

# Magnetic Transitions in a Doped Mott Insulator

## Filling Information Gap, Searching for New Phase

Michael Aling  
Mechanical Engineering

PI: Stephen Wilson  
Mentor: Julian Schmehr  
Materials Science



# Materials Science: A Broad Field

New materials create new technologies

Electronic and Magnetic

Structural

Nanomaterials

Biomaterials

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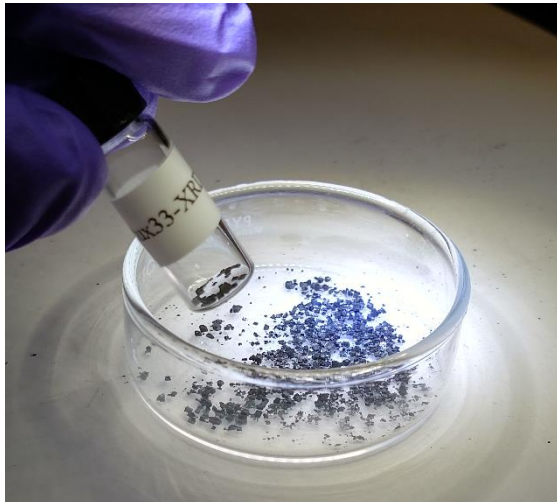
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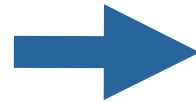
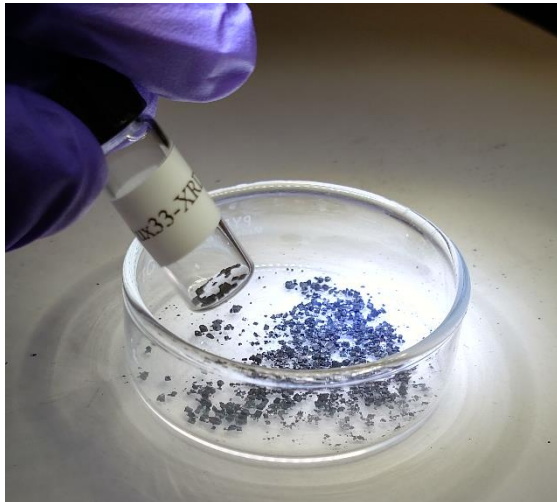
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Solid State Devices  
Next-Gen Electronics

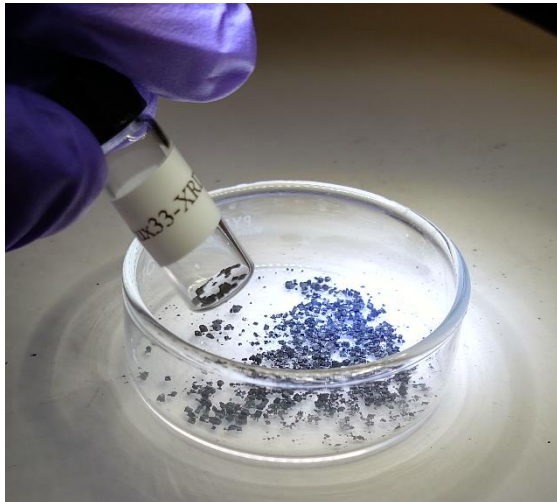


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New materials create new technologies

## Electronic and Magnetic

Semiconductors  
Superconductors  
Condensed Matter Physics



## Structural

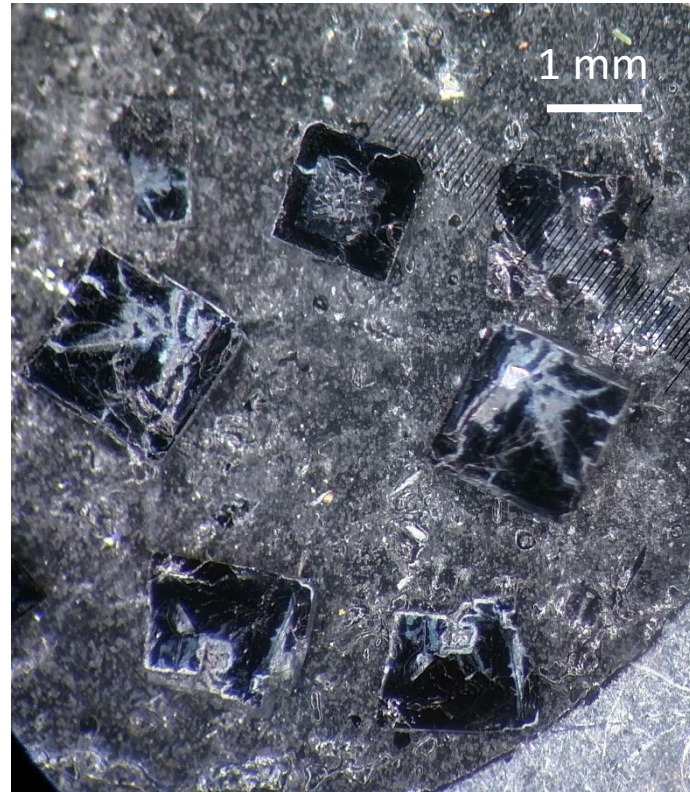
## Nanomaterials

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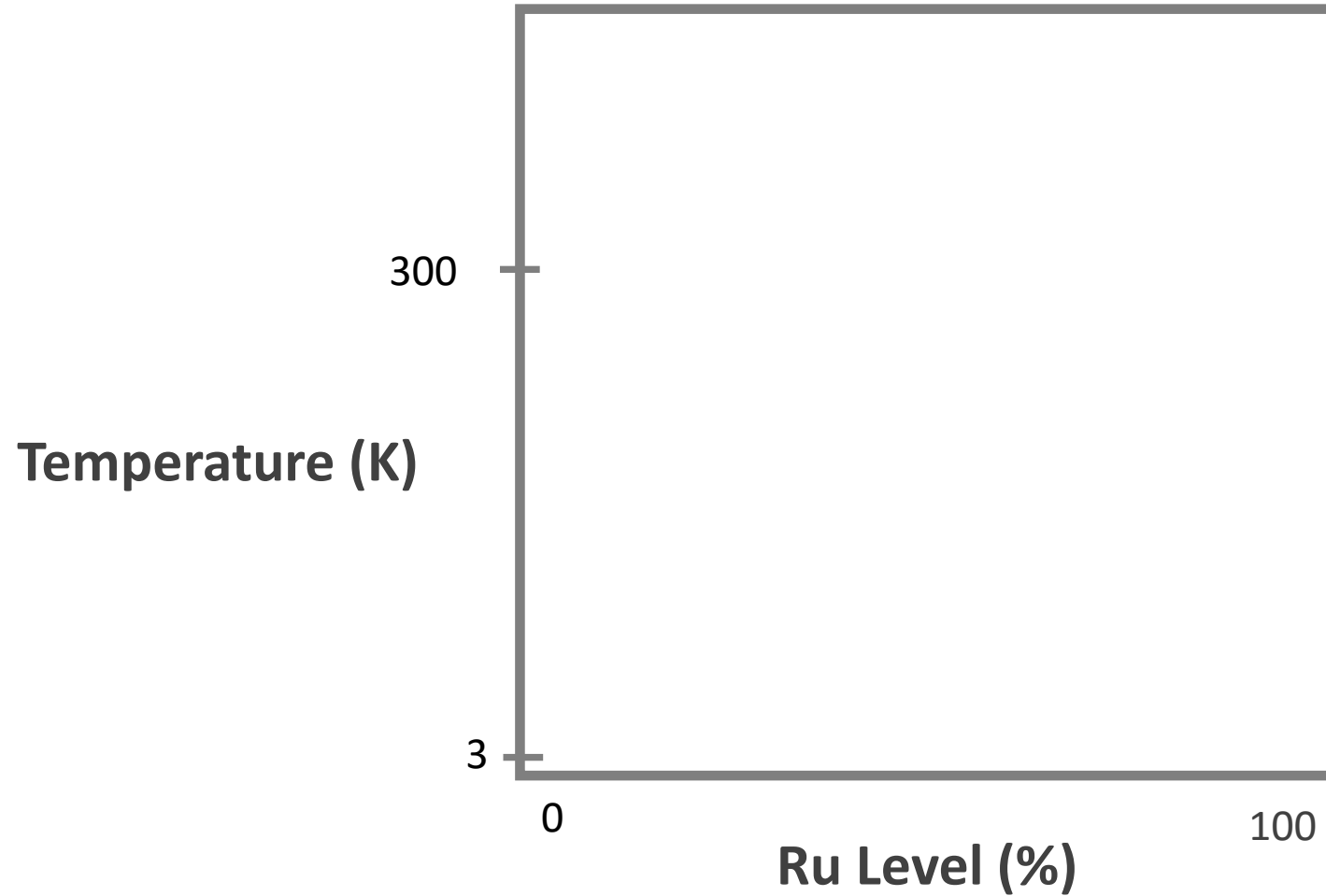
# Looking For a New Electronic Phase: Doping $\text{Sr}_3\text{Ir}_2\text{O}_7$ with Ru



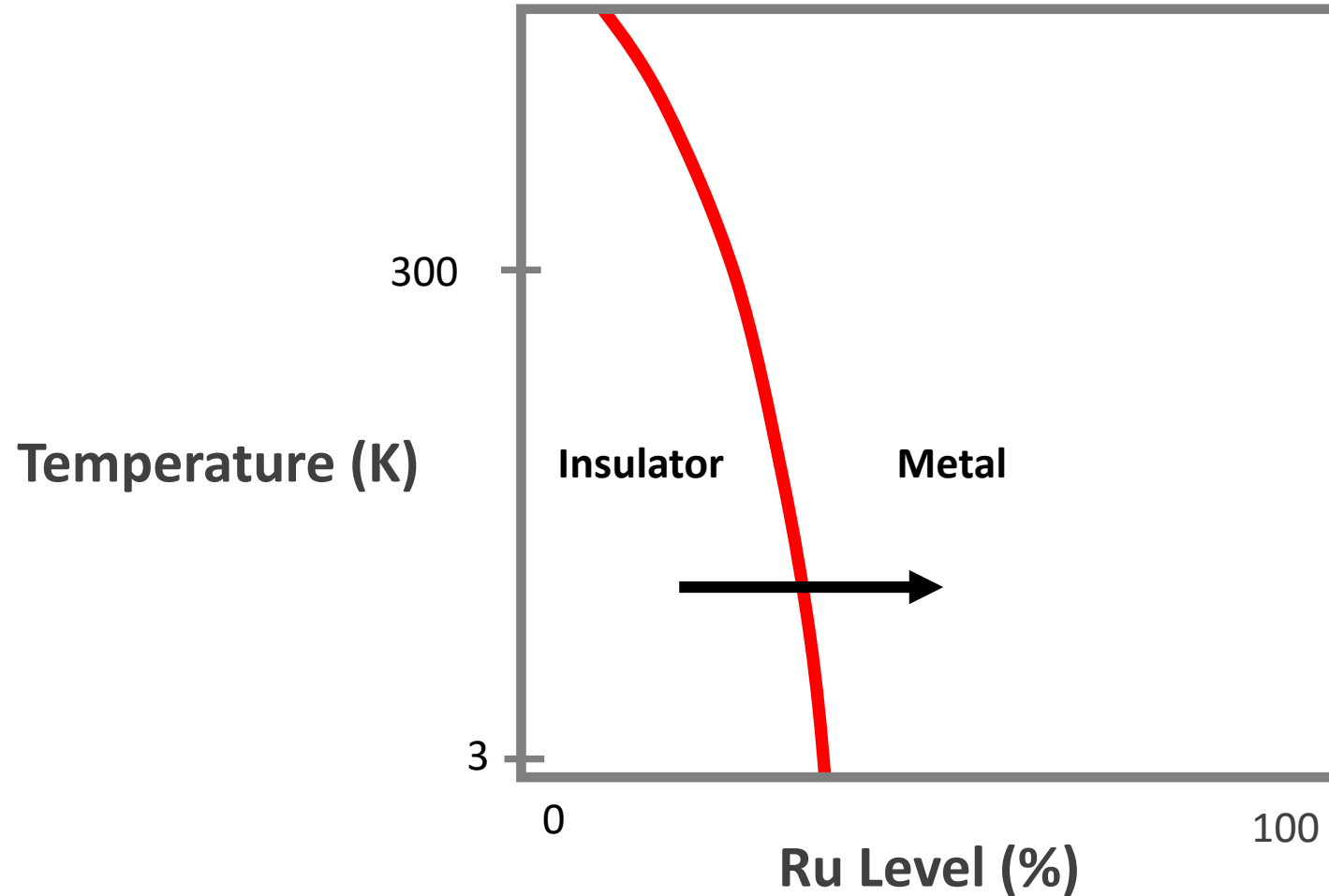
Crystals of  $\text{Sr}_3(\text{Ir}_{1-x}\text{Ru}_x)_2\text{O}_7$



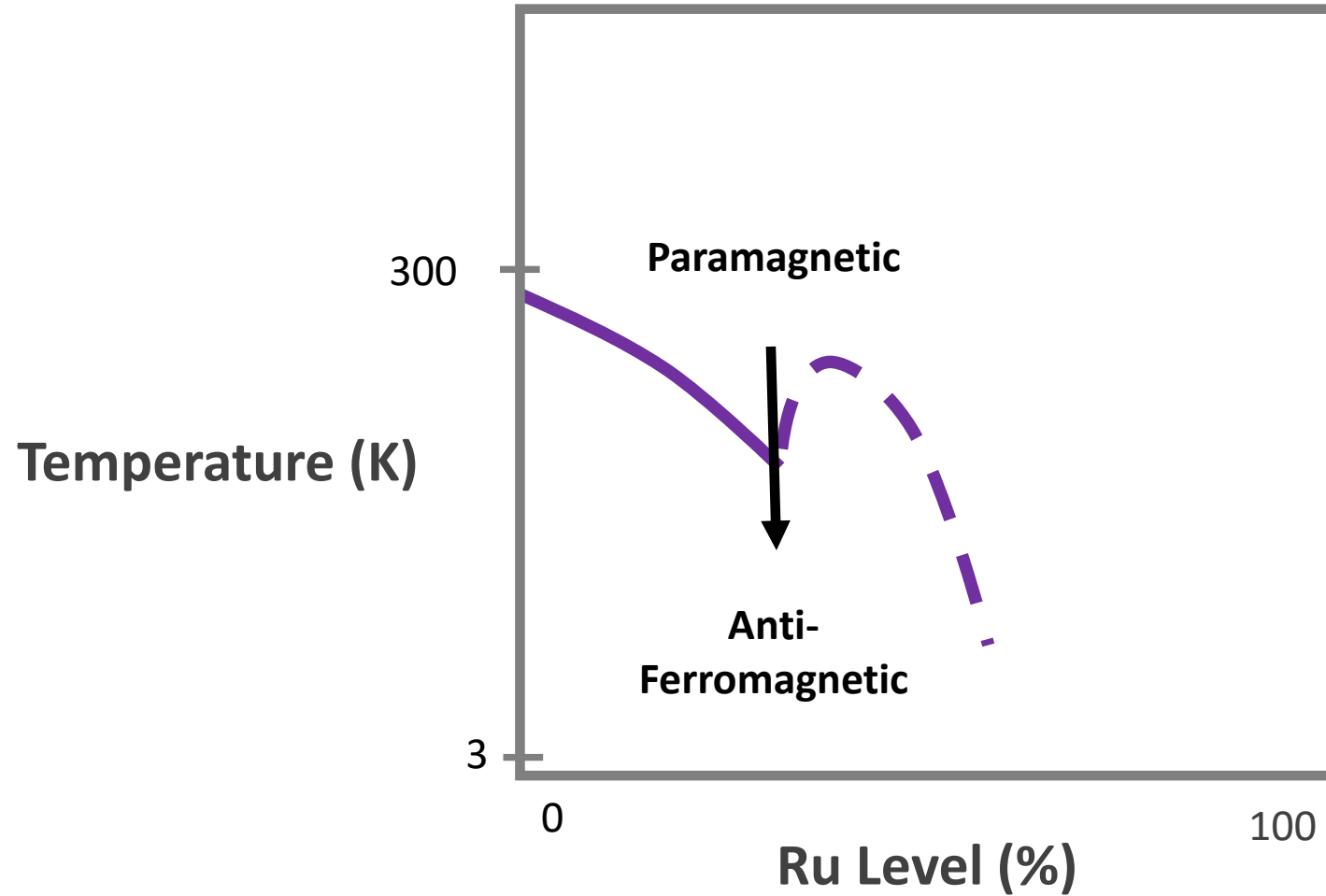
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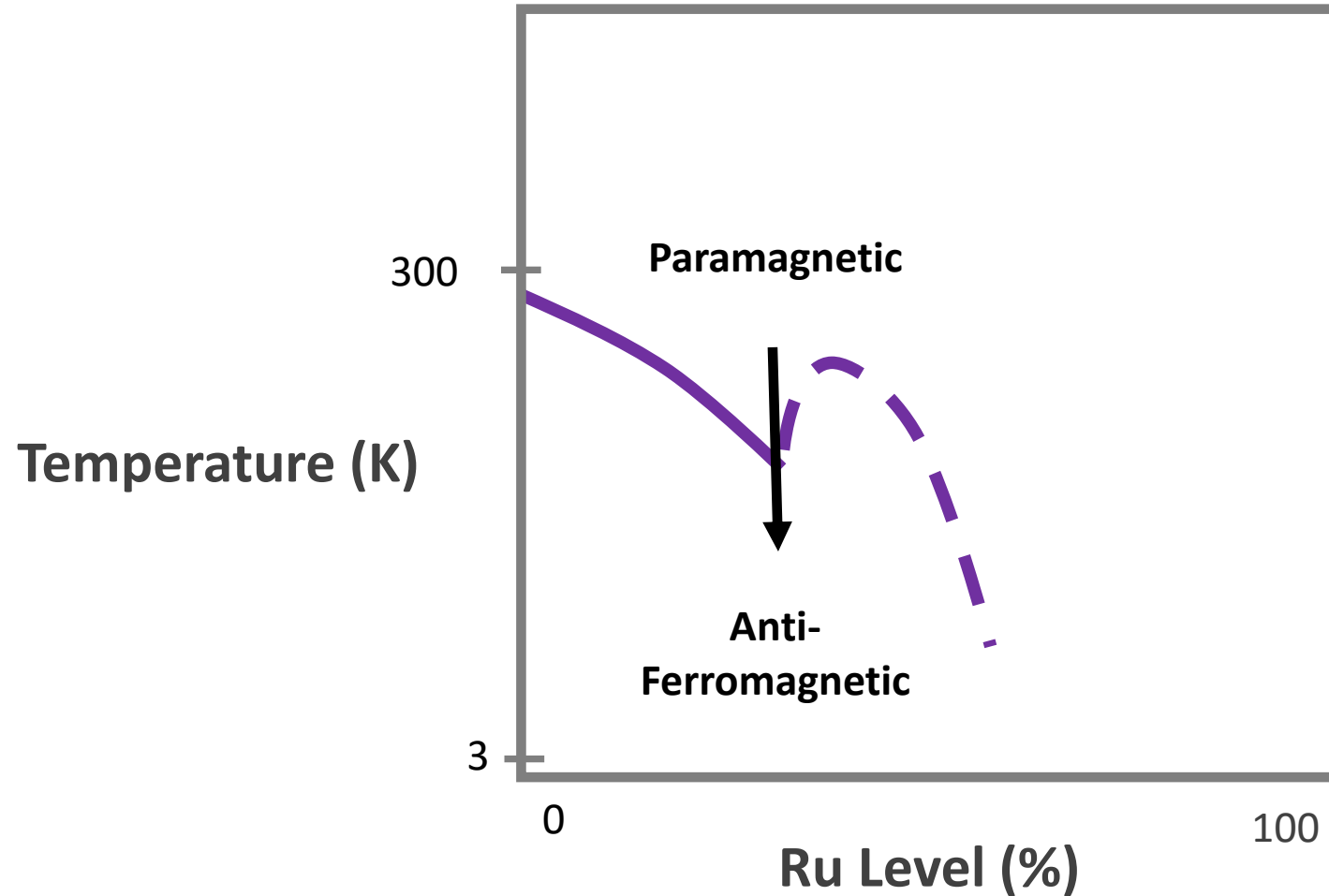
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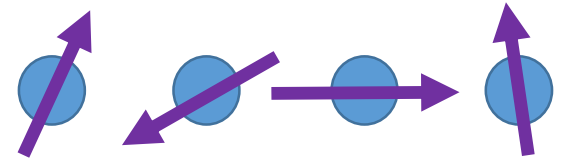
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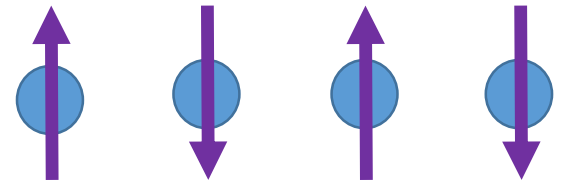
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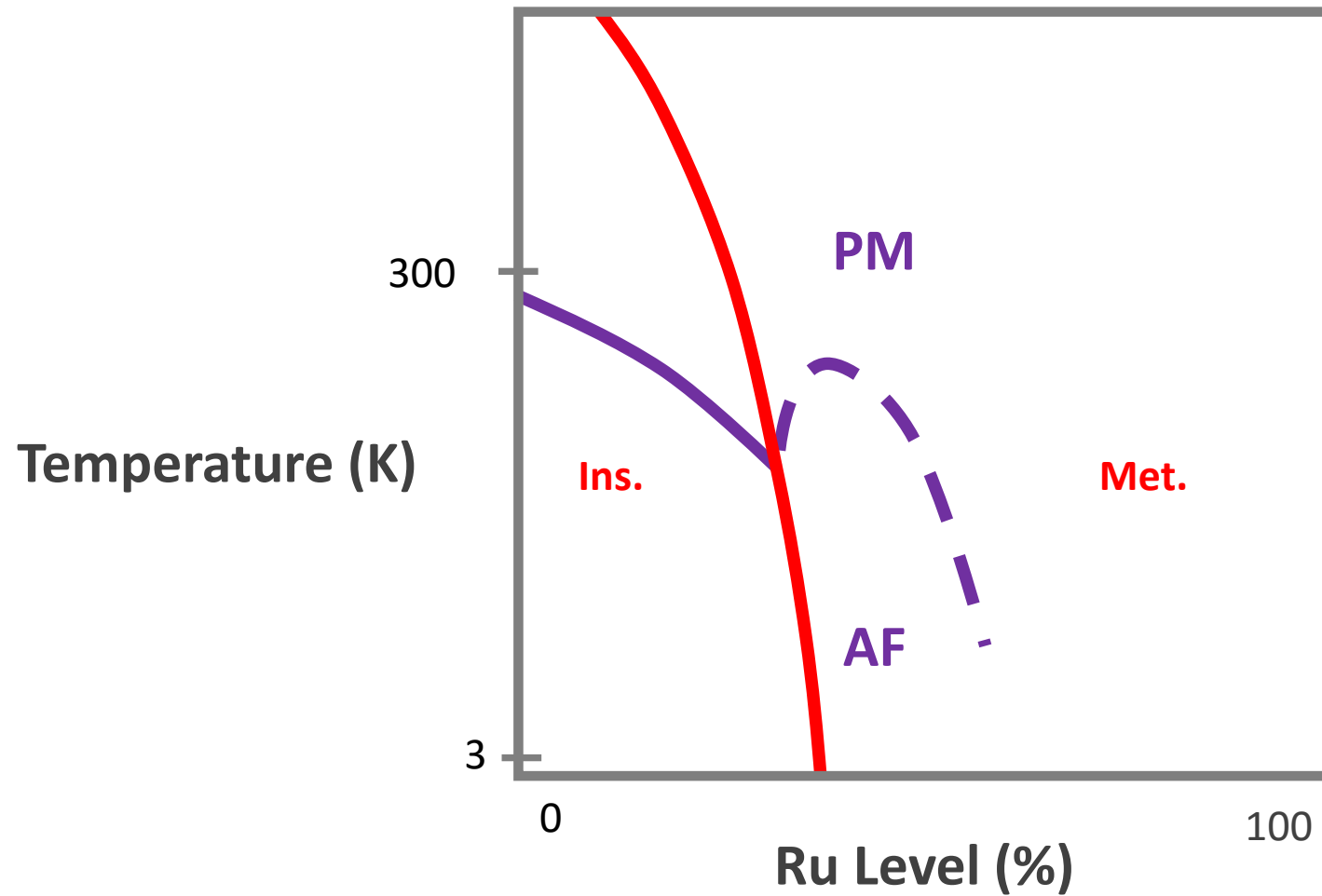
Paramagnetic: disordered



