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Title: Coexisting first- and second order electronic phase transitions in a correlated oxide

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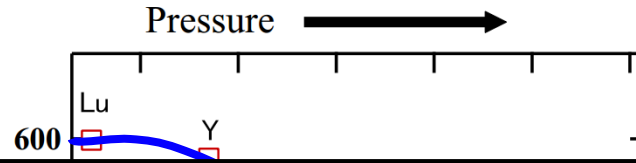
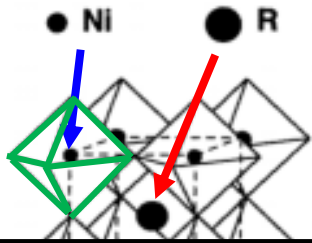
Coexisting first- and second- order electronic phase transitions in a correlated oxide

Kirk Post

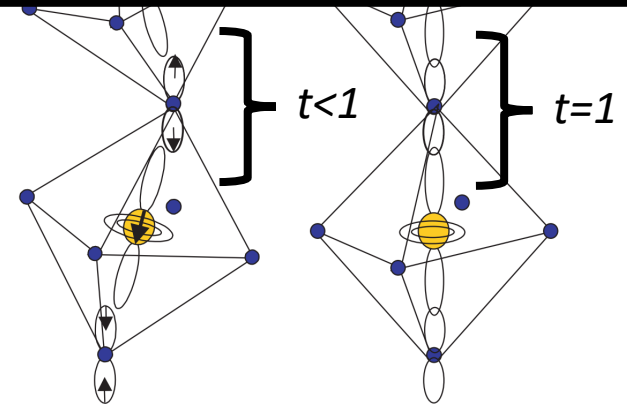
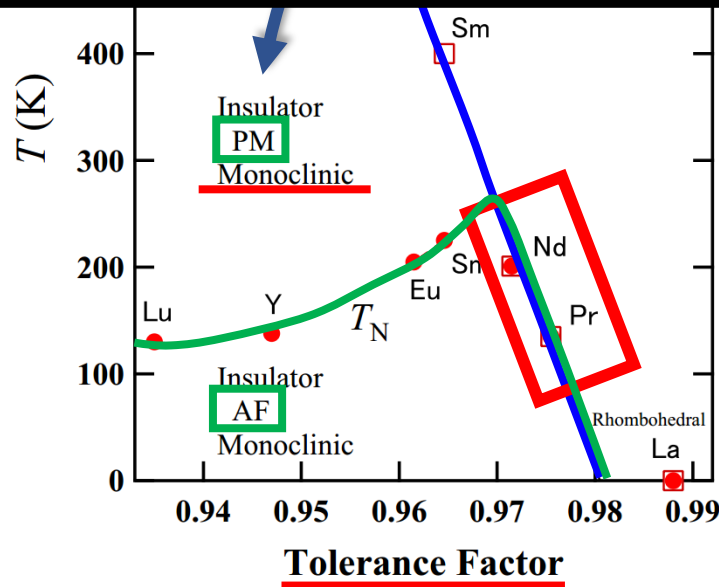
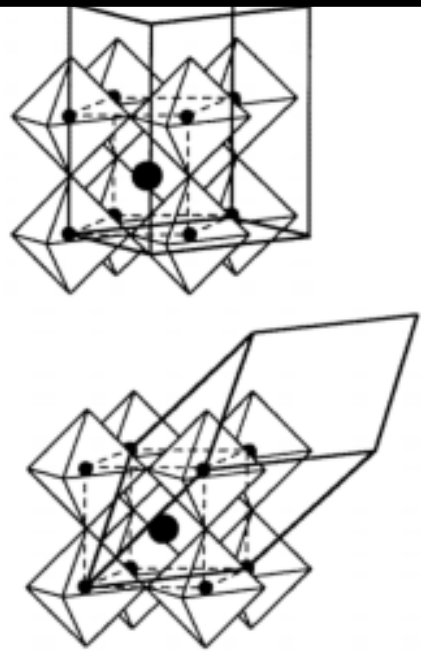
APS March Meeting

March 9, 2018

Nickelates

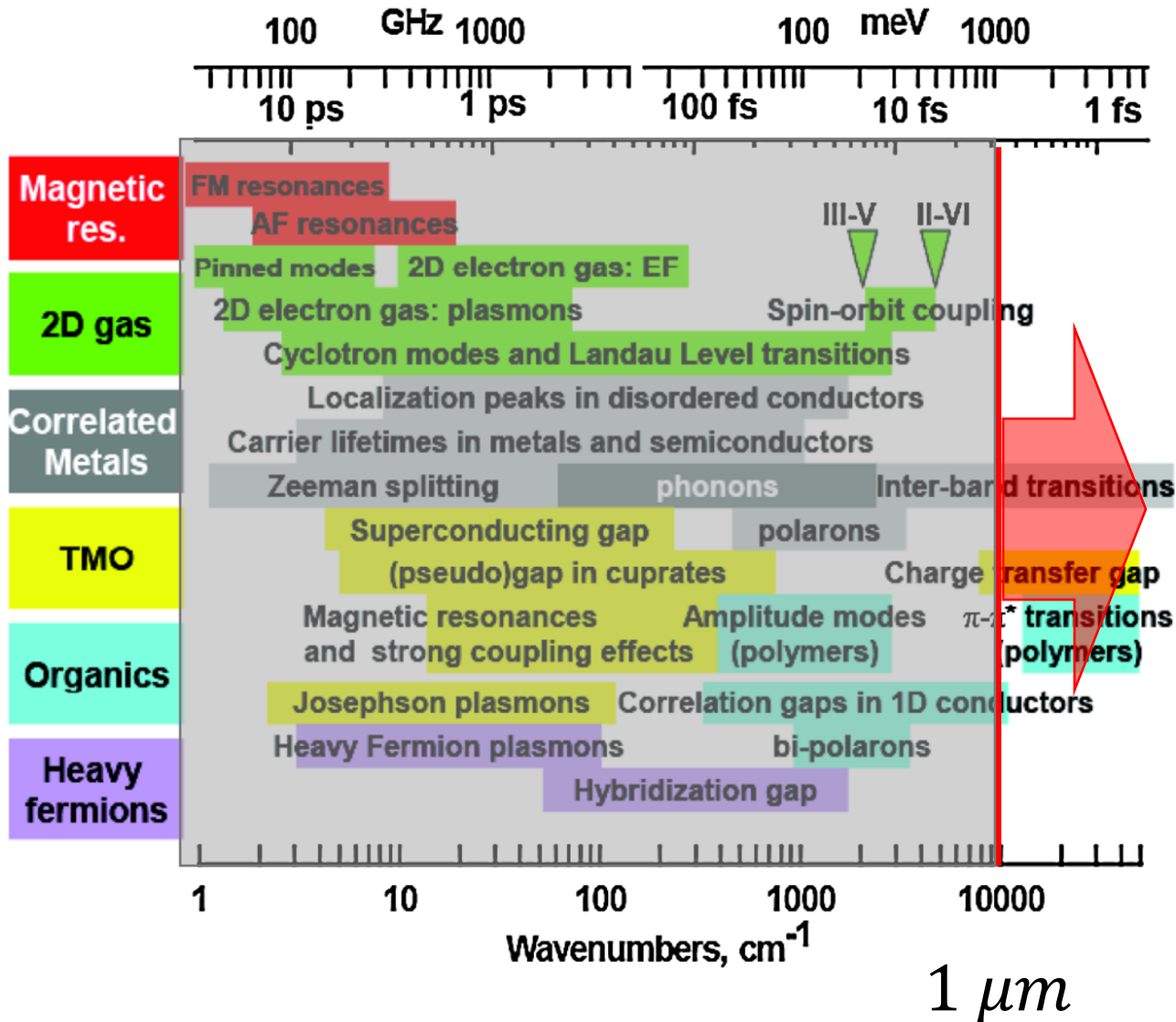


Local information may help disentangle relevant degrees of freedom to metal insulator transition, *e.g.* structural or electronic



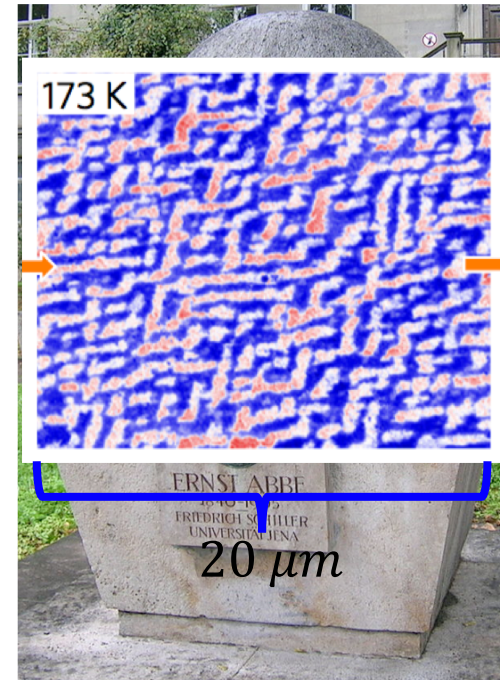
- Hisao Kobayashi, *et. al.*, Phys. Rev. B. **91**, 195148 (2015)
 M.L. Medarde, J. Phys: Cond. Matt **9**, 1679 (1997)
 G. Catalan, Phase Transitions, **81**, 729 (2008)

Infrared Excitations

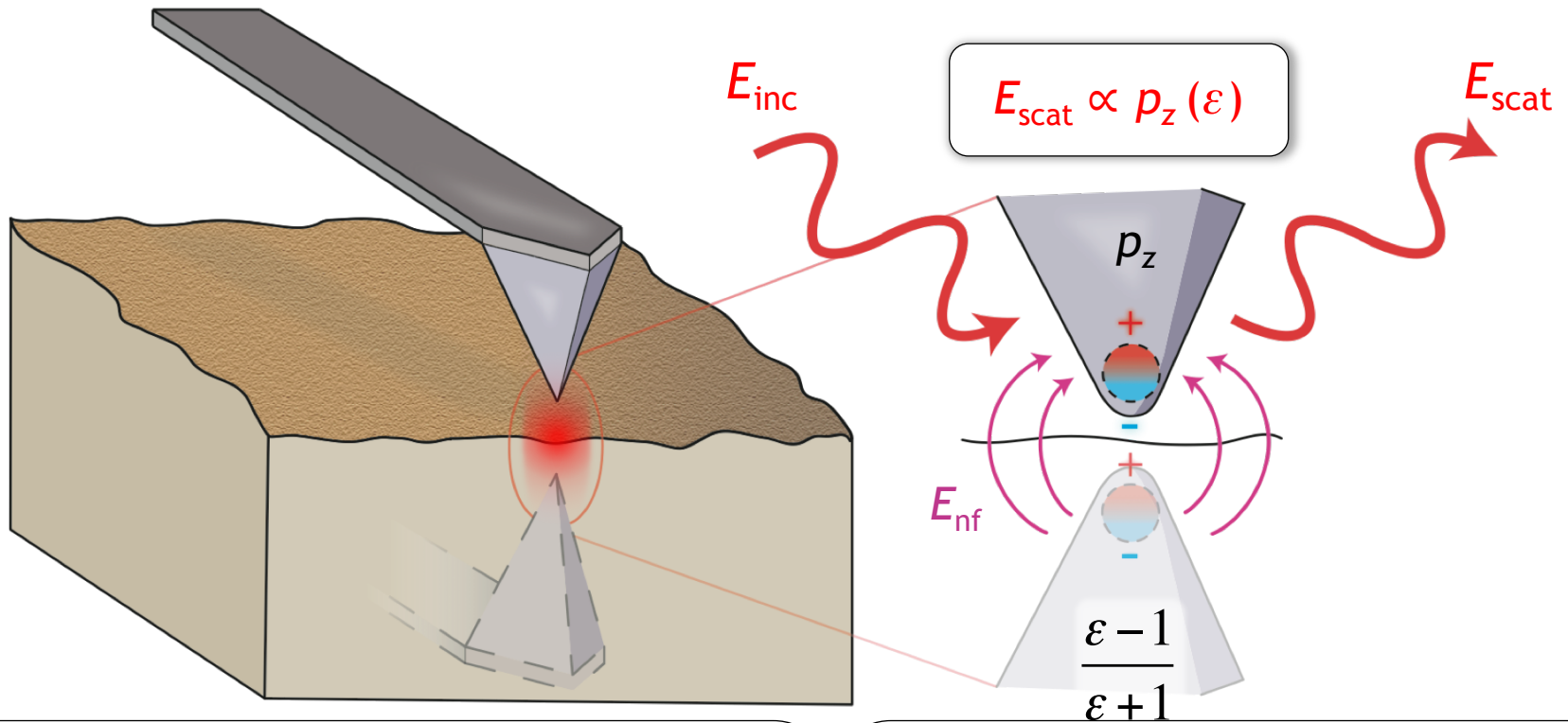


Diffraction limited

$$d = \frac{\lambda}{2n \sin(\theta)}$$



Achieving High Resolution

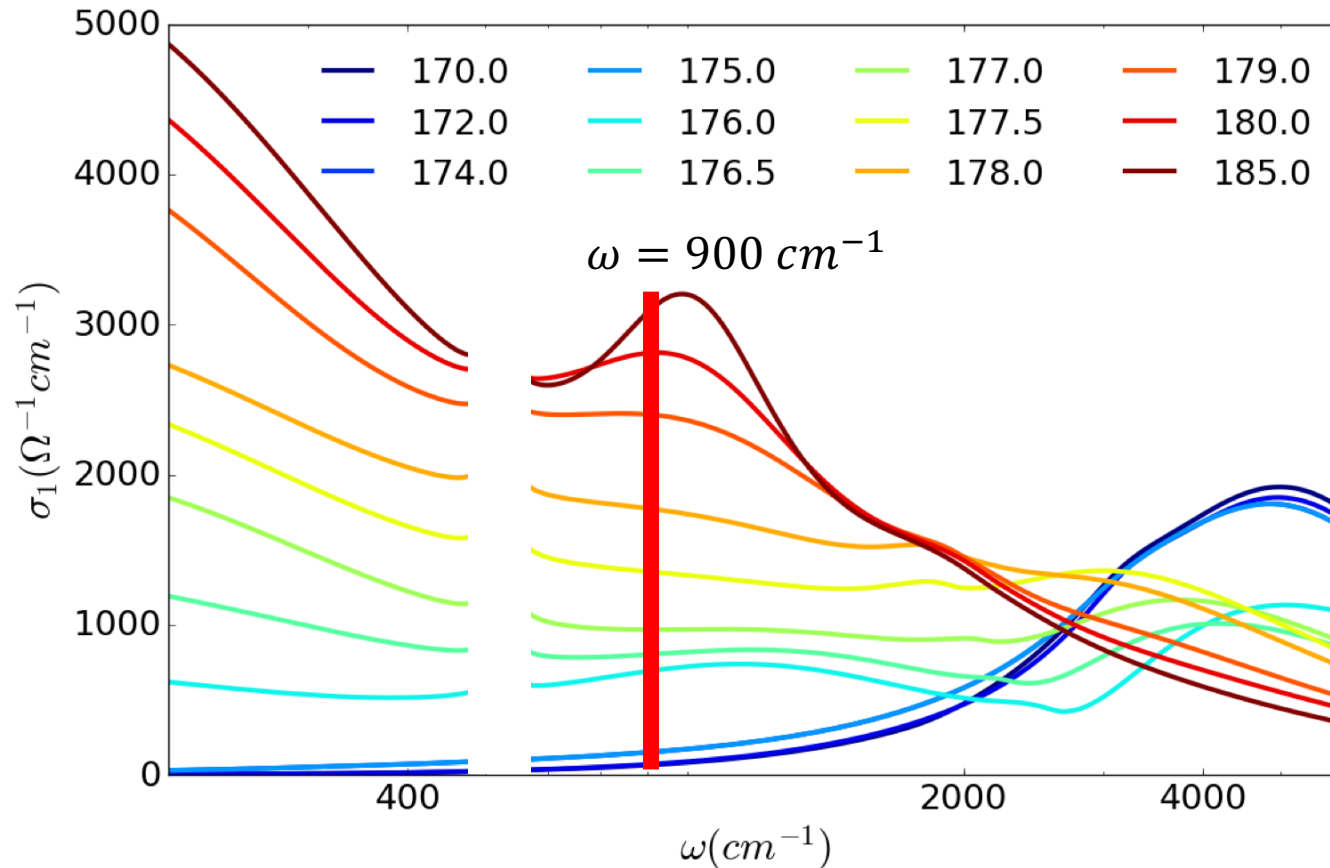


- Illumination of metallized AFM probe induces local **near-field interaction**
- E_{scat} encodes local sample permittivity ϵ, σ at 20 nm resolution (\approx radius of tip)

- Detecting E_{scat} while scanning sample enables sub-diffraction optical contrast

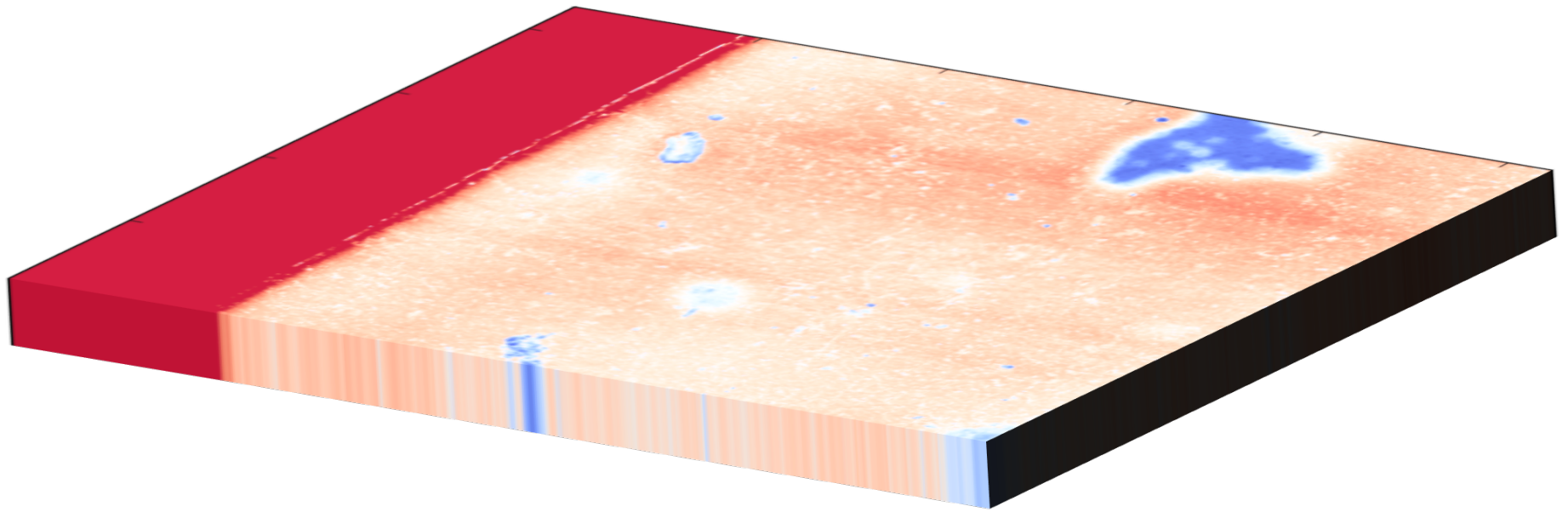
Nickelates

$S^{\text{SNOM}} \sim \sigma(\omega) \Rightarrow$ Measurements are guided by $\sigma(\omega)$



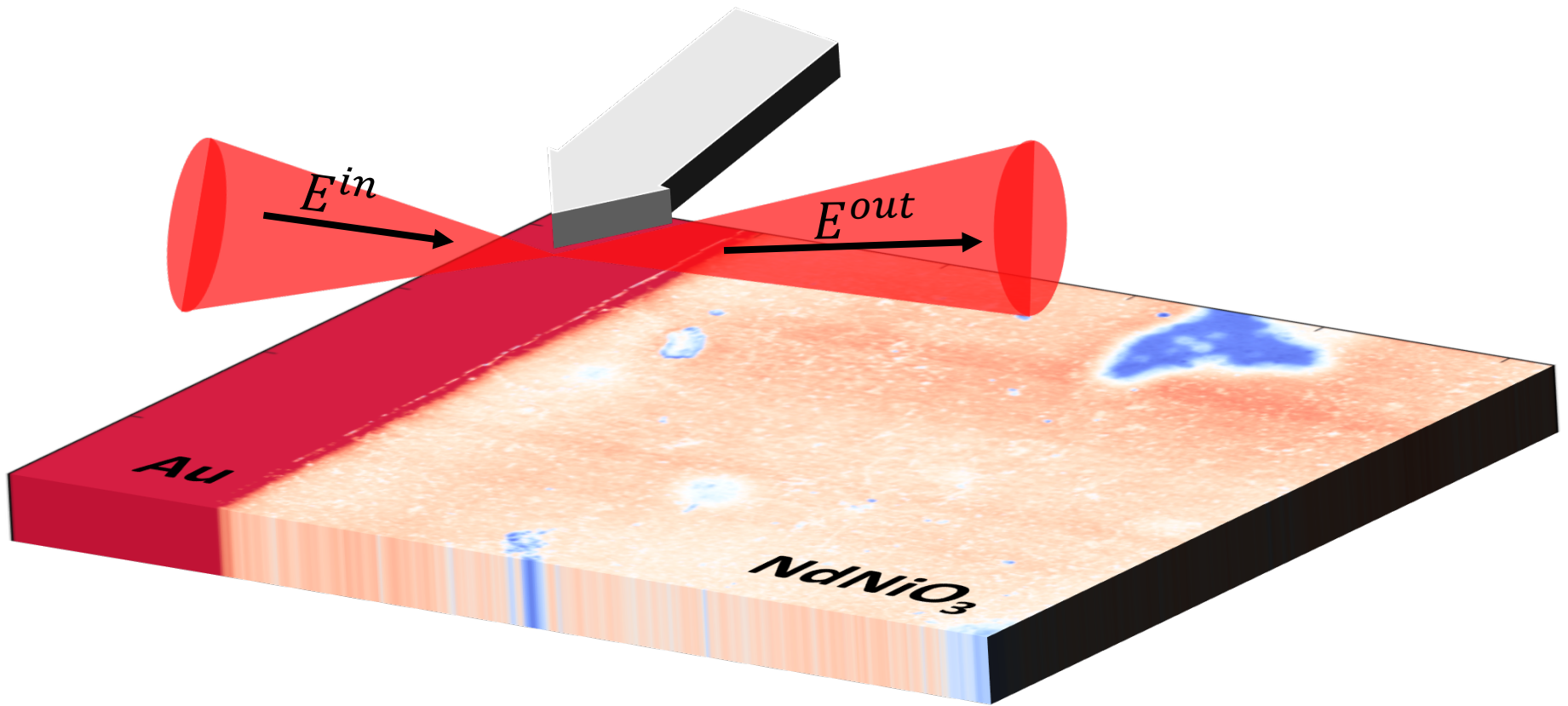
Percolative MIT in NdNiO_3

Absolute Signal



Percolative MIT in NdNiO₃

Absolute Signal

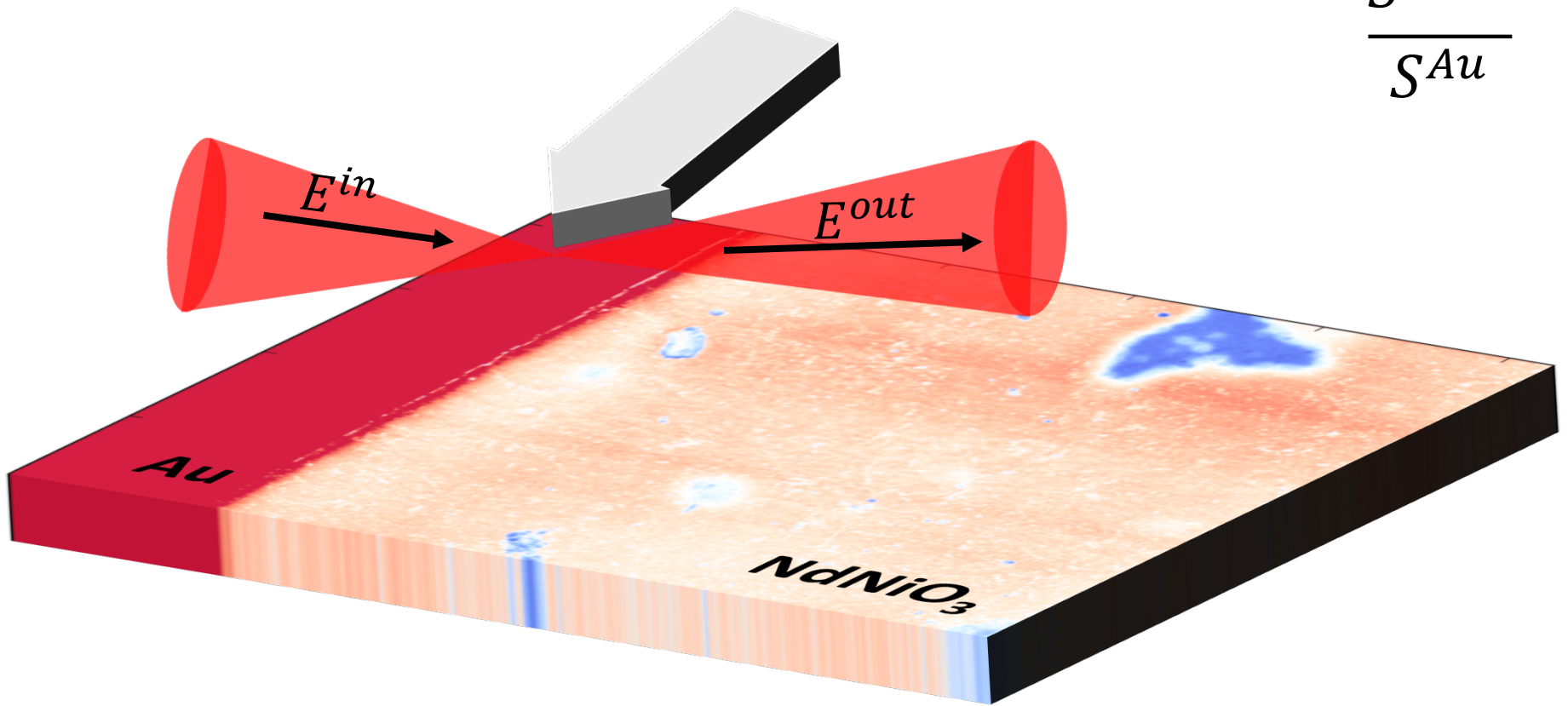


$$E^{out} \propto S^{Au}$$

Percolative MIT in NdNiO₃

Absolute Signal

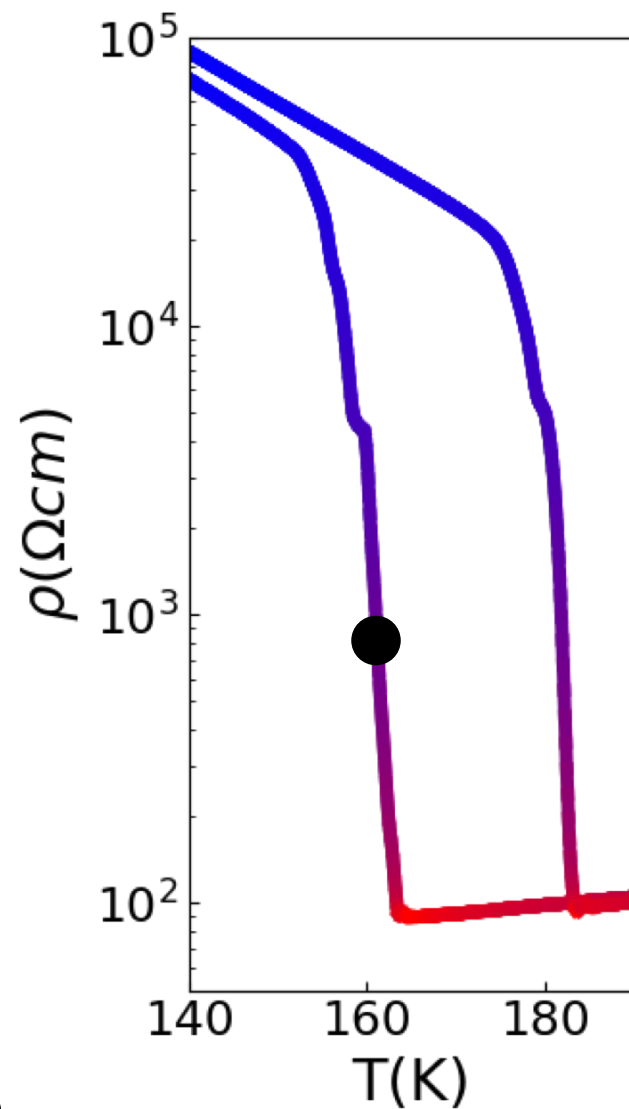
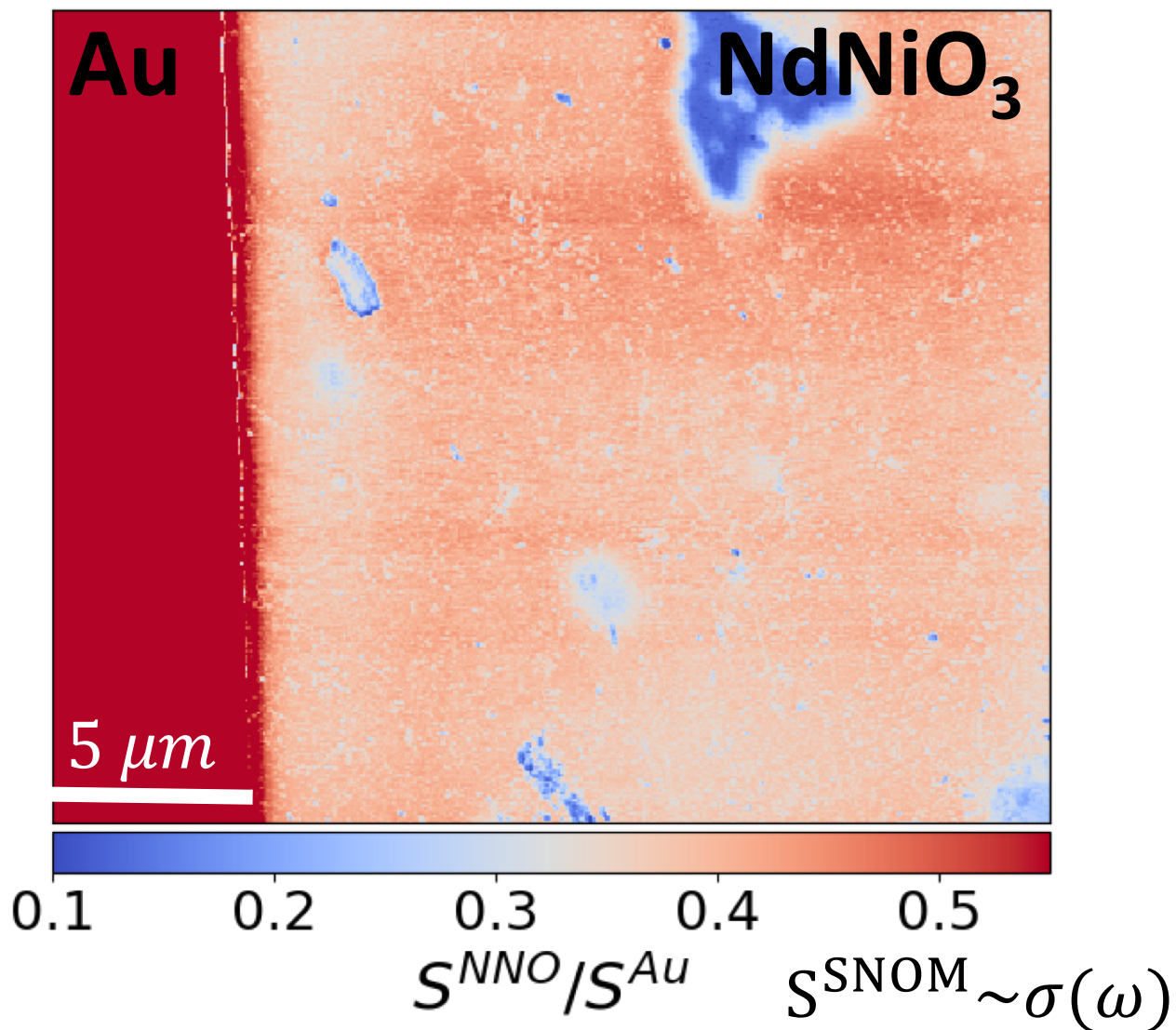
$$\frac{S^{NNO}}{S^{Au}}$$



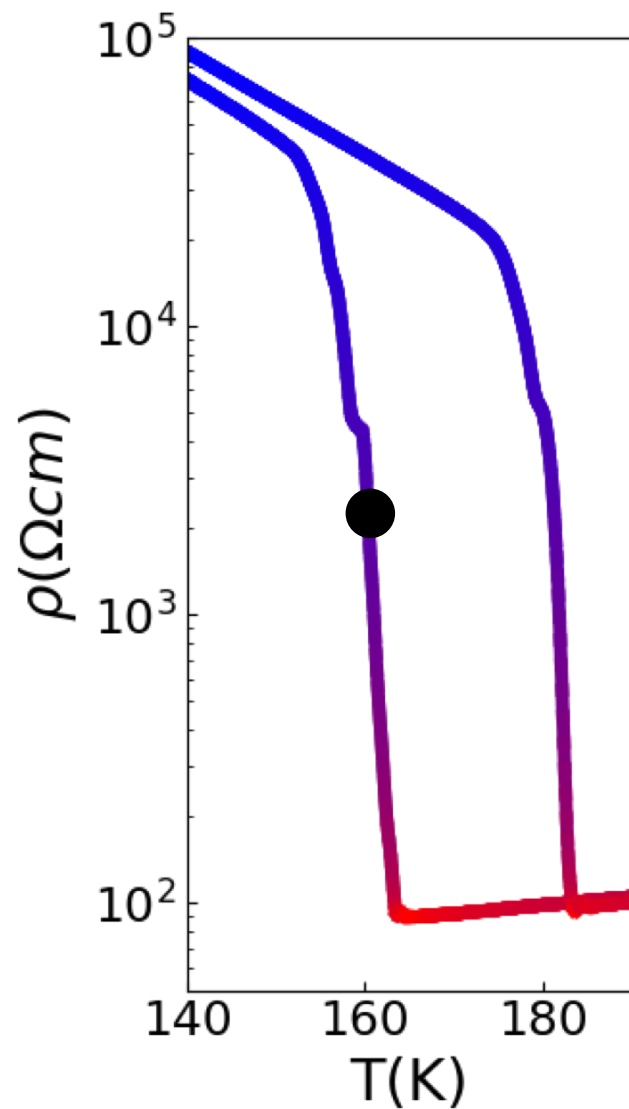
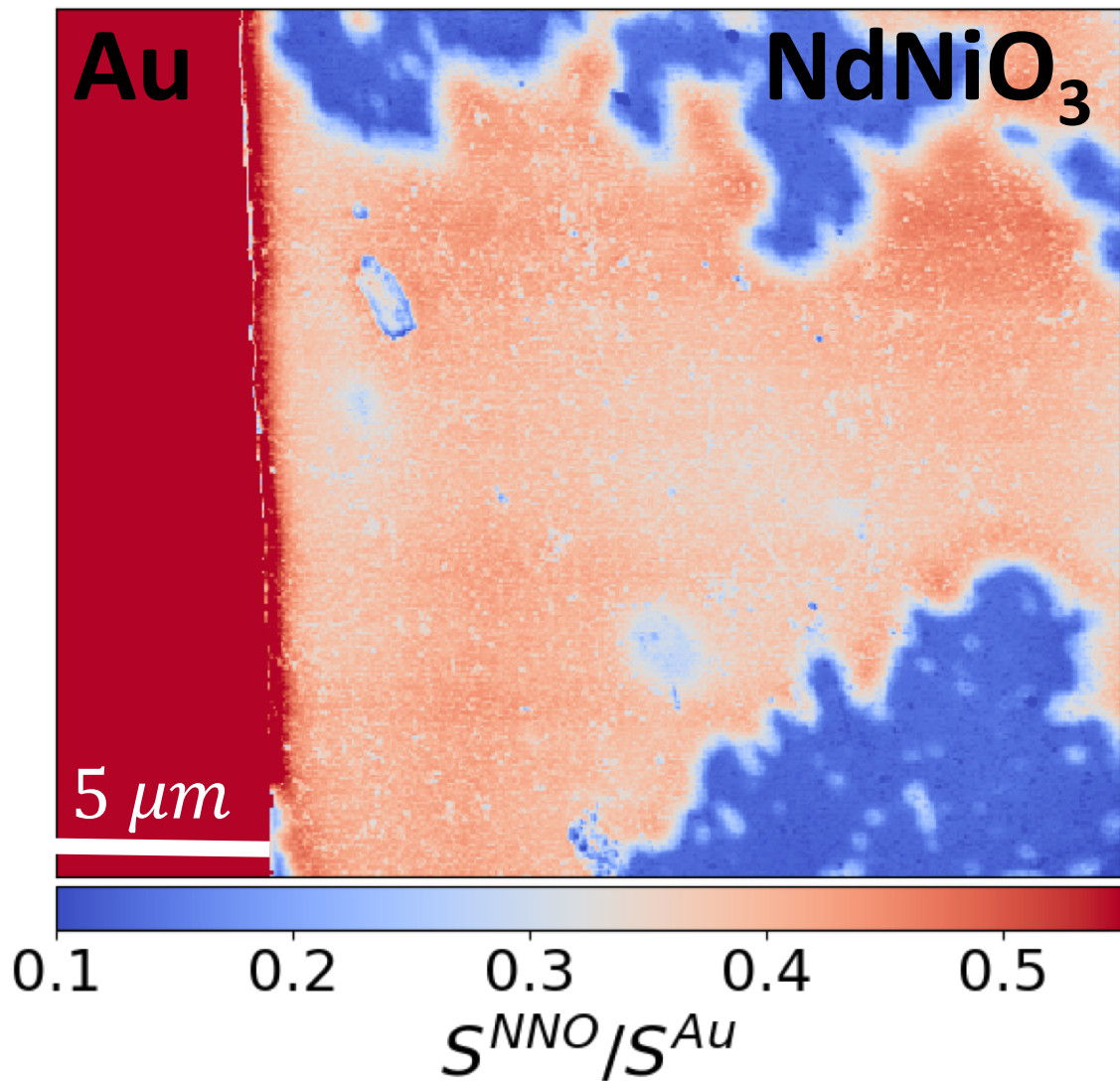
$$E^{out} \propto S^{Au}$$

