LA-UR-12-22618
Approved for public release; distribution is unlimited.

Title:	Portable MRI
Author(s):	Espy, Michelle A.
Intended for:	Program Development/ University Collaboration

Disclaimer:
Los Alamos National Laboratory, an affirmative action/equal opportunity employer,is operated by the Los Alamos National Security, LLC for the National NuclearSecurity Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Departmentof Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Portable MRI

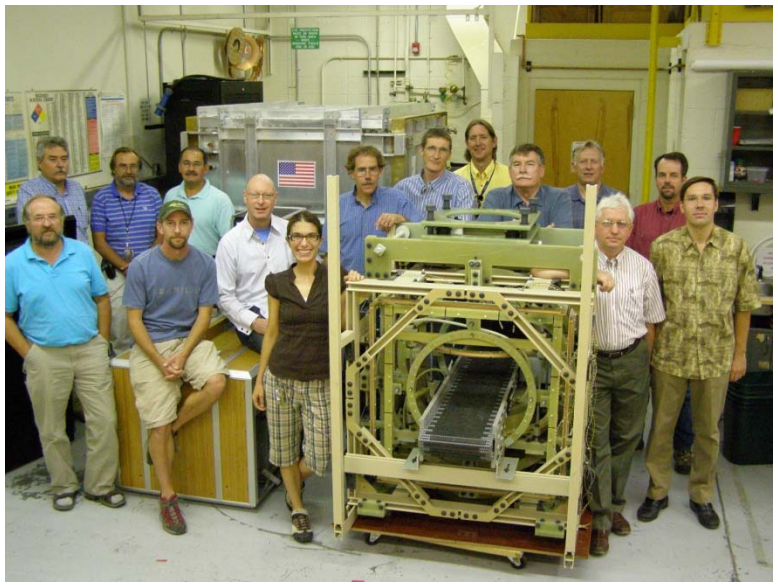
Michelle Espy, Ph.D.

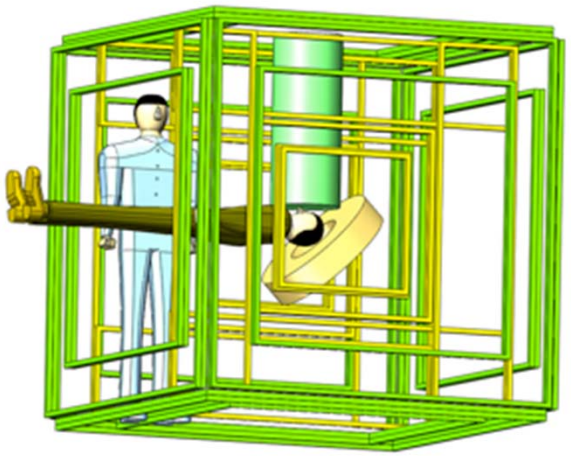
Los Alamos National Laboratory

Applied Modern Physics

What do we propose to do?

- **Provide the power of MRI to situations where it presently isn't available:**
  - How it works (low strength, pulsed fields)
  - Where it can work (no big magnets, folds up, deployable to emergency situations)
  - Who has access (disaster/terror victims, resource poor, subjects with metal)
  - What it does (situations high field can't)
- Perform the engineering required to move from lab to a functional prototype
- Leverage significant existing infrastructure and capability in ultra-low field MRI





Why does it matter?

