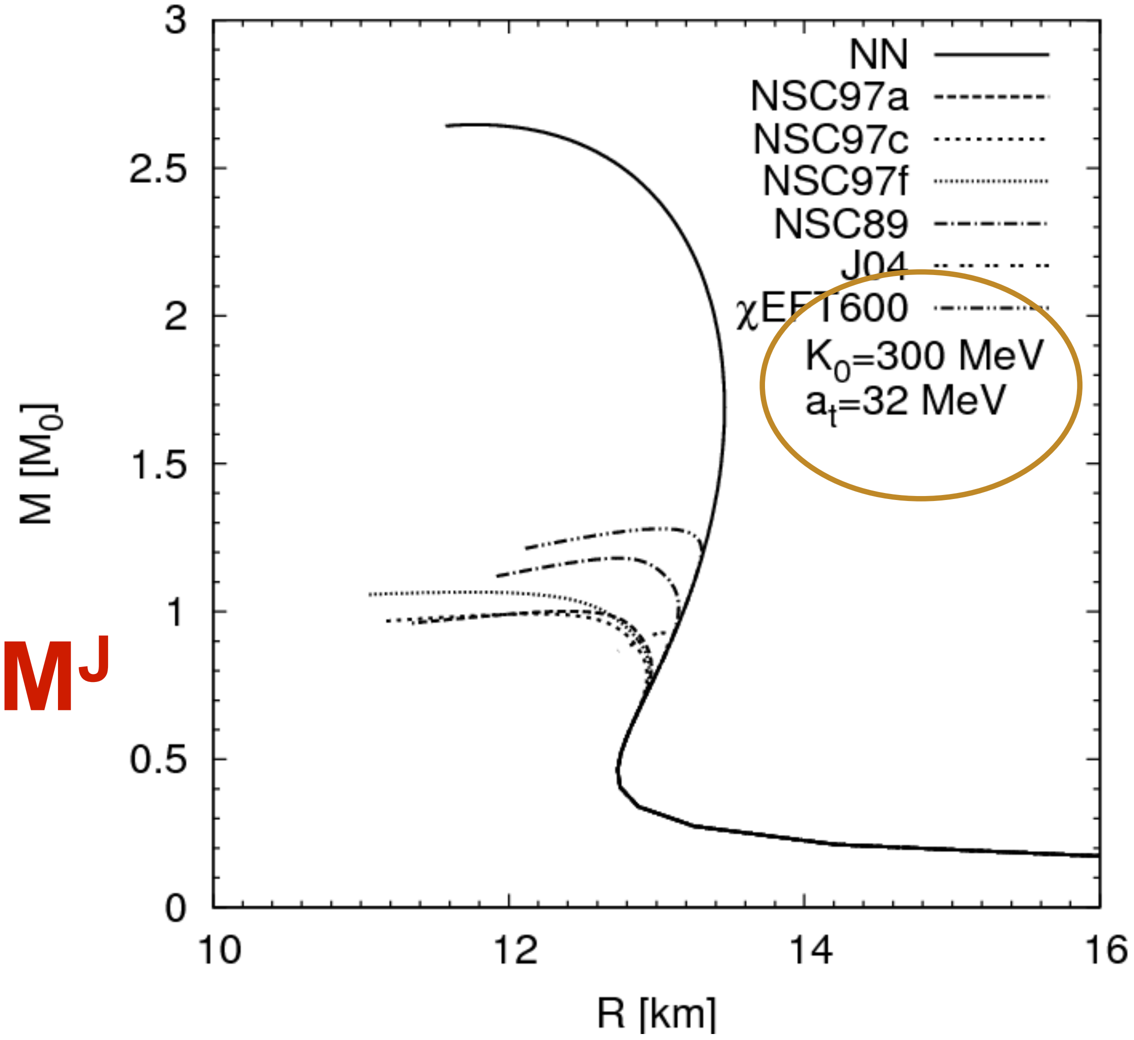


NN + NY interactions

HF model with hyperons from H. Djapo, B.-J. Schaefer and J. Wambach, Phys. Rev. C81, 035803 (2010)

?!

