Exotic Baryons in (Hot) Neutron Stars

Kauan Dalfovo Marquez
marquezkauan@gmail.com

with the collaboration of
D. P. Menezes, L. L. Lopes, M. R. Pelicer and A. Issifu

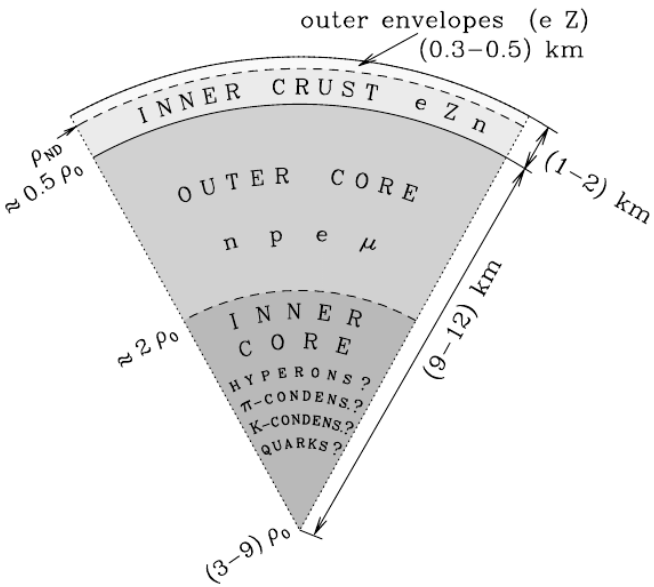
1 2 9 0

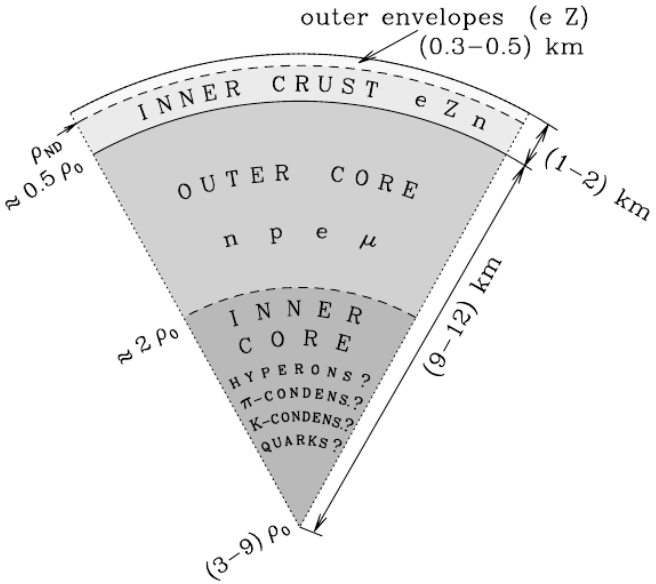
UNIVERSIDADE D COIMBRA

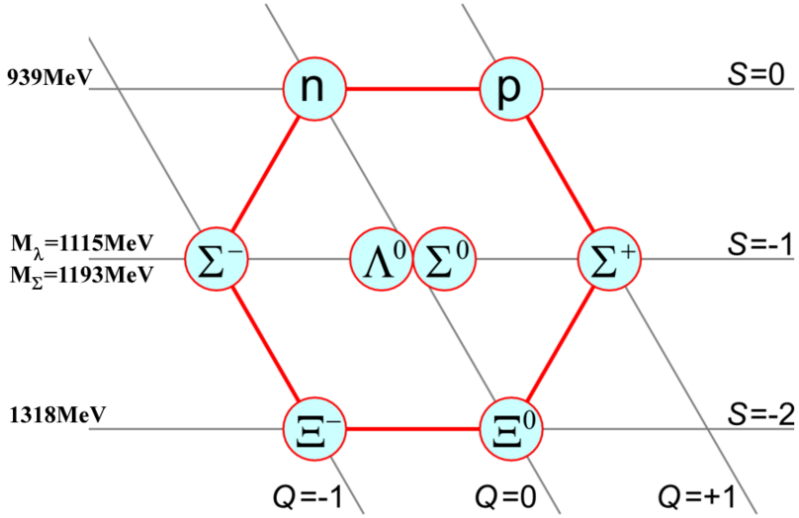
CFisUC PPGFSC CNPq INCT-FNA

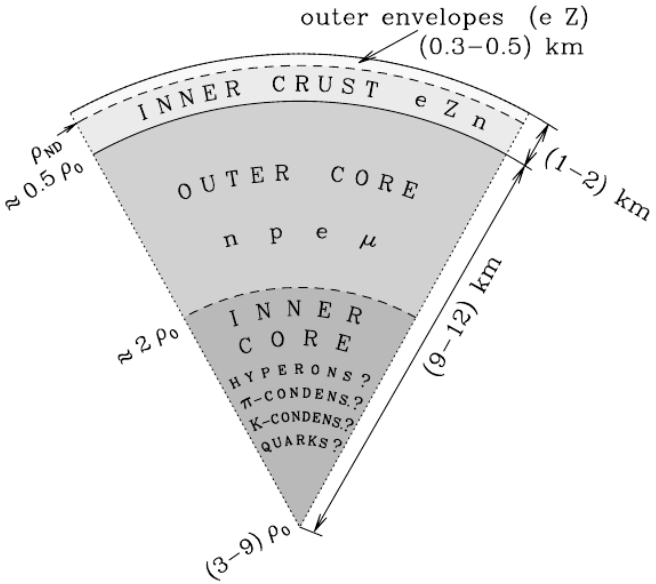
. **Walecka-type models and the baryon-meson coupling**
- Exotic baryons
- The Yukawa coupling
- SU(3) baryon-meson coupling scheme (vector part)
- SU(3) baryon-meson coupling scheme (scalar part)
- Some results

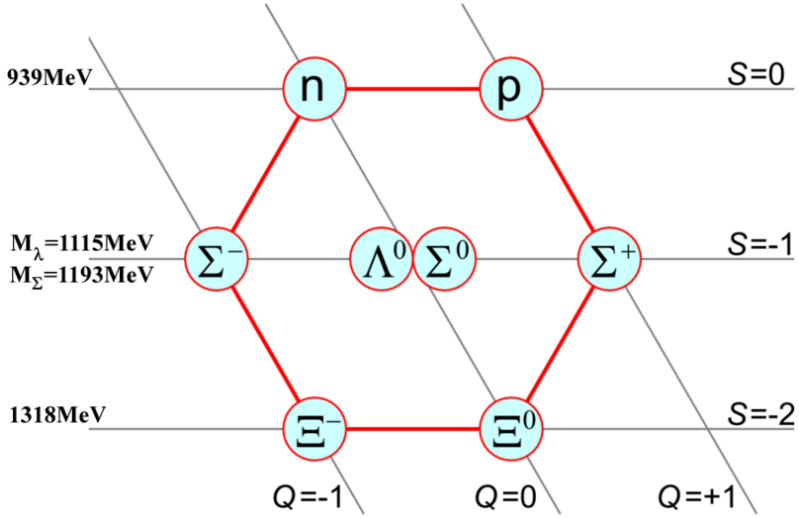
. **Deltas in hot neutron star matter**
- The equilibrium conditions
- Particle population and temperature profiles
- Mass-Radius diagrams

