Constraining the Neutron Star Mass and Radius Relation

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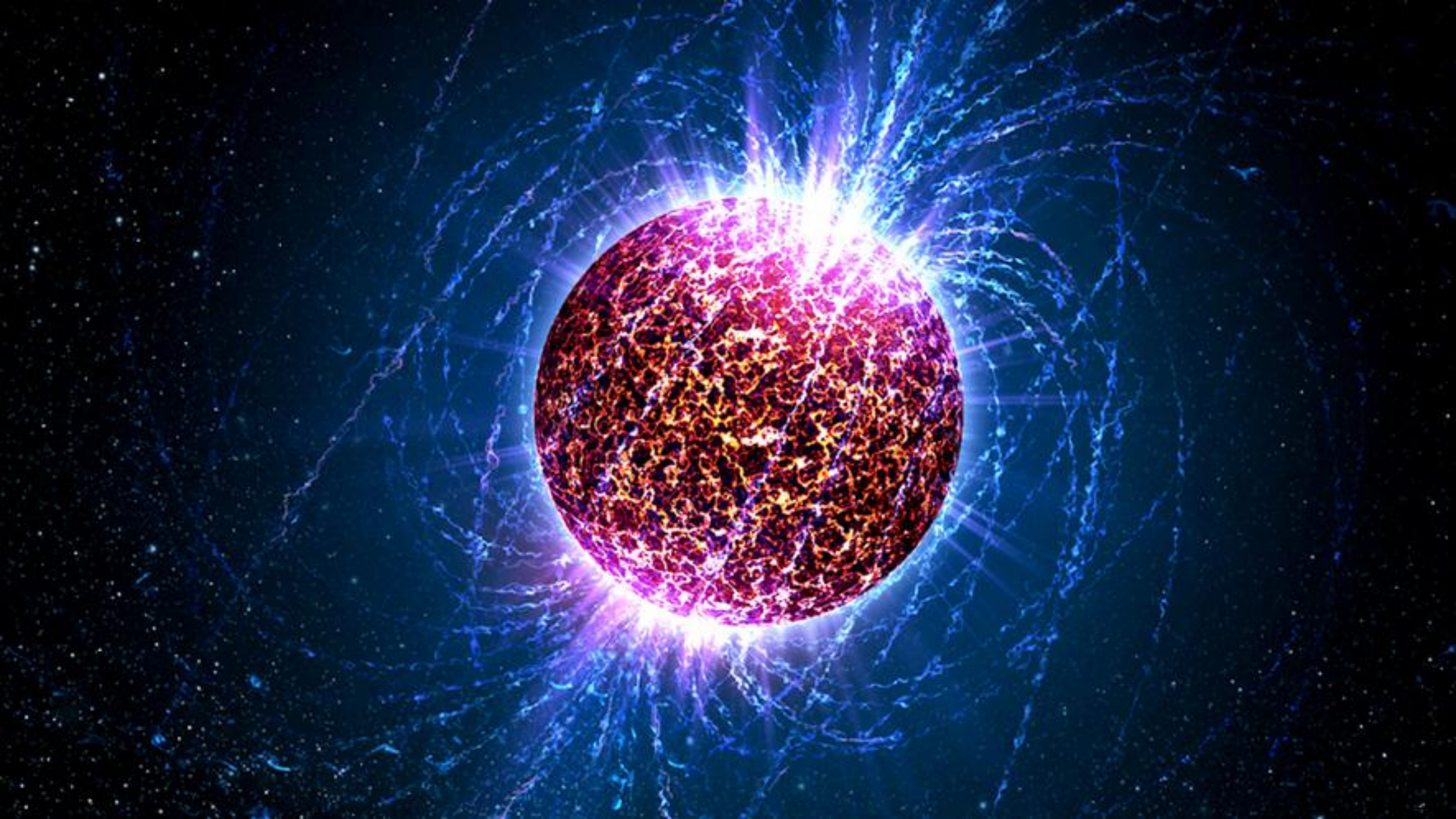
LA BEAUTÉ EST
féminin
LE BEAU EST
TOUJOURS BIZARRE
CROPP

