A Liquid Drop Model of Strangeon Matter
奇子物质液滴模型

Zheng Wang (王政)
School of Physics, Peking University
Supervisor: Renxin Xu (徐仁新)

FPS6

Jun. 29th, 2017; Wuhan

Outline

1. What is strangeon?
2. A liquid drop model of strangeon matter
3. A corresponding state approach
4. Results
5. Conclusions and discussions
6. Outlook

1. What is strangeon?

- In a pulsar, $E_{\text{scale}} \sim pc \sim \frac{\hbar c}{l} \sim \frac{200\text{MeV}\cdot\text{fm}}{0.5\text{fm}} \sim 0.4\ \text{GeV} < 1\text{GeV}$

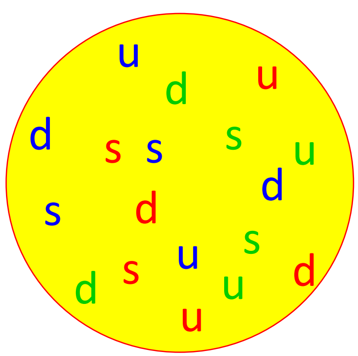
NQCD!

- 1984, **Witten's conjecture**:

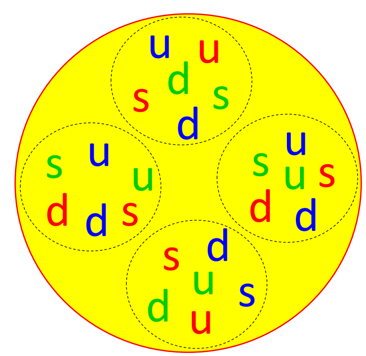
  Strange quark matter in bulk constitutes the true ground state of the strong-interaction matter rather than ^{56}Fe.

- A general Witten's conjecture:

  Strangeon matter in bulk constitutes the true ground state of the strong-interaction matter rather than ^{56}Fe.



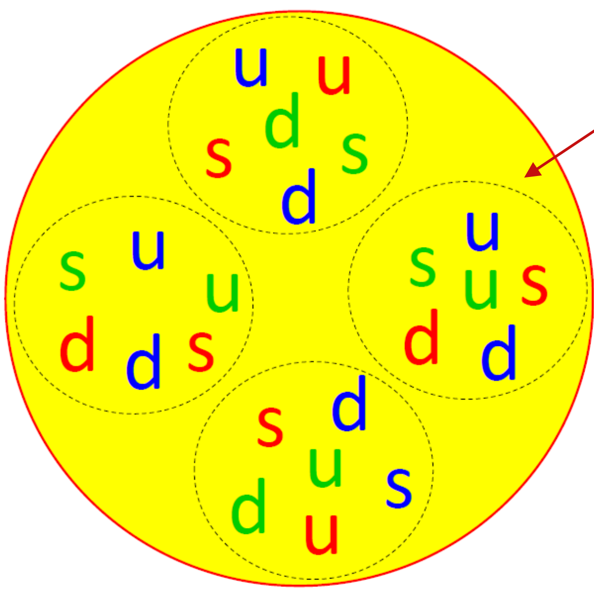
Strange ***Quark*** Matter



Strangeon Matter

1. What is strangeon?

- Strangeon = Strange nucleon
- Strangeon matter : 3-flavored nucleus consist of strangeons, the true ground state of the strong-interaction matter in bulk



Strangeon Matter

Strangeon

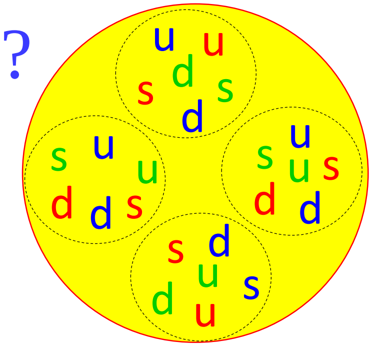
(coined by combining “strange nucleon”)

As an analogy of stable nucleon in nucleus, strangeon is conjectured to be stable in condensed matter of strangeons.

