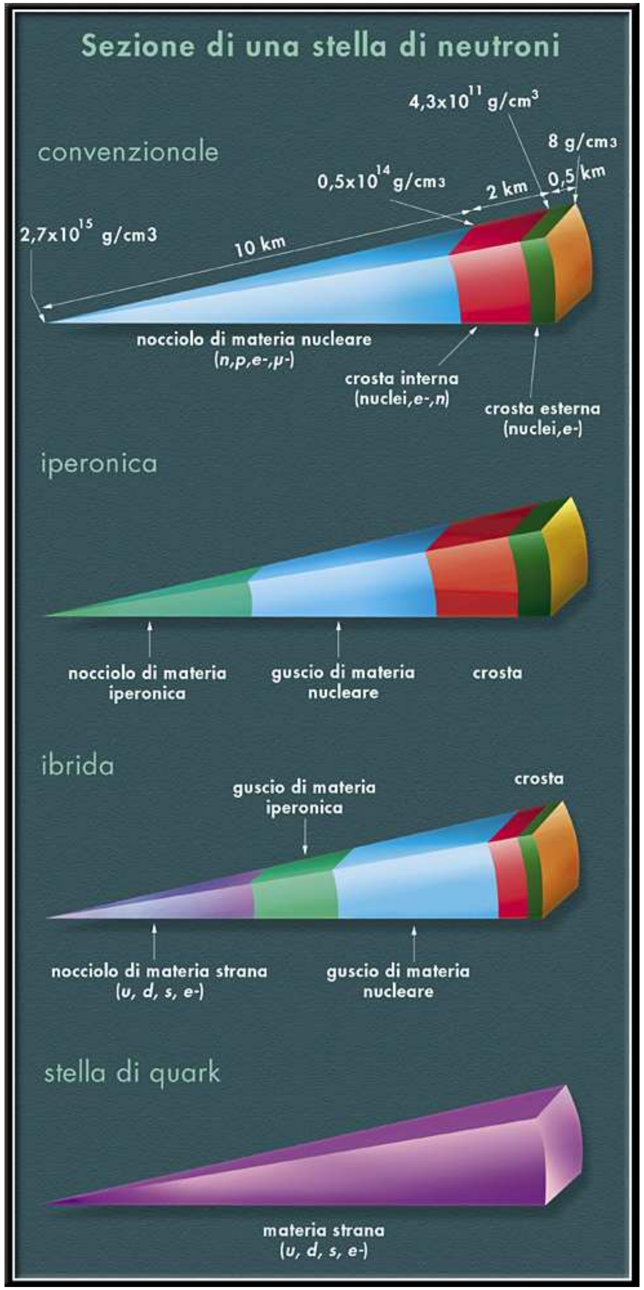
Role of Hyperons on the Hadron Star to Quark Star Conversion Model

I. Bombaci, I. Parenti and I. Vidaña

IN SUPREMÆ DIGNITATIS 1343

INFN Istituto Nazionale di Fisica Nucleare



Compact Objects

Hadronic Stars (HS)

