

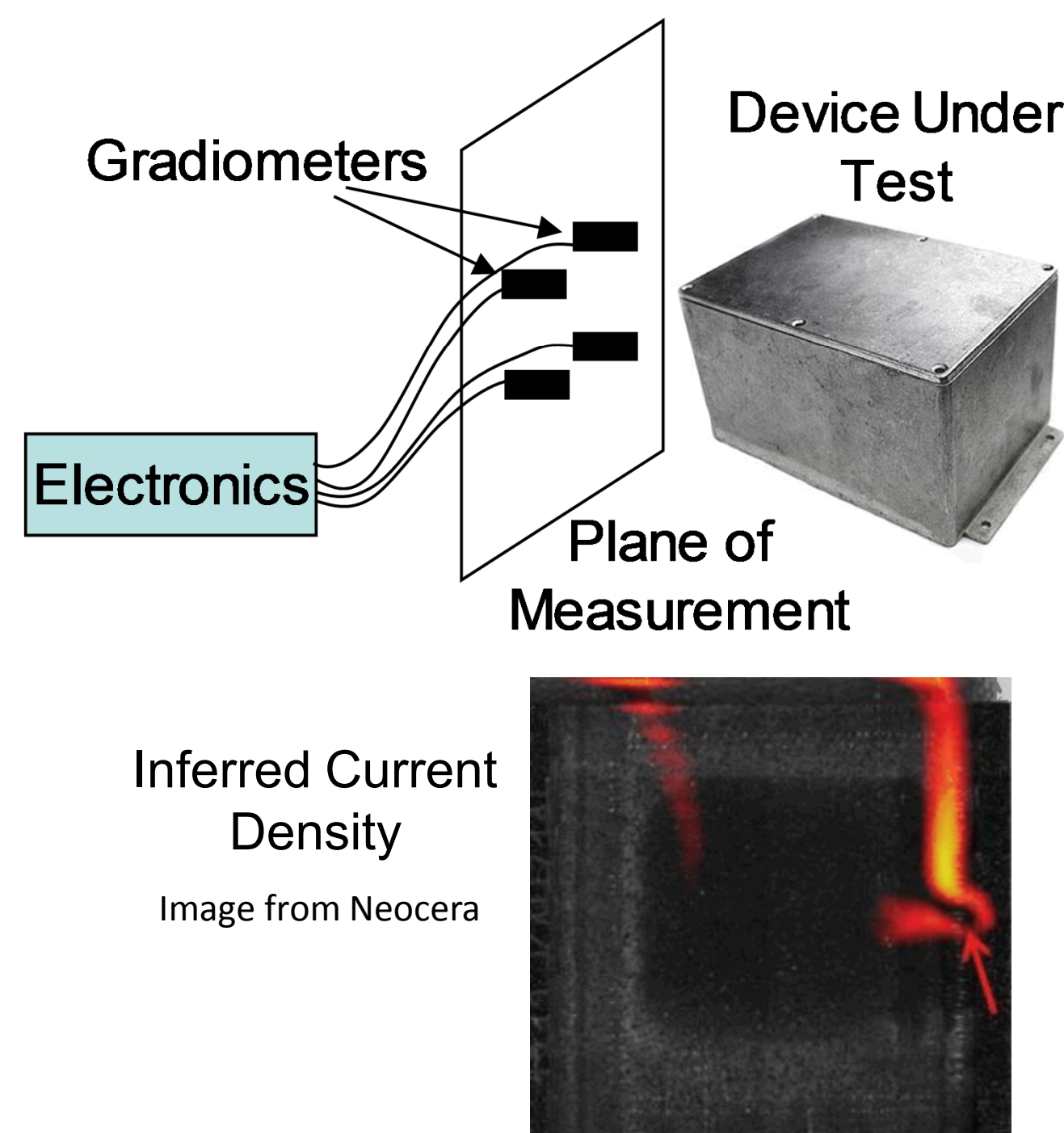
Magnetic Field Mapping for Characterizing Energized Electrical Circuits

