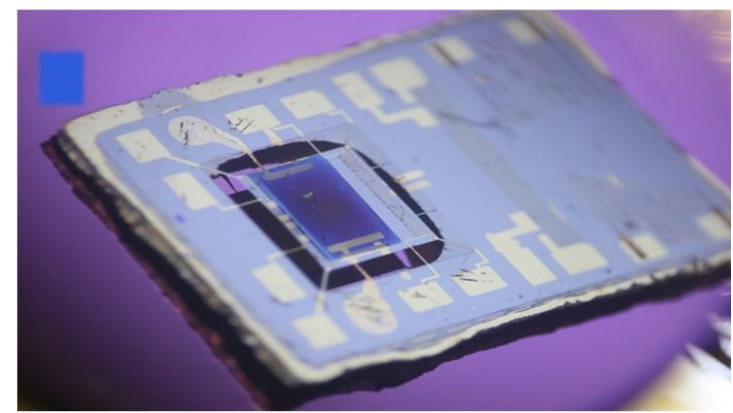


# Specific Heat Measurements through the Superconductor-Insulator Quantum Phase Transition

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**BIU**  
**Shachaf Poran**



**CNRS, Grenoble**  
**Tuyen Nguyen-Duc**  
**Olivier Bourgeois**

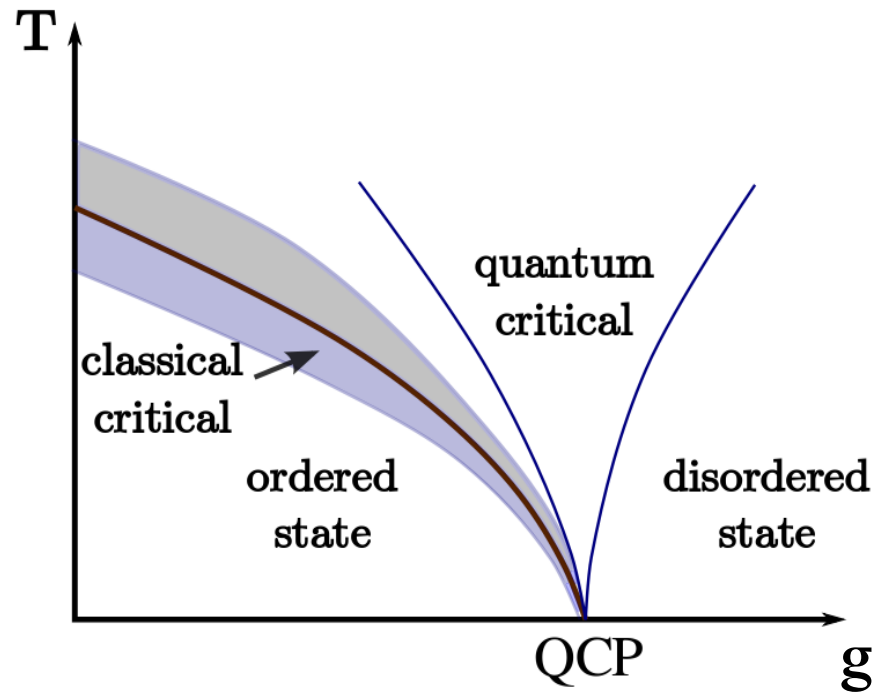


Nature communications, 2017

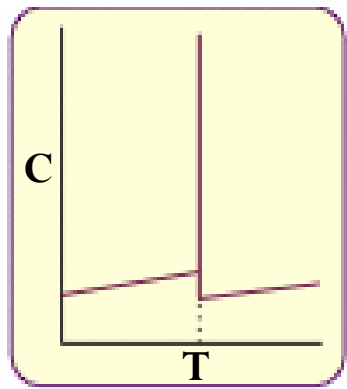
 welcome to the  
European Microkelvin Collaboration

 **lanef**  
Laboratoire  
d'Alliances  
Nanosciences-Energies  
du futur

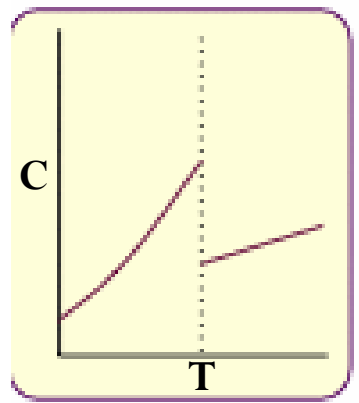
# Phase transitions and Specific heat



1<sup>st</sup> order



2<sup>nd</sup> order

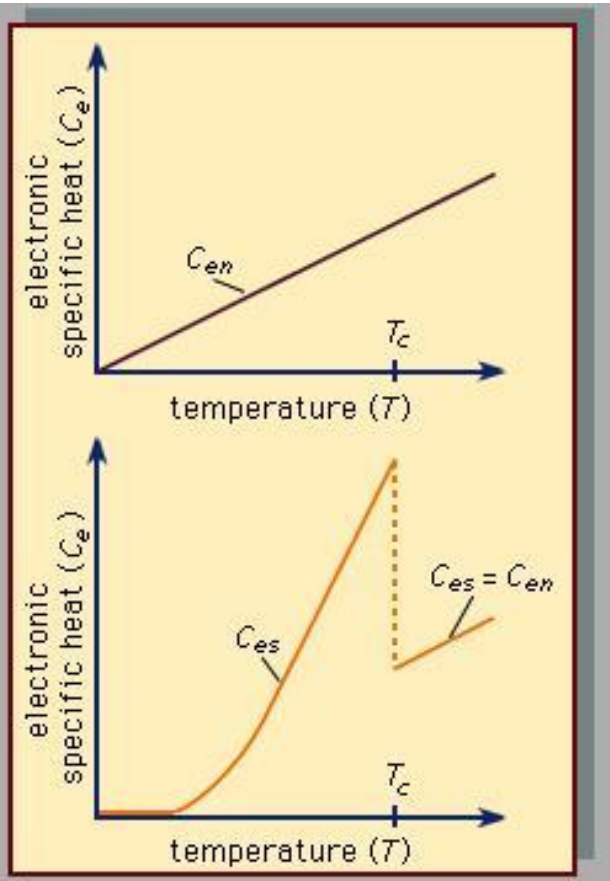


# Specific heat

$$c = \frac{dQ}{dT}$$

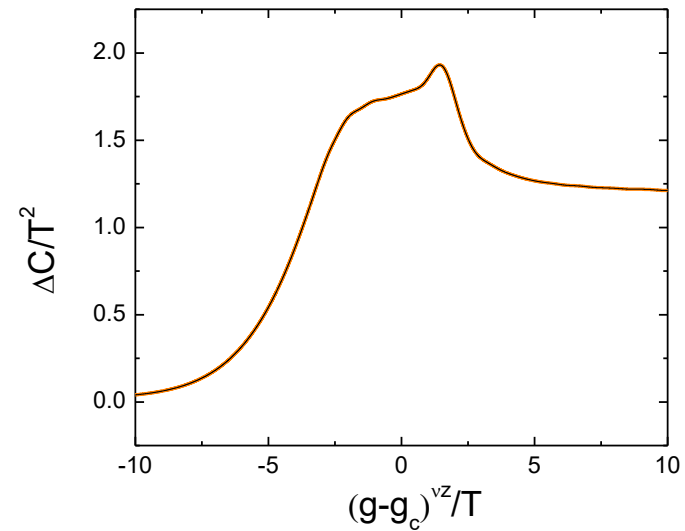
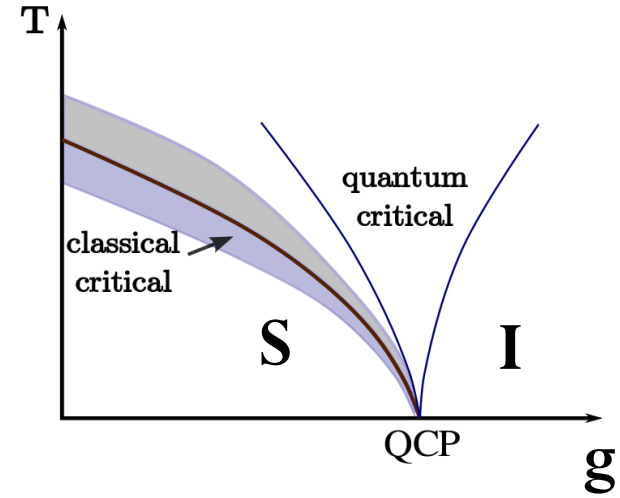
$$C = \frac{dQ}{dT} M$$

