Stellar and terrestrial observations from the *mean field* QCD model

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Aspects of QCD :

- ✓ Asymptotic Freedom (AF)
- ✓ Confinement
- ✓ Chiral Symmetry Restoration

Modeling QCD Properties:

We can build a phenomenological model representing QCD properties.

In that case, we can represent quark-quark interactions by a phenomenological potential which incorporates AF and confinement into its structure.

Richardson Potential

$$V(q) = -\frac{N_c+1}{2N_c}\frac{12\pi}{33-2N_f}\frac{1}{q^2\ln(1+\frac{q^2}{\Lambda^2})}$$

$$V(r) = -\frac{N_c+1}{2N_c}\frac{6\pi}{33-2N_f}\left[\Lambda^2 r - f(\Lambda r)\right]$$

$$f(t) = 1 - 4\int_1^{\alpha}\frac{dx}{x}\frac{\exp(-xt)}{\{\ln(x^2-1)\}^2+\pi^2}$$

$$\Lambda \sim 400\ MeV$$

J. Richardson, Phys. Lett. B 82 (1979) 272

H. W. Crater, P. Van Alstine, PRL 53 (1984) 1527

Dey et al, Phys. Rev. D 34 (1986) 2104

Dey et al, PLB 438 (1998) 123 $\Lambda \sim 100\ MeV$

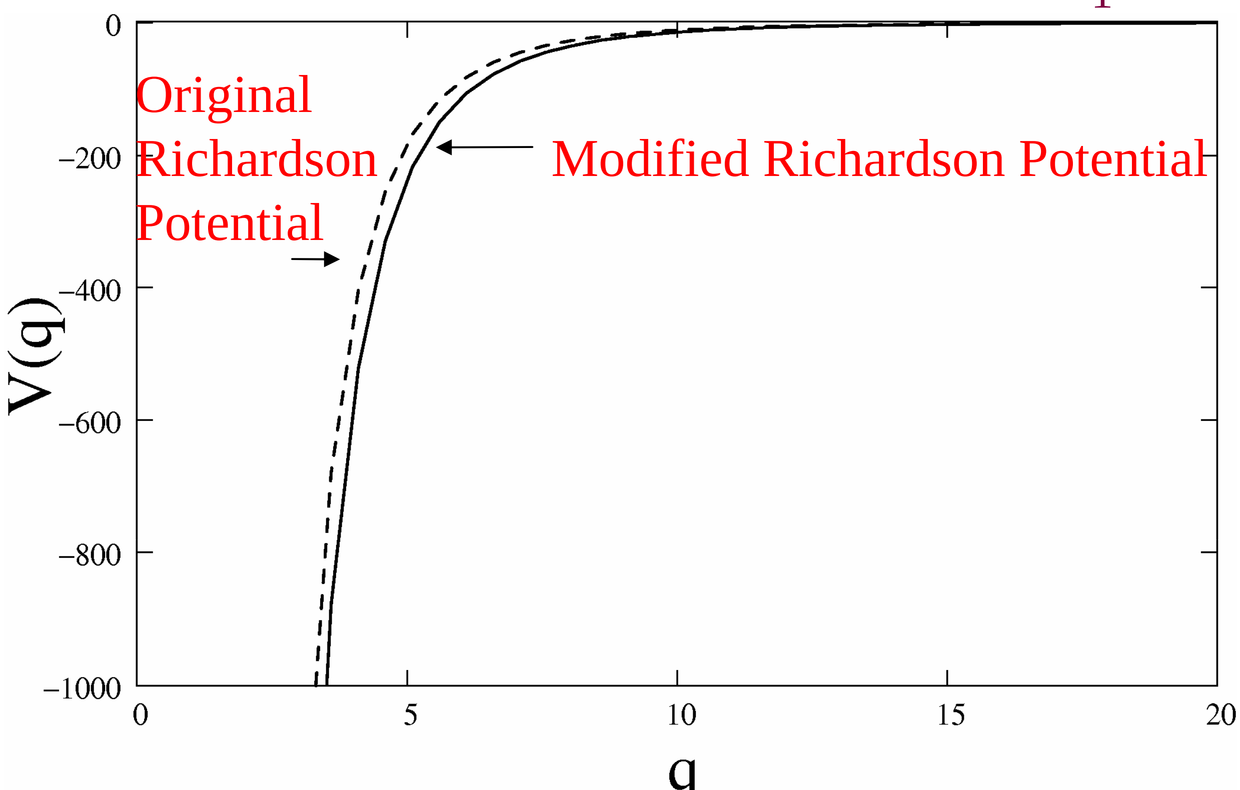
Modified Richardson Potential

$$V(q) = -\frac{N_c+1}{2N_c}\frac{12\pi}{33-2N_f}\left[\left(\frac{1}{q^2\ln(1+\frac{q^2}{\Lambda^2})} - \frac{\Lambda^2}{q^4}\right) + \frac{\Lambda'^2}{q^4}\right]$$

$$V(r) = -\frac{N_c+1}{2N_c}\frac{6\pi}{33-2N_f}\left[\Lambda'^2 r - f(\Lambda r)\right]$$

$$\Lambda = 100\ MeV;\ \Lambda' = 350\ MeV$$

$$f(t) = 1 - 4\int_1^{\alpha}\frac{dx}{x}\frac{\exp(-xt)}{\{\ln(x^2-1)\}^2+\pi^2}$$



AF and Confinement are inbuilt with correct scales.

Test of modified Richardson Potential in baryonic sector :

Bagchi et al, NPA 740 (2004) 109.

Bagchi et al, Europhys. Lett. 75 (2006) 548.

$$\Lambda = 100\ MeV;\ \Lambda' = 350\ MeV$$

Test of modified Richardson Potential in baryonic sector :

$$\phi_q(r) = \left[\frac{1}{4\pi}\right]^{\frac{1}{2}} \begin{pmatrix} iG(\vec{r})\chi_m \\ \vec{\sigma}.\hat{r}F(\vec{r})\chi_m \end{pmatrix}; \qquad q = u, d, s$$

$\phi_q(r)$ is the quark wave function, χ_m is the Pauli spinor

$$G(r) = \sum_n C_n R_{n0}(r)$$

$$F(r) = \sum_m D_m R_{m1}(r)$$

$$R_{nl}(r) = \sqrt{\frac{2n!}{\Gamma(n+l+\frac{3}{2})}} r^l exp(-\frac{1}{2}r^2) L_n^{l+\frac{1}{2}}(r^2)$$

$L_n^{l+\frac{1}{2}}(r^2)$ are Associated Laguerre polynomials

Test of modified Richardson Potential in baryonic sector :

$$H = \sum_{i}^{3} t_i + \sum_{i<j} V(r_{ij}) \qquad i = 1,2,3; \quad j = 1,2,3; \quad t_i = \vec{\alpha}.\vec{p}_i + \beta m_i$$

$$E = < \Psi_B | H | \Psi_B > \qquad [t_i + \omega_i(r_i)]\, \phi_i(r_1) = \epsilon_i \phi_i(r_1 i)$$

$$\omega_1(r_1) = \int \phi_2{}^{\dagger}(r_2) V(r_{12}) \phi_2(r_2) r_2{}^2 dr_2 + \int \phi_3{}^{\dagger}(r_3) V(r_{13}) \phi_3(r_3) r_3{}^2 dr_3$$

$$\frac{dG_i(r_i)}{dr_i} - (m_i - \omega_i(r_i) + \epsilon_i)\, F_i(r_i) = 0$$

$$\frac{dF_i(r_i)}{dr_i} + \left(\frac{2}{r_i}\right) F_i(r_i) + (\epsilon_i - \omega_i(r_i) - m_i)\, G_i(r_i) = 0$$

$$E = \sum_i \epsilon_i - \frac{1}{2} \sum_i \int \phi_i{}^{\dagger}(r_i) \omega_i(r_i) \phi_i(r_i) r_i^2 dr_i$$

$$M = E - T_{CM}$$

Test of modified Richardson Potential in baryonic sector :

$$\mu_q = \frac{e_q}{2} \int \left(\vec{r} \times \vec{j} \right) d^3 r \qquad \vec{j} = \phi_q \vec{\alpha} \phi_q$$

$$\mu_{q\uparrow(\downarrow)} = -(+) e_q \frac{2}{3} \int_0^\infty G(r) F(r) r^3 dr$$

Baryonic magnetic moments (μ_B) are found by combining μ_q s with the help of baryonic wave function $\Psi_{spin} \times \Psi_{flavor}$

Test of modified Richardson Potential in baryonic sector :

Baryons	Experimental Mass (MeV)	Theoretical Mass (MeV)
Δ's	1232	1251
Σ^*'s	1383 1384 1387	1361
Ξ^*'s	1532 1535	1455
Ω^-	1672	1556
N	939	938
Σ's	1189 1193 1197	1188
Λ^0	1116	1098
Ξ's	1315 1321	1282

Test of modified Richardson Potential in baryonic sector :

	Δ^{++}	Δ^{+}	Δ^{0}	Δ^{-}	Σ^{*+}	Σ^{*0}	Σ^{*-}	Ξ^{*0}	Ξ^{*-}	Ω^{-}
Ours	+5.77	+2.88	0.03	-2.86	+2.81	+0.17	-2.46	+0.30	-2.17	-1.92
Expt.	+6.14	+2.70	-	-	-	-	-	-	-	-2.02
QCDSR	+6.14	+3.02	0.0	-3.07	+1.90	-0.07	-2.03	+0.80	-2.71	-2.02
lattice	+6.09	+3.05	0.0	-3.05	+3.16	+0.33	-2.5	+0.58	-2.08	-1.73
χpt	+4.0	+2.1	-0.17	-2.25	+2.0	-0.07	-2.2	+0.10	-2.0	-
$1/N_c$	-	+3.04	0.0	-3.04	+3.35	+0.32	-2.79	+0.64	-2.36	-
Dai fit A	+5.84	-	-	-	-	-	-	-	-	-2.08
Dai fit B	+5.86	-	-	-	-	-	-	-	-	-2.06
		p	n		Σ^{+}	Σ^{0} , Λ^{0}	Σ^{-}	Ξ^{0}	Ξ^{-}	
Ours		+2.88	-1.91		+2.59	+0.83, -0.71	-0.92	-1.45	-0.62	
Expt.		+2.79	-1.91		+2.46	-0.61	-1.16	-1.25	-0.65	
QCDSR		+3.04	-1.79		+2.73	-0.50	-1.26	-1.32	-0.93	
CDM		+2.79	-2.07		+2.47	-0.71	-1.01	-1.52	-0.61	
Dai fit A		+2.84	-1.87		+2.46		-1.06	-1.28	-0.61	
Dai fit B		+2.80	-1.92		+2.46		-1.23	-1.26	-0.63	

Application of modified Richardson potential for study of strange star properties :

What is a Strange Star ?

Strange stars are stars composed of strange quark matter i.e. a very high density strange quark phase consisting of deconfined u, d and s quarks. In our model, strange stars are more compact than neutron stars.