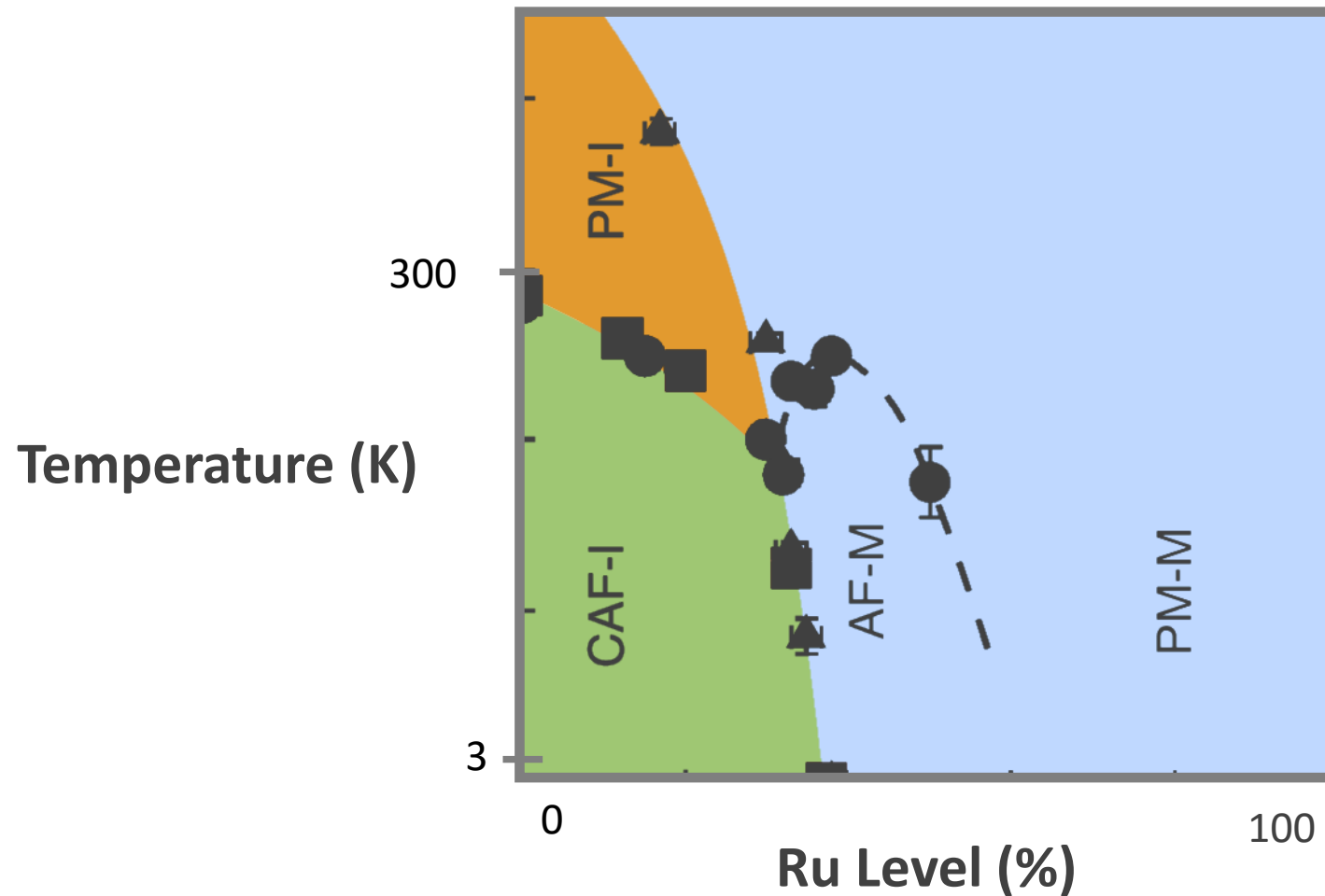
Antiferromagnetic: ordered



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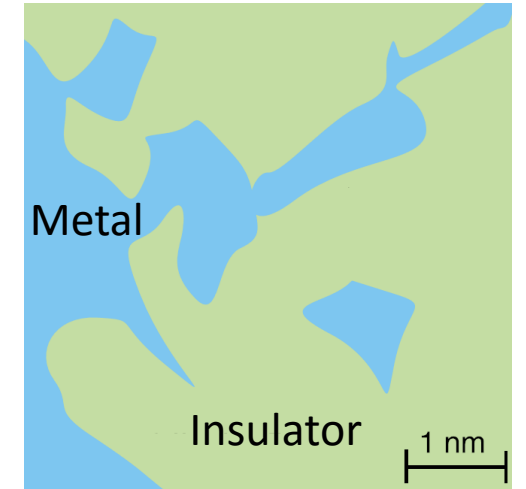
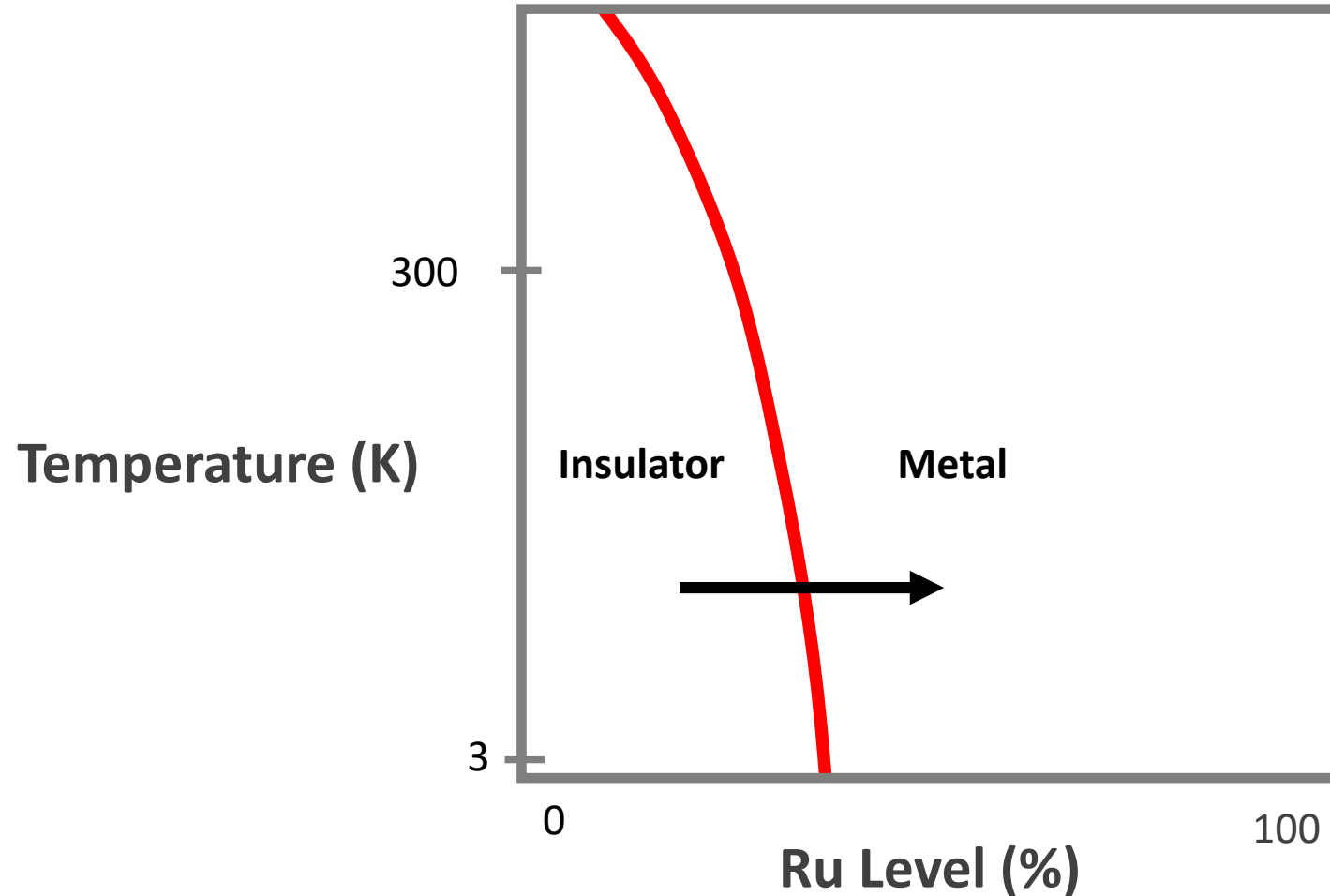


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Adapted from Dhital, et. al., 2014

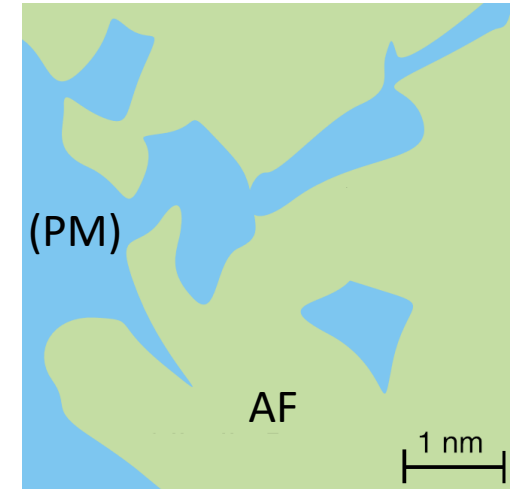
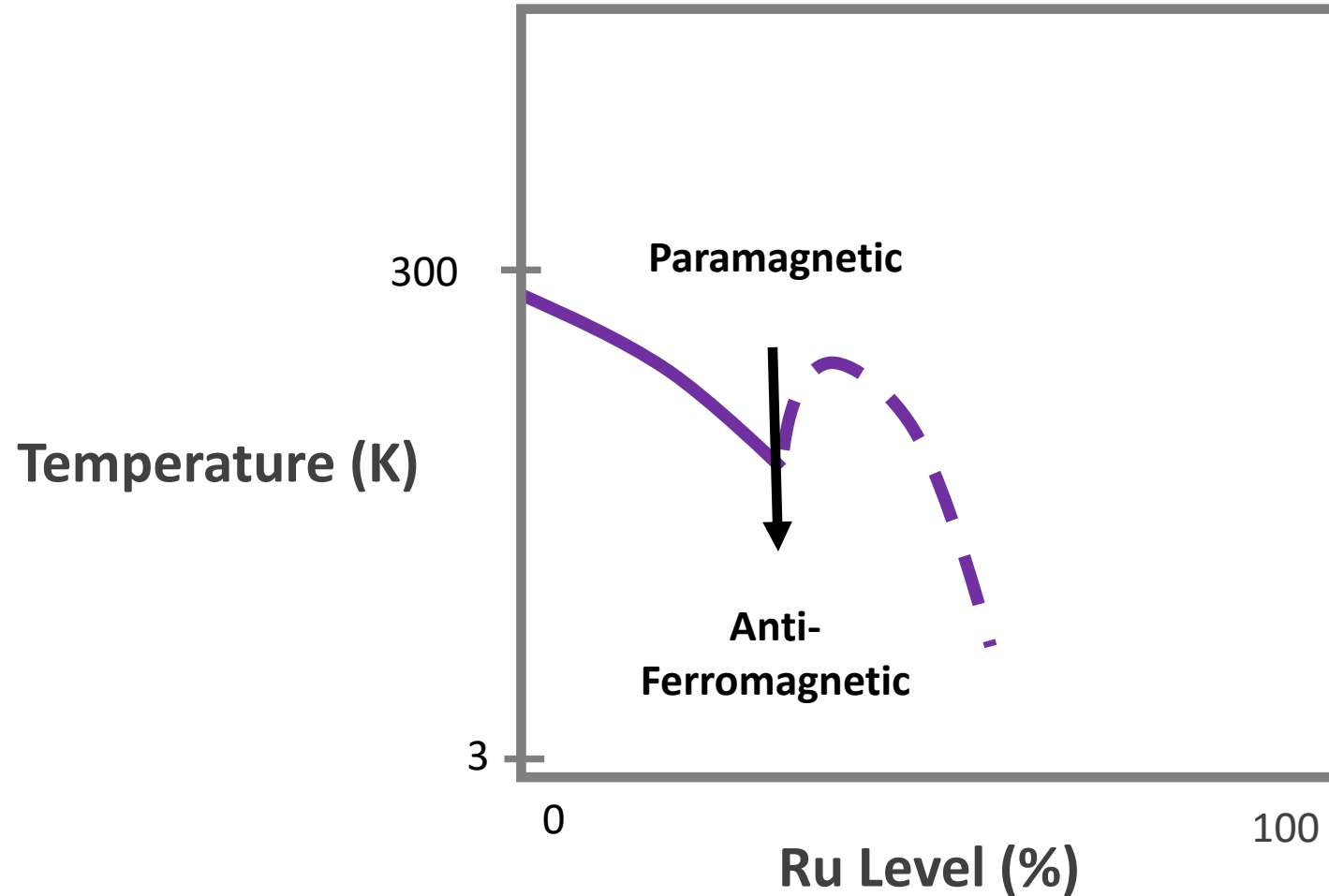
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Cross-section of a crystal  
near  $x=0.35$  (schematic)

