Quantum Critical Scaling in a metallic Kagome system

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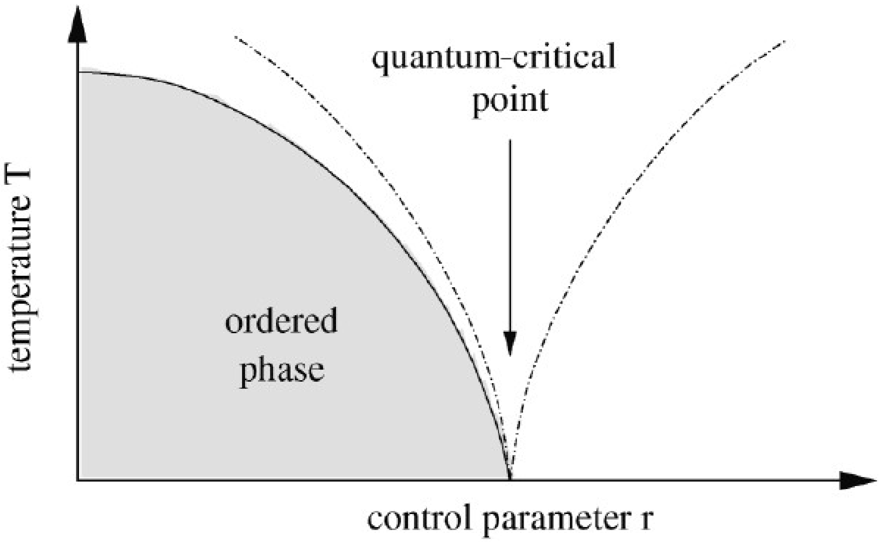
Quantum critical point



A phase transition driven by some control parameter that occurs at T = 0, is a quantum phase transition, and occurs at a quantum critical point.

Near a quantum critical point, the fluctuations are not determined by the temperature scale, and thus persist for a very large range of temperatures.

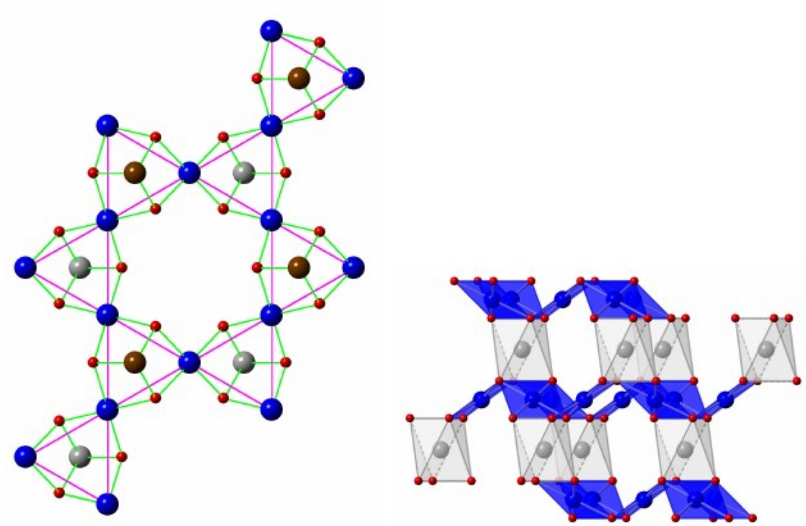
Length and time scales diverges with the tuning parameter to some critical exponent.

Kagome lattice

Kagome lattice is the 2d lattice composed of corner sharing triangles.

Famous for the possibility of of having a quantum spin liquid ground state.

Most well-known example is Herbertsmithite

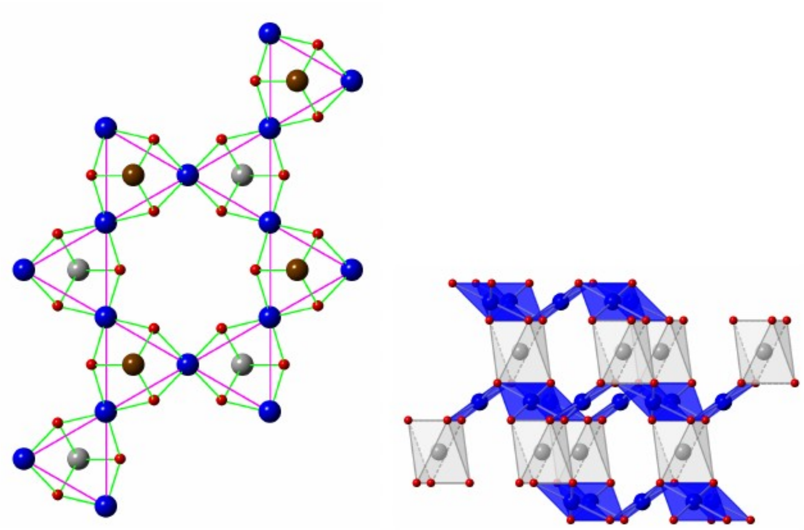


Structure of Herbertsmithite
Shores et al, (2005)

Herbertsmithite

Herbertsmithite, $ZnCu_3(OH)_6Cl_2$, has quantum critical behavior seen in the universal scaling of the magnetic susceptibility.

Measured both via magnetometer



Structure of Herbertsmithite
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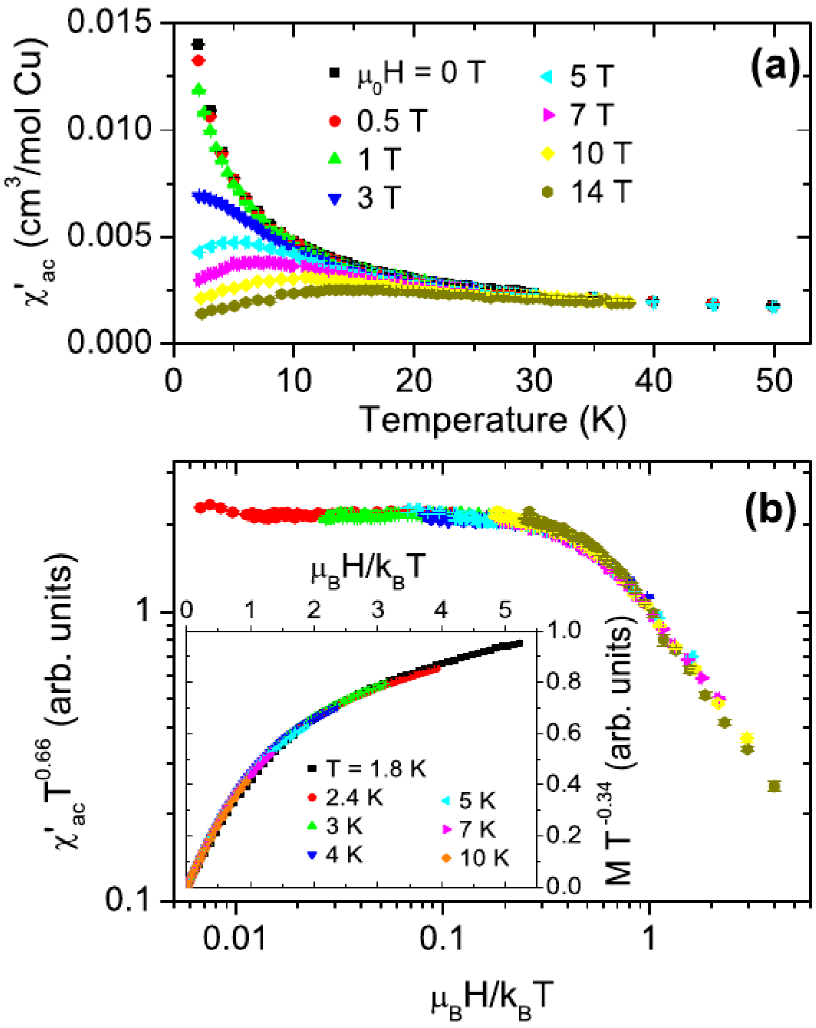
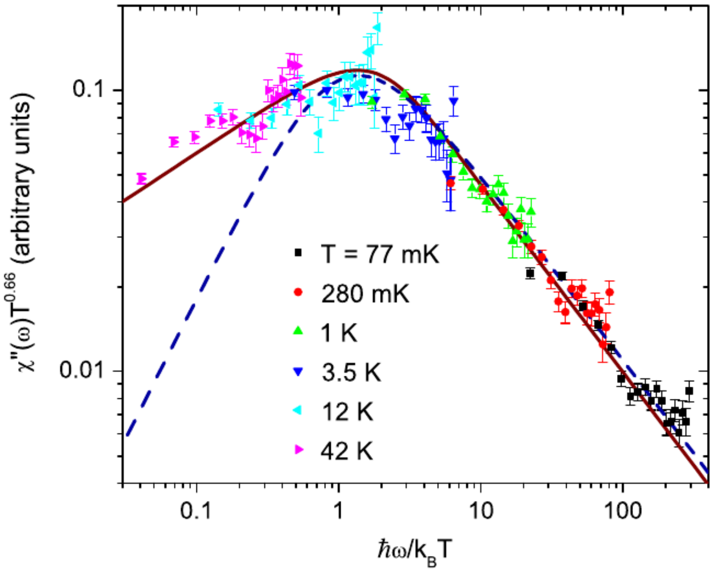


