Diamond Sensors for Brain Imaging

This material is based upon work supported by the Assistant Secretary of Defense for Research and Engineering under Air Force Contract No. FA8721-05-C-0002 and/or FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Assistant Secretary of Defense for Research and Engineering.

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MIT Lincoln Laboratory

6 March 2018

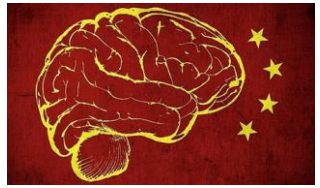
Brain Science

Human Brain Project
European Union

BRAIN INITIATIVE
BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES

Brain/MINDS
Japan

South Korea
Neuroscience



China Brain Project

The human brain is the most complicated biological structure in the known universe. We've only just scratched the surface in understanding how it works – or, unfortunately, doesn't quite work when disorders and disease occur.

- NIH Director Francis S. Collins, M.D., Ph.D.

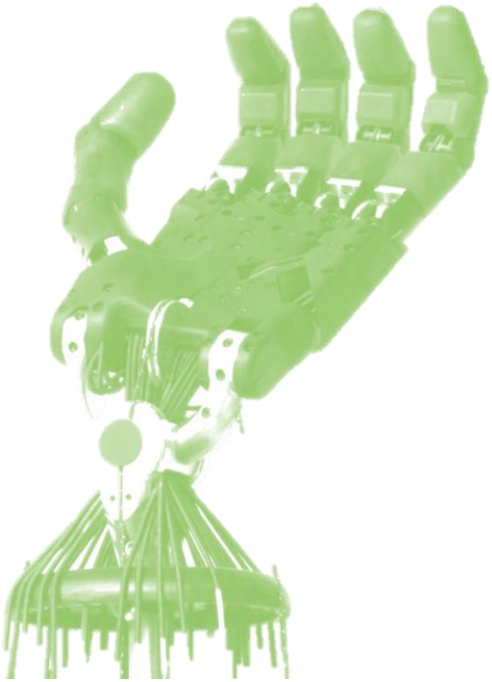
Brain Science

Parkinson's Disease
Huntington's Disease
Post-Traumatic Stress Disorder **Epilepsy**
Autistic Spectrum Disorders
Traumatic Brain Injury
Alzheimer's Disease Stroke

Neuronal activity is at the heart of this complex and nearly intractable system

These small electrical impulses may hold the key to memories, consciousness, and the cure to diseases

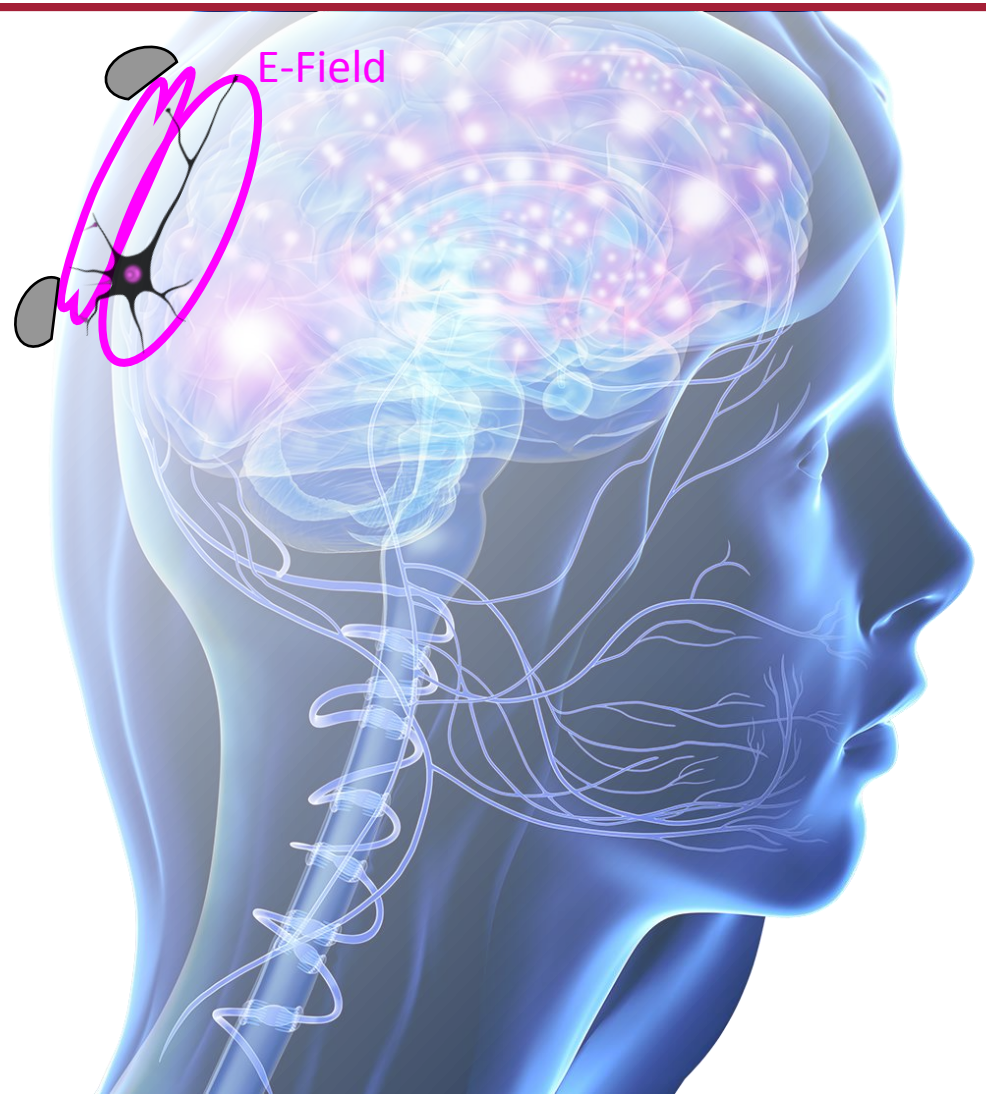
And may be the key to brain-machine interfaces



