Maximum mass of a Quark Star in the light of Combustion adiabat

Ritam Mallick, Department of Physics,
IISER Bhopal, India

Motivation

Aware of merging Black holes and Neutron stars as source of Gravitational waves (GW) (Nobel Prize in 2017)

Involves a binary always

What about single NS producing GW ?
If at all possible are they detectable?

What about phase transition in neutron stars

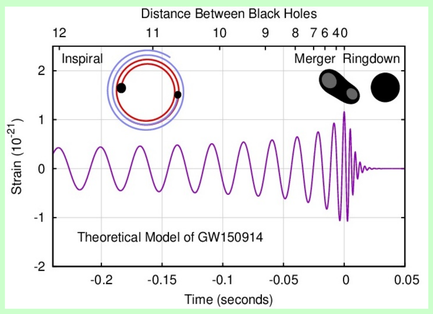
Neutron stars ⟶ Quark stars

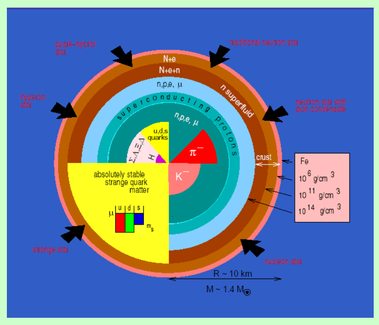
Very dense ⟶ 10^{15} gm/cc

High B field ⟶ 10^{8}-10^{12} G

After The PT ⟶ what is the mass of QS

Is there any maximum mass of QS produced after PT ?





Results

Starting from (X_h, p_h) ⟶ (X_h, p'_h) same curve ⟶ shock wave
Point (X_h, p_h) ⟶ (X'_q, p'_q) different EoS ⟶ detonation/deflagration

Changing the input values (X_h, p_h) ⟶ upstream curve
(X_h, p_h) as Input ⟶ solving the CA (QM EoS) ⟶ downstream (X'_q, p'_q)

R_I ⟶ initial Rayleigh line

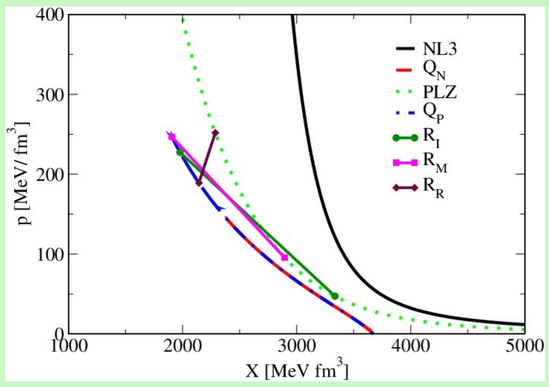
Maximum Point in the QM curve

R_M ⟶ Max Rayleigh Line

R_R ⟶ Retracing Rayleigh Line

Slope of Rayleigh line changes

Seen in both NL3/PLZ EoS

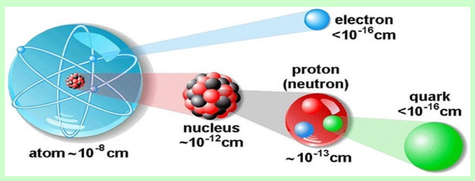


Phase transition

Shock Induced Phase transition ⟶ Two Step

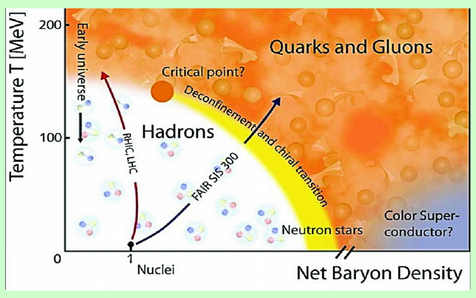
Nucler ⟶ 2 flavour Quark
Strong Interacting Timescale

Neutron star, mainly neutrons
Resulting in excess of down quarks



2 flavour ⟶ 3 flavour
Weak Reaction
u + d ⟶ u + s

Sudden density fluctuation ⟶ Shock
Shock Propagates ⟶ centre to surface
PT accompanied by shock
Shock condition studied by Rankine Hugoniot



Rankine Hugoniot to Combustion adiabat

Rankine Hugoniot jump condition

Energy Conv. $w_h\gamma_h^2 v_h = w_q\gamma_q^2 v_q;$

Momentum Conv. $w_h\gamma_h^2 v_h^2 + p_h = w_q\gamma_q^2 v_q^2 + p_q;$

Baryon number Conv. $n_h v_h \gamma_h = n_q v_q \gamma_q \equiv j;$

the mass flux can be written as (e3)

$$v_h\gamma_h = \frac{j}{n_h}, \qquad v_q\gamma_q = \frac{j}{n_q}.$$

using (e2 and e4)

$$w_h\left(\frac{j}{n_h}\right)^2 + p_h = w_q\left(\frac{j}{n_q}\right)^2 + p_q.$$

$$-j^2 = \frac{p_q - p_h}{\mu_q/n_q - \mu_h/n_h}.$$

Using e1 and e3 $\mu_h\gamma_h = \mu_q\gamma_q$

e6 can then be written as $\mu_q{}^2 - \mu_h{}^2 = (p_q - p_h)(\frac{\mu_h}{n_h} + \frac{\mu_q}{n_q}).$

