Astrophysics Vol. 37, No. 3, 1994

STRANGE QUARK MATTER AND MODELS OF STRANGE STARS

Yu. L. Vartanyan, A. R. Arutyunyan and A. K. Grigoryan UDC 524:354.6:539.12

In the framework of the MIT bag model we consider absolutely stable strange quark matter consisting of u, d, and s quarks and electrons. For a realistic range of parameters of the quark bag we compute the threshold density for the appearance of strange quark matter that is realized on the surface of self-sustaining strange stars. On the basis of twelve calculated equations of state we give a detailed study of the series of configurations of strange stars consistent with the best known observational data. We show that the binding energy of the models depends essentially on the quark-gluon interaction constant α_c.

1. Introduction. In the pioneering paper of Ambartsumyan and Saakyan [1] attention was first called to the fact that degenerate nuclear plasma may contain strange baryons—hyperons—as well as neutrons and a small number of protons and electrons. For the ideal gas model the thresholds of stability of various hyperons were computed and turned out to be significantly higher than the nuclear density, partly lying beyond the Landau-Oppenheimer-Volkov point (the point at which neutron stars become unstable). In the paper of Saakyan and Vartanyan [2] it was shown that taking account of nuclear interaction greatly lowers the threshold of stability of hyperons and makes it possible for them to exist in the cores of massive stable neutron stars, so that it would be more correct to call the latter baryon stars.

In the mid-80's new interest arose in strange nuclear plasma in connection with the physics of quarks. Witten [3] showed that the transition to the quark phase with the formation of a matter having strangeness -1 per baryon is energetically more advantageous than nonstrange quark plasma. Such matter, called strange quark matter, is assumed to be an absolutely stable state of cold superdense matter and contains approximately equal amounts of u, d, and s quarks with a small admixture of electrons or positrons to provide electrical neutrality. It may form self-sustaining bound states in the form of so-called "strange" stars.

The basic properties of strange stars were studied in [4] and [5]. The possibility that there exist arbitrarily small masses, an abrupt drop in density on the surface from supernuclear values to zero, and a rather weak increase in density toward the center are characteristic features of strange stars, connecting them with the pion stars proposed by Hartle [6] and studied in detail by Vartanyan et al. [7].

Due to the difficulties of the theory of strong interactions it is at present impossible to choose a single definite model of the equation of state for the quark phase. The criterion for the choice ought to be the identity of the computed integral parameters of superdense stars with the observational data on pulsars and compact X-ray sources, whose precision is unfortunately not yet sufficient.

In the present paper we consider the bag model developed at MIT for the equation of state of strange quark matter [8]. In this model the equation of state is determined by phenomenological parameters that are not known with sufficient precision—the bag constant B, the quark-gluon interaction constant α_c, and the mass of a strange quark m_s. For different sets of these constants equations of state are obtained that may lead to the realization of both the strange stars considered in the present paper and neutron stars with a quark nucleus.

We have studied twelve sets of bag parameters corresponding to their most probable ranges of variation. For the computed equations of state the system of equations of stellar equilibrium (the Tolman-Oppenheimer-Volkoff equations) were integrated by the standard method, and the integral parameters of strange stars were obtained. We study in detail the models of maximal mass and also models with masses $1.44\,M_\odot$ and $1.77\,M_\odot$ and gravitational redshift $Z_S = 0.23$, corresponding to the best known observational data.

In the next two sections we give a brief discussion of the formalism of the equation of state of strange quark matter and the Tolman-Oppenheimer-Volkoff system of equations. In Sect. 4 we give the results

Translated from *Astrofizika*, Vol. 37, No. 3, 1994. Original article submitted July 14, 1994.

0571-7256/94/3703-0271 $12.50

of computing the integral parameters of strange stars and compare them with observational data. In the concluding section we discuss the problem of the side-by-side existence of neutron stars and strange stars.