Non-Evasive Neuronal Imaging

Electroencephalography

- Measures electric field
- Resolution of cm
- Localization accuracy susceptible to conductivity profile variations
- Localizes tangential, radial, and deep sources



>100,000 worldwide

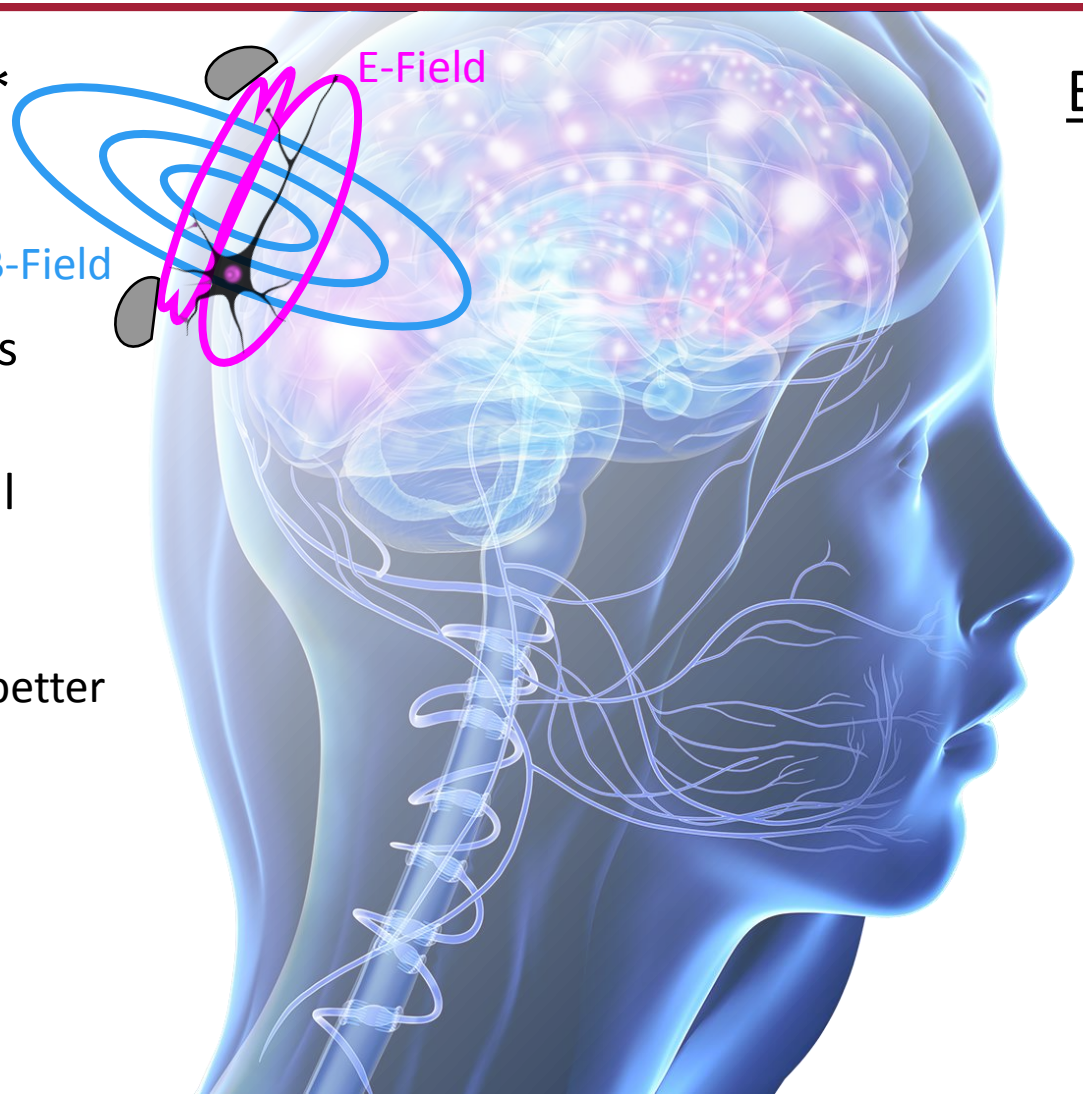
Non-Evasive Neuronal Imaging

Magnetoencephalography*

- Measures magnetic field
- High resolution of mm
- Localization robust to details of tissue, fluid, and bone
- BUT localizes only tangential sources

MEG sees less than EEG, but sees it better

~200 worldwide (29 in USA)



Electroencephalography

- Measures electric field
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>100,000 worldwide

*Magnetoencephalography invented at MIT by David Cohen

Magnetoencephalography (MEG)

