Magnetic effects in dense nuclear matter via Skyrme model

Based on: S. Chen, K. Fukushima, Z. Qiu,
Phys. Rev. D 105, L011502 (2022)

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Skyrmion vs. Chiral Soliton Lattice

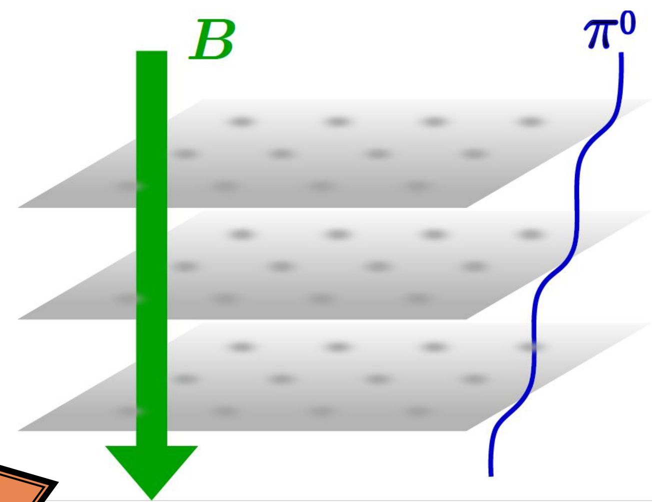
$$\text{Hadron LLL} \xrightarrow{\text{magnetic field } \boldsymbol{B}} \text{CSL}$$

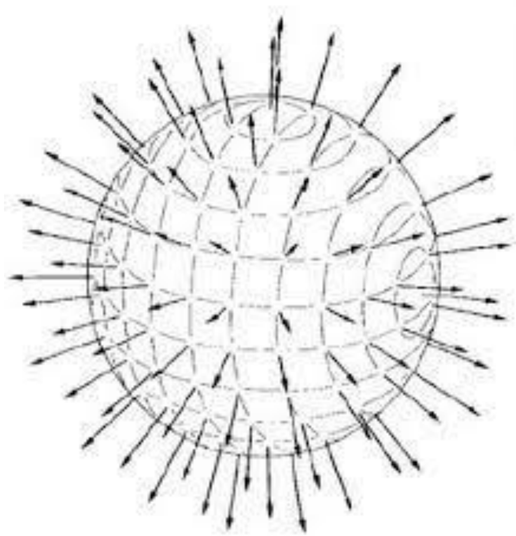
T. Brauner & N. Yamamoto, JHEP 04, 132 (2017).

$$\varepsilon^2 = p_z^2 + \boxed{2|eB|(\cancel{n} + 1/2) + \cancel{m}^2 - 2\cancel{s}eB}$$

$$\pi^{\pm} \xrightarrow{\boldsymbol{B}\uparrow} \text{massive; } \pi^0\text{: massless NG}$$

$$\exp(i\tau^3\pi^0) \in U(1);\ \pi_1\big(U(1)\big) = \mathbb{Z}$$





B induces

phase transition?

Baryon: $\exp(i\boldsymbol{\tau}\cdot\boldsymbol{\pi}) \in SU(N_f)$

Skyrme Model: $\pi_3\big(SU(2)\big) = \mathbb{Z}$

"Magnetized" Skyrmion Profiles

Magnetic field: $\boldsymbol{B} = -B\hat{z} \;\; (B > 0)$

Ansatz: $\Sigma = i\boldsymbol{\tau} \cdot \boldsymbol{\Pi} + \Pi_4, \quad \sum \Pi_i^2 = 1$