Our Equipment



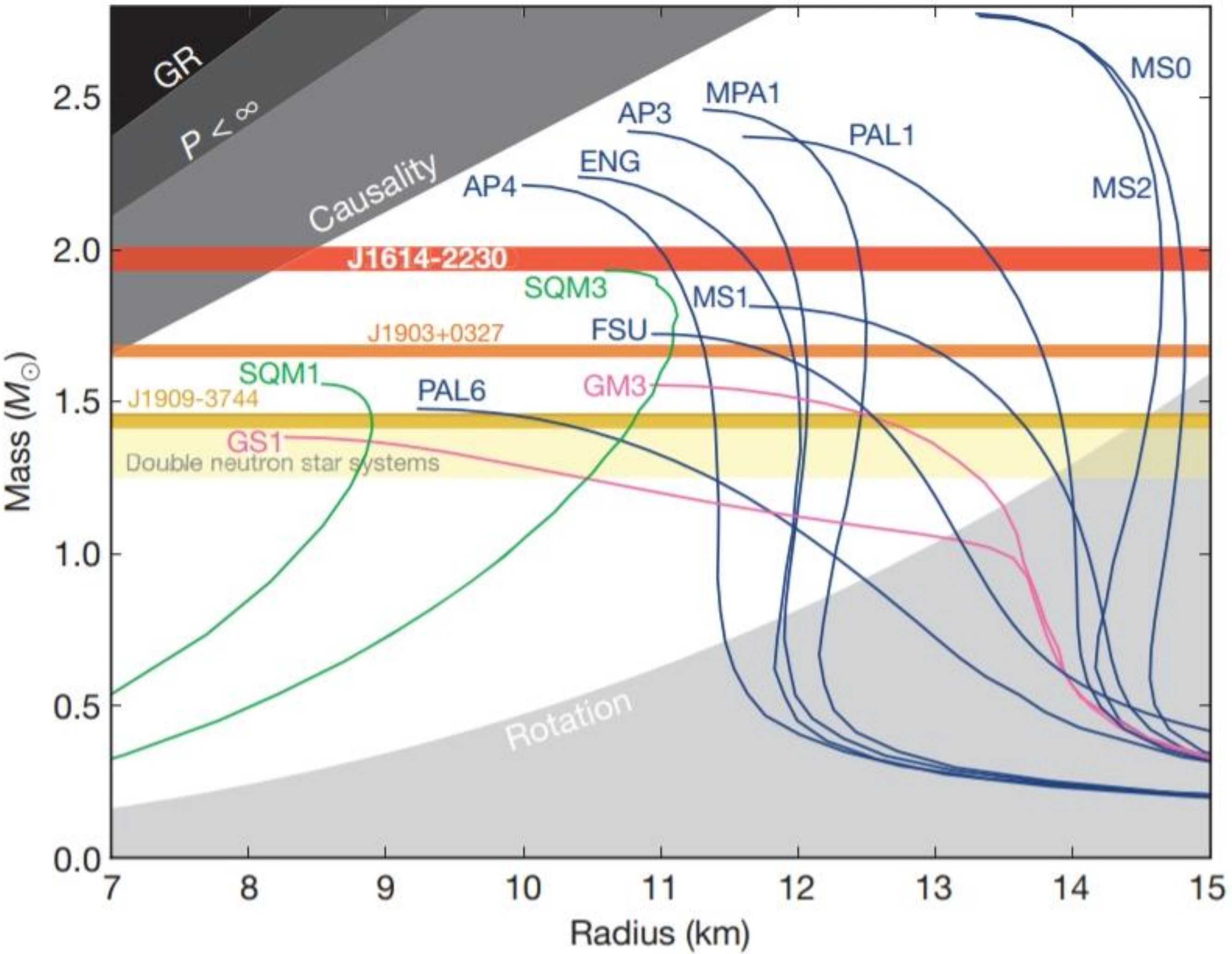
The TOV equations

$$\frac{dP}{dr} = -\frac{G\epsilon(r)m(r)}{c^2r^2}\left(1+\frac{P(r)}{\epsilon(r)}\right)\left(1+\frac{4\pi r^3 P(r)}{m(r)c^2}\right)\left(1-\frac{2Gm(r)}{c^2r}\right)^{-1}$$

$$\frac{dm}{dr} = \frac{4\pi r^2\epsilon(r)}{c^2}$$

Two equations for 3 unknown functions - we need a third one:

$$P = P(\epsilon)$$



GR
P < ∞
Causality
J1614-2230
J1903+0327
J1909-3744
Double neutron star systems
Rotation
SQM1
SQM3
GS1
GM3
PAL6
FSU
MS1
AP4
ENG
AP3
MPA1
PAL1
MS0
MS2
Mass ($M_{\odot}$)
Radius (km)
0.0
0.5
1.0
1.5
2.0
2.5
7
8
9
10
11
12
13
14
15

Where did we start ?

Symmetric nuclear matter:

$$\frac{\epsilon(n)}{n} = m_N + \frac{3}{5}\frac{\hbar^2 k_F^2}{2m_N} + \frac{A}{2}\left(\frac{n}{n_0}\right) + \frac{B}{\sigma+1}\left(\frac{n}{n_0}\right)^{\sigma}$$

Where A, B and σ are free parameters and n_0 is the nuclear saturation density ($n_0 \cong 0.16\, particles/fm^3$)

Nonsymmetric nuclear matter

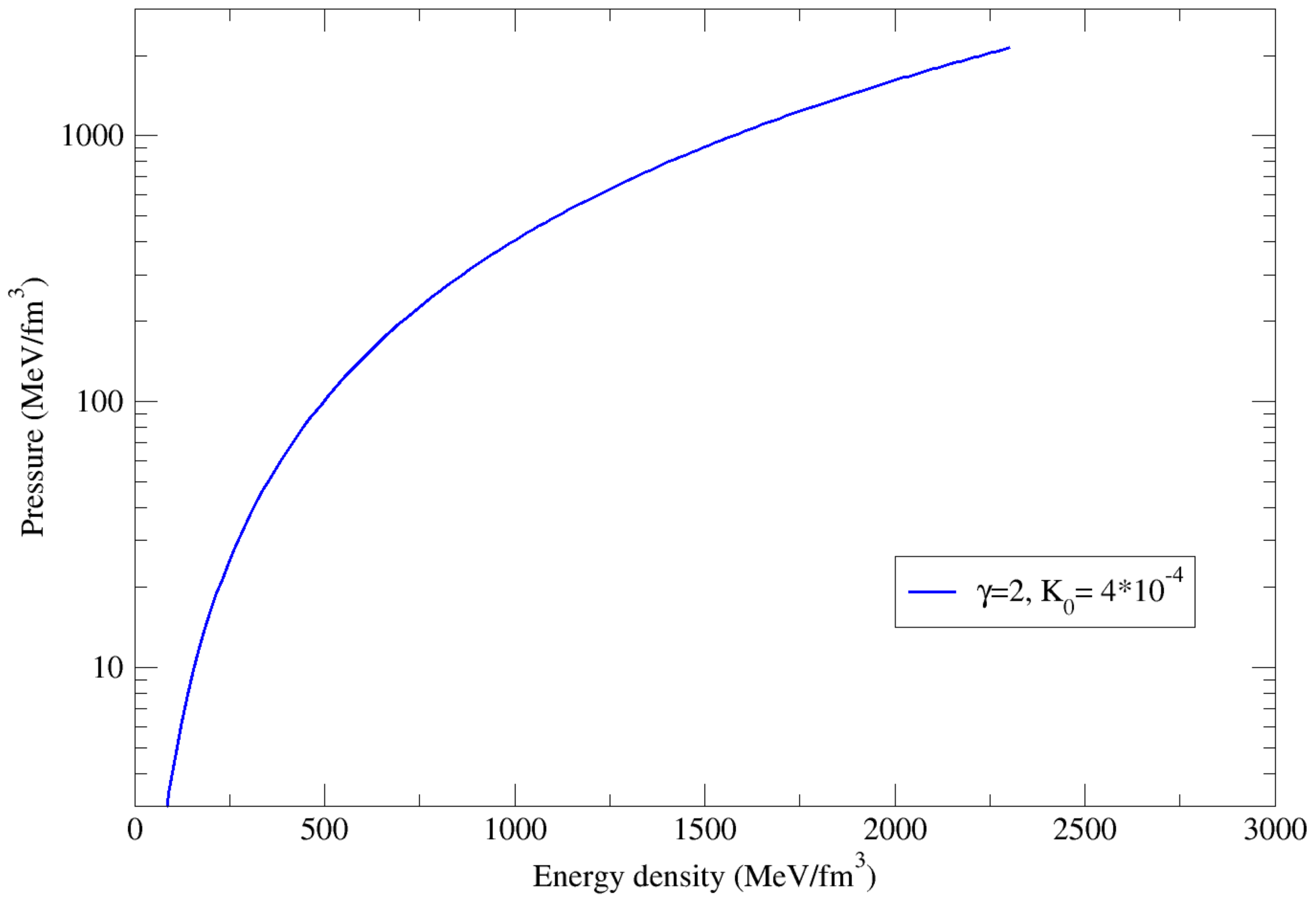
$$n_n = \frac{1+\alpha}{2} n \quad n_p = \frac{1-\alpha}{2} n$$

Nonsymmetry parametrization

$$E(n,\alpha) = E(n,0) + \alpha^2 S(n)$$

Where the function $S(n)$ is based on experimental data.

