



SPINTRONICS LAB USER GROUP LUNCH

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WELCOME USERS!

I will talk about ...

- Safety in lab
- Review of Spin Lab tools
- Review of some probes of magnetism
- Possible upgrades for lab
- Some cool techniques to know about
- Common measurement mistakes
- Tips for success

Elevator Award Symposium

- John Ribeiro (Y. Chen, physics)
- Terry Hung (Z. Chen, ECE)

WHO IS USING SPIN LAB?

- Joerg Appenzeller (ECE)
- Zhihong Chen (ECE)
- Cliff Johnston (Agronomy)
- Oana Malis (Physics)
- Mike Manfra (Physics)
- Ernesto Marinero (Materials E.)
- Shriram Ramanathan (Materials E.)
- Kaushik Roy (ECE)
- Corey Thompson (Chemistry)
- Haiyan Wang (Materials E.)
- Alex Wei (Chemistry)
- Mary Wirth (Chemistry)
- Alexandra Boltasseva (ECE)
- Sunil Bhave (ECE)
- Yong Chen (Physics)
- Dallas Morissette (ECE)
- Leonid Rokhinson (Physics)
- Xinghang Zhang (Materials E.)
- Babak Ziaie (ECE)

over 60 users

SAFETY IN THE LAB

Mental checklist ANY time you step away from the machine:

- Is the cap on the chamber?
 - Is the chamber pressure <10 torr?
 - Is the system going to be left at 300 K and zero field at conclusion of my run?
 - Is MultiVu software running?
 - Are all tools put away and the benchtop clean for the next user?
-
- *Please wear safety eyewear!*
 - *Quick Start guides for each option*





REVIEW OF SPIN LAB TOOLS

PPMS



- **General field/temperature platform:**
 - **Temperature: 1.8 – 400 K**
 - **Magnetic field: +/- 9 tesla (90 kOe)**
 - 25mm diameter sample space
- Pulse-tube cryocooler makes this “cryogen-free”
- Hosts wide variety of automated measurements...

MPMS-3



- **Most sensitive instrument for measuring bulk magnetic dipole moment m**
- Inductive measurement using gradiometer coils around a moving sample
- High speed: full magnetic $m(H)$ hysteresis loops in just minutes
- Uses a “SQUID” : superconducting interferometer
- Samples: film, bulk, crystals, powder
- 8mm diameter sample space (4x4mm film typical)
- 10⁻⁸ emu (10⁻¹¹ A·m²) sensitivity
- **Temp. : 1.8 – 400 K, oven : 300 – 1000 K**
- **Field : +/- 7 tesla (70 kOe)**
- EverCool: pulse-tube cryocooler recondenses the helium that evaporates from the dewar

PPMS: ELECTRICAL TRANSPORT

- magnetoresistance, Hall effect, I-V curves; external gating possible
 - Micro-ohm up to 5 giga-ohm
 - automated sample rotation
- attach leads
 - Au wire bonding (at BNC)
 - solder
 - pressed indium
 - spring-loaded press contacts
 - Ag paint...



