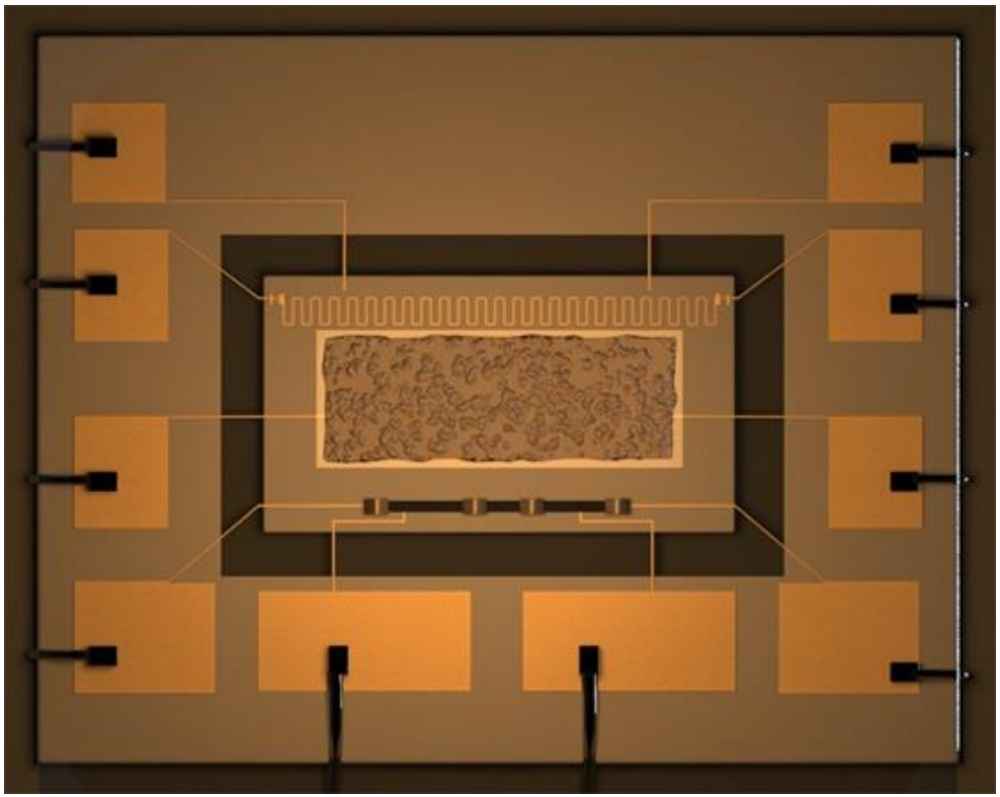
Specific Heat Measurements through the Superconductor-Insulator Quantum Phase Transition

Aviad Frydman, *Bar Ilan University*

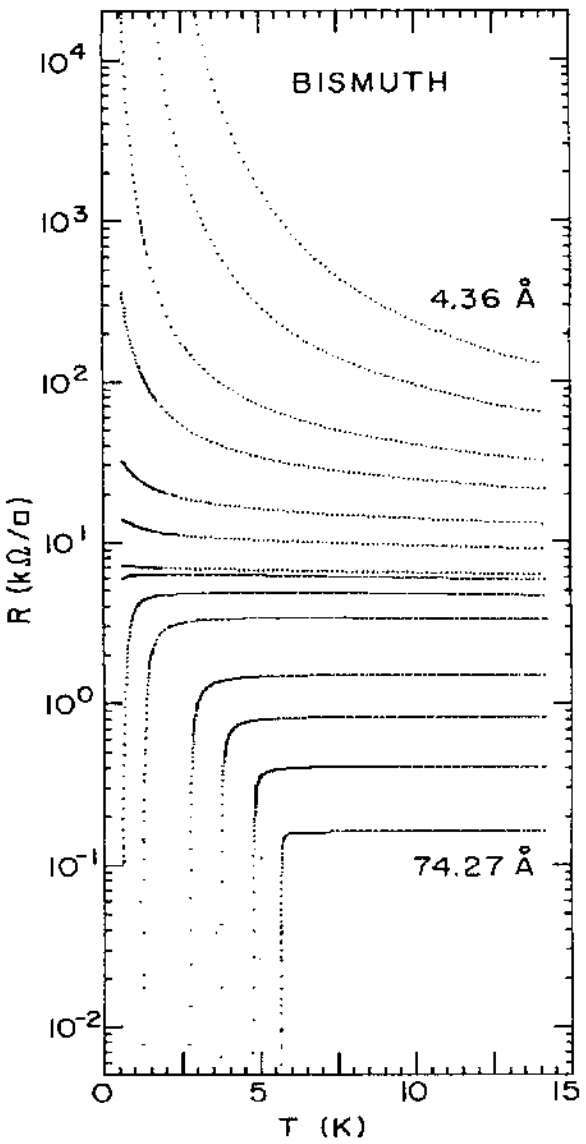


BIU
Shachaf Poran

Neel Inst. Grenoble
Olivier Bourgeois

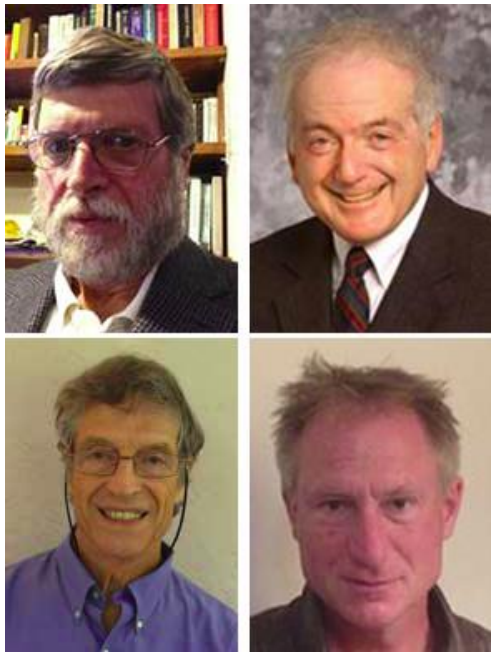
Technion
Assa Auerbach

The superconductor–insulator–transition



Haviland, Liu and Goldman , PRL 89

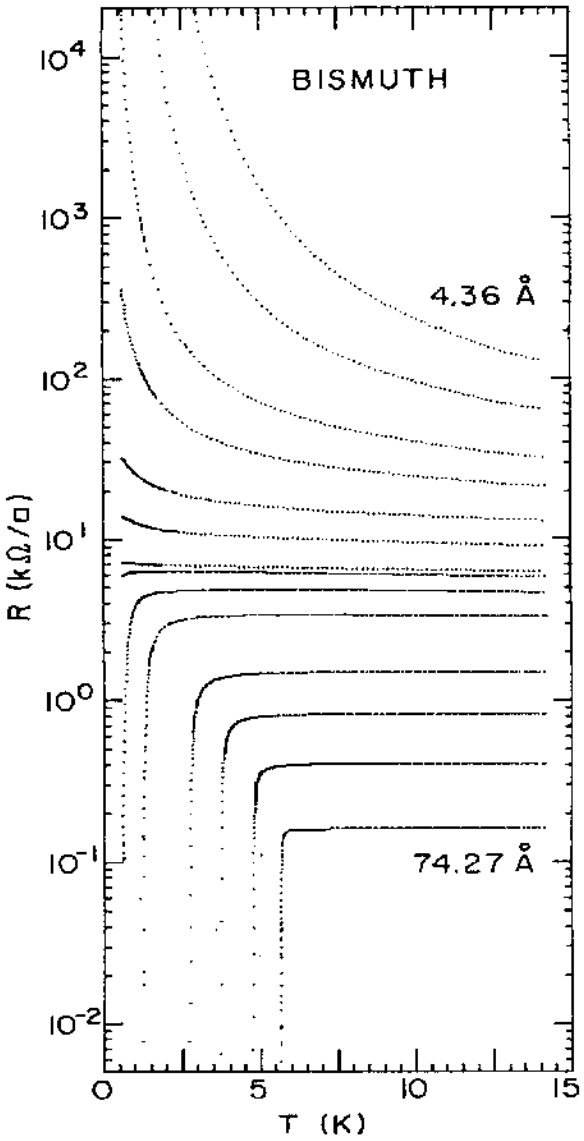
2015 Buckley Condensed matter physics prize



