Discovery of itinerant antiferromagnetism in Ti_3Cu_4

Alannah Hallas

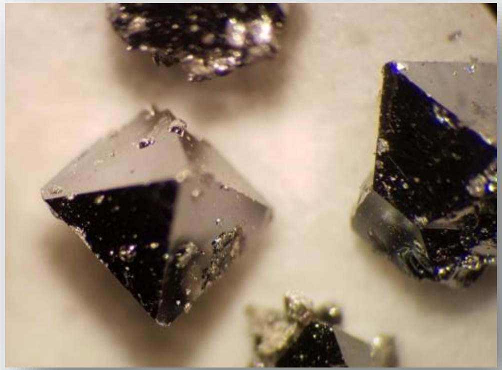
UBC

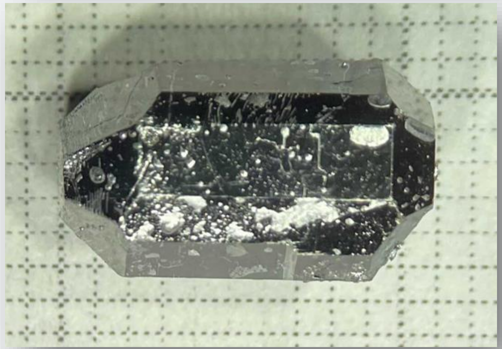
Stewart Blusson Quantum Matter Institute
THE UNIVERSITY OF BRITISH COLUMBIA

