Surface Properties of Strange Superheavy Nuclei

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- Motivation – in principle, neutral, strange, superheavy nuclei stable against strong decay can be arbitrarily large
- For some critical number of Λ's in the nuclear medium[1]

$$\Lambda + \Lambda \rightarrow N + \Xi$$

- Include Λ's and $\Xi = \begin{pmatrix} \Xi^0 \\ \Xi^- \end{pmatrix}$
- Construct an effective lagrangian - limit to scalar and vector mesons only
- Impose the conditions $Q = 0$ and $|S| / B = 1$
- The resulting SEMF is

$$\frac{E}{B} = a_1 + a_2 B^{-1/3}$$

1 J. Schaffner, C. Dover, A. Gal, C. Greiner, and H. Stocker. Phys. Rev. Lett. 71, 1328 (1993)

Modern approach to nuclear structure

- Construct an effective lagrangian using hadronic degrees of freedom and incorporate the following:
  - Special Relativity and Quantum Mechanics
  - The underlying symmetry structure of QCD
  - Nonlinear realization of spontaneously broken chiral symmetry
- The fields are small compared to M

$$\frac{\Phi}{M}, \frac{W}{M} \approx \frac{1}{3} \qquad \frac{k_F}{M} \approx \frac{1}{4}$$

- Now a controlled expansion is preformed in the effective lagrangian
- If we assume that the lagrangian provides an appropriate energy functional, then Density Functional Theory states that this lagrangian can be used to reproduce the exact ground-state scalar and vector densities, energy, and chemical potential

- Compute the density functional by assuming that the system is a local Fermi gas filled up to some $k_F(r)$
- Make the simplest approximation for both the nucleons and hyperons
- Retain a couple of nonlinear scalar field self couplings
- The energy density

$$\mathcal{E}[\phi_0, V_0, \rho_B] = \frac{4}{(2\pi)^3}\int_0^{k_F} d^3k\sqrt{\left(k^2+M^{*2}\right)} + \frac{4}{(2\pi)^3}\int_0^{k_F} d^3k\sqrt{\left(k^2+M_\Xi^{*2}\right)}$$
$$+\frac{2}{(2\pi)^3}\int_0^{k_{F\Lambda}} d^3k\sqrt{\left(k^2+M_\Lambda^{*2}\right)} + \frac{1}{2}\left[(\nabla\phi)^2 + m_S^2\phi_0^2\right] + \frac{\kappa_3 m_S^2}{3!}\frac{g_S\phi_0^3}{M}$$
$$+\frac{\kappa_4 m_S^2}{4!}\frac{g_S^2\phi_0^4}{M^2} + g_V\rho_B V_0 - \frac{1}{2}\left[(\nabla V_0)^2 + m_V^2 V_0^2\right]$$

- Effective mass

$$M^* \equiv M - g_S\phi_0$$

- Nucleon coupling constants[1]

1 B. Serot and J. D. Walecka Inter. J. of Mod. Phys. E6 515 (1997)

- Hyperon coupling constants
  - Fit scalar couplings to experimental data where it exists
  - Assume a universal vector coupling to the conserved baryon current
- The meson equations are

$$\left(\nabla^2 - m_S^2\right)\phi_0 = -g_S\rho_S + \frac{\kappa_3 m_S^2}{2}\frac{g_S\phi_0^2}{M} + \frac{\kappa_4 m_S^2}{6}\frac{g_S^2\phi_0^3}{M^2}$$

