General relativistic Mass twin stars and their astrophysical aspects

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Based on: **arXiv:1906.02522 [astro-ph.HE]**

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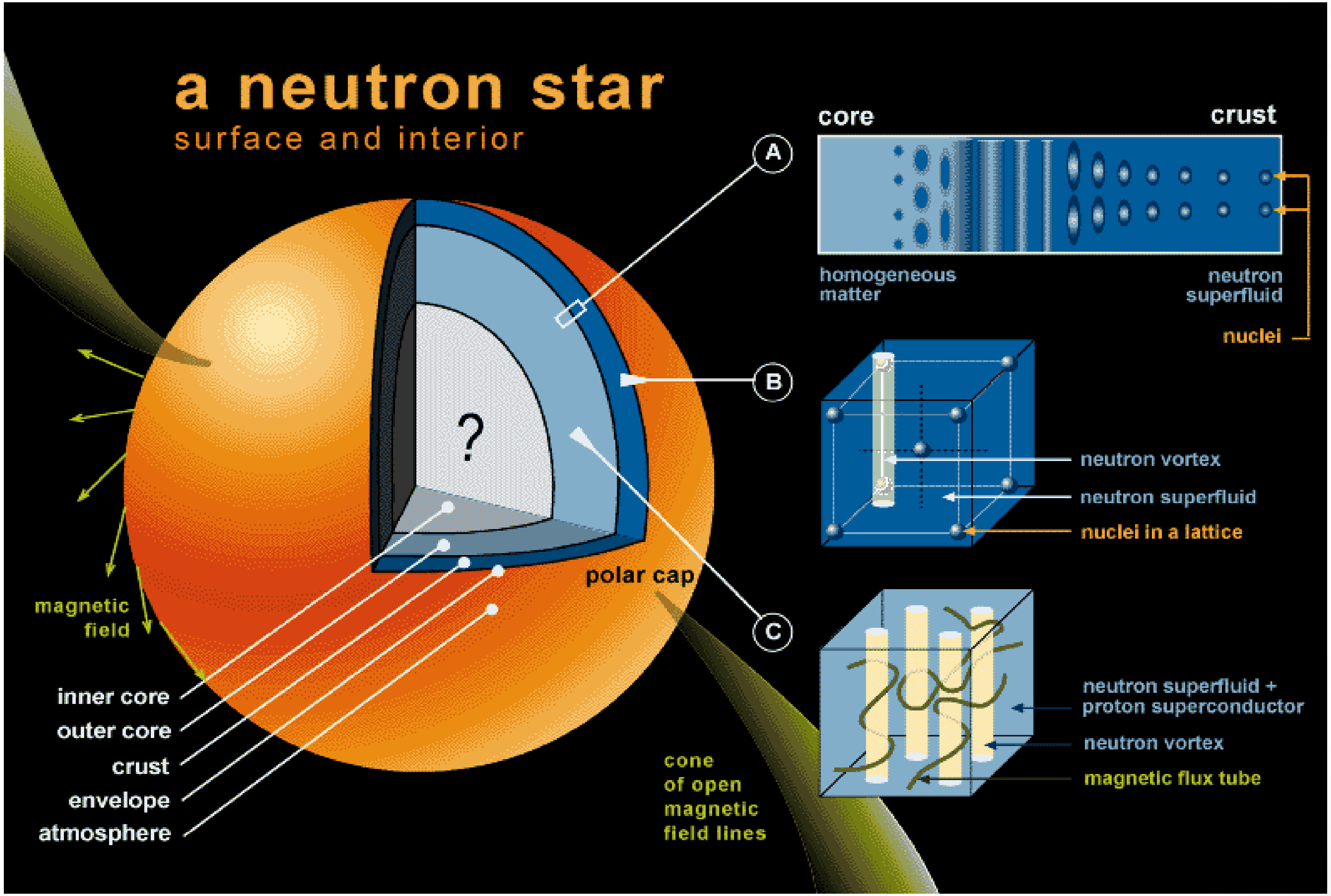
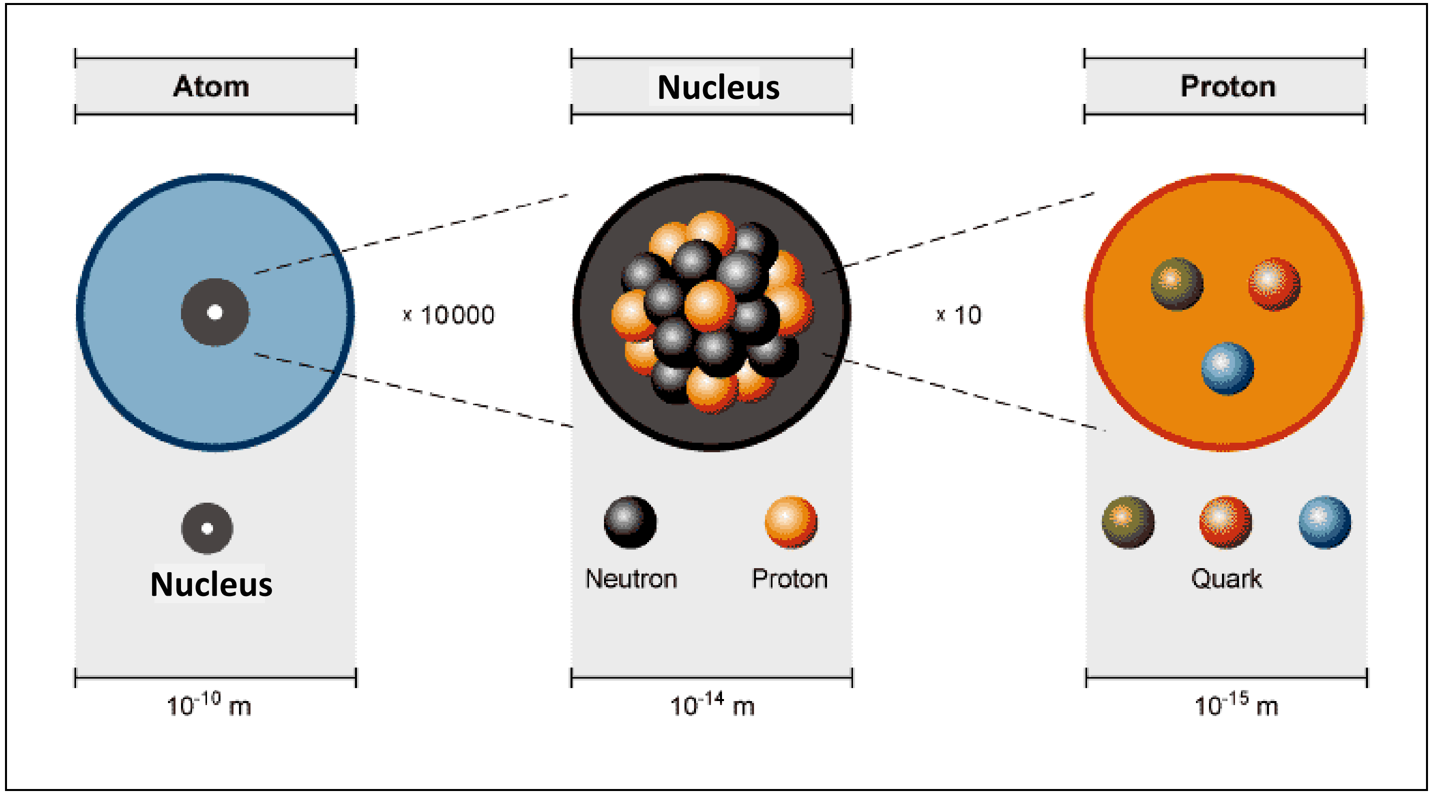
Superdense objects – what is inside?



Superdense objects – what is inside?



