A New Topological "Twist" To BR Scaling

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A Brief History

Little Bag, Pions and ChPT

- In 1979, Gerry and I proposed to do nuclear physics with Little Bags (LB) surrounded by pions, not Big MIT bags, popular in 1970's.
- Gave preeminent role to pions in nuclear systems, similar to Cutkosky model.
- The key element: chiral symmetry – rather than confinement – in nuclear dynamics.
- Revived the role of chiral symmetry in nuclear physics, first put forward in early 1970's.
- This presaged today's ChPT in nuclear physics, with Weinberg's 1979 counting rule implemented in nuclear physics (Erice lectures 1981)

Little Bag, Skyrmions, Chiral Bags

- The *skyrmion model* was resurrected in large N_c QCD (by future string theorists) in 1983.
- Baryons arise from pions as *topological solitons, i.e.*, skyrmions.
- The Cheshire Cat Principle (CCP) formulated by Nadkarni, Nielsen and Zahed, exploiting anomalies on the boundary, reconciled LB to MIT bag. Smile of CC, Little/Big duality.
- Chiral Bag (CB) unified.

Cheshire Cat and Topology

- Damgaard, Nielsen & Sollacher (1993): "the CB boundary conditions encoding the 'smile of CC' is a gauge parameter."
- Amounts to trading topology with the CB boundary conditions or parameters of Hamiltonian.
- XQCD of David Kaplan (2013): CB encoded in QCD?:

BR Scaling

- To do nuclear physics with LB, it is astute to introduce the "conformal compensator" (or "conformalon"), identify it with the dilaton χ that arises from spontaneous breaking of conformal symmetry.
- The spontaneous breaking $<\chi>\neq 0$ is triggered by the "explicit" breaking associated with the QCD trace anomaly (consistent with the Freund-Nambu "theorem").

Need for Two Condensates: Σ and D

- $D^* \equiv \langle\chi\rangle_n$, $\Sigma^* \equiv \langle\bar{q}q\rangle_n$
- It is $\langle\chi\rangle$ in medium, $\langle\chi\rangle^*$, that figures in BR scaling.
- Hadron mass is *directly* tied to D^*, but *only indirectly* to the chiral condensate Σ^*.
- $\Sigma^* \rightarrow 0$ does not *necessarily* lead to $D^* \rightarrow 0$.
- Hence mass needs not go to zero as the chiral condensate goes to zero.
- In 1991 (old BR), it was *incorrectly* assumed $D^* \propto \Sigma^*$.
- Correct interpretation leads to a big change in the nuclear tensor forces at large density.

End of History

Putting Skyrmions on Crystal

- Topology changes at high density, with the skyrmion fractionizing into ½- skyrmions.
- Its effect on the nuclear tensor forces related to the Brown-Weinberg (1990) dispute on the role of ρ meson (→ BR scaling).
- Parity-doublet symmetry “emerges” at high density: Nucleon mass in medium has two components, i.e.,

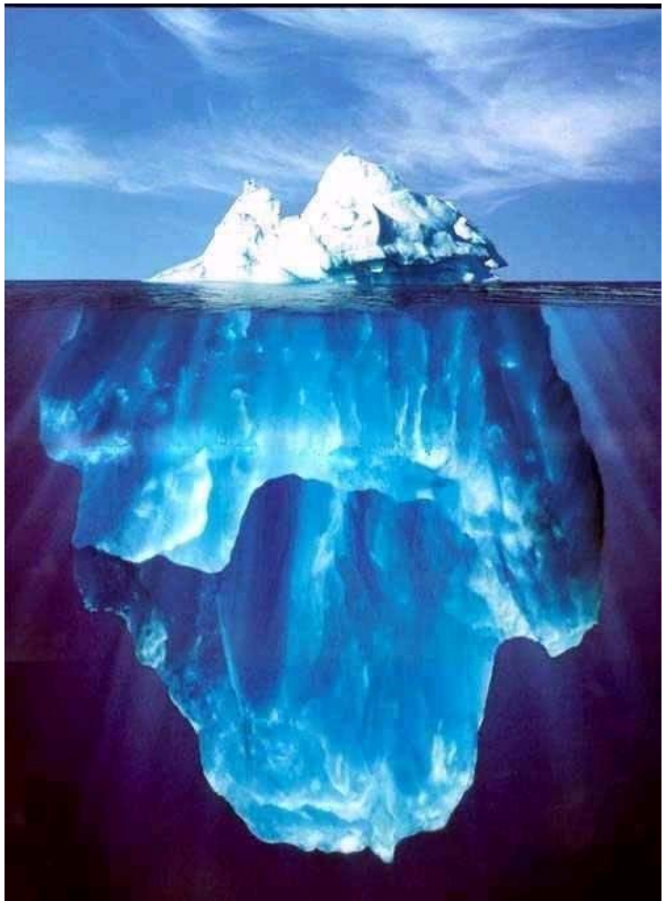
$$m^*_N = m_0 + \Delta(\Sigma^*) \rightarrow m_0 \text{ as } \Sigma^* \rightarrow 0$$

- Could lead to Fermi-liquid-to-non-Fermi liquid transition, invalidating RMF theory at high density.

How this started with Gerry

In early 2000's, at Korea Institute for Advanced Study, Gerry and I started to wonder how to rejuvenate the skyrmion description, by then abandoned by most of nuclear theorists. Our conviction was that the skyrmion as understood then In nuclear physics was like the tip of a giant iceberg.