2. The equation of state. In the present paper we use the "bag" phenomenological model to obtain the equation of state of strange quark matter. In the approximation of this model strange quark matter is a degenerate Fermi gas with u, d, and s quarks and electrons (positrons). It is assumed that the quarks and gluons are confined to a region of space called the "bag," in which vacuum pressure is maintained characterized by the bag constant B. The parameter of the model B is actually the energy density of the vacuum in the bag model. Other parameters determining the state of the strange quark matter are the quark-gluon interaction constant α_c and the mass of a strange quark m_s. We neglect the masses of u and d quarks and degenerate electrons due to their smallness. Equilibrium of a suspension of quarks in a quark-electron plasma is established by the weak interactions

$$\begin{aligned} &d \to u + e + \nu_e, \\ &u + e \to d + \nu_e, \\ &s \to u + e + \nu_e, \\ &u + e \to s + \nu_e, \\ &u + s \to d + u. \end{aligned} \tag{1}$$

From (1) we obtain the relations among the chemical potentials of the components:

$$\begin{aligned} \mu_d &= \mu_u + \mu_e, \\ \mu_d &= \mu_s \equiv \mu. \end{aligned} \tag{2}$$

Relations (2), supplemented by the condition of electrical neutrality of the system

$$\frac{2}{3}n_u - \frac{1}{3}n_d - \frac{1}{3}n_s - n_e = 0, \tag{3}$$

where $n_i(\mu_i) = -\partial\Omega_i/\partial\mu_i$ are the concentrations of the corresponding components ($i = u, d, s, e$), make it possible to obtain the fundamental thermodynamic quantities as functions of a single independent parameter, which we choose to be μ:

$$P(\mu) = -\sum_i \Omega_i(\mu) - B, \tag{4}$$

$$\rho_Q c^2 = \sum_i (\Omega_i + \mu_i n_i) + B, \tag{5}$$

$$n_Q = \frac{1}{3}(n_u + n_d + n_s), \tag{6}$$

$$\mu_Q(P) = (\rho_Q(P)c^2 + P)/n_Q(P), \tag{7}$$

Here Ω_i ($i = u, d, s, e$) [9] are the thermodynamic potentials obtained in first approximation with respect to α_c defining the properties of strange quark matter. These quantities depend on α_c and the corresponding μ_i, and in the case of Ω_s also on m_s and ρ_R, the renormalizing point for the mass of a strange quark, which is given the value 313 MeV [9]. Here ρ_Q, n_Q, and μ_Q denote respectively the energy density, the baryon density, and the baryon chemical potential of the quark phase.

Farhi and Jaffe [9] have studied in detail the influence of the parameters B, m_s, and α_c on the stability of strange quark matter. Benvenuto and Horvath [10] have studied the structure of strange stars in the entire range of values of the parameters of strong interaction in which strange quark matter is stable. In the same paper, using a generalization of the phenomenological and theoretical data of nonlepton physics, they have proposed realistic ranges of variation of the parameters of the bag model ($B \simeq 50$–$60\,\mathrm{MeV/fm^3}$, $m_s \simeq 175$–$200\,\mathrm{MeV}$, and $\alpha_s \simeq 0.5$–0.6).

In the present paper for 12 sets of bag parameters grouped into four series according to the values of B and m_s we have computed the equations of state. The main quantity that determines the binding

Table 1

VALUES OF MINIMAL ENERGY AND CORRESPONDING BARYON DENSITIES

Series	B, MeV/fm^3	m_s, MeV	$(\alpha_c)_{\lim}$	Model	α_c	$\varepsilon_{\min}$, MeV	$n_{\min}/n_0$
1	55	175	0.38	1.1	0.05	−45.985	1.84
				1.2	0.17	−30.778	1.81
				1.3	0.30	−12.732	1.78
				1.4	0.38	−0.051	1.77
2	55	200	0.31	2.1	0.05	−34.190	1.83
				2.2	0.17	−19.226	1.81
				2.3	0.31	−0.012	1.78
3	60	175	0.26	3.1	0.05	−28.452	1.97
				3.2	0.17	−13.022	1.94
				3.3	0.26	−0.028	1.92
4	60	200	0.18	4.1	0.05	−16.573	1.96
				4.2	0.18	−0.004	1.93

of strange quark matter is the mean energy per baryon ε as a function of the baryon concentration n, which is connected with the energy density ρ and the pressure P by the relations $\rho = m_0 n(1 + \varepsilon/m_0)$ and $P = n^2 \partial\varepsilon/\partial n$, where $m_0 = M(^{56}\mathrm{Fe})/56$. For strange and pion stars [7] the curve $\varepsilon(n)$ has a negative minimum $-\varepsilon_{\min}$ for a certain value $n_{\min}$, and it is this phenomenon that brings about the existence of strange stars, which are giant nuclei held together by the strong interaction. The mass of such objects is bounded above only by the effects of the general theory of relativity. The presence of gravitation also leads to only an insignificant increase in the density from the surface (where the density corresponds to $n_{\min}$) to the center.

