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Measurement of Magnetic Particle Concentrations in Wildfire Ash via Compact NMR

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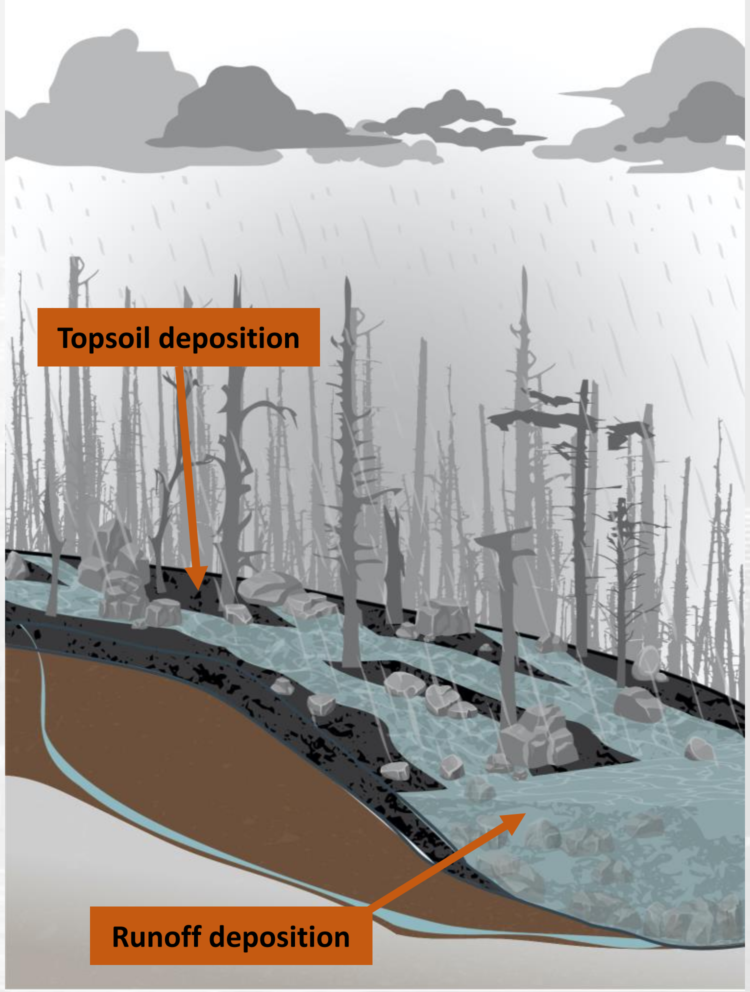
Why monitor magnetic contents of wildfire ash?

- Effects on topsoil
  - Ash deposits enhance magnetic content in soil
  - Magnetic properties are closely related to climate & rainfall
- Deposition through runoff water
  - Nearby bodies of water accumulate magnetic content
  - Nanoscale magnetite is linked to brain disease
- Understand fire severity and the reaches of magnetic deposition



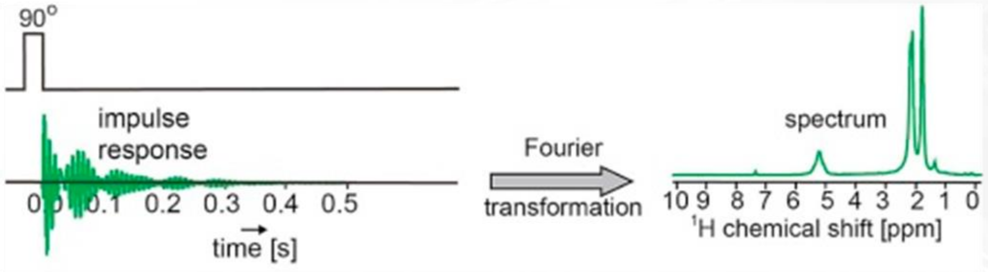
USGS, "How wildfires threaten U.S. water supplies," Water Data Labs, 06-Nov-2020. [Online]. Available: https://labs.waterdata.usgs.gov/visualizations/fire-hydro/index.html#/. [Accessed: 28-Oct-2022].

Goals

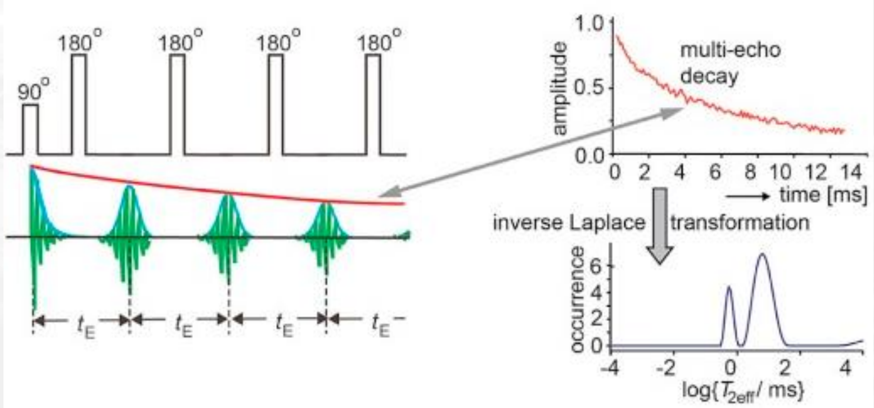
- Quickly assess total magnetic particle (MP) concentrations in ash & water
  - Magnetite + maghemite
  - Public health school currently uses synchrotron (complex, time-consuming, not portable)
- Develop a system for eventual in situ use
- Best candidate: nuclear magnetic resonance (NMR)