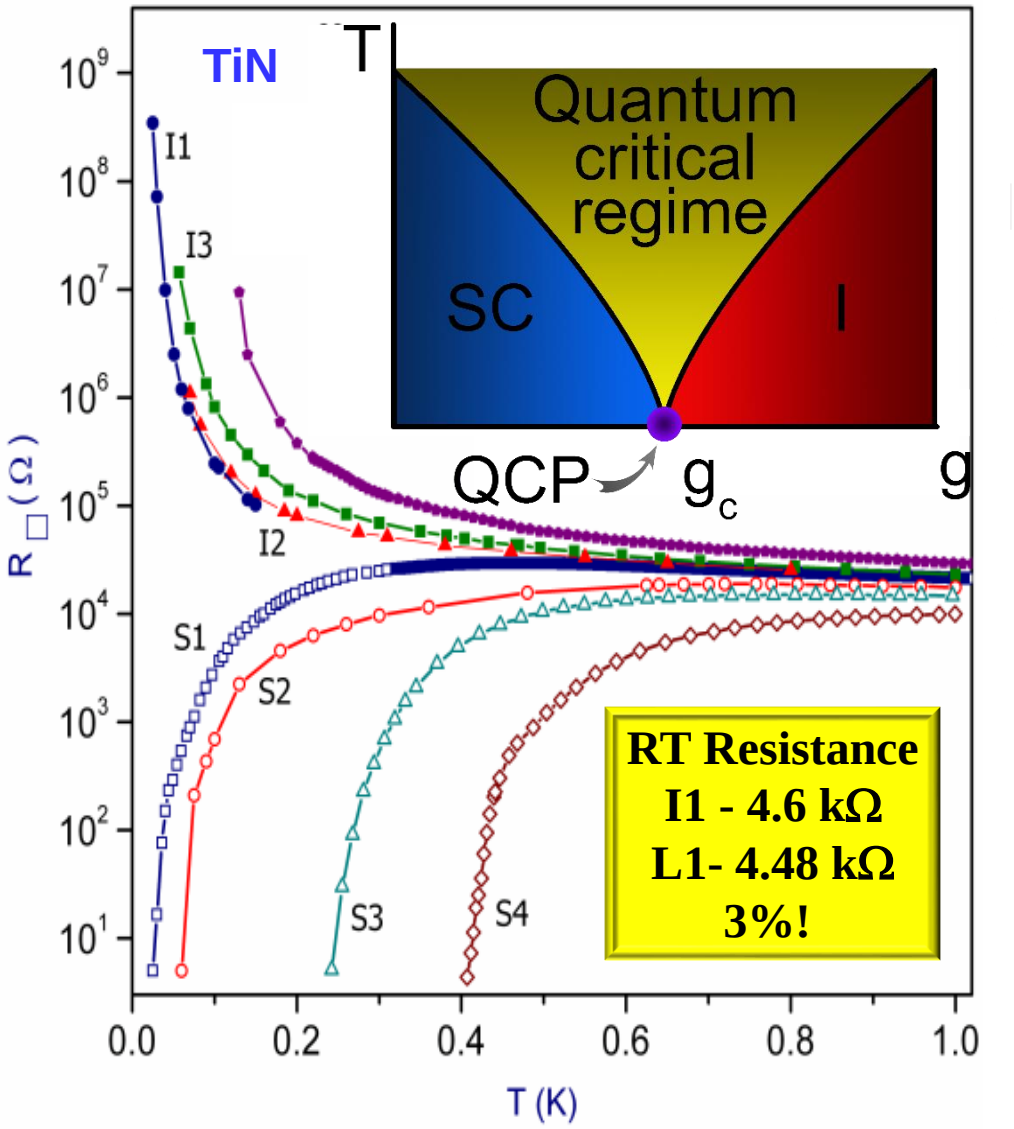
Aharon Kapitulnik
Allen Goldman
Art Hebard
Matthew Fisher

"For discovery and pioneering investigations of the superconductor-insulator transition, a paradigm for quantum phase transitions."

The superconductor–insulator–transition

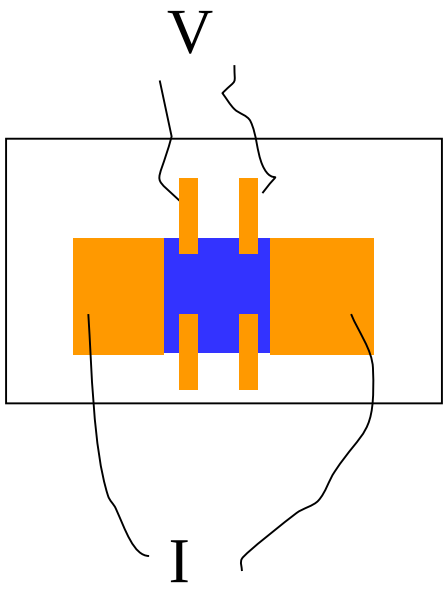


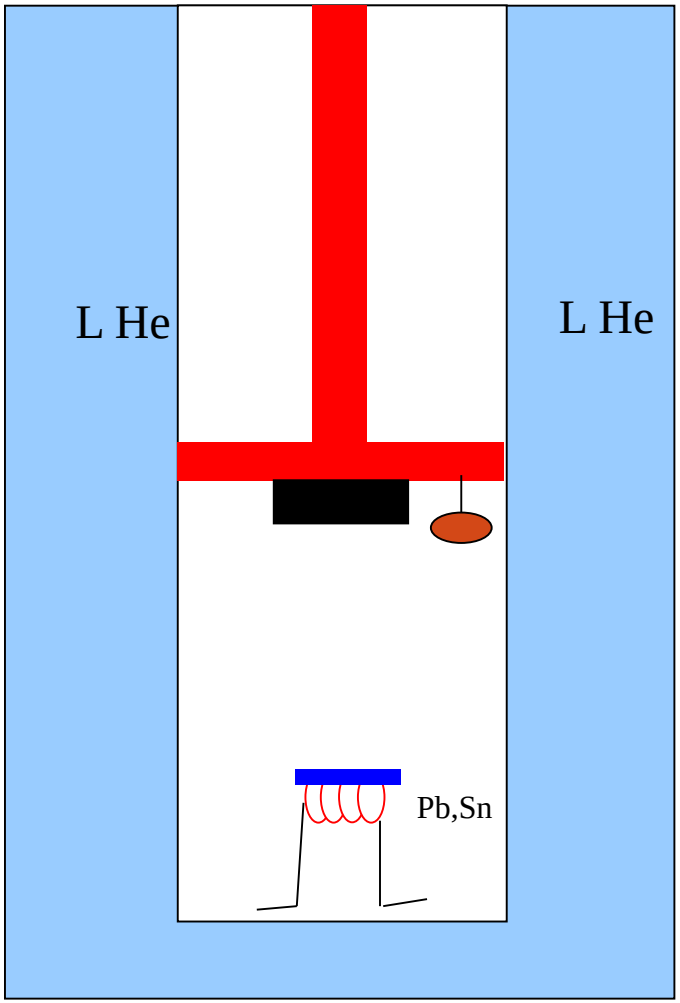
Haviland, Liu and Goldman , PRL 89



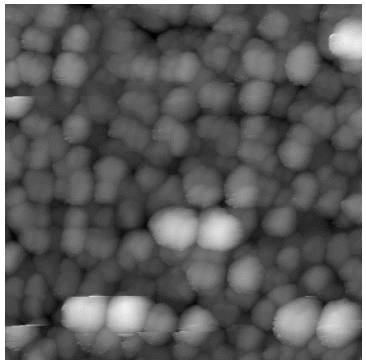
Baturina et.al. PRL (2007)