$$C_e = \gamma T + \beta T^3$$

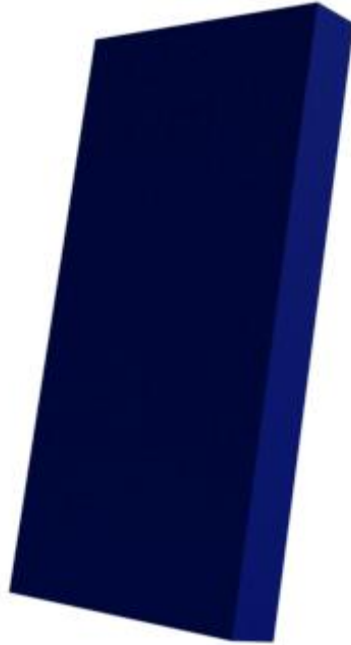


$$\frac{\Delta c}{C_{en}} = \frac{14.1}{\pi^2}$$

$$c_s(T) \simeq 10\gamma_n T_c \exp\left(-1.76 \frac{T_c}{T}\right)$$



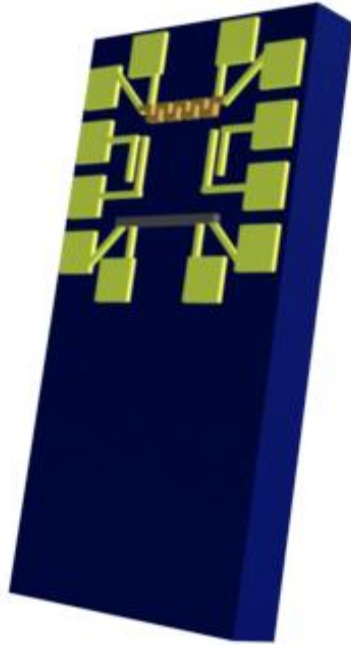
# Calorimeter fabrication



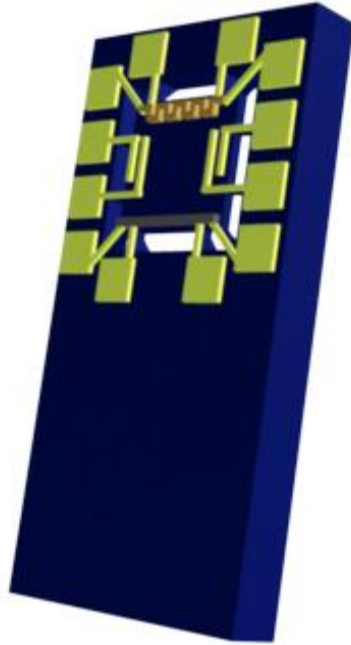
# Calorimeter fabrication



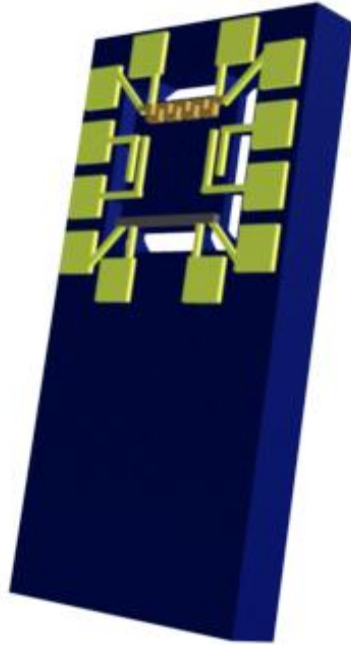
# Calorimeter fabrication



# Calorimeter fabrication

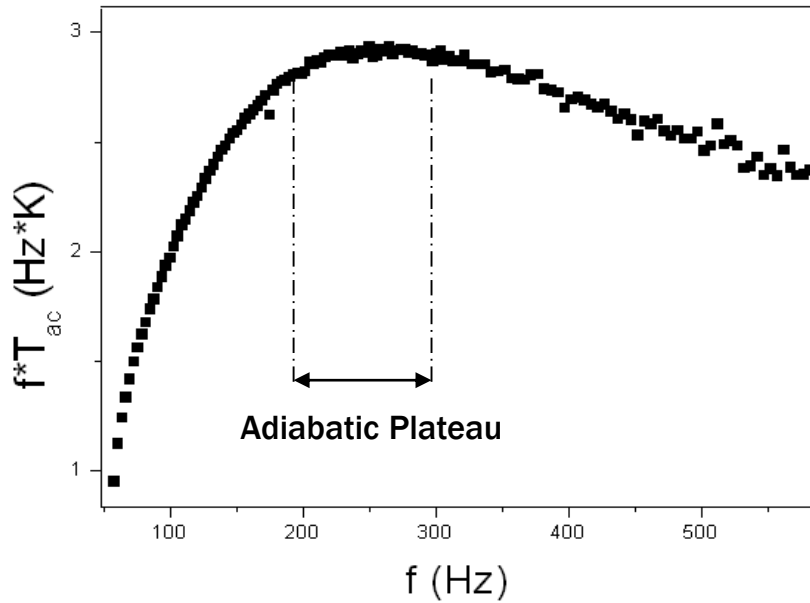


# Calorimeter fabrication

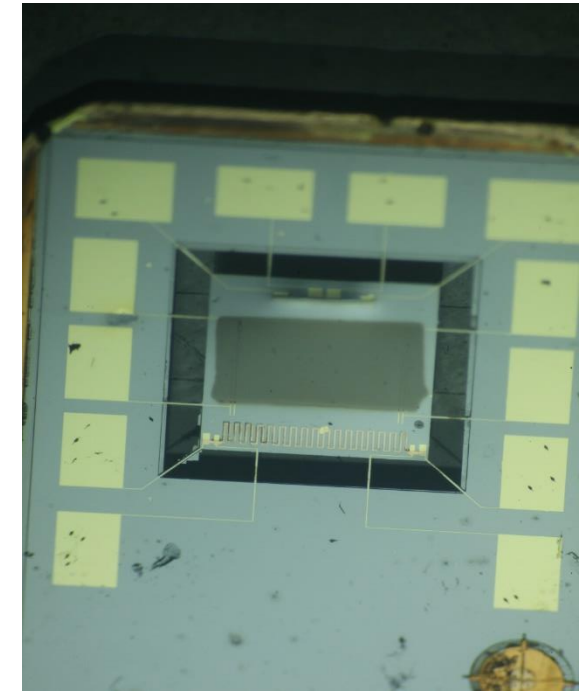
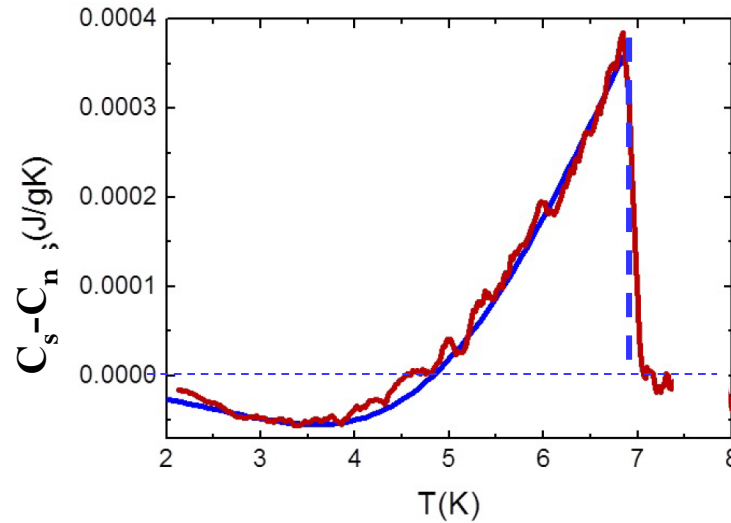




# Calorimeter



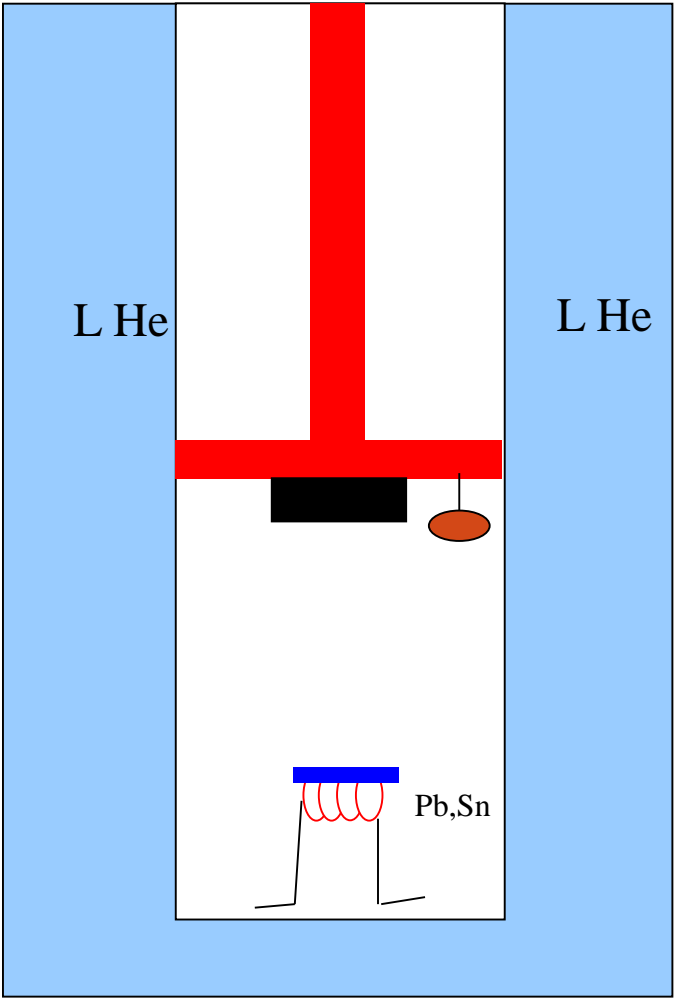
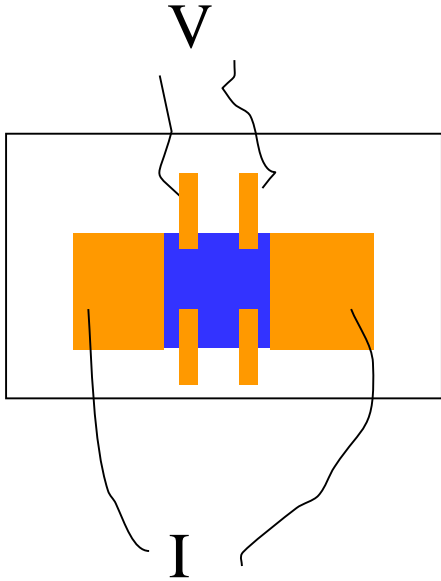
$$\tau_{diffusion}^{-1} \gg \omega \gg \tau_{bath}^{-1}$$



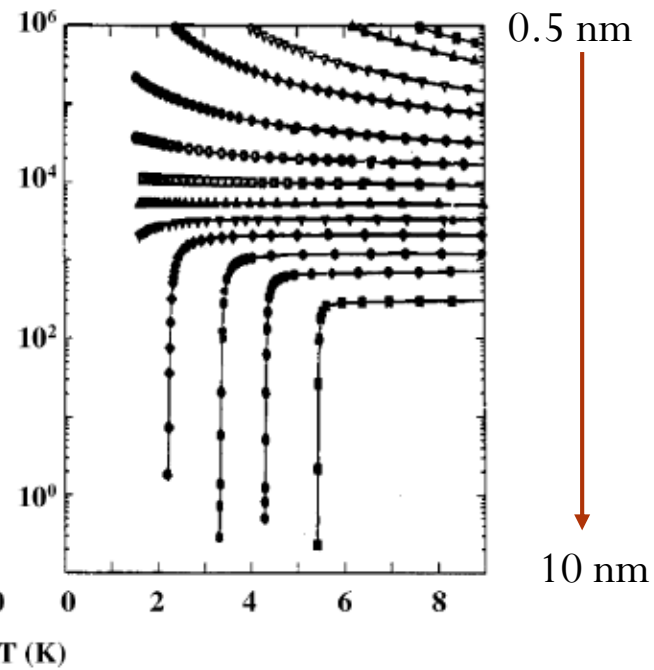
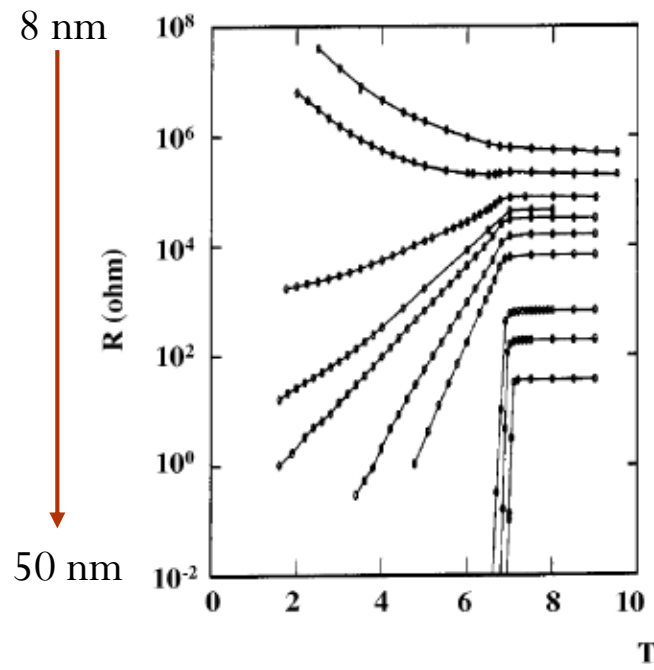
$$C \approx \frac{P_0}{f * \Delta T_{ac}}$$