R. Silbar, S. Reddy, arXiv:nucl-th/0309041



Pressure (MeV/fm^3)
1000
100
10
0
500
1000
1500
2000
2500
3000
Energy density (MeV/fm^3)
γ=2, K_0= 4*10^{-4}

Polytropic fit

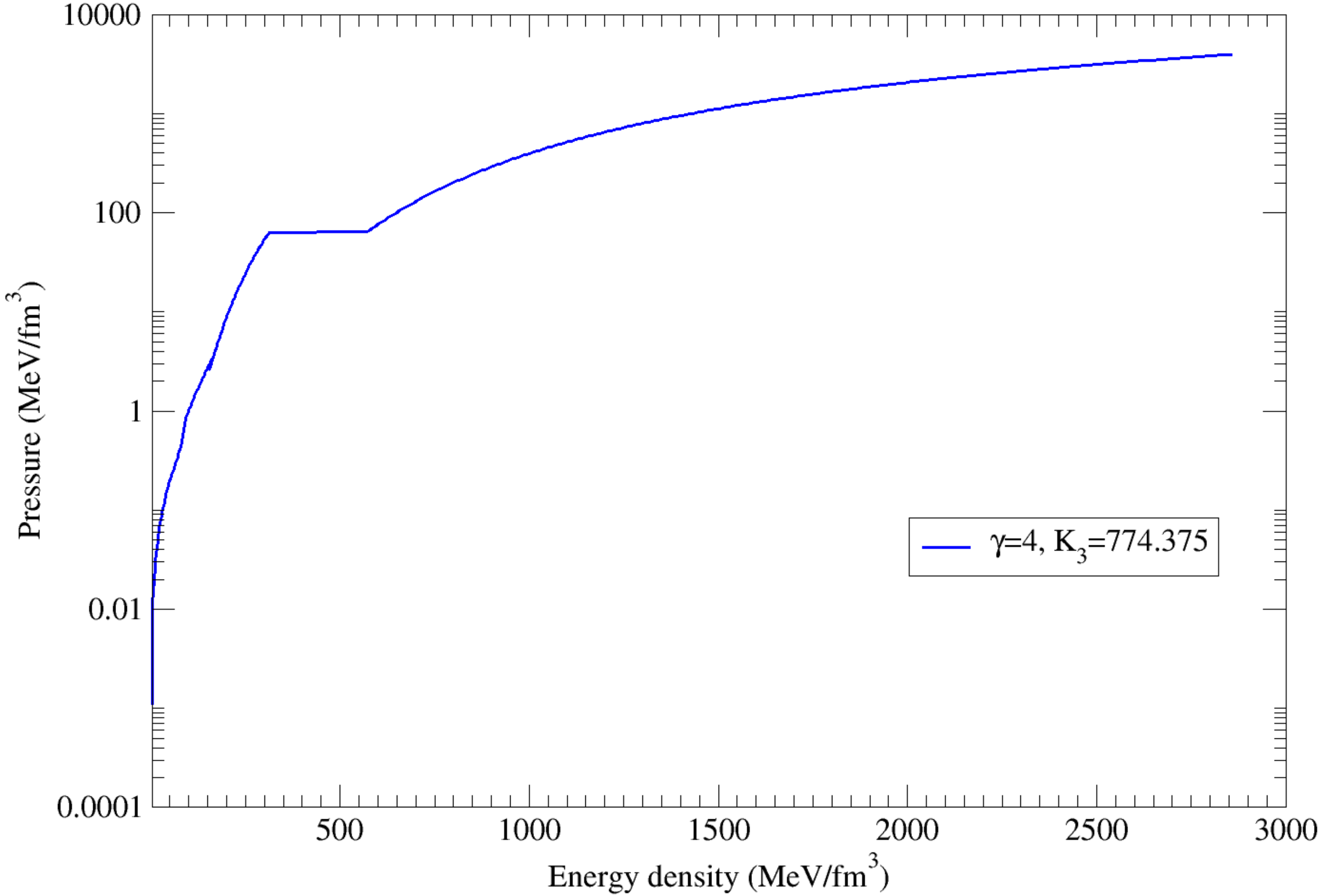
- We are using multi-polytropic fit for the EoS where the constants γ_i and K_i are determined by the respective phase:

$$P(n) = K_i n^{\gamma_i}$$

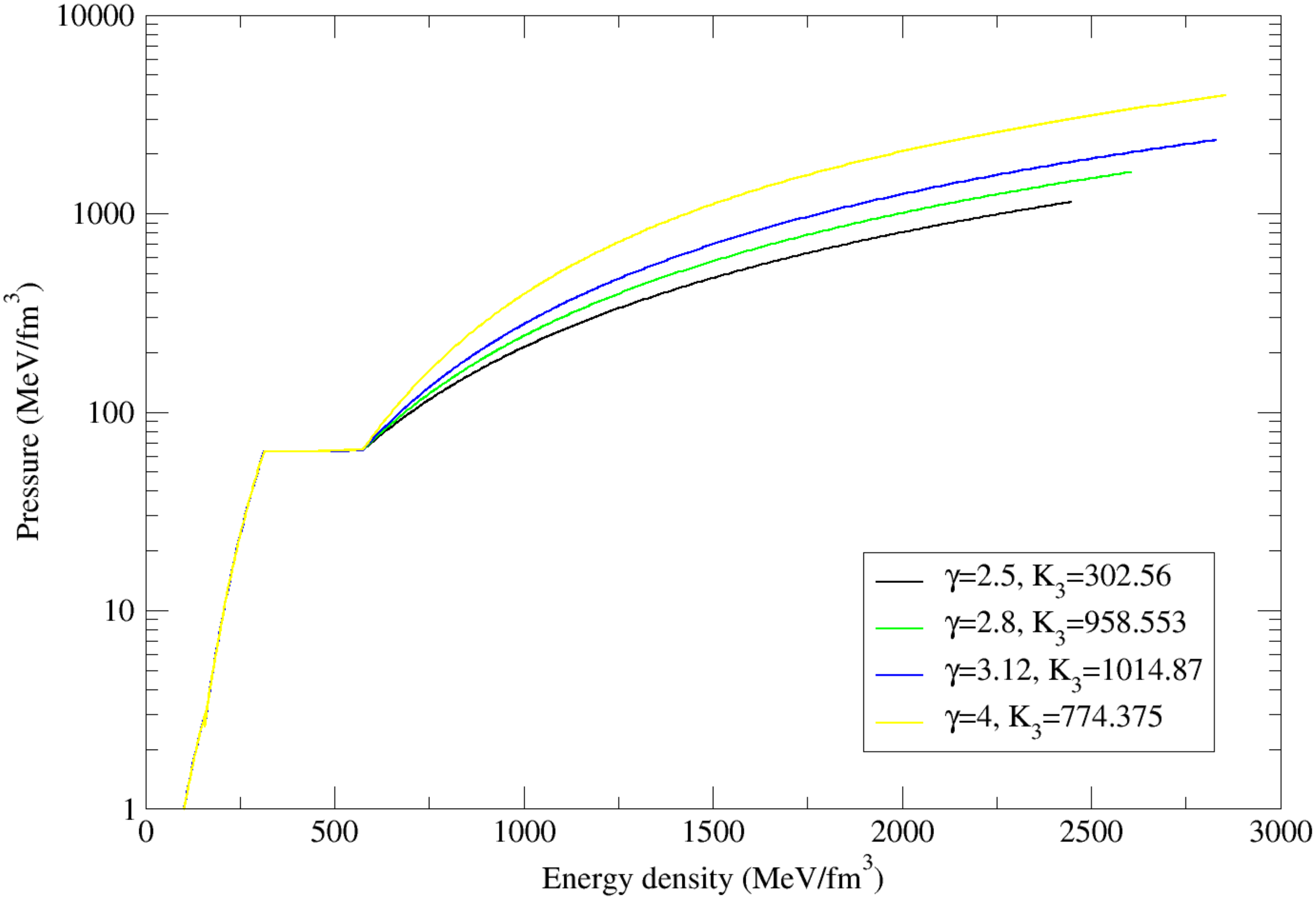
$$\epsilon(n) = \frac{K_i n^{\gamma_i}}{\gamma_i - 1} + m_N n$$

Hybrid parameters based on:

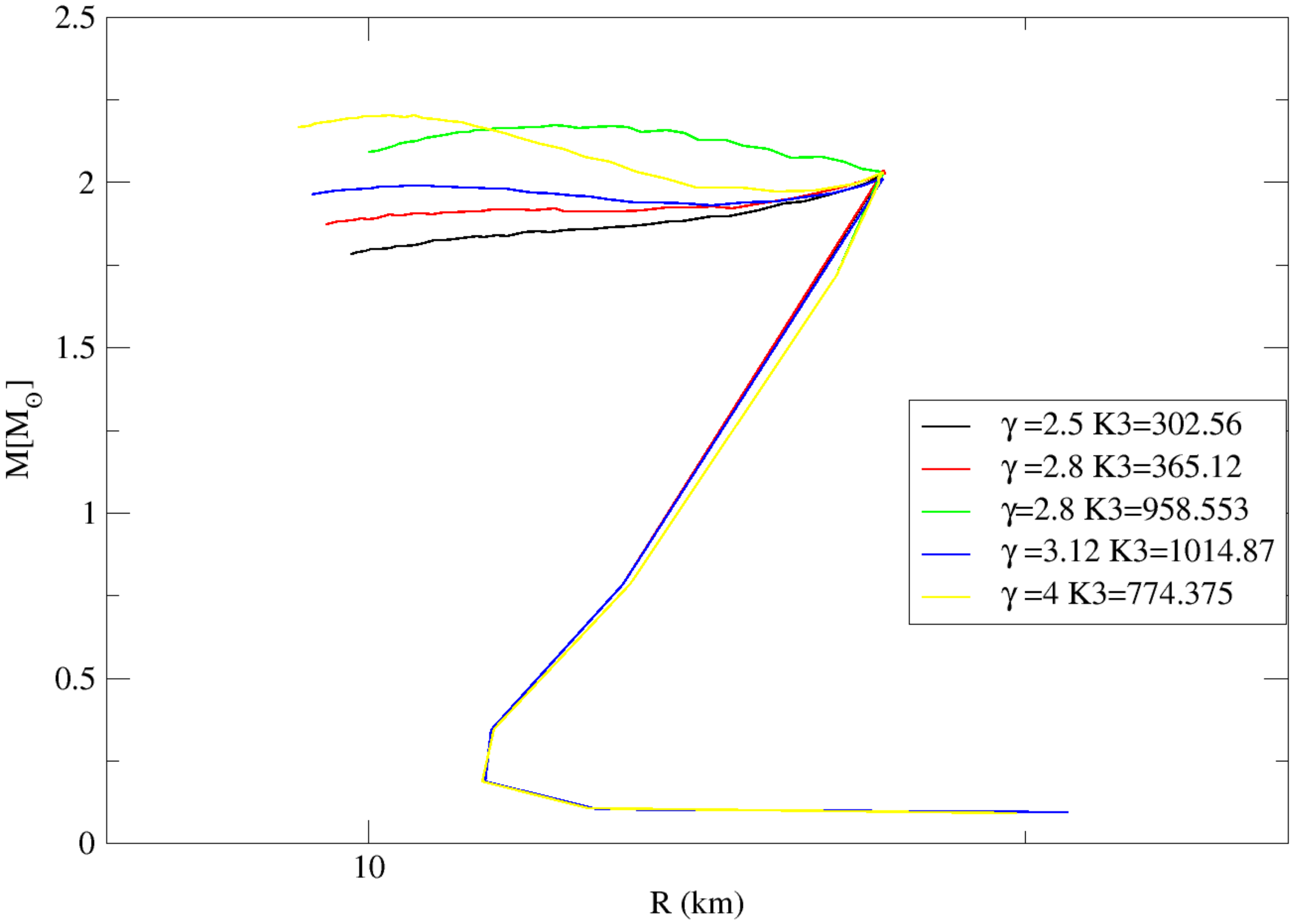
D.E. Alvarez-Castillo, D.B. Blaschke, arXiv:1703.02681