Helton et al, PRL 104 147201

Herbertsmithite

Herbertsmithite has quantum critical behavior seen in the universal scaling of the magnetic susceptibility.

And inelastic neutron scattering



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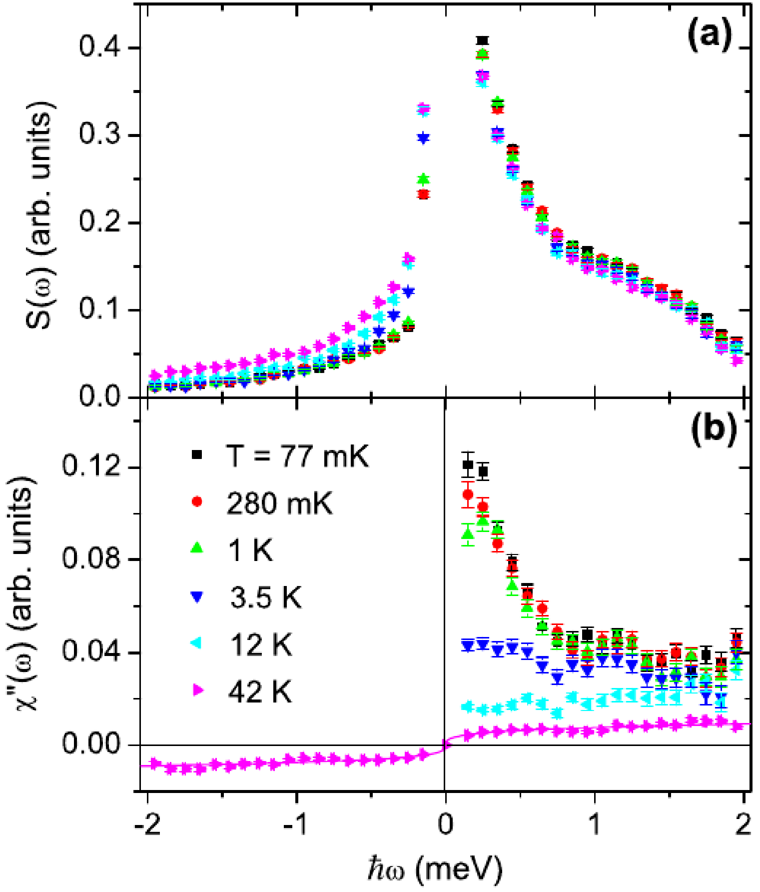
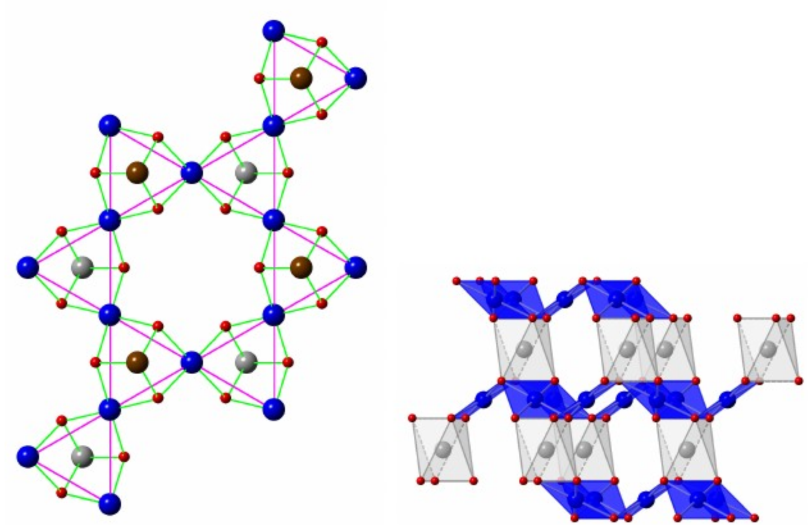


Helton et al, PRL 104 147201

Beyond Herbertsmithite

Motivated to find Heisenberg antiferromagnetic materials without the disorder of the intermediate layers.

Quantum spin liquids are expected to be superconductors when doped. A metallic system is easier to dope and modify the conduction band.



Structure of Herbertsmithite

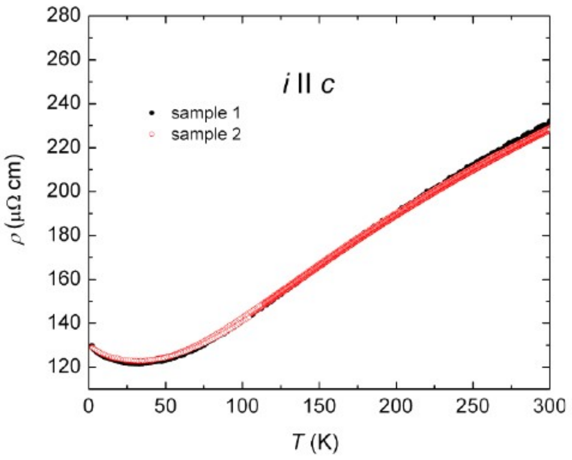
Shores et al, (2005)