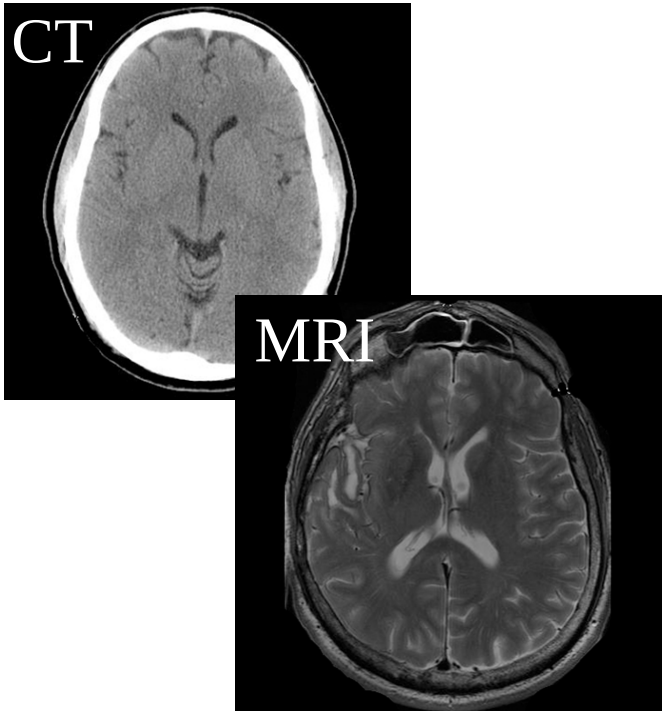
- MRI is the most powerful tool for imaging soft-tissue (e.g. brain)
- Billions don't have access due to cost or safety issues
    - metal will heat/move in high magnetic fields
- Millions of cases of traumatic brain injury in US alone
    - even more of non-traumatic brain injury
    - (e.g. stroke, infection, chemical exposure)
- Need for early diagnostic
- "Signature" wound of recent conflicts
- 22% of injuries
    - Implications for post-traumatic stress disorder
    - chronic traumatic encephalopathy

U.S. Marine Cpl. Burness Britt, wounded June 4, 2011 in an IED blast near Sangin, Afghanistan[1,2]

1. http://www.nytimes.com/2012/04/26/opinion/kristof-veterans-and-brain-disease.html?_r=1
2. http://themilitarysuicidereport.wordpress.com/2012/04/29/blast-exposures-linked-to-cte-brain-injuries-may-explain-some-military-suicide-cases-doctors-say/

Why does it matter?

- MRI is the "gold standard" for mild/moderate TBI
- Instead less informative CT is used[1]
- MRI doesn't get used[2,3] (cost/safety issues)
    - "heroic" effort to bring MRI to battlefield
    - 8.6M & 12 months to ship MRI
    - Mega-cargo Russian Antonov AN 124
- To date most troops flown to Landstuhl Germany
- 3000 miles, days later



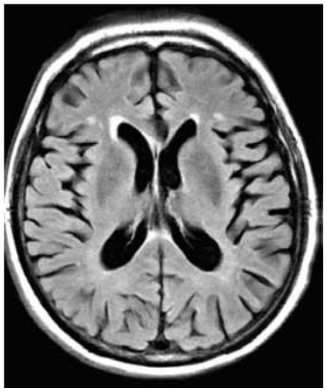
A MILITARY DOCTOR SCRUTINIZES A SHEET OF MRI IMAGES / DOD PHOTO

"The sooner you get at this, whether it's PTS or TBI," Mullen said, "the likelihood of resolution is much more positive."
Adm. Mike Mullen Chairman Joint Chiefs of Staff on the need for MRI in battlefield hospitals

1. http://www.seriousinjurylaw.co.uk/news/Brain-Injury-News/article/800502807/MRI-to-diagnose-brain-injury-in-Afghanistan.php
2. http://battleland.blogs.time.com/2011/06/20/reinforcements-dispatched-to-afghanistan-to-salvage-soldiers-brains/
3. http://www.navy.mil/search/display.asp?story_id=63216

The power of MRI as a diagnostic

- MRI developed in ~ 1980s; has saved countless lives
- Premier method for soft-tissue imaging
- Trend to higher and higher fields – signal scales with field
- Restricts MRI to wealthy, well- controlled settings, e.g. no metal
    - 2006 US had ~ 35 MRI machines/million[1]; India 0.5 MRI/million
    - In US, access depends on size of medical center[2]



Philips Achieva 3 Tesla MRI scanner

MRI machines are big and expensive

~$3-5 M

1 http://www.oecd.org/document/16/0,3343,en_2649_34631_2085200_1_1_1_1,00.html

2 Adit A. Ginde, MD, MPH, Anthony Foianini, BS, Daniel M. Renner, BE, Morgan Valley, MS, Carlos A. Camargo, Jr MD, DrPH "Availability and quality of computed tomography and magnetic resonance imaging equipment in US emergency departments" Academic Emergency Medicine, Volume 15, Issue 8, Article first published online: 18 AUG 2008

Do the fields have to be so high? No.