2. A liquid drop model of strangeon matter

For strangeons, we have such questions:

- Does strangeon matter exist?
- What is the nature of strangeon matter?
- What could be the minimum baryon number of strangeon matter?
- What parameter space is allowed for strangeon matter to exist?



A **Liquid Drop Model** can answer these questions!!!

2. A liquid drop model of strangeon matter

- In a conventional liquid drop model of nucleus, there are terms of volume, surface, Coulomb, and others:

$$E(A,Z) = ZM_{\mathrm{p}} + (A-Z)M_{\mathrm{n}} + b_{\mathrm{vol}}(1-k_{\mathrm{vol}}I^2)A$$
$$+b_{\mathrm{surf}}(1-k_{\mathrm{surf}}I^2)A^{2/3} + \frac{3}{5}\frac{e^2Z^2}{r_0A^{1/3}}$$

Where $I = (N-Z)/A$, represents the asymmetry of the nucleus.

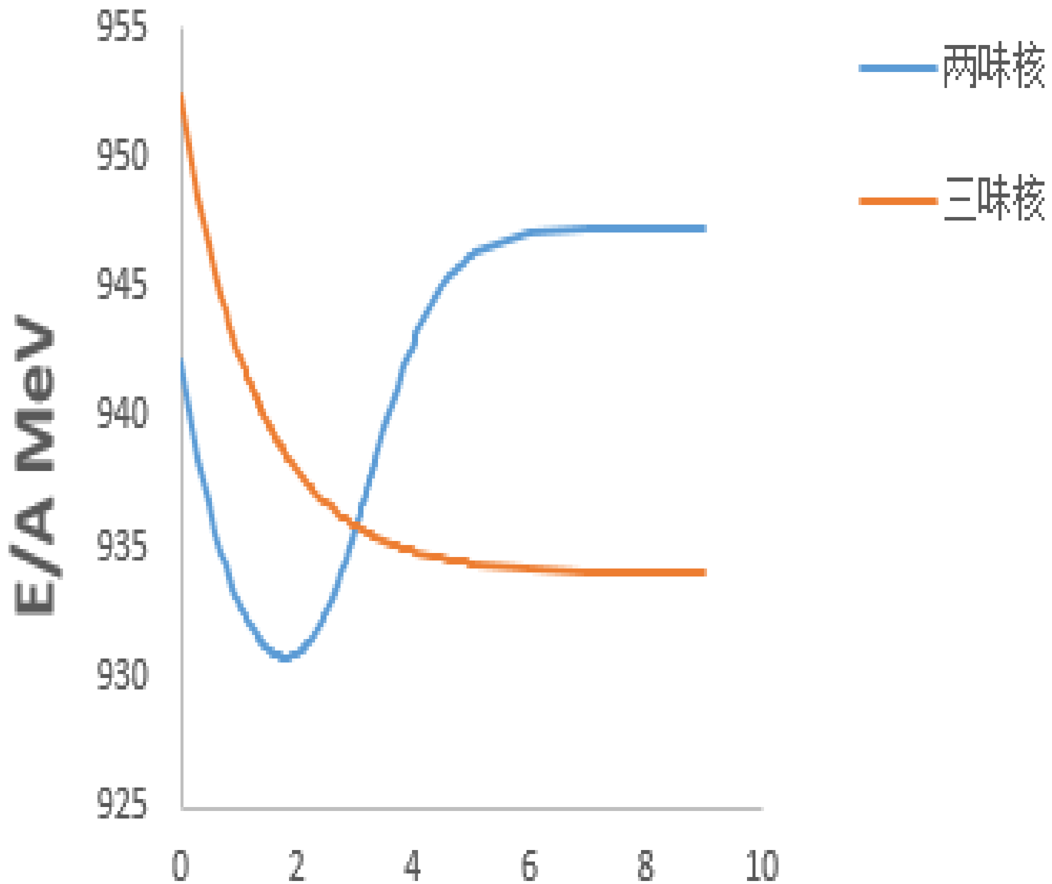
- For strangeon matter, only volume and surface energy remain:

$$E/A = M + b_{\mathrm{vol,s}} + b_{\mathrm{surf,s}}A^{-1/3}$$

2. A liquid drop model of strangeon matter

We except that strangeon matter could be more stable than 2-flavored nucleus when its baryon number A is greater than a critical value A_c if the general Witten's conjecture is correct.