$\Delta M = 1.6\ M^J$



NN + NY interactions

Possible reasons of much too low masses of the hyperon stars:

1. As already discussed, MISSING CONTRIBUTION OF NEW EXOTIC PARTICLES - WILBs
2. Inadequacy of OBE models of nuclear matter at high densities
3. Poor knowledge of the interaction forces between hyperons

2. Possible inadequacy of OBE models at high densities

The sphere of radius r is empty, the nearest neighbor is located in

$$dV = 4\pi r^2 dr.$$

Without correlations:

Probability distribution is given by: the product of probability of no nucleons inside V (Poisson law -> $\exp(-\rho V)$) and probability ρdV to find one nucleon in dV

$$dP = e^{-\rho V} \times \rho dV,$$

where $\rho = 0.16$ fm^{-3}

With correlations:

$$dP = Ce^{-\rho V} f^2(r)\rho dV,$$

where $f(r)$ is the Jastrow-like function

$$f(r) = 1 - \exp(-ar^2)(1 - br^2)$$

with a = 1.1 fm^{-2} and b = 0.68 fm^{-2} and $\int dP = 1$.

IN PROBABILITY THEORY
it is called
THE NEAREST NEIGHBOR DISTRIBUTION
has applications in astronomy, spectroscopy of atoms
and other areas

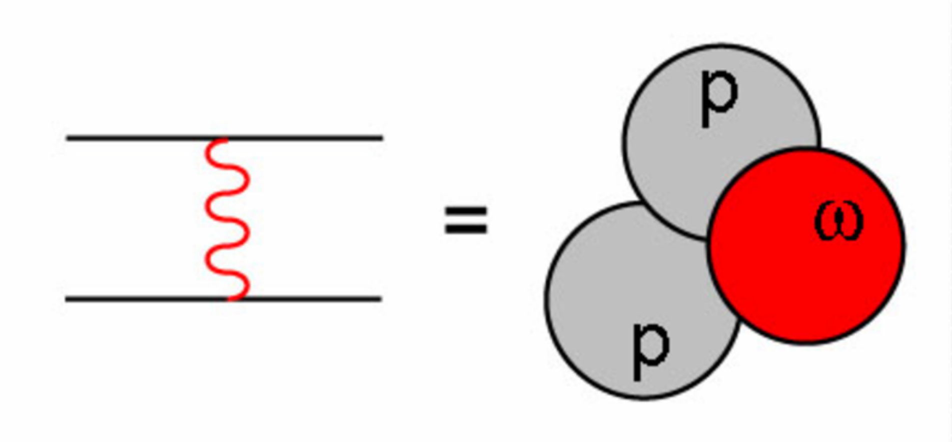
The average distance to the nearest neighbor:

$$\mathrm{E}[r] \pm (\mathrm{Var}[r])^{1/2} = \begin{cases} 1.02 \pm 0.37\,\mathrm{fm}, & \text{without correlations,} \\ 1.18 \pm 0.31\,\mathrm{fm}, & \text{with correlations.} \end{cases}$$

Proton charge radius:

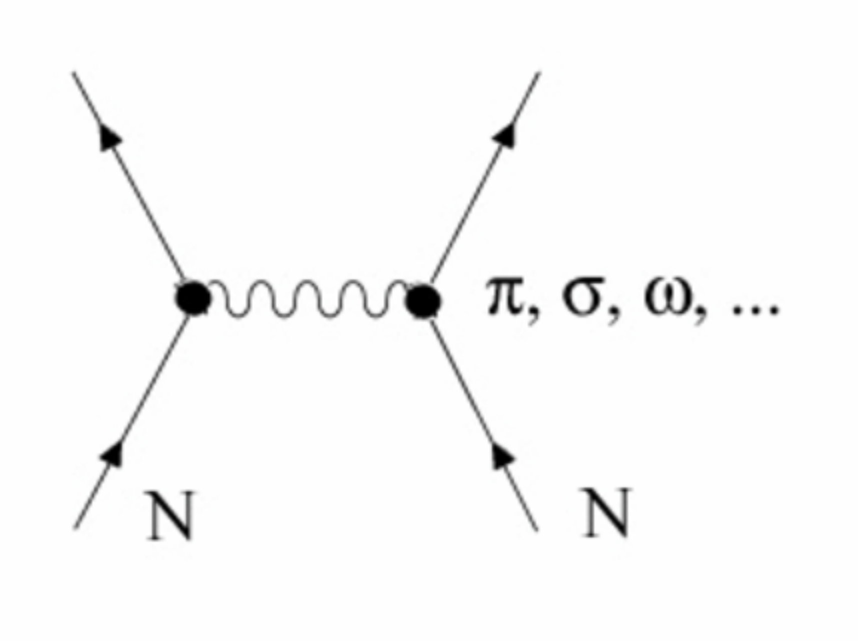
$$\mathrm{E}[r^2]^{1/2} = 0.8750 \pm 0.0068\,\mathrm{fm}.$$

