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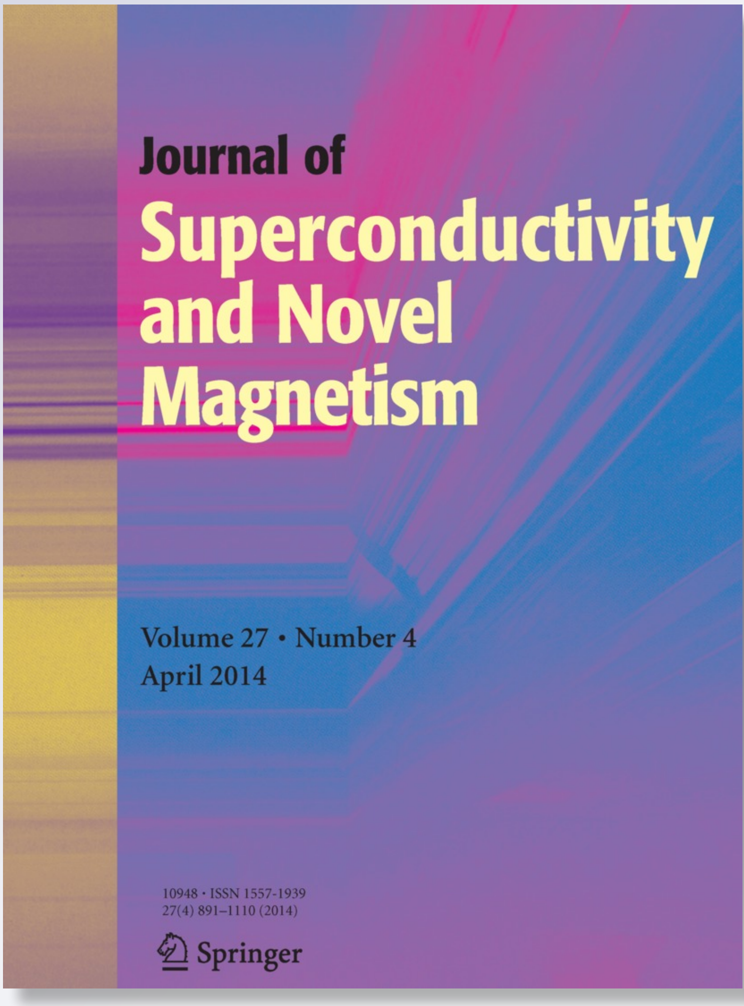

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PREFACE

Superstripes and Percolating Nanoscale-Striped Puddles in Heterostructures at Atomic Limit

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Abstract Lattice and electronic nanoscale phase separation in strongly correlated multiband systems confined in heterostructure at atomic limit called superstripes has been an object of the scientific debate at the international conference Superstripes 2013 focusing on "Quantum in Complex Matter: Superconductivity, Magnetism and Ferroelectricity" held in Ischia, Italy (May 27–June 1, 2013). The focus was on lattice granularity due to defects self-organization, lattice modulations at a critical misfit strain, and electronic phase separation in multiband Hubbard models near a 2.5 Lifshitz transition. The emerging superstripes scenario is a particular case of percolation superconductivity in networks of superconducting multicondensates superconducting puddles and their competition with phase-separated networks of nanoscale-striped magnetic puddles. This new emerging paradigm for high-Tc superconductor-layered oxides opens new perspectives for quantum electronics by controlling the complexity in functional oxides.

Keywords Nanoscale inhomogeneity · Transition metal oxides · Stripes · Quantum materials · Percolative superconductivity.

"Quantum in Complex Matter: Superconductivity, Magnetism and Ferroelectricity" has been the topic discussed at the Superstripes 2013 conference held in Ischia, Italy, from May 27 to June 1, 2013. The conference has been dedicated to a wide range of topics related to quantum electronic in complex heterostructures at atomic limit. The heterostructures at the atomic limit and atomic layer include cuprates [1], diborides [2, 3], and iron-based superconductors [4–6] where the CuO_2 atomic layer, the honeycomb boron atomic layer, and the atomic layers of $FeAs_4$ or $FeSe_4$ tetrahedral units are intercalated by variable spacer blocks. It is now feasible to tune the electronic structure by insertion of defects that get self-organized [6–13], under external pressure [14, 15], and lattice misfit strain [16] between the active atomic layers and the spacers and the gate voltage control [17]. Several authors have discussed electronic nanoscale phase separation in strongly correlated electronic systems [18–22]. There is a growing agreement that a generic feature of high temperature superconductors is phase separation in multiband Hubbard models in the proximity of a 2.5 Lifshitz transition in an interacting Fermi liquid [23] and that also cuprates show multiband or multicondensate superconductivity [24] like diborides [2] and iron-based superconductors [3]. Several sessions have been dedicated to the interplay of magnetic fluctuations and superconductivity [25–27] on inhomogeneous electronic crystals [28] and on cold Rydberg atoms for quantum simulation of exotic condensed matter interactions [29]. The emerging fundamental physics is a low-energy physics where electronic correlations, polaron formation [30–32], and defects self-organization determine and control minibands crossing the Fermi level where the Fermi level in each band is of the order of 50–100 meV [33].