But $b_{vol,s}$ and $b_{surf,s}$ is hard to understand and put the values.

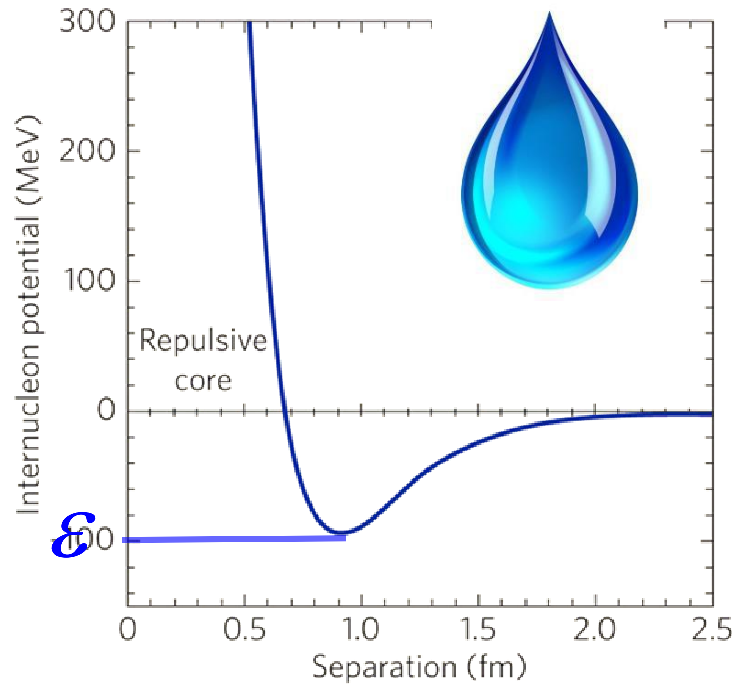


➡ Corresponding State Approach!

3. A corresponding state approach

The law of corresponding states (de Boer, 1948):

- The equation of state of substances with same form of interaction can be written in a reduced and universal form.



