Low-field MRI of laser polarized noble gas

Conventional magnetic resonance imaging (MRI) employs large magnetic fields (~ 1 tesla) to induce an observable thermal Boltzmann polarization in the nuclear spins of liquids such as water. However, laser-polarization of ^{3}He and ^{129}Xe does not require a large magnetic field, enabling efficient gas-phase MRI at low magnetic fields (< 0.01 tesla). We have demonstrated practical low-field MRI of laser-polarized noble gas in glass cells ("phantoms") and excised rat lungs using a prototype instrument operating at 21 gauss and adapted from our dual noble gas (^{129}Xe/^{3}He) maser (see Fig. 1-3).

Fig. 1. Prototype low magnetic field system for laser-polarized noble gas MRI.

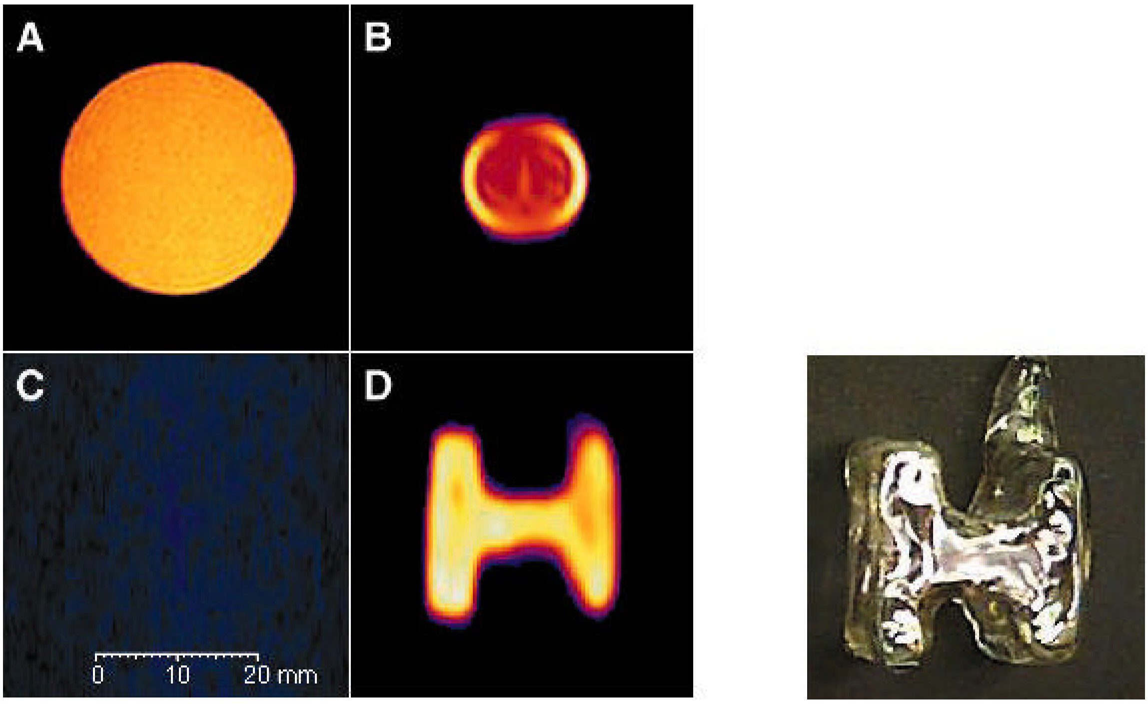

Fig. 2. Comparison of MRI at 47,000 gauss and 21 gauss. (A) Water inside a cylindrical Plexiglas cell at 47,000 gauss. (B) Laser-polarized ^{3}He gas inside a cylindrical glass cell at 47,000 gauss. (C) Water inside a cylindrical glass cell at 21 gauss. No image is seen because of the very low ^{1}H spin polarization at low magnetic fields. (D) Laser-polarized ^{3}He gas inside a roughly H-shaped glass cell at 21 gauss. (Right) Photograph of the glass "H" cell filled with 2.7 amagats ^{3}He, 100 torr N2, and Rb.