$$E^{out} \propto S^{NNO}$$

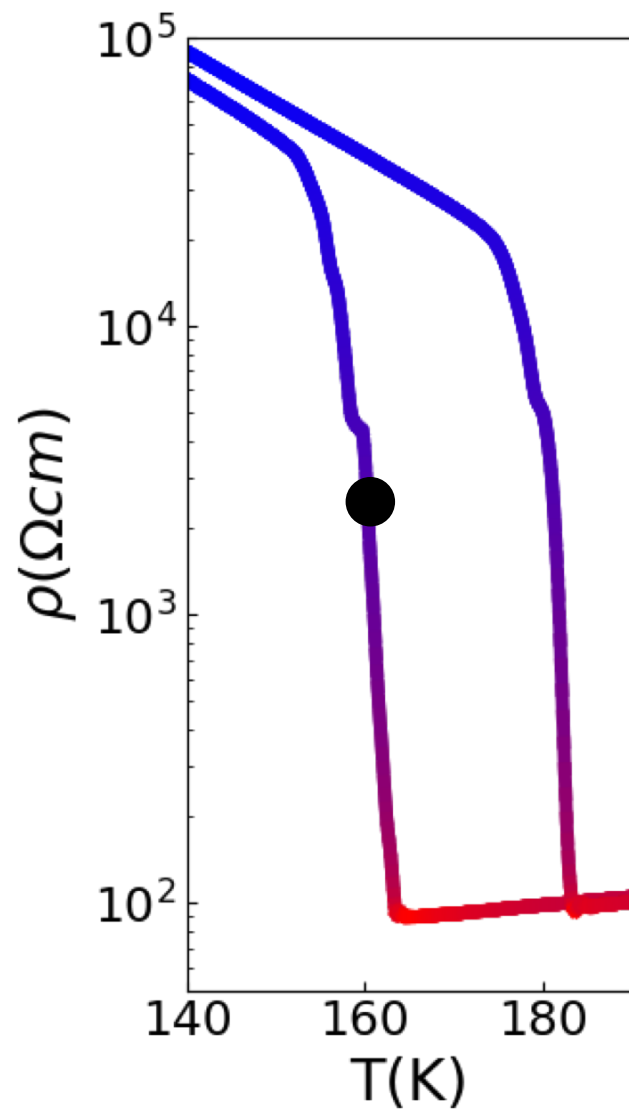
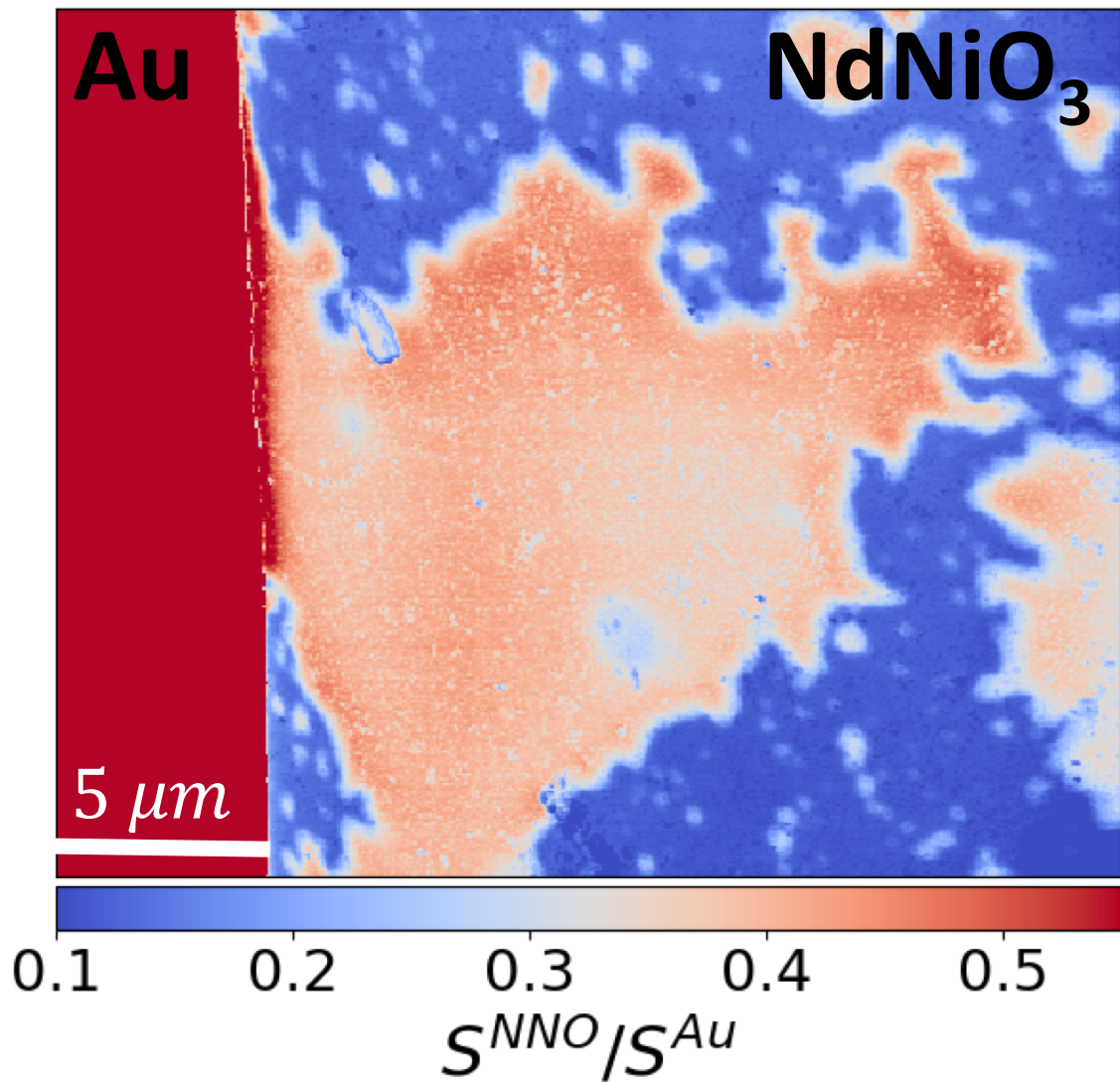
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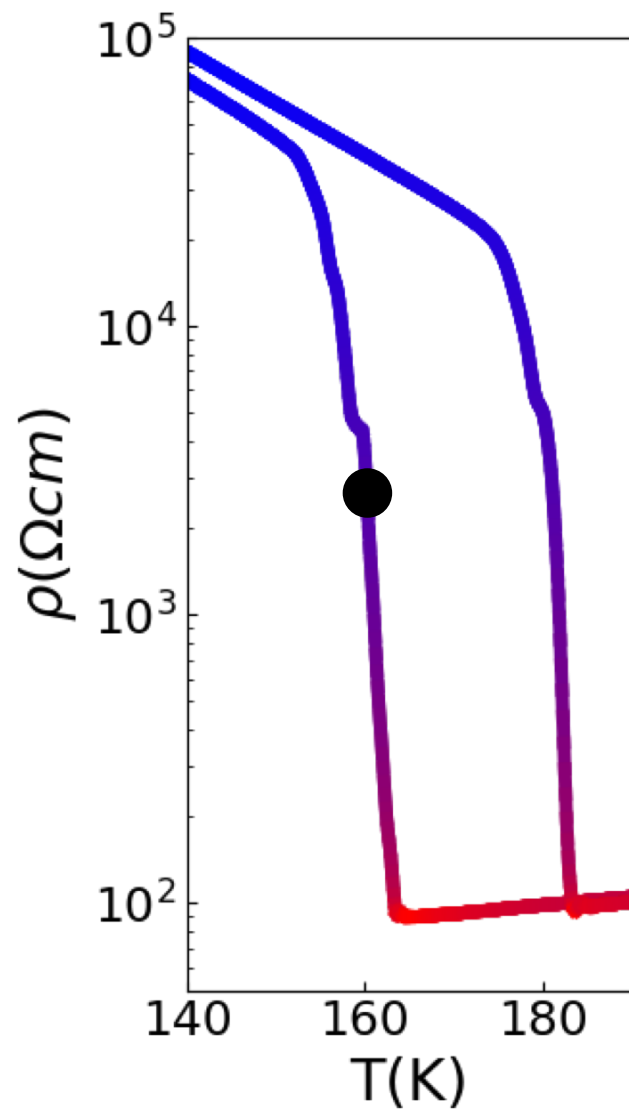
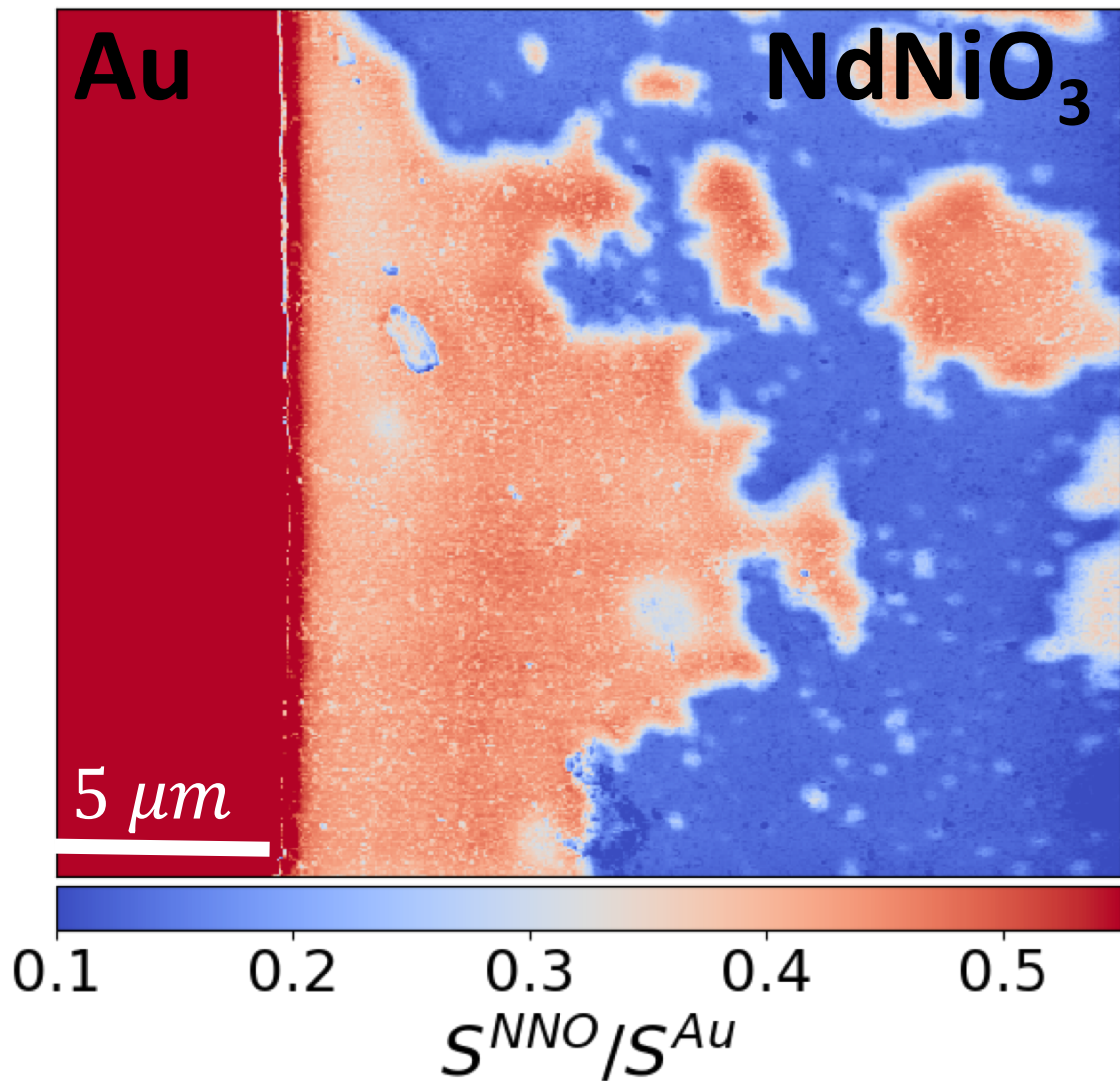
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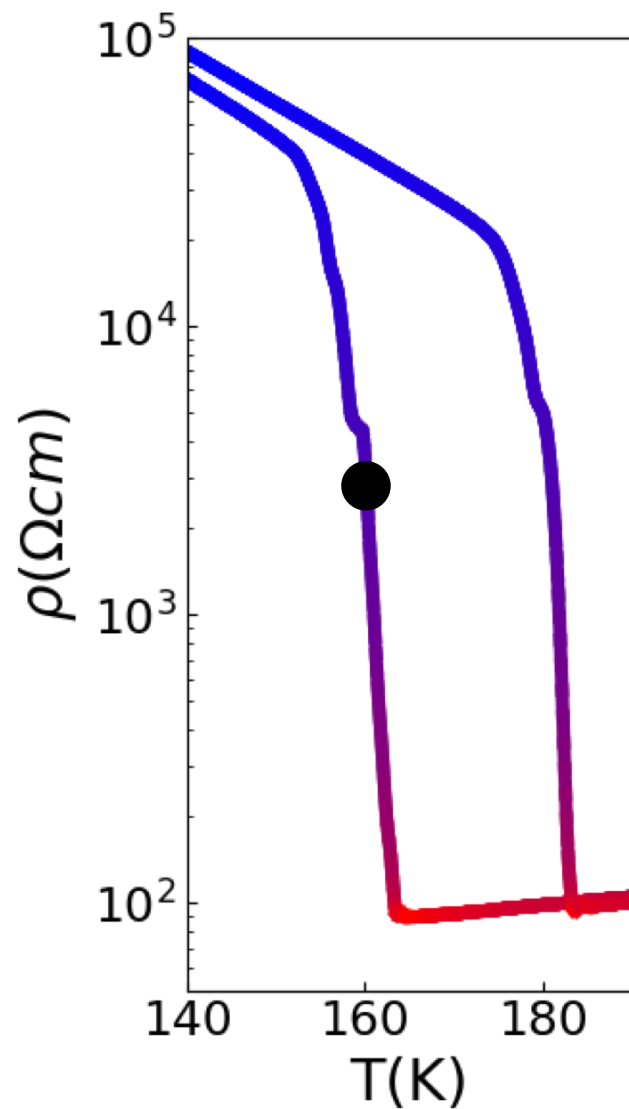
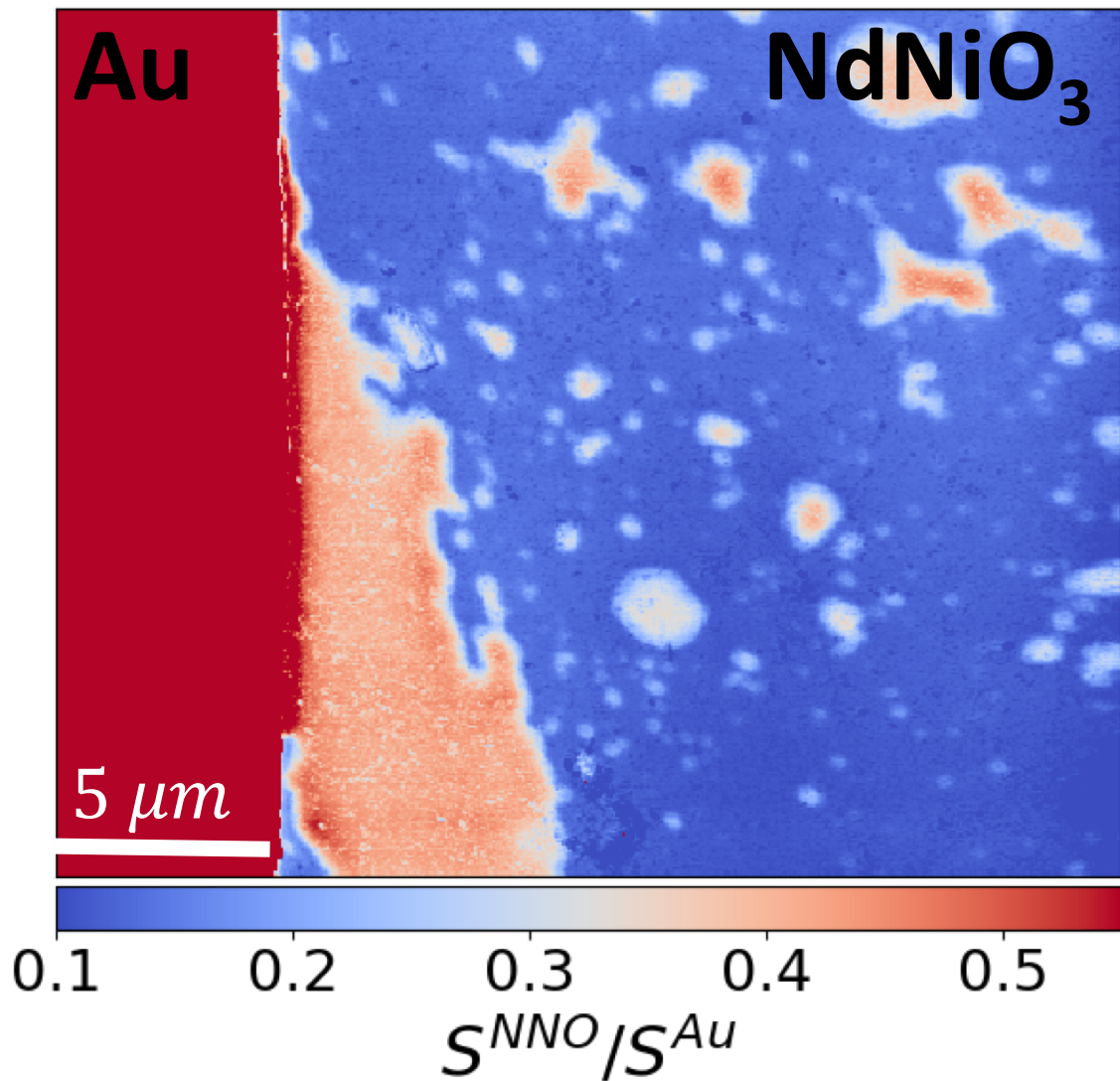
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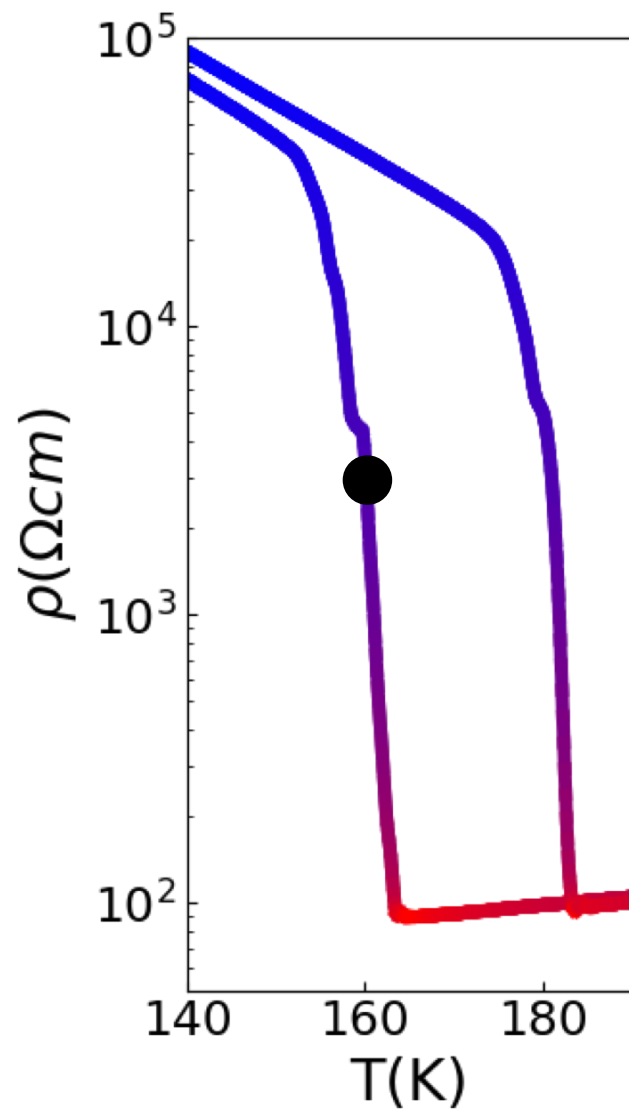
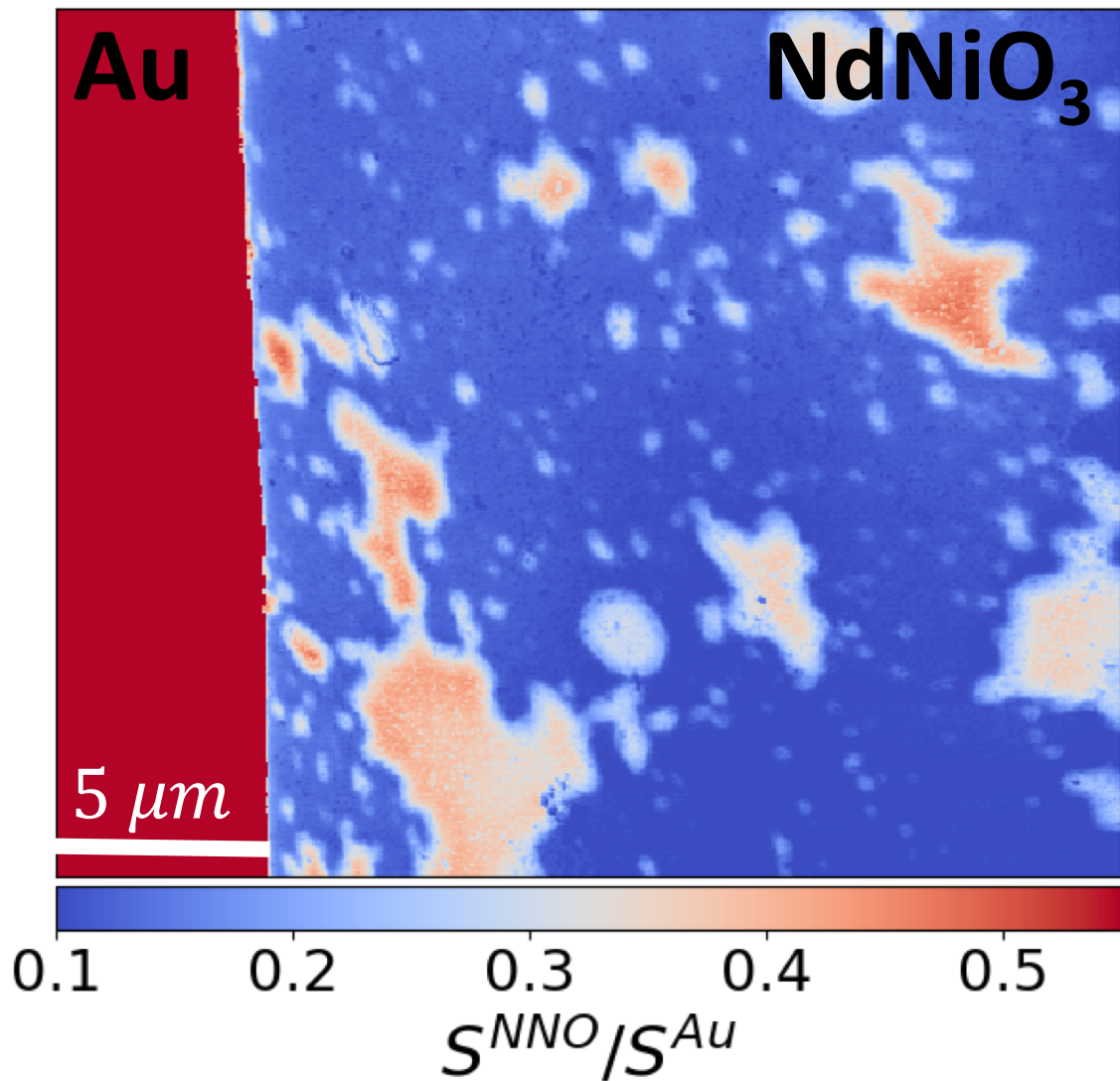
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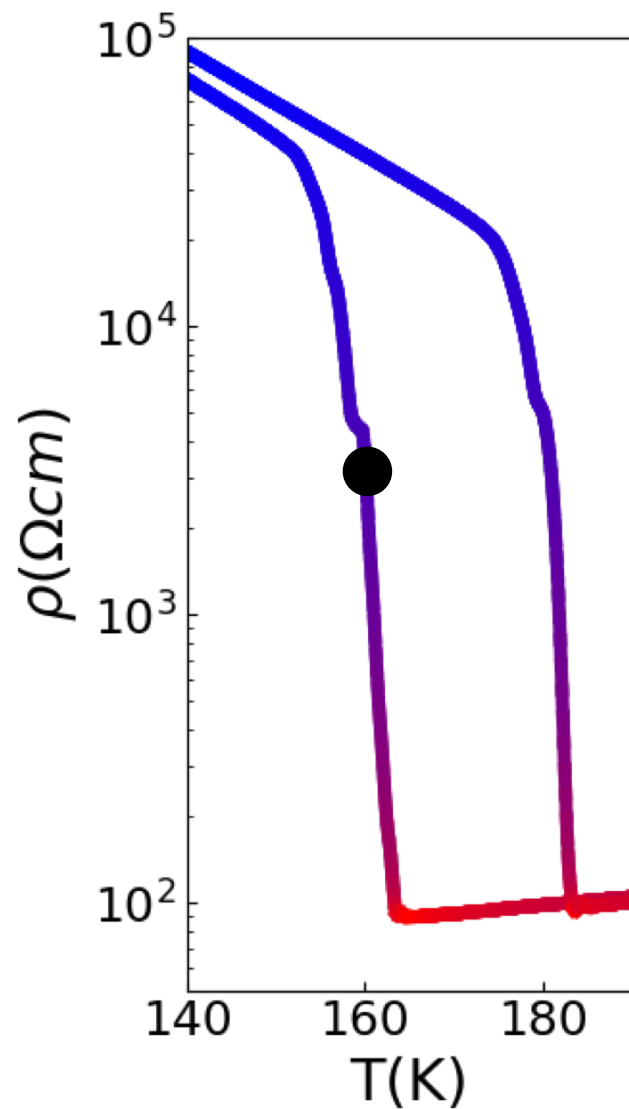
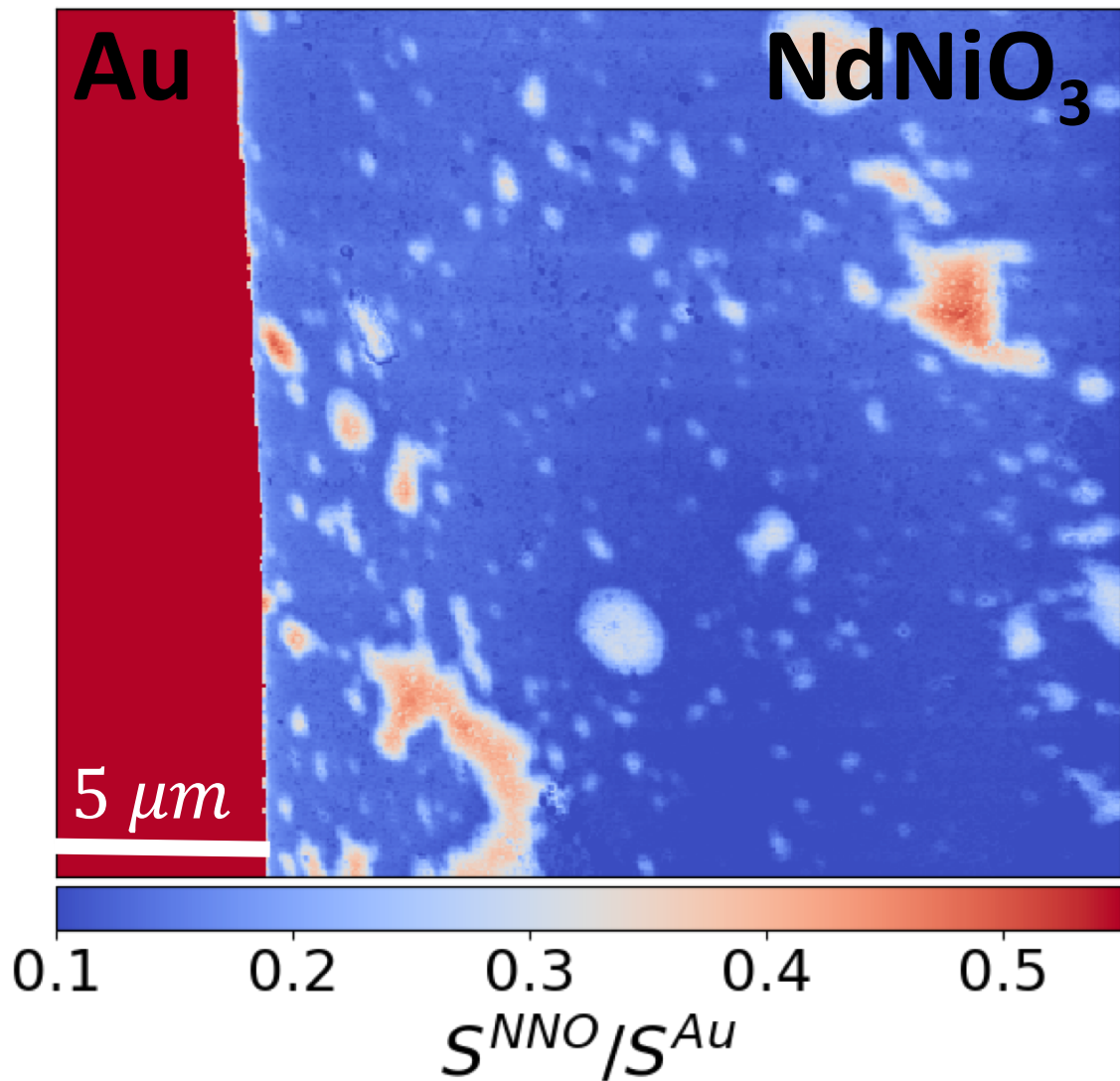
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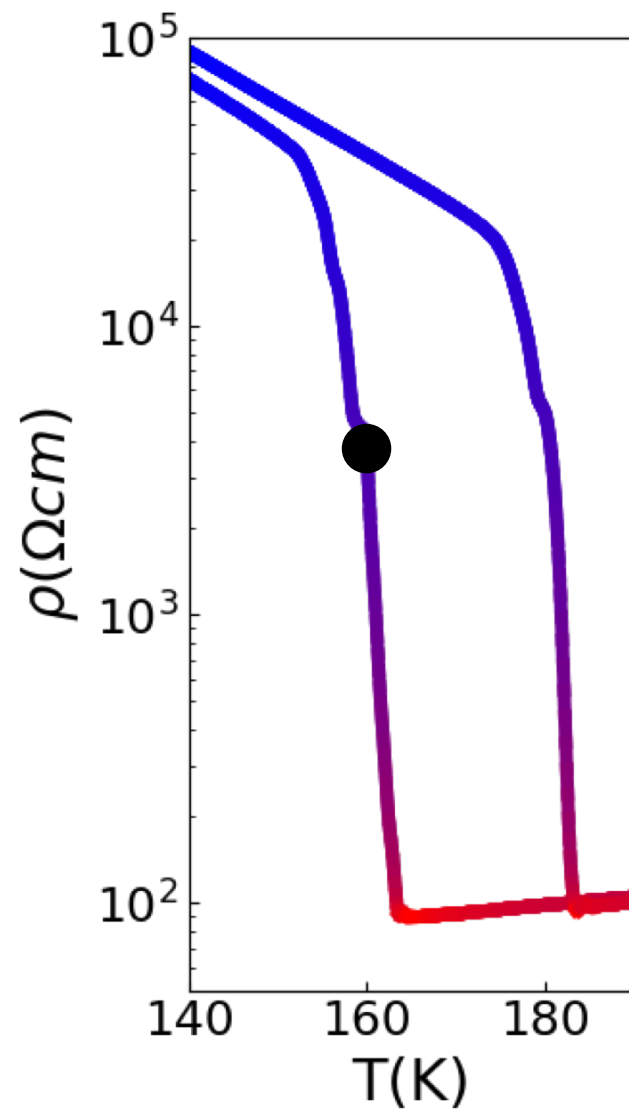
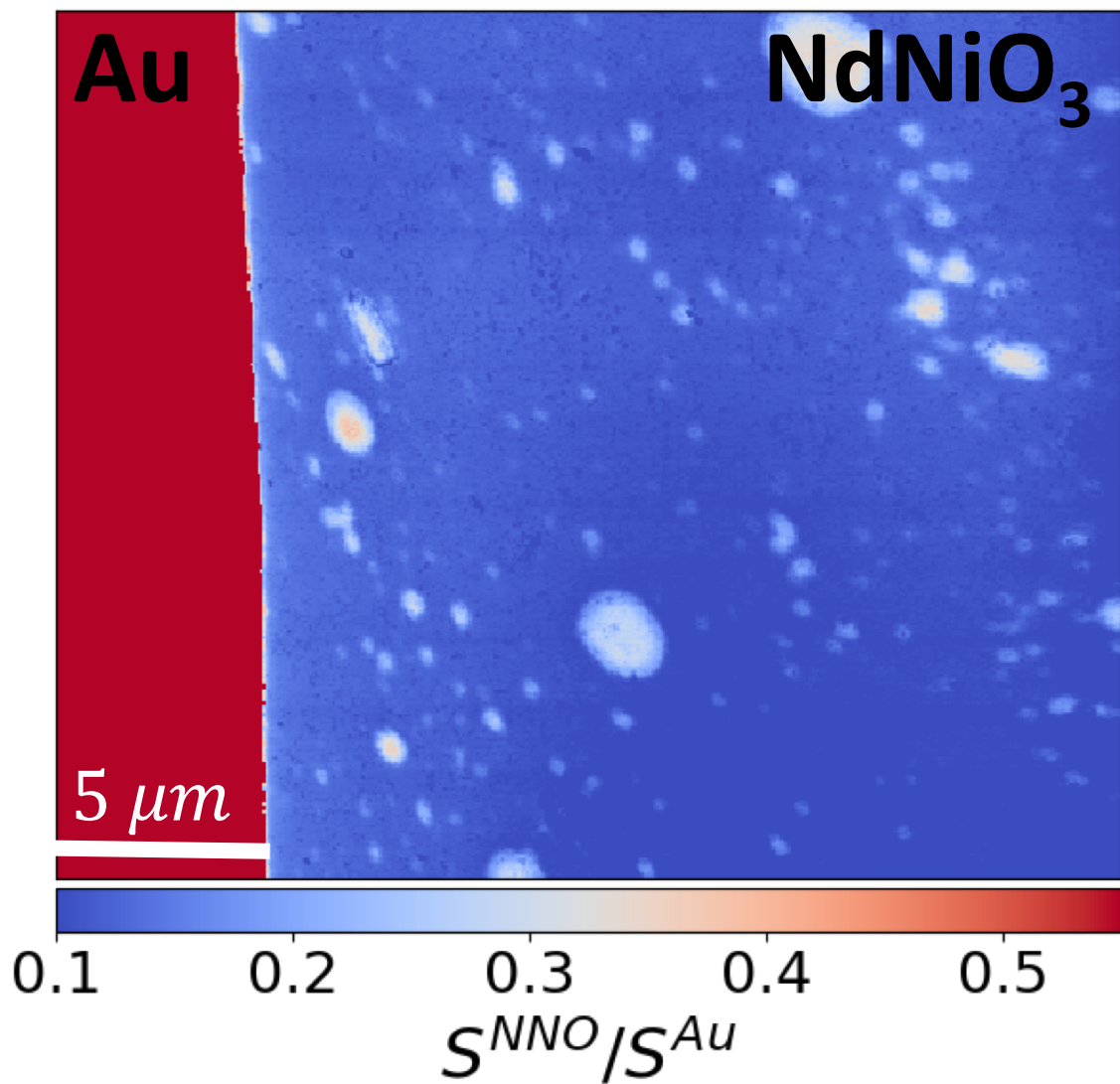
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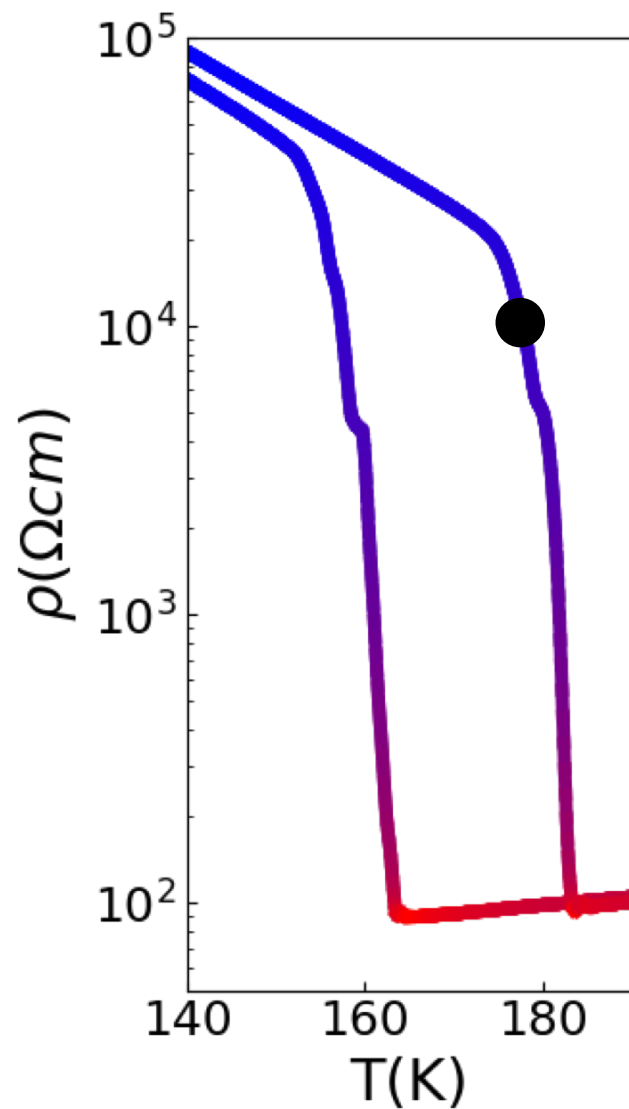
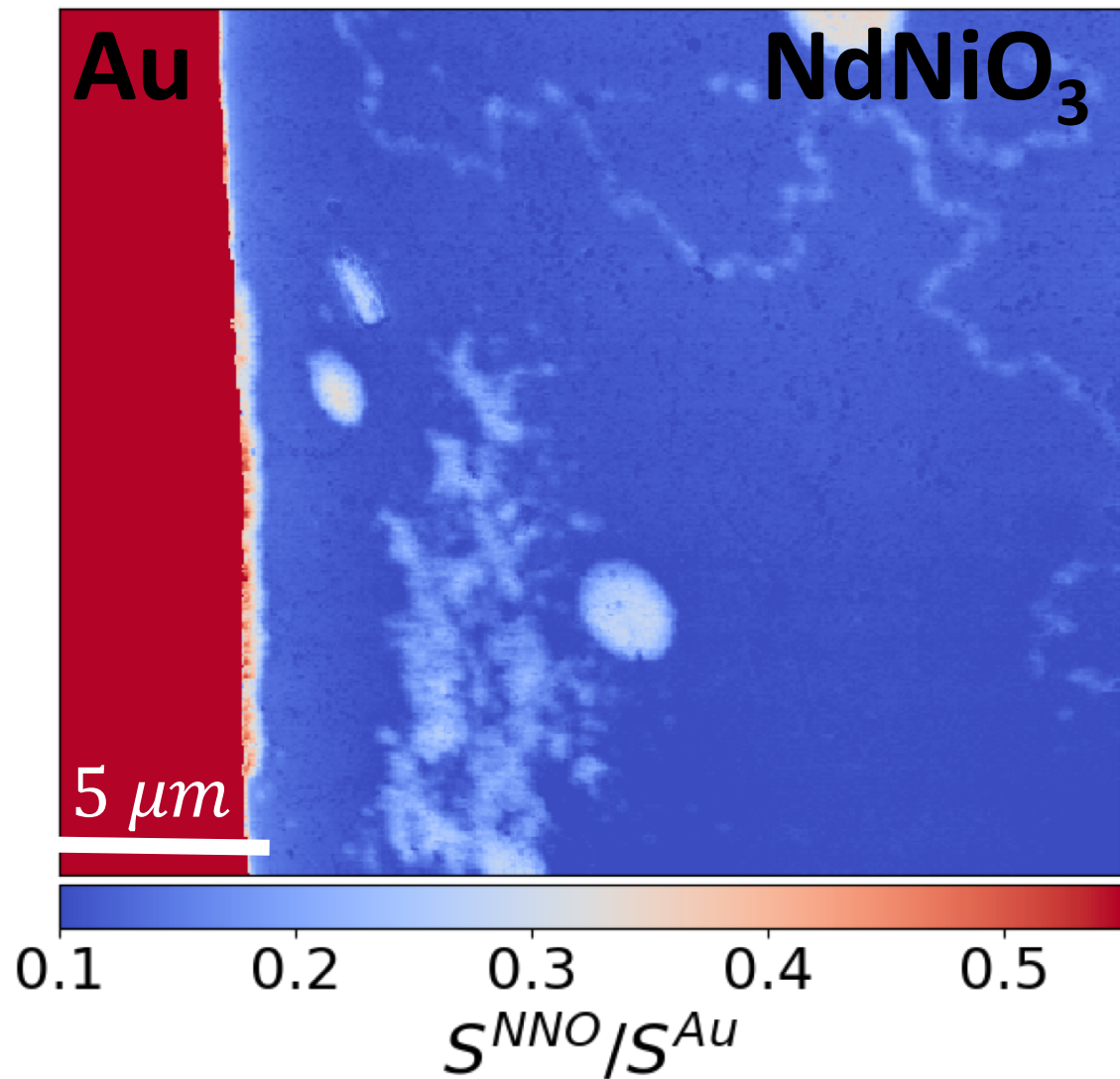
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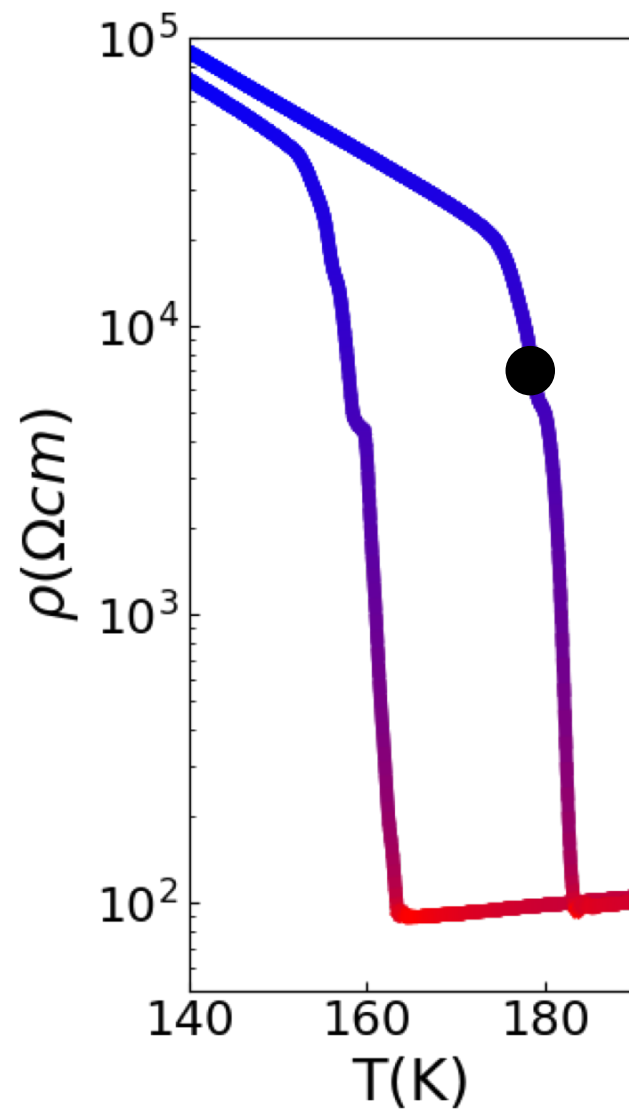
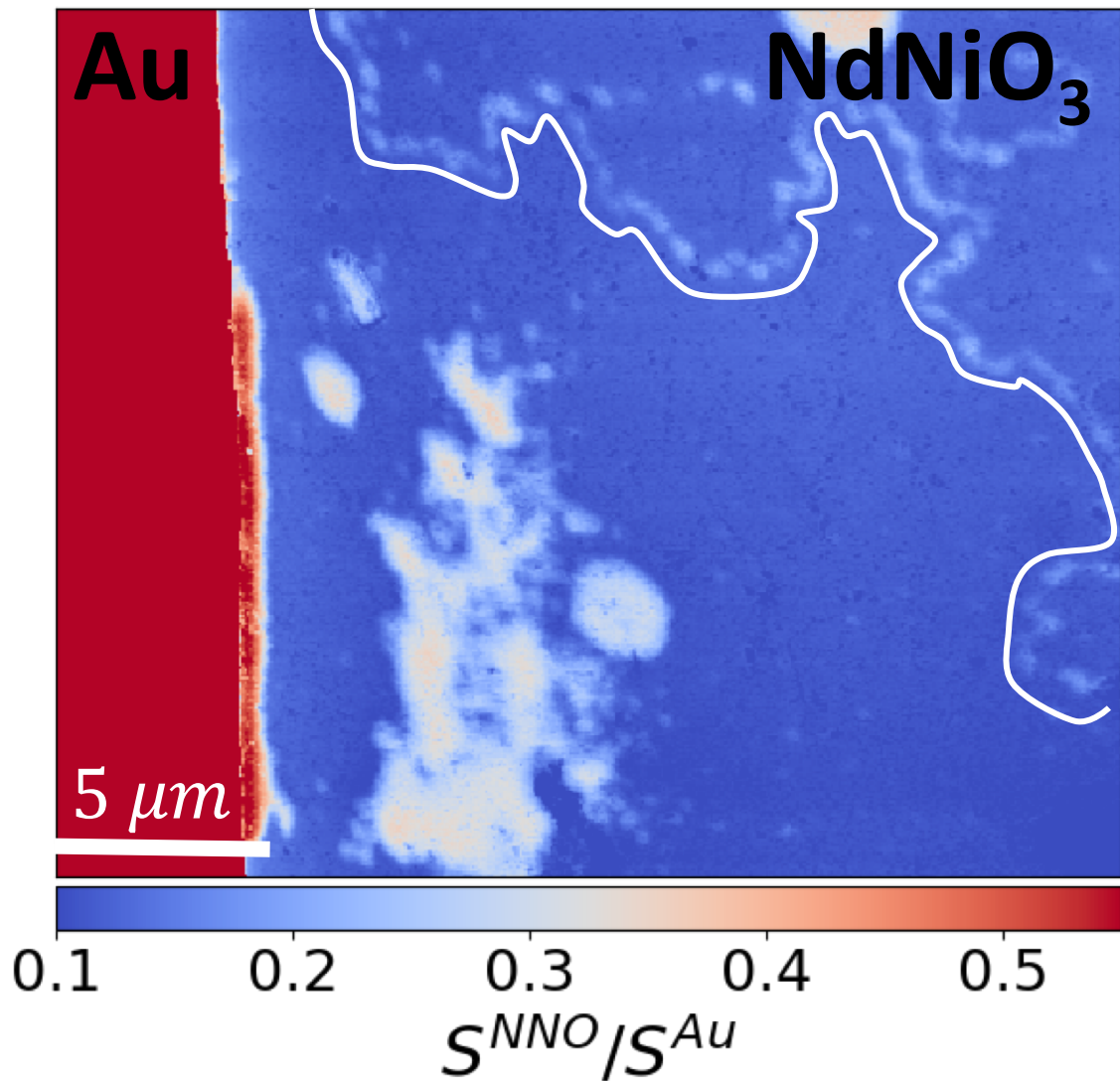
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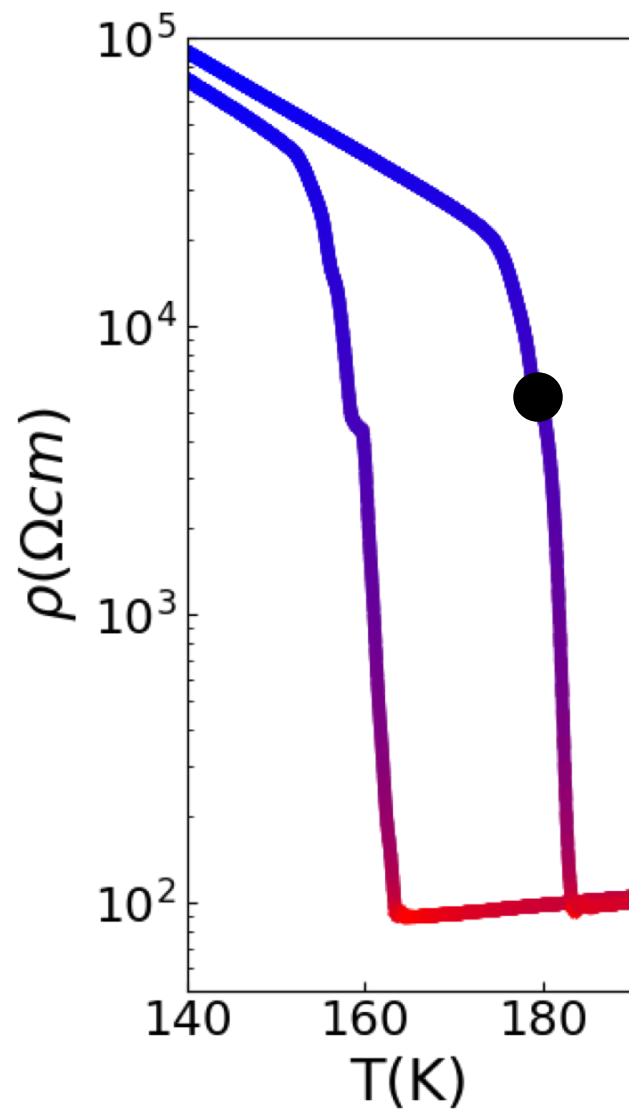
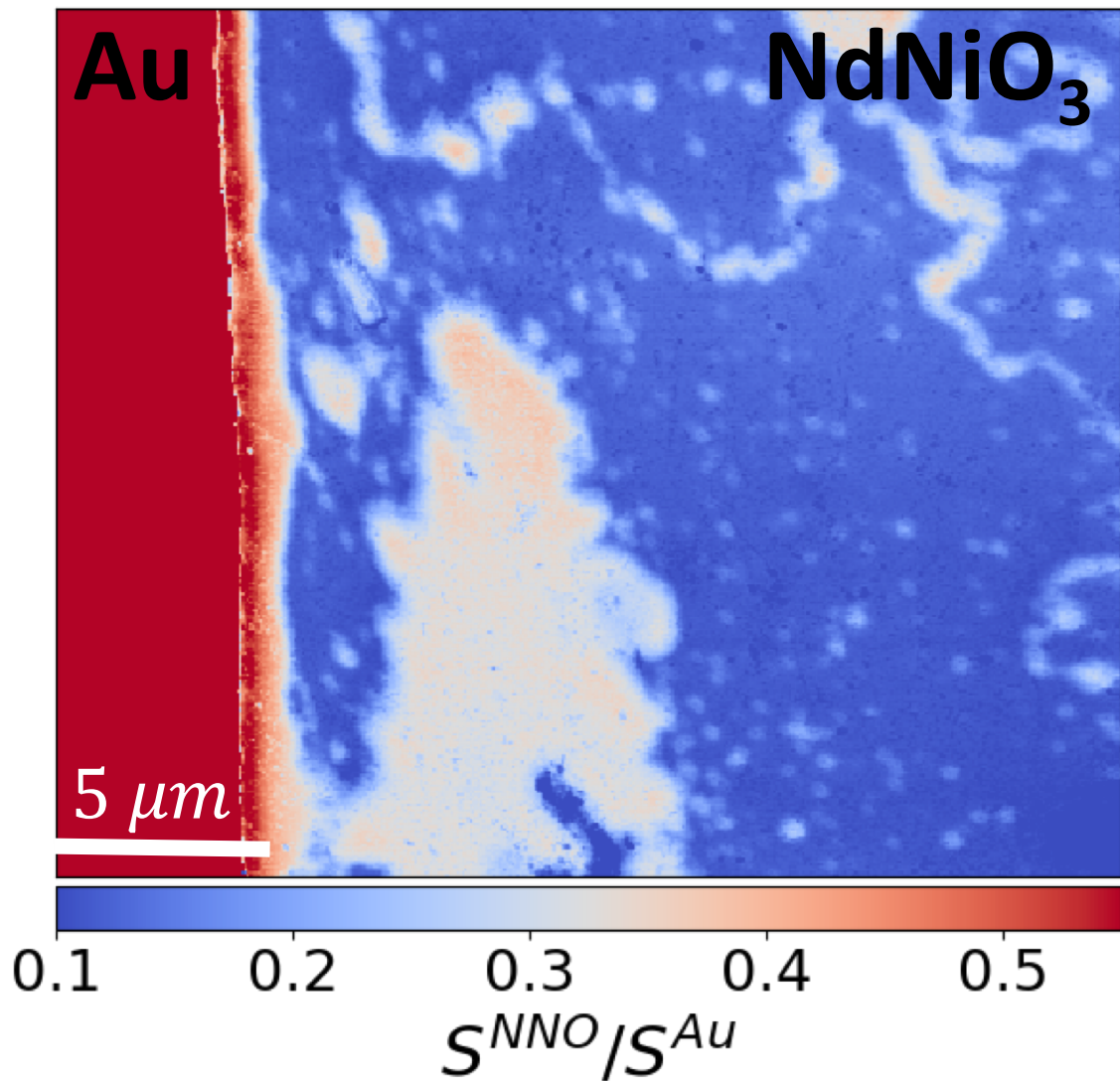
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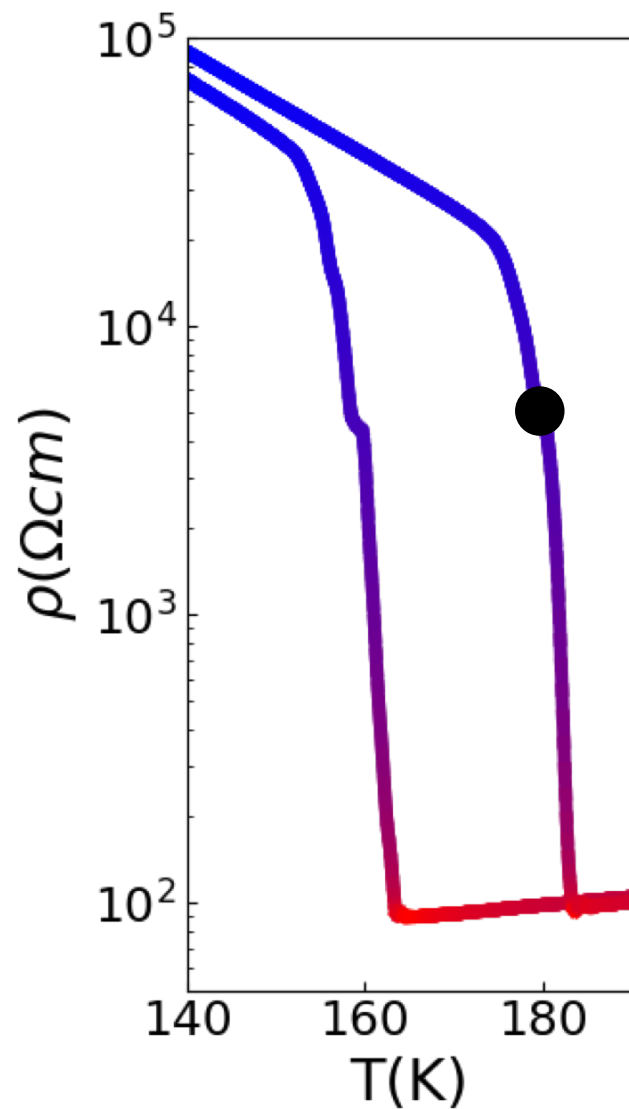
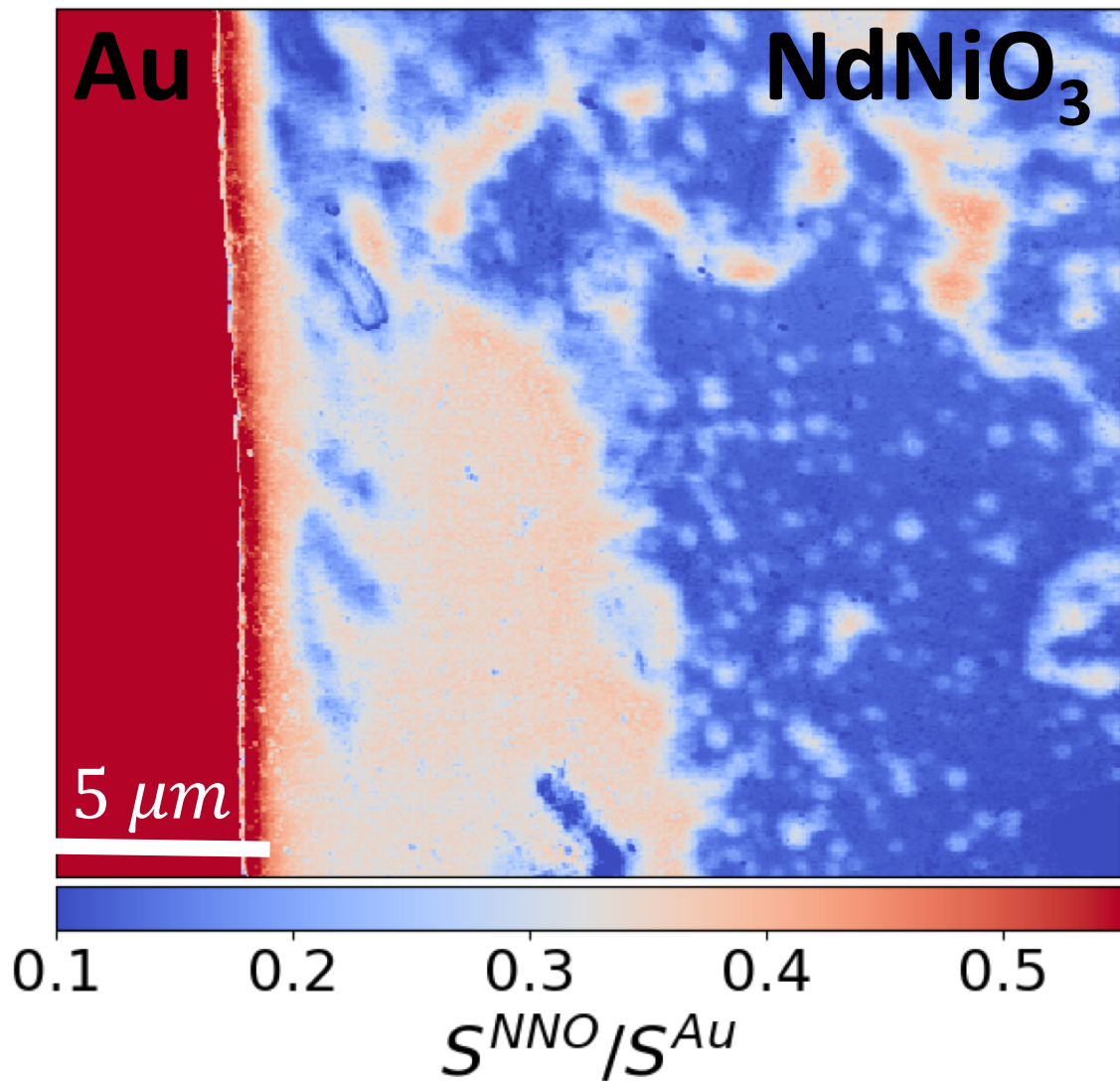
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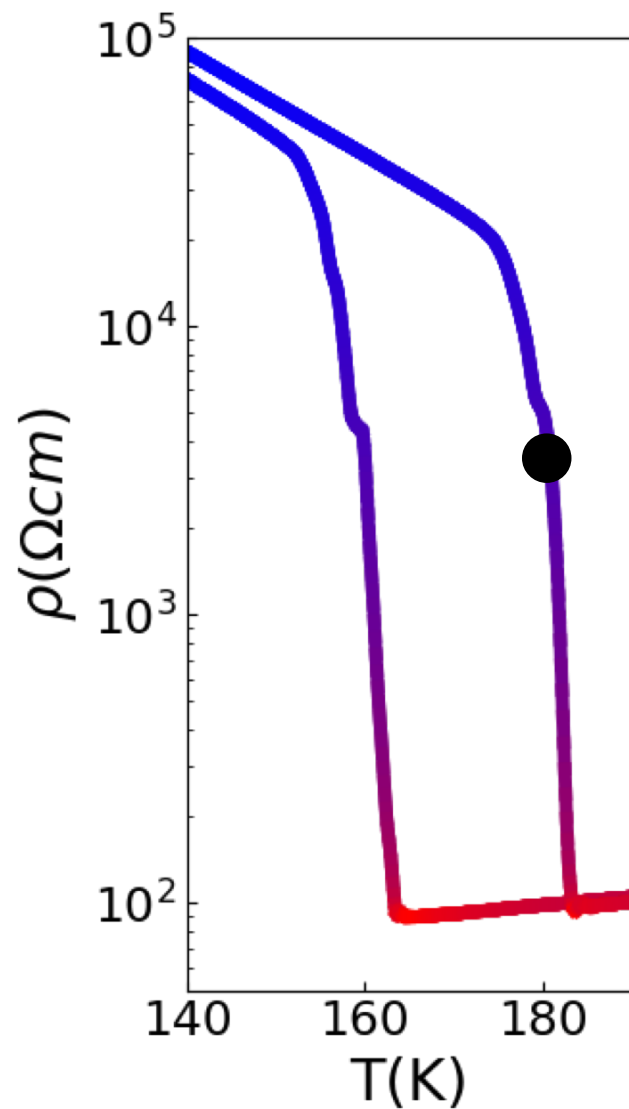
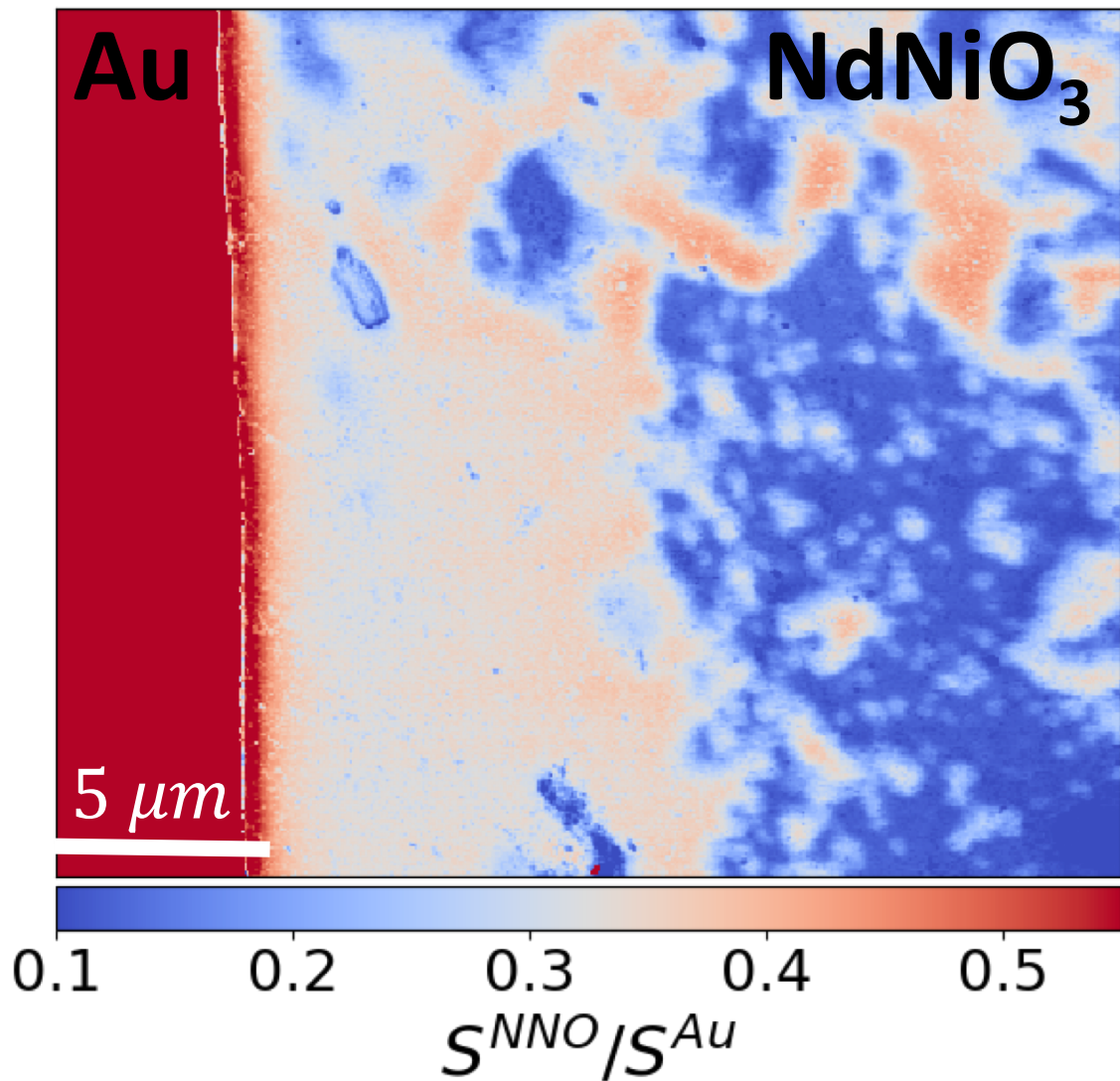
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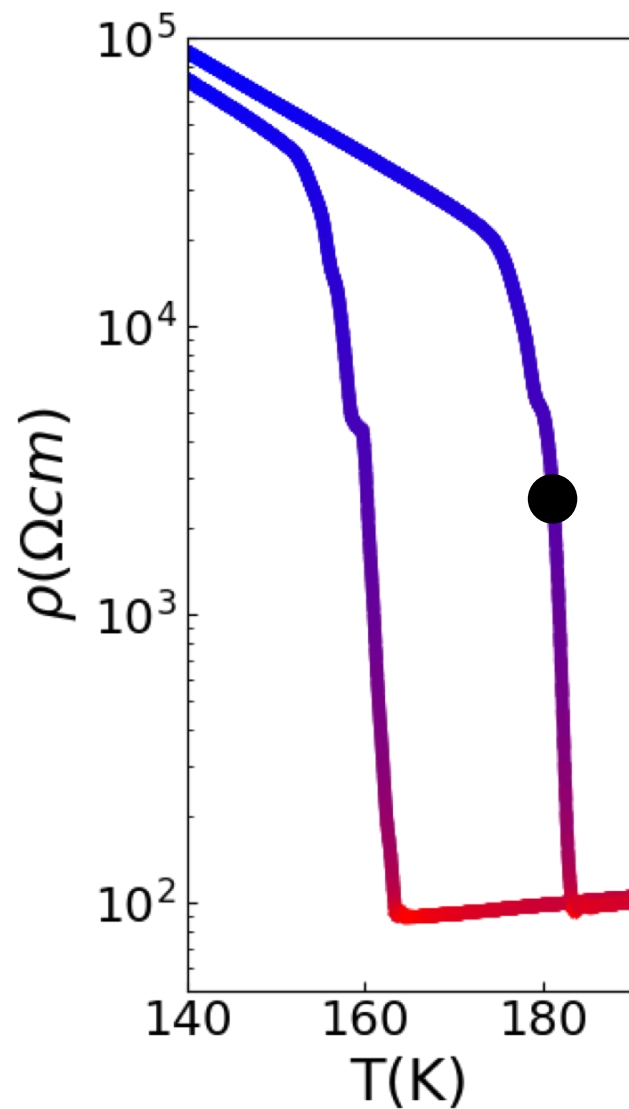
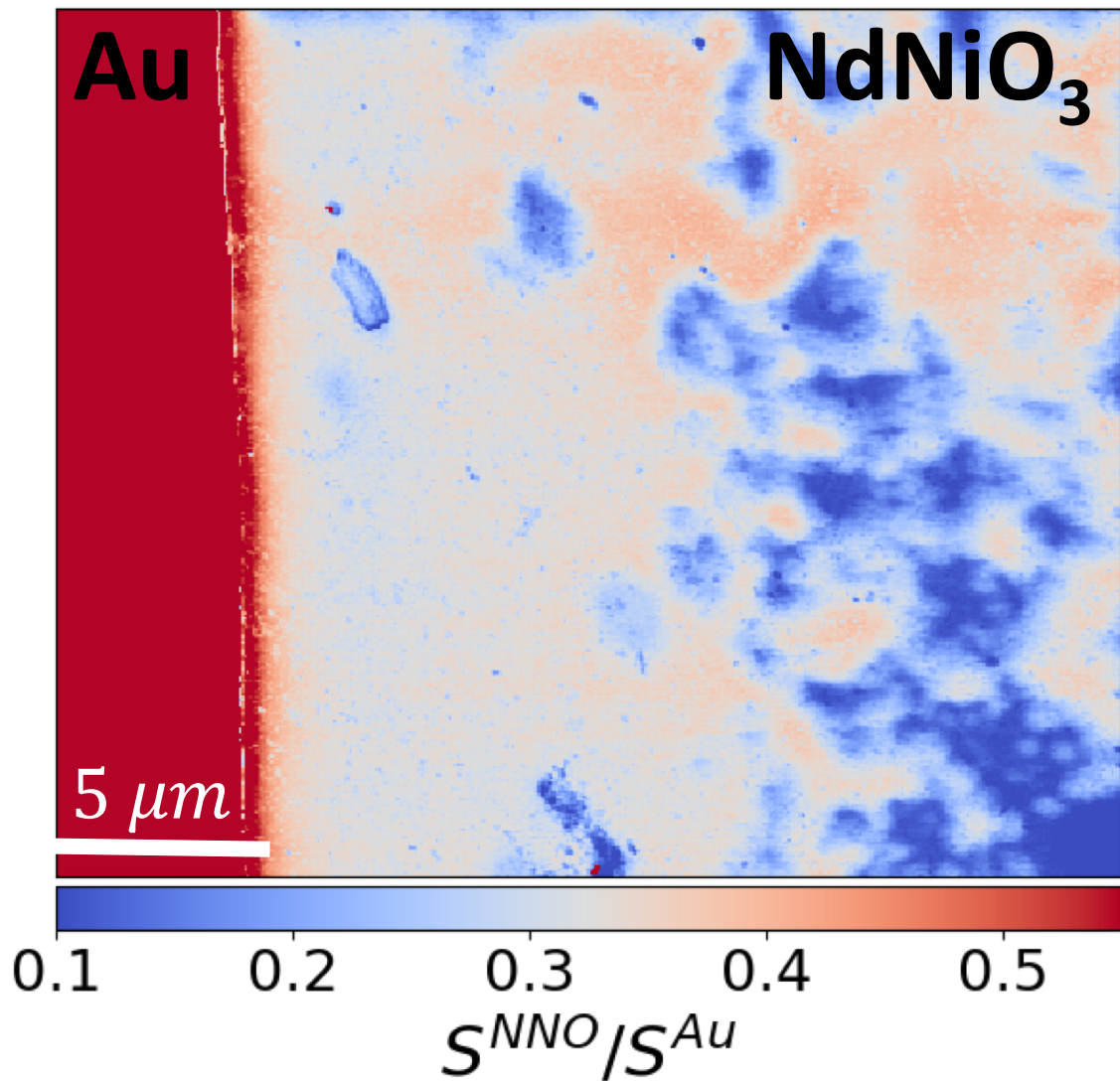
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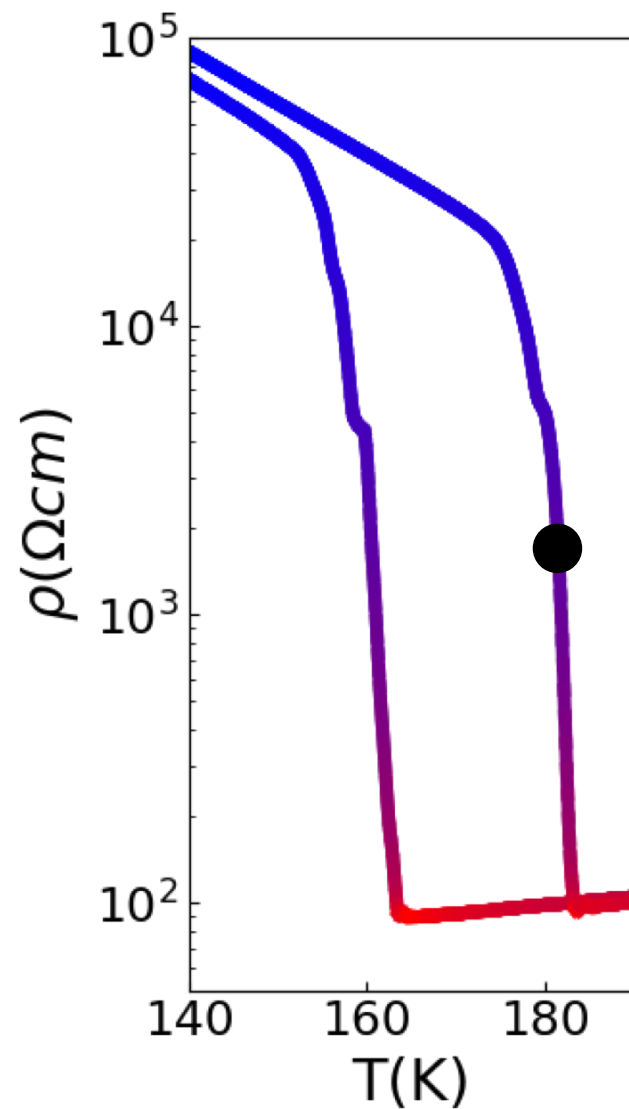
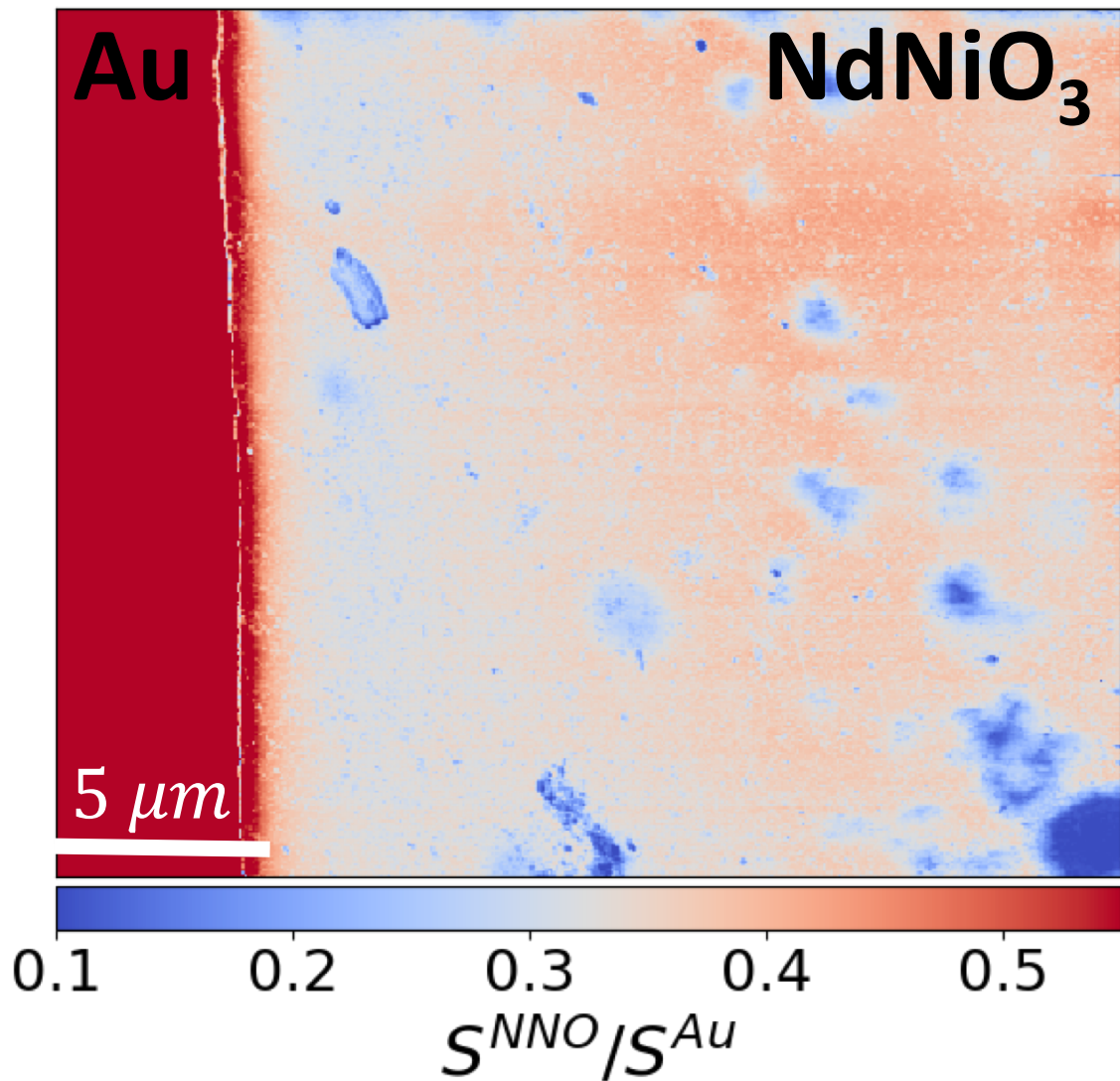
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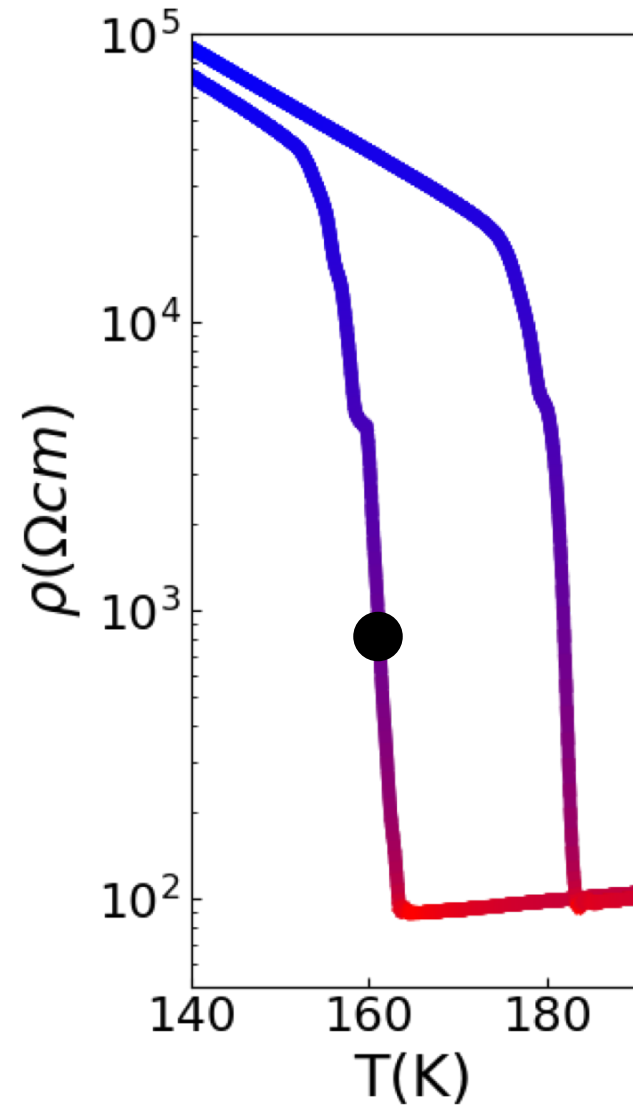
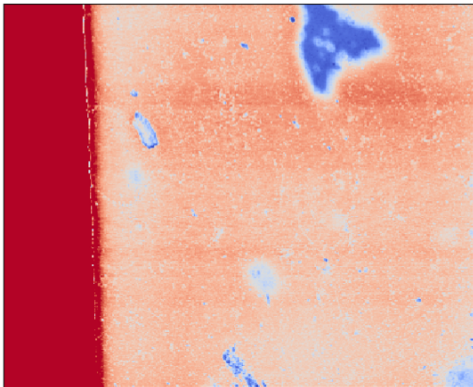
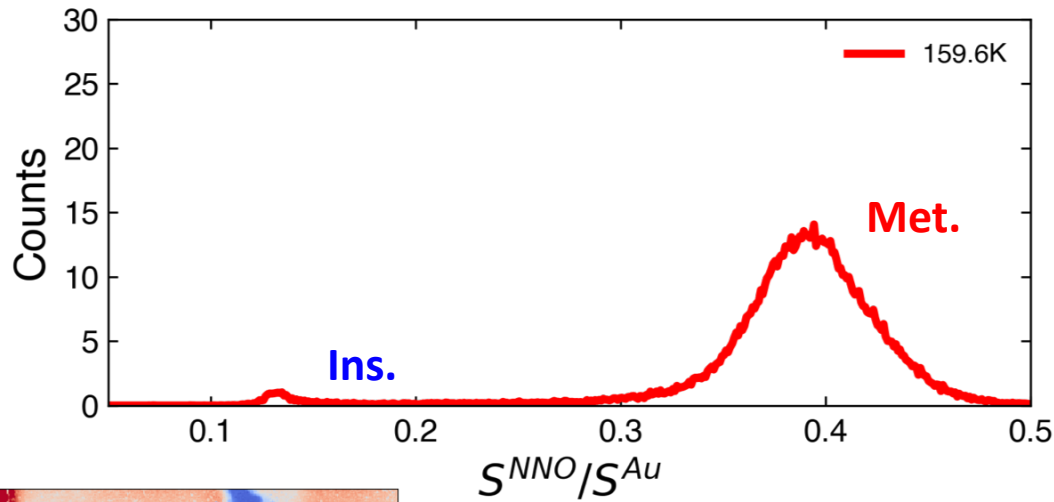
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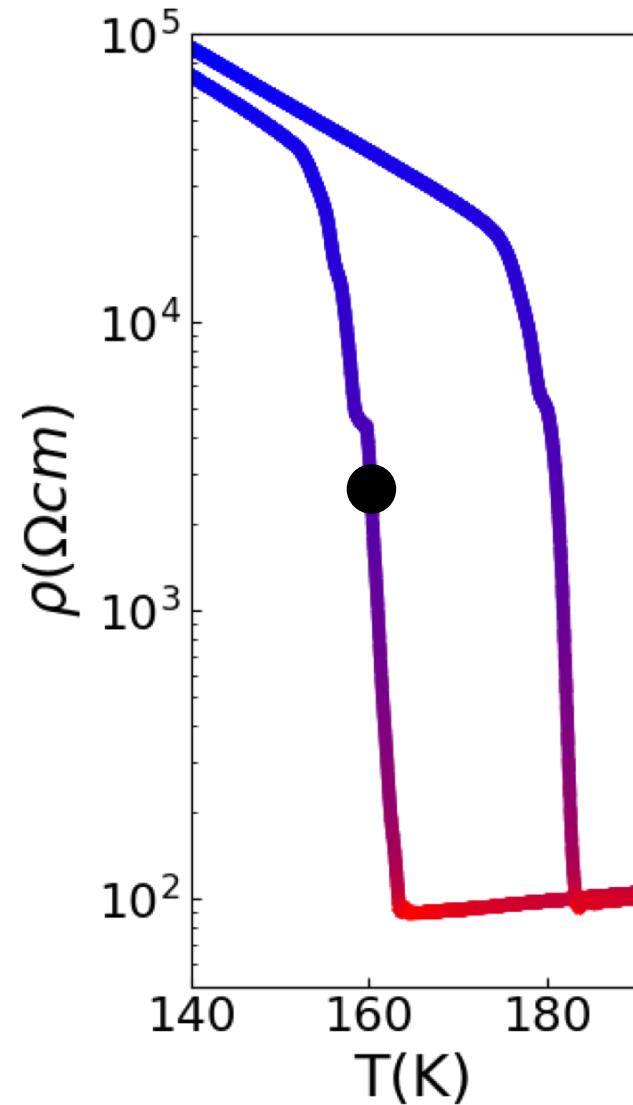
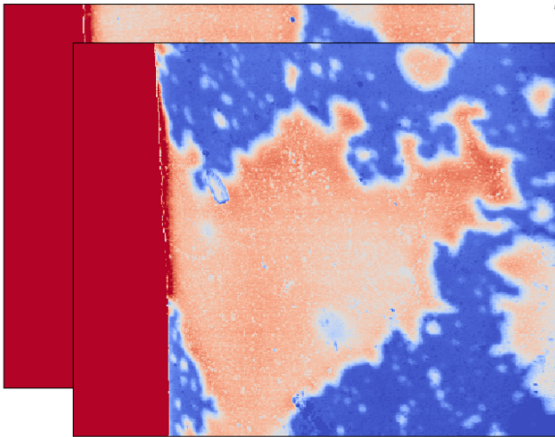
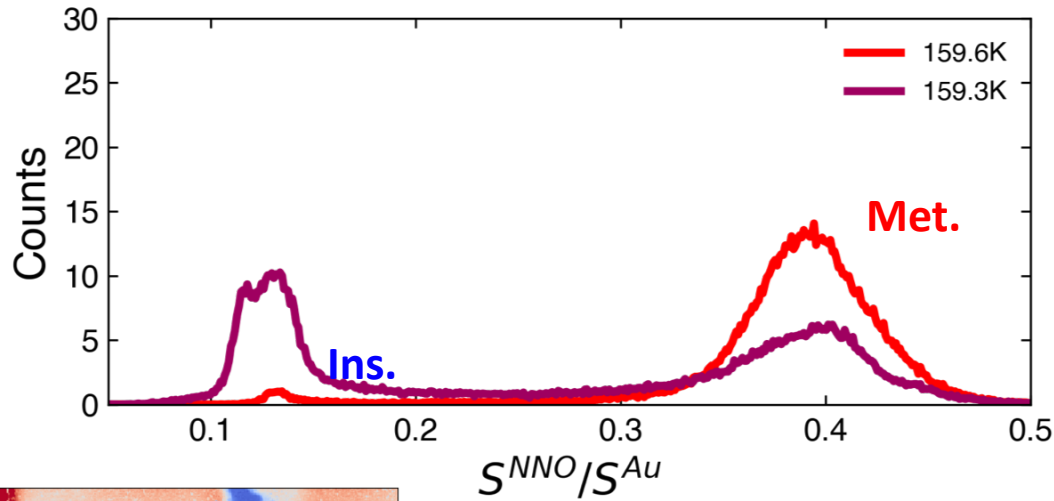
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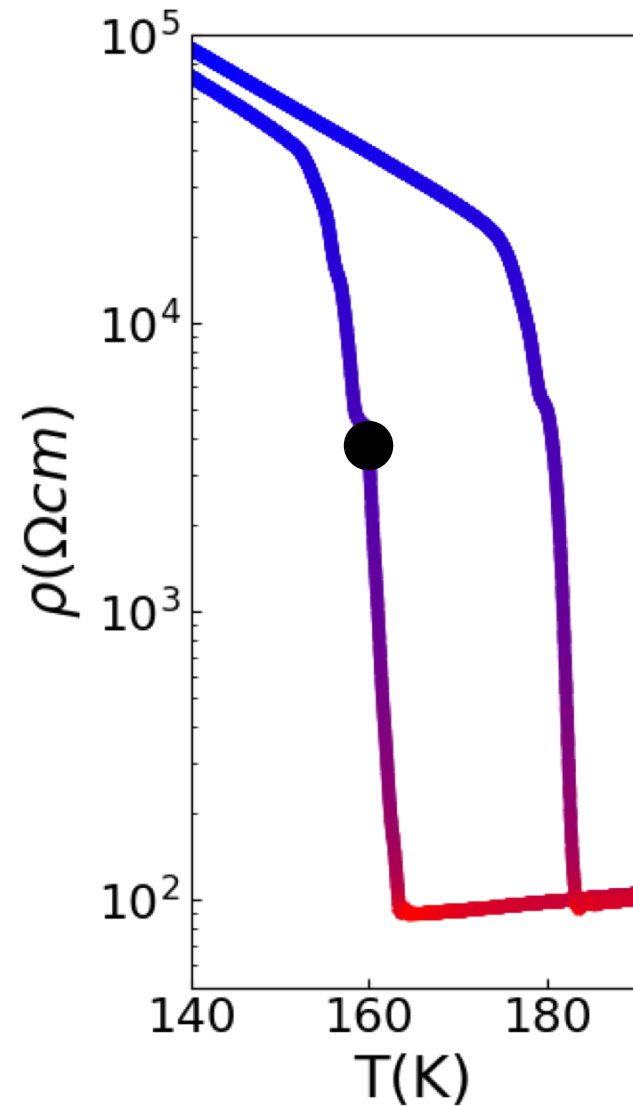
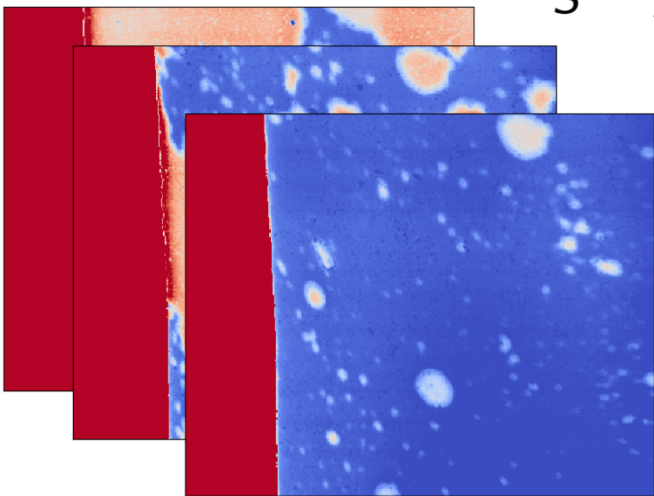
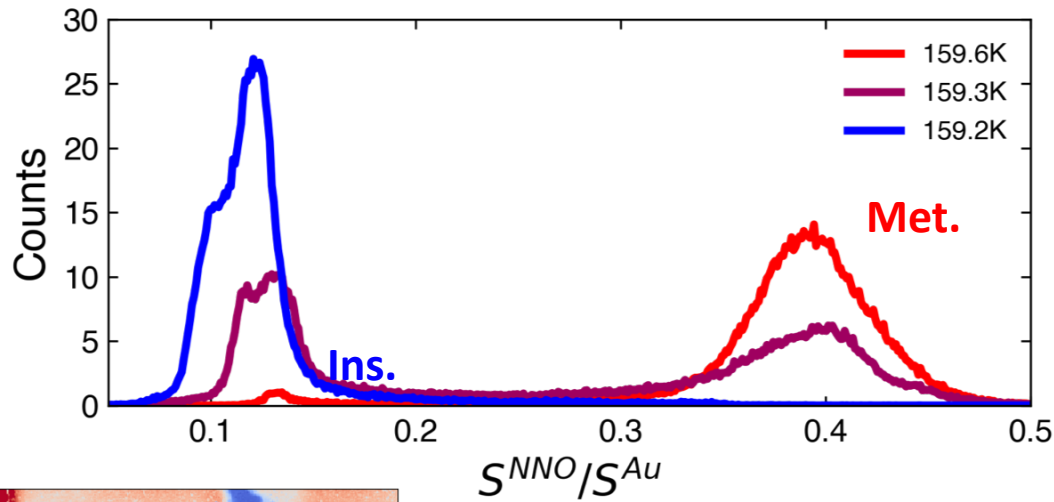
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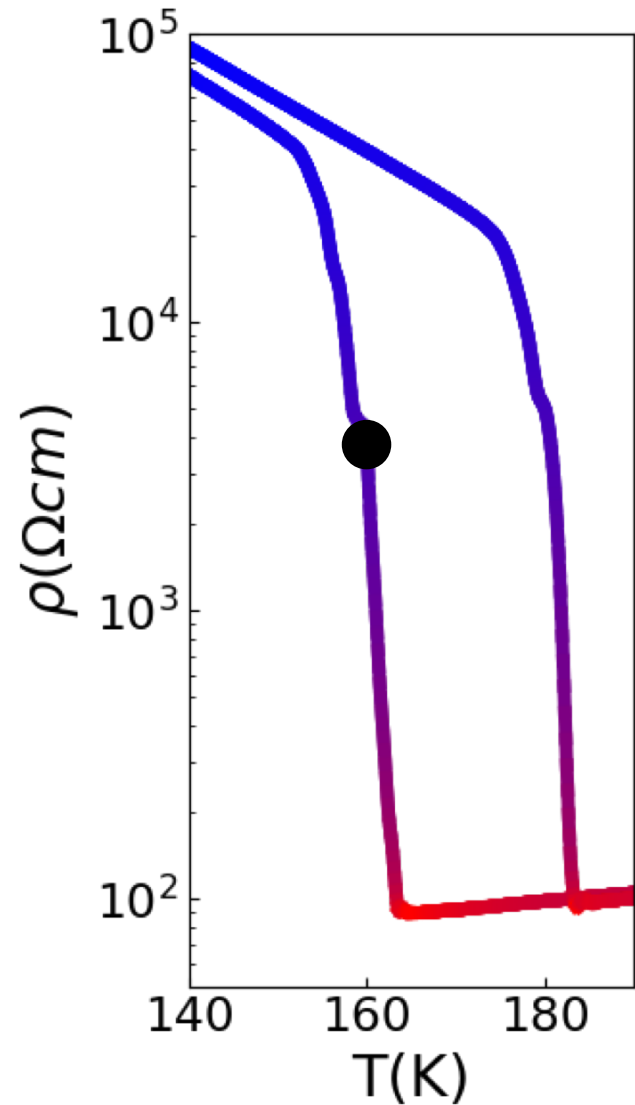
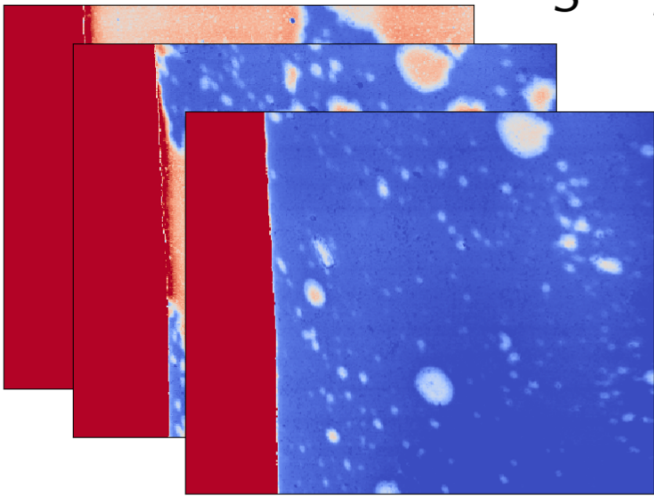
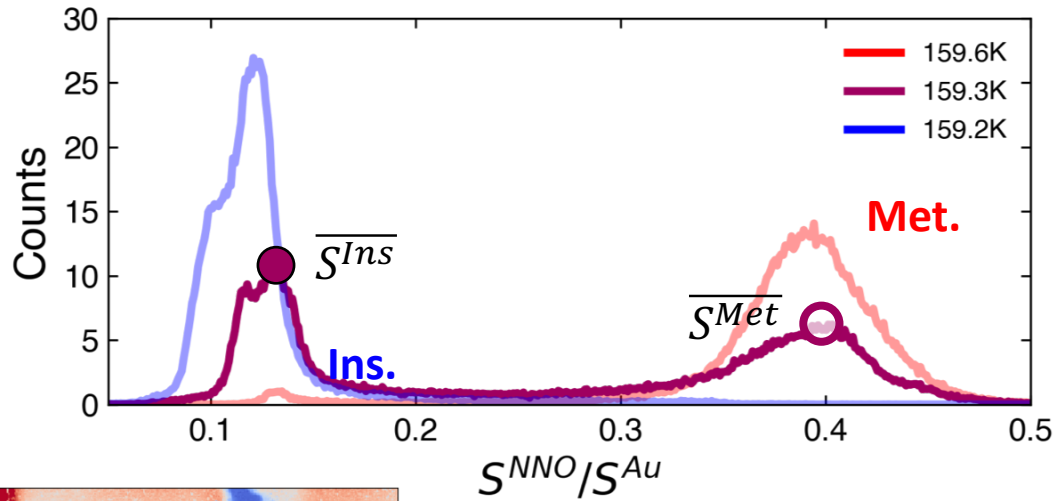
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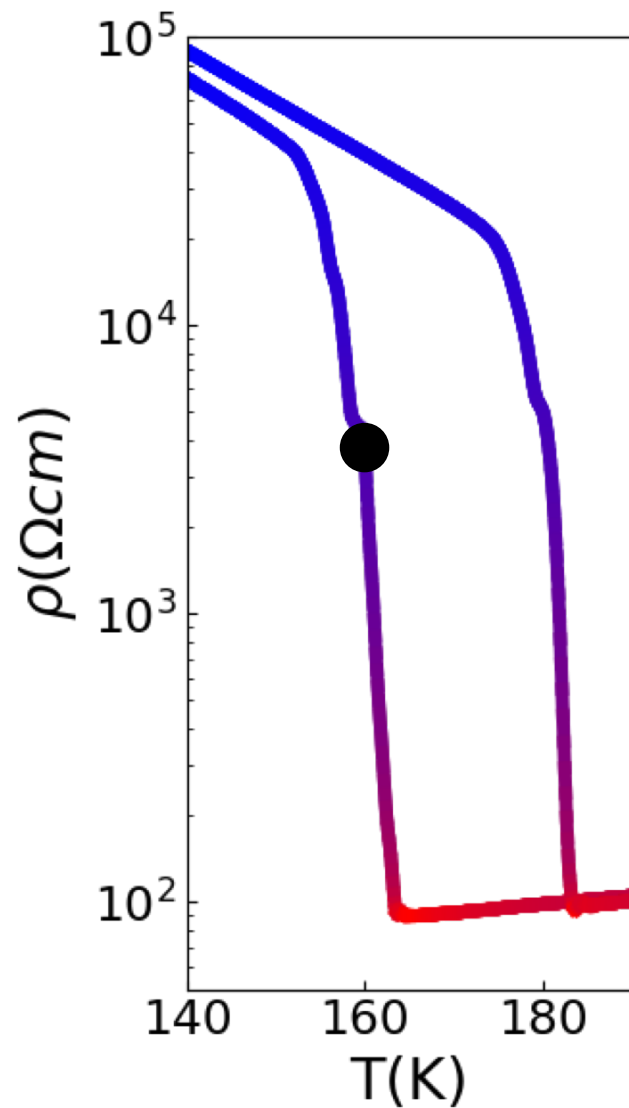
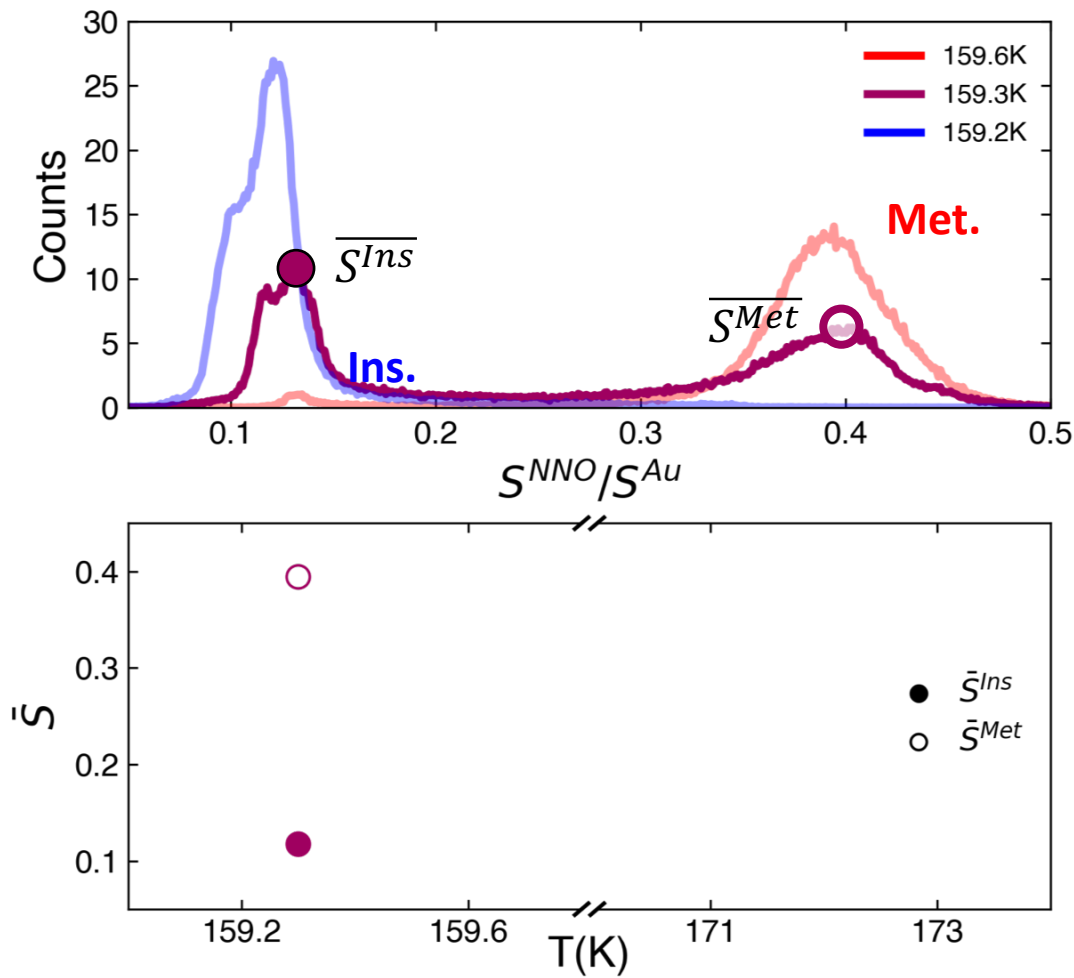
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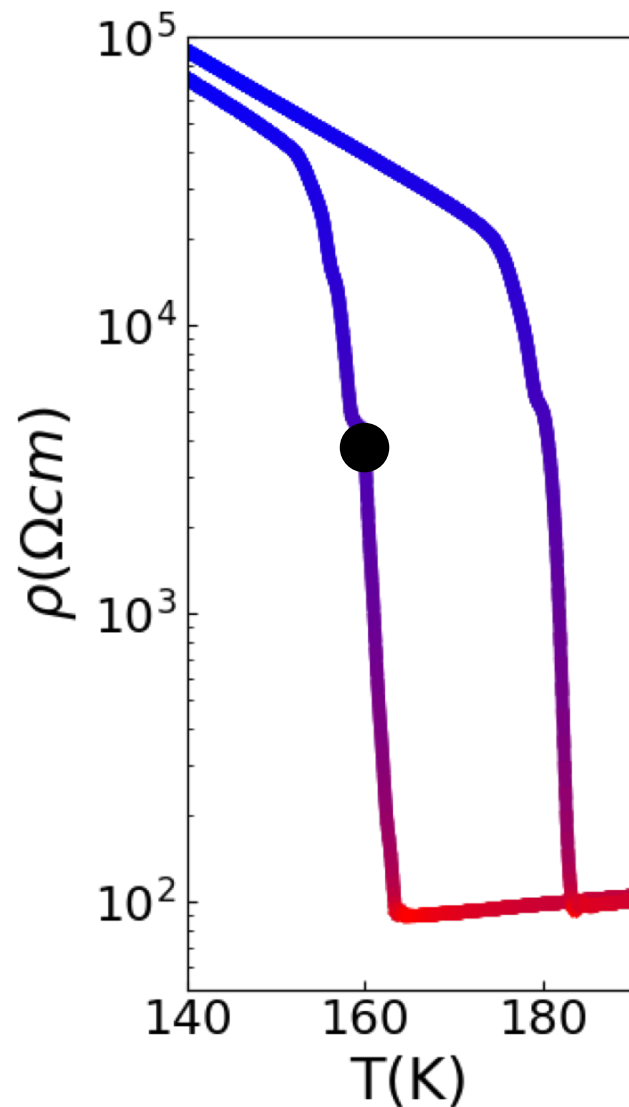
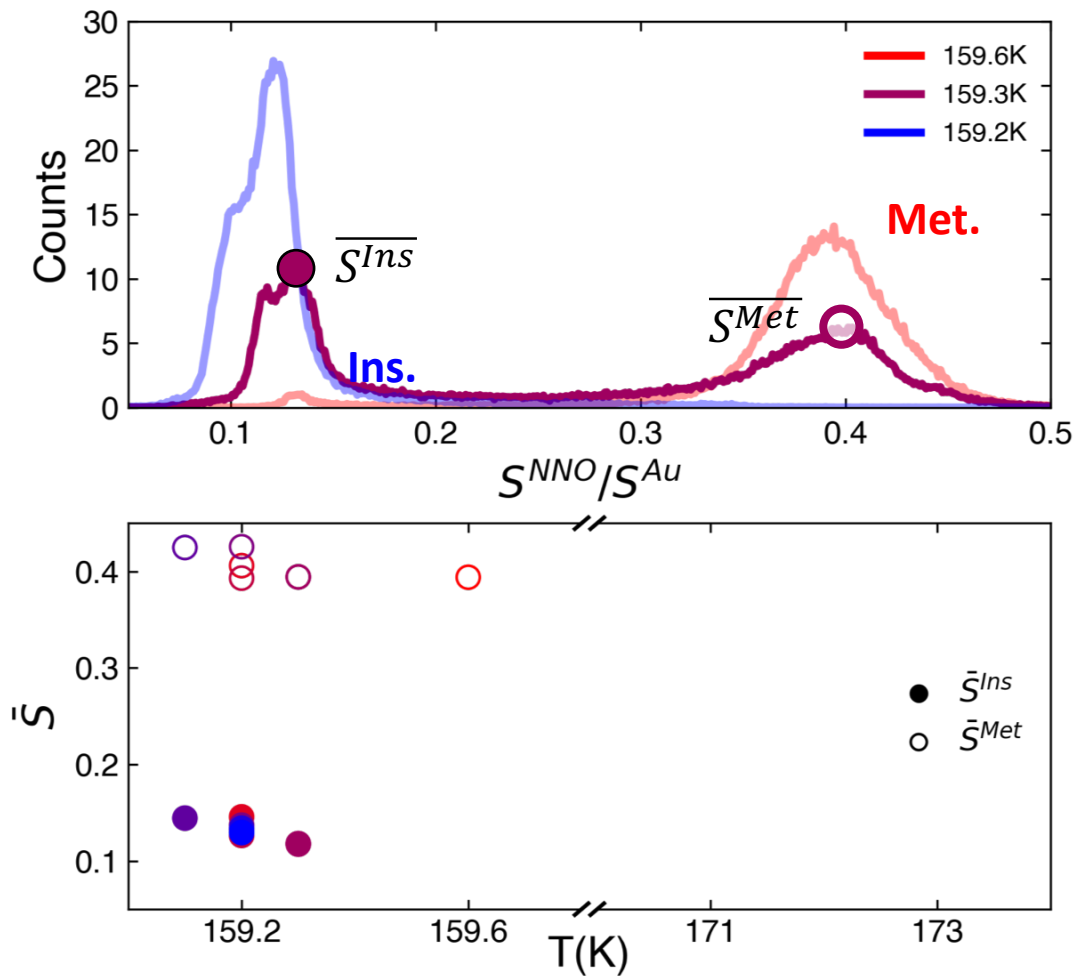
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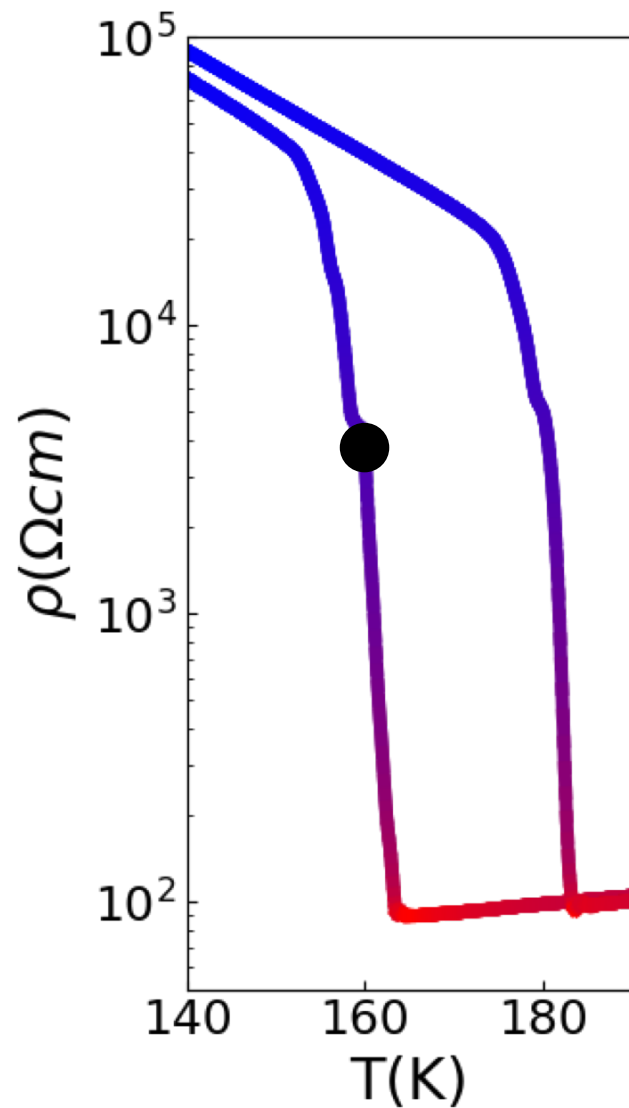
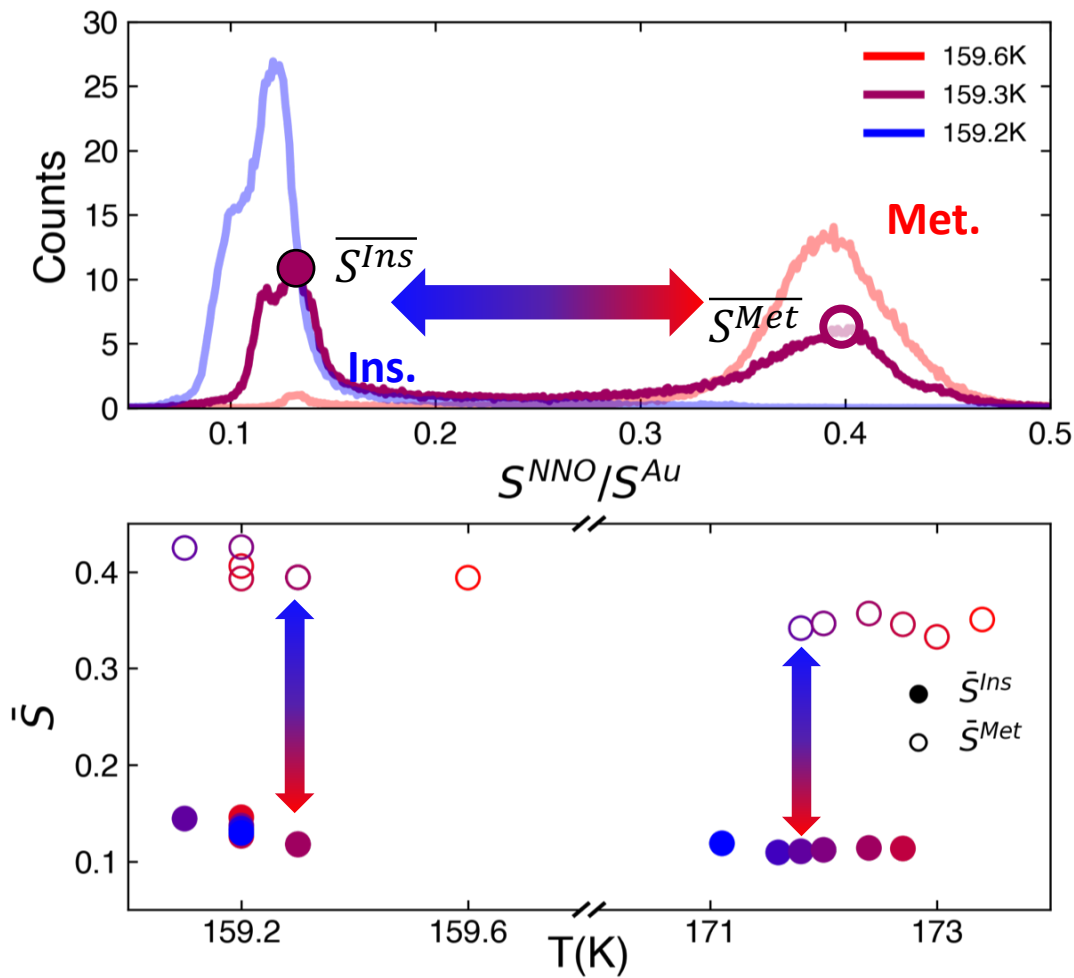
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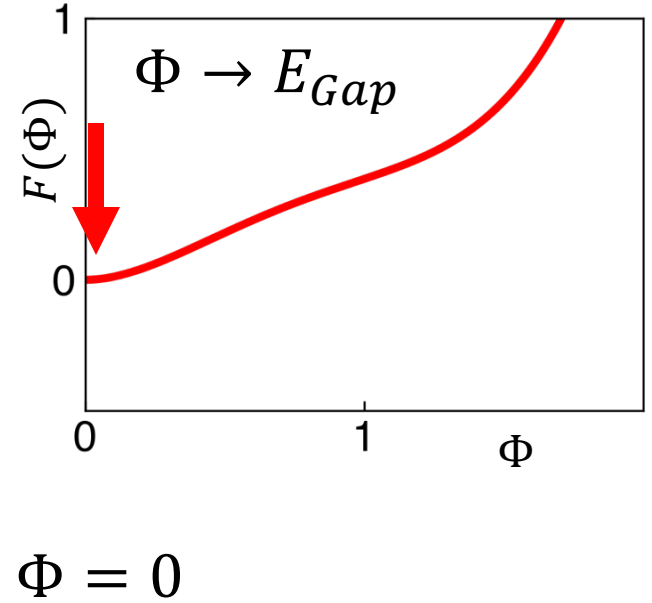
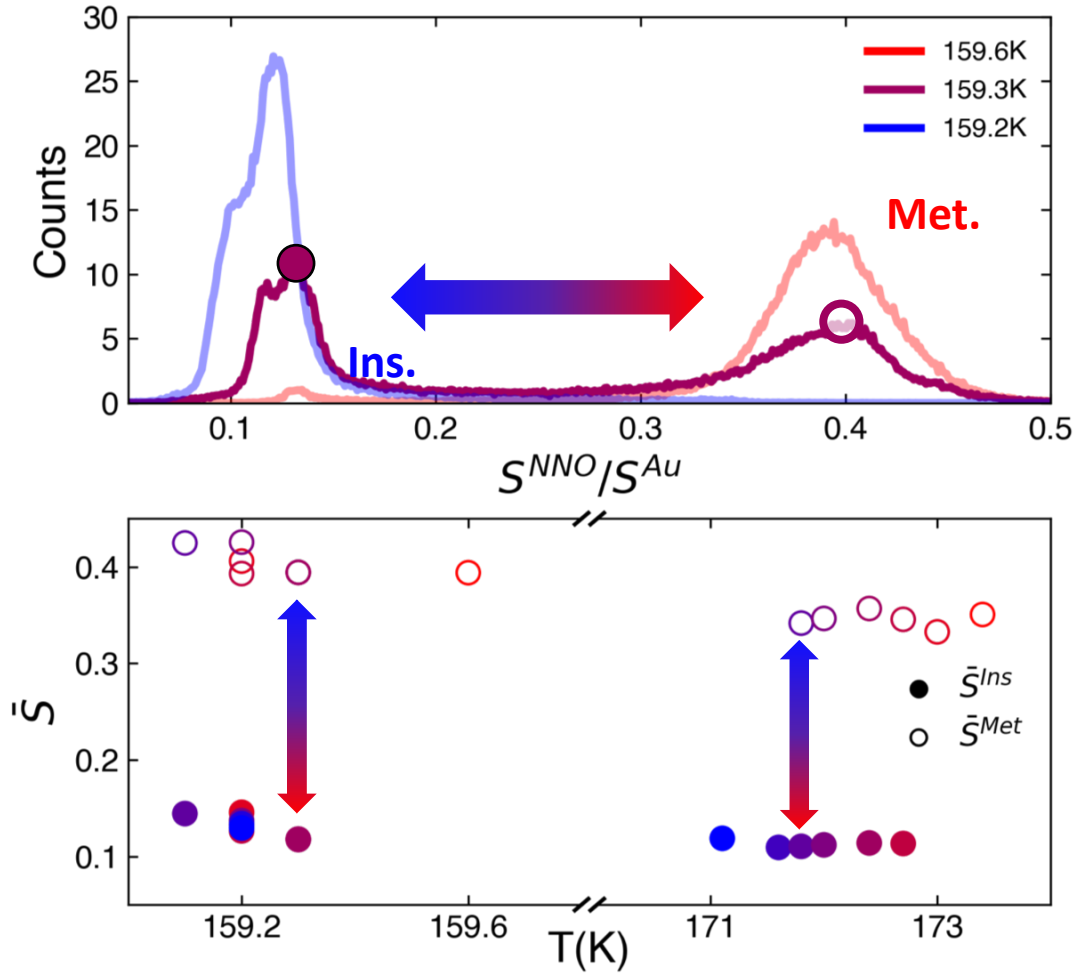
Percolative MIT in NdNiO₃