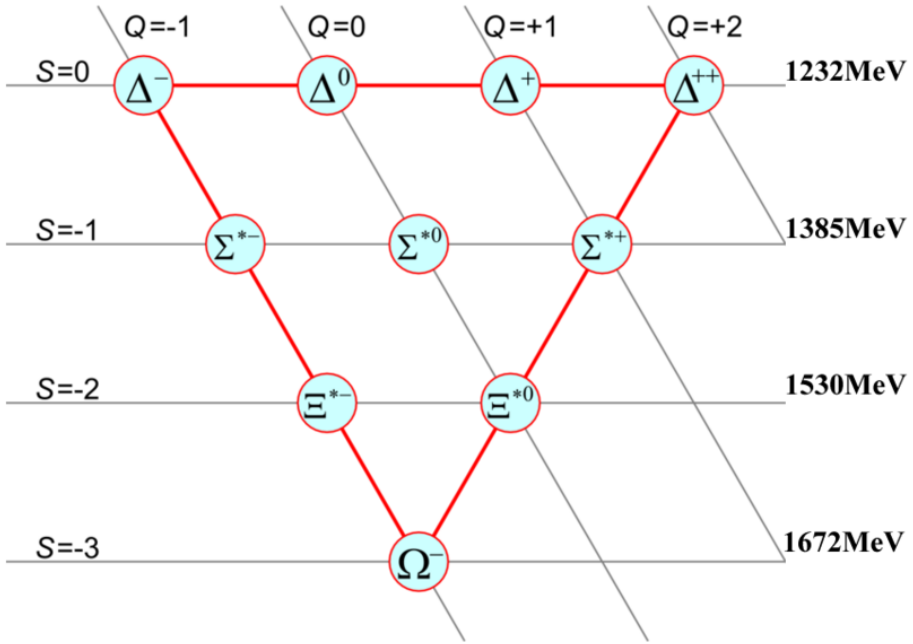

outer envelopes (e Z)
(0.3–0.5) km
INNER CRUST e Z n
ρ_{ND}
$\approx 0.5\,\rho_0$
OUTER CORE
n p e μ
(1–2) km
(9–12) km
$\approx 2\,\rho_0$
INNER CORE
HYPERONS ?
π–CONDENS.?
K–CONDENS.?
QUARKS ?
(3–9) ρ_0


outer envelopes (e Z)
(0.3–0.5) km
INNER CRUST e Z n
OUTER CORE
n p e μ
INNER CORE
HYPERONS ?
π–CONDENS.?
K–CONDENS.?
QUARKS ?
ρ_{ND}
≈ 0.5 ρ_0
≈ 2 ρ_0
(3–9) ρ_0
(1–2) km
(9–12) km


939MeV
n
p
S=0
M_λ=1115MeV
M_Σ=1193MeV
Σ^-
Λ^0
Σ^0
Σ^+
S=-1
1318MeV
Ξ^-
Ξ^0
S=-2
Q=-1
Q=0
Q=+1


outer envelopes (e Z)
(0.3–0.5) km
INNER CRUST e Z n
OUTER CORE
n p e μ
INNER CORE
HYPERONS ?
π–CONDENS.?
K–CONDENS.?
QUARKS ?
ρ_{ND}
≈ 0.5 ρ_0
≈ 2 ρ_0
(1–2) km
(9–12) km
(3–9) ρ_0


939MeV
n
p
S=0
M_λ=1115MeV
M_Σ=1193MeV
Σ^-
Λ^0
Σ^0
Σ^+
S=-1
1318MeV
Ξ^-
Ξ^0
S=-2
Q=-1
Q=0
Q=+1


Q=-1
Q=0
Q=+1
Q=+2
S=0
Δ^-
Δ^0
Δ^+
Δ^{++}
1232MeV
S=-1
Σ^{*-}
Σ^{*0}
Σ^{*+}
1385MeV
S=-2
Ξ^{*-}
Ξ^{*0}
1530MeV
S=-3
Ω^-
1672MeV

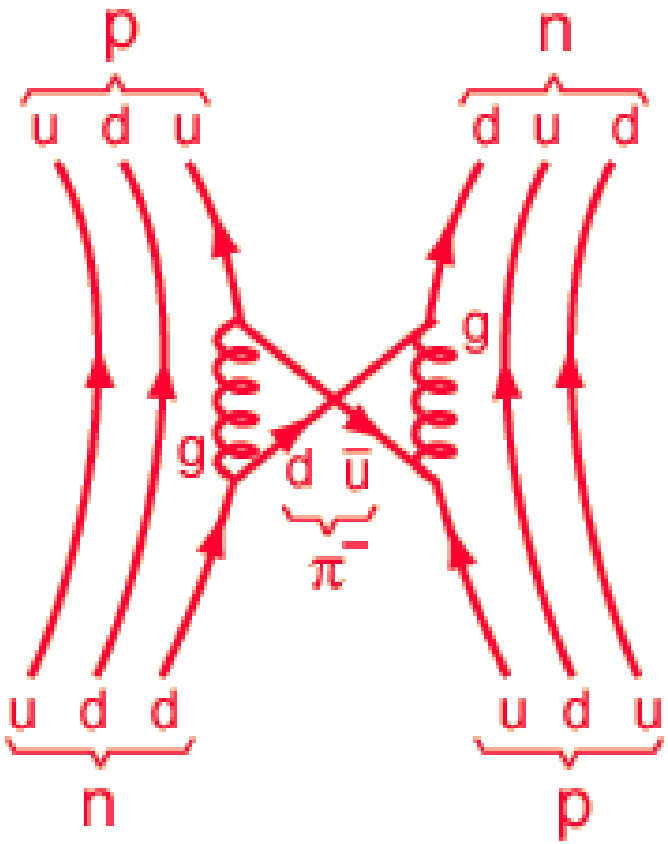


Figure: Feynman diagram representing the a proton-neutron scattering in terms of the QCD degrees of freedom.

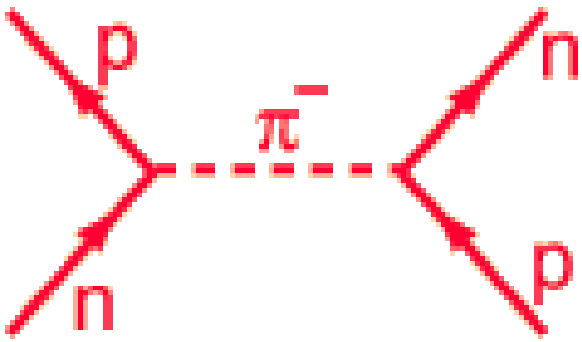


Figure: Feynman diagram representing the a proton-neutron scattering in terms of the hadronic degrees of freedom.