Nucleus, A nucleons: R_A=1.2 10^{-13} cm $A^{1/3}$; ρ_0=A1.67 10^{-24} g/(4π/3 $R_A^{\ 3}$)= 2.3 10^{14} g/cm^3

Neutron star: R= 10 km; ρ= 2 Mo/(4π/3 R^3) = 4 10^{33} g/(4 10^{18} cm^3)= 10^{15} g/cm^3 = 4 ρ_0

Piecewise polytrope EoS

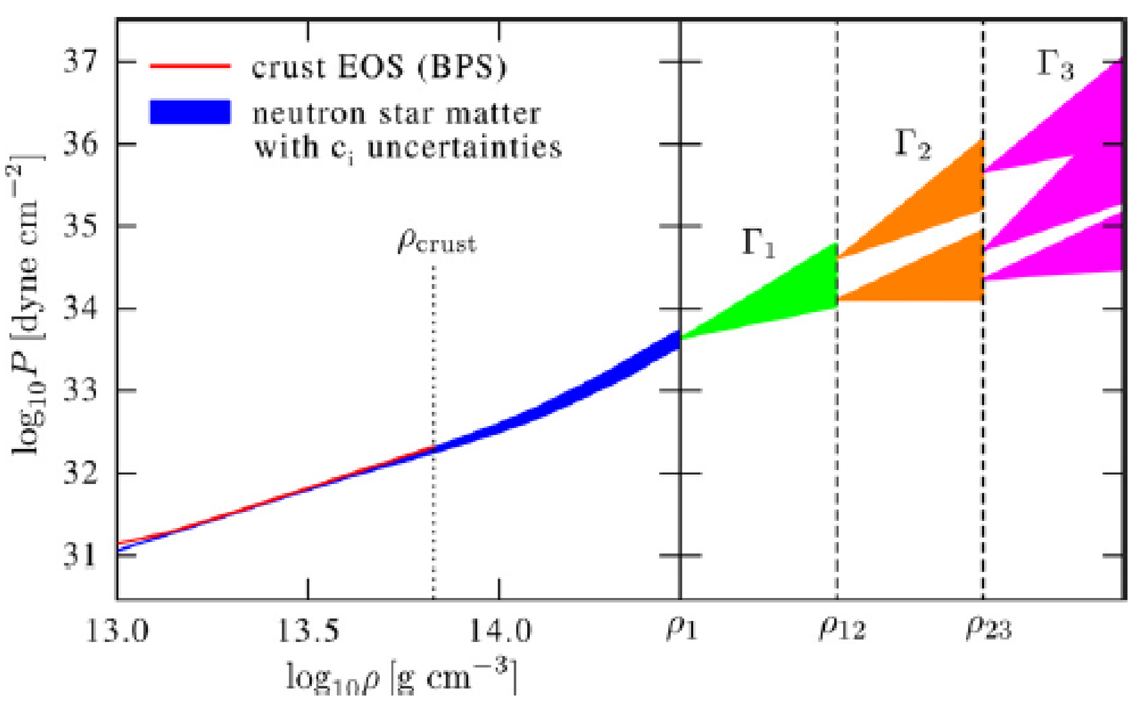
Hebeler et al., ApJ 773, 11 (2013)

$$P_i(n) = \kappa_i n^{\Gamma_i}$$

$$\begin{aligned} i = 1 &: n_1 \le n \le n_{12} \\ i = 2 &: n_{12} \le n \le n_{23} \\ i = 3 &: n \ge n_{23} \,, \end{aligned}$$

Here, 1st order PT in region 2:

$$\Gamma_2 = 0 \text{ and } P_2 = \kappa_2 = P_{\rm crit}$$



$$\begin{aligned} P(n) &= n^2 \frac{d(\varepsilon(n)/n)}{dn}, \\ \varepsilon(n)/n &= \int dn \frac{P(n)}{n^2} = \int dn\, \kappa n^{\Gamma-2} = \frac{\kappa\, n^{\Gamma-1}}{\Gamma-1} + C, \\ \mu(n) &= \frac{P(n)+\varepsilon(n)}{n} = \frac{\kappa\,\Gamma}{\Gamma-1} n^{\Gamma-1} + m_0, \end{aligned}$$

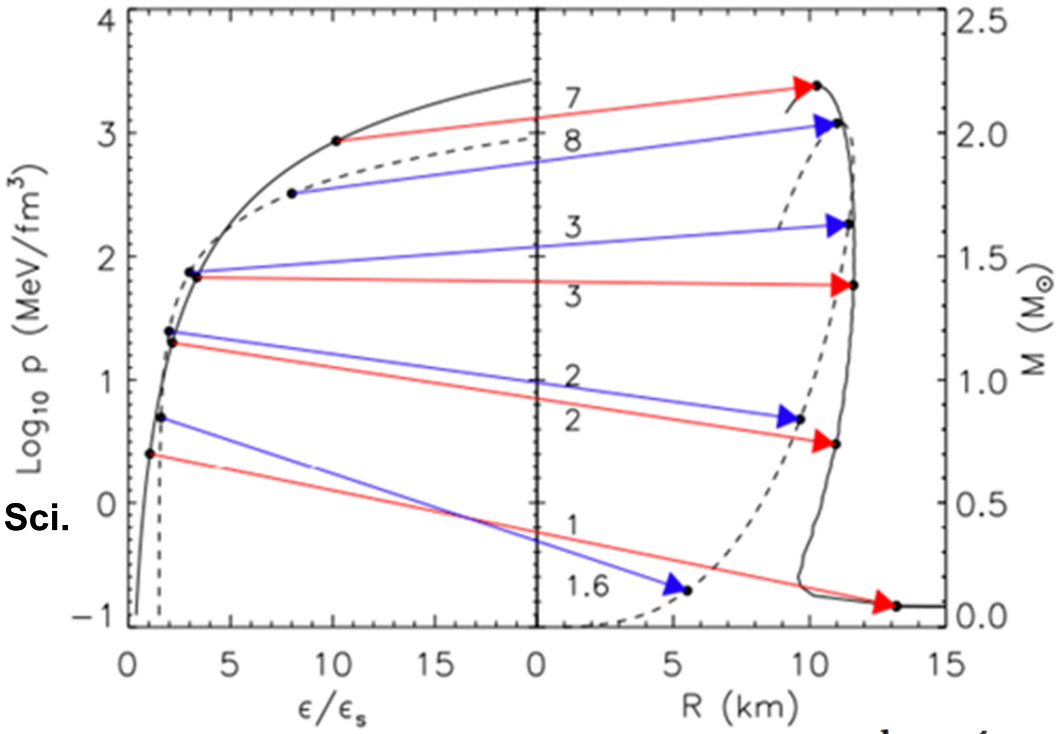
$$\begin{aligned} n(\mu) &= \left[(\mu - m_0)\frac{\Gamma-1}{\kappa\Gamma}\right]^{1/(\Gamma-1)} \\ P(\mu) &= \kappa \left[(\mu - m_0)\frac{\Gamma-1}{\kappa\Gamma}\right]^{\Gamma/(\Gamma-1)} \end{aligned}$$

Seidov criterion for instability: $\dfrac{\Delta\varepsilon}{\varepsilon_{\rm crit}} \ge \dfrac{1}{2} + \dfrac{3}{3}\dfrac{P_{\rm crit}}{\varepsilon_{\rm crit}}$

Maxwell construction:

$$\begin{aligned} P_1(\mu_{\rm crit}) &= P_3(\mu_{\rm crit}) = P_{\rm crit} \\ \mu_{\rm crit} &= \mu_1(n_{12}) = \mu_3(n_{23}) \end{aligned}$$

Compact Star Sequences
(M-R ⇔ EoS)