SL17-B Field Mapping-PD3Ja

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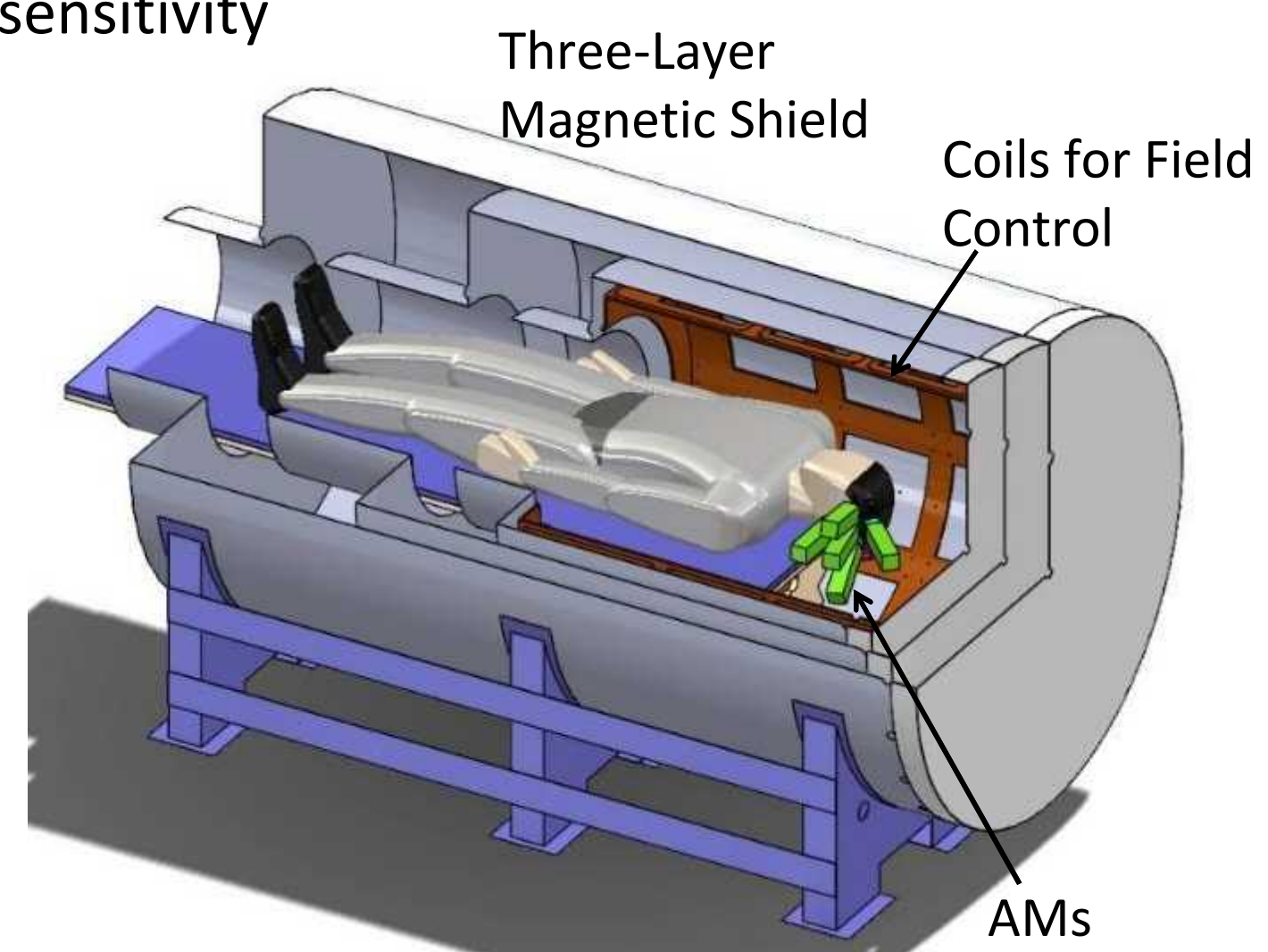
Long-Term Vision

- Use an array of highly sensitive magnetometers to map the magnetic field close to a device of interest.
- The magnetic field map is used to localize the electrical current.
- In conjunction with x-ray imaging, actionable information would be provided.
 - Localize critical circuit elements
 - Determine the state of the device



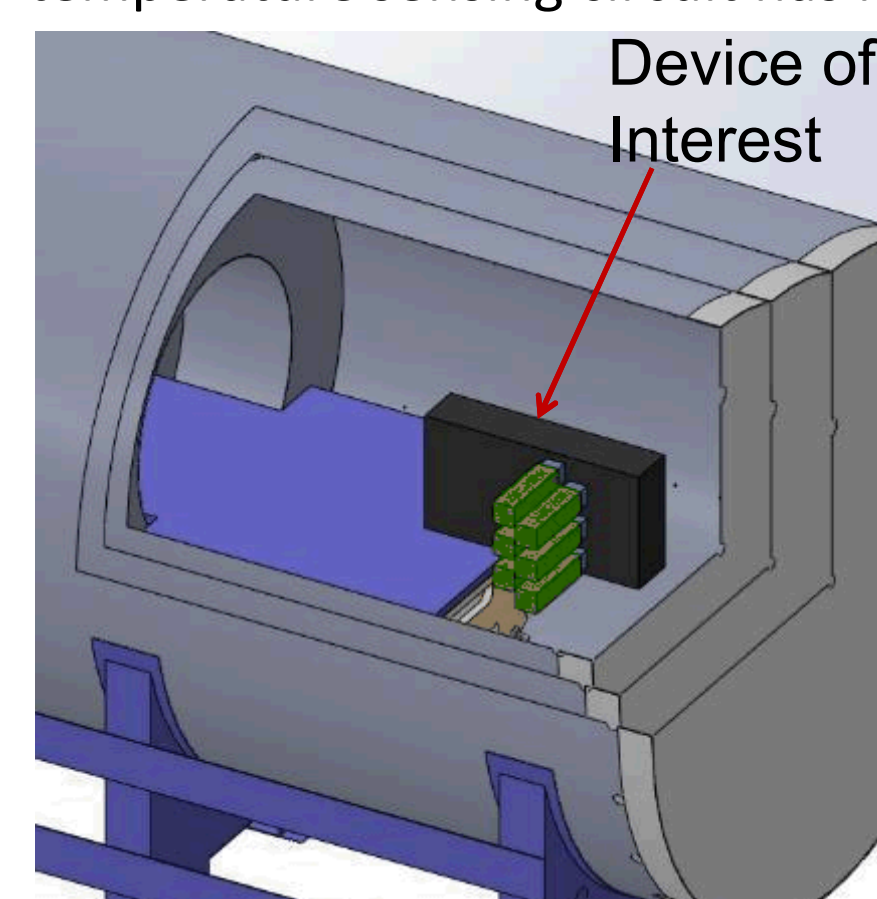
Current Atomic Magnetometer (AM) Array

- System designed for magneto-encephalography (measurement of the magnetic field of the brain)
- 20-channel AM array
 - Each sensor module has four independent magnetometers
- Fully functioning system with excellent field sensitivity



