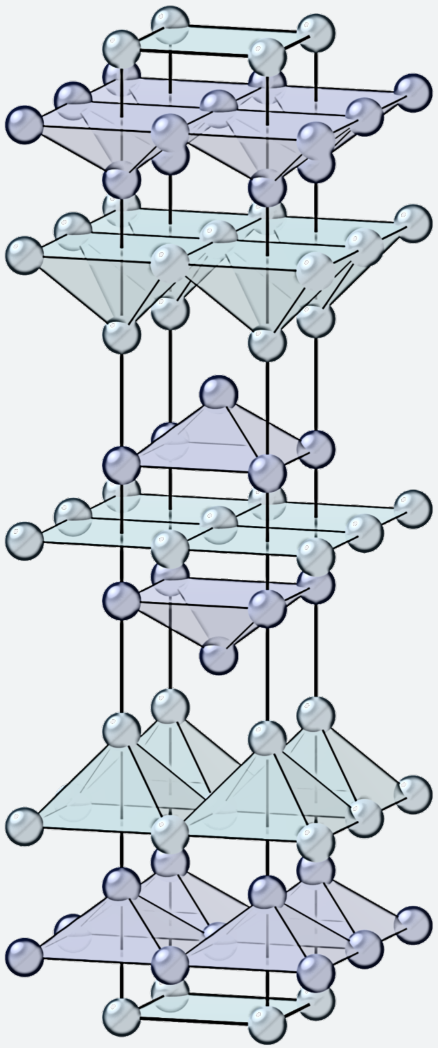
Muons and Quantum Materials



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Hallas Group @ SBQMI-UBC

The “classical” states of matter

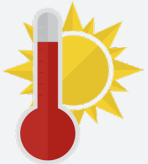
Gas
Water Vapour

Liquid
Water

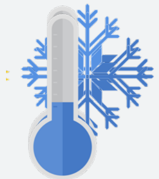
Solid
Ice

Condensation →
← *Evaporation*

Freezing →
← *Melting*



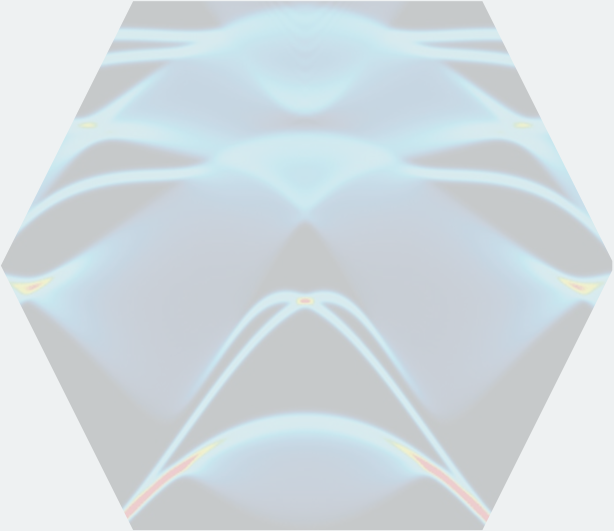
Temperature →



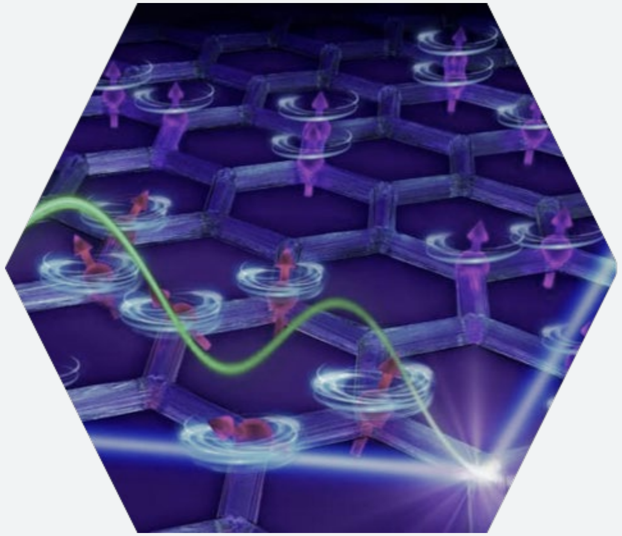
In quantum materials research, we are searching for quantum states of matter

High T_C Superconductors

Topological Materials



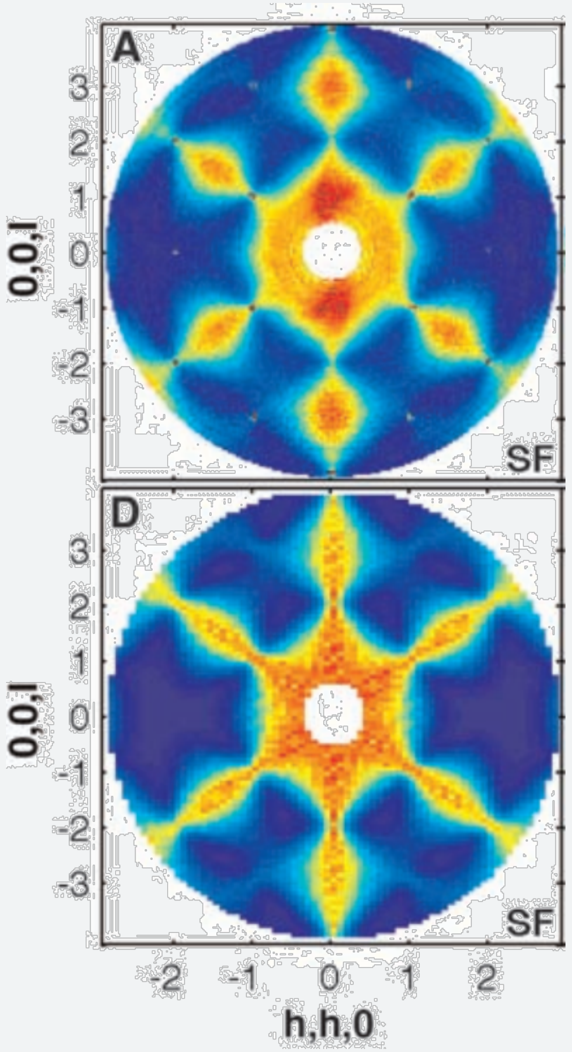
Quantum Magnets



Low temperature, necessary but (in many cases) not sufficient to reach these quantum states.

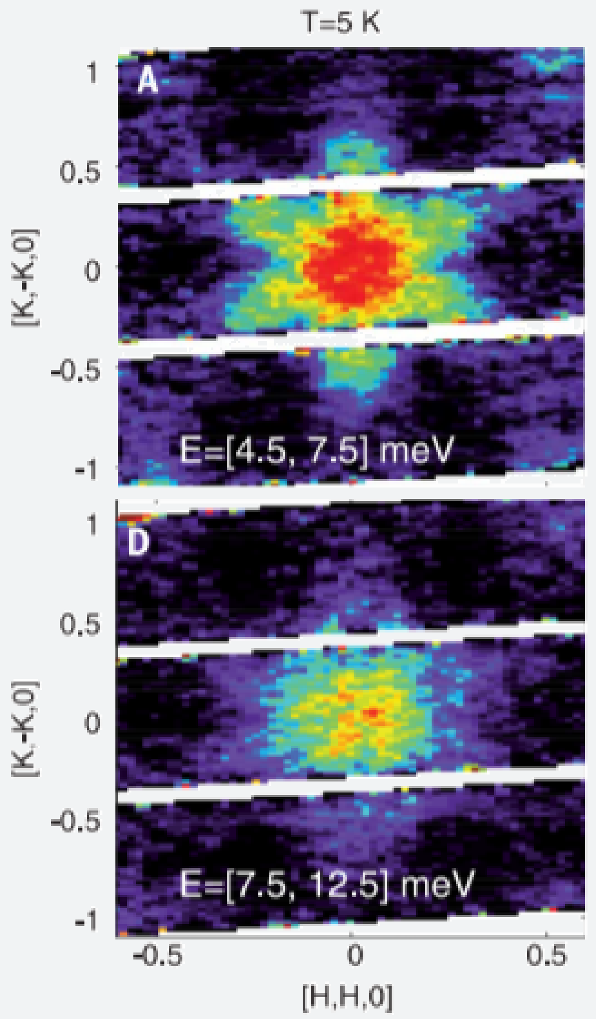
Emergent quasiparticles in magnetic quantum materials

