Magnetization Dynamics in Pyrochlore $Dy_2Ti_2O_7$

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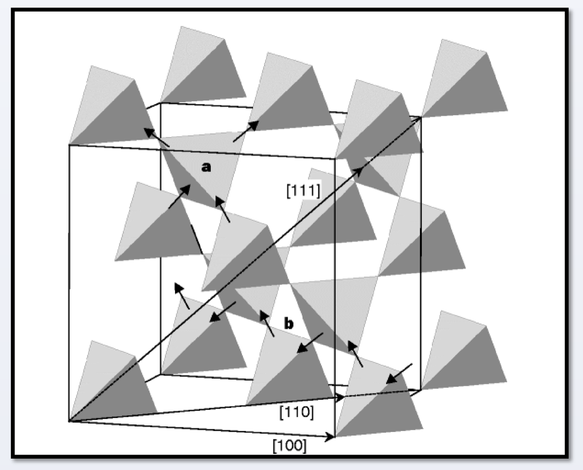
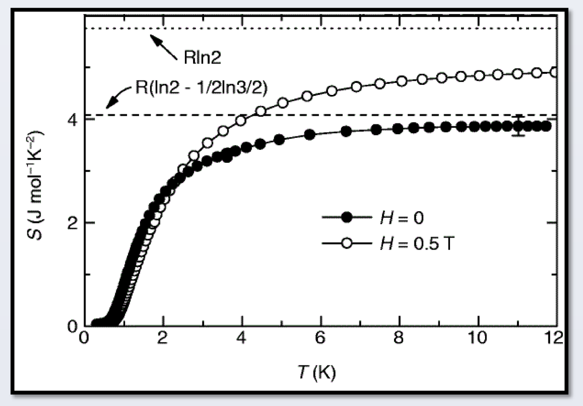
$Dy_2Ti_2O_7$ and the Spin Ice Analogy

Of interest: Triply ionized rare earth Dy^{3+} ions.

Magnetic moments are located at shared vertices of adjacent tetrahedra.
J=15/2, μ=10.6 μ_B

Ising spins: Spins can either point into or away from the center of each tetrahedron and are analogous to the hydrogen positions (bond lengths) in the water ice crystal.





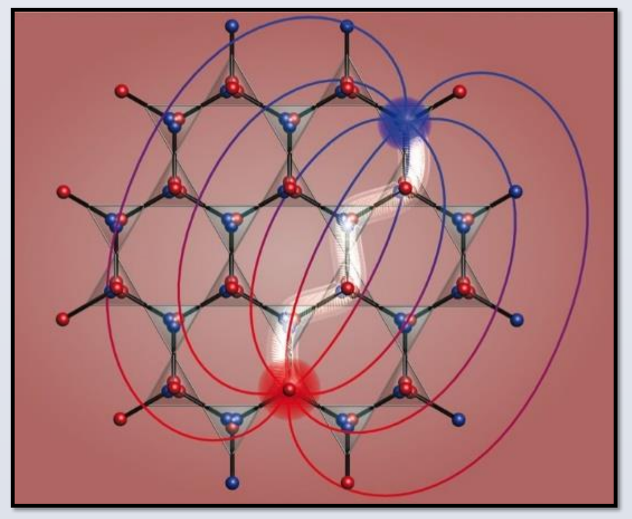
Low temperature heat capacity indicative of degenerate ground state.

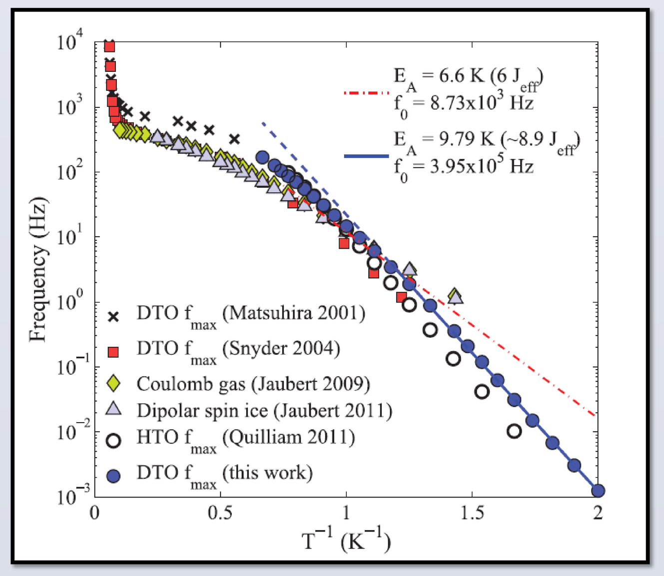
Entropy difference between high temperature and low temperature agrees with Pauling's calculation of water ice [1].