Nuclear magnetic resonance (NMR) techniques

- High-field NMR spectroscopy
  - High quality molecular structure data
  - Information about environment around nucleus
  - High cost, not portable, difficult to achieve magnetic field homogeneity
- Low-field NMR relaxometry
  - Very low-quality molecular structure data
  - Information about **environment around nucleus (relaxation rate)**
  - Low cost, portable, **no demands on field homogeneity**



B. Blümich, "Introduction to compact NMR: A review of methods," TrAC Trends in Analytical Chemistry, vol. 83, pp. 2–11, Oct. 2016.



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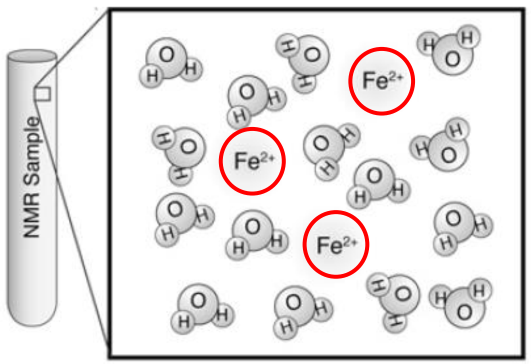
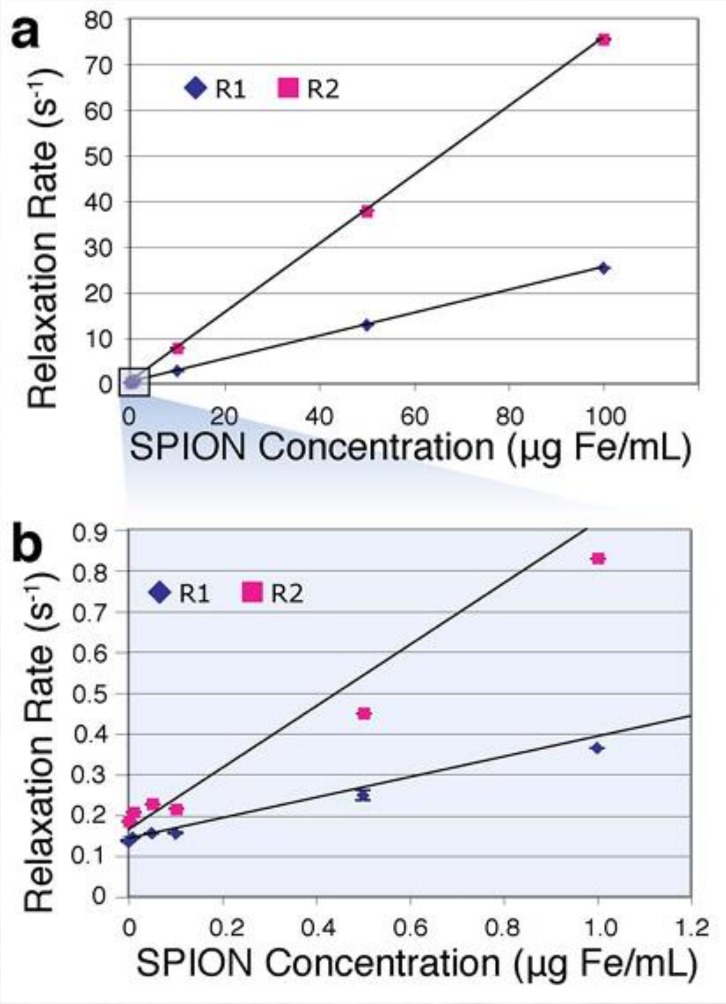
NMR Relaxometry with MPs

- Transverse relaxation (R2) rates are related to MP concentration (magnetic environment)
- Linear relationship is well established
- **Objective: Dissolve ashes in water to measure MP content via compact NMR**