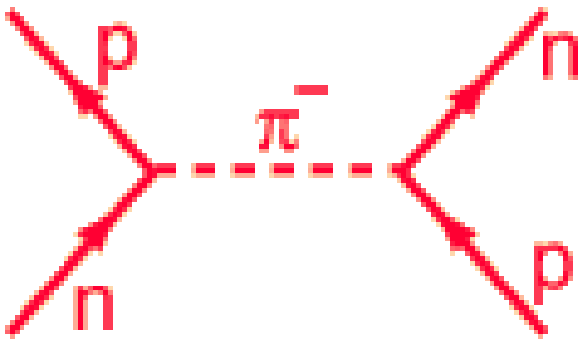


Figure: Feynman diagram representing the a proton-neutron scattering in terms of the hadronic degrees of freedom.

$$\mathcal{L}_{\text{Yukawa}} = -(g_{BM})(\bar{\psi}_B \psi_B) M, \quad (1)$$

where

- M is the field of an arbitrary (vector) meson: $\omega, \vec{\rho}, \phi$
- ψ_B is the field of the baryon B: p, n, *hyperons*, $\Delta, \cdots$
- g_{BM} is the Yukawa coupling constant of the baryon B with the meson M, given by

$$g_{BM} = \chi_{BM} g_{NB}.$$

- The Yukawa-type couplings are invariant under the flavor SU(3) symmetry group, and the relative coupling constants can be written in terms of only one free parameter α:

- ω meson:

$$\frac{g_{\Lambda\omega}}{g_{N\omega}} = \frac{4+2\alpha}{5+4\alpha}, \quad \frac{g_{\Sigma\omega}}{g_{N\omega}} = \frac{8-2\alpha}{5+4\alpha} \quad \frac{g_{\Xi\omega}}{g_{N\omega}} = \frac{5-2\alpha}{5+4\alpha},$$

$$\frac{g_{\Delta^*\omega}}{g_{N\omega}} = \frac{g_{\Delta\omega}}{g_{N\omega}} = \frac{9}{5+4\alpha}, \quad \frac{g_{\Sigma^*\omega}}{g_{N\omega}} = \frac{6}{5+4\alpha}, \quad \frac{g_{\Xi^*\omega}}{g_{N\omega}} = \frac{3}{5+4\alpha}, \quad \frac{g_{\Omega}}{g_{N\omega}} = 0,$$

- ϕ meson:

$$\frac{g_{\Lambda\phi}}{g_{N\omega}} = -\sqrt{2}\left(\frac{5-2\alpha}{5+4\alpha}\right), \quad \frac{g_{\Sigma\phi}}{g_{N\omega}} = -\sqrt{2}\left(\frac{1+2\alpha}{5+4\alpha}\right), \quad \frac{g_{\Xi\phi}}{g_{N\omega}} = -\sqrt{2}\left(\frac{4+2\alpha}{5+4\alpha}\right),$$

$$\frac{g_{\Sigma^*\phi}}{g_{N\omega}} = \frac{-3\sqrt{2}}{5+4\alpha}, \quad \frac{g_{\Xi^*\phi}}{g_{N\omega}} = \frac{-6\sqrt{2}}{5+4\alpha}, \quad \frac{g_{\Omega\phi}}{g_{N\omega}} = \frac{-9\sqrt{2}}{5+4\alpha},$$

- ρ meson:

$$\frac{g_{\Lambda\rho}}{g_{N\rho}} = 0, \quad \frac{g_{\Sigma\rho}}{g_{N,\rho}} = 2\alpha, \quad \frac{g_{\Xi\rho}}{g_{N\rho}} = -(1-2\alpha),$$

$$\frac{g_{\Delta^*\rho}}{g_{N\rho}} = 3, \quad \frac{g_{\Delta\rho}}{g_{N\rho}} = 1, \quad \frac{g_{\Sigma^*\rho}}{g_{N\rho}} = 2, \quad \frac{g_{\Xi^*\rho}}{g_{N\rho}} = 1, \quad \frac{g_{\Omega\rho}}{g_{N\rho}} = 0,$$

	α			
	1.00	0.75	0.50	0.25
$g_{\Lambda\omega}/g_{N\omega}$	0.667	0.687	0.714	0.75
$g_{\Sigma\omega}/g_{N\omega}$	0.667	0.812	1.0	1.25
$g_{\Xi\omega}/g_{N\omega}$	0.333	0.437	0.571	0.75
$g_{\Delta\omega}/g_{N\omega}$	1.0	1.125	1.285	1.5
$g_{\Delta^*\omega}/g_{N\omega}$	1.0	1.125	1.285	1.5
$g_{\Sigma^*\omega}/g_{N\omega}$	0.667	0.75	0.857	1.0
$g_{\Xi^*\omega}/g_{N\omega}$	0.333	0.375	0.428	0.667
$g_{\Omega\omega}/g_{N\omega}$	0.0	0.0	0.0	0.0
$g_{\Lambda\phi}/g_{N\omega}$	-0.471	-0.619	-0.808	-1.06
$g_{\Sigma\phi}/g_{N\omega}$	-0.471	-0.441	-0.404	-0.354
$g_{\Xi\phi}/g_{N\omega}$	-0.943	-0.972	-1.01	-1.06
$g_{\Sigma^*\phi}/g_{N\omega}$	-0.471	-0.530	-0.606	-0.707
$g_{\Xi^*\phi}/g_{N\omega}$	-0.943	-1.060	-1.212	-1.414
$g_{\Omega\phi}/g_{N\omega}$	-1.414	-1.590	-1.818	-2.212
$g_{\Lambda\rho}/g_{N\rho}$	0.0	0.0	0.0	0.0
$g_{\Sigma\rho}/g_{N\rho}$	2.0	1.5	1.0	0.5
$g_{\Xi\rho}/g_{N\rho}$	1.0	0.5	0.0	-0.5
$g_{\Delta\rho}/g_{N\rho}$	1.0	1.0	1.0	1.0
$g_{\Delta^*\rho}/g_{N\rho}$	3.0	3.0	3.0	3.0
$g_{\Sigma^*\rho}/g_{N\rho}$	2.0	2.0	2.0	2.0
$g_{\Xi^*\rho}/g_{N\rho}$	1.0	1.0	1.0	1.0
$g_{\Omega\rho}/g_{N\rho}$	0.0	0.0	0.0	0.0

	α			
	1.00	0.75	0.50	0.25
$g_{\Lambda\omega}/g_{N\omega}$	0.667	0.687	0.714	0.75
$g_{\Sigma\omega}/g_{N\omega}$	0.667	0.812	1.0	1.25
$g_{\Xi\omega}/g_{N\omega}$	0.333	0.437	0.571	0.75
$g_{\Delta\omega}/g_{N\omega}$	1.0	1.125	1.285	1.5
$g_{\Delta^*\omega}/g_{N\omega}$	1.0	1.125	1.285	1.5
$g_{\Sigma^*\omega}/g_{N\omega}$	0.667	0.75	0.857	1.0
$g_{\Xi^*\omega}/g_{N\omega}$	0.333	0.375	0.428	0.667
$g_{\Omega\omega}/g_{N\omega}$	0.0	0.0	0.0	0.0
$g_{\Lambda\phi}/g_{N\omega}$	-0.471	-0.619	-0.808	-1.06
$g_{\Sigma\phi}/g_{N\omega}$	-0.471	-0.441	-0.404	-0.354
$g_{\Xi\phi}/g_{N\omega}$	-0.943	-0.972	-1.01	-1.06
$g_{\Sigma^*\phi}/g_{N\omega}$	-0.471	-0.530	-0.606	-0.707
$g_{\Xi^*\phi}/g_{N\omega}$	-0.943	-1.060	-1.212	-1.414
$g_{\Omega\phi}/g_{N\omega}$	-1.414	-1.590	-1.818	-2.212
$g_{\Lambda\rho}/g_{N\rho}$	0.0	0.0	0.0	0.0
$g_{\Sigma\rho}/g_{N\rho}$	2.0	1.5	1.0	0.5
$g_{\Xi\rho}/g_{N\rho}$	1.0	0.5	0.0	-0.5
$g_{\Delta\rho}/g_{N\rho}$	1.0	1.0	1.0	1.0
$g_{\Delta^*\rho}/g_{N\rho}$	3.0	3.0	3.0	3.0
$g_{\Sigma^*\rho}/g_{N\rho}$	2.0	2.0	2.0	2.0
$g_{\Xi^*\rho}/g_{N\rho}$	1.0	1.0	1.0	1.0
$g_{\Omega\rho}/g_{N\rho}$	0.0	0.0	0.0	0.0

$$U_B(n_0) = g_{B\omega}\omega_0 - g_{B\sigma}\sigma_0$$

$$U_\Lambda = -28 \text{ MeV},$$
$$U_\Sigma = +30 \text{ MeV},$$
$$U_\Xi = -4 \text{ MeV},$$
$$U_\Delta = -98 \text{ MeV}$$