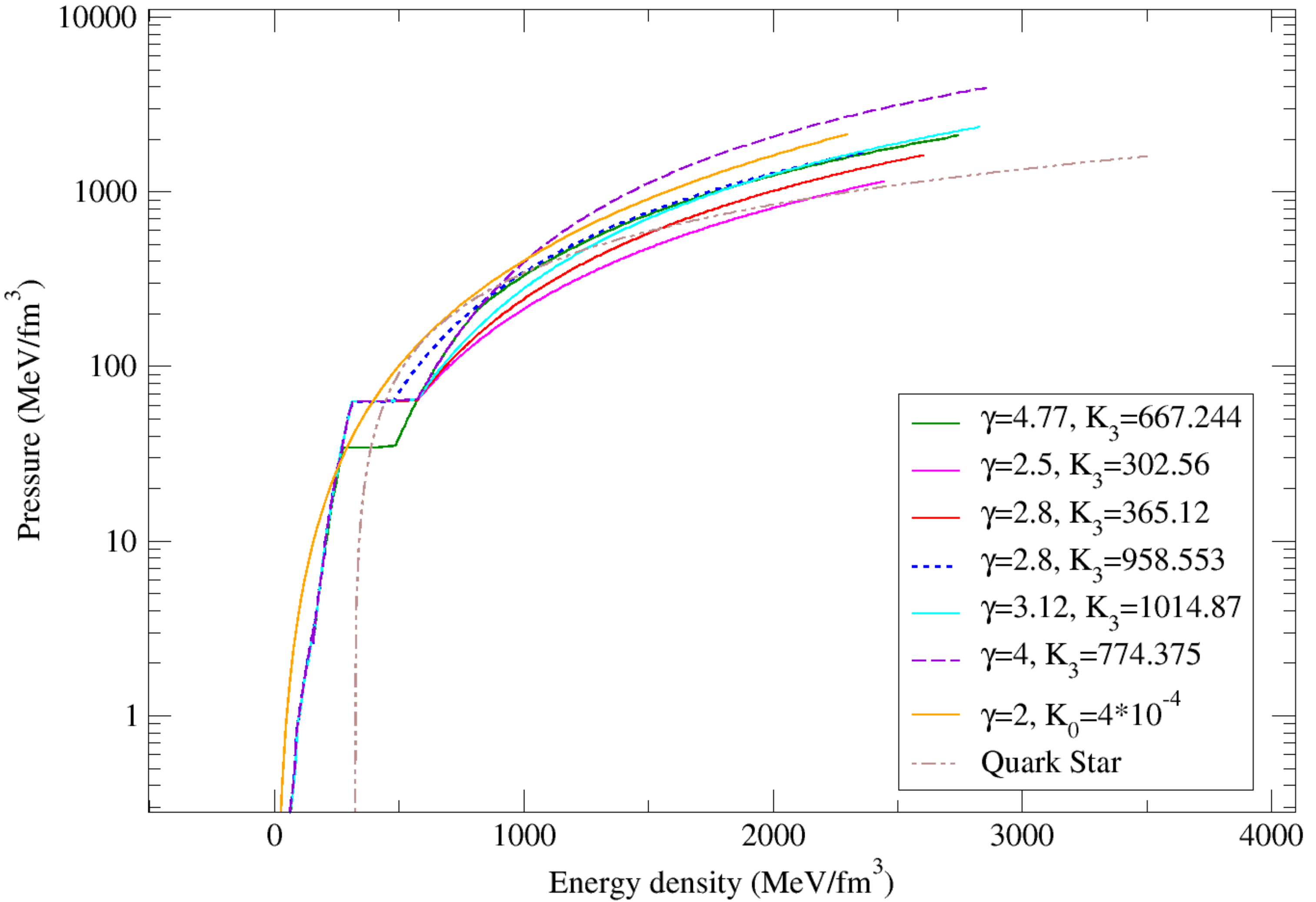
10000
100
1
0.01
0.0001
500
1000
1500
2000
2500
3000
Pressure (MeV/fm^3)
Energy density (MeV/fm^3)
γ=4, K_3=774.375



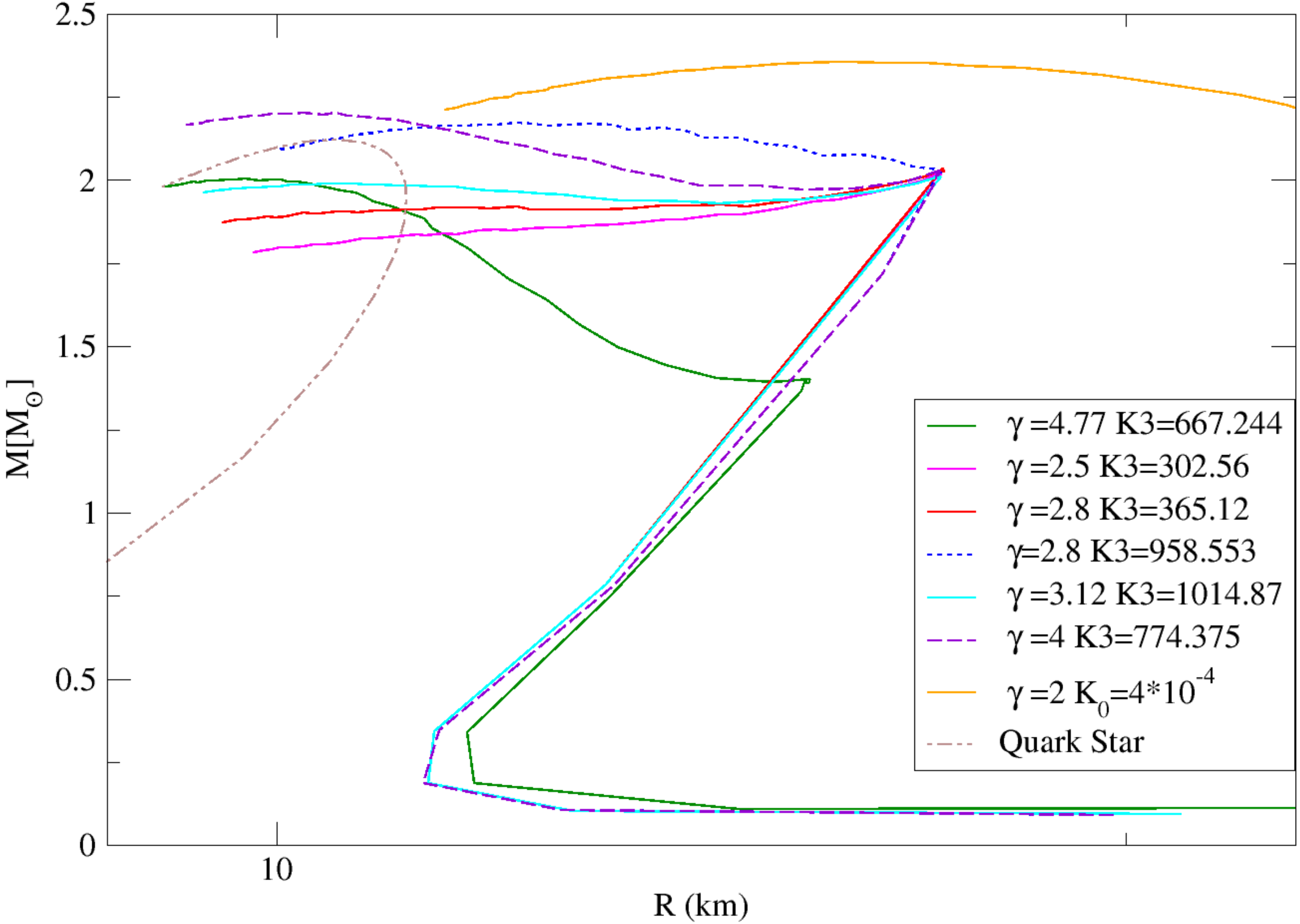
10000
1000
100
10
1
0
500
1000
1500
2000
2500
3000
Pressure (MeV/fm^3)
Energy density (MeV/fm^3)
γ=2.5, K_3=302.56
γ=2.8, K_3=958.553
γ=3.12, K_3=1014.87
γ=4, K_3=774.375