2001



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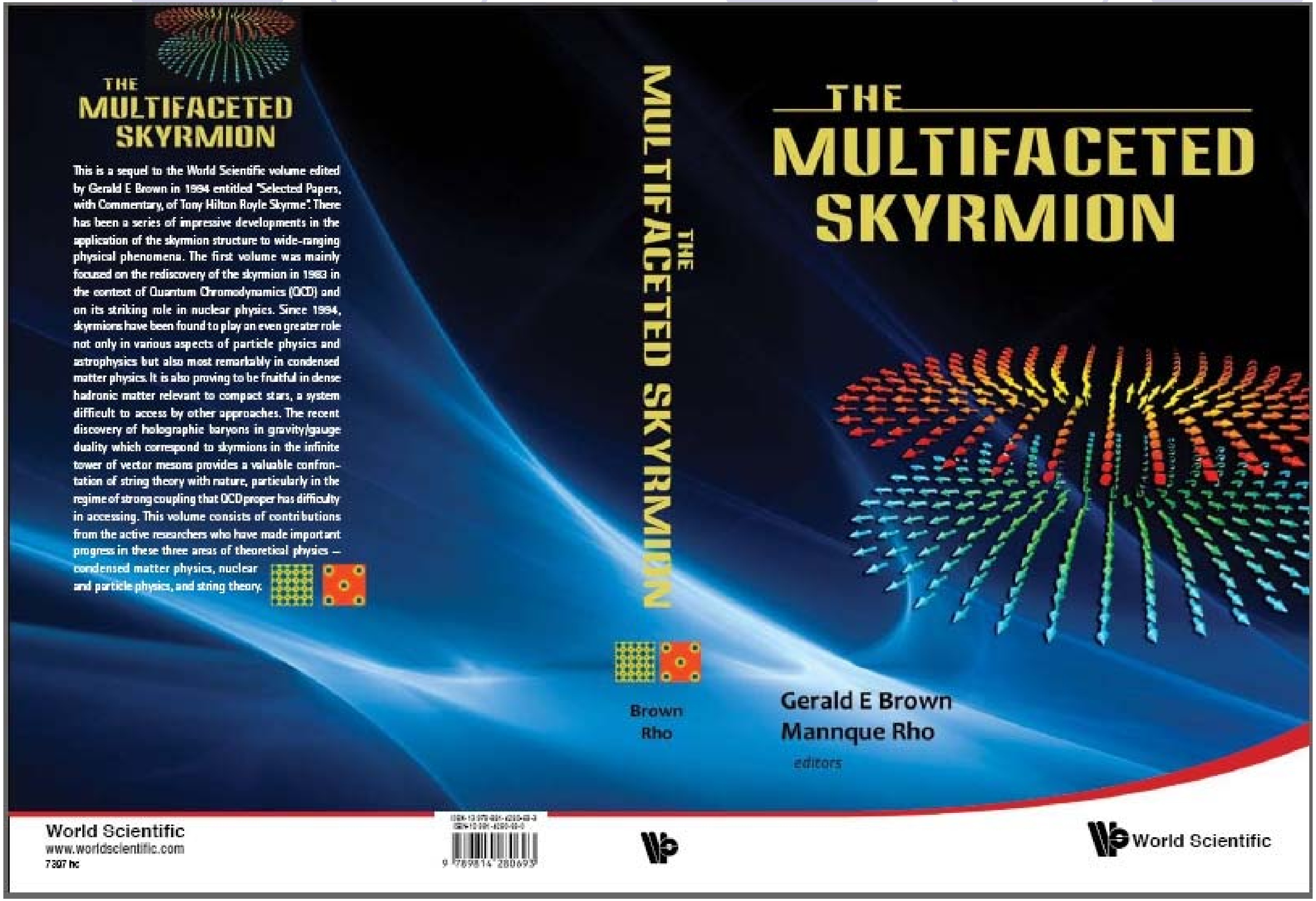
Skyrmion makeover

Celebrating the treasures of topological twists.

After re-emerging from the depths of obscurity several times over, the spotlight is back on skyrmions And a reader can only wonder what other neglected gems of mathematical ideas are tucked away in the literature, awaiting a creative scientist to recognize their value to the physical world? ■

What follows is a part of the story of what happened in our field. Sadly Gerry could not participate in the end.

Ed. G.E. Brown & MR (February 2010)



Topology Change on Crystal

- When solitonic baryons are put on crystals, be they skrymions (4D) or instantons (5D), ½-skyrmions (4D) or dyons (5D) can appear at certain density:

    A.S. Goldhaber and N.S. Manton 1987

    L. Castillejo et al 1989 …. and others

    S.-J. Sin, I. Zahed, MR 2010

- Model topology change in terms of boundary conditions (or parameters of the effective Lagrangian)

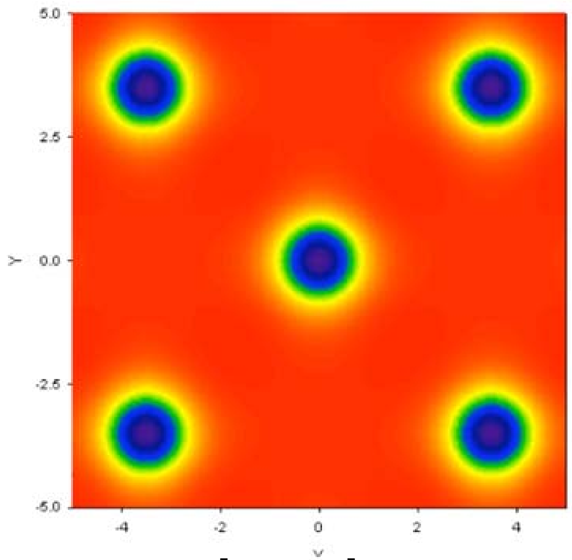
Appearance of ½-skyrmions is robust

B.Y. Park, V. Vento, MR et al since 1999

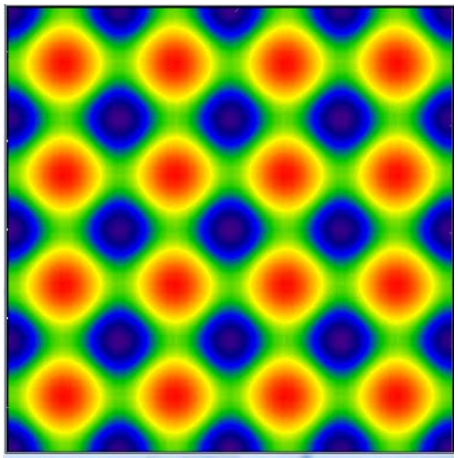
$$\mathbf{U} = \mathbf{e}^{\mathbf{2i}\pi/\mathbf{f}_\pi} \longrightarrow$$ **skyrmion**

$$\mathbf{U} = \xi_\mathbf{L}\xi_\mathbf{R}^\dagger, \quad \xi_\mathbf{L,R} \longrightarrow$$ **half-skyrmion**

$$\mathcal{L}_\xi = \frac{f_\pi^2}{2}\{\mathrm{Tr}\left[|D_\mu\xi_L|^2 + |D_\mu\xi_R|^2\right]$$



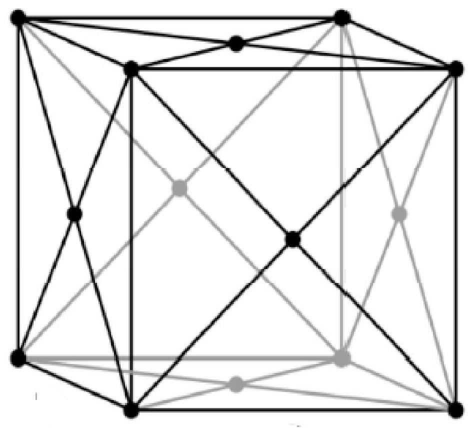
skyrmions



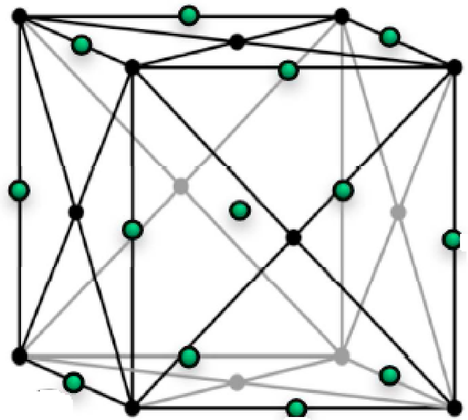
Half-skyrmions

Also in hQCD: “dyonic salt”