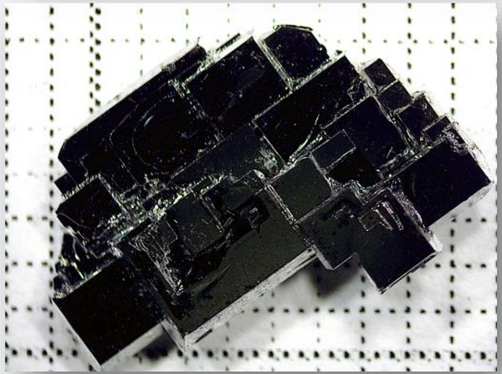
CIFAR

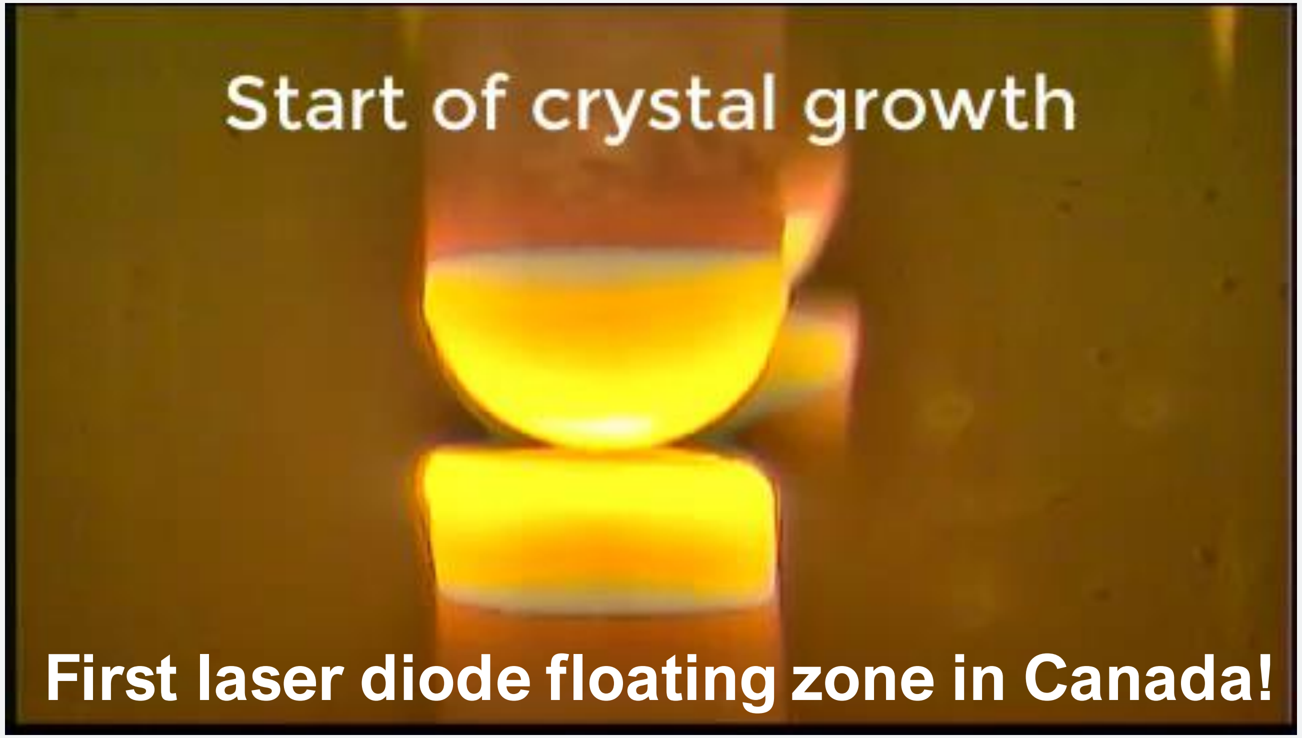
NSERC CRSNG

Crystal growth of quantum materials in the Hallas group at UBC









Website: hallas.phas.ubc.ca

Twitter: @AlannahHallas
for crystal photos

Itinerant Magnet Collaborators


Jaime Moya


Kyle Bayliff


Chien-Lung Huang


Emilia Morosan

RICE

Emilia Morosan
Jaime Moya
Kyle Bayliff
Chien-Lung Huang
Vaideesh Loganathan

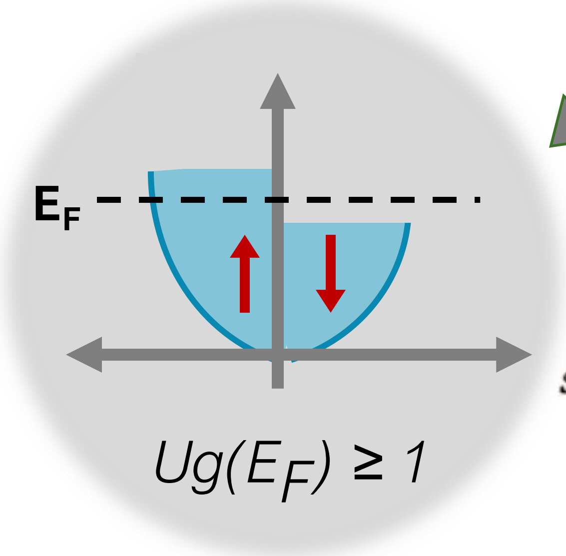
Graeme Luke
James Beare
Yipeng Cai

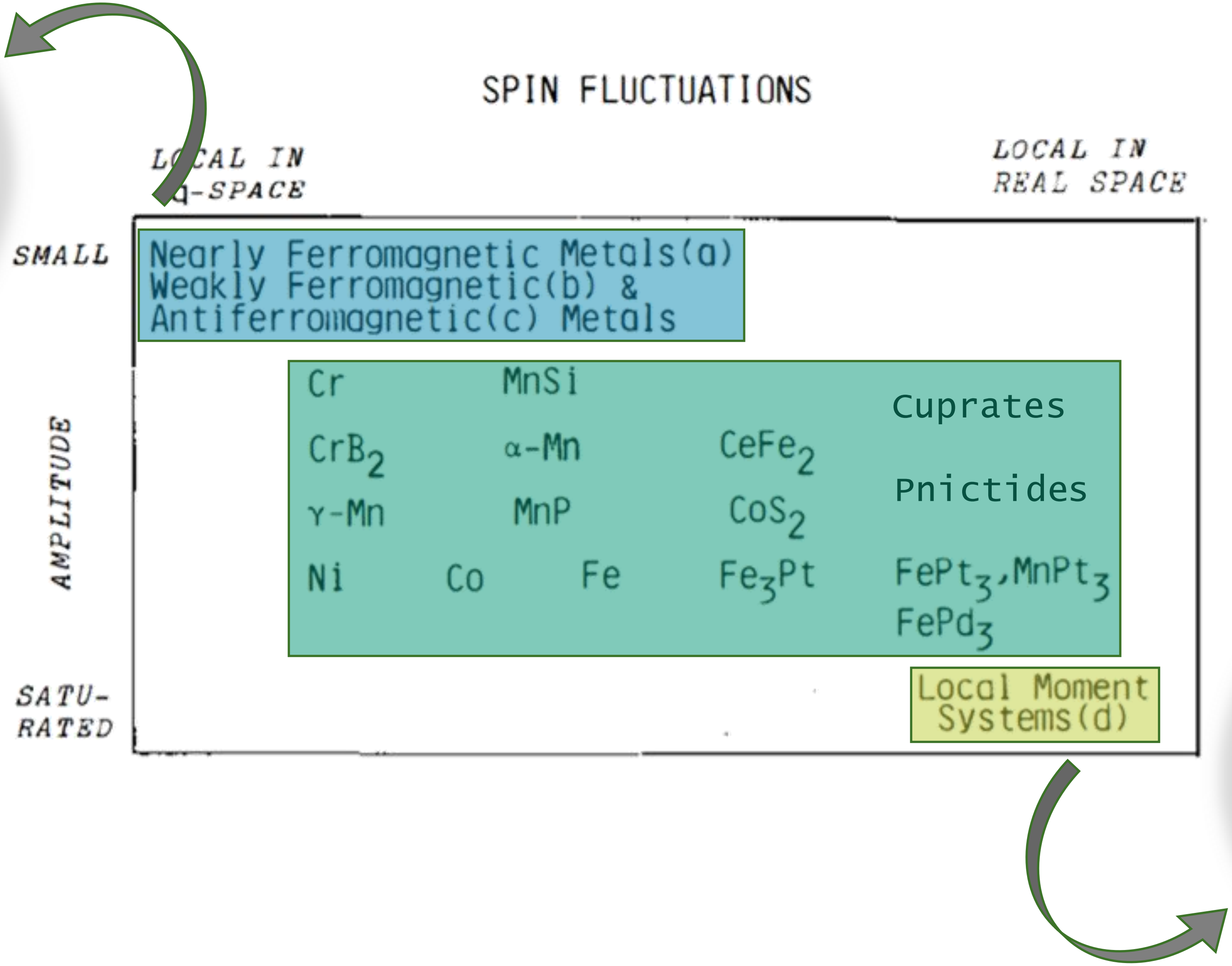
McMaster University

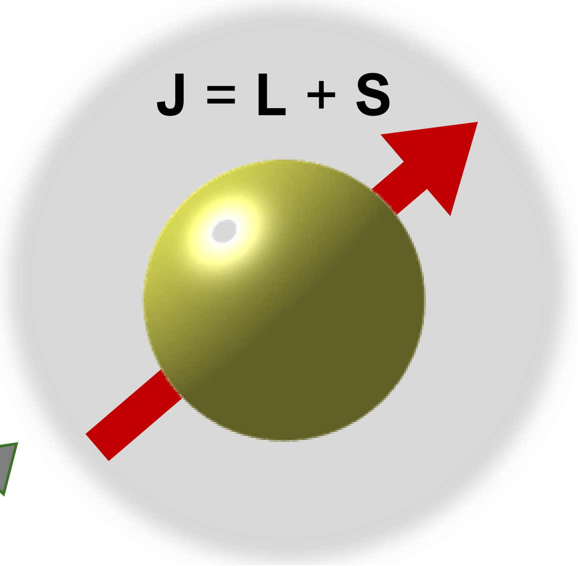
Yaohua Liu

Oak Ridge National Laboratory

The Magnetic Spectrum – from Local to Itinerant



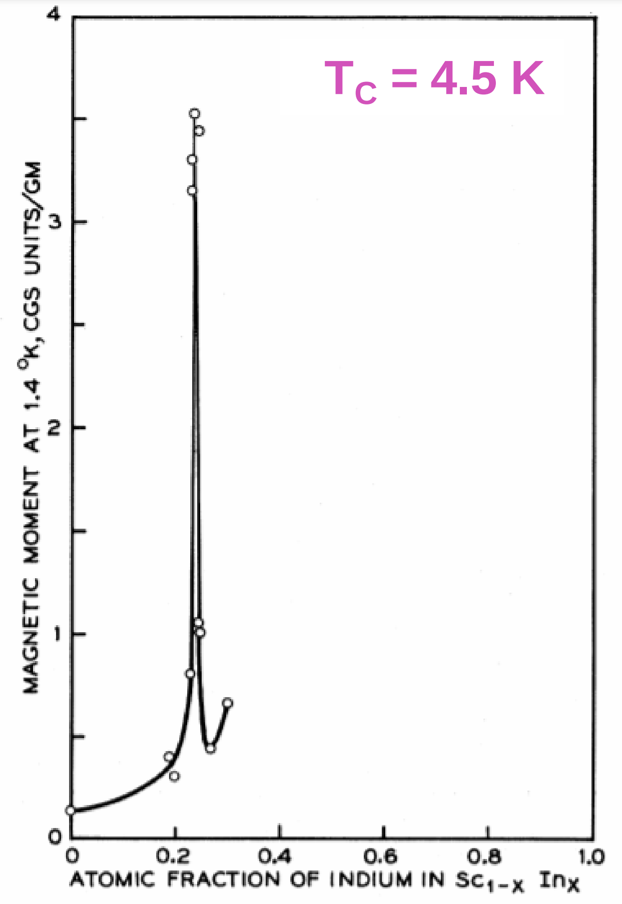




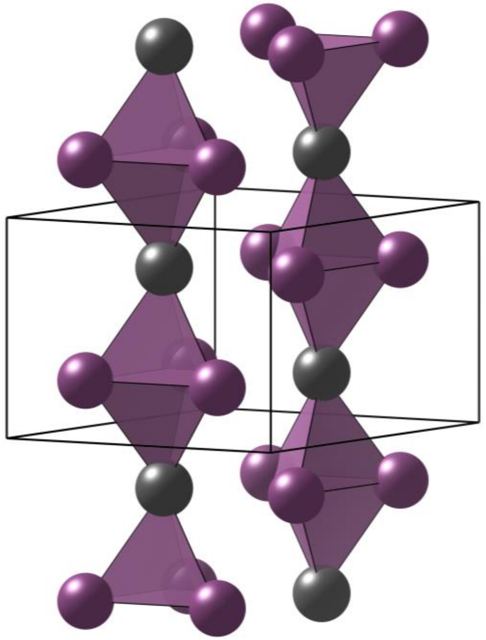
Moriya and Yoshinori. Ann. Rev. of Mat. Sci. (1984).

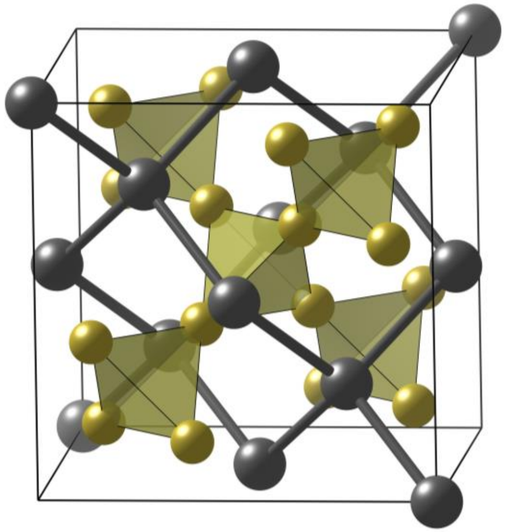
There are two known ferromagnetic metals without magnetic elements

B. T. Matthias, *et al.* PRL (1961)

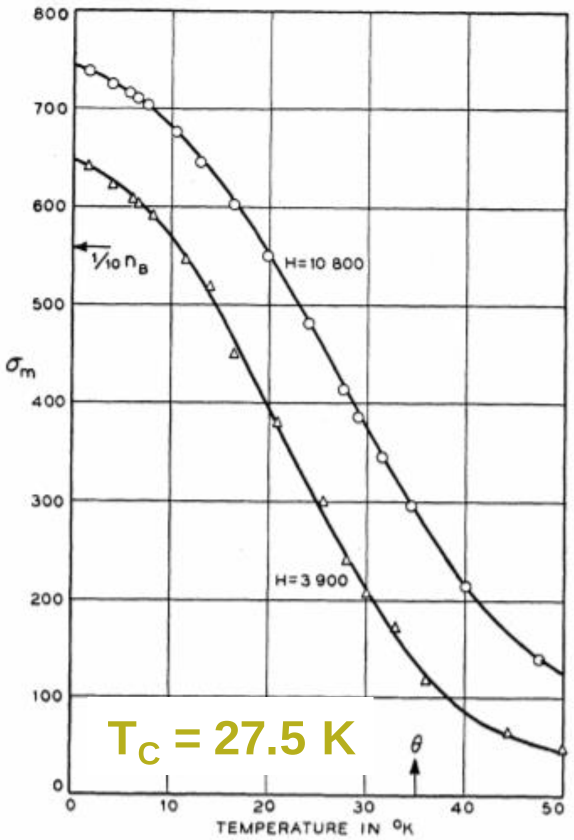


$Sc_{3.1}In$





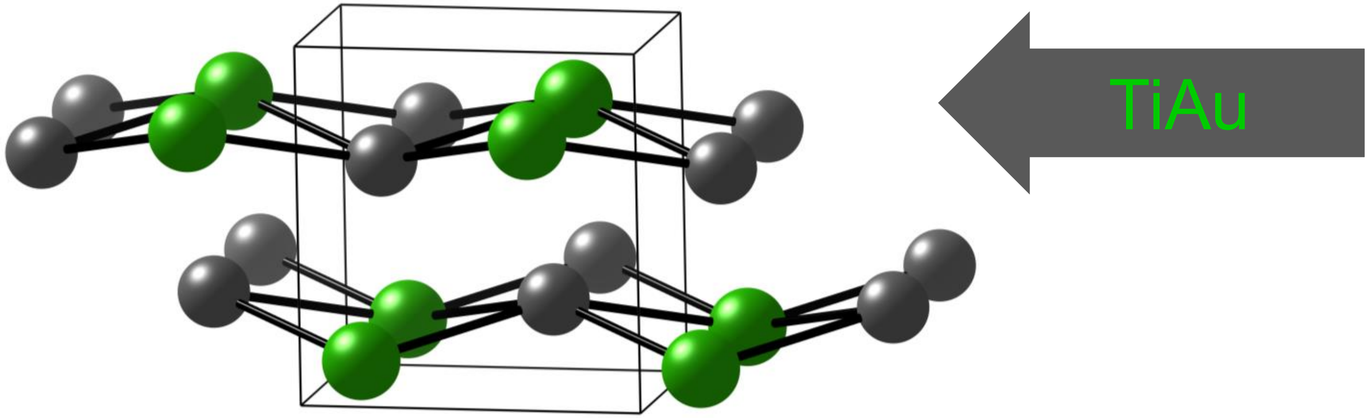
$ZrZn_2$



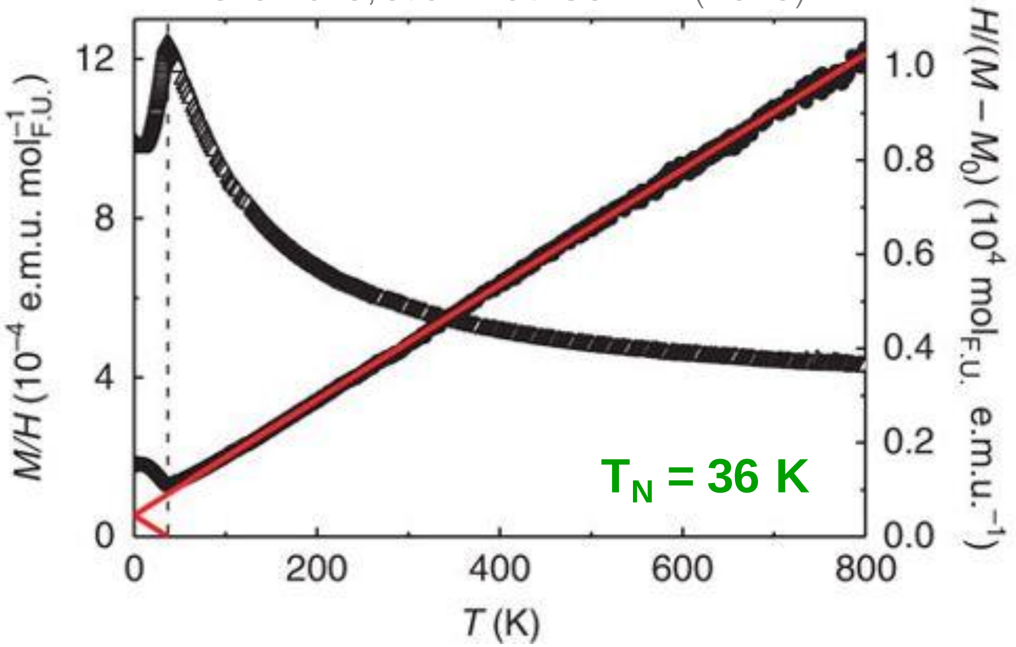
B. T. Matthias, *et al.* Phys. Rev. (1958)