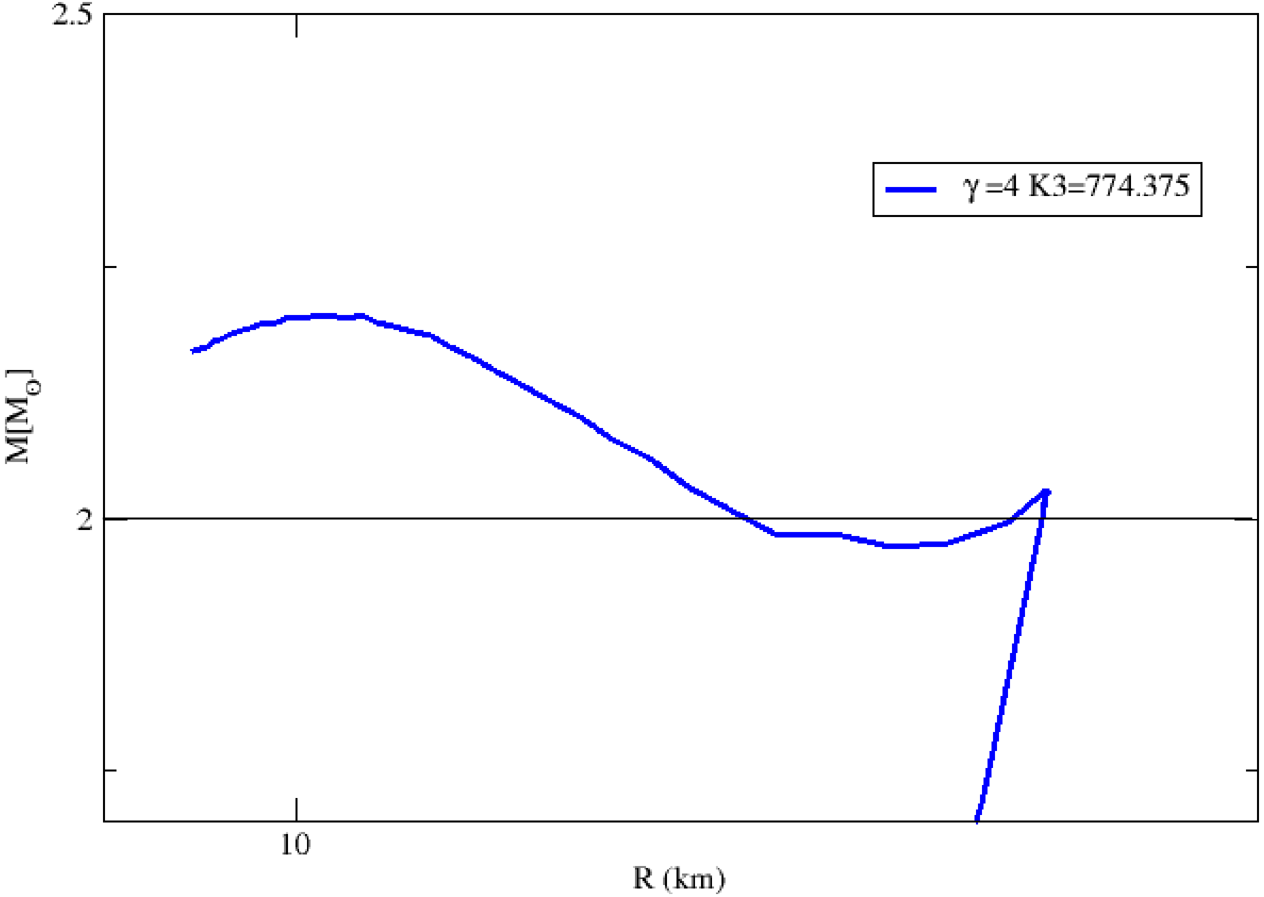
2.5
2
1.5
1
0.5
0
10
R (km)
M[M$_\odot$]
γ =2.5 K3=302.56
γ =2.8 K3=365.12
γ=2.8 K3=958.553
γ =3.12 K3=1014.87
γ =4 K3=774.375