Table 1 gives the choices of the values of the quark-gluon interaction constant α_c for each series corresponding to the realistic range of variation of the parameters B and m_s ($B = 55$–$60\,\mathrm{MeV/fm^3}$, $m_s = 175$–$200\,\mathrm{MeV}$), from 0.05 to the limiting admissible value of $(\alpha_c)_{\lim}$ at which the mean energy per baryon is negative at the minimum point. Here also for each model we give the threshold density for the appearance of strange quark matter $n_{\min}/n_0$ ($n_0 = 0.15\,\mathrm{fm}^{-3}$ is the nuclear density) which is realized on the surface of strange stars, and also the binding energy per baryon $\varepsilon_{\min}$ corresponding to that density, knowledge of which may be essential in the study of nuclear reactions occurring on the surface. For values of α_c larger than $(\alpha_c)_{\lim}$ conditions exist in each of these series under which the quark matter may be in thermodynamic equilibrium with the nucleon component. The use of these equations of state leads to the realization of models of neutron stars with a quark nucleus not considered in the present paper.

Figure 1 gives the dependence of the energy per baryon on the baryon density for two models differing in the value of α_c. As can be seen from the figure, the values of the minimal energy depend to a considerable extent on the quark-gluon interaction constant. It should be noted that for computing the energy of strange quark matter in the framework of the MIT model it is the dependence on this parameter of the quark bag that turns out to be decisive.

3. The fundamental equations. The fundamental parameters of spherically symmetric superdense stars are obtained by numerical integration of the relativistic equations of stellar equilibrium [11], supplemented by equations for determining the relativistic moment of inertia [12]. This system of equations has the following form [13]:

$$dP/dr = -0.5 r_g m r^{-2}(P + Q)(1 + b r^3 P/m)/(1 - r_g m/r), \tag{8}$$

$$dm/dr = b\rho r^2, \tag{9}$$

$$dm_0/dr = b\rho_0 r^2/(1 - r_g m/r)^{1/2}, \tag{10}$$

$$dm_P/dr = b\rho r^2/(1 - r_g m/r)^{1/2}, \tag{11}$$

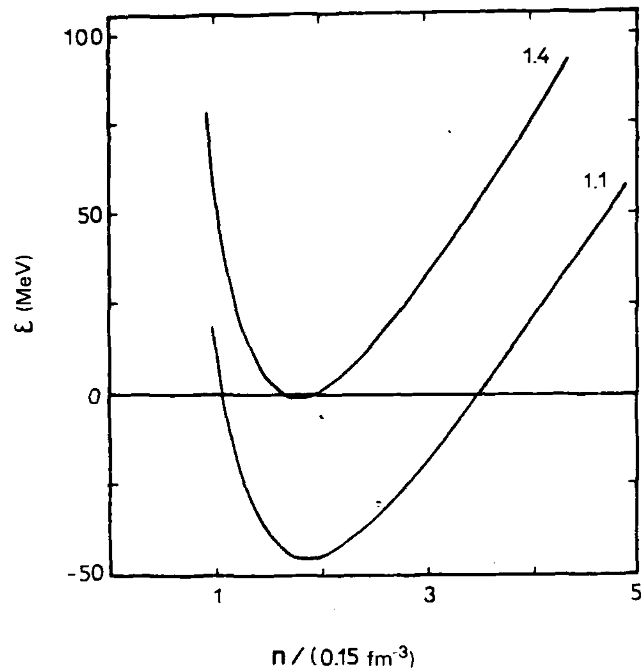

Fig. 1. Dependence of the energy per baryon ε on the baryon concentration n for models 1.1 and 1.4.

