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 Morisette (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?**

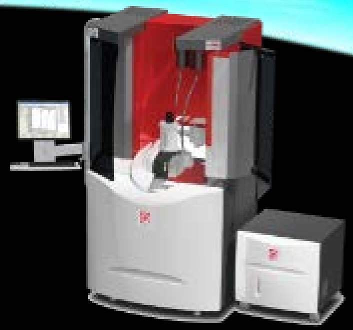
- ***Please wear safety eyewear!***
- ***Quick Start guides for each option***

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...

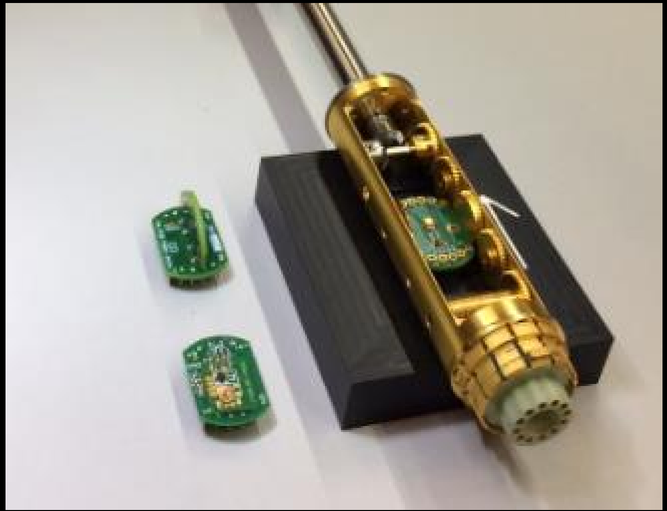
MPMS-3

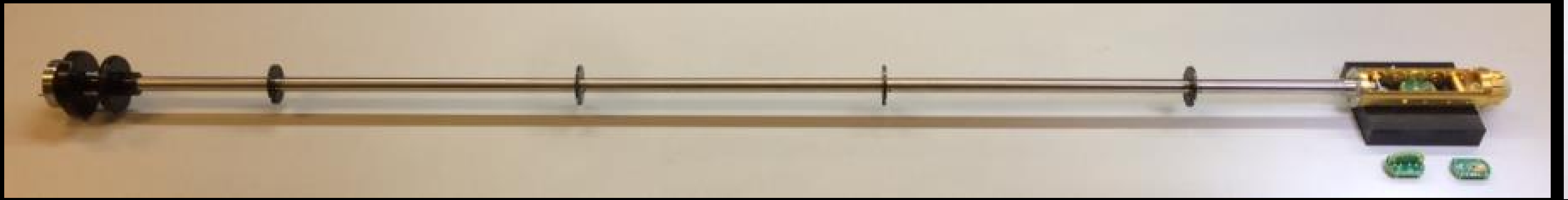


- **Most sensitive instrument for measuring bulk magnetic dipole moment *m***
- Inductive measurement using gradiometer coils around a moving sample
- High speed: full magnetic m(H) hysteresis loops in just minutes
- Uses a “SQUID” : superconducting interferometer
- Samples: film, bulk, crystals, powder
- 8mm diameter sample space (4x4mm film typical)
- 10-8 emu (10-11 A-m^2) 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...