Mean Field Model :

- Modified Richardson potential as interquark potential
- Screening of potential due to medium
  – dependence on density and temperature
- Density dependent quark mass
- Charge neutrality, beta equilibrium condition (hard part)
- Relativistic HF formalism to obtain EOS.
- Finite temperature through Fermi function
- TOV equations are solved to obtain the mass-radius of the stars

fermi function $F_i(\mathrm{k_i},T) = \dfrac{1}{\exp\left(\varepsilon_i - \varepsilon_i^f / T\right)}$

$$n_i = \frac{3}{\pi^2}\int_0^\infty k_i^2 F_i \, dk_i \quad \varepsilon_i = \frac{3}{\pi^2}\int_0^\infty \phi \, k_i^2 F_i \, dk_i$$

ϕ is single particle energy – comes from interquark potential

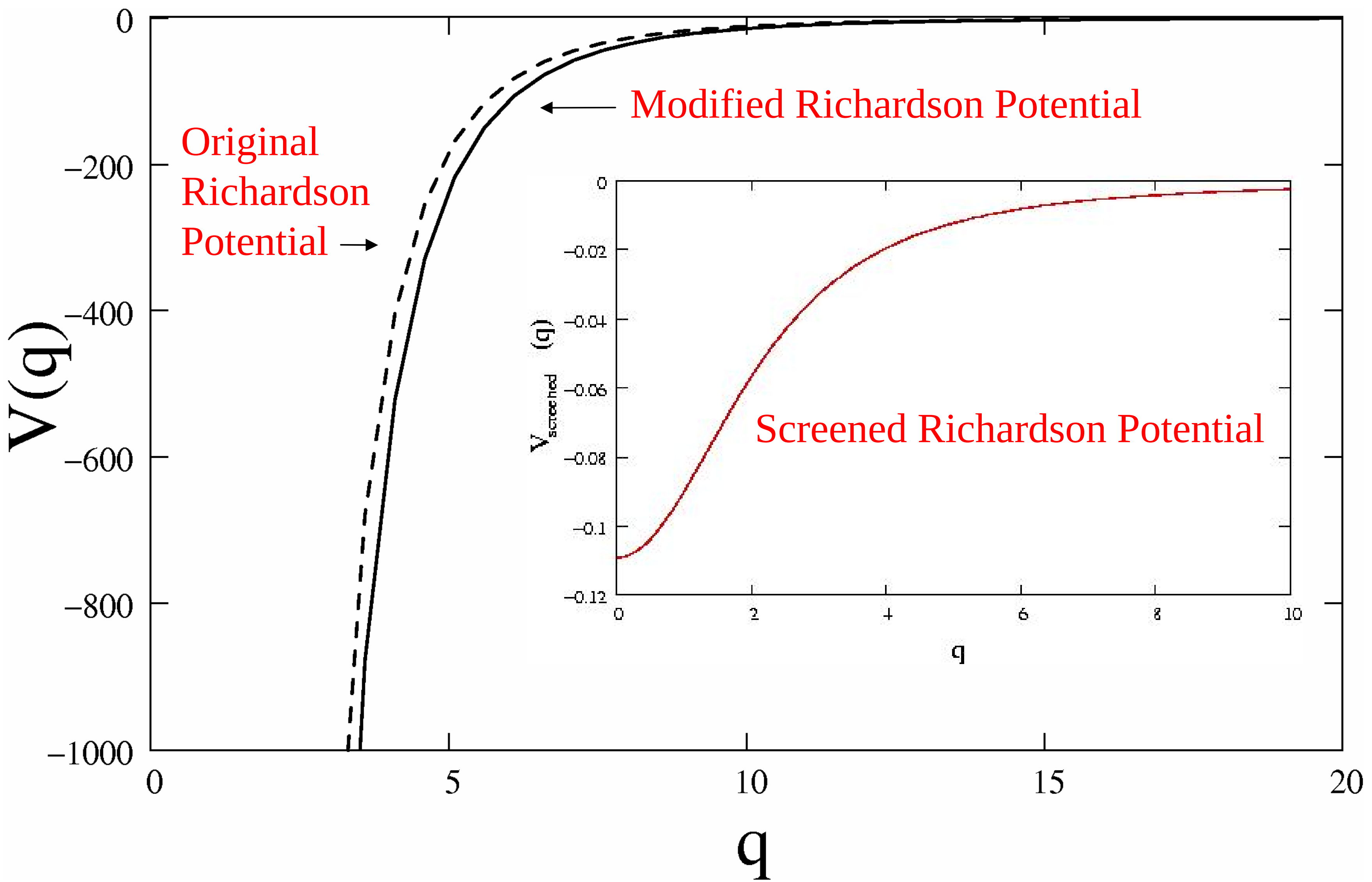
entropies

$$S_i = -\frac{3}{\pi^2}\int_0^\infty \mathrm{k_i^2} F_i(k_i,T)\ln\left(F_i(k_i,T)\right)\left(1-F_i(k_i,T)\right)\ln\left(1-F_i(k_i,T)\right)dk_i$$

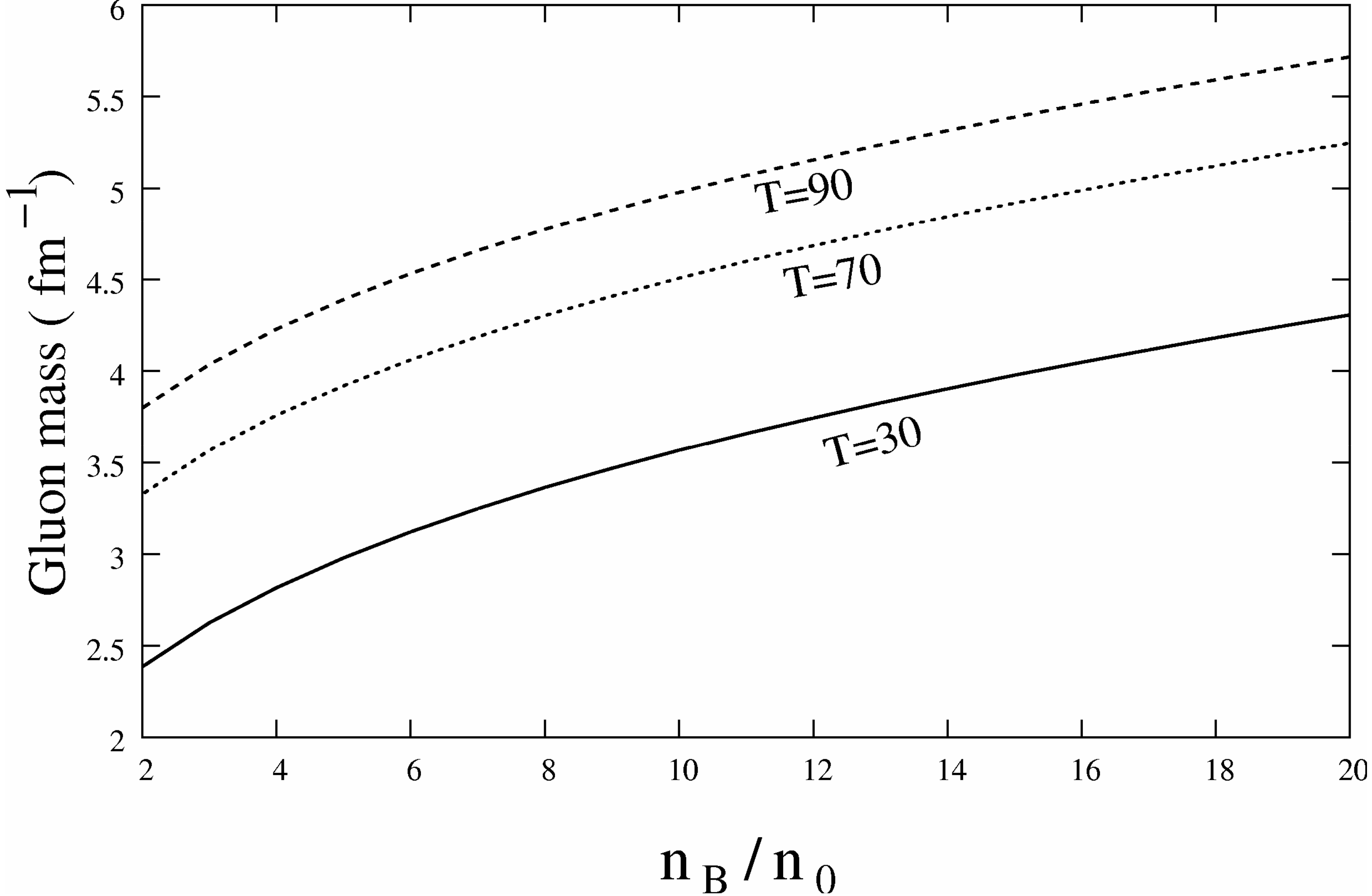
free energies $f_i = \varepsilon_i - TS_i$

pressure $P_i = n_i \dfrac{\partial f_i}{\partial n_i} - f_i \; ; P = \sum_i \mathrm{P_i}$

Bagchi et al, Astron. & Astrophys. 450 (2006) 431.

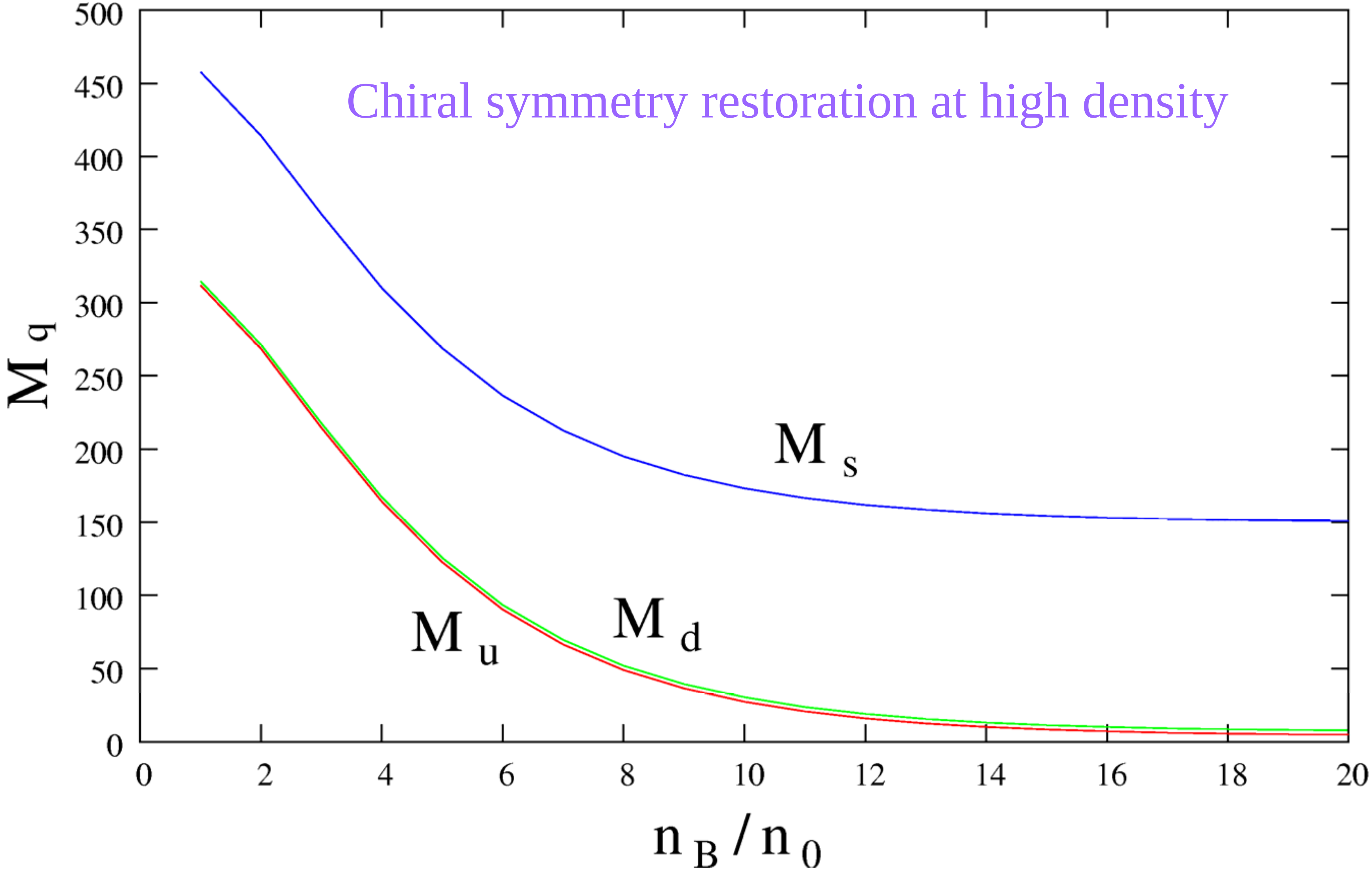


0
−200
−400
−600
−800
−1000
V(q)
0
5
10
15
20
q
Original
Richardson
Potential
Modified Richardson Potential
Screened Richardson Potential
0
−0.02
−0.04
−0.06
−0.08
−0.1
−0.12
$V_{screened}(q)$
0
2
4
6
8
10
q