Adapt System for Electrical Circuits

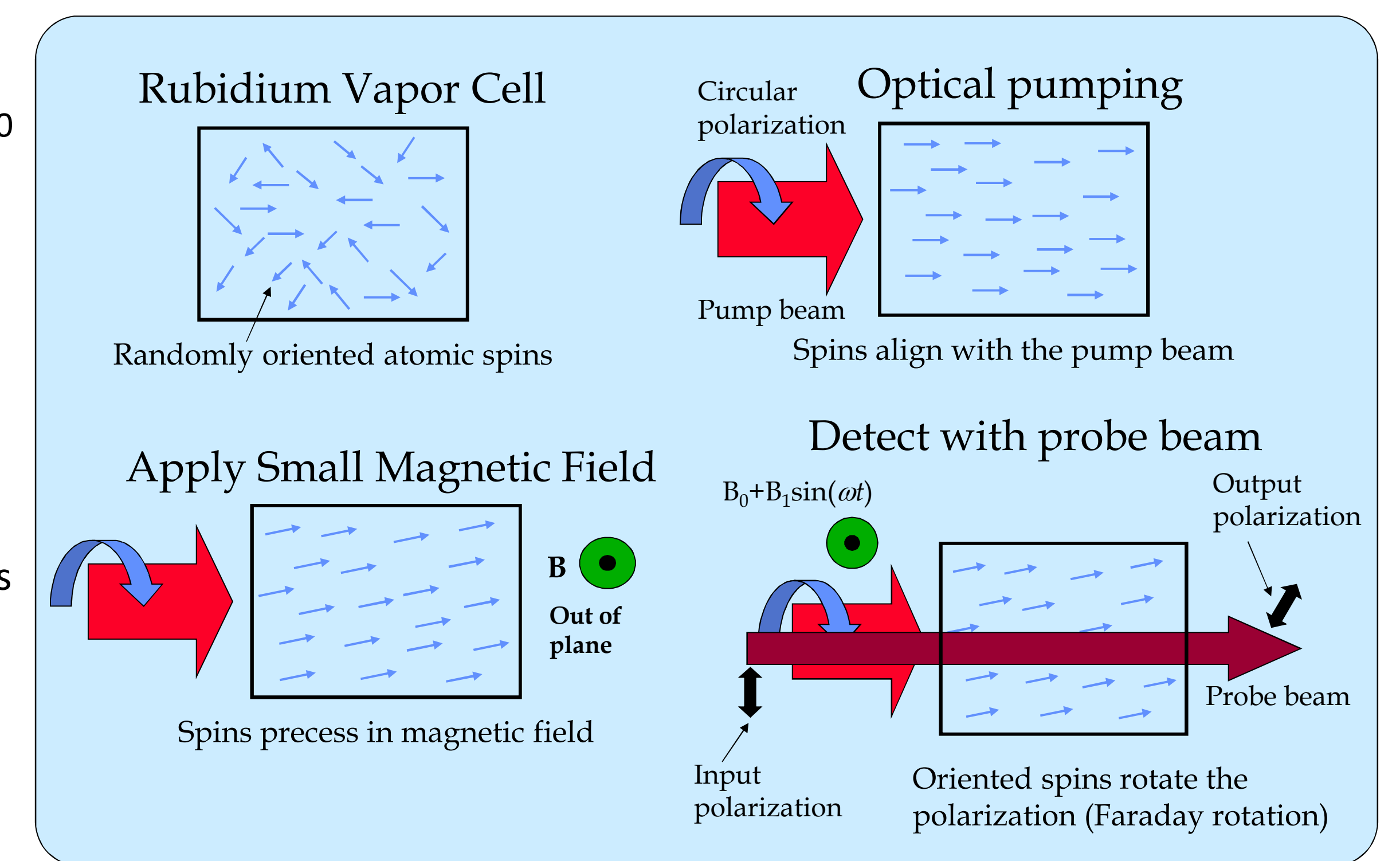
- Redesign for planar surfaces
 - Planning a 2x3 array
 - Raster device of interest over the array
- Upgrade system for more reliable and better calibrated operation
 - Work to remove drifts in sensor gain and sense angle (critical for localization)
- Implement a new heater driver for the array: temperature sensing circuit has noise



