MAGNETISM IN PURE AND DOPED Sr_2RuO_4.

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After the discovery of High-T_c superconductivity in cuprates many groups looked for superconductivity in other transition metal oxides. The only success came in Sr_2RuO_4 [1], which is isostructural to $(La,Sr)_2CuO_4$. However, in marked contrast to cuprates, superconductivity appears in Sr_2RuO_4 only at low temperature (~1.5 K) and out of a normal state that is a well-formed Landau Fermi liquid. Nevertheless, the superconductivity in Sr_2RuO_4 is rather unconventional. In particular, there is growing evidence that the pairing exhibits triplet symmetry [2] in agreement with the early proposal that superconductivity in Sr_2RuO_4 is mediated by ferromagnetic fluctuations [3].

The Fermi-surface in Sr_2RuO_4 separates into two distinct regions : (i) the α, β sheets are derived from the $4d_{xz}$ and $4d_{yz}$ orbitals, (ii) the γ sheet is derived from the $4d_{xy}$ orbital. The quasi-1D α,β sheets give rise to strong nesting effects peaking the bare spin susceptibility at incommensurate positions $(\pm 2\pi/3a, \pm 2\pi/3a, 0)$ [4], where a stands for the RuO_2 plane lattice parameter. Our inelastic neutron scattering (INS) studies confirmed this analysis perfectly. The imaginary part of the dynamical magnetic susceptibility seems to be dominated by incommensurate fluctuations at $\mathbf{q}_0=(\pm 0.6\pi/a, \pm 0.6\pi/a, 0)$ [5]. Analyzed within Stoner theory, Sr_2RuO_4 appears very close to a magnetic transition at the wave vector $\mathbf{q}_0$. Furthermore, incommensurate spin fluctuations should favor a d-wave spin singlet superconducting order parameter [4], as in High-T_c cuprates. Finally, the direct observation of ferromagnetic fluctuations being still missing, our INS studies cast some doubt about the predominant role of ferromagnetic fluctuations in the superconductivity of Sr_2RuO_4.
Substitution of nonmagnetic Ti^{4+} ions ($4d^0$) for Ru^{4+} ions ($4d^4$) quickly suppresses superconductivity. Our neutron diffraction measurements in a sample with 9% Ti demonstrate that Ti impurities trigger a short range magnetic ordering at $\mathbf{q}_0$ below 25K [6].

The condensation of the incommensurate fluctuations observed in pure Sr_2RuO_4 through Ti substitution strongly suggests that Sr_2RuO_4 lies close to a quantum critical point and this close quantum critical point should be taken into account in the superconducting compound. Likewise, the magnetic moment in the Ti-compound (0.3 μ_B) points along the c axis, revealing a weak out-of-plane anisotropy, which is likely due to spin-orbit coupling [7]. Considering an incommensurate spin fluctuation driven pairing mechanism, the persistence of such an anisotropy in pure Sr_2RuO_4 has been proposed to tune the superconducting order parameter from a spin singlet even parity to a spin triplet odd parity [8].

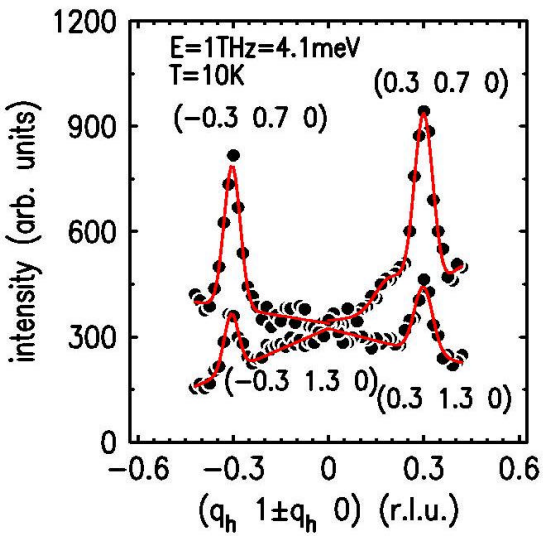

Figure 1: Constant energy scan at 4.1 meV along (110) and (-110) directions around the wave vector (0,1,0). Incommensurate spin fluctuations are located at wave vectors $Q_0=q_0+G$, where $q_0=(\pm 0{,}3, \pm 0.3, 0) =(\pm 0.6\pi/a, \pm 0.6\pi/a, 0)$ and G correspond to a zone center or a Z point in the (HK0) planes.