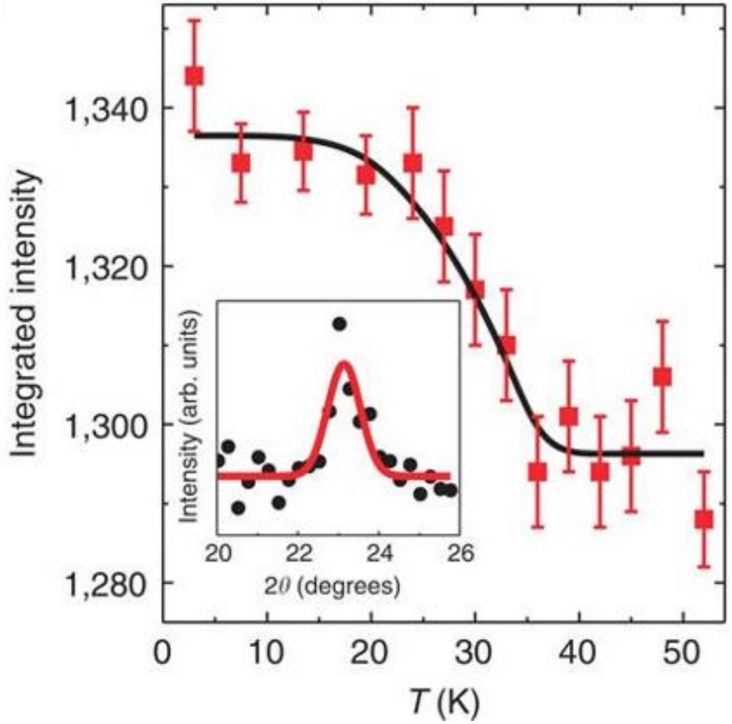
Discovered by Bernd Matthias around 1960

TiAu is the first itinerant antiferromagnet without magnetic elements



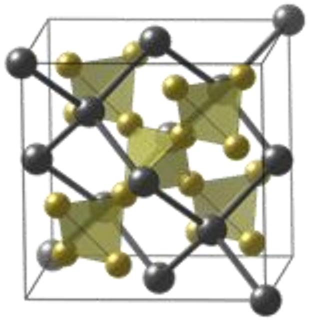
E. Svanidze, *et al.* Nat. Comm. (2015)



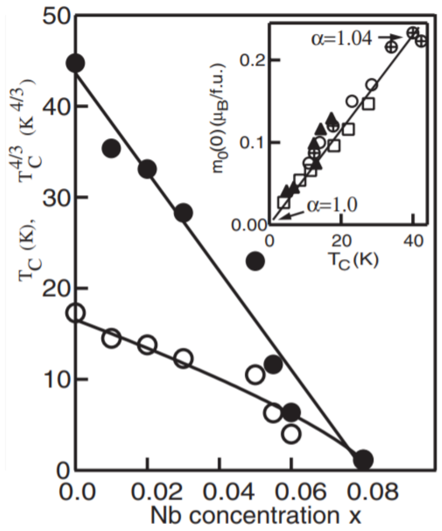


Discovered by Emilia Morosan in 2015

$ZrZn_2$

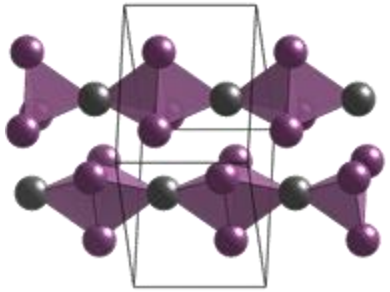


- 3D crystal structure
- Mean field ferromagnet
- Small single crystals
- Nb-doping induced QCP

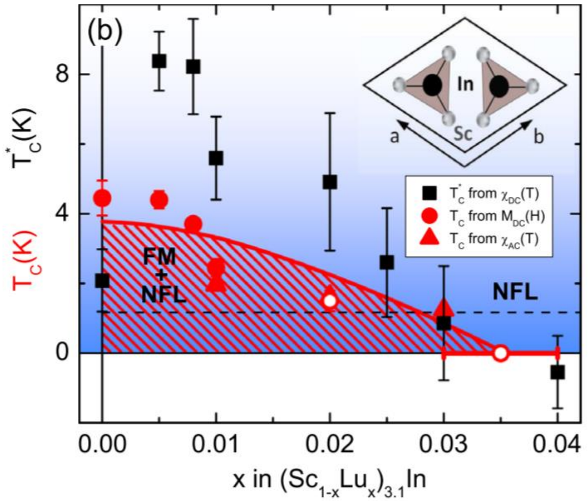


D.A. Sokolov *et al.*, PRL (2006)

$Sc_{3.1}In$

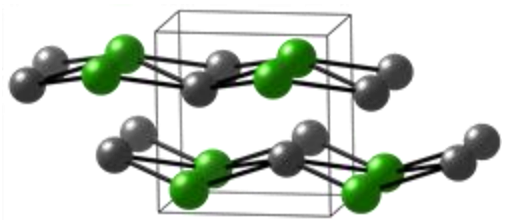


- Quasi-1D crystal structure
- Non-mean field ferromagnet
- No single crystals
- Lu-doping induced QCP

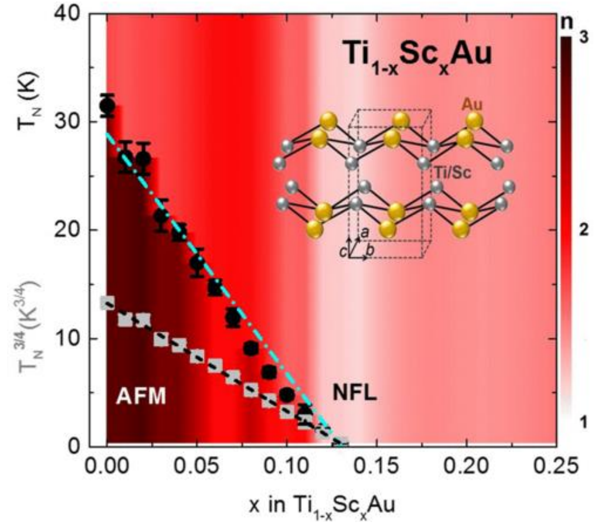


E. Svanidze *et al.* PRX (2015)

TiAu



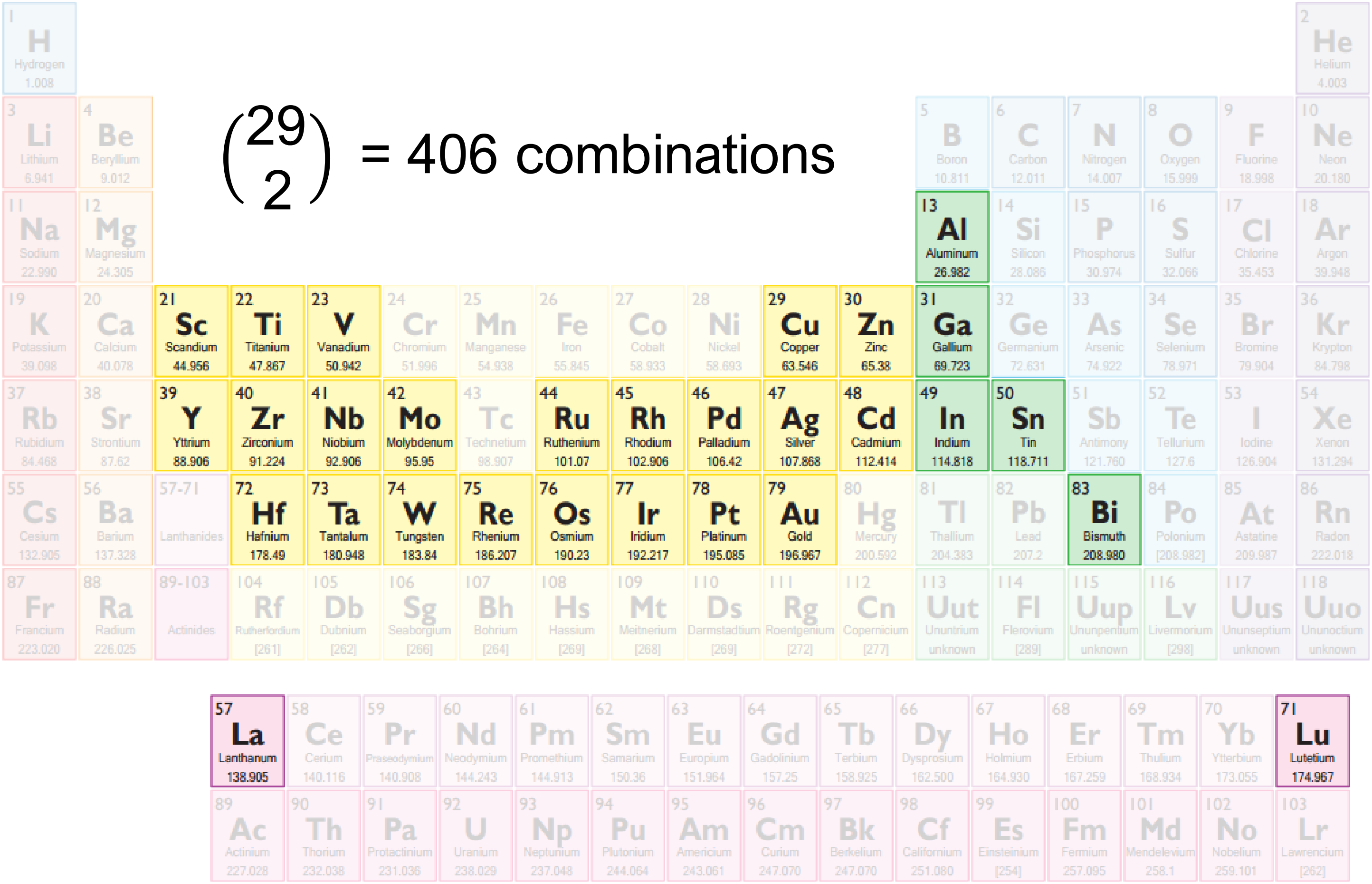
- Quasi-2D crystal structure
- Antiferromagnetic
- No single crystals
- Sc-doping induced QCP