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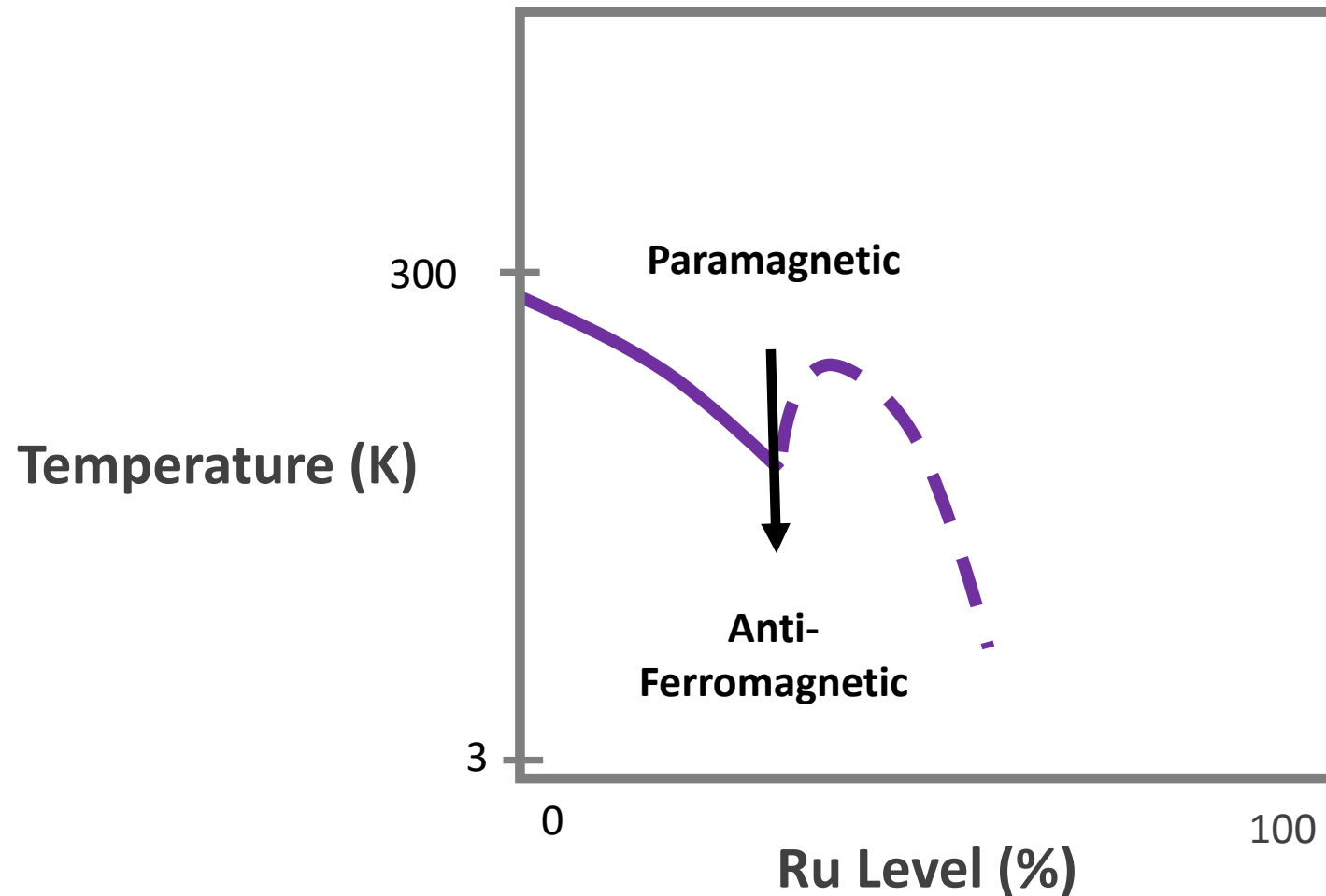


Cross-section of a crystal near  $x=0.35$  (schematic)

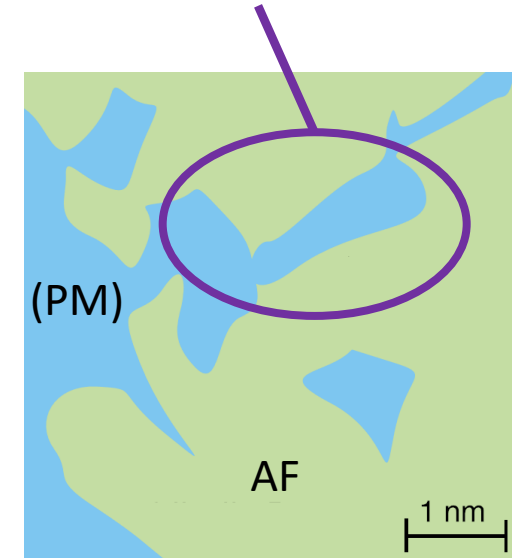
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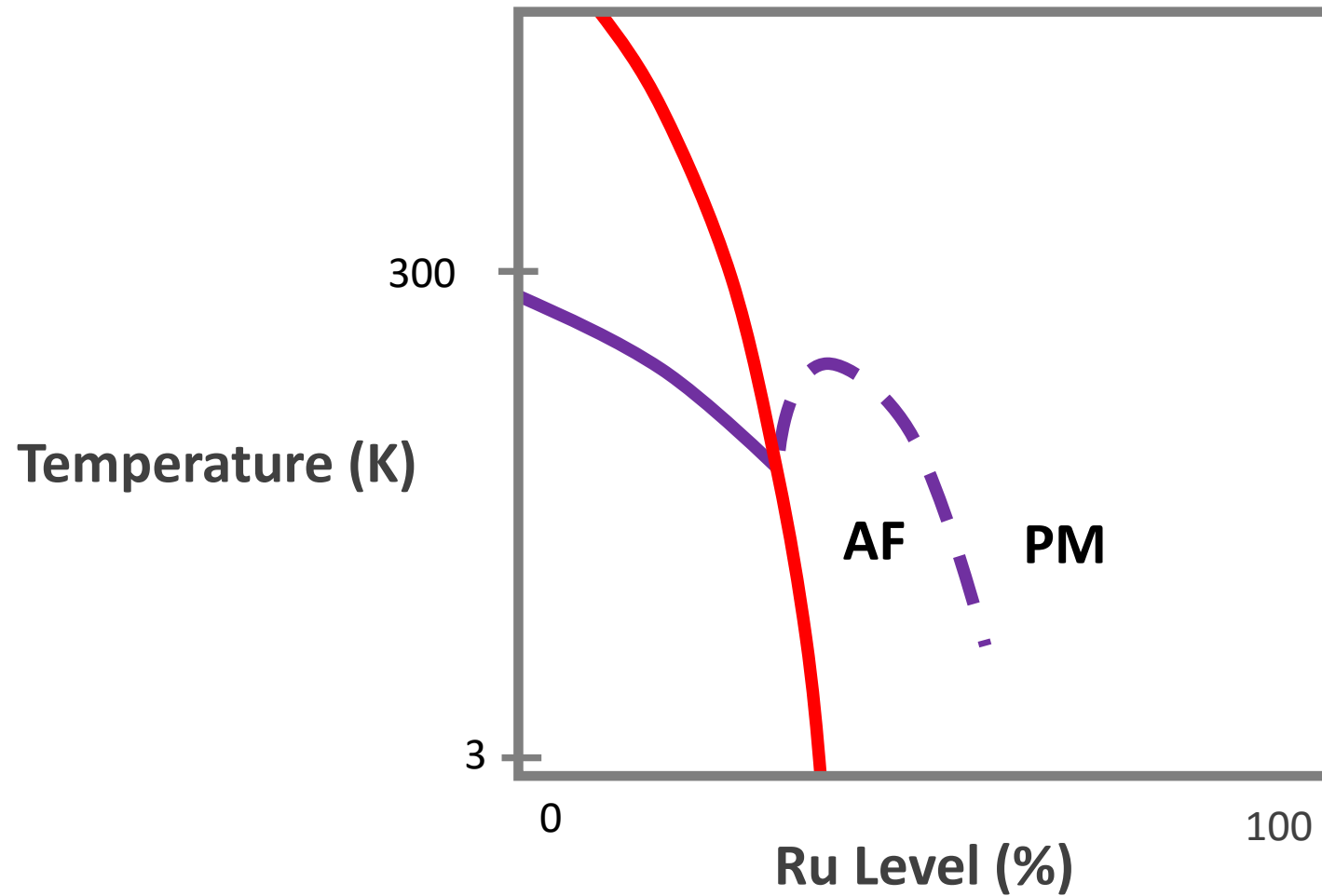
Proximity makes metal AF as well



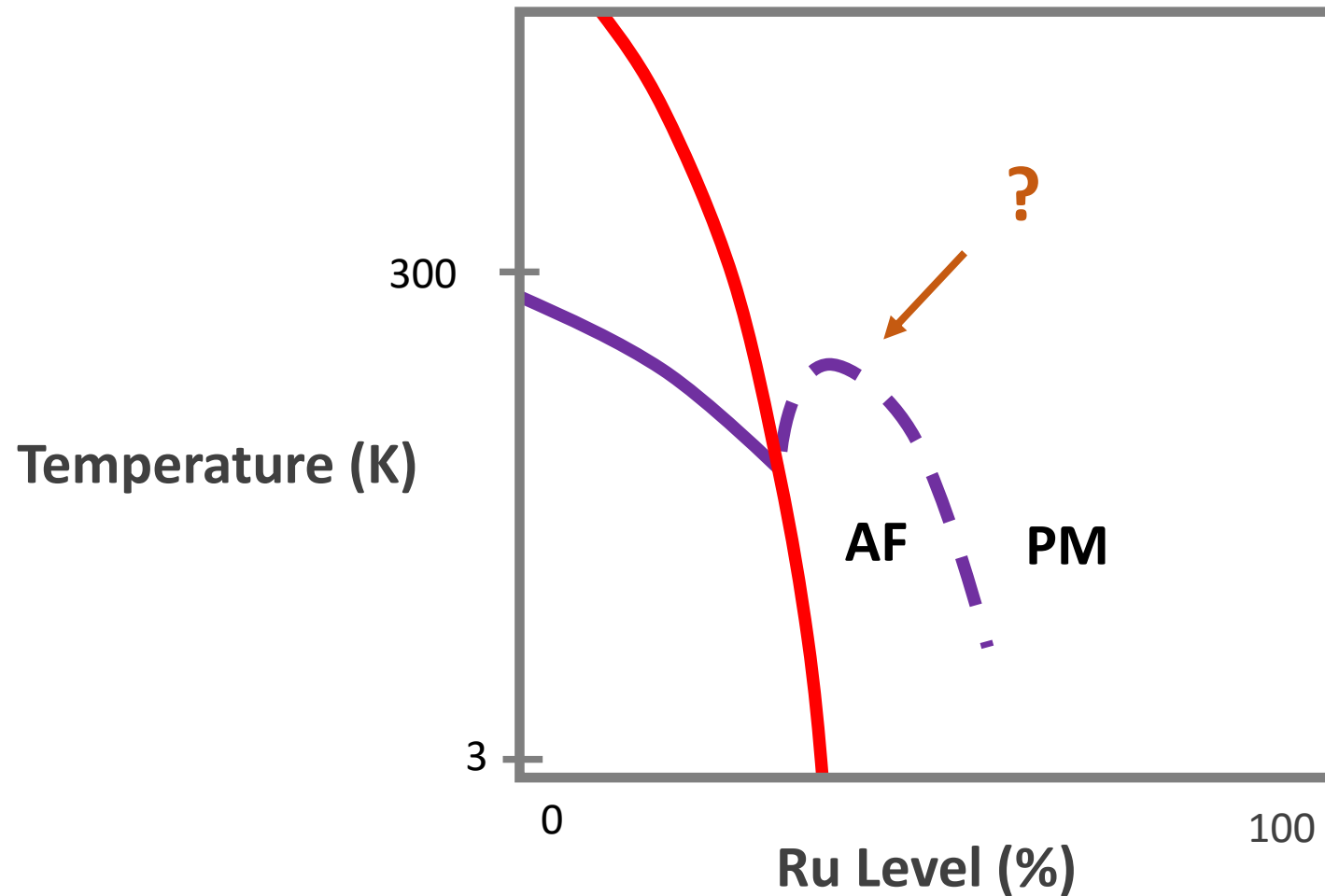
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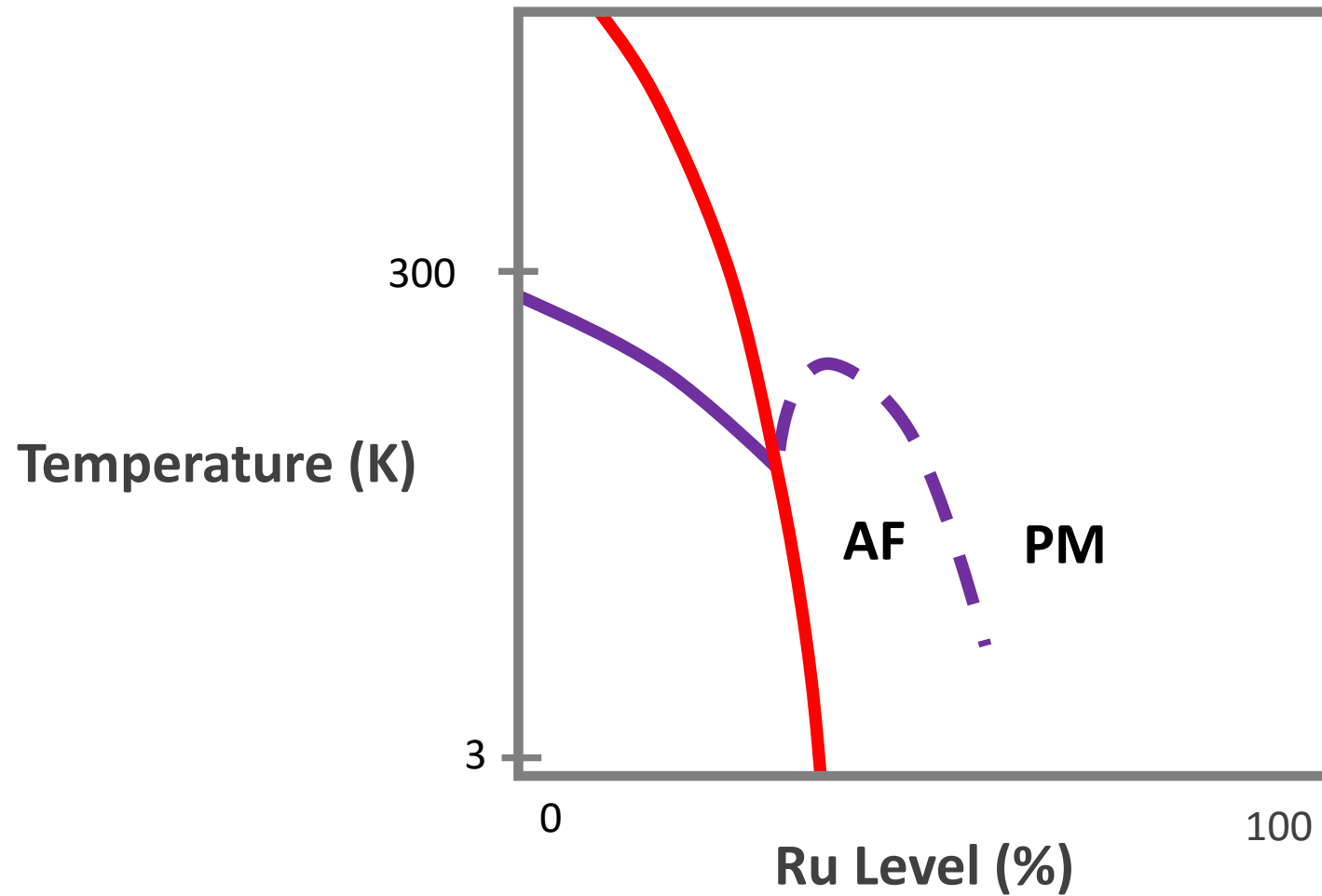


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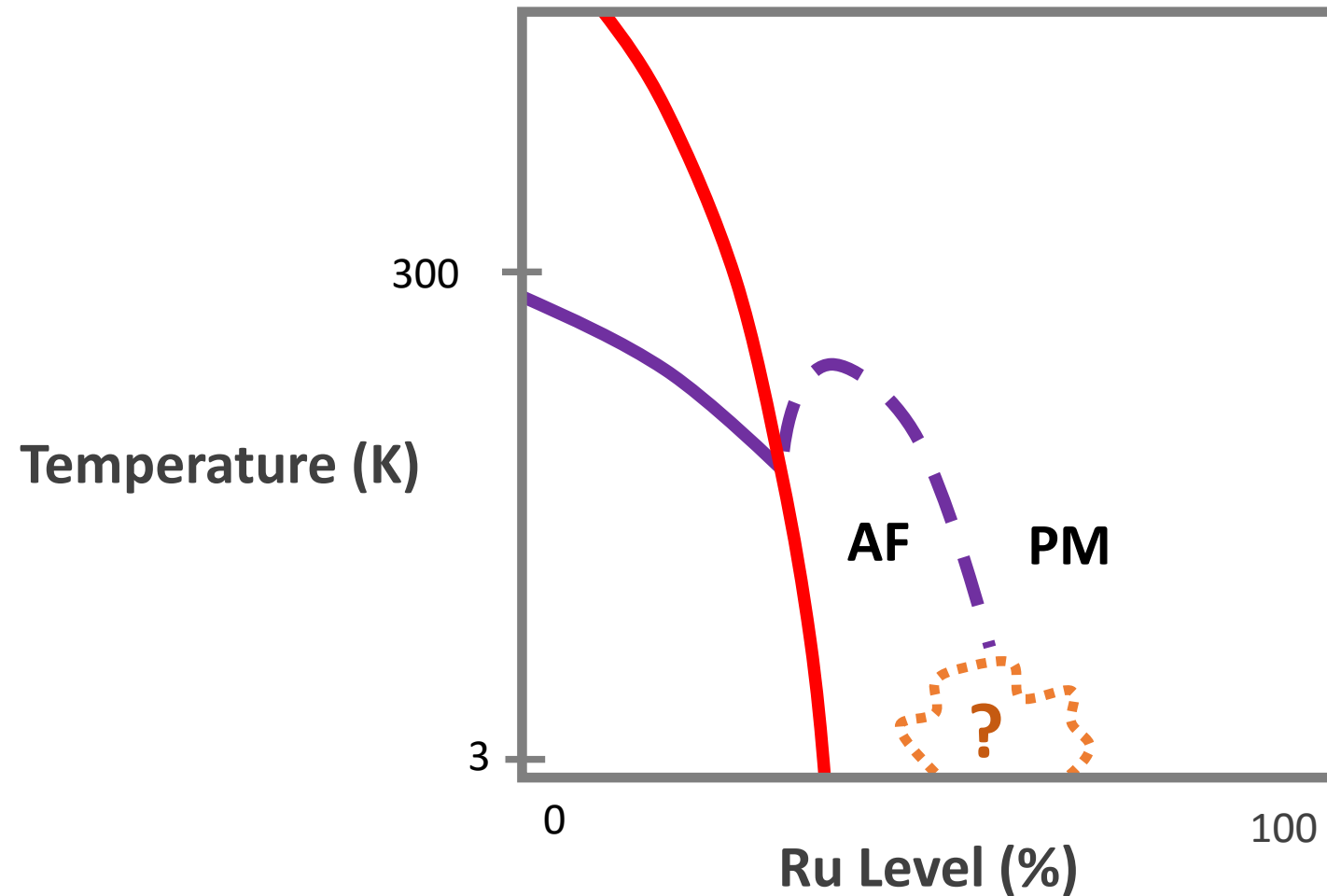


Enhancement: caused by increasing interaction between AF and PM regions?