**Lattimer,
Annu. Rev. Nucl. Part. Sci.
62, 485 (2012)
arXiv: 1305.3510**

- TOV Equations

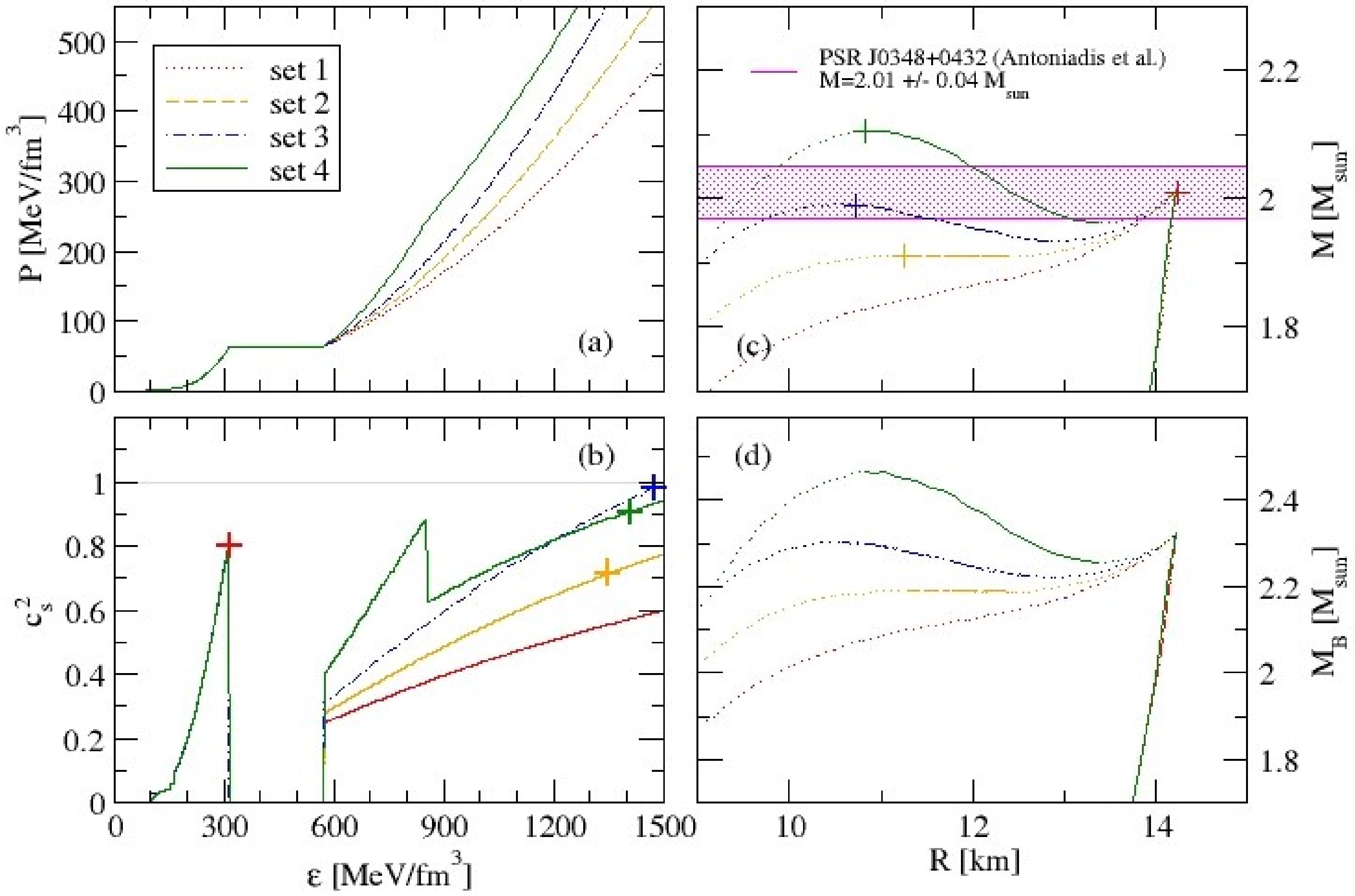
$$\frac{dp}{dr} = -\frac{(\varepsilon + p/c^2)G(m + 4\pi r^3 p/c^2)}{r^2(1 - 2Gm/rc^2)}$$

$$\frac{dm}{dr} = 4\pi r^2 \varepsilon$$

- Equation of State (EoS)

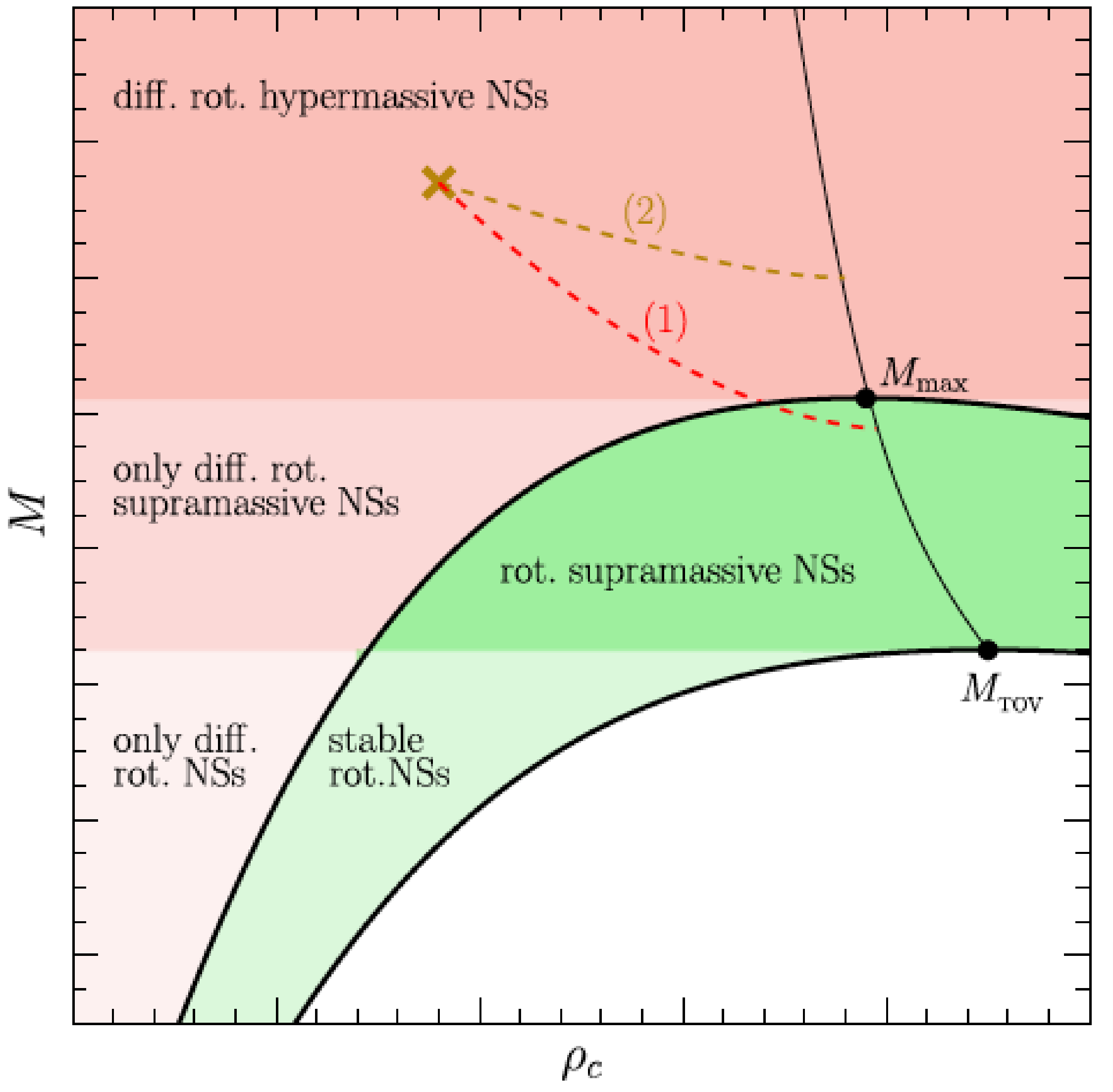
$$p(\varepsilon)$$

Compact Star Twins



Alvarez-Castillo, Blaschke (2017)
High mass twins from multi-polytrope equations of state
arXiv: 1703.02681v2, Phys. Rev. C 96, 045809 (2017)

Upper limit on the Maximum Mass M of nonrotating stars?