Sin, Zahed, R. 2010; Bolognesi, Sutcliffe 2013



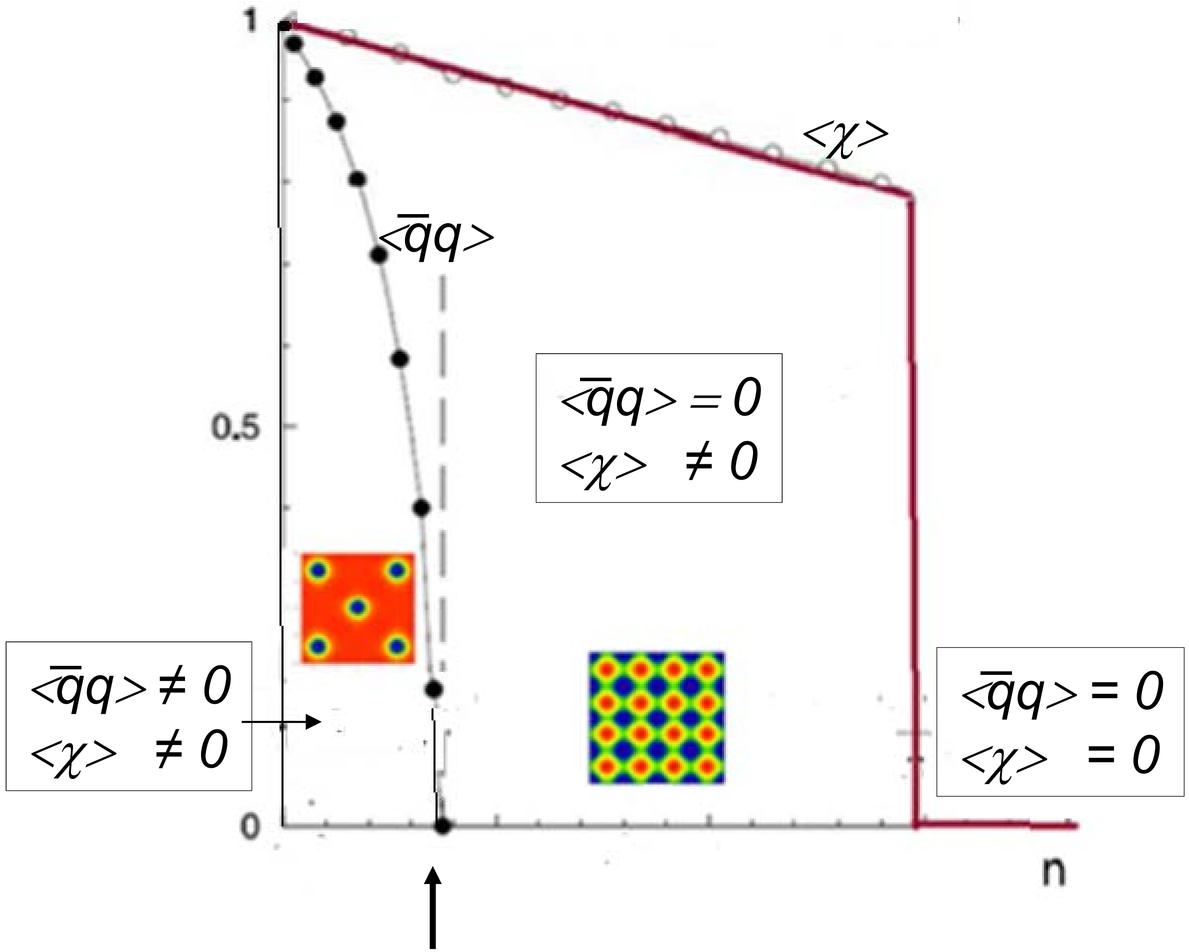
Increasing density



Instantons: FCC

½ instantons (dyons): BCC

Topology change = Phase Change

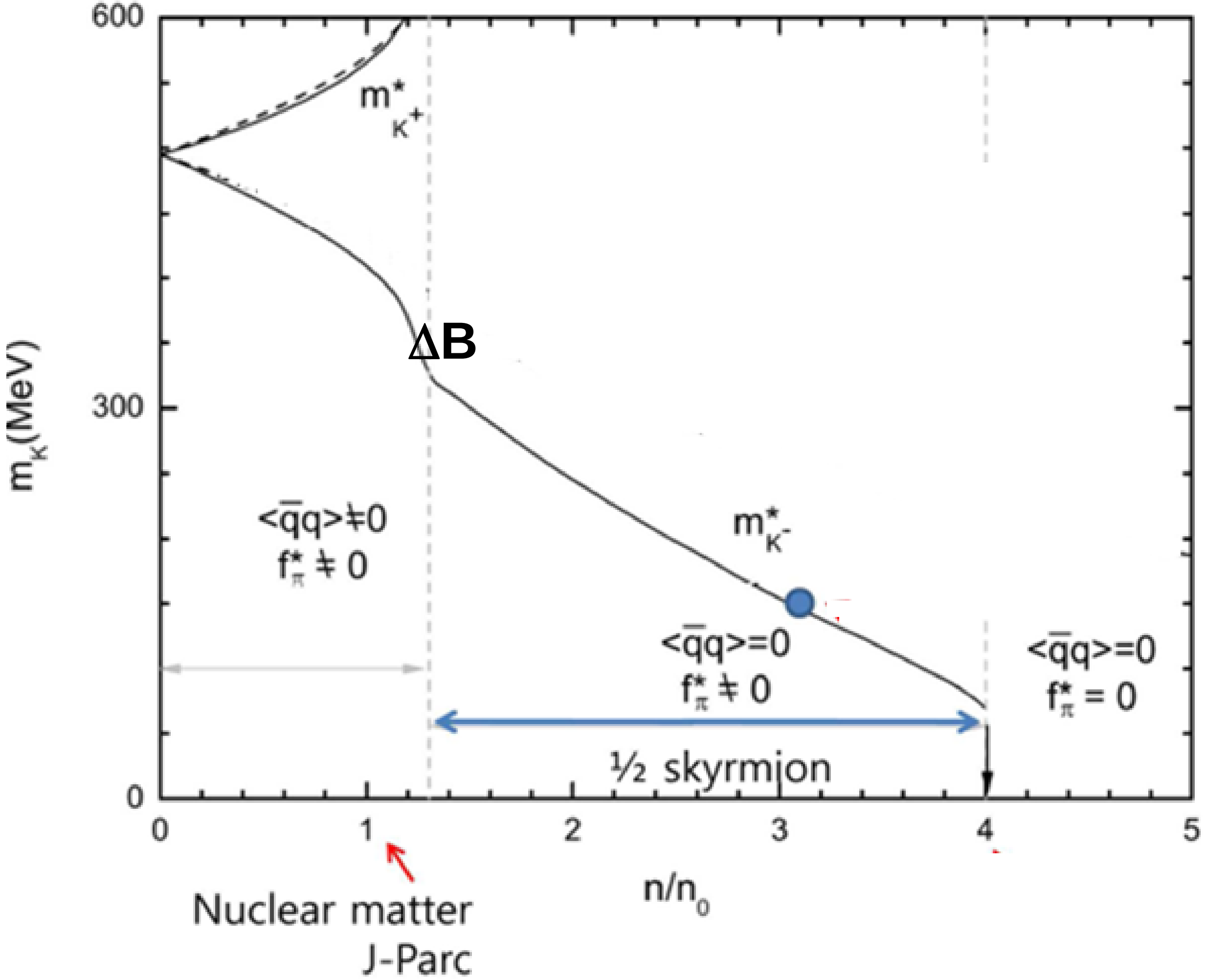


Estimate: $n_{1/2}$ ~ (1.3 – 2) n_0

Consequence-I

Anti-kaon "roaming" through ½-skyrmion matter: Wess-Zumino term