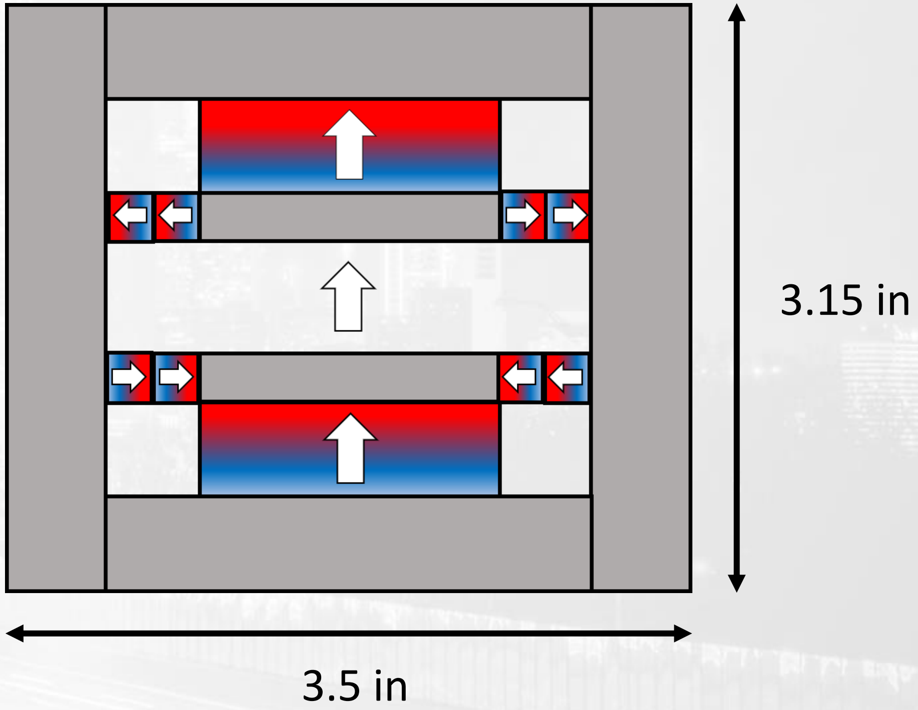


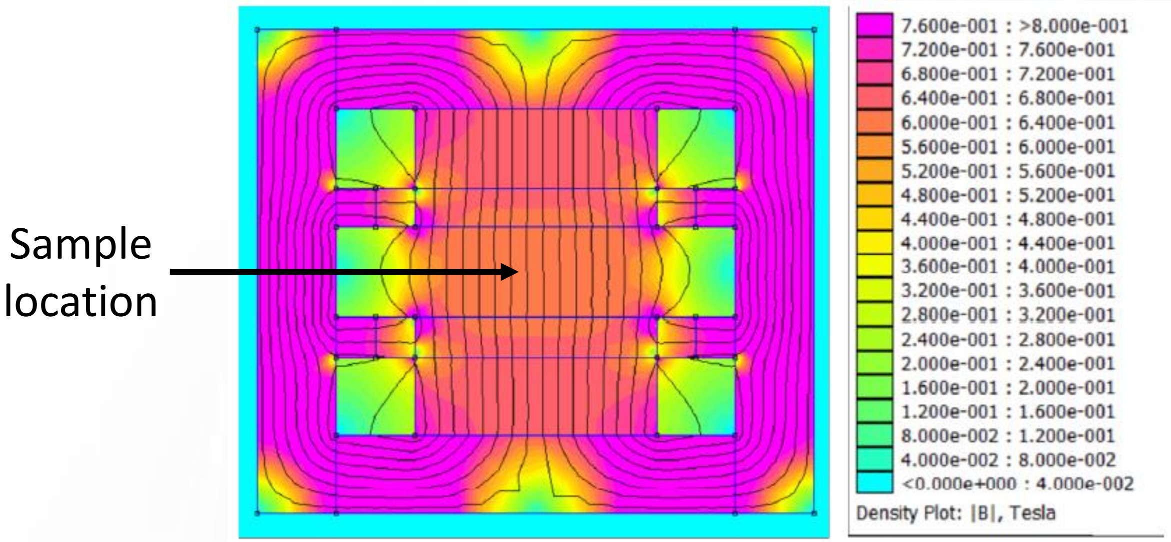


Gunn, J., Paranji, R. K., and Zhang, M., 2009. "A simple and highly sensitive method for magnetic nanoparticle quantitation using 1H-NMR spectroscopy". Biophys J, 97(9), Nov., pp. 2640–2647.

Permanent Magnet Array

- Components:
  - N42 NdFeB permanent magnets (8)
  - 1018 steel return yolks
  - 1018 steel magnet caps (2)
- 2D finite element simulation
  - Field strength ≈ 0.65 T