Lennard-Jones potential

assumed in the liquid drop model

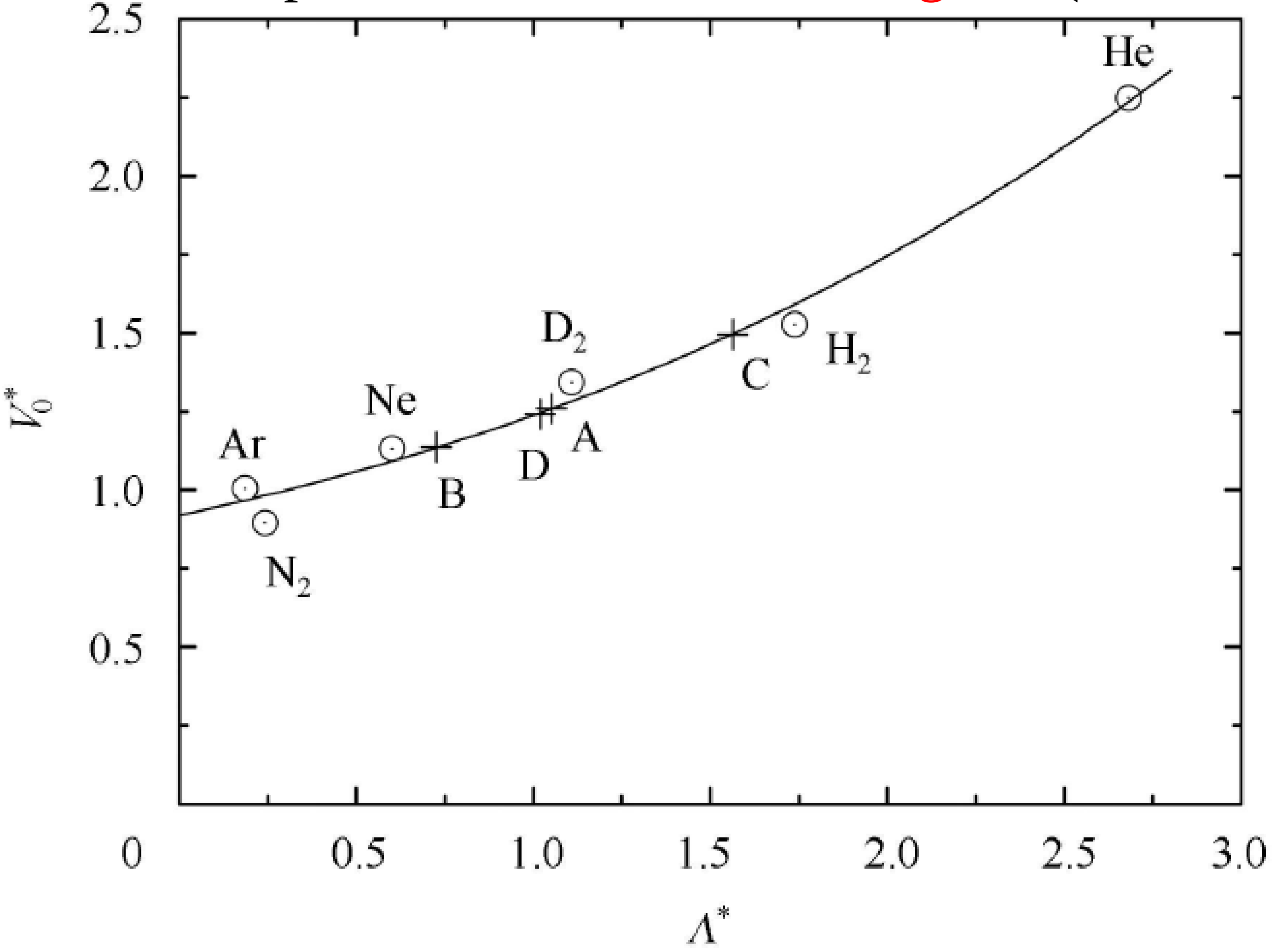
We assumed the interaction between two strangeons is Lennard-Jones-like, which is similar to the interaction between atom of inert gas:

$$\phi(r) = \epsilon\{\frac{4}{(r/\sigma)^{12}} - \frac{4}{(r/\sigma)^{6}}\}$$

Then we can use ϵ, σ (n) instead of $b_{\mathrm{vol,s}}$ and $b_{\mathrm{surf,s}}$.