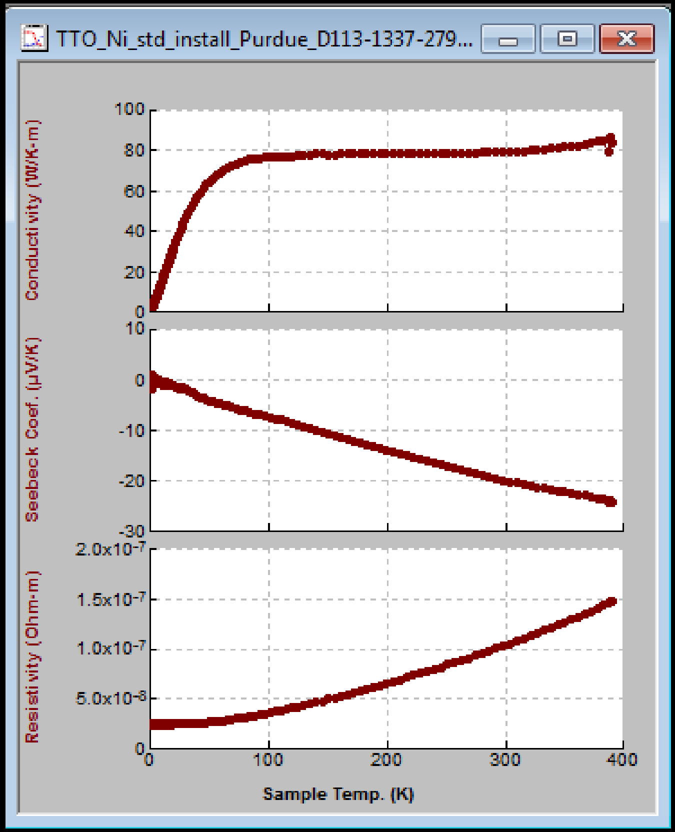


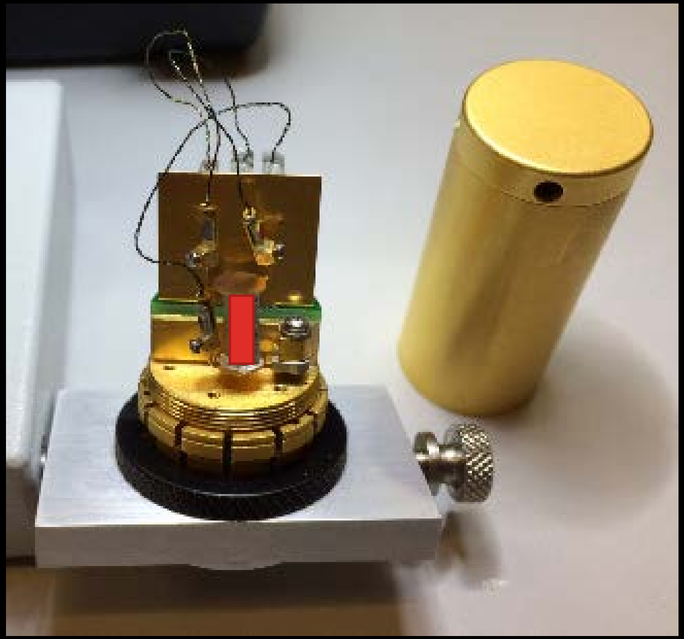
PPMS: MAGNETOMETRY

- **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