$$d\nu/dr = r_g m r^{-2}(1 + br^3 P/m)/(1 - r_g m/r), \tag{12}$$

$$dw/dr = 3r_g l r^{-4} e^{\nu/2}/(1 - r_g m/r)^{1/2}, \tag{13}$$

$$dl/dr = 2/3bw\rho r^4(1 + P/\rho)e^{-\nu/2}/(1 - r_g m/r)^{1/2}. \tag{14}$$

Here P, ρ, and ρ_0 are determined from the equation of state, $m(r)$ is the mass inside the sphere of radius r ($m(R) = M$, where M is the total mass of the star), and R is the radius of the star, which is determined from the condition $P(R) = 0$. Also, $M_0 = m_0(R) = m_0 A$, where A is the total number of baryons in the star and $m_0 = M(^{56}\mathrm{Fe})/56$. $M_P = m_P(R)$ is the proper mass. In the Newtonian limit both the gravitational energy E_G and the total internal energy $E_{\rm in}$ are determined by this quantity ($E_G = M - M_P$, $E_G = -(G/c^2)\int_0^M m(r)\,dm/r$ and $E_{\rm in} = M_P - M_0$, $E_{\rm in} = 1/c^2 \int_0^R n\varepsilon\,dv$). The metric coefficient $g_{00}(r)$ (where $ds^2 = g_{ik}\,dx^i\,dx^k$) is connected with the function $\nu(r)$ defined by (12) via the relation

$$g_{00}(r) = (1 - r_g M/R)e^{\nu(r)-\nu(R)}. \tag{15}$$

Through (15) we can compute the gravitational redshift

$$Z = \Delta\lambda/\lambda = [g_{00}(r)]^{-1/2} - 1. \tag{16}$$

Equations (13) and (14) serve to determine the relativistic moment of inertia I

$$I = I(R)/\Omega, \tag{17}$$

where

$$\Omega = w(R)e^{-\nu(R)}(1 - r_g M/R)^{1/2} + r_g l(R)/R^3. \tag{18}$$

In relations (8)–(14) the quantities P, ρ, and ρ_0 are expressed in units of $m_\pi = h = c = 1$, where m_π is the mass of a π-meson, h is Planck's constant, and c is the speed of light; m, m_0, and m_P are expressed in

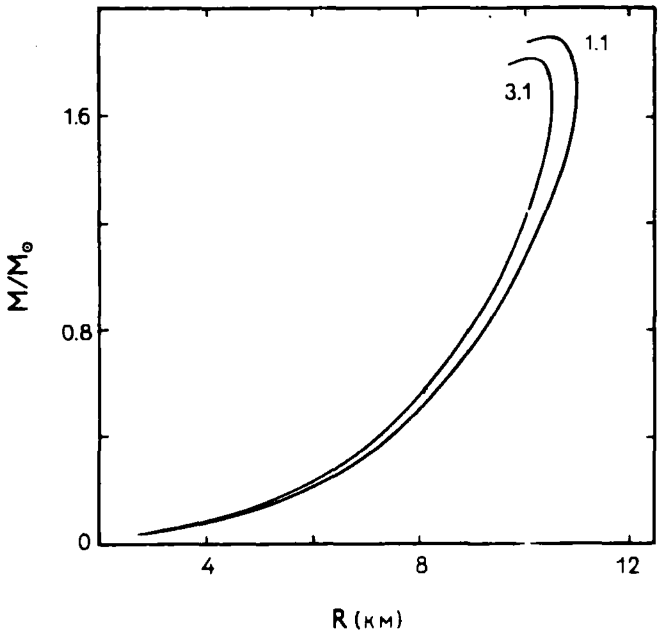

Fig. 2. Dependence of the total mass M on the radius R for models 1.1 and 3.1.

solar masses $M_\odot$, r in km, and the moment of inertia I in $M_\odot \mathrm{km}^2$ (i.e., in units of $1.989 \cdot 10^{43}\,\mathrm{g \cdot cm^2}$). The coefficient $r_g = 2GM_\odot/c^2 = 2.949\,\mathrm{km}$ is the gravitational radius of the Sun. The coefficient $b = 5.546 \cdot 10^{-4}$ results from the change from the CGS system to the one we are using.