MRI signal scales with magnetic field , conventional MRI = biggest magnets possible

Large, expensive, resource intensive systems

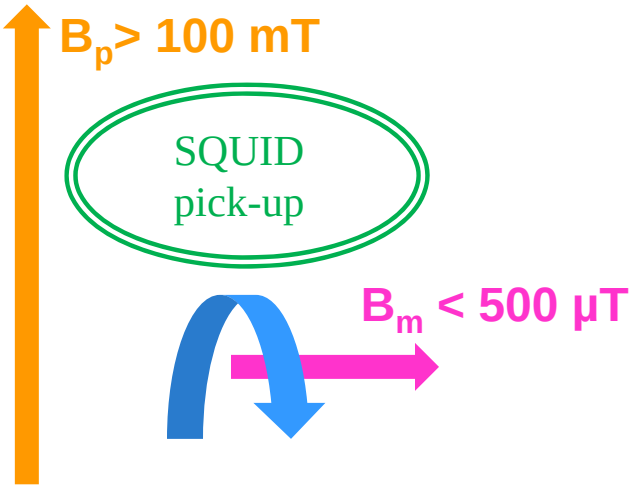
Safety impacts (projectiles, heating, no metal)

Our approach: Ultra-low field MRI (ULF)

Low field pulsed magnets (0.1 mT)

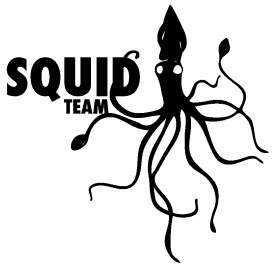
SQUIDs: very sensitive detectors

- Reduced susceptibility artifacts
- Fields can be inhomogeneous
- Metal-friendly



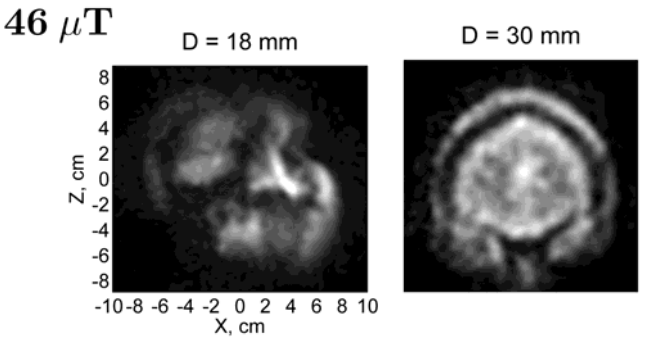
Superconducting QUantum Interference Device

- Most sensitive magnetic field detector
- Broad-band sensitivity

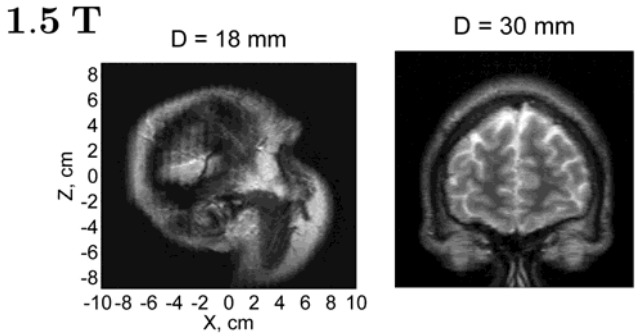


Do the fields have to be so high? No.

- Doesn't have to compete with HF MRI
- Does have to be diagnostically useful

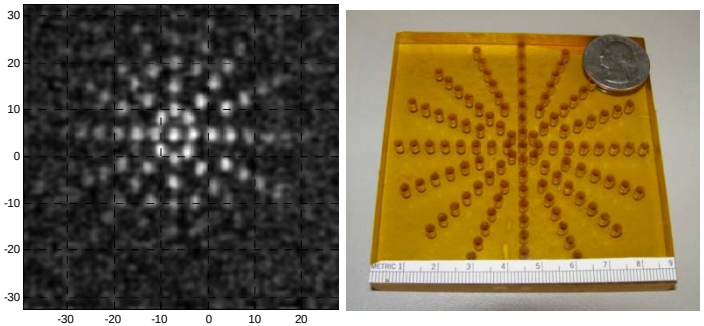


Ultra-low field (ULF)