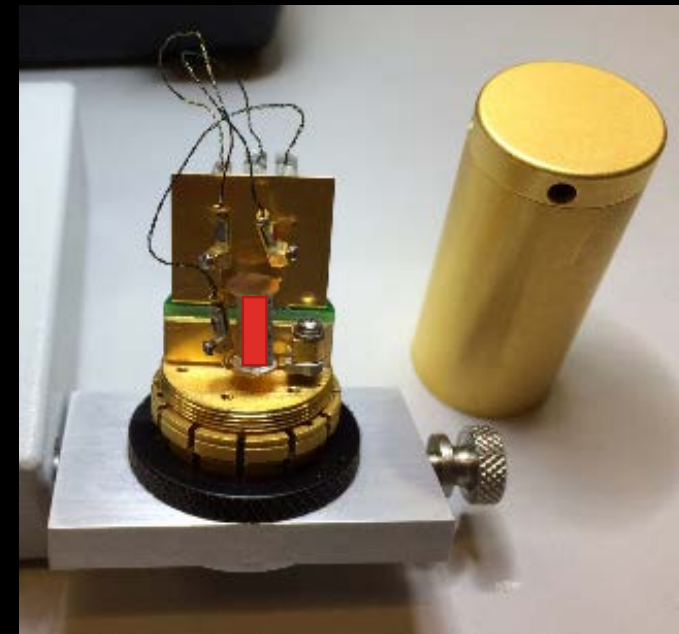
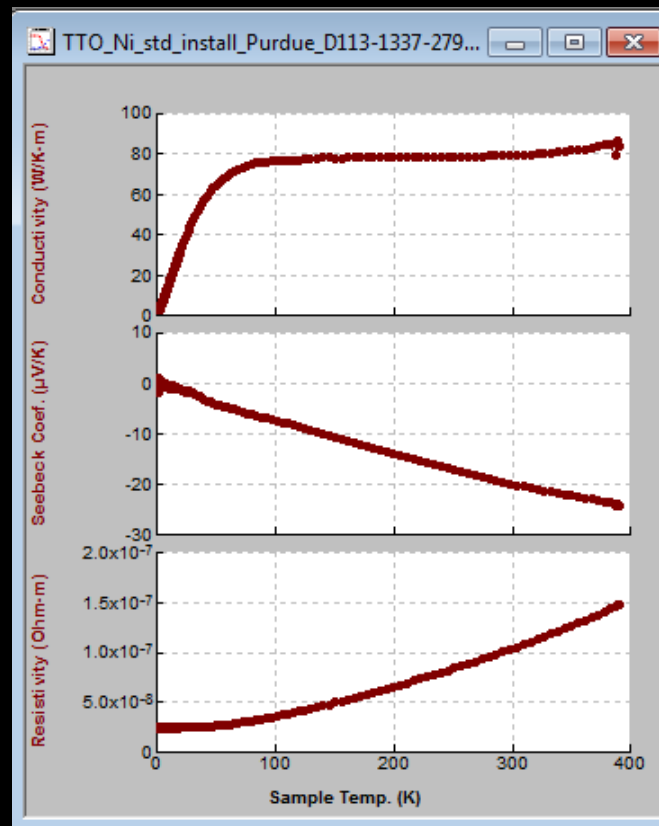
PPMS: MAGNETOMETRY

- **Magnetometry:** DC magnetic moment using VSM
 - 10^{-6} emu up to >100 emu
 - standard bore or large bore
 - max sample diameter:
 - standard coils: 4mm
 - large bore: 10mm



PPMS: THERMAL TRANSPORT

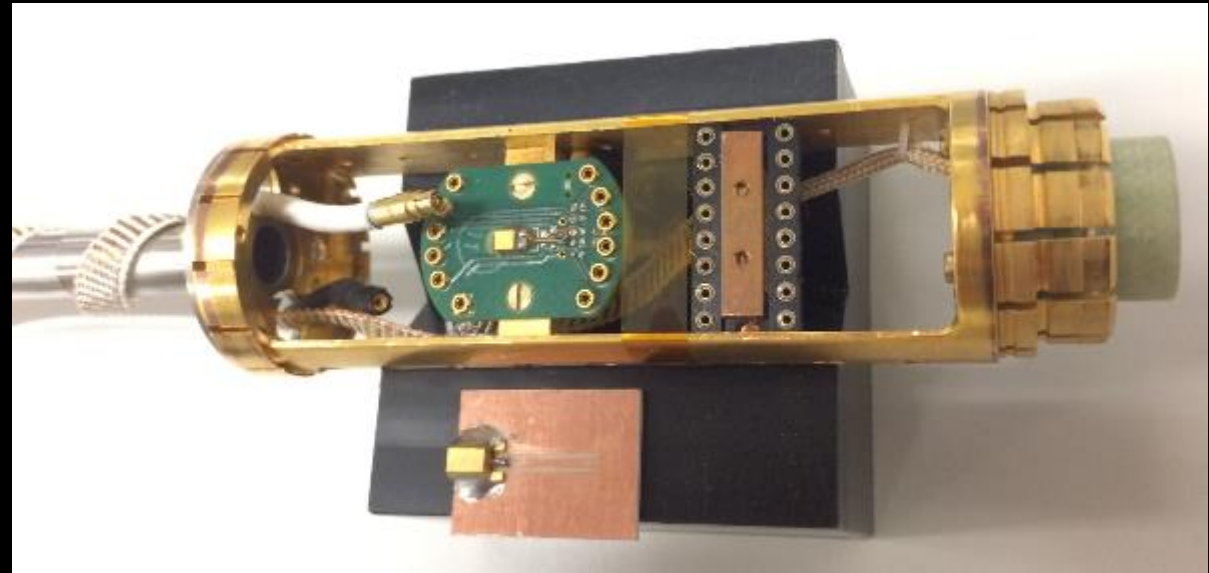
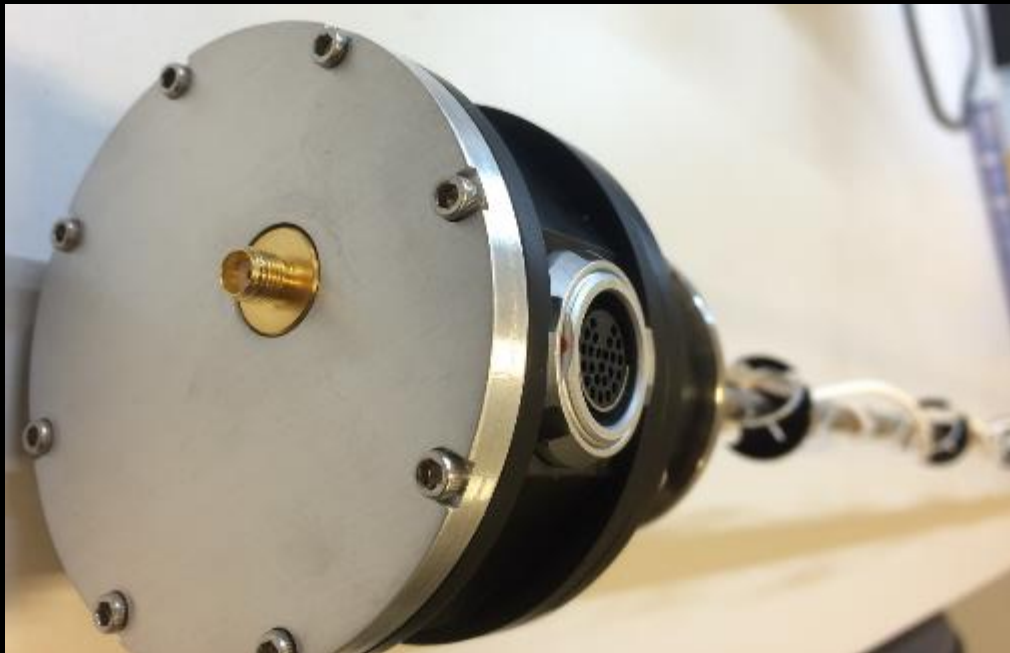
- simultaneous measurement of:
 - thermal conductivity
 - Seebeck
 - resistivity
- bulk samples
- attach leads with Ag epoxy