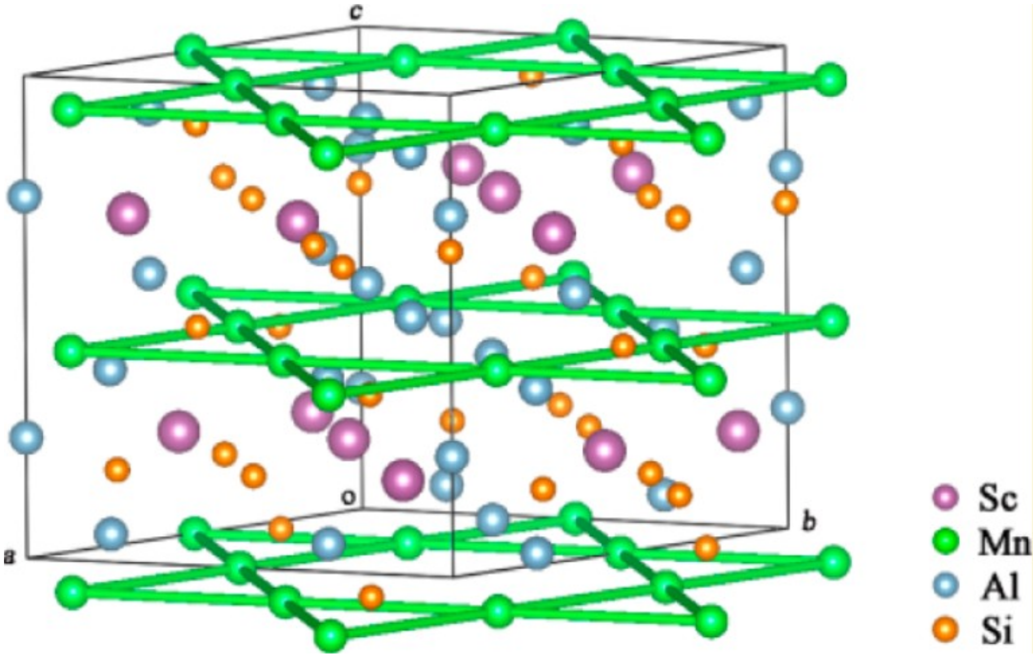
$Sc_3Mn_3Si_5Al_7$ (SMAS)

Metallic material with Mn atoms on Kagome planes.

XRD measurements showed no signs of site disorder.

Hua He *et al.*, Inorg. Chem. **53** 9115-9121

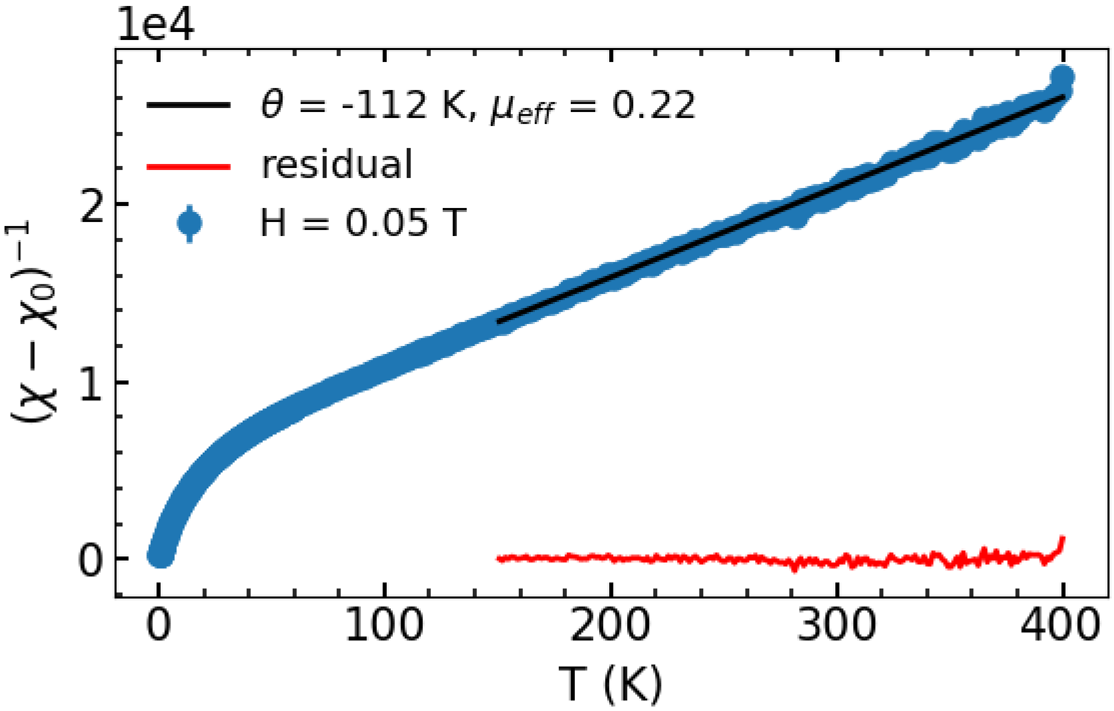




Magnetic susceptibility

With the Pauli paramagnetic component found we use the remainder to find an approximate Curie-Weiss temperature and moment size.

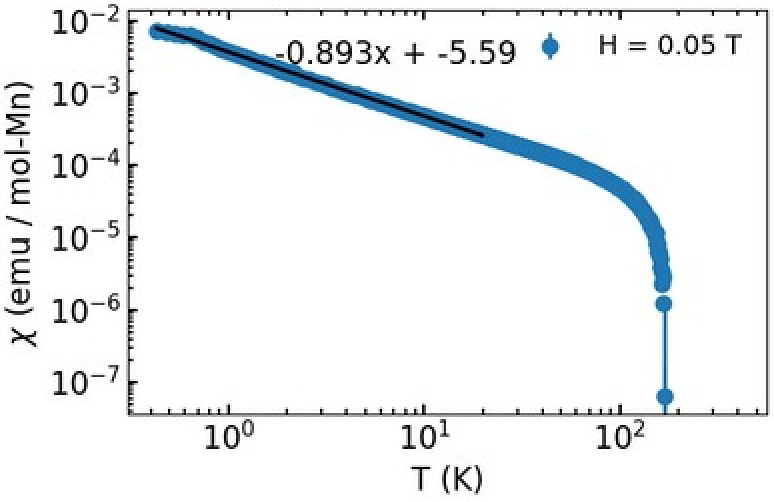
The Mn moment is highly renormalized to be only 0.22 μ_B



Magnetic susceptibility

Low temperature part of the susceptibility appears to follow a power law.

A sign of critical behavior.