The focus has been on the compelling evidence from many experiments that, in cuprates, there are different electronic states at the Fermi level and that they segregate in different spatial locations in the CuO_2 plane [34–37]. The magnetic correlations in cuprates from the underdoped to overdoped phase determined by inelastic magnetic scattering and resonant inelastic x-ray scattering are independent from

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the charge density waves determined by x-ray diffraction. There is clear evidence that high-temperature superconductivity appears to have broken lattice symmetry, and superstripes and multiple condensates appear in different positions in the k-space and in the real space. At the conference, it was clear that the proposal of mechanisms for high-temperature superconductivity based on a uniform electronic and lattice model have been falsified. The community is therefore looking now into very complex phase segregation landscapes at nanoscale where percolation superconductivity takes place in granular nanoscale matter as shown in Fig. 1.

Therefore, after many years of research on the mechanism of high-temperature superconductivity, following the discovery of Alex Müller in 1986 [38, 39], the scientific community has reached an agreement on the intrinsic heterogeneity of the CuO_2 plane in superconducting Cu oxides on the basis of new experimental results probing the nanoscale structure of these complex oxides. The magnetic response of the copper oxide-layered perovskites, in scattering experiments probing magnetic fluctuations from underdoped to overdoped phase, is due to nanoscale-striped "magnetic puddles" of localized singlets located on the Cu sites forming nanoscale horizontal or vertical stripes as shown in the upper part of Fig. 1. These magnetic nanoscale puddles coexist in different spatial locations in the same CuO_2 plane shown in the lower part of the figure with other different puddles shown in the lower panel of Fig. 1 made by O(2p) holes in the oxygen ion sublattice running in quasi 1D metallic stripes in the diagonal lattice direction.

This electronic and lattice complexity should be assigned to a complexity of interactions involving polaron self-organization, lattice modulations due to lattice parameter misfit strain, and self-organization of dopants in the spacer layers.

This scenario supports the presence of two electronic components at the Fermi level of cuprates: localized multielectron configurations $3d^9L$ detected in April 1987 [40, 41] by measuring many-body final states in XANES spectroscopy [42, 43] which can give either localized singlets on the Cu sublattice and itinerant oxygen 2p holes in the oxygen sublattice.

The superconducting nanoscale portions are confined in nanoscale puddles or at their interface in these heterostructures at the atomic limit. This scenario called "superstripes" in 2000 [44, 45] is a particular case of percolation superconductivity at a nanoscale proposed by several authors [46–49] where the disorder could favor the increase of critical temperature in the percolation regime where scale-free superconducting networks are formed [50, 51].

Finally, a novel scenario of percolation superconductivity made by nanoscale puddles in heterostructures at the atomic limit, involving granular nanoscale low-dimensional multicondensates, has emerged at the Superstripes 2013 in Ischia. A similar scenario has been reported to appear also in iron-based superconductors where the superstripes seem to be formed on the domain walls of magnetic puddles, and it is opening a new perspective for the design of new high-temperature superconductors.

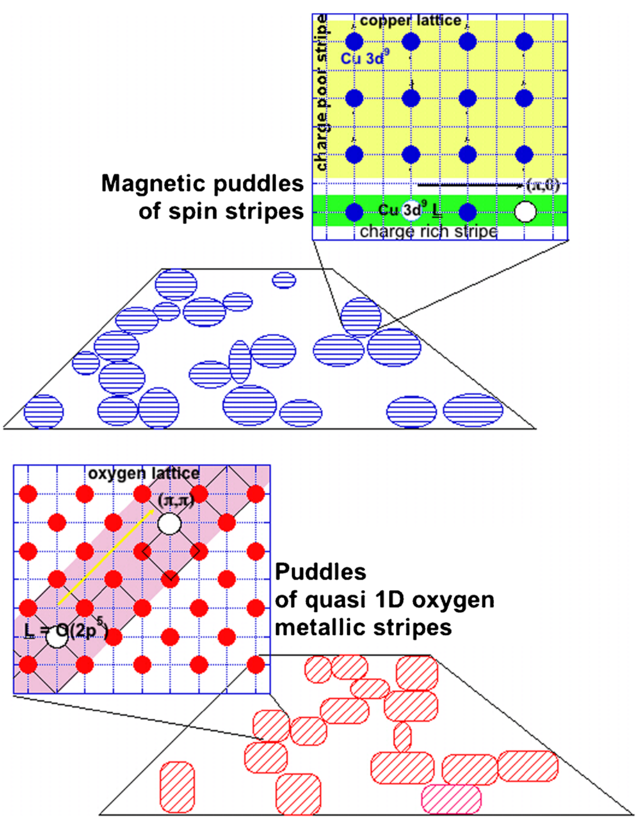

Fig. 1 *Upper panel*: A network of magnetic puddles (*horizontal blue stripes*) in 2D atomic CuO_2 plane where the localized singlets $3d^9L$ states in the Cu sites, induced by doping, form 1D stripes running in the direction of the Cu–O–Cu or $(0,\pi)$ antinodal direction. *Lower panel*: A network of different puddles (*diagonal red stripes*) in the 2D atomic CuO_2 plane where the $3d^9L$ states, induced by doping, form metallic 1D stripes running in the direction of the O–O direction called (π, π) nodal direction

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