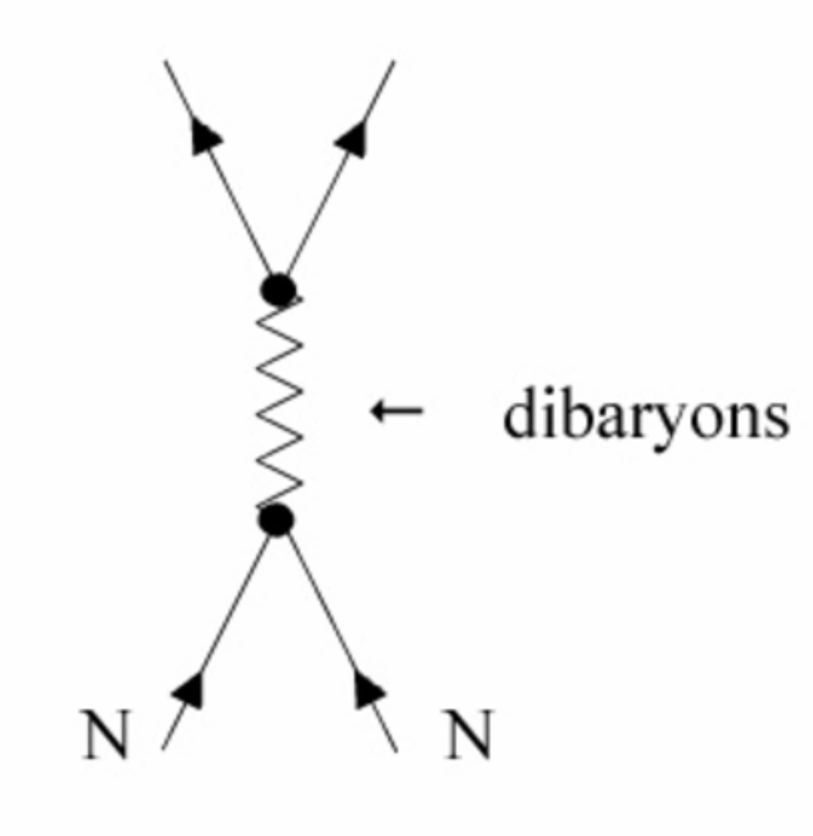
Typical configuration
in nuclear matter
in OBE models:
STRONG OVERLAP