Bulk neuronal activity

↓

Action currents

↓

Magnetic fields

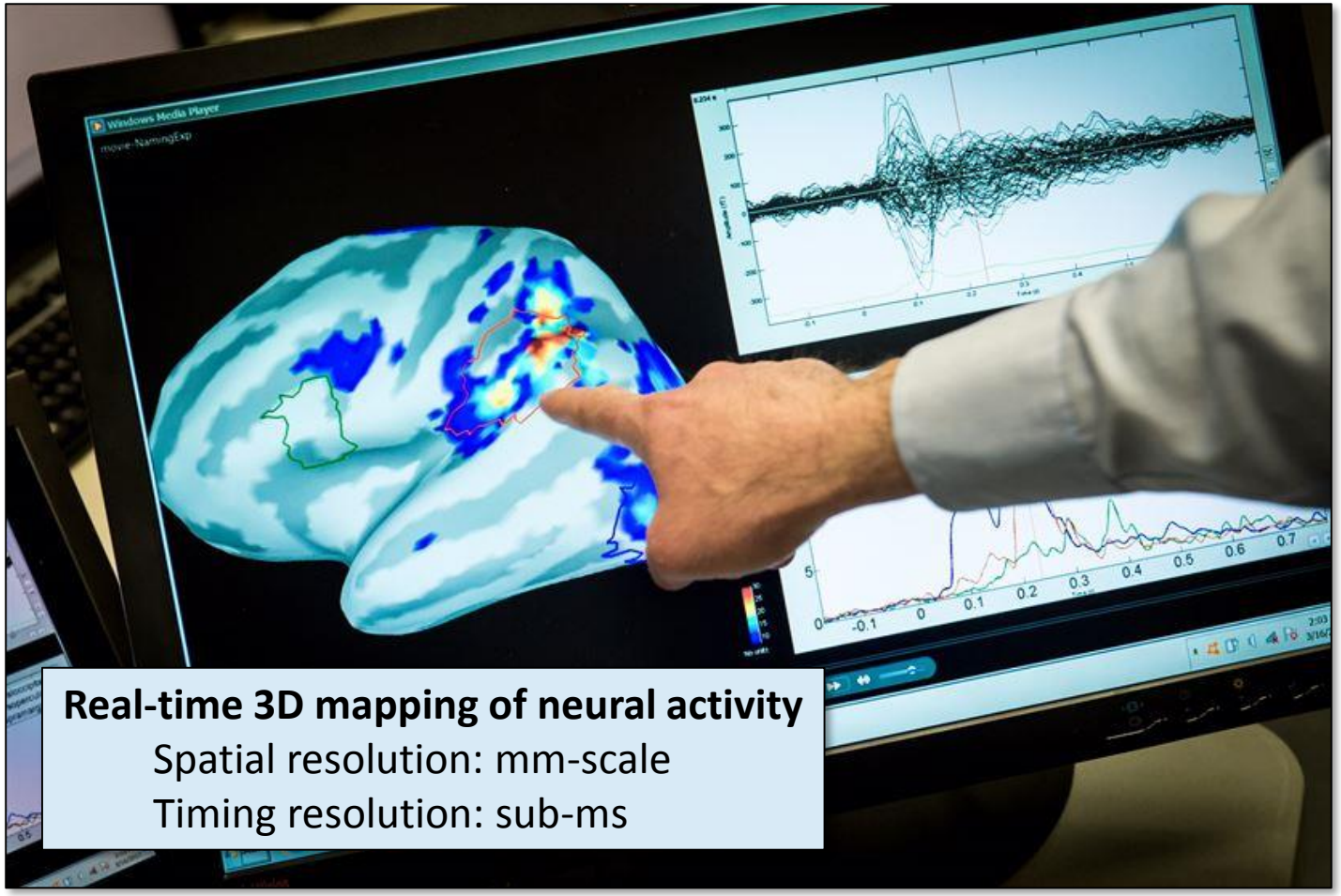
↓

Record with sensor array

↓

Solve biomagnetic inverse problem (localize current sources)

→



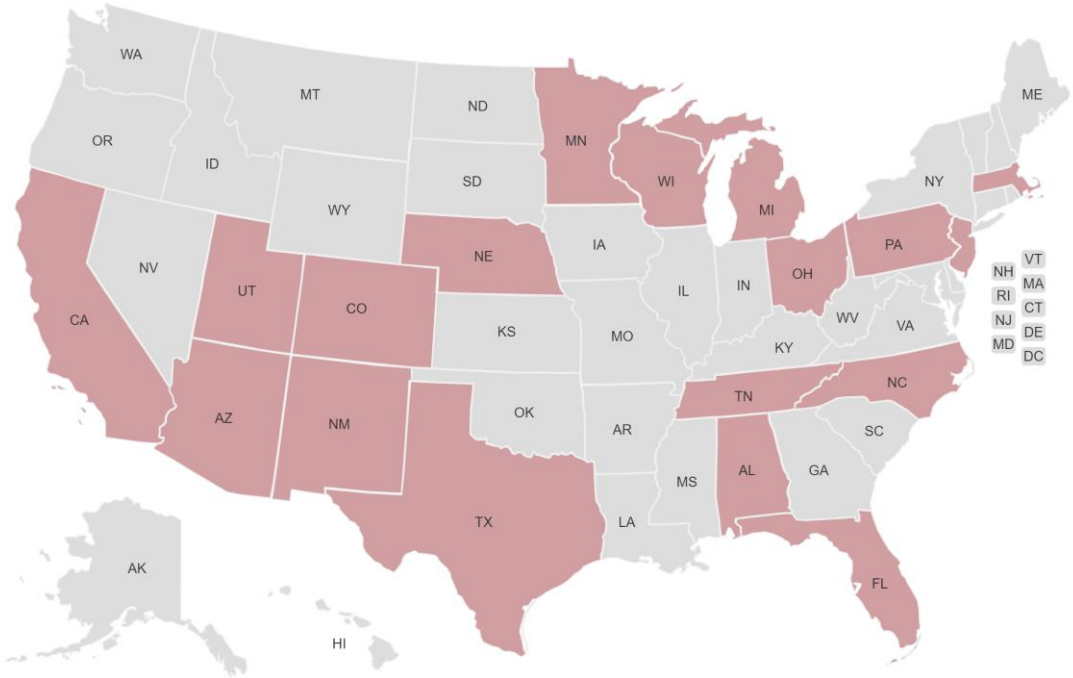
Real-time 3D mapping of neural activity
Spatial resolution: mm-scale
Timing resolution: sub-ms