- ac current applied at frequency  $f$
- Oscillation of temperature measured by the thermometer at  $2f$

# Quench condensation



# Quench condensed metallic films



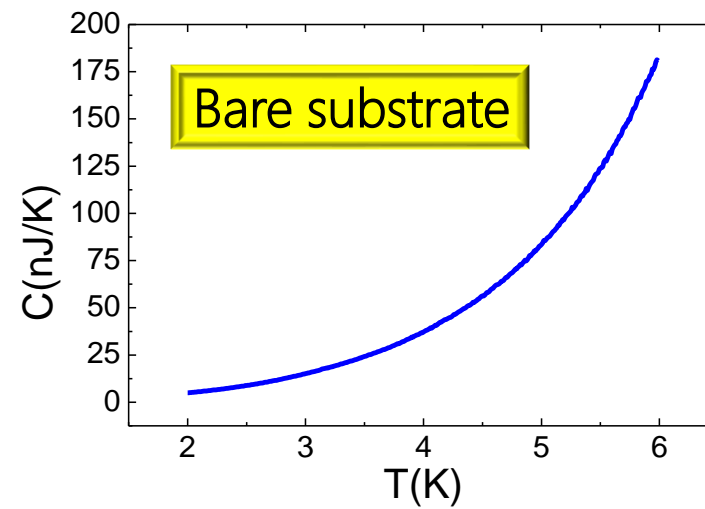
Bosonic

Fisher et al 1989

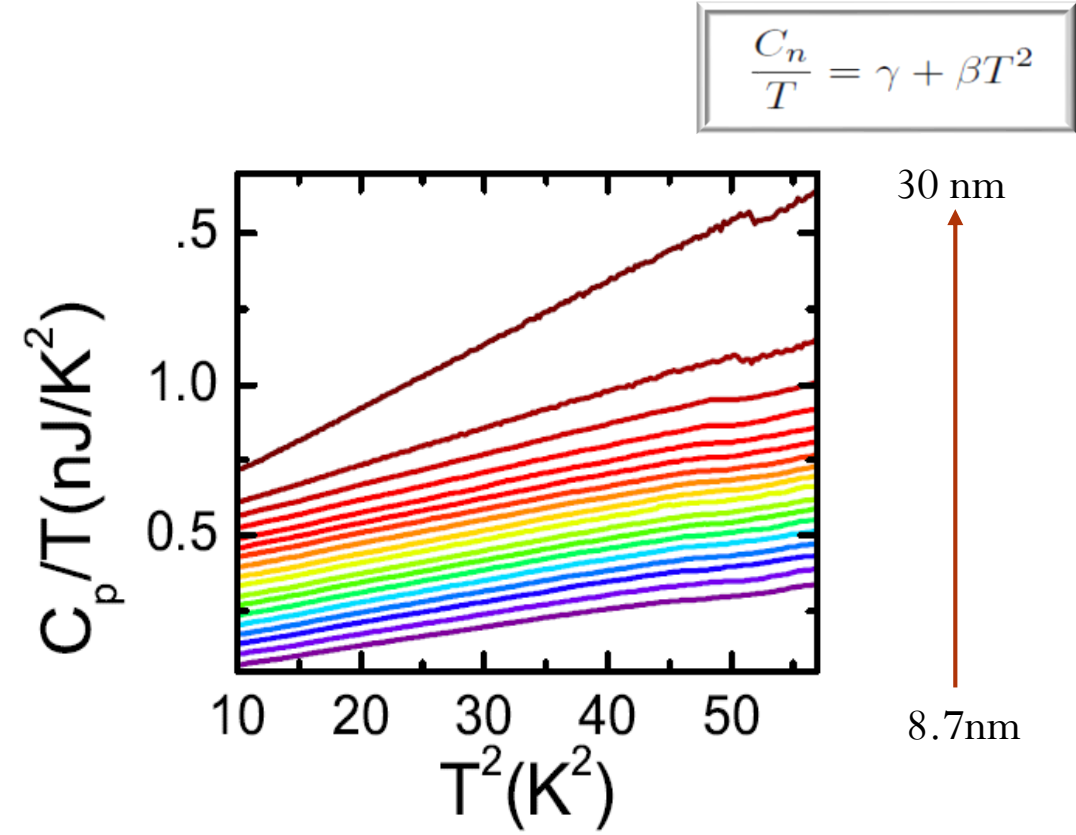
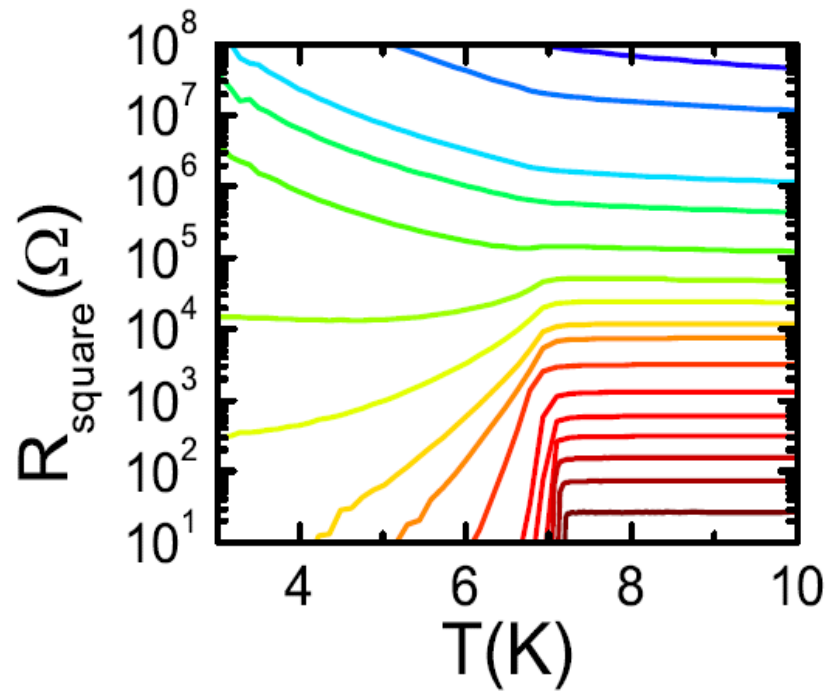
Fermionic