OBE MODELS
T-CHANNEL EXCHANGE

S-CHANNEL EXCHANG

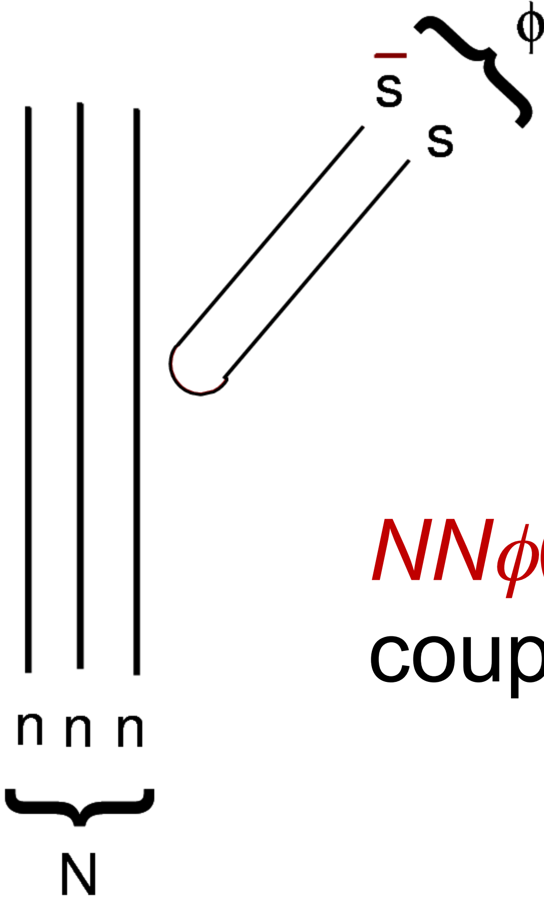




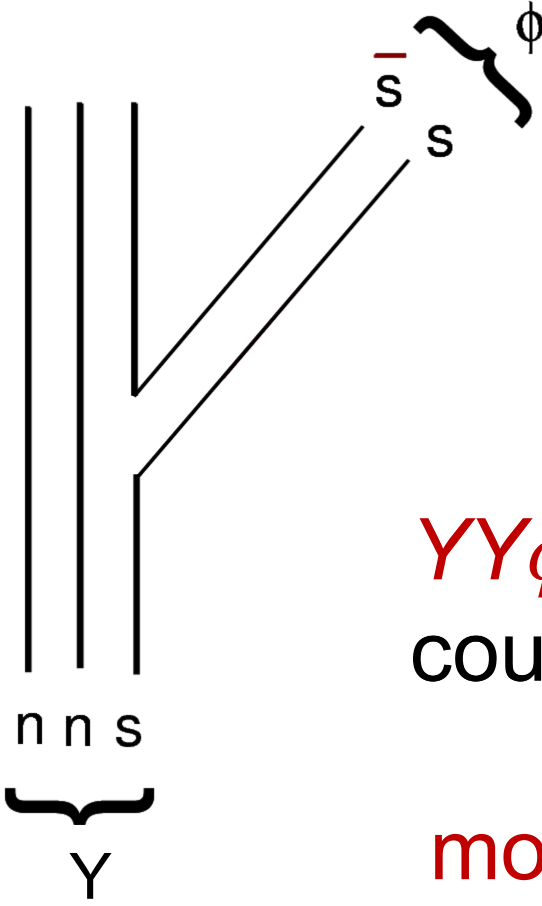
IS THERE DUALITY?

3. Poor knowledge of the interaction forces between hyperons

ϕ(1020)-meson subjected to **the OZI rule** is appropriate
to make stiff EOS (KSF, PRD79 (2009) 125023)



NNϕ(1020)
coupling is small



YYϕ(1020)
coupling is larg

⬇

more repulsion

Analysis made in

R. Lastowiecki, D. Blaschke, H. Grigorian and S. Typel, Acta Phys. Polon. Supp. 5, 535 (2012)

S. Weissenborn, D. Chatterjee, and J. Schaffner-Bielich, Phys. Rev. C 85, 065802 (2012)

had confirmed our observation quantitatively.

«the inclusion of the $\phi(1020)$ is vital»

Also,

- Three-body forces are important in nuclear matter at saturation density and may also play a role in the hyperon matter

Also,

- The popular “$\sigma\rho\omega\phi$” RMF model has a missing attractive part due to the SU(3) scalar meson σ^*