'Spin ice' - For each tetrahedron the lowest energy state corresponds to two spins pointing into the tetrahedron and two spins pointing away.

Proposed Model of Magnetization Dynamics

Spin flips resemble magnetic monopole-anti-monopole creation, and migration in the form of "Dirac strings" [2].



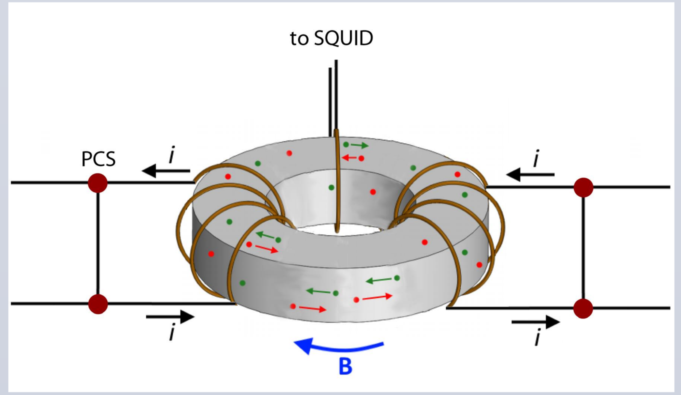


An accurate description of low temperature magnetization has not been discovered yet.

There is a discrepancy between monopole dynamics theory (Jaubert 2009, 2011) and experimental results (figure from [3]).

SQUID-Based Approach to Probe Magnetization Dynamics

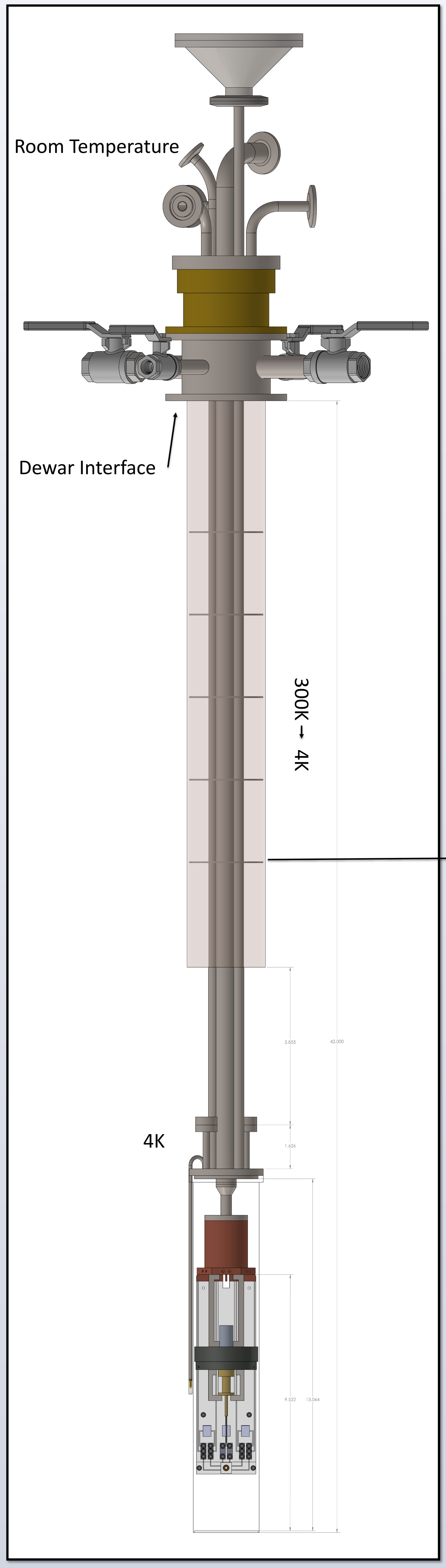
Periodic boundary conditions provide for the possibility of continuous transport of monopoles.



Boundary conditions remove data analysis complications arising from demagnetization effects.

Upcoming experiment: Use SQUID to measure driven magnetic effects due to persistent current sources.

