Chiral Symmetry Breaking and Stability of Strangelets

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The study of quark matter has become more important since the discovery of quark stars and recent experiments of heavy ion collisions. Theories of quark matter or high density matter has also been developed. Although many people have attempted to find a connection between theoretical results and observed data, it is still a difficult task due to a limited number of confirmative data. One of the candidates which links the theory and data is strangelet. Strangelets are finite volume quark matter with strange quarks which are bound by QCD. Quarks in strangelets are not hadronized unlike in nuclei. If there were such objects, they are of new type of matter and will be of great interest to understand the nature of QCD and the formation of the hadronic matter. In this report, we discuss the stability of the strangelet in comparison with the ordinary nuclear matter, or with the u d quark matter. It has been discussed that strangelets can exist as stable objects in universe and be detected in cosmic rays on the earth. Our aim is also to predict several observables of strangelets. In particular we study:

1. ⟨**Direct comparison theoretical results with observed data**⟩ It is possible to compare theoretical results with experimental data of strangelets detected in cosmic rays. We calculate observeble quantities of strangelets such as mass, radius, charge and so on.
2. ⟨**Impacts on astrophysics**⟩ When strangelets are detected as heavy particles in cosmic rays, we can obtain information about first order QCD transition in early universe and explosions or collisions of high dense compact stars.

It is one of the questions whether strangelets are more stable than ud quark droplets. Strange quarks can be changed to d quark by a weak process $u+d \leftrightarrow d+s$. From the Pauli principle and the number of degrees of freedom, s quarks could exist [1], [2]. However quark droplets become heavier when s quarks have much larger mass than u or d quarks. This competition dtermines the s quark ratio to the total number of quarks.

We discuss the stability of strangelets based on the NJL lagrangian with $U(3)_L \times U(3)_R$ symmetry in order to consider chiral symmetry breaking which is important in low energy quark physics [4]. Though there were discussions about stability of quark matter, they did not include the surface effects which are necessary in strangelets [5]. We impose the MIT boundary condition on the surface of strangelet to include surface effects [6]. Particularly we apply MRE (Multiple Reflection Expansion) method in order to take into account the surface effects [3]. Then we considered the NJL gap equation for quarks in droplet by using the parameters $\Lambda = 600$ MeV and $G\Lambda^2 = 4.249$ to reproduce the quark mass $m_u, m_d = 280$ MeV and $m_s = 550$ MeV in vacuum and set current mass of each flavor $m_u^0, m_d^0 = 0$ MeV and $m_s^0 = 150$ MeV to discuss realistic strangelets

We have obtained results of the baryon number dependence of strangelet mass (rest energy) by mean-field approximation of thermodynamic potential with the MRE correction in Fig.1 (a). We have fixed the ratio of strangeness N_s to the total number of quarks N_q for each line to see the effects of inclusion of finite number of strange quarks N_s. We find that strangelets are more stable than u d quark droplets for baryon number smaller than ~ 370.

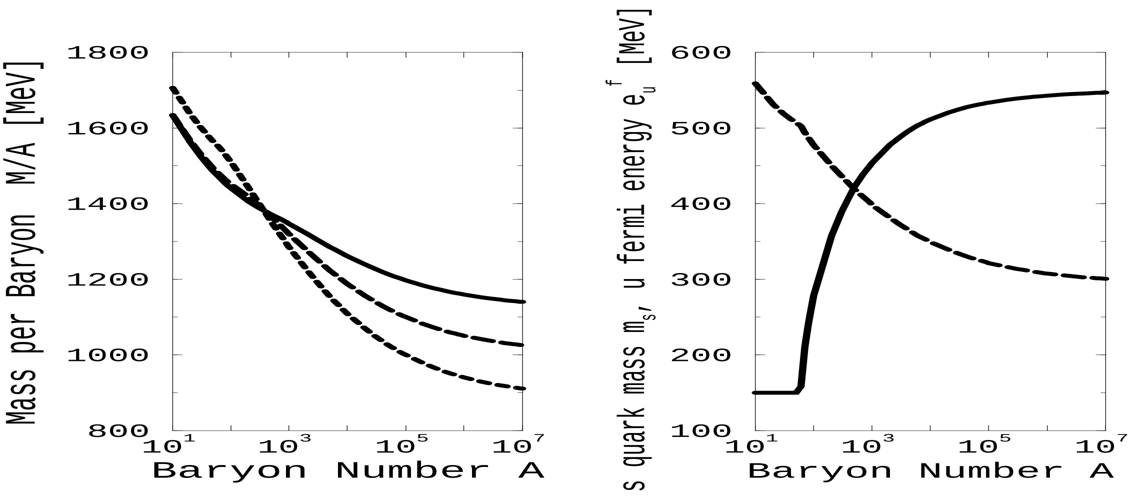

Figure 1: Left hand side (a); energy per baryon of strangelet. M is total mass (rest energy) of strangelet and A is baryon number. $N_s/N_q = 30\%$ (solid line), 15% (long-dashed line), 0% (short-dashed line). Right hand side (b); baryon number dependence of strange quark mass m_s (solid line) and u or d fermi energy ϵ_u^f (dashed line).

On the other hand u d quark droplets are more stable than strangelets for baryon number larger than ~ 370.

We can explain this behaviour as follows. The strange quark mass m_s and u or d fermi energy ϵ_u^f as function of baryon number A are plotted in Fig.1 (b). We can see the stability of strangelets against u d quark droplets. Strange quark mass m_s is smaller than u fermi energy ϵ_u^f for baryon number smaller than ~ 370. That means it is energetically favoured to change u or d quarks to s quark by weak process and strange quarks can exist in quark droplets. In short strangelets can exist for smaller baryon number. On the other hand, s quark mass m_s is larger than u or d fermi energy ϵ_u^f for baryon number A larger than ~ 370 due to chiral symmetry breaking. That means u or d quarks cannot decay into strange quarks because of the energy difference. Quark droplets are consist of only u and d quarks for larger baryon number.

In conclusion the baryon number dependence of strangelet mass is obtained by NJL model. Strangelets with samller baryon number are more stable than ud quark droplets and strangelets are not stable for larger baryon number because of chiral symmetry breaking. In future we study the effects of color superconductivity which are important phase in high density quark matter.

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