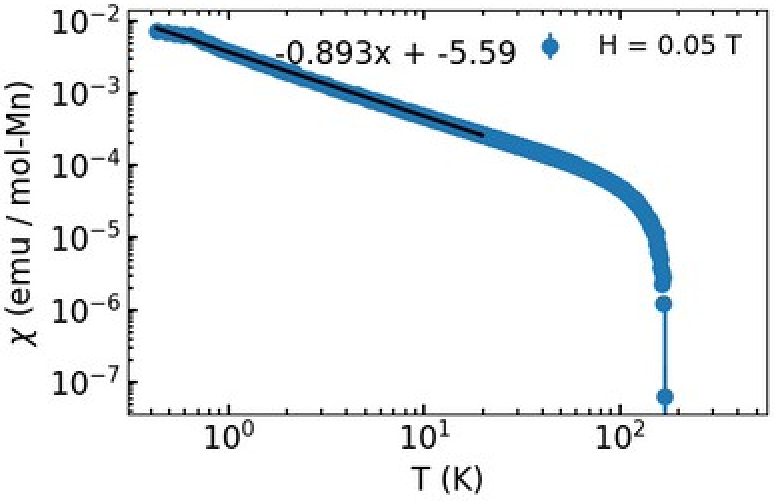


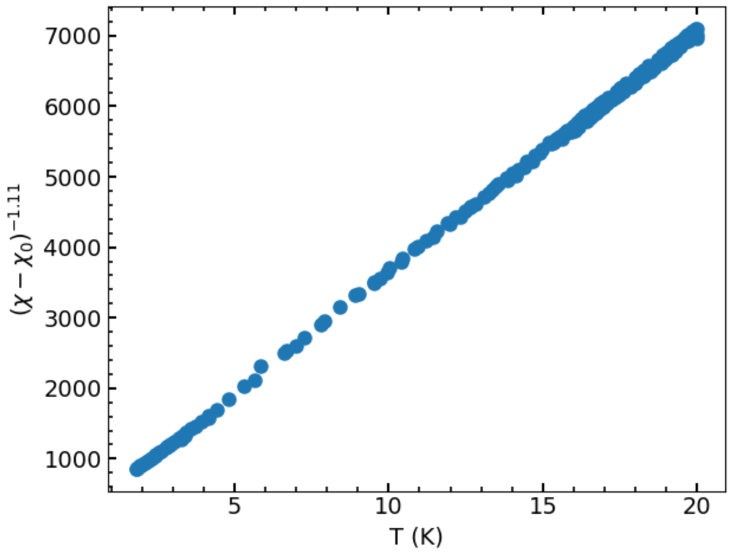
Magnetic susceptibility

Low temperature part of the susceptibility appears to follow a power law.

A sign of critical behavior.

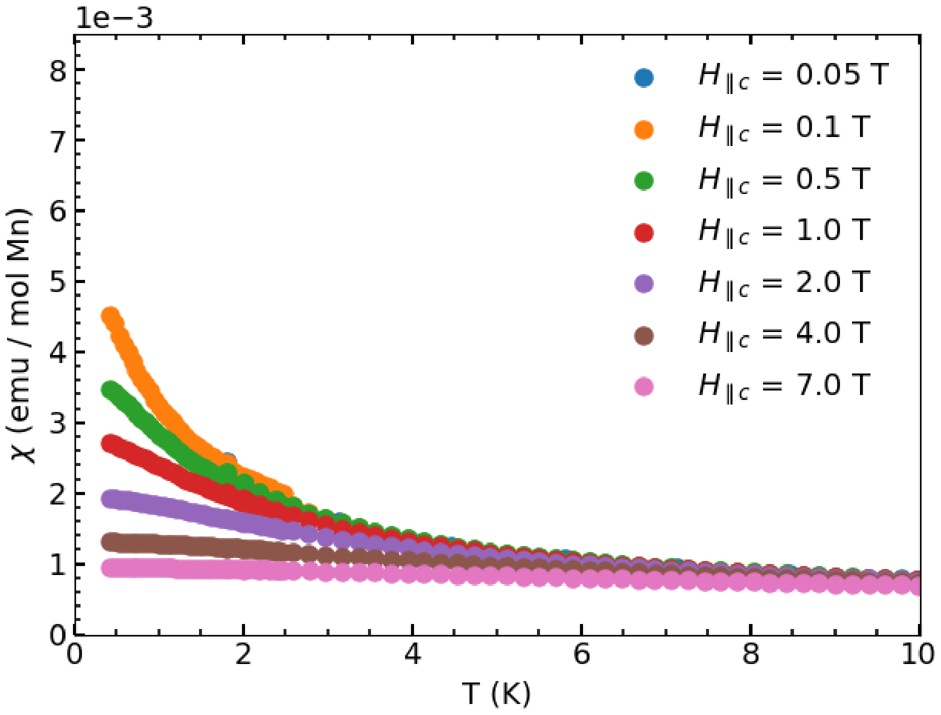
Indeed plotting the inverse susceptibility to the – 0.89^{-1} = -1.11 power results in a straight line.

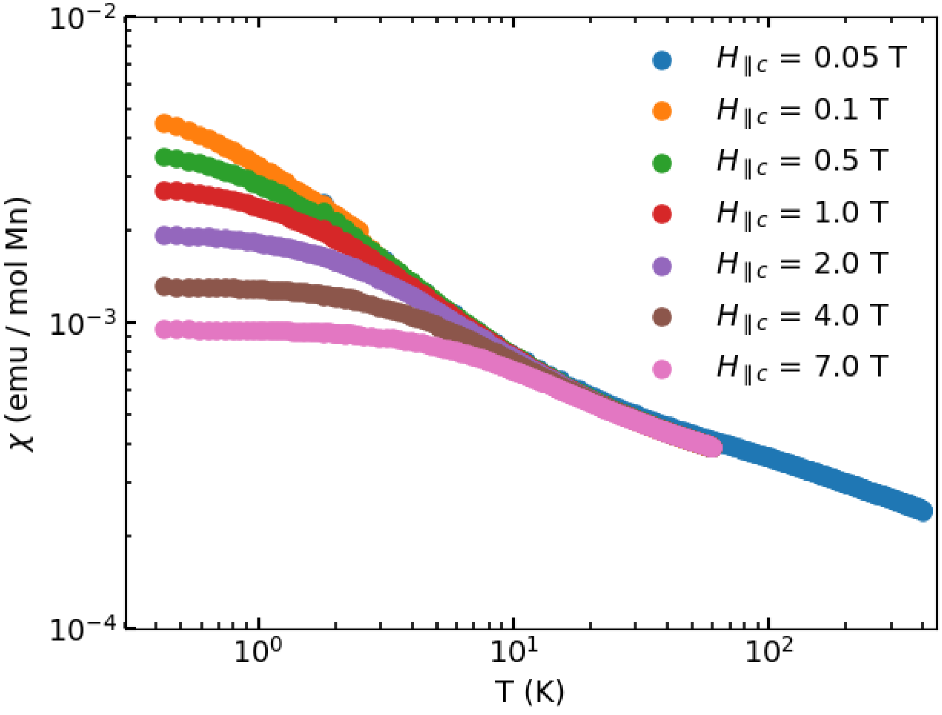




Magnetic susceptibility

As a function of applied field we see that there is a decrease in susceptibility at increased field.