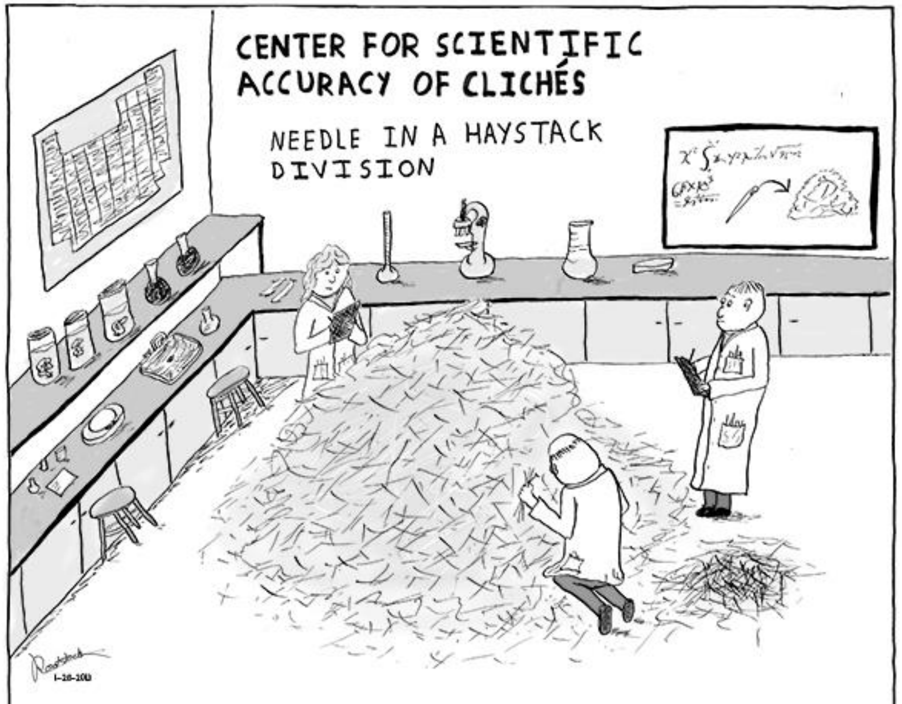


E. Svanidze *et al.* PRB(R) (2017)

How to design a purely itinerant magnet
ie. How to search for a needle in a haystack

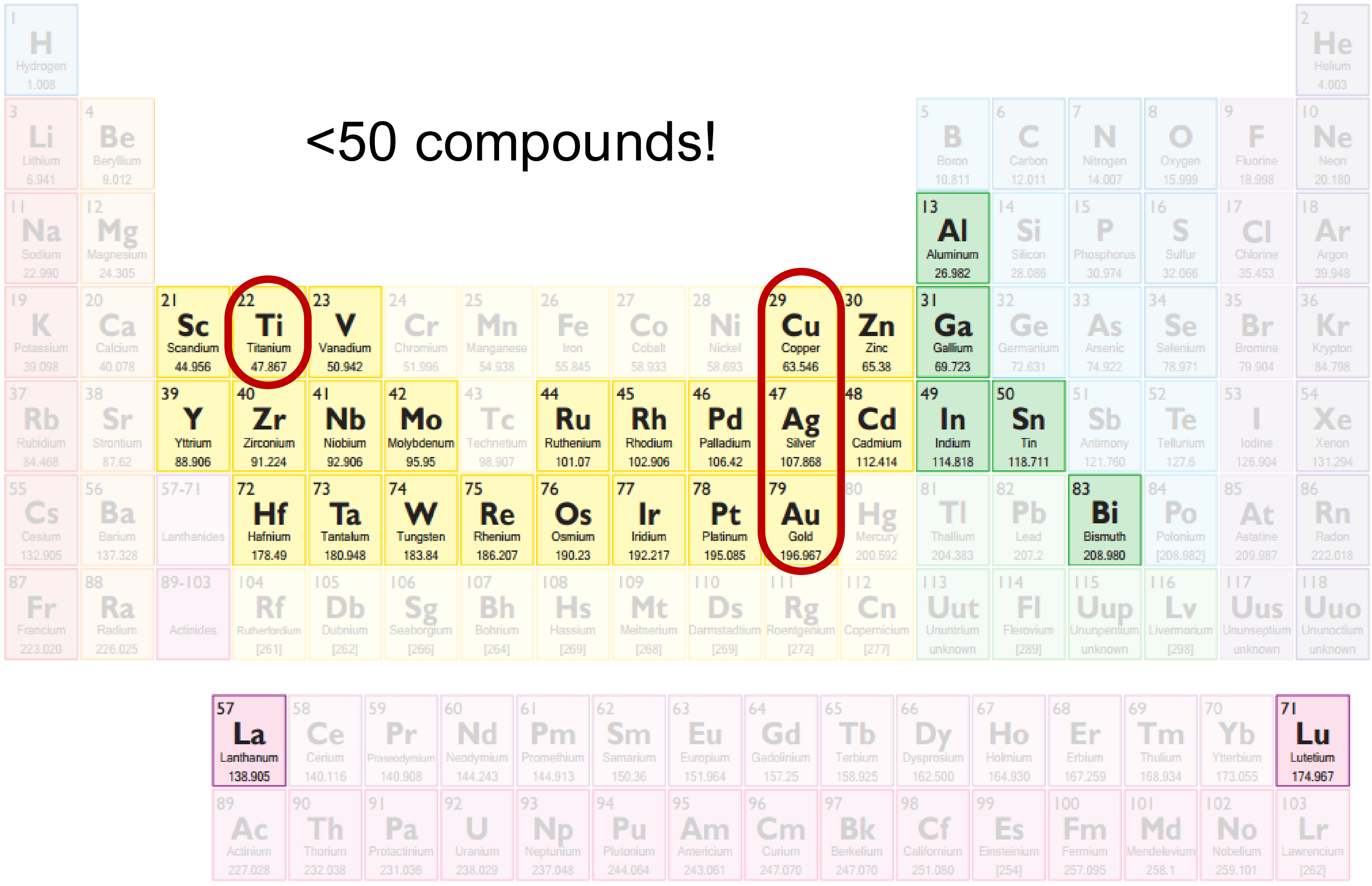
$$\binom{29}{2} = 406 \text{ combinations}$$





For the first time, scientists were close to determining how difficult it is to actually find a needle in a haystack.

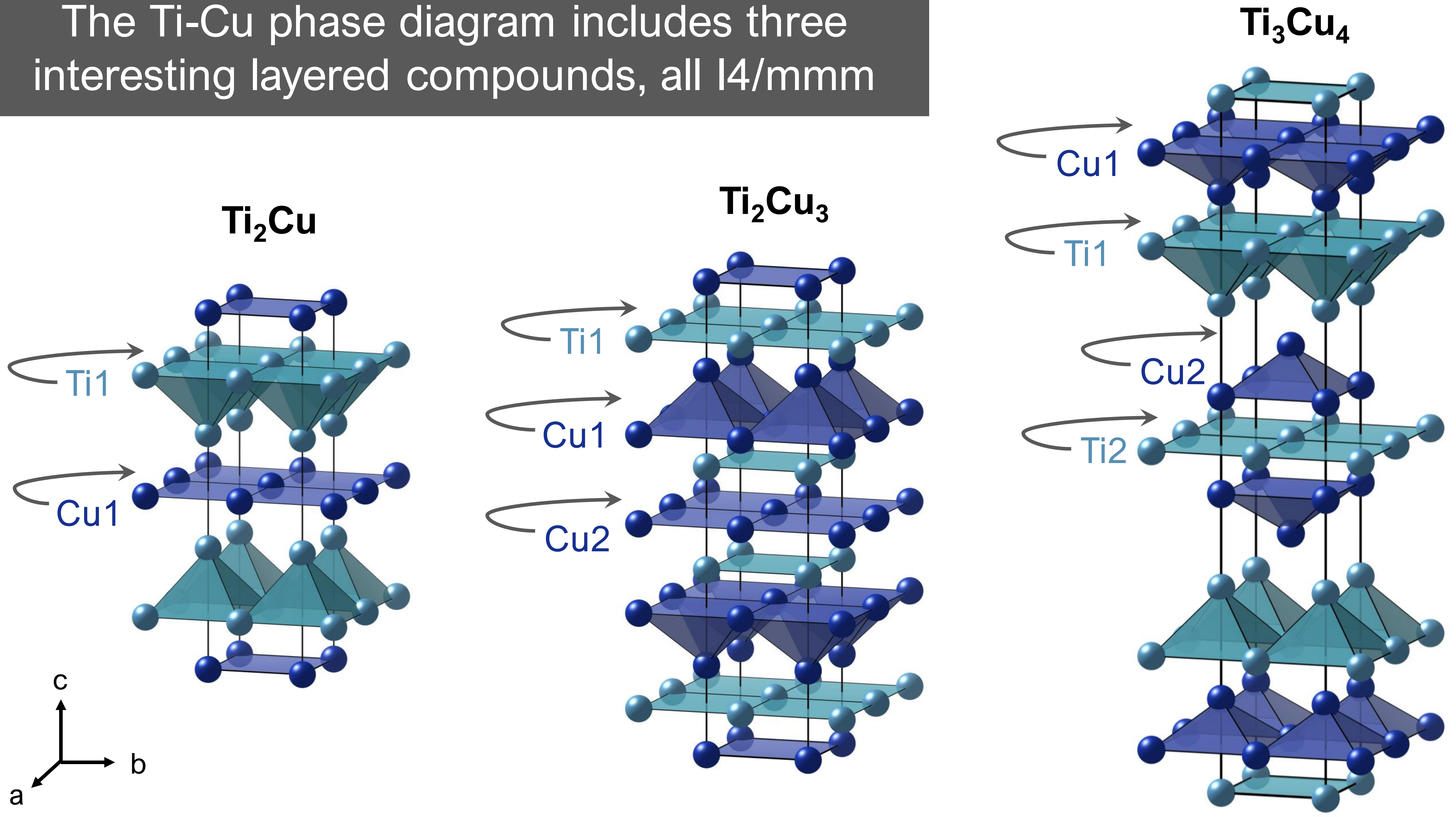
How to design a purely itinerant magnet
ie. How to search for a needle in a haystack