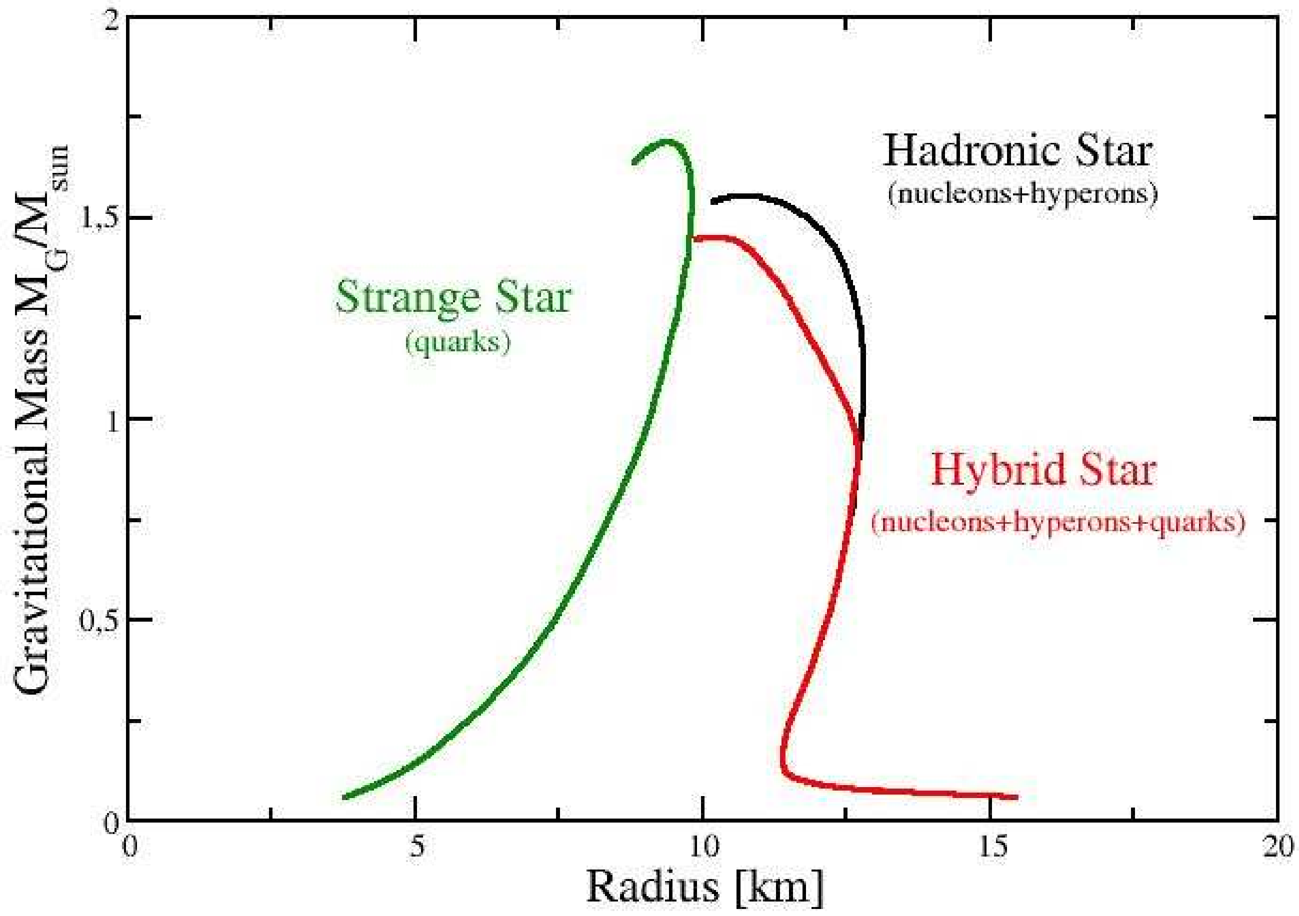
- Traditional NS

- Hyperonic Stars

Hybrid Stars (HyS)

Quark Stars

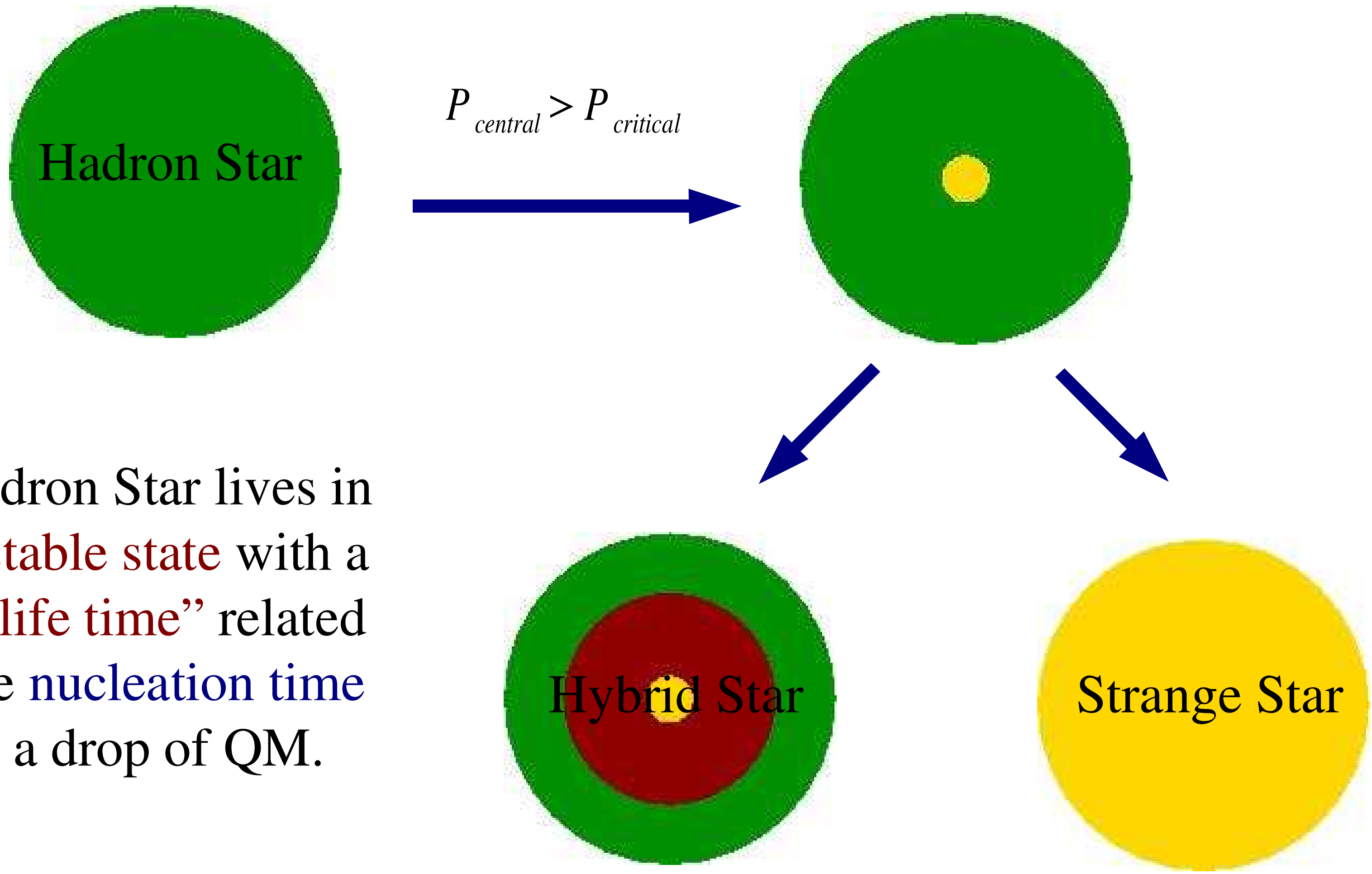
Strange Stars (SS)