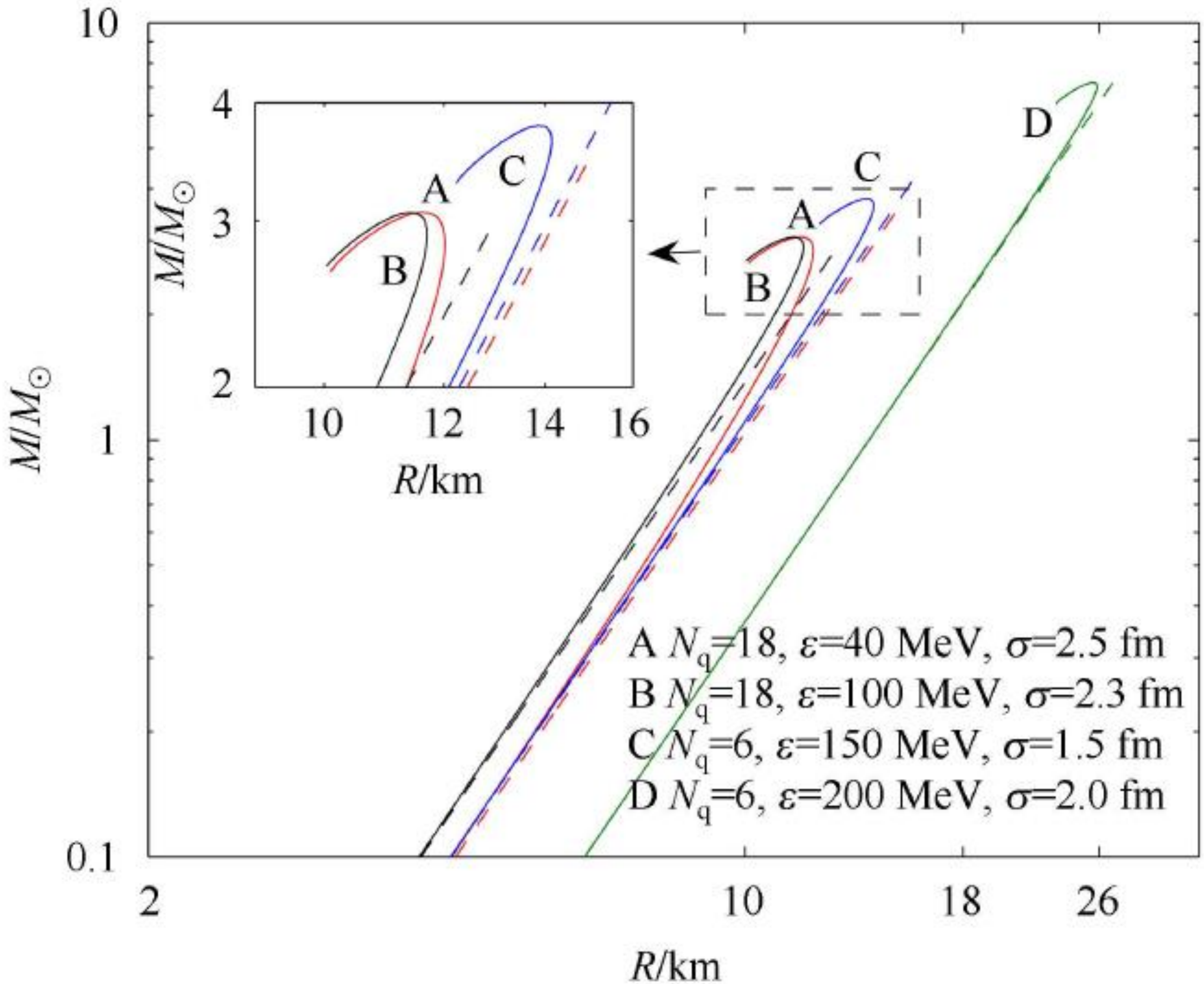
3. A corresponding state approach

- Fit the experimental data of reduced volume V_0^* and Λ^* at zero temperature and pressure for different inert gases (Guo et al., 2014).