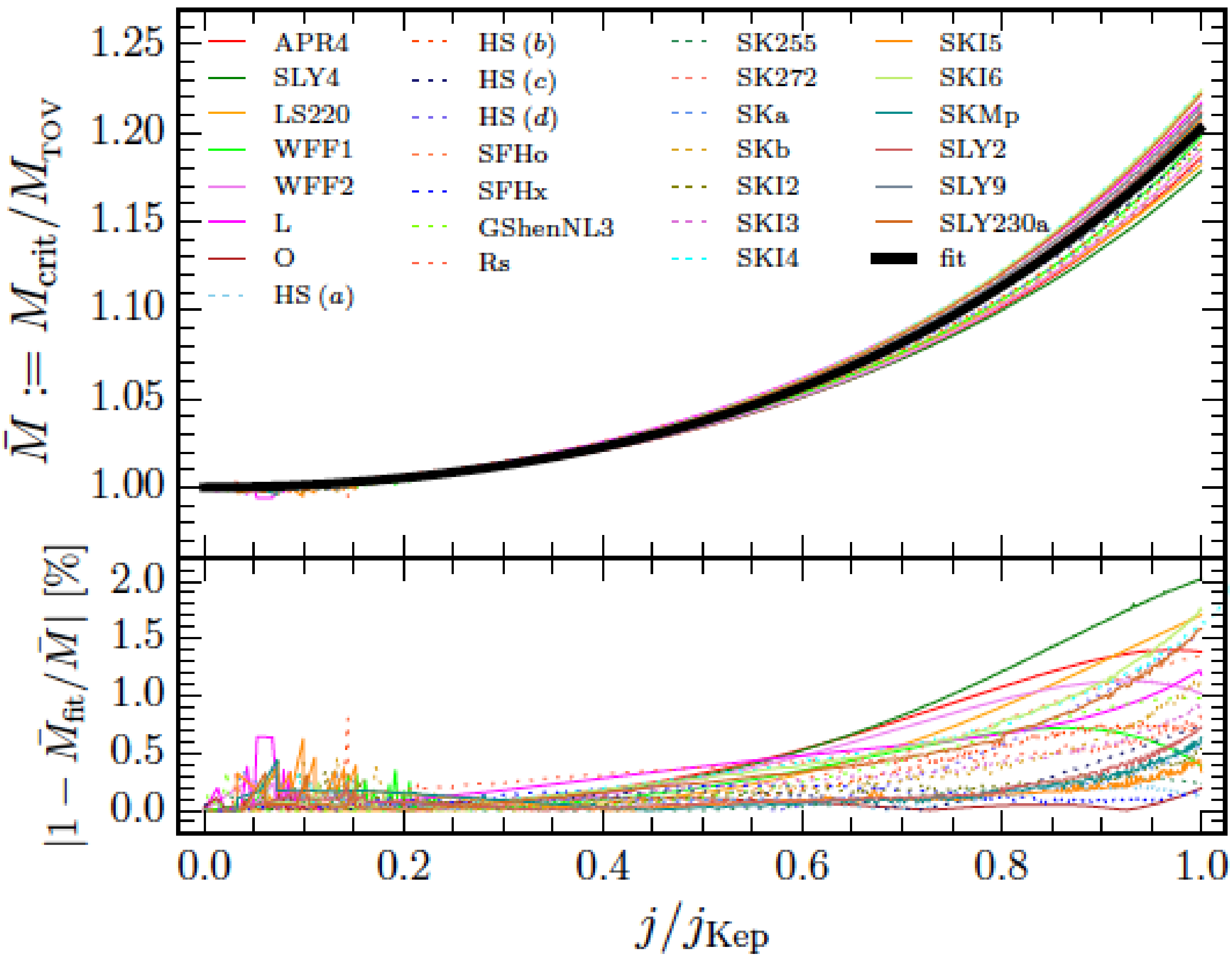
Rezzolla et al., ApJ Lett 852 (2018) L25

Universal relation for maximum mass increase upon rigid rotation

$$\frac{M_{\rm crit}}{M_{\rm TOV}} = 1 + a_2 \left(\frac{j}{j_{\rm Kep}}\right)^2 + a_4 \left(\frac{j}{j_{\rm Kep}}\right)^4$$

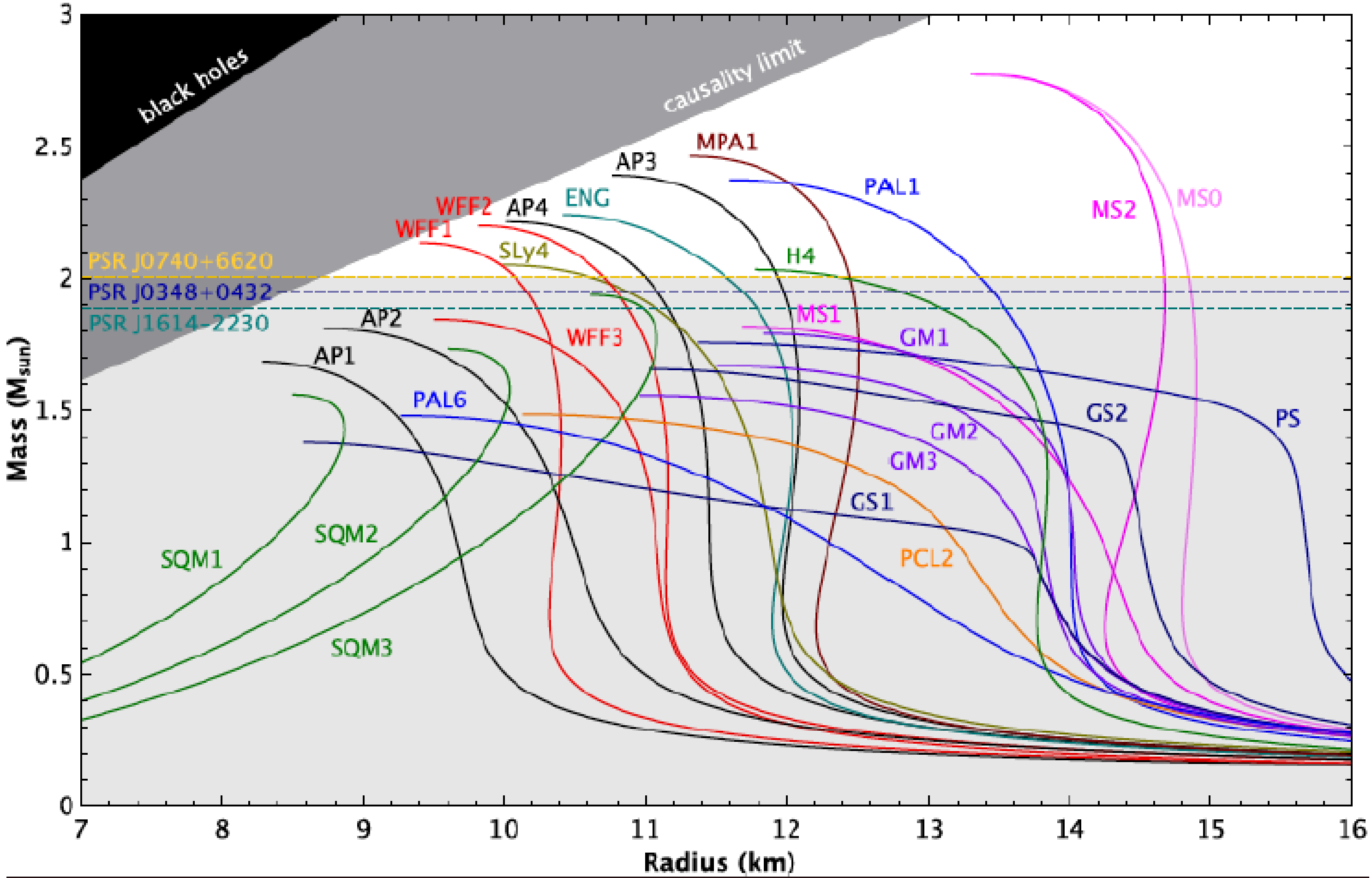
$$M_{\max} := M_{\rm crit}(j = j_{\rm Kep}) = (1 + a_2 + a_4)\, M_{\rm TOV} \simeq (1.203 \pm 0.022)\, M_{\rm TOV}$$