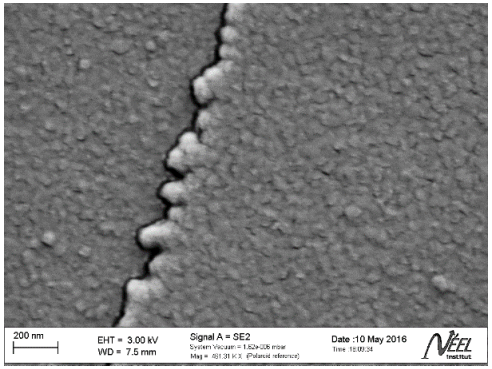
Quench condensation

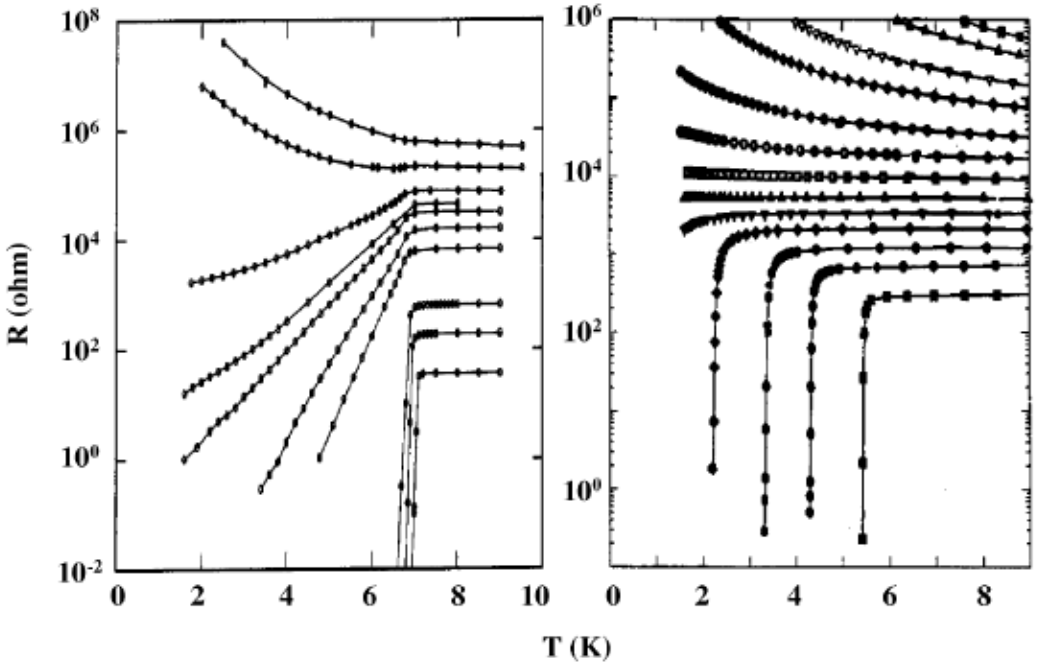




Ultrathin metallic films







AF, PRB 2003

Ultrathin metallic films

Phase

$$\Psi = |\Psi| e^{i\phi}$$

Amplitude

Bosonic

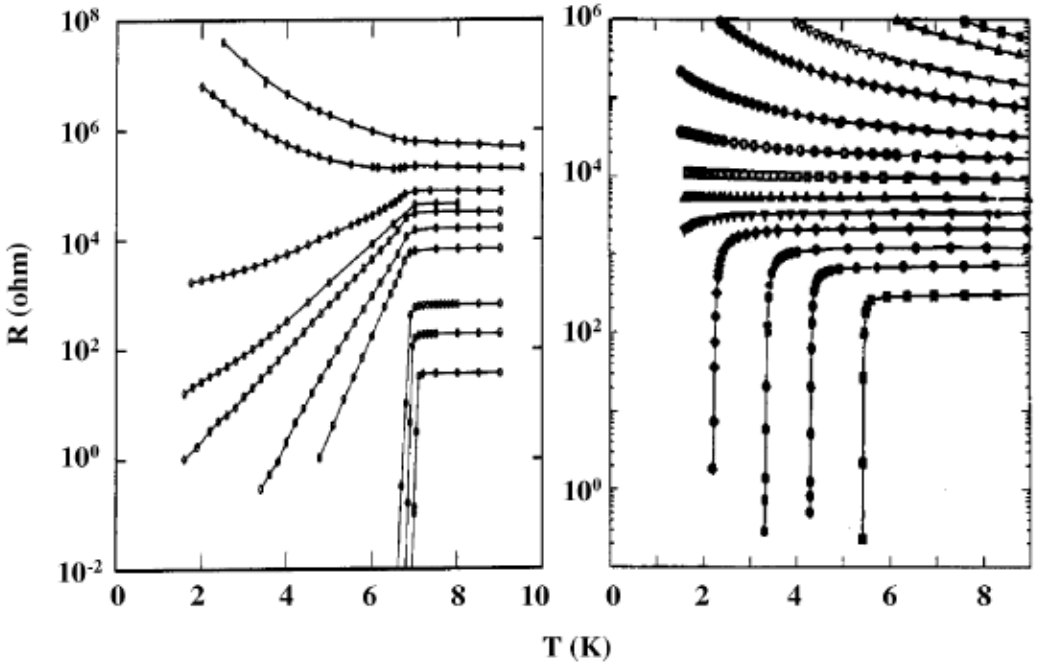
Fisher & Lee 1989

Fermionic

Finlelstein 1989

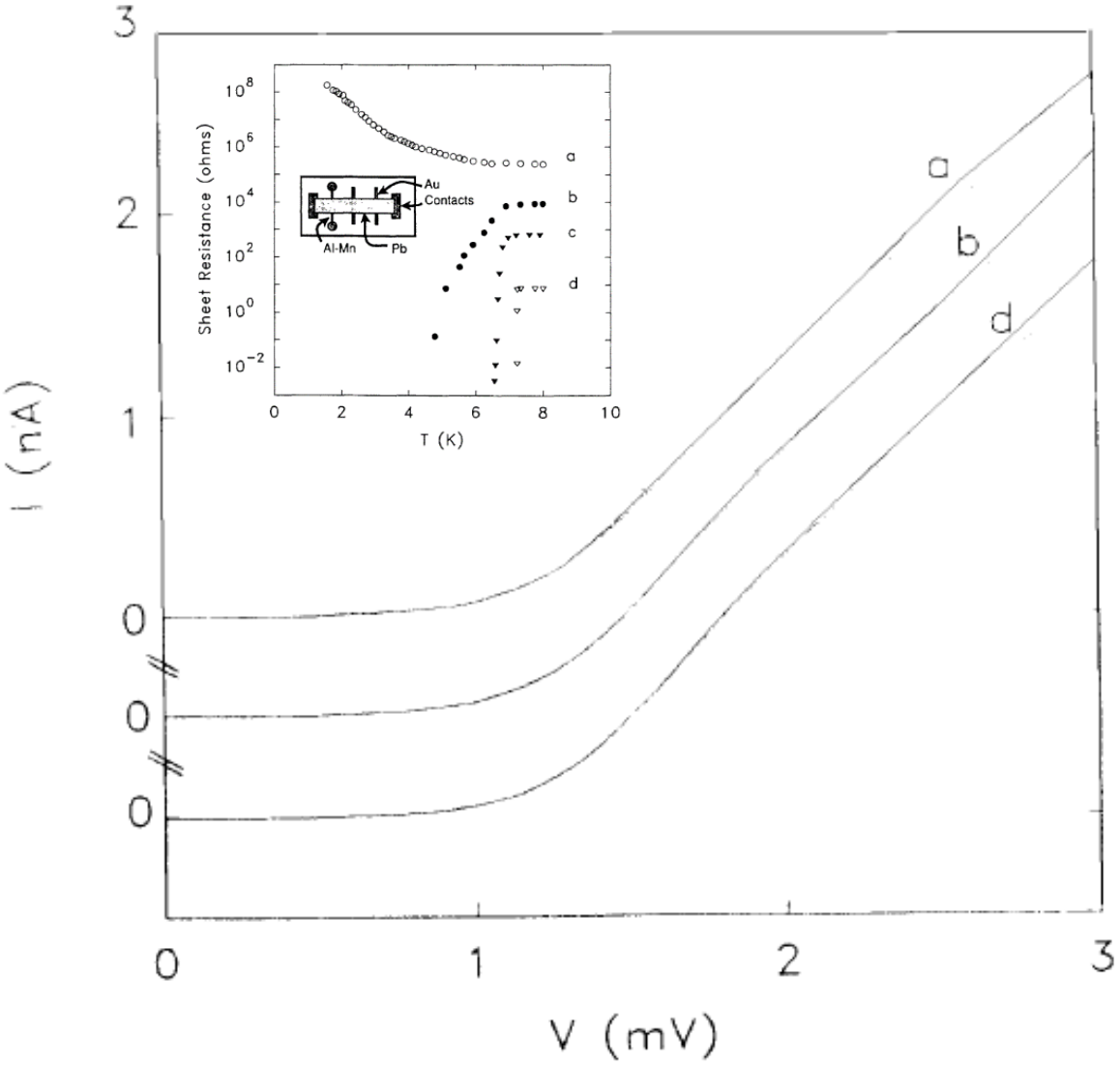
$T_{mf} \sim \Delta$

$T_{\Phi} \sim \rho_s$



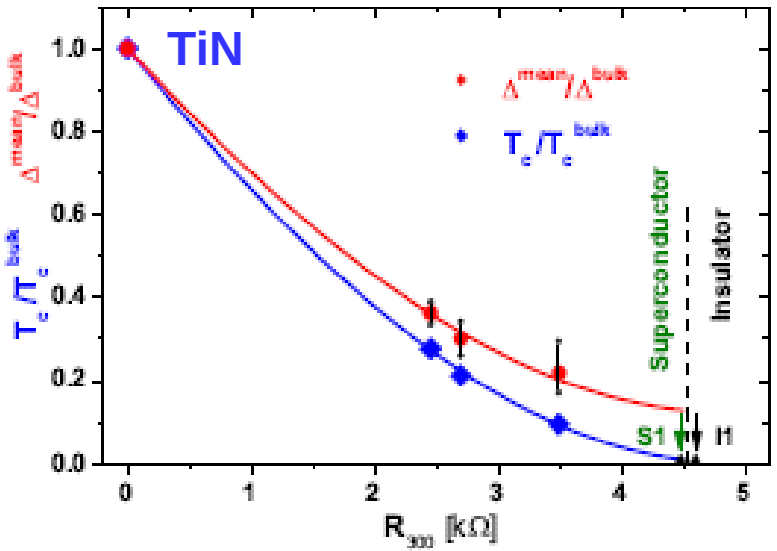