→ can easily be compensated by additional repulsion from vector WILBs

Also,

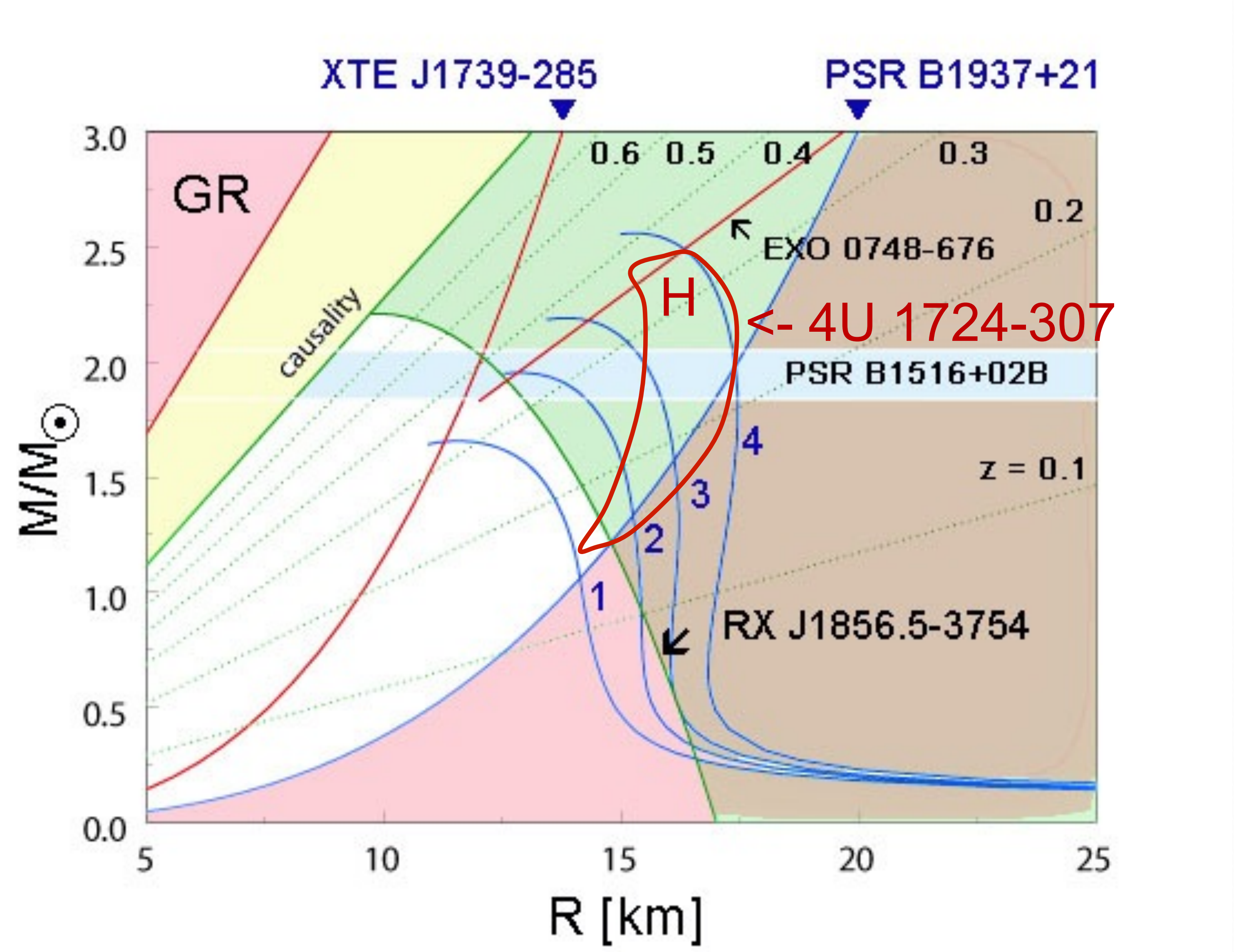
- The ratio $g_{\phi N}/g_{\omega N}$ of the coupling constants is determined from the electromagnetic nucleon form factors

Hohler et al., Nucl.Phys. B114, 505 (1976):

$$g_{\phi N}/g_{\omega N} \sim -0.5$$

→ within the $SU(3)_f$ symmetry scheme this ratio corresponds to the almost stiffest EoS of the hyperon matter

1. Missing contribution of new exotic particles – WILBs



	g^2/μ^2 [GeV^{-2}]
1	0
2	25
3	50
4	100

More on the neutron stars and WILBs:

- D.-H. Wen, B.-A. Li and L.-W. Chen, Phys. Rev. Lett. 103, 211102 (2009),
- A. Sulaksono, E. Marliana and A. Kasmudin, Mod. Phys. Lett. A26, 367 (2011).
- D.-R. Zhang et al., Phys. Rev. C83, 035801 (2011)
- H. Zheng and L.-W. Chen, Phys. Rev. D85, 043013 (2012)
- R. Chen et al., Phys. Rev. C85, 024305 (2012)
- W.-Z. Jiang, B.-A. Li, L.-W. Chen, Astrophys. J. 756, 56 (2012)

CONCLUSION

Stiff EOS of the β-equilibrated neutron star matter can
be attributed to:

WILBs coupled to the 2nd family of quarks with strength

$g^2/\mu^2 \sim 100\ \mathrm{GeV}^{-2}$

and Compton wavelengths 10 fm - 10 km

Possible manifestations of WILBs in astrophysics and in decays of strange hadrons to missing energy channels can shed more light on nature of