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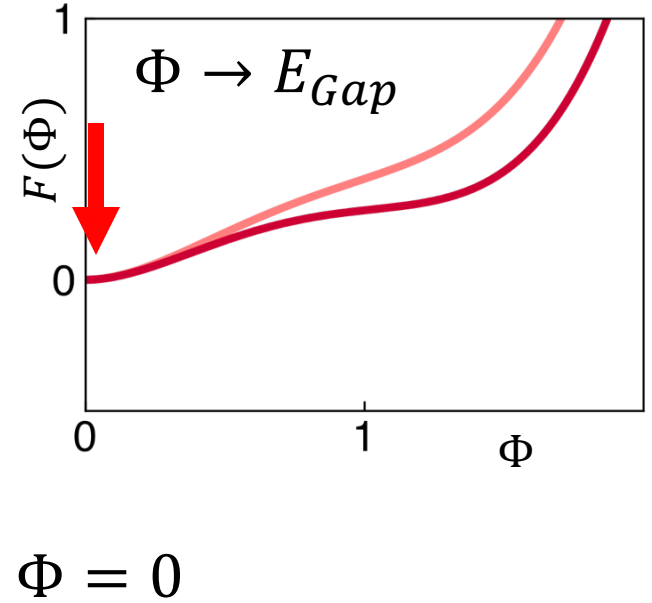
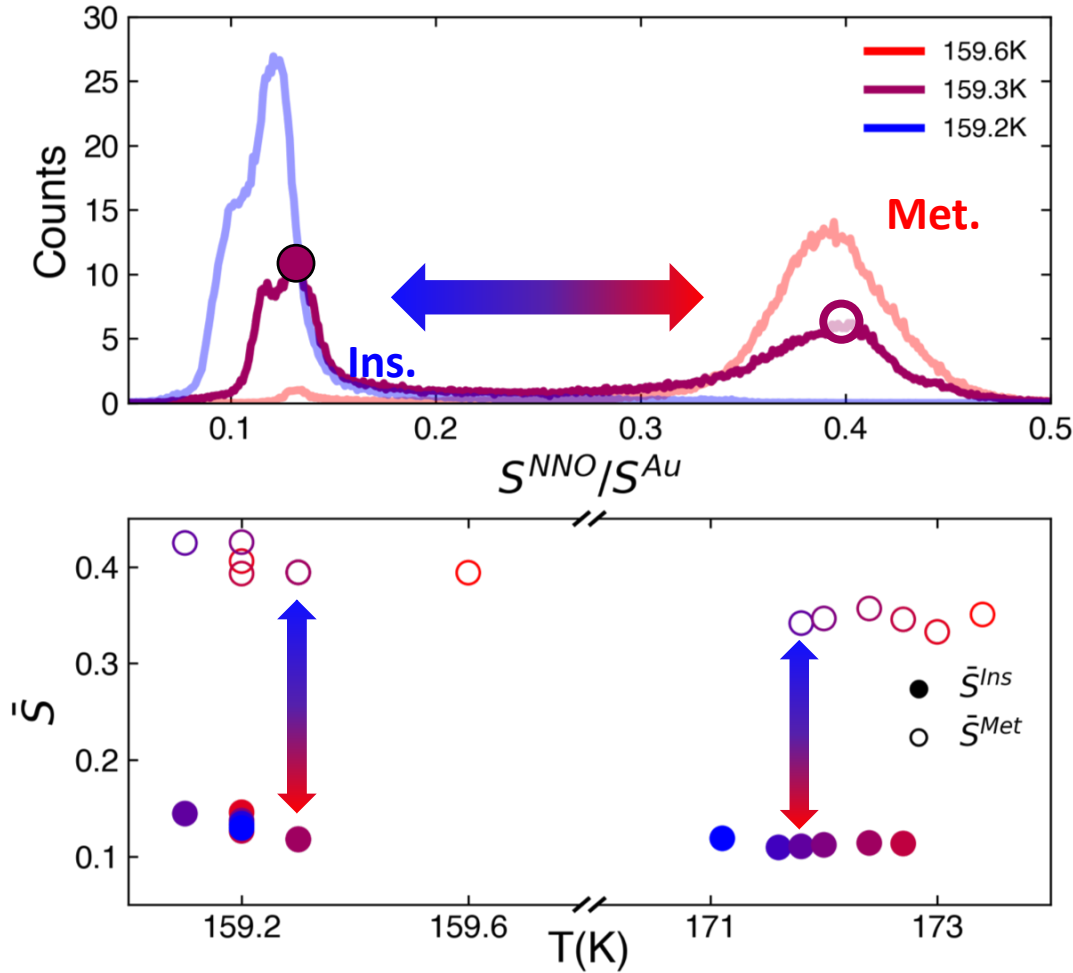


