PROCEEDINGS OF THE YEREVAN STATE UNIVERSITY

Physical and Mathematical Sciences 2015, № 2, p. 57–61

Physics

MASS DEFECT OF STRANGE STARS

H. A. SHAHINYAN *

Chair of Wave Process Theory and Physics YSU, Armenia

The mass defect of the strange stars has been studied in the present work. The strange quark matter with minimal energy consisted of *u*, *d*, *s* quarks and electrons was observed in the framework of the bag model. For certain values of the bag parameters the integral parameters for three models of the strange stars with maximal masses twice exceeding sun mass were obtained depending on central density. The dependencies of inner energy E_{in} and bond energy $\Delta_2 M$ on total mass M for data of the strange star models were presented. It was shown that the packing coefficient of strange stars consisted of strange quark matter is significantly higher than the analogous one of neutron stars.

Keywords: strange stars, maximal masses, gravitation packing coefficient.

Introduction. The strange quark matter is in more bound state than the matter in atomic nuclei [1, 2]. In the present work the bag model elaborated in Massachusetts Technological Institute [3] is accepted for the quark matter, which depends on three phenomenological constants: the bag constant B (vacuum pressure), the quark-gluon interaction constant α_c and the strange quark masses m_s. We have observed three models of the strange stars corresponding to three groups of the bag parameters:

I. $B = 48\ MeV / f^3$, $m_s = 150\ MeV$, $a_c = 0.50$;

II. $B = 46\ MeV / f^3$, $m_s = 175\ MeV$, $a_c = 0.05$;

III. $B = 44\ MeV / f^3$, $m_s = 200\ MeV$, $a_c = 0.60$.

For the first two models the curve of average energy per baryon has a negative minimum $\varepsilon_{\min} < 0$ at the certain value of concentration of baryons: I. $\varepsilon_{\min} = -19.5\ MeV$, $n_{\min} / n_0 = 1.56$; II. $\varepsilon_{\min} = -80.9\ MeV$, $n_{\min} / n_0 = 1.61$, where $n_0 = 0.15\ f^{-3}$ is the nuclear density. It indicates that for such values of the bag parameters the quark matter may be in self-bounded state and the possibility of existence of the self-confined stars so called "strange stars" appears [4]. Main properties and structure of the strange stars were examined in [5–7]. For the third model the curve of average energy has a positive minimum ($\varepsilon_{\min} = 0.74\ MeV$,

* E-mail: hasmik.shahinyan@gmail.com

$n_{\min} / n_0 = 1.49)$. Configurations corresponding to this case are accepted to call "hybrid stars" [8, 9]. They have a nucleus consisted of the strange quark matter, where the main mass of star is accumulated, and a crust consisted of the matter of neutron stars.

Integrating systems of relativistic equations of star equilibrium (TOV equations) [10, 11], for wide group of the quark bag parameters depending on central density [12] as well as for quark configurations the mass of which is equal to the mass of pulsars measured from observations with big precision [13–16], the integral parameters of strange stars with maximal mass, which twice exceeds Solar mass, were presented.

Calculation and Results. In the present work the mass defect of above mentioned quark configurations has been studied. For this goal the physical meanings of the total gravitation mass *M*, the rest mass M_0 and the own mass M_p were discussed that are necessary for defect calculation of the super-dense star mass. Depending on value of the central density energy ρ_c values of star radius $R(P(R) = 0,$ *P*-pressure and gravitation mass M were calculated:

$$M = \frac{4\pi}{c^2} \int_0^R \rho r^2 dr,$$

$$\text{the rest mass } M_0 = 4\pi m_0 \int_0^R n r^2 \exp\left(\frac{\lambda}{2}\right) dr,$$

$$\text{the own mass } M_p = \frac{4\pi}{c^2} \int_0^R \rho r^2 \exp\left(\frac{\lambda}{2}\right) dr,$$

were n is concentration of baryons, $\exp(\lambda)$ is radical component of matrix tensor [9, 10], ρ is density of energy $\rho = \rho_0 (1 + \varepsilon / m_0 c^2)$, $\rho_0 = m_0 n$ is the rest mass density, $m_0 = M(\mathrm{Fe}_{56})/56.$ It should be mentioned that $M_0 = m_0 B,$ where B is the total number of baryons in equilibrium configuration.