PPMS: CUSTOM PROBE

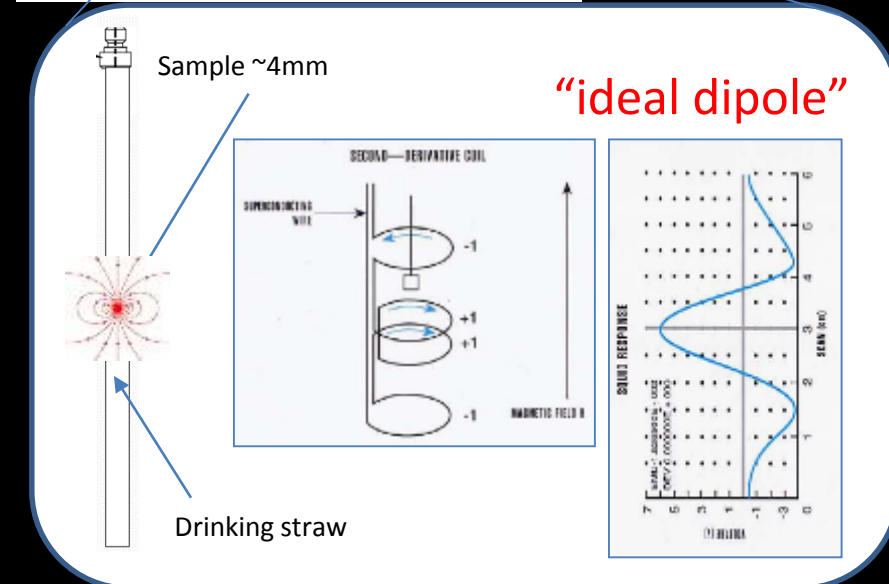
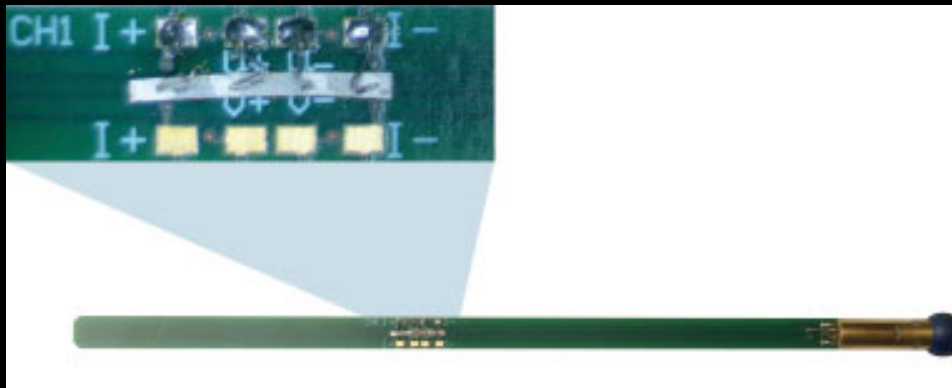
We have one Multifunction probe "MFP"