Commercial MEG at Mass General Hospital Martinos Center

Conventional Magnetoencephalography Barriers

- **Cryogenic Sensors**
- **Rigid Helmet**

- **High Cost**
- **Shielded Room**



High cost of MEG limits widespread use

MEG=Magnetoencephalography

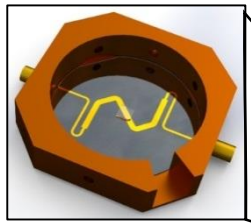
Room Temperature MEG

Current MEG Facility Requirements Hamper Widespread Clinical Applications:

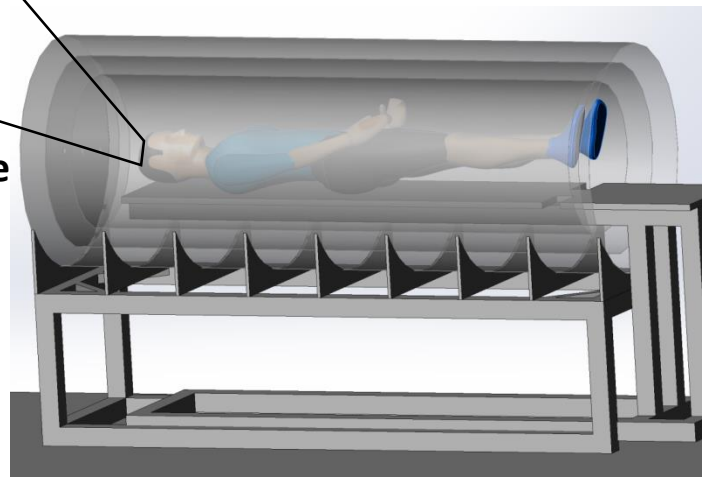
- Cryogenic Sensors
- Rigid Helmet

- High Cost
- Shielded Room

MIT-LL Proposed Room-Temperature MEG with Diamond Sensors Overcomes Traditional Barriers:



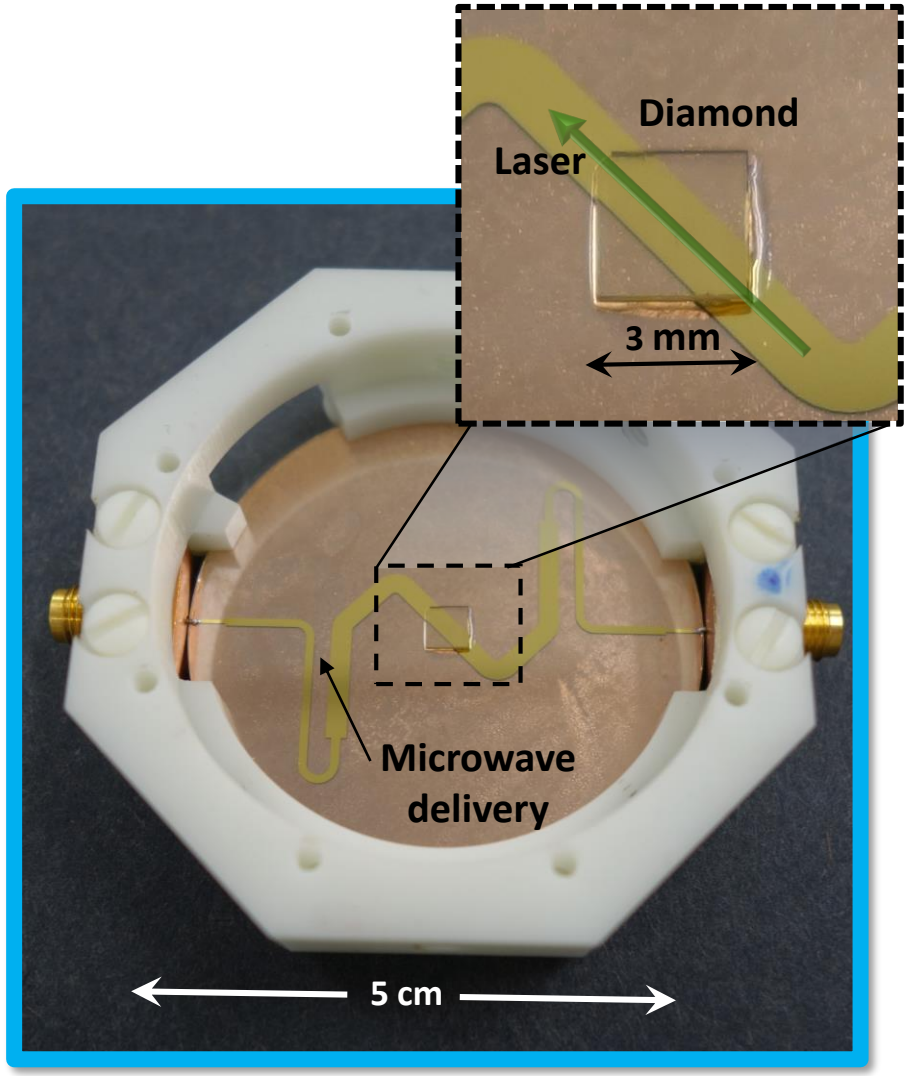
- Room Temperature Sensors
- Flexible Helmet
- Low Cost
- Small Shield