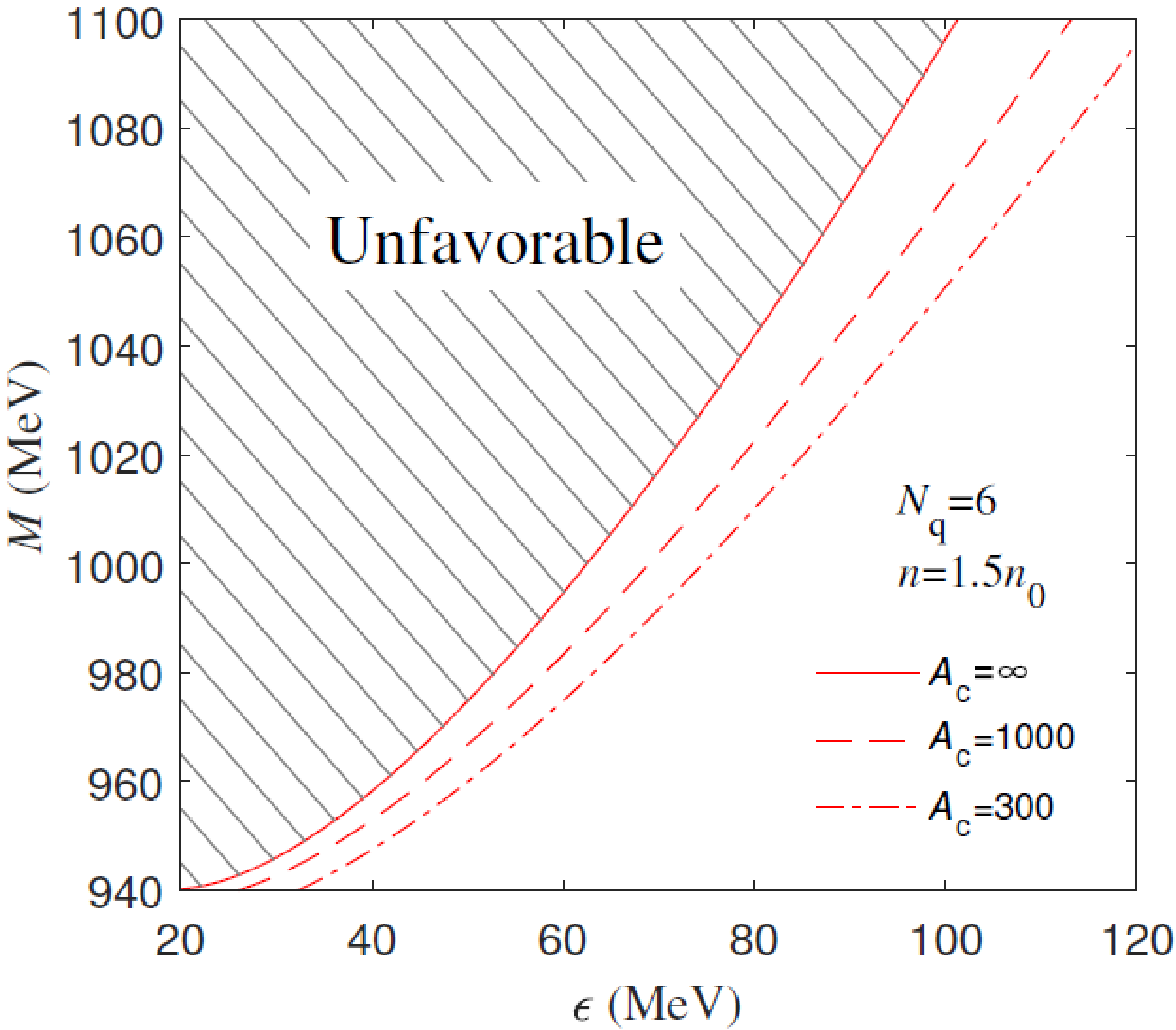
3. A corresponding state approach

A mass-radius curves of strangeon star using the law of correspon-ding states (Guo et al., 2014).