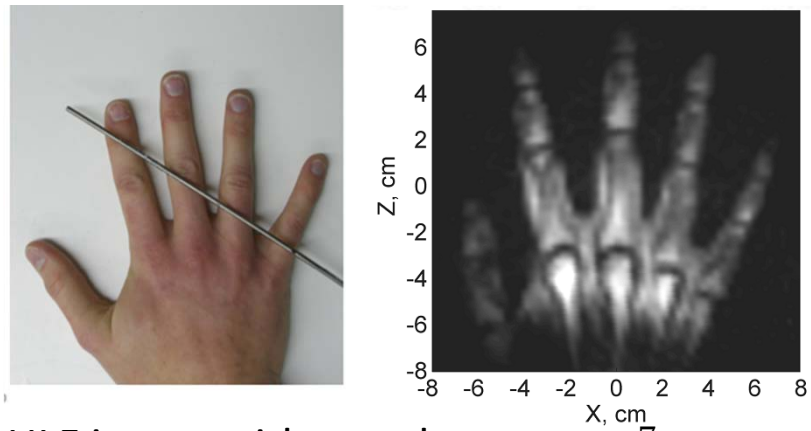


High Field (HF)

ULF MRI system



We recently attained < 2 mm^2 resolution



ULF image with metal:
not possible with conventional MRI

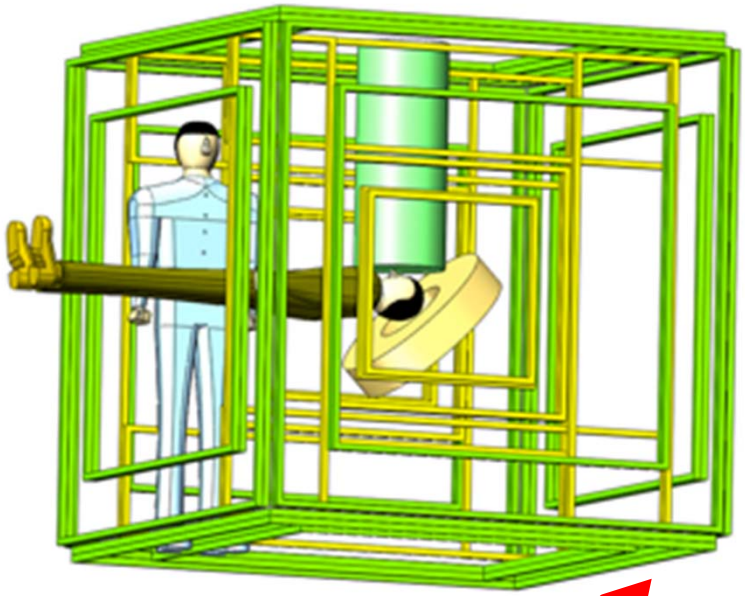
How do we get there?

Present brain images

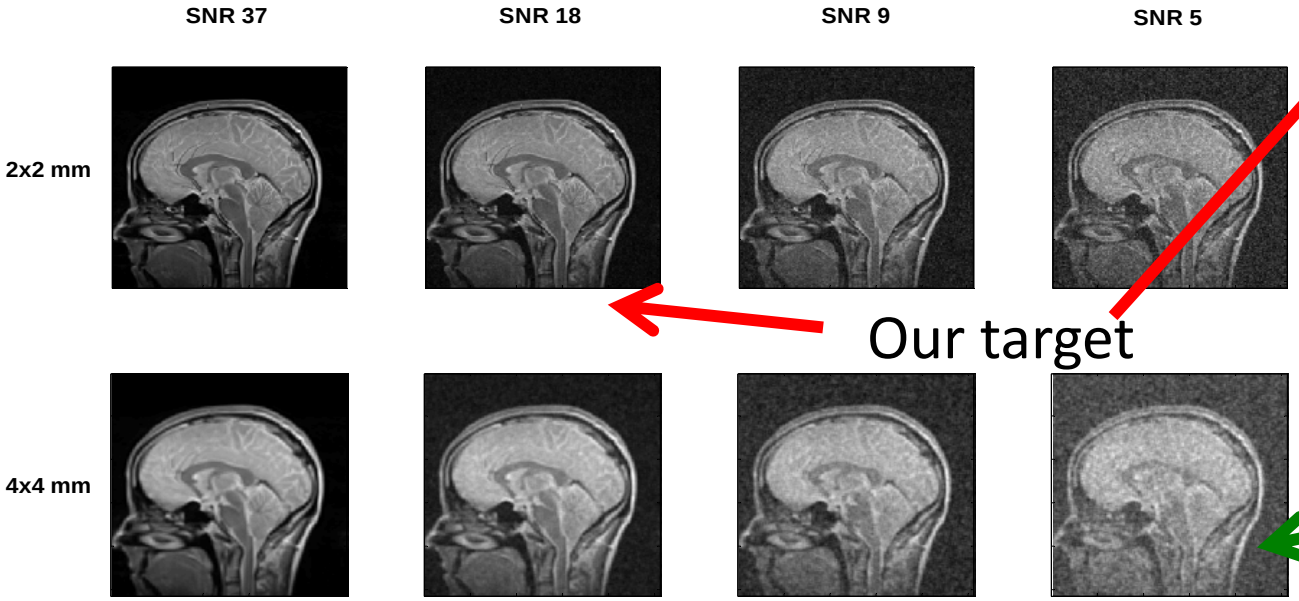
3x3x6 mm^3 with SNR of ~7.