Magnetic Monopoles



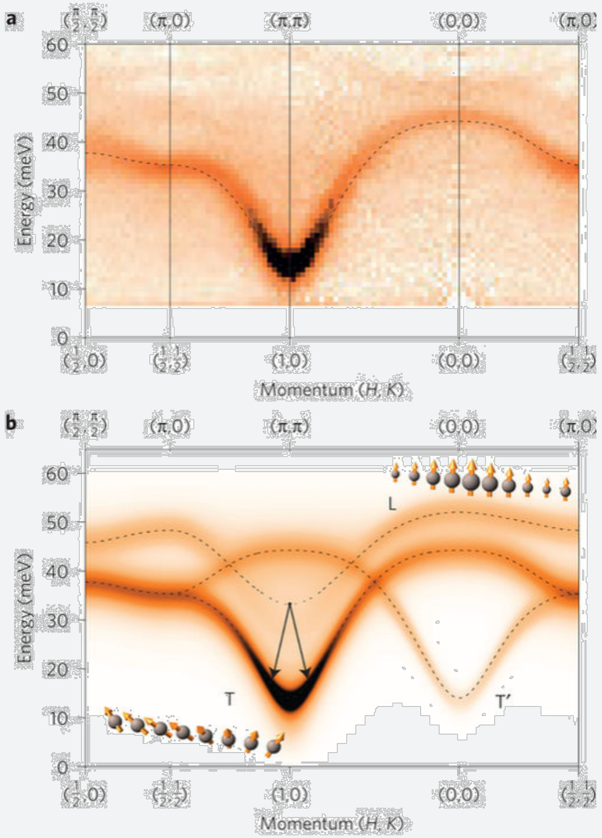
Fennel *et al.*, Science 326 (2017)

Majorana Fermions



Banerjee et al., Science 356 (2017)

Higgs Mode



Jain *et al.*, Nature Physics (2017)

The Quantum Matter Institute at UBC

268!

Grad Students	138
Postdoctoral Fellows	55
Scientific/Tech Staff	33
Operations Staff	19
Faculty	23

Quantum Matter Institute PIs

• Physics • Chemistry • Electrical Engineering •


Andrea **Damascelli**


Sarah **Burke**


Curtis **Berlinguette**


George **Sawatzky**

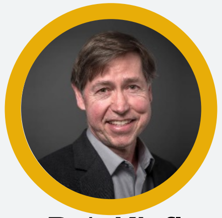

Mona **Berciu**


Jeff **Young**


Doug **Bonn**


Lukas **Chrostowski**


Josh **Folk**


Rob **Kiefl**


David **Jones**


Joerg **Rottler**


Alireza **Nojeh**


Marcel **Franz**


Mark **MacLachlan**


Ian **Affleck**


Andrew **MacFarlane**


Robert **Raussendorf**


Kenji **Kojima**


Ziliang **Ye**


Ke **Zou**

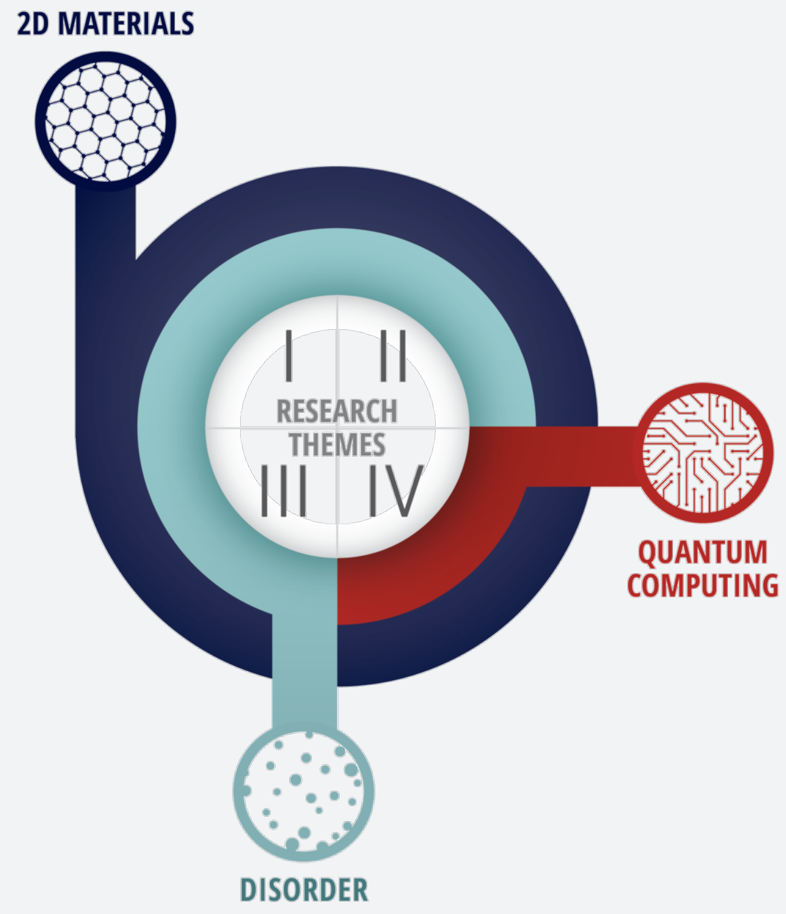

Alannah **Hallas**


Steven **Dierker**


Meigan **Aronson**

The next decade of research at QMI will be guided by three Grand Challenges

Materials　　Experimentation　　Modelling



RESEARCH THEMES

I Atomic Level Design of Quantum Materials

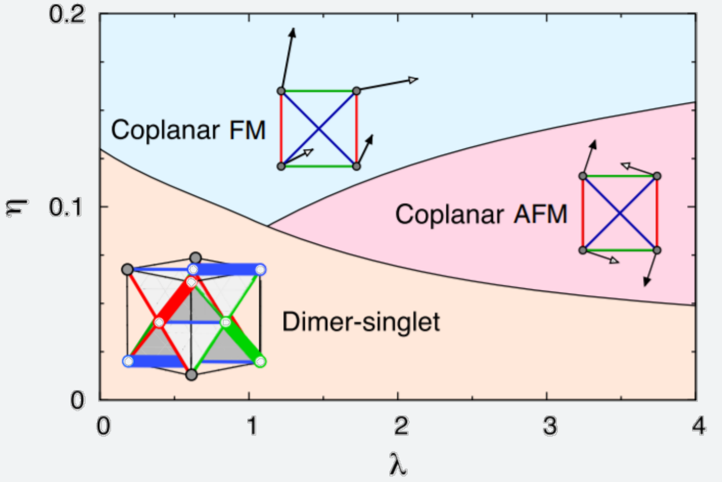
II Emergent Electronic Phenomena at Interfaces

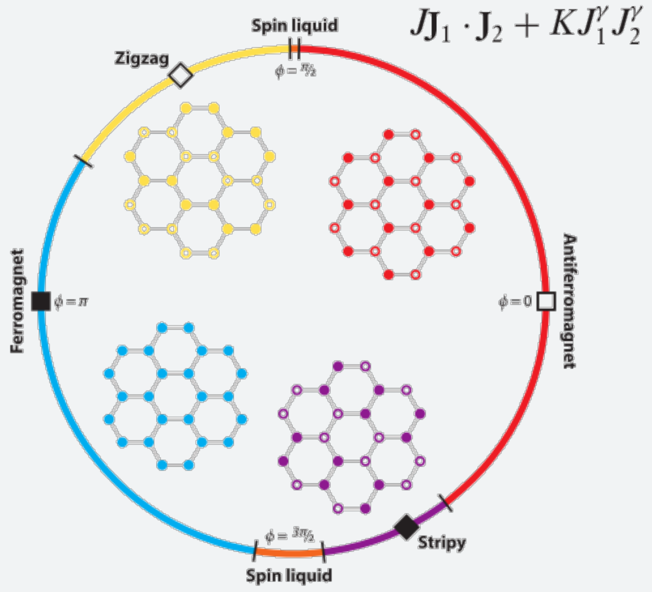
III Topologically Protected Quantum States

IV Photonic Manipulation of Quantum States

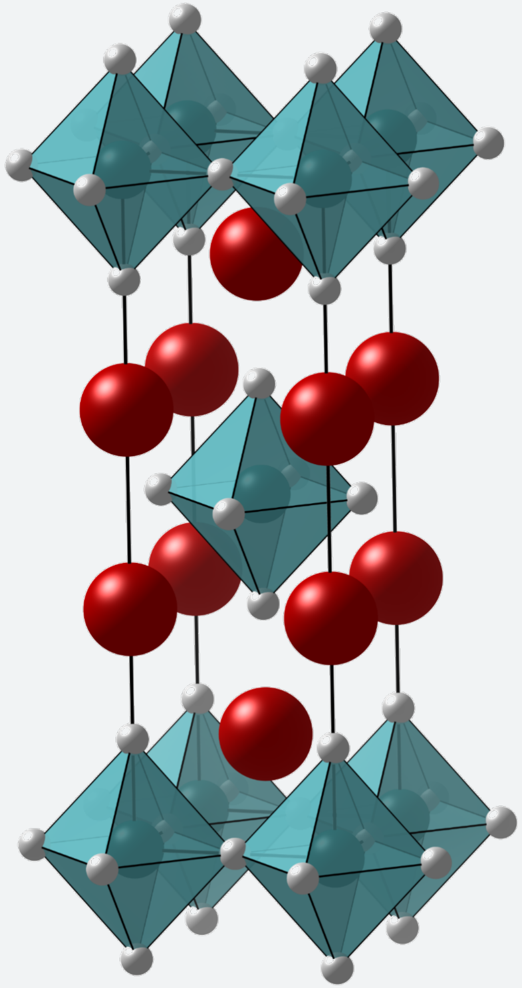
My group designs and then grows single crystals of new magnetic quantum materials

Romhányi *et al.*, PRL **118**, 217202 (2017).