Gravitational Mass M_G/M_{sun}
Radius [km]
Hadronic Star
(nucleons+hyperons)
Strange Star
(quarks)
Hybrid Star
(nucleons+hyperons+quarks)
0
0,5
1
1,5
2
0
5
10
15
20

Scenario for HS to HyS(SS) conversion

Central Pressure increase due to
spin down or mass accretion

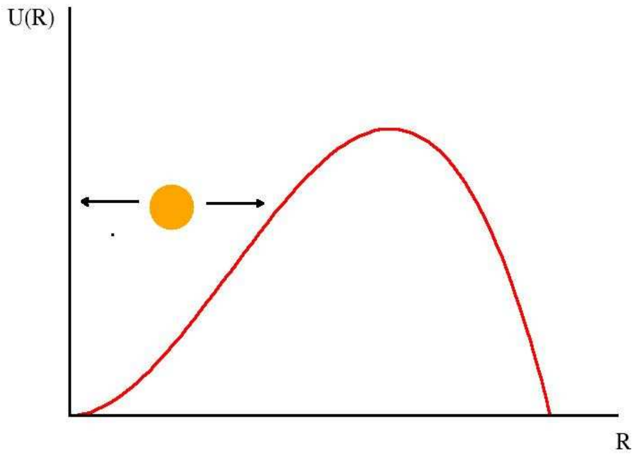
Formation of drop of QM



The Hadron Star lives in a metastable state with a "mean-life time" related with the nucleation time to form a drop of QM.

QM drop formation

A virtual QM drop moves back and forth in the potential well separating the two phases on a time τ set by the strong interaction

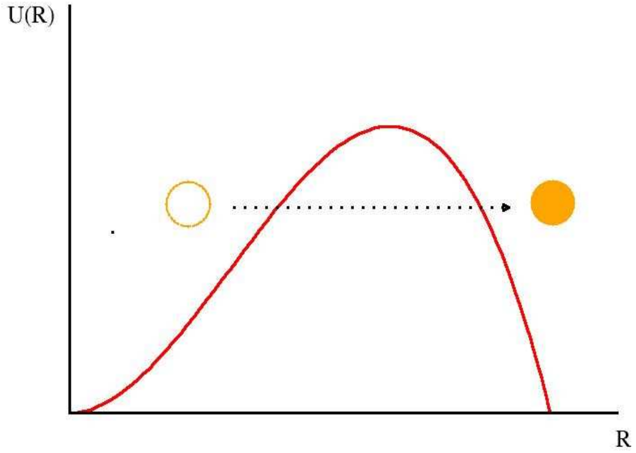


Quark flavor conserved during deconfinement

Equal to that of β-stable hadronic system at the static transition point

$$\begin{pmatrix} x_u \\ x_d \\ x_s \end{pmatrix} = \begin{pmatrix} 2 & 1 & 1 & 2 & 1 & 0 & 1 & 0 \\ 1 & 2 & 1 & 0 & 1 & 2 & 0 & 1 \\ 0 & 0 & 1 & 1 & 1 & 1 & 2 & 2 \end{pmatrix} \begin{pmatrix} x_p \\ x_n \\ x_\Lambda \\ x_{\Sigma^+} \\ x_{\Sigma^0} \\ x_{\Sigma^-} \\ x_{\Xi^0} \\ x_{\Xi^-} \end{pmatrix}$$

After a time τ the virtual QM drop tunnels the potential well becoming a real QM drop