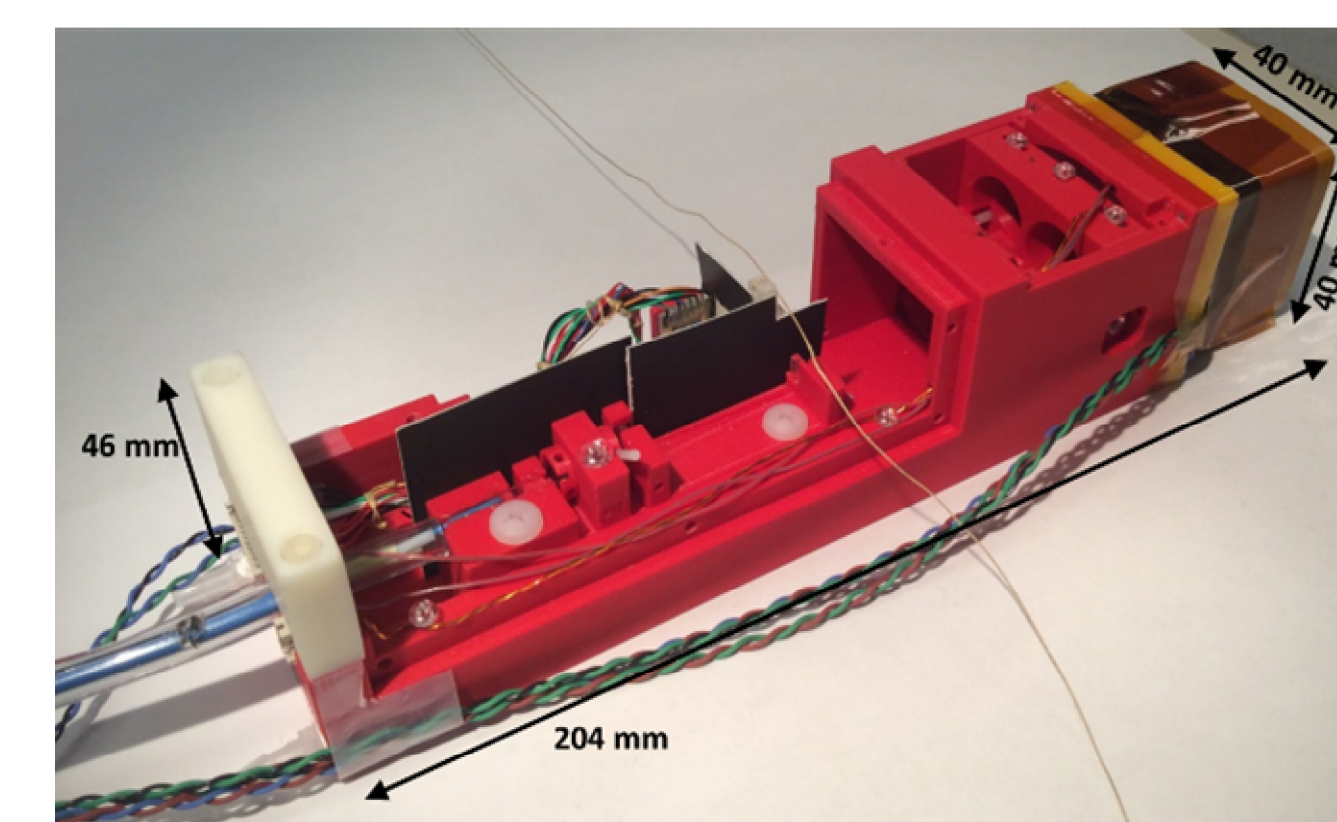
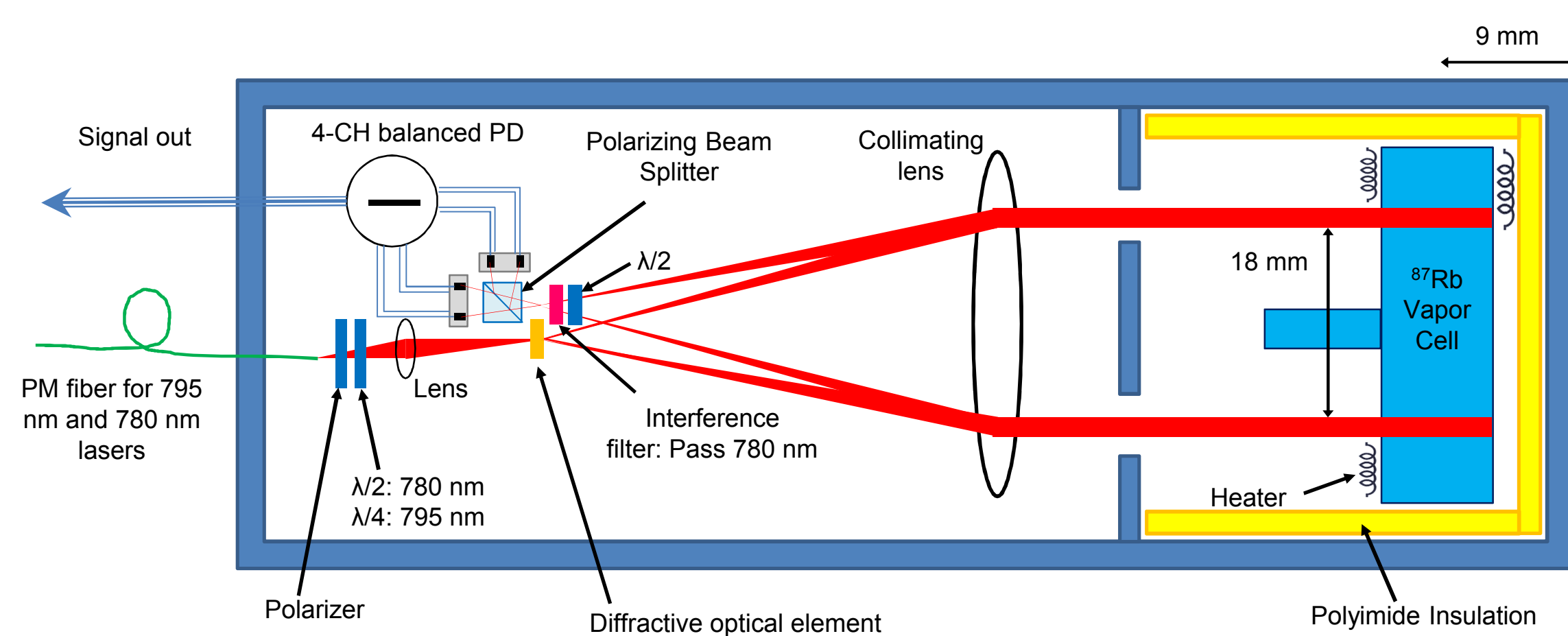
Risks and Mitigation

- Devices of interest may produce large DC/AC fields, saturating the AMs.
 - Mitigation: For DC and low frequency field these fields can be cancelled at the location of the magnetometers. Frequencies of 10 Hz to 10 kHz are a concern.
 - We may need to redesign our coil drivers to cancel larger fields.
- Using AMs outside of magnetic shield
 - Ambient fields and noise can saturate an unshielded AM.
 - Mitigation: Employ coils to cancel ambient fields and combine magnetometers to form gradiometers to exclude common mode noise.
- Device container can shield magnetic fields
 - A ferromagnetic box can shield low frequency magnetic fields and a conductive box shields high frequencies.
 - Mitigation: Perform modeling to understand shielding properties of containers to show the effectiveness of magnetic mapping.