Rau *et al.*, ARCMP **7**:195 (2016).



- **Apply chemical pressure**

  e.g. $Ge^{4+} < Ti^{4+} < Sn^{4+}$

- **Reduce the spin**

  e.g. Ni^{2+} (S = 1) → Cu^{2+} (S = ½)

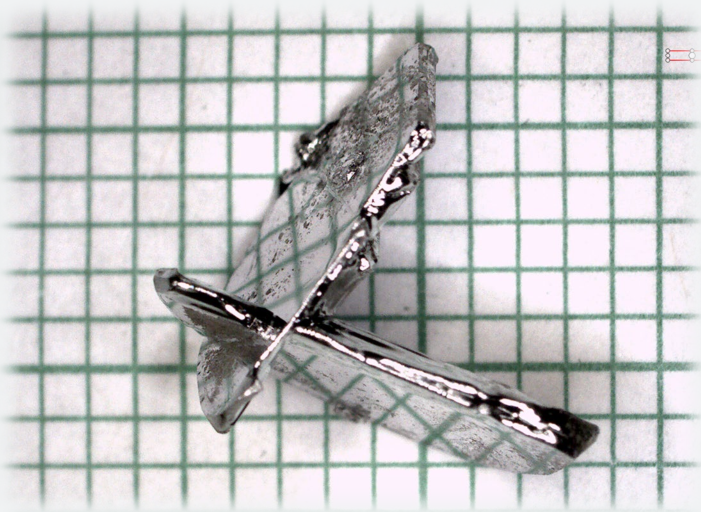
- **Tune the oxidation state**

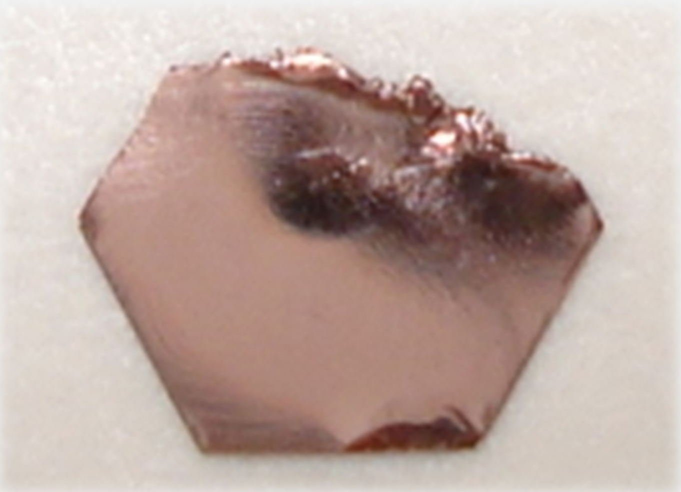
  e.g. Anion substitution (O^{2-} → N^{3-})

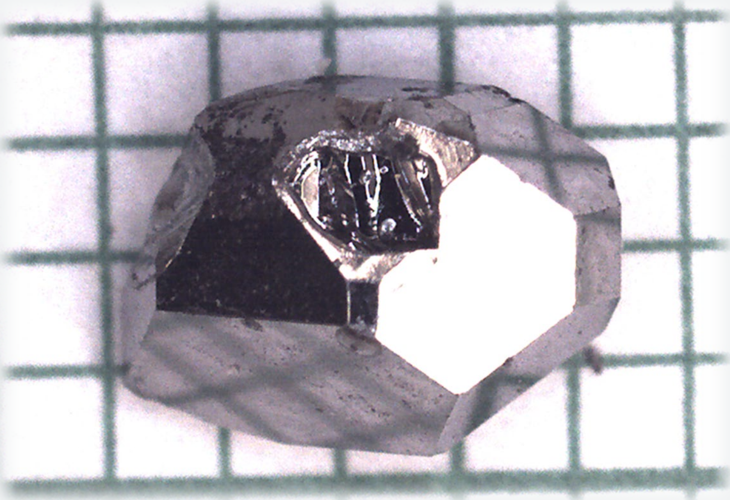
- **Enhance spin-orbit coupling**

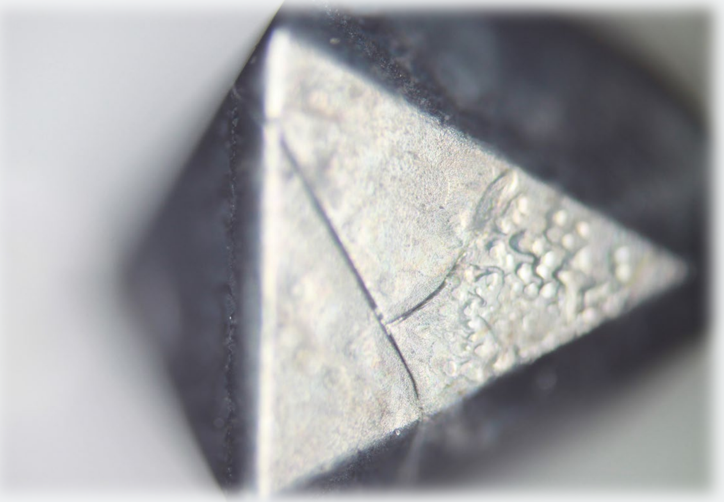
  e.g. Ru^{3+} (Z = 44) → Os^{3+} (Z = 76)

My group designs and then grows single crystals of new magnetic quantum materials