"universal" increase of maximum mass by 20% due to rigid rotation at maximum (critical) angular momentum



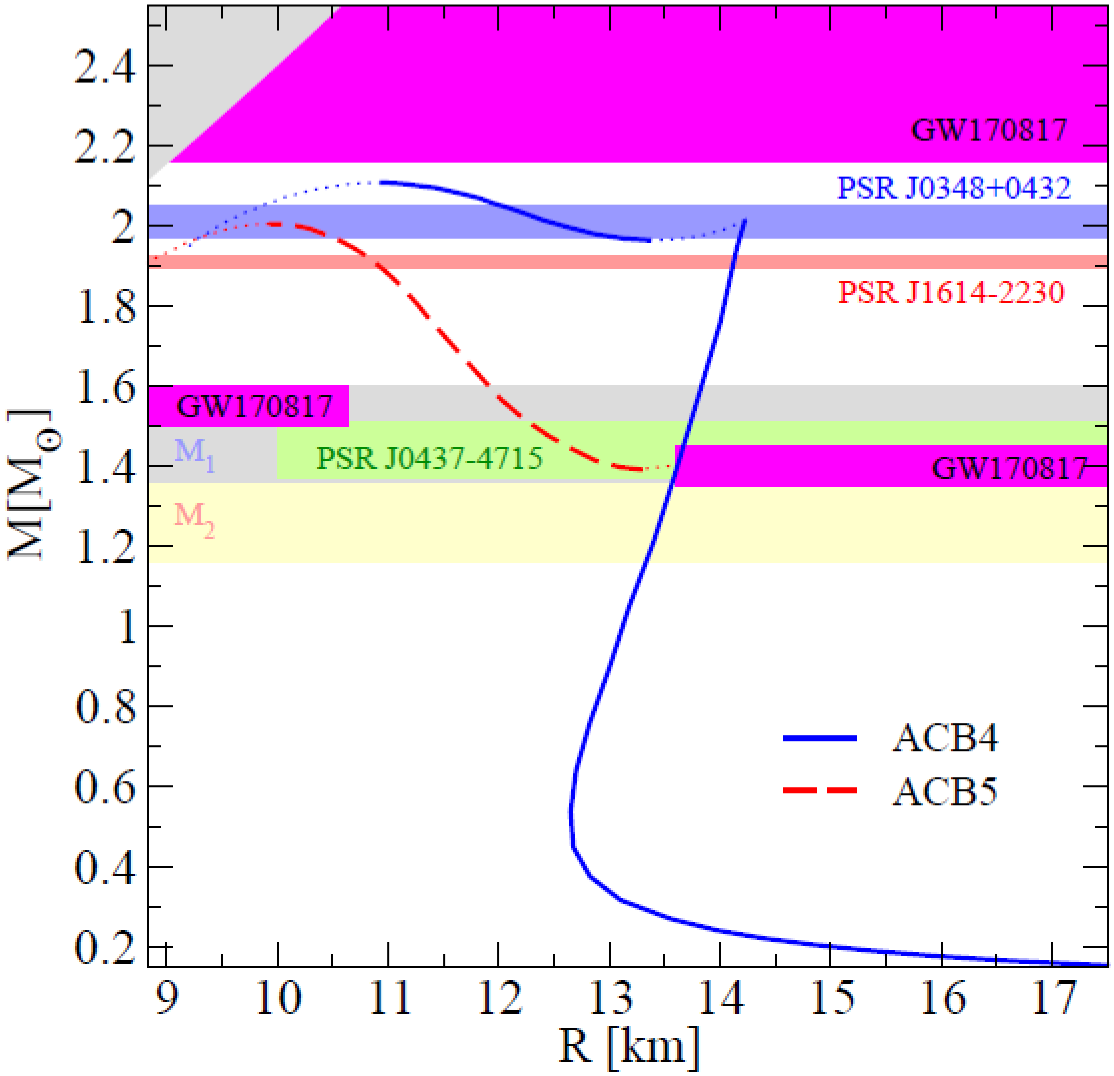
Breu & Rezzolla et al., MNRAS (2016)

Massive Neutron stars:
Is there a concrete upper limit for the mass?



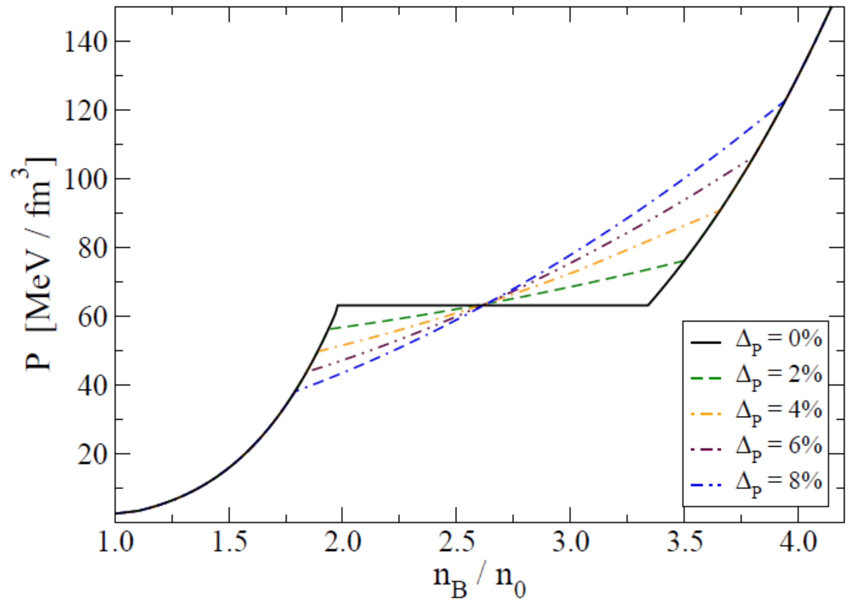
www3.mpifr-bonn.mpg.de/staff/pfreire/NS_masses.html

ACB4 and ACB5 M-R: observations and constraints

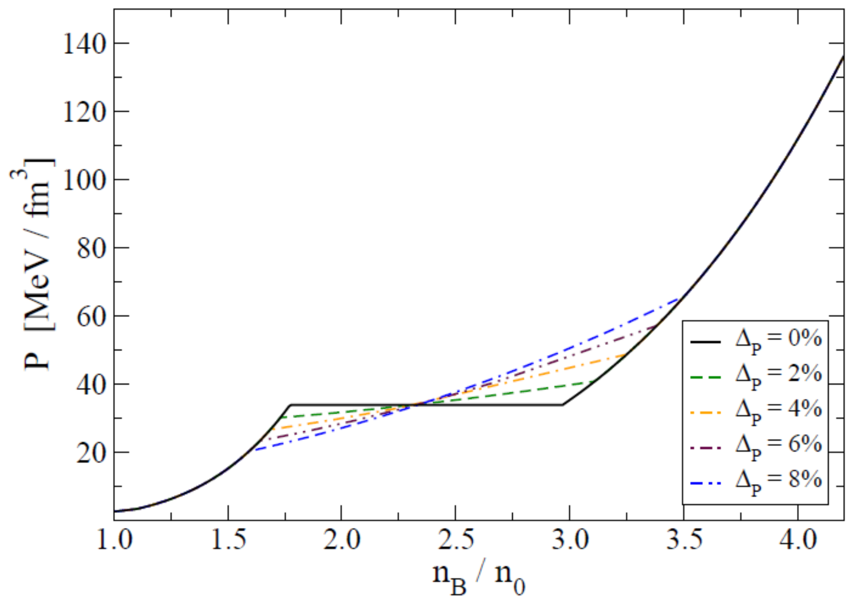


Blaschke et al., arXiv:1906.02522 [astro-ph.HE](2019)