CAD of MIT LL Apparatus

NV diamond-based sensors are optimized as a room-temperature alternative to SQUID-based, cryogenic, commercial sensor arrays

NV Sensor Advantages over Conventional MEG

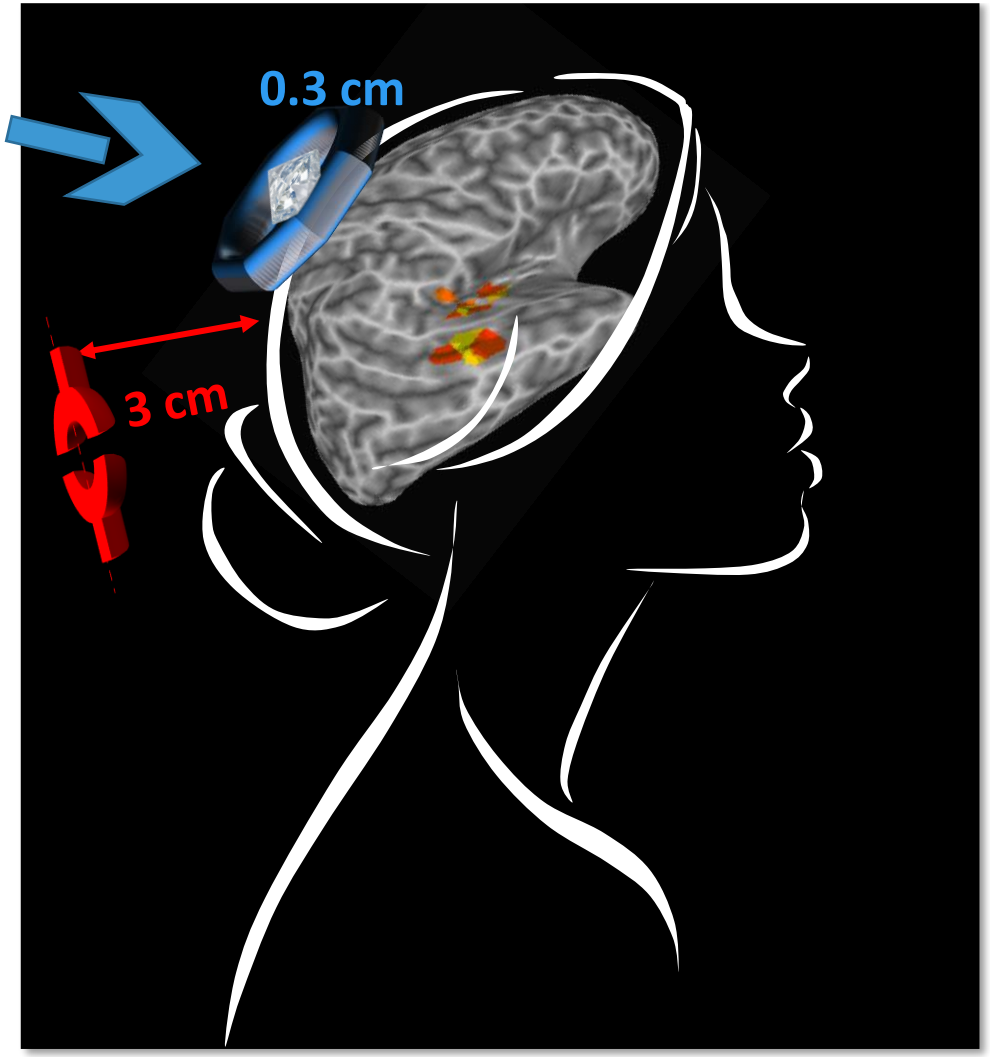


NV Sensor

- Close proximity to head
  ~100 fT field
- Room temperature
- Full vector field

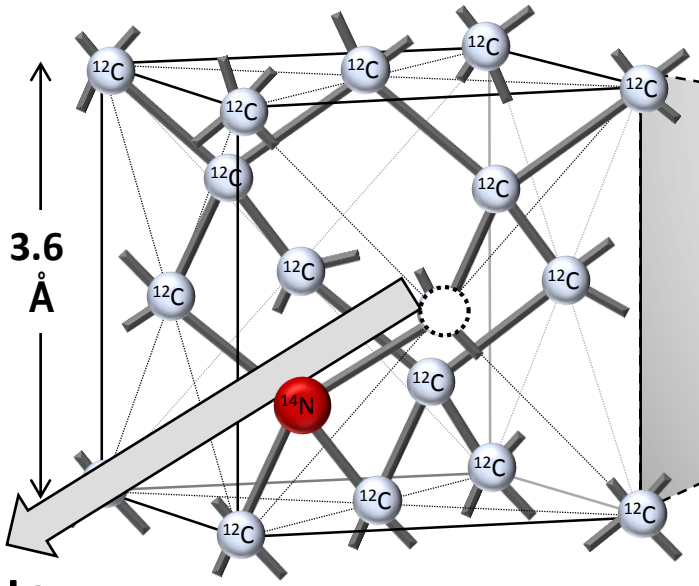
Conventional SQUID MEG

- Standoff detection
  ~ 10 fT field
- Cryogenic sensors
- Detects only radial field