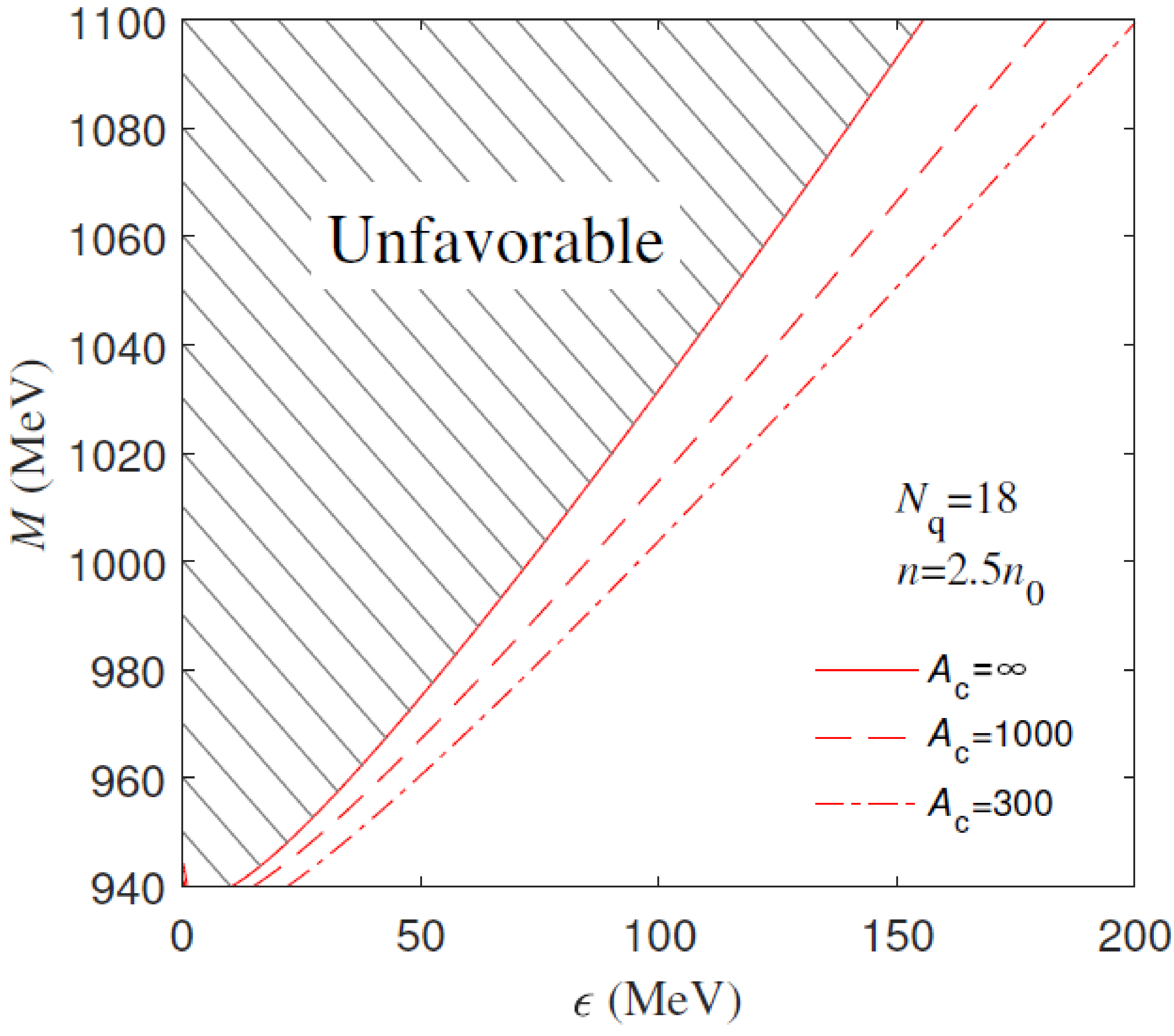


4. Results

- For a given baryon number density, n (to be a few nuclear density, n_0), and the quark number of one strangeon, N_q, we have two free parameters to calculate the energy per baryon (E/A): M and ϵ.
- If strangeon matter exits stably, the energy per baryon of strangeon drop should be lower than that of normal nuclei with baryon number $A > A_{\mathrm{c}}$.
- The energy per baryon of strangeon matter is always greater than that of 2-flavored nucleus or 938MeV (mass of proton) in the hatched region labelled “Unfavorable”.