AF, PRB 2003

Superconducting gap, Δ

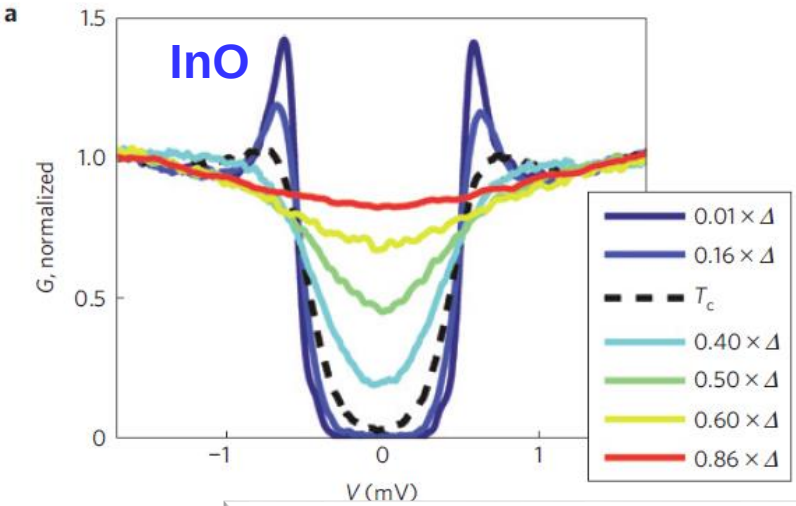


Barber et-al, 94

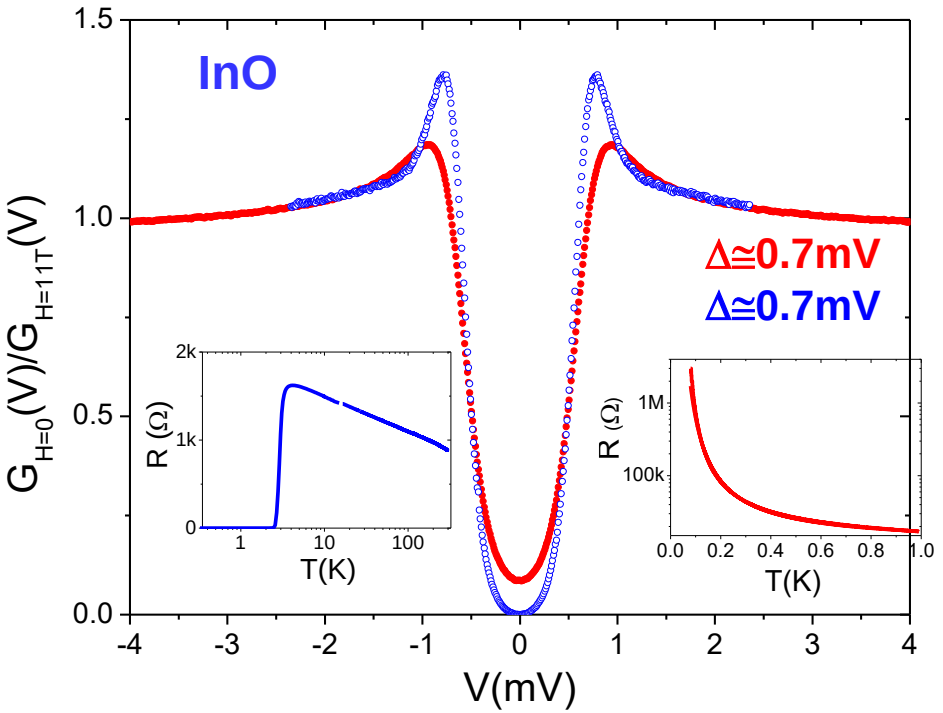
Δ remains finite across the SIT and above T_C



Sacepe et.al. PRL (2008)



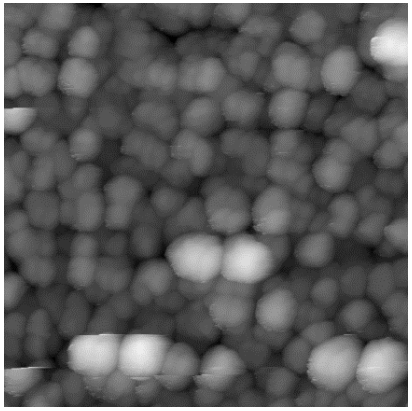
Sacepe et.al. Nature Physics (2011)

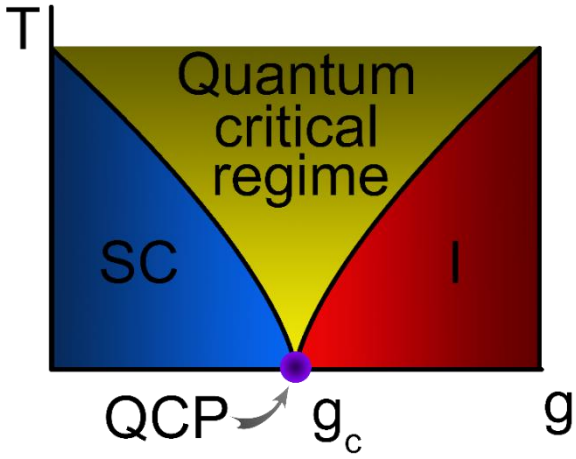


$R_{barrier} >> R_{sample}$

Sherman, Kopnov, Shahar and Frydman, PRL (2012)