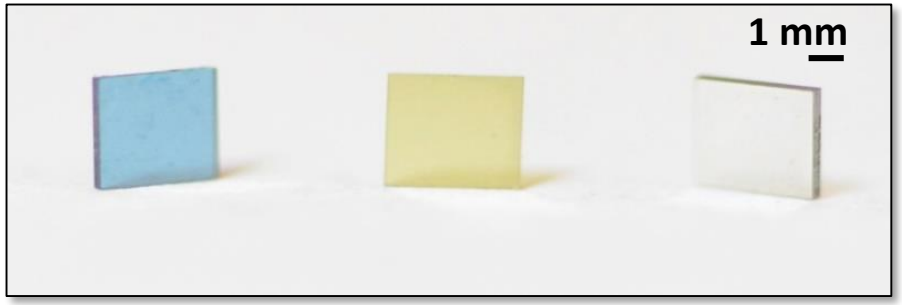
http://kurage.nimh.nih.gov/library/Main/brainmovie.gif

Quantum Systems in Diamond



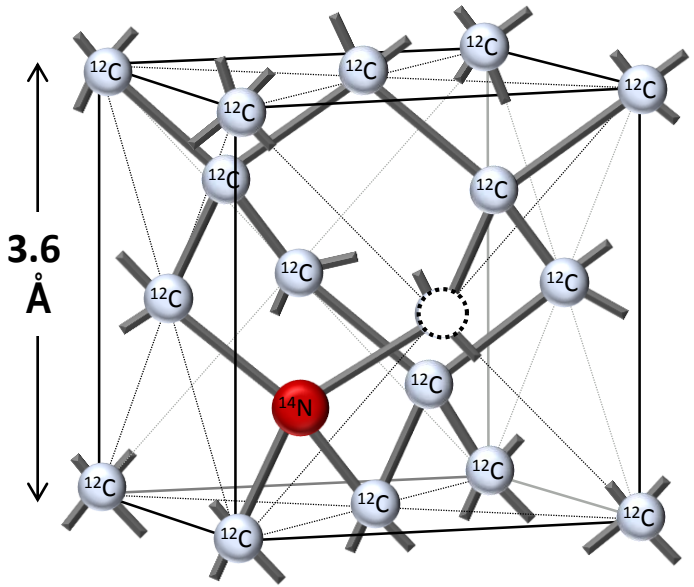
Sensitive to Magnetic Field

Natural Diamond



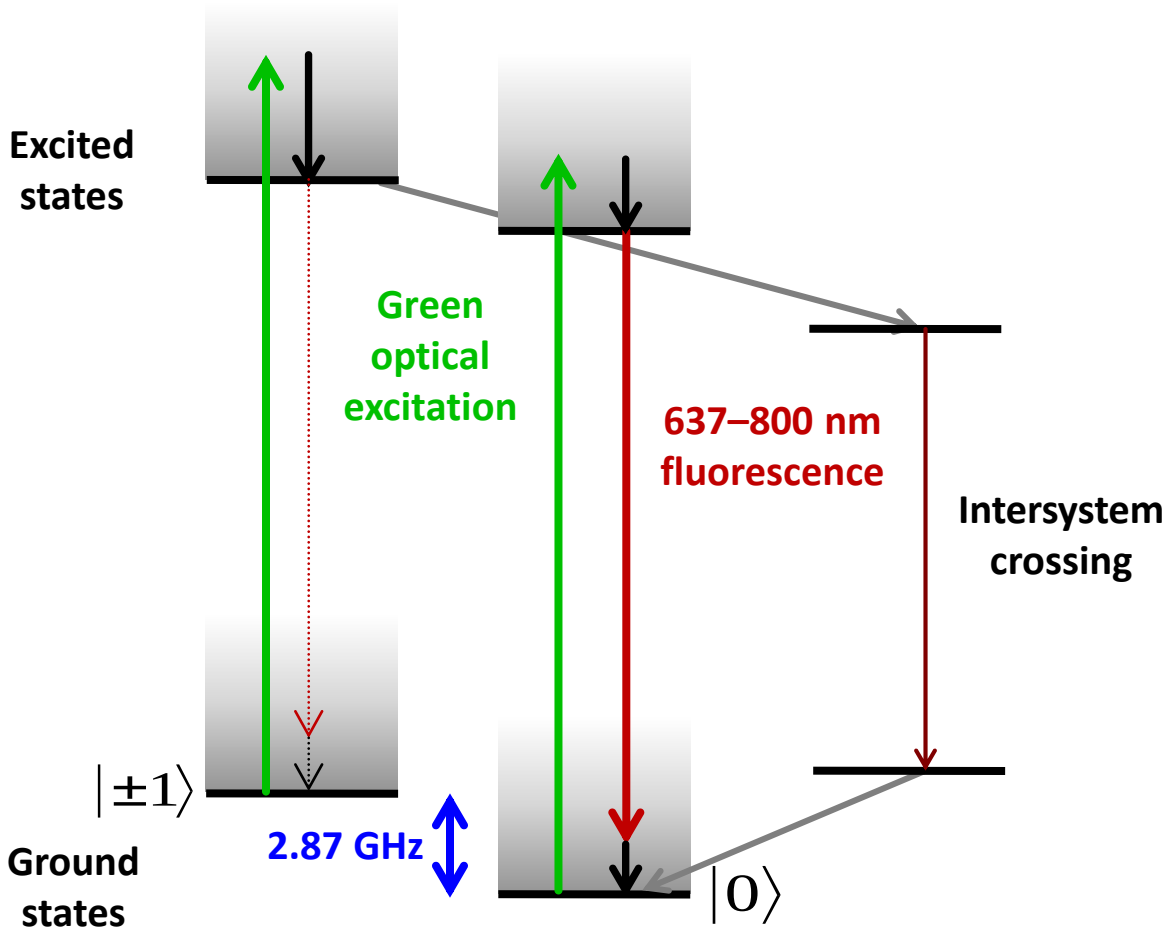
Engineered Diamond

Nitrogen Vacancy (NV) Diamond Physics



Technical Approach

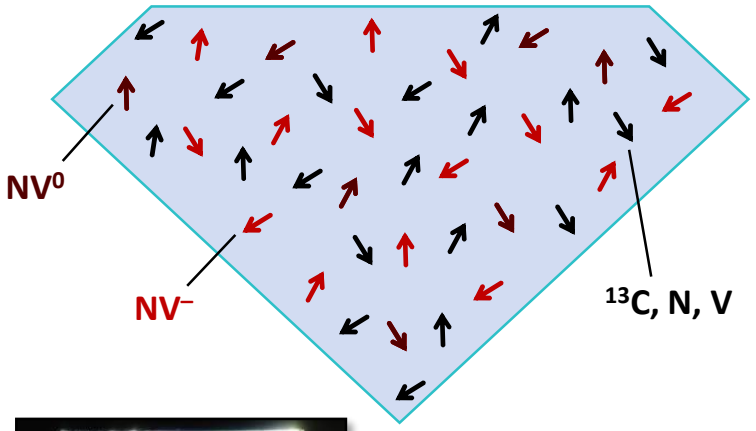
- Initialized optically
- Manipulated with RF
- Long coherence at room temperature



MIT LL Nitrogen Vacancy Diamond Magnetometer

Quantum System

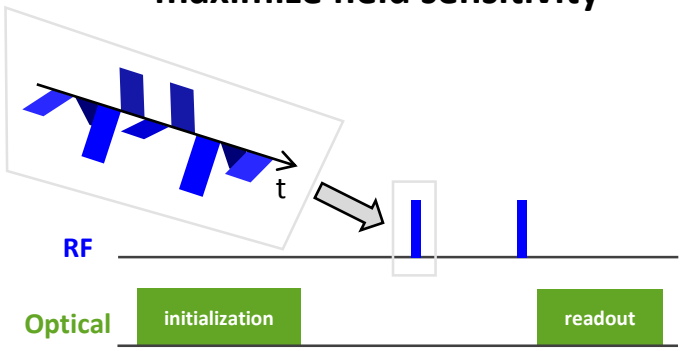
Engineer the quantum system and its environment through tailored diamond growth