Finkelstein 1989

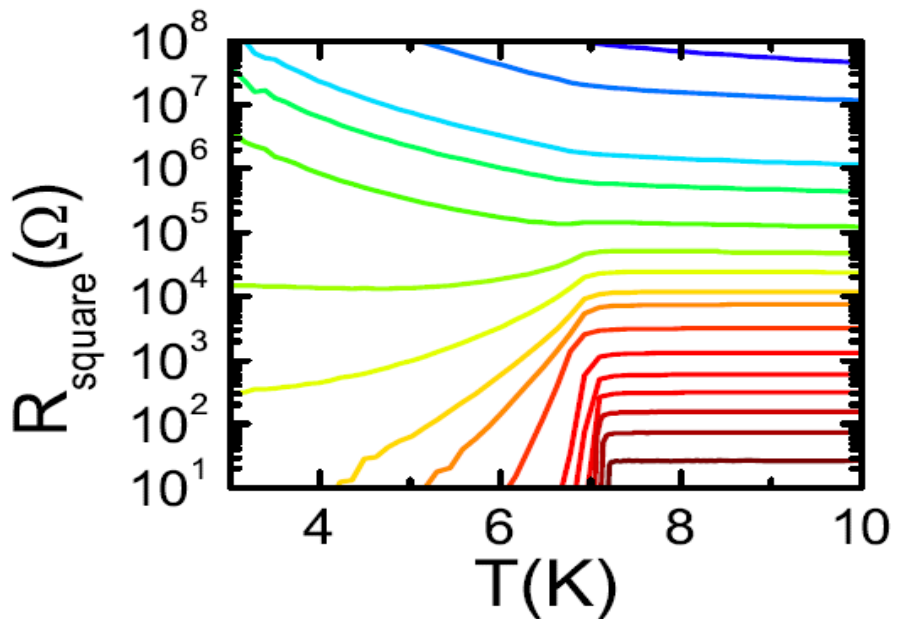
# Quench condensation set-up



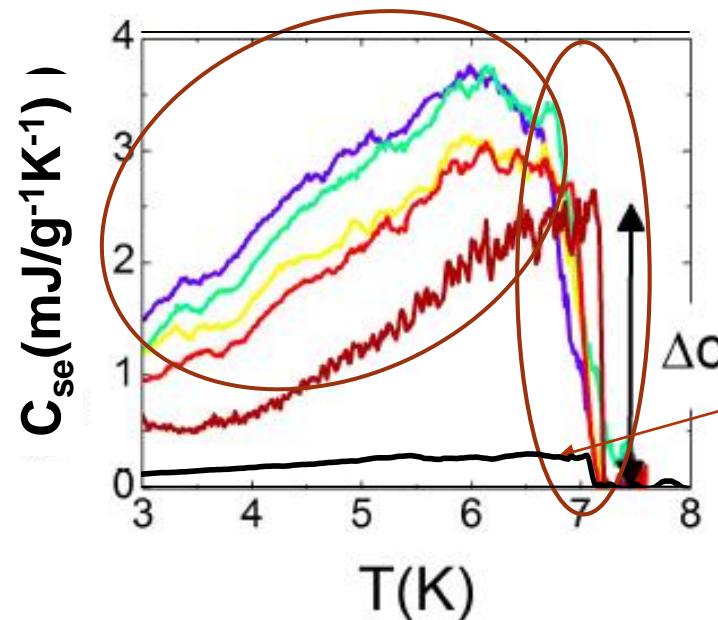
# Resistance and heat capacity



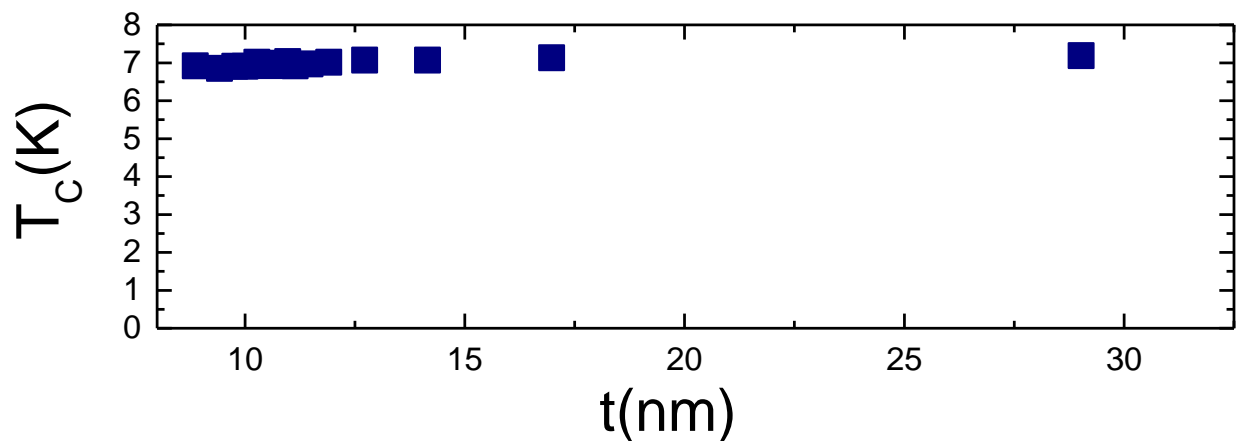
# Specific heat close to the QCP



$$C_{se}(T) = C_{total}(T) - C_n(T)$$

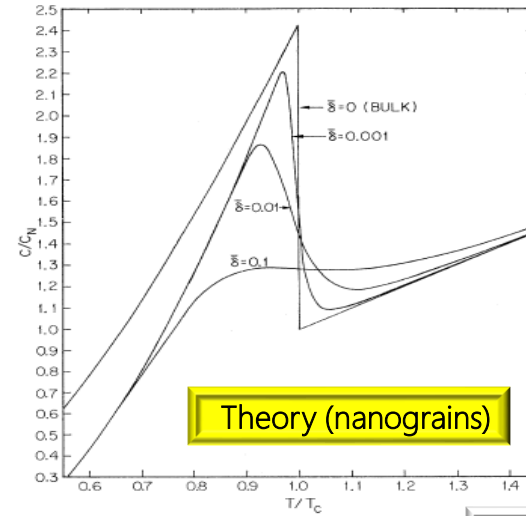
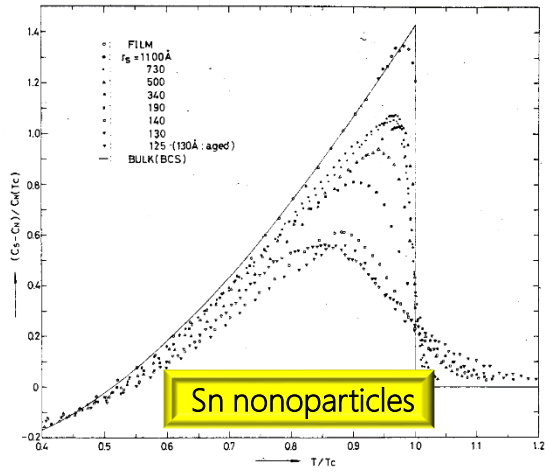


bulk  
 $C_{\text{bulk}} = 0.3 \text{ mJ/gK}$

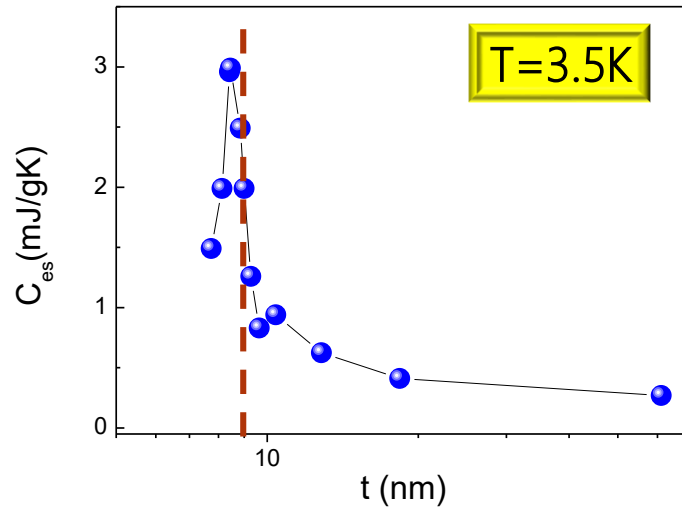


$$T_{mf} \neq T_{\Phi}$$

# Specific heat of small particles

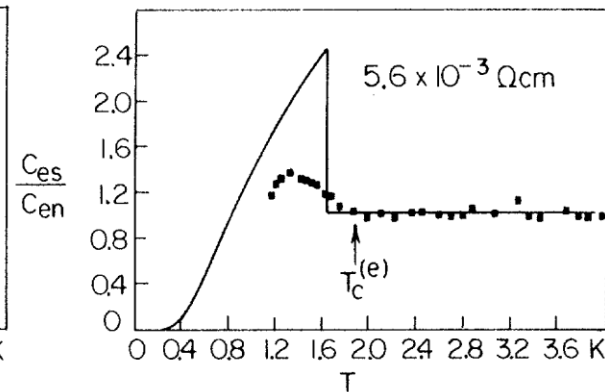
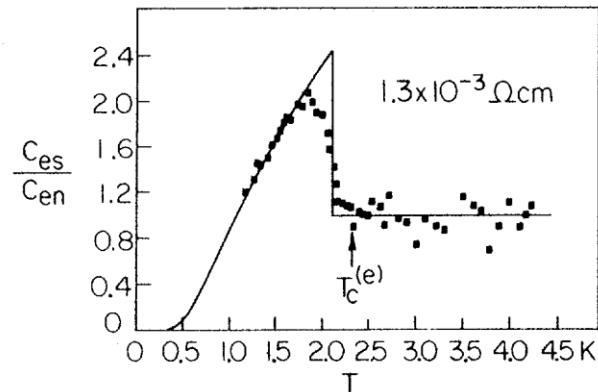
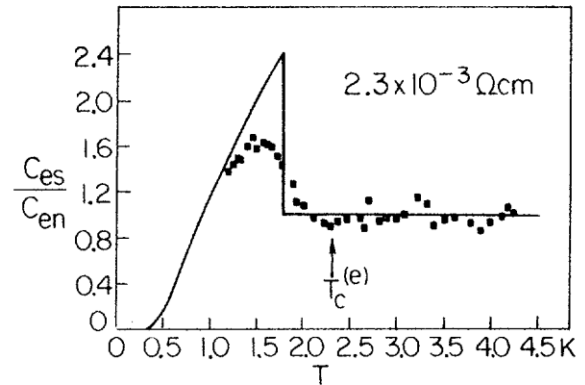
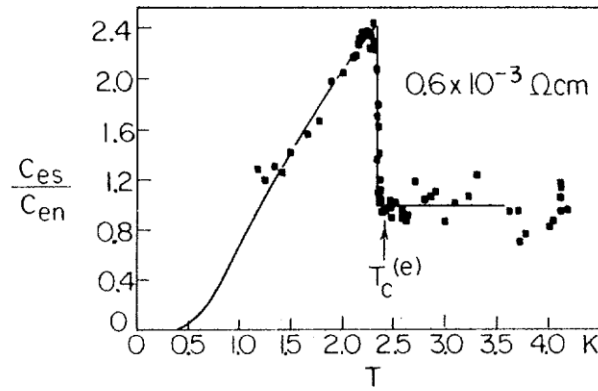


Muhlschlegel *et al.* 1972



# Thick granular aluminium

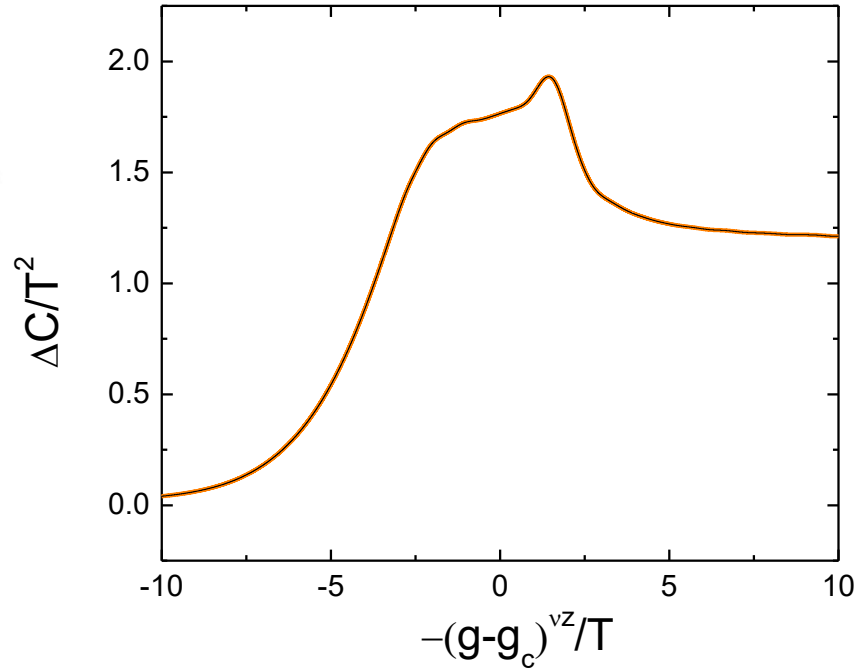
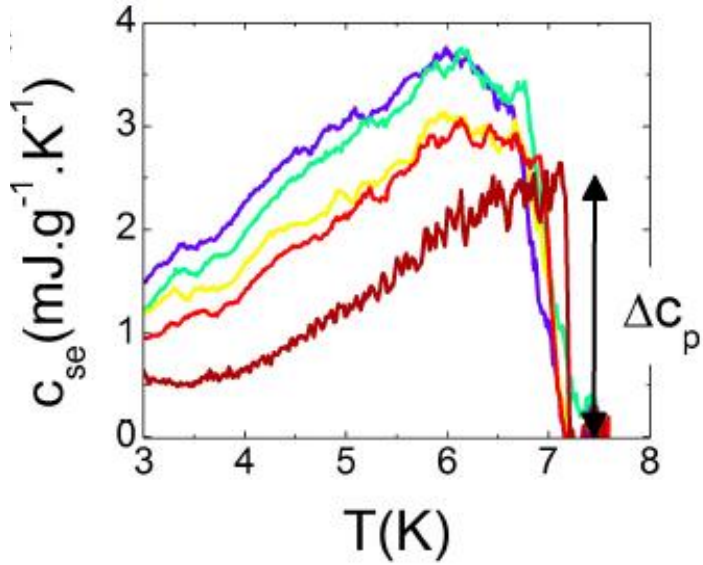
- Oxidized aluminum
- 10 $\mu\text{m}$  thick
- Disappearance of superconductivity