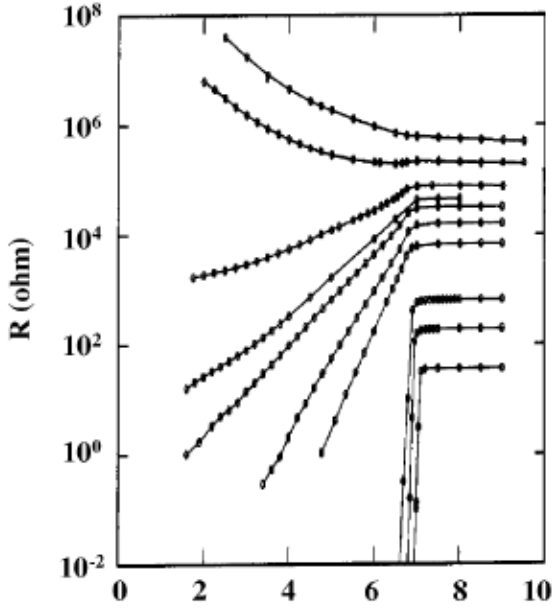
Quantum fluctuations in the QCR





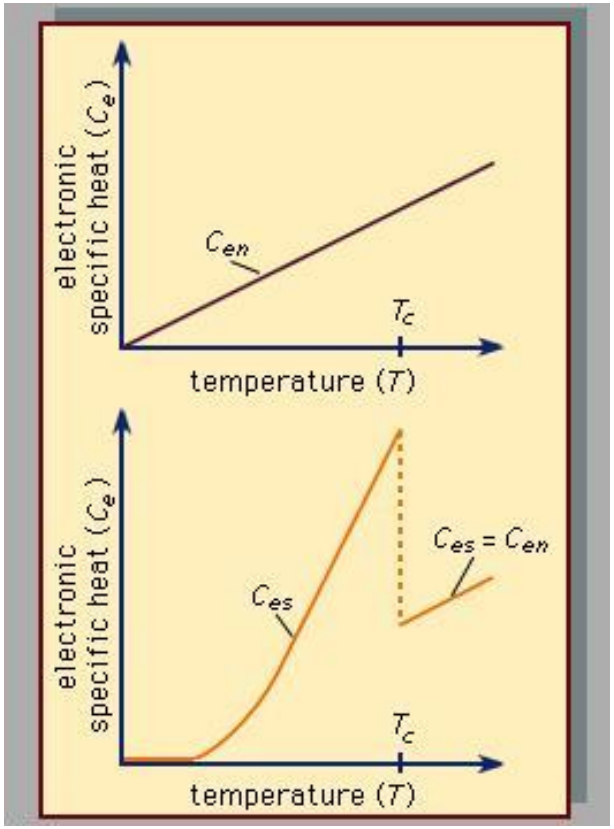
$T_{mf} \sim \Delta$

$T_{\Phi} \sim \rho_s$

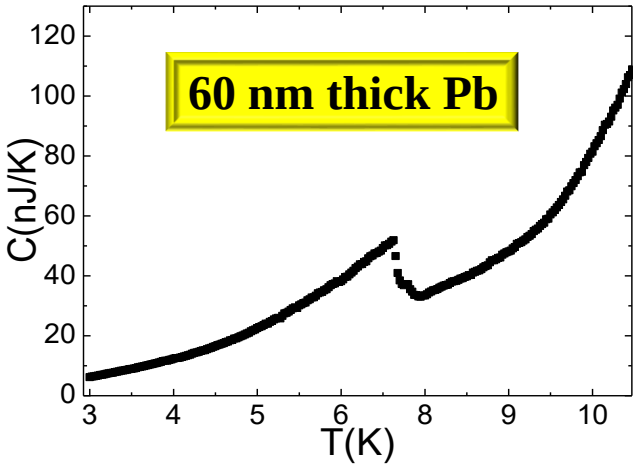


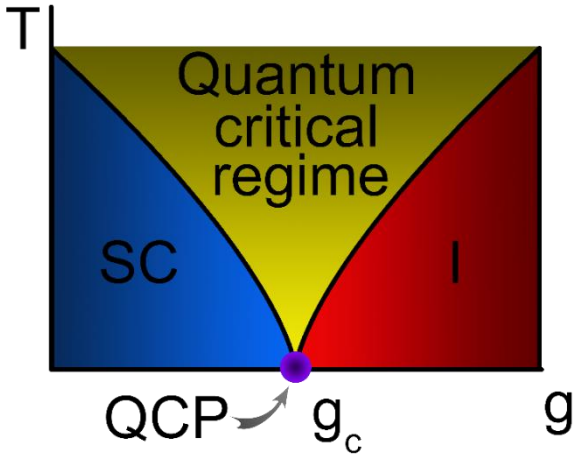
Specific heat

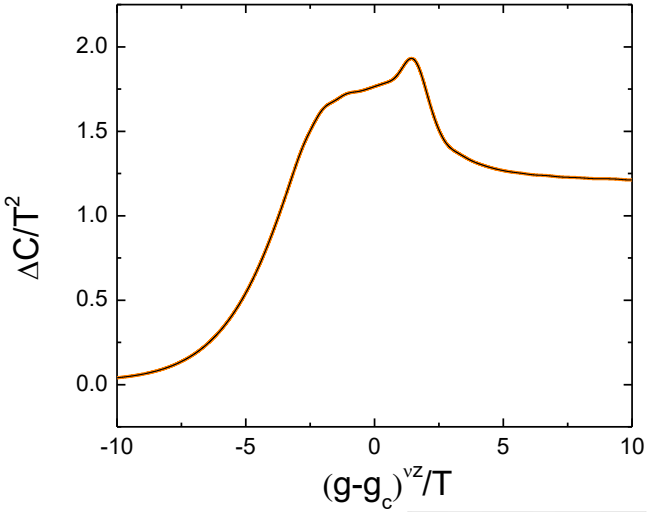
$$C_e = \gamma T + \beta T^{3h}$$



$$c_{\mathrm{BCS}} \simeq 10\gamma T_c \exp\left(-1.76\frac{T_c}{T}\right)$$



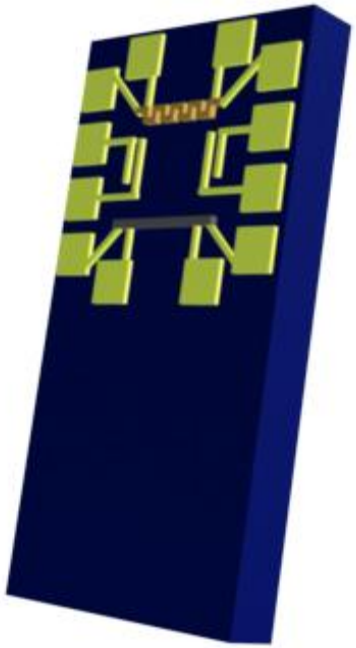




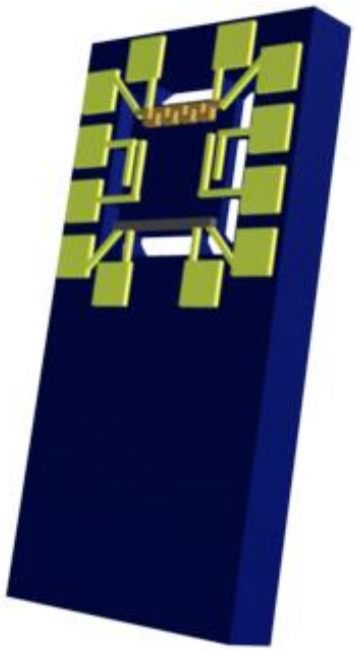
Nicolas Dupius

Calorimeter fabrication

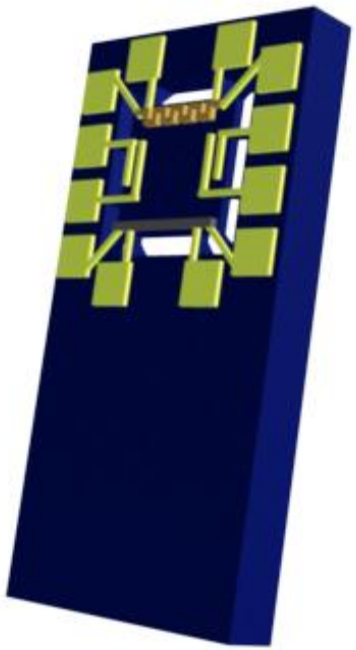
Calorimeter fabrication



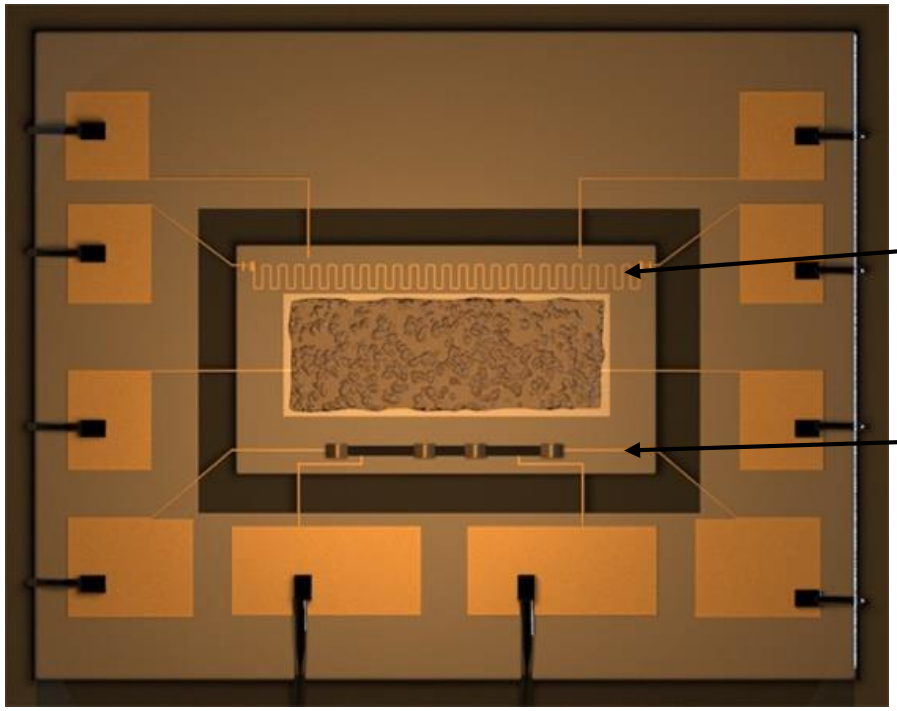
Calorimeter fabrication

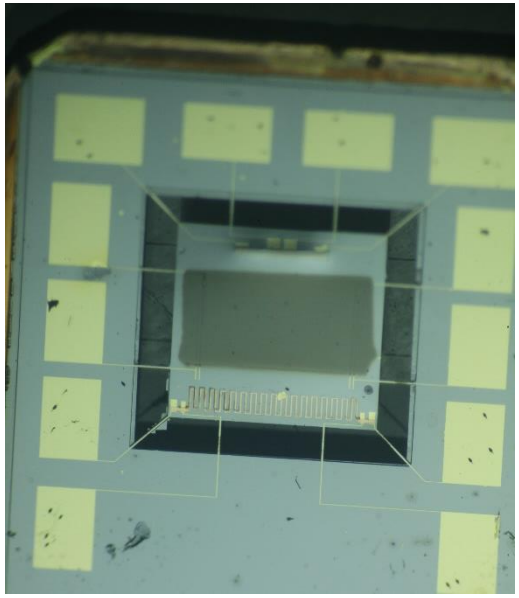


Calorimeter fabrication



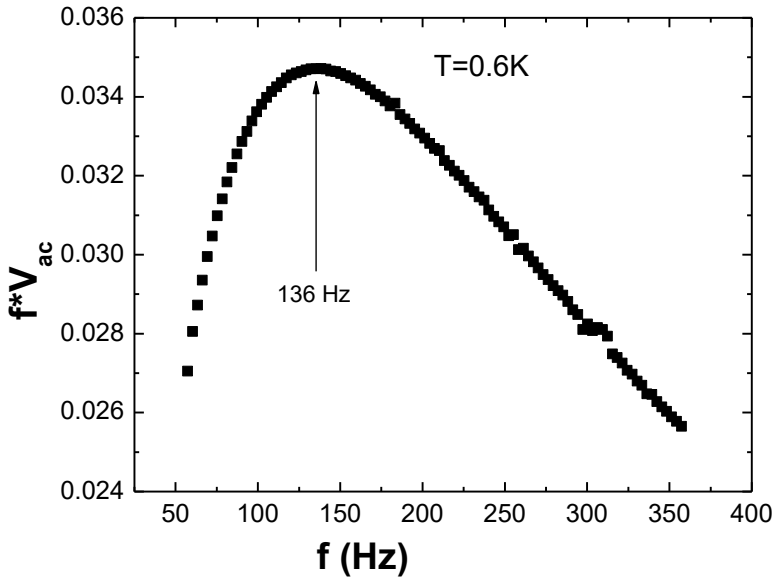
Calorimeter



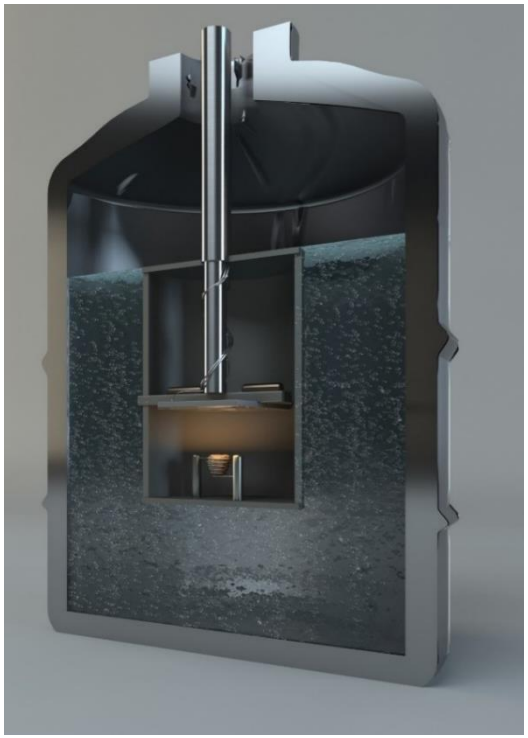


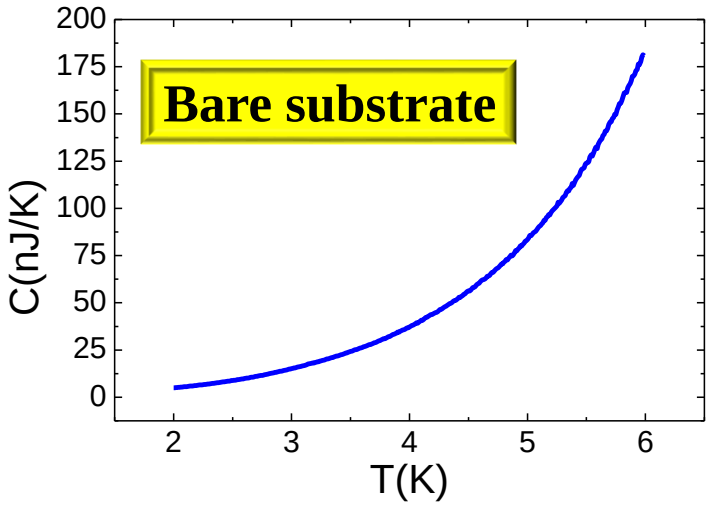
$$C = \frac{P_{ac}}{2\omega\ \delta T_{ac}}$$