	α			
	1.00	0.75	0.50	0.25
$g_{\Lambda\omega}/g_{N\omega}$	0.667	0.687	0.714	0.75
$g_{\Sigma\omega}/g_{N\omega}$	0.667	0.812	1.0	1.25
$g_{\Xi\omega}/g_{N\omega}$	0.333	0.437	0.571	0.75
$g_{\Delta\omega}/g_{N\omega}$	1.0	1.125	1.285	1.5
$g_{\Delta^*\omega}/g_{N\omega}$	1.0	1.125	1.285	1.5
$g_{\Sigma^*\omega}/g_{N\omega}$	0.667	0.75	0.857	1.0
$g_{\Xi^*\omega}/g_{N\omega}$	0.333	0.375	0.428	0.667
$g_{\Omega\omega}/g_{N\omega}$	0.0	0.0	0.0	0.0
$g_{\Lambda\phi}/g_{N\omega}$	-0.471	-0.619	-0.808	-1.06
$g_{\Sigma\phi}/g_{N\omega}$	-0.471	-0.441	-0.404	-0.354
$g_{\Xi\phi}/g_{N\omega}$	-0.943	-0.972	-1.01	-1.06
$g_{\Sigma^*\phi}/g_{N\omega}$	-0.471	-0.530	-0.606	-0.707
$g_{\Xi^*\phi}/g_{N\omega}$	-0.943	-1.060	-1.212	-1.414
$g_{\Omega\phi}/g_{N\omega}$	-1.414	-1.590	-1.818	-2.212
$g_{\Lambda\rho}/g_{N\rho}$	0.0	0.0	0.0	0.0
$g_{\Sigma\rho}/g_{N\rho}$	2.0	1.5	1.0	0.5
$g_{\Xi\rho}/g_{N\rho}$	1.0	0.5	0.0	-0.5
$g_{\Delta\rho}/g_{N\rho}$	1.0	1.0	1.0	1.0
$g_{\Delta^*\rho}/g_{N\rho}$	3.0	3.0	3.0	3.0
$g_{\Sigma^*\rho}/g_{N\rho}$	2.0	2.0	2.0	2.0
$g_{\Xi^*\rho}/g_{N\rho}$	1.0	1.0	1.0	1.0
$g_{\Omega\rho}/g_{N\rho}$	0.0	0.0	0.0	0.0

$$U_B(n_0) = g_{B\omega}\omega_0 - g_{B\sigma}\sigma_0$$

$$U_\Lambda = -28 \text{ MeV},$$
$$U_\Sigma = +30 \text{ MeV},$$
$$U_\Xi = -4 \text{ MeV},$$
$$U_\Delta = -98 \text{ MeV}$$

	α			
	1.00	0.75	0.50	0.25
$g_{\Lambda\sigma}/g_{N\sigma}$	0.610	0.625	0.646	0.674
$g_{\Sigma\sigma}/g_{N\sigma}$	0.406	0.518	0.663	0.855
$g_{\Xi\sigma}/g_{N\sigma}$	0.269	0.350	0.453	0.590
$g_{\Delta\sigma}/g_{N\sigma}$	1.110	1.208	1.331	1.5
$g_{\Delta^*\sigma}/g_{N\sigma}$	1.110	1.208	1.331	1.5
$g_{\Sigma^*\sigma}/g_{N\sigma}$	?	?	?	?
$g_{\Xi^*\sigma}/g_{N\sigma}$	?	?	?	?
$g_{\Omega\sigma}/g_{N\sigma}$	?	?	?	?