Mixed phase effects
(Pasta phases)

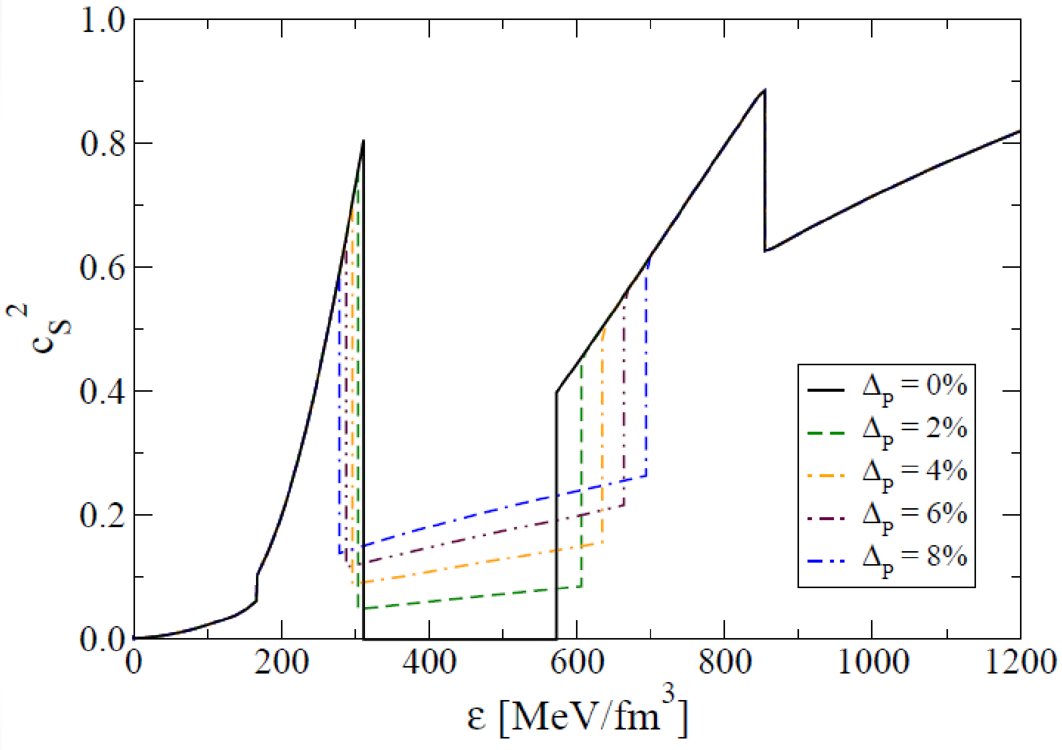


High mass twin stars
(ACB4)

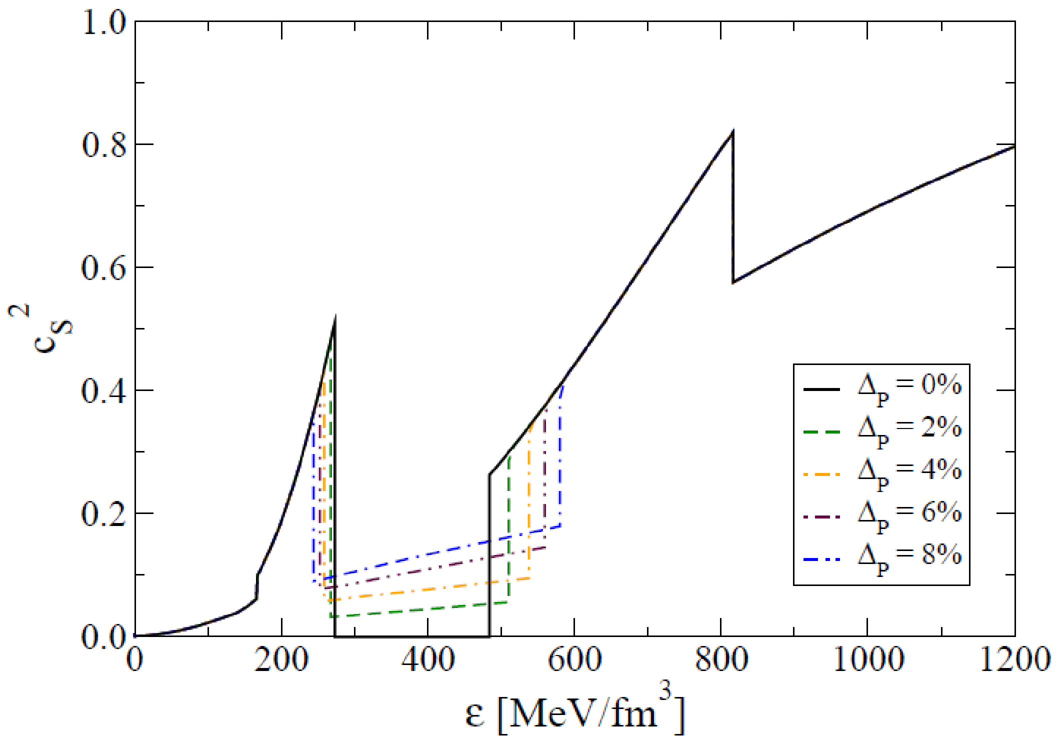


Low mass twin stars
(ACB5)

Causality

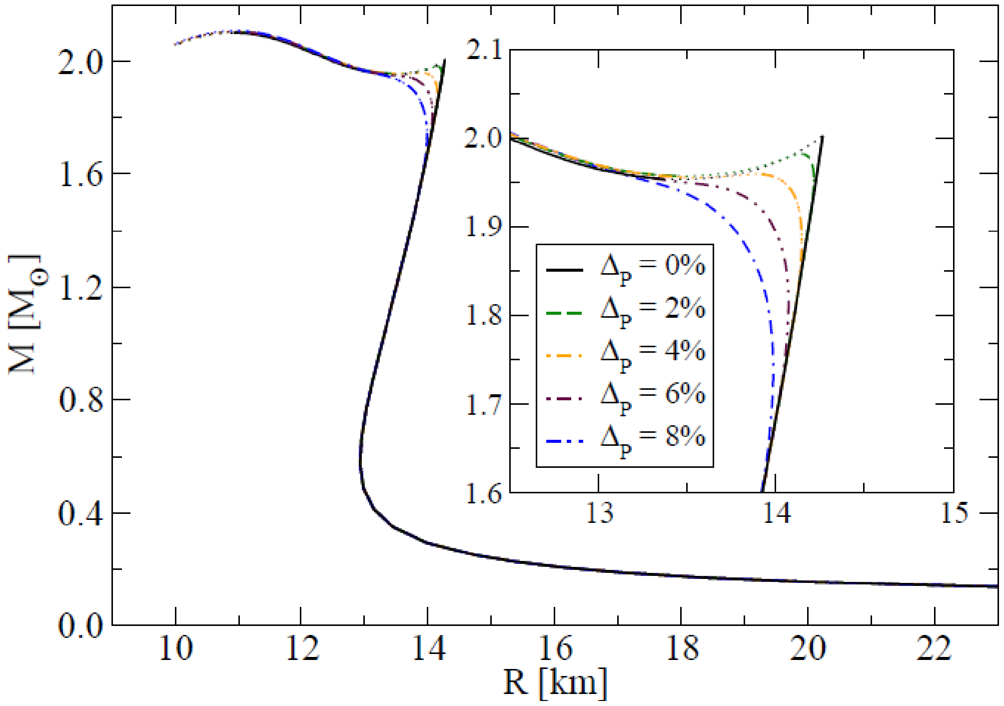


High mass twin stars
(ACB4)