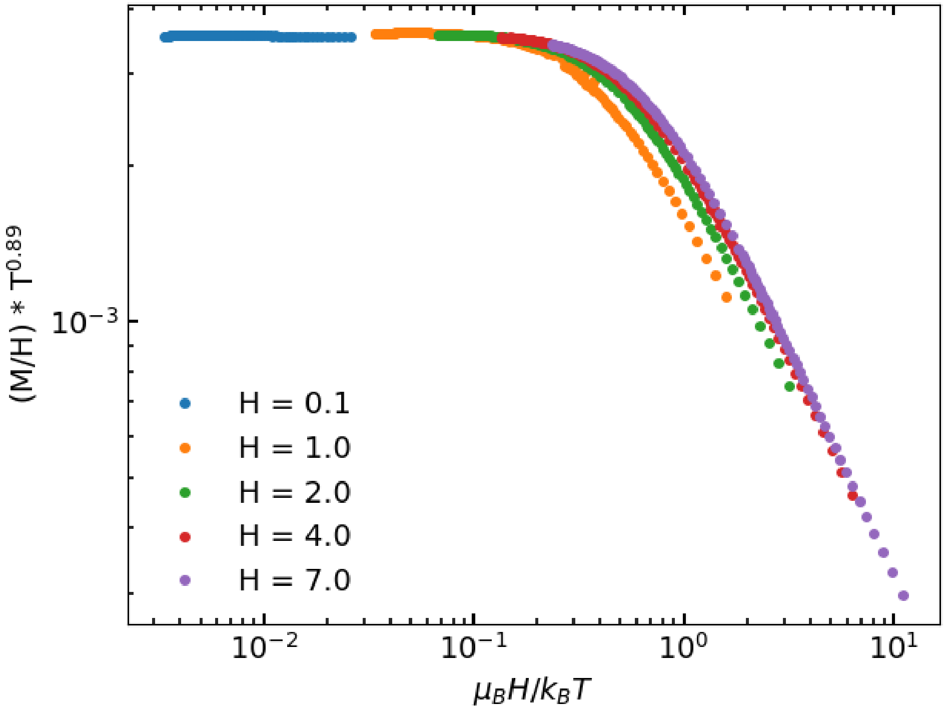


Scaling of χ

Fitting scaling parameters was done testing the overlap between field curves.

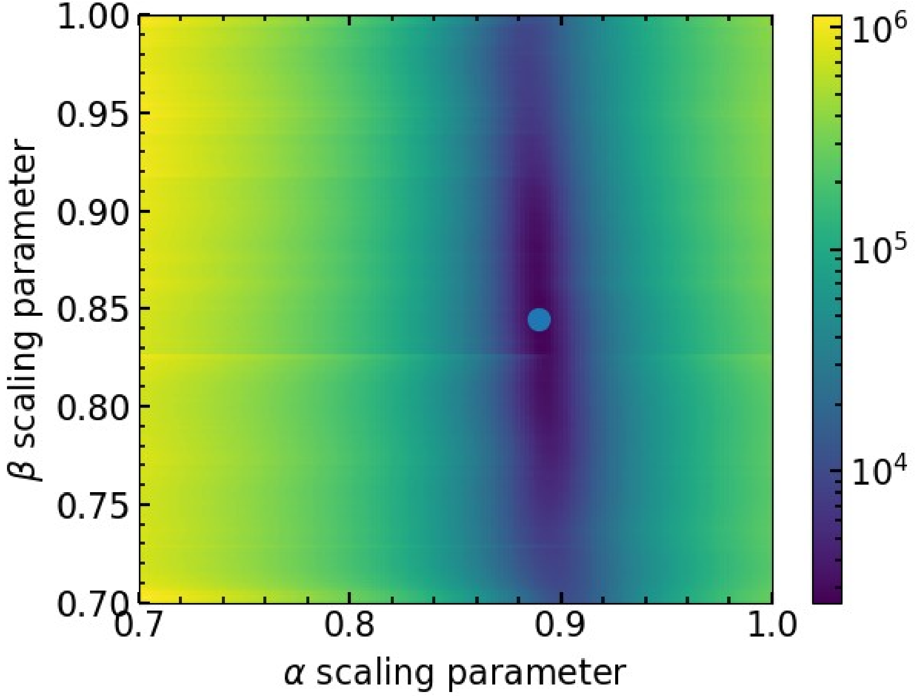
A single scaling parameter, like Herbertsmithite is not enough. We need scaling on the x-axis as well.

Data from T = [0.4,20] K

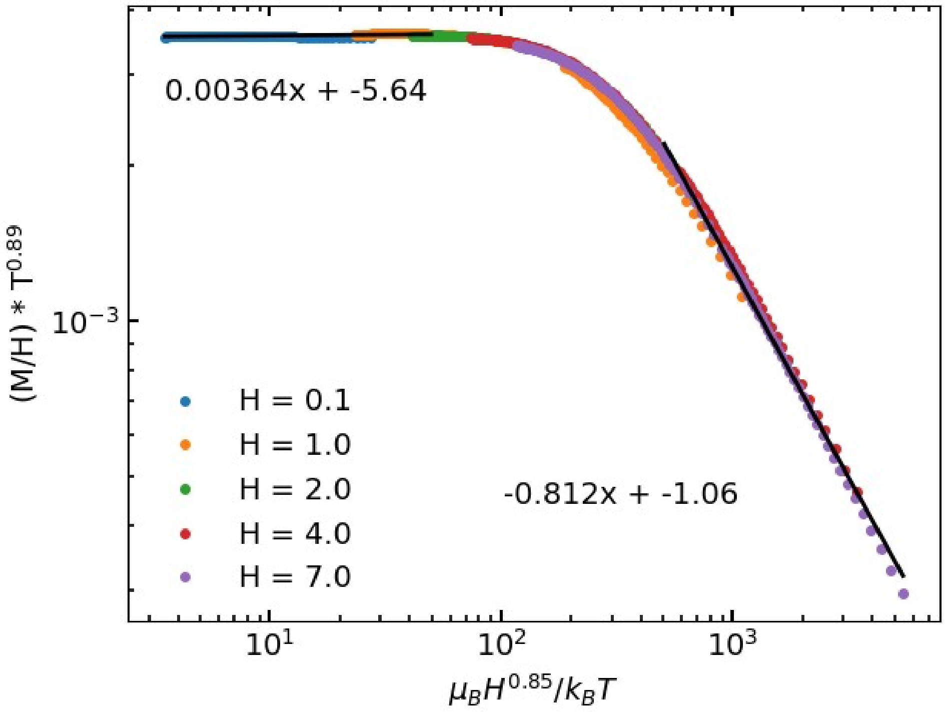


Scaling of χ

Fitting scaling parameters was done testing the overlap between field curves with all combinations of the scaling parameters.