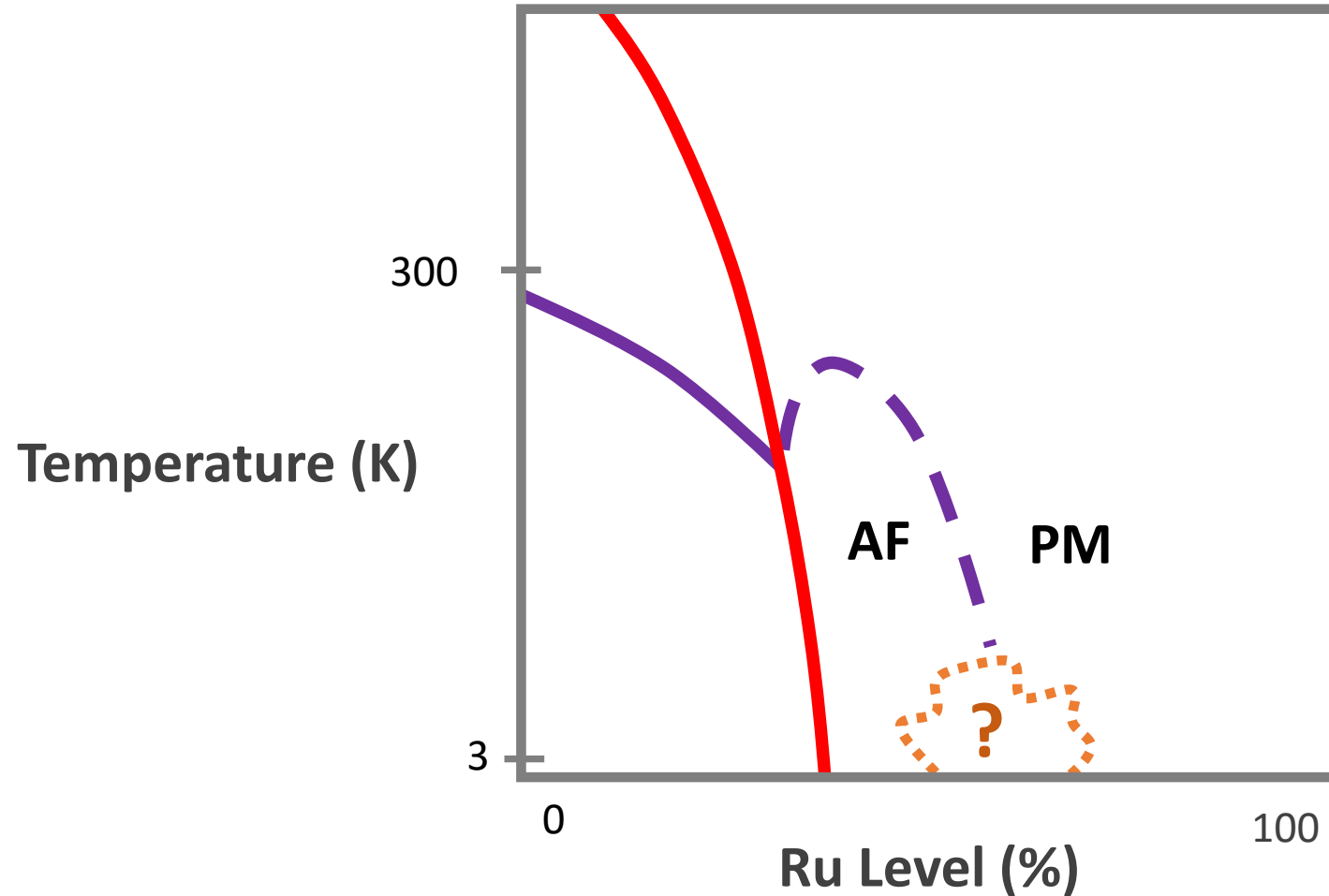
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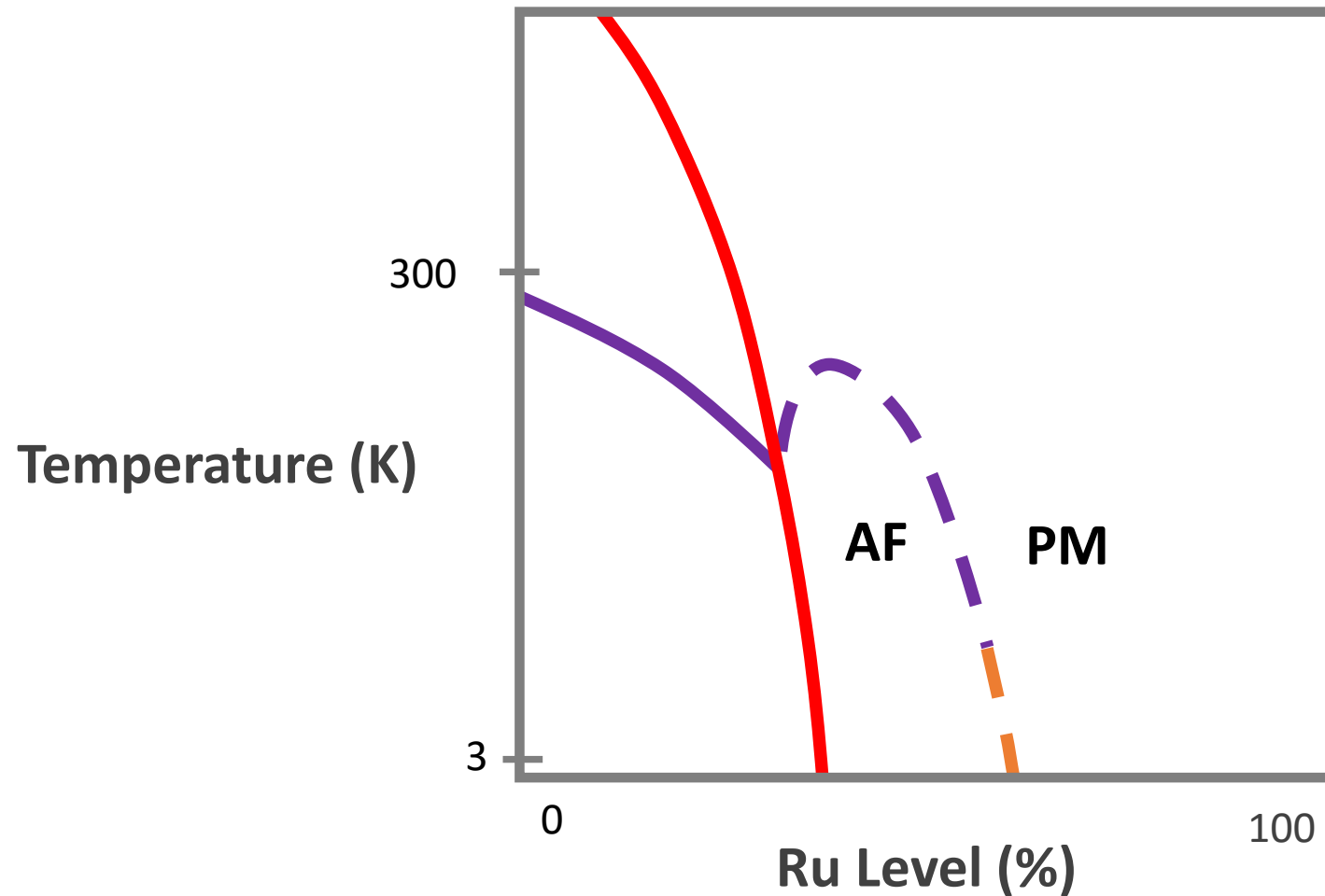
# Looking For a New Electronic Phase: Doping $\text{Sr}_3\text{Ir}_2\text{O}_7$ with Ru



Could be...

- Another magnetic phase
- Other interesting phases
- Superconducting...?

# Looking For a New Electronic Phase: Doping $\text{Sr}_3\text{Ir}_2\text{O}_7$ with Ru



Goal:  
Develop understanding of  
both AF phase and the  
phase diagram

# Characterization Necessitates Multiple Steps

Recreate Prior Dopant Level (33%)



Grow New Dopant Levels (40-60%)



Perform Measurements



Map and Characterize New Phase



# Characterization Necessitates Multiple Steps

Recreate Prior Dopant Level (33%)



Grow New Dopant Levels (40-60%)