- 2D material based devices, gated transport
- Ferromagnetic Resonance (FMR) -- 6 GHz



MPMS-3

- DC moment: “DC Scan” or “VSM mode”
- AC susceptibility: $f = 0.1 - 1000$ Hz
- oven to $T = 1000$ K
- electrical transport or V-biasing **while** measuring magnetic moment



REVIEW OF SOME PROBES OF MAGNETISM

- **Mechanical**

- Force (Faraday, MFM)
- Torsion

$$F = \nabla(\mathbf{m} \cdot \mathbf{H})$$
$$\tau = \mathbf{m} \times \mathbf{H}$$

(levitation)
(compass)

- **Inductive**

- SQUID
- Vibrating Sample Magnetometer
- AC susceptibility
- Epstein frame (transformer)

$$V(z) = \Phi(z)$$
$$V(t) = -d\Phi(z)/dt$$
$$V(t) \propto \chi' * \cos(\omega t) + \chi'' * \sin(\omega t)$$

\mathbf{m} : magnetic moment
 $M = \mathbf{m} / \text{volume}$
 $\chi = dm/dH$
 $\Phi = B * \text{area}$ (flux)

- **Electrical**

- (Anomalous) Hall effect
- Planar Hall effect
- Tunneling MR, GMR

$$V_{\text{Hall}} \propto \mathbf{B}_z \quad (V_{\text{Hall}} \propto \mathbf{M}_z)$$
$$V_{\text{Hall}} \propto \mathbf{M}_x * \mathbf{M}_y$$

(hard drive read heads)

- **Magnetic Resonance**

- Ferromagnetic Resonance

$$f = \frac{\gamma}{2\pi} \sqrt{B(B + \mu_0 M)}$$

- **Optical**

- Magneto-Optical Kerr Effect
- diamond NV center fluorescence

$$\theta_{\text{Kerr}} \propto M$$

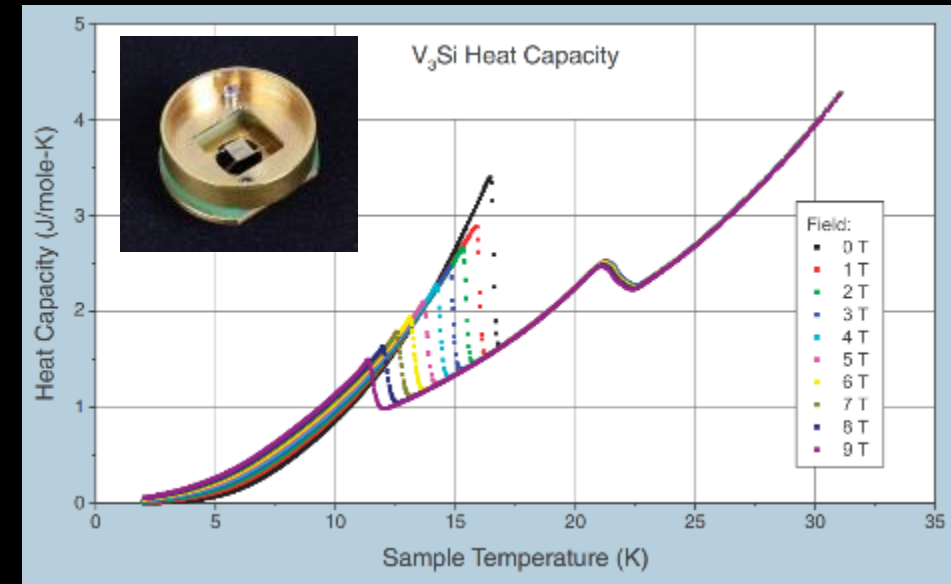
(Y. Chen group, Physics)
(Shalaev group developing)

Spin lab has these already

UPGRADES FOR LAB?