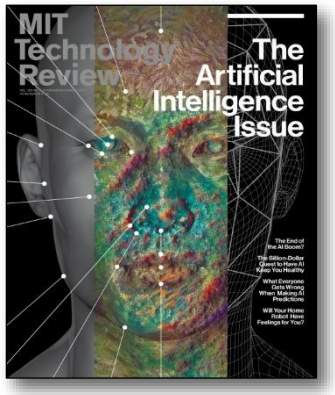


MIT LL grown diamond

Quantum Engineering

Coherently control the quantum state to maximize field sensitivity

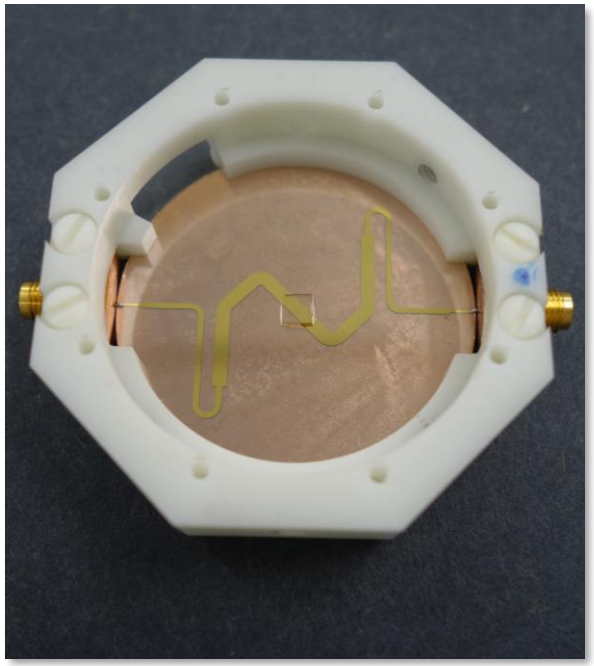




Machine learning algorithms search for optimized quantum control

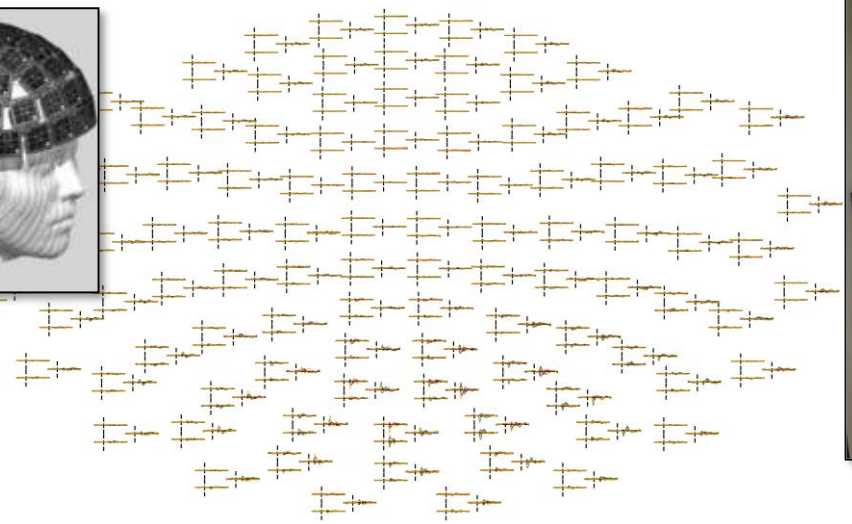
System Design

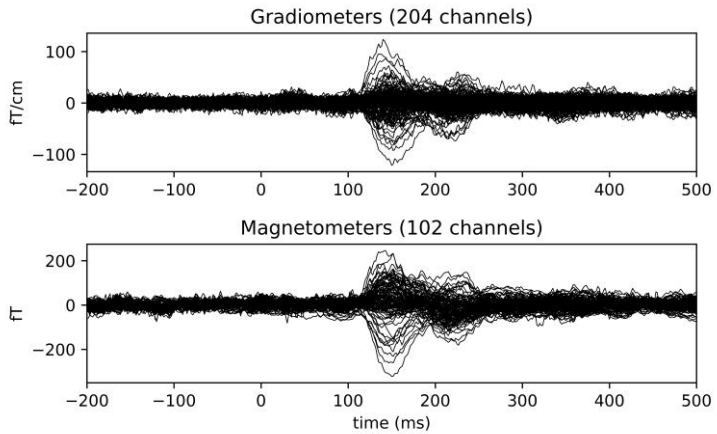