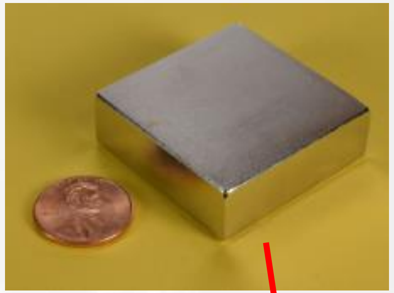




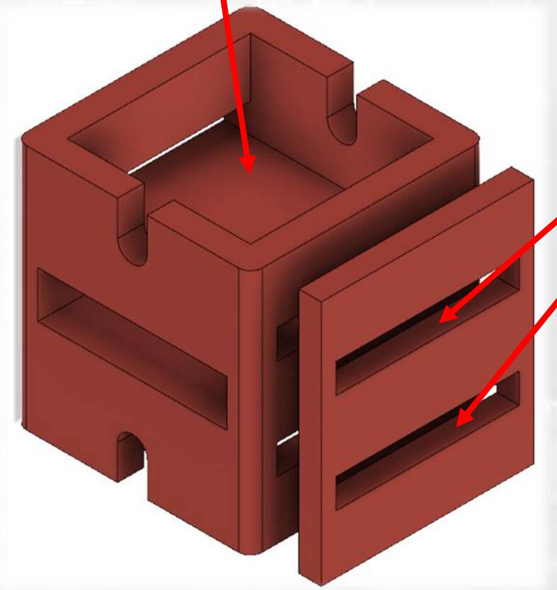
Permanent Magnet Array

- **0.565 T** strength at 23°C
  - -800 ppm/K gradient
- Larmor (operating) frequency:
  - $f_{Larmor} = \gamma B = \left(42.58 \frac{MHz}{T}\right)(0.565\ T) \approx \mathbf{24\ MHz}$
- 150 ppm homogeneity
- 4.4 lbs