B.-Y. Park et al 2010



△B ~ 50-60 MeV

- Issues:

(1) Brown-Bethe scenario

(2) Dense kaon nuclei

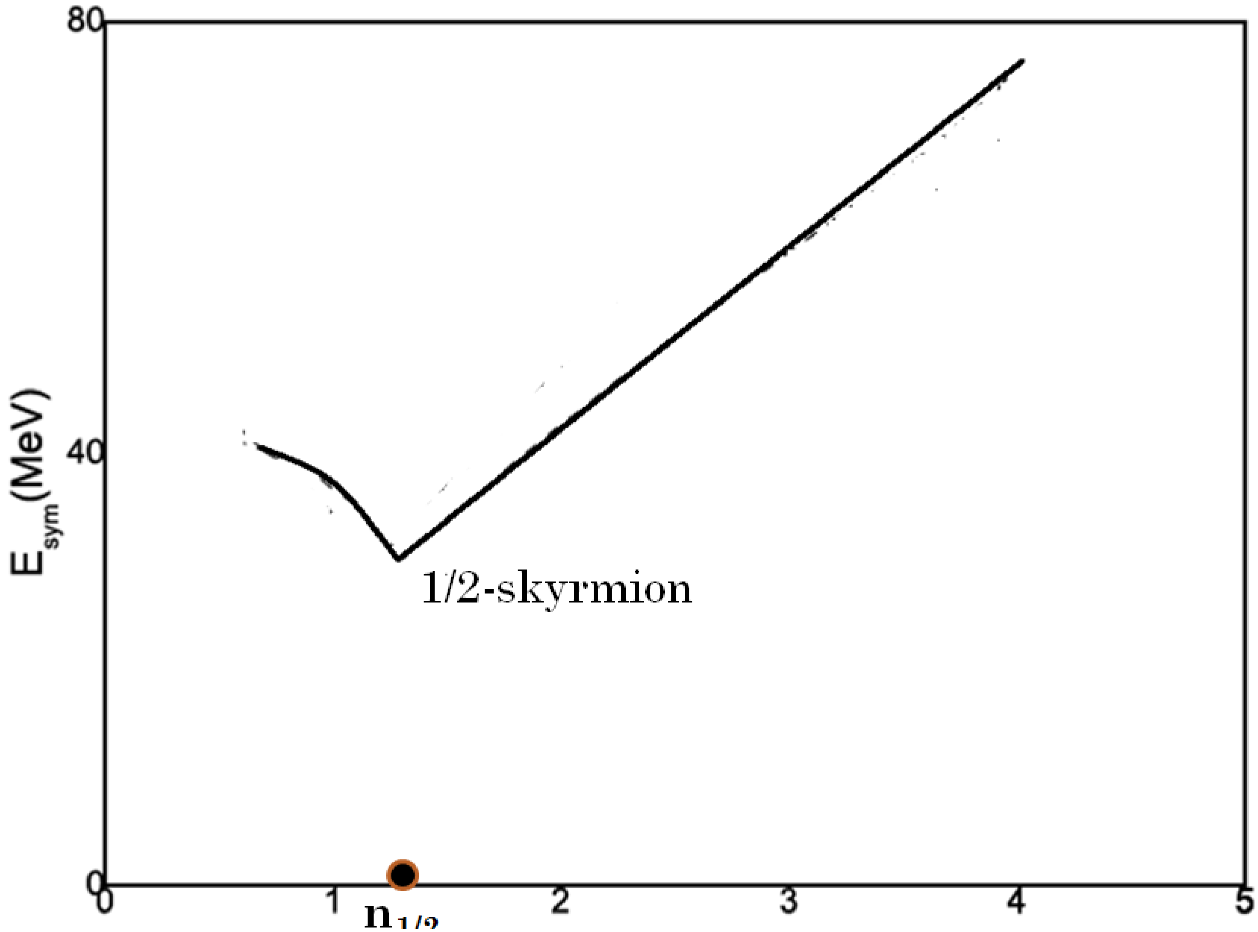
(3) 1.97 M_{solar} star

Consequence-II

B.Y. Park et al 2010

Nuclear symmetry energy

$$E(n,\delta) = E(n,0) + E_{sym}\delta^2 + \mathcal{O}(\delta^4)$$
$$\delta = (n_p - n_n)/(n_n + n_p)$$

