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Continuity from neutron matter to color-superconducting quark matter with $^3P_2$ superfluidity

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Quark-hadron continuity has been well understood for three-flavor symmetric nuclear and quark matter, which is however a theoretically over-idealized environment. In this talk we clarify how quark-hadron continuity can be applied to neutron matter in the realistic neutron star environment. Our key observation is that neutron matter can be smoothly connected to the two-flavor color-superconducting (2SC) state mixed with a condensate of $\langle dd \rangle$. We give three convincing arguments: The first one is the symmetry-breaking argument, the second one is the argument based on rearrangement of gauge-invariant order parameters, and the last one is the dynamical argument associated with nuclear forces in terms of d-quark exchanges. Interestingly, in the quark sector, we have found a universal dynamical mechanism to favor $^3P_2$ superfluidity above a certain threshold density, below which the ground state is a $^0S_1$ superfluid. Such transitional behavior of the favored ground state has been long known in nuclear physics, and as should be the case if quark-hadron continuity holds for neutron matter, quark matter turns out to share the same properties.

Our finding provides us with an important theoretical foundation for the phenomenological construction of the equation of state (EoS) in the neutron star environment. We conclude that, even in the presence of a $^3P_2$ component of superfluidity, a prescription to interpolate the EoS smoothly between the nuclear and quark sides perfectly makes sense. We also emphasize that such a state of the 2SC with tensorial $\langle dd \rangle$ in accord with $^3P_2$ superfluidity is an absolutely novel state of quark matter that nobody had ever considered. We discuss physical properties of this novel color-superconducting state and give an account of possible enhancement of tensorial $\langle dd \rangle$ due to Fierz mixing with the energy-momentum tensor.

Primary authors: FUKUSHIMA, Kenji (The University of Tokyo); FUJIMOTO, Yuki (The University of Tokyo); Prof. WEISE, Wolfram (Technische Universitaet Muenchen)

Presenter: FUJIMOTO, Yuki (The University of Tokyo)

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