$$\left(\nabla^2 - m_V^2\right)V_0 = -g_V\rho_B$$

- The constraint equations - to be solved for $k_F(r)$

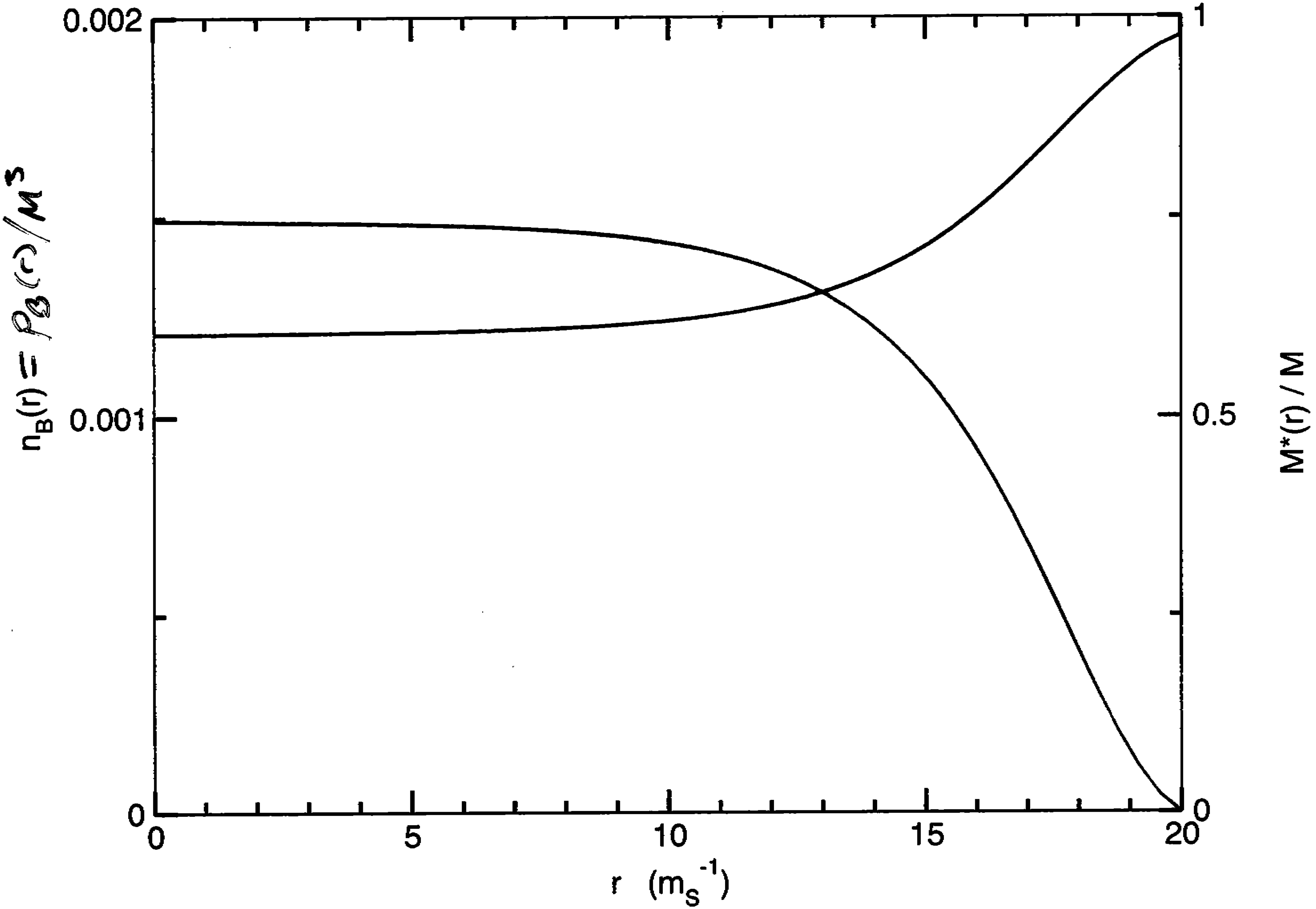
$$\mu = g_V V_0 + \frac{1}{2}\left[\left(k_F^2 + M^{*2}\right)^{1/2} + \left(k_F^2 + M_\Xi^{*2}\right)^{1/2}\right]$$