Perform Measurements

- Resistivity
- Magnetization
- Heat capacity



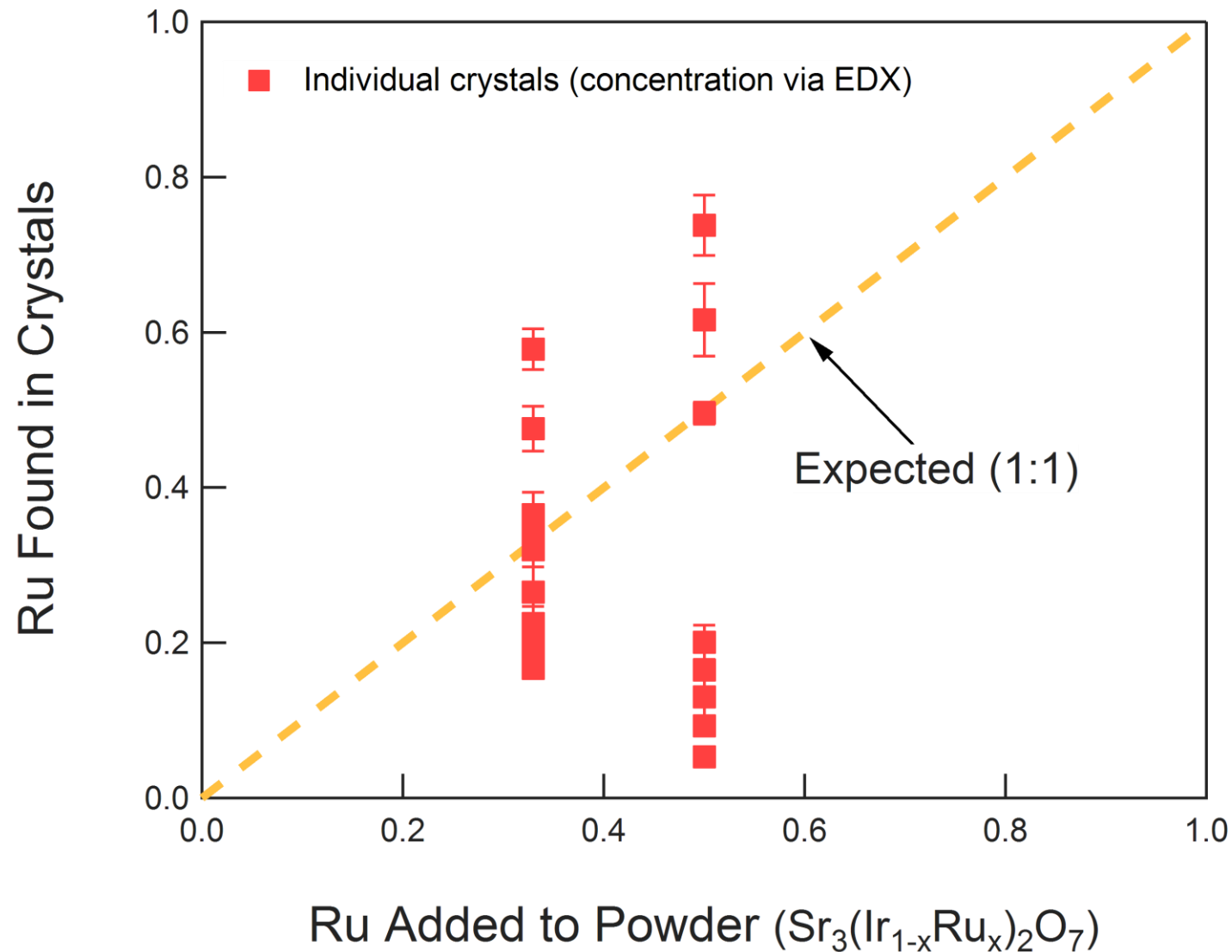
Map and Characterize New Phase



Seven-Day Growth &  
Verifying Purity

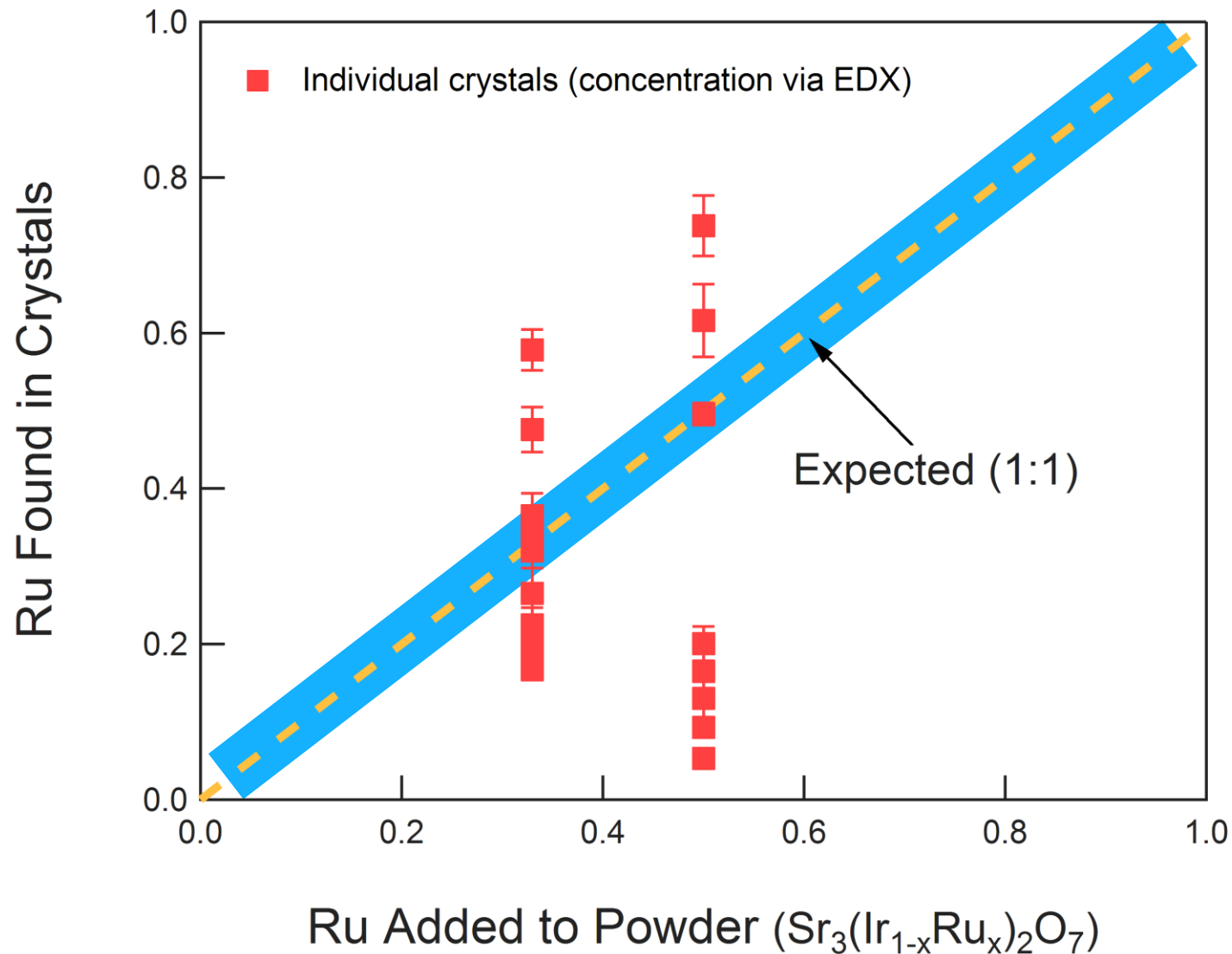
# Uncertainty Exists in Growth Process

Dopant Level Varies Significantly, Even Among Best Samples

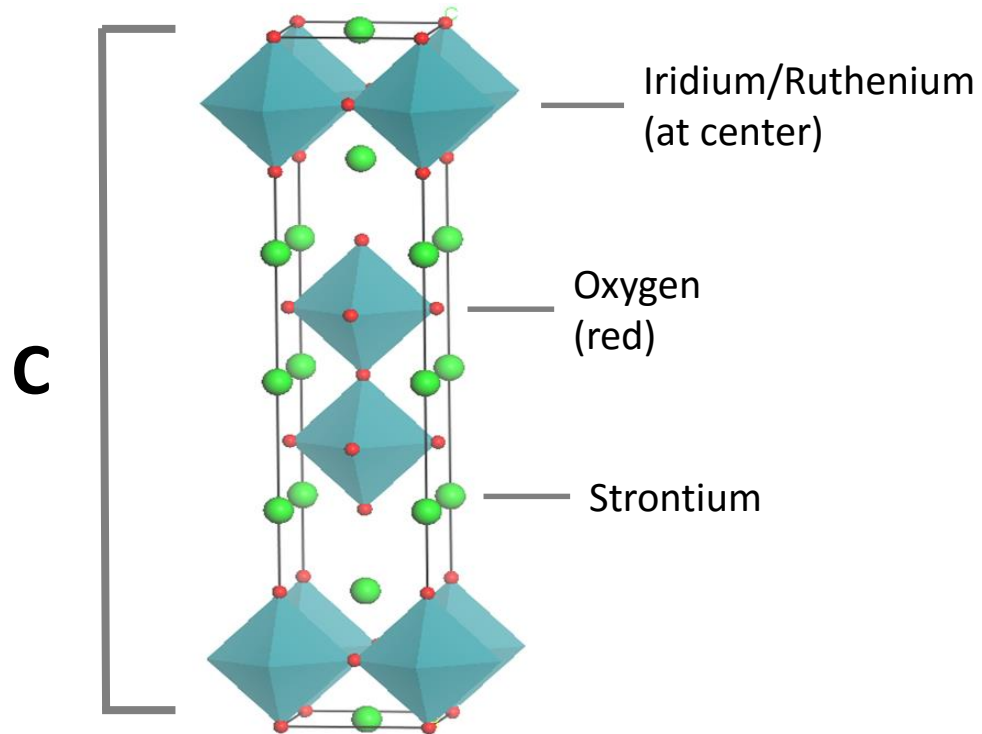


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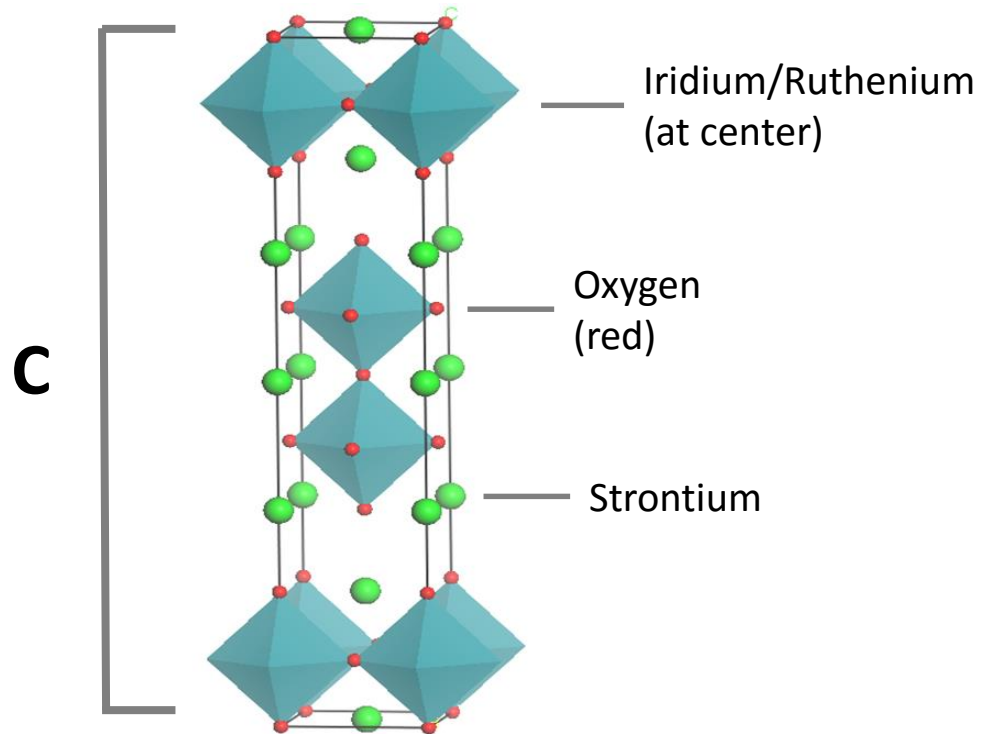


# Purity Estimation by Lattice Parameter: Reducing Costly EDX Tests

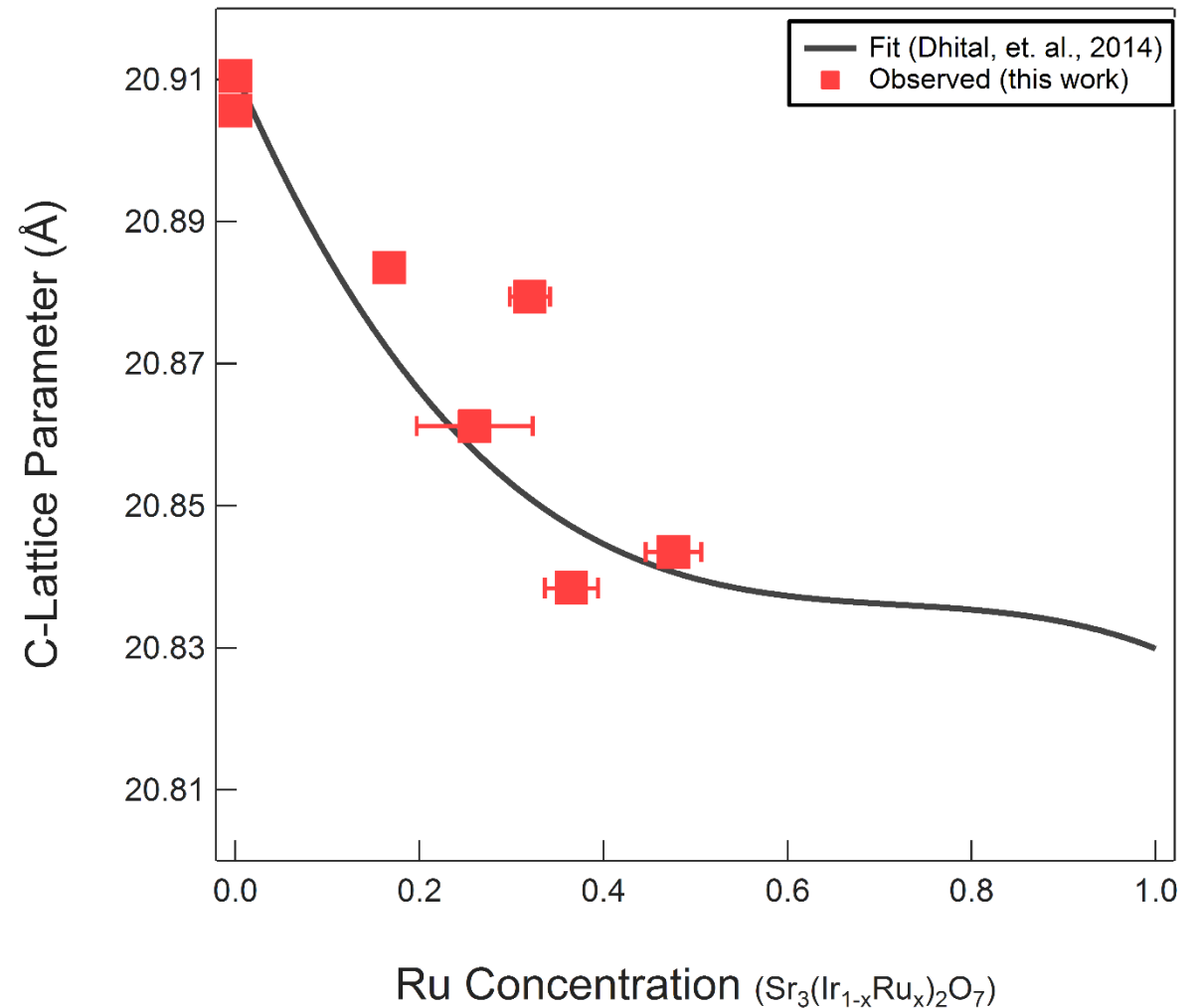


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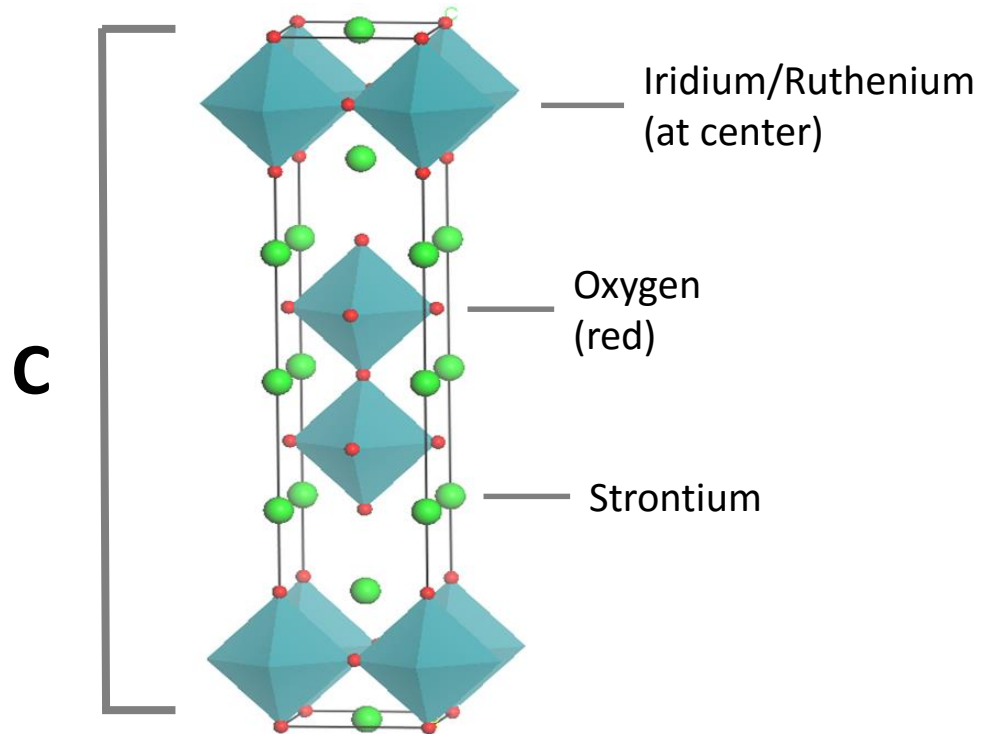
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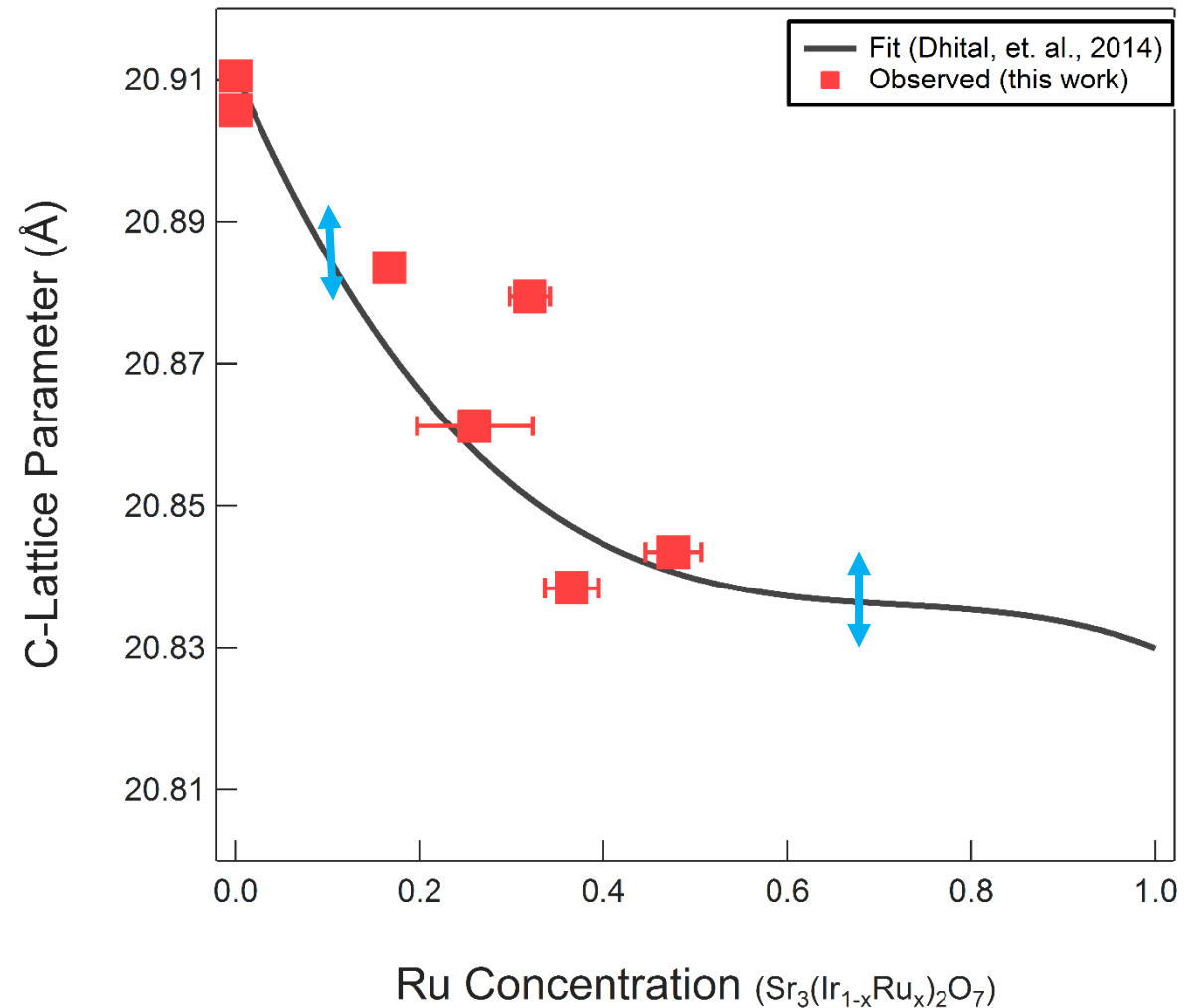
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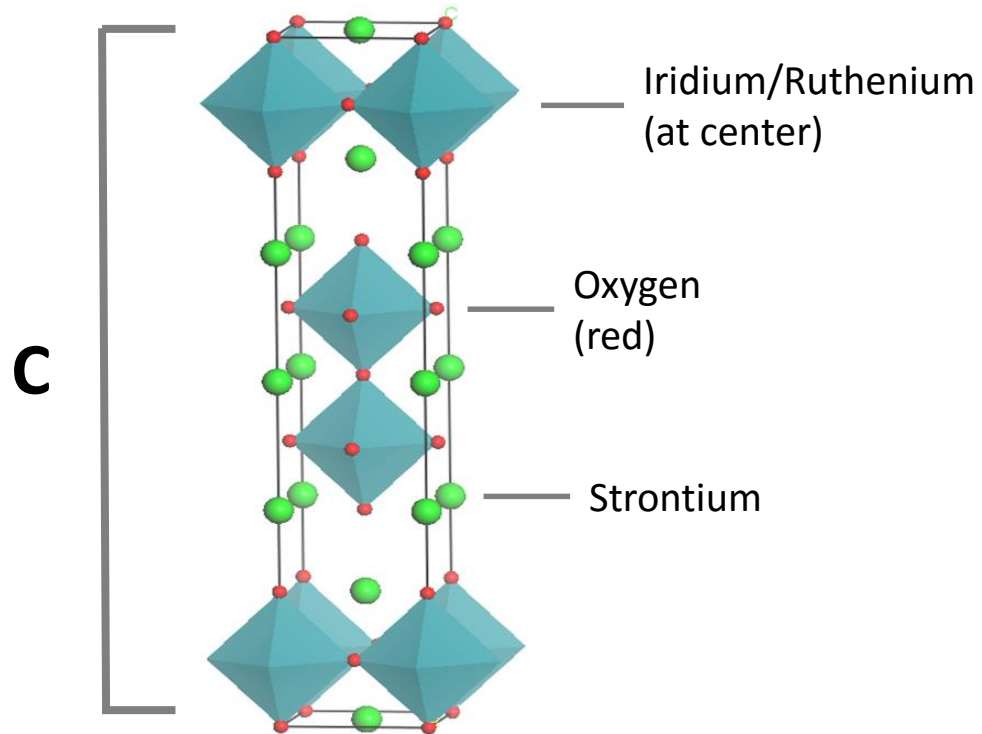
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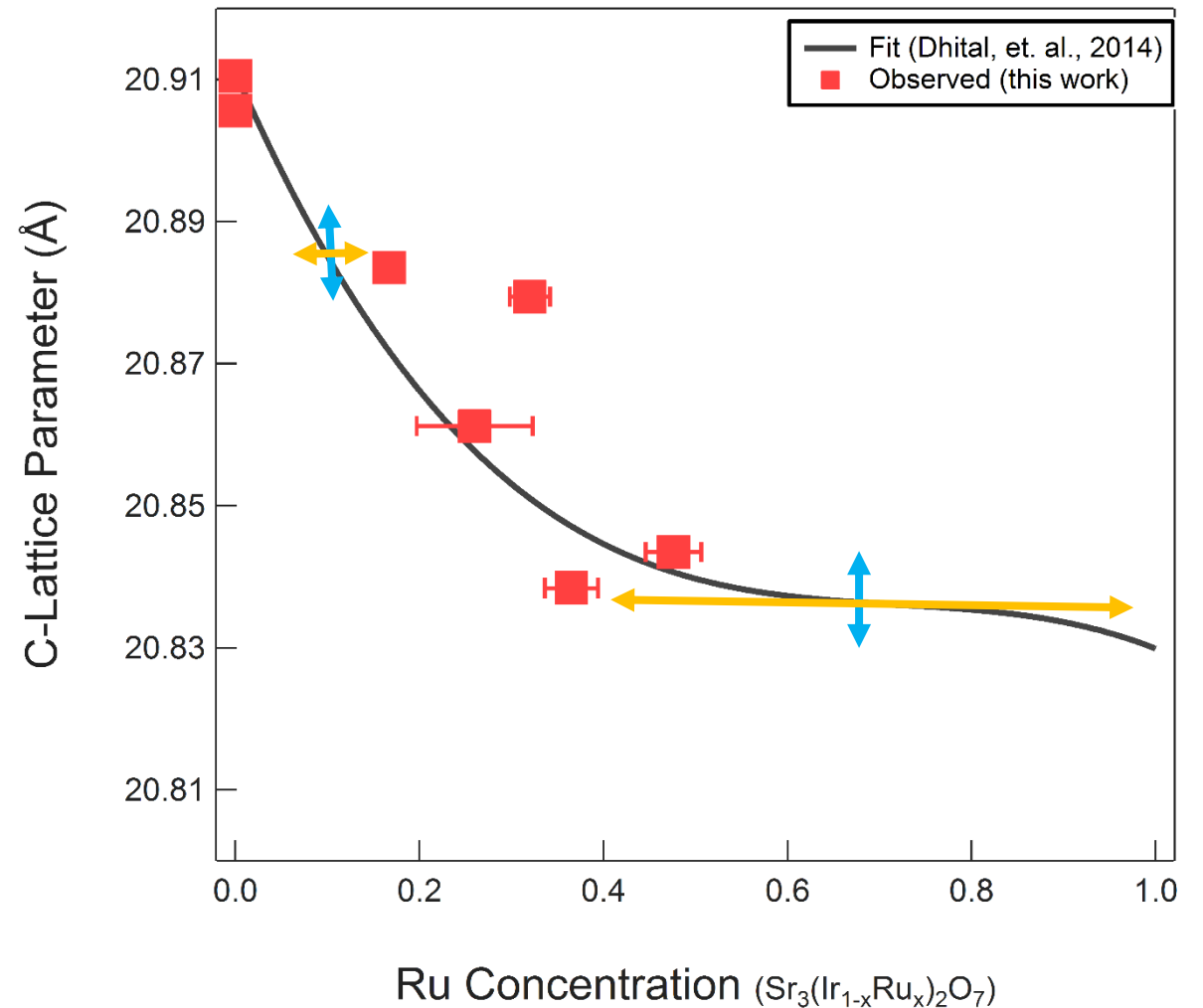
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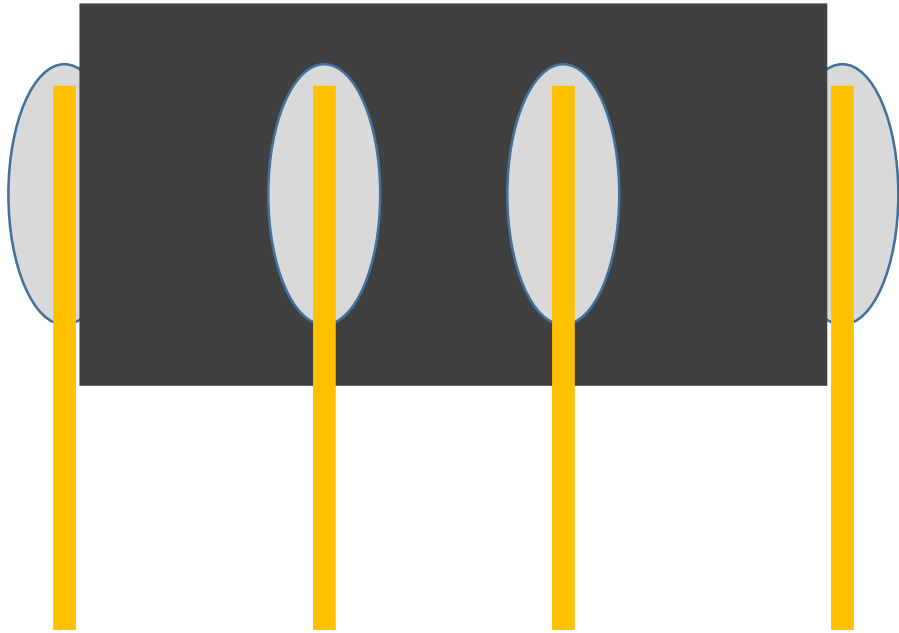