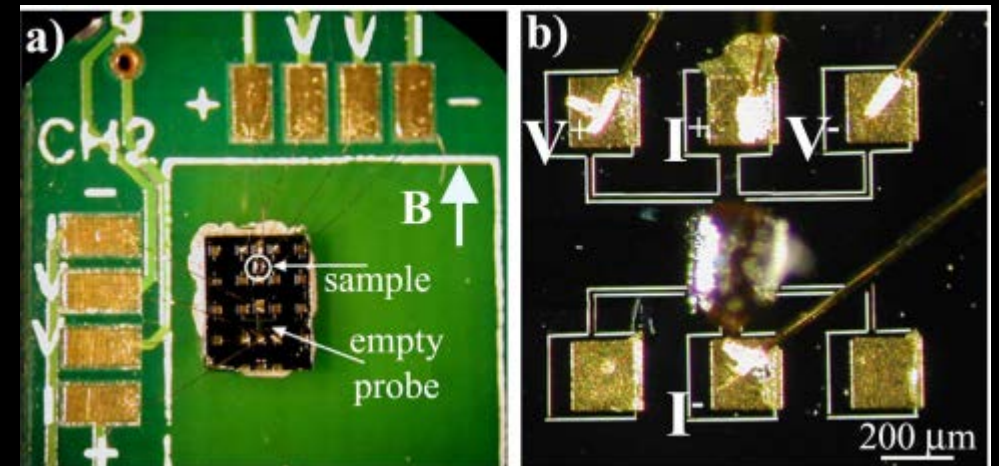
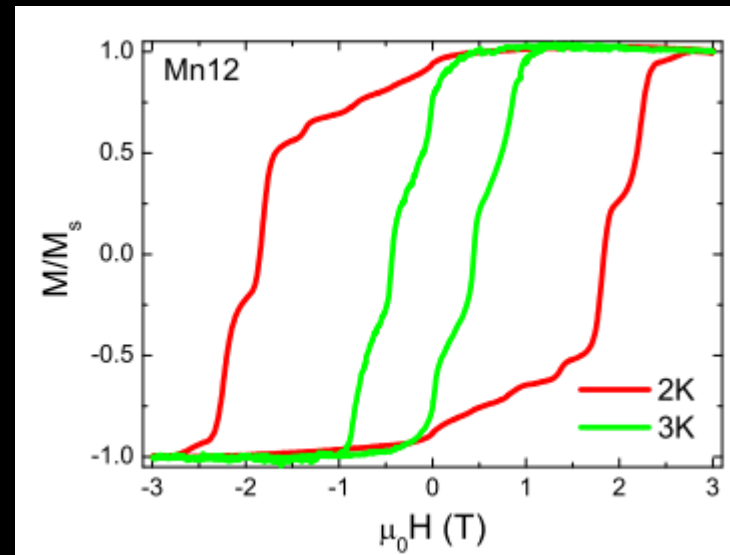
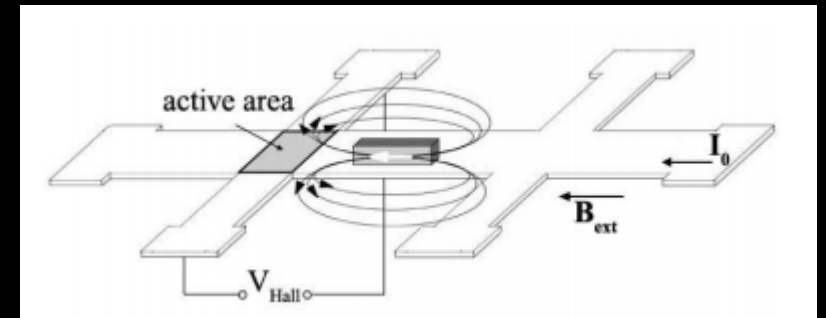
PPMS

- Heat Capacity
- FMR to 20 GHz, transmission mode
- Raman, Luminescence, other optical probes



