Mesonic Superfluidity in Isospin Matter under Rotation

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Based on: **HZ**, D. Hou and J. Liao, arXiv:1812.11787

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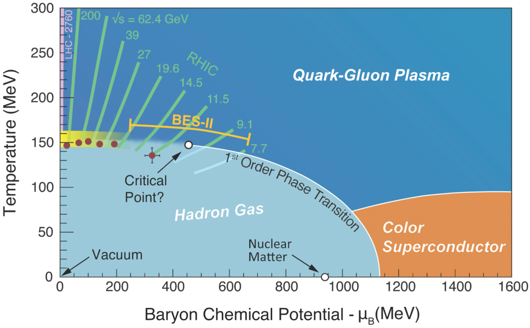
Outline

Typical QCD Phase Diagram



New dimension $\Rightarrow$ change the phase diagram & CEP

μ_I, Magnetic field, Rotation, etc.

Introduction

QCD with large angular momentum: HIC

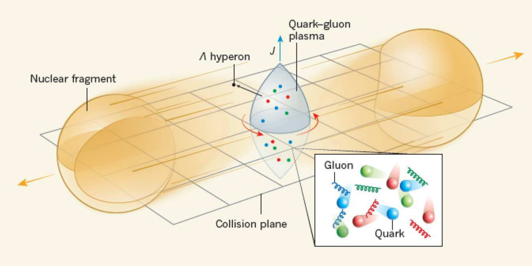


Figure: Off-central HIC

Rotational polarization effect → Anomalous effects: Chiral vortical effect, Chiral vortical wave. . .

QCD with large angular momentum: Neutron Stars

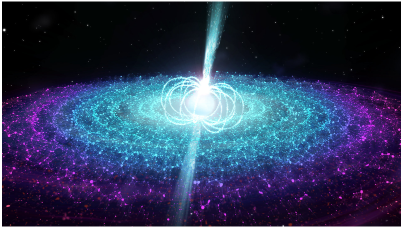


Figure: Spin Neutron Star.

Rotational Supression of fermion pairing in J=0 (PRL117, no.19(2016)192302) This study (first): isospin matter
Isospin chemical potential: imbalance between the u-flavor and d-flavor of quarks

Model

$$\mathcal{L} = \bar{\psi}(i\gamma_\mu\partial^\mu - m_0 + \frac{\mu_I}{2}\gamma_0\tau_3)\psi + G_s\left[\left(\bar{\psi}\psi\right)^2 + \left(\bar{\psi}i\gamma_5\boldsymbol{\tau}\psi\right)^2\right] - G_v\left(\bar{\psi}\gamma_\mu\boldsymbol{\tau}\psi\right)^2 . \tag{1}$$

$$\mathcal{L}_R = \psi^\dagger\left[(\vec{\omega}\times\vec{x})\cdot(-i\vec{\partial}) + \vec{\omega}\cdot\vec{S}_{4\times 4}\right]\psi \tag{2}$$

MF approximation:

$$\sigma = \langle\bar{\psi}\psi\rangle,\ \pi = \langle\bar{\psi}i\gamma_5\boldsymbol{\tau}\psi\rangle,\ \rho = \langle\bar{\psi}i\gamma_0\tau_3\psi\rangle. \tag{3}$$

Model

$$\Omega = G_s(\sigma^2 + \pi^2) - G_v\rho^2$$
$$-\frac{\mathrm{N_c N_f}}{16\pi^2}\sum_n \int \mathrm{d}k_t^2 \int \mathrm{d}k_z [J_{n+1}(k_t r)^2 + J_n(k_t r)^2] T \times$$
$$\Big[\ln\Big(1+\exp(-\frac{\omega^+ - (n+\frac{1}{2})\omega}{T})\Big) + \ln\Big(1+\exp(\frac{\omega^+ - (n+\frac{1}{2})\omega}{T})\Big)$$
$$+\ln\Big(1+\exp(-\frac{\omega^- - (n+\frac{1}{2})\omega}{T})\Big) + \ln\Big(1+\exp(\frac{\omega^- - (n+\frac{1}{2})\omega}{T})\Big)\Big]$$

$$\omega^\pm = \sqrt{4G_s^2\pi^2 + (\sqrt{(m_0 - 2G_s\sigma)^2 + k_t^2 + k_z^2} \pm \widetilde{\mu_I})^2}, \quad \widetilde{\mu_I} = \frac{\mu_I}{2} + G_v\,\rho$$

Gap equation: $\frac{\partial\Omega}{\partial\sigma} = \frac{\partial\Omega}{\partial\pi} = \frac{\partial\Omega}{\partial\rho} = 0$

Results—σ, π Channel

Rotational Suppression on Pion Superfluidity

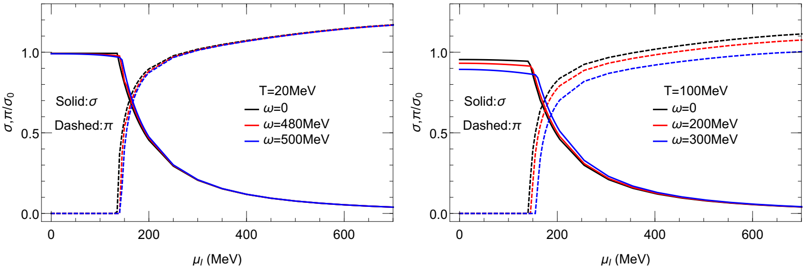


Figure: Suppression effect is consistent with (PRL117, no.19 (2016) 192302). inverse catalysis effect