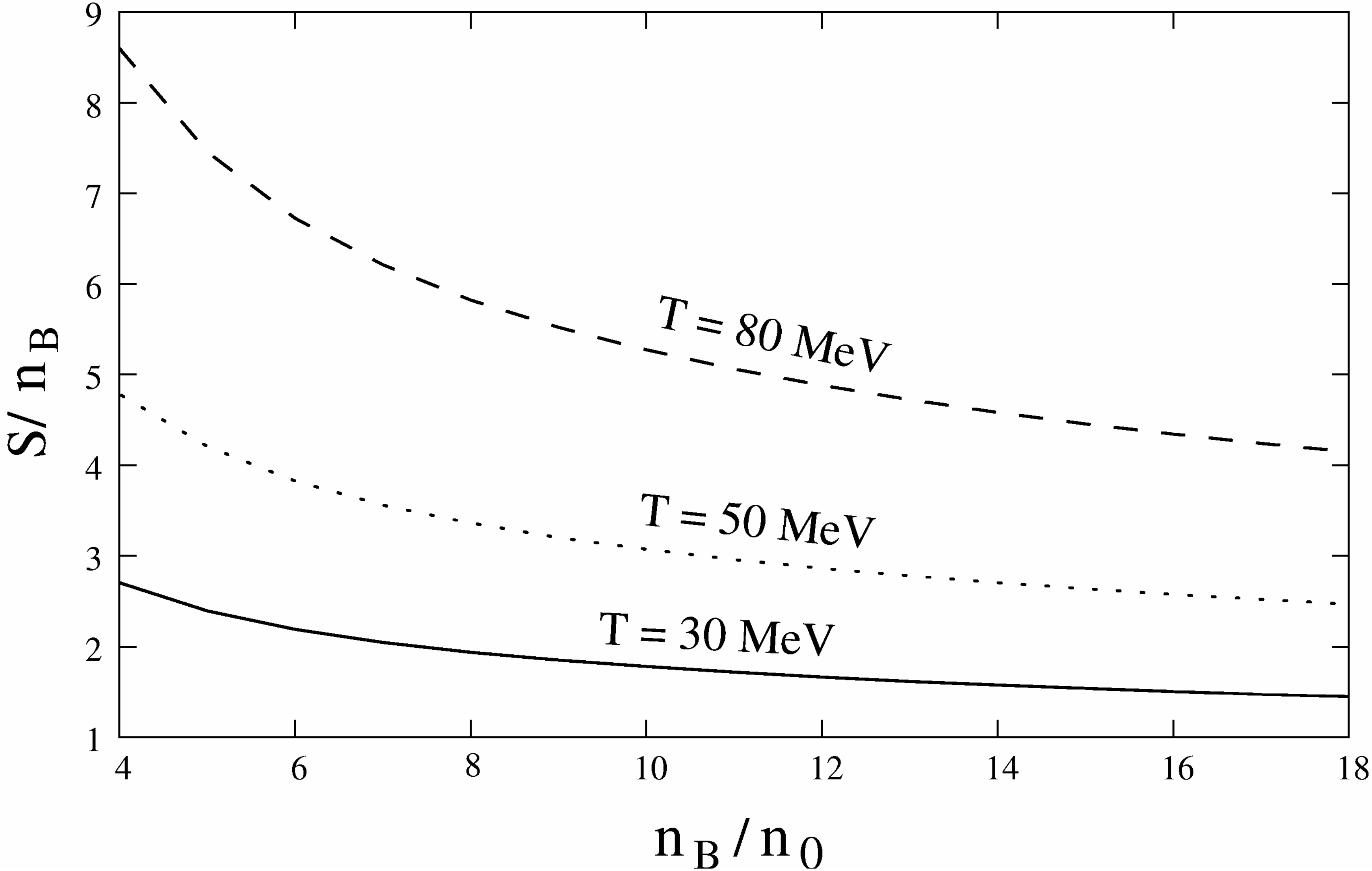


$$q^2 \to q^2 + D^{-2}$$

$$D^{-1} = mg = \left[\frac{2\alpha_0}{\pi} \sum_{i=u,d,s} k_i^f \sqrt{\left(k_i^f\right)^2 + m_i^2} \right]^{1/2} + 7.152\alpha_0 T$$



$$M_q = m_q + M_Q \sec h\left(\frac{n_B}{n_0 N}\right)$$



9
8
7
6
5
4
3
2
1
4
6
8
10
12
14
16
18
S/ n B
n B / n 0
T = 80 MeV
T = 50 MeV
T = 30 MeV

$$\frac{dP}{dr} = -\frac{G}{c^4}[P(r)+\varepsilon(r)]\left[\frac{M(r)c^2 + 4\pi r^3 P(r)}{r^2\left(1-\frac{2GM(r)}{c^2 r}\right)}\right]$$

$$\frac{dM}{dr} = \frac{4\pi r^2 \varepsilon(r)}{c^2}$$

$$\frac{2}{3}n_u - \frac{1}{3}n_s - \frac{1}{3}n_d - n_e = 0 \qquad n_q = \frac{\left(k_q^f\right)^3}{\pi^2},\ n_e = \frac{\left(k_e^f\right)^3}{3\pi^2}$$

$$\mu_s = \mu_d \qquad \mu_s = \mu_u + \mu_e$$

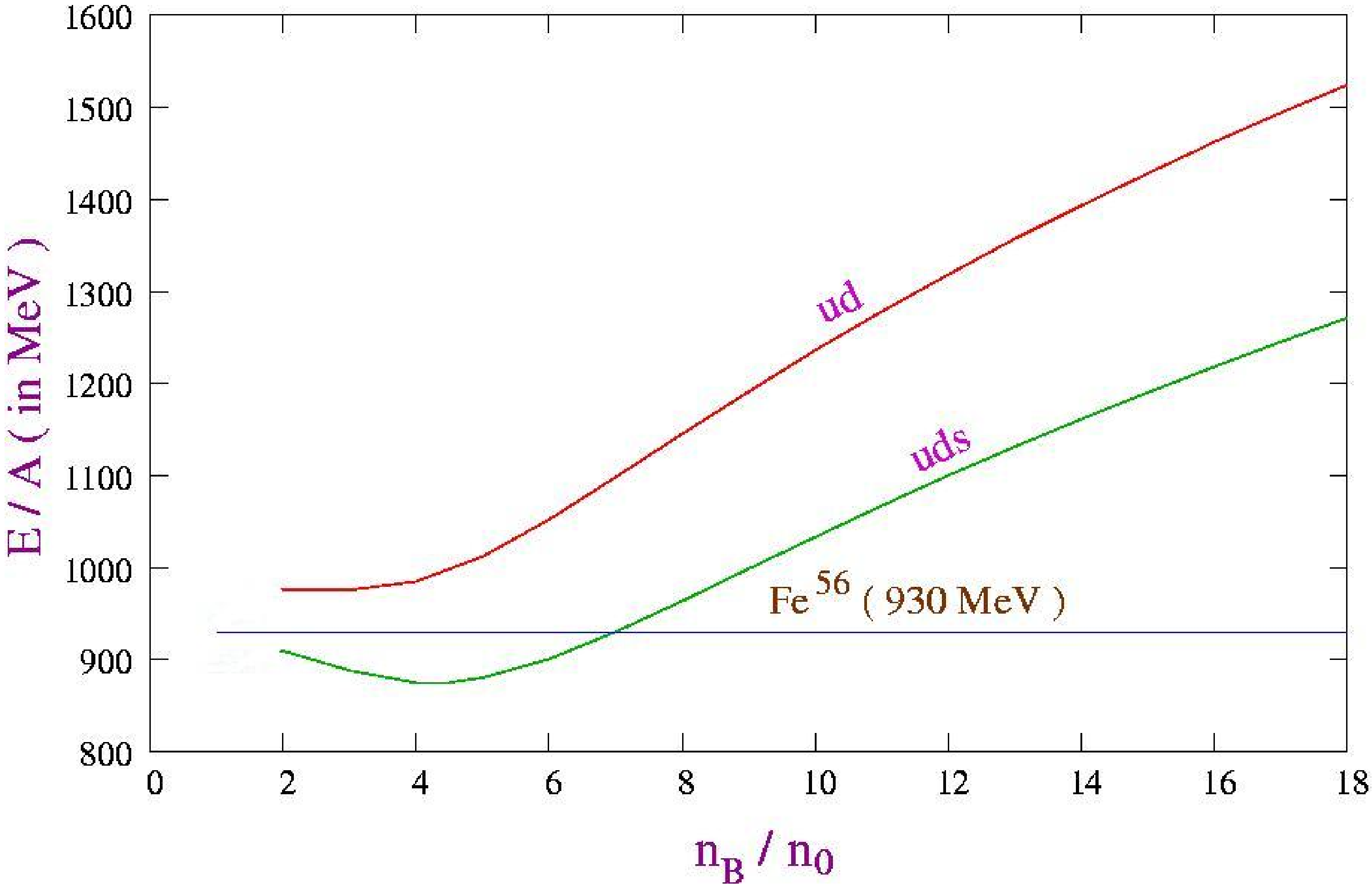
$$s + u \rightleftarrows d + u \qquad s \rightleftarrows u + e + \bar{\nu}$$

$$H = \sum_i \overrightarrow{\alpha_i} . \overrightarrow{p_i} + \beta_i M_i + \sum_{i<j} V_{ij}$$

$$dQ = TdS = dE + PdV - \mu dN$$

$$P = \left(\sum_i \mu_i n_i - \varepsilon_i \right) + \mu_e n_e - \varepsilon_e$$

Property of Strange Quark Matter



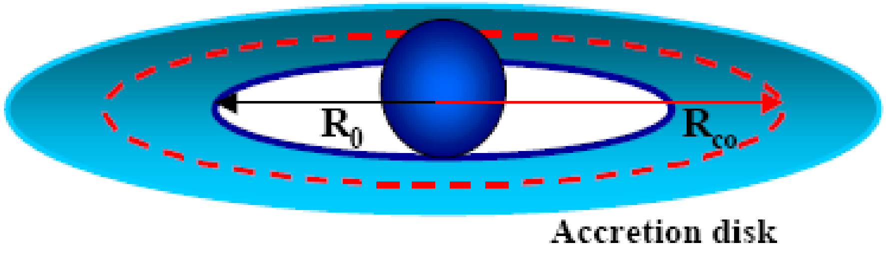
At high density the strange quark matter is hypothesized to be more favorable energetically to normal matter (Bodmer 1971, Witten 1984)