Data from T = [0.4,20] K

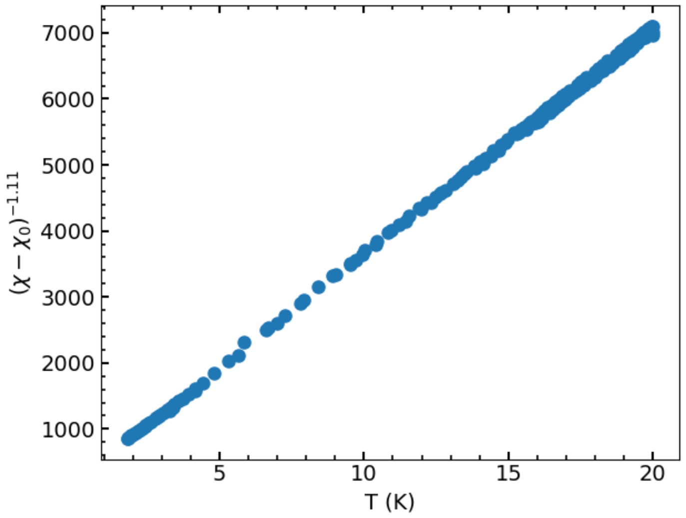


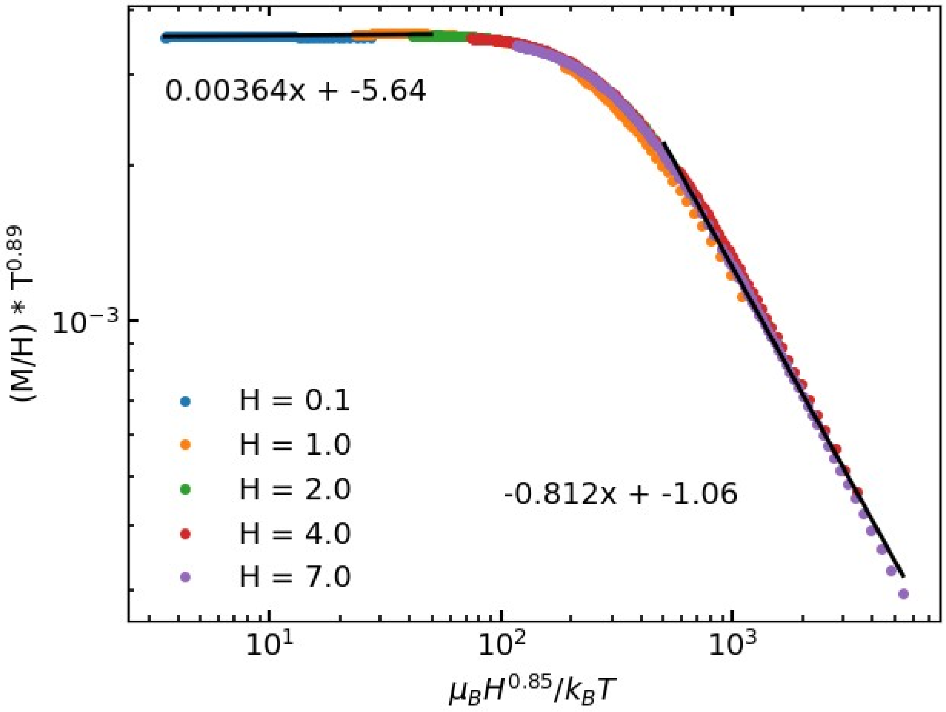
Scaling of χ

Indeed the scaling parameters of ~0.89 matches what was found from previous looks at the data at low H and T.

Data from T = [0.4,20] K

$-0.89^{-1} = -1.11$



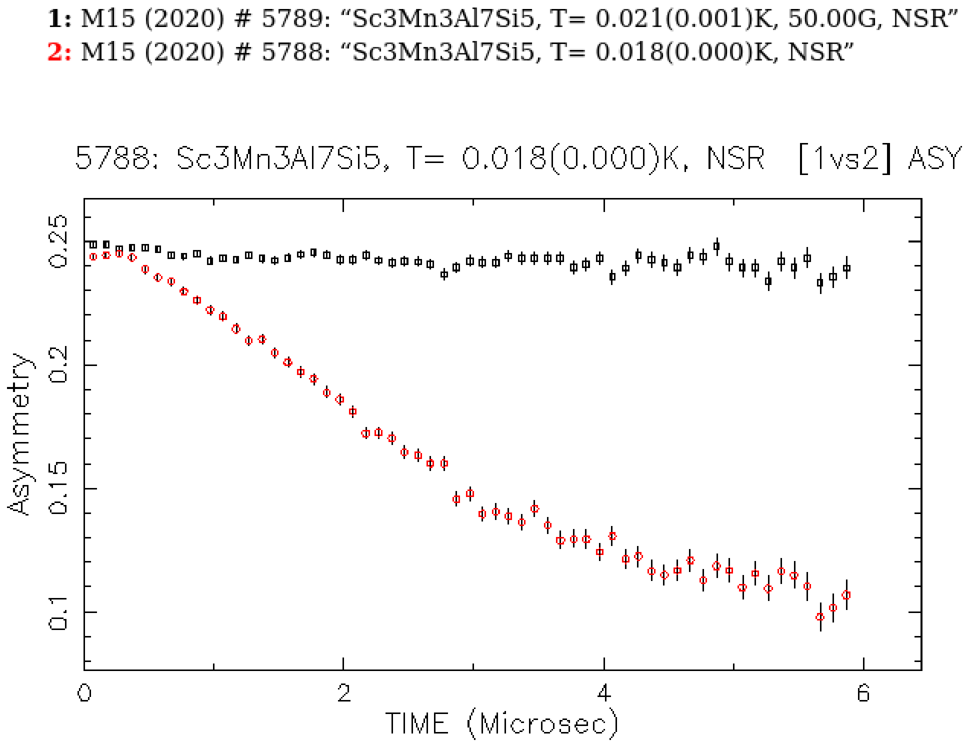


TRIUMF ZF, LF

Zero field measurements show a slow relaxation. However, this is associated with the nuclear dipole moment.

A longitudinal field (LF = 50 G) is able to decouple it completely.

Even at T < 0.03 K, there is no significant relaxation, and no oscillation.