$$d \rightarrow u + e^- + \bar{\nu}_e$$

$$u + e^- \rightarrow d + \nu_e$$

$$s \rightarrow u + e^- + \bar{\nu}_e$$

$$u + e^- \rightarrow s + \nu_e$$

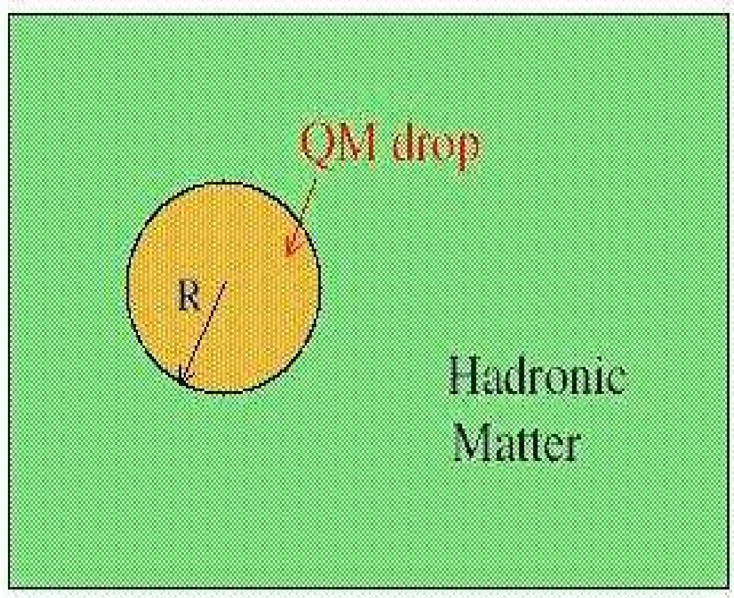
Weak interactions acts changing the quark flavor fraction of deconfined QM drop to lower its energy and a drop of β-stable SQM is formed

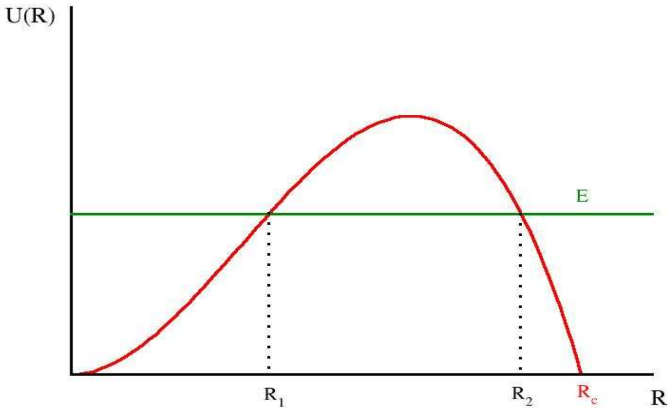
Lifshitz-Kagan quantum nucleation theory

Quantum fluctuation of a virtual drop of QM in HM

$$L = -M(R)\sqrt{1-\left(\frac{dR}{dt}\right)^2} + M(R) - U(R)$$

$$M(R) = 4\pi\rho_H\left(1-\frac{n_Q}{n_H}\right)^2 R^3$$





$$U(R) = \frac{4}{3}\pi n_Q\left(\mu_Q - \mu_H\right)R^3 + 4\pi\sigma R^2$$

$$\sigma \sim 10 - 50\ MeV/fm^2$$

Nucleation Time

Oscillation frequency of the virtual drop inside the potential well and Penetrability of the potential barrier (WKB)

$$\nu_0 = \left(\frac{dI}{dE} \right)^{-1} \quad at\ E = E_0$$

$$p_0 = \exp\left[-\frac{A(E_0)}{\hbar} \right]$$

$$I(E) = 2 \int_0^{R_1} dR \sqrt{[2M(R) + E - U(R)][E - U(R)]}$$

$$A(E) = 2 \int_{R_1}^{R_2} dR \sqrt{[2M(R) + E - U(R)][U(R) - E]}$$

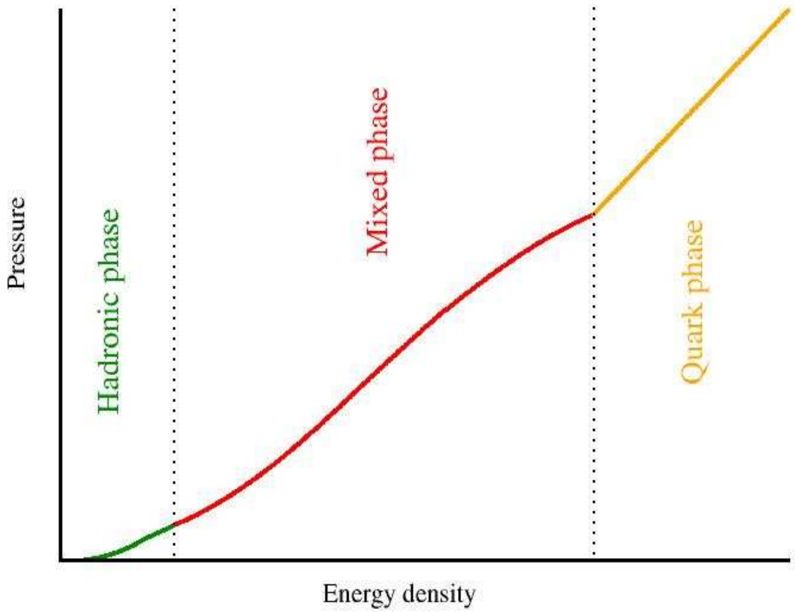
Action over and under the barrier

Nucleation time $\tau = (\nu_0 p_0 N_c)^{-1} \quad , \quad N_c \sim 10^{48}$

The EoS of dense matter

GM1: K=300 MeV, $m^*/m=0.7$
GM3: K=240 MeV, $m^*/m=0.78$

B/A=-16.3 MeV, ρ=0.153
a_{sym}=32.5 MeV



Hadronic phase: Relativistic Mean Field Theory of hadrons interacting meson exchange. [Glendenning & Moszkowsky, Phys. Rev. Lett. 67 (1991)]