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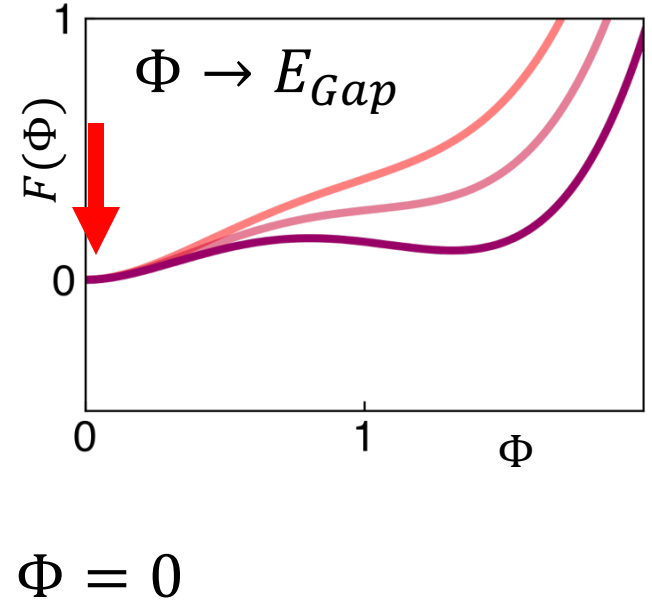
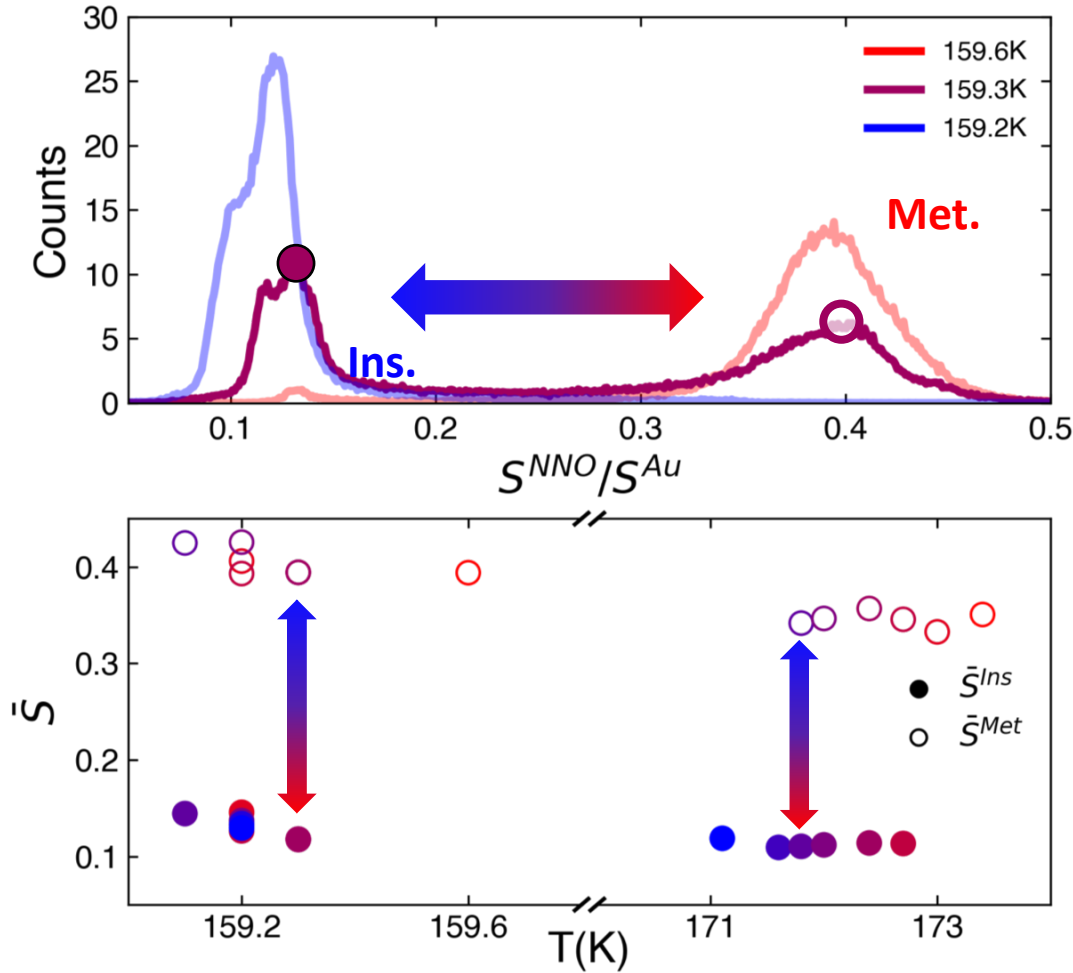


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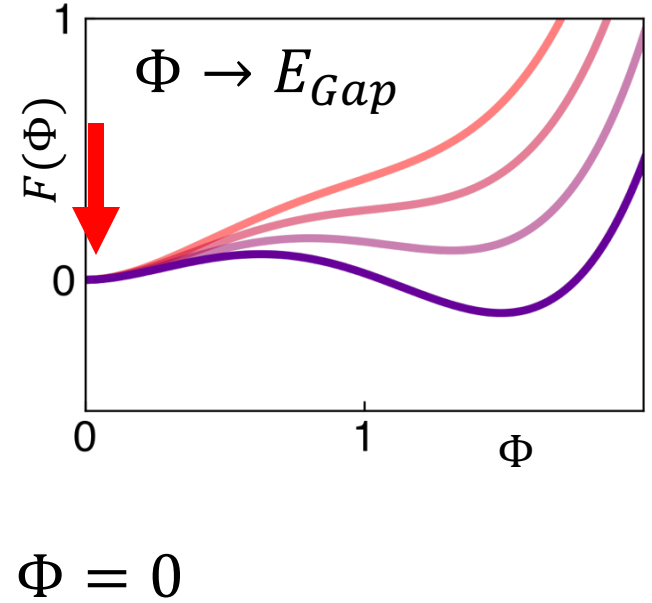
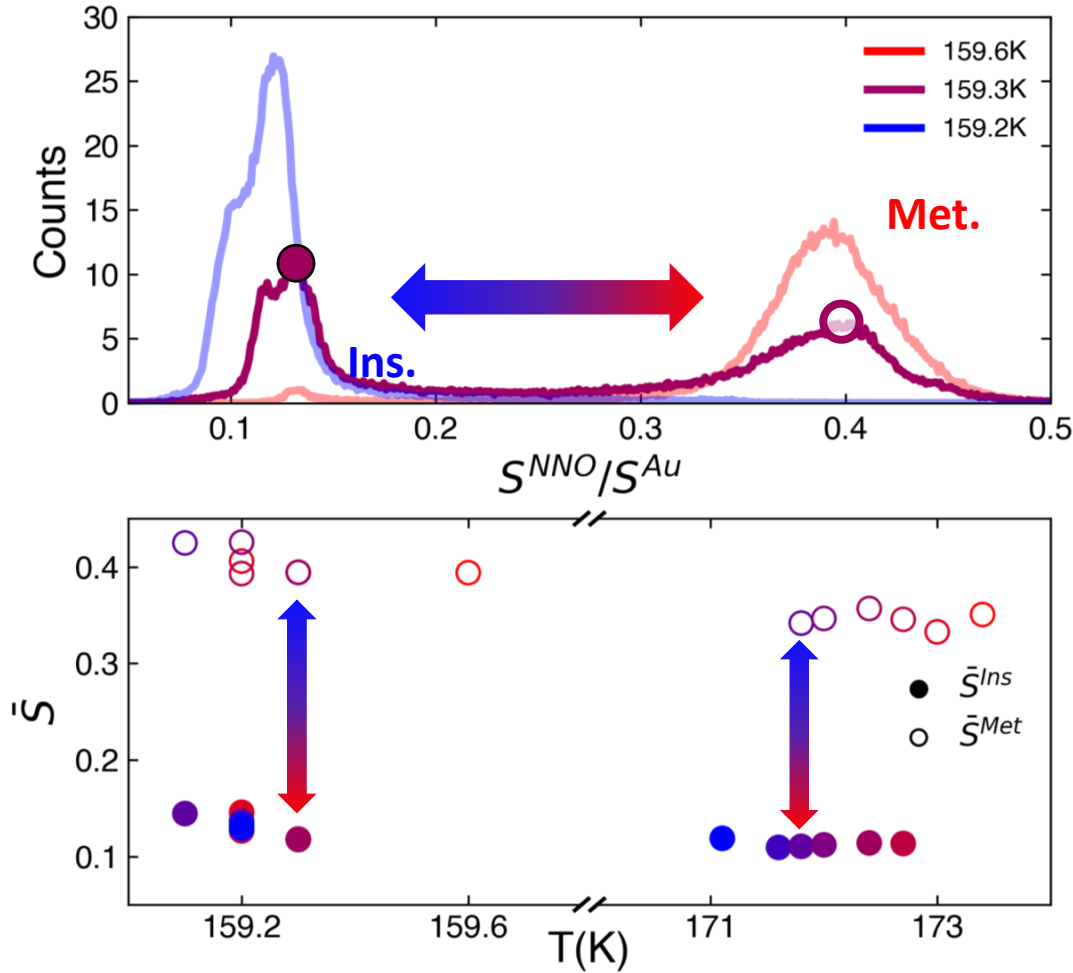
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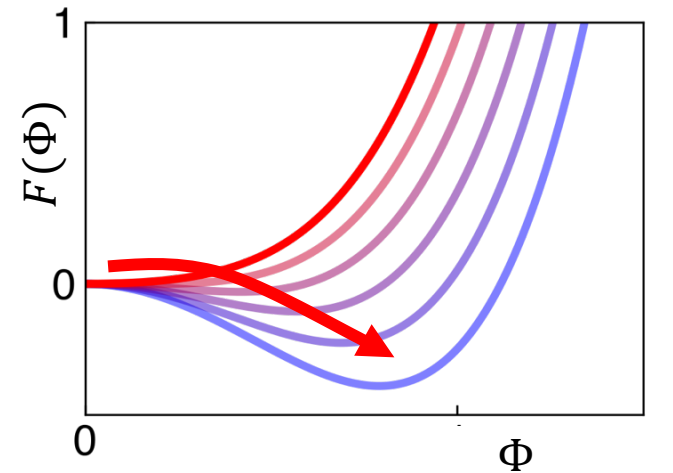
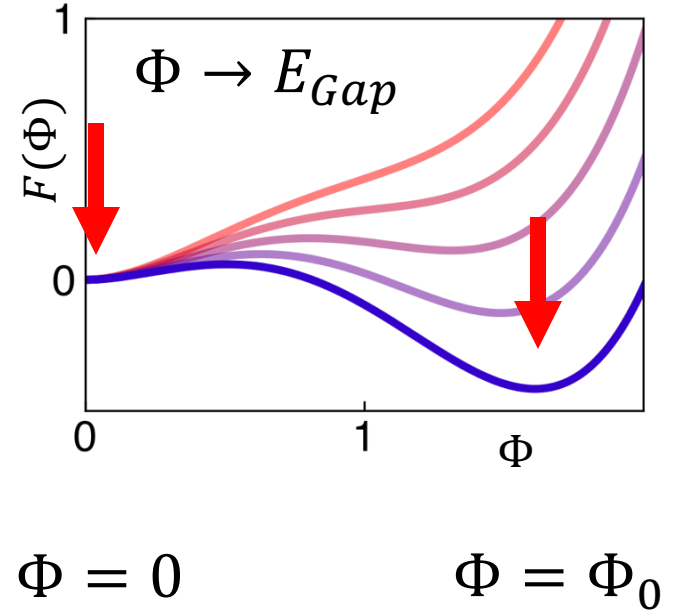
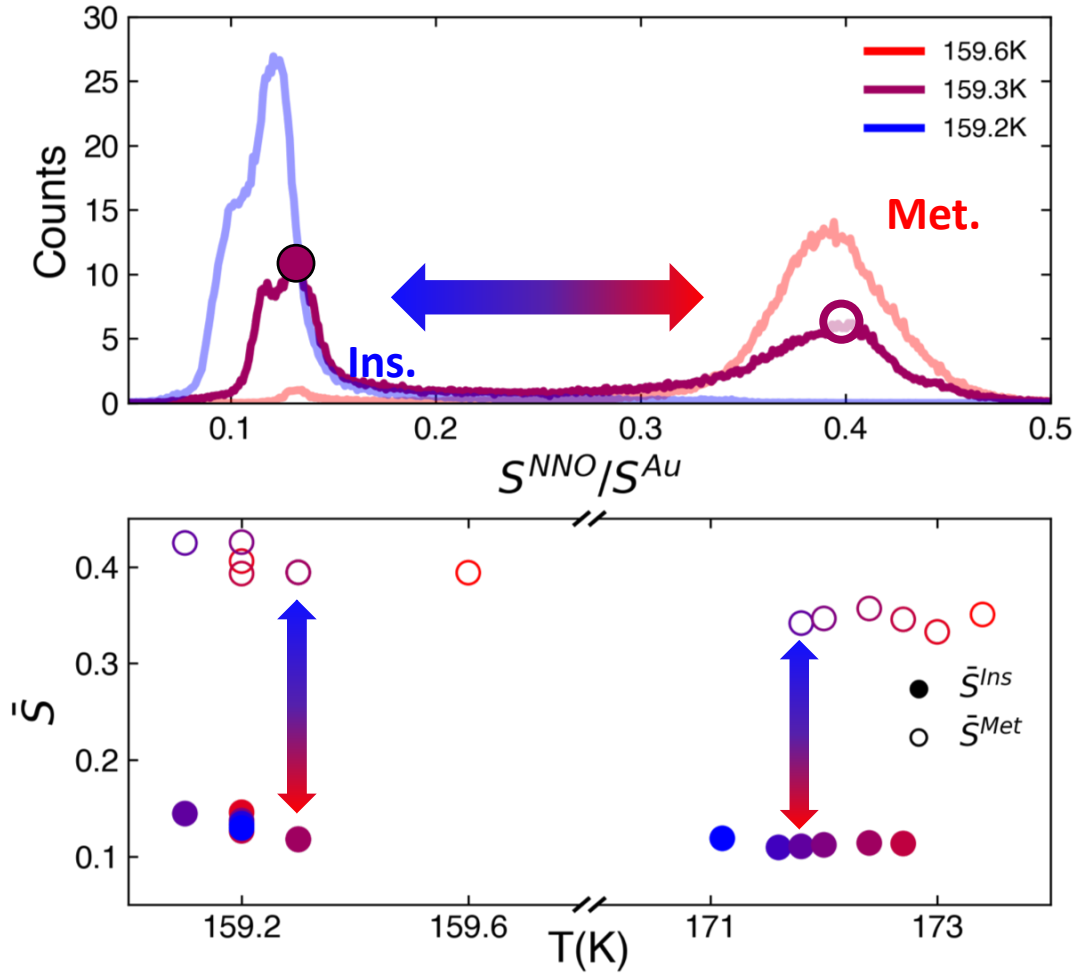
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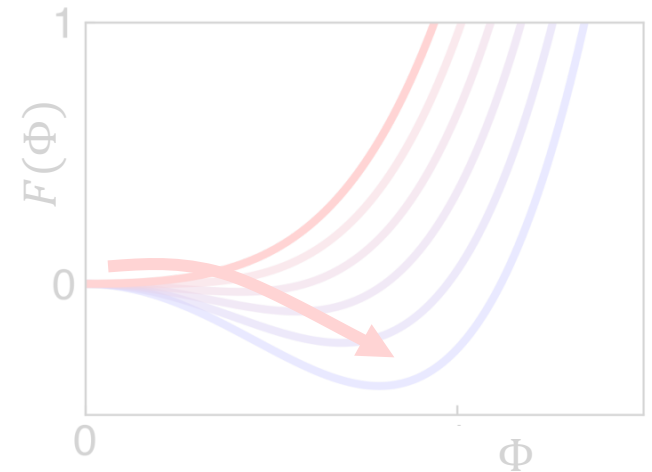
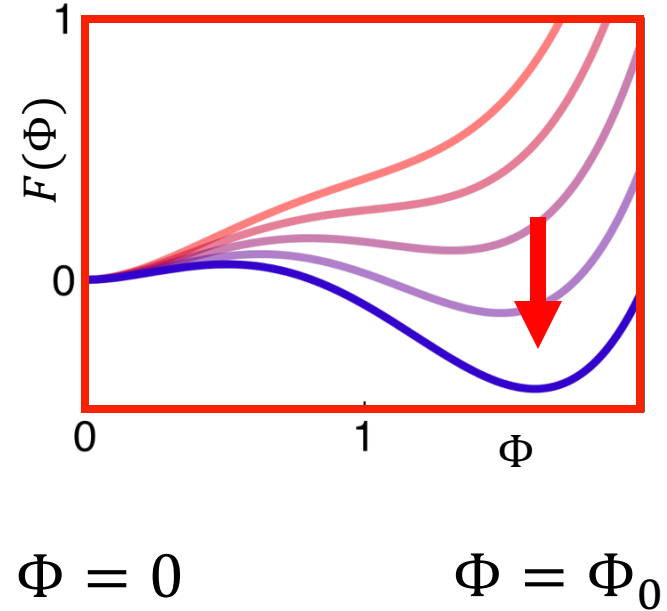
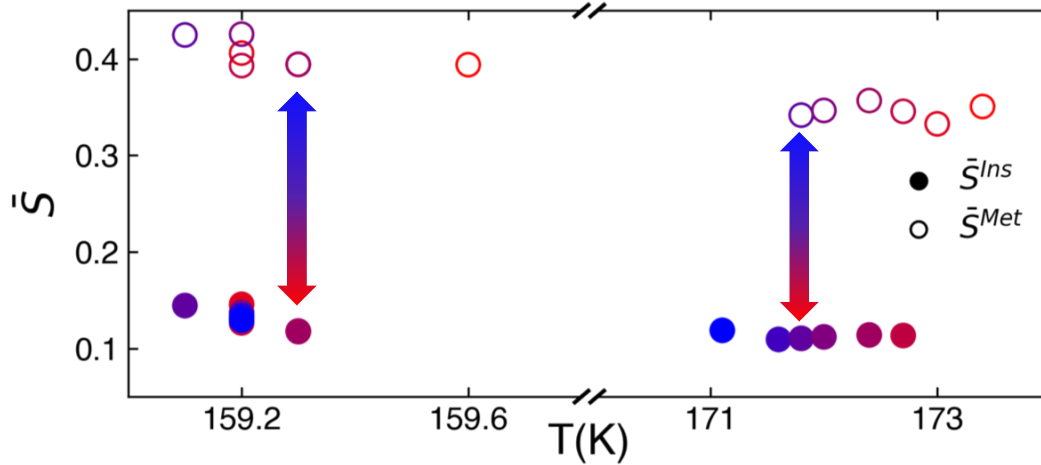
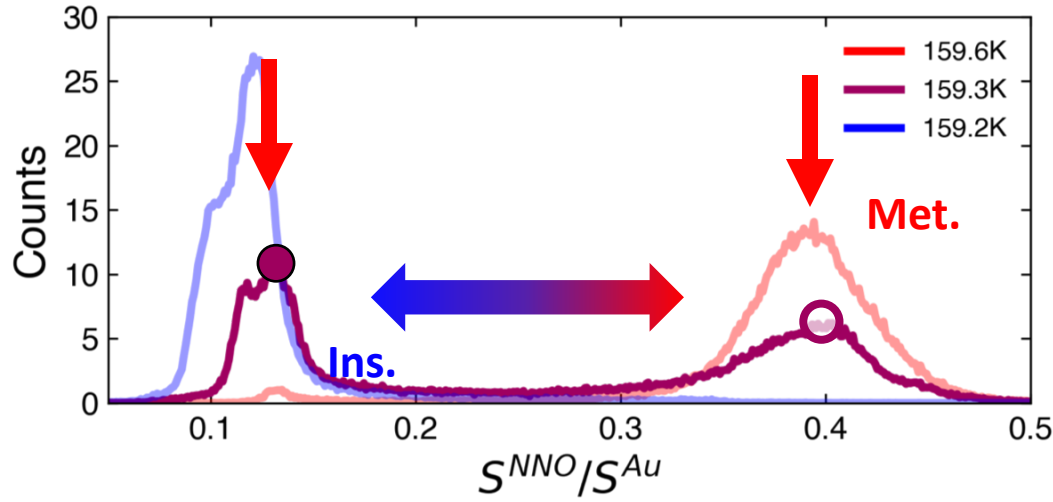


Percolative MIT in NdNiO₃



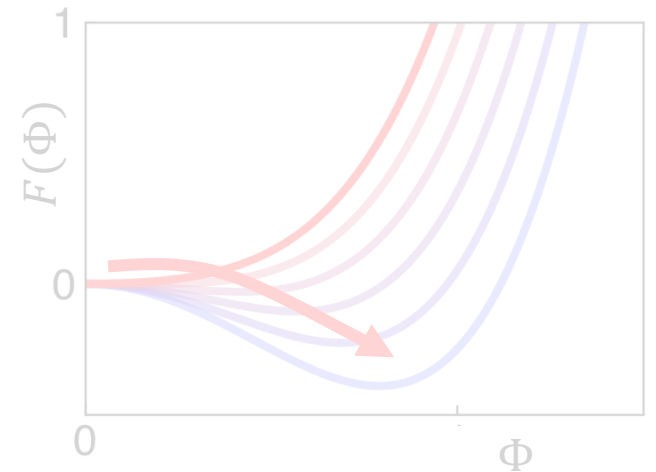
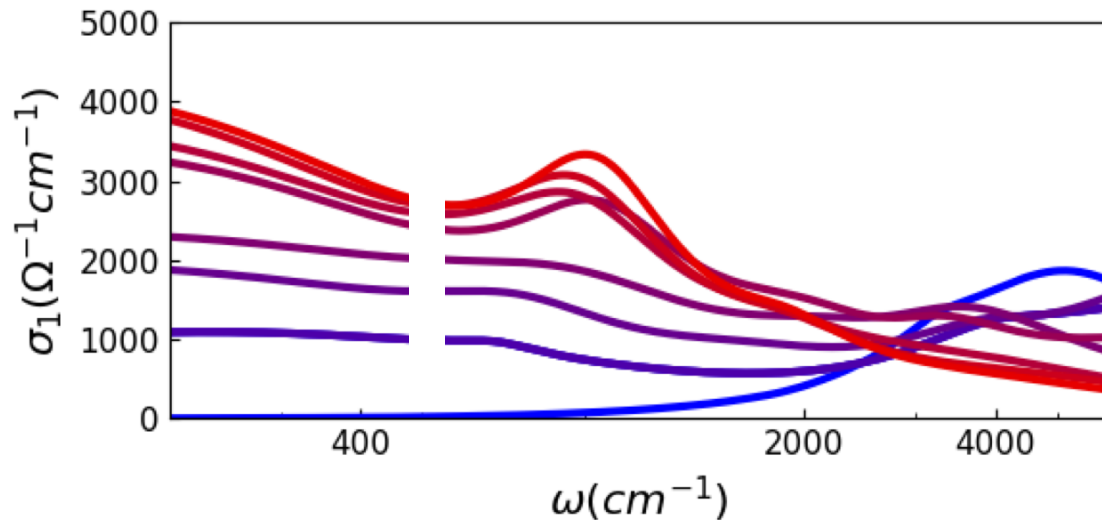
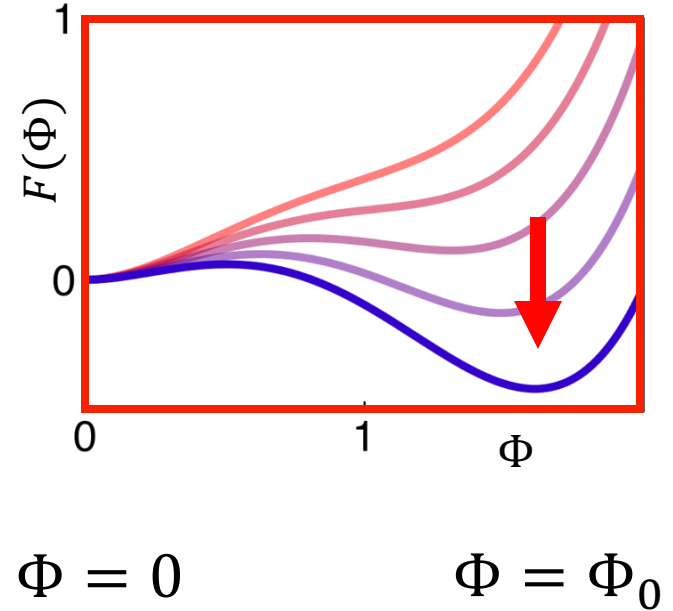
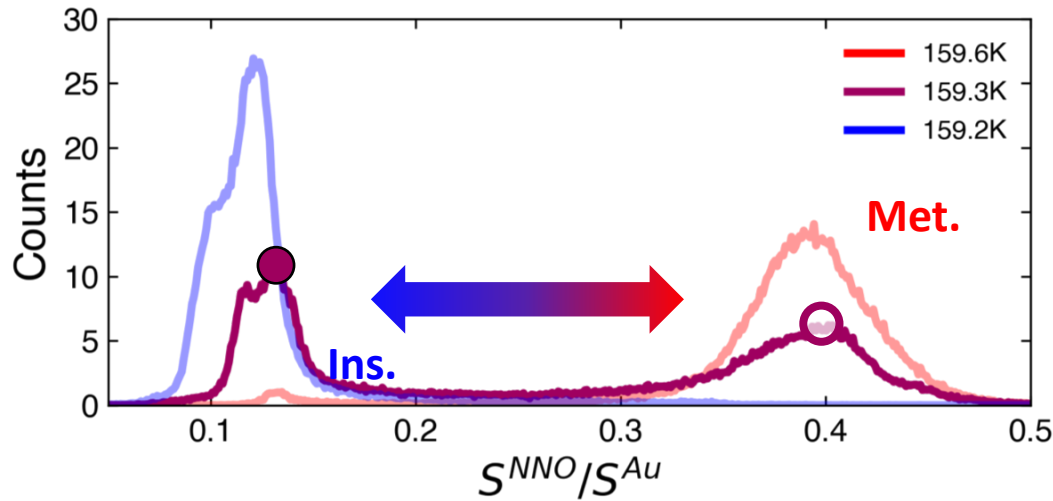
Percolative MIT in NdNiO₃

Ideally 1st order phase transition



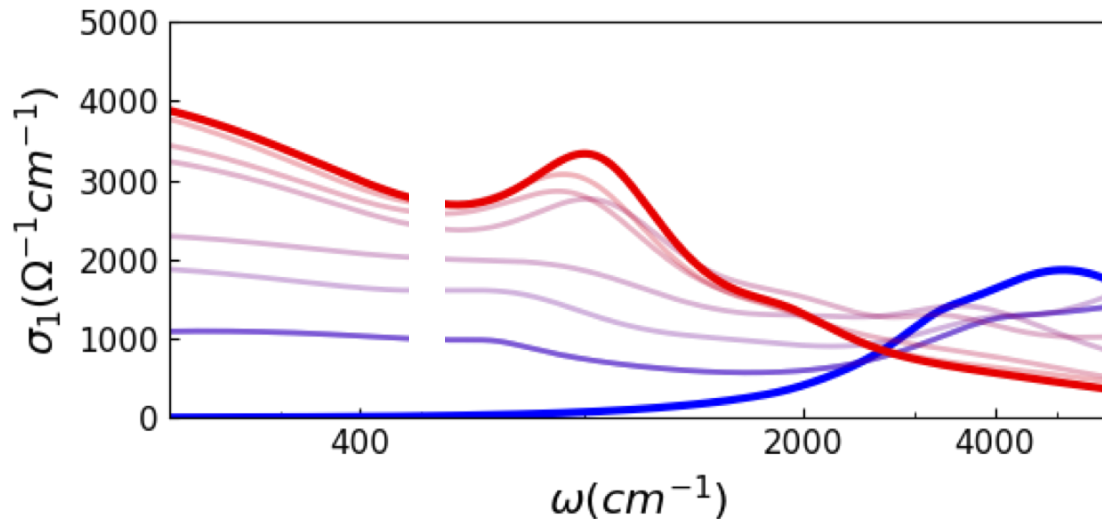
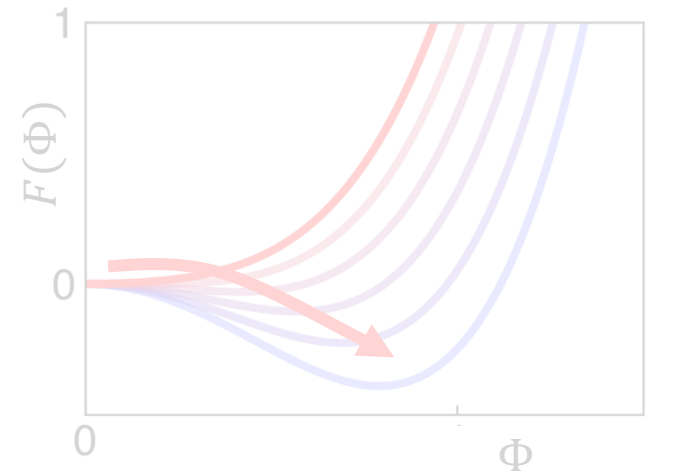
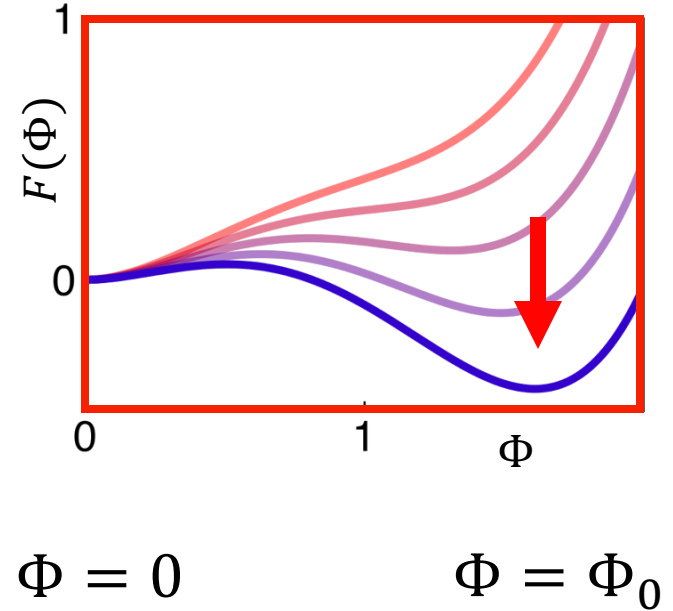
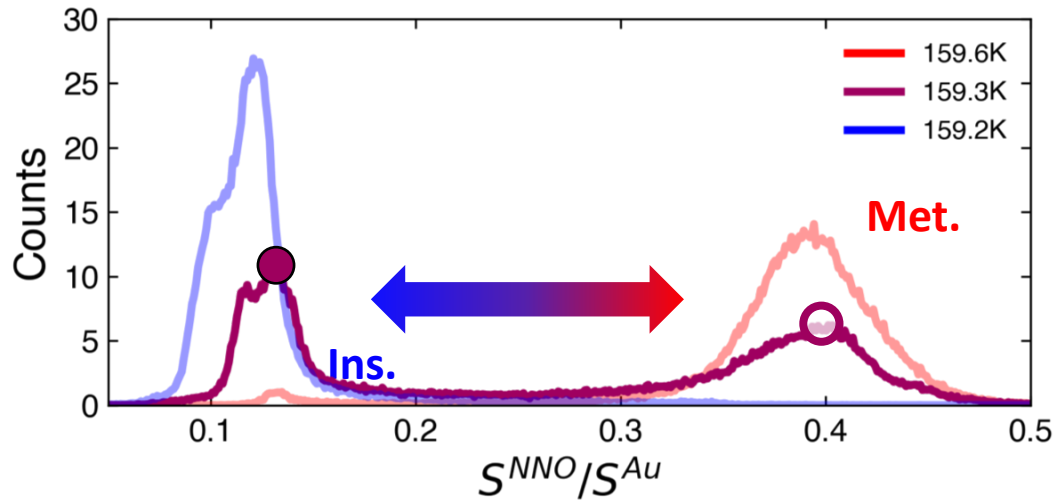
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Ideally 1st order phase transition



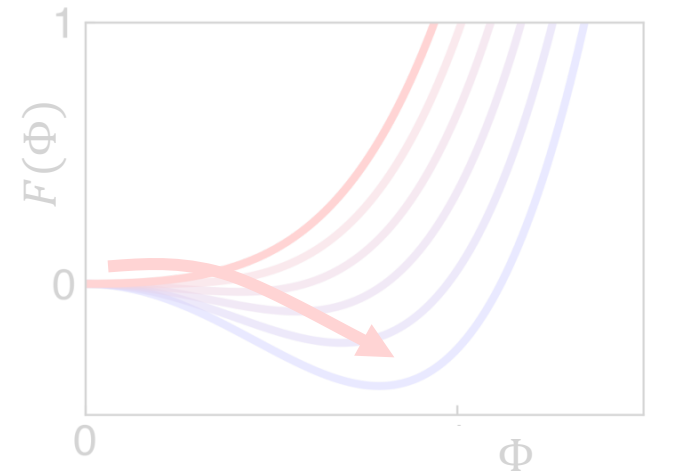
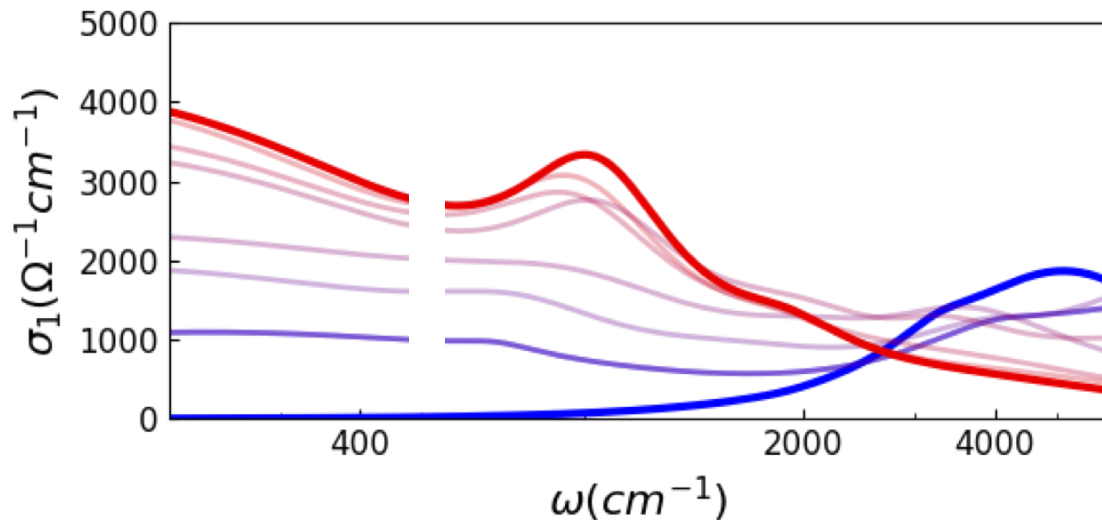
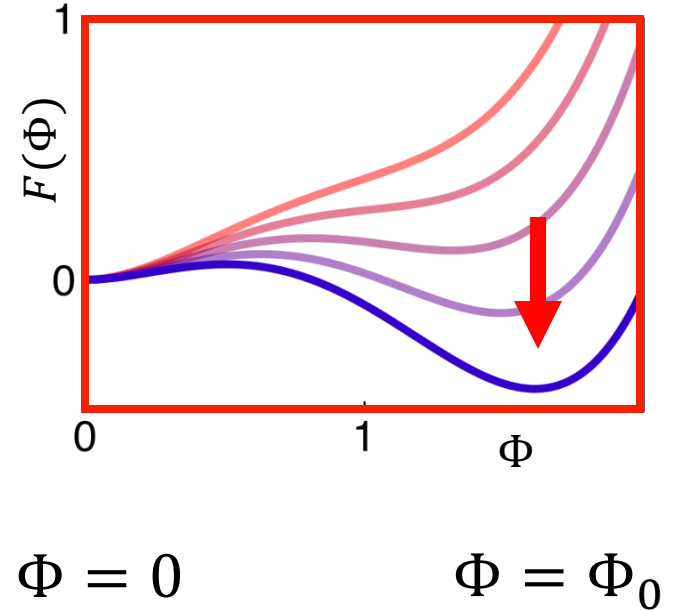
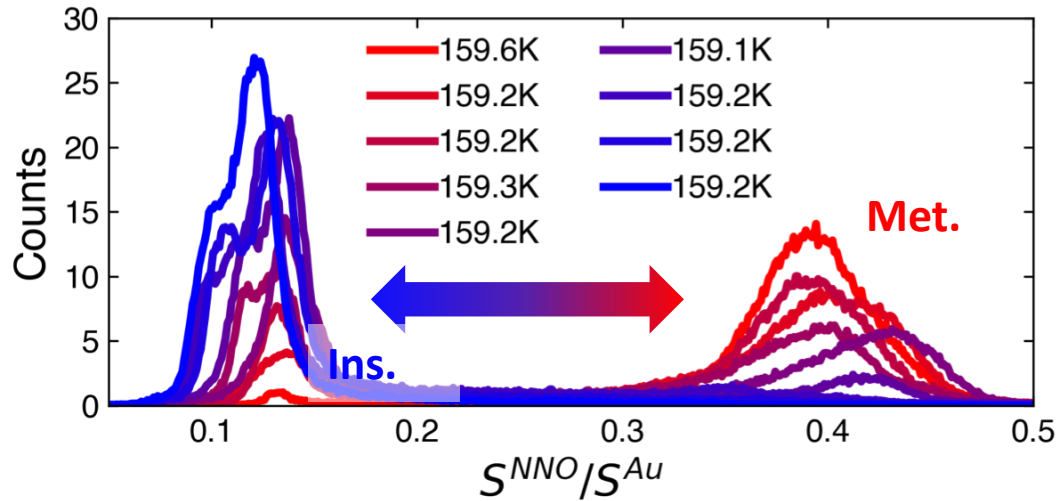
Percolative MIT in NdNiO_3

Ideally 1st order phase transition



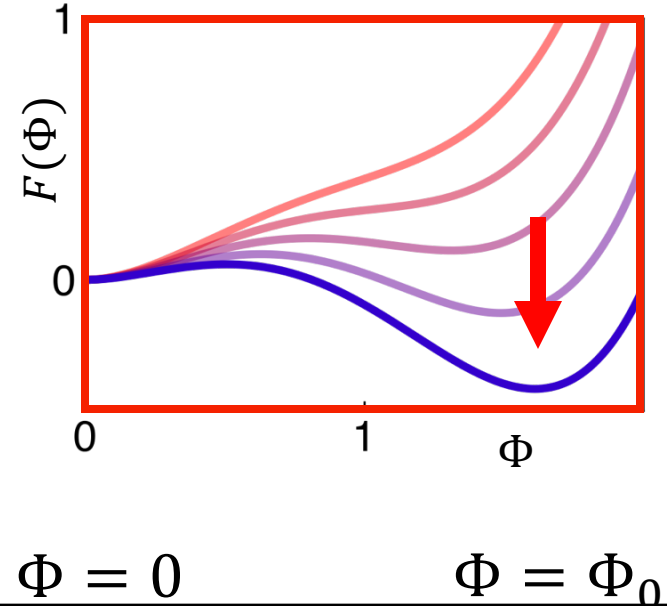
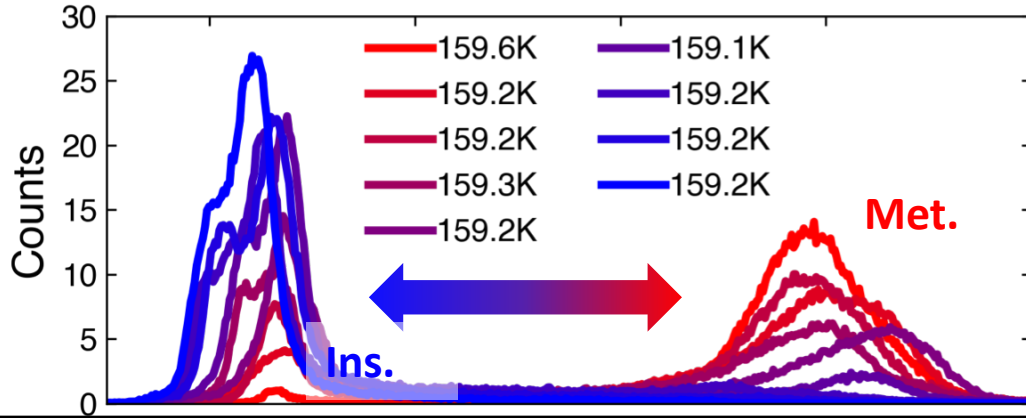
Percolative MIT in NdNiO₃

Ideally 1st order phase transition

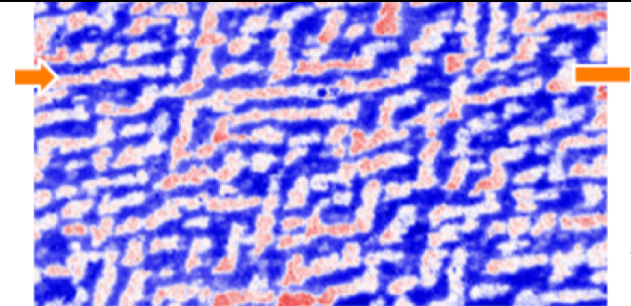
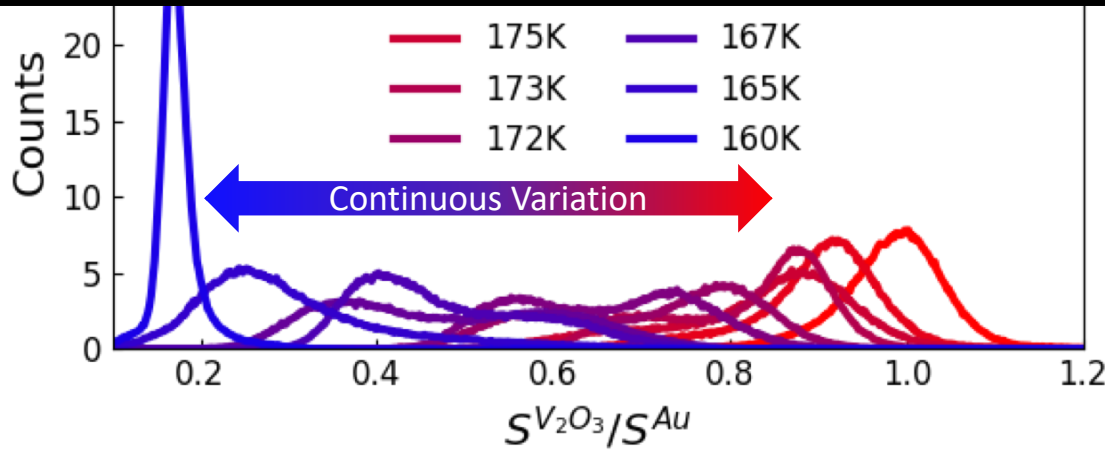