L3$\omega\rho$

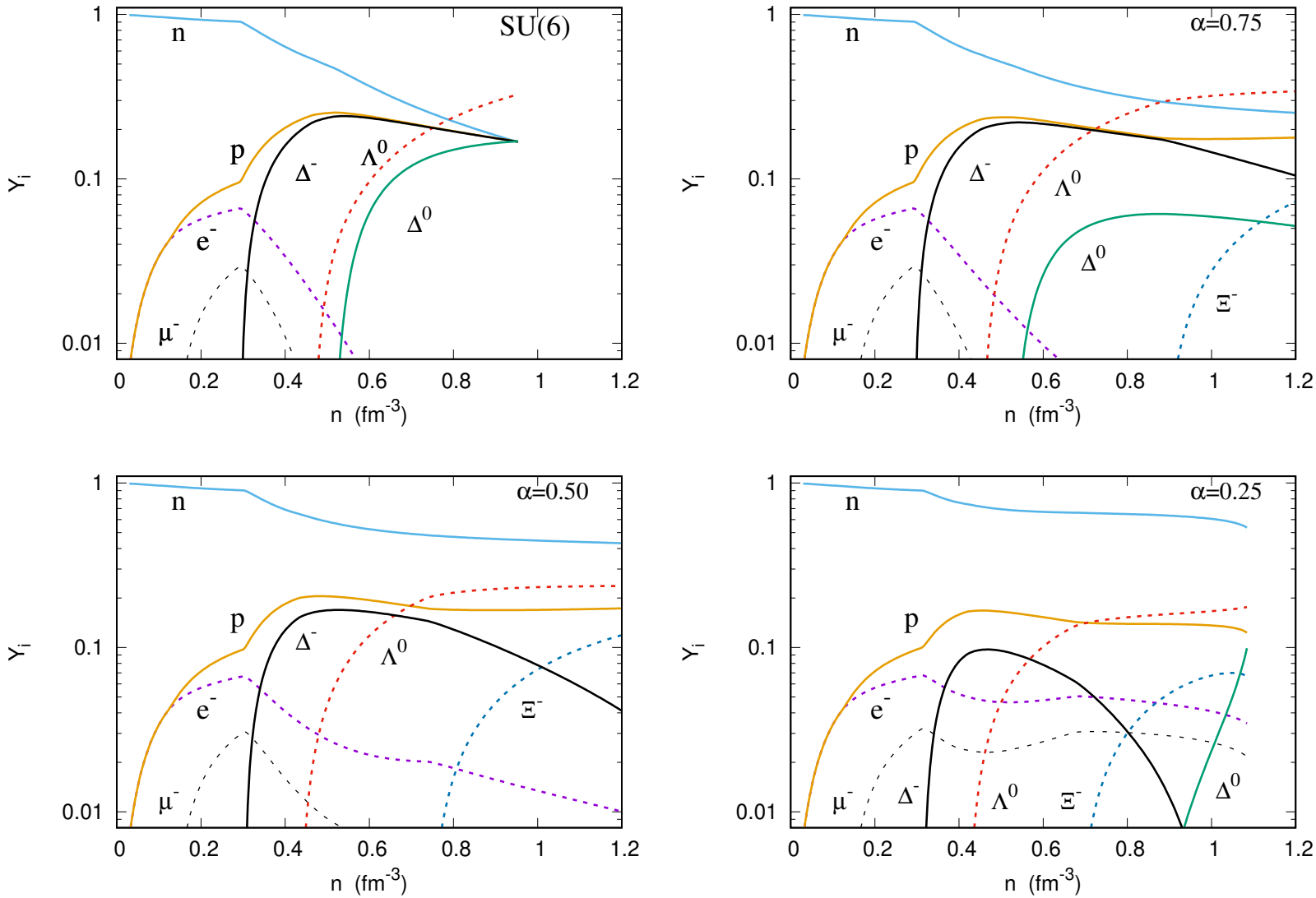
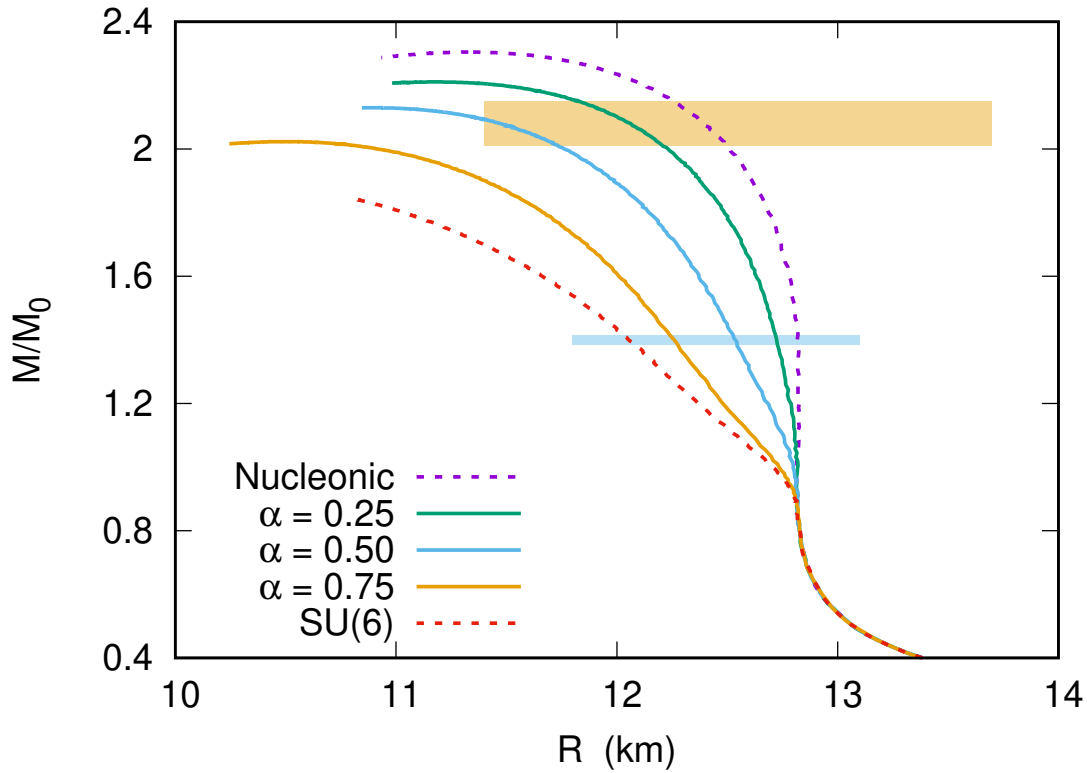


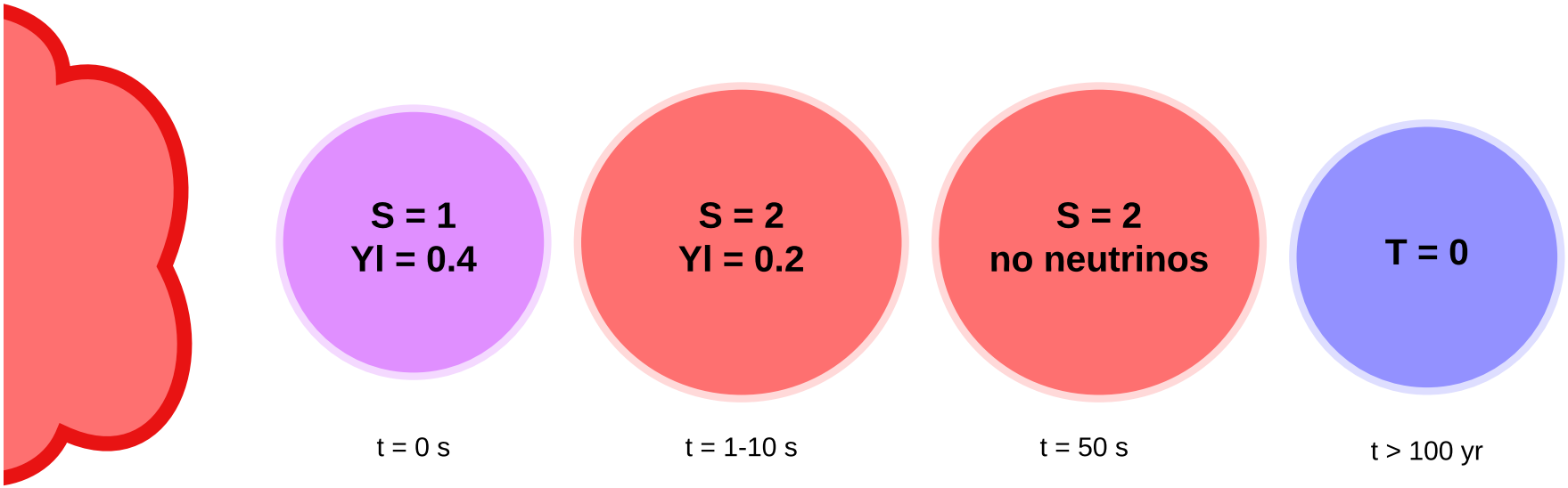
Figure: Particle population for different values of α for Δ-admixed hyperonic stellar matter.

