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Quantum Turing-like patterns in superconductivity of $EuFe_2(As_{0.79}P_{0.21})_2$

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One of the most intriguing examples of competing orders is ferromagnetism and superconductivity. The internal exchange energy in ferromagnets is usually significantly larger than the superconducting condensation energy. Consequently, strong exchange fields destroy singlet Cooper pairs via the paramagnetic and orbital effects, making the coexistence of ferromagnetism and superconductivity a very rare phenomenon. Only a triplet superconductivity could coexist with a strong ferromagnetism - a situation expected in ferromagnetic superconductors UGe2, URhGe and UCoGe, in which the ferromagnetic transition temperature TFM is substantially higher than the superconducting (SC) critical temperature Tc. As a result, the superconductivity appears in these compounds when a strong ferromagnetic (FM) order already exists, leading to the absence of the Meissner phase and in a domain structure of the vortex phase.

In this context the FM transition at 18K in $EuFe_2(As_{0.79}P_{0.21})_2$ below its SC critical temperature 24K is of great interest. The condition $T_{FM} < T_c$ offers a unique opportunity to explore the influence of superconductivity on a weak emergent ferromagnetism at $T < T_{FM}$, and to follow the interplay between the two orders with temperature. In our talk we will demonstrate that this competition leads to unprecedented superconducting phases characterized by Turing-like patterns at nanoscale. Just below Curie temperature a striped domain Meissner state is realized. Upon cooling down, a spontaneous generation of the quantum vortex-antivortex pairs at domain boundaries occurs, and the system undergoes a phase transition into a patterned vortex-antivortex state. We develop a quantitative theory of this phenomenon and put forth a new way to realize superconducting superlattices and control the vortex-antivortex matter by tuning magnetic domains - unprecedented opportunity to consider for advanced superconducting hybrids.

1. https://arxiv.org/abs/1709.09802 (submitted to Science Advances)