Percolative MIT in NdNiO₃

Ideally 1st order phase transition

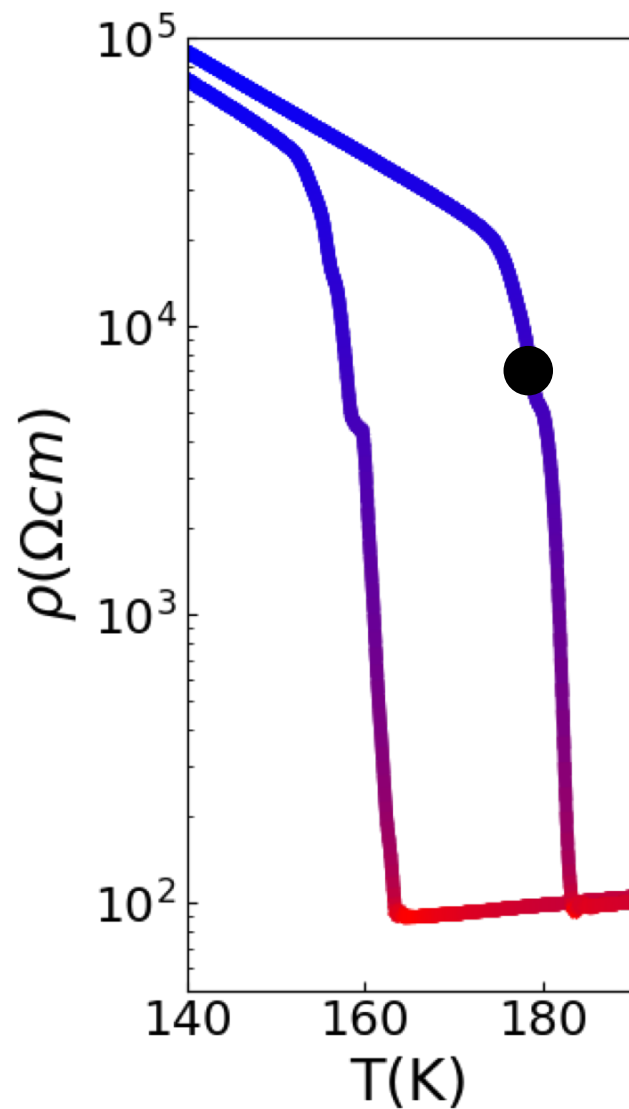
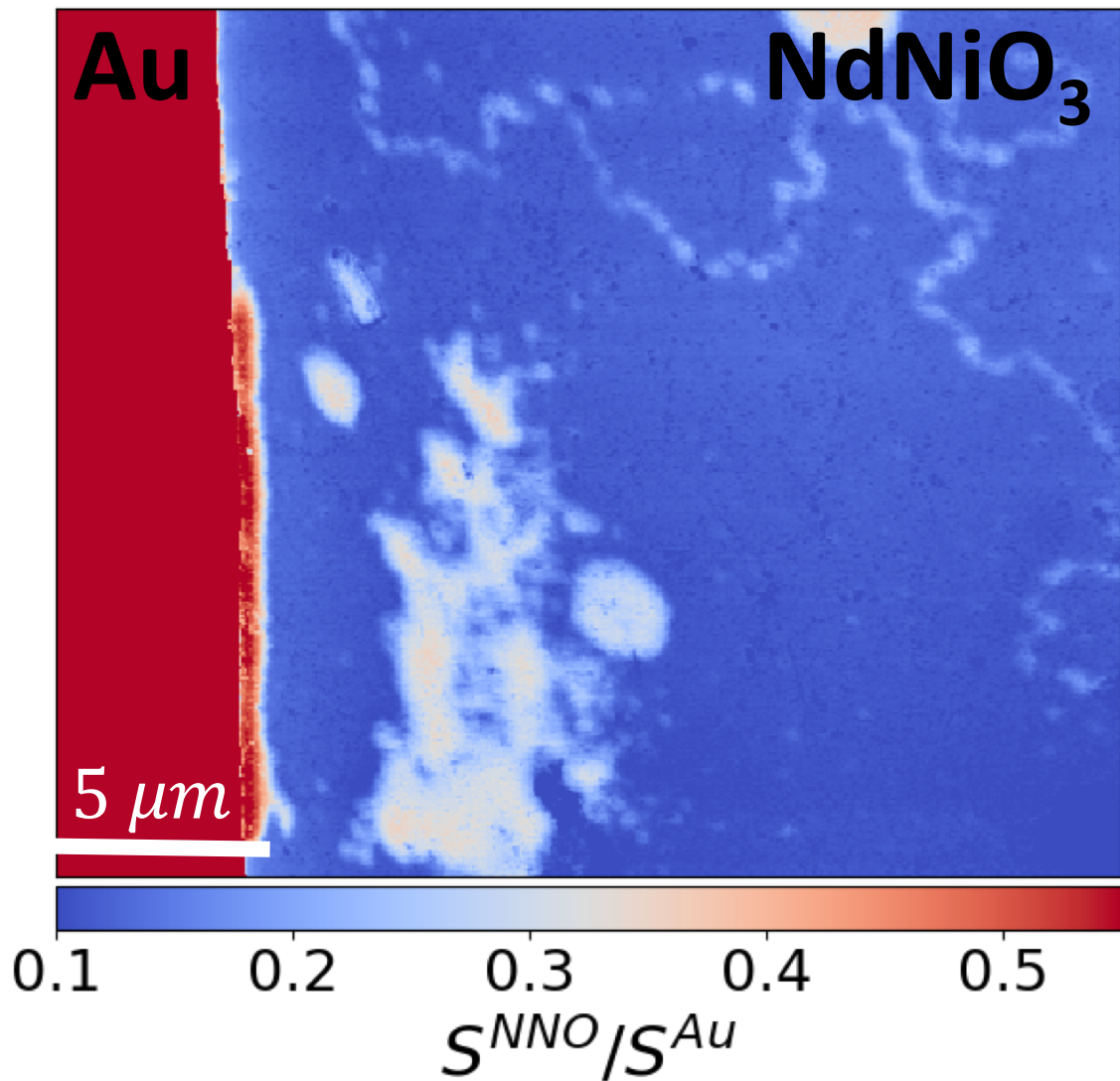


Near field imaging has revealed the discrete, 1st order nature of the phase transition in NdNiO₃

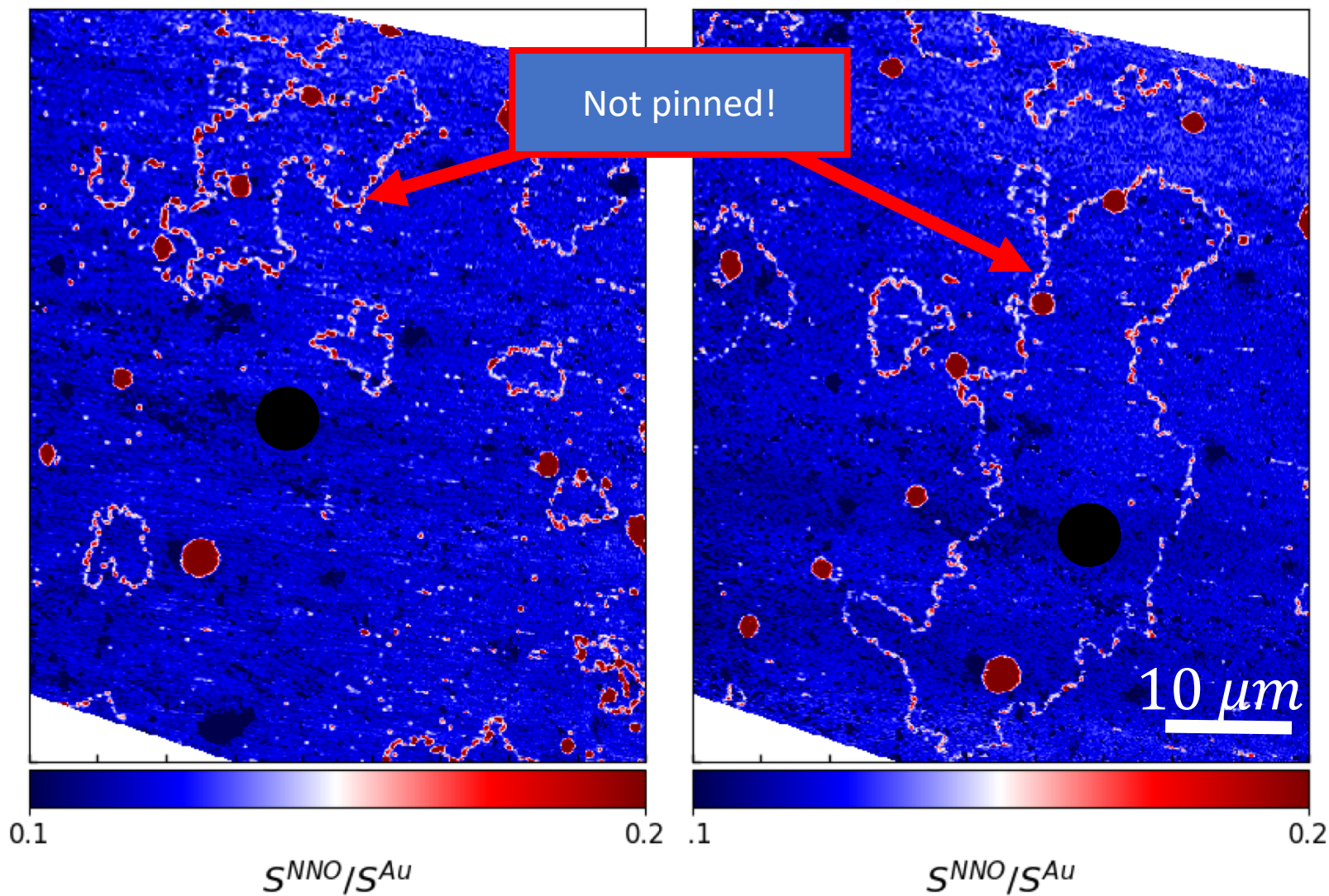


A.S. Mcleod, Nat. Phys. 2017
 Kurt Binder, Rep. Prog. Phys. (1987)

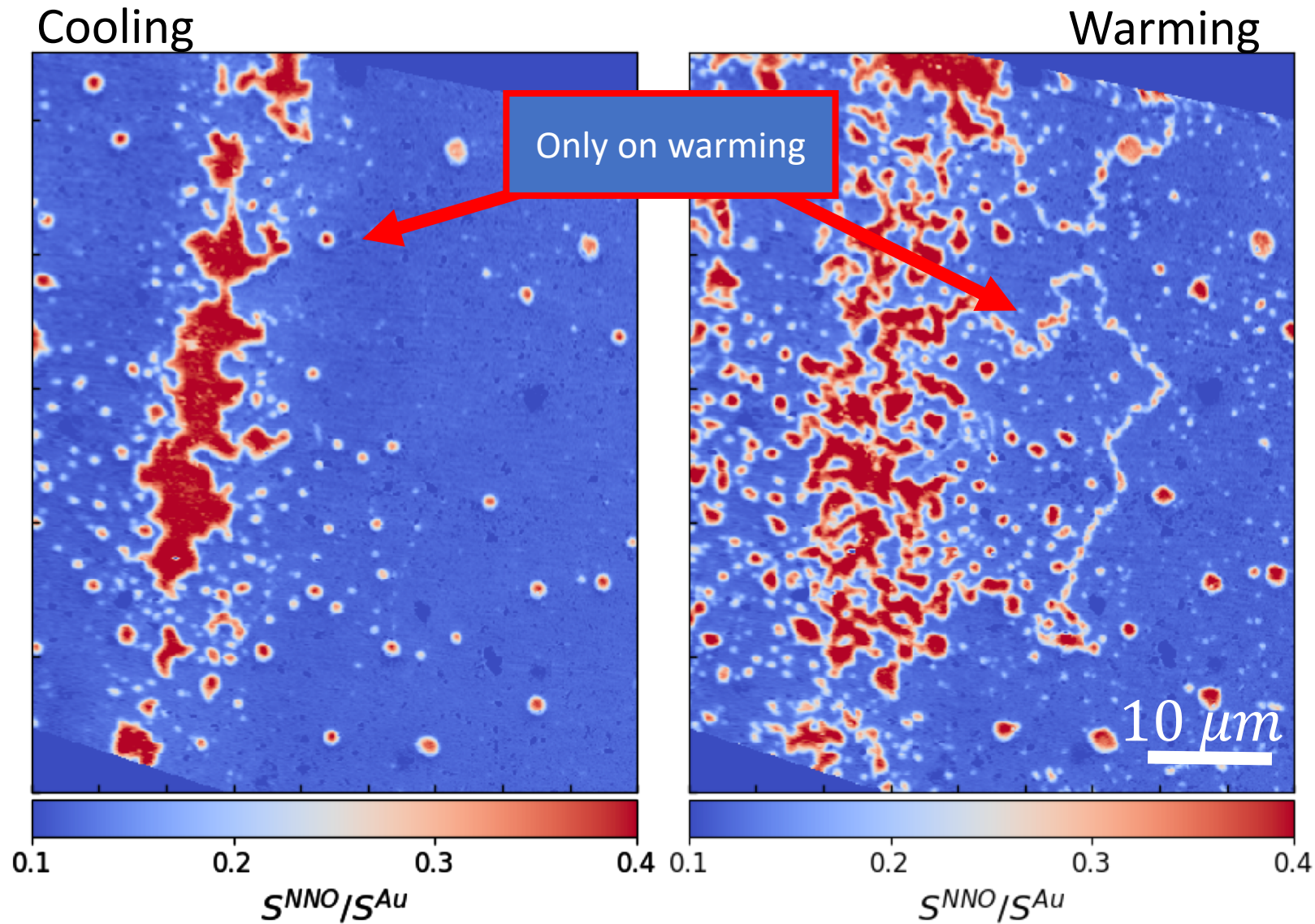
NdNiO₃: Conducting Channels



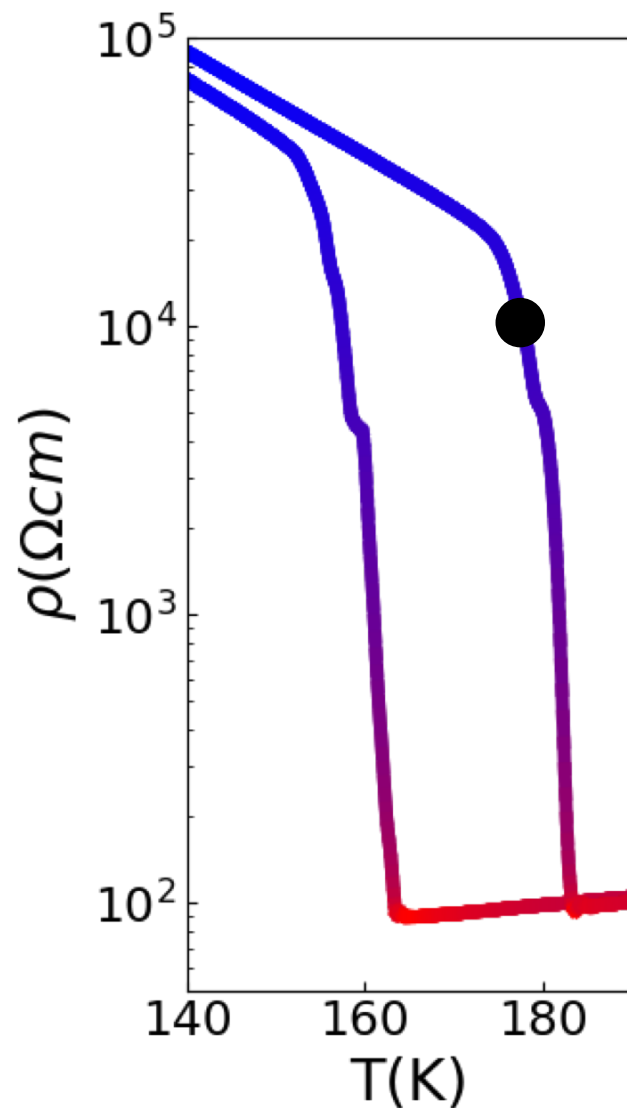
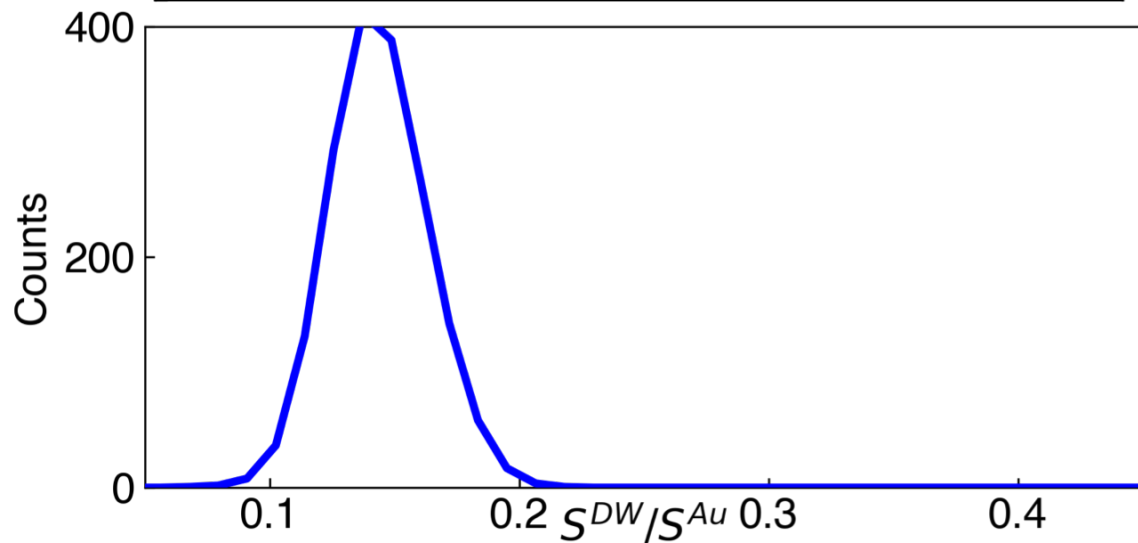
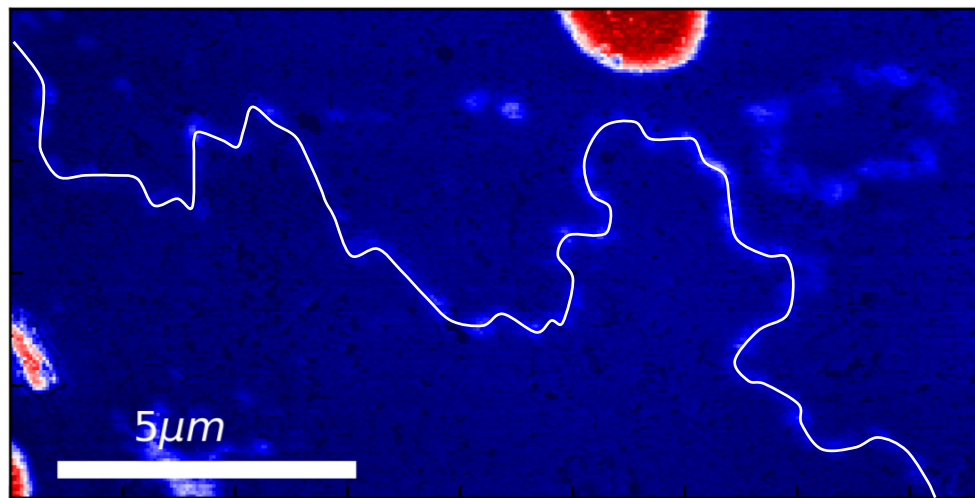
NdNiO₃: Conducting Channels



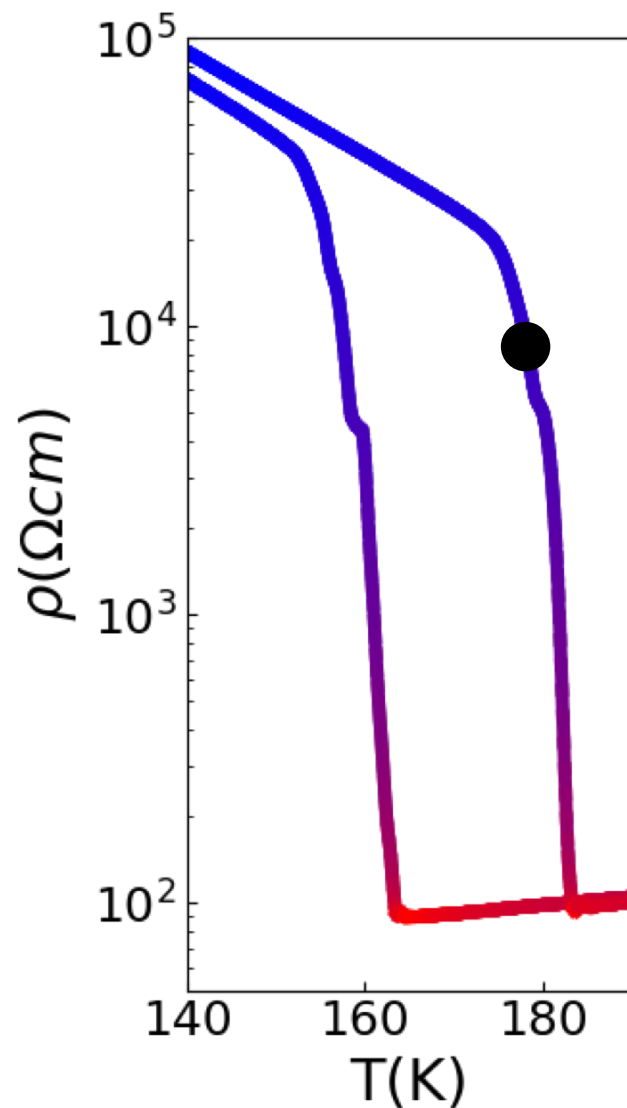
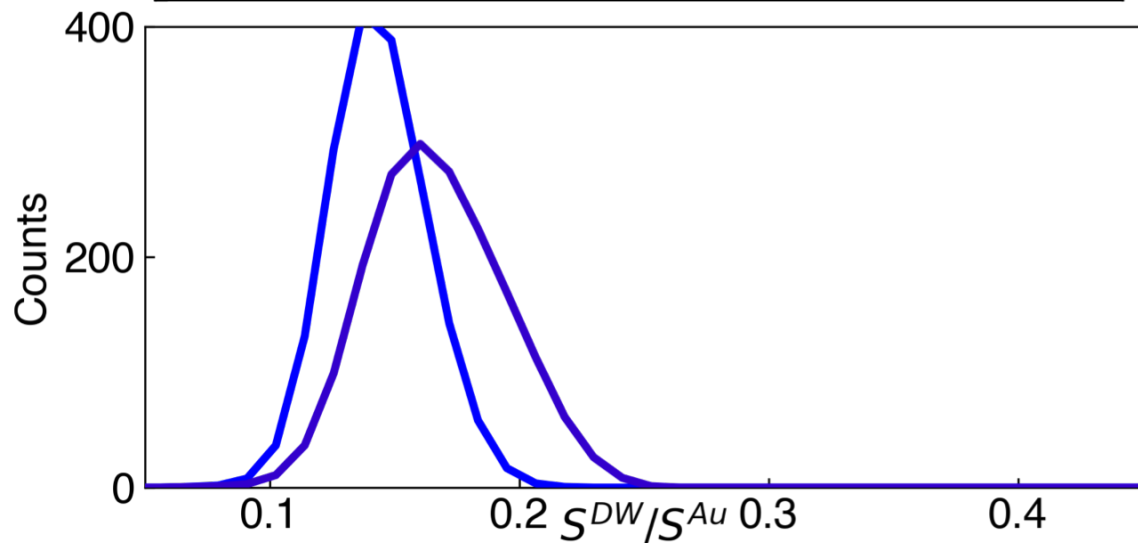
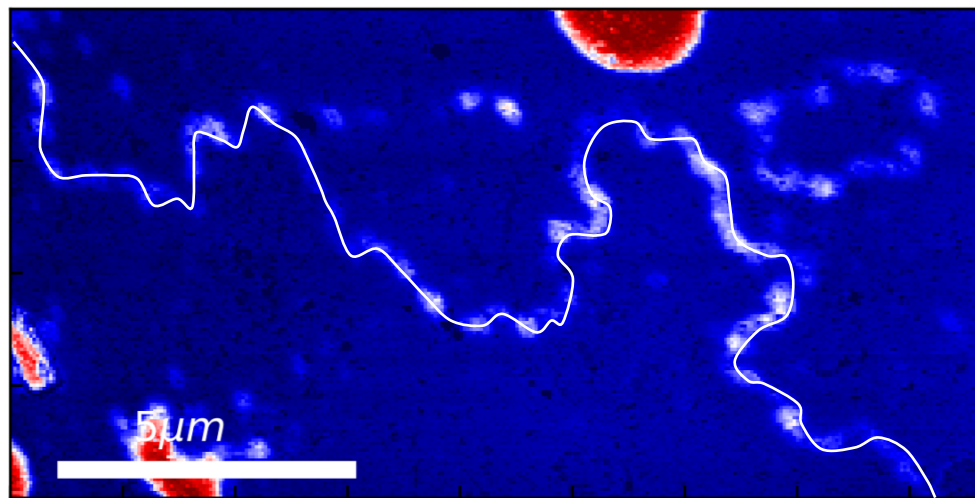
NdNiO₃: Conducting Channels



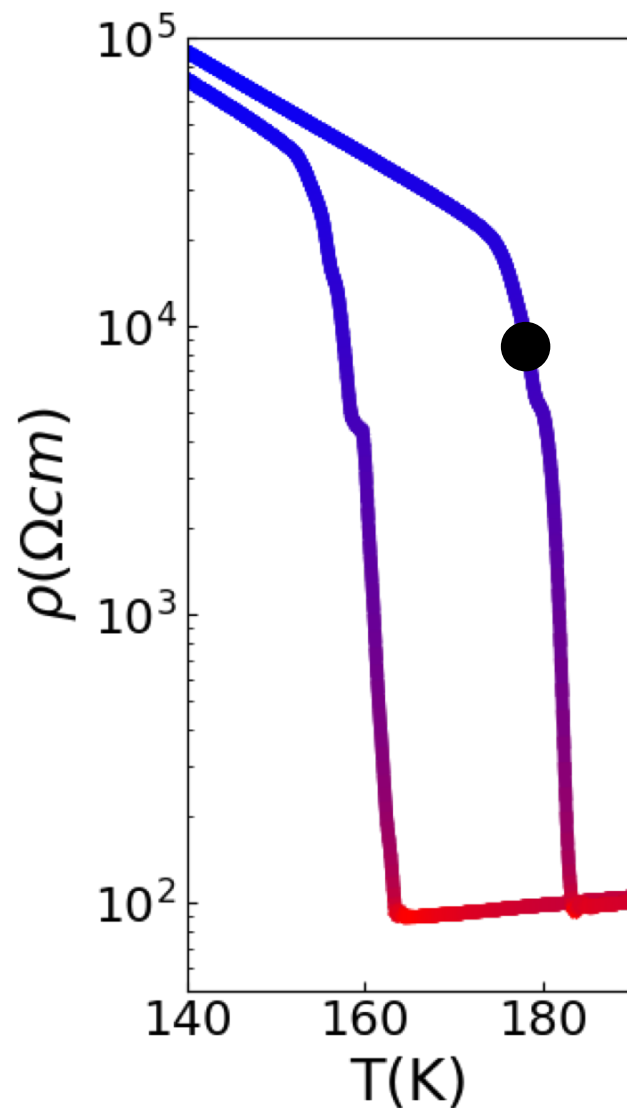
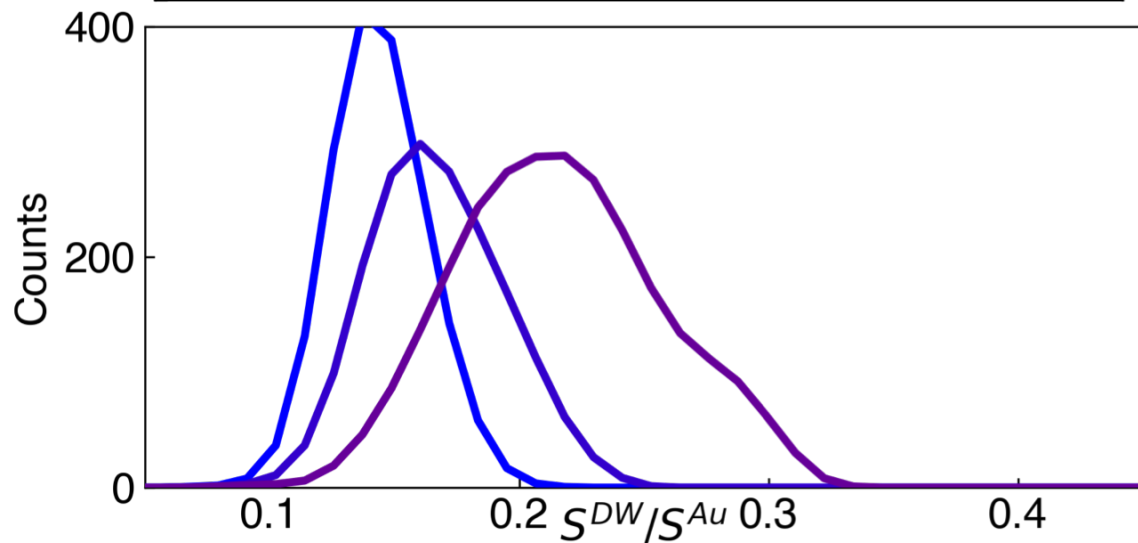
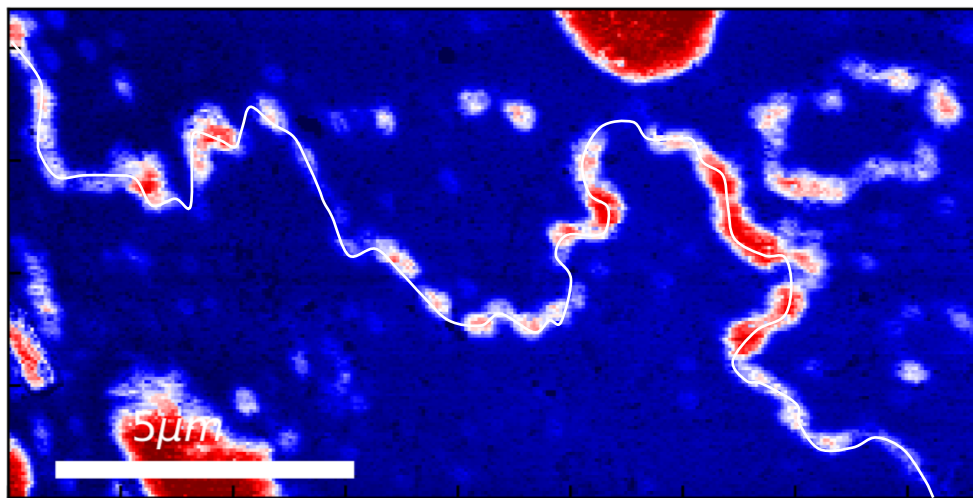
NdNiO₃: Conducting Channels



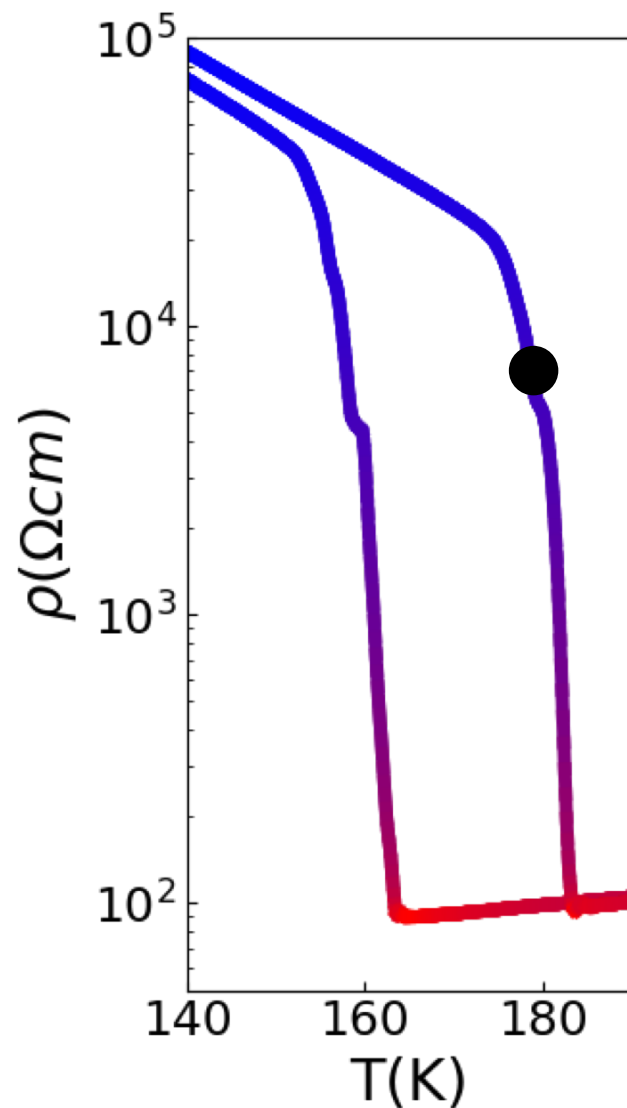
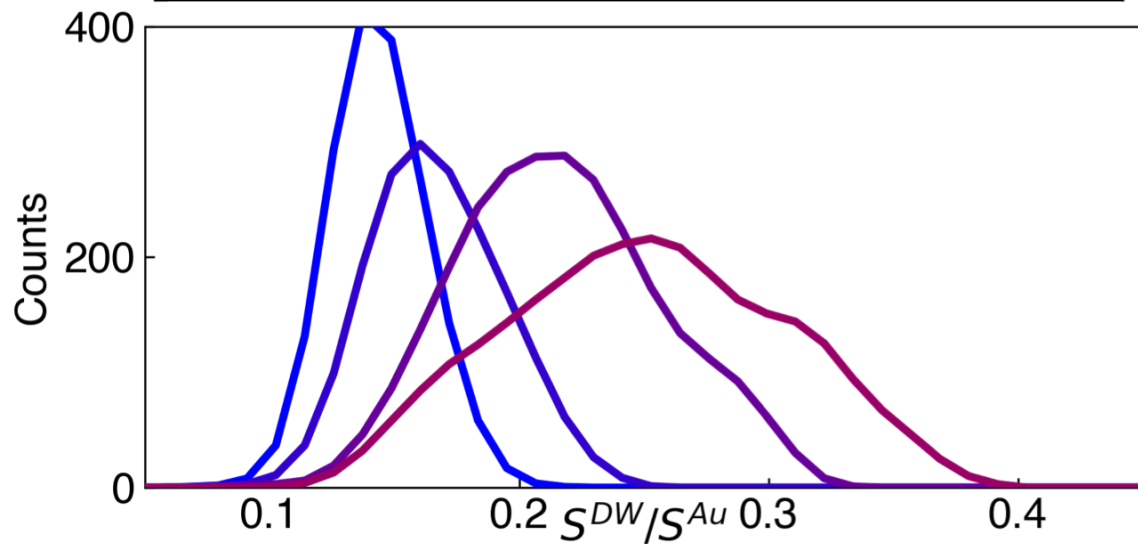
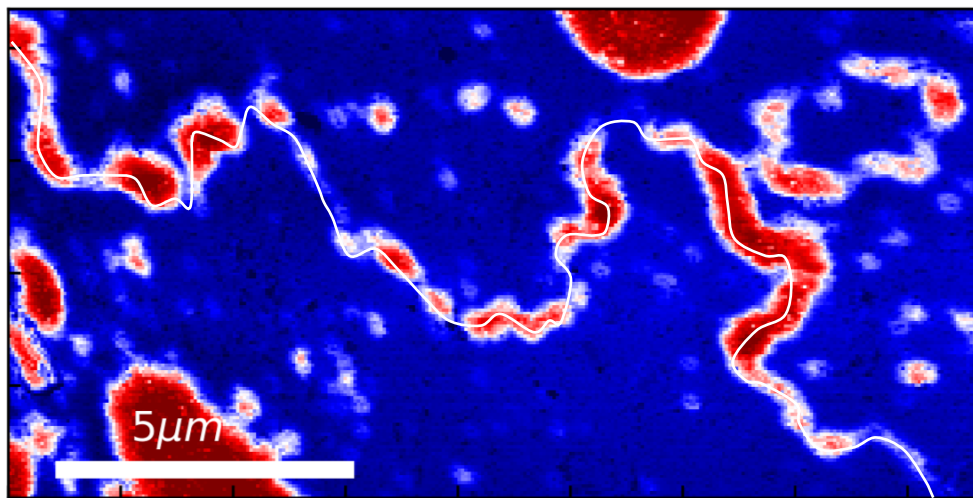
NdNiO₃: Conducting Channels



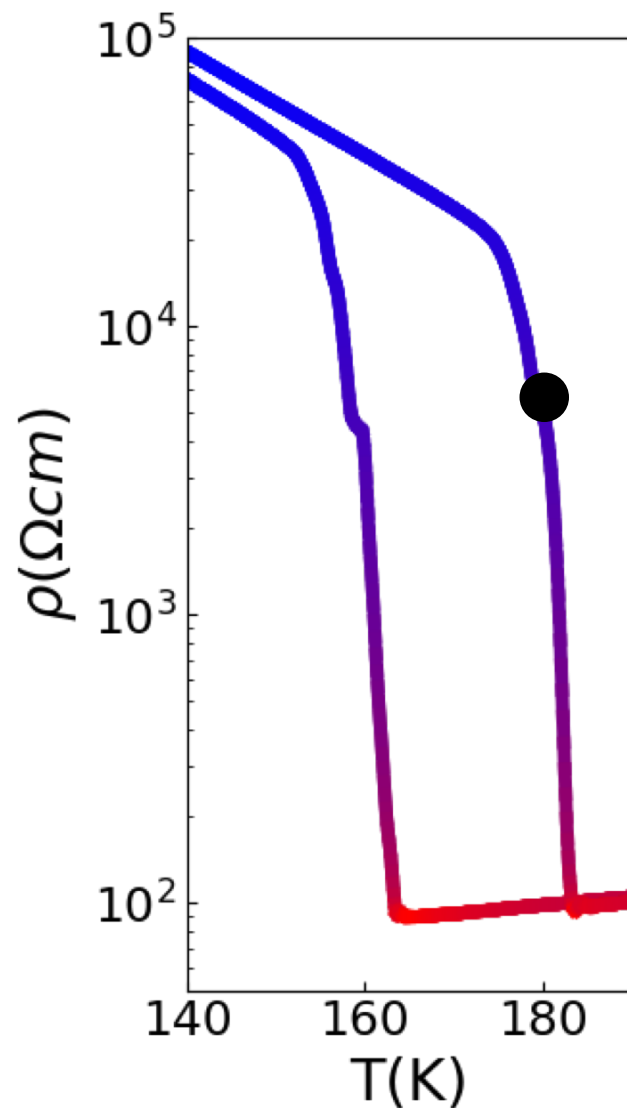
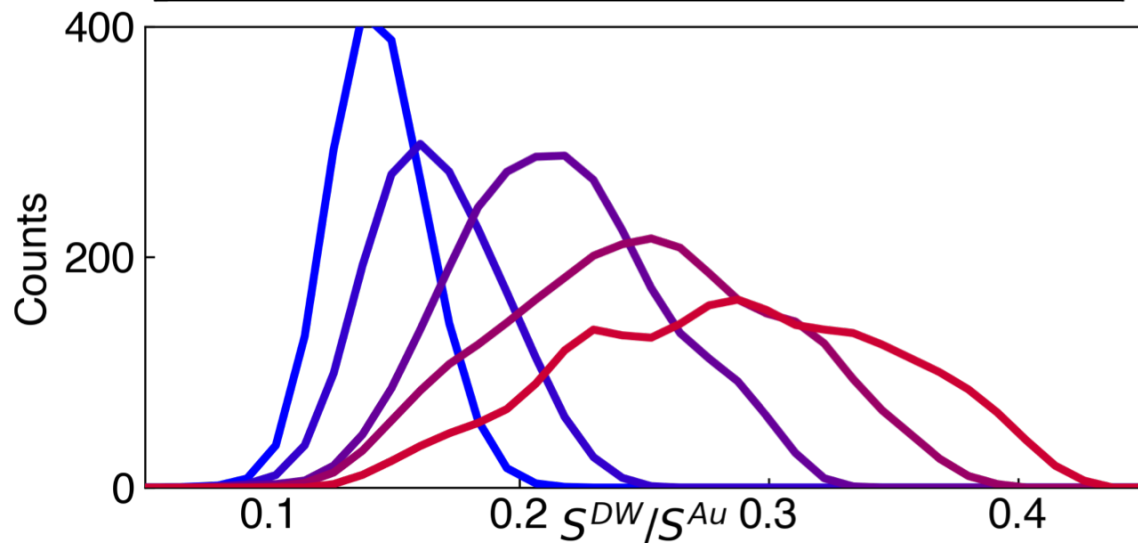
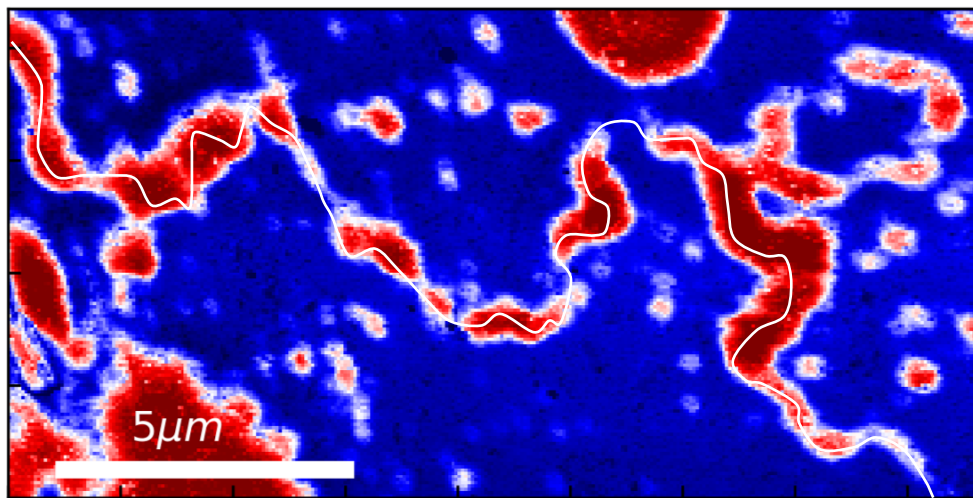
NdNiO₃: Conducting Channels



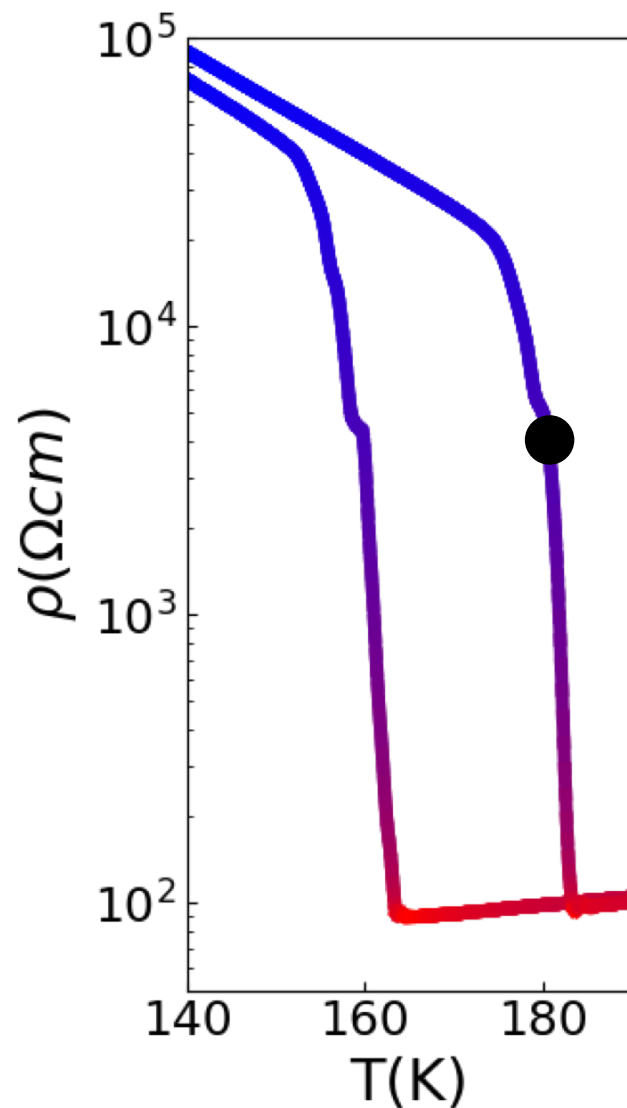
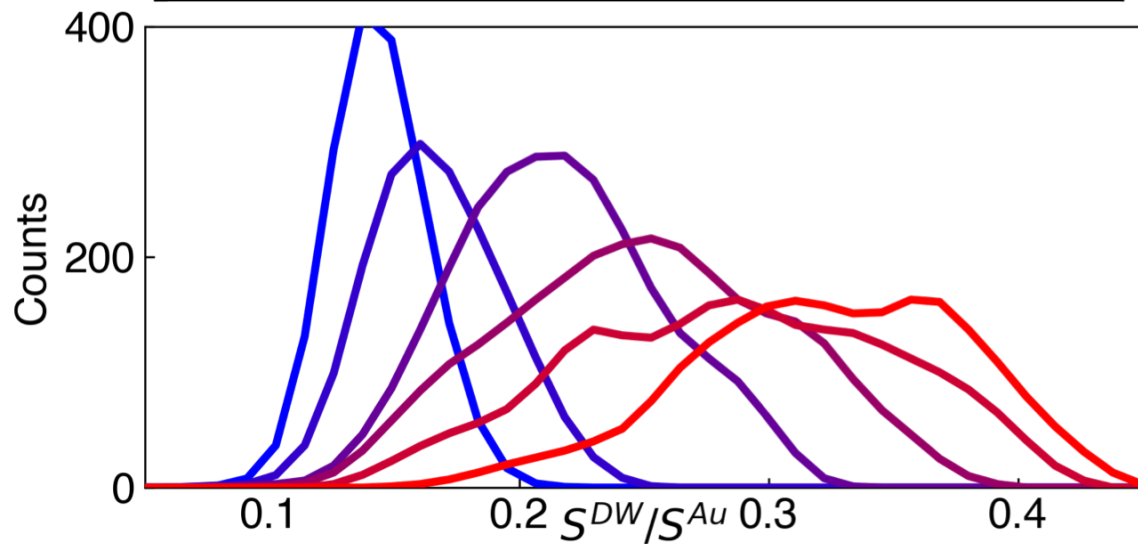
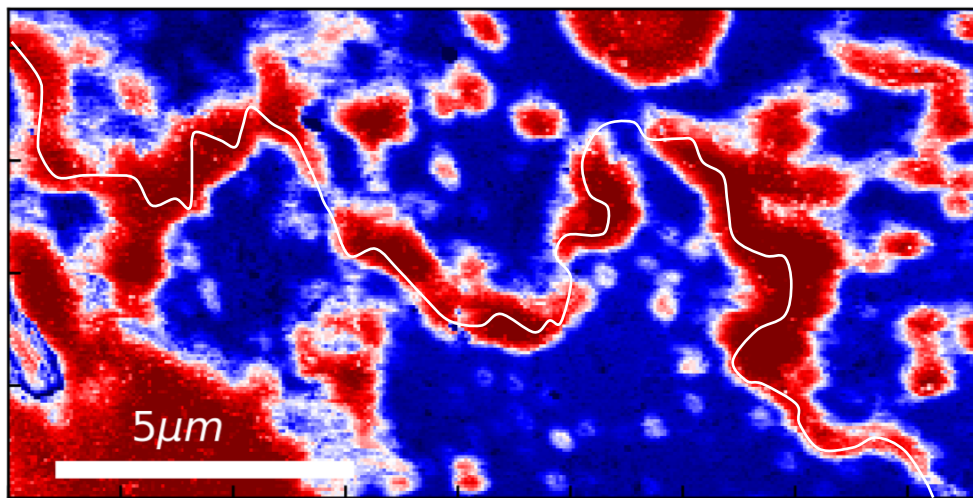
NdNiO₃: Conducting Channels



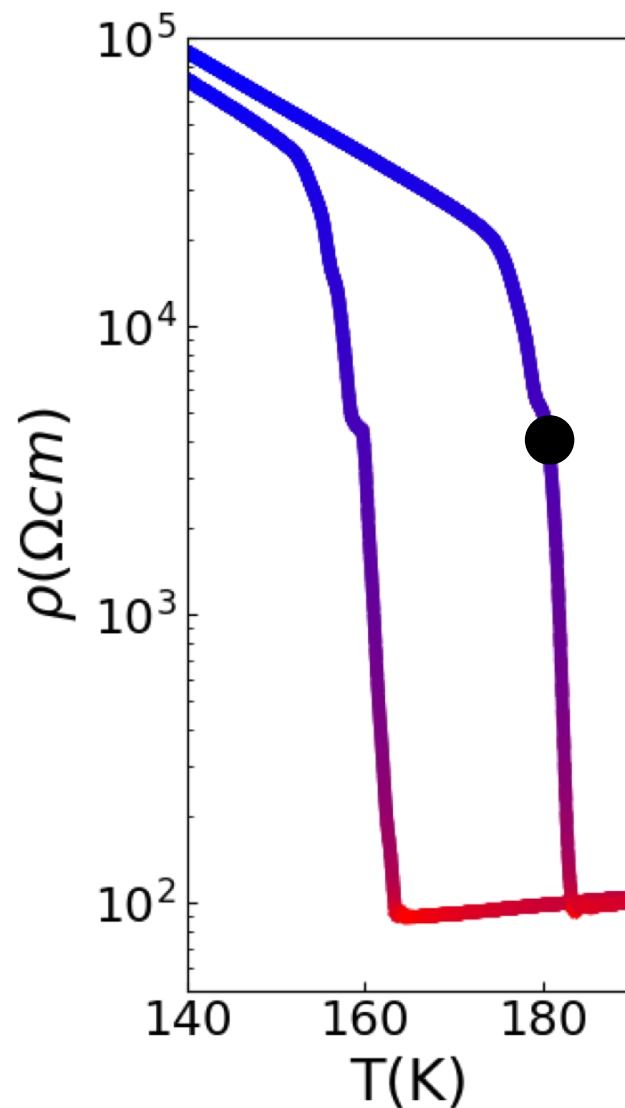
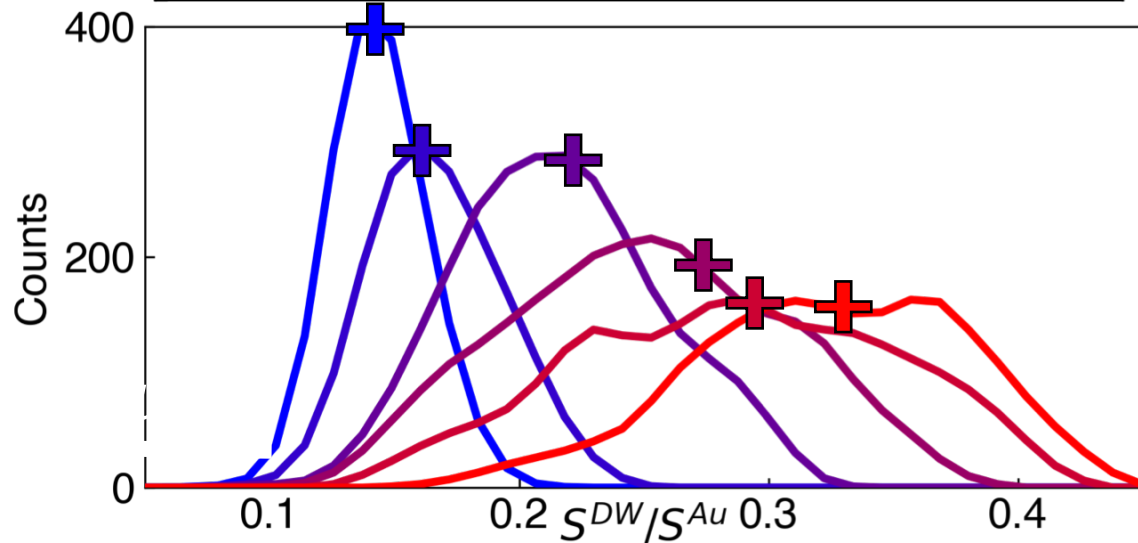
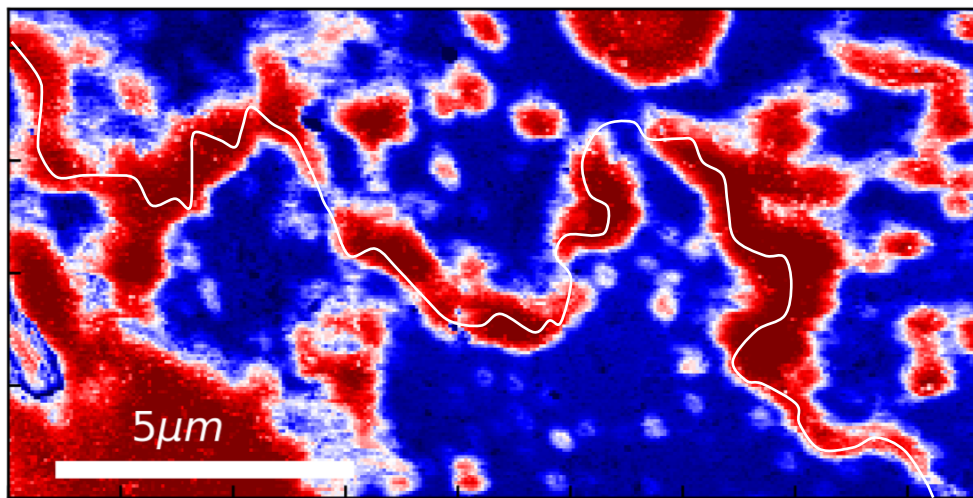
NdNiO₃: Conducting Channels



