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Understanding oxide interfaces: From microscopic imaging to electronic phases

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In the last decade, the advent of complex oxide interfaces has unleashed a wealth of new possibilities to create materials with unexpected functionalities. A notable example is the two-dimensional electron system formed at the interface between $LaAlO_3$ and $SrTiO_3$ (LAO/STO), which exhibits ferromagnetism, superconductivity, and a wide range of unique magneto-transport properties. A key challenge is to find the microscopic mechanisms that underlie these emergent phenomena. While there is a growing understanding that these phenomena might reflect rich structures at the micro-scale, experimental progress toward microscopic imaging of this system has been so far rather limited due to the buried nature of its interface. In this talk I will discuss our experiments that study this system on microscopic and macroscopic scales. Using a newly-developed nanotube-based scanning electrometer we image on the nanoscale the electrostatics and mechanics of this buried interface. We reveal the dynamics of structural domains in STO, their role in generating the contested anomalous piezoelectricity of this substrate, and their direct effects on the physics of the interface electrons. Using macroscopic magneto-transport experiments we demonstrate that a universal Lifshitz transition between the population of d-orbitals with different symmetries underlies many of the transport phenomena observed to date. We further show that the interactions between the itinerant electrons and localized spins leads to an unusual, gate-tunable magnetic phase diagram. These measurements highlight the unique physical settings that can be realized within this new class of low dimensional systems.