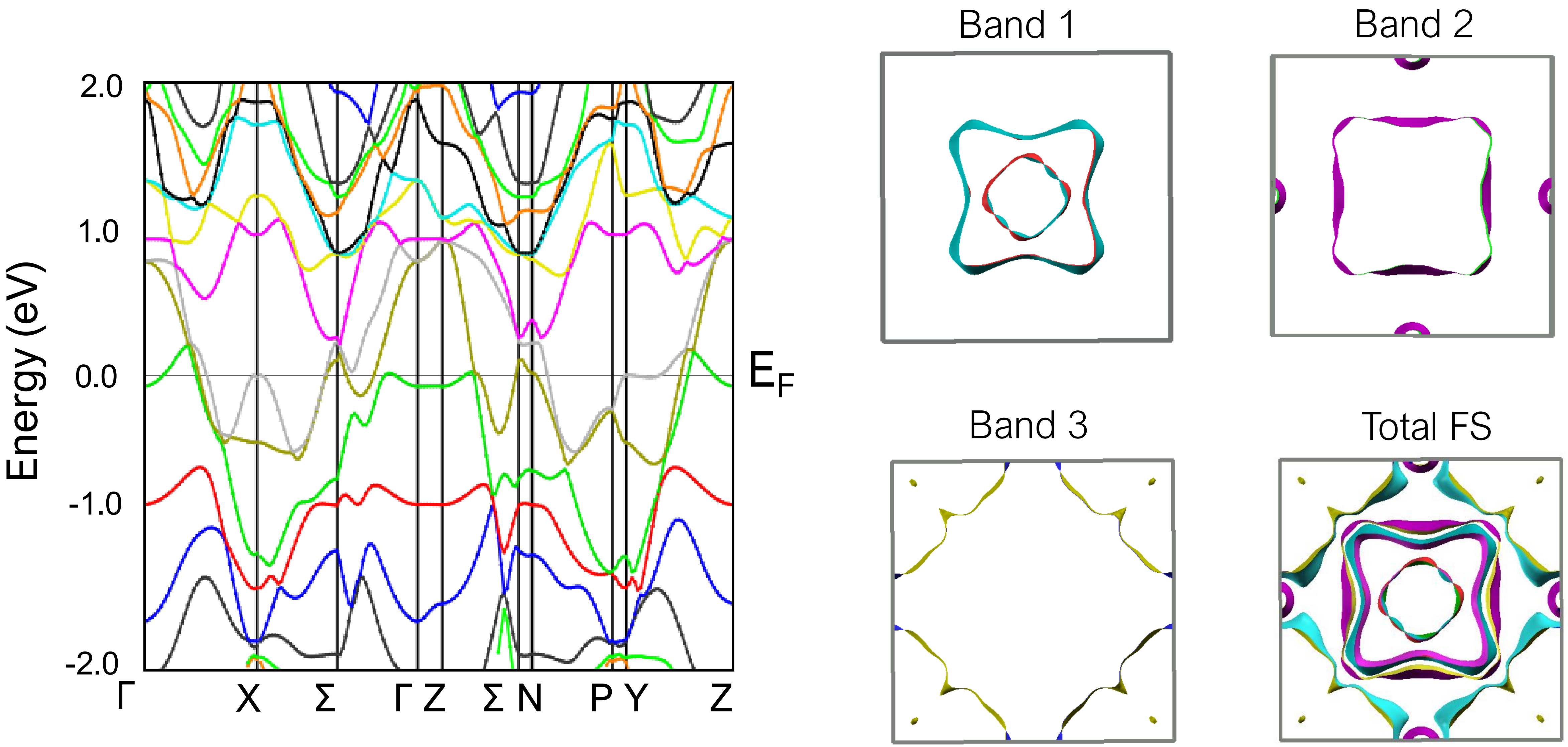
Let's Build a Binary Intermetallic

1. No unstable, radioactive, inert, or deadly elements
2. Exclude non-metals and metalloids
3. Exclude elements that are commonly magnetic in intermetallics *semi-empirical

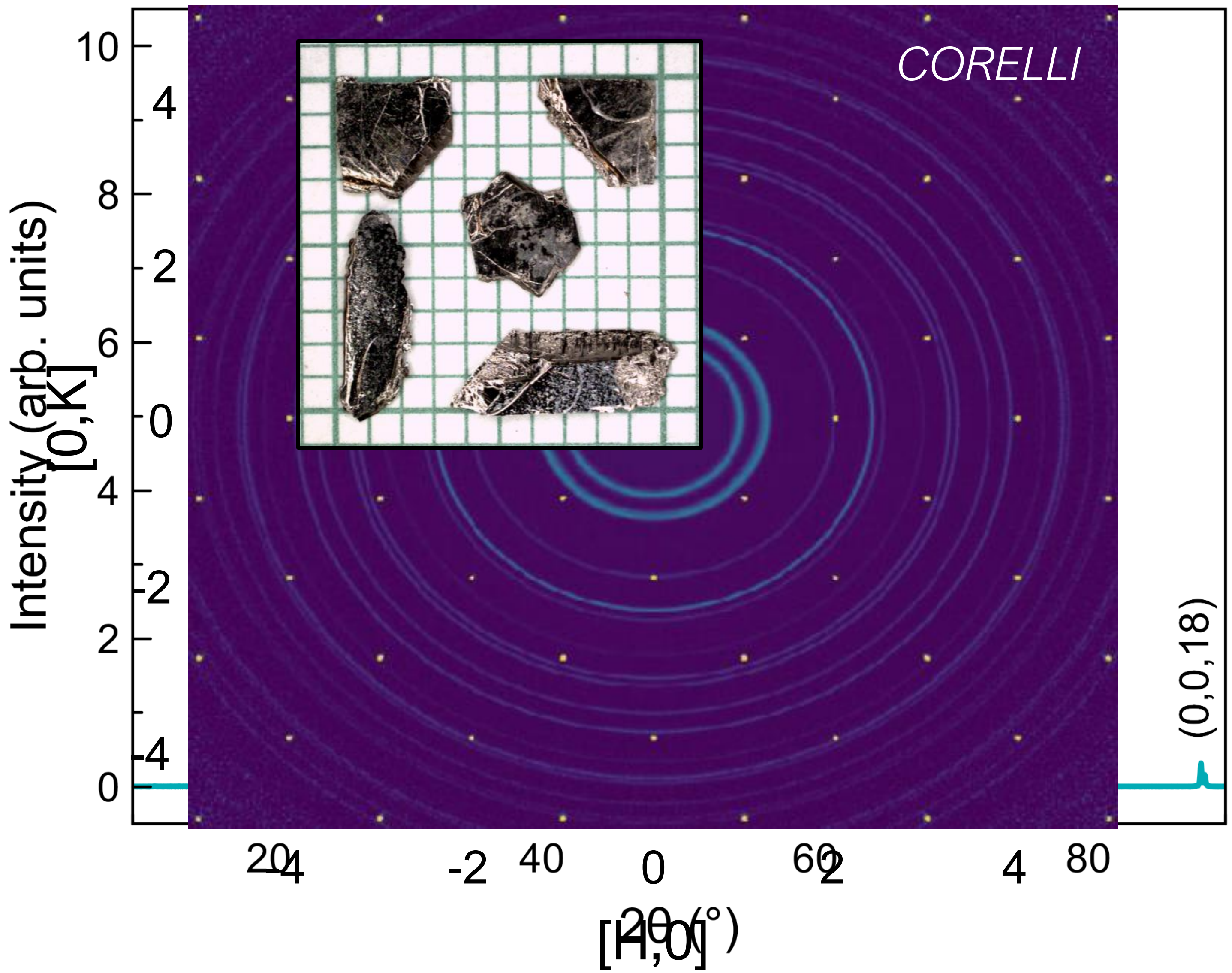
The Ti-Cu phase diagram includes three interesting layered compounds, all I4/mmm