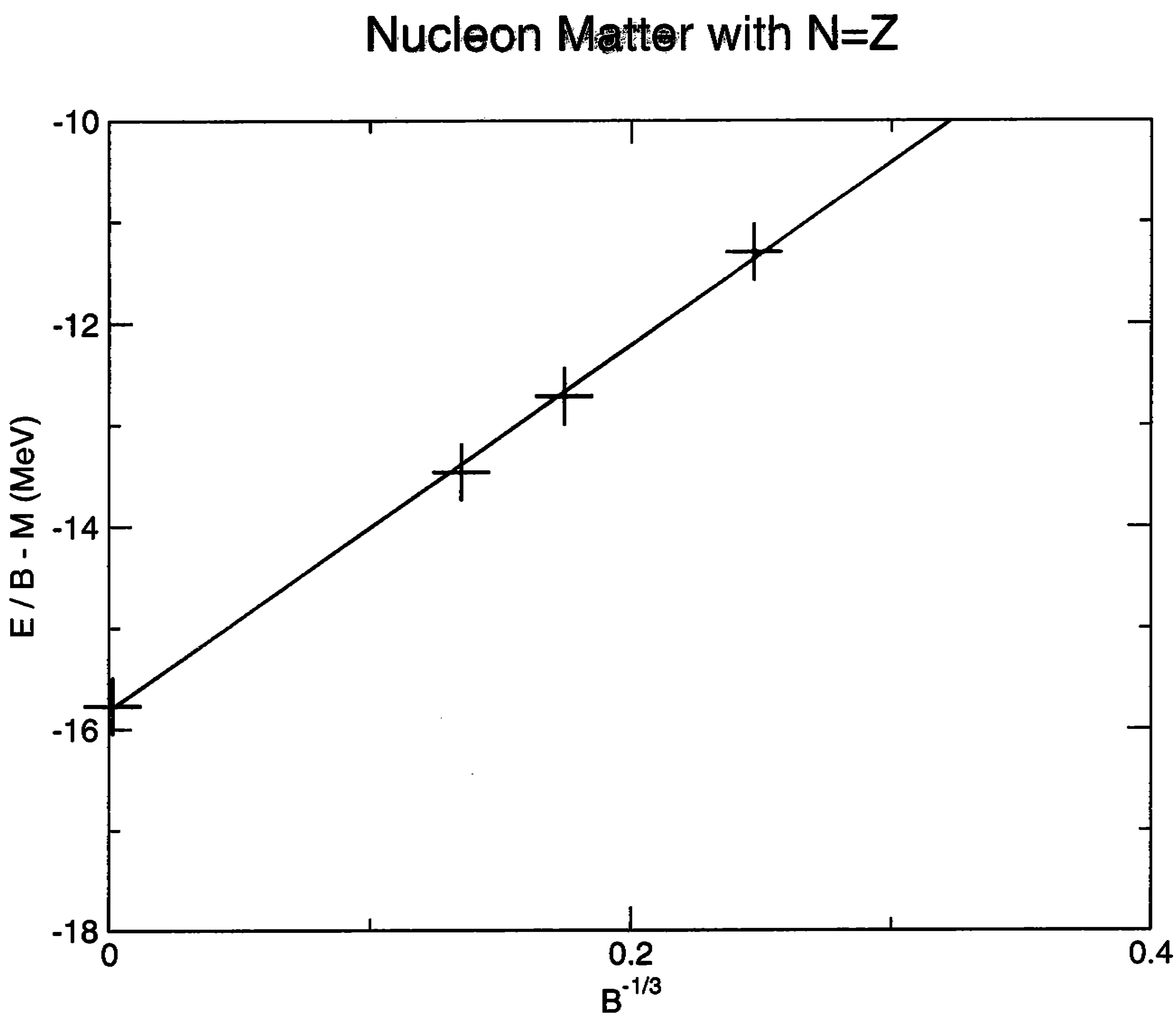
$$\mu = g_V V_0 + \left(k_{F\Lambda}^2 + M_\Lambda^{*2}\right)^{1/2}$$