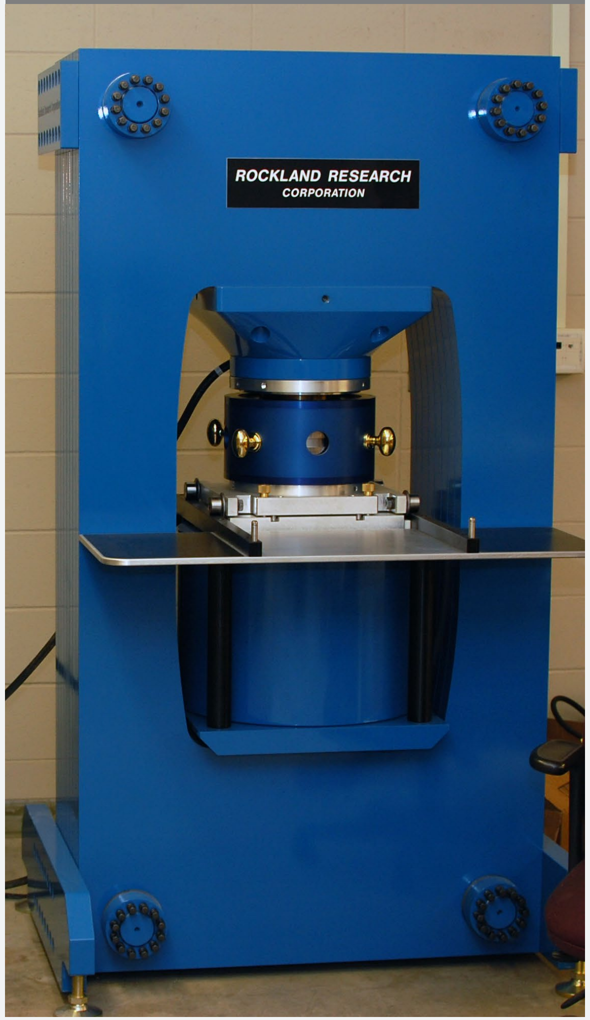


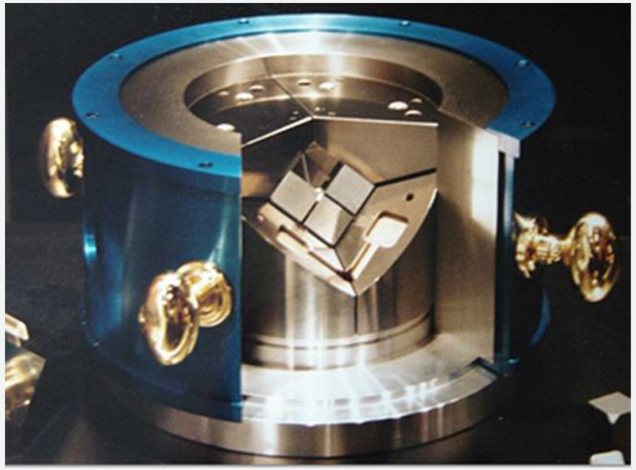


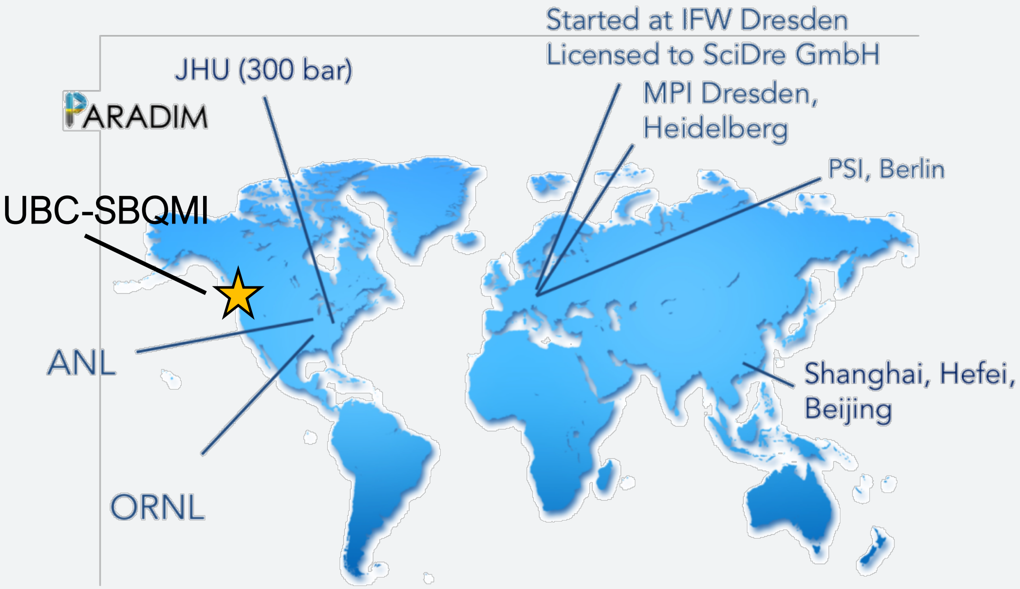
Partial image credit: Morosan Lab @ Rice

High pressure synthesis at the Quantum Matter Institute

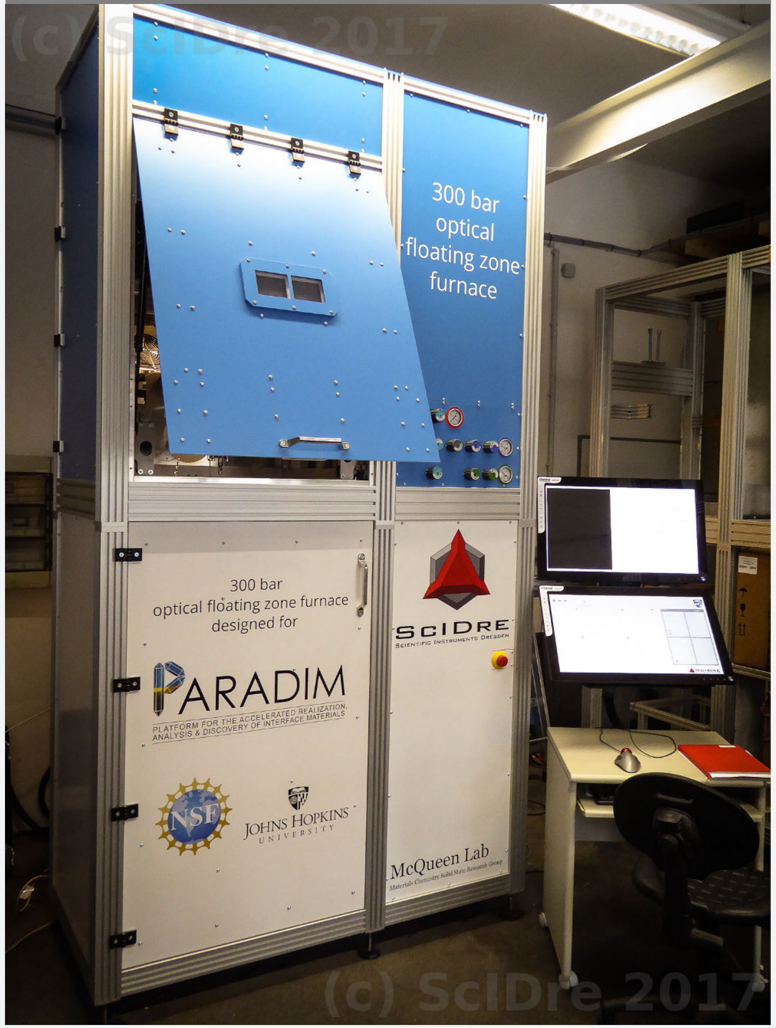
Multi-anvil apparatus – pressures up to 250 kbar