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# Resistivity Quickly Reveals Features:

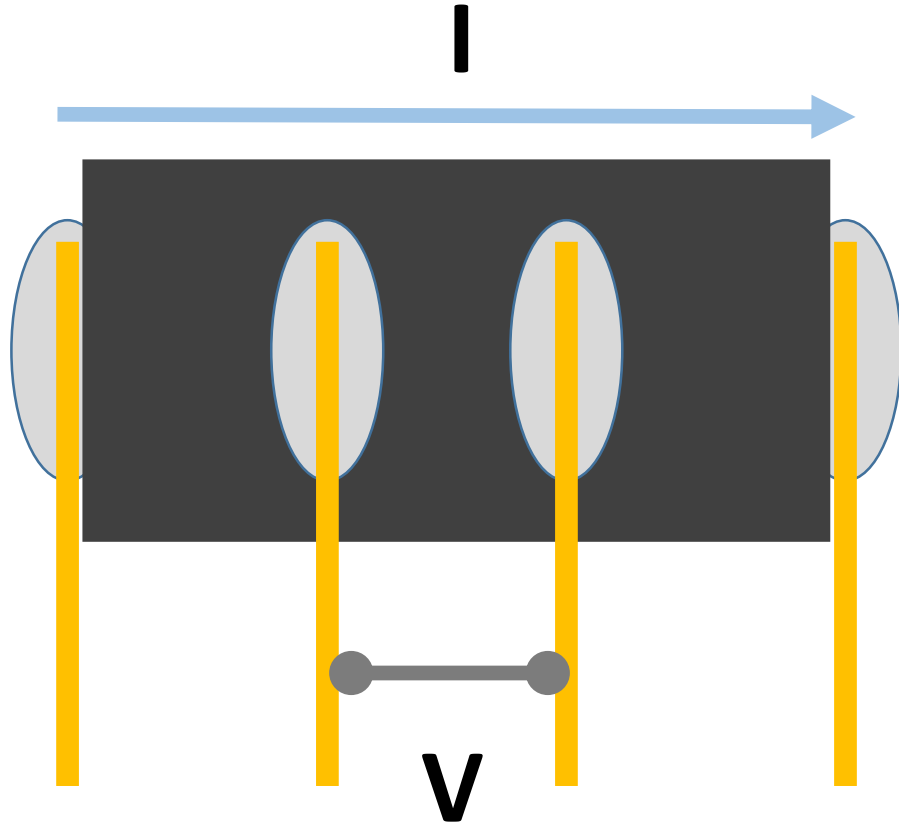
Next step after obtaining pure samples



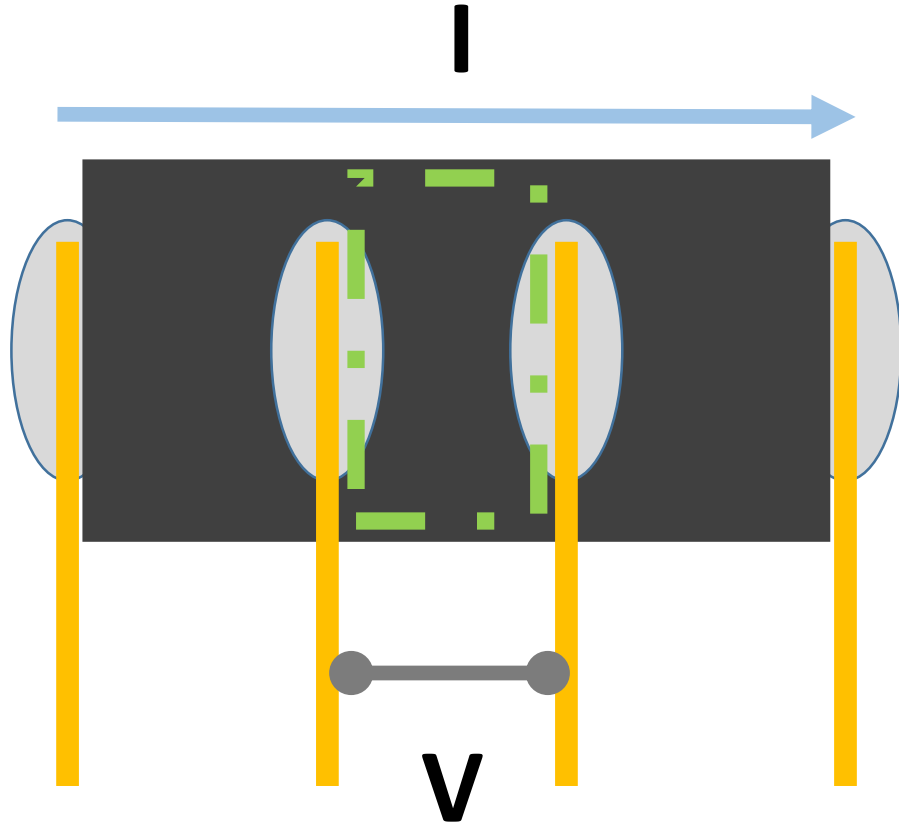


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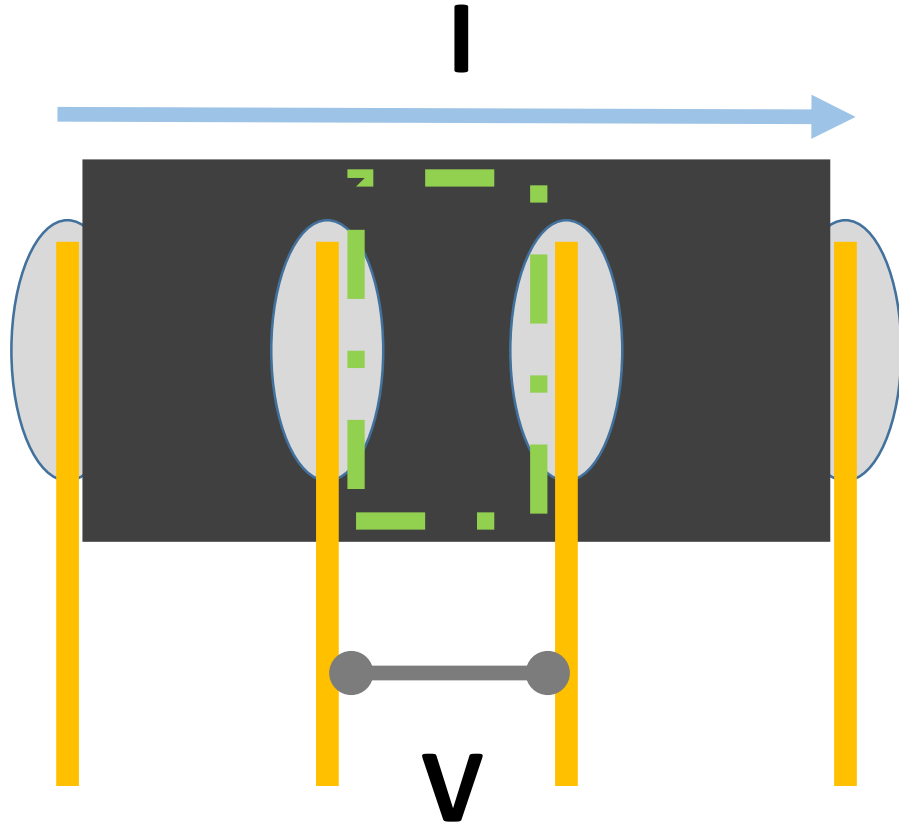
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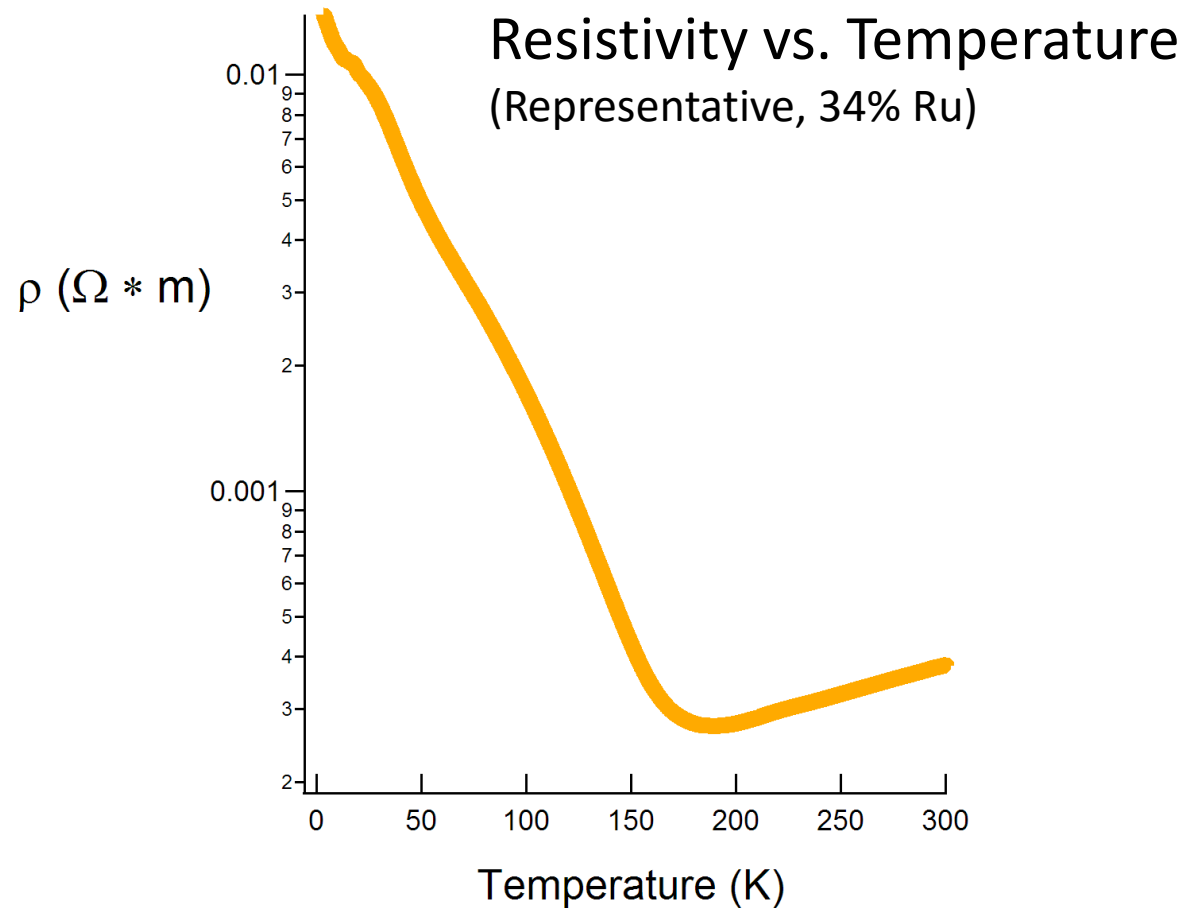


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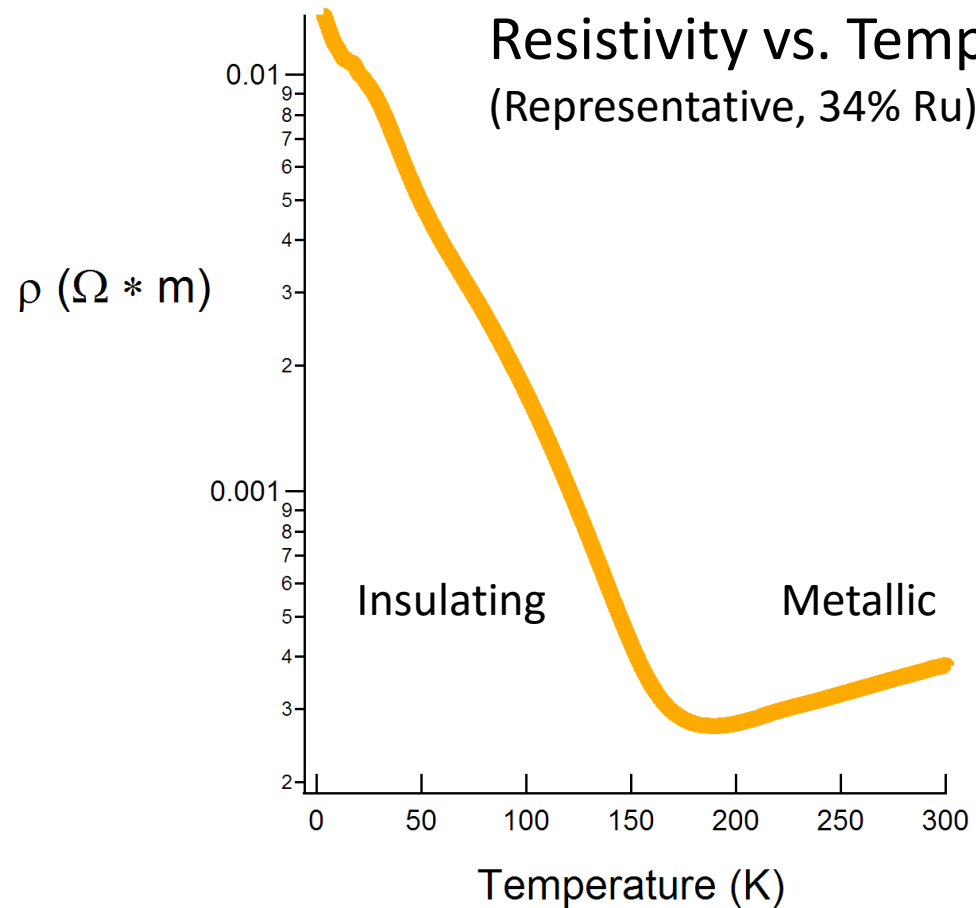