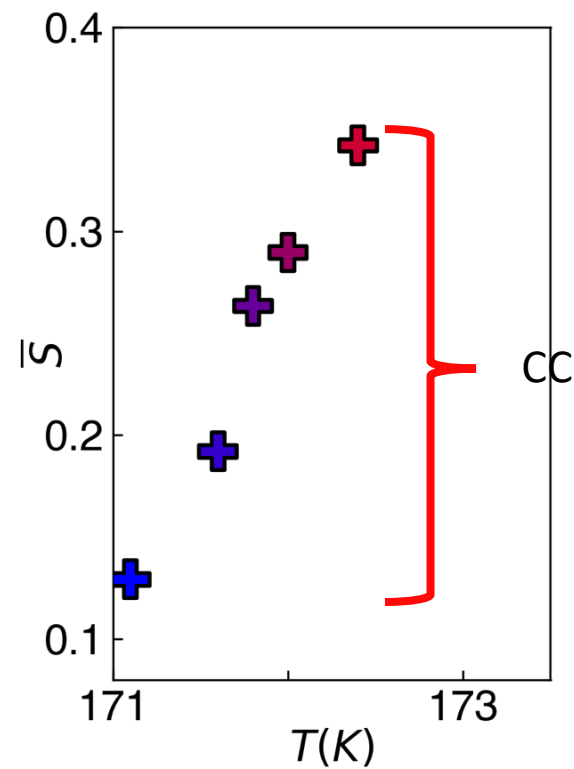
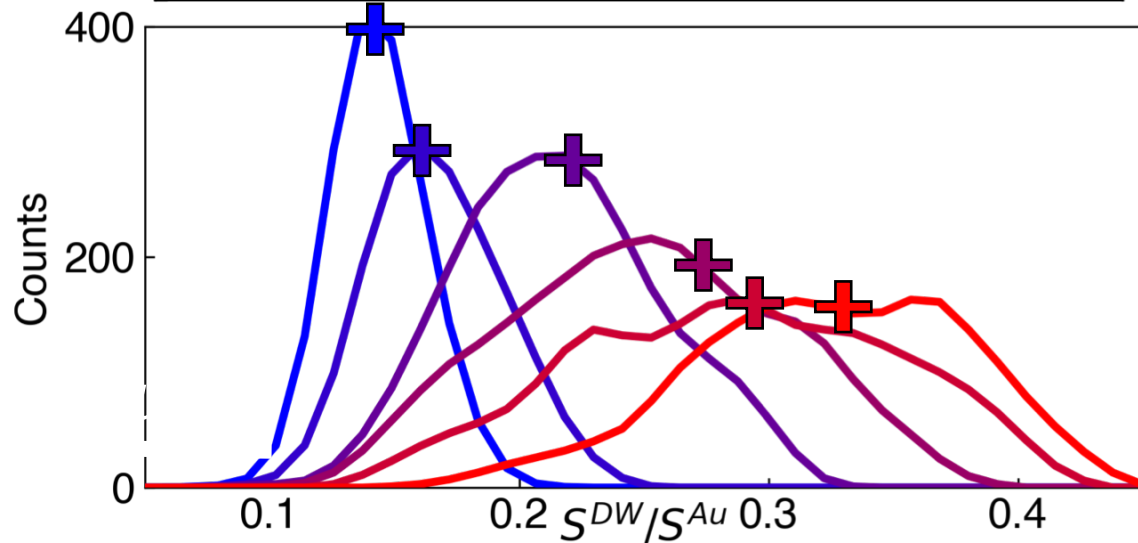
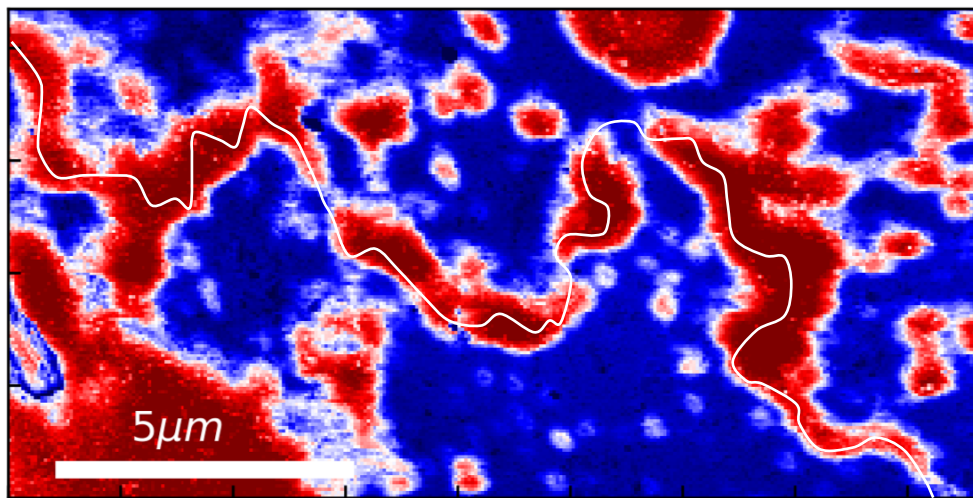
NdNiO₃: Conducting Channels



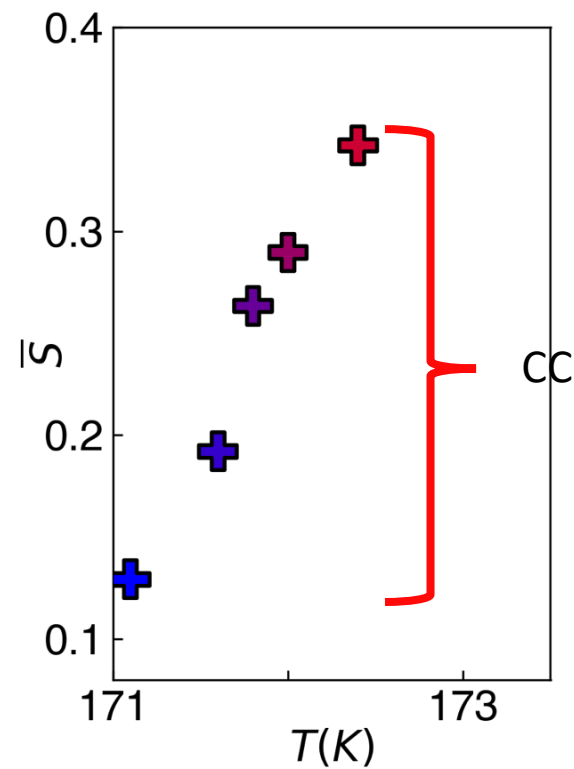
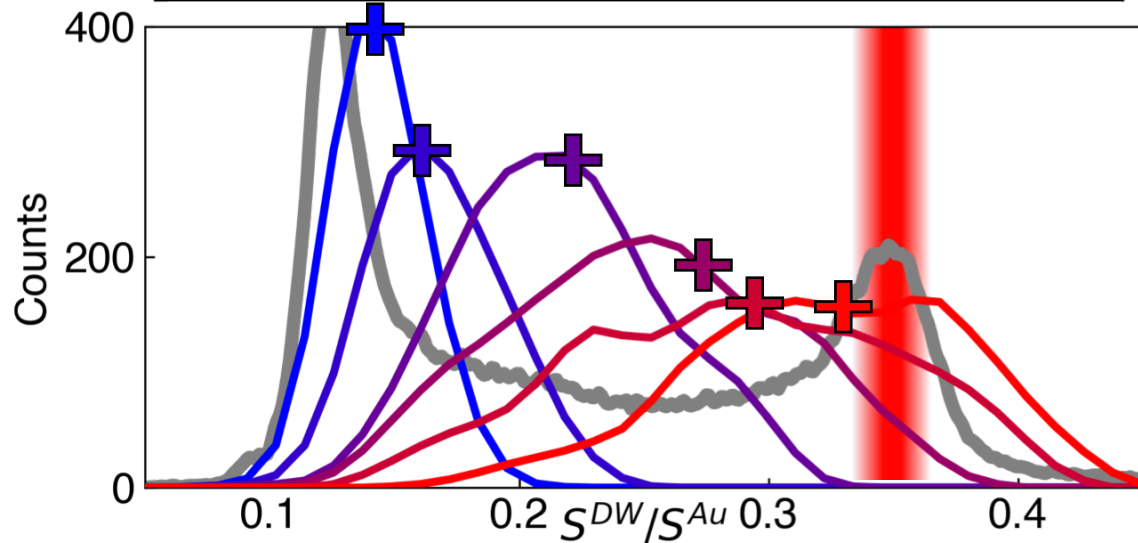
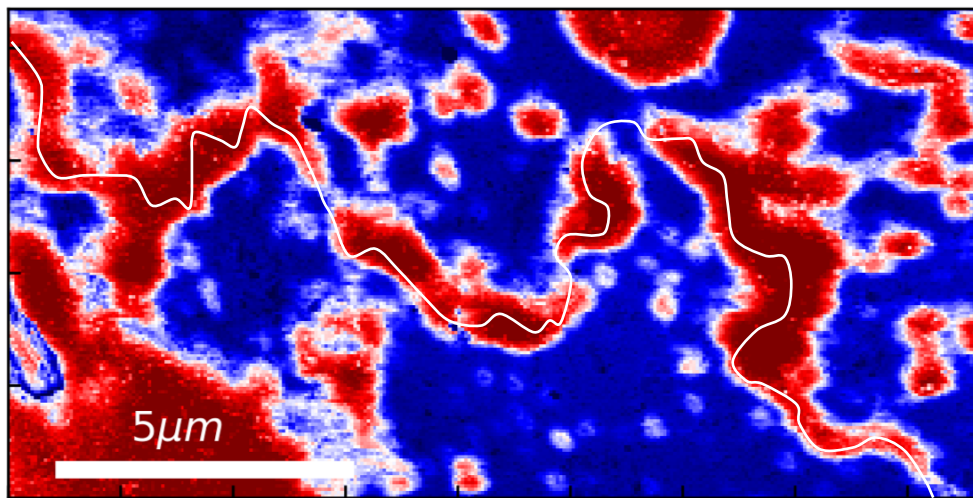
NdNiO₃: Conducting Channels



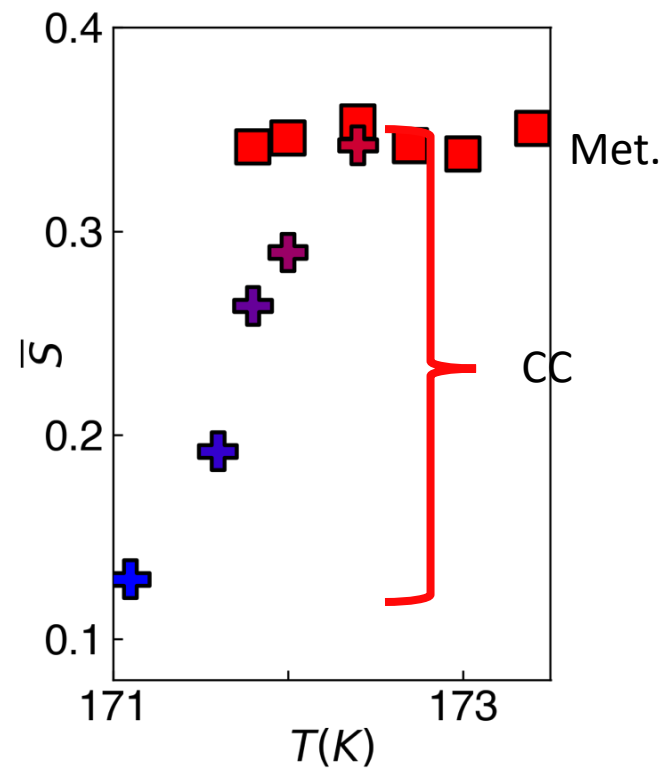
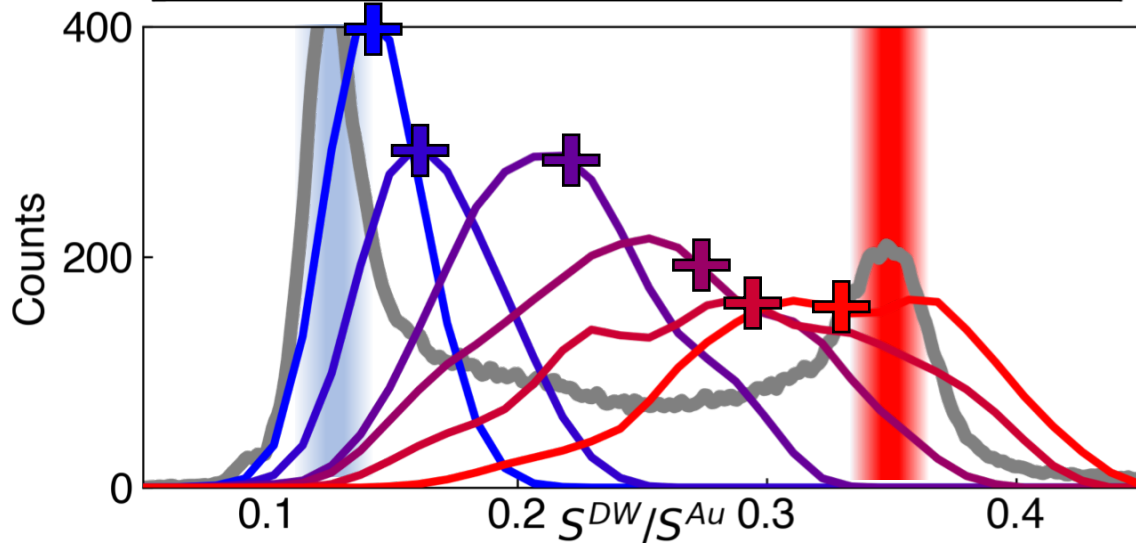
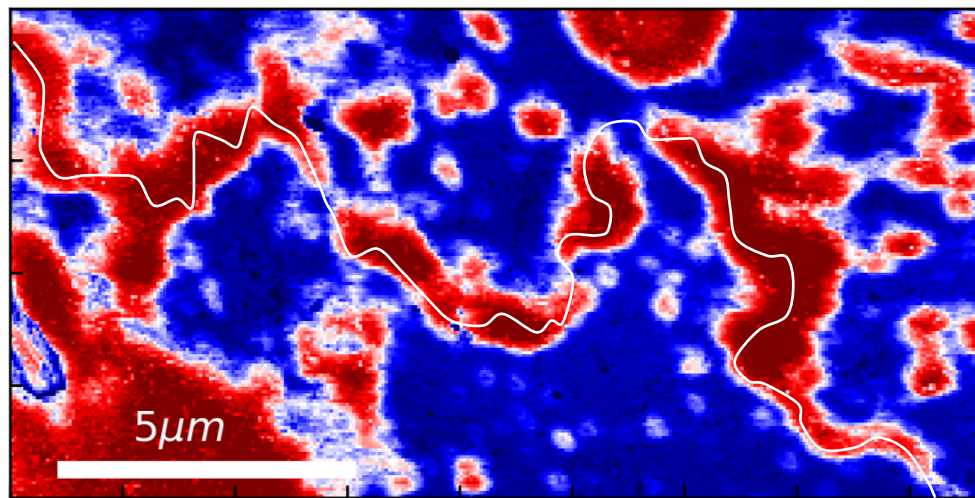
NdNiO₃: Conducting Channels



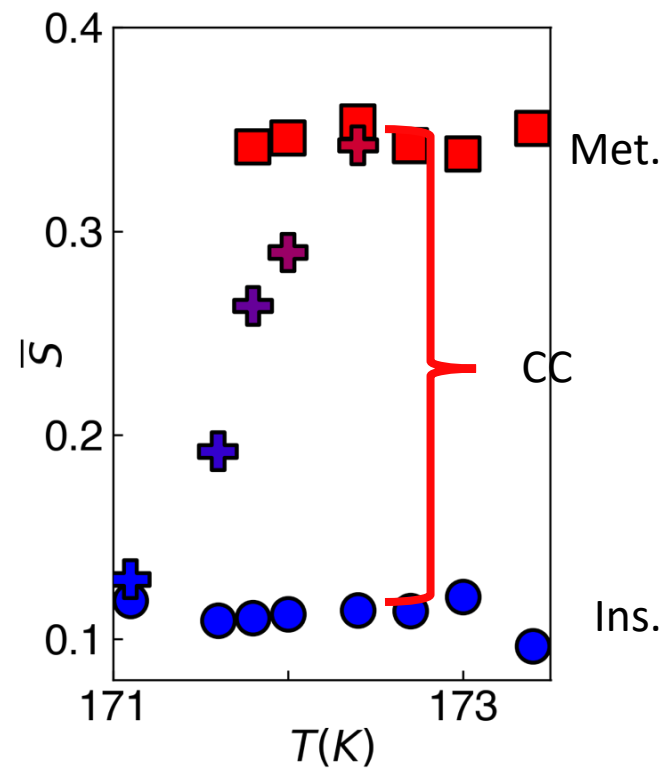
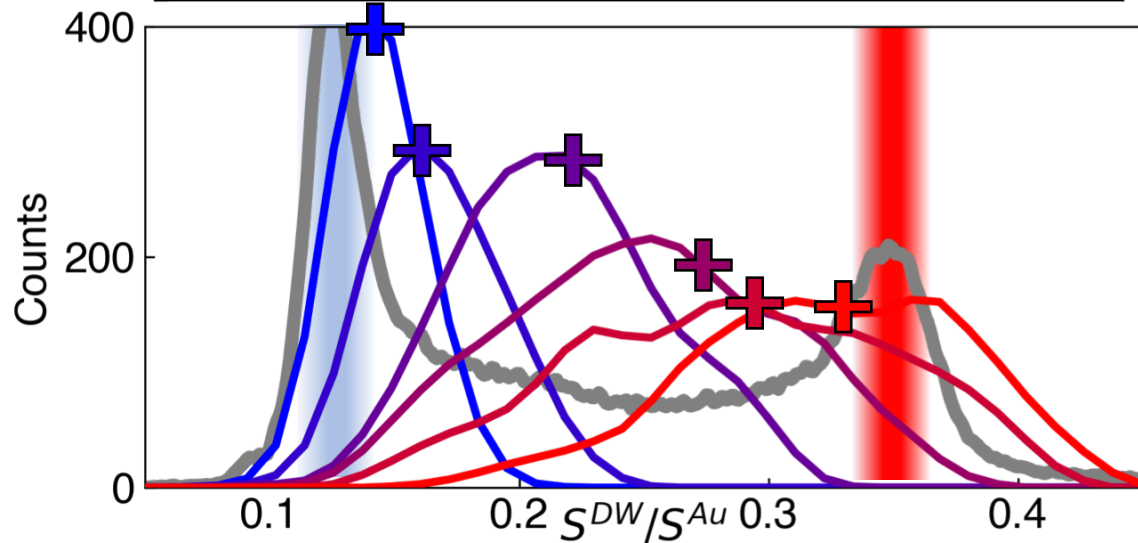
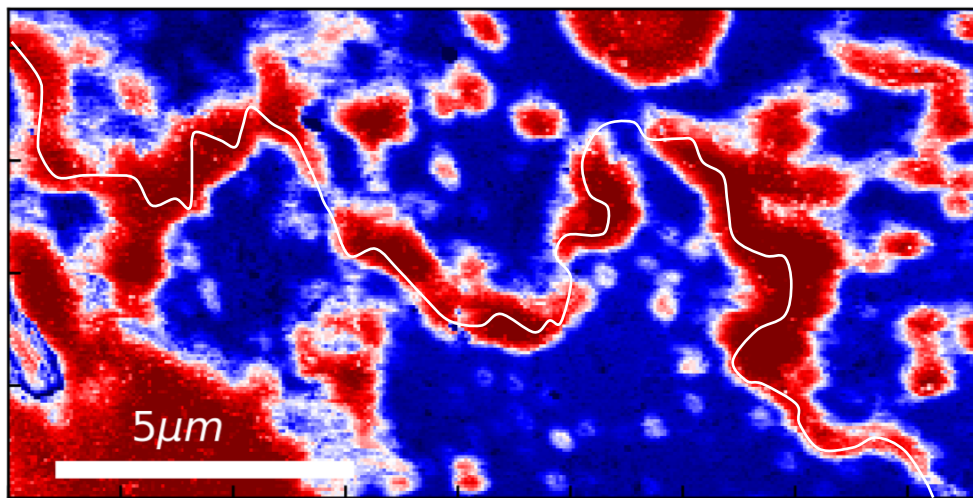
NdNiO₃: Conducting Channels



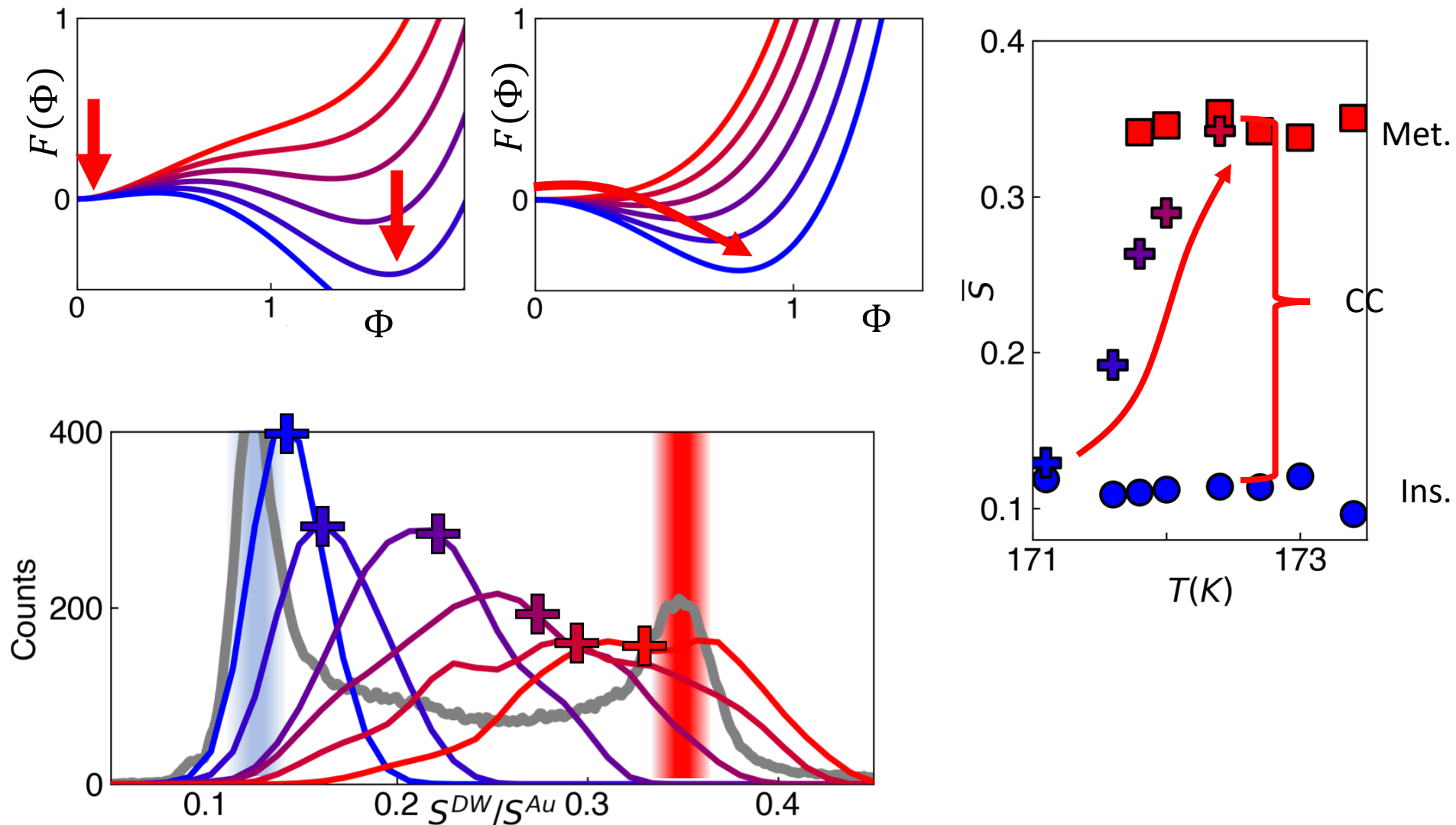
NdNiO₃: Conducting Channels



NdNiO₃: Conducting Channels

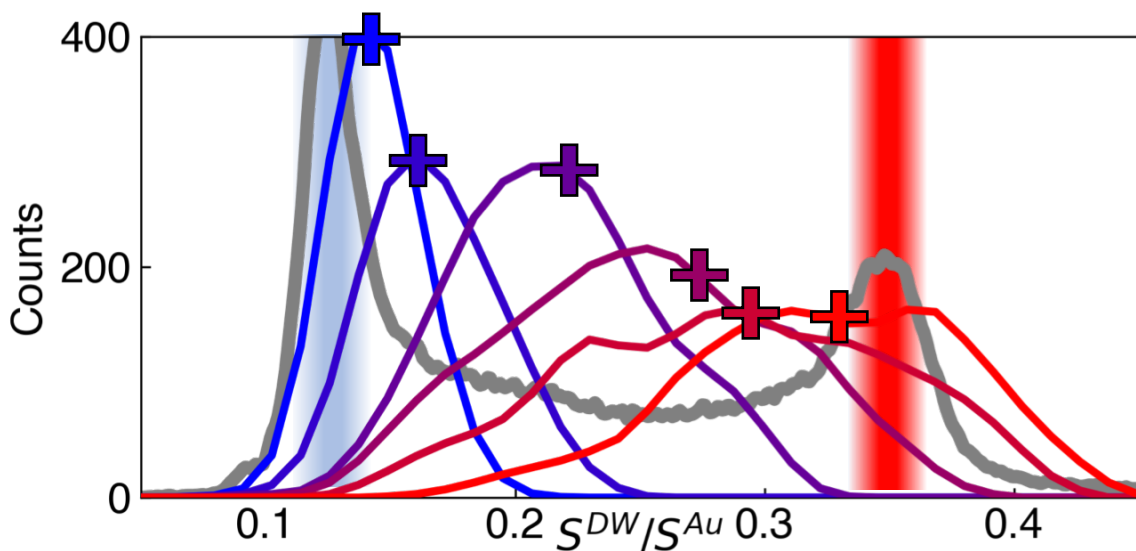
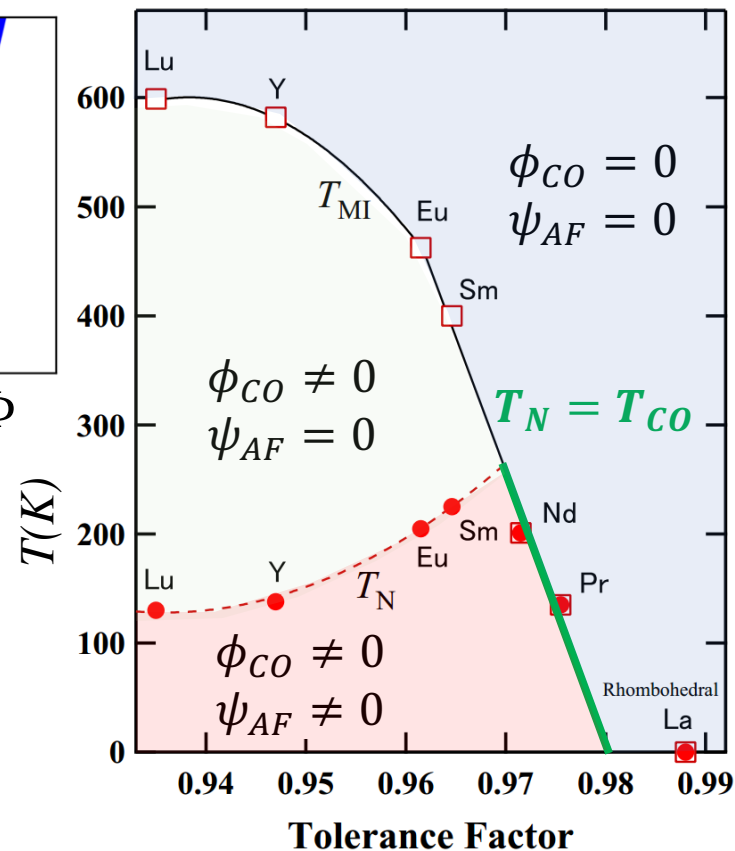
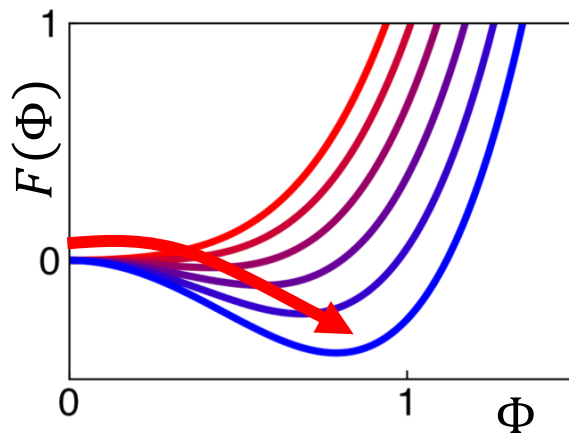
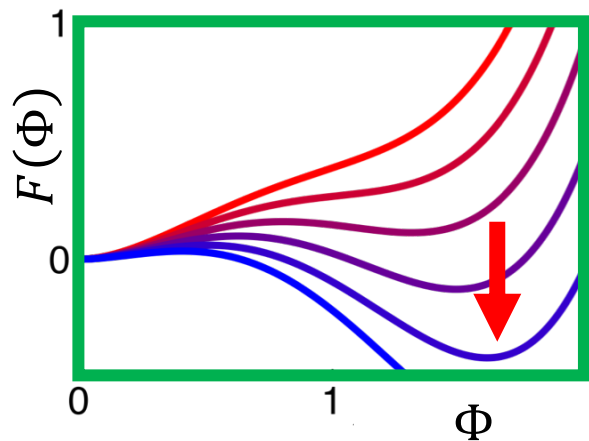


NdNiO₃: Conducting Channels



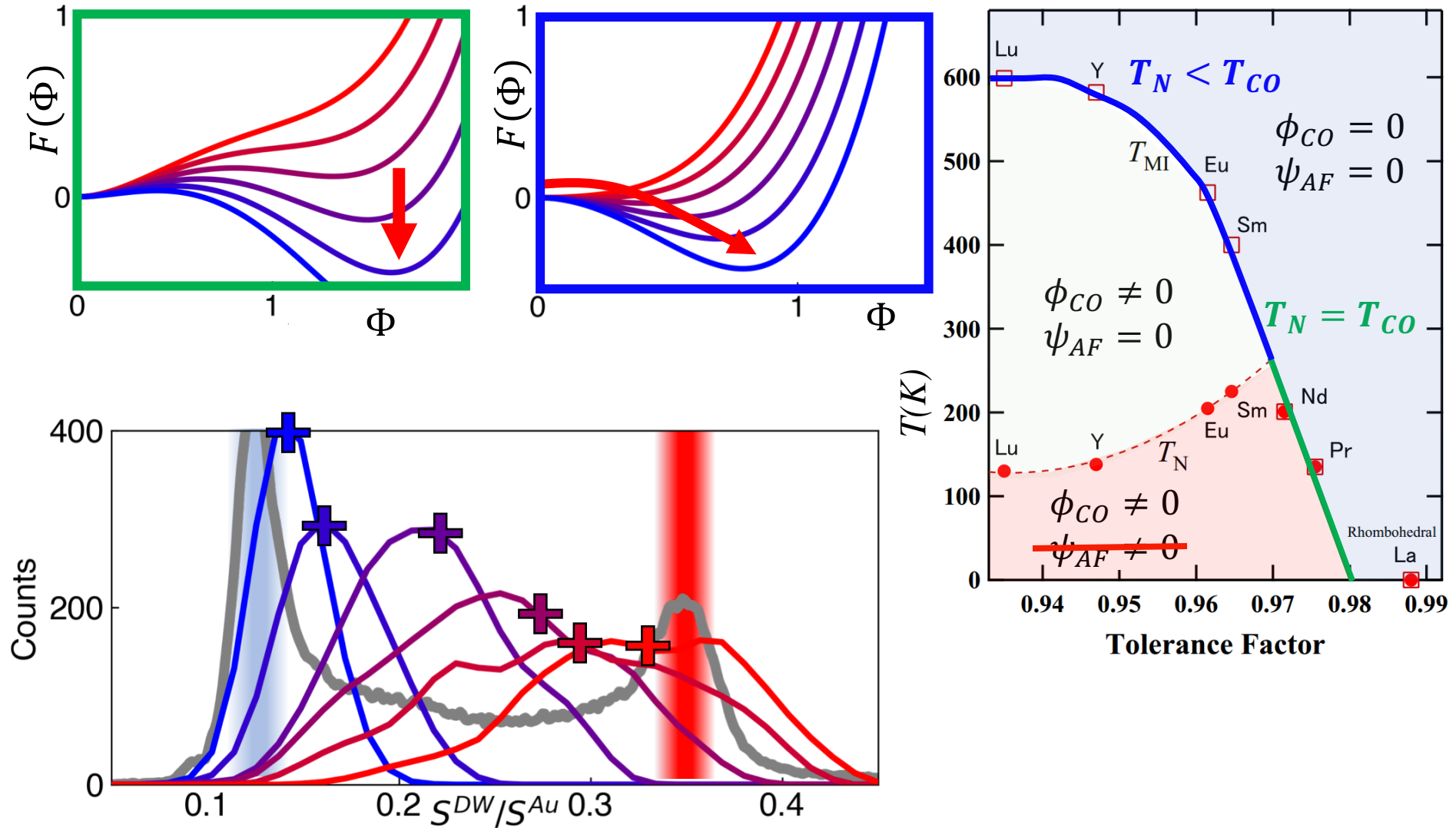
Second Order behavior along the conducting channel

NdNiO₃: Conducting Channels



Second Order behavior along the conducting channel

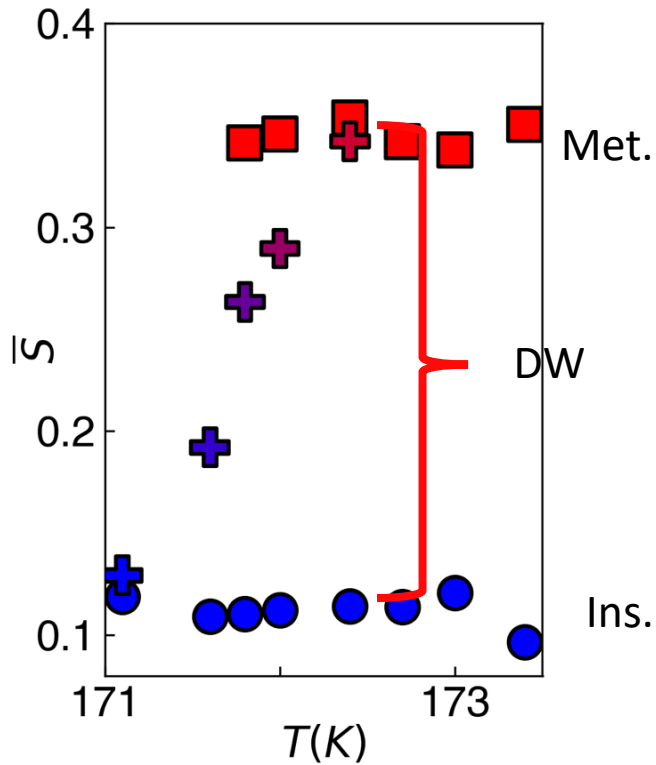
NdNiO₃: Conducting Channels



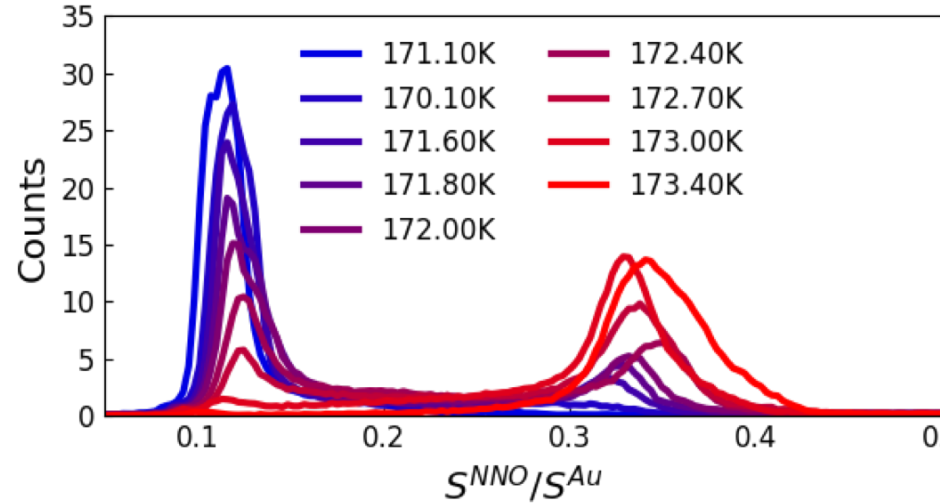
Second Order behavior along the conducting channel

Highlights

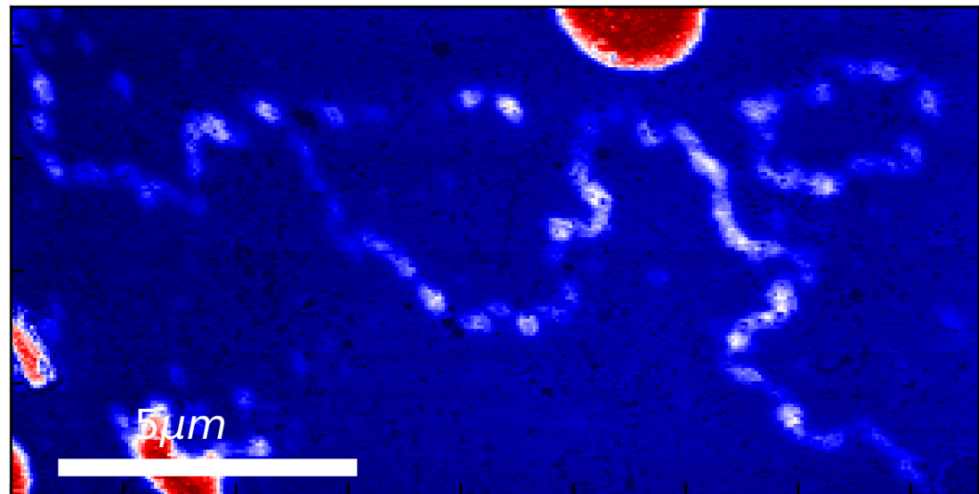
Conducting channels undergo a 2nd order phase transition, which coexist with bulk 1st order transition



Clarified ideal 1st order transition of NdNiO_3



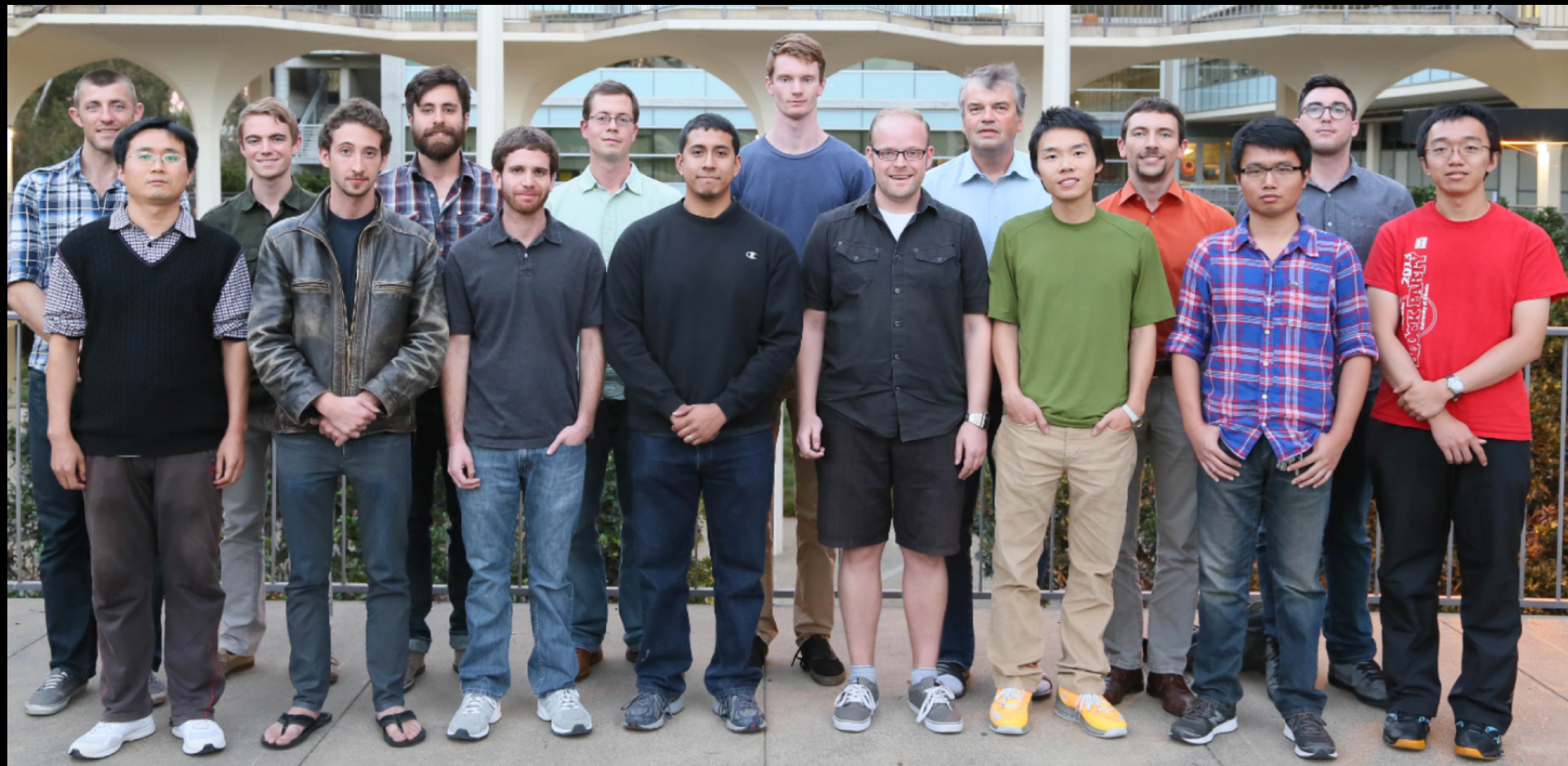
likely arising from antiferromagnetic domain walls



Acknowledgements



Acknowledgements



Acknowledgements

UCSD:

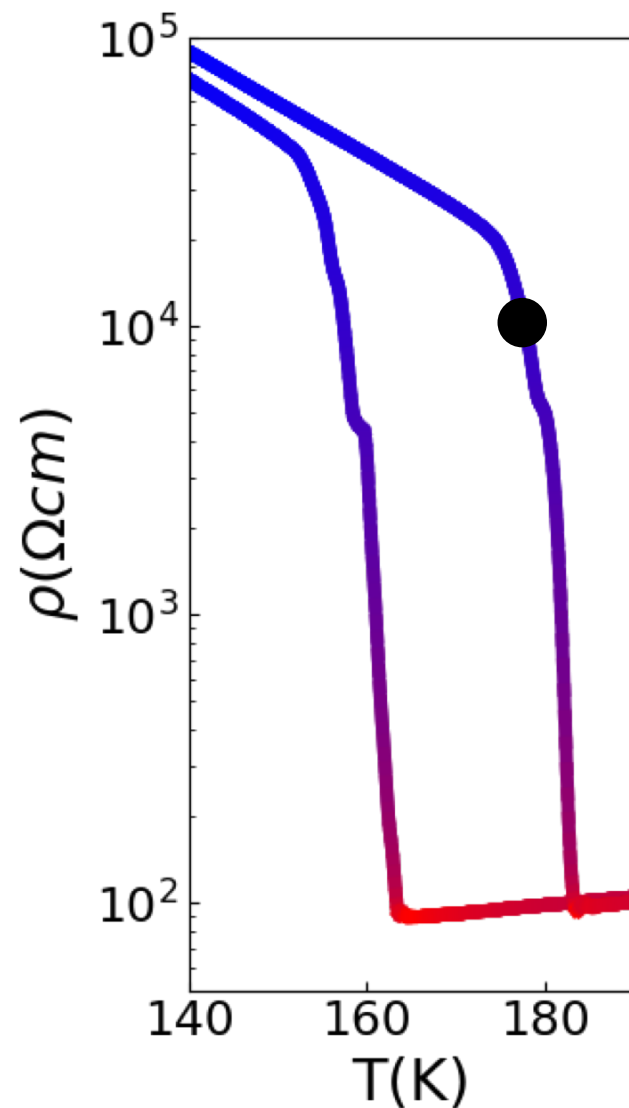
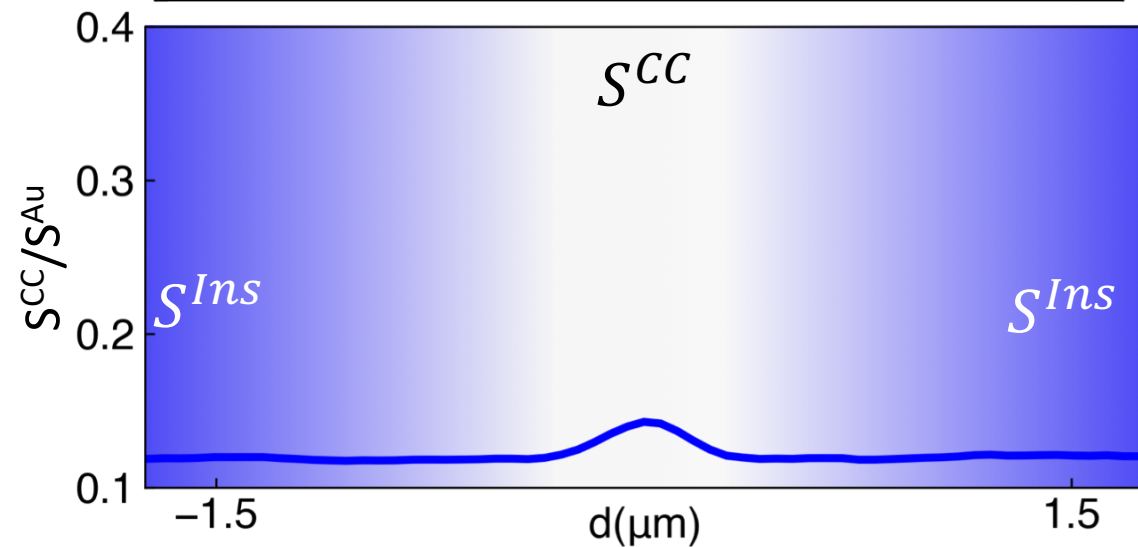
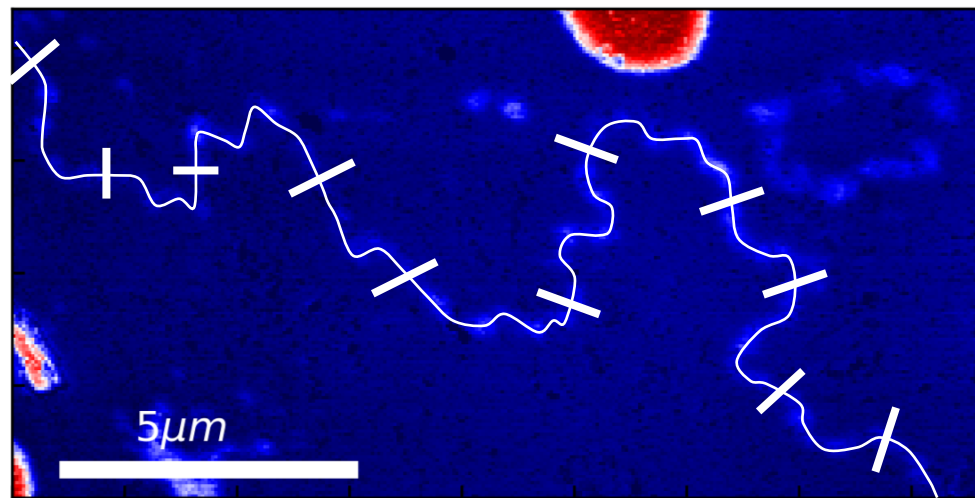
- Dmitri Basov
- Alex McLeod
- Yinming Shao
- Brian Chapler
- Aaron Sternbach
- Alex Schafgans
- Michael Goldflam
- Ted Stinson
- Alex Frenzel
- Aliaksei Charnhukha

MPI – Stuttgart

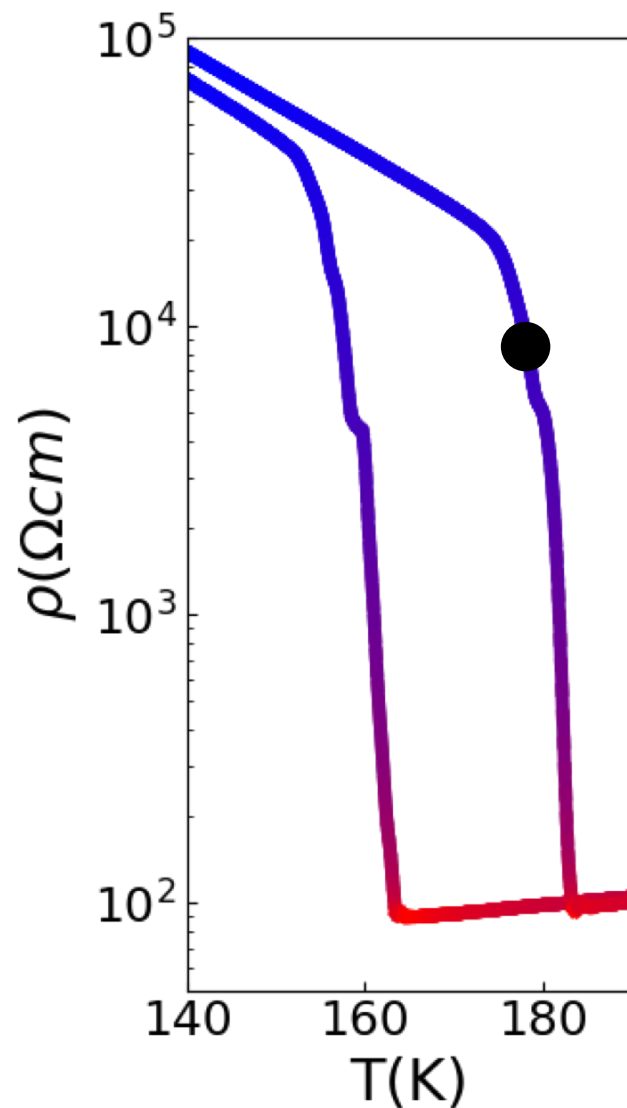
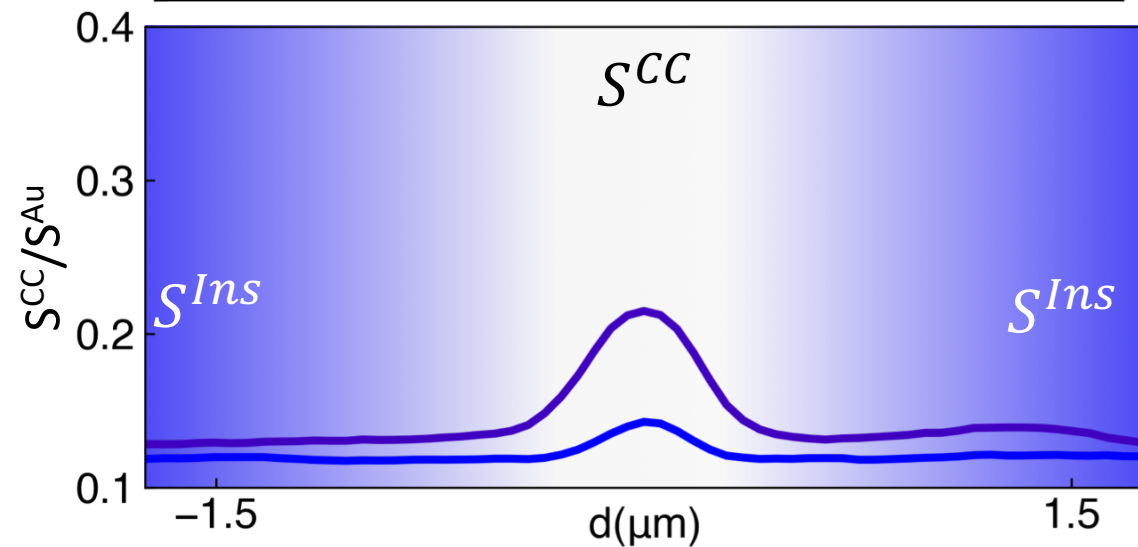
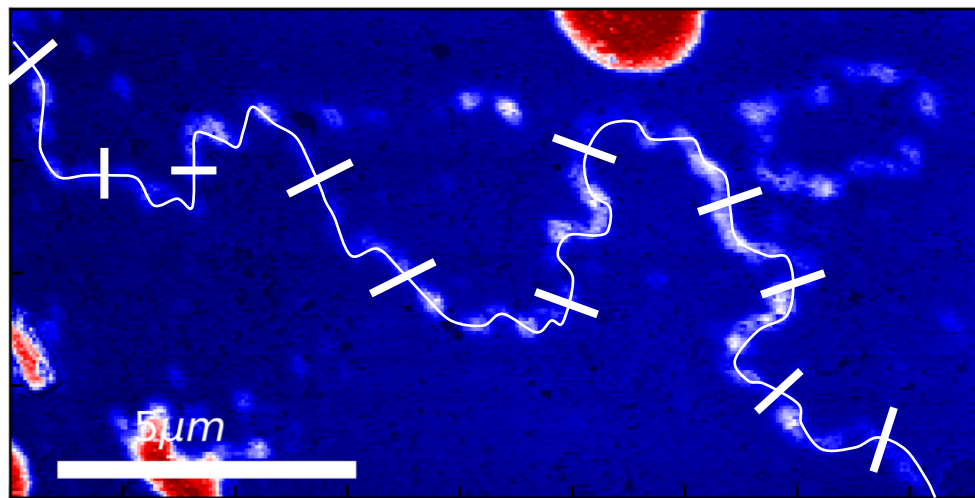
- Bernard Keimer
- Matthias Hepting
- Martin Blushke
- Eva Benckiser