$$\tau_{diffusion}^{-1} \gg \omega \gg \tau_{bath}^{-1}$$



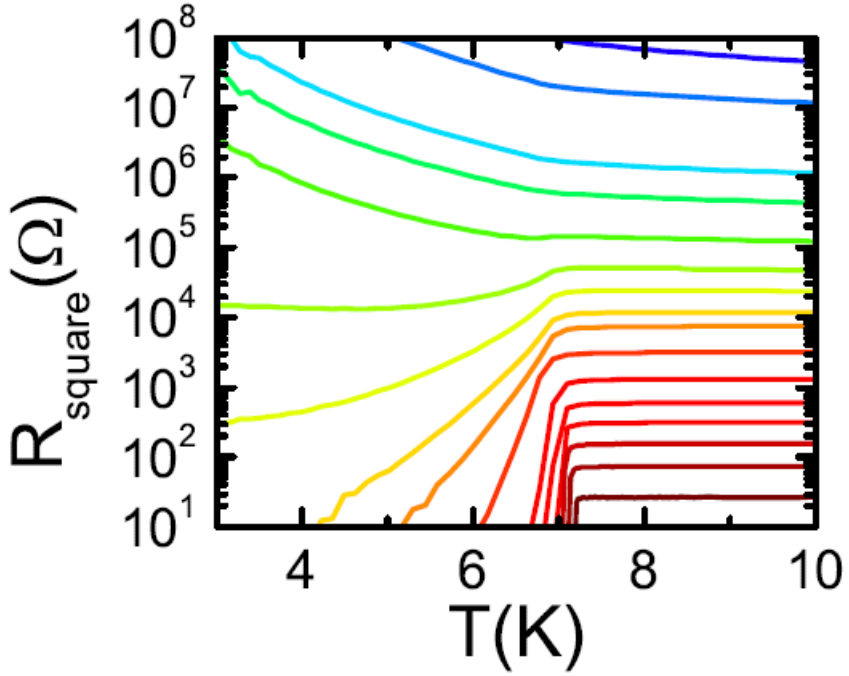
Quench condensation set-up

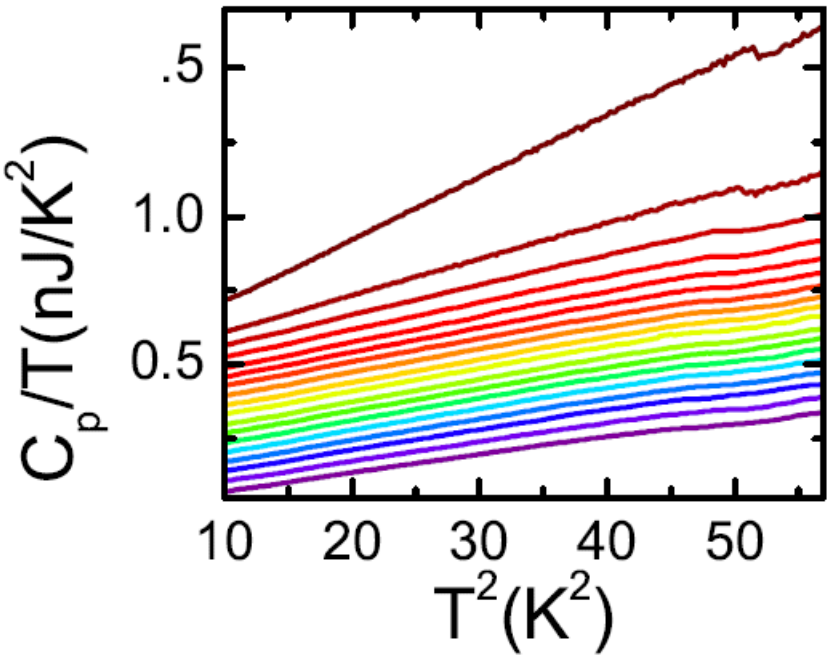




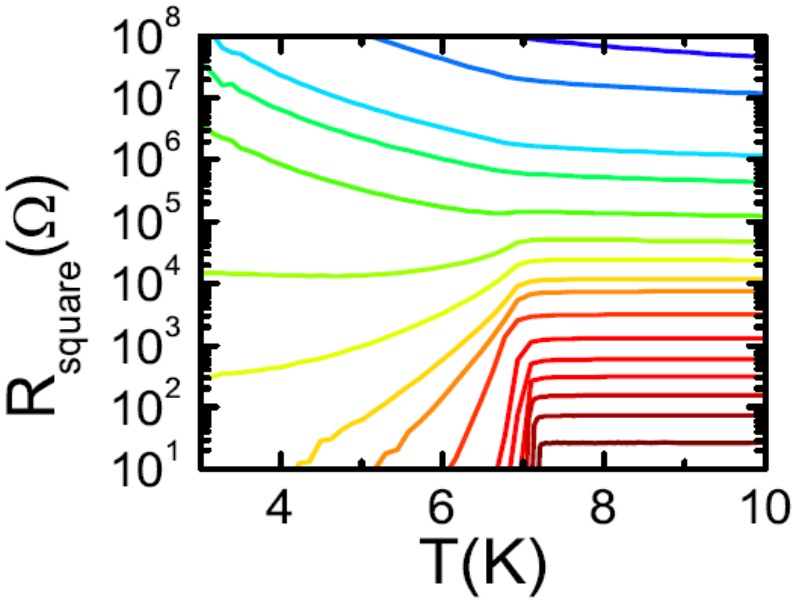
Resistance and heat capacity

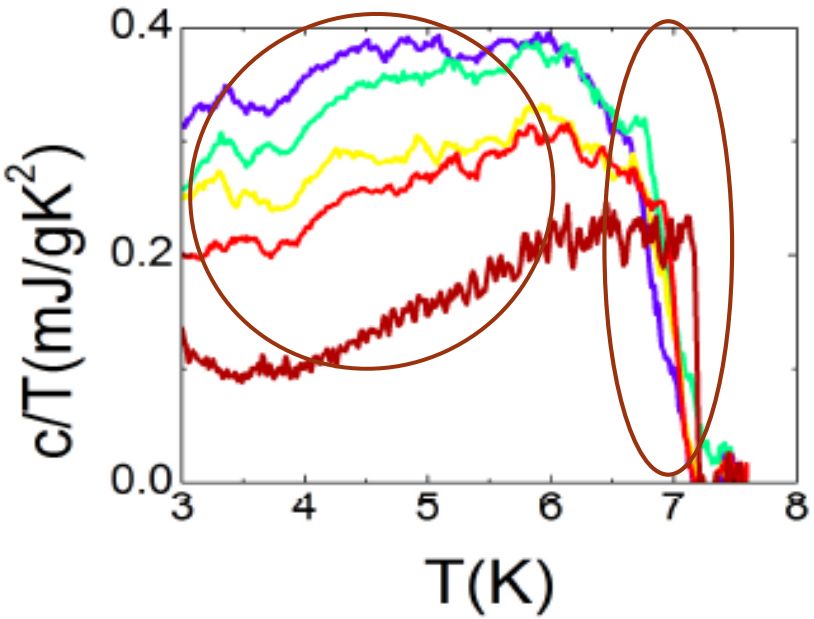
$$\frac{C_n}{T} = \gamma + \beta T^2$$

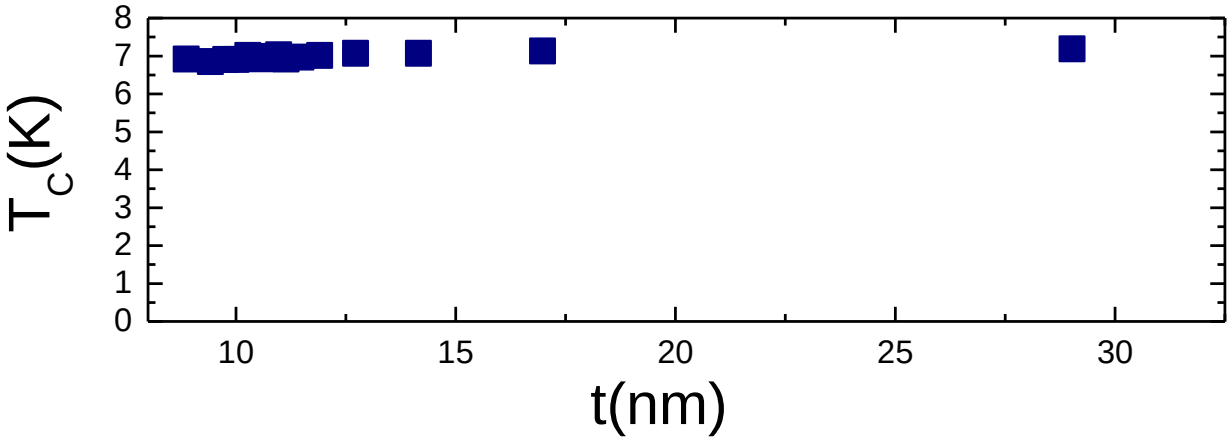




Specific heat close to the QCP



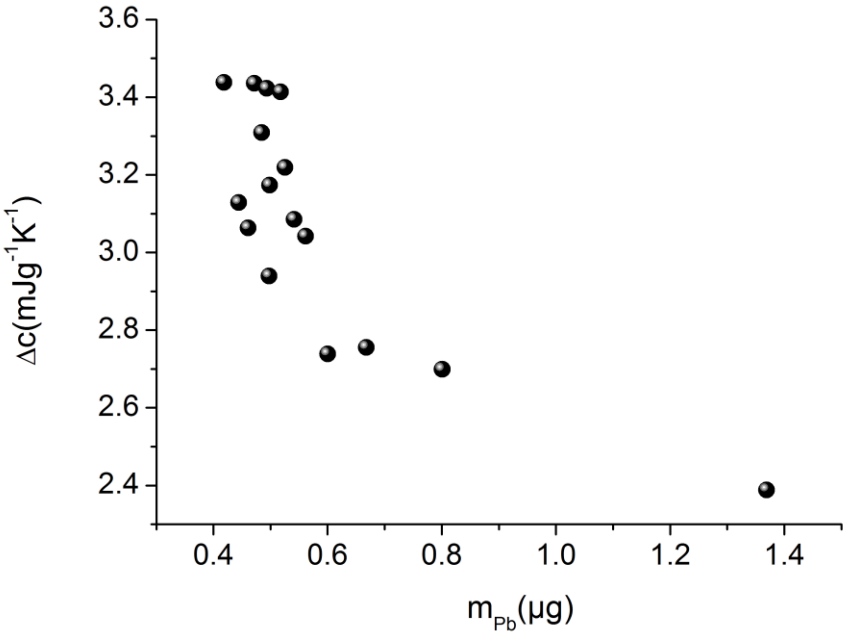




$T_{mf} \neq T_{\Phi}$