1.5mm

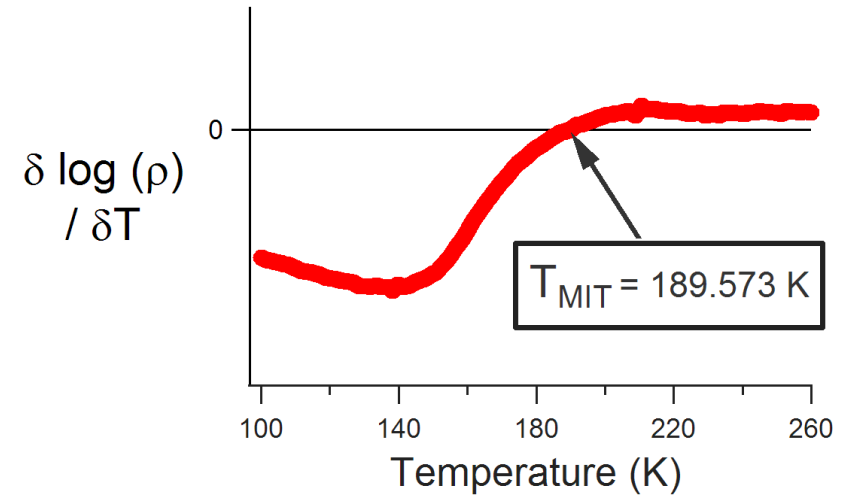
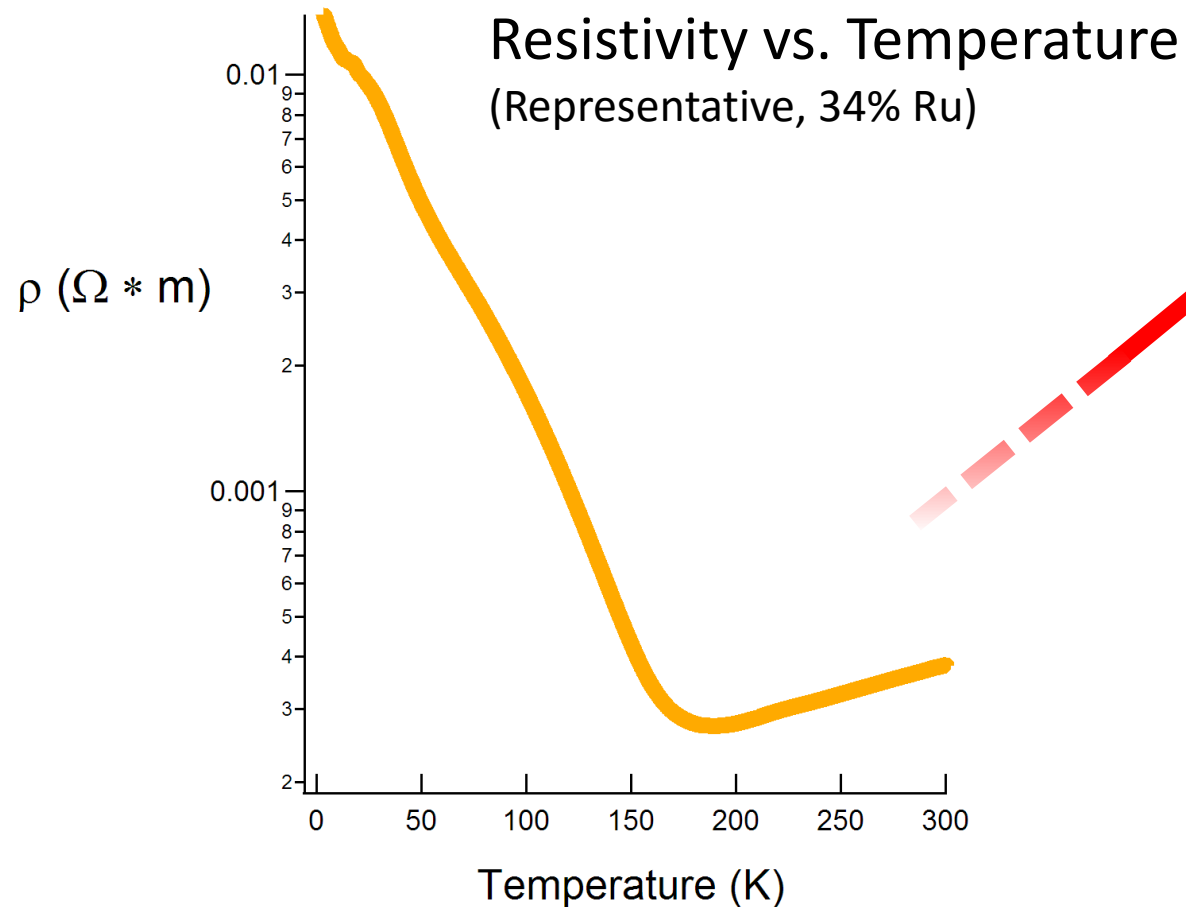
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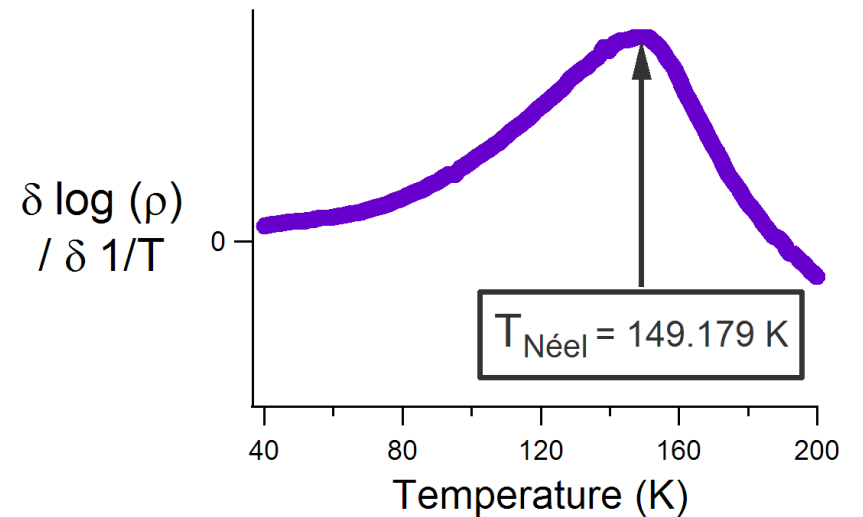
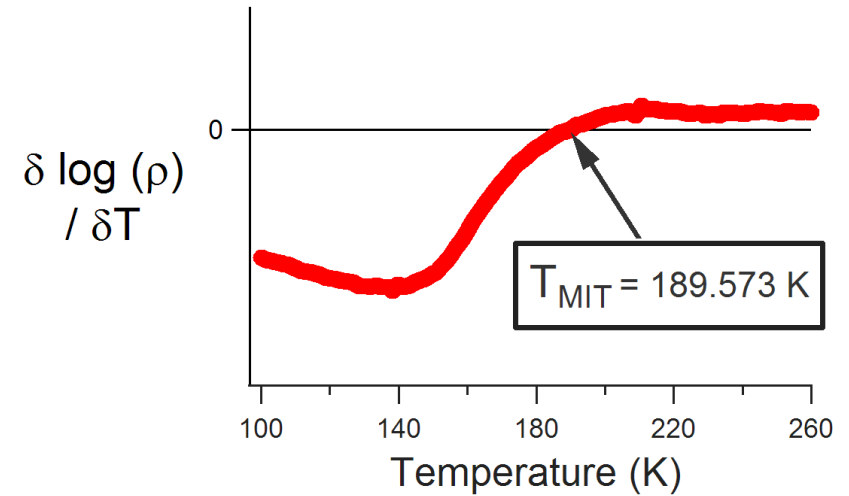
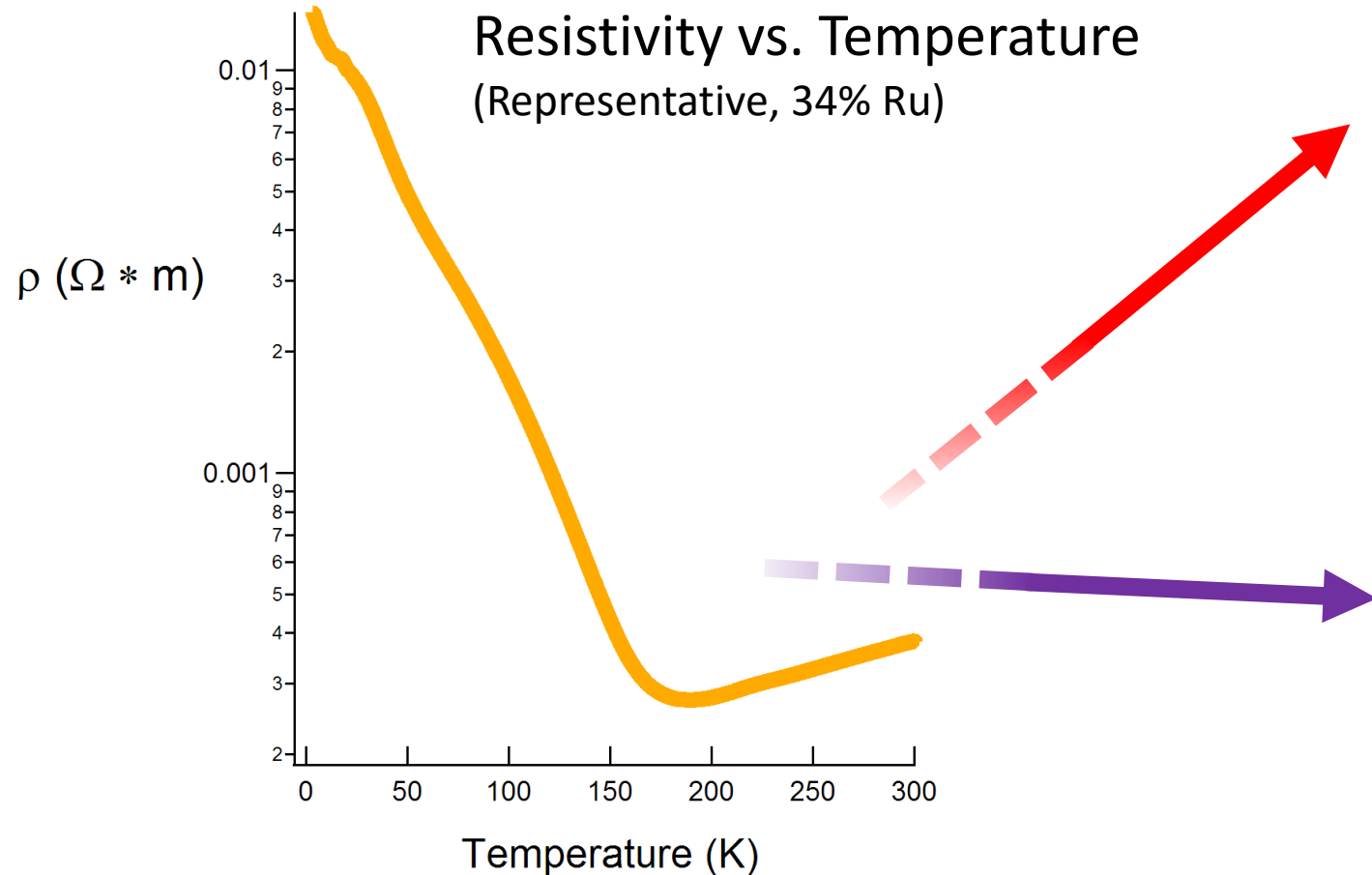
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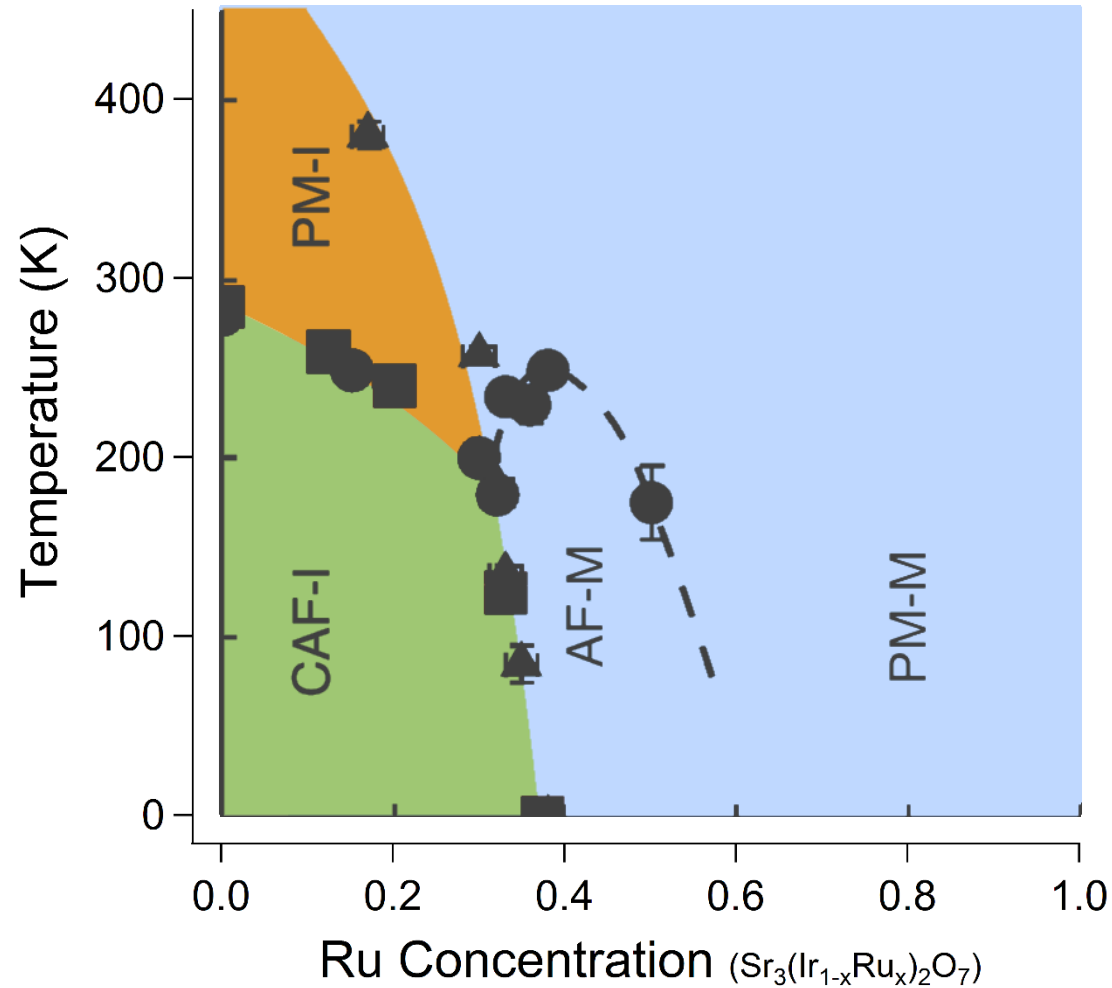


# Resistivity Quickly Reveals Features: Next step after obtaining pure samples



# Preliminary Progress on Phase Diagram Expansion

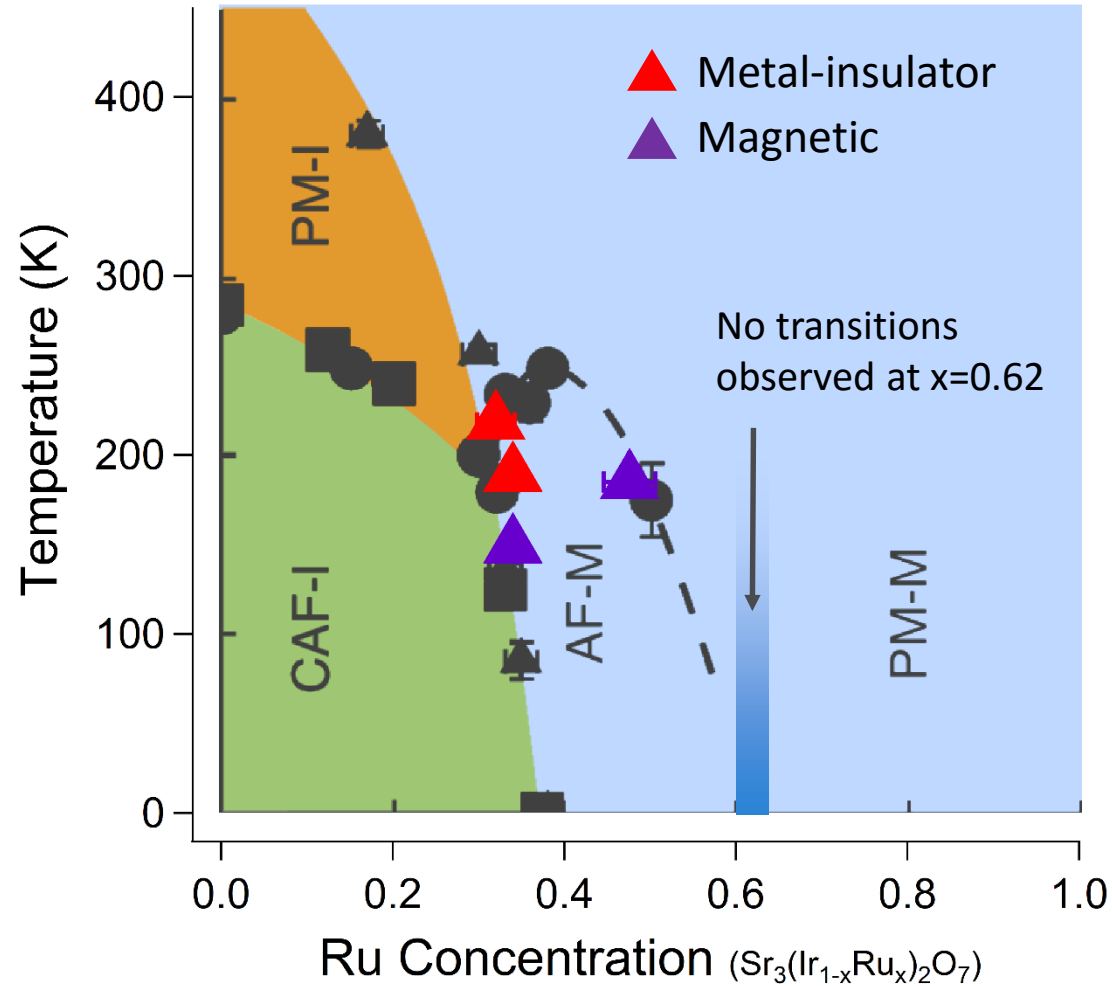
Measurements Currently Limited to Resistivity





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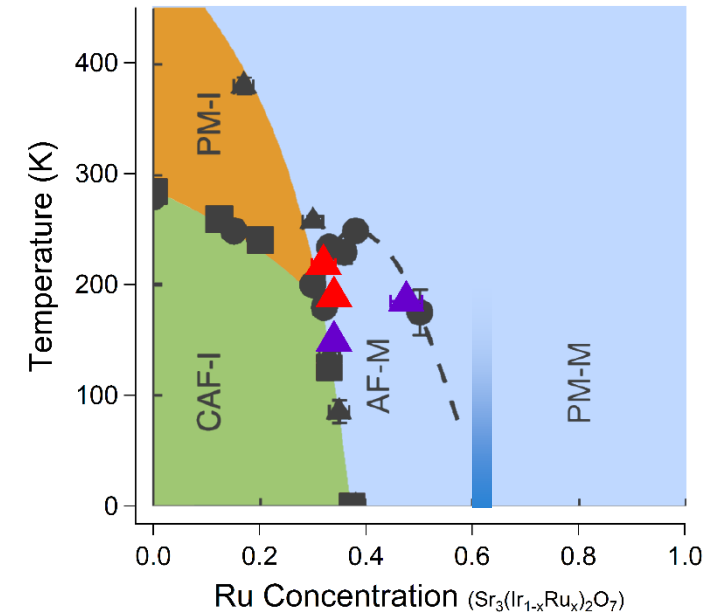
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# Future Work

The roadmap continues this year

Goal: Complete the phase diagram and study the antiferromagnetic metal



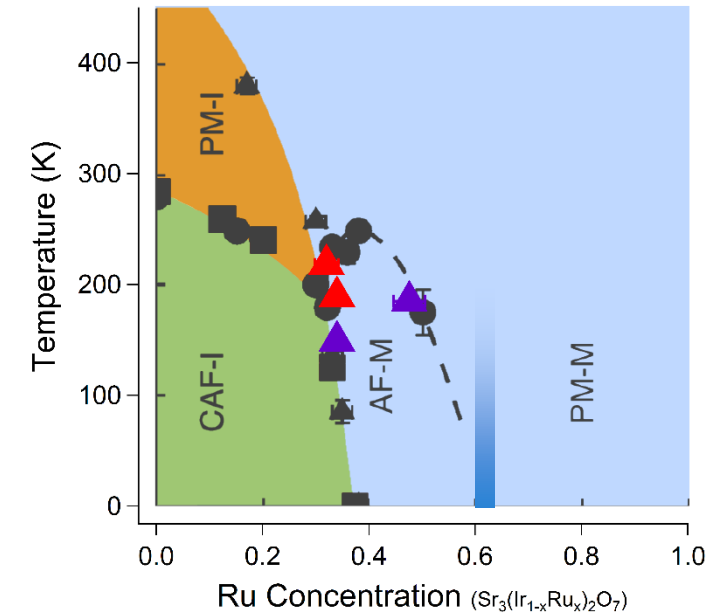
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Already achieved:

- Multiple dopant levels grown, with little contamination
- Samples sent to collaborators in Korea ( $x=0.33$ )
- Several successful resistivity runs
- Lattice parameter measurements
- Data so far agrees with previous analysis



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Ready to move forward:

- More growths with 50-70% Ru ( $x=0.5$  to  $0.7$ )
- More resistivity runs on current and future samples
  - Magnetization and heat capacity measurements
  - Sub-Kelvin resistivity measurements