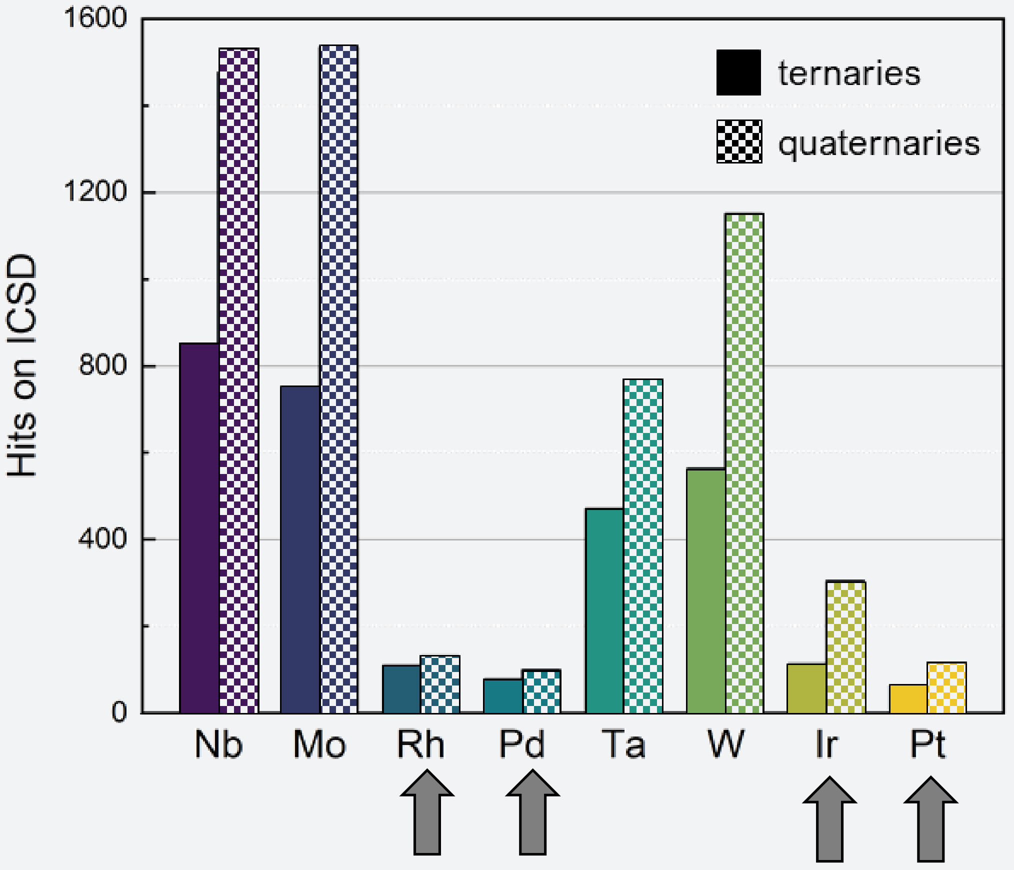


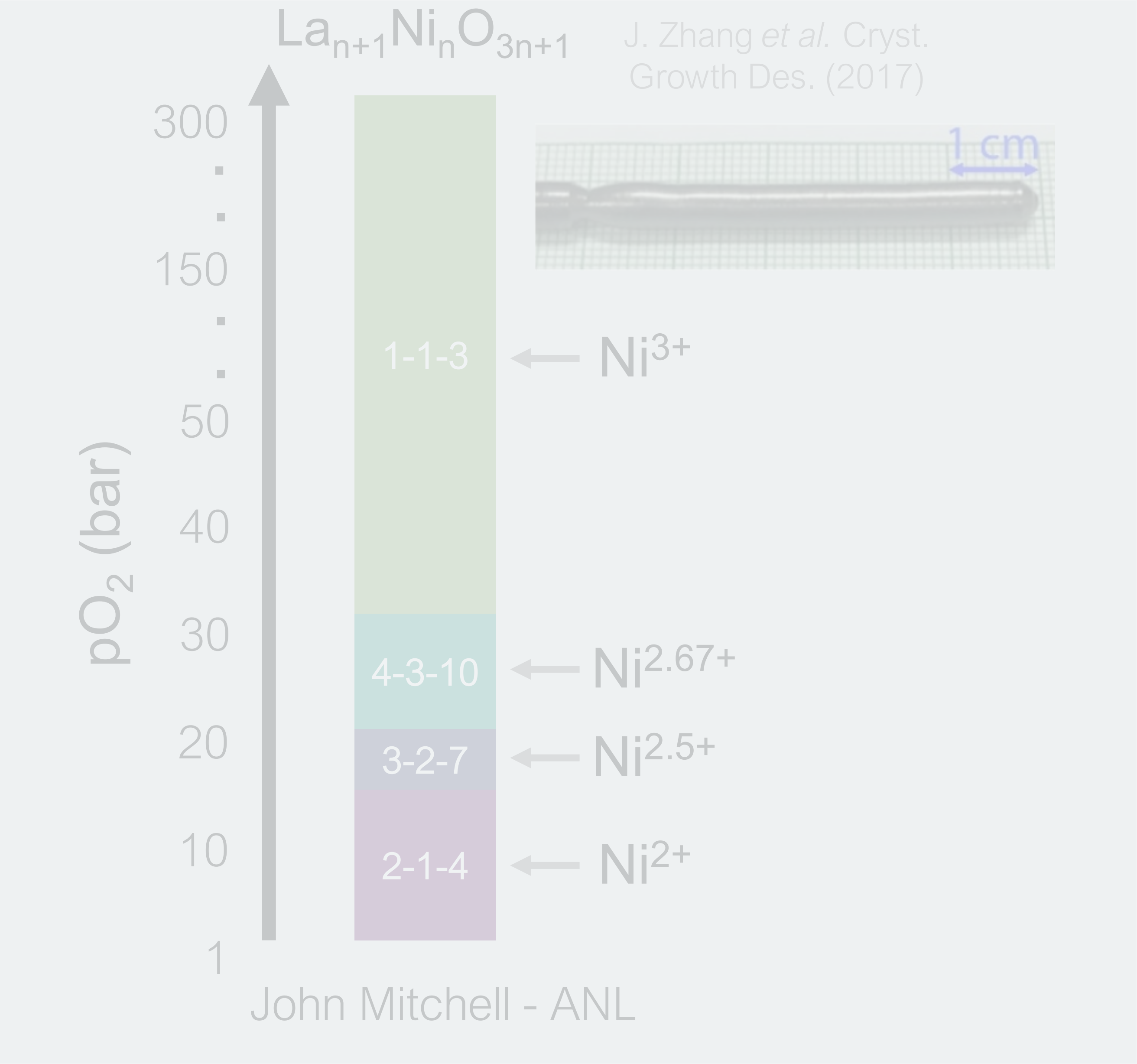
High pressure floating zone – Gas Pressures up to 300 bar



High pressure synthesis extends the materials discovery landscape

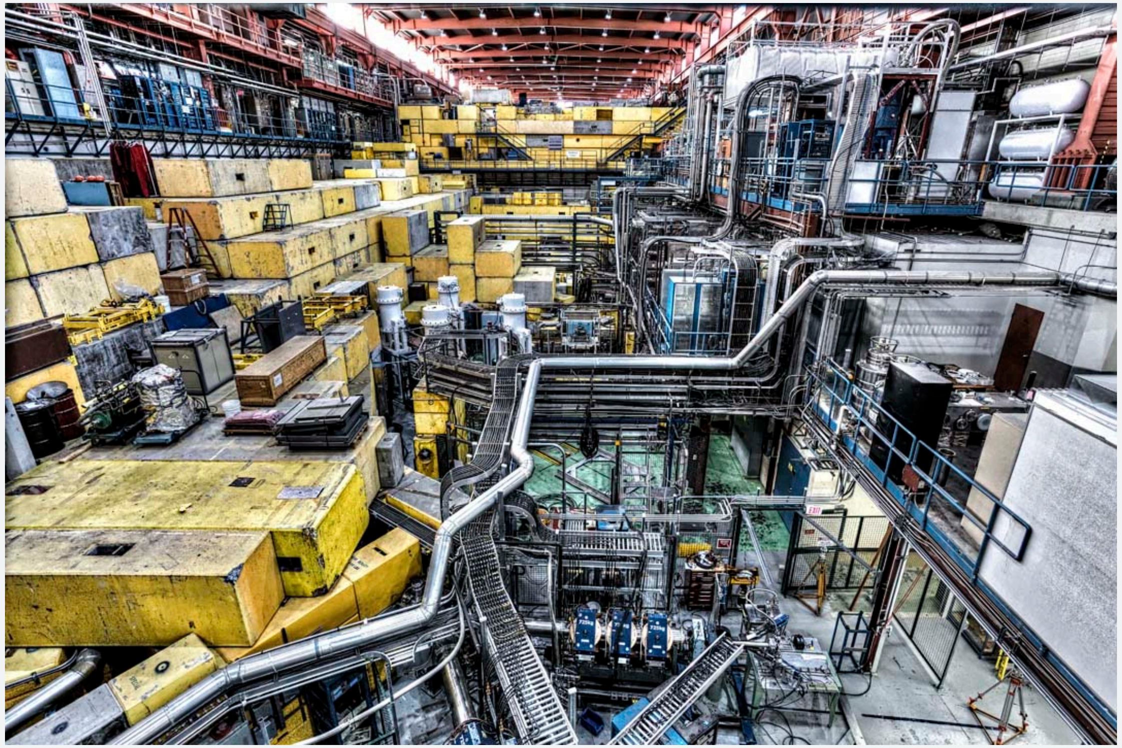
4d block:	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd
5d block:	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg

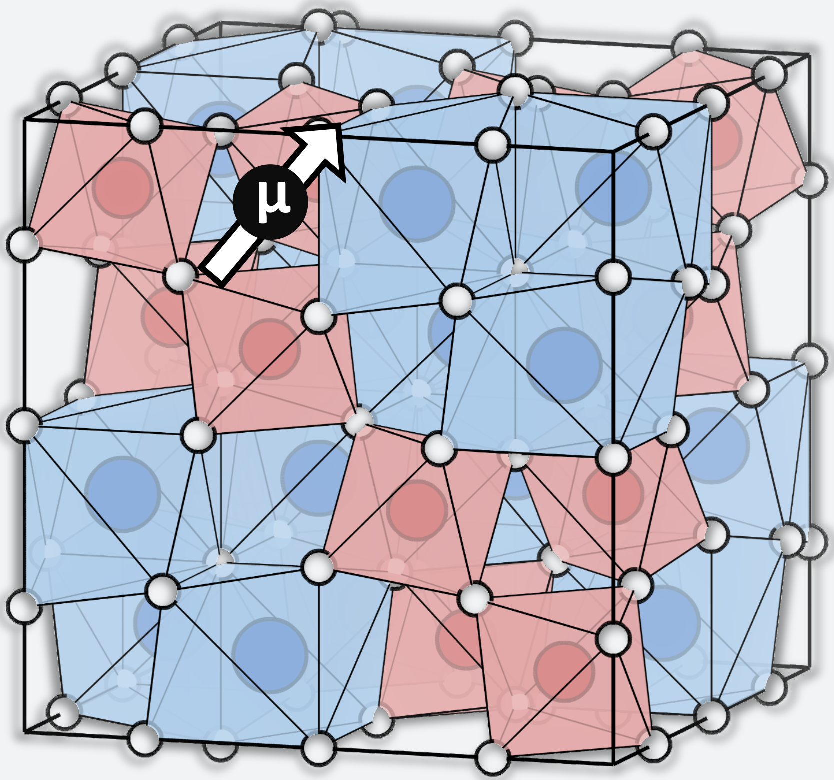




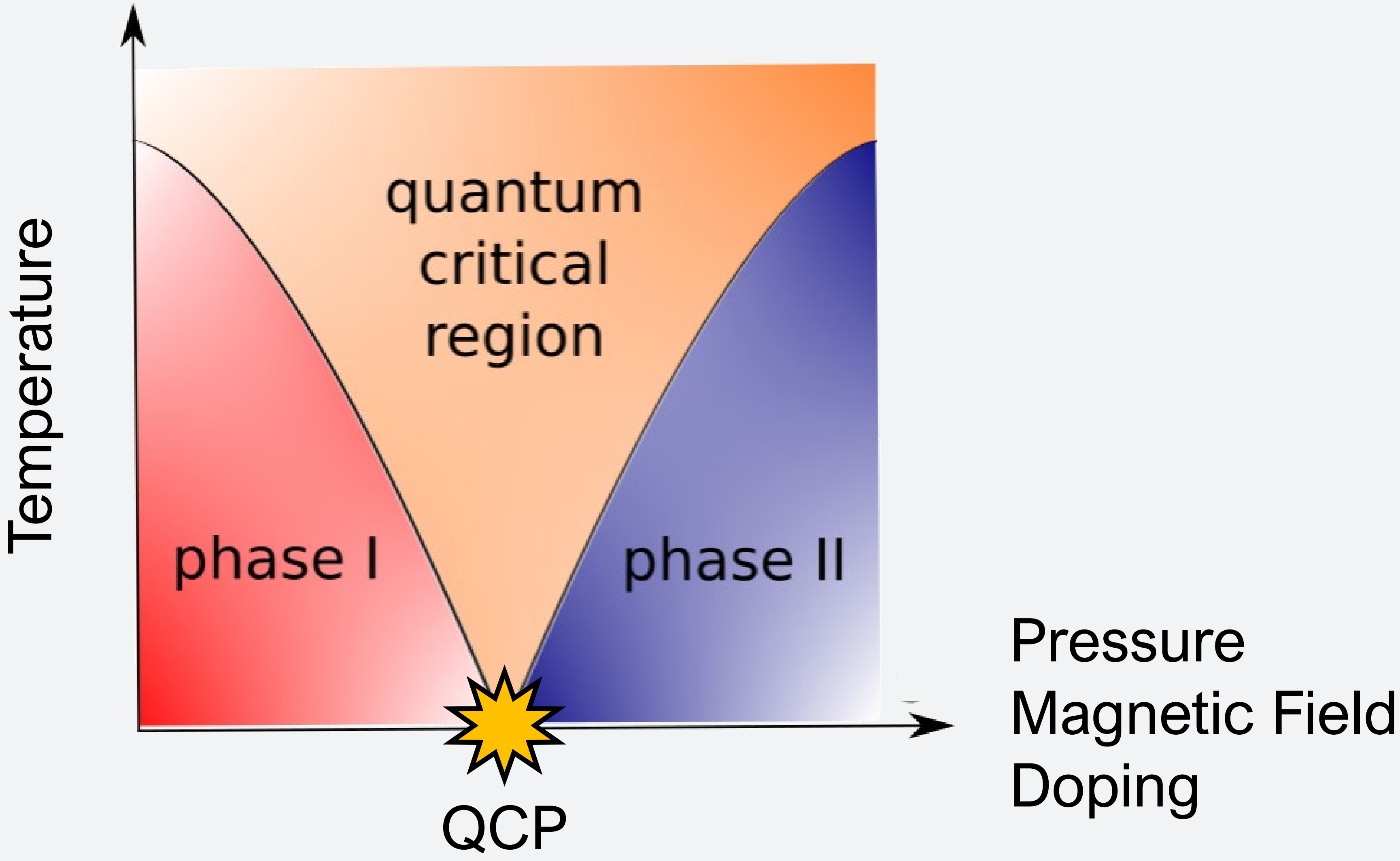
How we use muons at TRIUMF to study magnetic quantum materials

1. Highly sensitive local probe of magnetism
2. Sensitive to spin fluctuations on the time scale of MHz
3. Volume sensitive technique





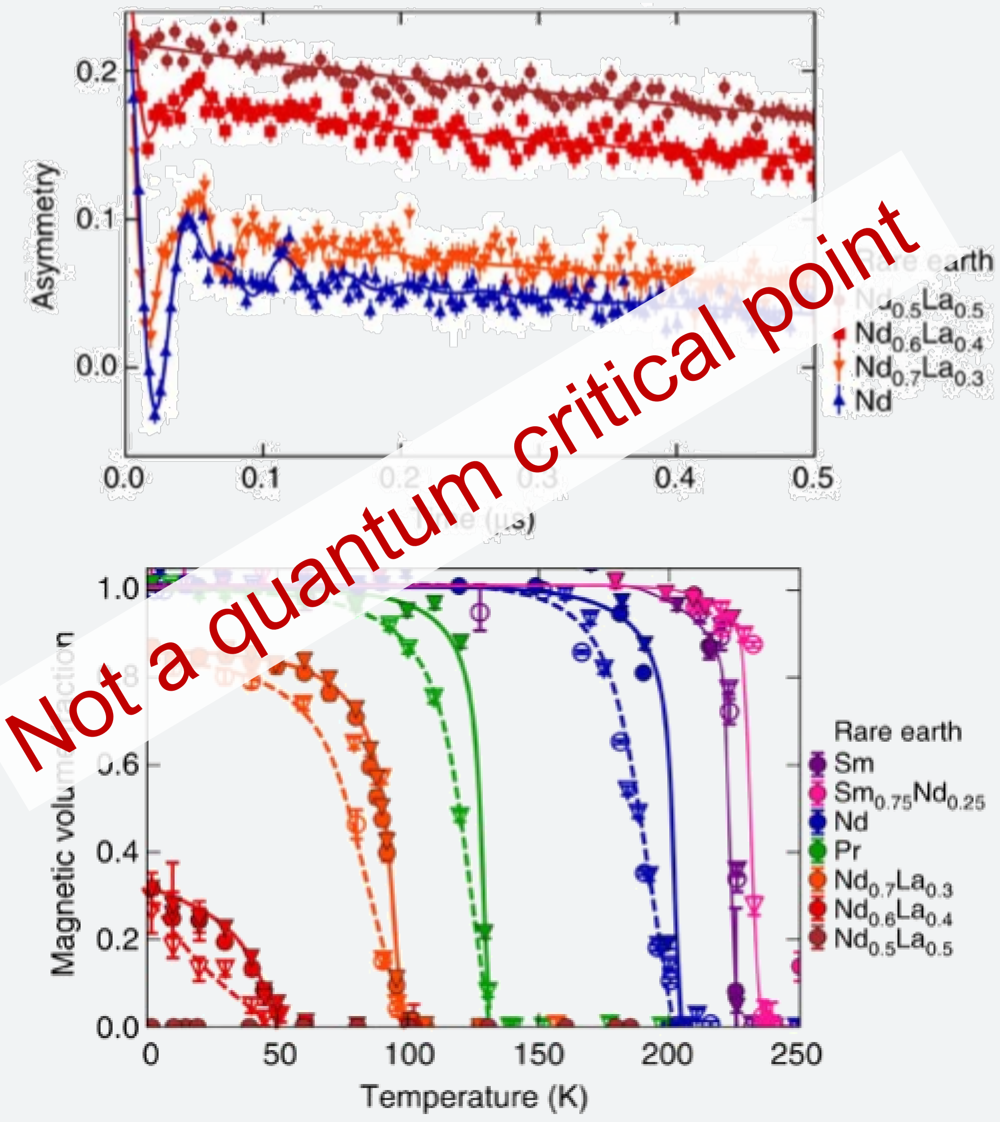
Example 1: The search for quantum critical points