Specific heat of small particles

Our Pb films



Powder of Sn particles

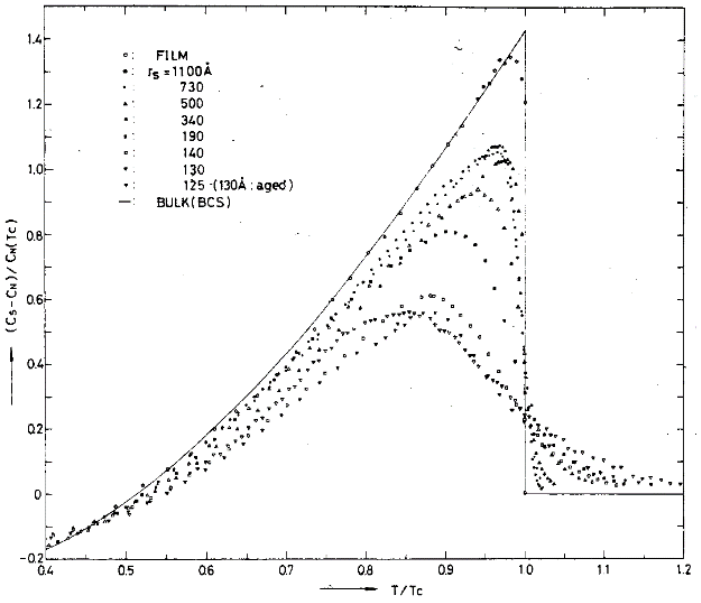
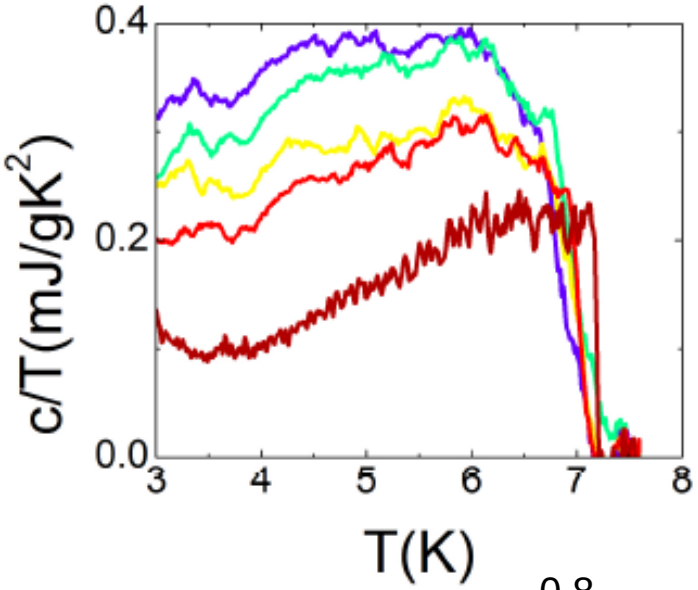
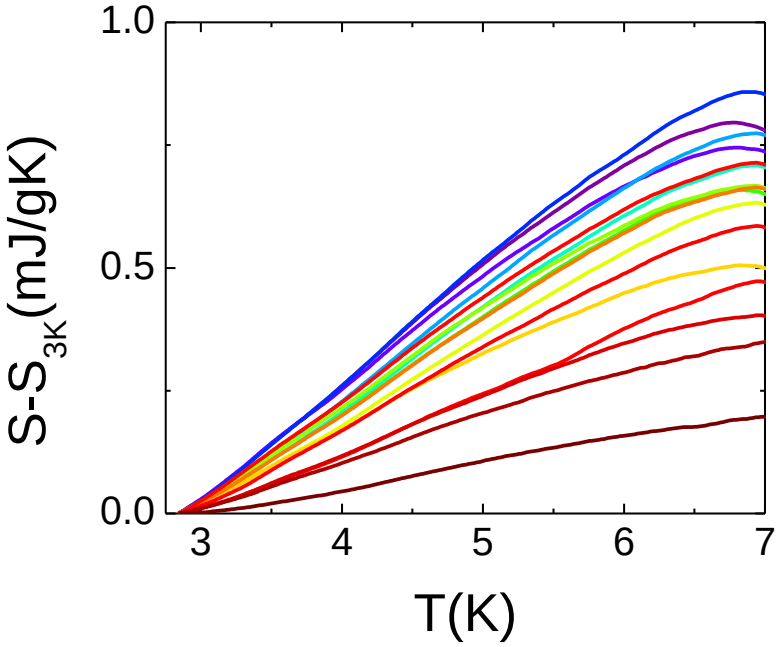
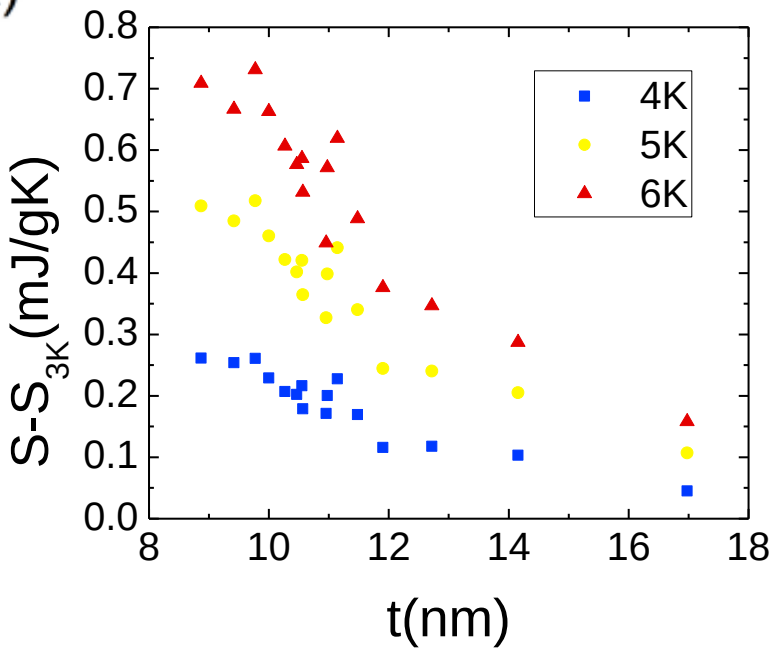


Fig. 3. Specific heat difference for Sn particles with different particle sizes as a function of the reduced temperature. The difference is normalized to $C_N(T_c)$, where $C_N(T_c)=\gamma T_c$ with $\gamma=1.78$ mJ·K^{-2}·mol^{-1}.