- First reproduce nucleon matter with N = Z

1 B. Serot and J. D. Walecka. Advances in Nuclear Physics V16 (Plenum, 1986)

Nucleon Matter with N=Z





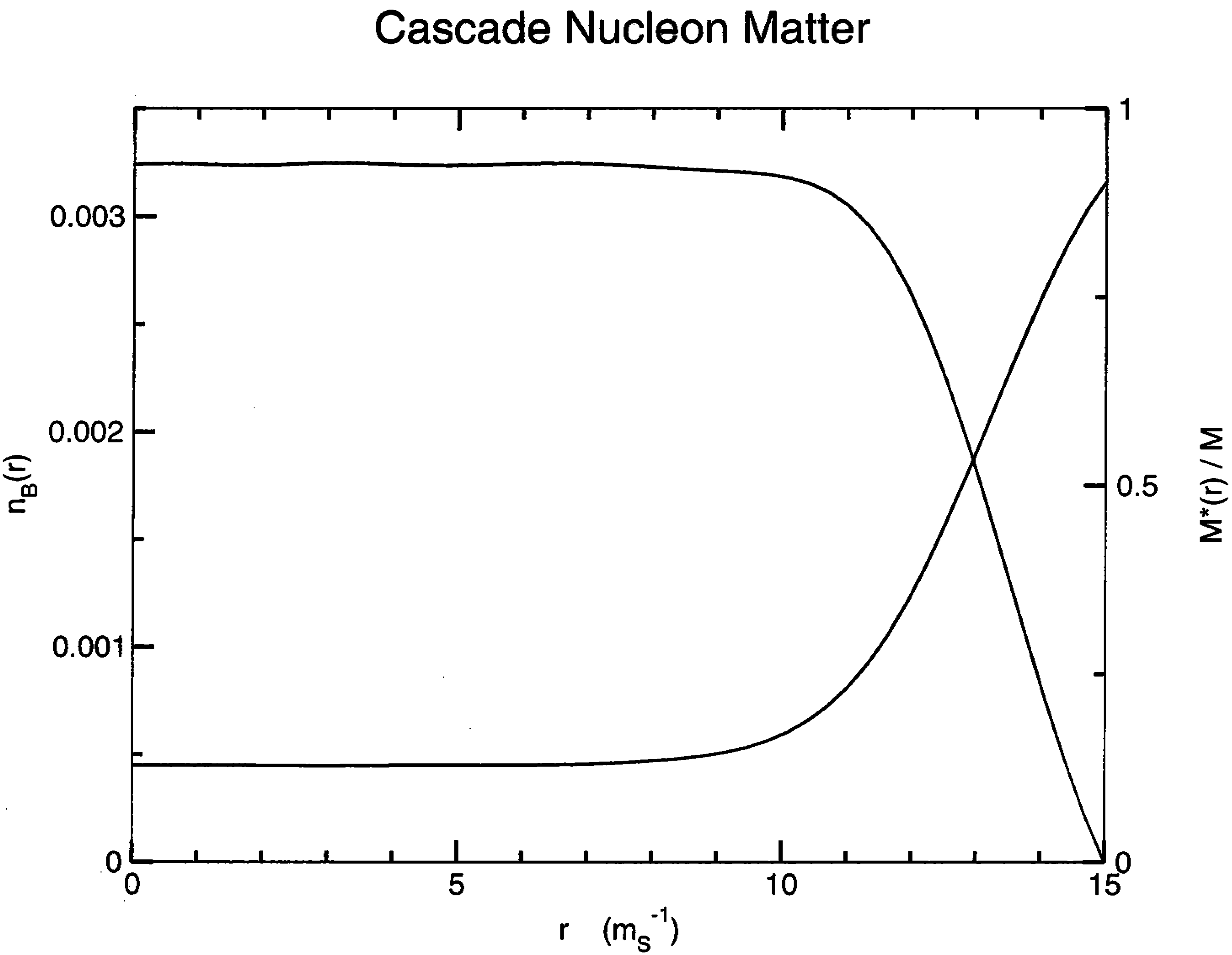
Nucleon Matter with N=Z
E / B - M (MeV)
-10
-12
-14
-16
-18
0
0.2
0.4
$B^{-1/3}$