Example 1: The search for quantum critical points

$RNiO_3$

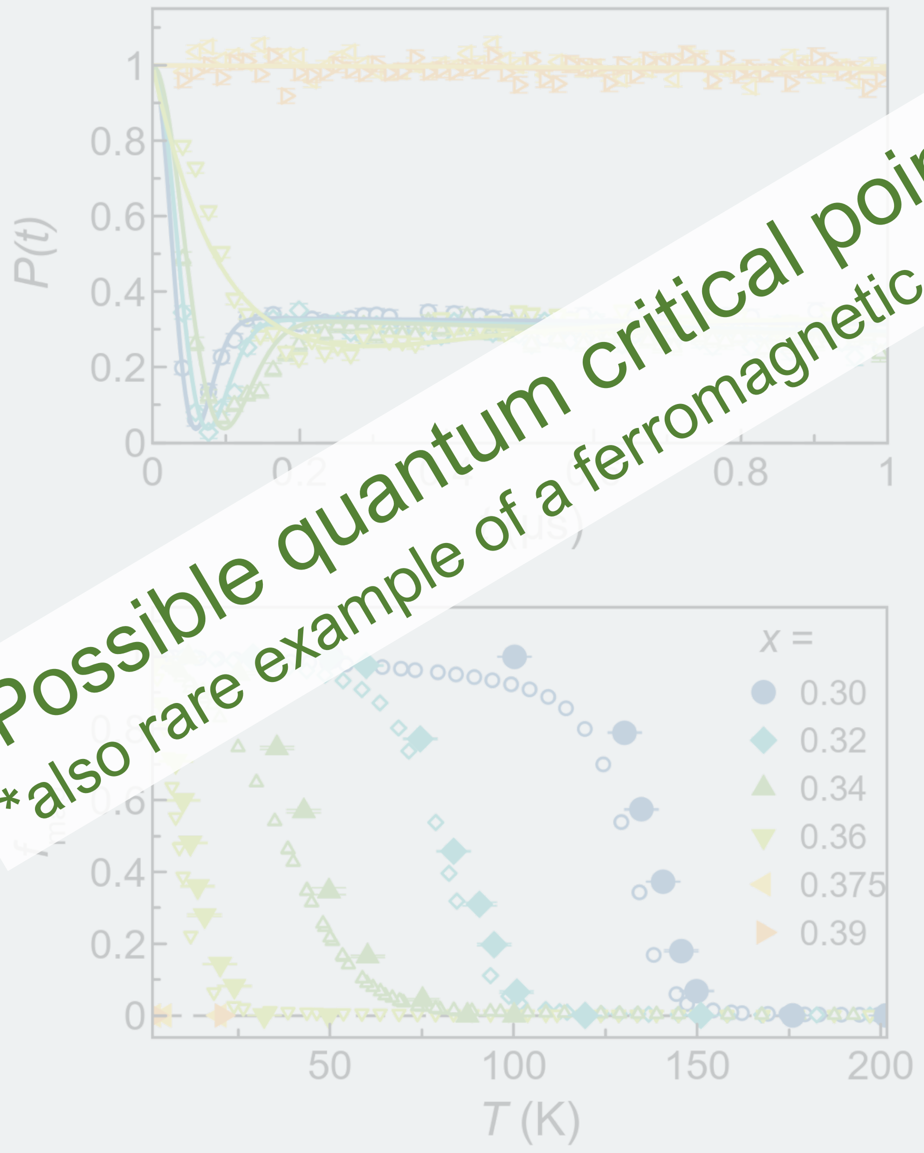
Frandsen *et al.*, Nature Communications (2016)



Not a quantum critical point

$Ni_{1-x}Rh_x$

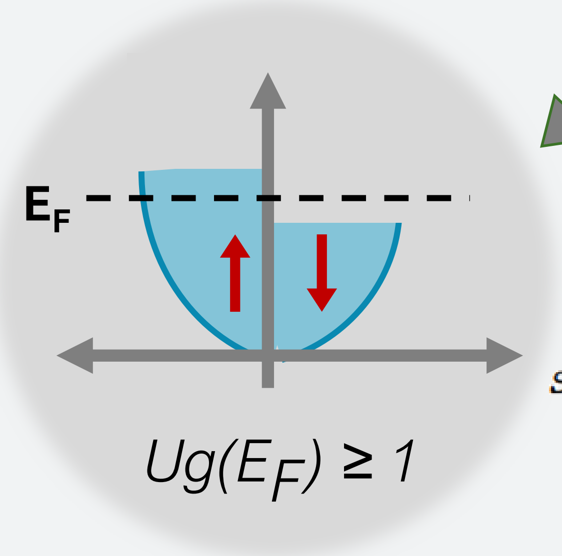
Huang et al., Physical Review Letters (2020)