Cryostat Design

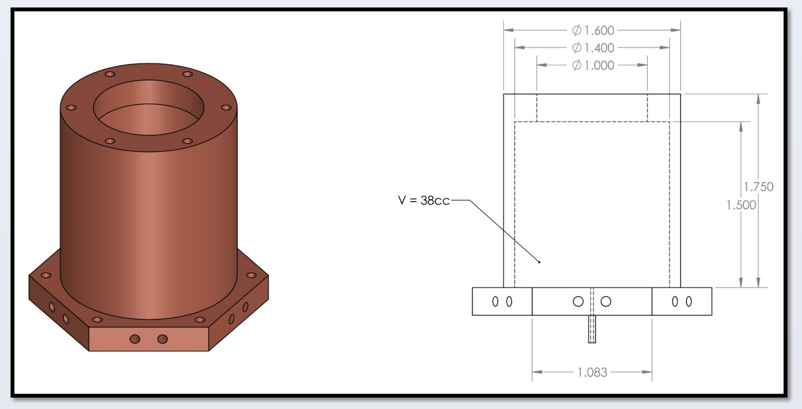


Cryostat dips into 100L helium bath.

We will be building the cryostat in the student and professional machine shops in Clark Hall over the next several months.

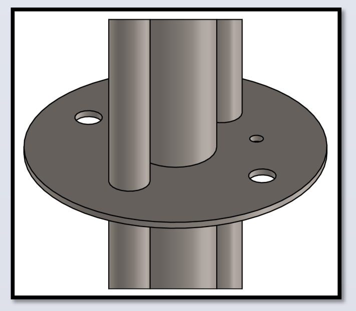
The cryostat uses evaporative cooling of ^4He to reach temperatures close to 1 Kelvin.

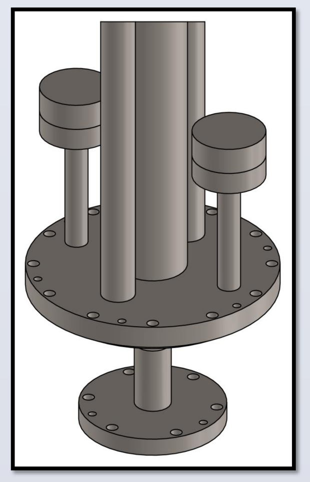
The diameter of the pot pumping line is very large: ¾" line for low pumping impedance.



Valves at room temperature allow venting of helium vapors.

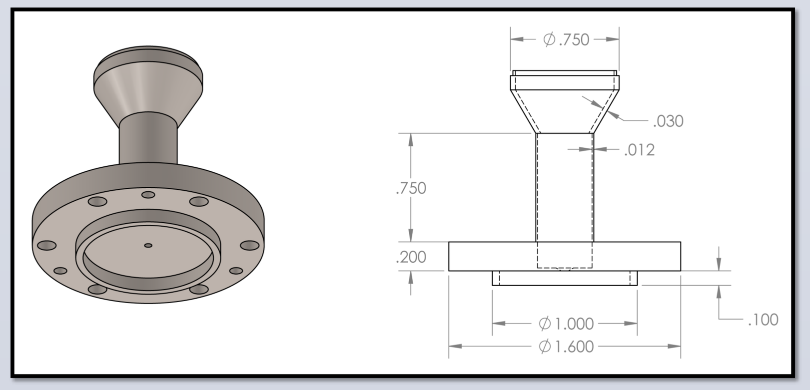
A series of baffles between 300K and 4K reflect radiation to reduce heating from the dewar neck.