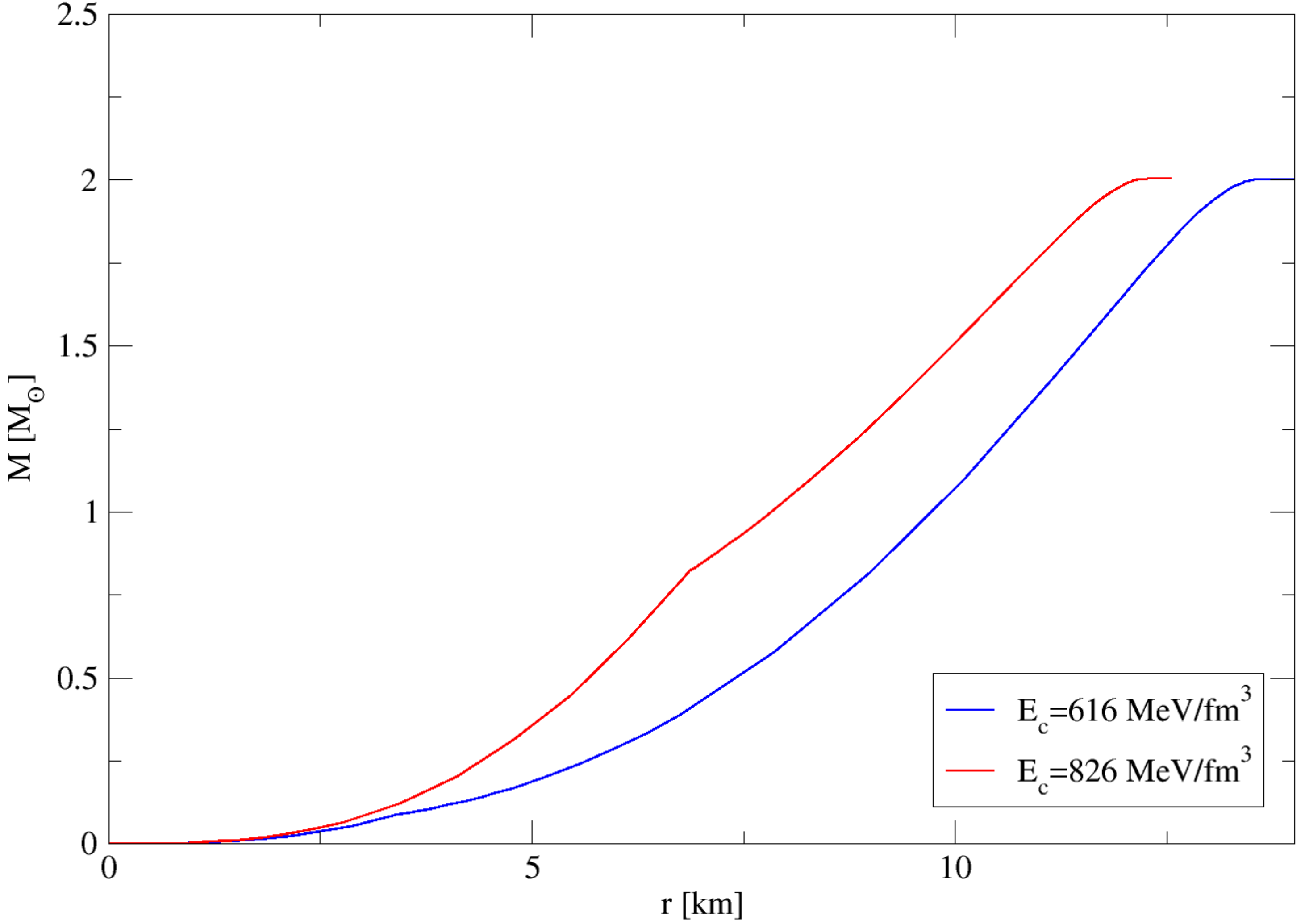


10000
1000
100
10
1
0
1000
2000
3000
4000
Pressure (MeV/fm^3)
Energy density (MeV/fm^3)
γ=4.77, K3=667.244
γ=2.5, K3=302.56
γ=2.8, K3=365.12
γ=2.8, K3=958.553
γ=3.12, K3=1014.87
γ=4, K3=774.375
γ=2, K0=4*10^-4
Quark Star