Surface energies for nucleon matter

	a2 (MeV)
L2[1]	26.51
NLC[1]	18.01
Q1[1]	19.11
Expt.	17.8

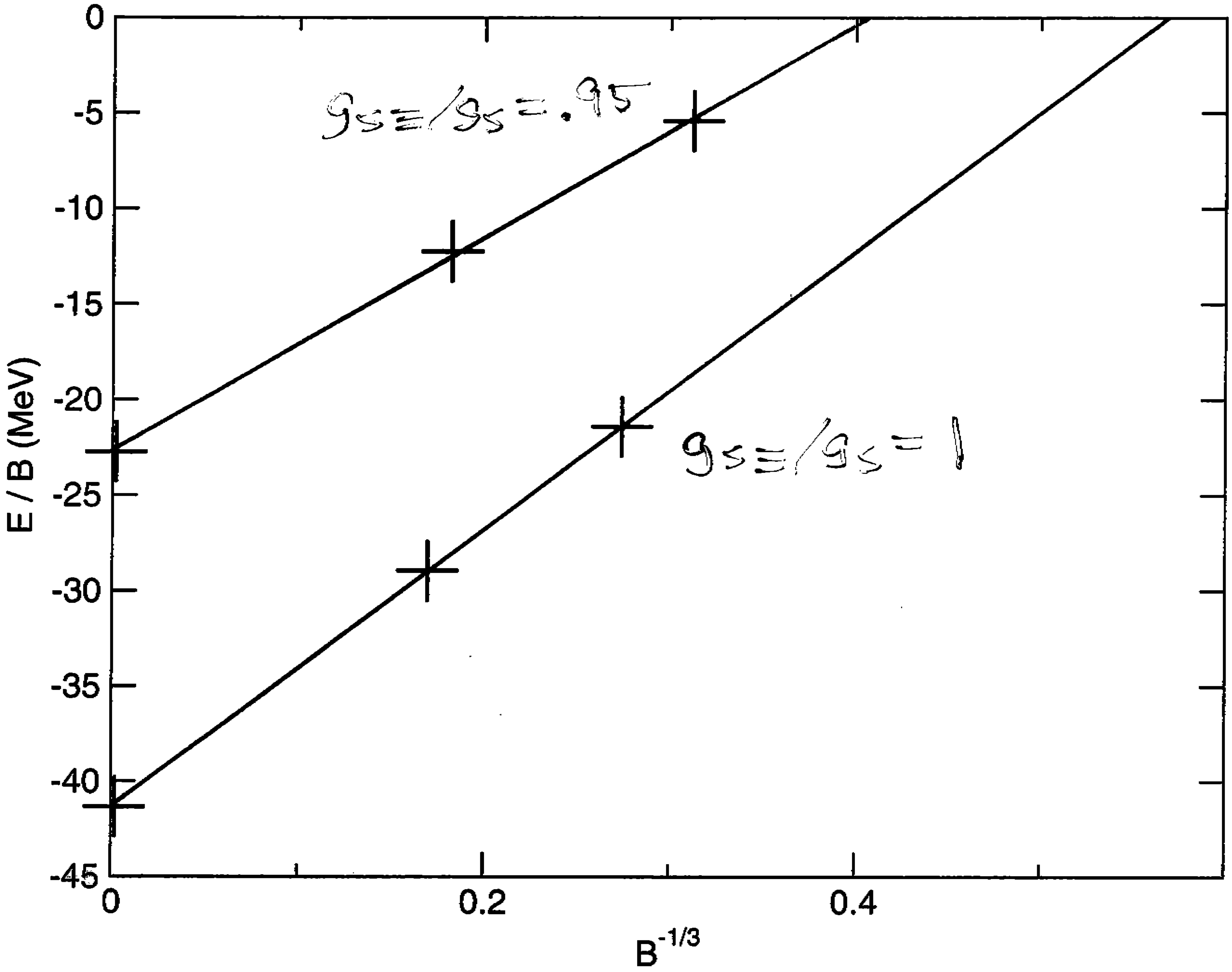
– This <u>calibrates</u> the approach

1 B. Serot and J. D. Walecka Inter. J. of Mod. Phys. E6 515 (1997)



Cascade Nucleon Matter
0.003
0.002
0.001
0
$n_B(r)$
0
5
10
15
r (m_S^{-1})
1
0.5
0
$M^*(r) / M$