$\Pi_1 = \sin f \; \sin g \; \cos \varphi \qquad \Pi_3 = \sin f \; \cos g$

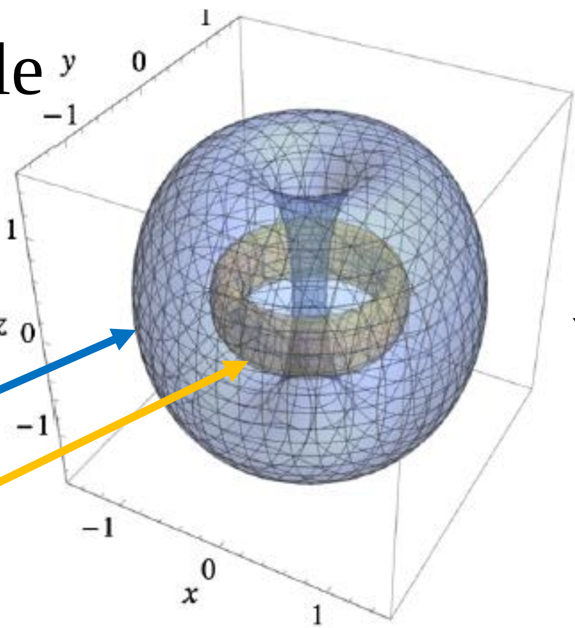
$\Pi_2 = \sin f \; \sin g \; \sin \varphi \qquad \Pi_4 = \cos f$