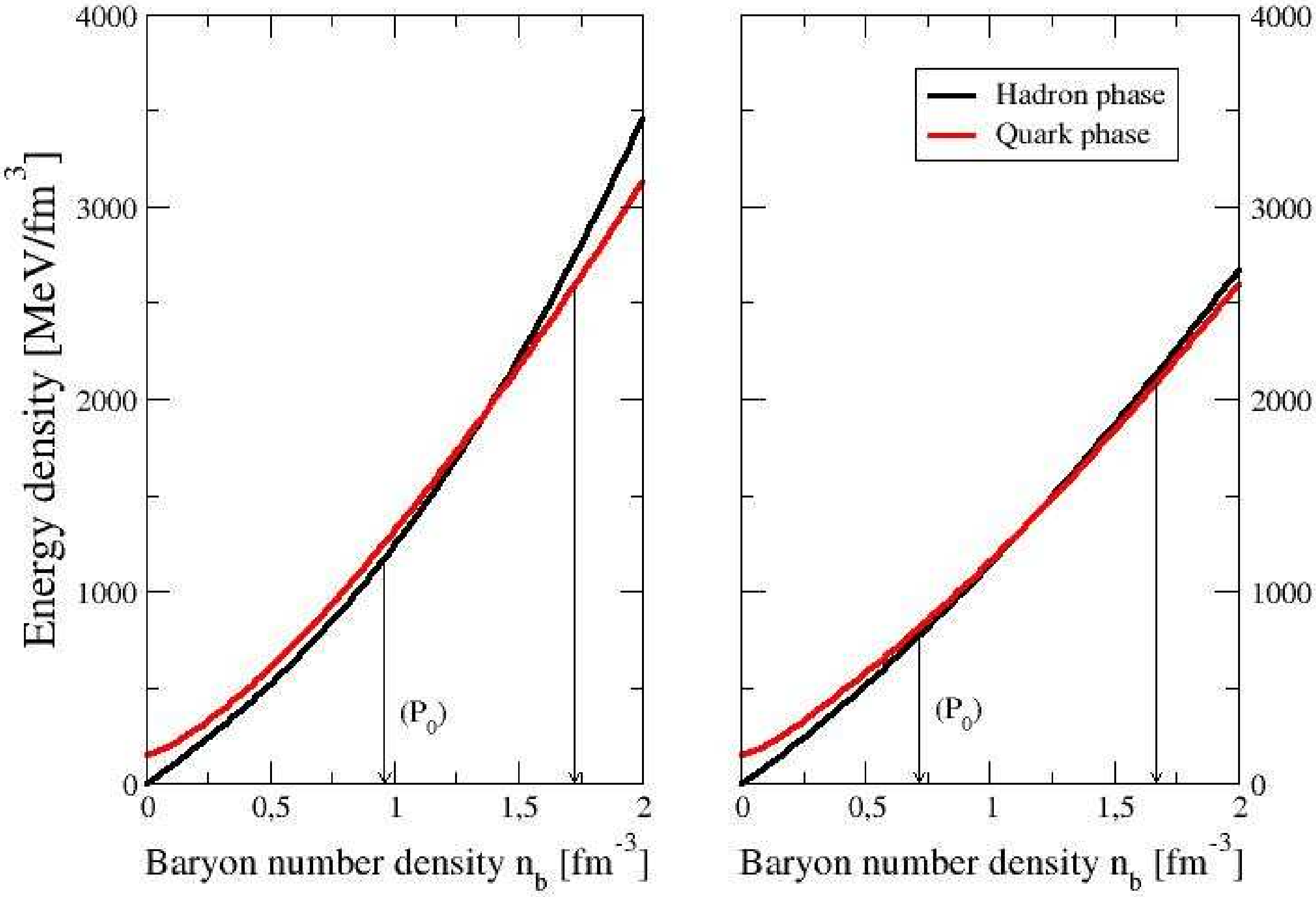
Mixed phase: Gibbs construction for a multicomponent system with two conserved "charges". [Glendenning, Phys. Rev. D 46 (1992)]

Quark phase: EoS based on the MIT Bag Model for hadrons. [Farhi & Jaffe, Phys. Rev. D 46 (1992)]