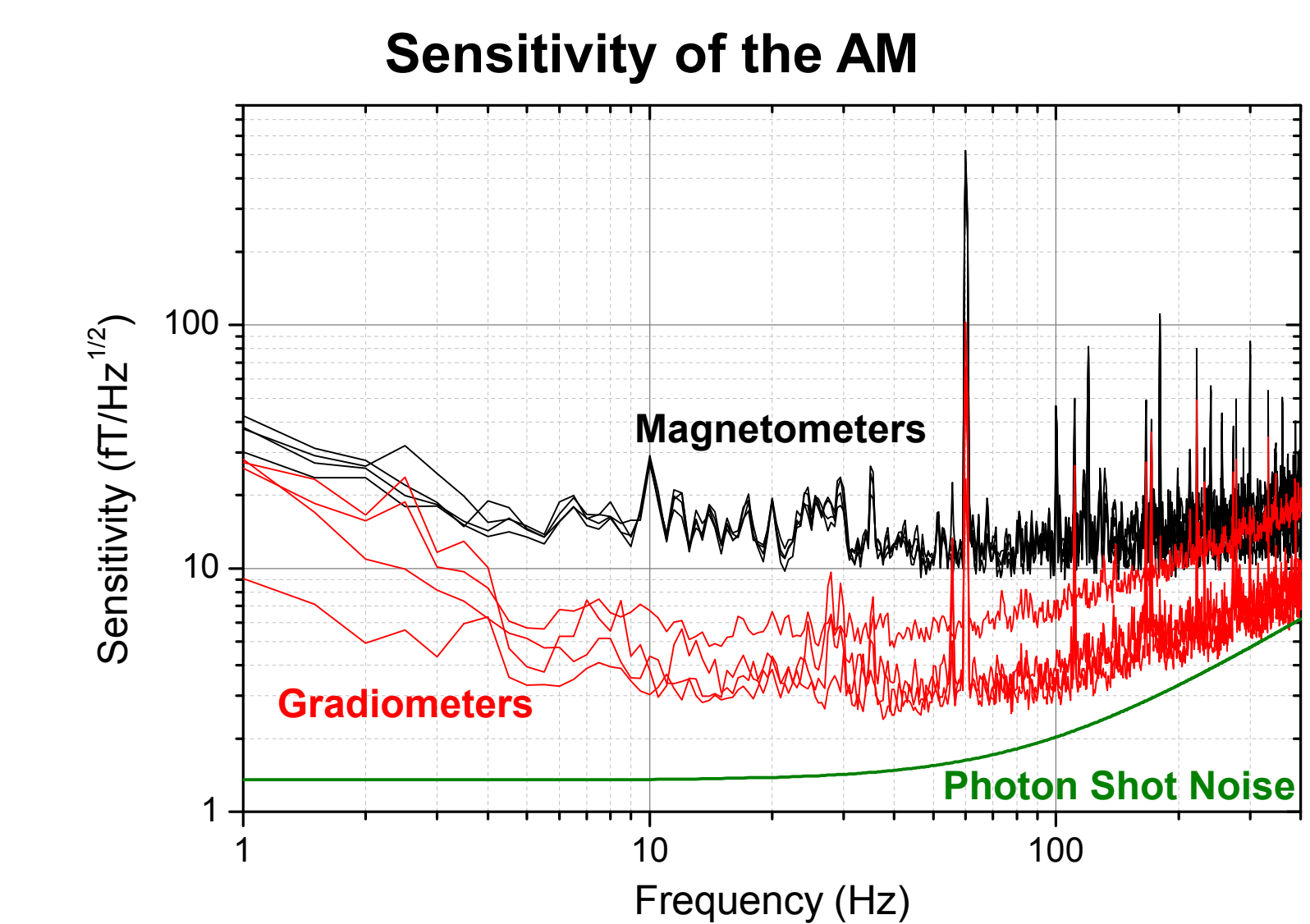
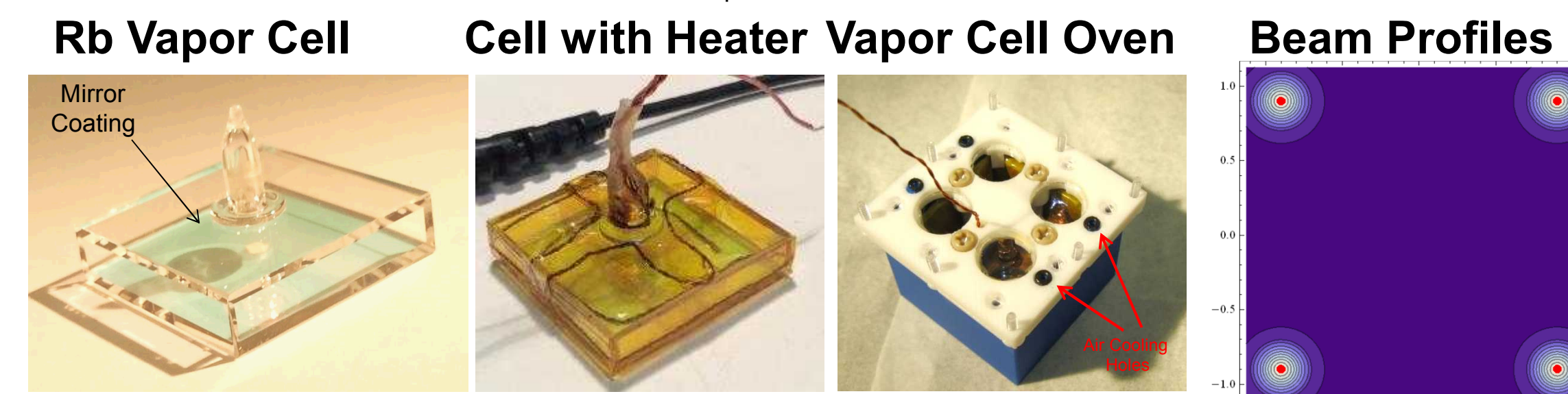
Low-field Optically Pumped Atomic Magnetometers