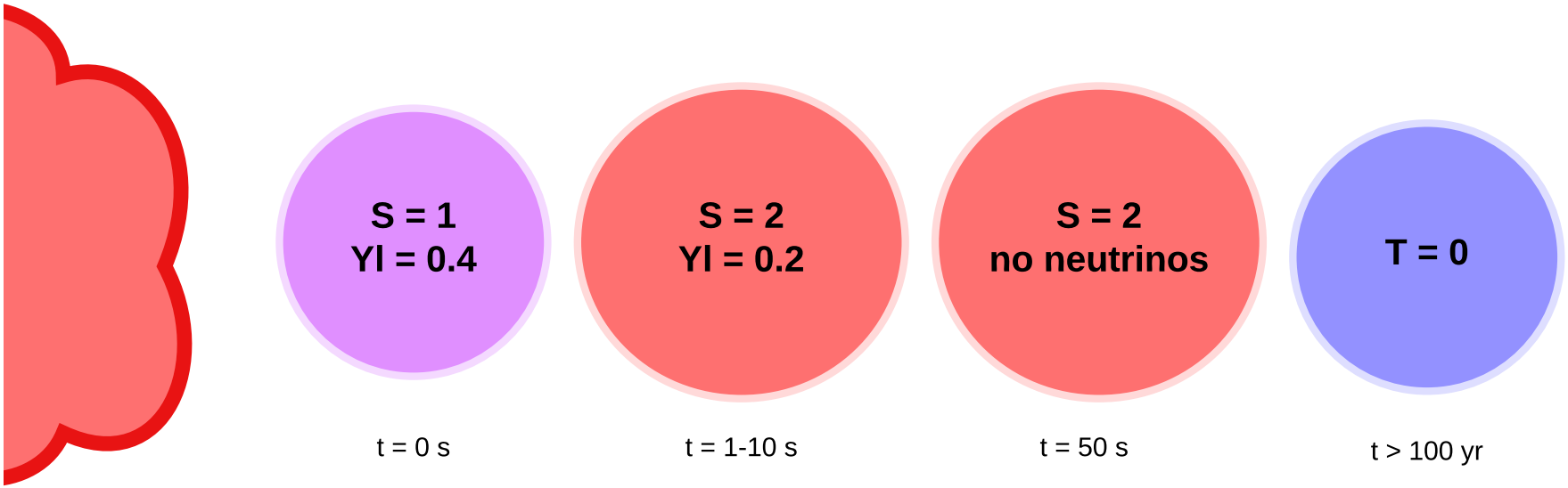
	α				
α_v	SU(6)	0.75	0.50	0.25	Nucl.
$M_{max}/M_\odot$	1.84*	2.02	2.13	2.21	2.30
n_c (fm^{-3})	0.95*	1.14	1.05	0.98	0.94
R (km)	10.81*	10.50	10.90	11.18	11.34
$R_{1.4}$ (km)	12.05	12.25	12.53	12.73	12.82
$\Lambda_{1.4}$	311	360	428	489	516



. **Walecka-type models and the baryon-meson coupling**
- Exotic baryons
- The Yukawa coupling
- SU(3) baryon-meson coupling scheme (vector part)
- SU(3) baryon-meson coupling scheme (scalar part)
- Some results

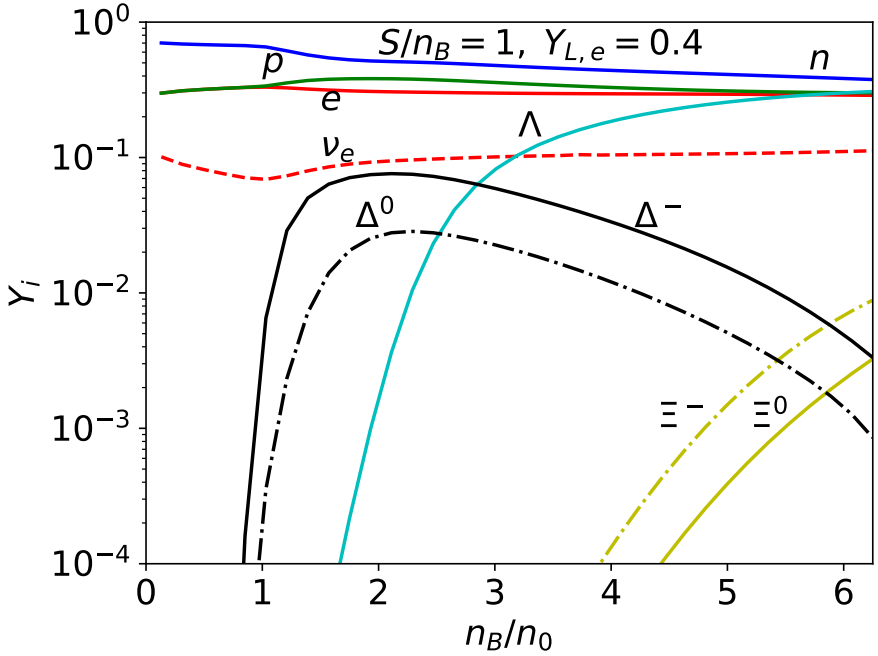
. **Deltas in hot neutron star matter**
- The equilibrium conditions
- Particle population and temperature profiles
- Mass-Radius diagrams

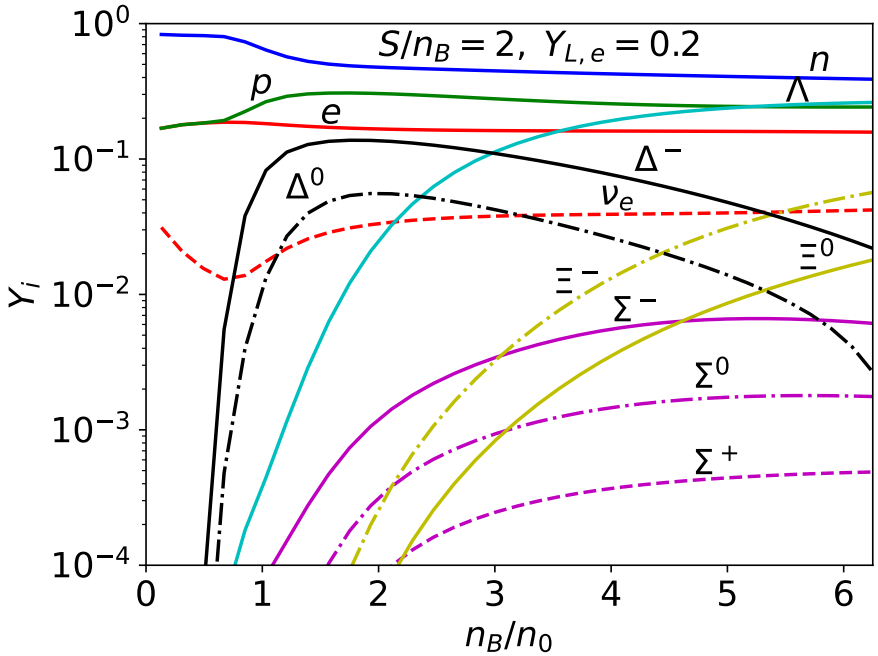

S = 1
Yl = 0.4
S = 2
Yl = 0.2
S = 2
no neutrinos
T = 0
t = 0 s
t = 1-10 s
t = 50 s
t > 100 yr