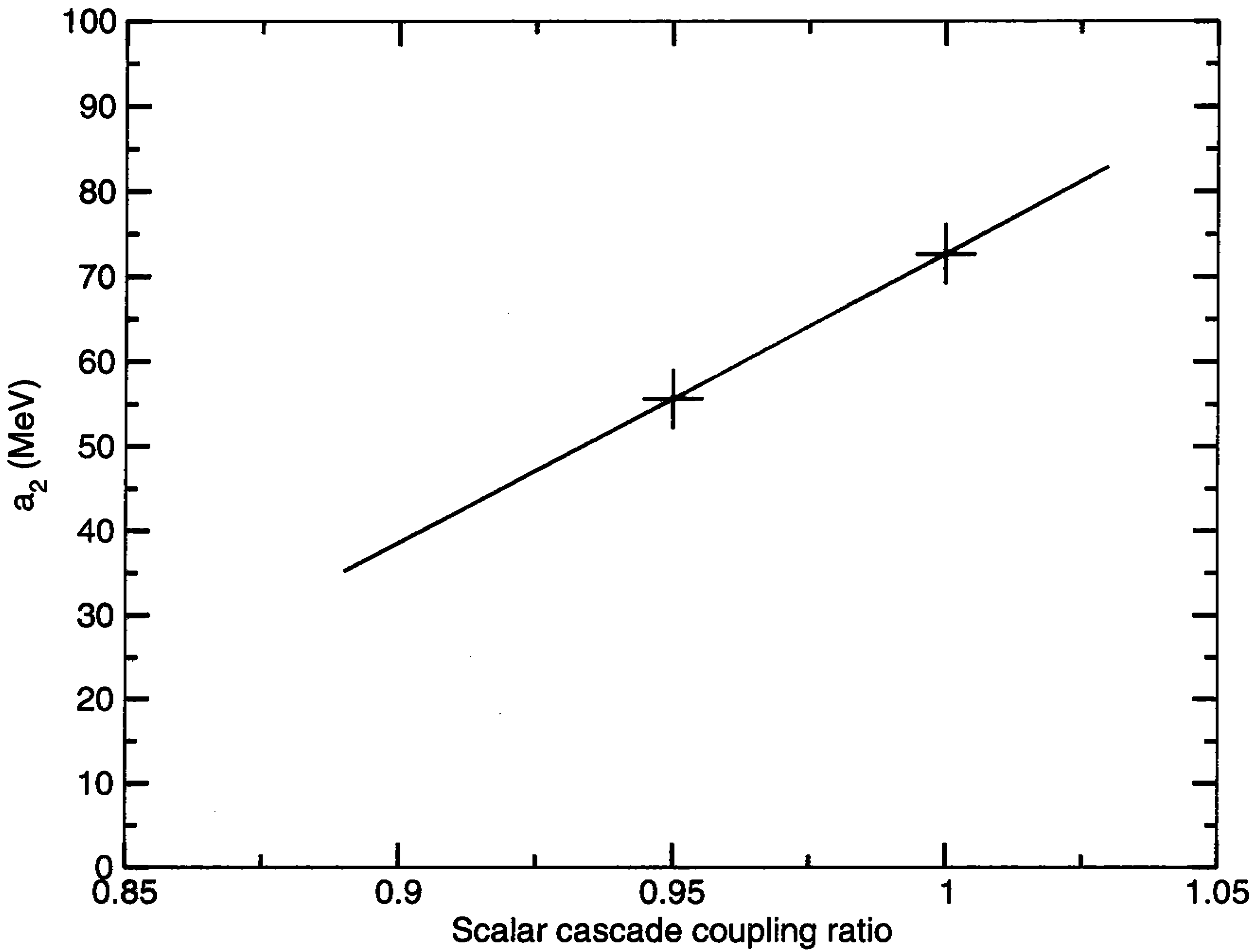
Cascade Nucleon Matter



Surface energies for cascade-nucleon matter[1]