We need

2x2x4 mm^3 with SNR of 20



- Sensor array – SQUIDs for highest sensitivity
- Pulse sequence optimization
- Magnet and cryo-engineering (reduce footprint, weight, maintenance)
- Removal of the requirement for shielding



Expected Results

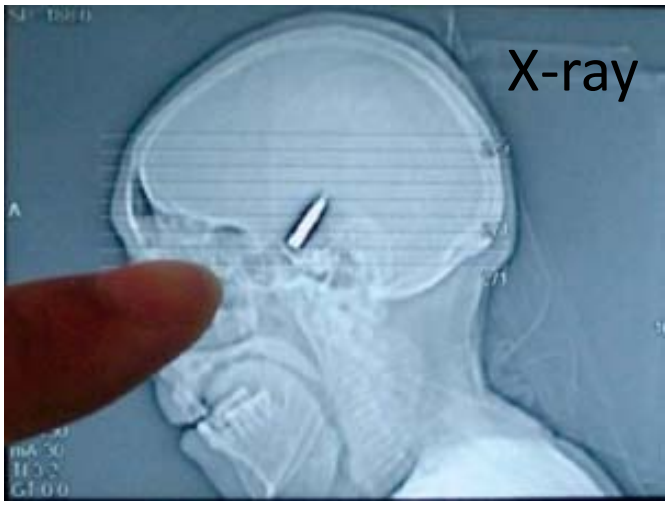
Design Goals / Performance Metrics	
Image Quality	SNR 20, 2x2x4 mm^3
Image Time	< 20 min
Size	2x2x2 m^3
Cost	< $500k
Cryo. refill	> 6 months
Weight	< 1 ton

MRI can be delivered this way!

Not like this!

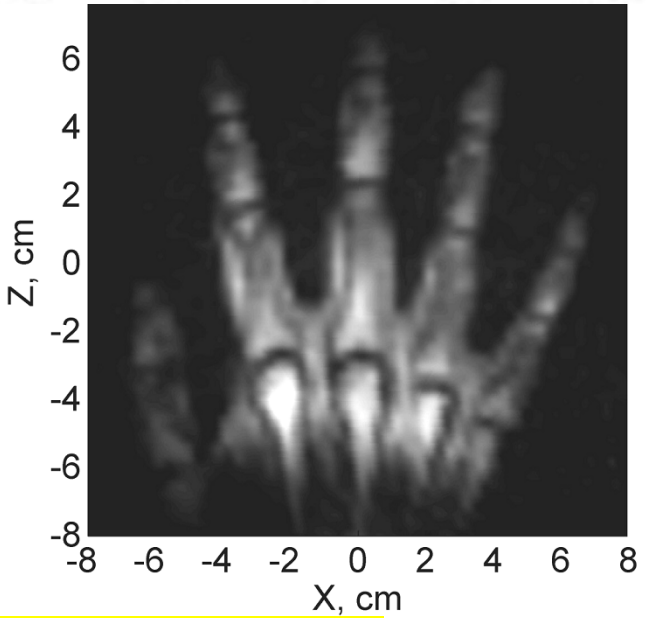
A compact, MRI machine suitable for rapid deployment to field hospitals and emergency rooms and will provide a path forward for a new generation of low resource MRI diagnostics.

http://www.norfolknavyflagship.com/news/navy_medicine/article_fe25b3f8-fa7a-11e0-9446-001cc4c03286.html



How do we get it out? She survived the bullet but a high-field MRI might kill her.

Imaging in the presence of metal is safe and accurate with ULFMRI



There are important applications for ultra-low field MRI