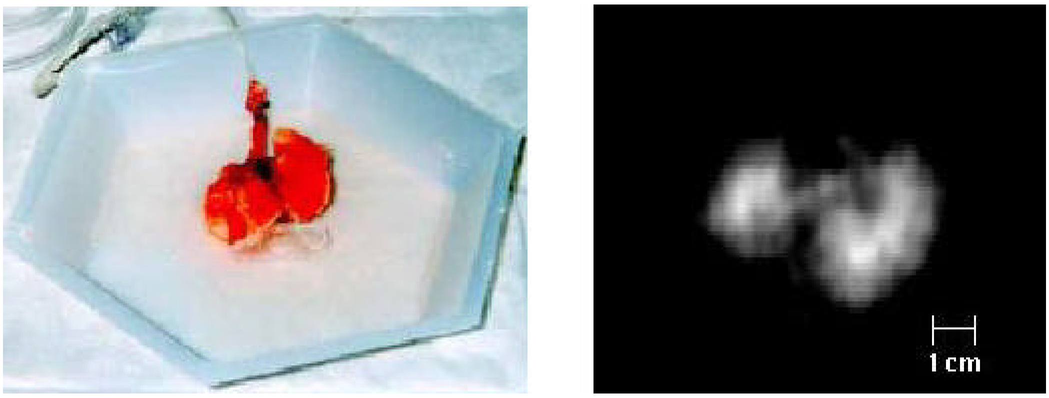

Fig. 3. Example of low-field noble gas MRI performed with the prototype instrument. Excised rat lungs (photo on left) were filled with laser-polarized ^{3}He gas and imaged with MRI at 21 gauss (right). The two-dimensional spatial resolution is 1 mm^2, with a 20 mm slice thickness, and the imaging time was ~ 25 seconds. Conventional, thermally-polarized water proton MRI is impractical at such low magnetic fields.

With these demonstrations, the door is opened to a wide variety of new MRI applications. Examples in the biomedical field include portable noble gas systems for diagnostic lung imaging in humans, and inexpensive table-top imaging systems for the non-invasive characterization of lung disease models in animals. Furthermore, a low-field noble gas MRI system would be compatible with operation in restricted environments, such as onboard a space station, and may permit lung imaging of patients with artificial transplants such as pacemakers.

In the physical sciences, low-field noble gas MRI will be effective in imaging voids in two classes of materials that are problematic for high-field MRI: (i) heterogeneous systems, such as porous and granular media, which distort high-field MRI because of large, solid-gas magnetic susceptibility gradients (see Fig. 4); and (ii) electrical conductors, which prevent high-field MRI by Faraday (i.e., RF) shielding (see Fig. 5). Also, low-field NMR measurements of the restricted diffusion of noble gas imbibed in porous media (e.g., reservoir rock) may provide an effective and practical diagnostic of fluid permeability in these systems.