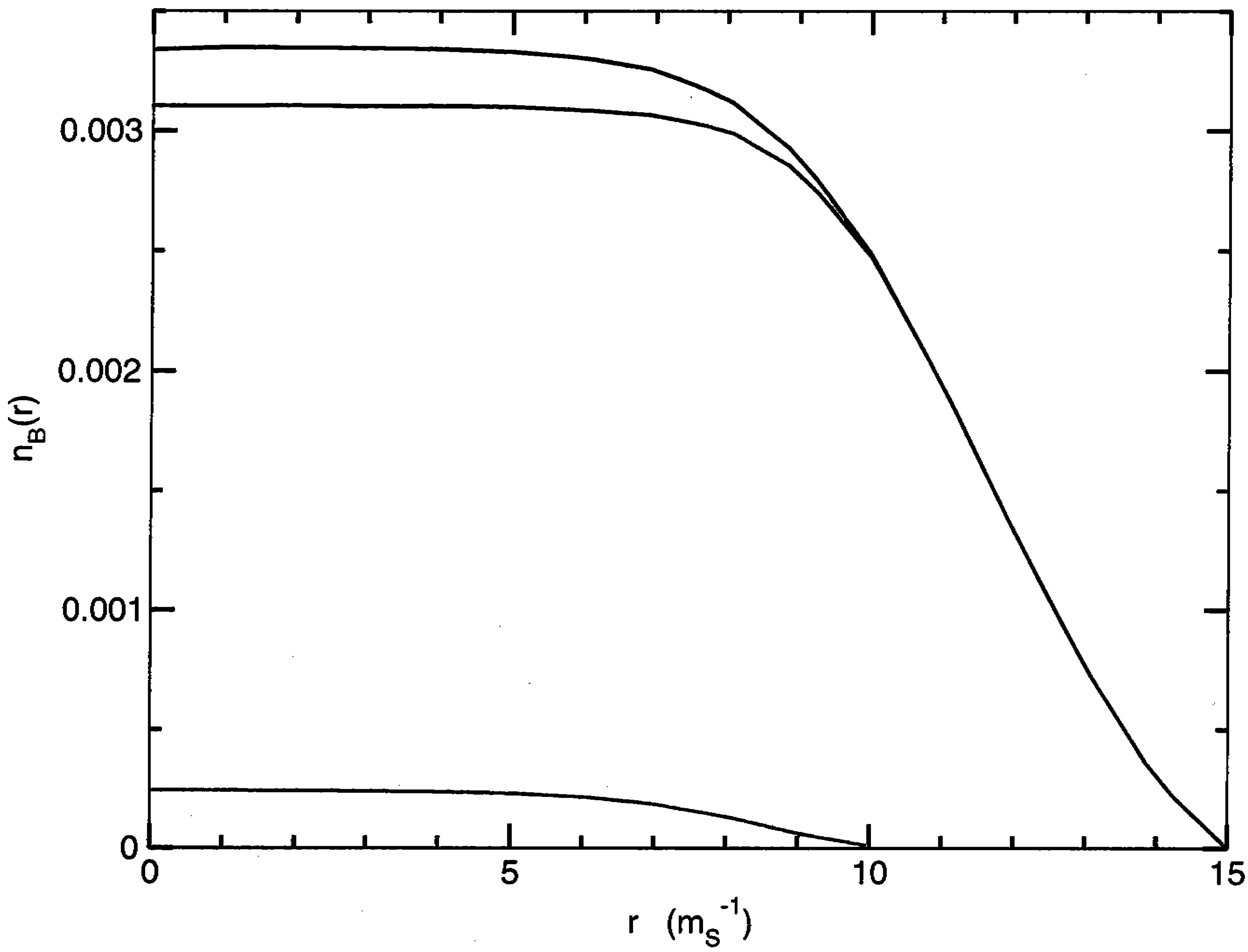
	$g_{s\Xi} / g_s$	min B	a2 (MeV)
NLC	1	5.4	72.69
	0.95	14.6	55.64

1 J. McIntire. Phys. Rev. C66 064319 (2002)



a2 (MeV)
100
90
80
70
60
50
40
30
20
10
0
0.85
0.9
0.95
1
1.05
Scalar cascade coupling ratio

Lambda Cascade Nucleon Matter



Conclusions

- Reproduced the surface energy for ordinary nuclei
- Calculated the surface energy and structure for strange superheavy nuclei