Besides, the substitution of Sr by isovalent Ca allows one to explore an astonishingly rich phase diagram [9,10], see Fig. 2. The smaller ionic radius

of the Ca drives a series of structural phase transitions characterized by rotations of the RuO_6-octahedra around distinct axes [9]. These structural distortions are coupled with anomalous magnetic and electronic phenomena. The most interesting behavior is observed for the end-member Ca_2RuO_4 which exhibits a transition from a paramagnetic metallic to an antiferromagnetic insulating state. This transition is accompanied by a prominent change in its crystal structure and has to be interpreted as a Mott-metal insulator transition. Due to its well defined crystal structure, Ca_2RuO_4 appears a very promising material for the study of such transitions.

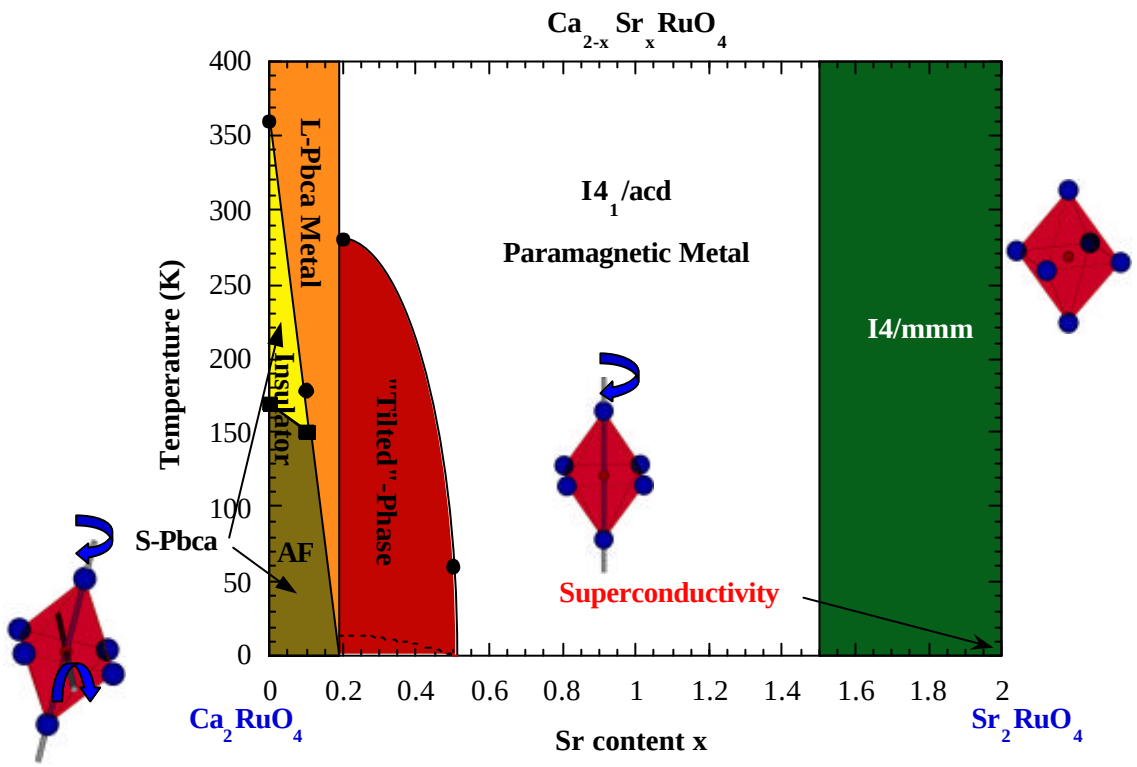

Figure 2. Phase diagram of $Ca_{2-x}Sr_xRuO_4$ [9] presenting the different structural and magnetic phases. Note that all phases are metallic except for S-Pbca. The drawings illustrate the different tilt and rotation schemes of the octahedra.

[1] Y. Maeno et al., *Nature* **372**, 532 (1994).
[2] K. Ishida et al., *Nature* **396**, 698 (1998); G. Luke et al., *Nature* **394**, 558 (1998).
[3] T.M. Rice and M. Sigrist, *J. Phys. Condens. Matter* **7**, L643 (1995).
[4] I.I Mazin et al., *Phys. Rev. Lett.* **82**, 4324 (1999).
[5] Y. Sidis et al., *Phys. Rev. Lett.* **83** , 3320 (1999).
[6] M. Braden et al., submitted to *Phys. Rev. Lett.* (2001).
[7] K.K Ng and M. Sigrist, *J. Phys. Soc. Jpn* **69**, 3764 (2000).
[8] M. Sato and M. Komoto, *J. Phys. Soc. Jpn* **69**, 3505 (2000), T. Kuwabara and M. Ogata, *Phys. Rev. Lett.* **85**, 4586 (2001).
[9] O. Friedt et al., Phys. Rev. B**63,** 174432 (2001), M. Braden et al. Phys. Rev. B**58**, 847 (1998).
[10] S. Nakatsuji et al., Phys. Rev. Lett. **84**, 2666 (2000).