The integration begins at the center of the configuration with $r = 0$ and ends with $r = R$ when $P(R) = 0$.

4. Results of the computation and observational data. The computations were carried out using the equations of state for the models considered above. Depending on the central density ρ_0 we computed the series of values of the stellar radius R, total mass M, rest mass M_0, proper mass M_p, relativistic moment of inertia I, and redshift from the surface of the star Z_S.

Figure 2 gives the dependence of the mass on the radius for two models that differ only in the choice of the value of the bag constant B. In contrast to the case of neutron stars, in our models the radius increases with the mass on almost the whole curve. This results from the fact that strange stars are held together by the strong interaction and may exist even without self-gravitation. Gravitation begins to dominate in models corresponding to the upper bend of the curve, leading to the existence of a maximal mass.

Figure 3 shows the dependence of the total energy density on the distance from the center for configurations of various masses. Even for the stellar models with $M = 1.44\,M_\odot$ the density on the surface decreases relative to the central density only by a factor of 2, which indicates very small compressibility of the configurations considered.

Table 2 gives the basic parameters of stellar configurations of maximal mass. For the range of bag parameters we are considering the following values are obtained for the maximal mass: $M_{\max} = (1.75 - 1.86)\,M_\odot$ with corresponding radii $R_{\max} = (9.8 - 10.4)\,\mathrm{km}$ and central densities $(\rho_0)_{\max} = (2.2 - 2.5) \cdot 10^{15}\,\mathrm{g/cm^3}$. It is necessary to note that only the bag parameter B has any significant influence on the maximal mass of strange stars, while the influence of m_s and α_c is negligibly small. The computation of the configurations of maximal mass was carried out because of the importance of comparing the parameters of the theoretical models with the observable parameters of stellar objects, by means of which the problem of deciding which of the various theoretical models to realize is solved.

The double radio pulsar PSR 1913+16 is at present considered to have the most precisely determined mass $M = (1.442 \pm 0.003)\,M_\odot$ [14], and it is reproduced in all our models. Of special interest to us is

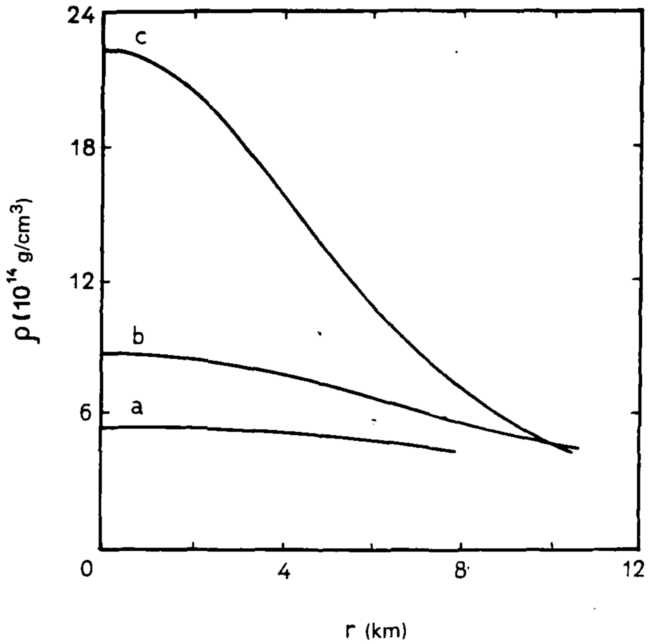

Fig. 3. Dependence of the total energy density ρ on the distance from the center r for the model 1.3 (a. $M = 0.5\,M_\odot$; b. $M = 1.44\,M_\odot$; c. $M = M_{\max}$).