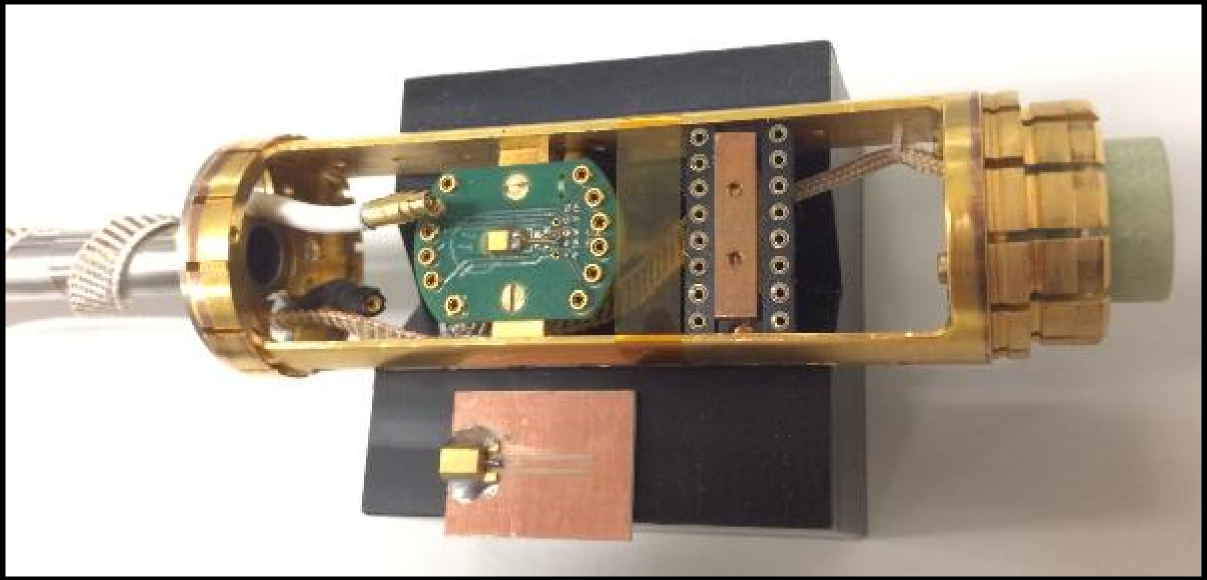


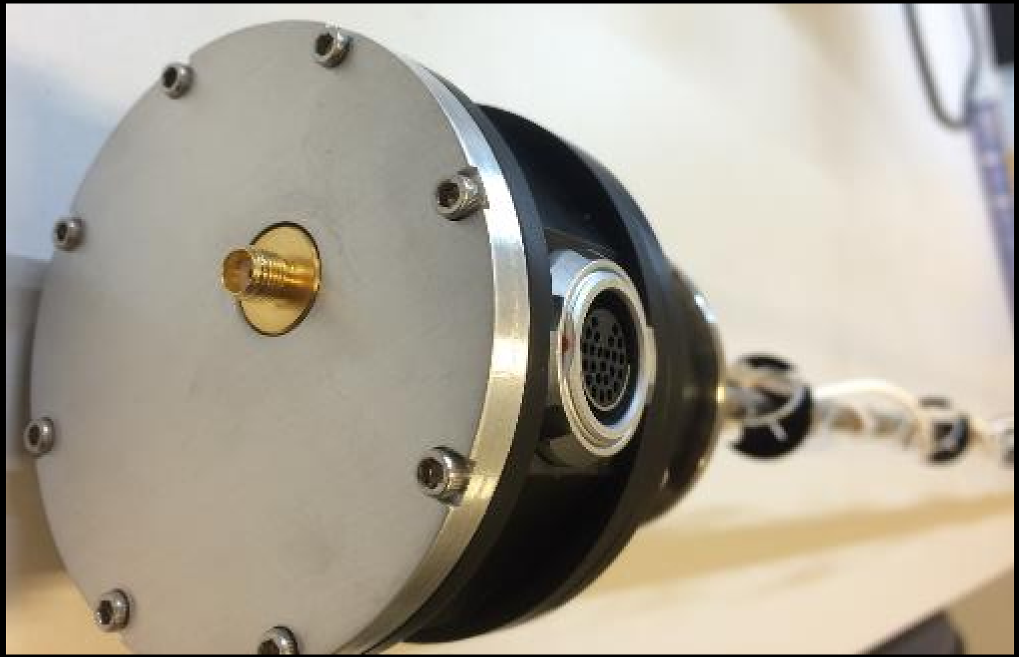


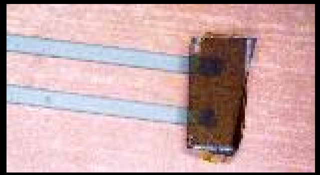
PPMS: CUSTOM PROBE

We have one Multifunction probe “MFP”