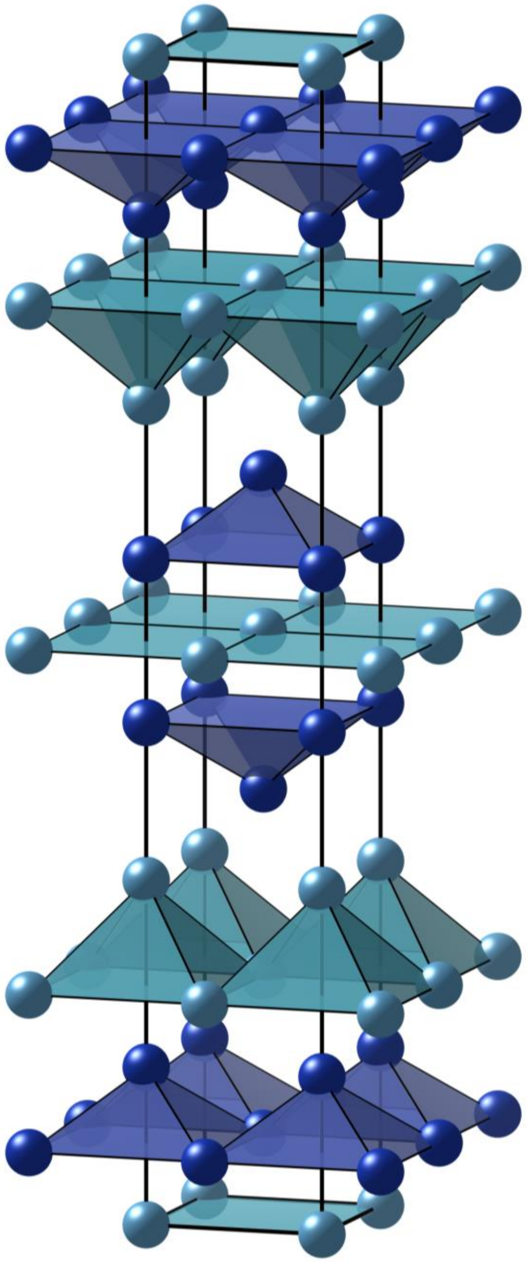


The Fermi surface of Ti_3Cu_4 is heavily nested

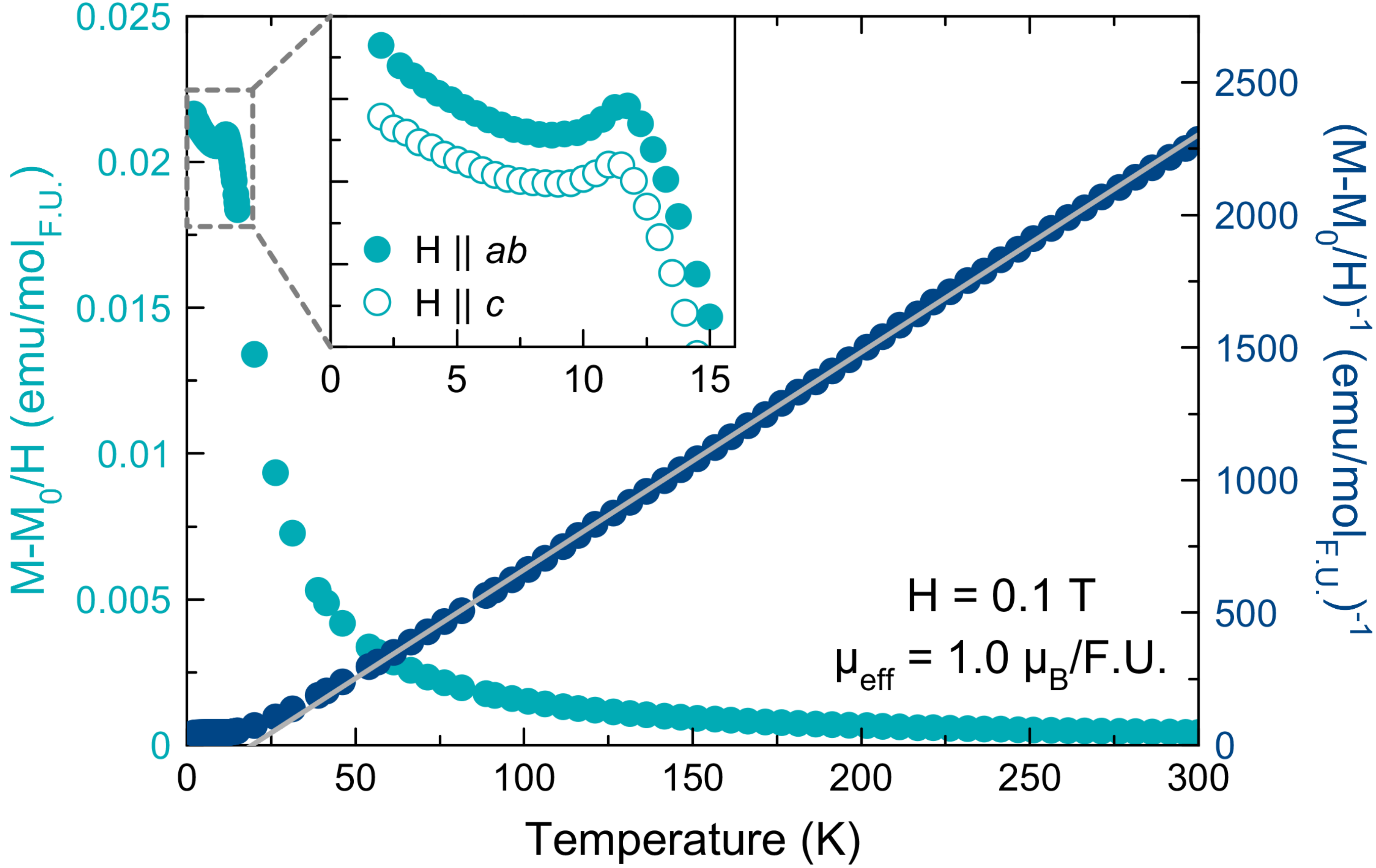


We were able to grow large single crystals of Ti_3Cu_4





Ti_3Cu_4 orders antiferromagnetically at T_N = 11 K



Ferromagnets:

$ZrZn_2$:
T_C = 27.5 K
μ_{eff} = 1.8 μ_B

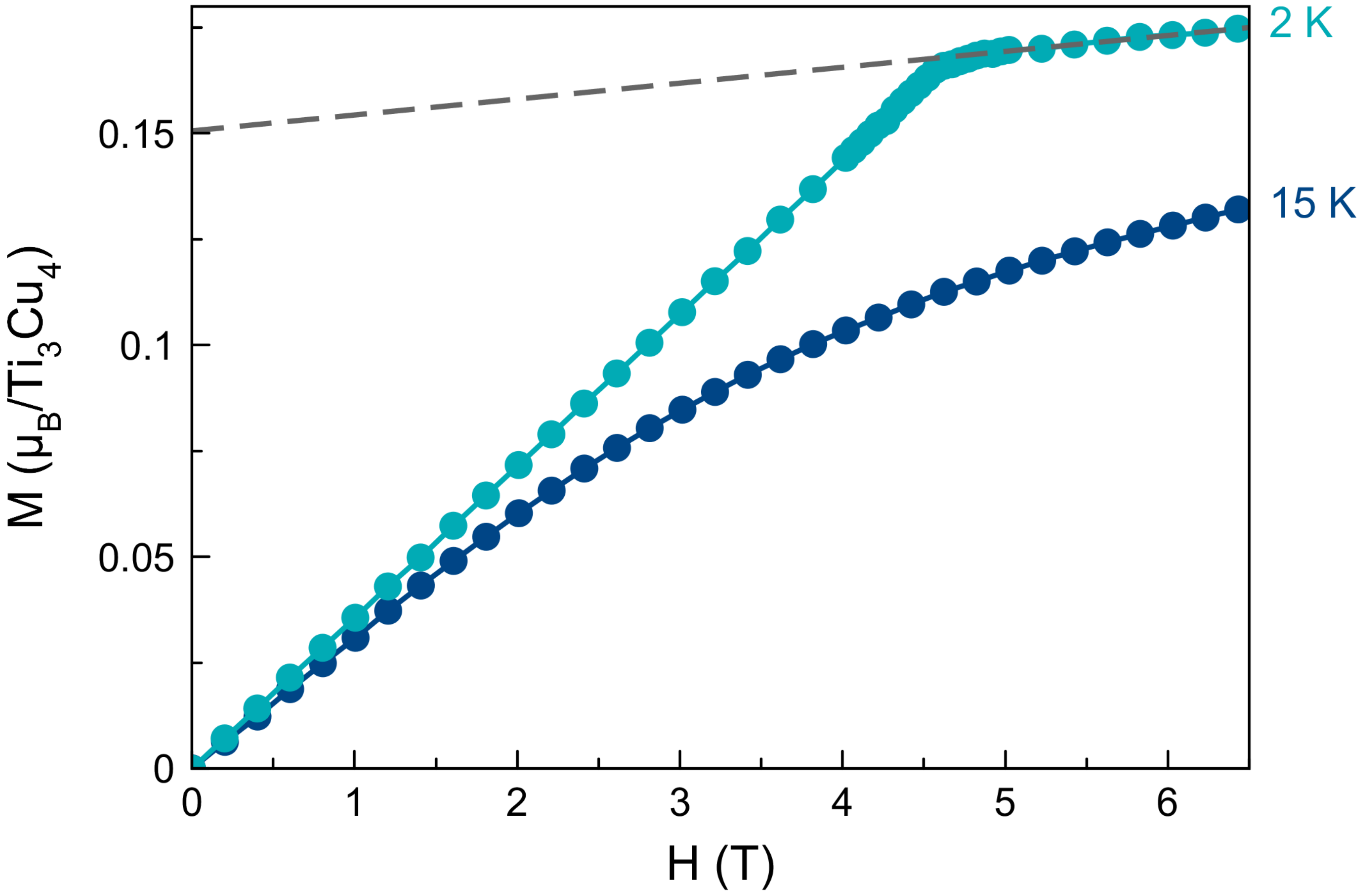
$Sc_{3.1}In$:
T_C = 4.5 K
μ_{eff} = 1.3 μ_B

Antiferromagnets:

TiAu:
T_N = 36 K
μ_{eff} = 0.8 μ_B

Ti_3Cu_4:
T_N = 11 K
μ_{eff} = 1.0 μ_B

Ti_3Cu_4 has a saturated magnetic moment of 0.15 μ_B



Ferromagnets:

$ZrZn_2$:
μ_{sat} = 0.17 μ_B/f.u.

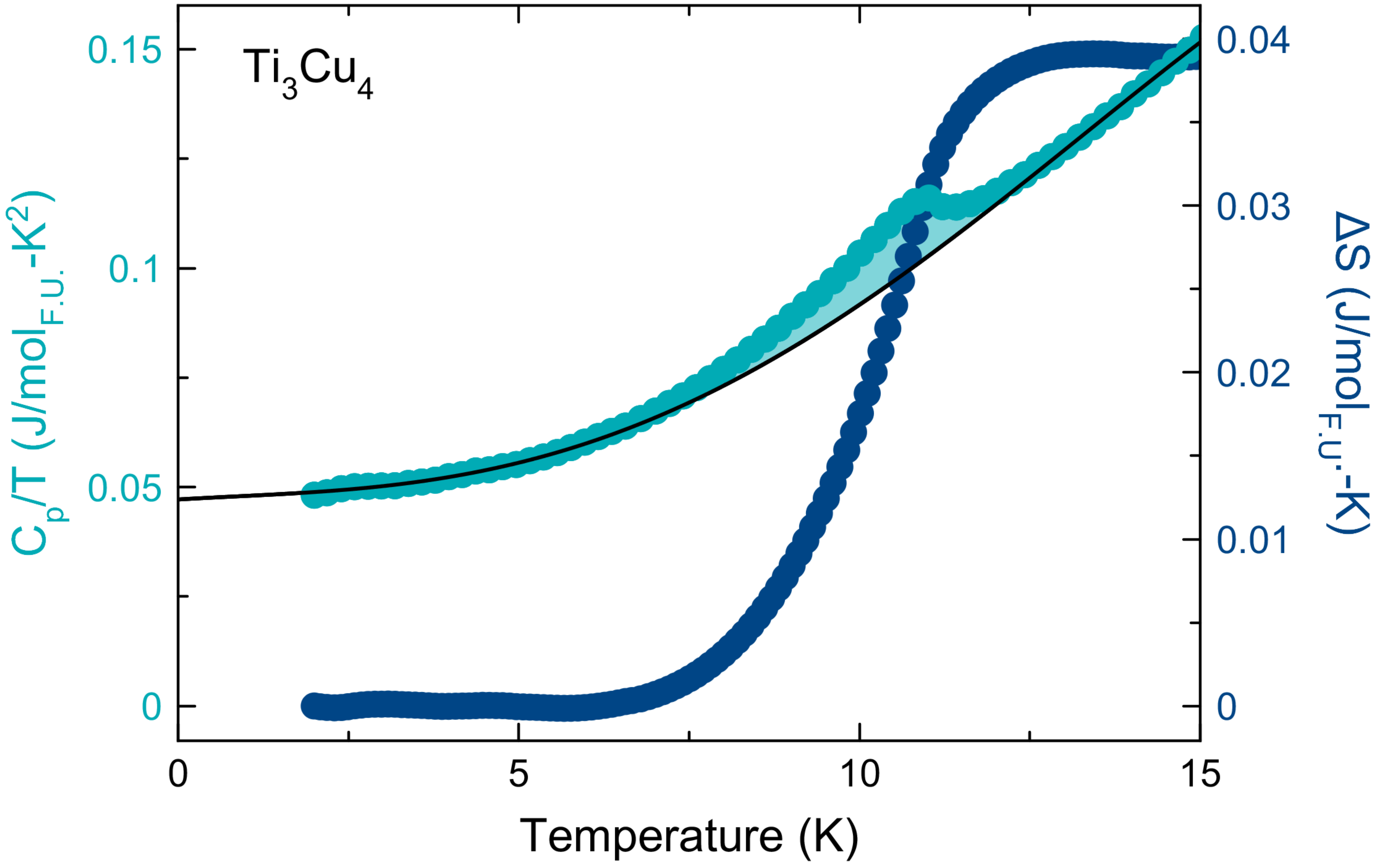
$Sc_{3.1}In$:
μ_{sat} = 0.2 μ_B/f.u.