The Mass-Radius relation for SAX J1808.4 -3658

Detection of X-ray pulsation requires:

(1) $R < R_0$

(2) $R_0 < R_{co}$



R = radius of the compact star

R_0 = radius of the inner edge of the accretion disk

R_{co} = corotation radius: $P_{orb}(R_{co}) = P$

$$R_{co} = \left[\frac{GM}{4\pi^2} P^2 \right]^{1/3}$$

The Mass-Radius relation for SAX J1808.4 -3658

- **Spherical accretion (and dipolar magnetic field)**

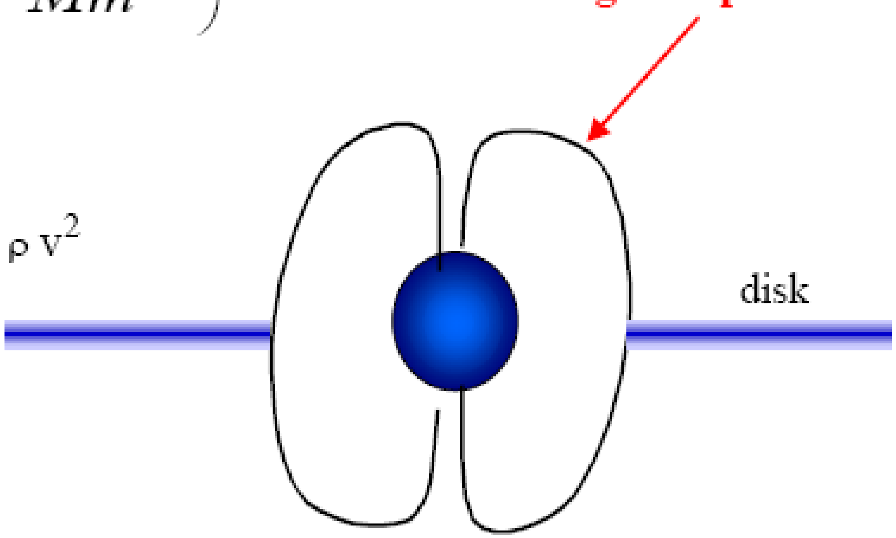
$$R_0 = R_A = \left(\frac{2\pi^2}{G\mu_0^2}\right)^{1/7}\left(\frac{B_s^4 R^{12}}{M\dot{m}^2}\right)^{1/7}$$

Alfvén radius

radius of the stellar magnetosphere

$\dot{m}$ = **mass accretion rate**

$$p_{mag} = p_{ram}\ , \quad p_{mag} \approx B_s^2\left(\frac{R}{r}\right)^6\ , \quad p_{ram} = \rho\, v^2$$



- **Disk accretion**

$$R_0 = \xi\ R_A \qquad \xi \approx 1$$

ξ does not depend on the accretion rate

The Mass-Radius relation for SAX J1808.4 -3658

F = X-ray flux measured with the RXTE

$F = k\,\dot{m}$ k = const

$$R_0 = \xi \left(\frac{2\pi^2}{G\mu_0^2}\right)^{1/7} \left(\frac{B_s^4 R^{12}}{M}\right)^{1/7} k^{-2/7} F^{-2/7} \equiv A\, F^{-2/7}$$

$F_{min} \leq F \leq F_{max}$ X-ray flux variation observed during april-may 1998

Using (1) and (2)

$$R < \frac{A}{F_{max}^{2/7}} < \frac{A}{F_{min}^{2/7}} < R_{co} \Longrightarrow R < \left(\frac{F_{min}}{F_{max}}\right)^{2/7} R_{co}$$

The Mass-Radius relation for SAX J1808.4 -3658

upper limit for the radius of the compact object in SAX J1808.4-3658

$$R < (F_{min} / F_{max})^{2/7} (G M_{\odot} / 4\pi^2)^{1/3} P^{2/3} (M / M_{\odot})^{1/3}$$

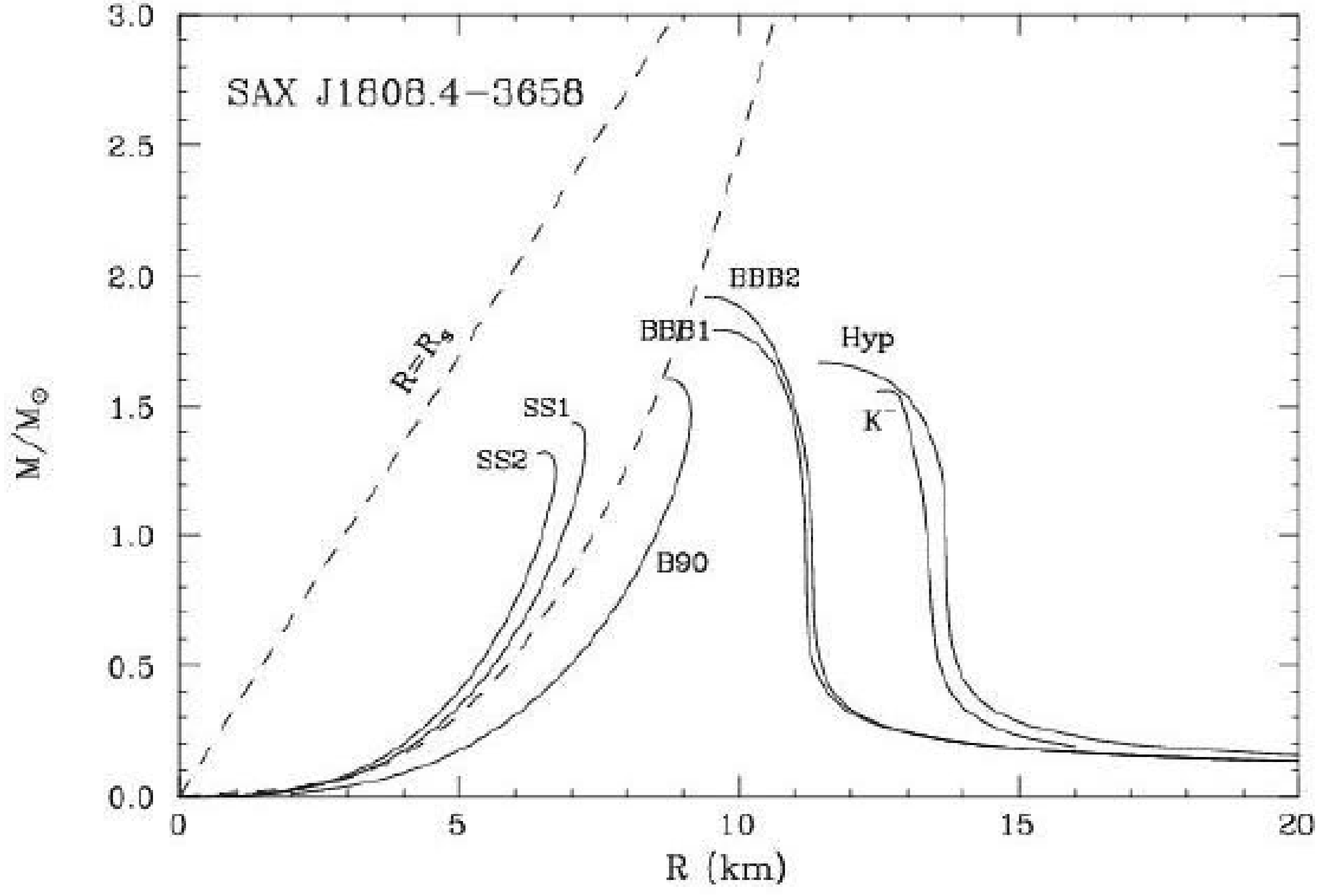
F_{min} = X-ray flux measured during the "low state" of the source
F_{max} = X-ray flux measured during the "high state" of the source

$F_{max} / F_{min} \sim 100$

P = period of the X-ray PSR

X.-D. Li, I. Bombaci, M. Dey, J. Dey, E.P.J. Van den Heuvel,
Phys. Rev. Lett. 83, (1999), 3776

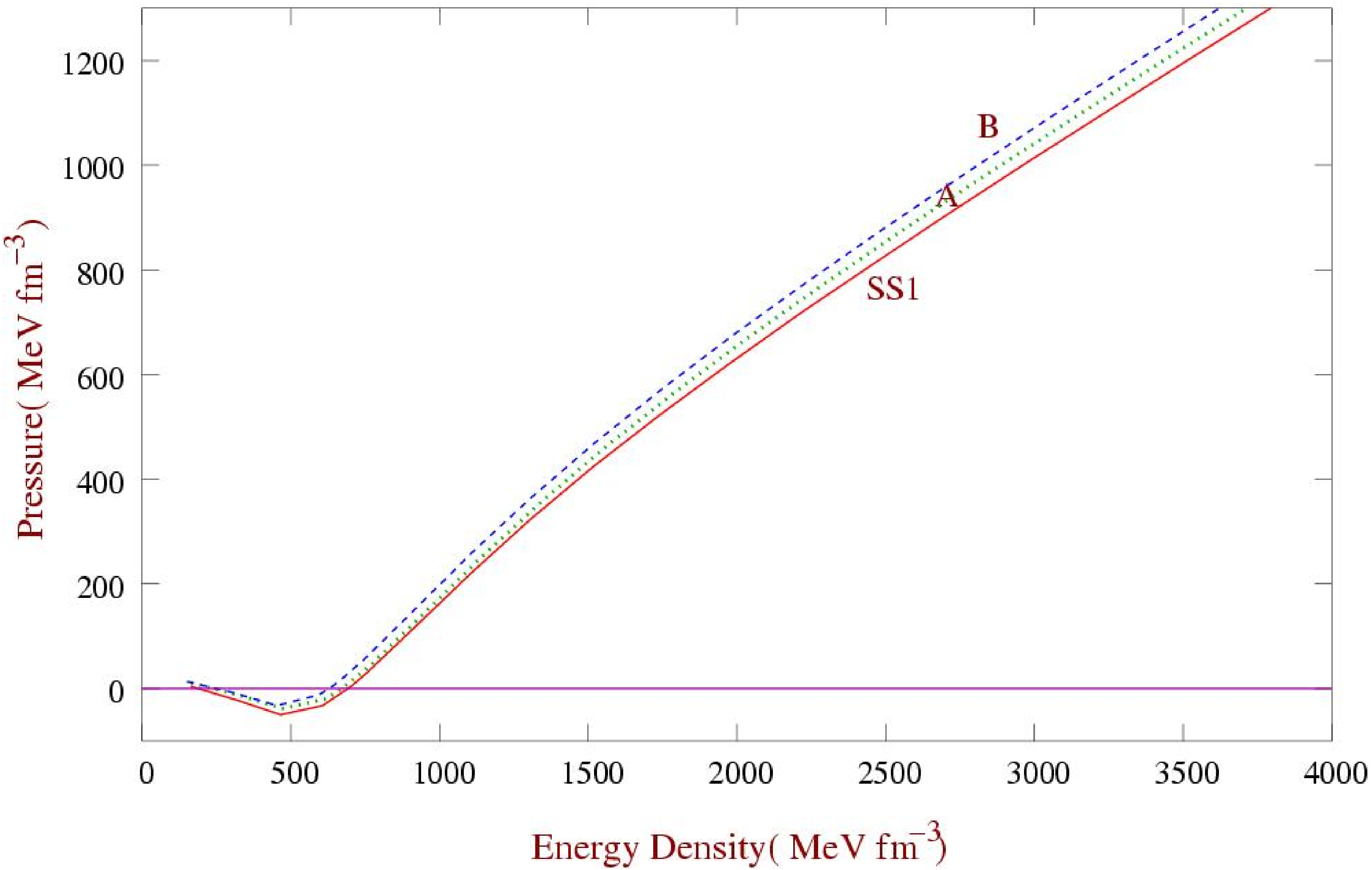
A strange star candidate: SAX J1808.4 –3658