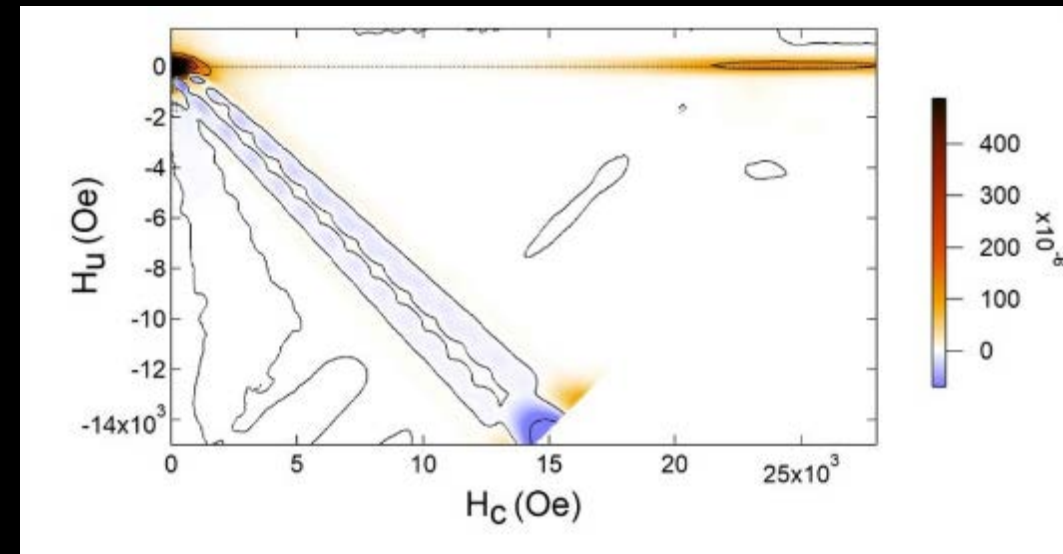
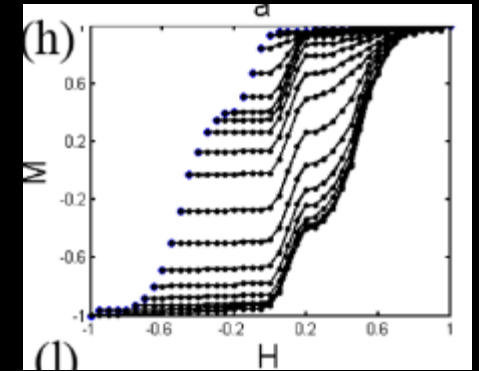
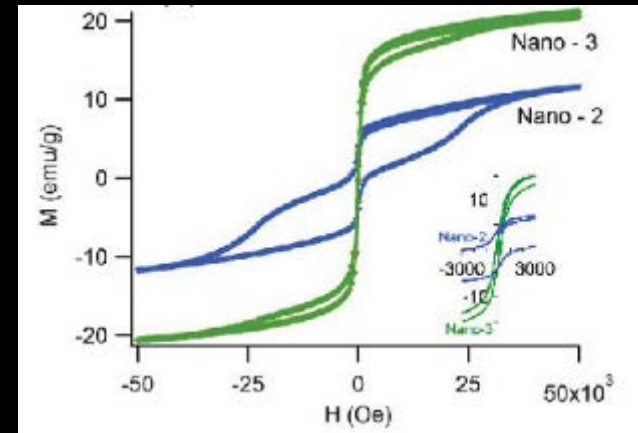
WE COULD DO THIS EASILY: HALL MAGNETOMETRY

- small $\sim\mu\text{m}$ Hall sensors probe stray field from μm size sample
- see 1084-701 at www.qdusa.com
- single molecule magnet $M(H)$
- single crystal