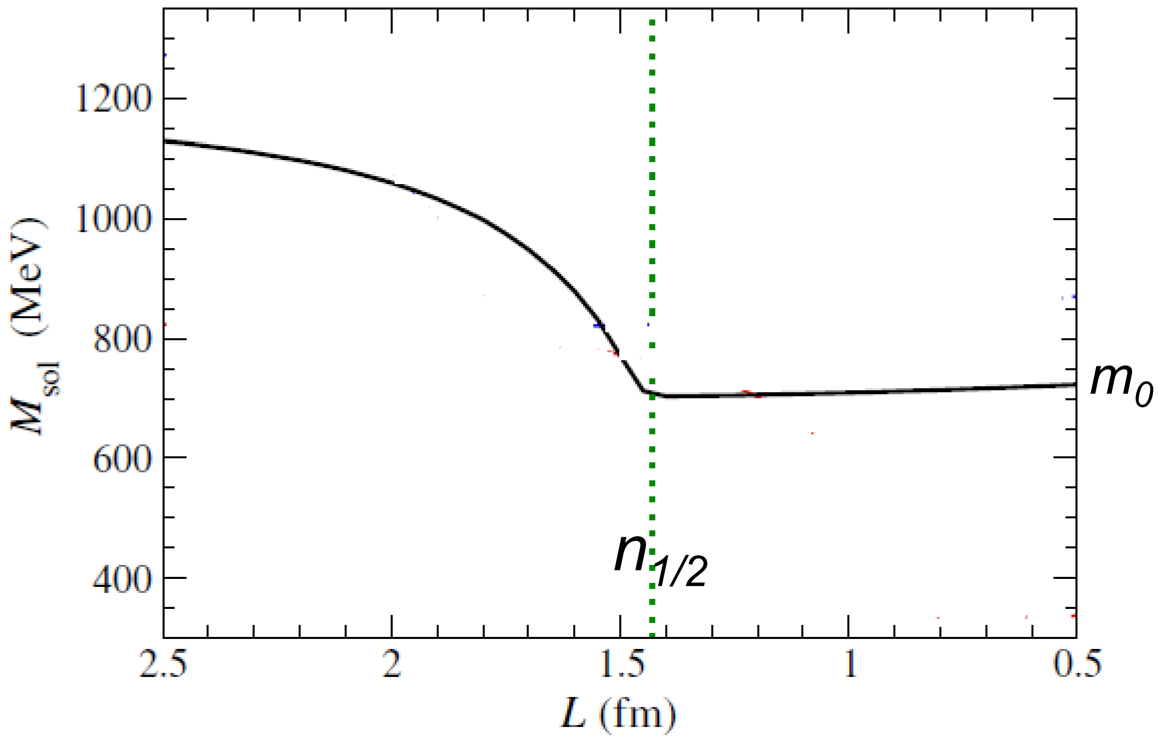


Consequences – III

Where does the nucleon mass come from?

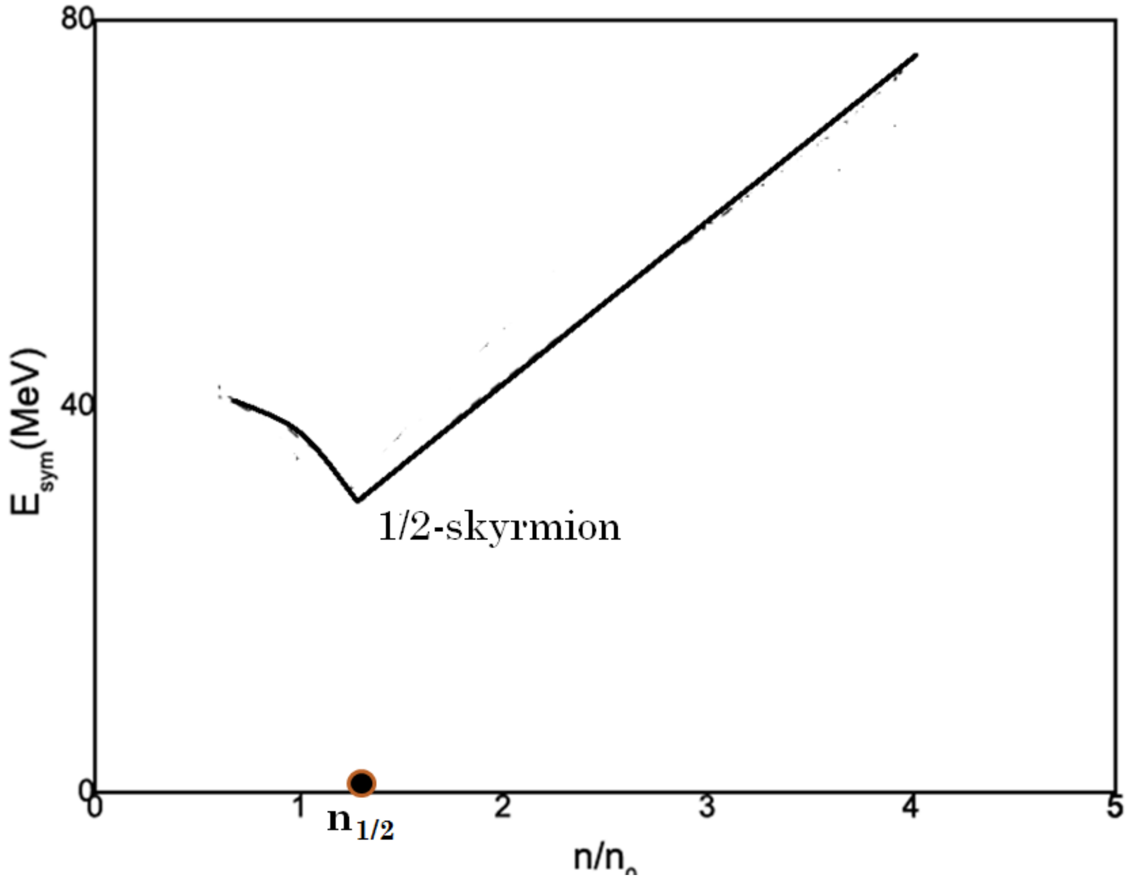
- "Emergent" parity-doublet symmetry for nucleons: $m^* = m_0 + \Delta(\Sigma^*)$

Y.L. Ma et al 2003



Focus on E_{sym} in ½-skyrmion matter

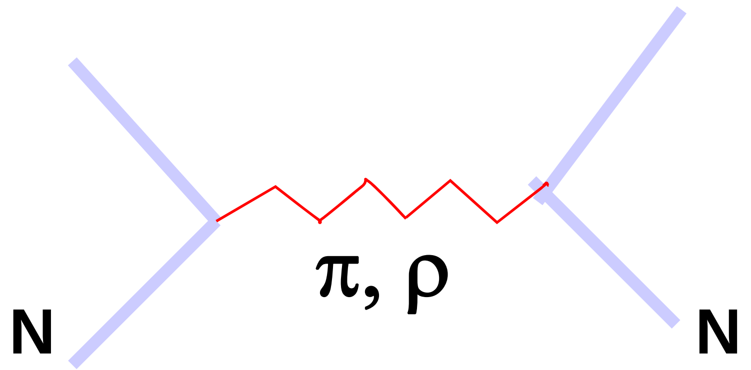
$$E_{sym} = \frac{1}{8\lambda_I} \propto N_C^{-1}$$



Is the cusp real?