Rotational Suppression on Pion Superfluidity

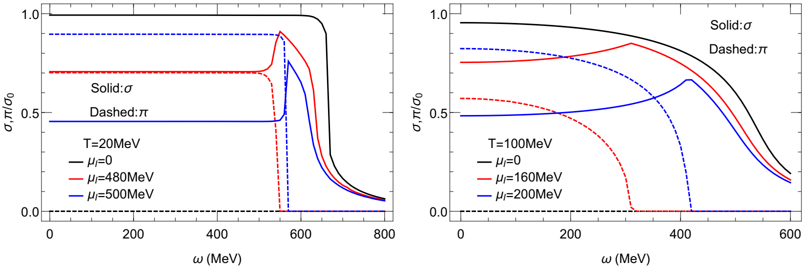


Figure: Prefer σ than π

$\sigma : s = 1, L = 1, J = 0;$ $\quad$ $\pi : s = 0, L = 0, J = 0$

Rotation weaken spin 0 condensate: inverse catalysis effect

Pion superfluidity phase diagram in $T - \mu_I$

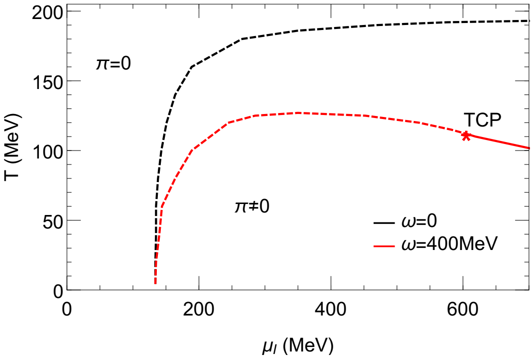


Figure: Dashed line stands for the second-order phase transition, while solid for the first-order. The star denotes a tri-critical point (TCP).

Enhanced ρ Superfluidity under Rotation—σ, π, ρ Channel

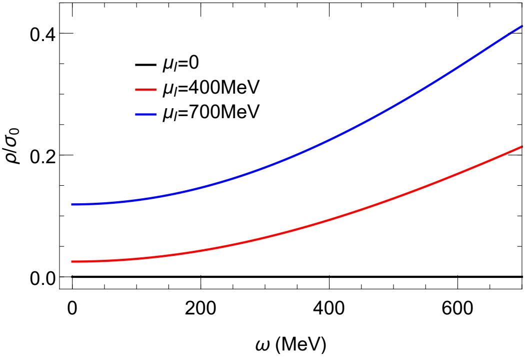


Figure: Rotation weaken spin 0 condensate, Rotation enhance spin 1 condensate

Enhanced ρ Superfluidity under Rotation—σ, π, ρ Channel

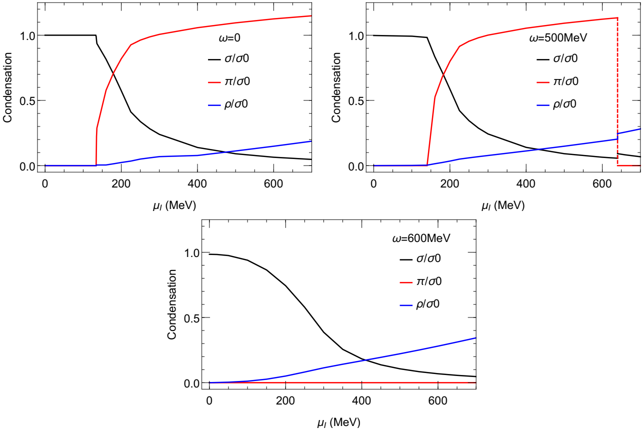


Figure: σ, π, ρ dominated phase

Phase diagram in $\omega - \mu_I$

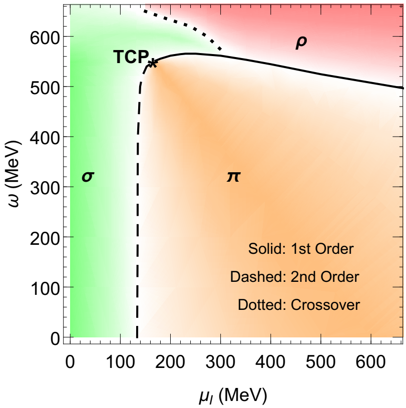


Figure: New phase diagram, New Tri-Critical End Point

Summary

- π and ρ meson superfluidity under rotation in NJL model.
- inverse catalysis effect on the π superfluidity (spin-0 channel).
- Rotation weaken spin 0 condensate (1606.03808). And enhance nonzero ones (this work).
- ρ condensate at $T = \mu = 0$ with none zero isospin chemical potential under rotation.
- A new type phase diagram in the $\omega - \mu_I$ plane and a new TCP $\sim (\mu_I^c = 165, \omega^c = 548)$ MeV.

Outlook

Rotational
Isospin
Matter

- Boundary effect
- Introduce Confinement
- possible splitting of deconfinement and chiral transitions
- Isospin matter is relevant for understanding the properties of neutron stars.

Thank you for your attention!

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Backup

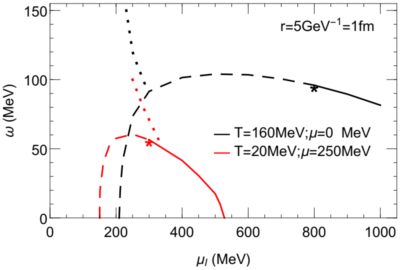

Figure: More realistic case.