The difference $M - M_p$ in non-relative boundary determines the gravitation energy:

$$M - M_p = \frac{E_G}{c^2} = -\frac{G}{c^2} \int_0^M m(r)\, dm\,(r)/r,$$

but the difference $M - M_0$ determines a sum of gravitation and inner energies $M - M_0 = E_{in} / c^2 + E_G / c^2,$ where $E_{in} = 4\pi \int_0^R n \varepsilon r^2 d\, r.$

The star total mass M is not equal to the sum of masses of its volume elements M_p and $M < M_p$. The difference of $\Delta_1 M = M_p - M$ is called total gravitation defect of mass and the relation of $a_1 = \Delta_1 M / M$ is the gravitation packing coefficient. In the common case a_1 characterizes a relation of gravitation energy to total one. The difference of $\Delta_2 M = M_0 - M$ is called non total or simply defect of mass (bond energy). The packing coefficient $a_2 = \Delta_2 M / M_0$ shows a total part of energy per baryon in the common case, which is released at star formation.

Model	ρ_c, $10^{14} g/cm^3$	ρ_s, $10^{14} g/cm^3$	R, km	$M_{\max}$, $M_\odot$	M_0, $M_\odot$	M_p, $M_\odot$	a_1	a_2
I	19.2	3.8	11.17	2.023	2.473	2.567	0.268	0.182
II	18.67	3.65	11.29	2.022	2.643	2.556	0.264	0.235
III	18.9	3.64	11.25	2.016	2.404	2.551	0.265	0.161

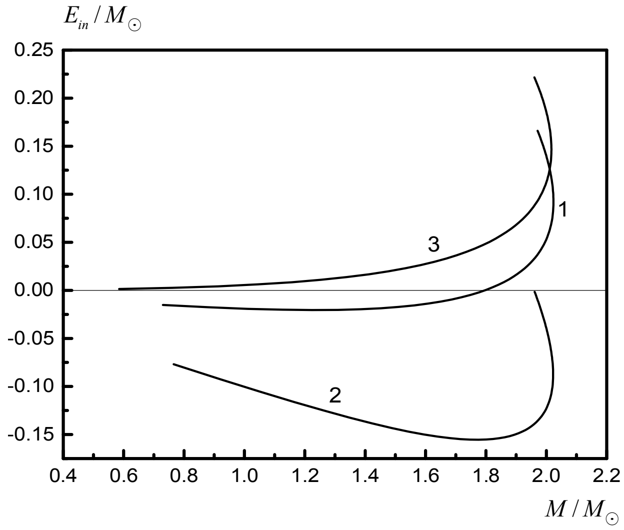

Fig. 1. The dependence of inner energy E_{in} of observed models on gravitation mass M.

Values of central density ρ_c, density on surface ρ_s, radius R, total mass M, rest mass M_0, own mass M_p, gravitation packing coefficient a_1 and packing coefficient a_2 are presented in the Table for observed models of configurations with maximal mass. For the III model these values are presented for quark nucleus. The dependence of inner energy $E_{in} = M_p - M_0$ of observed models on gravitation mass M is presented on Fig. 1.

It is obvious from Fig. 1, that for the second model all stable configurations have a negative minimum $M_p < M_0$ due to the high values of negative minimum of the average energy per baryon. For the I model due to the small values of negative minimum of the average energy per baryon the inner energy $(E_{in} > 0)$ becomes positive until the reaching of maximal masses at $M \approx 1.79\ M_\odot$. For the III model the inner energy has positive sign for all configurations.