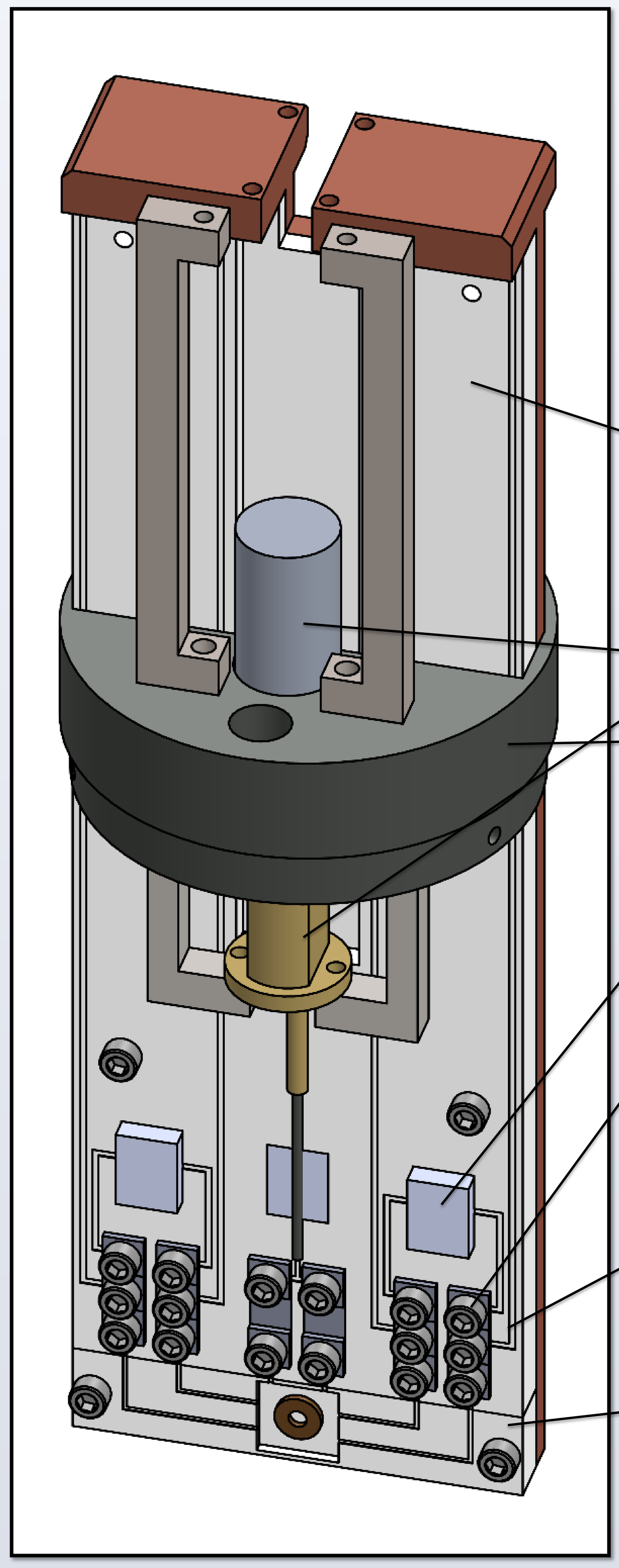
Extra inlets to vacuum can allow for future inclusion of a ^3He evaporation chamber to probe temperatures down to 300mK.

Thin-walled adapter from pot pumping line to pot reduces heat flow from 4K to 1K and has a small orifice to reduce splashing of hot helium back down into the pot.



Experimental assembly mounts directly to the ^4He pot and can be easily removed for alterations or transferal onto a dilution refrigerator for longer and colder testing.

Experiment Design



Experiment schematic:

Drive current with persistent current switches (PCS) hot.

Turn off PCS heaters, then cut off current source. Conservation of flux establishes a persistent current through the solenoids.

Measure changes in flux with SQUID!

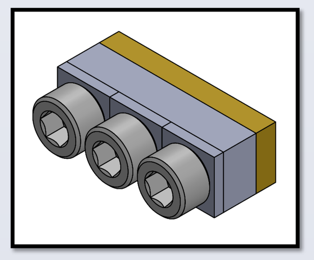
"Circuit board" made from Macor, a machinable ceramic material with thermal contraction similar to metals (importantly non-magnetic and an insulator).

SQUID mount and niobium shield.

Top of lead shield that will enclose entire experimental assembly.

Persistent current switch.

Superconducting joints made from solid niobium ensure lossless current loops.



All wires will be bonded to the circuit board in grooves with GE varnish to avoid noise from vibration and to keep every circuit component in a single plane.

Sample mounting section is independently removable for quick replacement of samples.

Future directions

Will we observe magnetic supercooled liquid dynamics as in Kassner *et al.* [4] in our lab previously?

Universality: Can other spin ice materials like $Ho_2Ti_2O_7$ show similar effects to what we will measure?

References

1 A. P. Ramirez *et al.*, *Nature* **399**, 333 (1999).
2 C. Castelnovo *et al.*, *Nature* **451**, 42 (2008).
3 L. R. Yaraskavitch *et al.*, *Phys. Rev. B* **85**, 020410 (2012).
4 E. R. Kassner, A. B. Eyvazov, B. Pichler, T. J. S. Munsie, H. A. Dabkowska, G. M. Luke, J. C. S. Davis, *Proc. Natl. Acad. Sci. U.S.A.*, **112** 8549 (2015).

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Acknowledgements

GORDON AND BETTY MOORE FOUNDATION
EPSRC Engineering and Physical Sciences Research Council