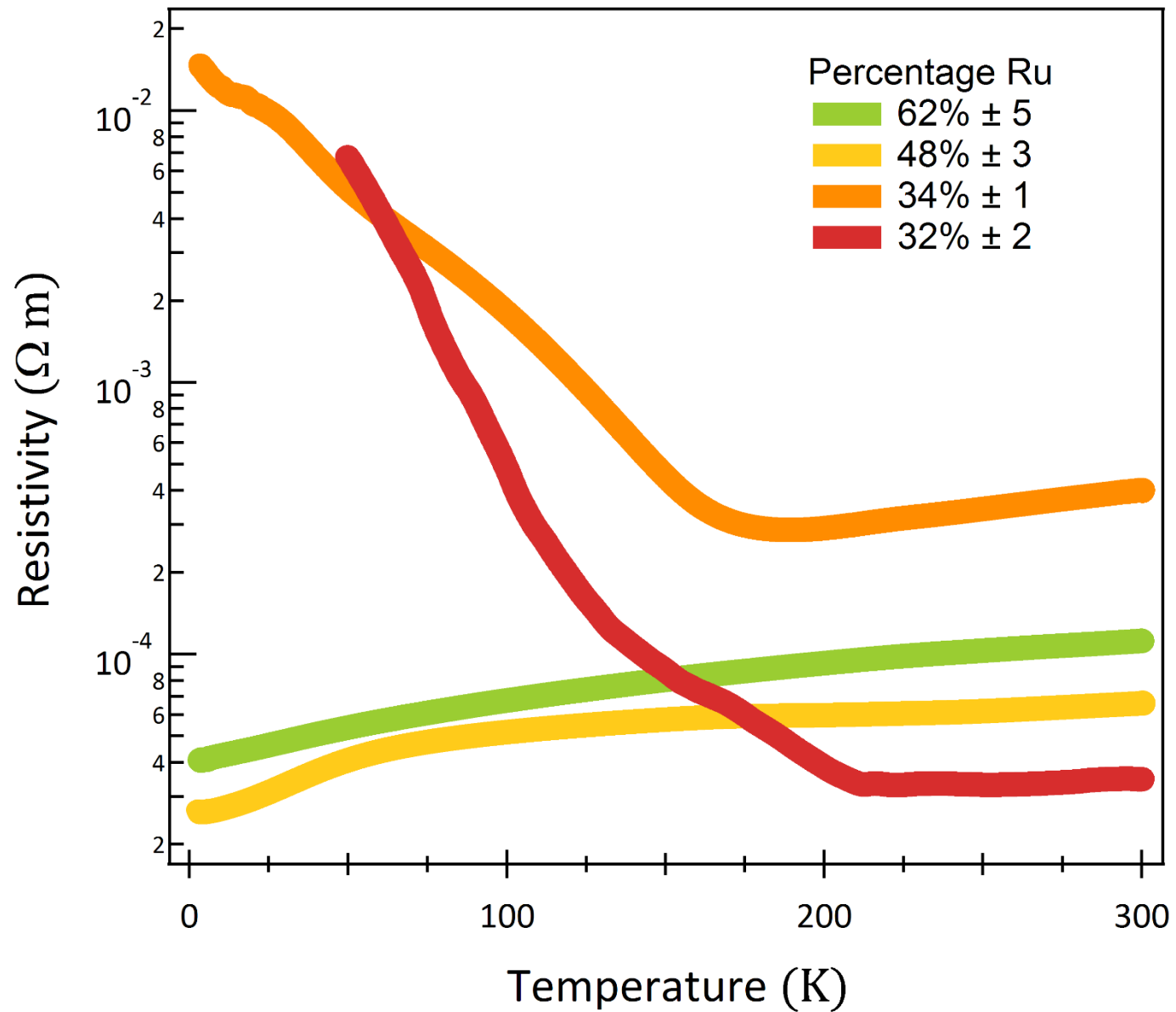
# Acknowledgements

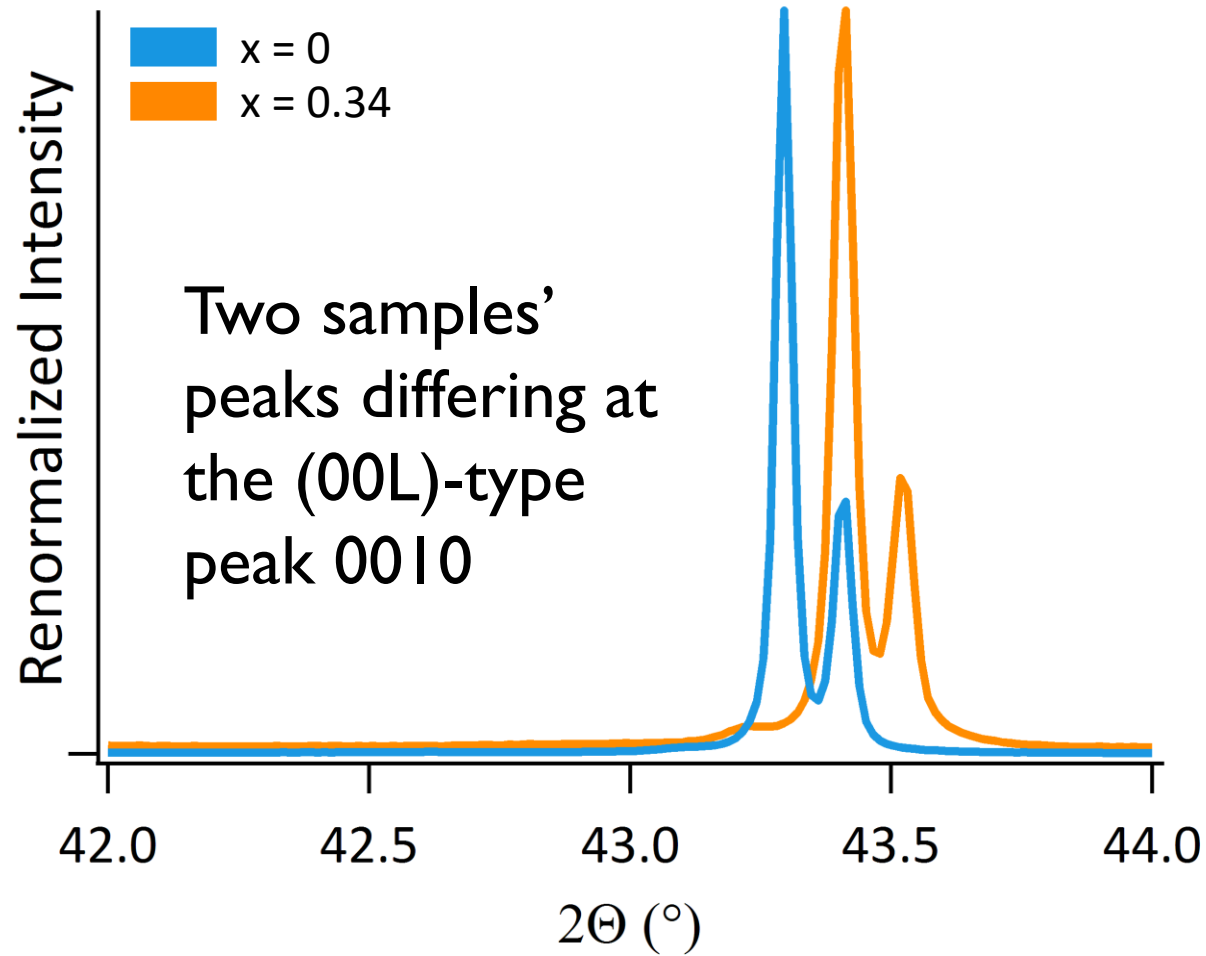


## References

1. Dhital, C. et al. Carrier localization and electronic phase separation in a doped spin-orbit-driven Mott phase in  $\text{Sr}_3(\text{Ir}_{1-x}\text{Ru}_x)_2\text{O}_7$ . Nat. Commun. 5:3377 doi: 10.1038/ncomms4377 (2014).
2. Dhital, C. et al. Spin ordering and electronic texture in the bilayer iridate  $\text{Sr}_3(\text{Ir}_{1-x}\text{Ru}_x)_2\text{O}_7$ . Physical Review B 86, 100401(R) (2012).
3. Jesche, A. et al. X-Ray diffraction on large single crystals using a powder diffractometer. Philosophical Magazine (2016).

# Supplemental Slides



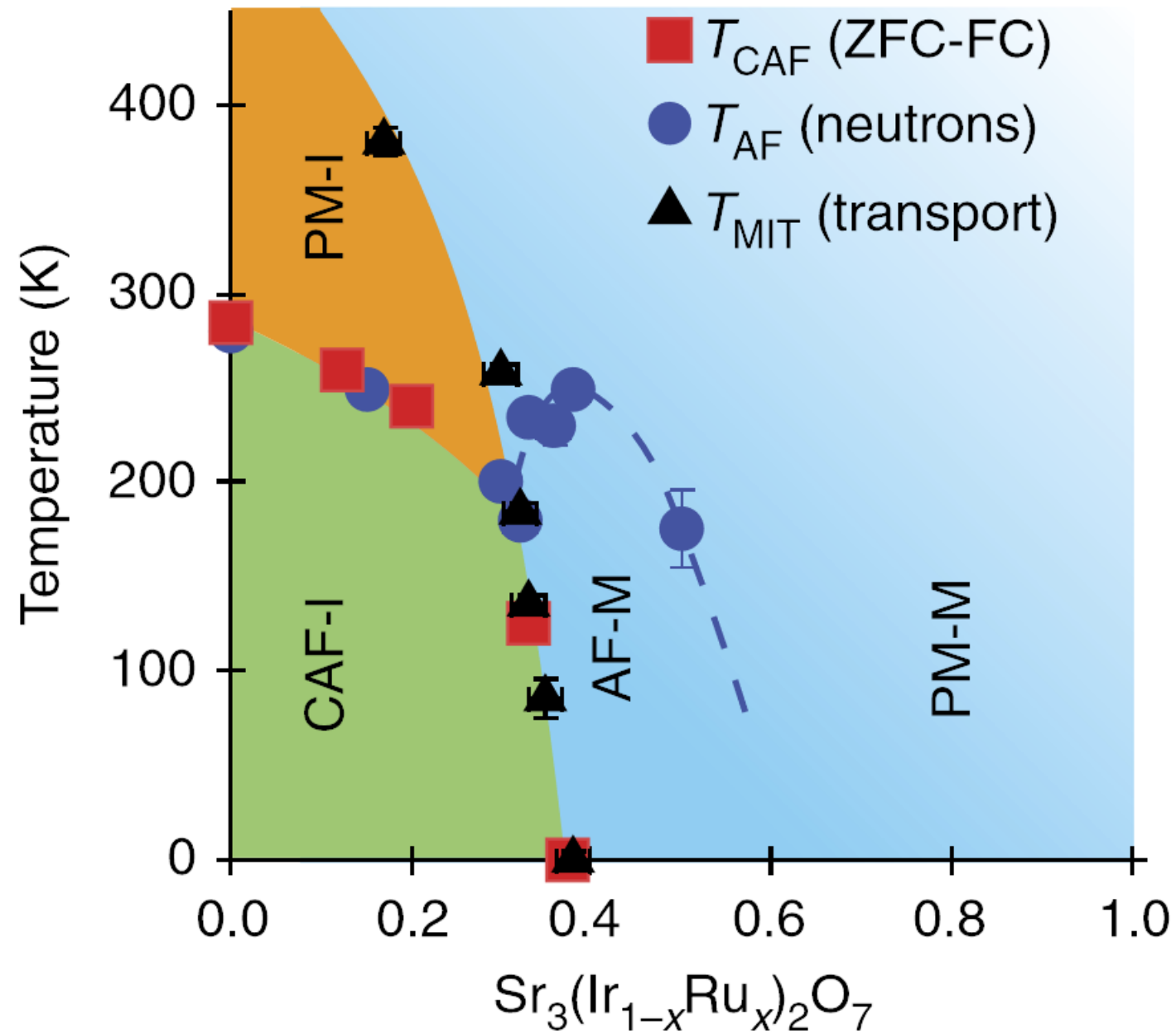


Modified Bragg's Law:

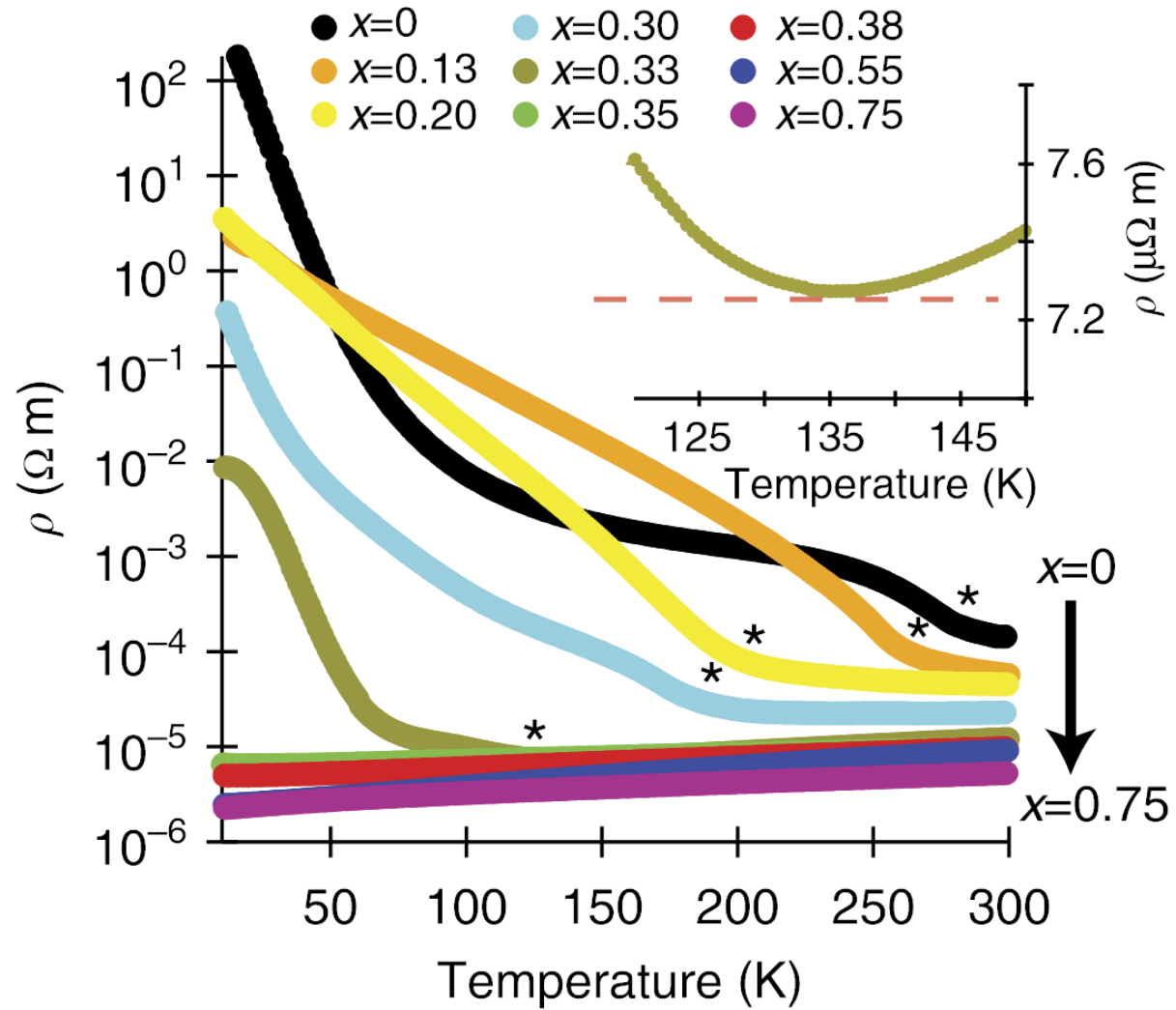
$$2c \sin \left( \Theta - \frac{H}{R} \cos \Theta \right) = L \lambda$$

↑  
Offset

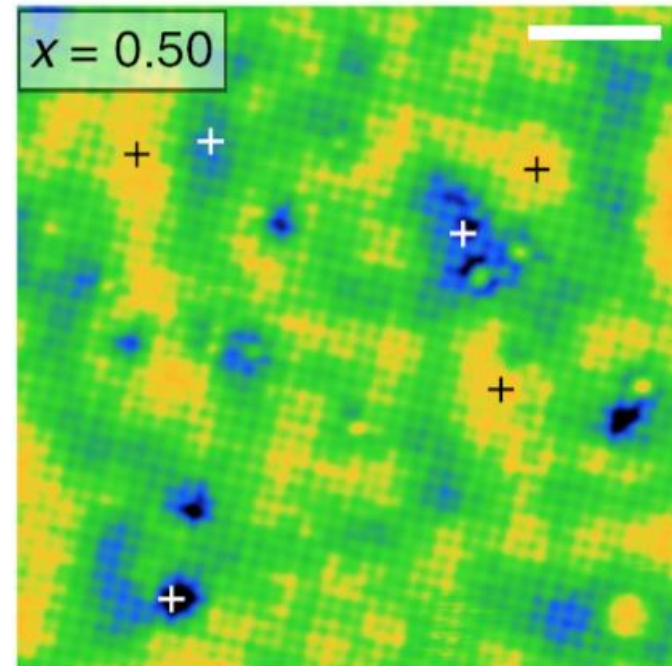
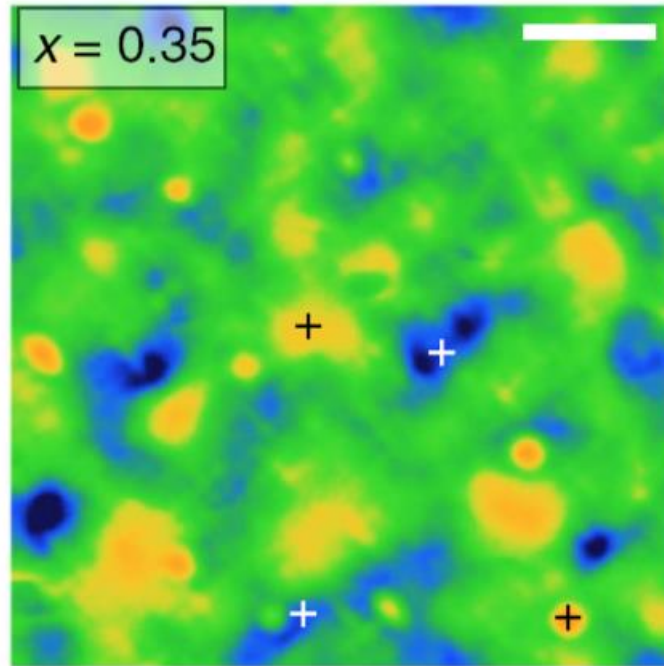




# Resistivity



# STS Measurements



Insulating

Metallic