X.D. Li, I. Bombaci, M. Dey, J. Dey, E.P.J. Van den Heuvel, Phys. Rev. Lett. 83 (1999) 3776

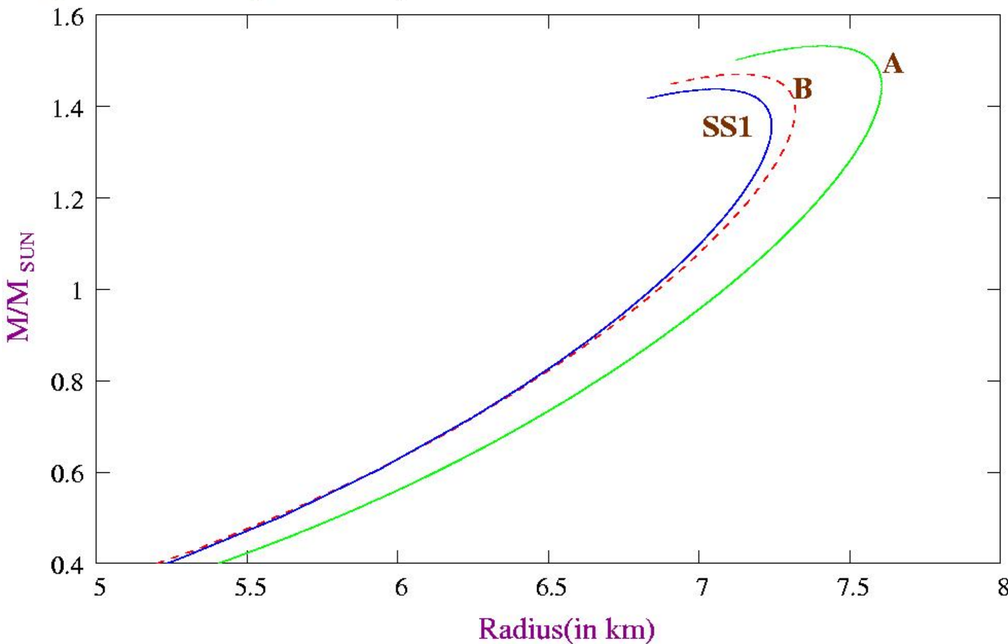
SS1, SS2: M. Dey, I. Bombaci, J. Dey, S. Ray, B.C. Samanta, Phys. Lett. B438 (1998) 123

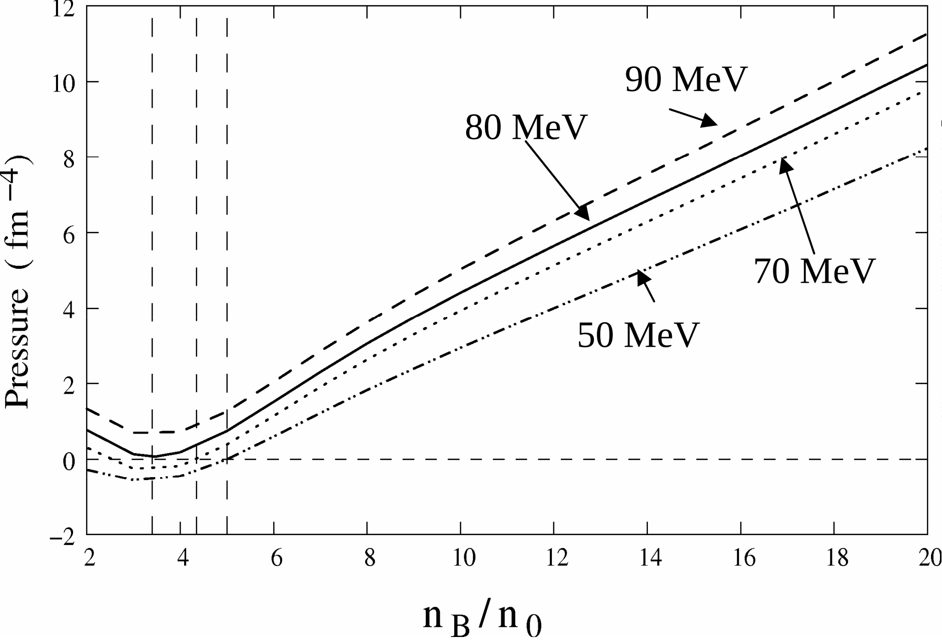
Property of Strange Quark Matter

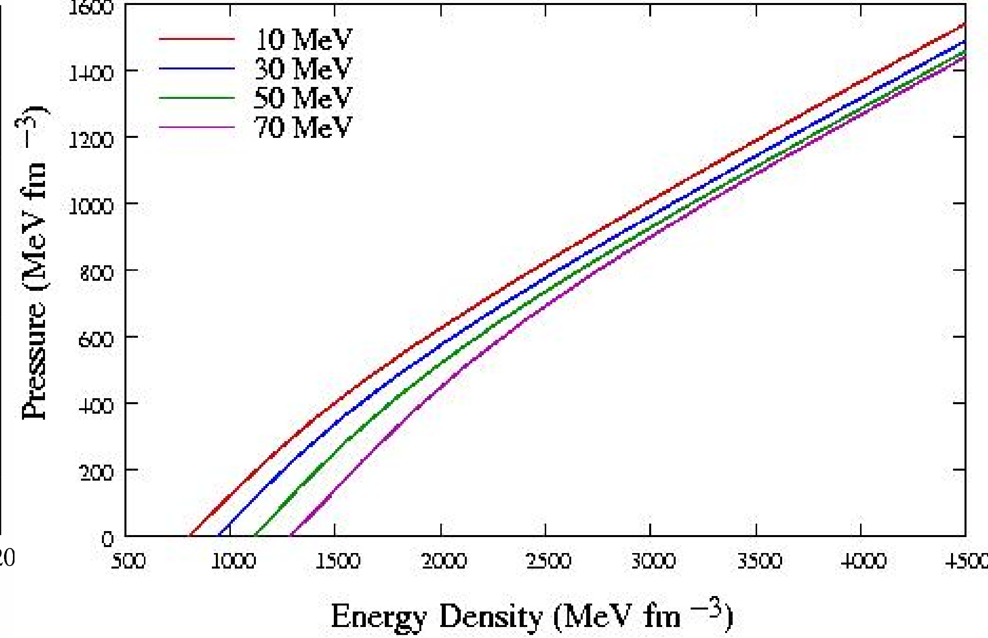


New results

EOS Label	Λ' (MeV)	M_q (MeV)	N	α_0	$(E/A)_{min}$ (MeV)	M_{max} $(M_\odot)$	R (km)
A	350	325	3.0	.55	874.0	1.532	7.411
B	350	325	3.0	.65	907.0	1.470	7.140
C	300	325	2.7	.55	877.0	1.554	7.530
D	300	325	3.0	.55	906.0	1.463	7.110
E	300	335	3.0	.55	912.0	1.447	7.022

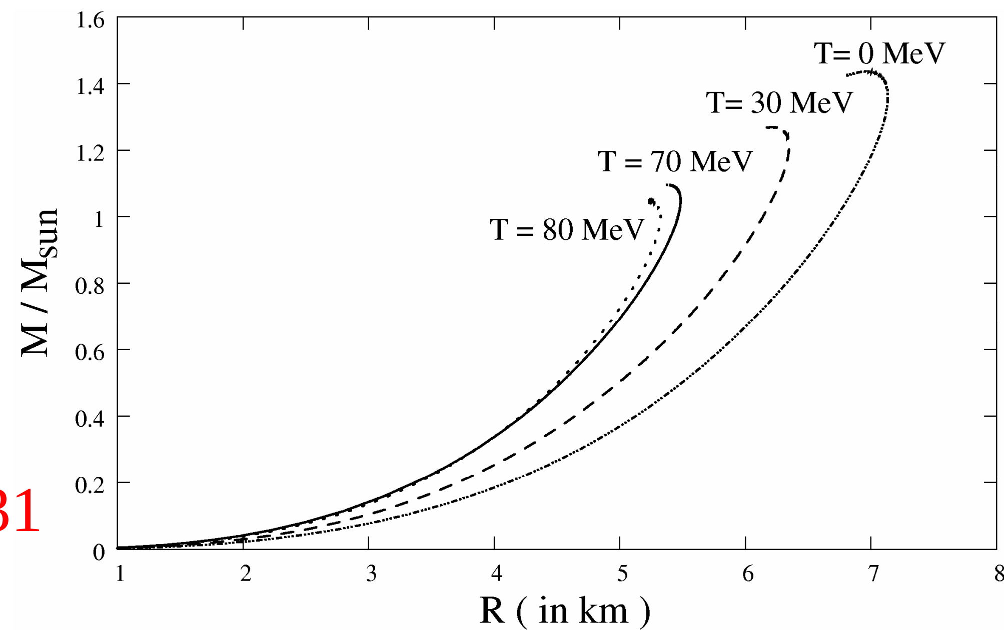






Temp. (MeV)	Mmax (M_{SUN})	Radius (km)	Baryon No. (10^{57})
0	1.44	6.96	2.17
10	1.38	6.72	2.00
30	1.27	6.21	1.64
50	1.12	5.76	1.29
70	1.09	5.37	0.99
80	1.05	5.20	0.85

Bagchi et al, A & A. 450 (2006) 431



New results

Witten argued that if strange quark matter is the ground state, then strange stars can be born in the early universe around a temperature of 100 MeV. From our model we found that stable star structure is possible upto a temperature of 80 MeV. This closeness to Witten's hypothesis supports our SS model. Furthermore, the Kovtun, Sons and Starinets bound is also saturated at this temperature ArXiv 0705.4645 !

Surface Tension

Surface tension is the surface energy per unit area. For ordinary fluid, it is the property of the interaction between the media forming an interface and gravitation does not play any significant role.

Defining Surface Tension

SS is a huge drop of strange quark matter, the pressure difference across the surface can be expressed in terms of S. The pressure on top of the surface is zero.

$$|\Delta P|_{r=R} = \frac{2S}{R} \quad \text{where} \quad |\Delta P|_{r=R} = h\left|\frac{dP}{dr}\right|_{r=R}$$

$$P_{r=R} = \mathbf{0}$$

so $$S = \frac{hR}{2}\left|\frac{dP}{dr}\right|_{r=R}$$

$$\left.\frac{dP}{dr}\right._{r=R} \neq \mathbf{0}$$

What is the relevant thickness h ??