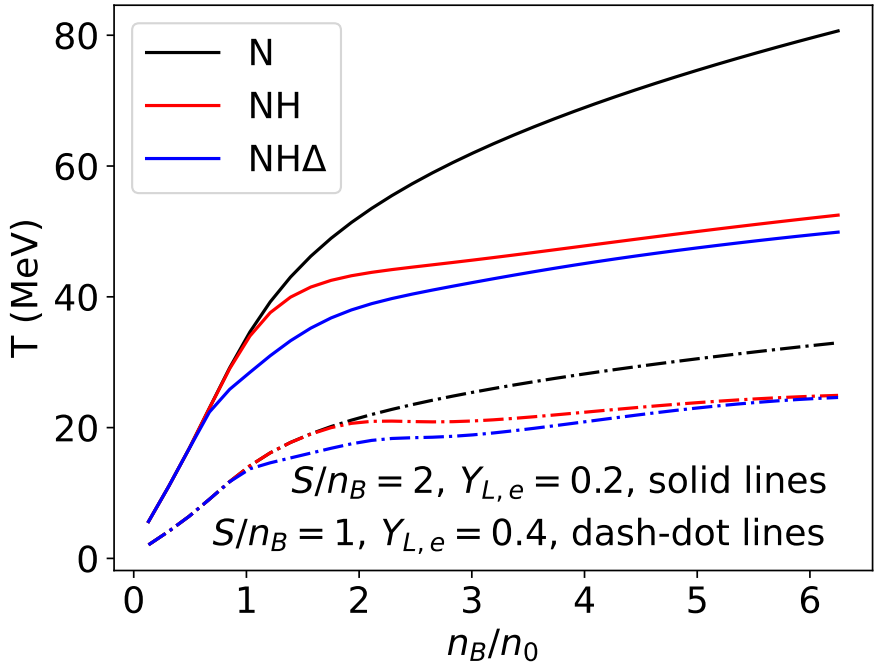


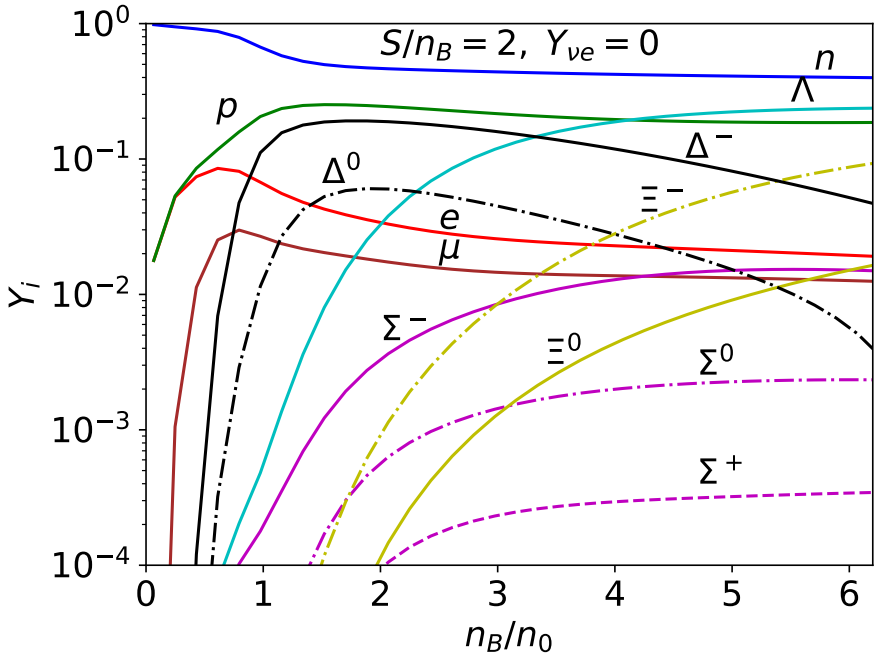
$$\mu_Q = \mu_{\nu l} - \mu_l \qquad \mu_Q = -\mu_l$$

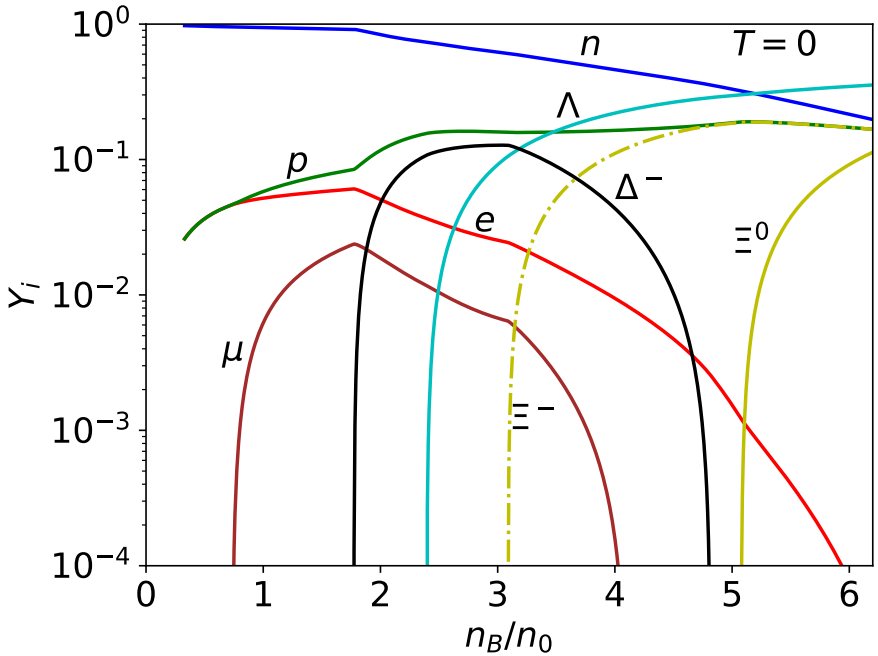
$$\begin{aligned}
\mu_\Lambda = \mu_{\Sigma^0} = \mu_{\Xi^0} = \mu_{\Delta^0} = \mu_n = \mu_B, \\
\mu_{\Sigma^-} = \mu_{\Xi^-} = \mu_{\Delta^-} = \mu_B - \mu_Q, \\
\mu_{\Sigma^+} = \mu_{\Delta^+} = \mu_p = \mu_B + \mu_Q, \\
\mu_{\Delta^{++}} = \mu_B + 2\mu_Q,
\end{aligned}$$