The Equation of State

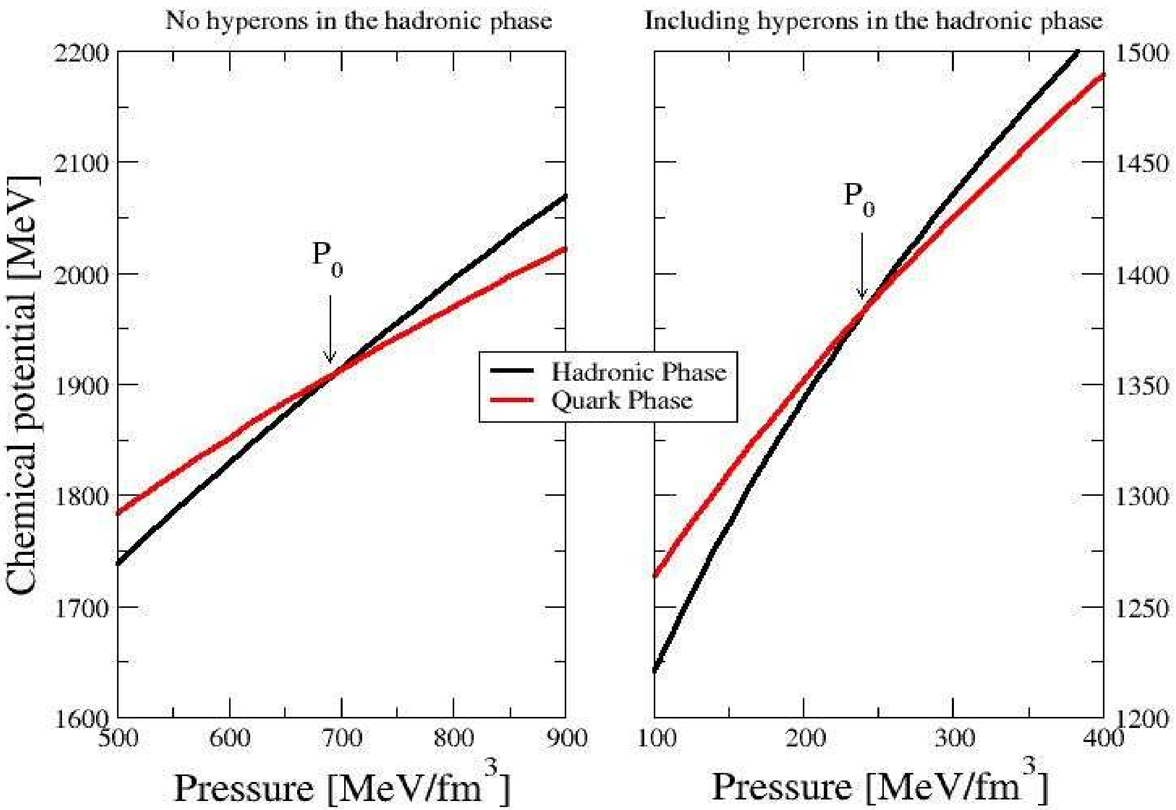
Without hyperons

With hyperons



Chemical potentials

Without hyperons — With hyperons

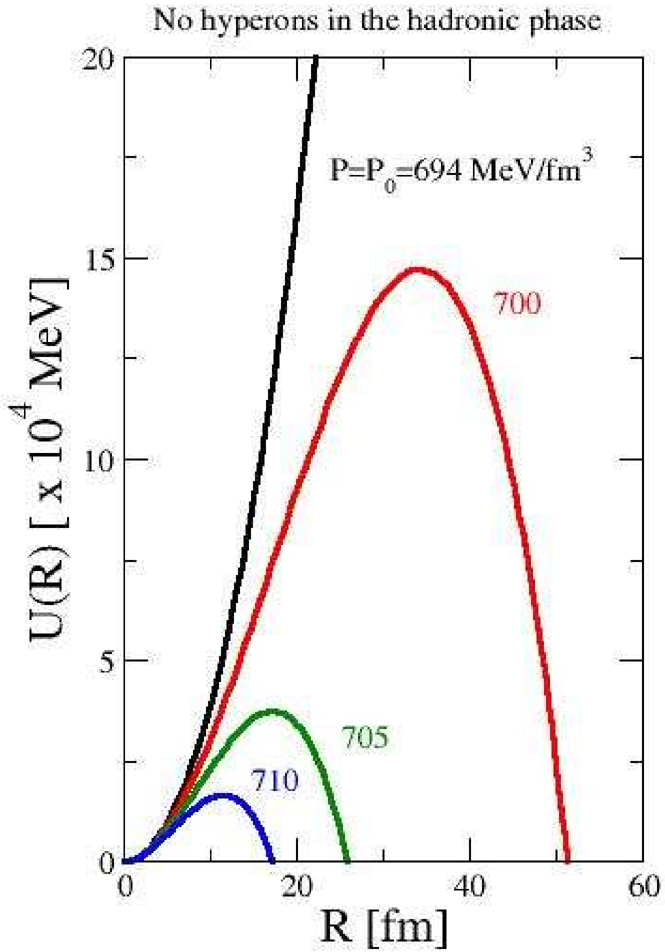


$$\mu_H = \mu_Q \equiv \mu_0 \quad , \quad P_H(\mu_0) = P_Q(\mu_0) \equiv P_0$$

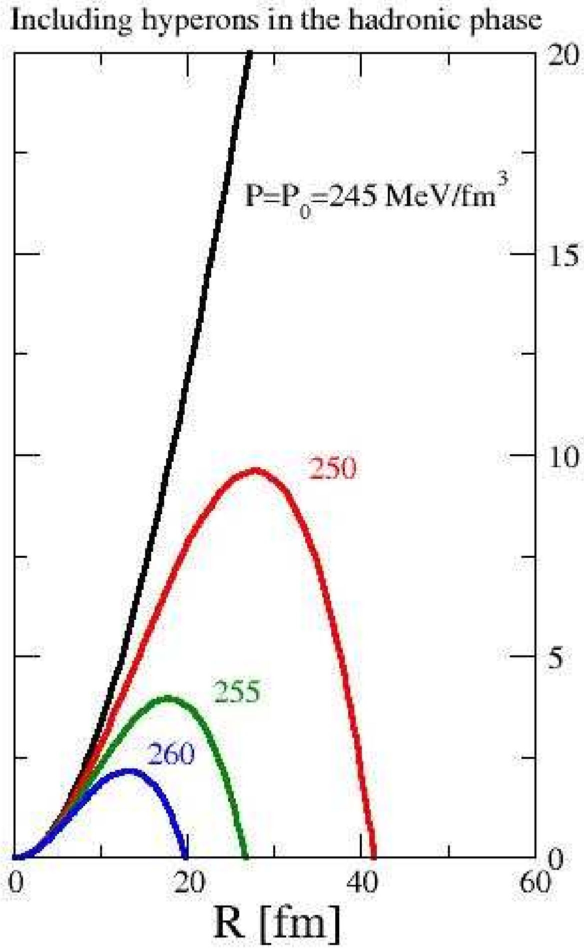
$$\mu_H = \frac{\epsilon_H + P_H}{n_H} \quad , \quad \mu_Q = \frac{\epsilon_Q + P_Q}{n_Q}$$