E_{sym} is dominated by the tensor forces

G.E. Brown and R. Machleidt 1994 … A. Carbone et al 2013



$$V_M^T(r) = S_M \frac{f_{NM}^2}{4\pi} m_M \tau_1 \cdot \tau_2 S_{12} \left(\left[\frac{1}{(m_M r)^3} + \frac{1}{(m_M r)^2} + \frac{1}{3 m_M r} \right] e^{-m_M r} \right)$$

$$M = \pi, \rho, \; S_{\rho(\pi)} = +1(-1)$$

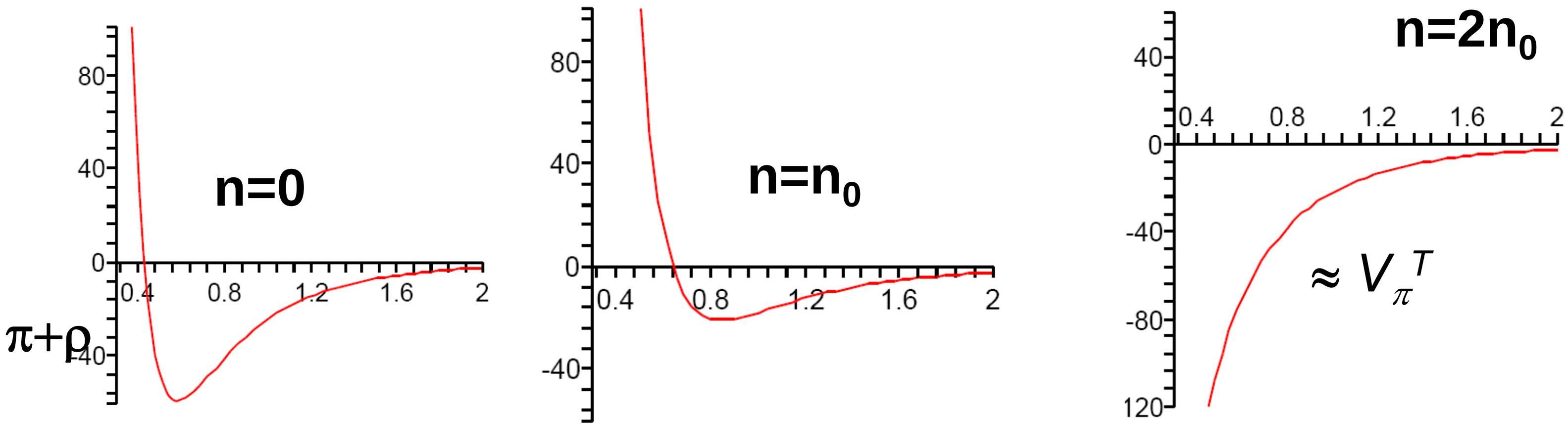
G.E. Brown and S. Weinberg dispute 1990

- Weinberg's proposal -- that nuclear physics could be done with the chiral Lagrangian with pion fields only – was challenged by Gerry on two points: (a) Vector dominance in the baryon EM form factors and (b) nuclear tensor forces.
- In both, the vector mesons ρ and ω are believed to play a prominent role and Gerry argued that Weinberg's ChPT could not work for (a) and (b).
- Gerry faxed me the discussions. I joined the dispute from Seoul.
- Both Gerry and Weinberg were right but in different regimes.

Gerry was supported by:

- ❖ “HLS” à la Harada and Yamawaki
- ❖ Weinberg’s “mended symmetry” ↔ “HLS”
- ❖ Seiberg duality (Komargodski 2011)

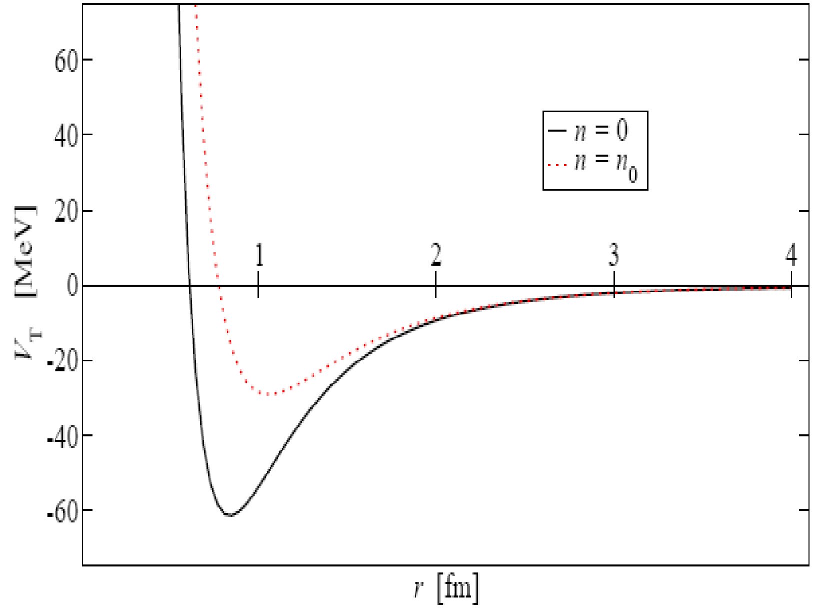
Tensor forces are drastically modified in the ½-skyrmion phase

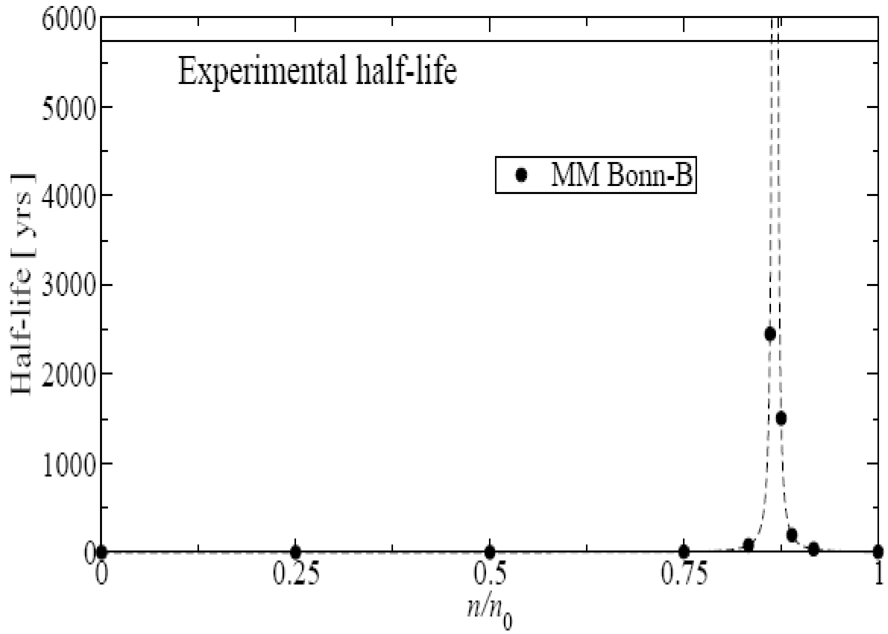


Above $n_{1/2,}$ the ρ tensor gets “killed,” triggers the *π^0’s to condense* $\rightarrow$ pionic crystal in dense neutron matter (Pandharipande and Smith 74).