The dependence of values of a_1 coefficient on $\lg \rho_c$ for three models of strange stars is plotted on Fig. 2, a. It should be mentioned that the maximal values of the gravitation packing coefficient for the three models are the following: $a_{1\max} = 0.299$ for the I model, 0.297 for the II model, 0.298 for the III model. It concerns to those configurations, the central densities of which are higher compared to them in corresponding point of stability loss. It means that in reality the existing configurations (stable configurations) have small values of a_1.

The dependence of values of a_2 coefficient on $\lg\rho_c$ for three models of stars is presented on Fig. 2, b. It is obvious from Figure, that maximal values of the packing coefficient a_2 are achieved in the case of configuration with maximal masses. The following values are obtained from the calculations: $a_{2\max} = 0.182$ for the I model, 0.235 for the II model and 0.161 for the III model. It should be also noted that for all three models the mass defect has a positive sign $\Delta_2 M > 0$.

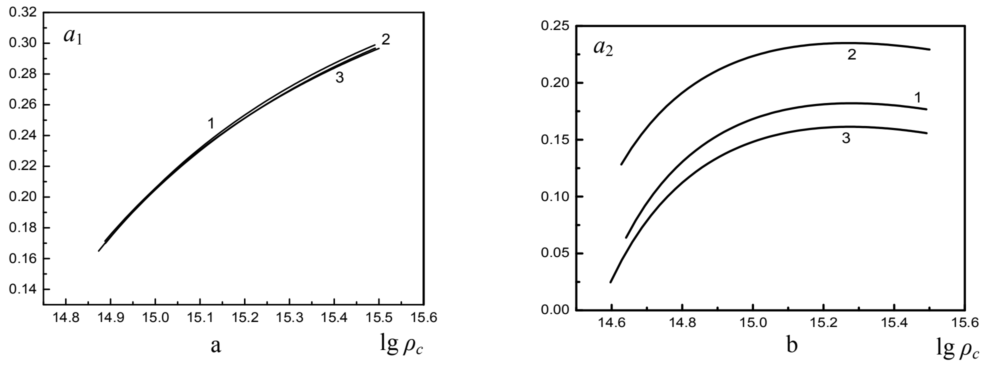

Fig. 2. Dependence of the gravitation packing coefficient a_1 (a) and a_2 (b) on $\lg\rho_c$ for three models of strange stars.

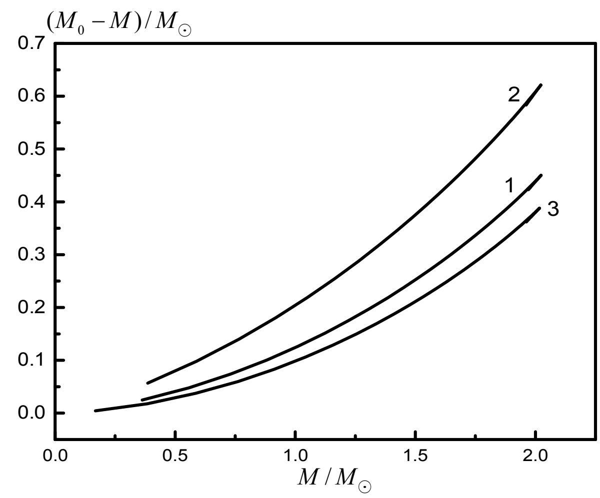

Fig. 3. Dependence of bound energy $\Delta_2 M$ on total mass M for three models of strange stars.

The dependence of the mass defect $\Delta_2 M$ on M mass for the observed three models is presented on Fig. 3. It should be mentioned that the defect of mass of configurations with maximal masses for our chosen models has the following values: $\Delta_2 M / M_\odot = 0.450;\ 0.621;\ 0.388$ respectively.

Conclusion. It is concluded from the calculations that for the certain values of group of phenomenological parameters of the bag, the maximal masses are obtained that are twice higher from the Sun mass: $M_{\max} > 2M_{\odot}$. The values of the total gravitation defect of mass $\Delta_1 M$ for three chosen models $(\Delta_1 M / M_{\odot} \sim 0.534 \div 0.544)$ were calculated. It was shown that the bond energy of strange stars consisted of strange quark matter per baryon is significantly higher compared to the analogous one of neutron stars.