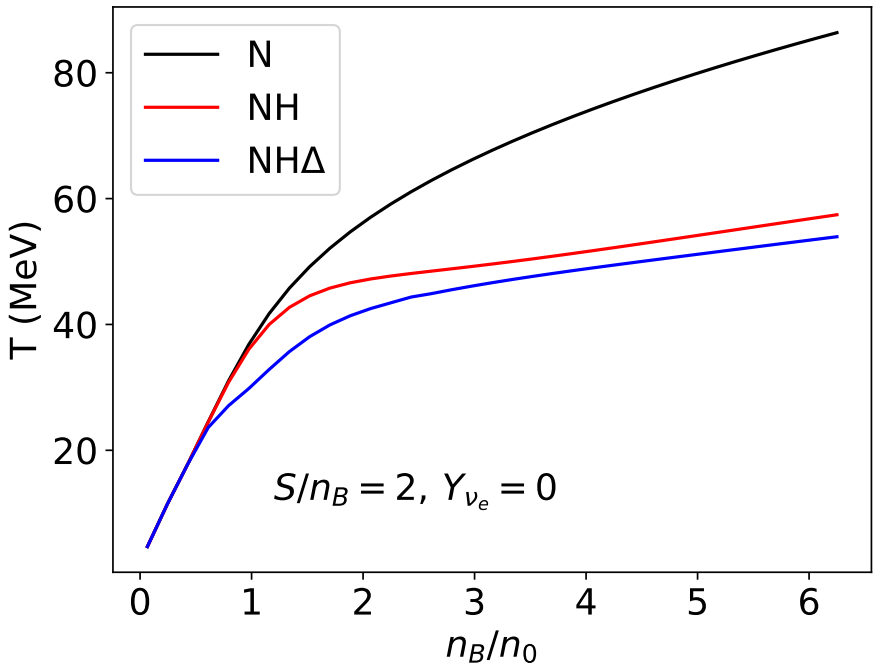

$S/n_B = 1,\ Y_{L,e} = 0.4$
p
n
e
Λ
ν_e
Δ^0
Δ^-
Ξ^-
Ξ^0
Y_i
n_B/n_0


$S/n_B = 2,\ Y_{L,e} = 0.2$
p
n
e
Λ
Δ^-
Δ^0
ν_e
Ξ^0
Ξ^-
Σ^-
Σ^0
Σ^+
Y_i
n_B/n_0

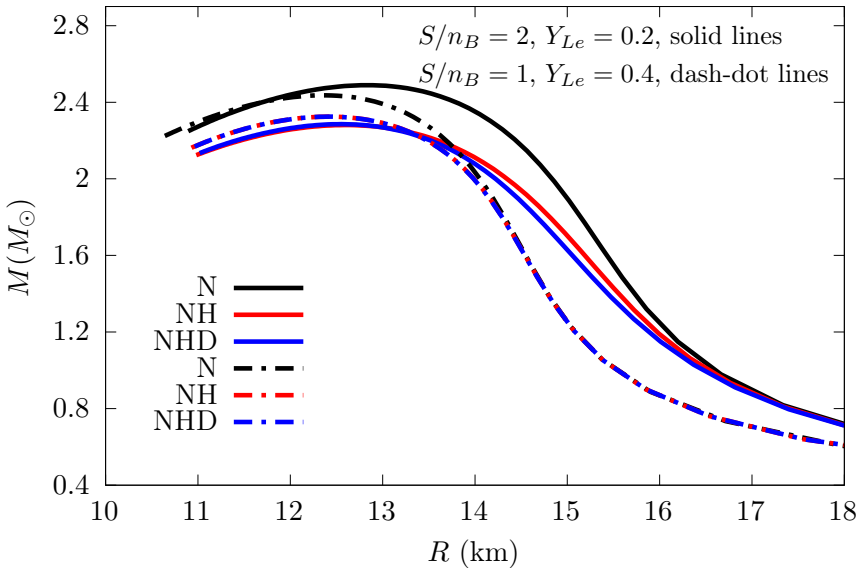

N
NH
NHΔ
$S/n_B = 2,\ Y_{L,e} = 0.2$, solid lines
$S/n_B = 1,\ Y_{L,e} = 0.4$, dash-dot lines
T (MeV)
n_B/n_0

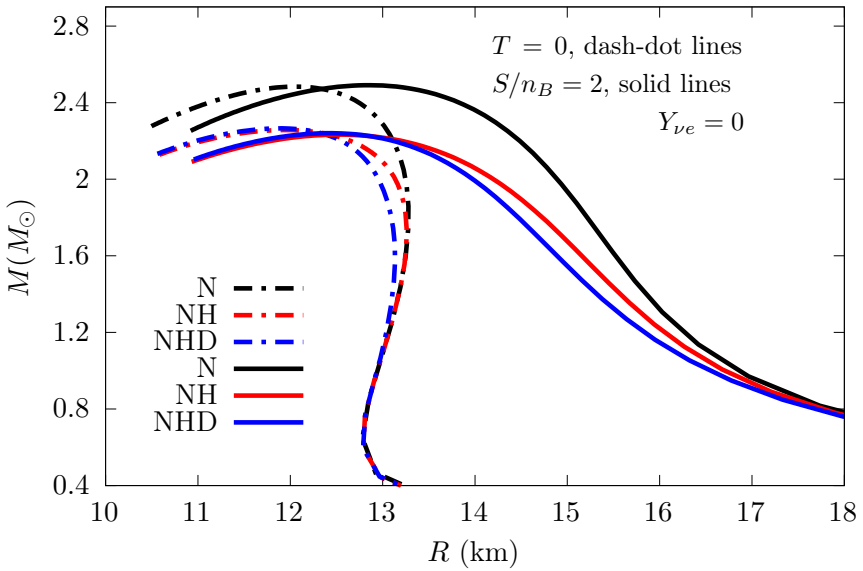

$S/n_B = 2,\ Y_{\nu e} = 0$
n
Λ
p
Δ^-
Δ^0
Ξ^-
e
μ
Σ^-
Ξ^0
Σ^0
Σ^+
Y_i
n_B/n_0


$T = 0$
n
Λ
p
Δ^-
e
Ξ^0
μ
Ξ^-
Y_i
n_B/n_0


N
NH
NHΔ
$S/n_B = 2,\ Y_{\nu_e} = 0$
T (MeV)
n_B/n_0

S/n_B; $Y_{L,e}$	Matter content	$M_{\max}/M_\odot$	R/km
1; 0.4	N	2.44	12.34
	NH	2.32	12.41
	$NH\Delta$	2.32	12.41
2; 0.2	N	2.49	12.83
	NH	2.29	12.59
	$NH\Delta$	2.29	12.56
2; $Y_{\nu e}=0$	N	2.49	12.87
	NH	2.24	12.51
	$NH\Delta$	2.24	12.41
$T=0$	N	2.48	12.03
	NH	2.26	11.96
	$NH\Delta$	2.26	11.91





- LOPES, Luiz L.; MARQUEZ, Kauan D.; MENEZES, Débora P. *Baryon coupling scheme in a unified SU (3) and SU (6) symmetry formalism*. **Physical Review D**, v. 107, n. 3, p. 036011, 2023. [arXiv:2211.17153]
- ISSIFU, Adamu; MARQUEZ, Kauan D.; PELICER, Mateus R.; MENEZES, Débora P. *Exotic baryons in hot neutron stars*. **Monthly Notices of the Royal Astronomical Society**, v. 522, n. 3, p. 3263-3270, 2023. [arXiv:2302.04364]

- LOPES, Luiz L.; MARQUEZ, Kauan D.; MENEZES, Débora P. *Baryon coupling scheme in a unified SU (3) and SU (6) symmetry formalism*. **Physical Review D**, v. 107, n. 3, p. 036011, 2023. [arXiv:2211.17153]
- ISSIFU, Adamu; MARQUEZ, Kauan D.; PELICER, Mateus R.; MENEZES, Débora P. *Exotic baryons in hot neutron stars*. **Monthly Notices of the Royal Astronomical Society**, v. 522, n. 3, p. 3263-3270, 2023. [arXiv:2302.04364]

avaliable @ livrariadafisica.com.br

- LOPES, Luiz L.; MARQUEZ, Kauan D.; MENEZES, Débora P. *Baryon coupling scheme in a unified SU (3) and SU (6) symmetry formalism*. **Physical Review D**, v. 107, n. 3, p. 036011, 2023. [arXiv:2211.17153]
- ISSIFU, Adamu; MARQUEZ, Kauan D.; PELICER, Mateus R.; MENEZES, Débora P. *Exotic baryons in hot neutron stars*. **Monthly Notices of the Royal Astronomical Society**, v. 522, n. 3, p. 3263-3270, 2023. [arXiv:2302.04364]

avaliable @ livrariadafisica.com.br

Muito Obrigado!

Kauan Dalfovo Marquez
marquezkauan@gmail.com

Exotic Baryons in (Hot) Neutron Stars

Kauan Dalfovo Marquez
marquezkauan@gmail.com

with the collaboration of
D. P. Menezes, L. L. Lopes, M. R. Pelicer and A. Issifu

1 2 9 0

UNIVERSIDADE D COIMBRA

CFisUC PPGFSC CNPq INCT-FNA