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

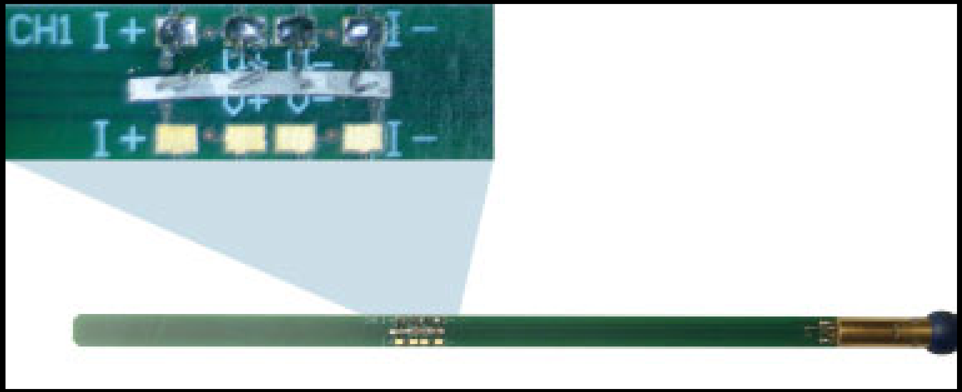


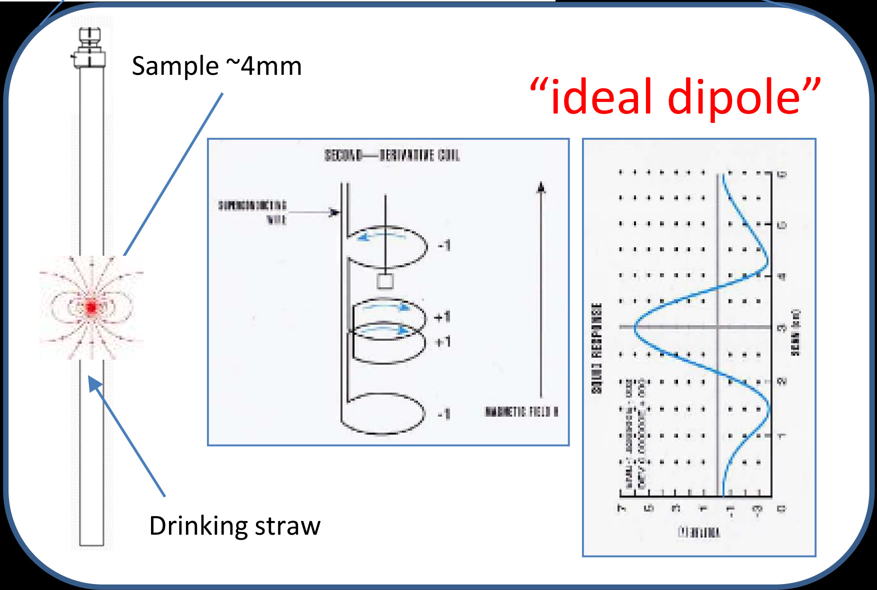




MPMS-3

- 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

m: magnetic moment
M = **m** / volume
χ = d**m**/dH
Φ = B*area (flux)

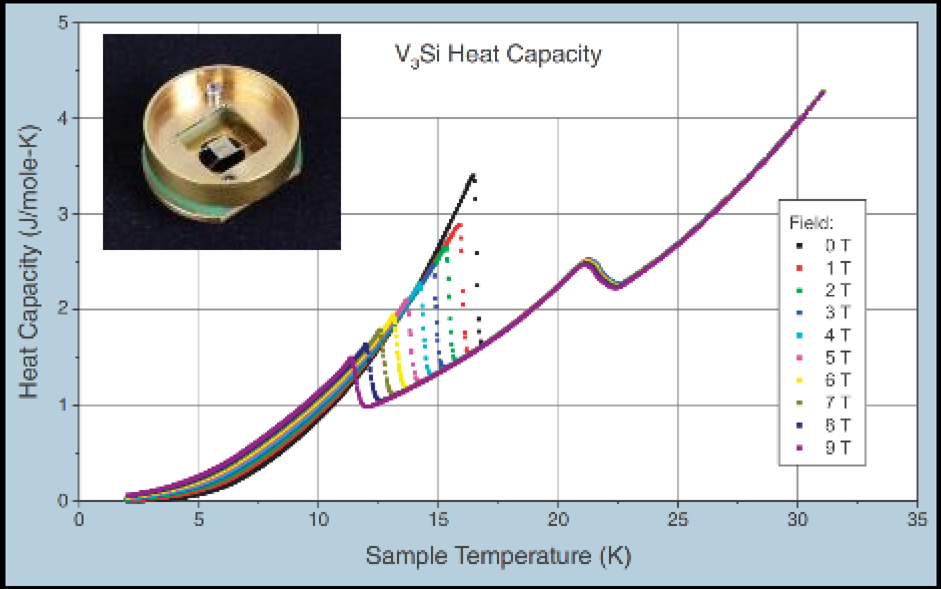
- **Mechanical**
  - Force (Faraday, MFM) — $F = \nabla(\mathbf{m} \cdot H)$ — (levitation)
  - Torsion — $\tau = \mathbf{m} \times H$ — (compass)
- **Inductive**
  - SQUID — $V(z) = \Phi(z)$
  - Vibrating Sample Magnetometer — $V(t) = - d\Phi(z)/dt$
  - AC susceptibility — $V(t) \propto \chi' * \cos(\omega t) + \chi'' * \sin(\omega t)$
  - Epstein frame (transformer)
- **Electrical**
  - (Anomalous) Hall effect — $V_{Hall} \propto \mathbf{B}_z$ ($V_{Hall} \propto \mathbf{M}_z$)
  - Planar Hall effect — $V_{Hall} \propto \mathbf{M}_x * \mathbf{M}_y$
  - Tunneling MR, GMR — (hard drive read heads)
- **Magnetic Resonance**
  - Ferromagnetic Resonance — $f = \frac{\gamma}{2\pi}\sqrt{B(B + \mu 0 M)}$
- **Optical**
  - Magneto-Optical Kerr Effect — $\theta_{Kerr} \propto M$ — (Y. Chen group, Physics)
  - diamond NV center fluorescence — (Shalaev group developing)

