Measuring, Processing and Analyzing Hysteresis Loops

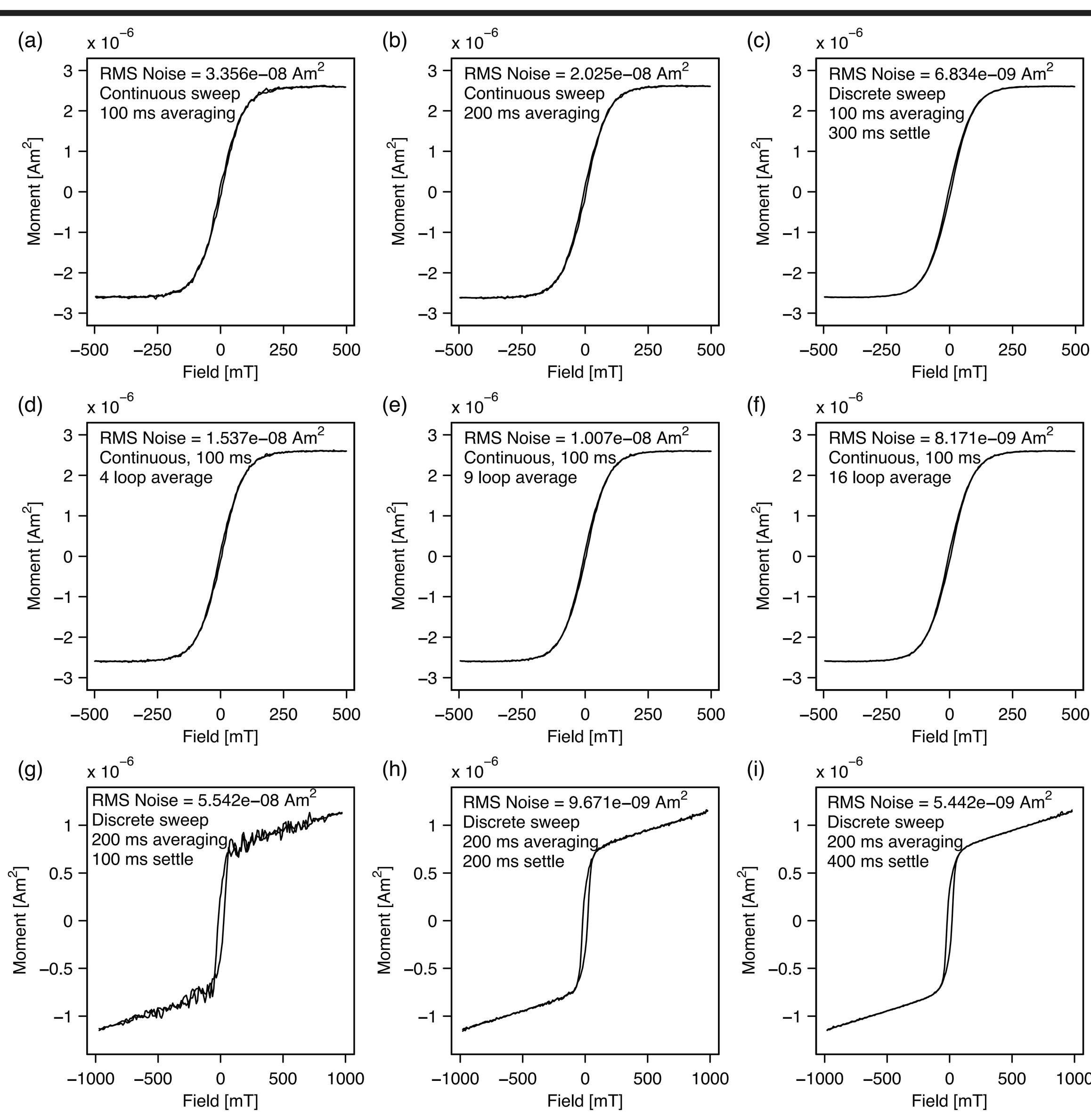
Greig A. Paterson[1,2], Xiang Zhao[3], Mike Jackson[4], Dave Heslop[3]

[1]University of Liverpool, UK, E-mail: **greig.paterson@liverpool.ac.uk**
[2]Institute of Geology and Geophysics, Chinese Academy of Sciences China,
[3]Australian National University, Australia, [4]University of Minnesota, USA.