Solution profile

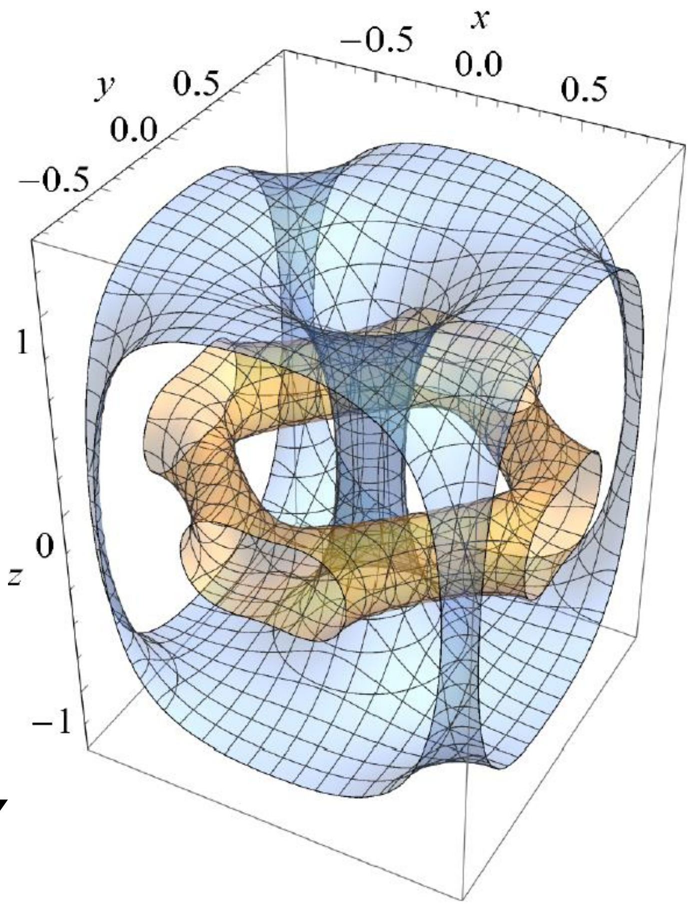
Isolated Skyrmion

Outer: $\Pi_3^2 + \Pi_4^2$

Inner: $\Pi_1^2 + \Pi_2^2$



B



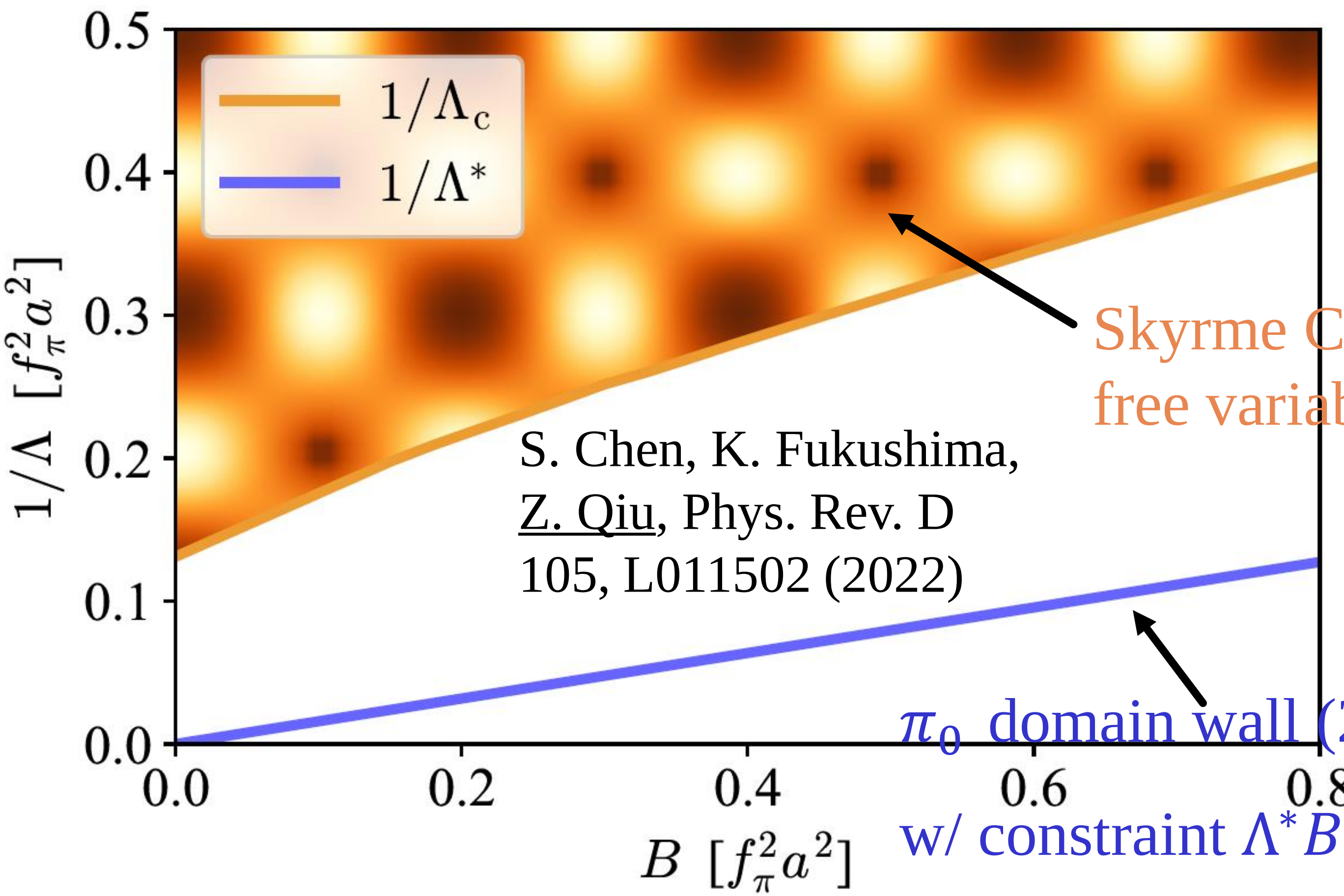
Skyrme **Crystal** (unit cell)
"bonding" adjacent cells

Skyrme Crystal Phase Diagram

Λ: unit crystal cell transverse area.

1 baryon (Skyrmion) per cell.

(Λ^{-1}: baryon density)



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Skyrme Crystal w/ free variables Λ, B

π_0 domain wall (2D CSL) w/ constraint $\Lambda^* B \equiv 2\pi$

Inhomogeneous ground state for high density / low magnetic field

Conclusion

1. A Skyrmion is deformed by the magnetic field into **prolate spheroid**, maintaining the $\pi_3(SU(2))$

2. A multi-Skyrmion crystal can emerge as either an inhomogeneous **baryonic phase or a $\boldsymbol{\pi_0}$ domain wall (CSL)**, depending on boundary conditions.

3. A first-order **phase transition** from the $\pi_3(SU(2))$ Skyrme crystal to the $\pi_1(U(1))$ CSL occurs when the baryon density decreases from above to $B/2\pi$.