- <u>Interaction radius</u> "r_0" of the quarks.

surface area of an SS = $4 \pi R^2$

thickness of a shell of one quark layer = r_0

volume of the shell = $4 \pi R^2 r_0$

quark number inside the shell $n_t = 4 \pi R^2 r_0 n$

number density at star surface

projection of a quark = πr_0^2

quark number at the surface $n_s = 4 \pi R^2 / \pi r^2 = 4R^2 / r^2$

for densely packed system, $n_s = n_t$

giving $r = \left(\frac{1}{\pi n} \right)^{1/3}$ $r_0 \sim 0.5$ fm - r_0 at surface does not depend on star size. But for a particular star, r_0 increases from centre to surface

" *interaction radius*" of the quarks

A check of interaction radius

$$\sigma_{qq} = \pi r^2$$

$\sigma_{pp} = 3\,\sigma_{qq}$ **Heiselberg, Pethick, PR D 48 (1993) 2916.**

σ_{pp}=25 mb ⟶ **matches with experiment**

Estimated value of surface tension

$$S = \frac{R}{2}\left(\frac{1}{\pi n}\right)^{1/3} \left|\frac{dP}{dr}\right|_{r=R}$$

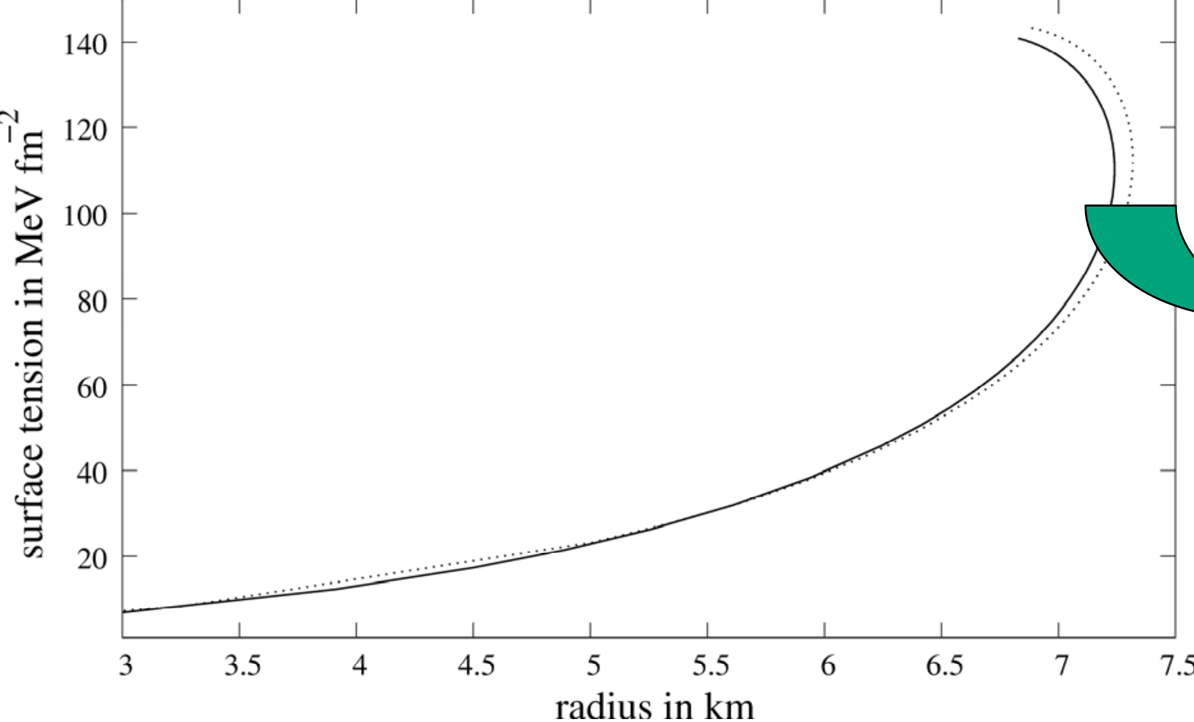
Putting h = r

- Large value of surface tension

  → upto 140 MeV fm^{-2} (174 MeV^{3}). [Typical values of S used in literature range within 10 – 50 MeV fm^{-2} Heiselberg, Pethick, PRD 48 (1993) 2916 : Iida, Sato, PRC 58 (1998) 2538.]

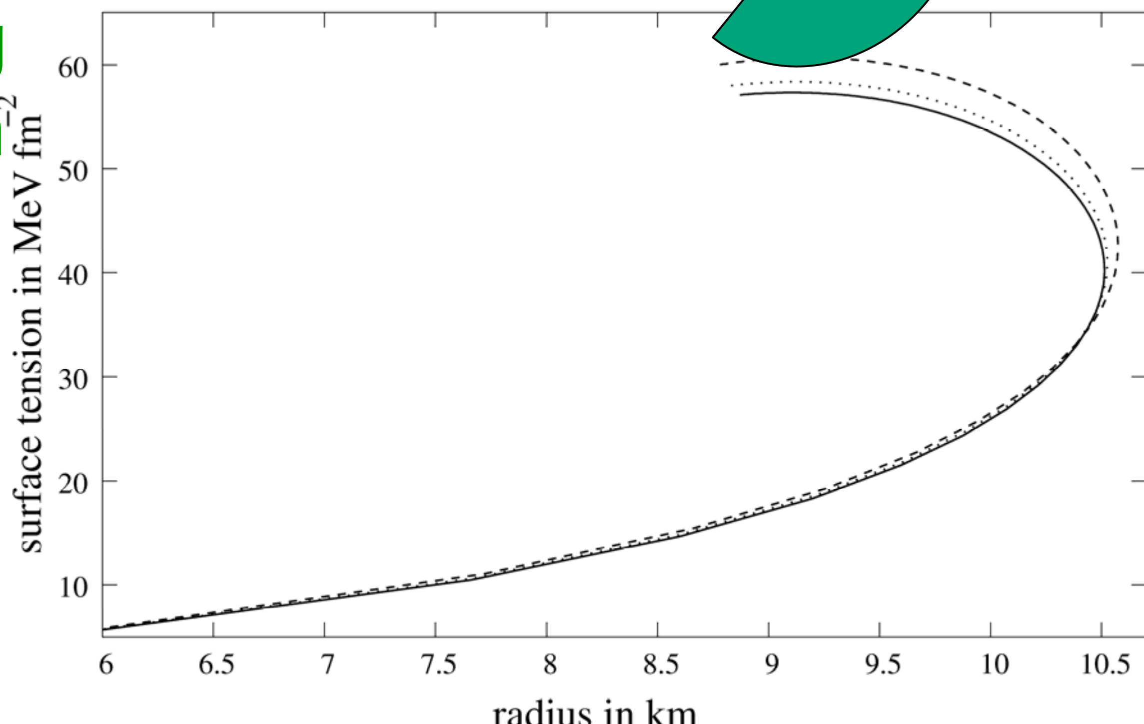
- For us S depends on star size !! Gravitation plays an Important role.

Bagchi et. al, A & A, 440 (2005) L33.



Our Model

MIT Bag Model



Instead of TOV, putting Newtonian expression for dP/dr, S becomes much lower

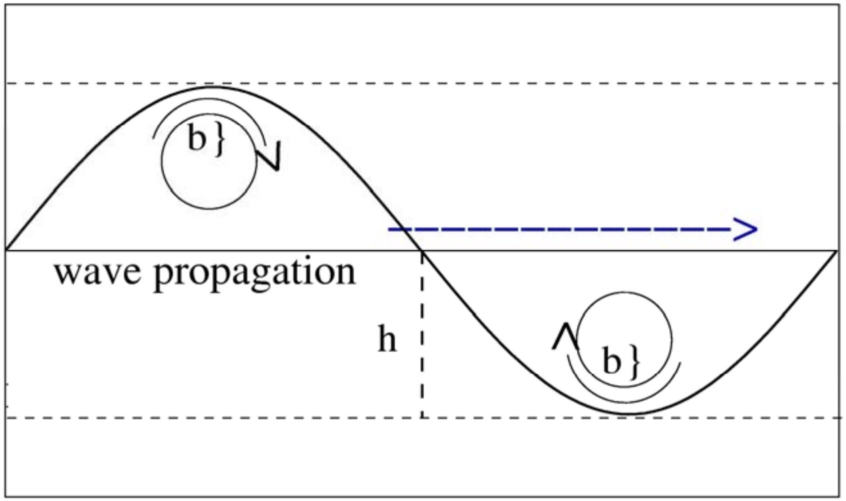
~ 50 MeV fm^{-2}

even for our EoS.

Study of surface wave

We have used our estimated value of surface tension to study the properties of surface waves at the surface of a strange star.

Study of surface wave



$$y = h \sin\left(\frac{2\pi x}{\lambda}\right)$$

h –> amplitude, v -> velocity,
T -> time period, λ -> wavelength
b -> radius of curvature

$$\mathbf{b} = \frac{\left(1 + (dy/dx)^2\right)^{3/2}}{d^2y/dx^2} = \mp \frac{v^2T^2}{4\pi^2 h}$$

- at crest, + at trough

where $\lambda = vT$

correction to velocity due to circular motion of fluid particle:

$$\mathbf{v} \rightarrow \mathbf{v} + \frac{2\pi|b|}{T}$$ →(crest)

$$\mathbf{v} \rightarrow \mathbf{v} - \frac{2\pi|b|}{T}$$ →(trough)

Study of surface wave

condition for streamline flow-Bernoulli's equation

$$gz + \frac{v^2}{2} + \frac{p}{\rho} = 0$$

$$z \to (R \pm h) \to (R \pm h)\left(1 - \frac{R_S}{R \pm h}\right)^{-1/2}$$ + at crest, - at trough

where $R \to R\left(1 - \frac{Rs}{R}\right)^{-1/2}$ $R_S = \frac{2GM}{c^2} \to$ Schwarzsclild Radius

$$p \to \frac{S}{b} \qquad \rho \to \frac{\varepsilon}{c^2} \qquad \frac{p}{\rho} \to \frac{Sc^2}{\varepsilon b}$$

Study of surface wave

$$\frac{GM\left(1-\frac{Rs}{R+h}\right)^{1/2}}{R+h}+\frac{1}{2}\left(v+\frac{2\pi|b|}{T}\right)^{2}-\frac{Sc^{2}}{|b|\varepsilon}=\frac{GM\left(1-\frac{Rs}{R-h}\right)}{R-h}+\frac{1}{2}\left(v-\frac{2\pi|b|}{T}\right)^{2}+\frac{Sc^{2}}{|b|\varepsilon}$$