C14 dating probes up to n_0

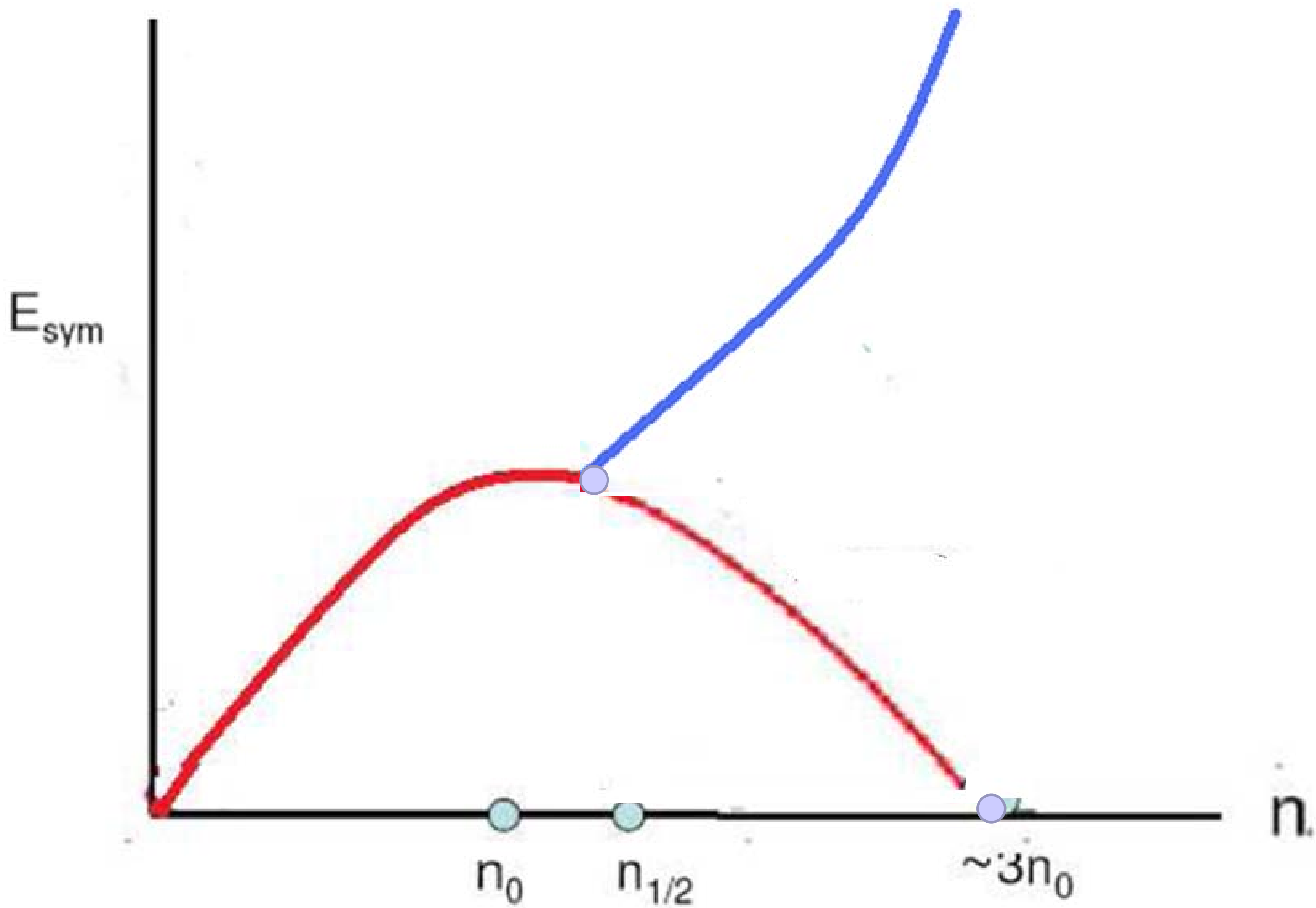
J.W. Holt, G.E. Brown, T. Kuo … 2008



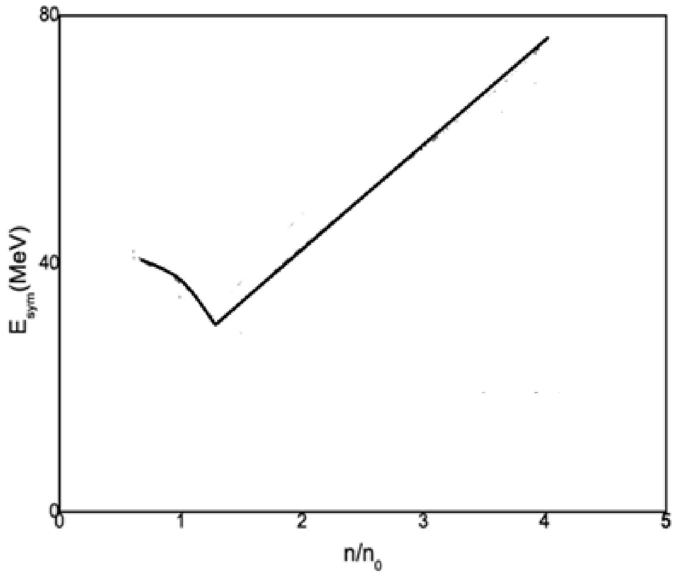


Note: Chiral 3-body forces can *also* do the job.
But it's *not an alternative* mechanism.