Table 2

INTEGRAL PARAMETERS OF STELLAR CONFIGURATIONS OF MAXIMAL MASS

Model	$\frac{M_{\max}}{M_\odot}$	$\frac{M_0}{M_\odot}$	$\frac{M_p}{M_\odot}$	ρ_0 10^{14} g/cm^3	Z_S	R km	I $10^{45}\cdot$ g $\cdot$ cm^2
1.1	1.860	2.335	2.351	21.974	0.456	10.377	1.883
1.2	1.860	2.296	2.352	22.064	0.458	10.361	1.877
1.3	1.860	2.252	2.355	22.272	0.460	10.338	1.871
1.4	1.861	2.223	2.356	22.289	0.460	10.333	1.870
2.1	1.829	2.263	2.307	22.592	0.452	10.262	1.802
2.2	1.827	2.223	2.308	22.681	0.453	10.236	1.792
2.3	1.825	2.177	2.308	22.745	0.454	10.209	1.784
3.1	1.785	2.200	2.258	23.863	0.457	9.955	1.665
3.2	1.786	2.163	2.259	23.945	0.458	9.942	1.662
3.3	1.787	2.134	2.261	24.030	0.459	9.932	1.660
4.1	1.756	2.131	2.217	24.364	0.452	9.850	1.596
4.2	1.755	2.092	2.117	24.577	0.454	9.821	1.586

the massive double X-ray pulsar 4U0900-40 with mass $M = (1.56 - 1.98)\,M_\odot$ [15]. The most probable value of the mass of this pulsar, $M = 1.77\,M_\odot$, is not reached in our models of the fourth series. A more precise determination of the mass of 4U0900-40 may significantly limit the admissible range of bag parameters. Tables 3 and 4 give the basic parameters of stellar configurations with masses $M = 1.44\,M_\odot$ and $M = 1.77\,M_\odot$ that reproduce the most probable observed masses of the pulsars PSR 1913+16 and

Table 3

INTEGRAL PARAMETERS OF STELLAR CONFIGURATIONS WITH TOTAL MASS $M = 1.44\,M_\odot$

Model	$\frac{M_0}{M_\odot}$	$\frac{M_p}{M_\odot}$	ρ_0 10^{14} g/cm^3	Z_S	R km	I $10^{45}\cdot$ g $\cdot$ cm^2
1.1	1.738	1.674	8.626	0.290	10.647	1.500
1.2	1.709	1.674	8.662	0.290	10.631	1.496
1.3	1.675	1.674	8.696	0.291	10.615	1.491
1.4	1.655	1.677	8.726	0.292	10.607	1.491
2.1	1.718	1.677	8.959	0.293	10.579	1.480
2.2	1.690	1.678	9.035	0.294	10.553	1.473
2.3	1.654	1.678	9.109	0.295	10.522	1.465
3.1	1.713	1.685	9.833	0.305	10.282	1.405
3.2	1.684	1.685	9.915	0.306	10.268	1.402
3.3	1.661	1.686	9.944	0.306	10.260	1.401
4.1	1.694	1.690	10.324	0.309	10.209	1.385
4.2	1.663	1.690	10.396	0.310	10.183	1.378

Table 4

INTEGRAL PARAMETERS OF STELLAR CONFIGURATIONS WITH TOTAL MASS $M = 1.77\,M_\odot$

Model	$\frac{M_0}{M_\odot}$	$\frac{M_p}{M_\odot}$	ρ_0 10^{14} g/cm^3	Z_S	R km	I $10^{45}\cdot$ g $\cdot$ cm^2
1.1	2.202	2.158	13.343	0.391	10.810	1.947
1.2	2.164	2.158	13.388	0.391	10.793	1.942
1.3	2.122	2.159	13.426	0.392	10.777	1.937
1.4	2.094	2.160	13.438	0.393	10.769	1.936
2.1	2.175	2.170	14.752	0.400	10.658	1.888
2.2	2.141	2.173	14.969	0.402	10.624	1.878
2.3	2.098	2.175	15.146	0.404	10.500	1.867
3.1	2.176	2.206	19.017	0.433	10.182	1.733
3.2	2.141	2.208	19.021	0.434	10.167	1.729
3.3	2.112	2.208	19.087	0.434	10.162	1.729

4U0900-40 respectively.

Another very important parameter for the observational manifestations of strange stars is the moment of inertia. The values of $I_{\max} = (1.58 - 1.88)\cdot 10^{45}$ g $\cdot$ cm^2 obtained by us significantly exceed the estimate of the lower limit of the moment of inertia for the pulsar in the Crab Nebula: $I \geq 0.8\cdot 10^{45}$ g $\cdot$ cm^2 [16], but unfortunately there are as yet no other data.