Four-Channel Atomic Magnetometer

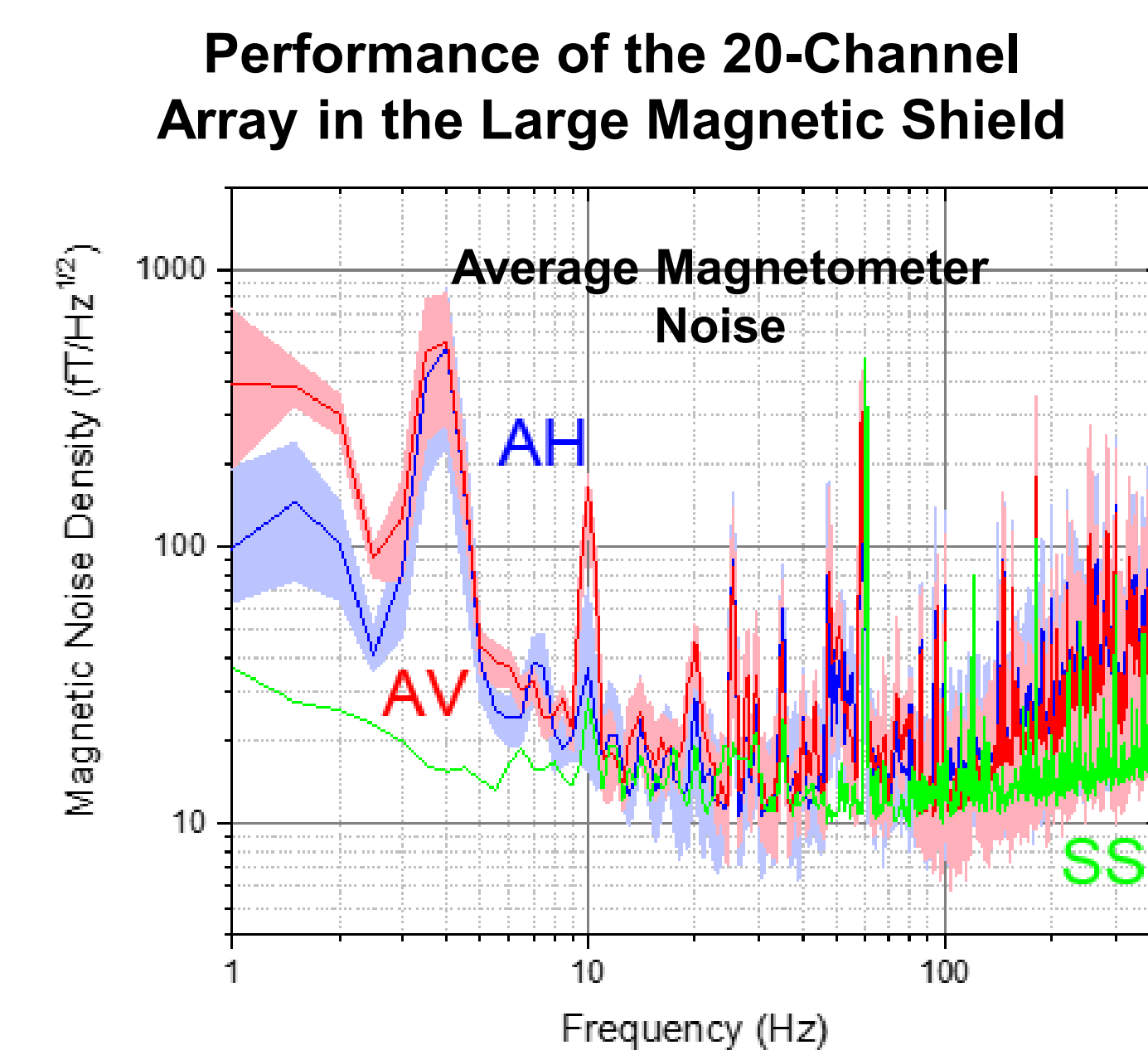


- Cell: 25 x 25 x 4 mm³, 600 Torr N₂
- ~2.5 mm FWHM beam diameters
- Current sensitivity: < 10 fT/Hz^{1/2} over 5-100 Hz
- Bandwidth: ~85 Hz

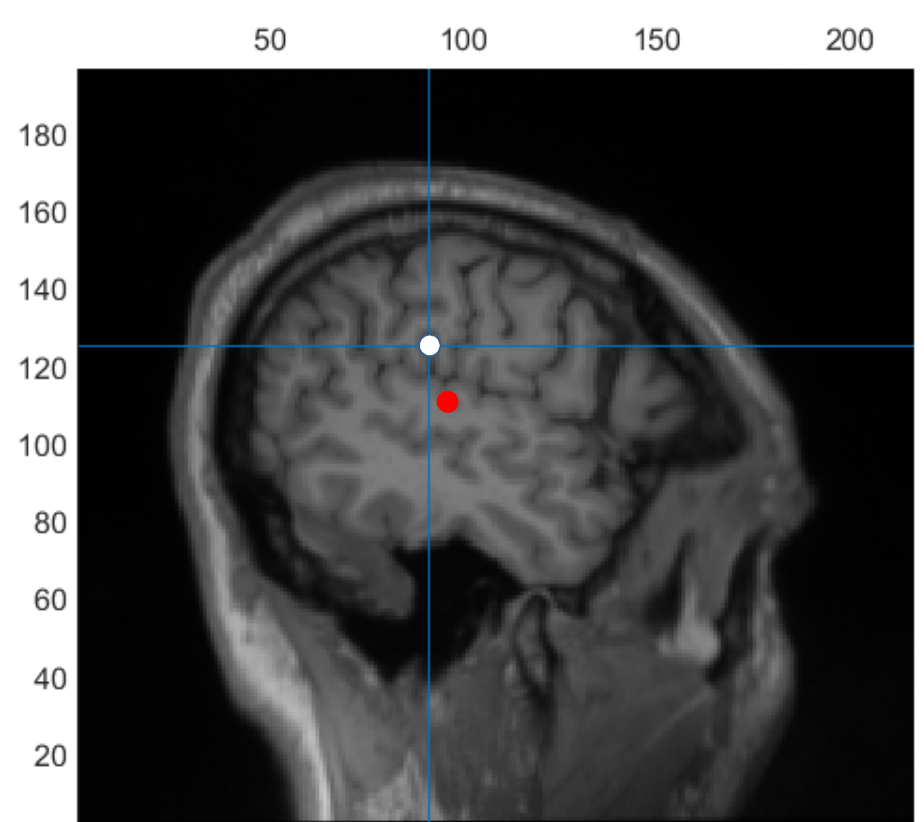
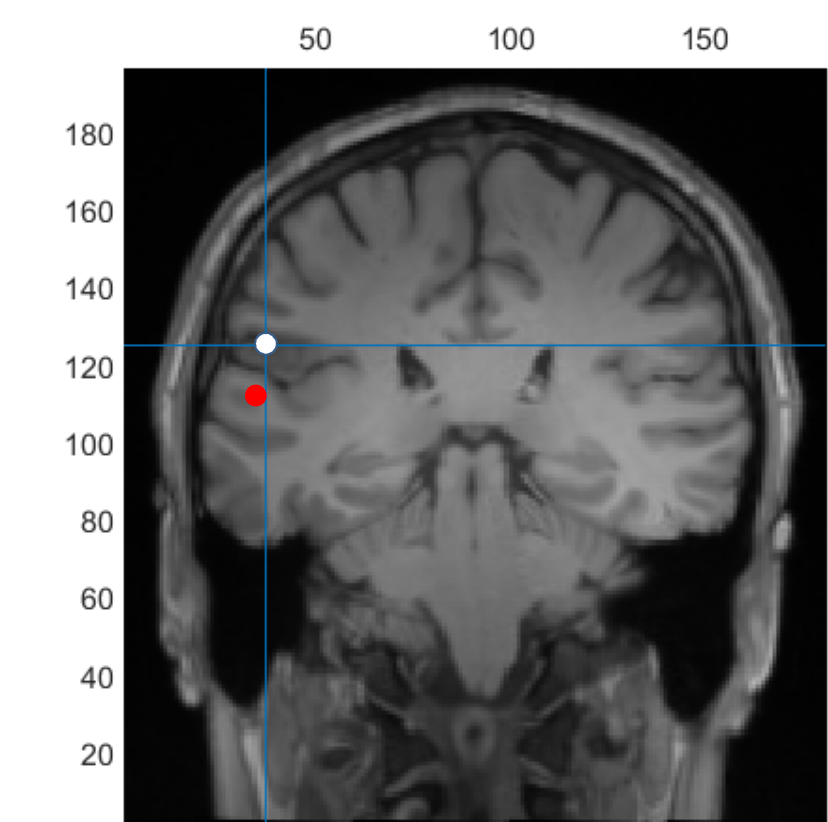