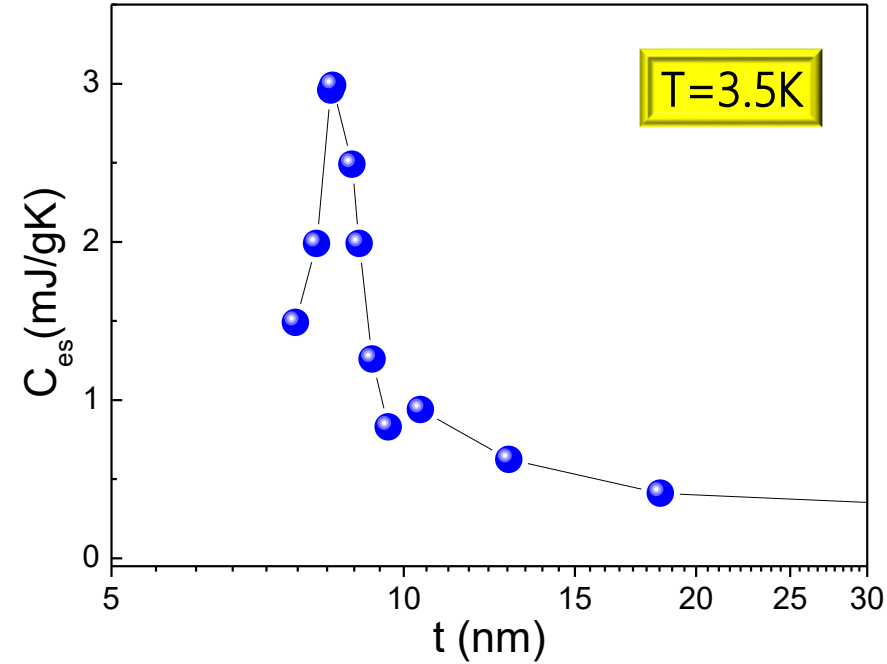
Worthington, Lindenfeld, Deutscher, PRL 41, 316 (1978)



# Quantum fluctuation contribution to $C_p$



Nicolas Dupius



$$C^{\text{boson}} \sim \#\text{grains} \cdot k_B$$

$$C^{\text{fermion}} \sim \#\text{pairs} \cdot k_B$$

# Fermionic origin of excess specific heat

Bulk superconductors

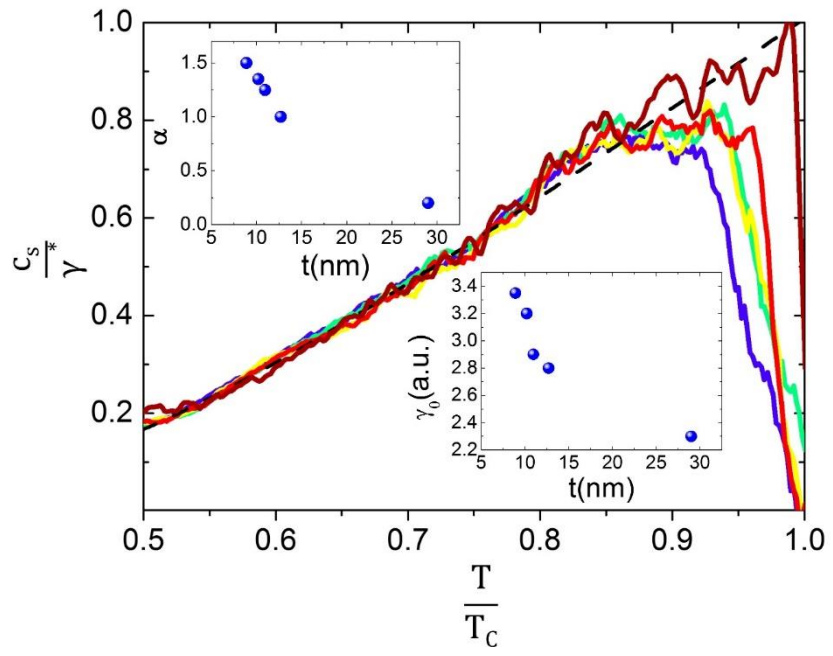
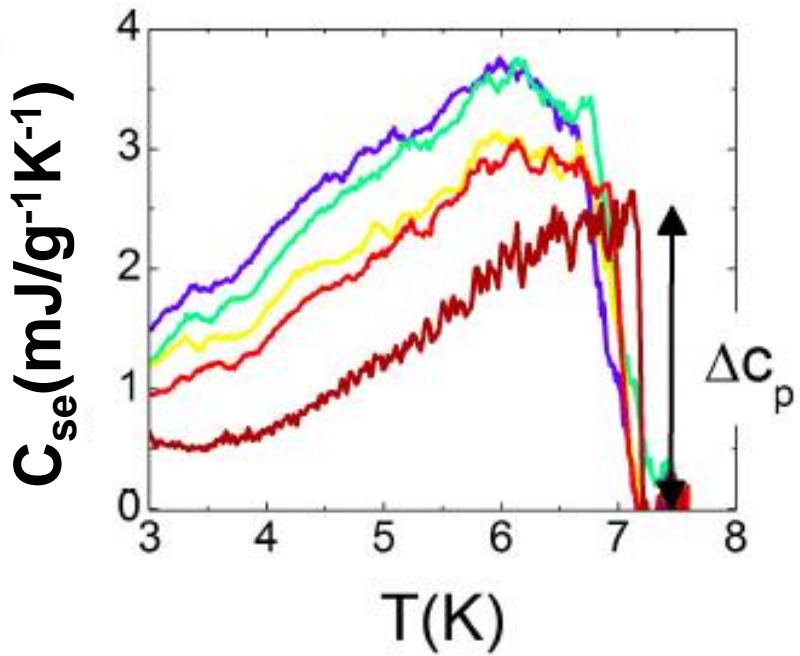
$$c_s(T) \simeq 10\gamma_n T_c \exp\left(-1.76 \frac{T_c}{T}\right)$$

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

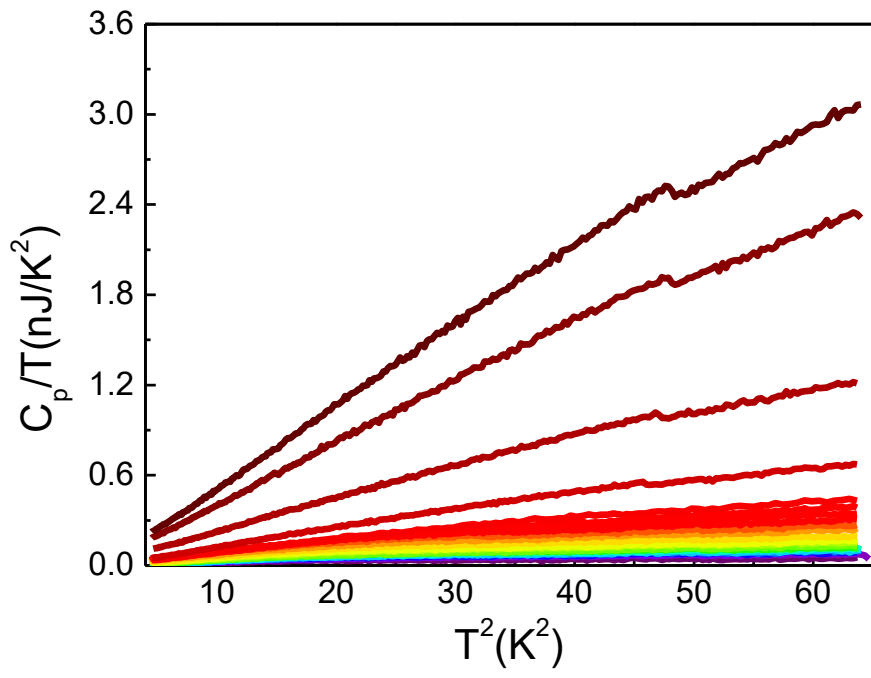
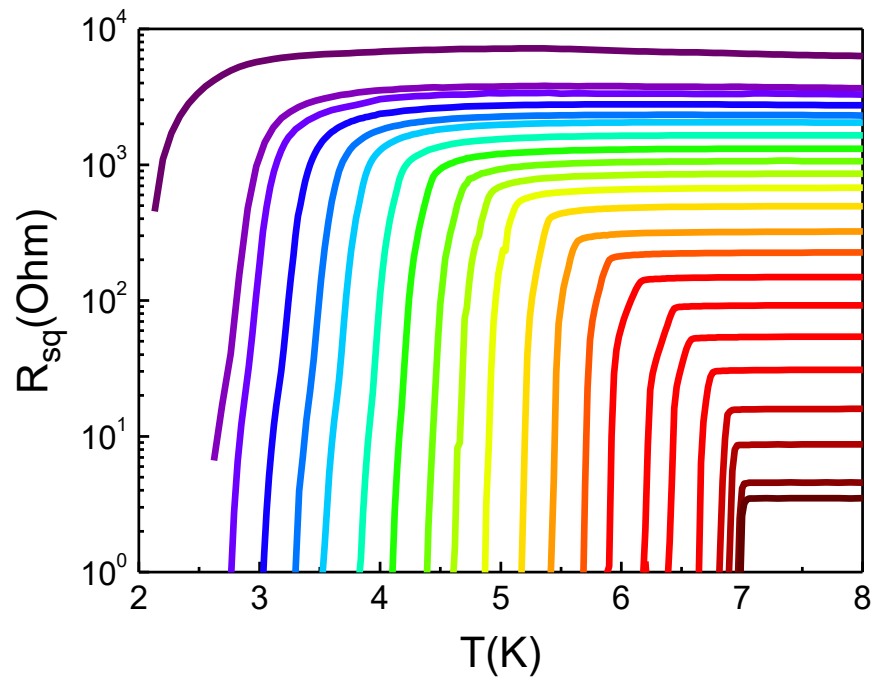
Close to a QPT