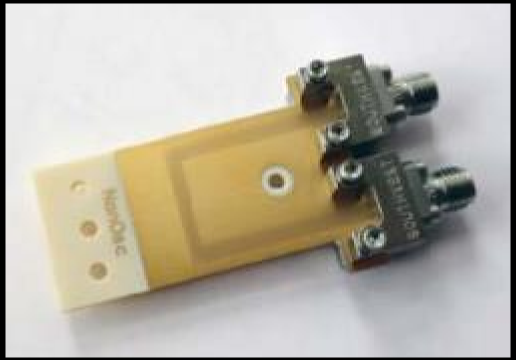
Spin lab has these already

UPGRADES FOR LAB?

PPMS

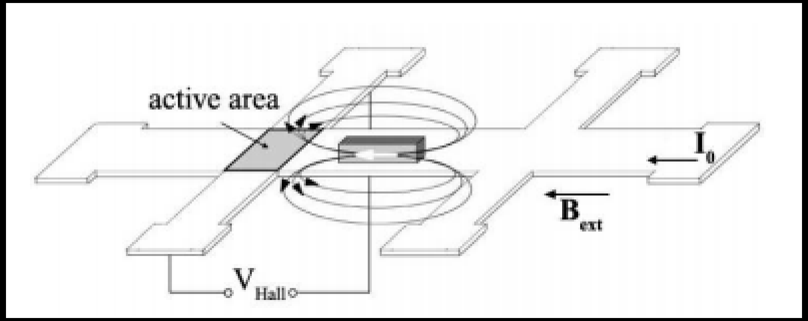
- Heat Capacity
- FMR to 20 GHz, transmission mode
- Raman, Luminescence, other optical probes