Antiferromagnets:

TiAu:
μ_{sat} = 0.13 μ_B/f.u.

Ti_3Cu_4:
μ_{sat} = 0.15 μ_B/f.u.

The entropy release in Ti_3Cu_4 at T_N = 11 K is very small



Ferromagnets:

$ZrZn_2$:
ΔS = 3% *R*ln2

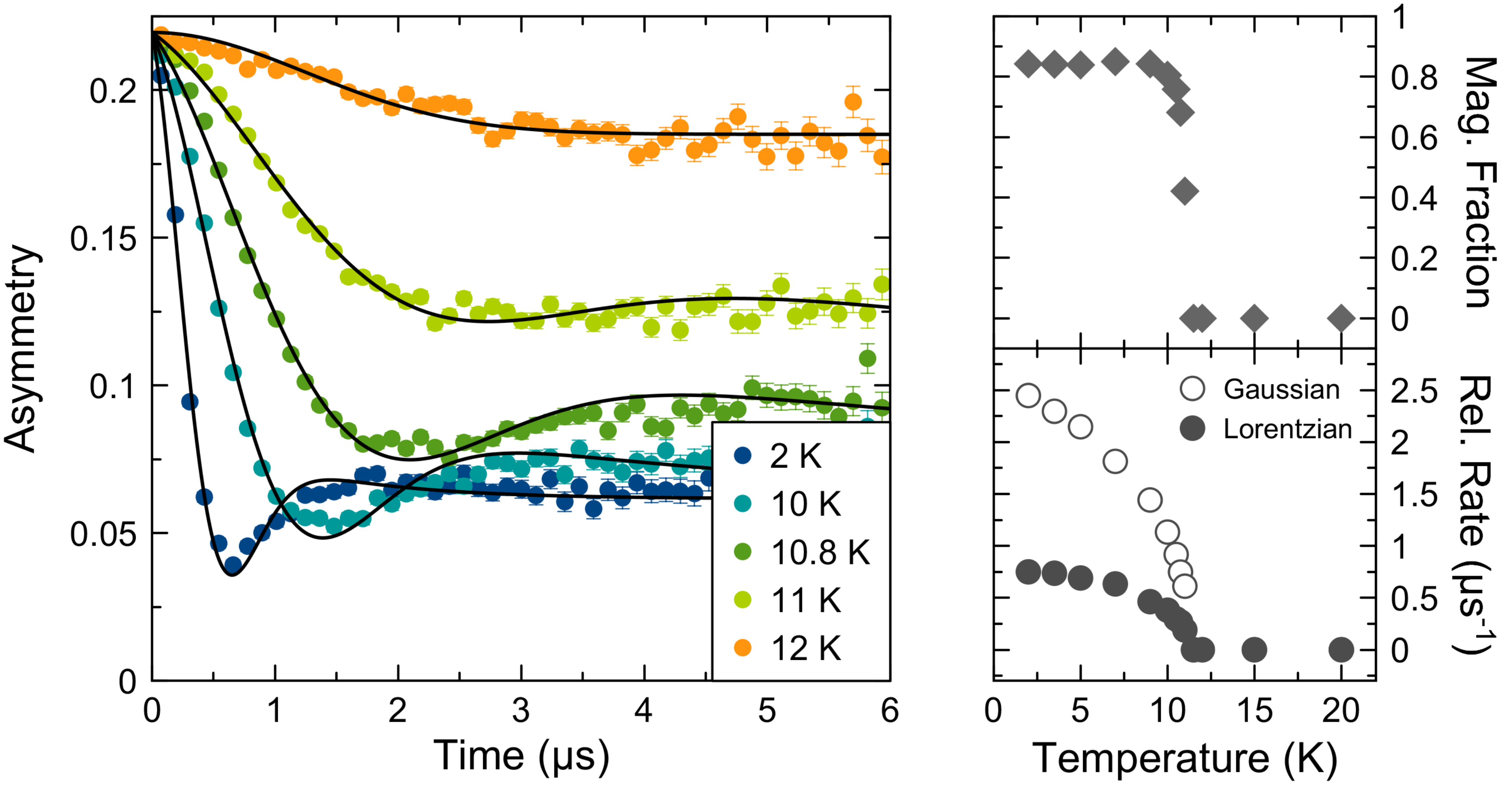
$Sc_{3.1}In$:
ΔS = 2% *R*ln2

Antiferromagnets:

TiAu:
ΔS = 3% *R*ln2

Ti_3Cu_4:
ΔS = 0.7% *R*ln2

Muon spin relaxation confirms that the magnetic order in Ti_3Cu_4 is bulk



Summary: Ti_3Cu_4 is the second known purely itinerant antiferromagnet and the first such compound in single crystal form.

communications physics

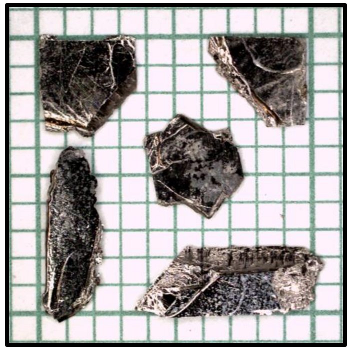
ARTICLE

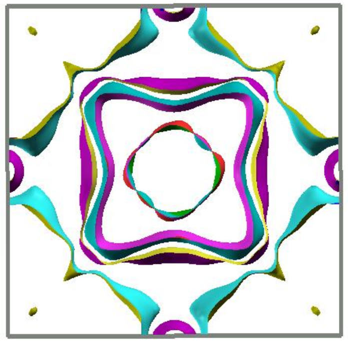
Check for updates

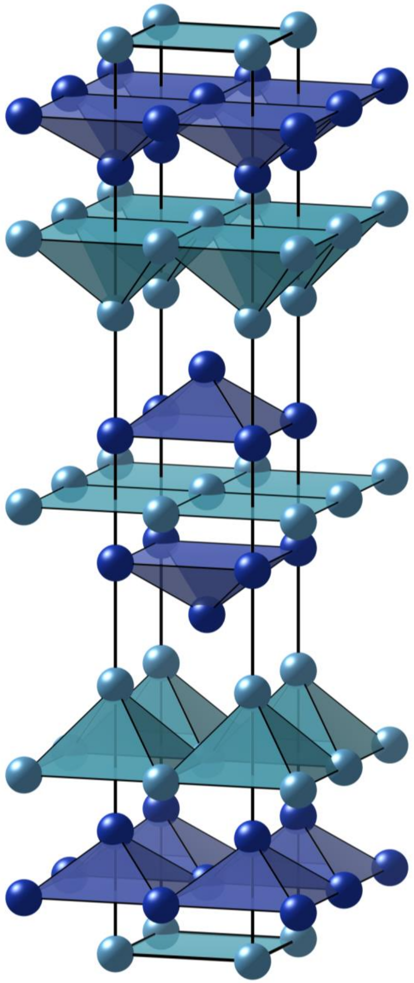
https://doi.org/10.1038/s42005-022-00901-7 OPEN

Field-induced quantum critical point in the itinerant antiferromagnet Ti_3Cu_4

Jaime M. Moya[1,2], Alannah M. Hallas[2,3], Vaideesh Loganathan[2], C.-L. Huang[2,4], Lazar L. Kish[5], Adam A. Aczel[6], J. Beare[7], Y. Cai[7], G. M. Luke[7,8], Franziska Weickert[9], Andriy H. Nevidomskyy[2], Christos D. Malliakas[10], Mercouri G. Kanatzidis[10], Shiming Lei[2], Kyle Bayliff[11] & E. Morosan[2✉]





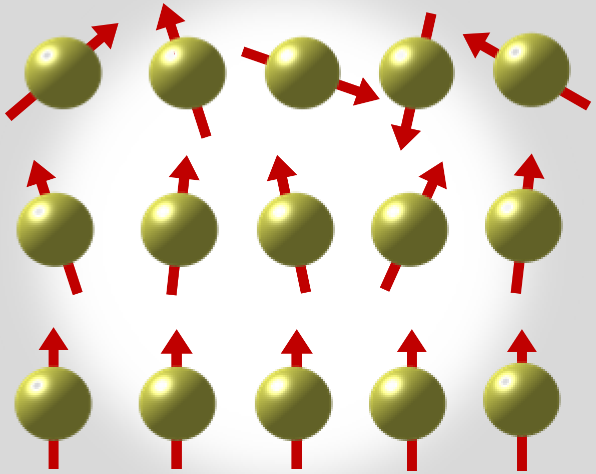


The Local Limit

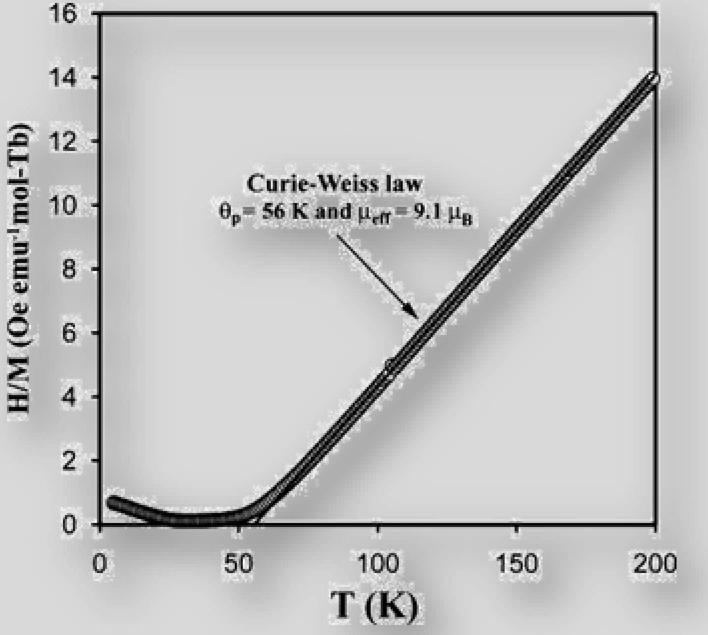
$T > T_C$

$T \approx T_C$

$T = 0$



Mean-field Curie-Weiss law gives $\chi \propto {}^{1}/_{T}$ for temperatures above T_C/T_N