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

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

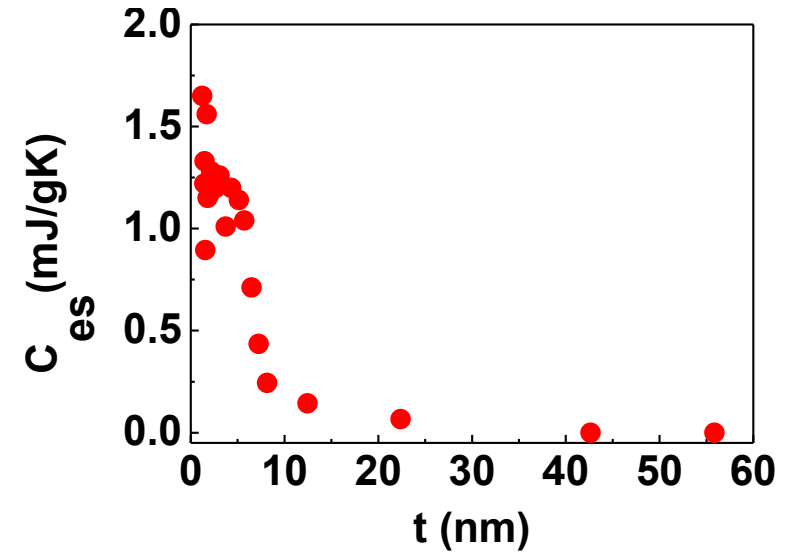
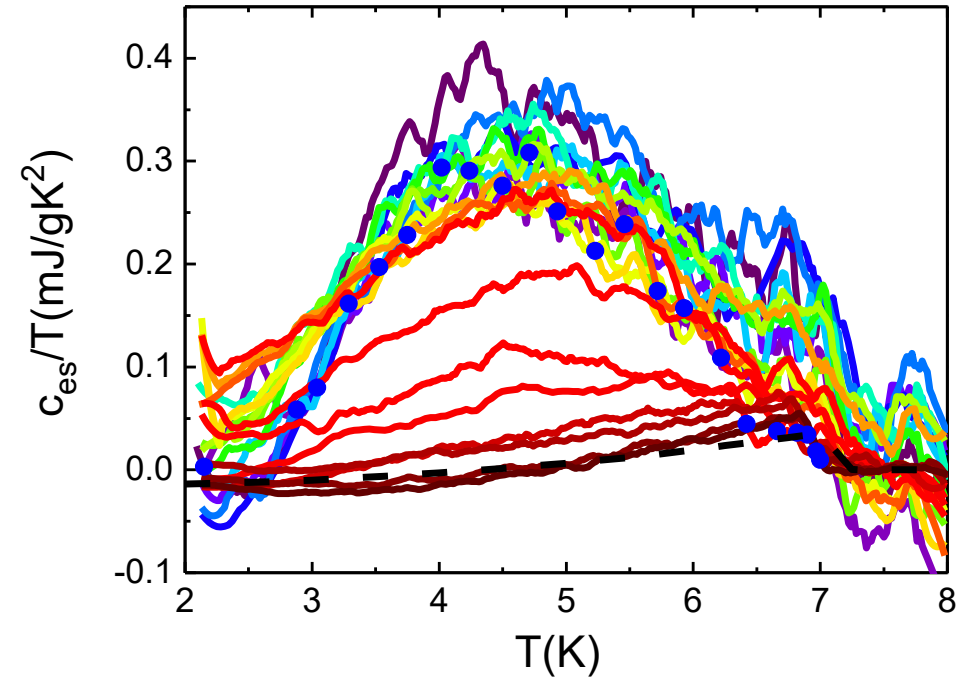
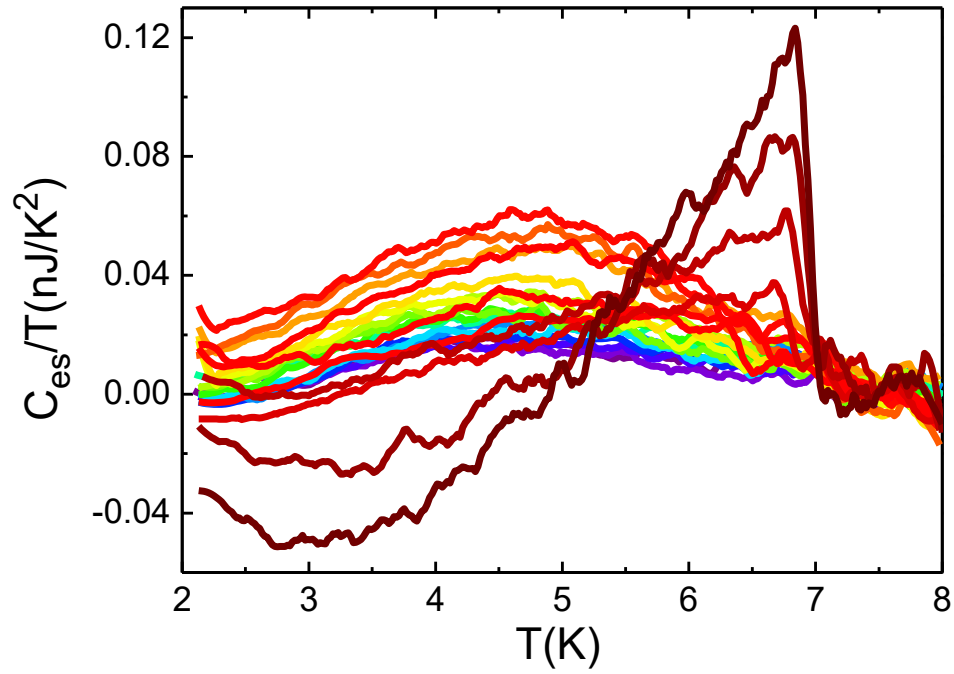


# Cp measurements of ultrathin continuous films

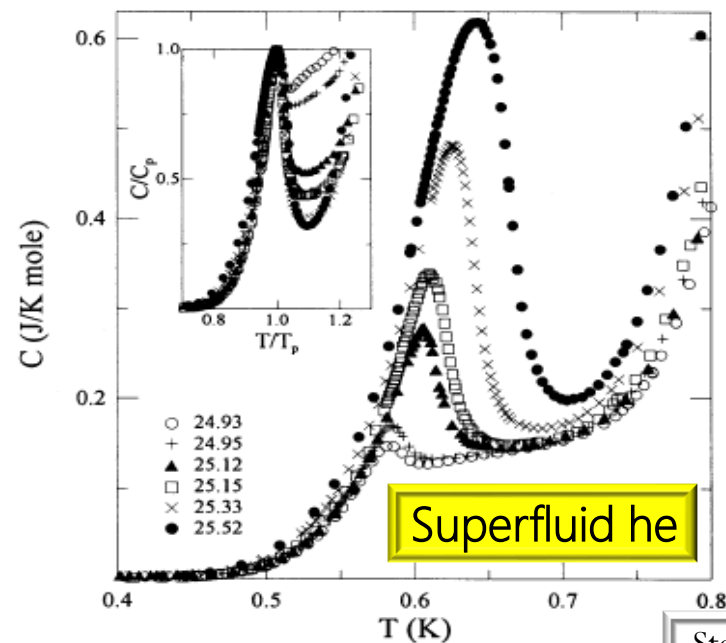
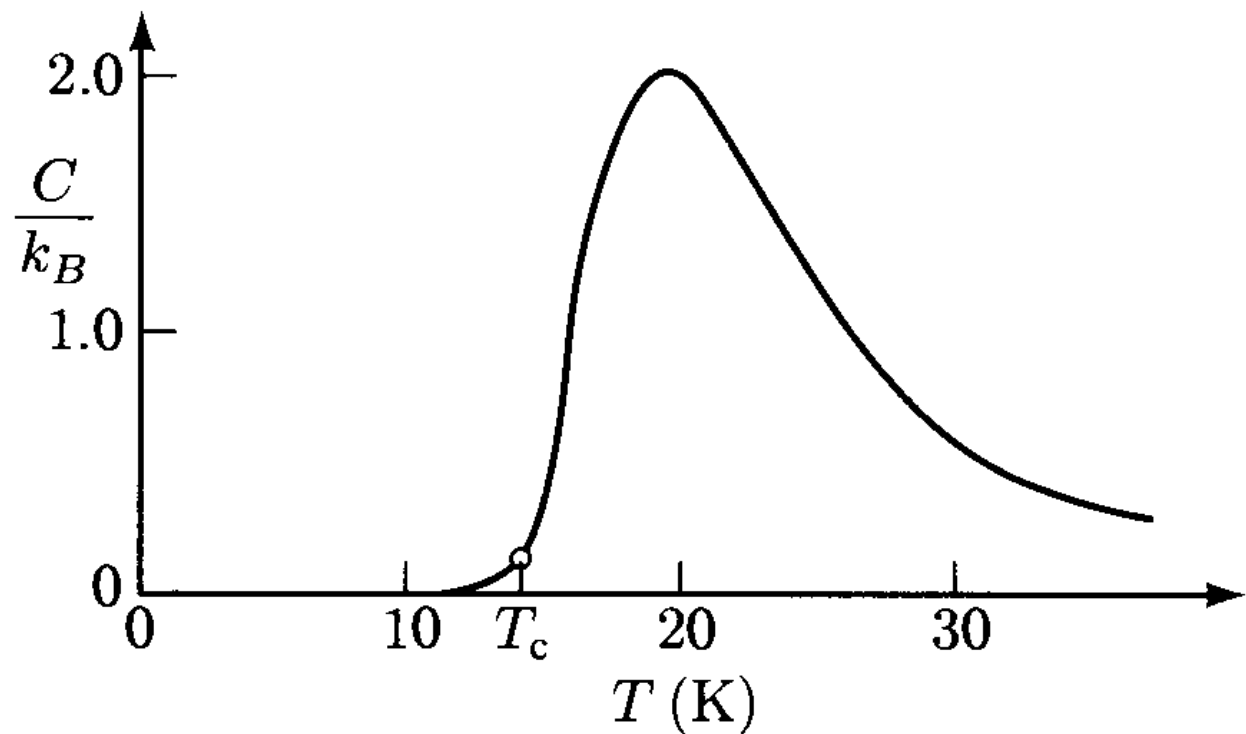