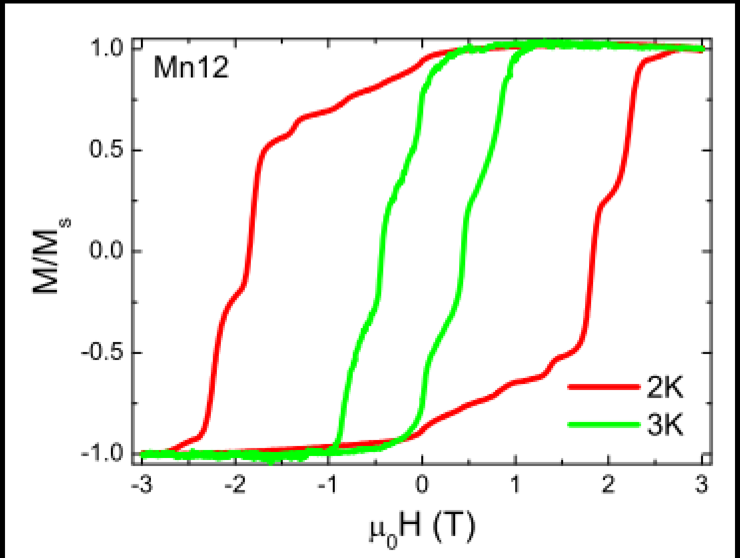


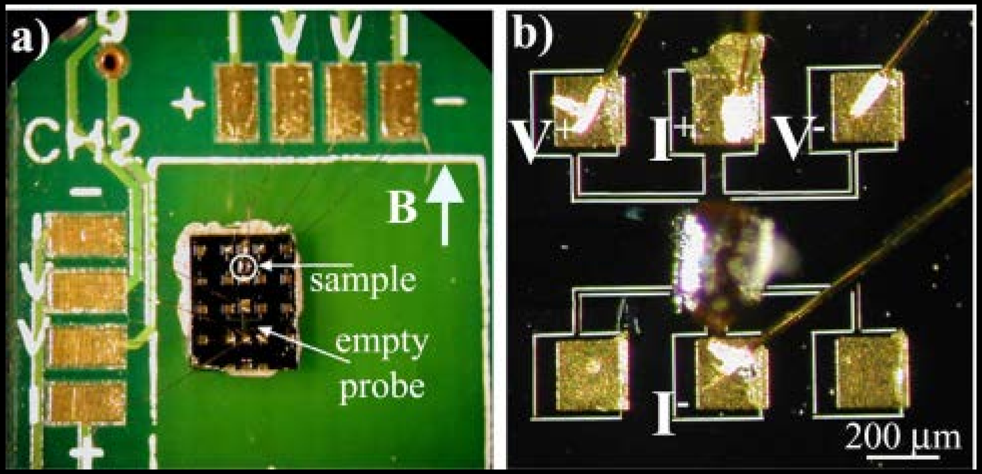


WE COULD DO THIS EASILY: HALL MAGNETOMETRY

- small ~μm Hall sensors probe stray field from μm size sample
- see 1084-701 at www.qdusa.com
- single molecule magnet M(H)
- single crystal