We have computed the gravitational redshift Z_S from the surface of the star, which theoretically is also a directly observable parameter. The values obtained for $Z_S = 0.45 - 0.46$, corresponding to configurations with maximal mass are smaller than in the case of neutron stars. In [17] and [18] there is a study of a

Table 5

INTEGRAL PARAMETERS OF STELLAR CONFIGURATIONS WITH GRAVITATIONAL REDSHIFT $Z_S = 0.23$

Model	$\frac{M}{M_\odot}$	$\frac{M_0}{M_\odot}$	$\frac{M_p}{M_\odot}$	ρ_0 10^{14} g/cm^3	R km	I $10^{45}\cdot$ g $\cdot$ cm^2
1.1	1.168	1.365	1.307	7.110	10.148	1.071
1.2	1.167	1.354	1.319	7.180	10.153	1.082
1.3	1.163	1.322	1.313	7.192	10.127	1.072
1.4	1.160	1.301	1.310	7.198	10.112	1.066
2.1	1.158	1.348	1.308	7.297	10.097	1.059
2.2	1.157	1.325	1.308	7.350	10.071	1.054
2.3	1.155	1.296	1.306	7.404	10.040	1.046
3.1	1.121	1.297	1.266	7.776	9.752	0.958
3.2	1.117	1.270	1.262	7.787	9.731	0.951
3.3	1.114	1.250	1.259	7.794	9.716	0.946
4.1	1.112	1.269	1.257	7.946	9.681	0.936
4.2	1.111	1.246	1.256	7.994	9.657	0.931

mechanism for determining the gravitational redshift from the surface of superdense stars by measuring the redshift of the annihilation lines observed in the spectral interval between 300 and 511 keV during γ-bursts. From analysis of the illumination of the source of the March γ-burst in 1979, which was identified with the object SNR N49, a gravitational redshift of $Z_S = 0.23 \pm 0.05$ was obtained [19]. The large set of realistic equations of state of the matter of neutron stars gave values of the mass $M = (1.1 - 1.6)\,M_\odot$ and radius $R = (10 - 14)$ km for configurations with $Z_S = 0.23$.

Table 5 gives the main parameters of the configurations with $Z_S = 0.23$ for the models of strange stars we are considering. The narrow intervals of values of $M = (1.11 - 1.17)\,M_\odot$ and $R = (9.7 - 10.2)$ km obtained may significantly simplify the identification of strange stars in the case of determining the mass of SNR N49.

In contrast to the preceding papers we have computed the binding energy of strange stars E_B ($E_B = M_0 - M$). For all the models considered the binding energy has the normal sign and decreases significantly as α_c increases, as shown by Fig. 4, which gives the dependence of the binding energy for two models that differ in the value of α_c. The values obtained for the packing fraction $\alpha = 0.16 - 0.2$ ($\alpha = 1 - M/M_0$) show that these models are significantly more strongly bound than neutron stars.

The problem of rapid rotation of superdense stars has been studied by a number of authors (cf., for example, [20] and the references therein). As an absolute upper bound for the angular frequency of homogeneous rotation we have the Kepler frequency corresponding to the orbital velocity of a particle on the equator of the star. The minimal period of revolution of configurations with maximal mass can be well approximated by the expression [21]

$$P_{\min} = 0.0276\left[\frac{(R/\text{km})^3}{M/M_\odot}\right]^{1/2} \text{msec.}$$

For the models we have considered the minimal period of revolution is $P_{\min} = (0.64 - 0.68)$ msec, while the most rapid pulsar recorded to date, PSR 1937+21 has period $P = 1.558$ msec [22]. More rapid rotation ($P = 0.3$ msec) is obtained in the case of pion stars. However, they satisfy the observational restrictions on the mass only for an extremely restrictive equation of state [23]. The discovery of submillisecond pulsars would advance the solution of the problem of choosing theoretical models.