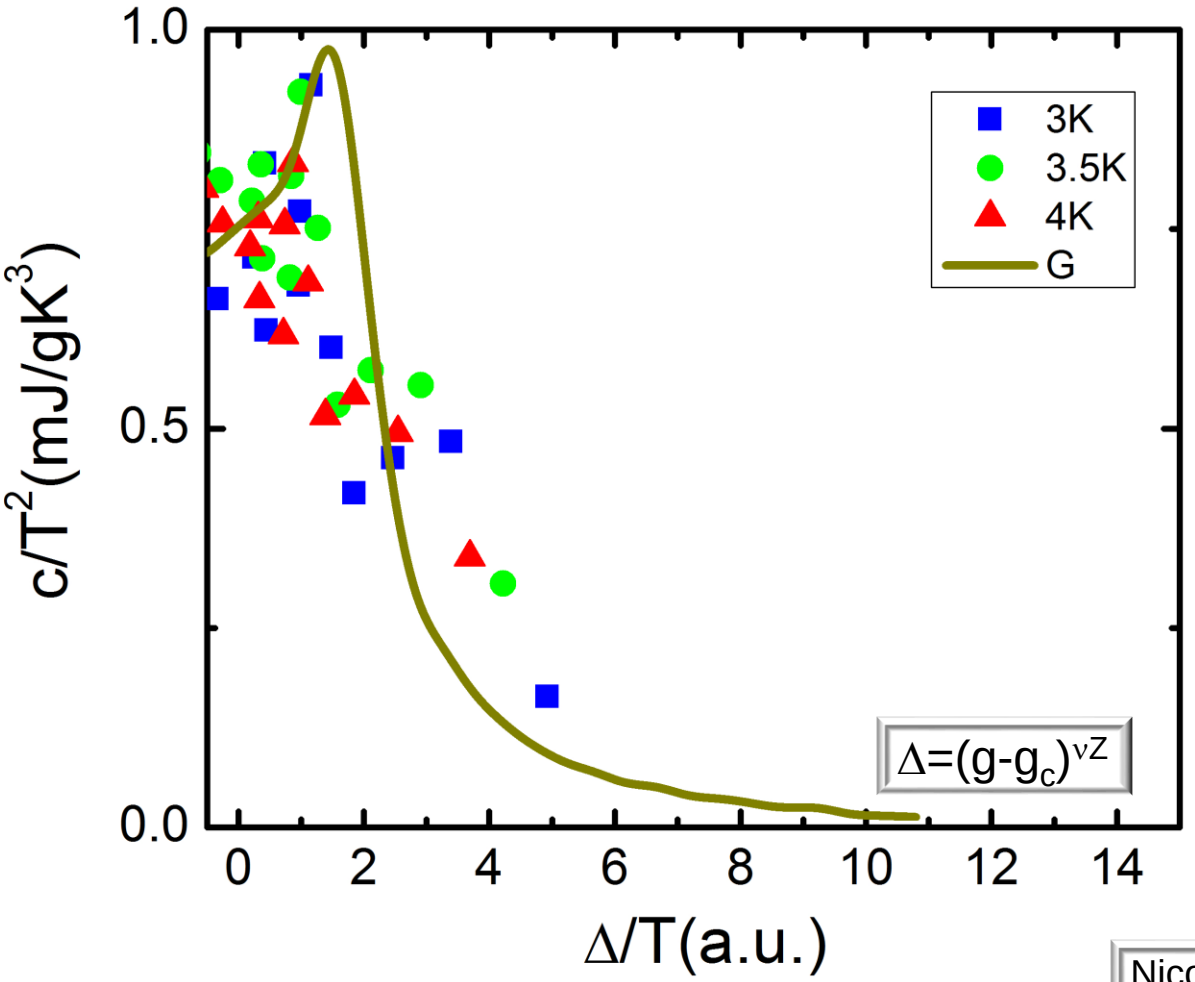
Specific heat and entropy







Collective mode contribution to Cp

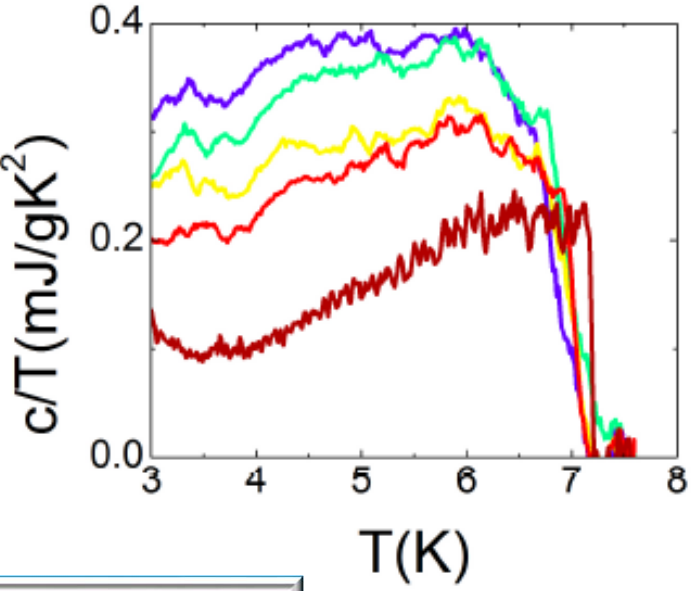


Nicolas Dupius

$C^{boson} \sim \#grains * k_B$

$C^{fermion} \sim \#pairs * k_B$

Fermionic origin of excess specific heat



$$c_{\mathrm{BCS}} \simeq 10\gamma T_c \exp\left(-1.76\frac{T_c}{T}\right)$$

$$\gamma = m\frac{k_B^2 k_F}{3\hbar^2}$$

REVIEWS OF MODERN PHYSICS, VOLUME 79, JULY–SEPTEMBER 2007

Fermi-liquid instabilities at magnetic quantum phase transitions

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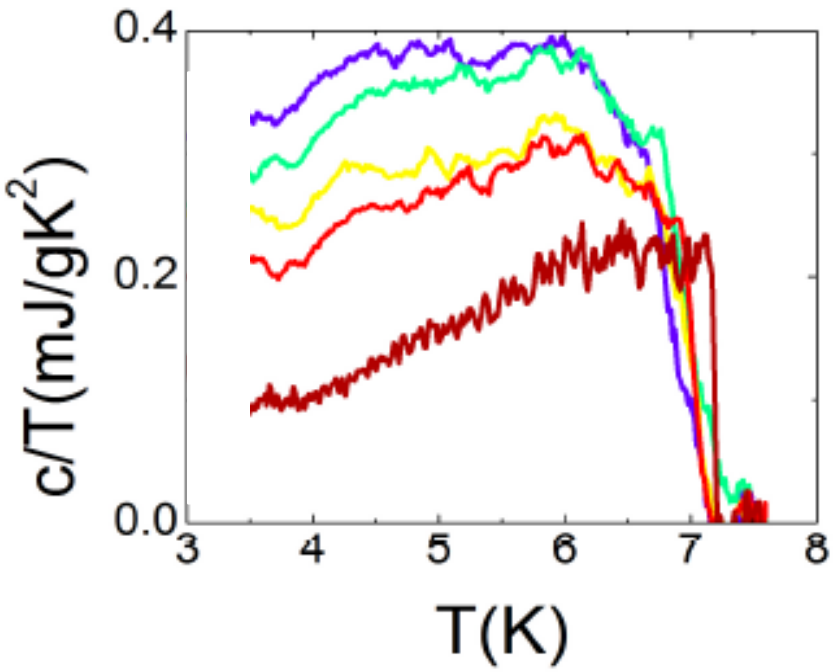
(Published 17 August 2007)

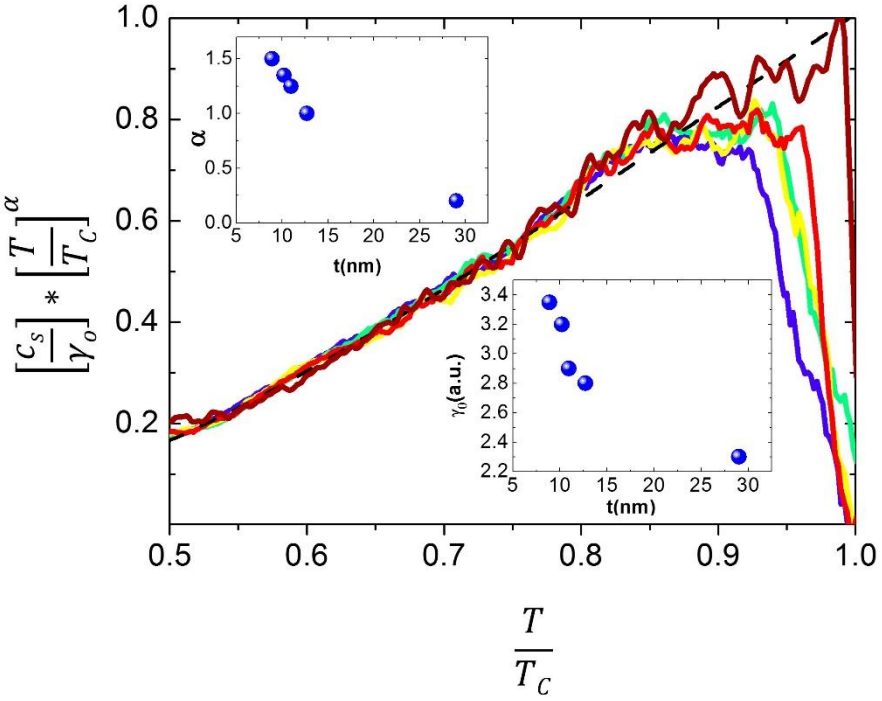
$$\frac{\gamma^*}{\gamma} = \frac{1+\partial_{\epsilon_k}\Sigma(\epsilon_{k_F},\omega)}{1-\partial_\omega\Sigma(\epsilon_{k_F},\omega)}$$

$$c_{\rm BCS} \simeq 10\gamma T_c \exp\left(-1.76\frac{T_c}{T}\right) \qquad \gamma = m\frac{k_B^2 k_F}{3\hbar^2}$$

$$c_s(T,t) \simeq 10 T_c^{mf} \gamma^*(T,t) \exp\left(-1.76\frac{T_c^{mf}}{T}\right)$$

$$\gamma^* = \gamma_0 [T_c^{mf}/T]^\alpha,$$





Summary

- **The specific heat grows towards the QCP in a granular superconductor.**
- **This is interpreted as an increase of the electronic effective mass in the vicinity ohf the quantum phase transition presumably due to interactions between the fermions and bosonic collective modes which become pronounced close to the quantum critical point of the SIT .**
- **Signs for quantum criticality**