Substituting e3 we get $j^2\left(\frac{\mu_h^2}{n_h^2} - \frac{\mu_q^2}{n_q^2}\right) = (p_q - p_h)\left(\frac{\mu_h}{n_h} + \frac{\mu_q}{n_q}\right)$

Finally the CA becomes $(\mu_h u_h)^2 - (\mu_q u_q)^2 = (p_q - p_h)\left(\frac{\mu_h}{n_h} + \frac{\mu_q}{n_q}\right)$

$X_i = w_i/n_i^2 = \mu_i/n_i$

$$w_q X_q - w_h X_h = (p_q - p_h)(X_h + X_q).$$

H ⟶ the hadronic upstream quantities — Same EoS ⟶ TA

Q ⟶ The quark downstream quantities — Different EoS ⟶ CA

The maximum downstream pressure ⟶ the maximum point of the burnt curve

⟶ Beyond which retraces its path

Density/Pressure of the QM has a maximum (when phase transformed from NM)

NS ⟶ QS ⟶ also has a Max

Initail part (R_I, $P_Q > P_H$)

Later part (R_R, $P_Q < P_H$) ⟶ Samll QS

QS has a maximum bound

Large energy output ⟶ GW, GRB, neutrino

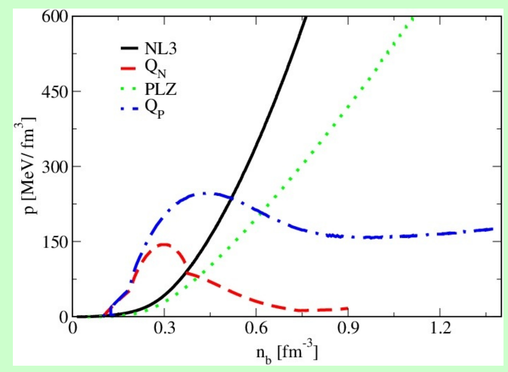
$$|v_h| = \left[\frac{(p_q - p_h)(\varepsilon_q + p_h)}{(\varepsilon_q - \varepsilon_h)(\varepsilon_n + p_q)}\right]^{1/2}$$

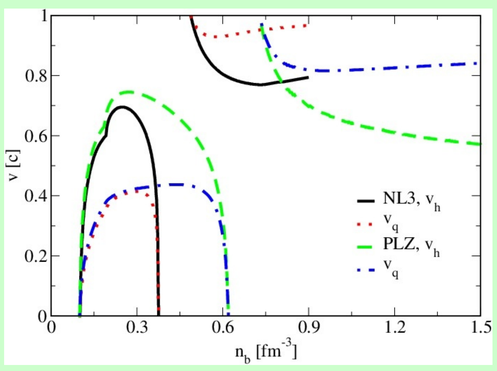
$$|v_q| = \left[\frac{(p_q - p_h)(\varepsilon_h + p_q)}{(\varepsilon_q - \varepsilon_h)(\varepsilon_q + p_h)}\right]^{1/2}$$

(i) $v_q > v_h$, detonation.
(ii) $v_q < v_h$, deflagration.

Low density ⟶ Deflagration

High density ⟶ Detonation





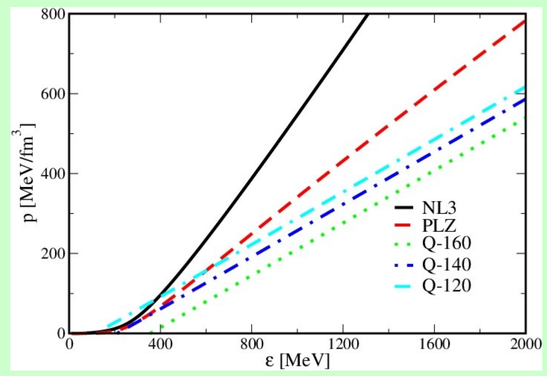
Discussion

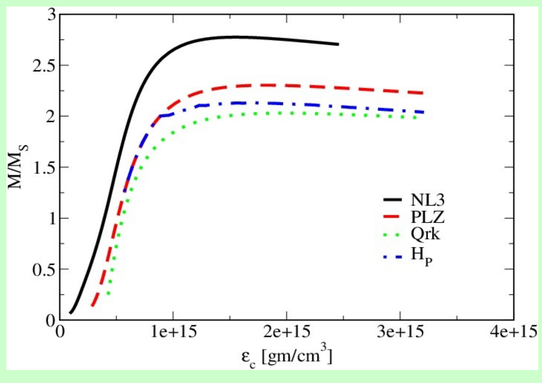
Finding the maximum mass

Maximum of Pressure (pressure figure)
Maximum of energy density (EoS figure)
Maximum of mass (M-E curve)

PLZ EoS
NS(1.9 M_S) ⟶ QS(1.7 M_S)
HS

The PT QS has a maximum mass





The velocity curve
Deflagaration ⟶ Massive QS
Detonation ⟶ Samll QS

For some density of NS ⟶ PT does not occur

All NS does not suffer PT

Strangeness In Quark Matter 2019
10-15 June, 2019, Bari, Italy

Contact: mallick@iiserb.ac.in

webpage: http://home.iiserb.ac.in/~mallick/

Reference:
Combustion adiabat and the maximum mass of Quark star
Ritam Mallick & Mohammad Irfan, MNRAS, doi:10.1093/mnras/stz454, 2019