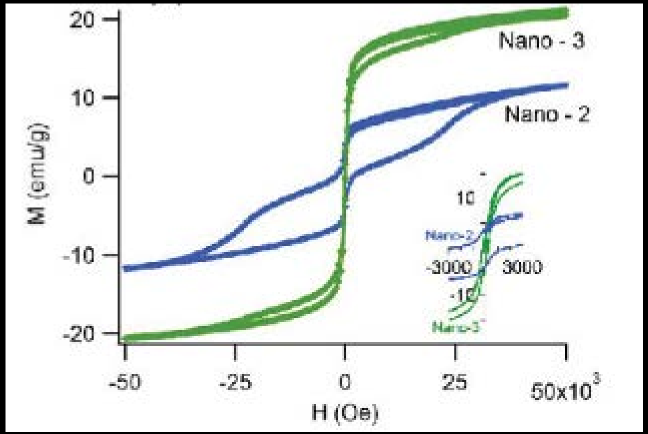


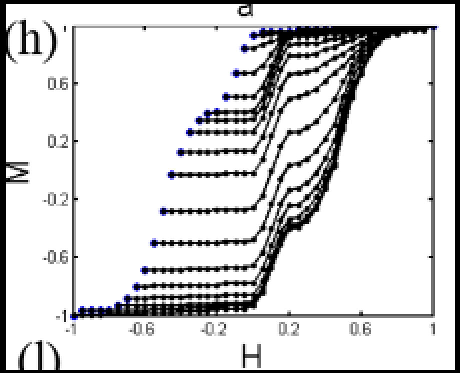


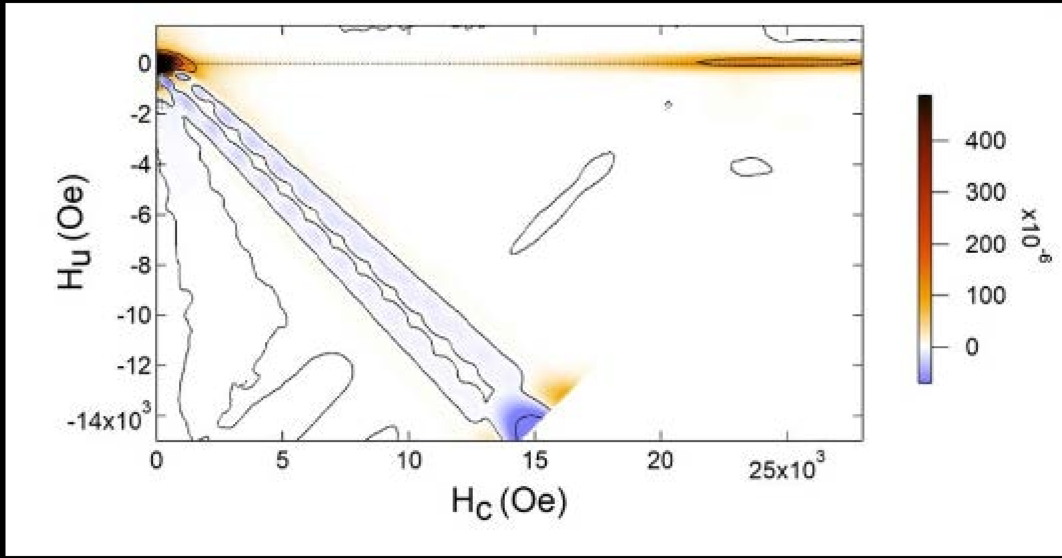


WE CAN DO THIS:
"FORC" MAGNETIC ANALYSIS

- 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



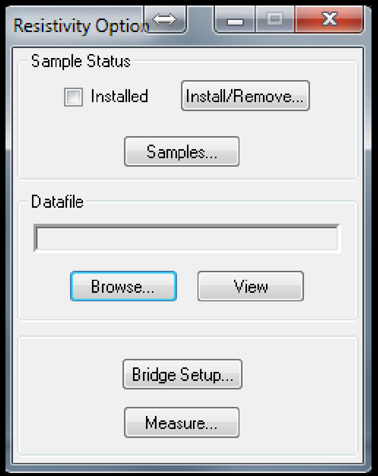


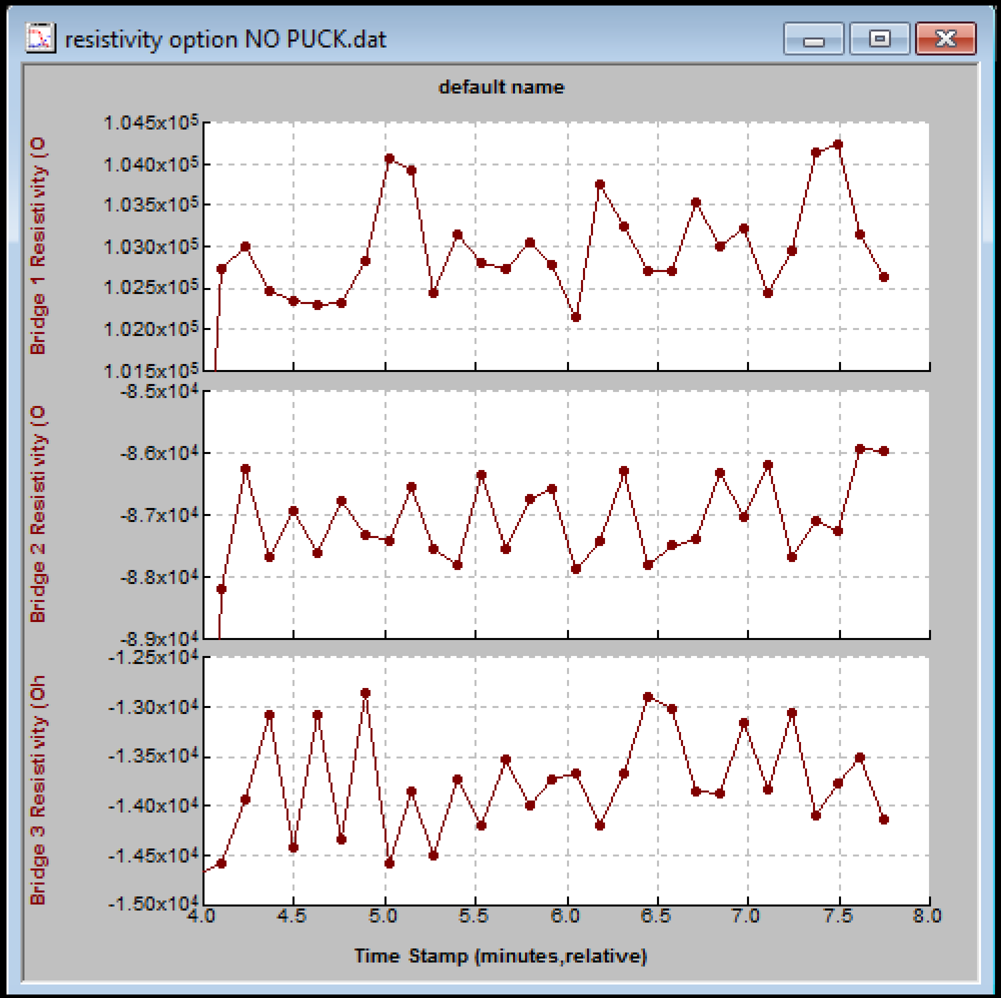