55 nm  
↑  
1.1 nm

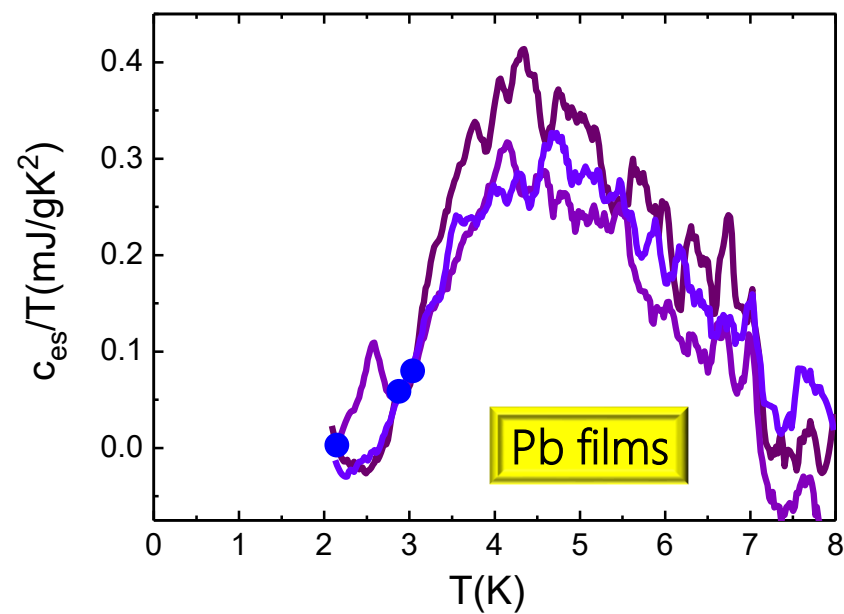
# Specific heat of continuous films



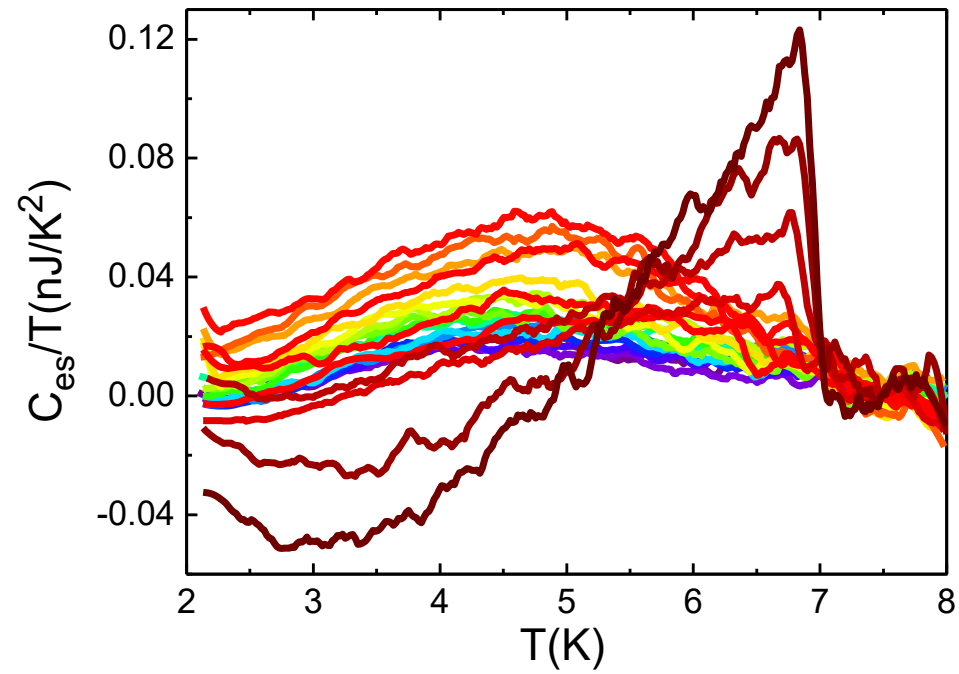
# BKT physics



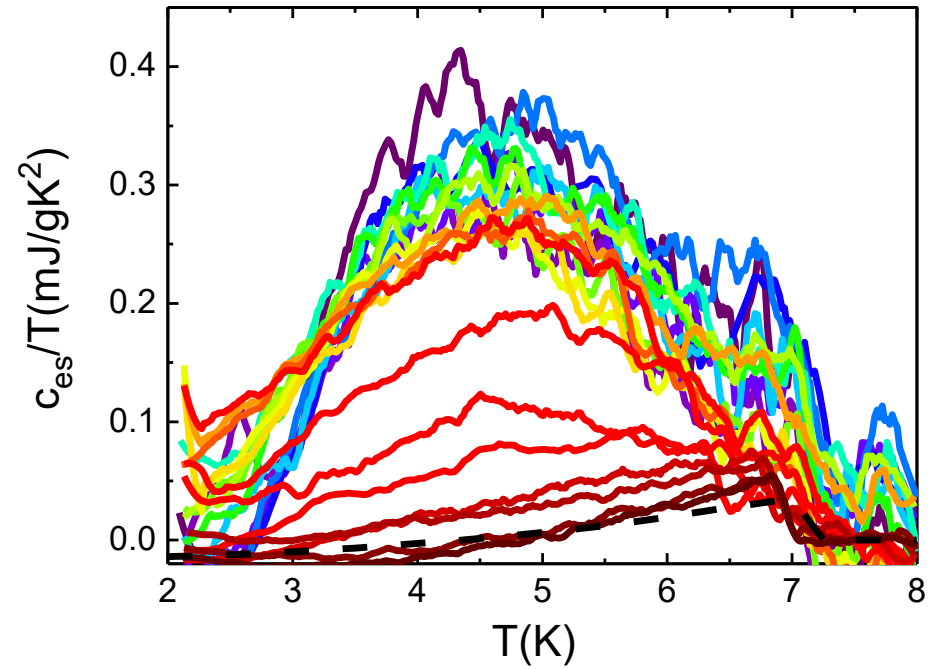
Steel *et al.* 1993



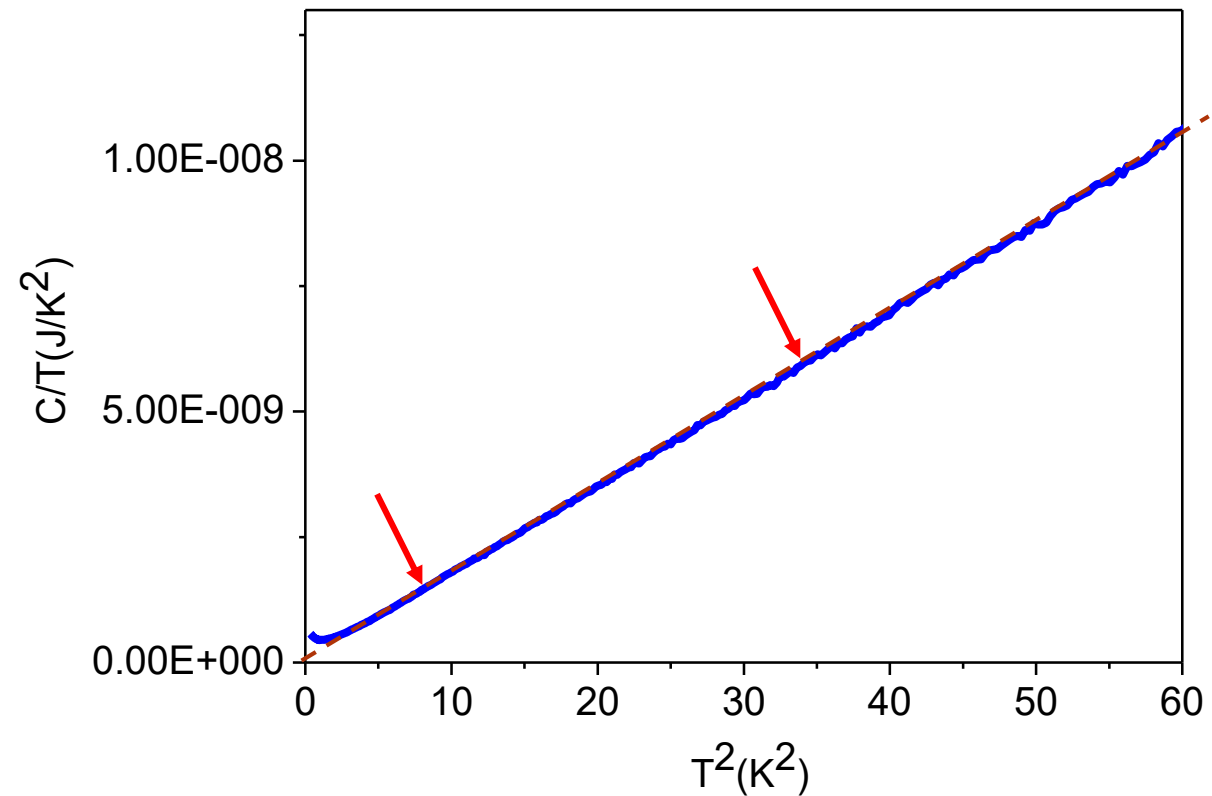
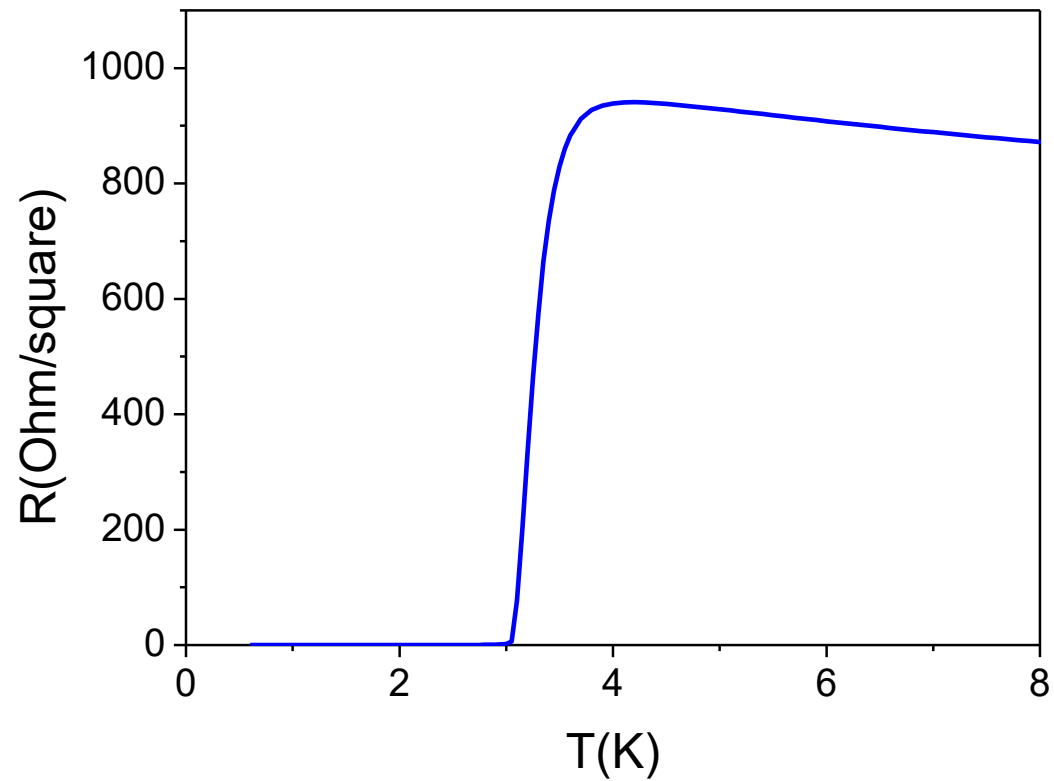
## 2D physics