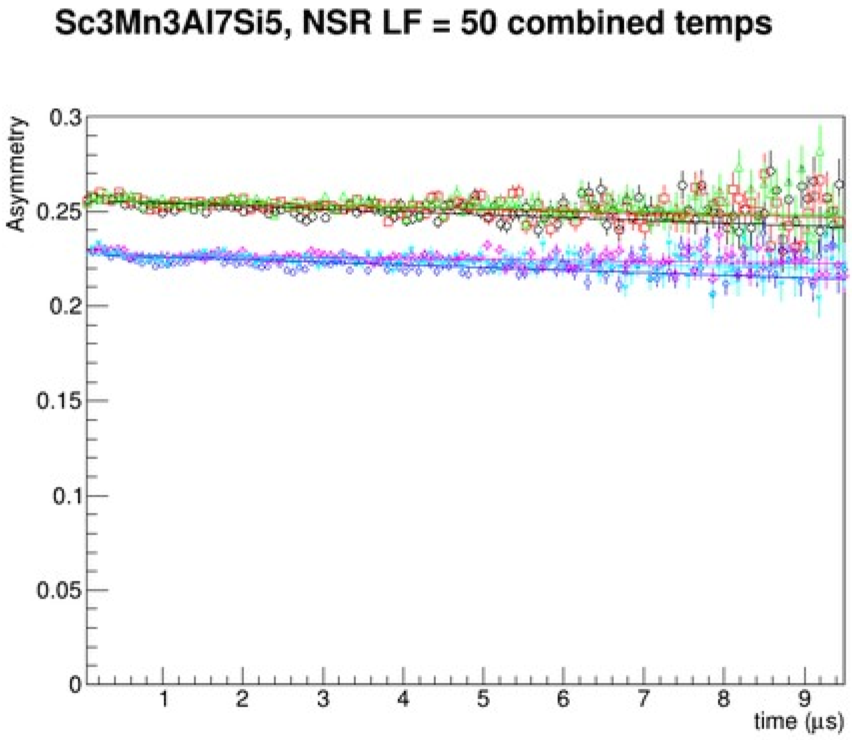


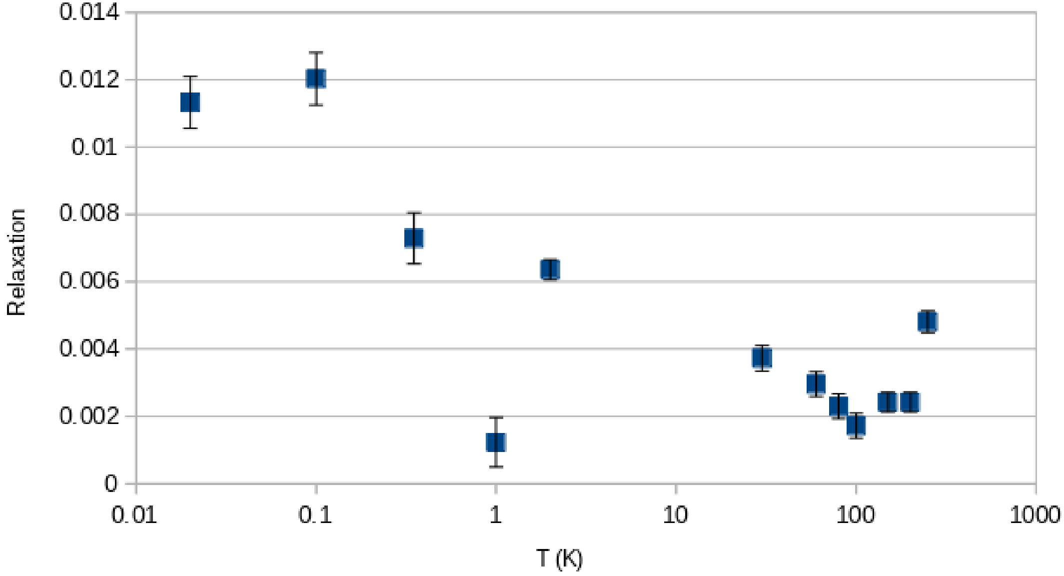
Relaxation

The remaining relaxation that does not decouple at LF = 50G can be fit.

For a slight temperature dependence on the relaxation

Likely fluctuation rates are beyond the limit for μSR $\tau < 10^{-12}$ s





Conclusion

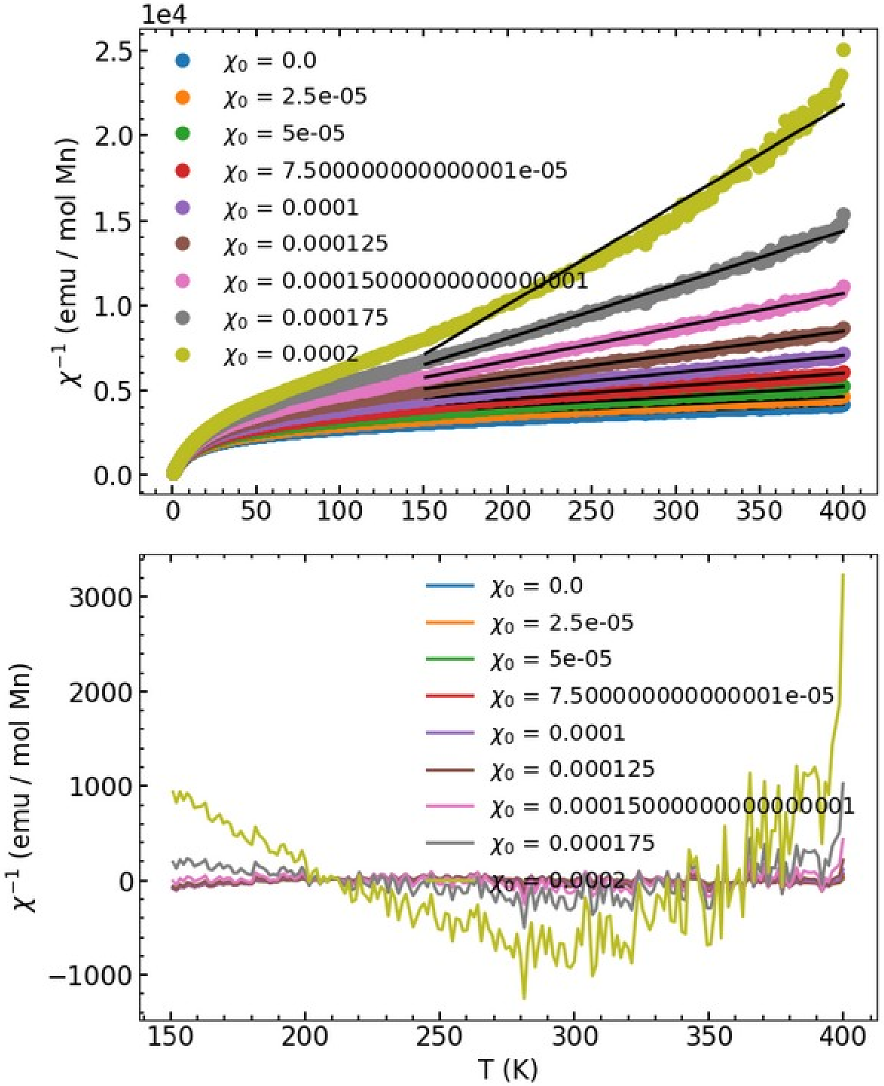
- $Sc_3Mn_3Al_7Si_5$ is shown to be near a quantum critical point
- Magnetic scaling similar to Herbertsmithite
- Magnetic fluctuations are beyond the range that muons are susceptible to.

Magnetic susceptibility

First we need to find the contribution to the susceptibility from Pauli paramagnetism.

This gives a constant offset to the susceptibility.

This is done by looking at the high temperature part of the susceptibility and subtracting constants until we find the best fit to a line.

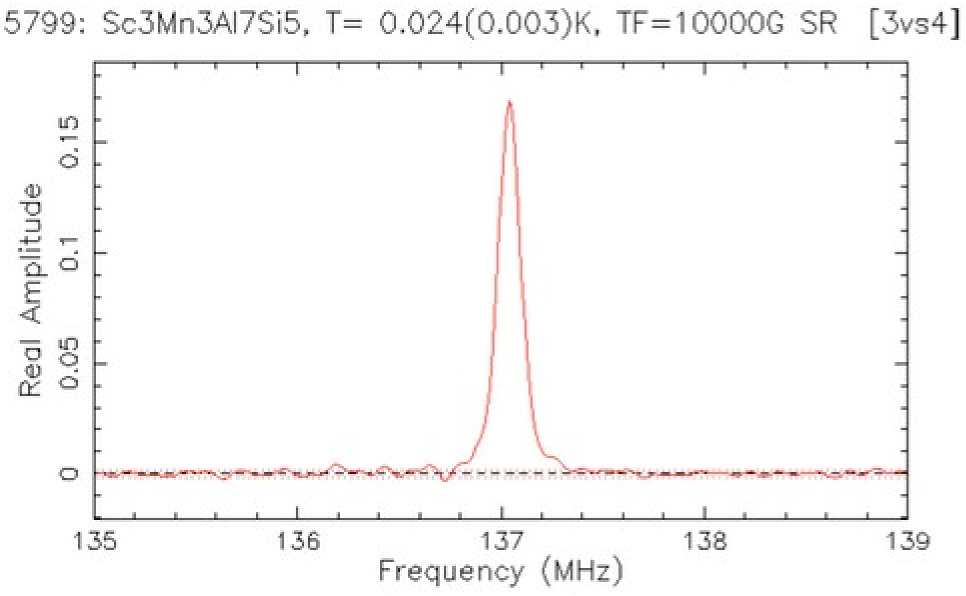


Knight shift

Applying a strong transverse field, we can measure the precessions frequency of the sample and compare to the silver from the sample holder.