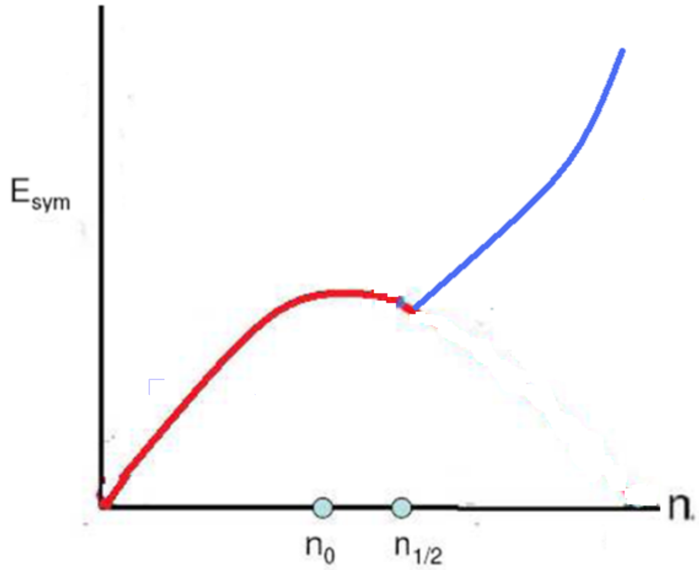
How the ½-skyrmions act on E_{sym}



Topology change



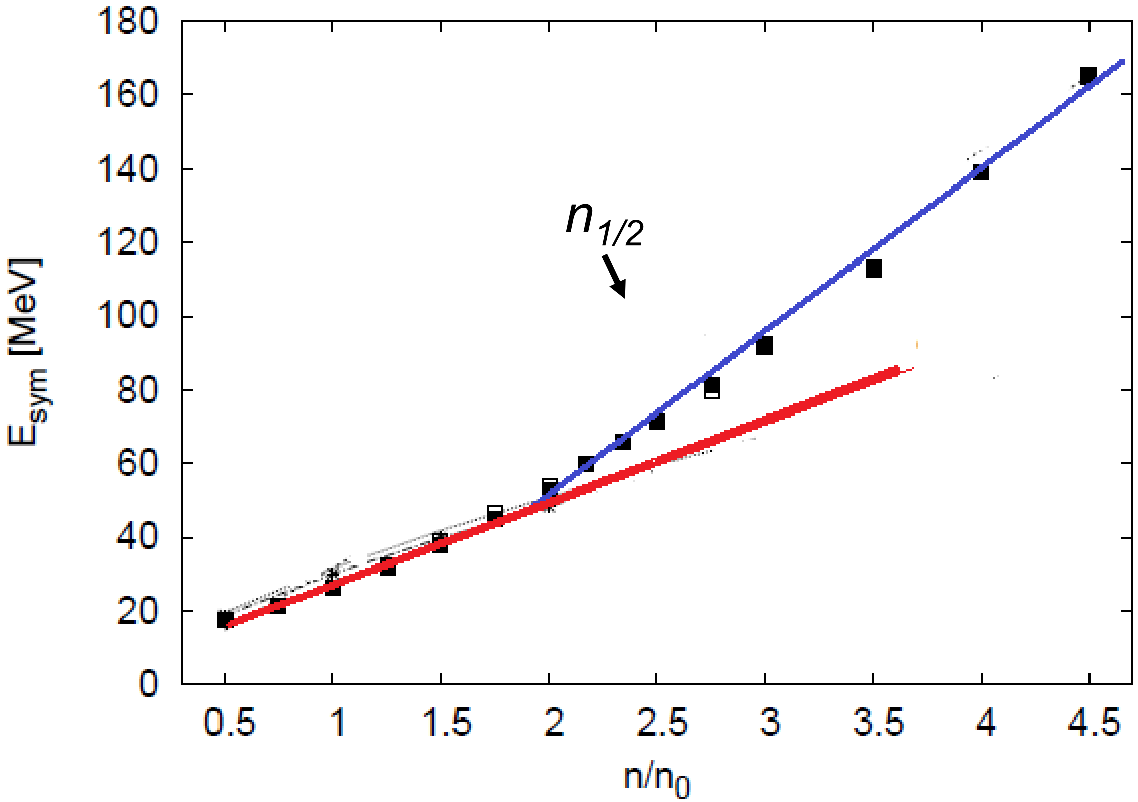
Scaling parameter change



But this is not exactly what Nature looks like!

“Nature” with many-body correlations

Dong, Kuo et al 2013

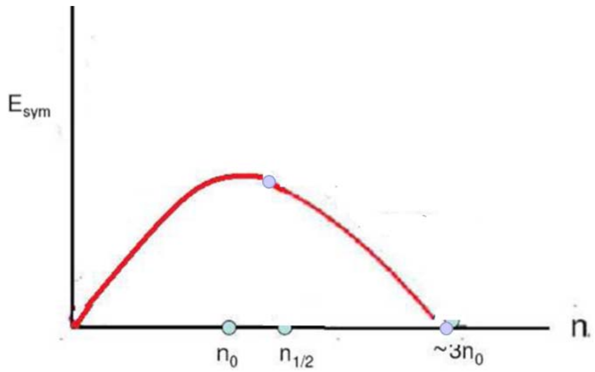


(Consistent with
1.97 solar-mass star)

Lesson from Condensed Matter

In condensed matter (MnSi), topology change signals Fermi liquid ⟺ non-Fermi liquid

- The slope change in E_{sym} $\rightarrow$ phase change
- "Dilaton limit fixed point" is approached as density goes above $n_{1/2}$. Then the ρ decouples because $g_{\rho NN} \rightarrow 0$. Thus in RMF, $E_{sym}/n \propto (g_{\rho NN})^2 \rightarrow 0$ giving an E_{sym} going like



The RMF must be breaking down at near $n_{1/2}$

Puzzles Abound

1) The tensor forces in the nuclear *monopole matrix elements (RIB physics)* are *un-renormalized* by strong interactions (T. Otsuka et al, PRL 25, 2005)
   $\rightarrow$ *Pristine signal for BR at near normal density*
2) Heavy nuclei can be *highly reliably* described by BPS skyrmions (A.~Wereszczynski et al, PRL, 2013).

Why??

3) Where does the nucleon mass come from?

Gerry's Last Unfinished Work

Back to Ericson-Ericson-Lorenz-Lorentz
after 34 years

$\rightarrow$ E^2L^2 (or g_0'), DD ("double decimation")
& BR

$\rightarrow$ Universal nuclear interactions

FAX

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Date: 4 April 2007
Number of pages including cover sheet

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Phone:
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REMARKS:

☐ Urgent ☐ For your review ☐ Reply ASAP ☐ Please comment

Dear Mannque,

I'll try to FAX this to you from the University; otherwise from my home. I believe that this is an universal or Brown/Rho scaling. I'm trying to say: It's magical how the $\varepsilon^2 \delta^2$ runs the show and makes, together with B/R scaling, all forces equal.

Best,

Gerry

The Dominant Role of the Ericson-Ericson Lorentz-Lorentz Interaction in Nuclear Structure

~~[illegible]~~

~~[illegible]~~

I. Introduction

We develop the renormalization group description of ~~[illegible]~~ Schwenk et al (A. Schwenk, G.E. Brown and B. Friman, Nucl. Phys. A 703 (2002) 745) which introduced the effective interaction $V_{low}(k)$. The effective pion emerges in terms of low energy scale Fermi liquid interactions

We believe that we can offer a qualitative understanding of one of the main points of nuclear structure physics without detailed calculation; namely, why the one-bubble correction to the mean field (shell model) spectrum is very important as is well known in the Kuo-Brown interactions.

....

This is because the $\mathcal{L}^2 \mathcal{L}^2$ interaction is by far the strongest one and it is largely spent in the single bubble.