Potential barrier

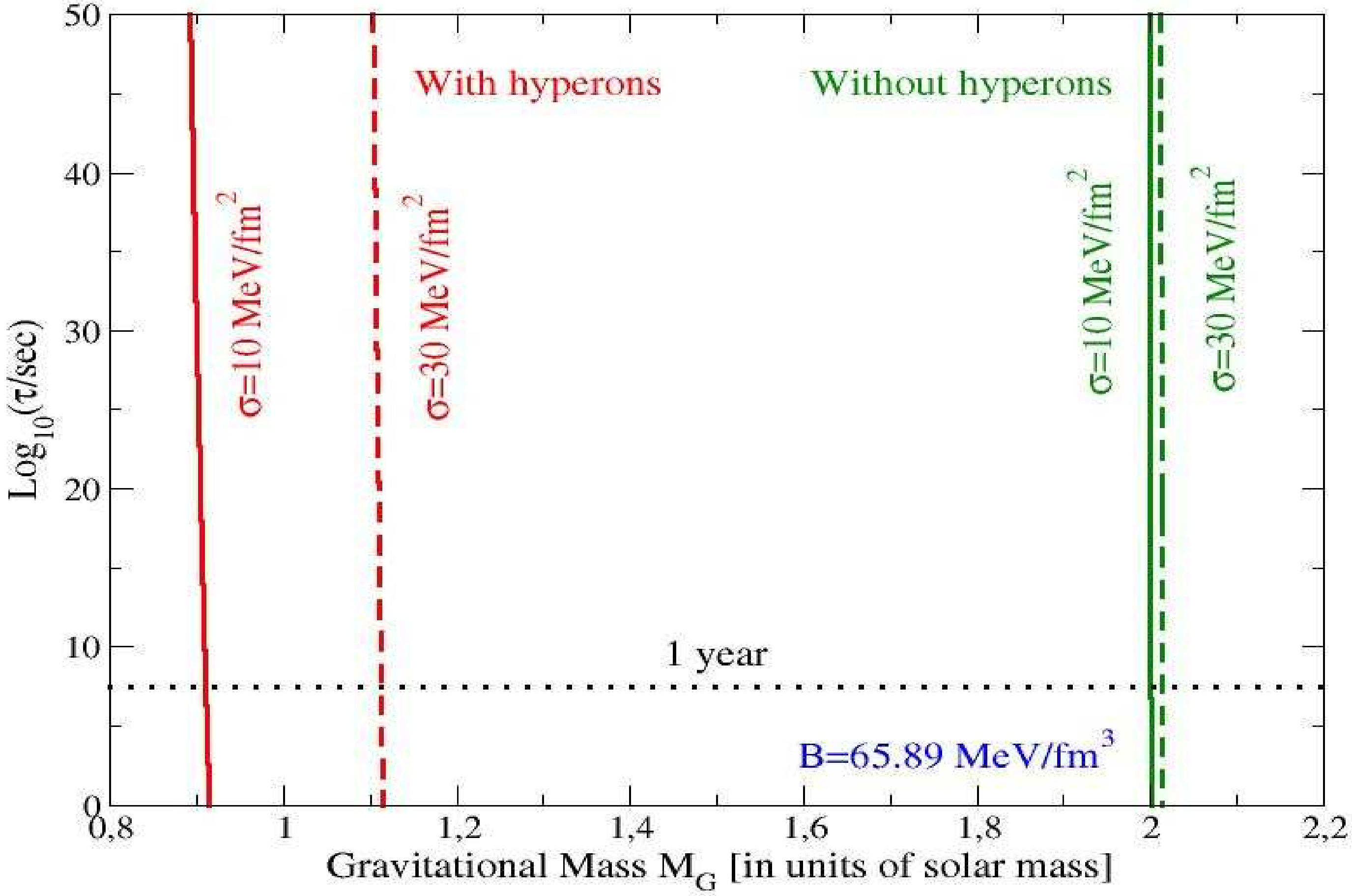
Without hyperons



With hyperons



Hadronic Star mean-life time

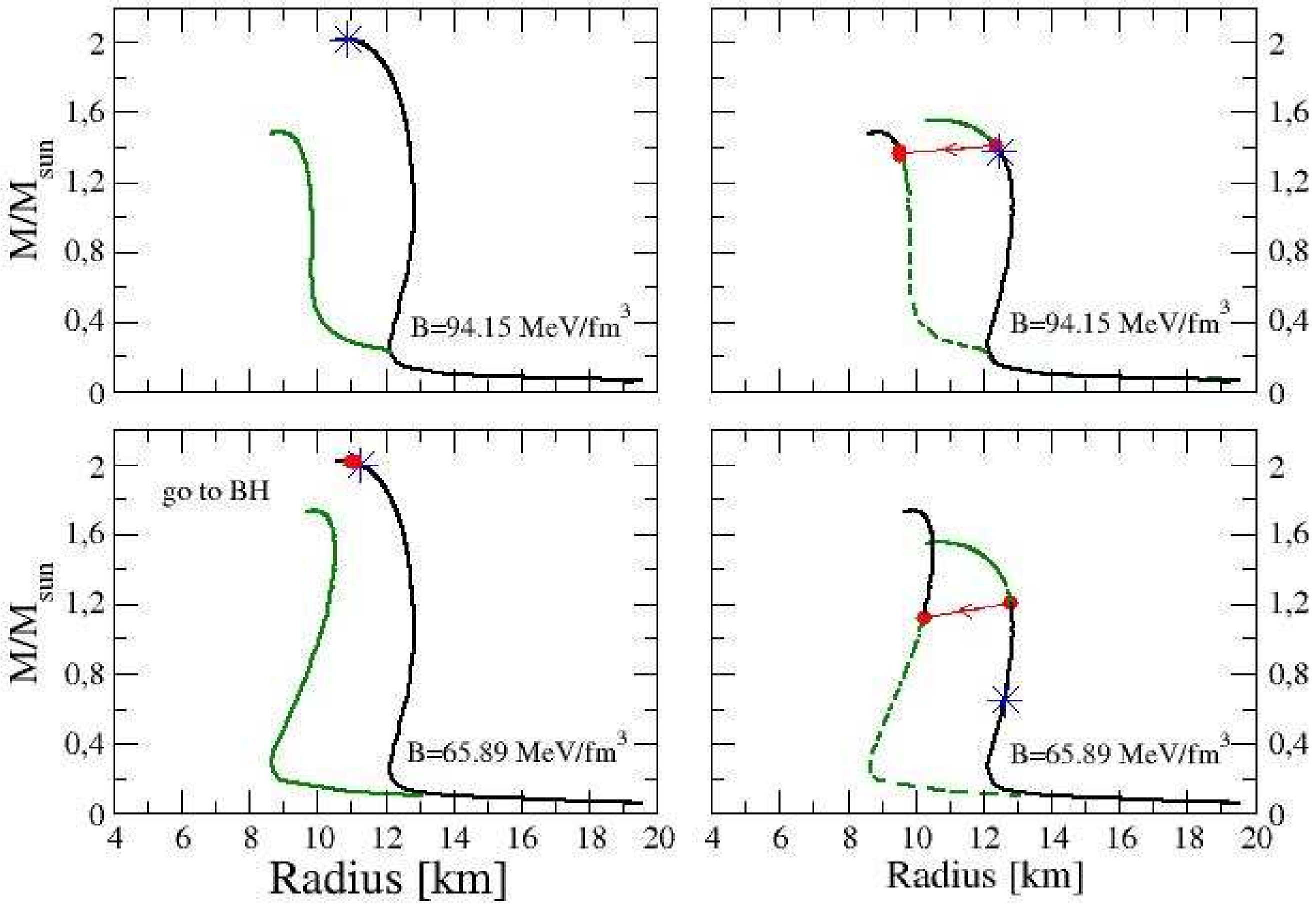


The increase of less than $0.01\ M_{sun}$ reduces τ from

$\tau >>$ age universe to a τ of few years

Conversion of a HS into a HyS(SS)

Without hyperons   With hyperons



Summary and Conclusions

I-. Existence of two different families of compact objects: Hadronic Stars and Hybrid or Strange Stars.

II-. Hadronic Stars are metastable to “decay” to Hybrid Stars or to Strange Stars. The HS mean-life time range within $\tau \gg$ age of the universe to few years (days) and depends dramatically on the central pressure.

III-. The conversion mechanism is favoured by the presence of hyperons.