COMMON MISTAKES

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"

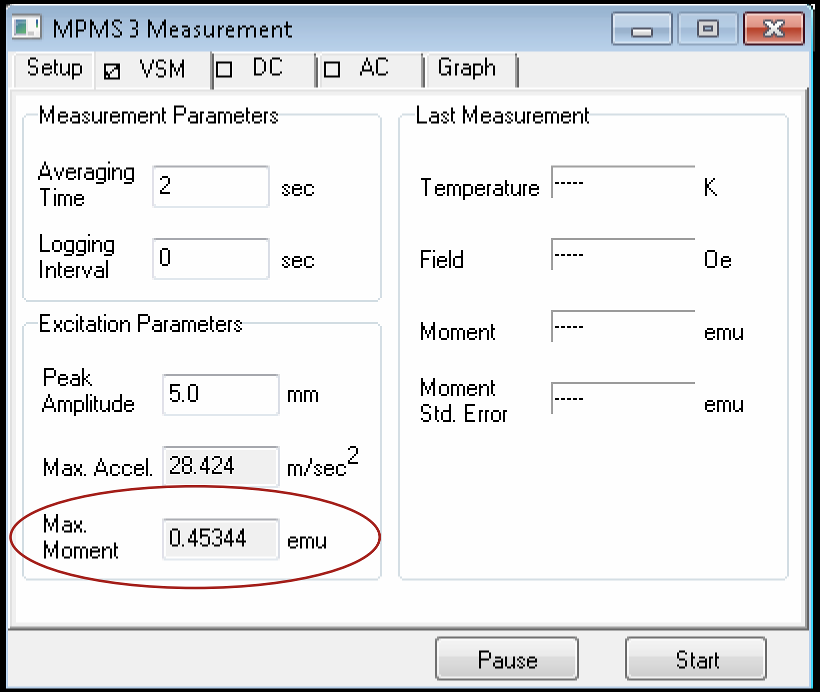


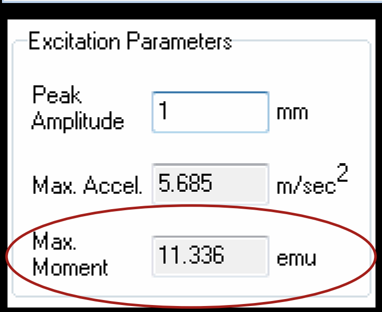


COMMON MISTAKES

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**

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