N42 magnet

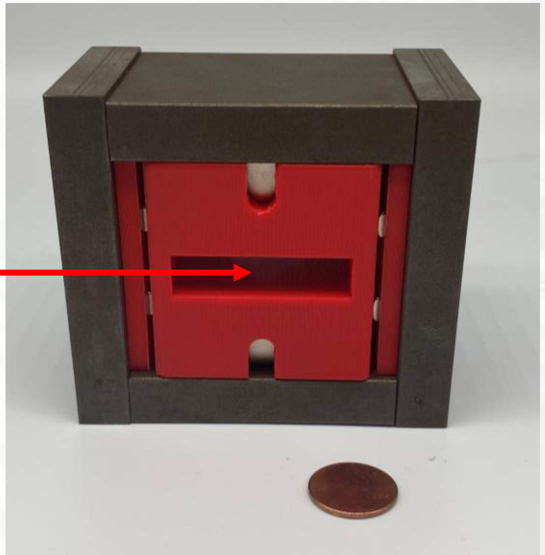


N42 magnet



3D printed guide

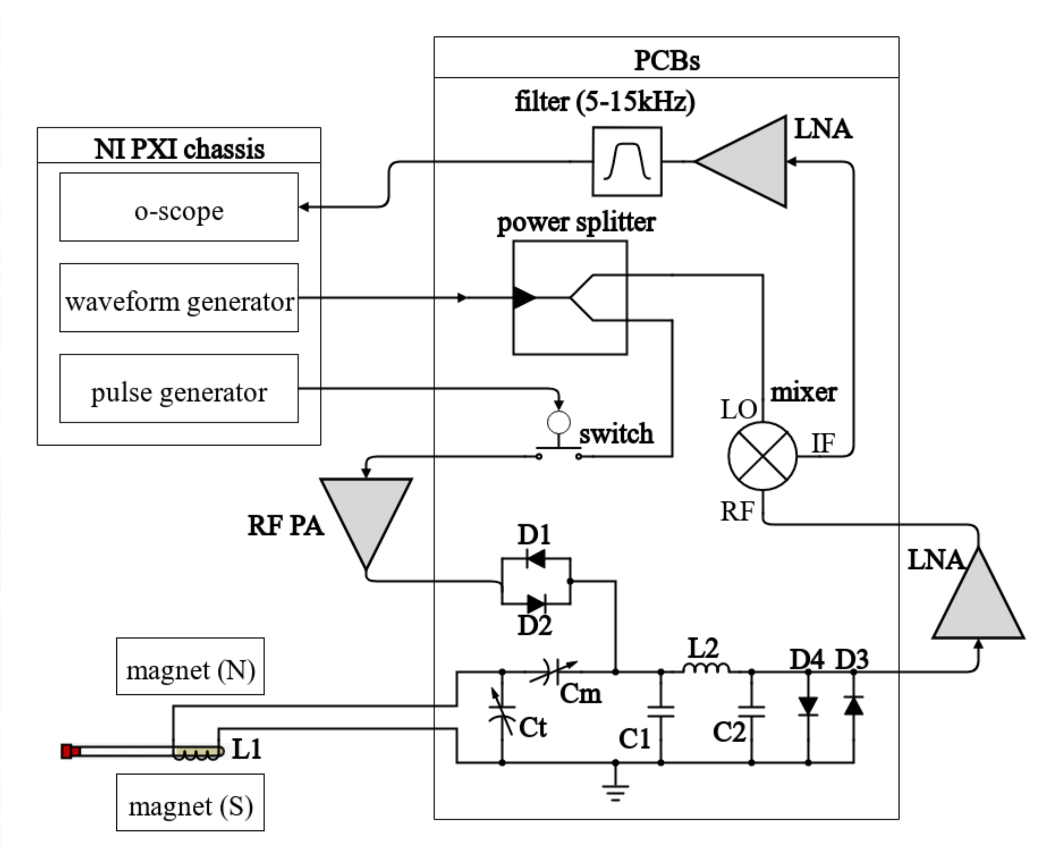
Sample location



Fully assembled

Signal Processing & Amplification Electronics

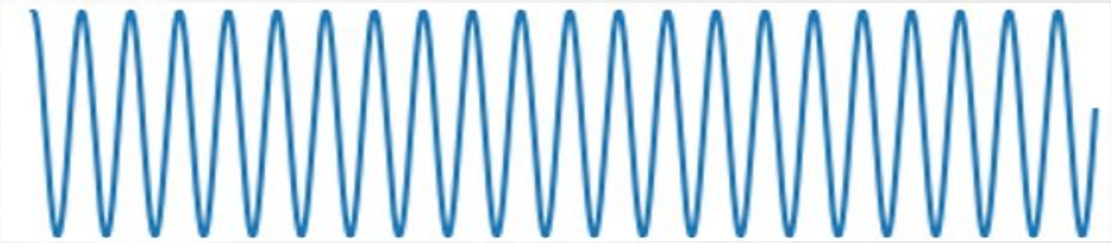
- All ports & PCB traces matched to 50 Ω
- One 24 V power supply required
- 24 MHz pulse amplified to 35 dBm
- Duplexer isolates probe and LNA
- NMR signal amplified 80 dB before acquisition



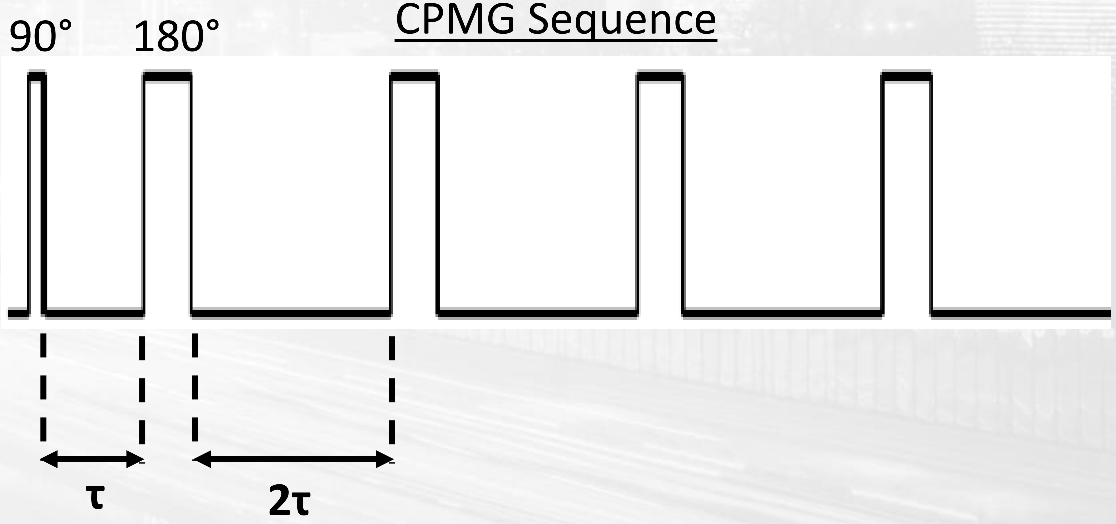
Signal Generation, Control, & Data Acquisition

- NI PXI chassis
  - Arbitrary waveform generator
  - Pulse train generator
  - 16-bit digitizer
- CPMG pulse sequence
  - 90° pulse time = 6 μs
  - τ = 0.625 ms