1. Introduction

- Magnetic hysteresis loops are one of the most widely used rock magnetic data types in Earth sciences, but despite their simplicity correctly measuring, processing and analyzing loops can be complicated.
- Here we outline methods to better work with hysteresis data (particularly aimed at a VSM). More detail can be found in Paterson et al. (2018, accepted G-Cubed, doi: 10.1029/2018GC007620).
- Pre-print @ https://www.essoar.org/doi/abs/10.1002/essoar.bde1036562e67449.6b8028d96d114023.1
- All these ideas are implemented in the new *HystLab* software package available @ https://github.com/greigpaterson/HystLab

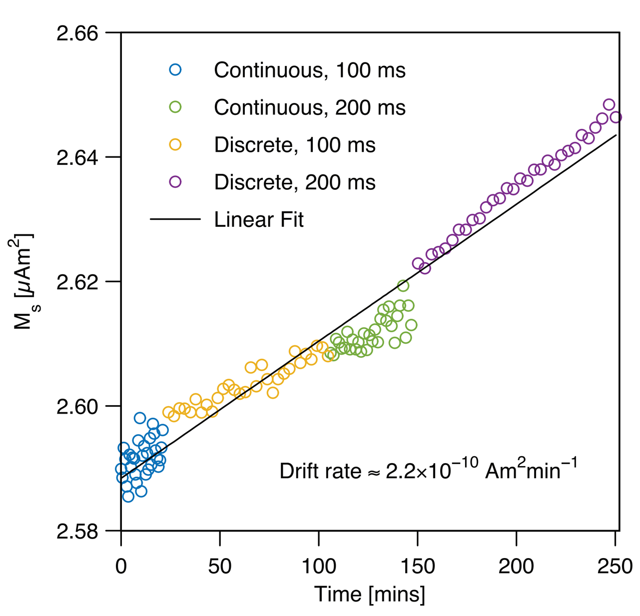
2. Measuring Loops



- Modern instruments have a wide range of settings to help measure loops, especially for weak specimens.
- Increasing the measurement averaging time of each point by a factor *n*, reduces noise by a factor $\sqrt{n}$ (a & b).
- For fast measurements the applied field can be contiuous swept, but during each measurement the field changes. The field sweep can also be paused and allowed to settle before measurement (discrete sweep mode). For this specimen an *n* times increase in measurement time yields an *n* times reduction in noise (compare a and c)
- Stacking or averaging *n* loops reduces noise by a factor $\sqrt{n}$ (d - f).
- In discrete field sweep mode, the settling or pause time before measurement can be adjusted. Increasing the settle time by a factor *n*, reduces noise by a factor ~n^2 (g - i), but this rapidly approaches the instrumental nominal sensitivity; > 500 ms offers no further improvement.
- For weak and noisy hysteresis loops, measuring in discrete field sweep mode with averaging times of 100–300 ms and settling times of ~300 ms offers the best balance between maximizing signal-to-noise, while maintaining a reasonable measurement time.
- For strong specimens (e.g., volcanics) measurement in continuous mode with short (~100 ms) averaging times is usually sufficient.

3. Measurement Drift

- The sources of drift can be difficult to characterize and quantify, many can be related to temperature or mechanical effects.
- Mechanical factors can be related to the solidity/friability of the specimen, specimen position during measurement, or the physical mechanisms of the instrument being used.
- Right is an example of long-term drift from a specimen slowly moving during measurement.