$$|b|=\frac{v^{2}T^{2}}{4\pi^{2}h}$$

$$R_{S}=\frac{2GM}{c^{2}}$$

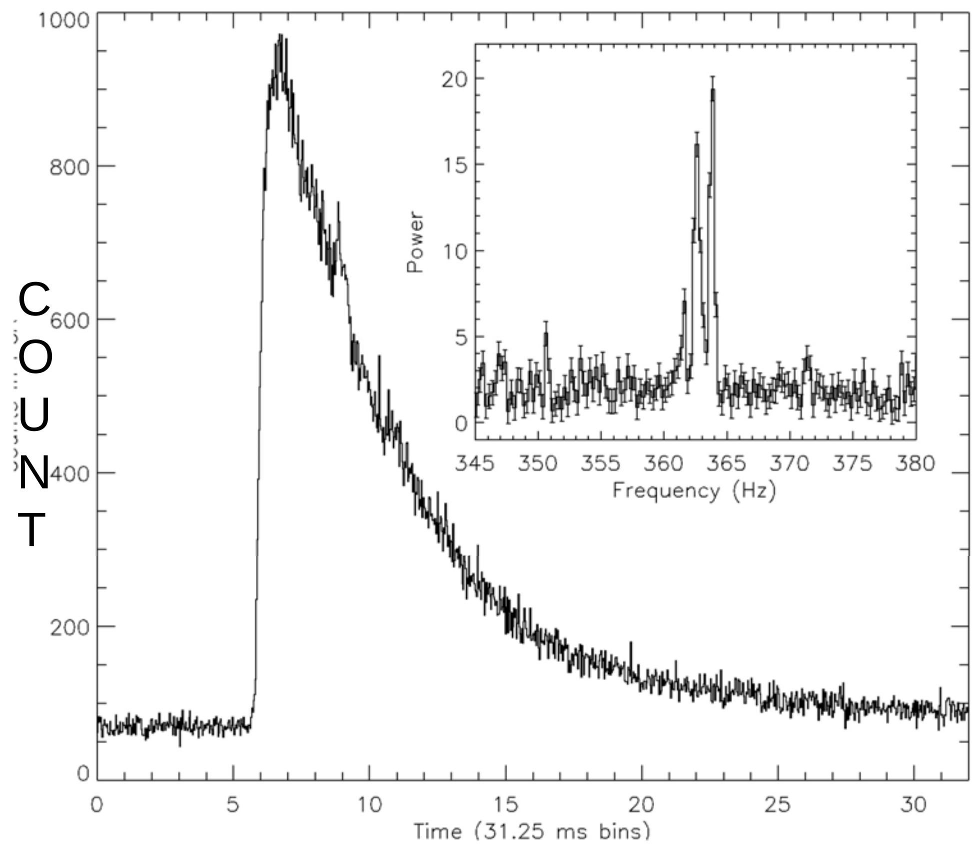
$$\frac{\pi h v^{2} R_{S} c^{2}}{2T}\left[\frac{\left(1-\frac{R_{s}}{R+h}\right)^{1/2}}{R+h}-\frac{\left(1-\frac{R_{s}}{R-h}\right)^{1/2}}{R-h}\right]=-\left[v^{5}+\frac{8\pi^{3}h^{2}Sc^{2}}{\varepsilon T^{3}}\right]$$

$$B(v,h,T) \qquad\qquad A(v,h,T)$$

Study of surface wave

Type I X-ray bursts are observed from 7 LMXB by RXTE.

- **rise time t_{rise}~ 1 sec**
- **decay time ~ 10 sec**
- **a peak in power density spectrum – burst oscillation**

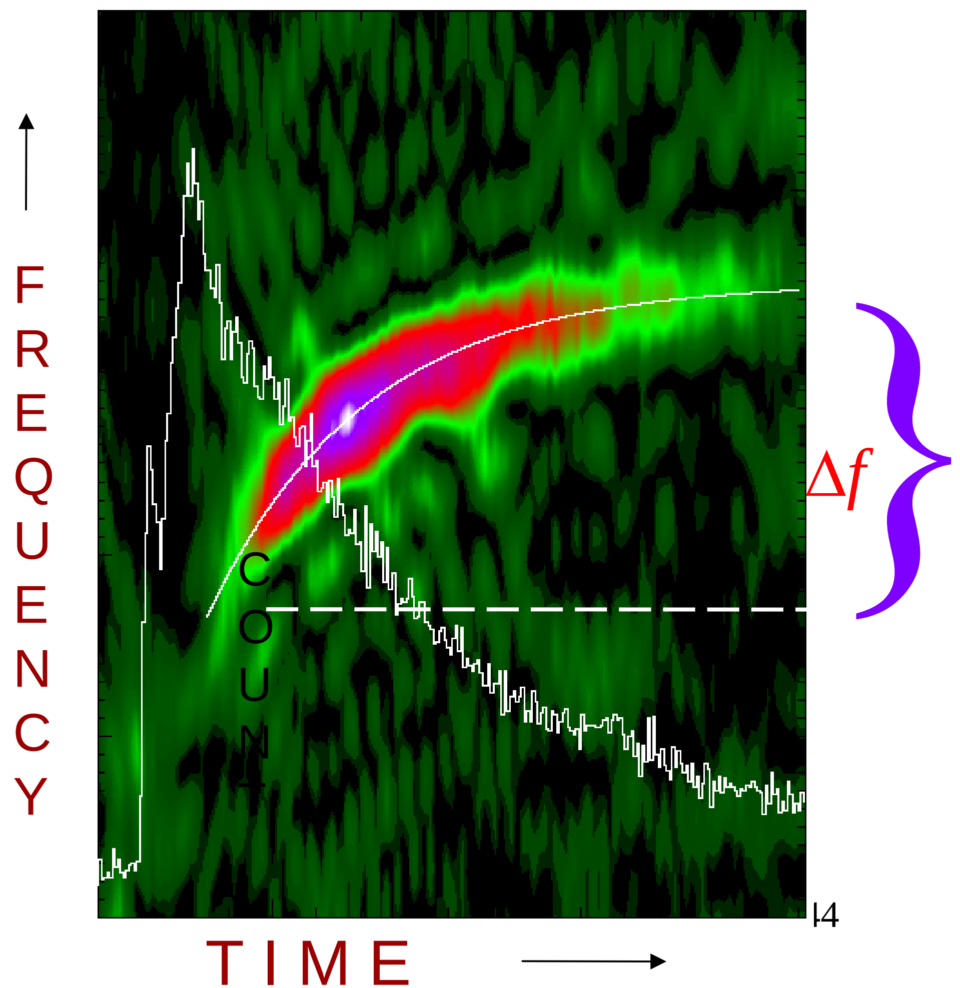


M. van der Klis, Ann. Rev. Astron. Astrophys. 38 (2000) 717.
Strohmayer et al, Astrophys. J. 469 (1996) L9.

Study of surface wave

The frequency of oscillation
is not constant, it increases
– becomes constant near the burst tail –
"Asymptotic Frequency"
[light curve in white]
frequency shift
Δf ~ 1.5 HZ

http://lheawww.gsfc.nasa.gov/users/stroh/



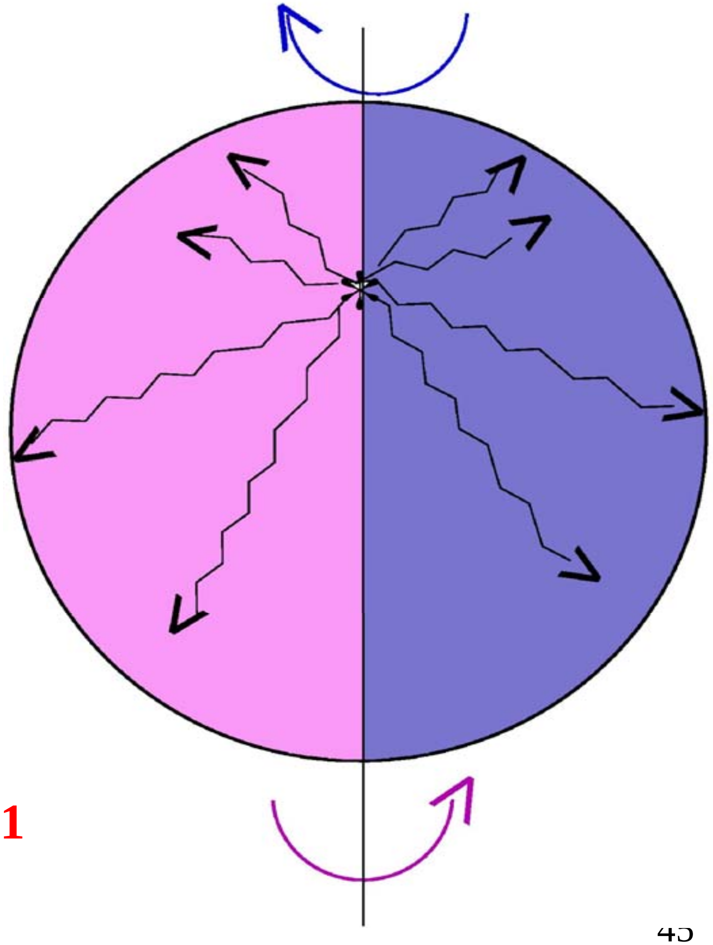
Study of surface wave

We claim this frequency shift is the onset of a surface wave as the burst proceeds and due to the anticoupling of the wave's power to the burst power.

Bagchi et al,
A & A 440 (2005) L33

$$v = \frac{\pi R}{t_{rise}}$$

$$T = (\Delta f)^{-1}$$



Study of surface wave

Burst from 4U 1728-34 observed by RXTE on February 16 (1996) ; t_{rise} = 0.6 sec,

Δf = 1.5 HZ

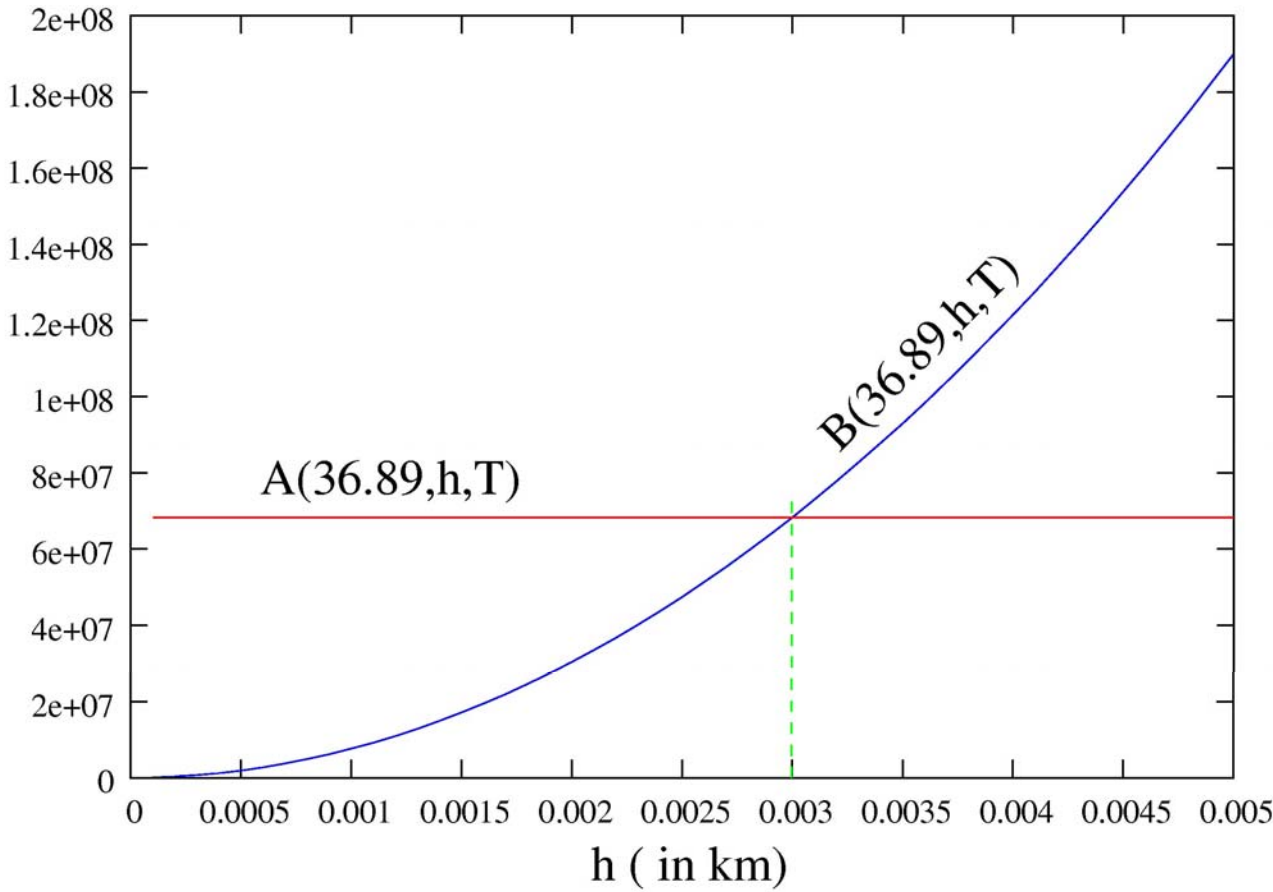
→ T = 2/3 sec.

v = 36.89 km/sec

(R = 7.05 km)

graphical solution gives

h = 300 cm



Application of density dependent mass ansatz

The Nambu Jona-Lasinio (NJL) model was proposed by Nambu and Jona-Lasinio in 1961 [2, 3] *i.e.* when QCD or even the quarks were unknown. The original NJL model was therefore a model of interacting nucleons. The problem was to find a mechanism which explains the large nucleon mass without destroying the chiral symmetry. To solve this problem, they introduced a Lagrangian as :

$$\mathcal{L} = \bar{\psi}(i\partial\!\!\!/ - m)\psi + G[(\bar{\psi}\psi)^2 + (\bar{\psi}i\gamma_5\vec{\tau}\psi)^2] \qquad (4.28)$$

where ψ is the nucleon field, m is the small bare mass of the nucleon, $\vec{\tau}$ is a Pauli matrix acting on isospin space and G is a dimensionful coupling constant. The self energy induced by the interaction generates an effective mass M which can be considerably larger than m and stays large, even when m is taken zero ("chiral limit").