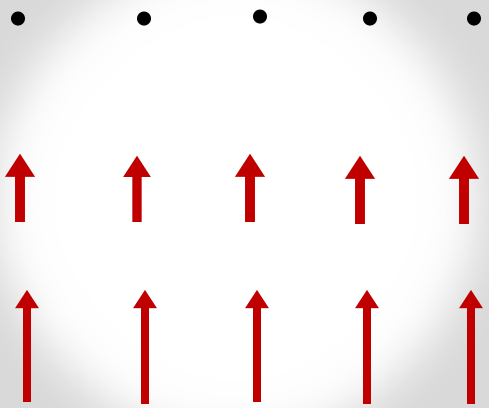


The Itinerant Limit

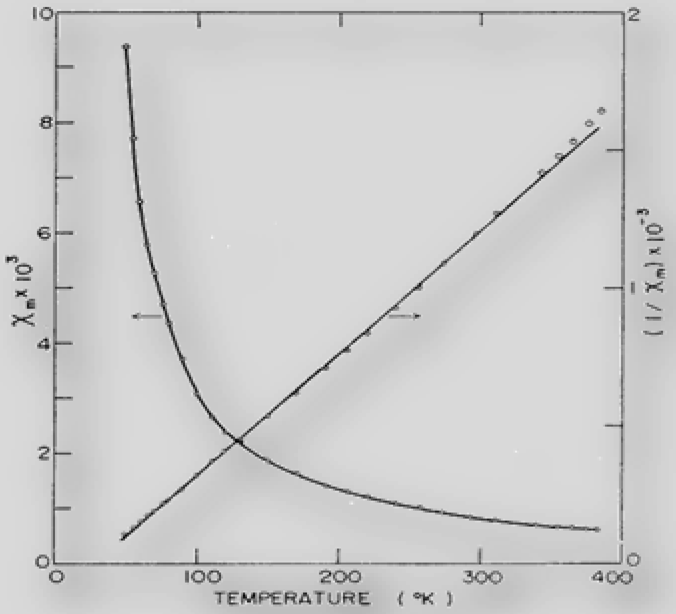
$T > T_C$

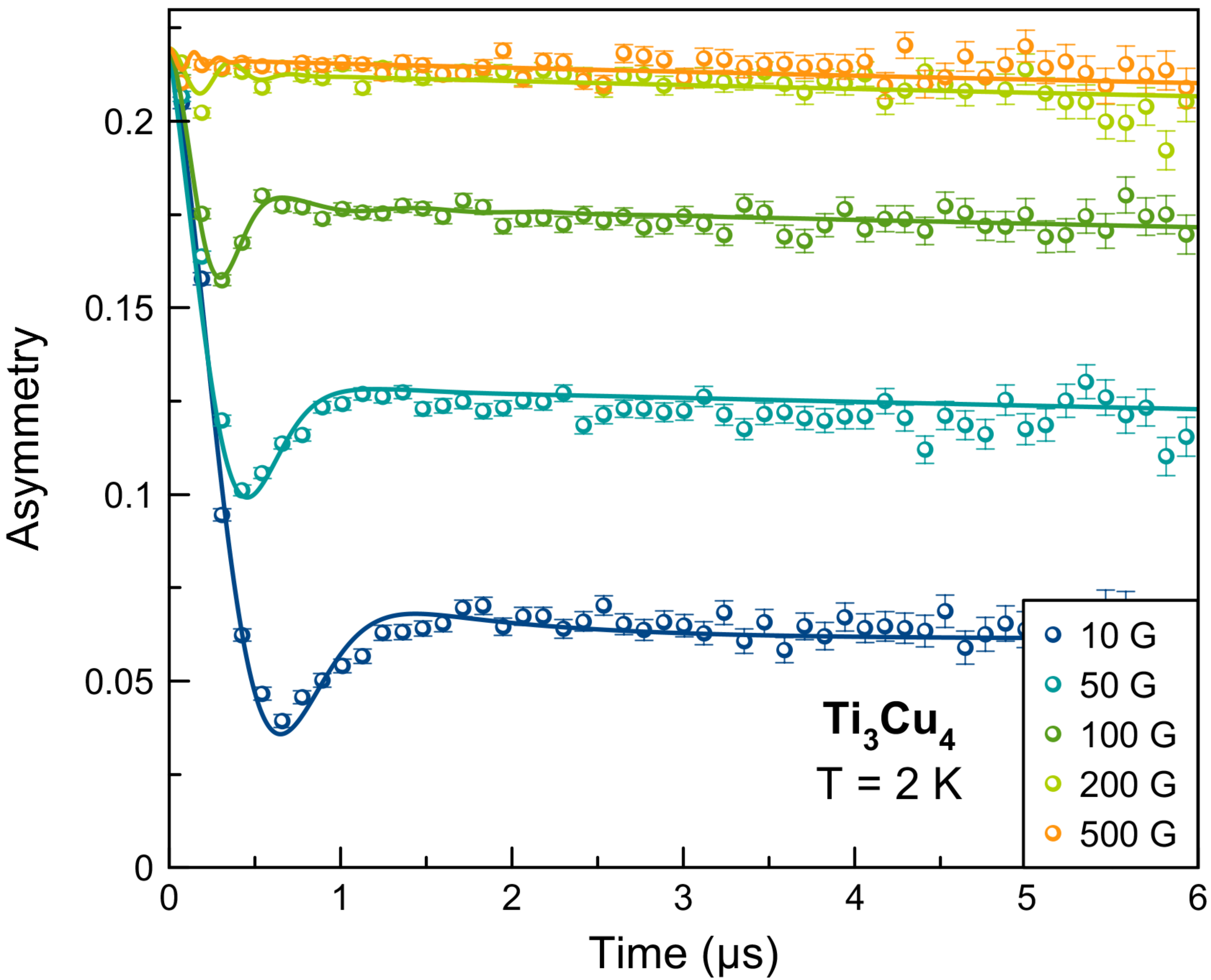
$T \approx T_C$

$T = 0$



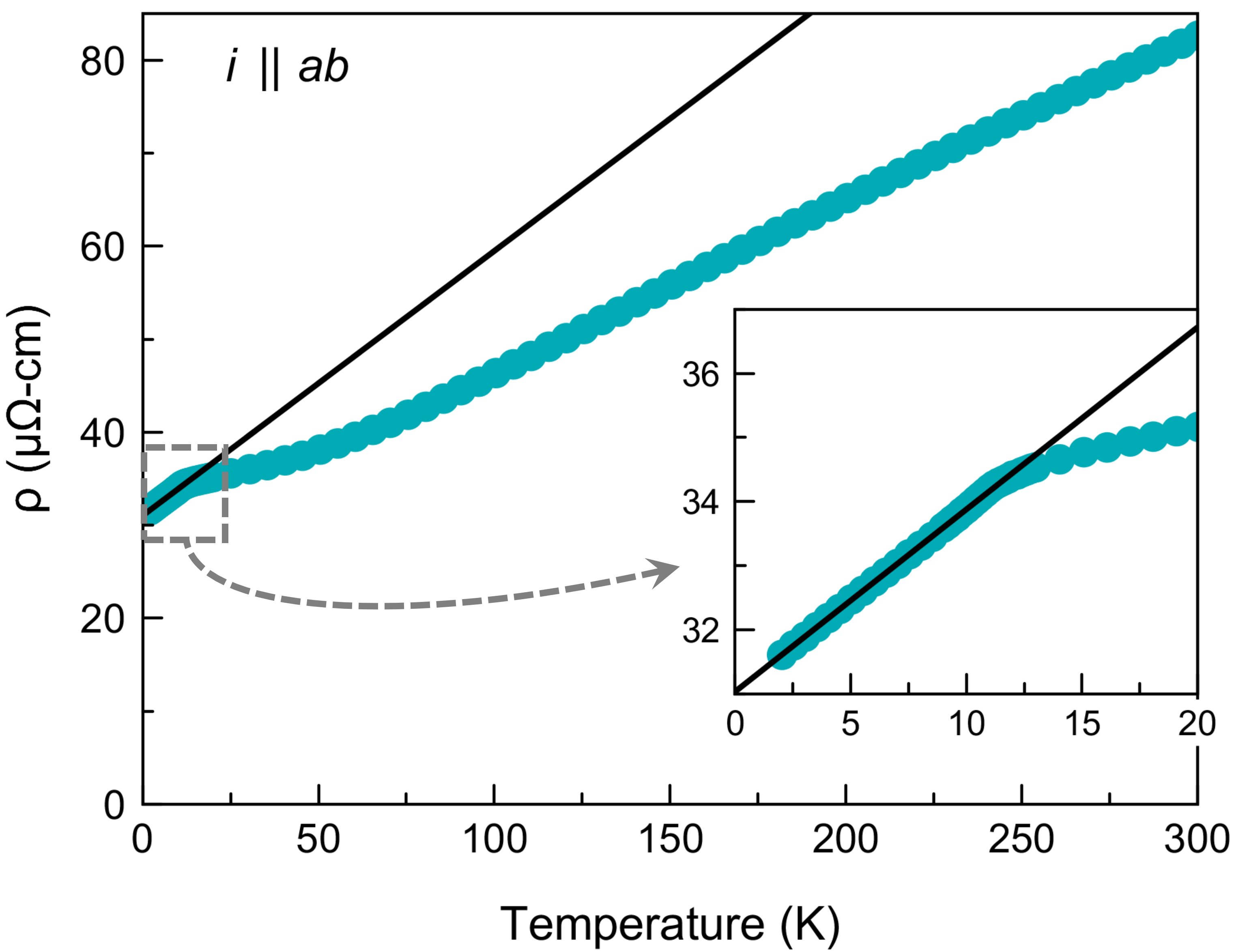
SCR theory of spin fluctuations gives $\chi \propto {}^{1}/_{T}$ for temperatures above T_C/T_N





Asymmetry
Time (μs)
0
0.05
0.1
0.15
0.2
1
2
3
4
5
6
Ti_3Cu_4
T = 2 K
10 G
50 G
100 G
200 G
500 G

Ti_3Cu_4 has T-linear resistivity below T_N = 11 K



Ferromagnets:

$ZrZn_2$:
$\rho(T) \propto T^{5/3}$

$Sc_{3.1}In$:
$\rho(T) \propto T$

Antiferromagnets:

TiAu:
$\rho(T) \propto T^3$

Ti_3Cu_4:
$\rho(T) \propto T$