- Thermal factors are relevant not only to the temperature of the specimens being measured, but also to the temperature in the measurement space and to warming of the experimental apparatus as the experiments proceed.
- Part (a) below is a specimen that experiences thermal drift, which changes the paramagenti contribution.
- Existing drift correction methods fail (c), so we introduce a new paramagnetic drift correction.
- Paramagentic magnetization:

$$M_p(B,T) = \frac{CB}{\mu_0 T},$$

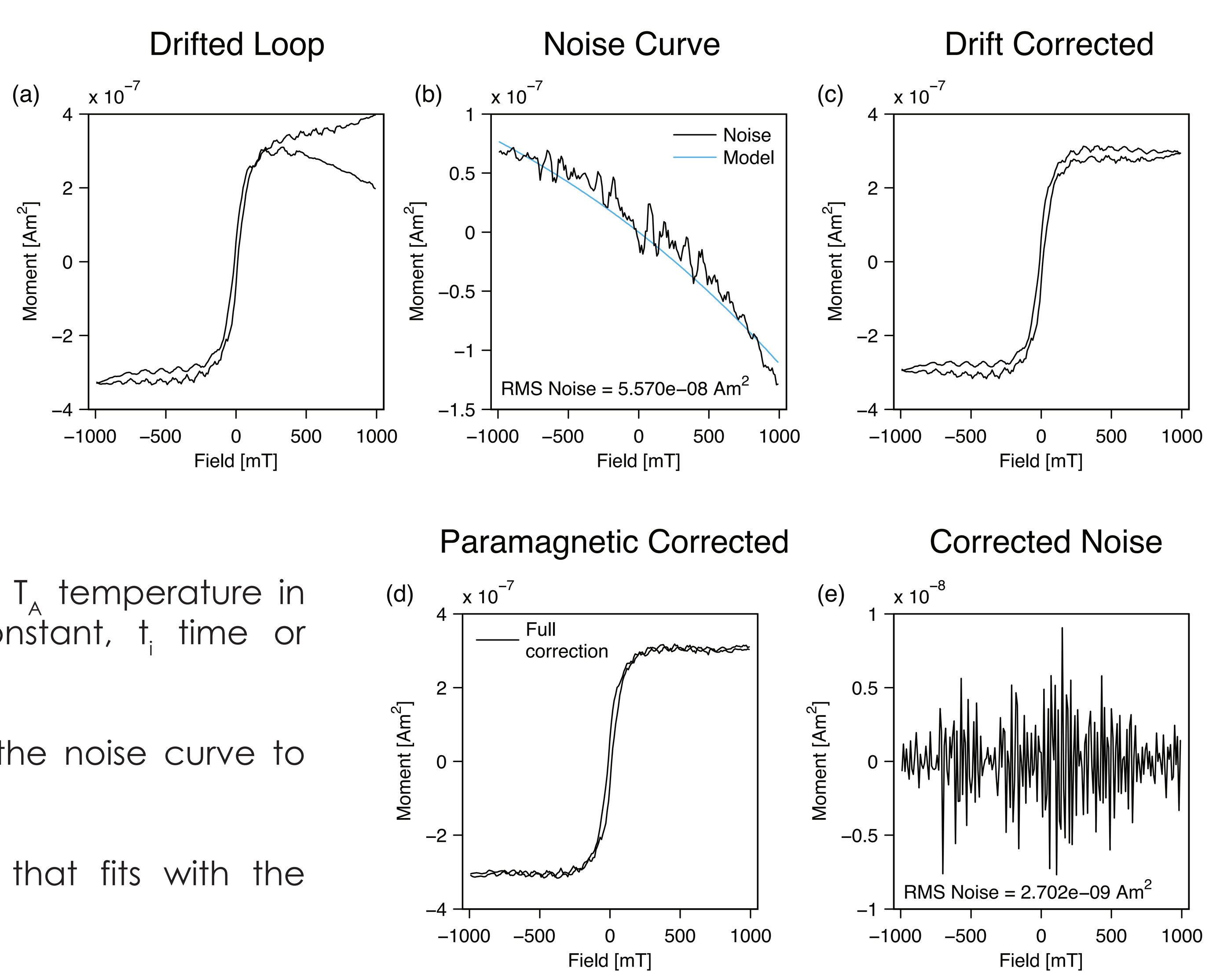
- As temperature changes:

$$M_p(B,T_i) = M_p(B,T_0)\frac{T_0}{T_i}.$$

- Newtonian cooling:

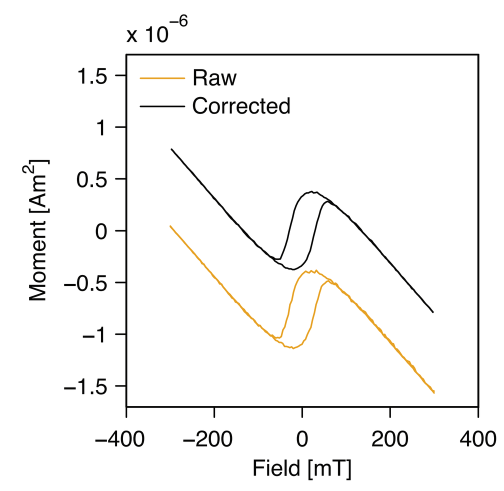
$$T(t_i) = T_A + (T_0 - T_A)\exp(-kt_i).$$

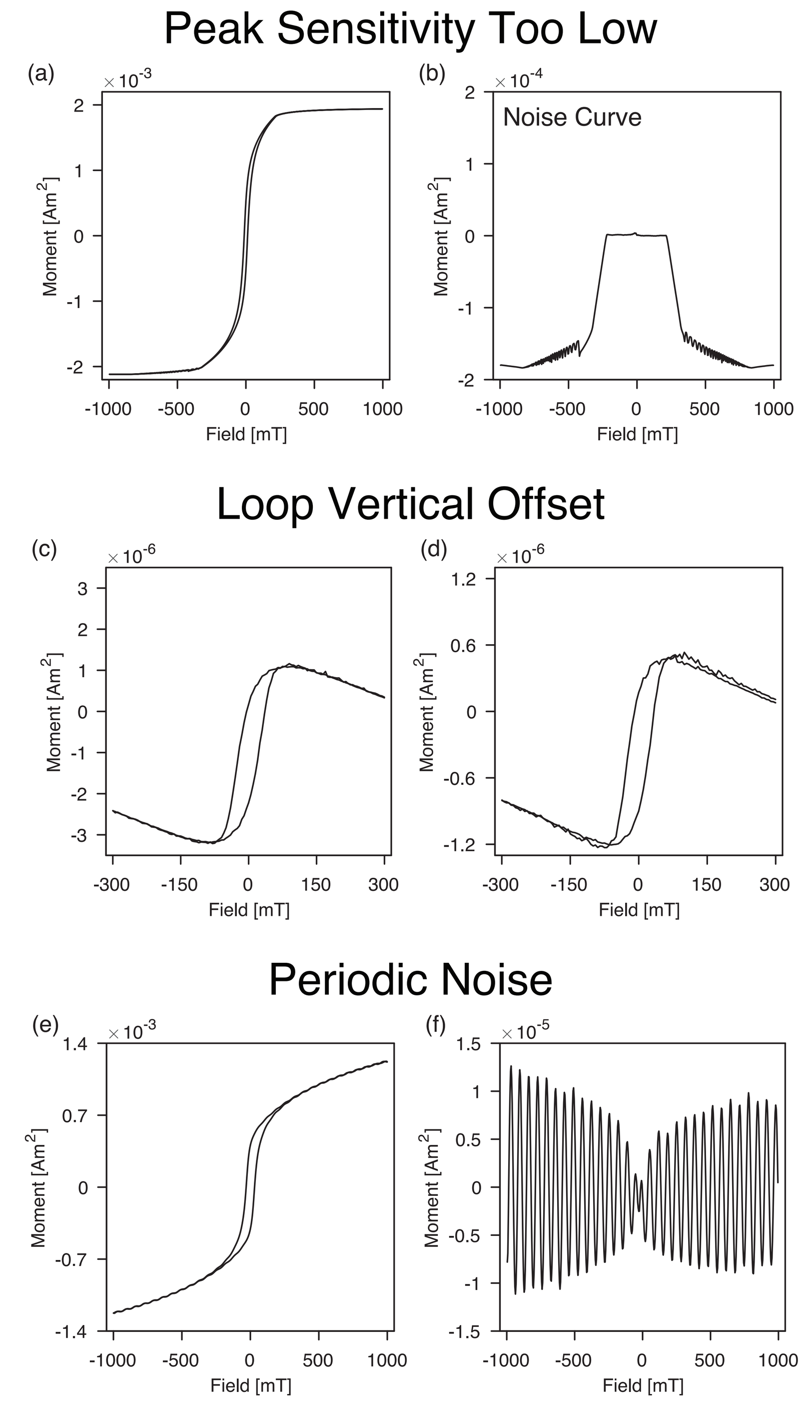
- T_0 specimen start temperature; T_A temperature in measurement space; k rate constant, t_i time or measurement number.
- The above model is fitted to the noise curve to correct for drift (b).
- Yields more satisfactory loop that fits with the geological context (magnetite).