WE CAN DO THIS: "FORC" MAGNETIC ANALYSIS

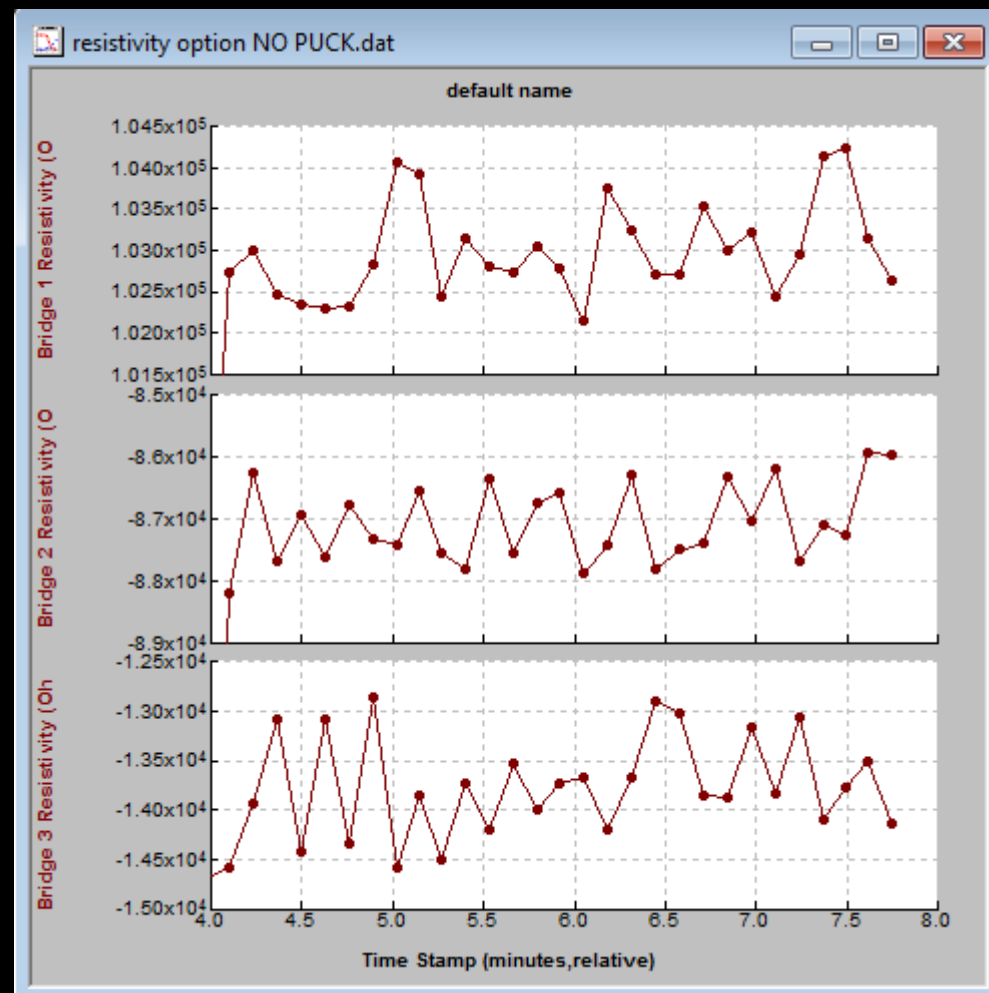
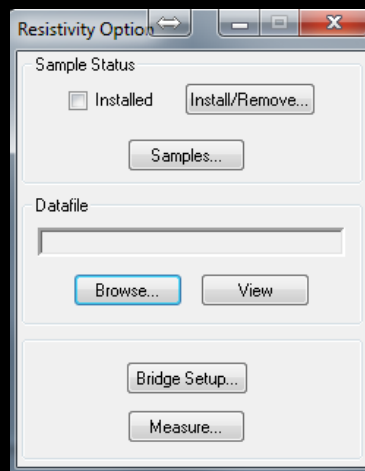
- First Order Reversal Curves
- PPMS VSM or MPMS-3
- many minor M(H) loops
- separates contributions to total signal
- distributions in switching fields
- multi-phase materials



COMMON MISTAKES

PPMS Resistivity Option

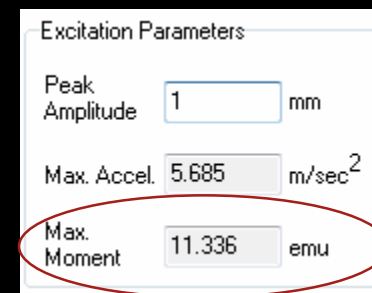
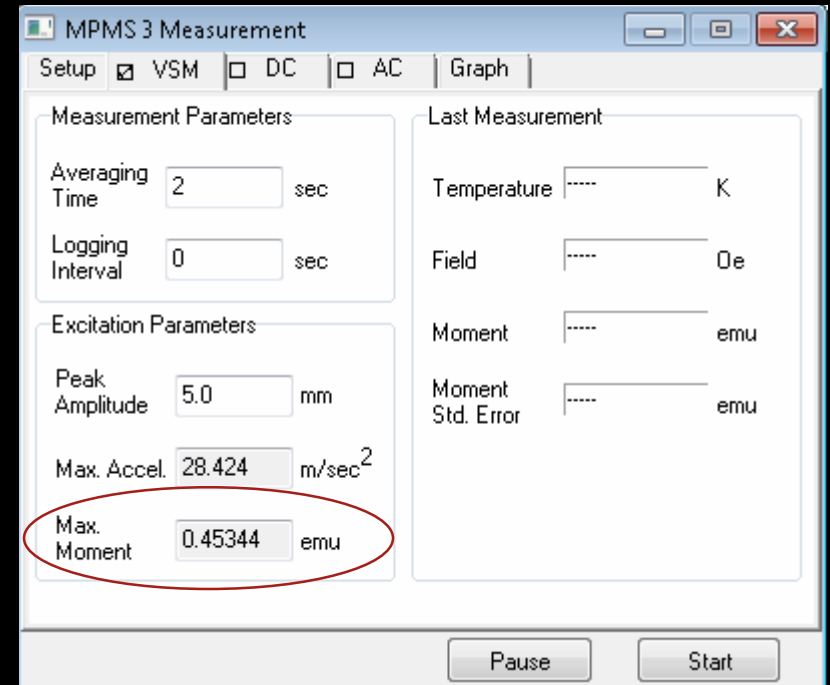
- open contacts → bogus data!
- can look like a real signal
- check contacts with ohmmeter
- **ETO a better choice**
 - has diagnostics like “phase angle”