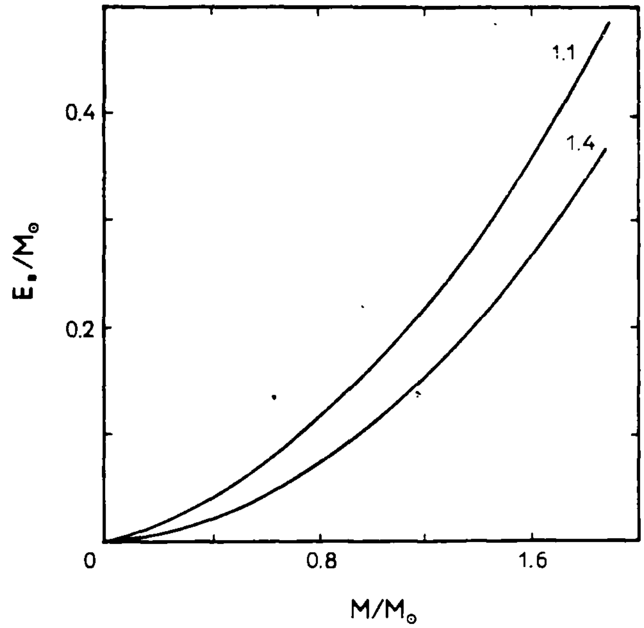

Fig. 4. Dependence of the binding energy E_B on the total mass M for the models 1.1 and 1.4.

5. Conclusion. In the present paper we have studied models of strange stars for the most probable range of variation of bag parameters in the context of comparing them with observational data. It is important to consider the possibility of observationally distinguishing between these objects and neutron stars in order to establish the existence of one or both types of superdense stars.

Table 6

COMPARISON OF MODELS OF NEUTRON STARS AND STRANGE STARS CORRESPONDING TO THE MASS OF PULSAR PSR 1913+16

Model	$\rho_0/\rho_{\rm nuc}$	$P_{\rm min}$ (msec)	$\log I$	Z_S
Neutron stars	2–5	0.7–1	44.95–45.2	0.23–0.45
Strange stars	3.5–4.5	0.75–0.8	45.14–45.18	0.29–0.31

Table 6 gives a comparison of the central density, Kepler period of revolution, moment of inertia, and redshift of strange stars and neutron stars with mass $1.44\,M_\odot$. For neutron stars we used the results of computation with the sixteen equations of state studied in [19], while for strange stars we used our own results. While noting the considerable similarity of the results, we remark that the gravitational redshift Z_S appears to be the most important parameter distinguishing strange stars and neutron stars. In this connection one can place some hope in determining the mass of the object SNR N49, which would play an important role in choosing an equation of state for superdense matter. We remark also that models of strange stars having no envelope encounter great difficulties in the standard explanation of pulsar glitches.

It should be noted that if the assumption of the appearance of strange quark matter at densities comparable with nuclear density is true, this casts doubt on the existence of massive neutron stars. In this case the range of existence of neutron stars would be bounded above not by the central density $\rho_{\rm capt}$ corresponding to the maximum of the curve $M(\rho_0)$ (the Landau-Oppenheimer-Volkov point), but by the density for appearance of strange quark matter ρ_Q. For the models we have considered $\rho_Q = (1.77 - 1.97)\,\rho_{\rm nuc}$, and only the most restrictive equations of state [24, 25] could reproduce the masses

$(1.1 - 1.8)\, M_\odot$ under such central densities. These masses are the most commonly encountered ones for pulsars and X-ray sources [15]. The data of the discussion, of course, do not exclude the possibility that there exist neutron stars of small mass, for which, to be sure, no observational data yet exist.

Taking account of the difficulties of the theory of strong interactions and the model character of our description of the quark phase, the authors believe that the question of the existence of strange stars remains open. In an alternative model of the equation of state [26] the formation of strange quark matter occurs in the nuclei of neutron stars at densities more than five times as large as that of the nucleus. In this case even for certain realistic equations of state of neutron matter the side-by-side existence of massive neutron and strange stars is possible. Further theoretical study of models of strange stars and more precise observational data would seem to be helpful in solving this problem.

The authors are grateful to E. V. Chubaryan and A. M. Atoyan for assistance in overcoming the information blockade. The present paper was written in the framework of area 46/101 93-353, supported by the Ministry of Higher Education and Science of the Republic of Armenia.

Erevan State University

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