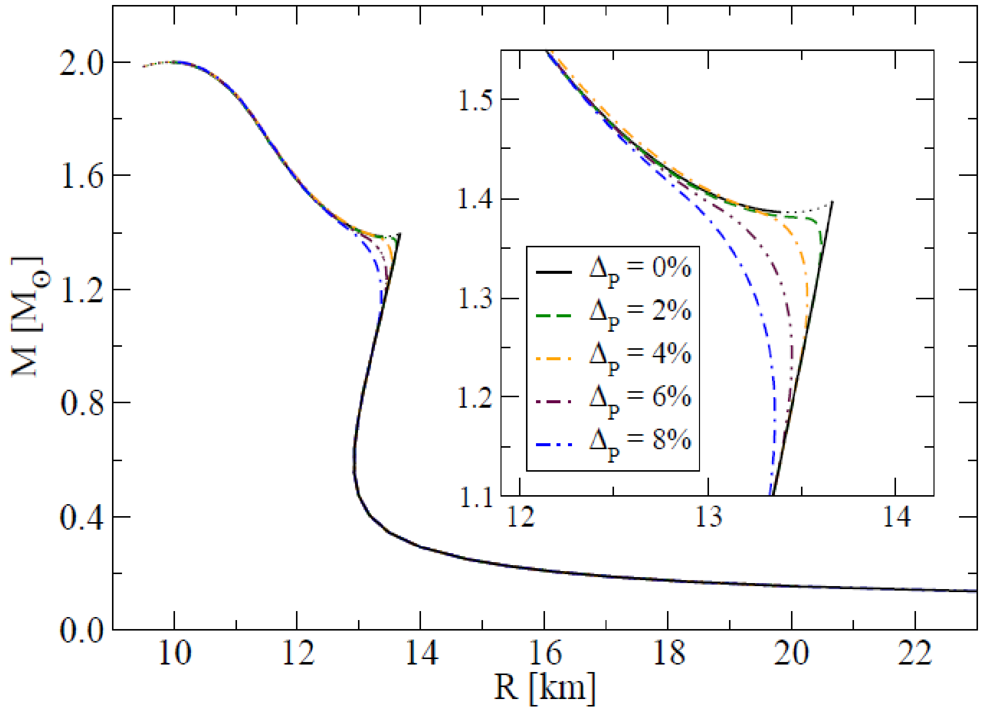


Low mass twin stars
(ACB5)