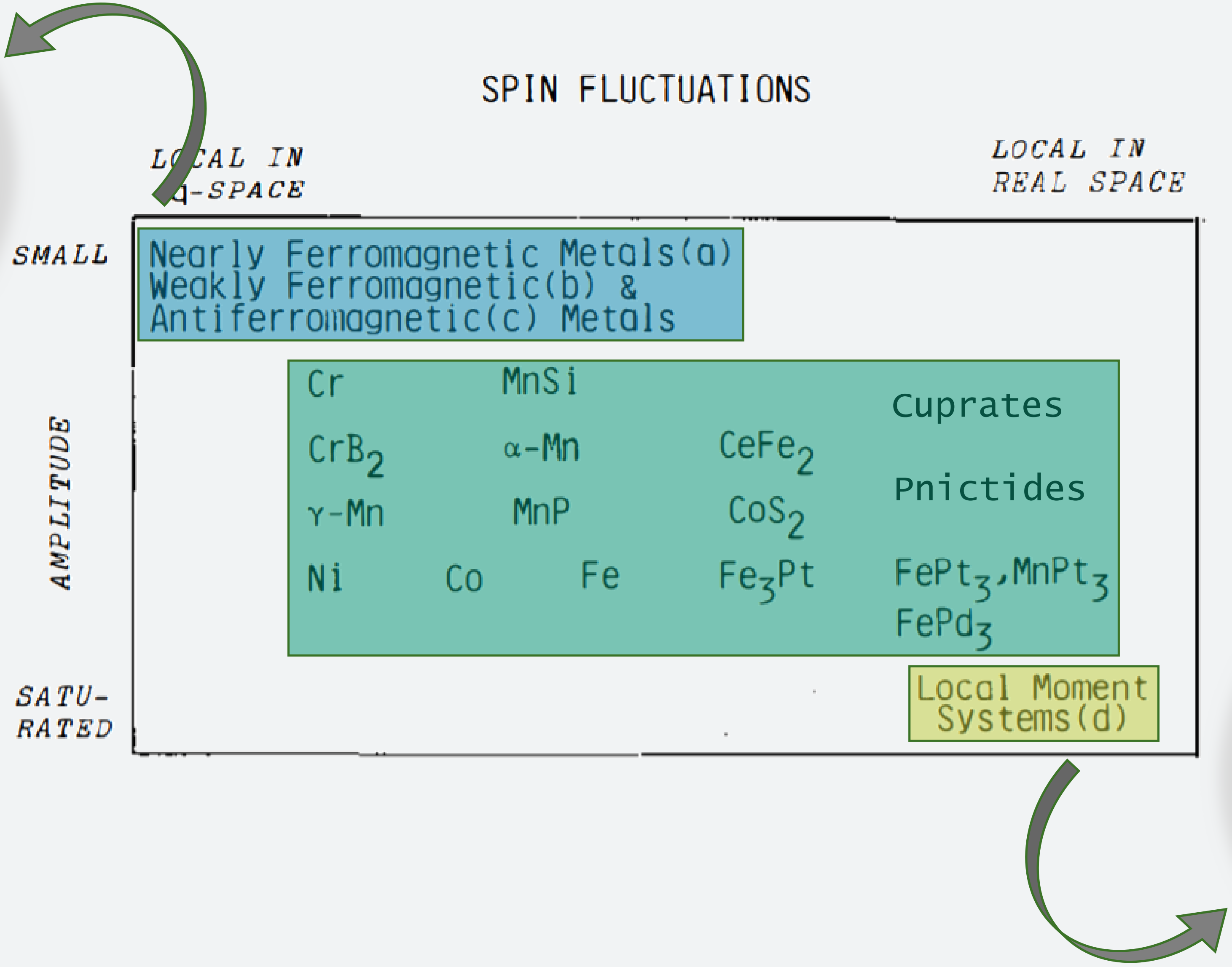


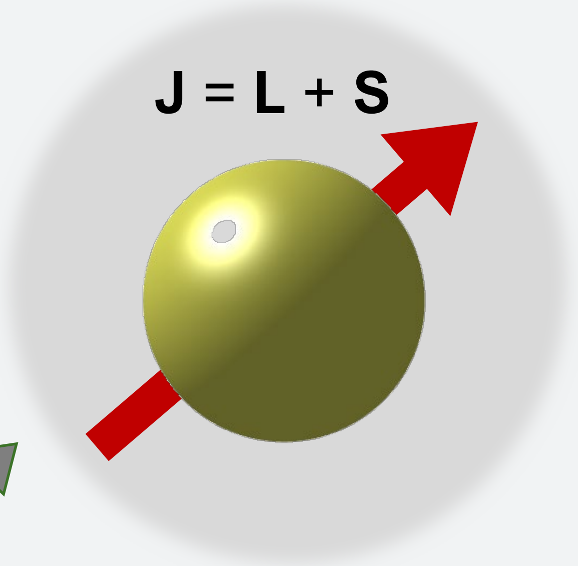
Possible quantum critical point

* also rare example of a ferromagnetic QCP

Example 2: The search for purely itinerant magnets







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

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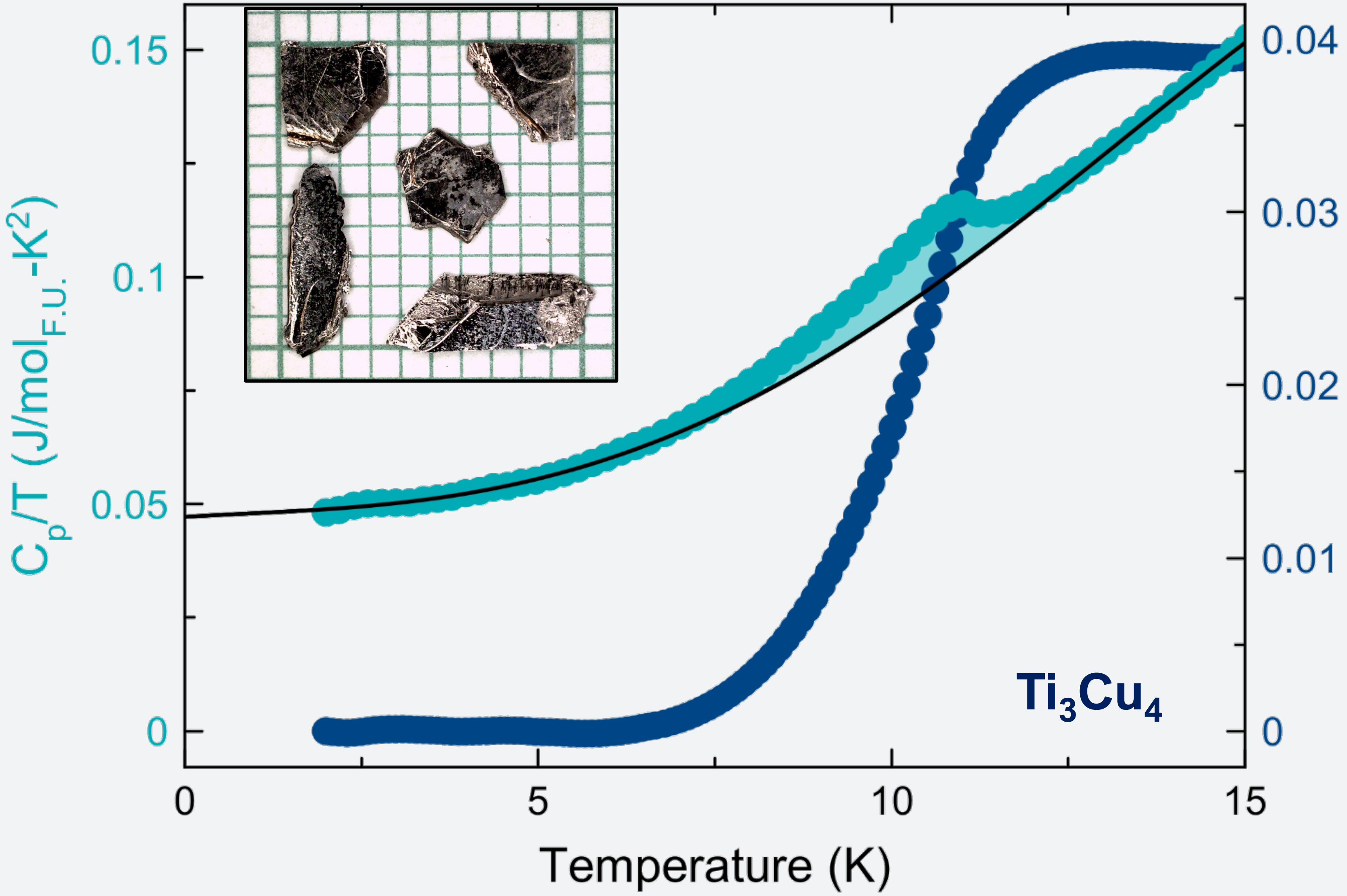

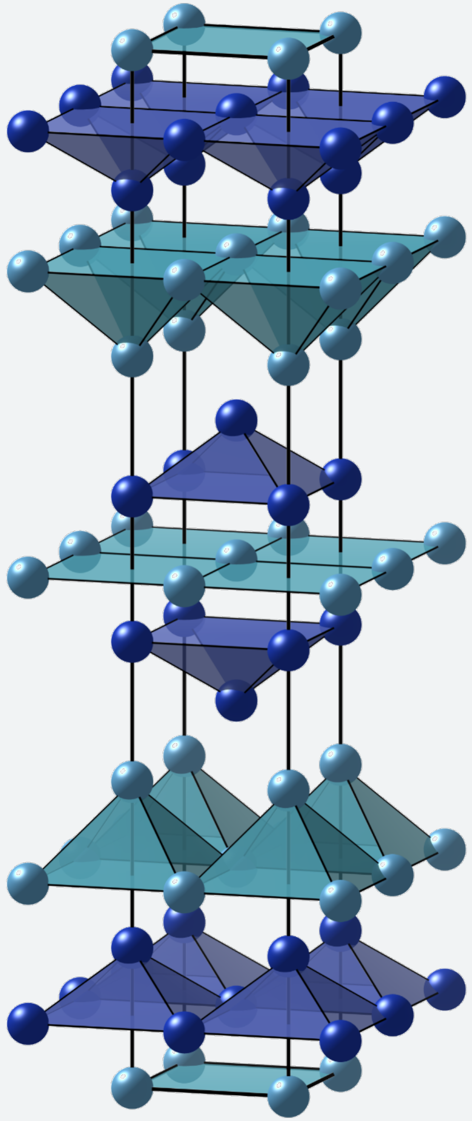

Moya *et al.*, submitted (2020)

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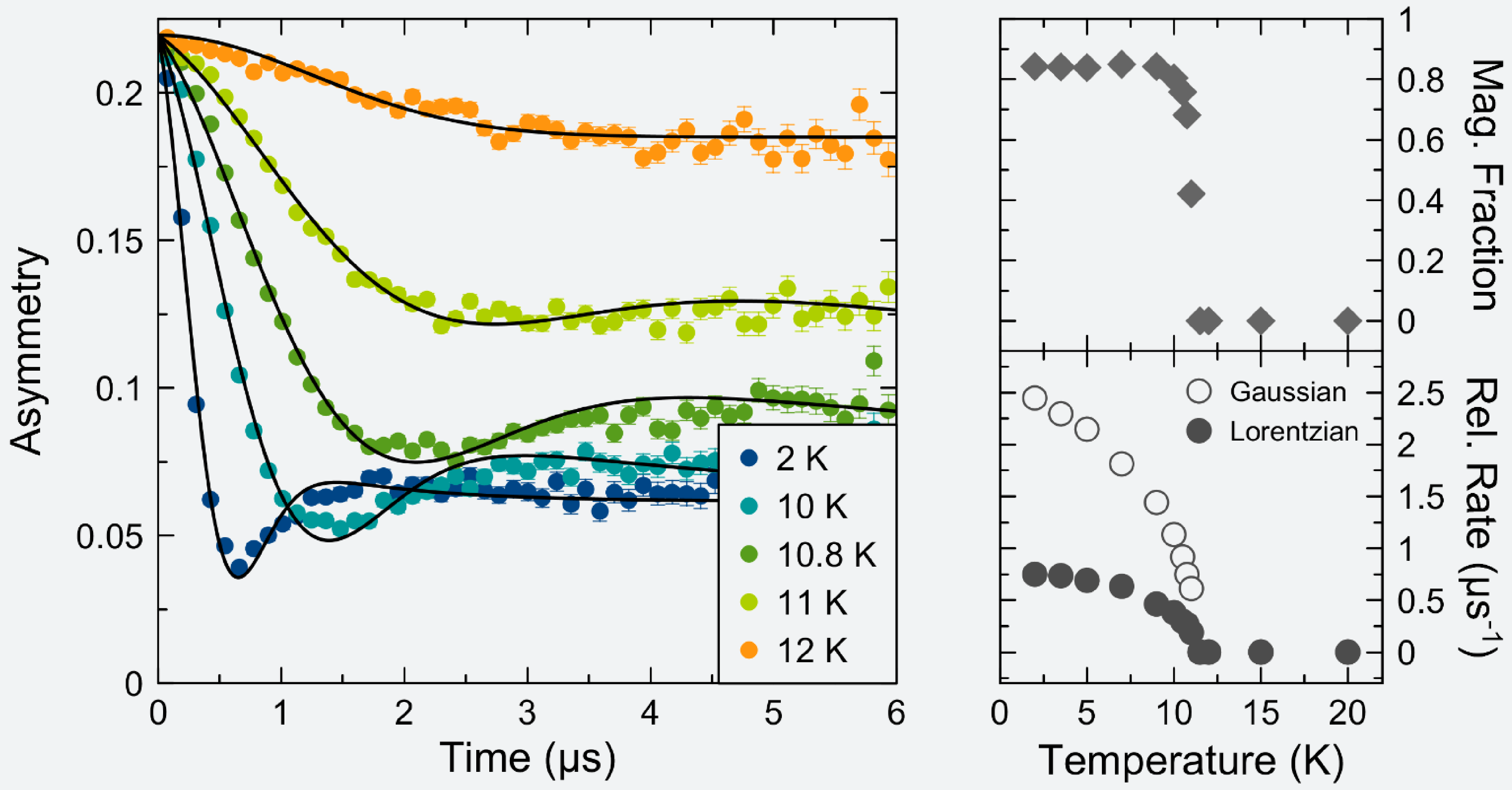

Moya *et al.*, submitted (2020)

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