Gain and Bandwidth of the 4 Channels

Channel	Gain	3 dB BW
Ch 1	0.158 V/nT	83 Hz
Ch 2	0.14 V/nT	85 Hz
Ch 3	0.158 V/nT	87 Hz
Ch 4	0.228 V/nT	86 Hz



Preliminary Source Localization

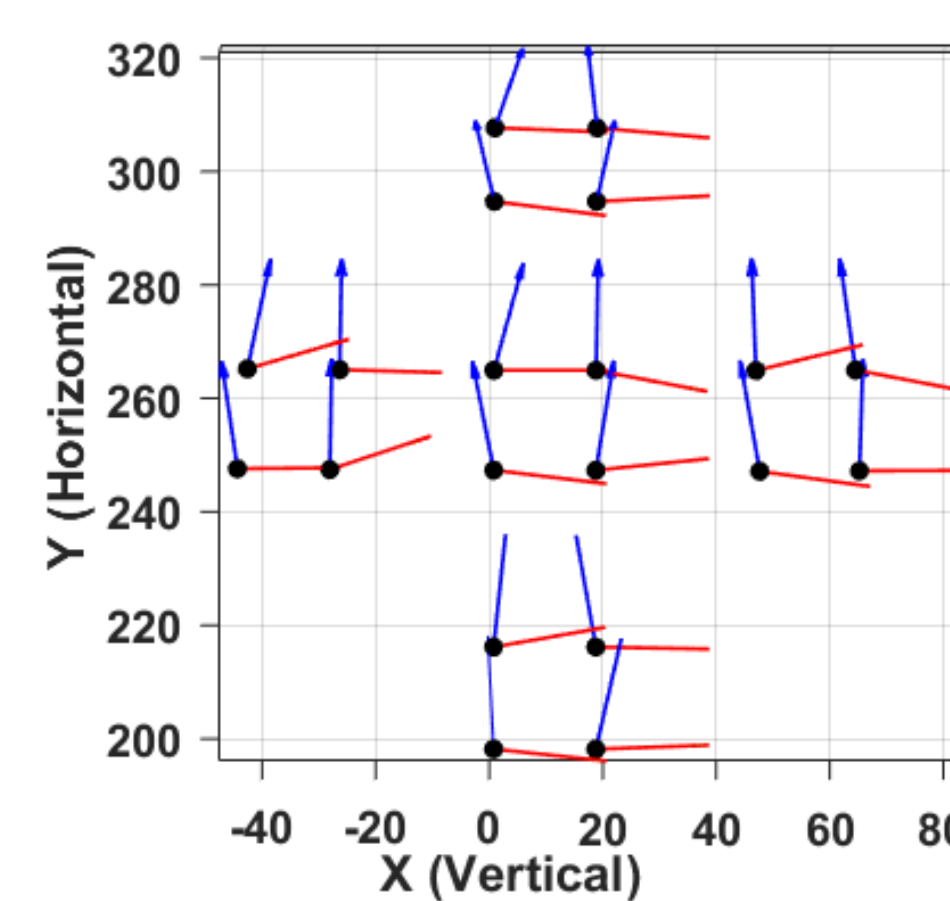


- Compare localization of brain magnetic sources by a commercial SQUID MEG system and the AMs
- Auditory Stimulation: 1000 Hz tone
- Red dot: Elekta SQUID system and software
- White dot: OPM data and Fieldtrip analysis software
- Difference: 1.5 cm