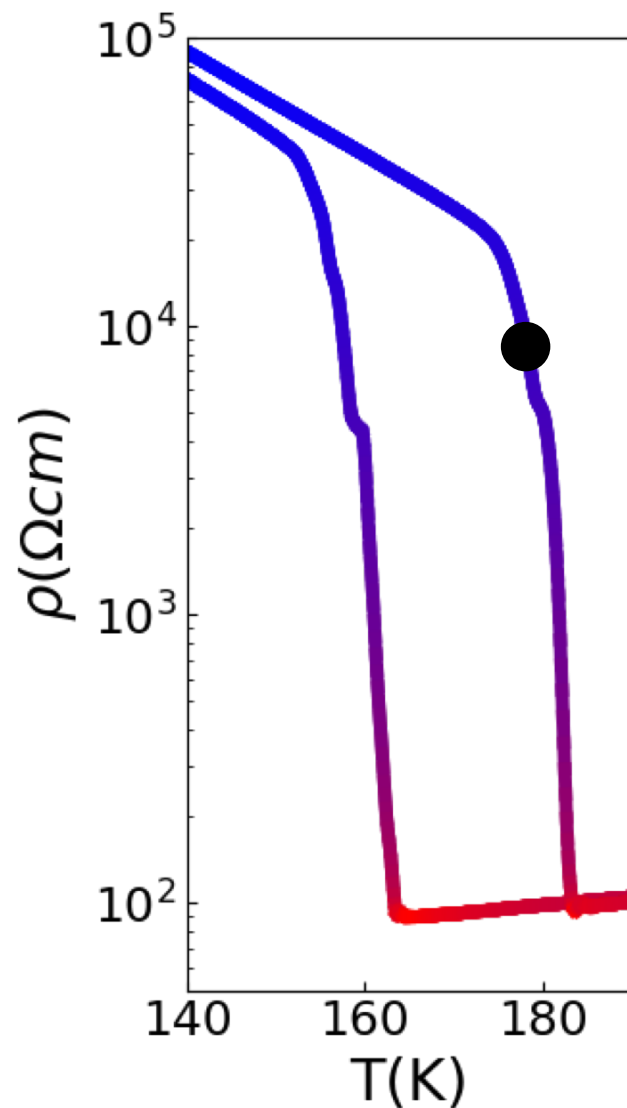
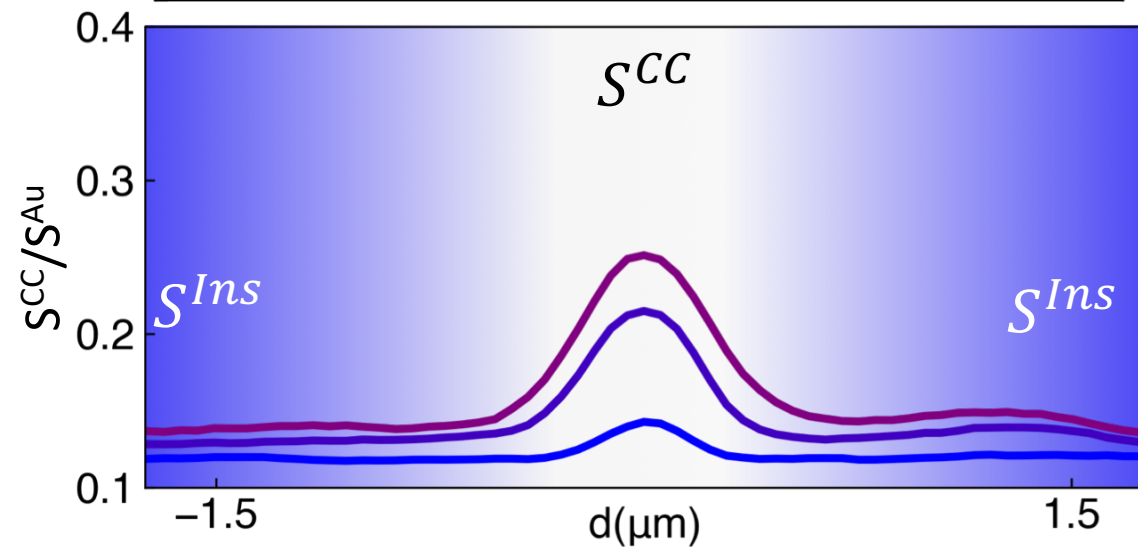
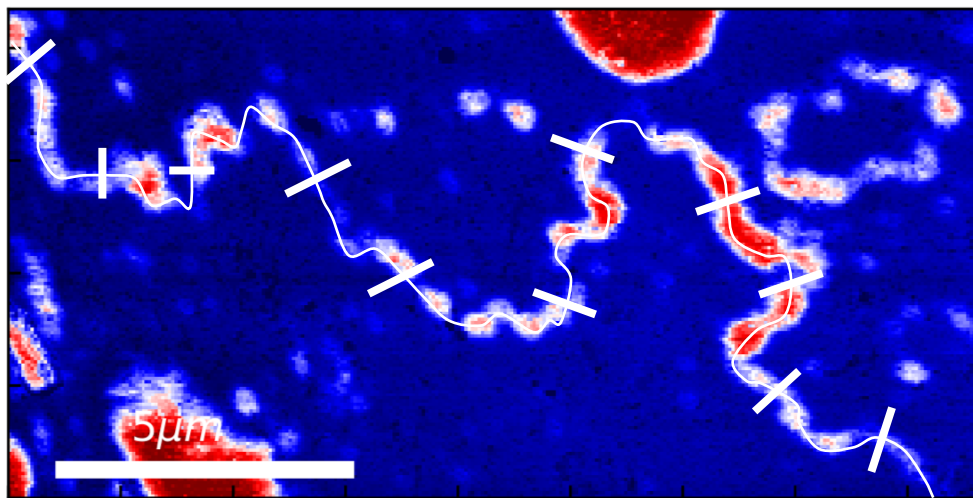
NdNiO₃: Conducting Channels



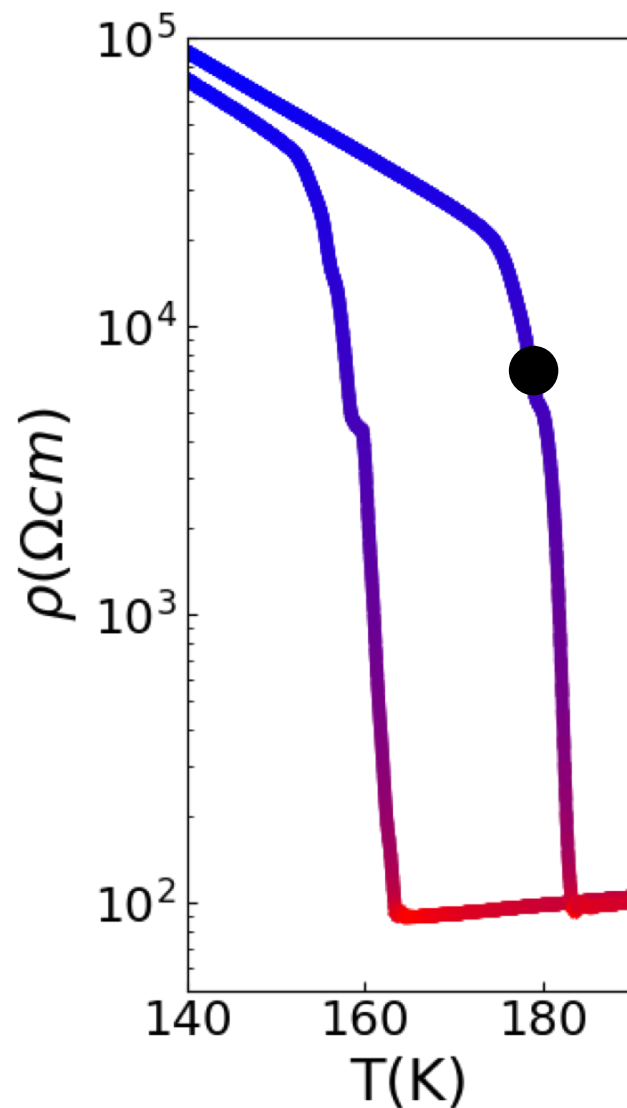
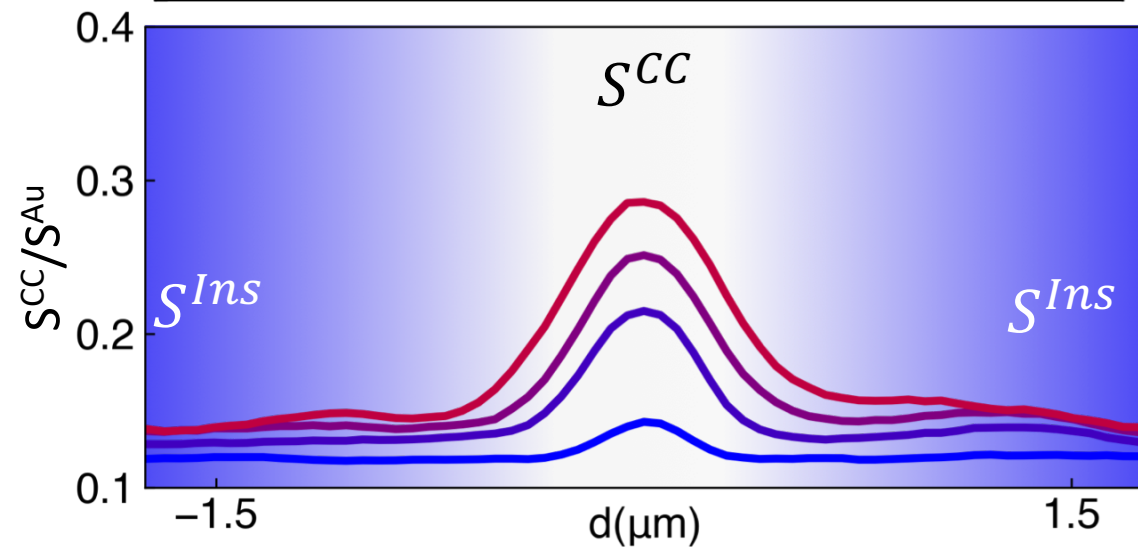
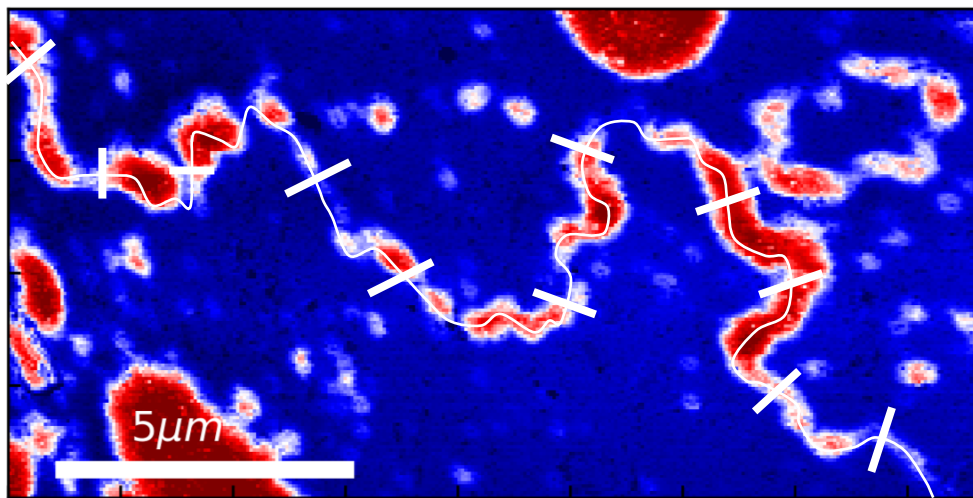
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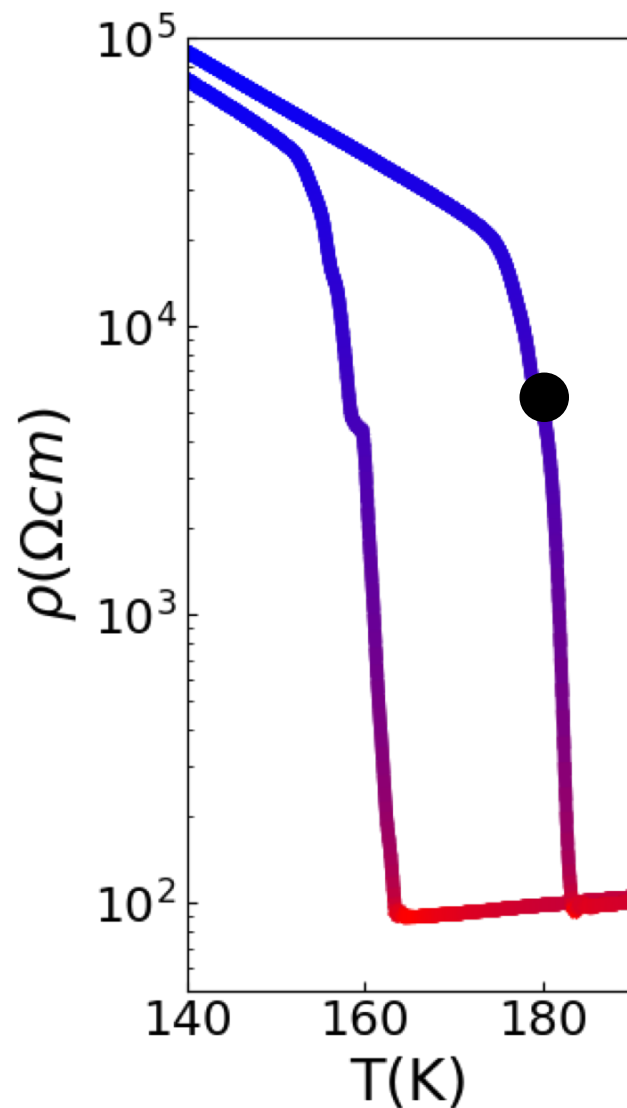
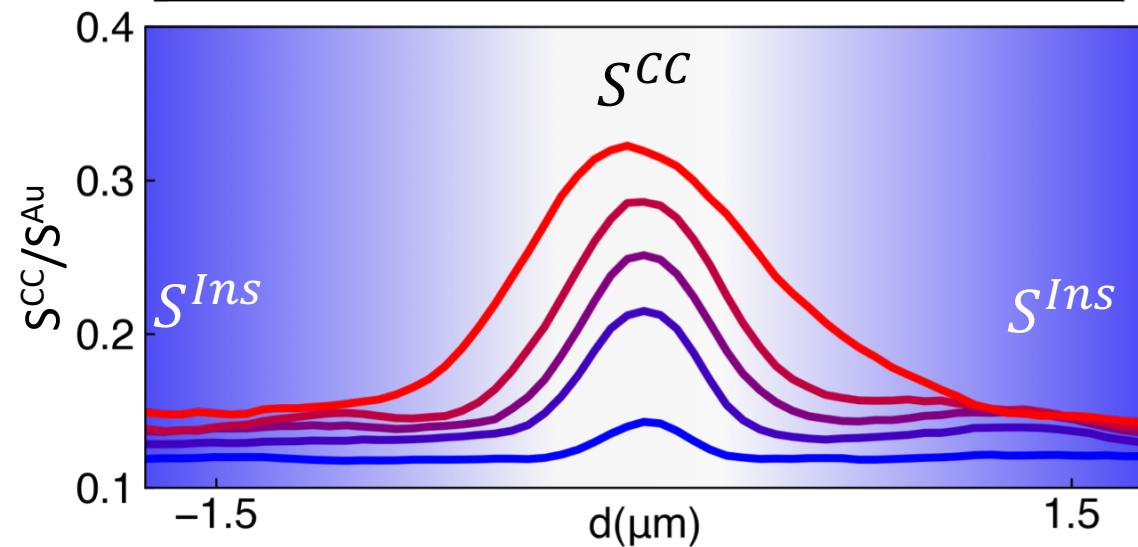
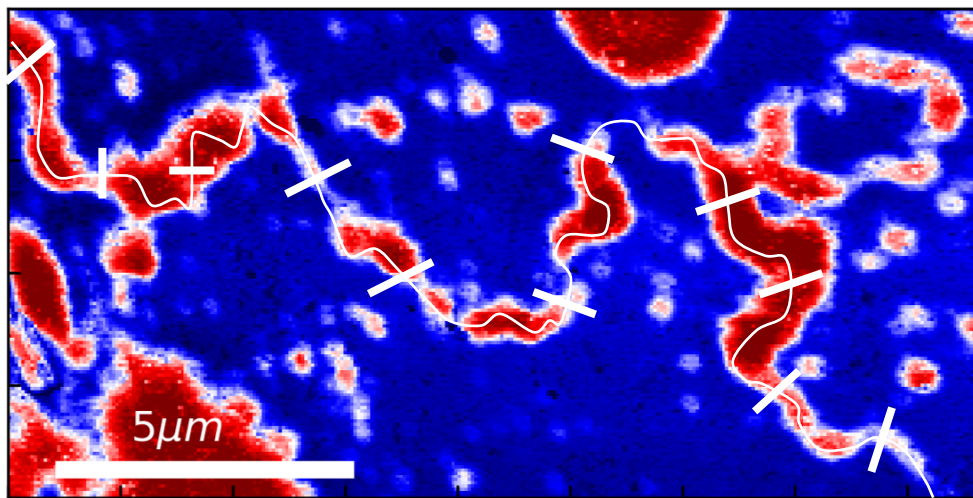
NdNiO₃: Conducting Channels



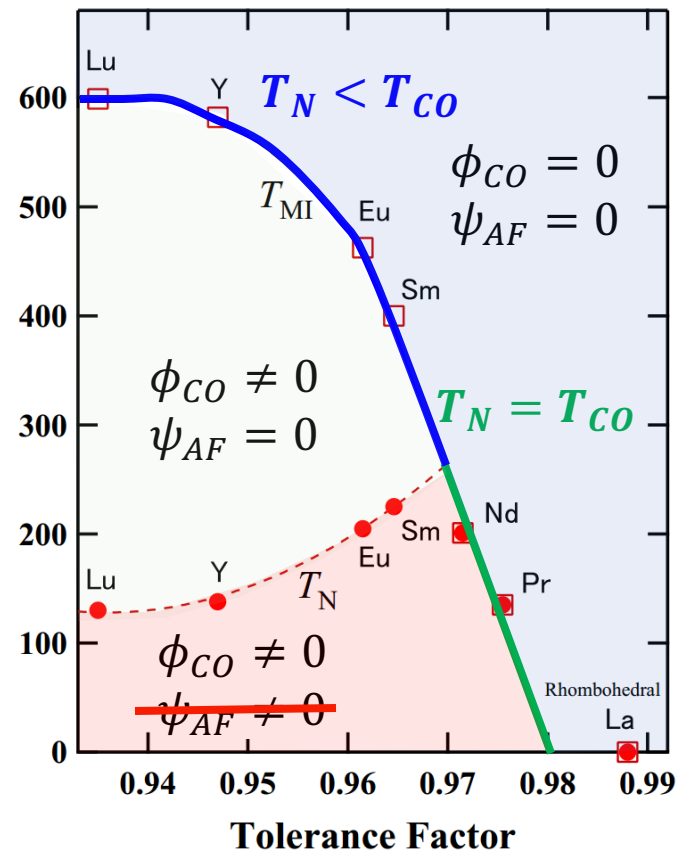
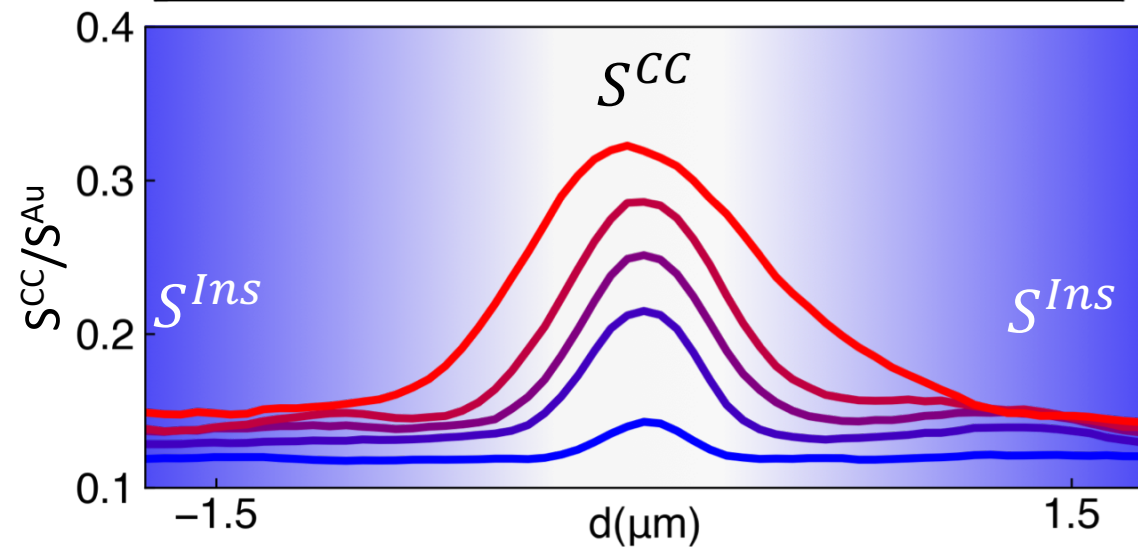
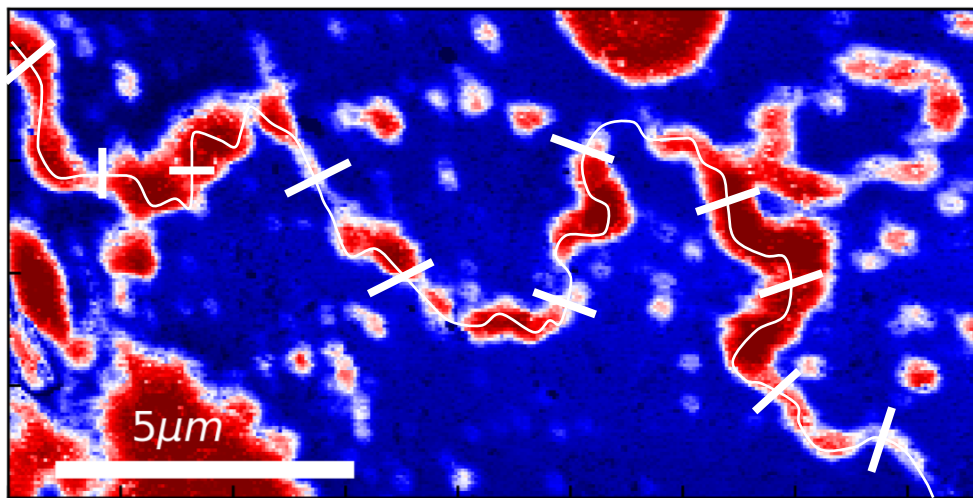
NdNiO₃: Conducting Channels



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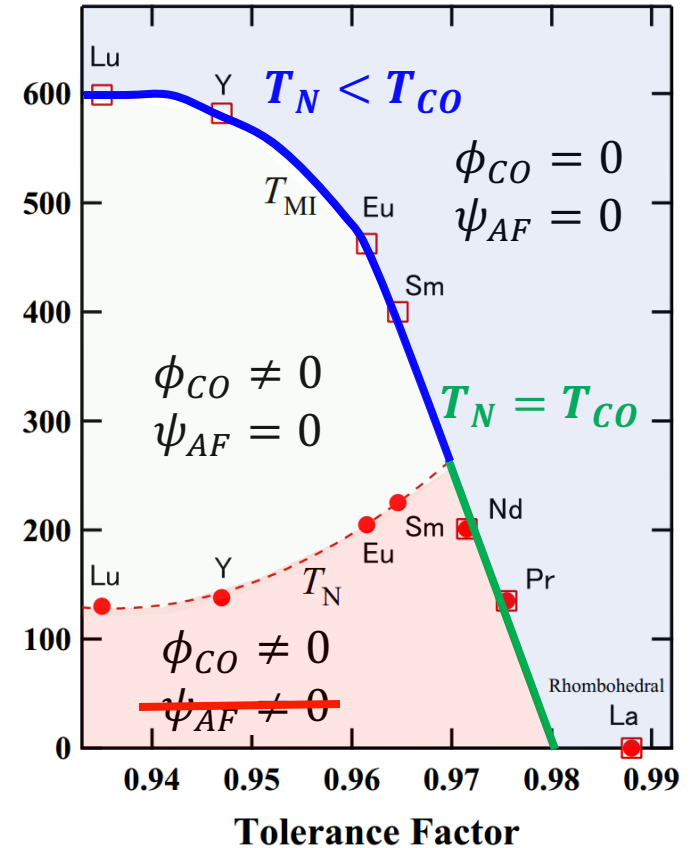
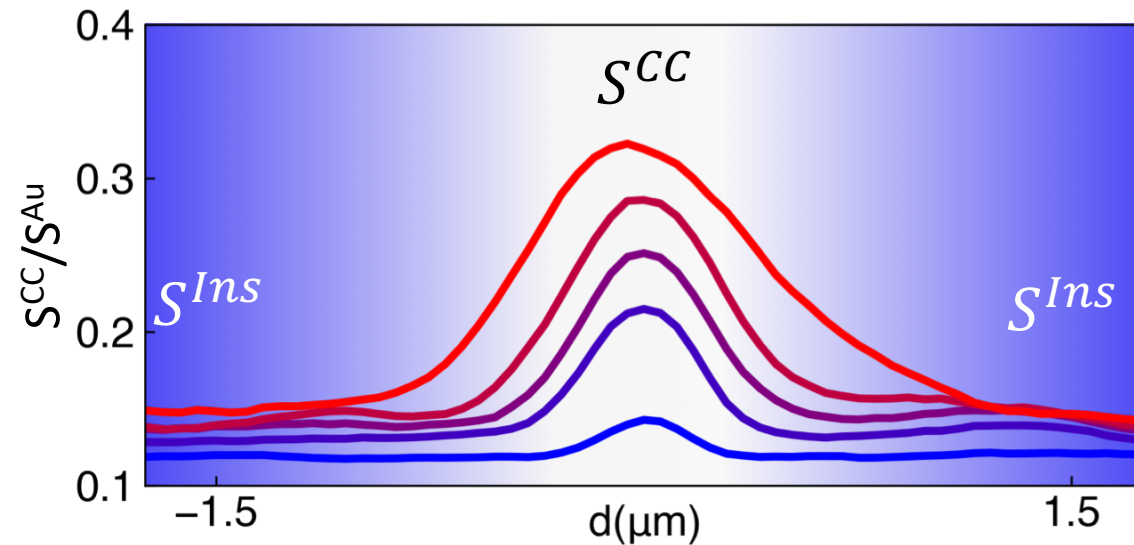


NdNiO₃: Conducting Channels

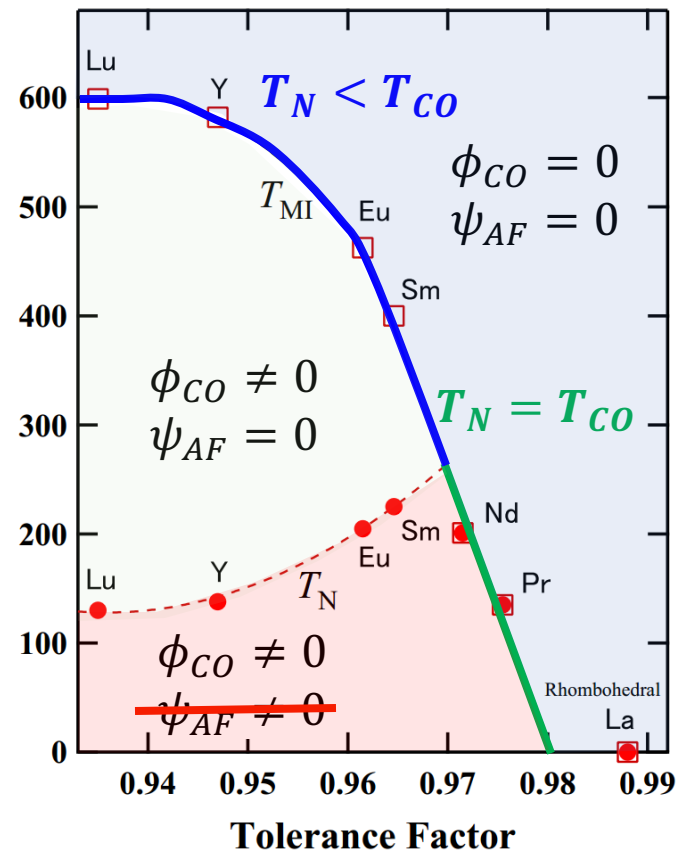
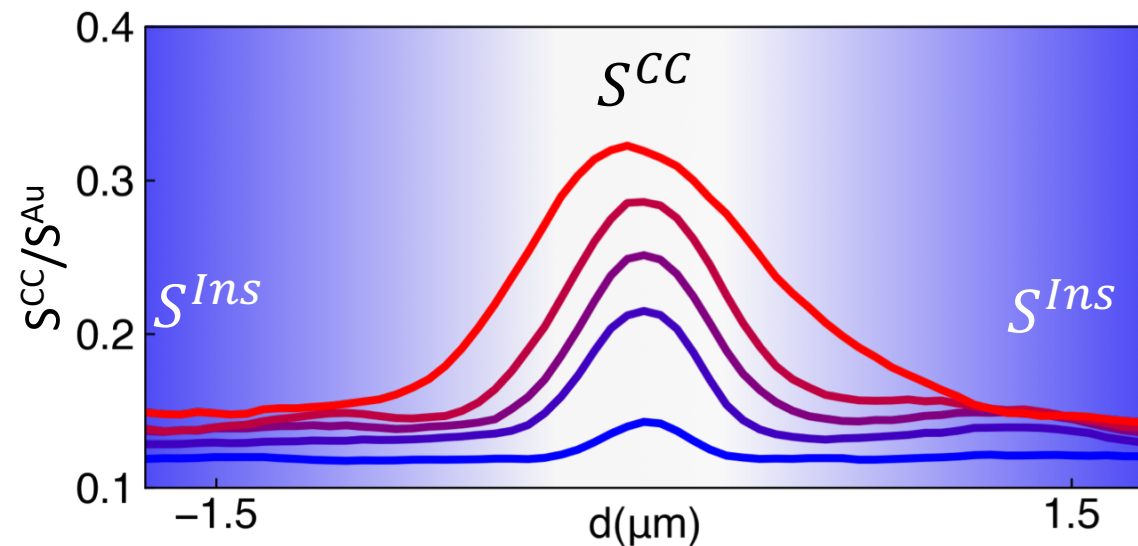
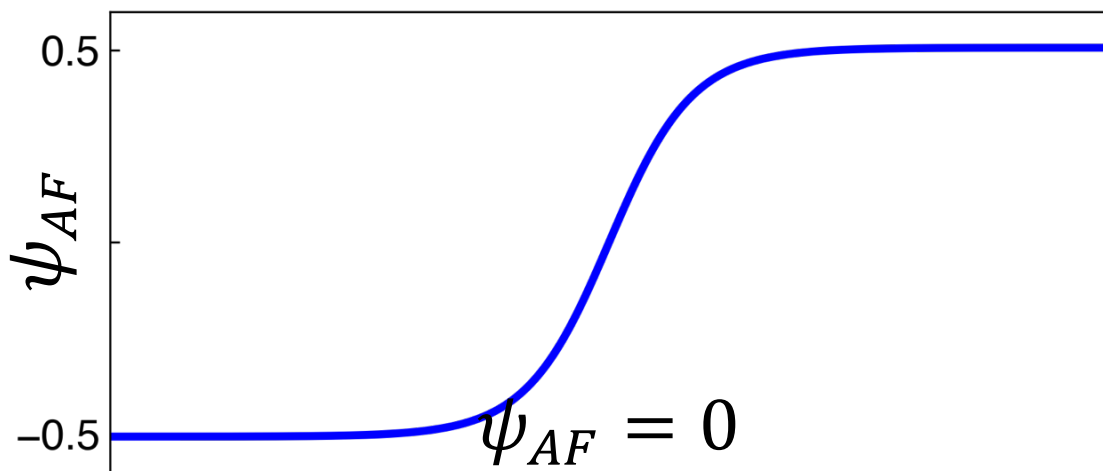


NdNiO₃: Conducting Channels

$$F(\psi_{AF}, \phi_{CO}) = \left(r_\phi \frac{T - T_\phi}{T_\phi} \phi^2 + \phi^4 + \frac{\zeta_\phi^2}{6} (\nabla\phi)^2 \right) + \left(r_\psi \frac{T - T_\psi}{T_\psi} \psi^2 + \psi^4 + \frac{\zeta_\psi^2}{6} (\nabla\psi)^2 \right) - \lambda \psi^2 \phi.$$



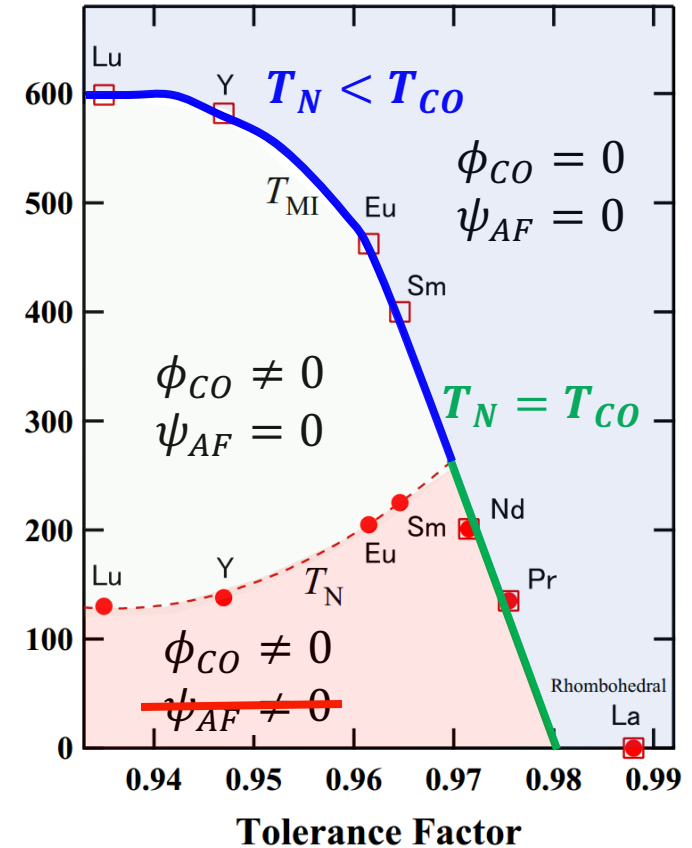
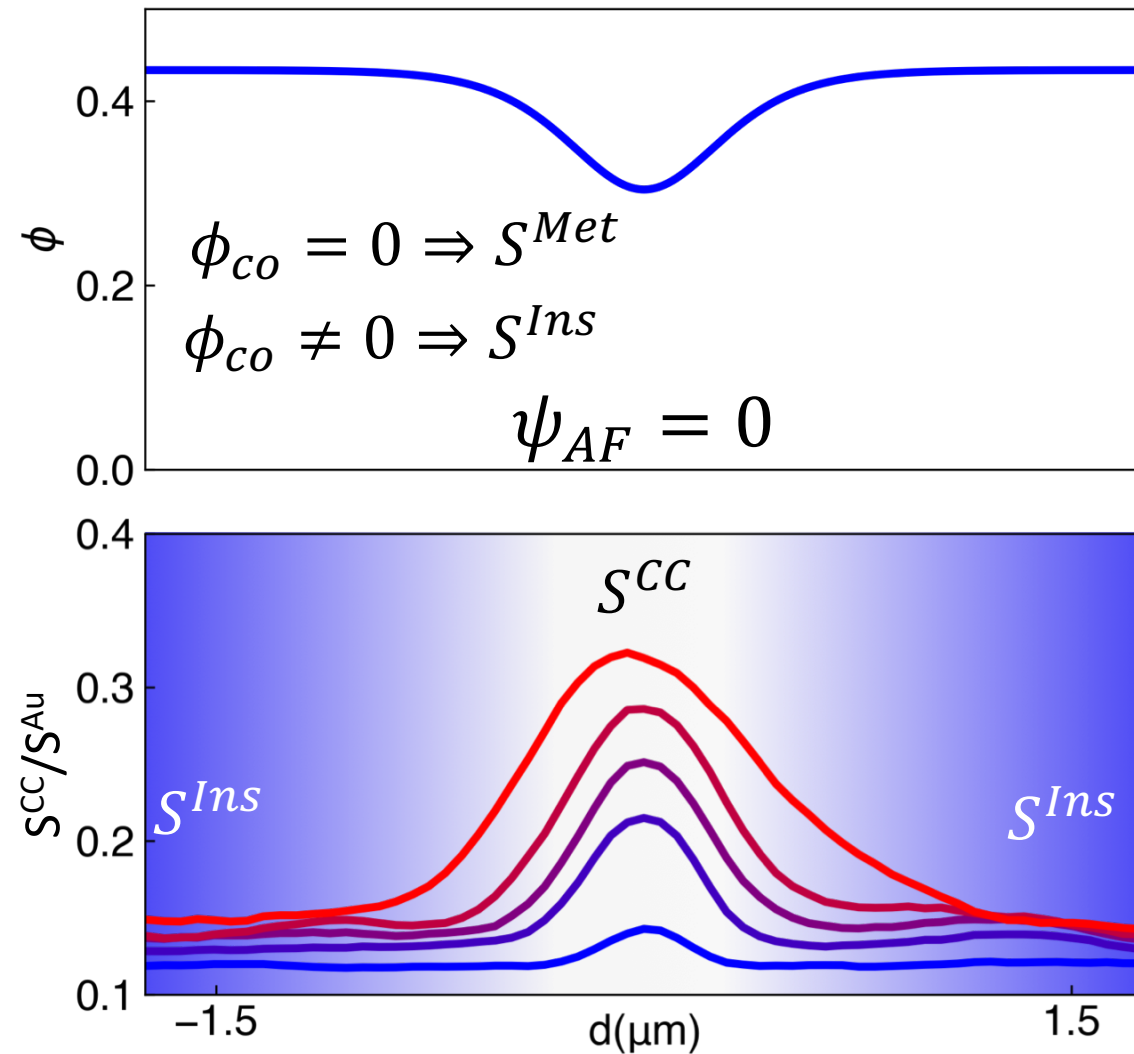
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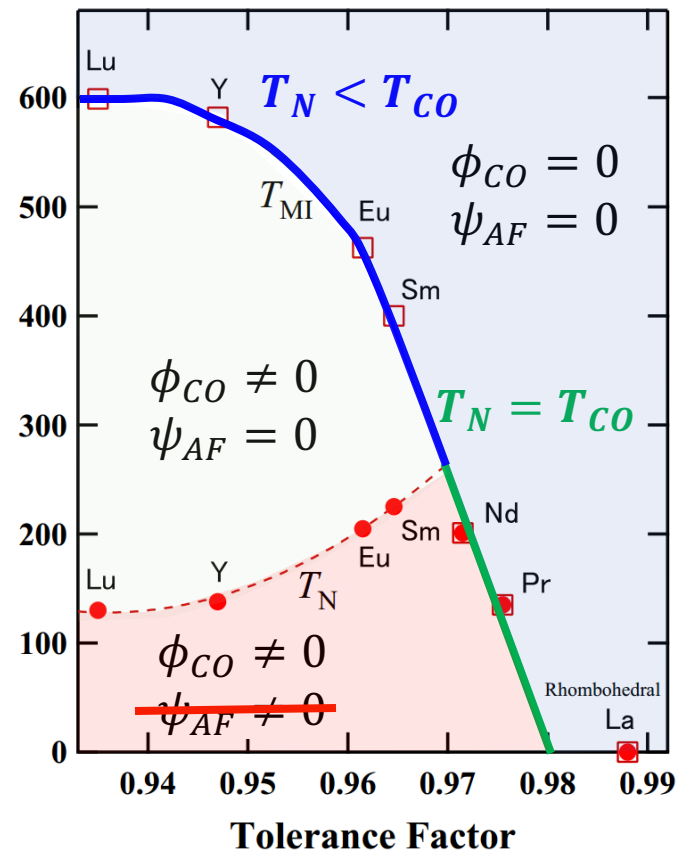
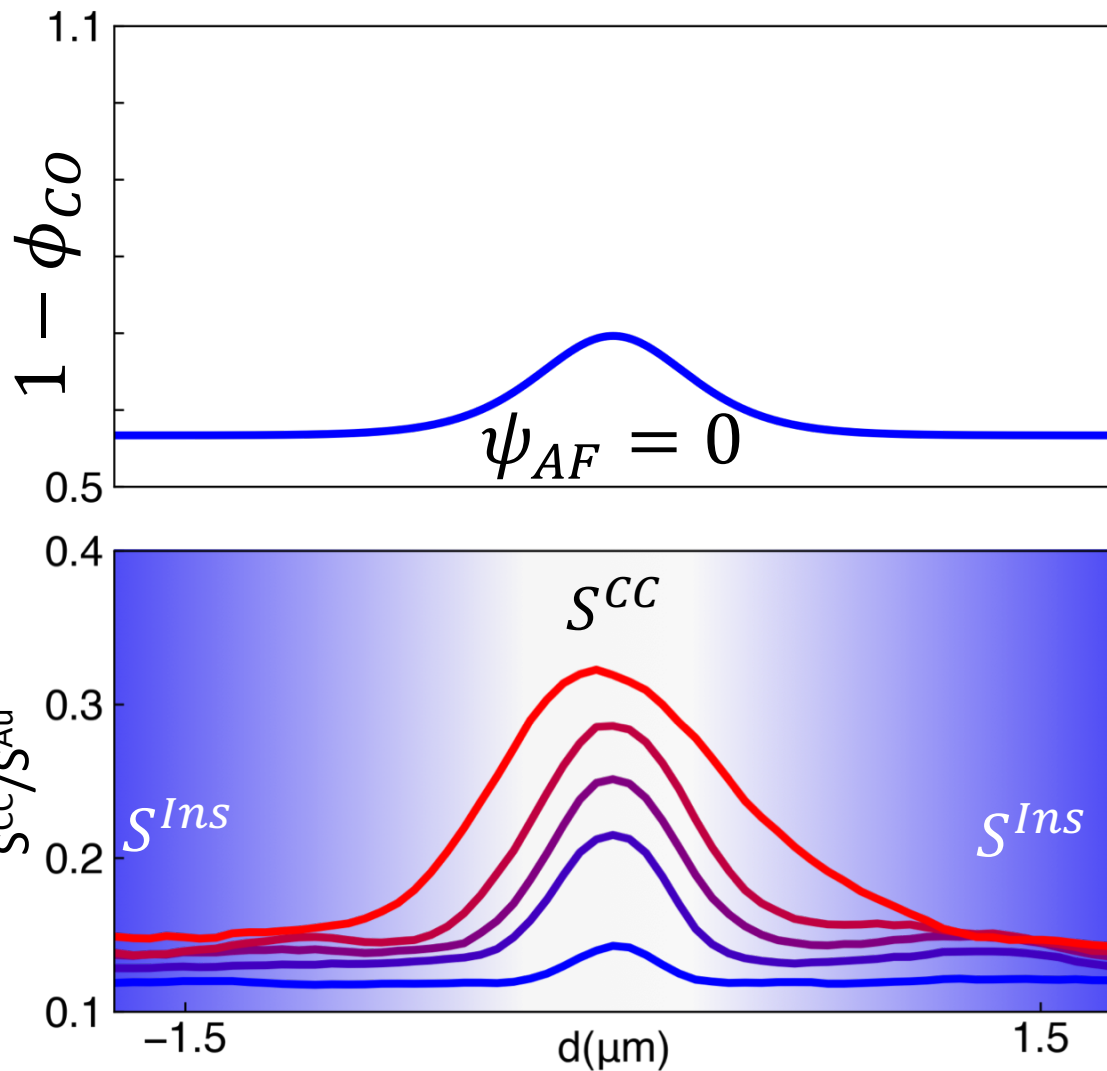
S.B. Lee, PRL 2011