24 MHz sine wave

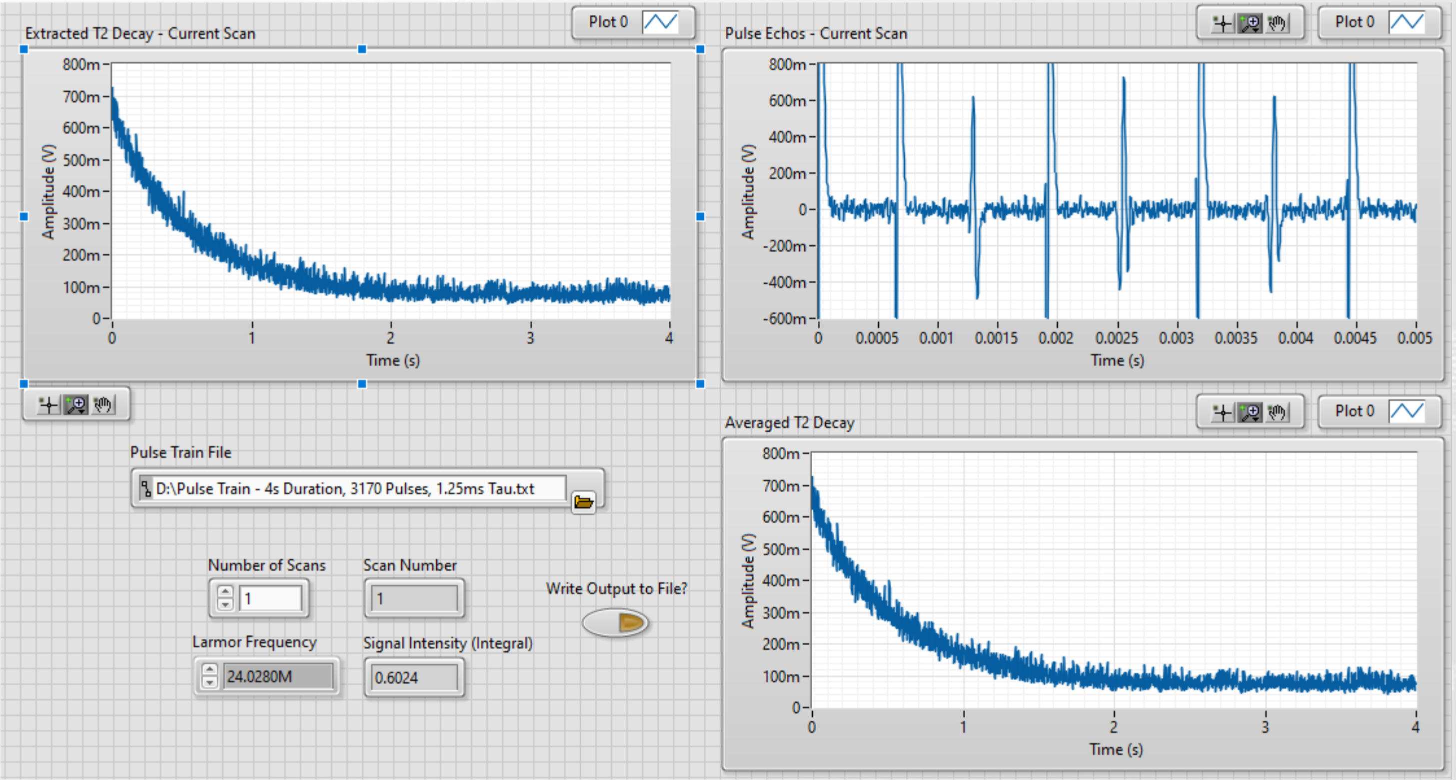


CPMG Sequence

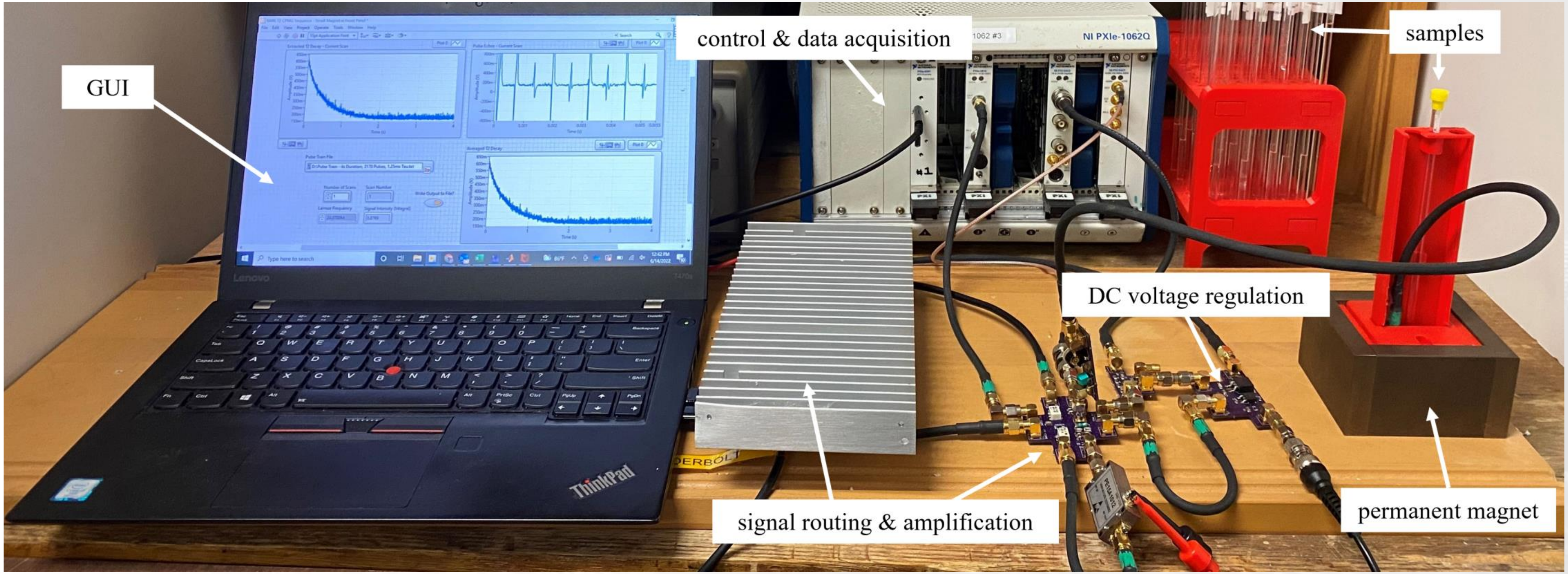


Signal Generation, Control, & Data Acquisition

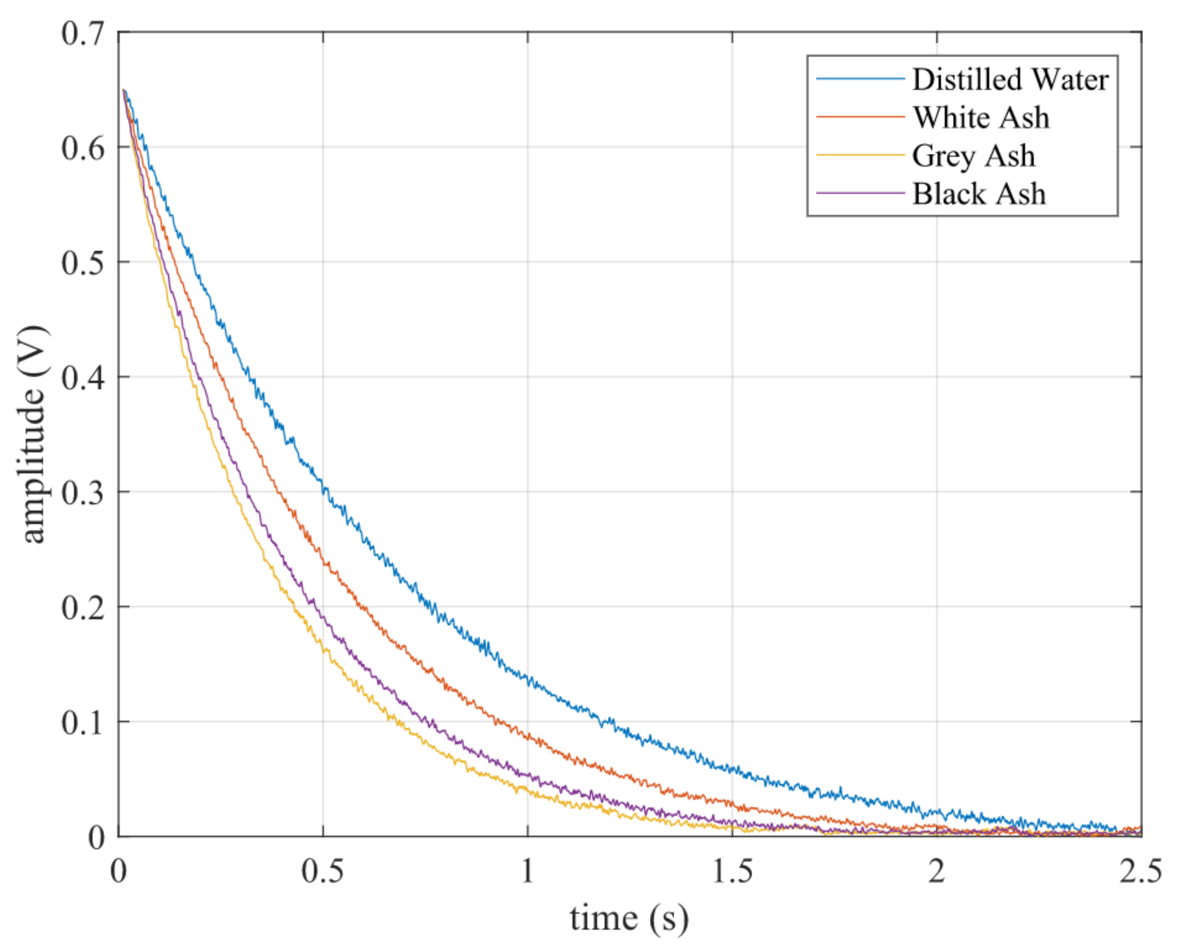
- Thermocouple used for frequency calibration (magnet gradient)
- LabVIEW GUI
- 8 scans (averages) takes 2 min.
- Transverse decay model:
  - $M_{xy} = M_0 \exp(-R_2 t)$