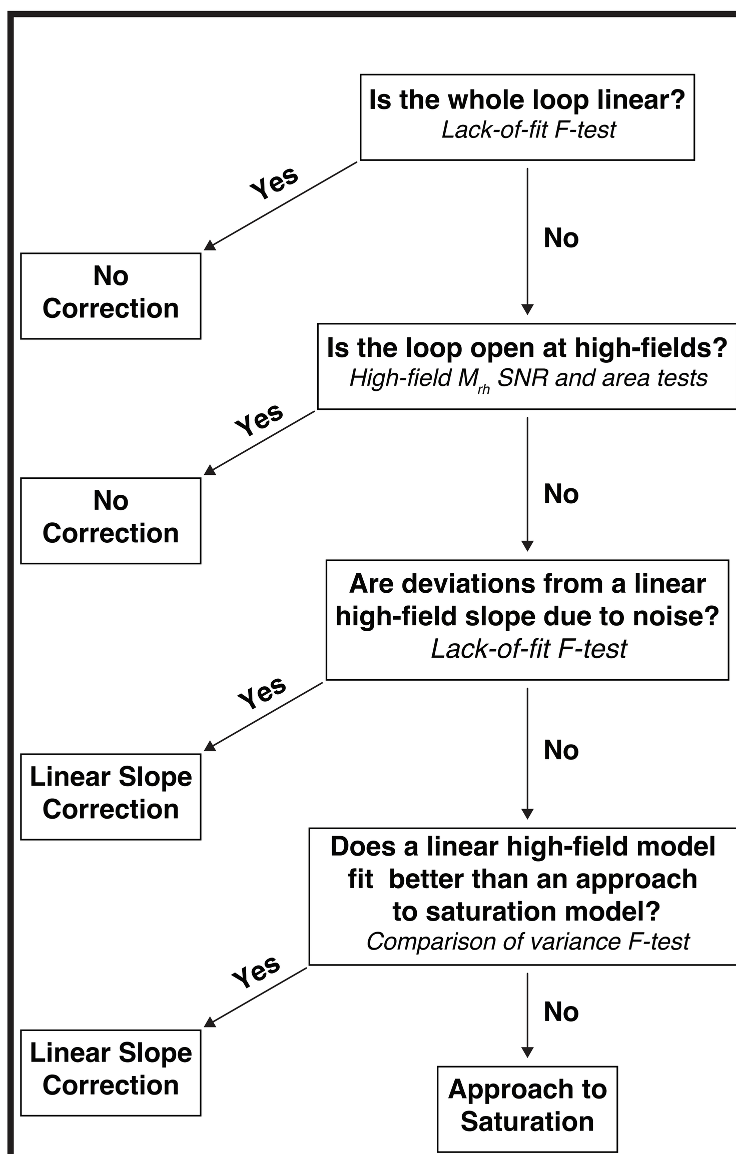
4. Unusual Behavior

- Sometimes unusal behavior manifests, but is usually an artifact.
- If measurement sensitivity is too low, loops appear to saturate (a, b).
- Electrostatic charges on plastic cubes can yield vertically shifted loops (c, d).
- Highly periodic noise is an indicator of vibrational instability (e, f), here likely due to electronic feedback.
- Some effects require remeasurement (and instrument checking), other can be corrected.
- Correcting loop offset.