COMMON MISTAKES

MPMS

- Large sample signal >0.4 emu
- saturates the SQUID
 - it was designed for 10^{-8} emu!
- use smaller VSM amplitude
- slower DC scan (8 sec)



COMMON MISTAKES

PPMS VSM

- straws ONLY in large bore coils
- sample should not be able to slide
 - photo shows a *wrong* method for PPMS



PPMS VSM vs. MPMS-3

- **PPMS:** *goes faster*
 - sweep field 200 Oe/sec
 - **vibrations are much stronger >100 m/s²**
- **MPMS-3:** *take it slow*
 - **STABLE field during measure, no sweep**
 - vibrations less (esp. DC Scan)

TIPS FOR SUCCESS

- Consult Quick Start guides for each option!
 - red tab in binder
- all training material on Birck Wiki page

<https://wiki.itap.purdue.edu/display/BNCWiki/Electrical+and+Magnetic+Properties>

- Example sequences will get you started
 - `c\QdDyancool\Sequence`
 - `c\QdSquidVsm\Sequence`

Pages / ... / Electrical and Magnetic Properties

PPMS - Quantum Design DynaCool

Created by Wirth, Justin C, last modified by Dilley, Neil R on Oct 12, 2017

Blog: Spin Lab Newsletter Archive

PPMS - Quantum Design DynaCool



iLab Name: **PPMS**
iLab Kiosk: **BRK Characterization Core**
PIC: Joerg Appenzeller
Owner: **Neil Dilley**
Location: BRK 1157A
Maximum Wafer Size:

- 1 Trained user quick reference
 - 1.1 ETO quick start guide
 - 1.2 VSM quick start guide
- 2 Pre-training
- 3 Training
 - 3.1 Electrical Transport
 - 3.2 VSM
 - 3.3 Thermal Transport
 - 3.4 Custom measurements
- 4 Questions & Troubleshooting
- 5 Process Library
- 6 References

TIPS FOR SUCCESS

- **Demo samples**
 - MPMS user kit
 - PMA, IMA CoFeB films
 - Kapton tape with dust: Dust is enemy #1!
 - ETO user kit: resistors
 - Rotator user kit: Hall sensor
 - TTO user kit: nickel alloy standard; aluminum
- **Best demo sample: measure nothing!**
 - blank sample holder
 - substrate
 - known control sample
- MPMS-3 Accuracy of reported moment
 - use Sample Geometry Simulator

The screenshot shows the 'MPMS 3 Sample Geometry Simulator' window. It is divided into four main sections: Reference Geometry (Pd Cylinder), Sample Geometry, Measurement Parameters, and Estimated Correction Factors. The Reference Geometry section includes Height (mm) at 3.80, Diameter (mm) at 2.80, and DC Scan Length (mm) at 35. The Sample Geometry section has a dropdown menu set to 'Thin Film (Field ⊥ ab)', with 'a (mm)' and 'b (mm)' both set to 4, and 'Radial Offset (mm)' set to 1. The Measurement Parameters section shows 'VSM Amplitude (mm)' at 5 and 'DC Scan Length (mm)' at 35. The Estimated Correction Factors section displays 'VSM Measurement' at 1.182 and 'DC Scan' at 1.092. A 'Calculate' button is located at the bottom right of the window.

Section	Parameter	Value
Reference Geometry (Pd Cylinder)	Height (mm)	3.80
	Diameter (mm)	2.80
	DC Scan Length (mm)	35
Sample Geometry	Sample Type	Thin Film (Field ⊥ ab)
	a (mm)	4
	b (mm)	4
	Radial Offset (mm)	1
Measurement Parameters	VSM Amplitude (mm)	5
	DC Scan Length (mm)	35
Estimated Correction Factors	VSM Measurement	1.182
	DC Scan	1.092