## 3D physics

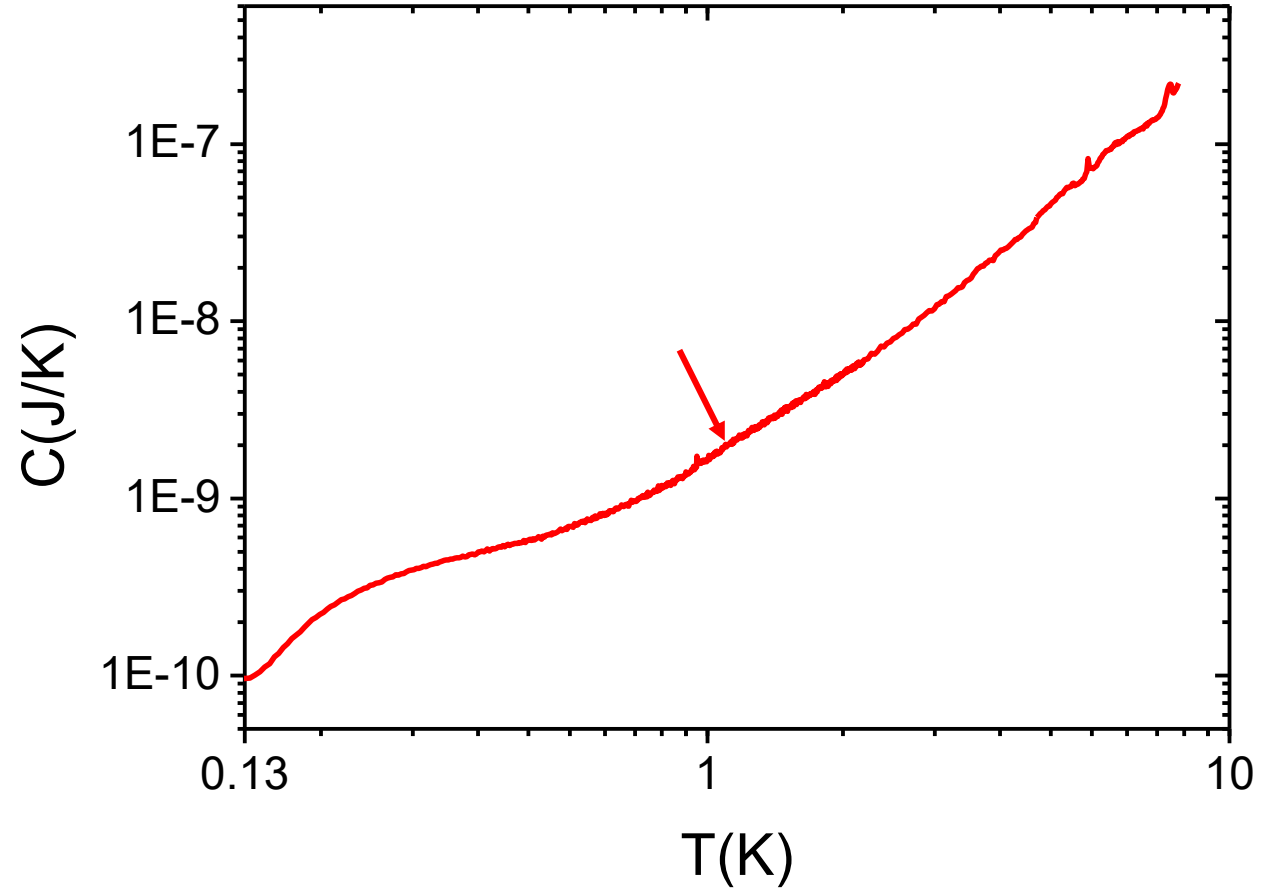
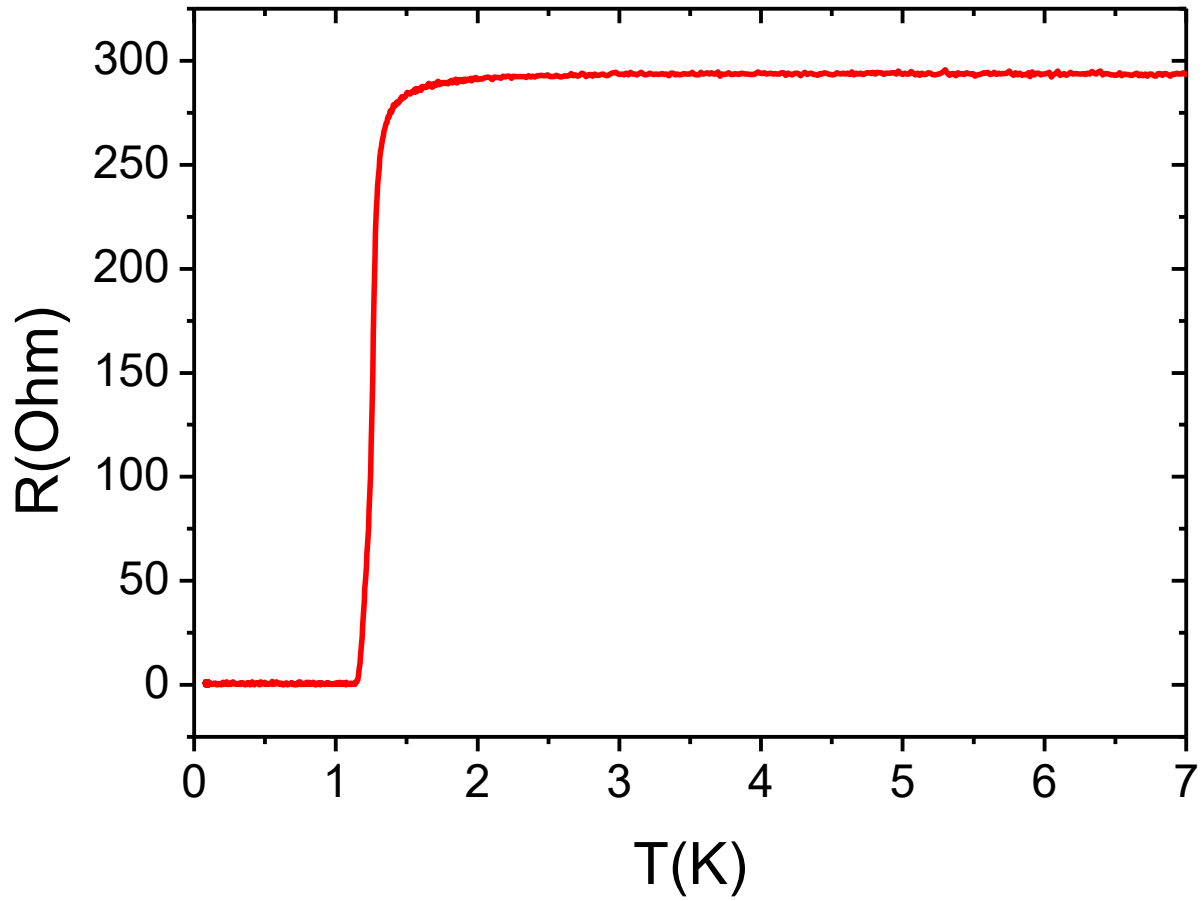


# Indium Oxide



NbSi

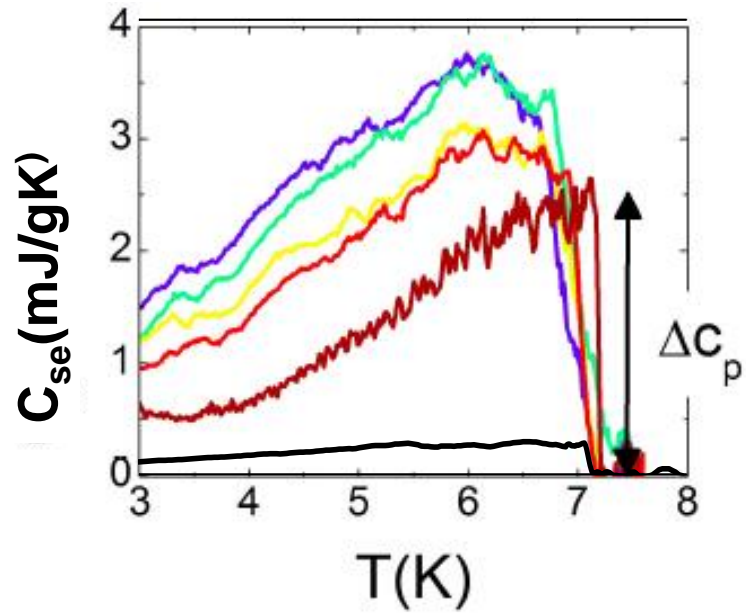
*with*  
**Claire Marrache Kikuchi**



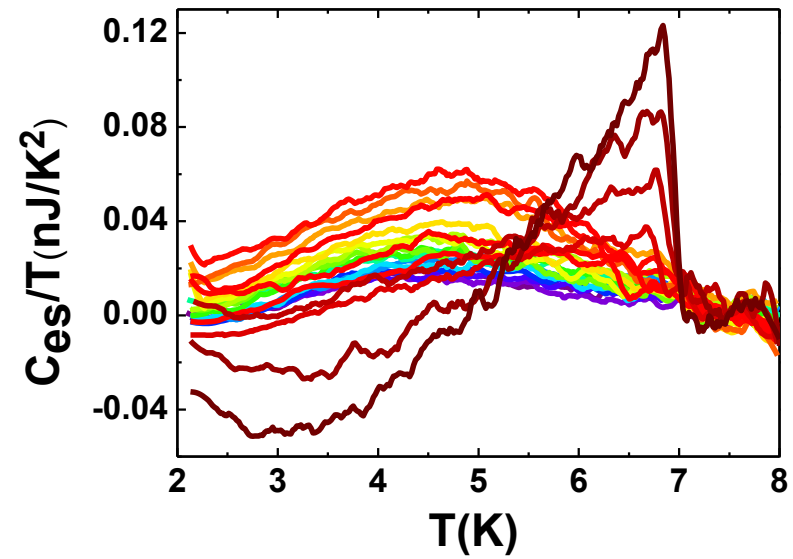


# Summary

## Granular PB



## Uniform Pb



## NbSi