1100
1080
1060
1040
1020
1000
980
960
940
20
40
60
80
100
120
M (MeV)
ε (MeV)
Unfavorable
N_q=6
n=1.5n_0
A_c=∞
A_c=1000
A_c=300



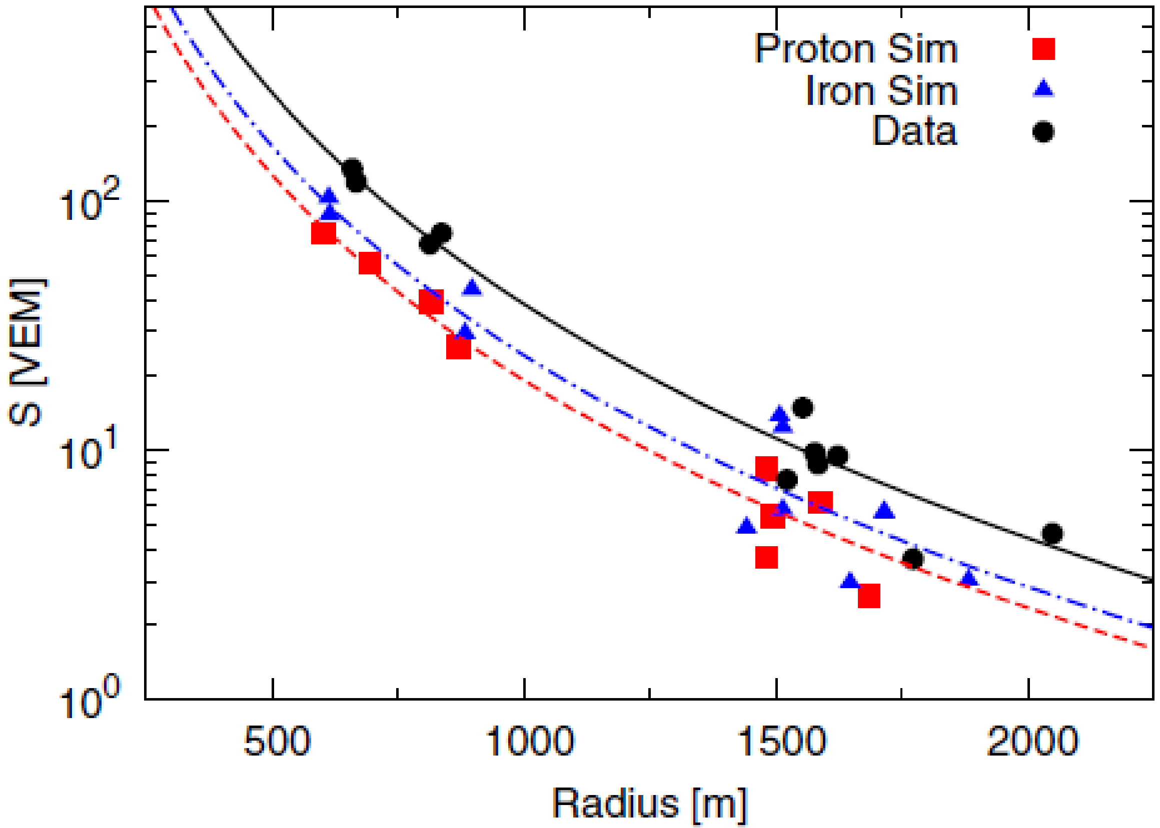
1100
1080
1060
1040
1020
1000
980
960
940
M (MeV)
0
50
100
150
200
ϵ (MeV)
Unfavorable
N_q=18
n=2.5n_0
A_c=∞
A_c=1000
A_c=300

5. Conclusions and discussions

- There is huge parameter space for strangeon matter to exist stably in this liquid drop model.
- Strangeon matter could be stable even its baryon number to be as low as 300 if the mass per baryon of a strangeon in vacuum is M~GeV and the potential deep in-between is ϵ~100 MeV.
- It supplies a unique possibility to explain very deferent manifestations in the Universe (the nature of pulsar, cosmic ray, and dark matter) with the strangeon matter conjecture.

6. Outlook

- To find strangeon matter in cosmic rays.
- Auger observatory: muon excess in air showers (A. Aab et. all, 2016). → Strangeon Matter?



Thanks for your attention