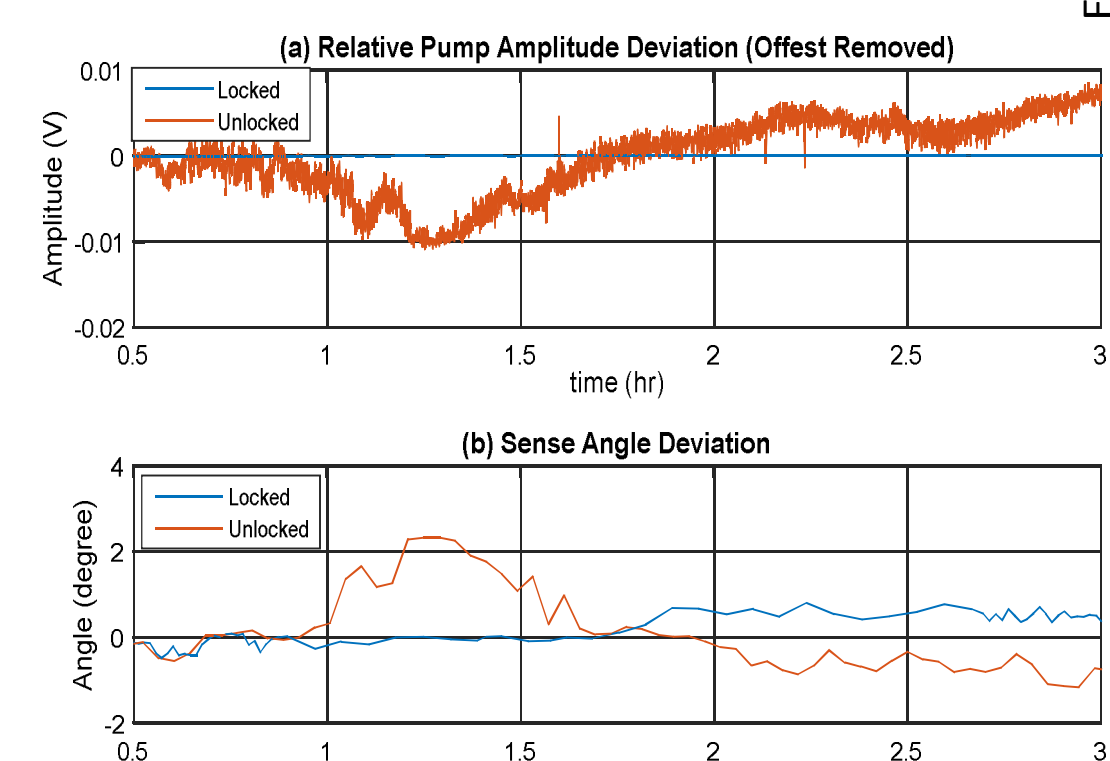
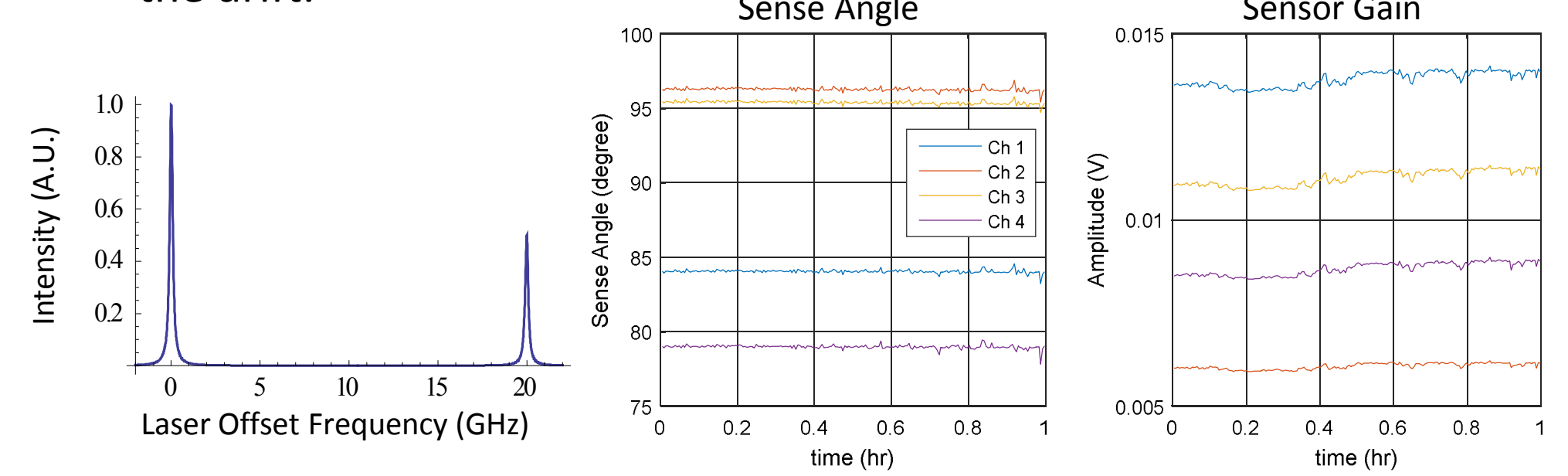
Studying Drifts in Sense Angle and Gain

- Source localization requires excellent calibration of the AMs.
- Sensor gain and sensing angle need to be known to < 1%.

Sense-Angle (Orientation)



- Pump laser is made up of two frequencies.
- Pump laser gives a fictitious magnetic field, which rotates the sense angle.
- Locked the relative frequency and amplitude but still saw drift.
- Using a single frequency pump laser greatly reduces the drift.



Tasks and Goals

Measure electronic devices of interest with our shielded atomic magnetometer (AM) array: (Years 1 and 2)

- Adapt our system to accommodate shoebox-sized test devices.
- Develop magnetic source localization algorithms.
- Measure devices of interest
 - Determining available signals in the 1 to 100 Hz range
 - Localizing current paths in the circuitry.

Demonstrate measurements outside of a shielded environment: (Years 2 and 3)

- Purchase eight newly developed high-sensitivity commercial AMs.
- Adapt the commercial AMs to the field mapping problem.
 - Difficult to operate in high noise environments
 - Employ gradient measurements of the magnetic field and field cancellation coils.
- Demonstrate the mapping of the magnetic field of a device of interest.

Gradiometry improves the performance



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