The different field strength in the silver and sample should lead to a peak splitting. However we see no such splitting.

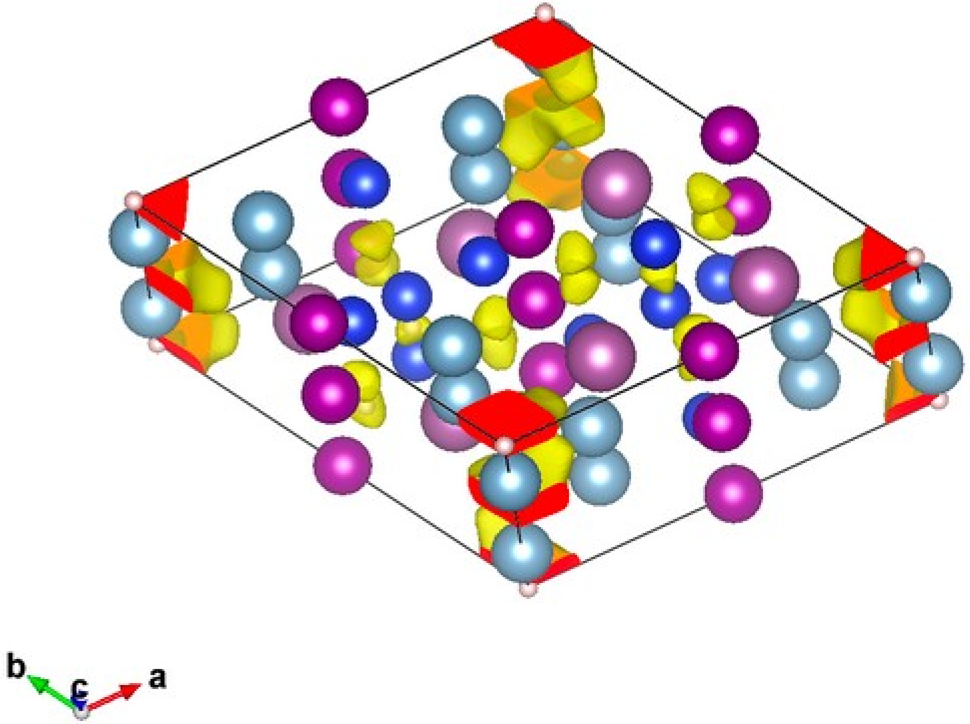
No such splitting was observed, however considering the small magnetization of the sample, the expected shift would be within the order of the peak width.



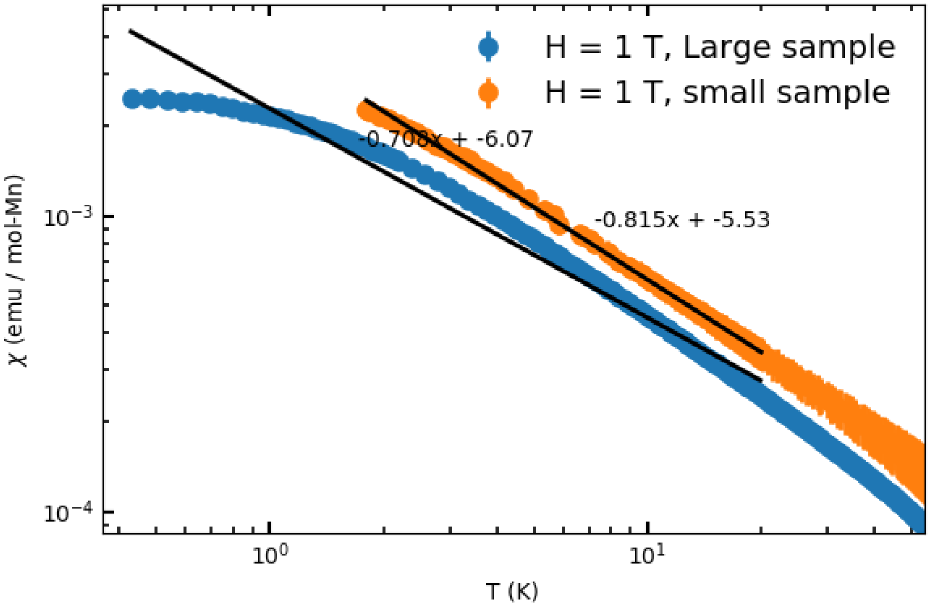
Stopping site

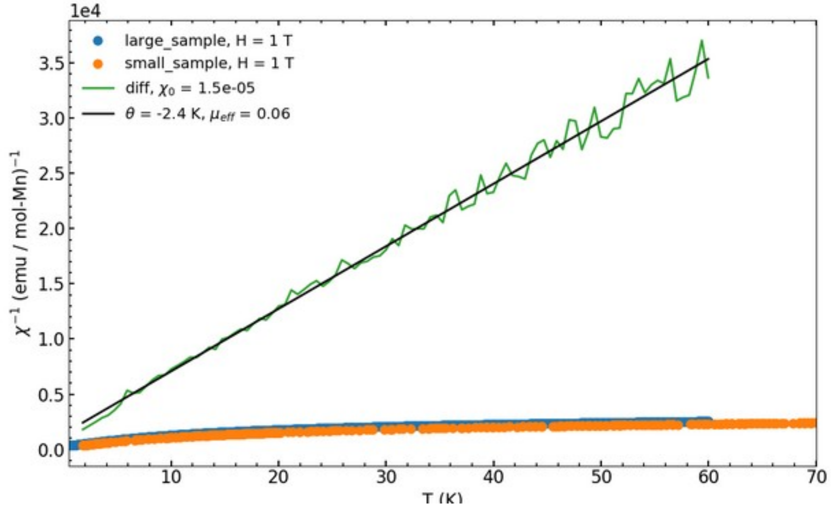
Hartree potential calculation for stopping site.

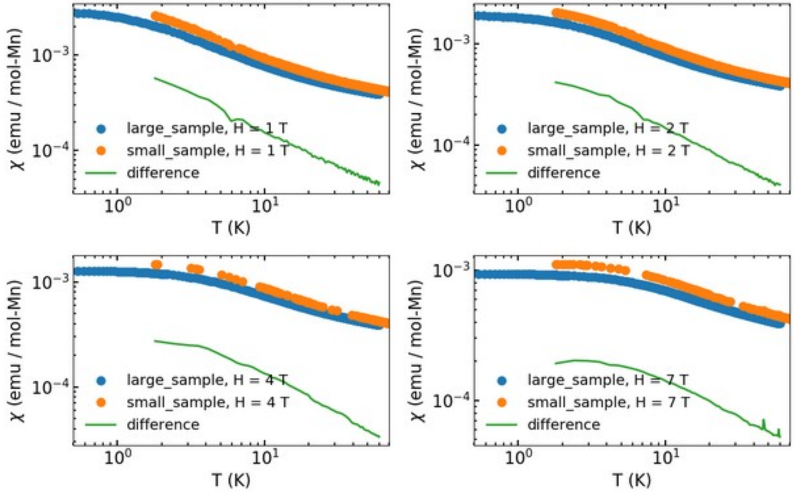
Minima at (0,0,0) and shallower minima at (1/3, 2/3, ¼), for $D_{\mu\text{-Mn}}$ = 4.83 Å, or 1.9 Å



Multiple crystals







Multiple crystals

Large sample

Small sample