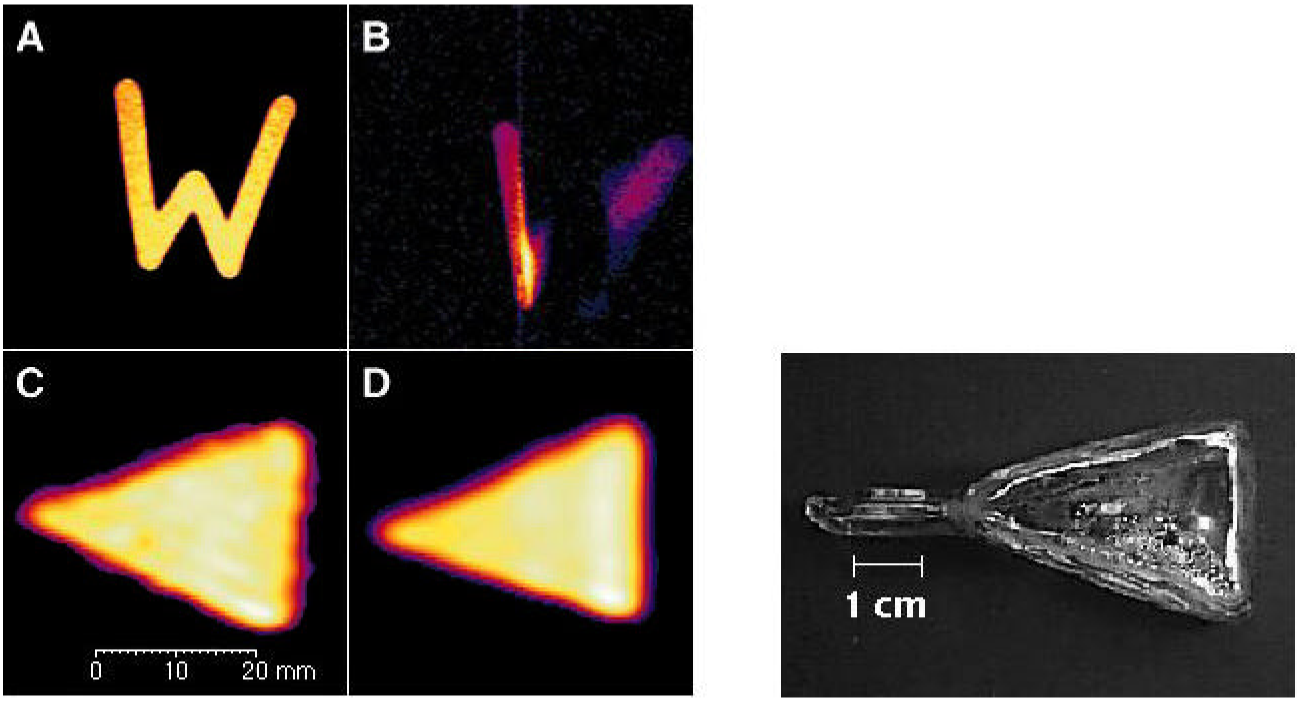

Fig. 4. Reduced magnetic susceptibility distortion at low magnetic fields. At 47,000 gauss, MRI of a W-shaped water sample is (a) undistorted when no high magnetic susceptibility materials are nearby; but is (b) severely distorted when placed next to four tubes of paramagnetic salts. However, at 21 gauss MRI of laser-polarized ^{3}He gas in a triangular glass cell is undistorted both (c) without, and (d) with, the nearby tubes of paramagnetic salts. (Right) Photograph of the triangular glass cell filled with 2.7 amagats ^{3}He, 100 torr N2, and Rb.

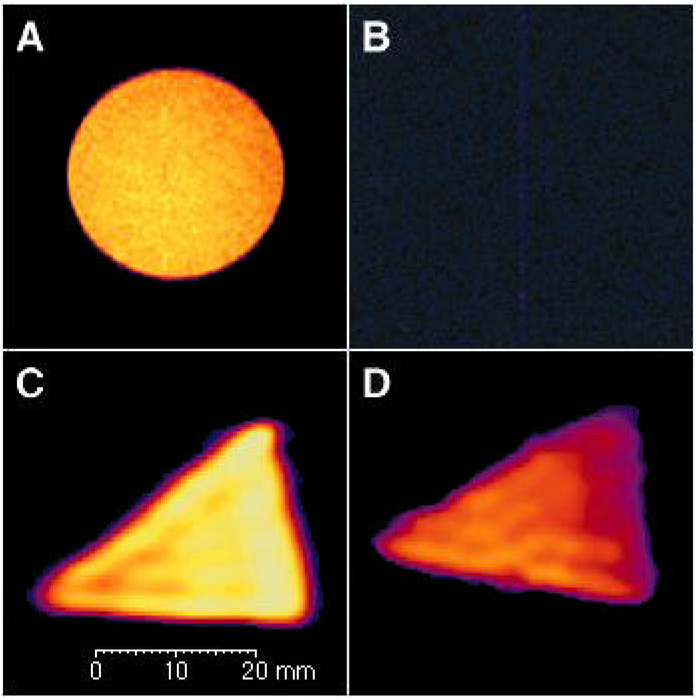

Fig. 5. Imaging of voids within a conductor. MRI was performed at 47,000 gauss of (a) a cylindrical water sample, and (b) the same sample encased in 25 micron thick brass shield, illustrating the impracticality of MRI within an electrical conductor at high magnetic fields due to Faraday (i.e., RF) shielding. Comparison images were obtained successfully at 21 gauss of (c) laser-polarized ^{3}He gas in a triangular glass cell, and (d) the same ^{3}He sample

encased in the brass shield.

***Note*: These investigations were performed in close collaboration with Prof. David Cory at MIT, Prof. Bill Hersman's group at the Univ. of New Hampshire, and scientists at the NMR Center of the Massachusetts General Hospital.**

Reference:

Low field MRI of laser polarized noble gas
C.H. Tseng, G.P. Wong, V.R. Pomeroy, R.W. Mair, D.P. Hinton, D. Hoffmann, R.E. Stoner, F.W. Hersman, D.G. Cory, and R.L. Walsworth, Physical Review Letters **81**, 3785 (1998).

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