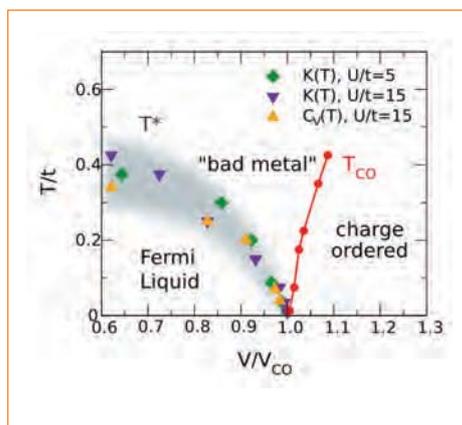


## Fluctuating charge order destroys metallic behavior

Phase transitions are ubiquitous: from the crystallization of water into ice, to the alignment of electron spins inside a magnet, to the emergence of superconductivity in a cooled metal. In the case of continuous, second-order, transitions, the transformation from one phase to the other does not come suddenly: it is generally announced by a strong increase in the fluctuations of an “order parameter”. The most familiar example is the phenomenon of critical opalescence, reflecting the increase in density fluctuations at the approach of the liquid-gas transition.

In recent years, there has been a growing interest in critical phenomena taking place at (or sufficiently close to) the absolute zero of temperature. This has revealed a new class of phase transitions, called quantum phase transitions. In contrast to ordinary phase transitions, where the control parameter is the temperature, quantum phase transitions are driven by the zero point quantum fluctuations associated with Heisenberg's uncertainty principle. Quantum Critical Points (QCPs) typically occur in physical systems where several ground states are in competition, so that it is possible to tune from one ground state to another by adjusting an external control parameter such as pressure, magnetic field, or chemical composition.



Phase diagram illustrating the emergence of non-Fermi liquid properties induced by the proximity to a charge ordering transition driven by Coulomb electron-electron interactions.

The proximity to a quantum critical point can result in a very unusual state of matter. In a metal, for example, the electrons are so strongly scattered by the quantum critical fluctuations that significant deviations from the usual “Fermi liquid” behaviour can arise, a fact that has measurable consequences – the analogue of the phenomenon of critical opalescence. More strikingly, the system might even prefer to avoid such anomalous behavior and adopt other forms of order such as superconductivity, novel types of magnetism, or other forms of “hidden” order.

Proximity to a quantum critical point may be the cause of anomalous properties in a variety of materials even when the QCP itself is not observed.

While most studies of quantum criticality in recent years have been devoted to the study of QCPs at magnetic phase transitions, QCPs related to charge order instabilities have remained mostly unexplored. In the present work, we have focused on a theoretical model that describes the charge ordering driven by the strong Coulomb repulsion between electrons, as observed in a class of layered organic conductors – the quarter-filled theta-(BEDT-TTF)<sub>2</sub>X salts. Upon applying pressure or by chemical substitution, the critical temperature  $T_c$  of the transition can be made to vanish, and a quantum critical point is obtained.

Our theoretical results show that the properties of the electronic system are strongly affected by the existence of the QCP. A new temperature scale  $T^*$  emerges in the normal phase, above which the elementary electronic quasi-particles that are at the very basis of the Fermi liquid behaviour are strongly slowed down and eventually disappear [Fig.1]. The resulting state exhibits a “bad” metallic behaviour, testified by a strong increase in the effective mass and a consequent reduction of the system's kinetic energy. At the same time, the “Drude” conduction characteristic of metals is strongly suppressed.

These observations agree quite well with what is observed in the theta-(BEDT-TTF)<sub>2</sub>X salts by both transport and optical spectroscopy measurements. The emergence of superconductivity in the theta-(BEDT-TTF)<sub>2</sub>I<sub>3</sub> compound – the only superconducting member of this class of materials, which is also the one lying closest to the quantum critical point – could well be related with the present scenario. Also, due to the universality of the concepts involved, phenomena similar to those evinced here should in principle apply also to other classes of materials exhibiting charge order, such as the transition metal dichalcogenides.

### CONTACTS

Simone FRATINI  
simone.fratini@grenoble.cnrs.fr  
Tel: +33 476 88 10 85

### FURTHER READING

L. Cano-Cortés, J. Merino and S. Fratini,  
Phys. Rev. Lett. 105, 036405 (2010).