Optimize quantum system for neuron imaging



Next Steps

Martinos Center Baseline with 302-Channel Conventional MEG

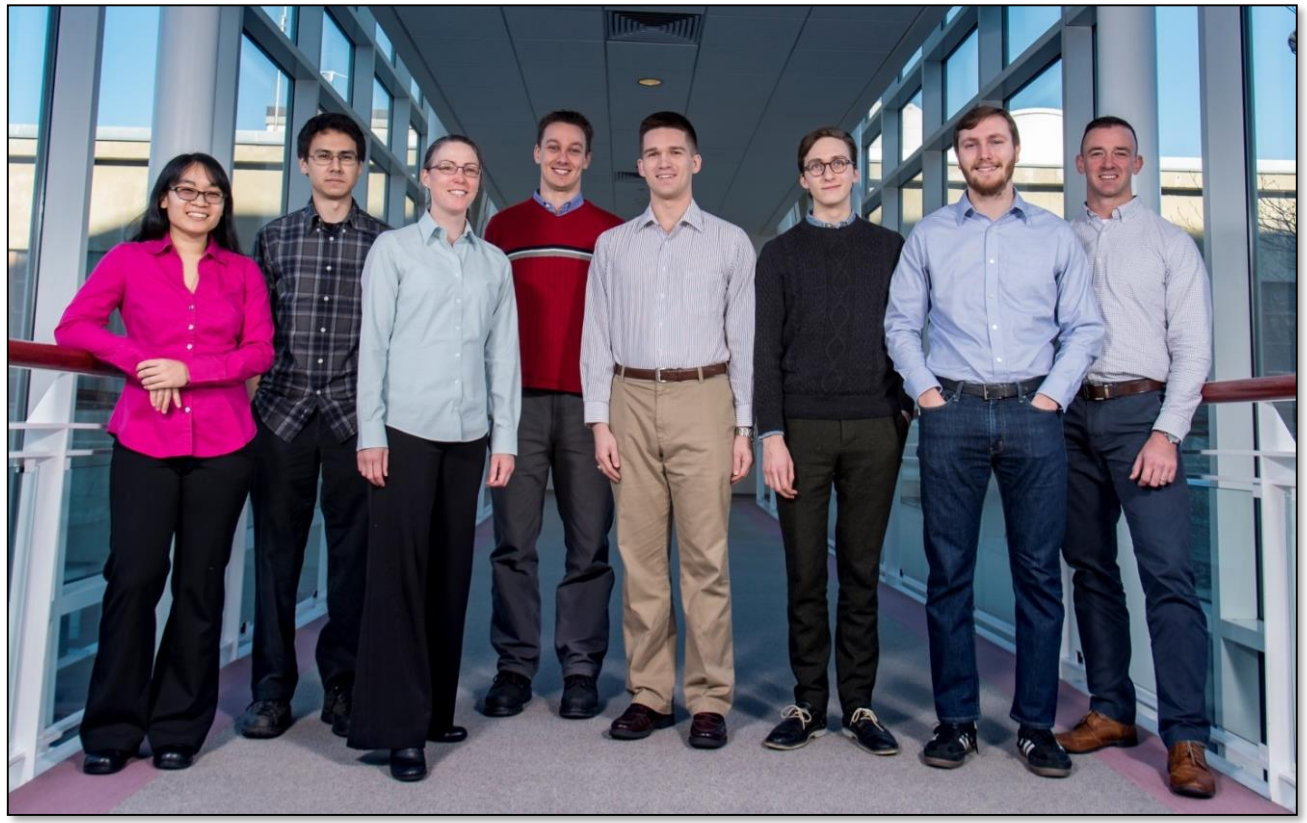




MIT LL Room Temperature Single Sensor Demonstration

Diamond room-temperature demonstration coming soon

Room Temperature MEG Contributors



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