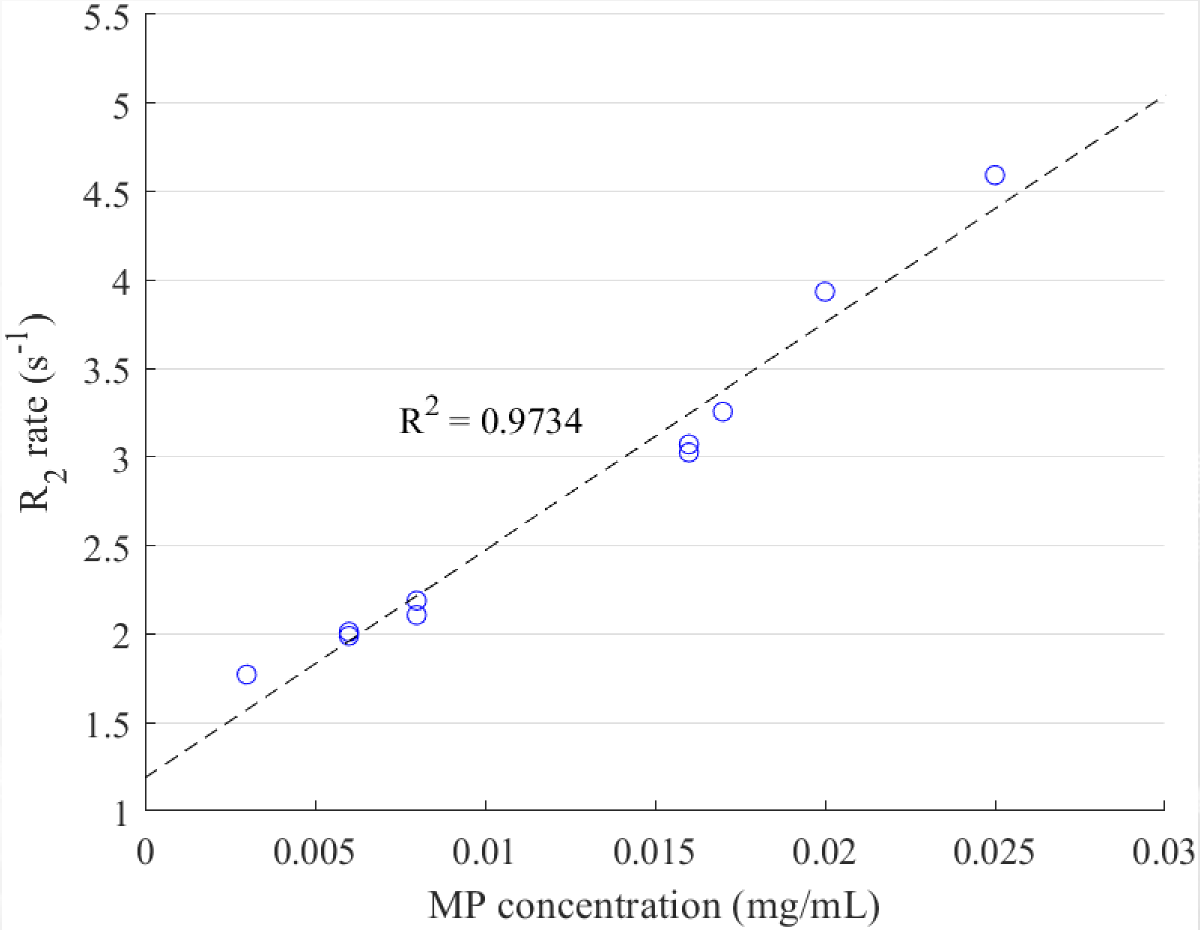
Full Desktop System



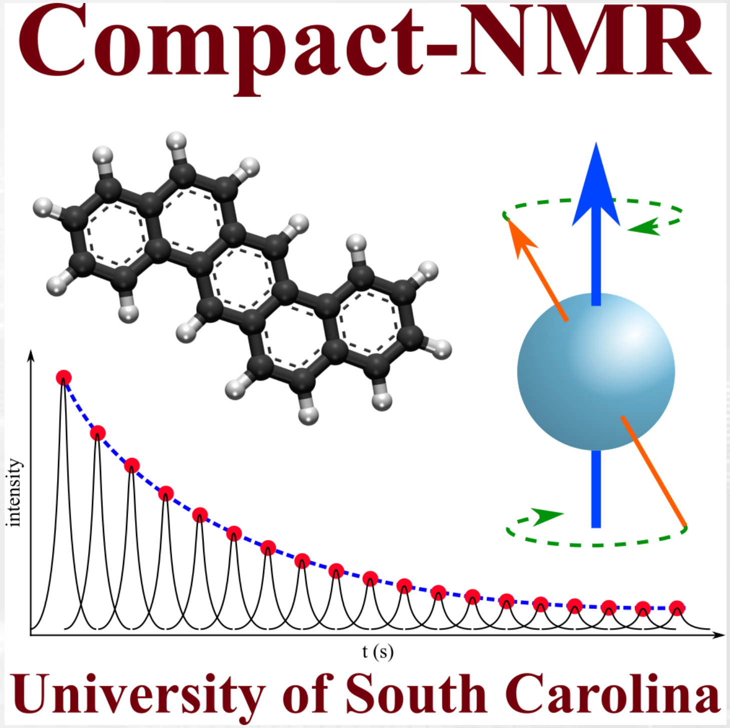
- 10 total ash samples
- 20 mg in 20 mL of water
- Distilled water used as reference
- R_2 extracted via least squares regression
  - $M_{xy} = M_0 \exp(-R_2 t)$



- Ash samples analyzed using synchrotron
- Total iron content collected
- Only magnetic iron (**maghemite & magnetite**) affect R2 rates
- Linear relationship verified



- Magnetic content in wildfire ash can be measured via compact NMR
- Robust and compact permanent magnet array sufficient for 5mm NMR tubes
- Simple and rapid tests to quantify MP content compared to current method
- Currently working to implement for in situ monitoring



Thank you!

Questions?