Received 21.04.2015

REFERENCES

1. **Bodmer A.R.** Collapsed Nuclei. // Phys. Rev., v. D 4, 1971, p. 1601–1606.
2. **Witten E.** Cosmic Separation of Phases. // Phys. Rev., 1984, v. D 30, p. 272–285.
3. **Chodos A., Jaffe R.L., Johnson K., Thorn C.B., Weisskopf V.F.** A New Extended Model of Hadrons. // Phys. Rev., 1974, v. D 9, p. 3471–3495.
4. **Farhi E., Jaffe R.L.** Strange Matter. // Phys. Rev., 1984, v. D 30, p. 2379–2390.
5. **Alcock C., Farhi E., Olinto A.** Strange Stars. // Astrophys. J., 1986, v. 310, p. 261–272.
6. **Hansel P., Zdunik J.L., Shaeffee R.** Strange Quark Stars. // Astrophys., 1986, v. 160, p. 121–128.
7. **Benvenuto O.G., Horvarth J.E., Vucetich H.** Strange-Pulsar Models. // Intern. J. of Modern Phys., 1991, v. A 6, № 27, p. 4769–4830.
8. **Alaverdyan G.B., Harutyunyan A.R., Vartanyan Yu.L.** Neutron Stars with a Quark Core. I. Equations of State. // Astrophysics, 2003, v. 46, № 3, p. 361–367.
9. **Alaverdyan G.B., Harutyunyan A.R., Vartanyan Yu.L.** Neutron Stars with a Quark Core. II. Basic Integral and Structural Parameters. // Astrophysics, 2004, v. 47, № 1, p. 52–64.
10. **Tolman R.C.** Static Solutions of Einstein's Field Equations for Spheres of Fluid. // Phys. Rev., 1939, v. 55, p. 364–373.
11. **Oppenheimer J.R., Volkoff G.M.** On Massive Neutron Cores. // Phys. Rev., 1939, v. 55, p. 374–381.
12. **Vardanyan Yu.L., Grigoryan A.K., Shahinyan H.A.** Maximal Mass of Strange Stars and Pulsars with More Précised Measured Masses. // Astrophysics, 2015, v. 58, № 2, p. 297.
13. **Taylor J.H., Weisberg J.M.** Further Experimental Tests of Relativistic Gravity Using the Binary Pulsar PSR 1913+16. // Astrophys. J., 1989, v. 345, p. 434–450.
14. **Demorest P., Pennucci T., Ransom S.M., Roberts M.S.E, Hessels J.W.T.** A Twosolar-Mass Neutron Star Measured Using Shapiro Delay. // Nature, 2010, v. 467, p. 1081–1083.
15. **Lynch R.S., Boyles J., Ransom S.M., Stairs I.H., Lorimer D.R., McLaughlin M.A., Hessels J.W.T., Kaspi V.M., Kondratiev V.I., Archibald A.M., Berndsen A., Cardoso R.F., Cherry A., Epstein C.R., Karako-Argaman C., McPhee C.A., Pennucci T., Roberts M.S.E., Stovall K., van Leeuwen J.** The Green Bank Telescope 350 MHz Drift-Scan Survey II: Data Analysis and the Timing of 10 New Pulsars, Including a Relativistic Binary. // Astrophys. J., 2013, v. 763, № 81, p. 1–14.
16. **Antoniadis J., Freire P.C.C., Wex N., Tauris T.M., Lynch R.S., van Kerkwijk M.H., Kramer M., Bassa C., Dhillon V.S., Driebe T., Hessels J.W.T., Kaspi V.M., Kondratiev V.I., Langer N., Marsh T.R., McLaughlin M.A., Pennucci T.T., Ransom S.M., Stairs I.H., van Leeuwen J., Verbiest J.P.W., Whelan D.G.** A Massive Pulsar in a Compact Relativistic Binary. // Science, 2013, v. 340, № 6131, p. 448.