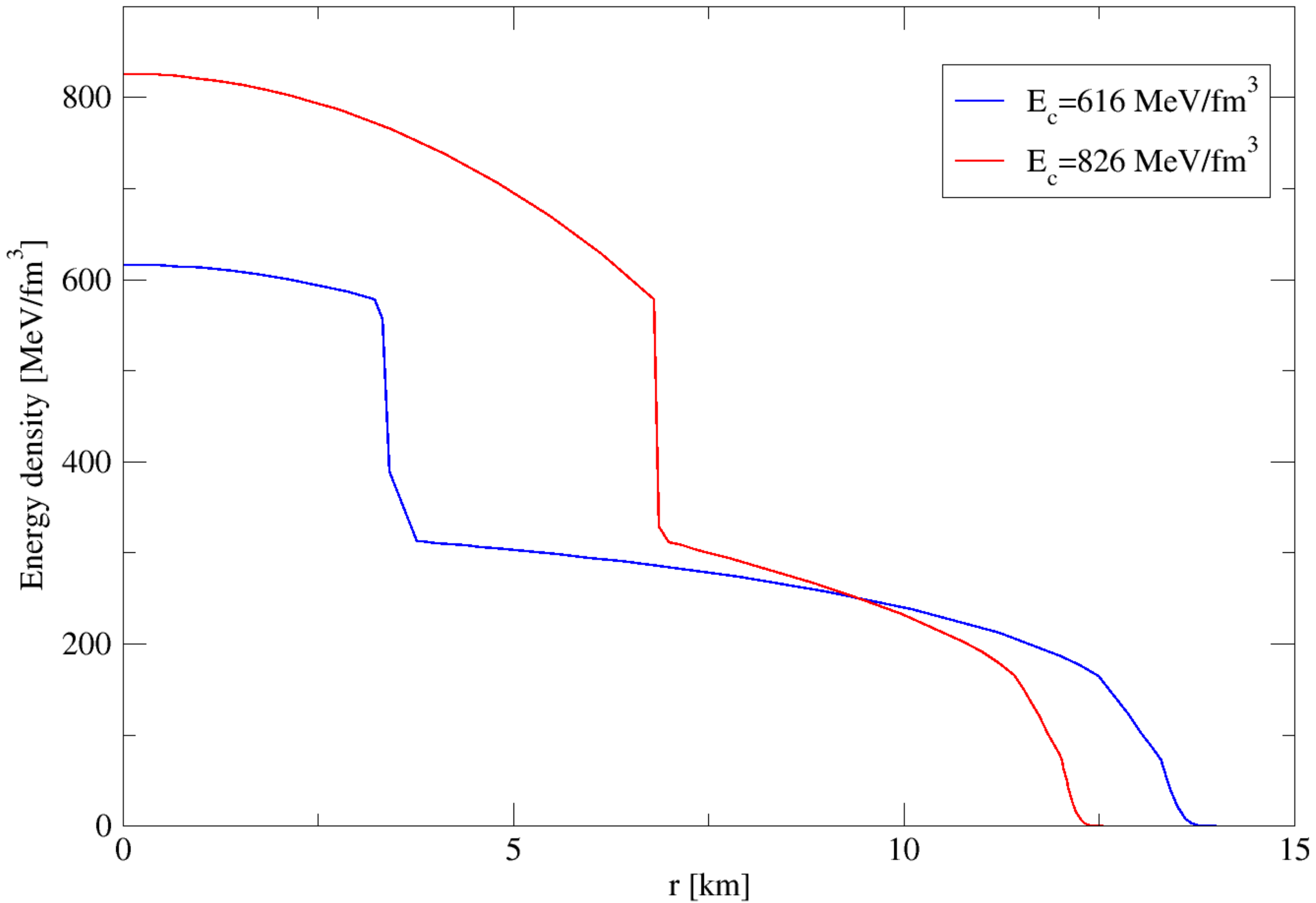

2.5
2
1.5
1
0.5
0
10
M[M$_\odot$]
R (km)
γ =4.77 K3=667.244
γ =2.5 K3=302.56
γ =2.8 K3=365.12
γ=2.8 K3=958.553
γ =3.12 K3=1014.87
γ =4 K3=774.375
γ =2 K$_0$=4*10^{-4}
Quark Star

Twin Neutron Stars

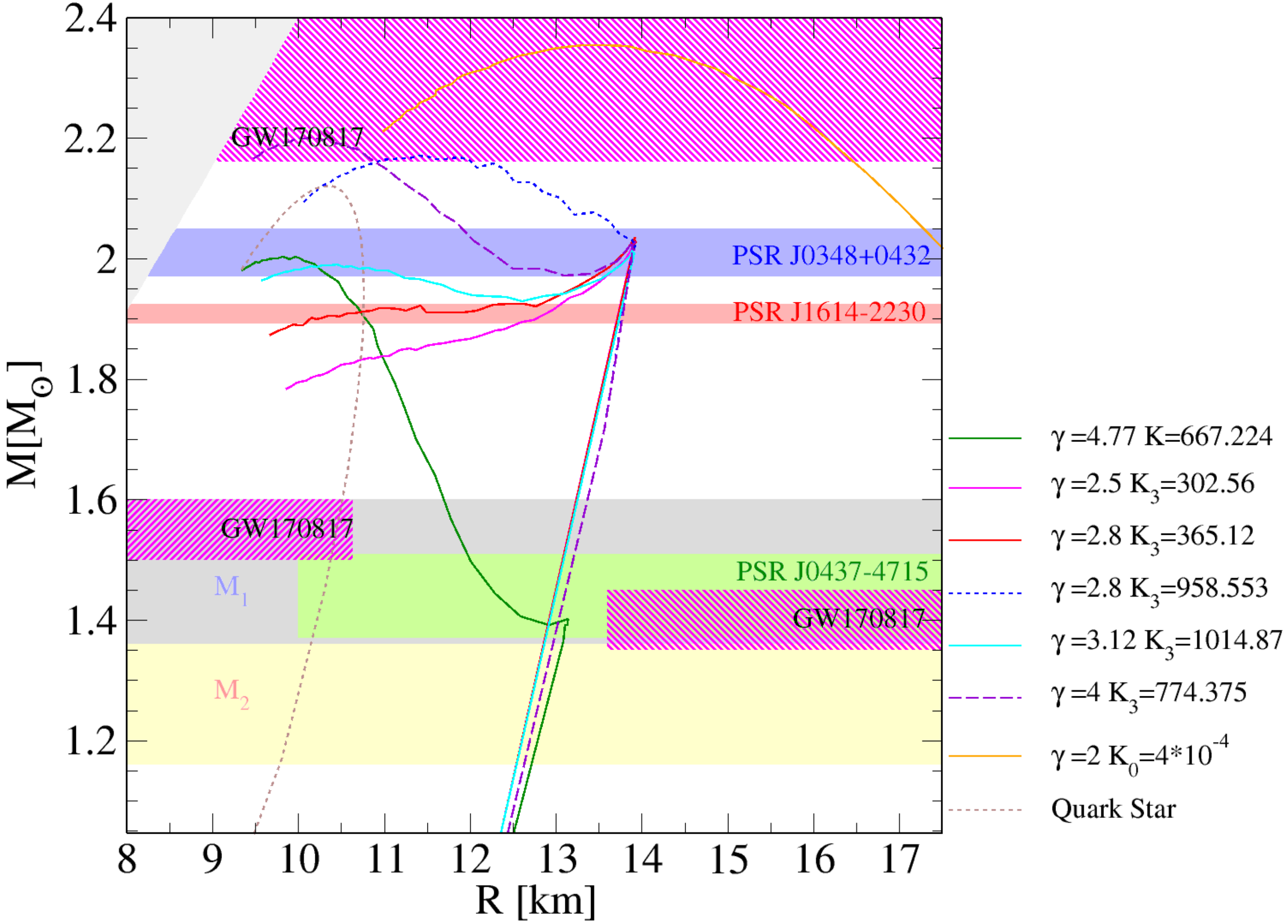




2.5
2
1.5
1
0.5
0
M [M⊙]
0
5
10
r [km]
E_c=616 MeV/fm^3
E_c=826 MeV/fm^3



E$_c$=616 MeV/fm^3
E$_c$=826 MeV/fm^3
Energy density [MeV/fm^3]
r [km]
0
200
400
600
800
0
5
10
15



M[M$_\odot$]
R [km]
GW170817
GW170817
GW170817
PSR J0348+0432
PSR J1614-2230
PSR J0437-4715
M$_1$
M$_2$
γ =4.77 K=667.224
γ =2.5 K$_3$=302.56
γ =2.8 K$_3$=365.12
γ =2.8 K$_3$=958.553
γ =3.12 K$_3$=1014.87
γ =4 K$_3$=774.375
γ =2 K$_0$=4*10^{-4}
Quark Star

Conclusions:

1. Neutron stars observations provide us with indirect constraints on nuclear structure, QGP and other exotic EoS
2. Indirect observations of neutron stars radii can provide us with direct evidence for the existence of twin neutron stars with different internal structure
3. The present constraints allow us to rule out certain EoS and provide us with a tool that can complement experiments such as NICA at studying high-density nuclear matter and QGP

Thank you!

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Questions?