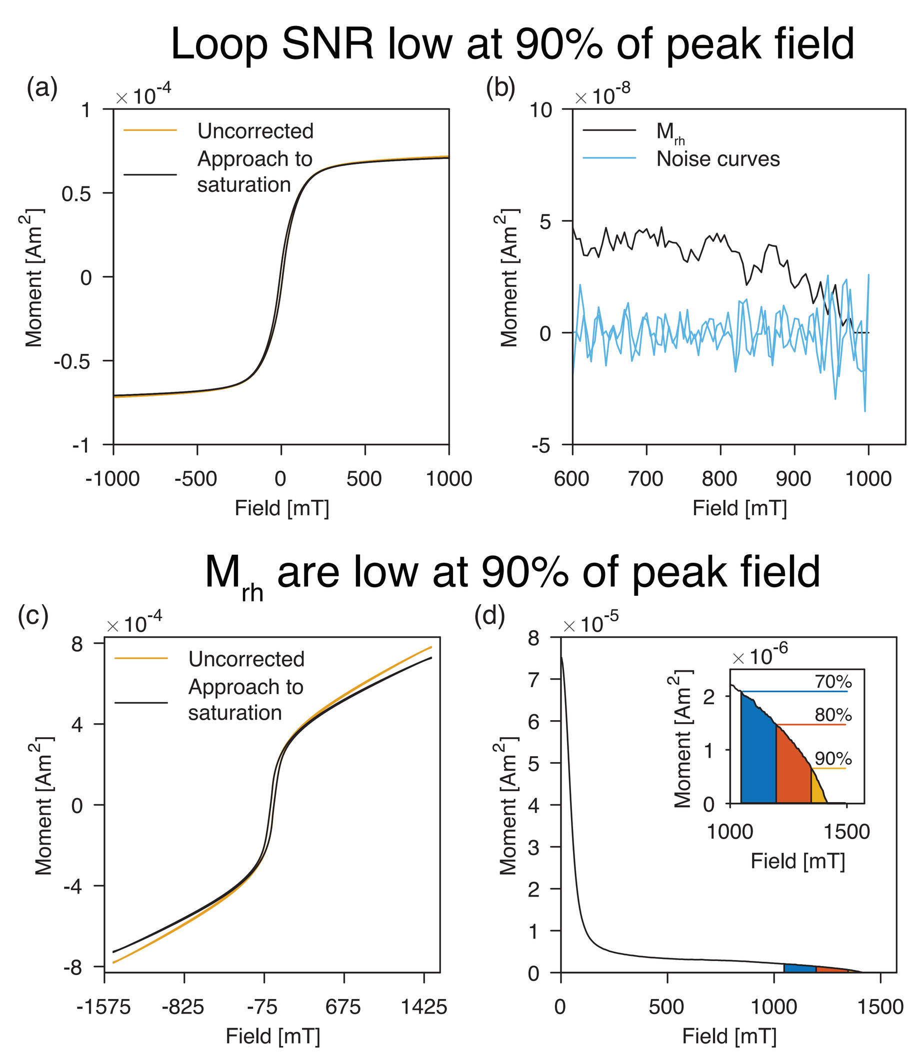
5. High Field Corrections



- High-field slope corrections need to be applied, but are not always appropriate and it is difficult to decide what method to use.
- We define a decision process to apply no correction, a linear high-field slope correction, or an appraoch to saturation correction.
- Expands on the apprach of Jackson & Solheid (2010, G-Cubed, doi: 10.1029/2009GC002932).
- If a loop is open, no correction is appropriate, so we develop new tests for loop openness:

  1) Signal-to-noise ratio of high-field M_{rh} curve should be high (can see a signal).

  2) Area of high-field M_{rh} curve should be a large portion of the total area (the signal should be large).



6. HystLab

- To help process loop data and do these new things we developed HystLab.
- MATLAB based GUI (no extra tool boxes).
- Supports a wide range of formats:
  - Princeton VSMs and AGMs
  - Lake Shore 7400/8600 VSMs
  - Microsense VSM
  - If we don't have it we will add it!
  - Quantum Designs MPMS
  - VFTB
  - MagIC support in development (data input and output)
- Also performs loop fitting.
- Loop quality quantification and a wide range loop statistics.
- Publication ready images.

Time for a demonstration!!

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