[2] Y. Nambu, G Jona-Lasinio, Phys. Rev. 122 (1961) 345.

[3] Y. Nambu, G Jona-Lasinio, Phys. Rev. 124 (1961) 246.

Application of density dependent mass ansatz

$$M^* = m_0 + 4G\left(N_c N_f + \frac{1}{2}\right) M^* \int^{\Lambda} \frac{d^3p}{(2\pi)^3}\frac{1}{E}$$

$$f_\pi^2 = N_c M^{*2} \int^{\Lambda} \frac{d^3p}{(2\pi)^3}\frac{1}{E^3}$$

$$< \bar{q}q > = < \bar{u}u > = < \bar{d}d > = -6M^* \int^{\Lambda} \frac{d^3p}{(2\pi)^3}\frac{1}{E}$$

Here the number of color $N_c = 3$ and the number of flavor $N_f = 2$ (for a two flavor SU(2) calculation).

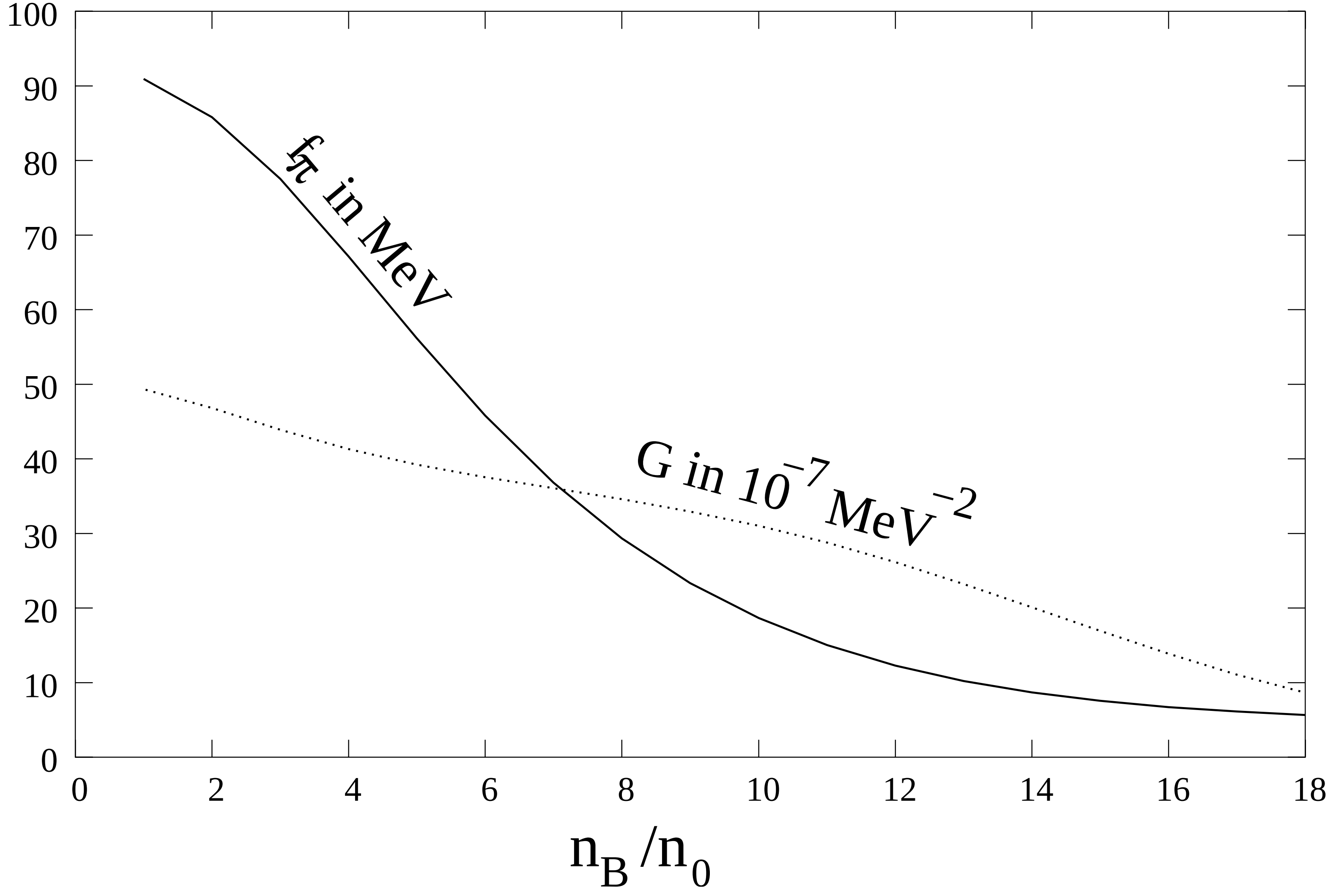
S.P. Klevansky, Rev. Mod. Phys. 64 (1992) 649.

$$M_i = m_i + M_q \ \ sech\left(\frac{n_B}{Nn_0}\right), \qquad i = u, d, s.$$

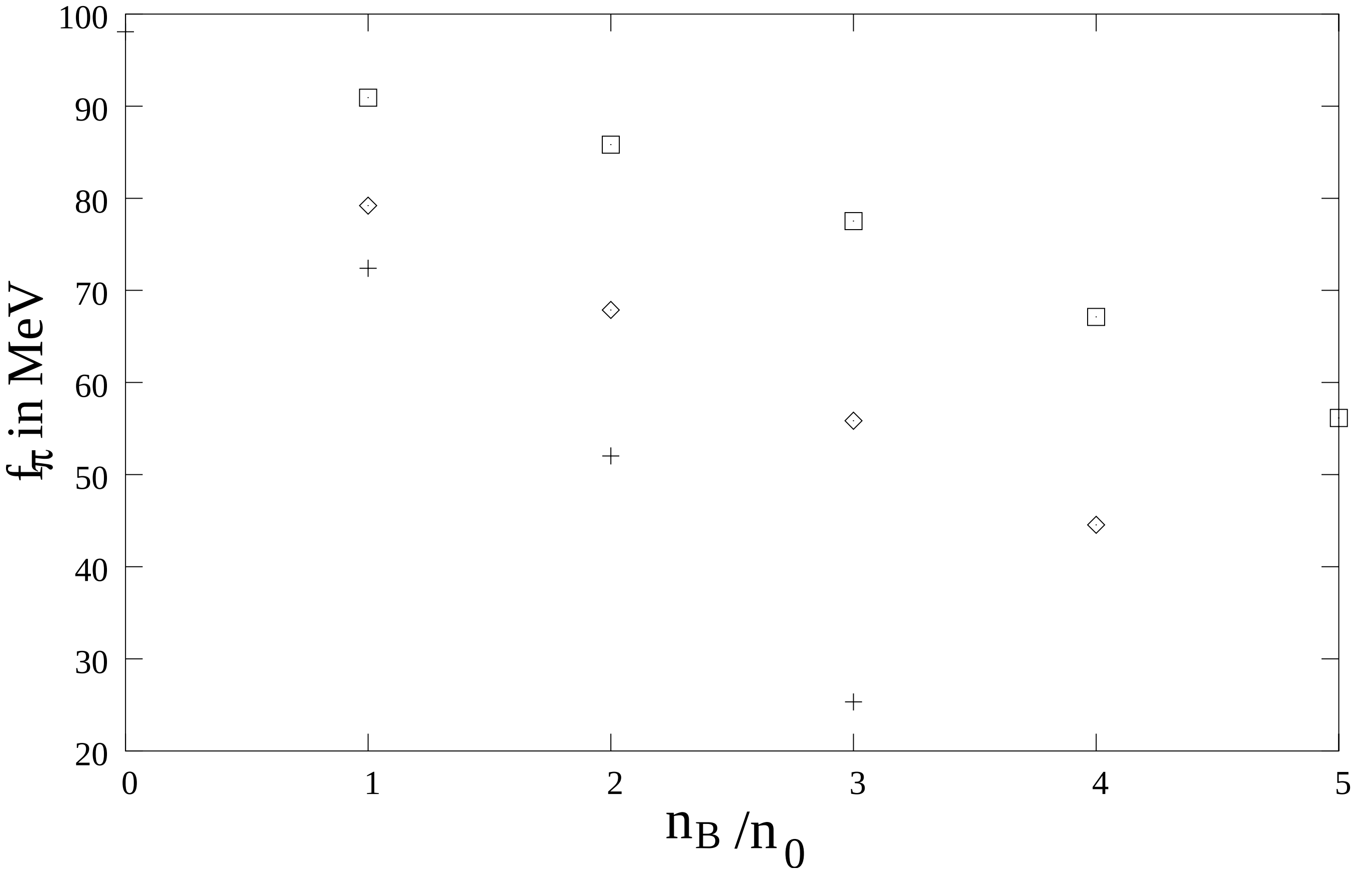
$$M^* = m_0 + M_q \ \ sech\left(\frac{n_B}{Nn_0}\right),$$

where $m_0 = (m_u + m_d)/2$.

Application of density dependent mass ansatz



Application of density dependent mass ansatz



Density f_π from different models upto $5n_0$: + corresponds to the nuclear matter model of ZM3, diamonds corresponds to QCDSR results, squares correspond to the SQM.

Concluding Remarks

- Existence of Strange Star is not still well established.

  We hope further study of x-ray and radio astronomy will help to remove the dispute.

But why we are so much interested to Strange Stars ?

- QCD properties are still inaccessible to terrestrial experiments. Experimentalists tried to get signatures of asymptotic freedom and confinement in laboratory – RHIC, but could NOT succeed.

So Strange Star serves as the lab set up by nature for us to test QCD properties.!!

Further study of Strange Star properties will be interesting. Connecting RHIC data to SS is possible through viscosity/entropy ratio.

THANK YOU

- **I liked Bob Rutledge's question.** ***The take home for astrophysicists is observations are good. The one for Nuclear Model people is – u r doing well.***
- **For phenomenologists like us the message is : look for discrepancies and try simple QCD models.**