O. Zachar, PRB 1998

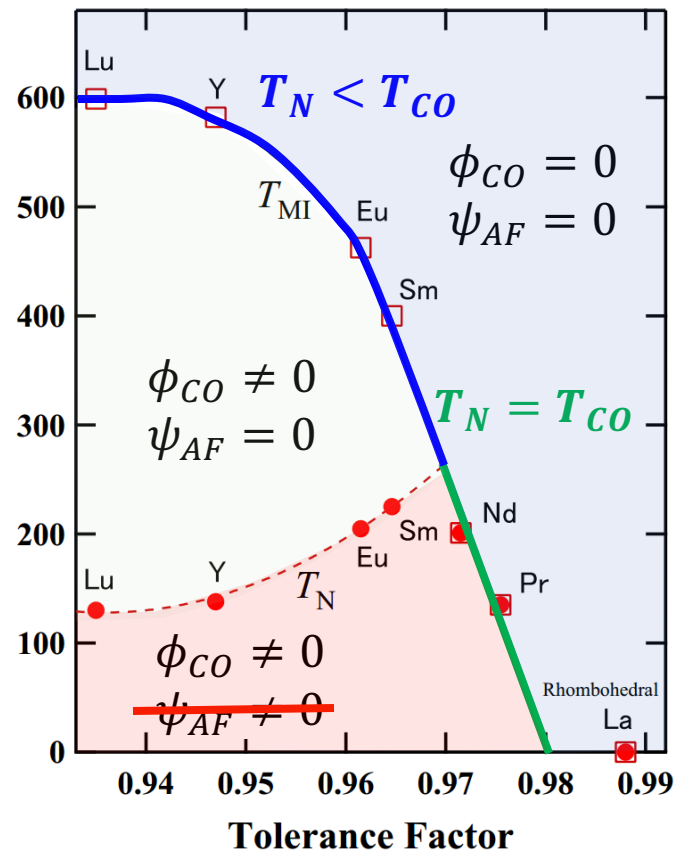
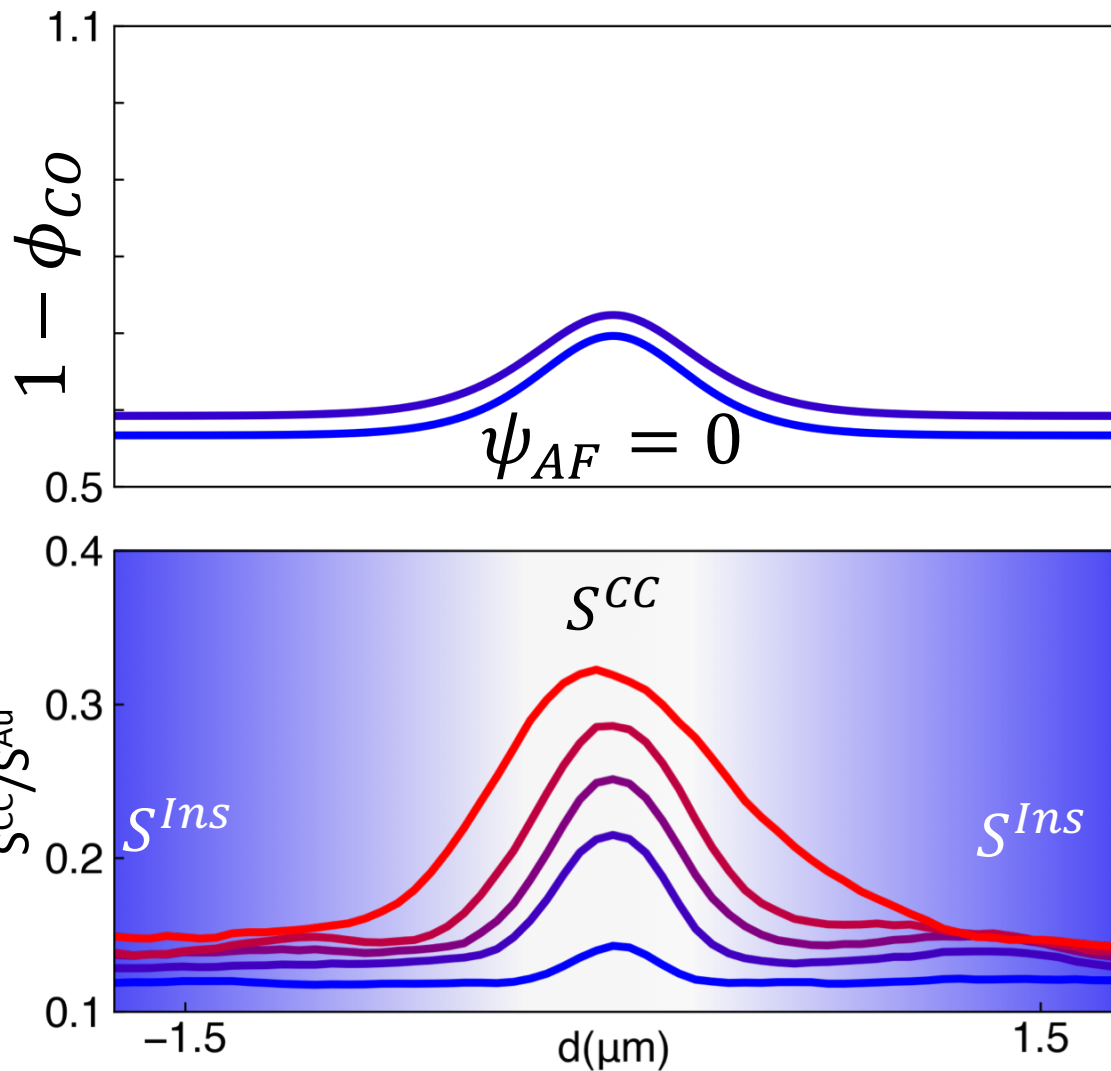
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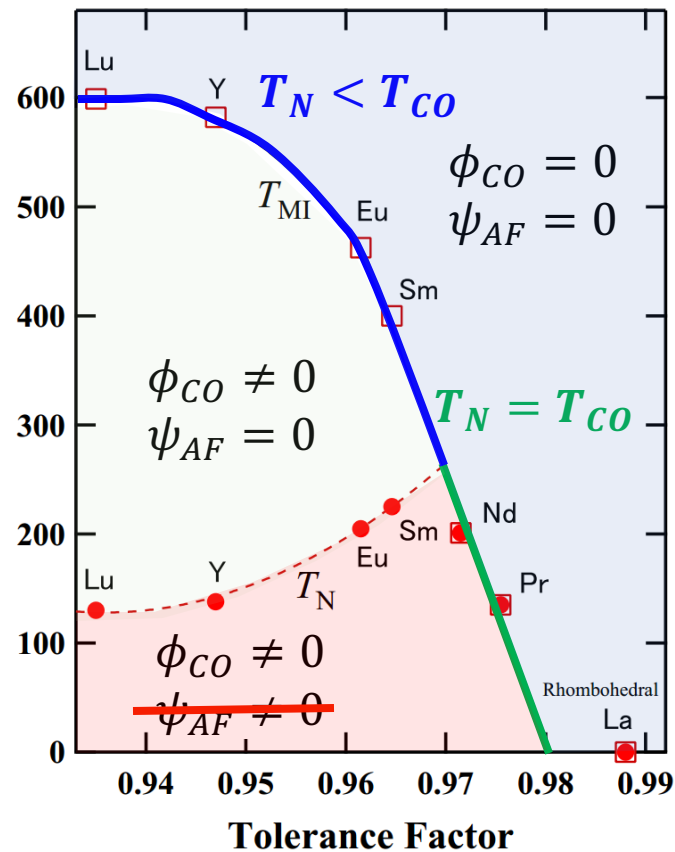
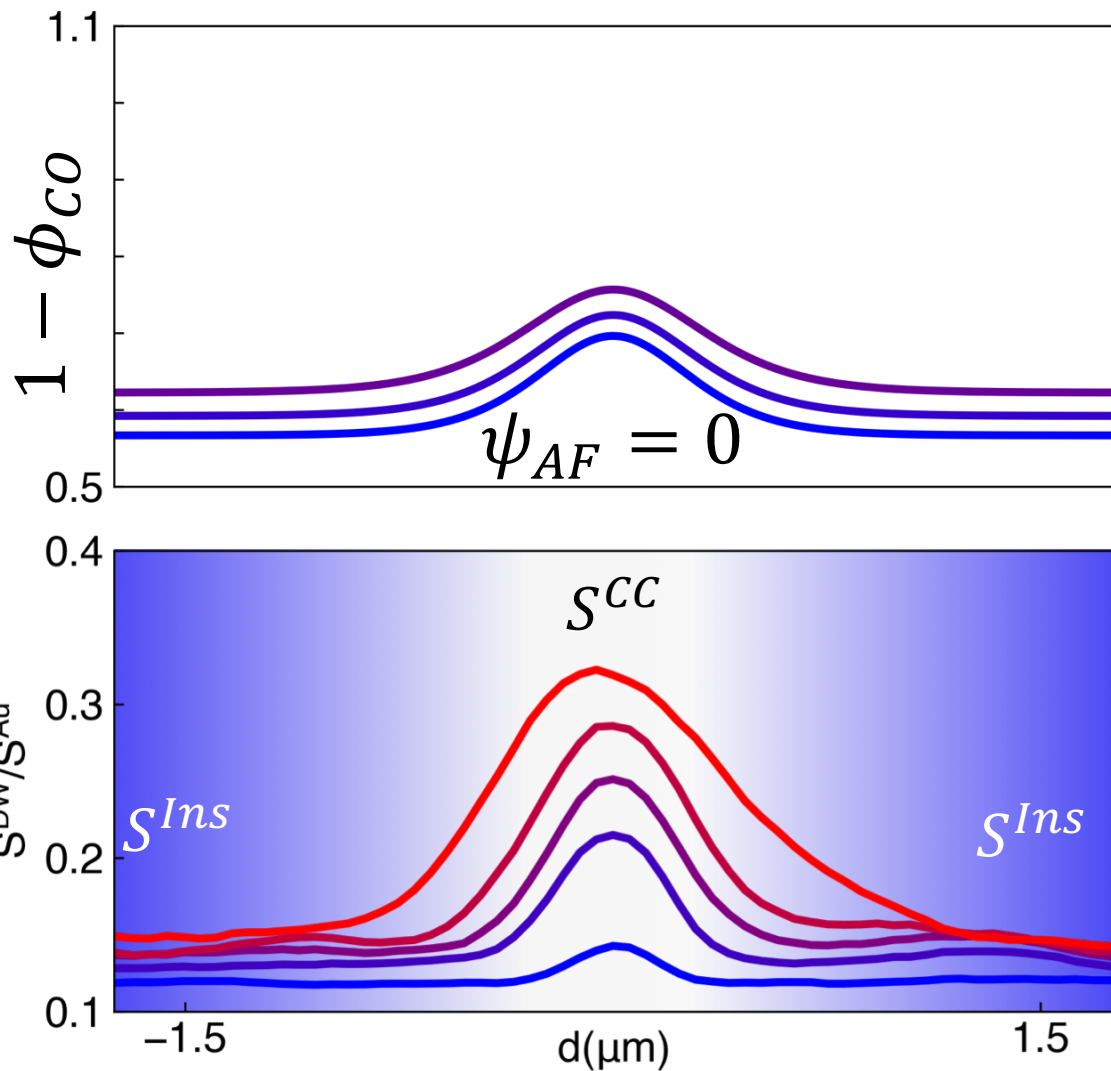
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S.B. Lee, PRL 2011

O. Zachar, PRB 1998

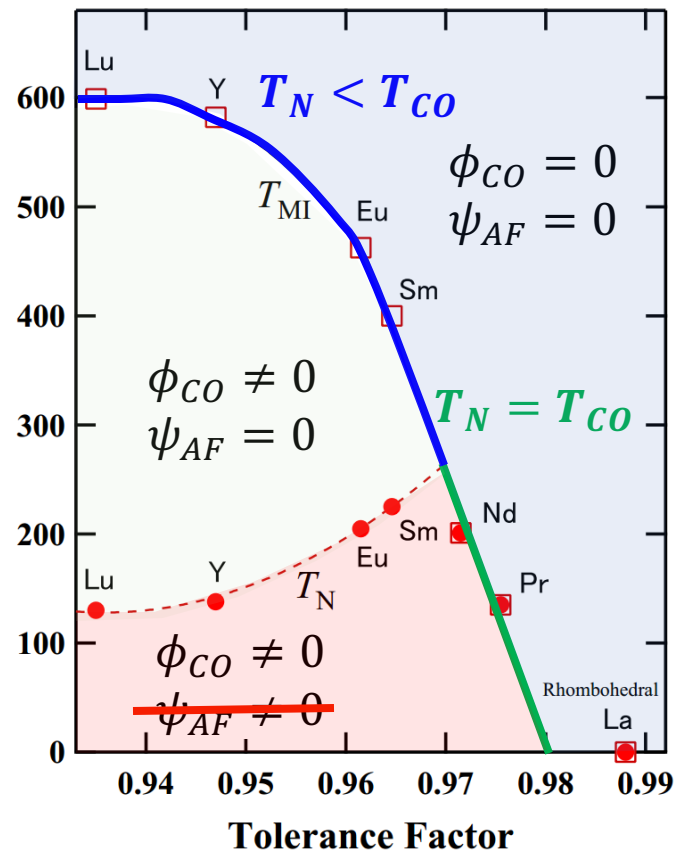
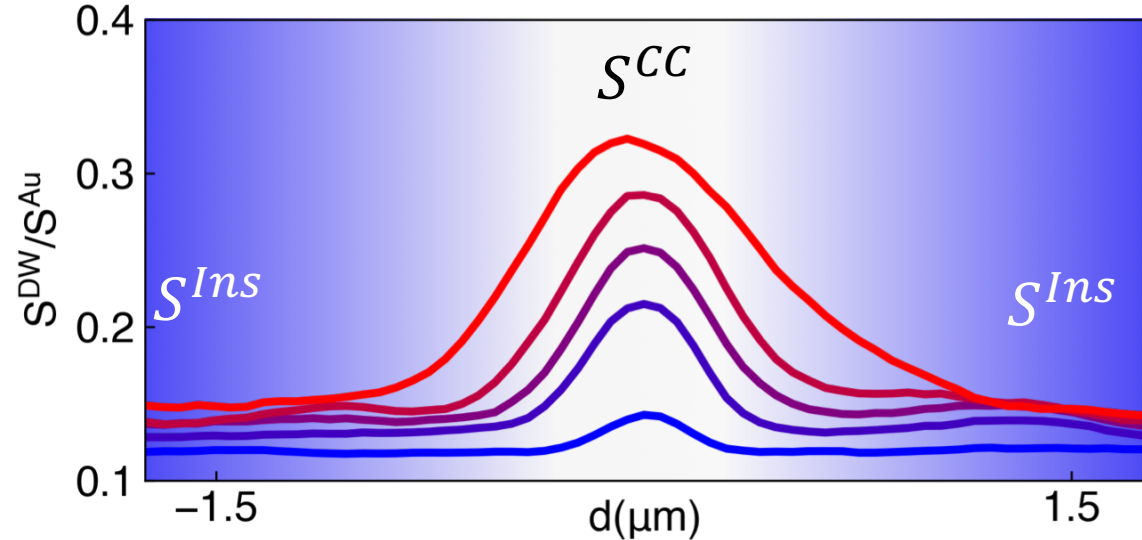
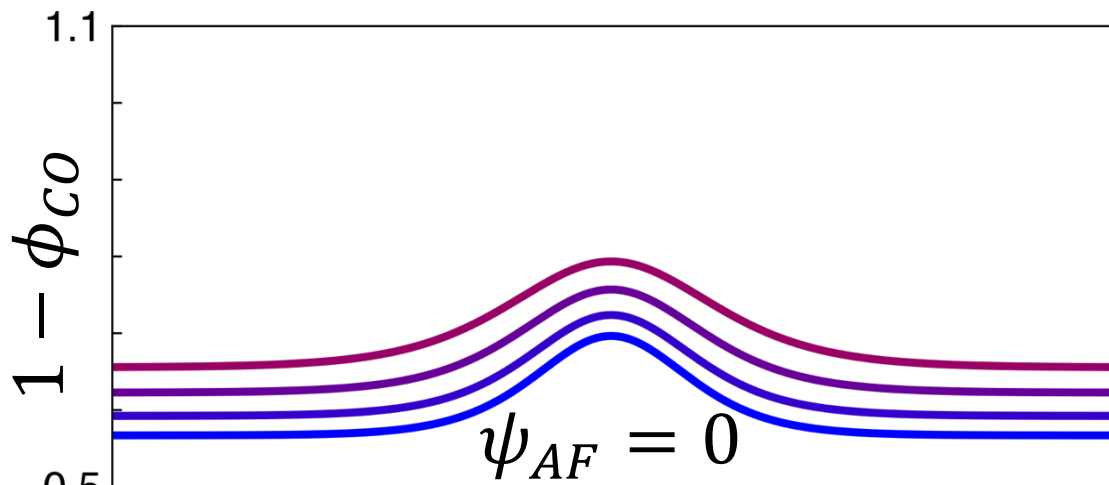
NdNiO₃: Conducting Channels



S.B. Lee, PRL 2011

O. Zachar, PRB 1998

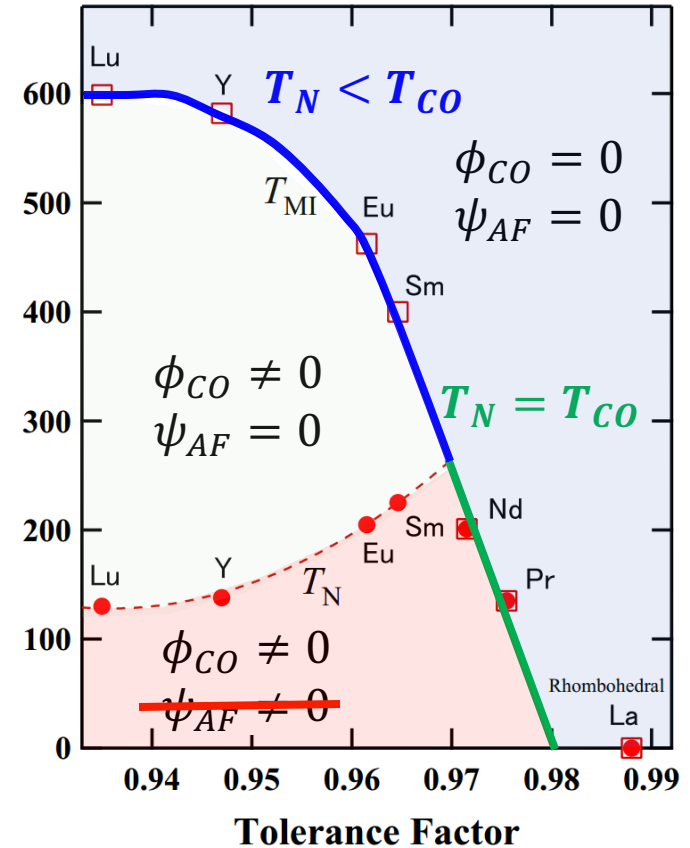
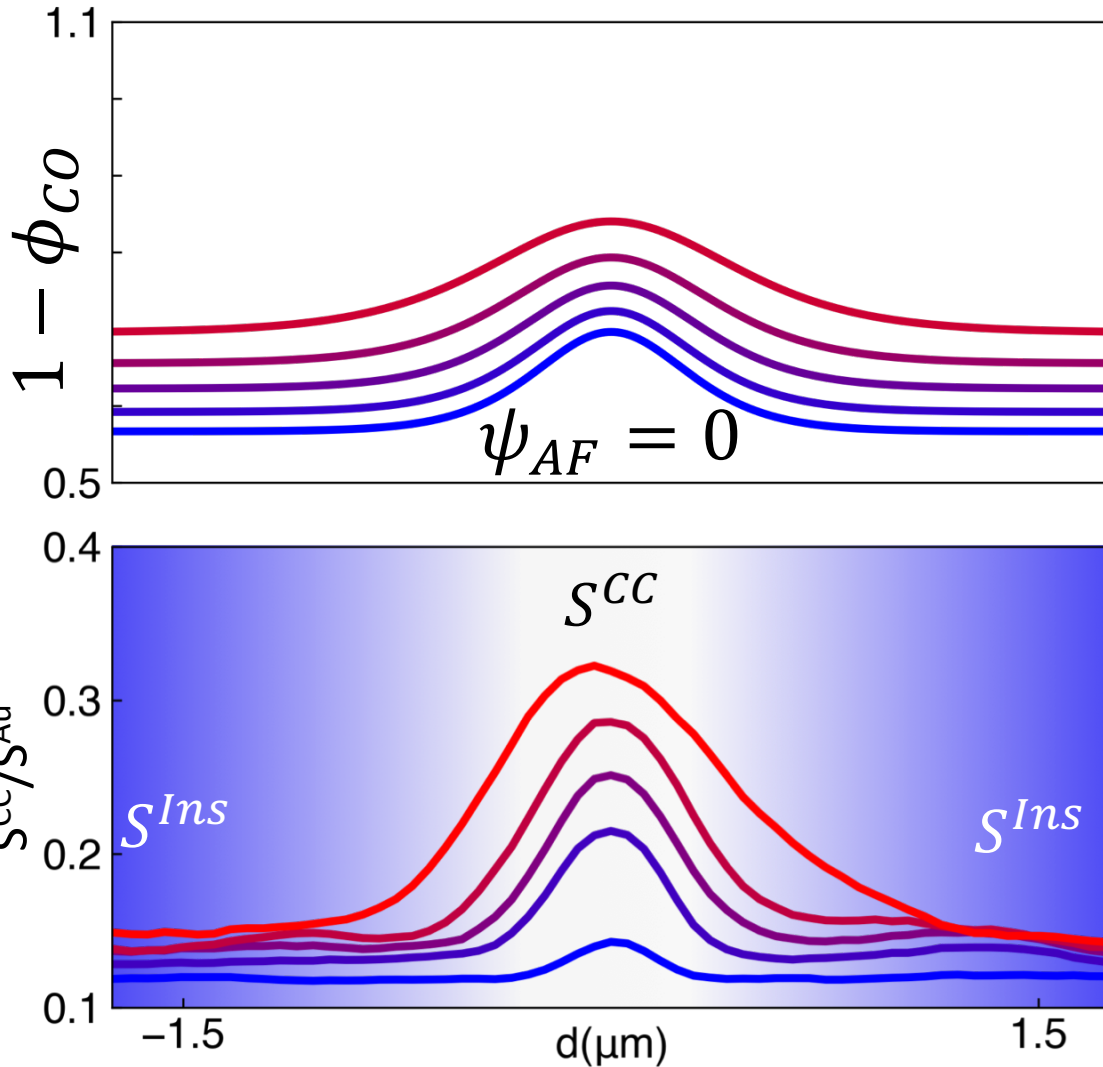
NdNiO₃: Conducting Channels



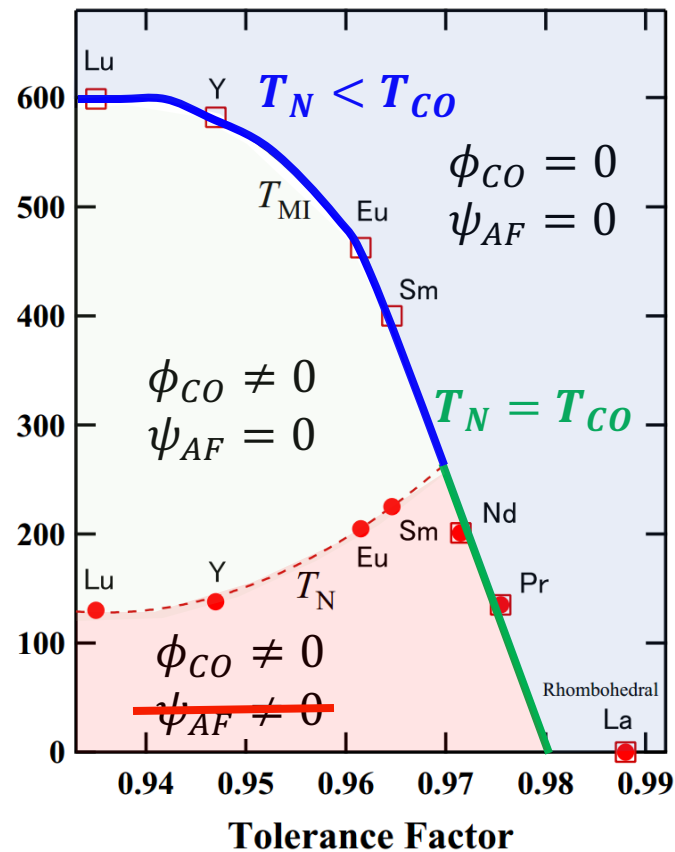
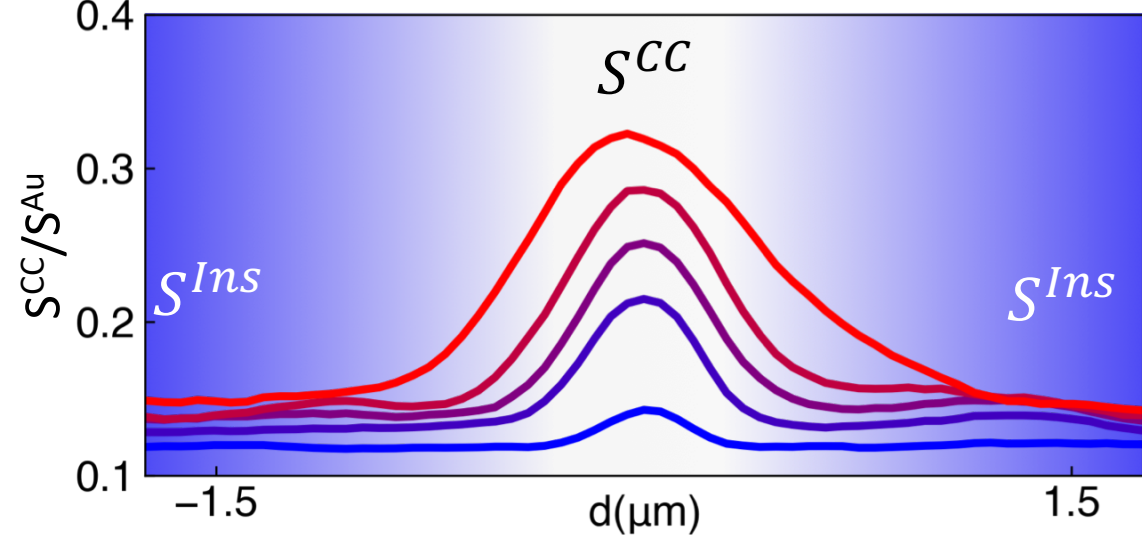
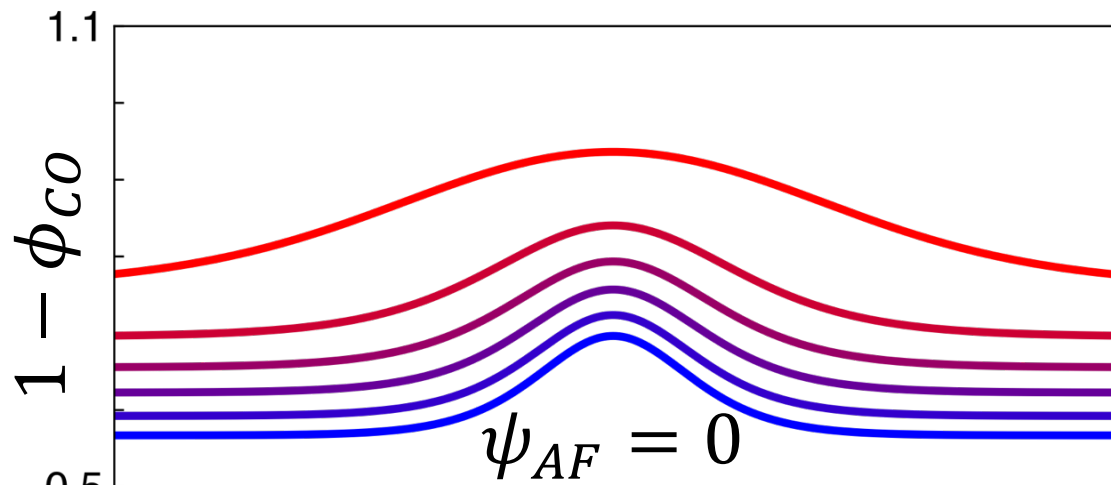
S.B. Lee, PRL 2011

O. Zachar, PRB 1998

NdNiO₃: Conducting Channels



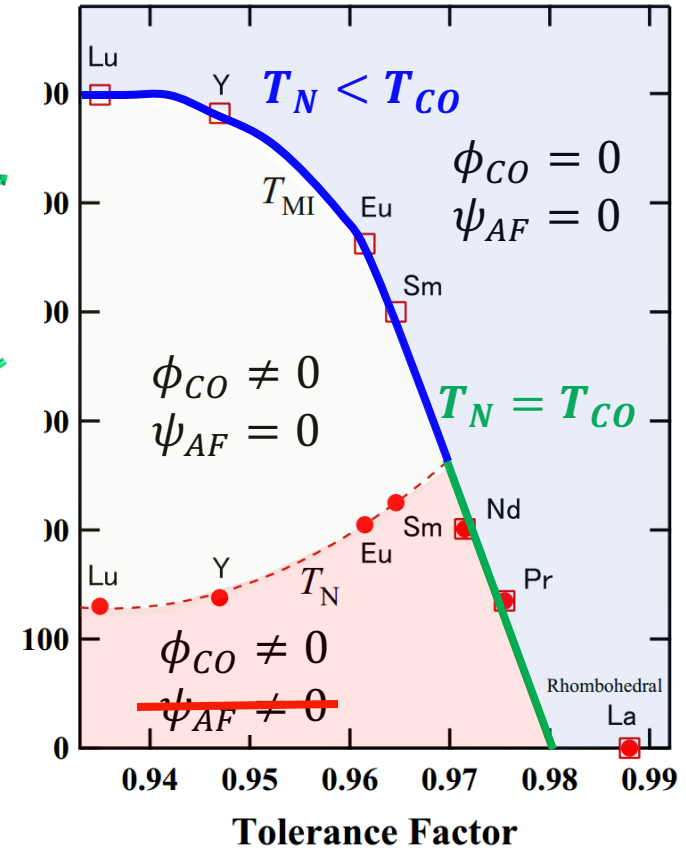
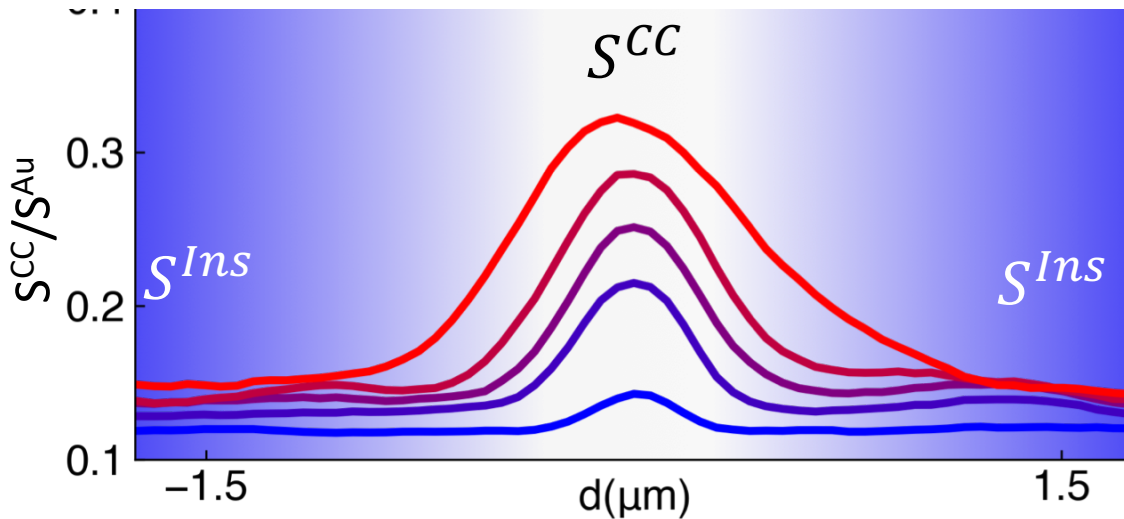
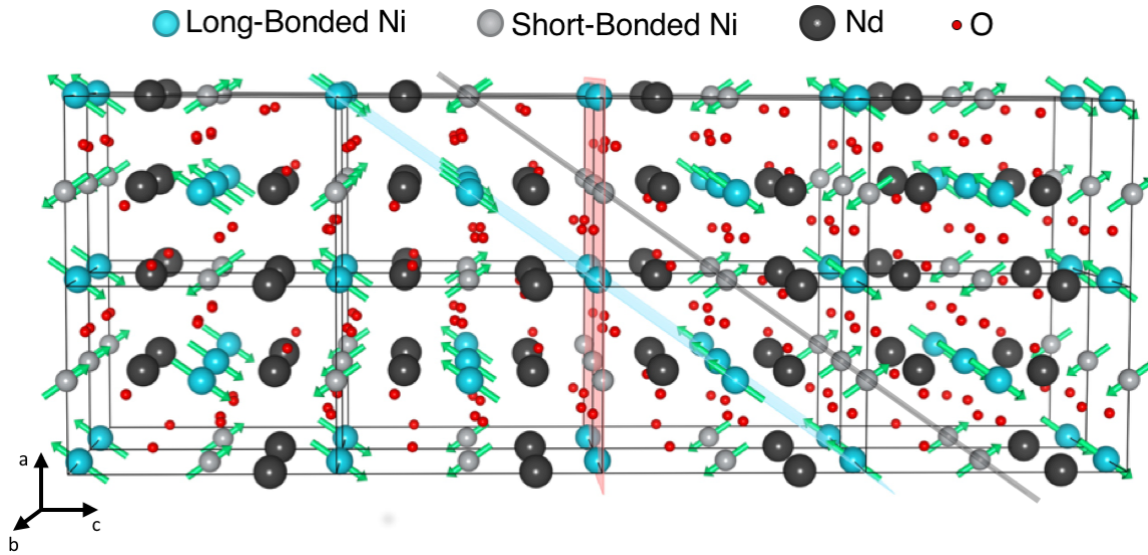
NdNiO₃: Conducting Channels



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O. Zachar, PRB 1998

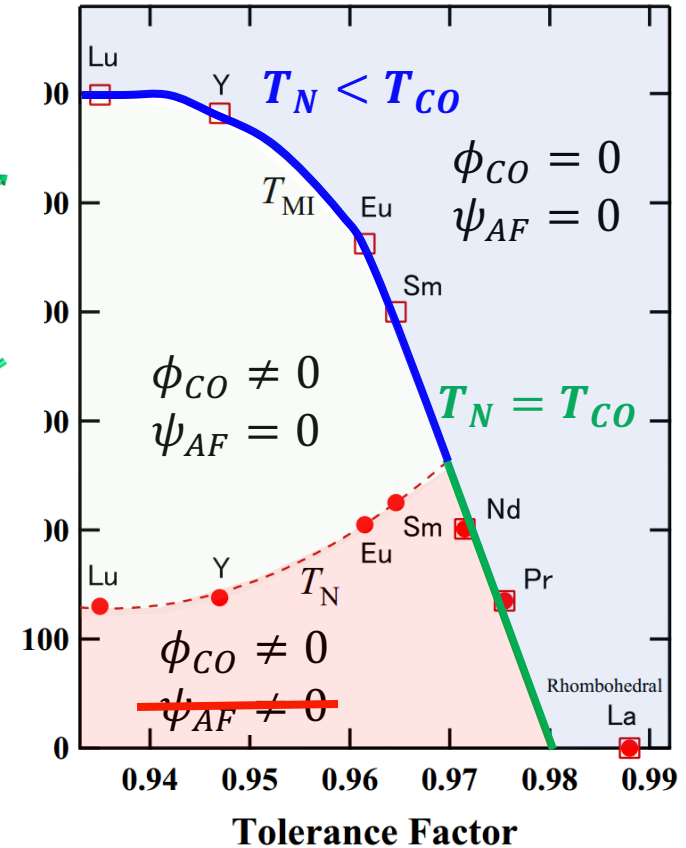
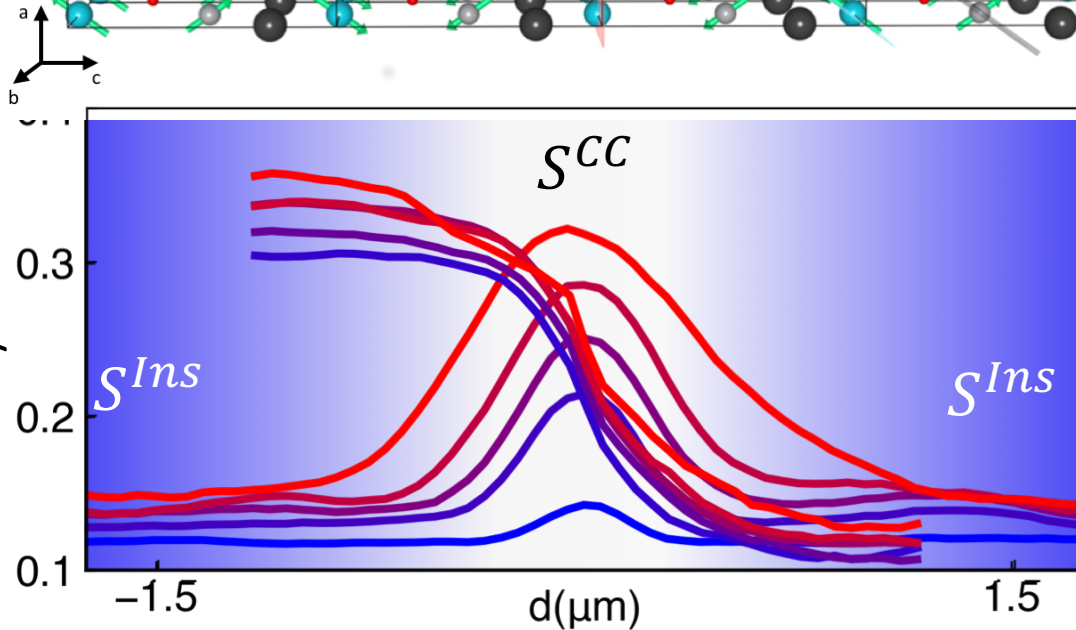
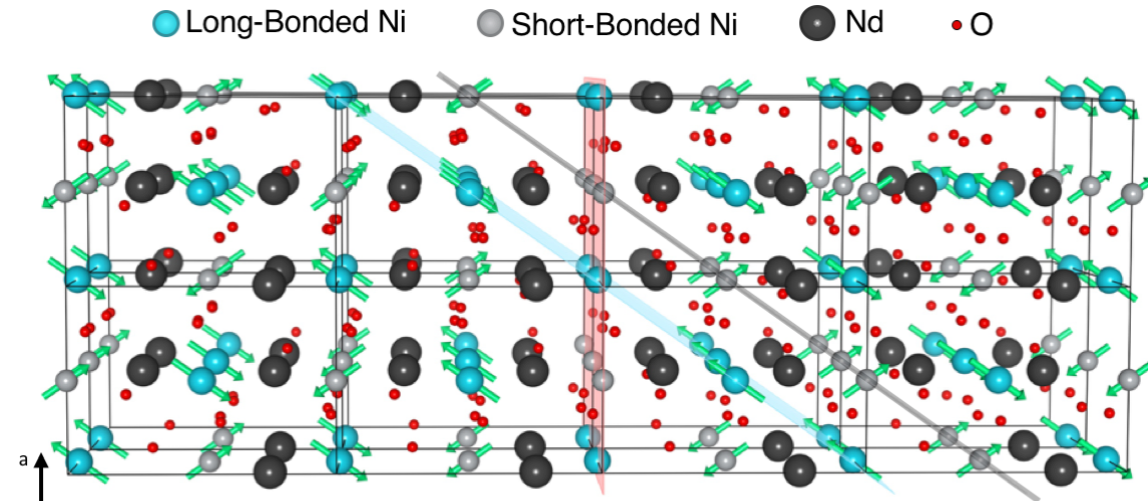
NdNiO₃: Conducting Channels



S.B. Lee, PRL 2011

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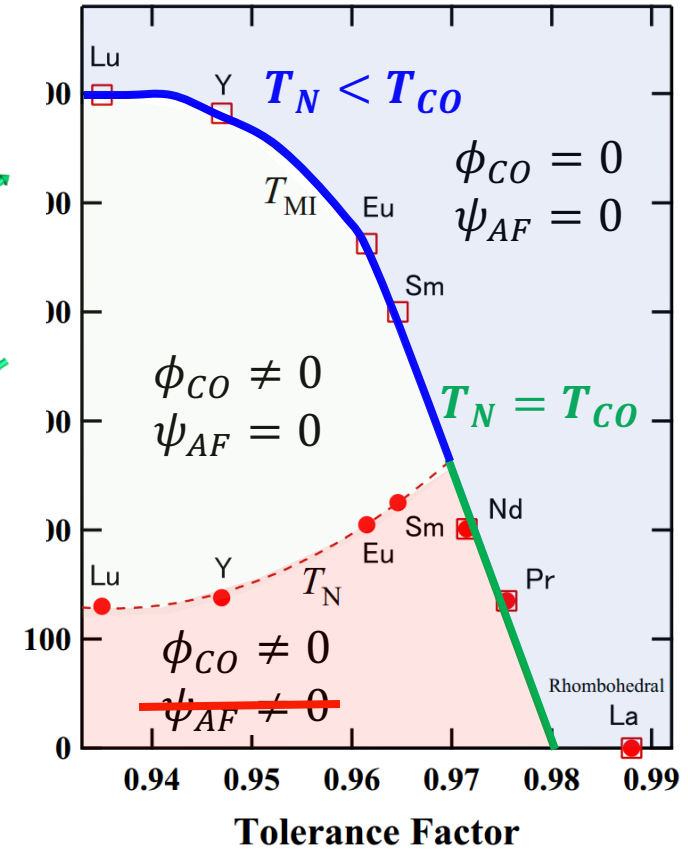
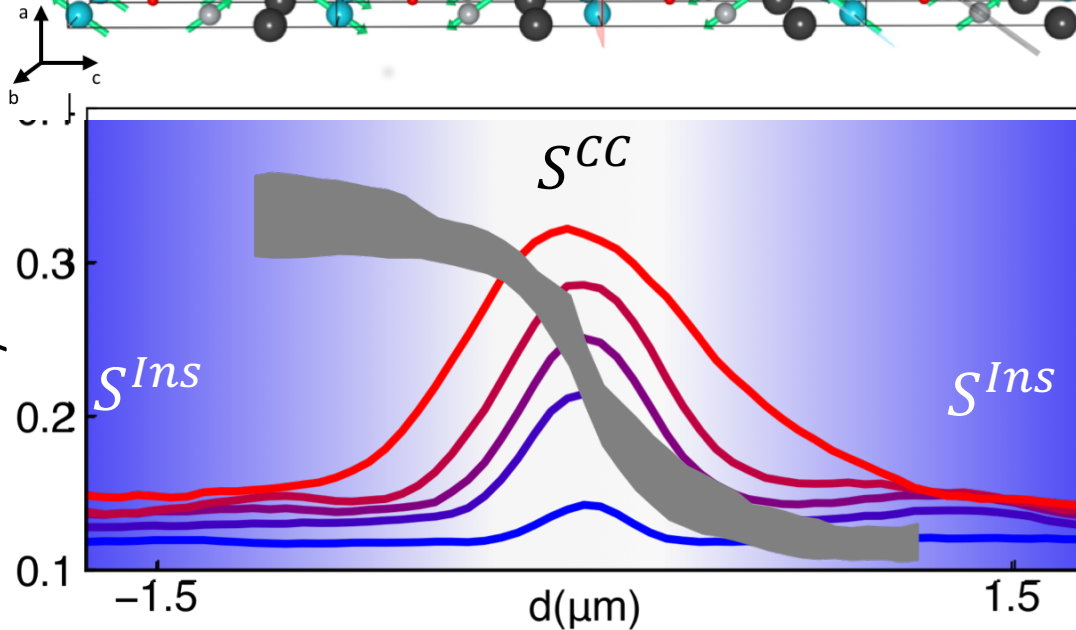
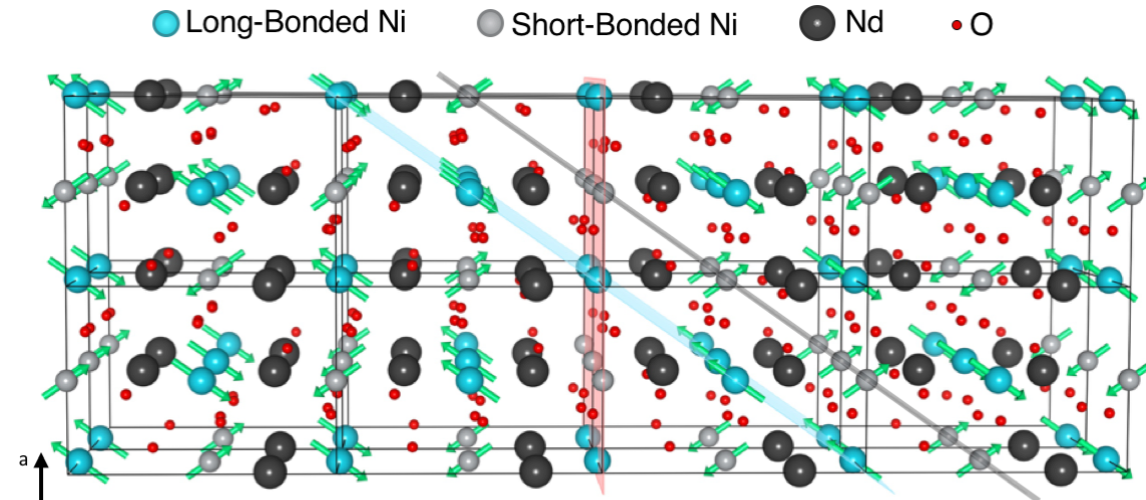
NdNiO₃: Conducting Channels



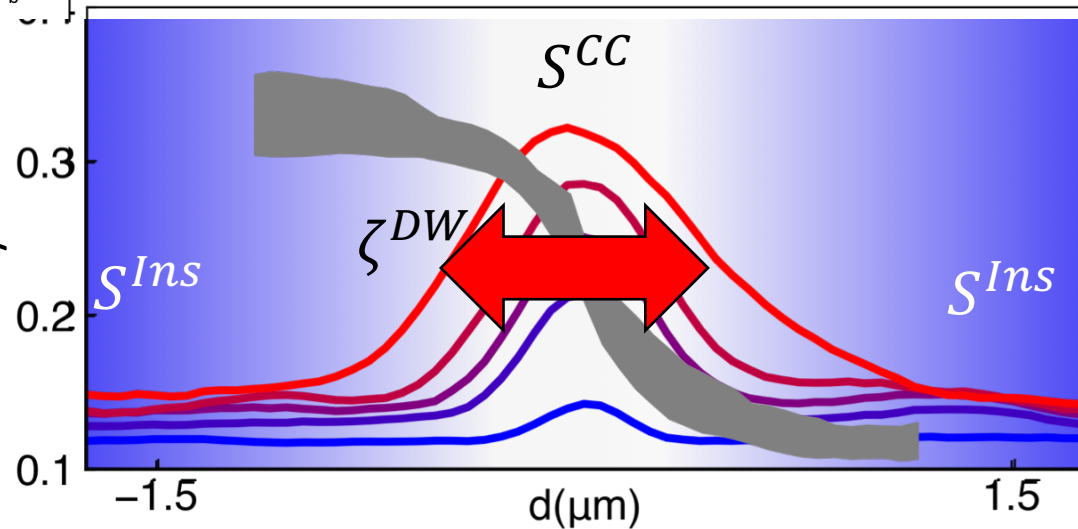
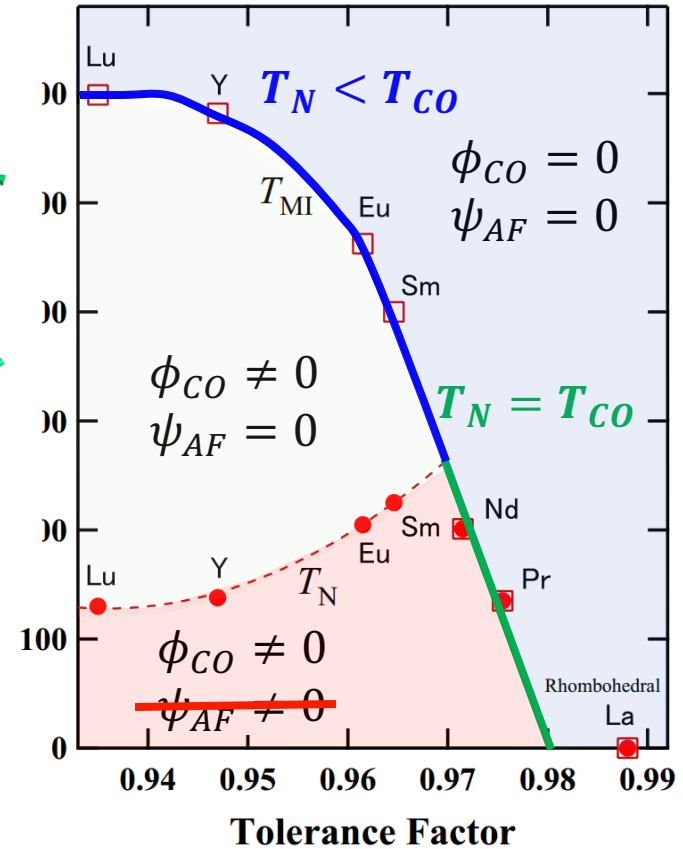
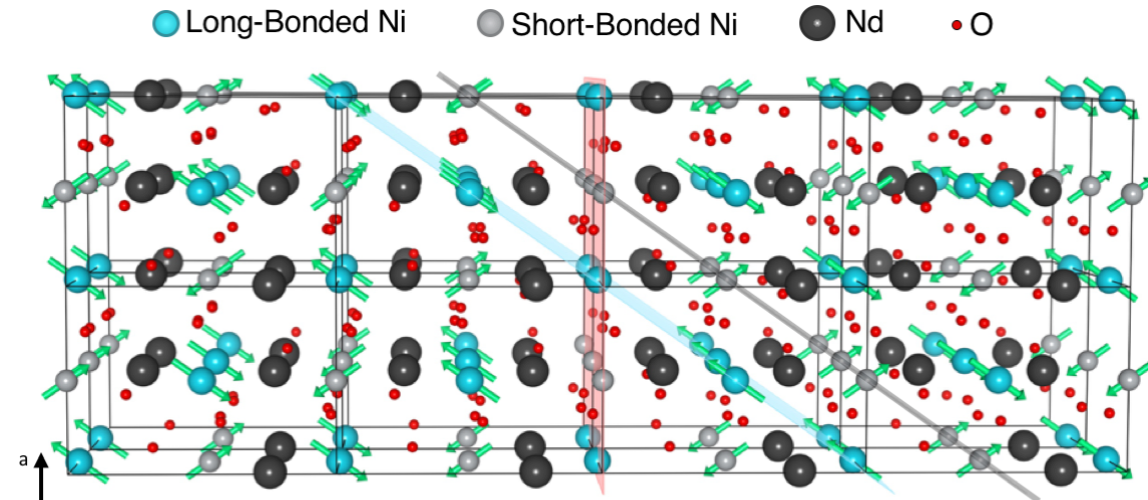
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NdNiO₃: Conducting Channels

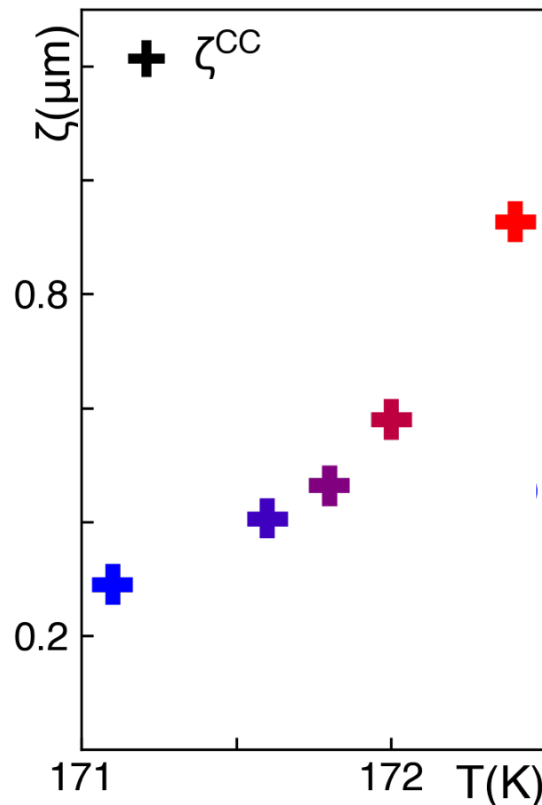
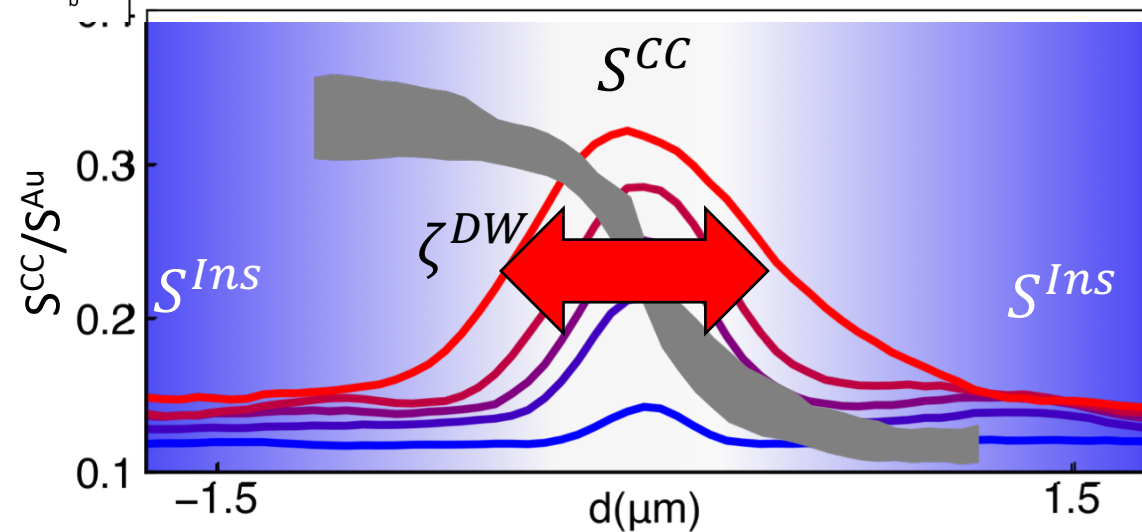
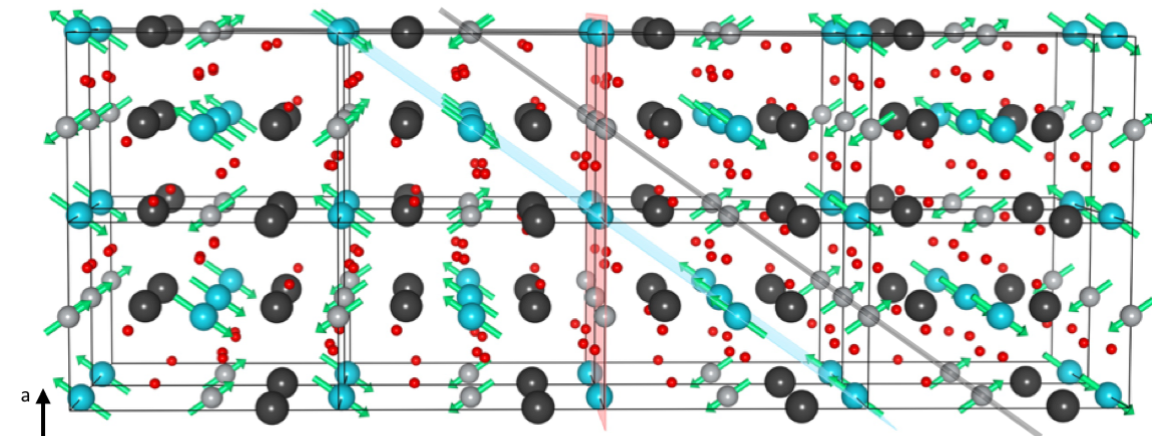


NdNiO₃: Conducting Channels



NdNiO₃: Conducting Channels

● Long-Bonded Ni ● Short-Bonded Ni ● Nd ● O



NdNiO₃: Conducting Channels