Mass-Radius Diagrams



ACB4

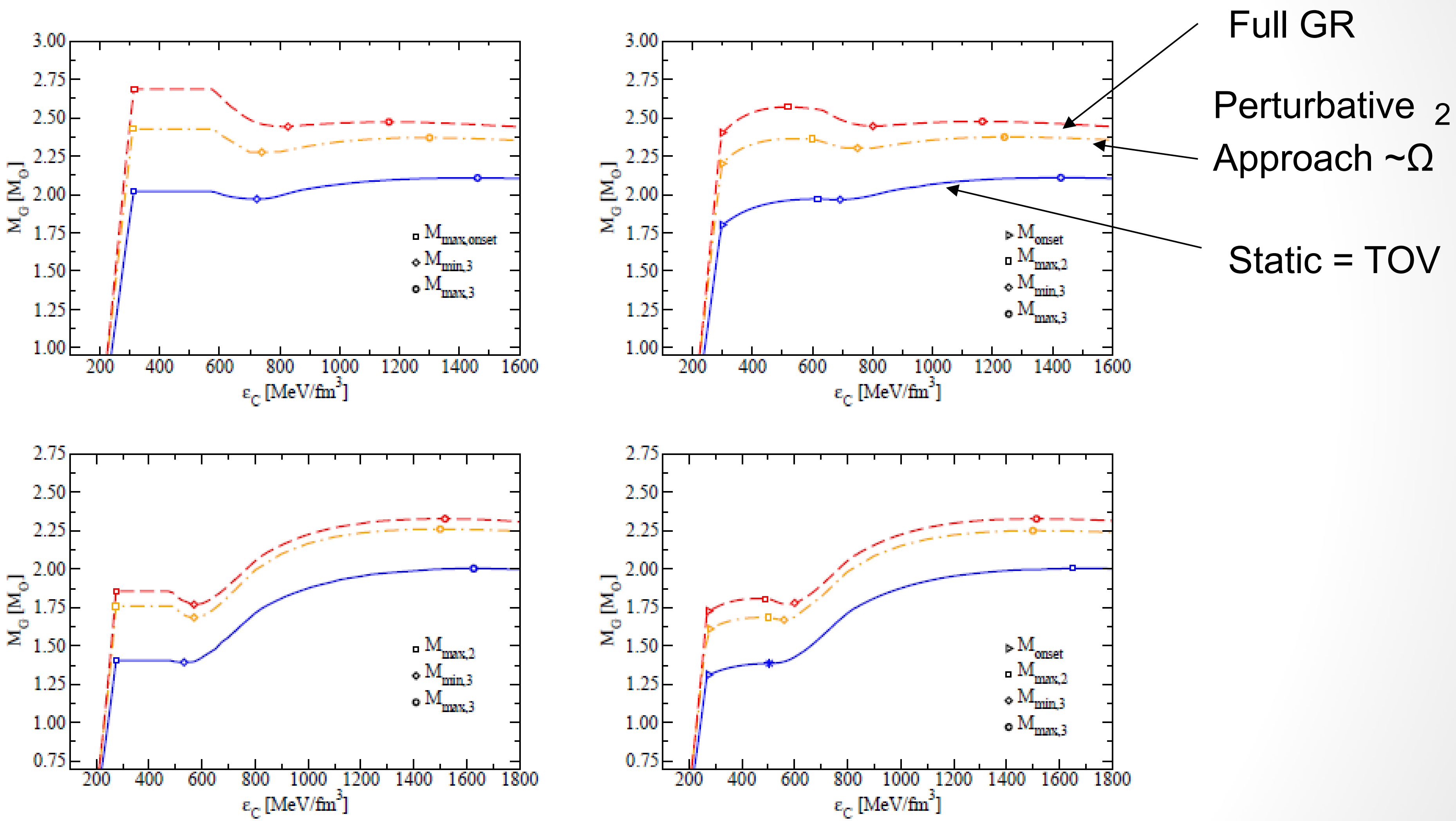


ACB5

Effect of Rotation and mixed phase

ACB4

ACB5



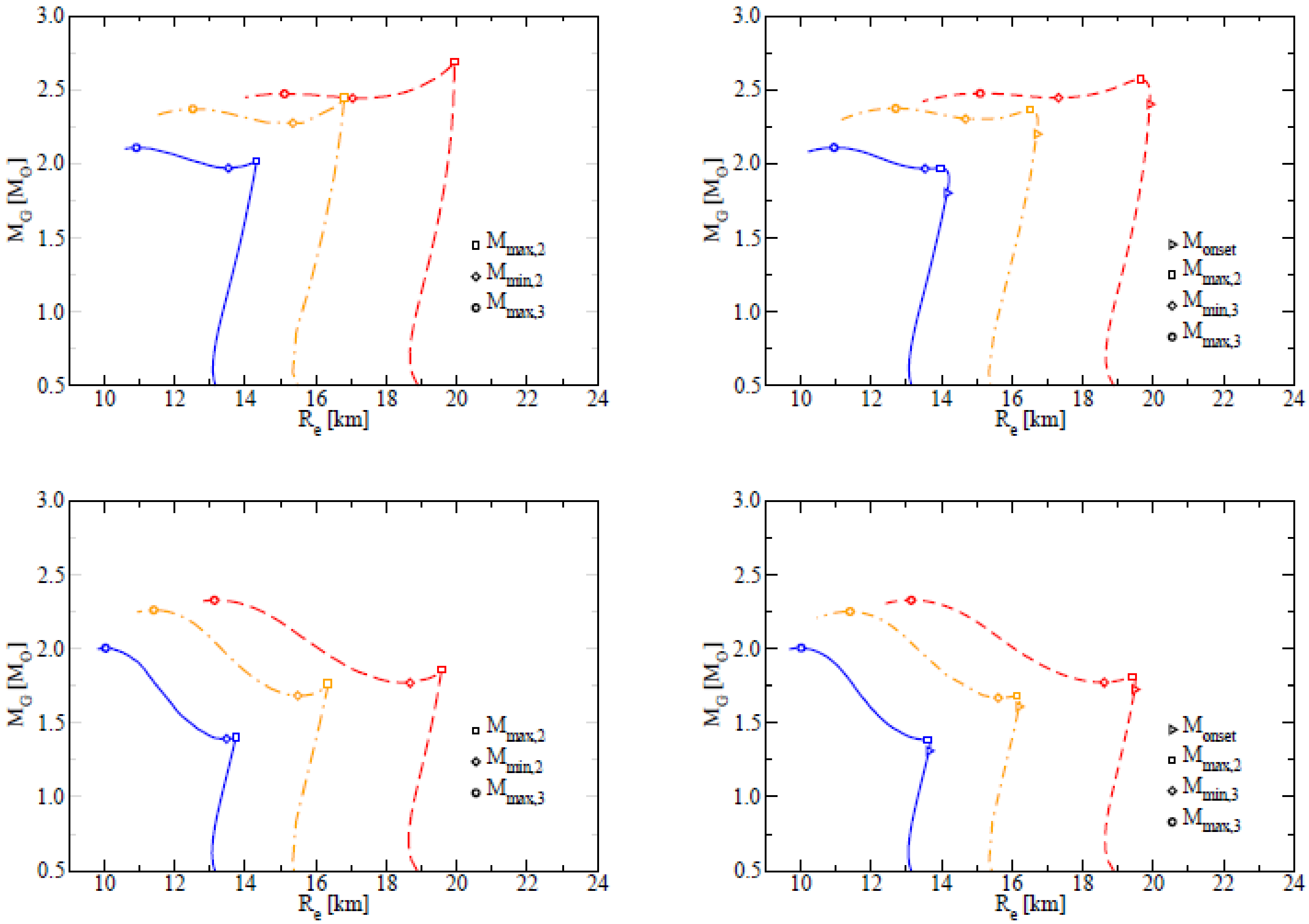
Maxwell construction

Critical value of Mixed-phase parameter

Effect of Rotation and mixed phase

ACB4

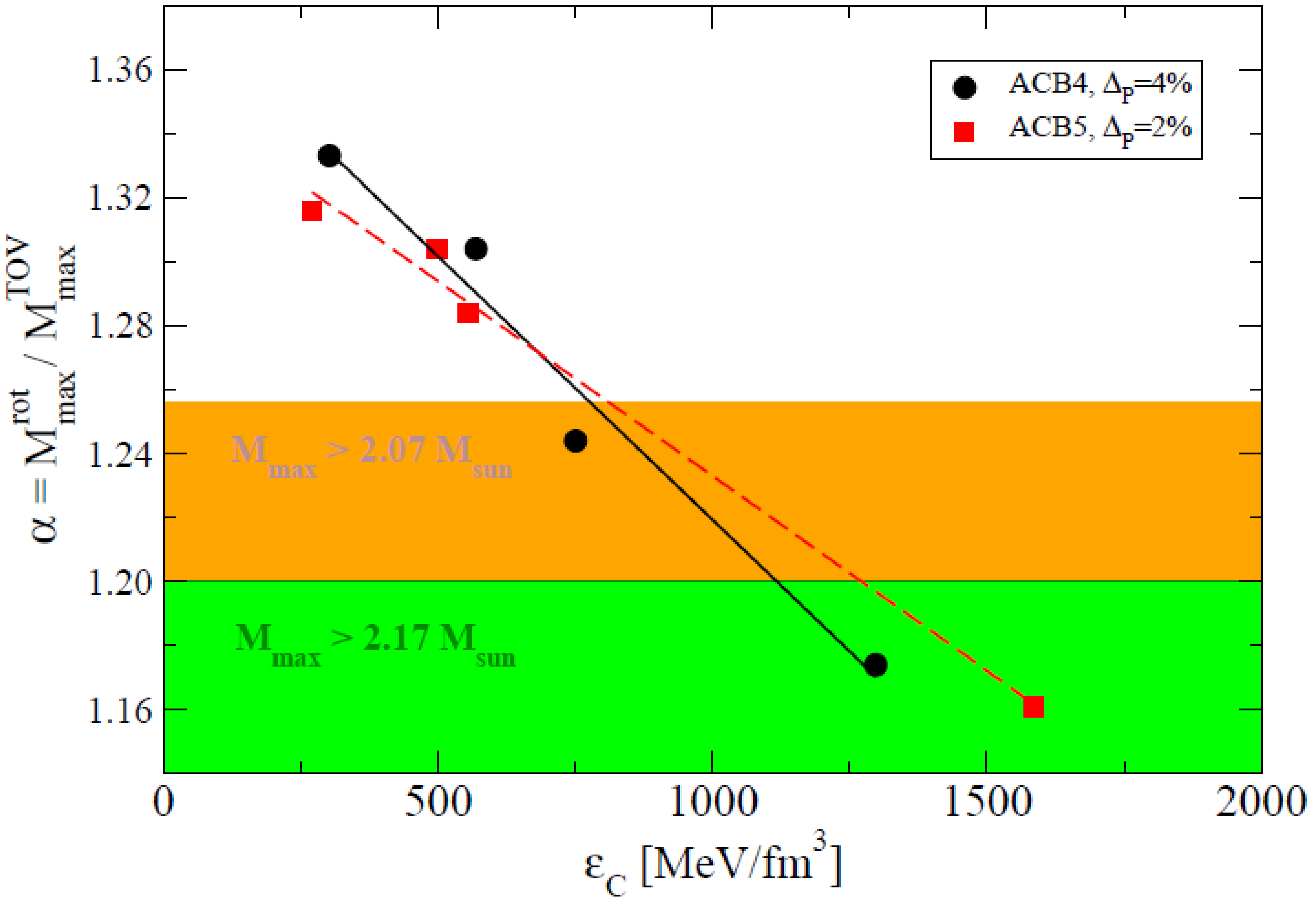
ACB5



Maxwell construction

Critical value of Mixed-phase parameter

Universal relationship for rotating CS



Conclusions

1)
The existence of mass twins invariably signals the existence of a strong phase transition in compact star matter at supersaturation densities.
“Strong transition”: energy density changes by about the value of the critical energy density in a sufficiently small region of pressures around the critical one of the Maxwell construction.
This can also support the existence of a critical endpoint (CEP) of first order phase transitions in the QCD phase diagram.

2)
The mixed phase construction mimics the pasta phase in accordance with a full pasta calculation.
The result is a “broadening” of the phase transition over a certain pressure region, similar to the Gibbs construction in matter with more than one conserved charge and global charge conservation [Glendenning (1992)]. The construction makes the approach more realistic and Has advantages for numerical treatment of hybrid stars in general relativity.

3)
The conjecture of an upper limit on the maximum mass of nonrotating compact stars derived from GW170817 is revisited. We find a criterion for the minimal central energy density in the maximum mass configuration that would correspond to the core of GW170817. The equation of state at high densities must be effectively soft, either as a relatively soft hadronic one or a hybrid one with a strong phase transition. The NICER radius measurement could be decisive.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متشکرم