Low Field MR Imaging of Laser-Polarized Noble Gas

G.P. Wong¹, C.H. Tseng¹,², V.R. Pomeroy³, R.W. Mair¹, D.P. Hinton⁴, D. Hoffmann¹, R.E. Stoner¹, F.W. Hersman³, D.G. Cory², R.L. Walsworth¹

¹Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA; ²Department of Nuclear Engineering, MIT, Cambridge, MA, USA; ³Department of Physics, University of New Hampshire, Durham, NH, USA; ⁴Massachusetts General Hospital, NMR Center, Charlestown, MA, USA.

Purpose
The purpose of this study was to demonstrate the utility for lung imaging of laser-polarized (LP) noble gas MRI at low magnetic fields (< 50 gauss). The high spin-polarizations characteristic of LP ³He and ¹²⁹Xe obviate the need for a large (~ 1 Tesla) polarizing magnetic field, while working at low magnetic fields offers advantages for various experimental situations. Our recent results include low field T¹ and T² measurements, as well as images, of LP ³He inside excised rat lungs.

Introduction
Laser-polarization of ³He and ¹²⁹Xe enables high resolution gas-space imaging, most notably of the lungs [1]. Unlike conventional proton MRI, the spin polarization of LP noble gas is independent of the main magnetic field, relying instead upon optical pumping details such as available laser power and gas pressures. For example, one can achieve greater than 10% polarization in ³He, which is nearly five orders of magnitude larger than the polarization of ¹H in a clinical magnet. Therefore, with suitable (low frequency) electronics, one can expect effective gas-space imaging at low magnetic fields. There are significant benefits to working at reduced magnetic fields, and various groups are investigating low field MRI with LP noble gases [2,3]. We have developed a novel system for noble gas MRI at ~ 20 gauss and imaged glass phantoms filled with LP ³He under circumstances that highlight the benefits of low field MRI [4]. Recently, we used this system to image LP ³He in excised rat lungs.

Methods
A home-made wire-wound solenoid, capable of providing a field of up to 100 gauss, was used as the primary magnet. Imaging gradients were produced with standard design Golay and anti-Helmholtz coils, while orthogonal sets of Helmholtz coil pairs were used as drive and pickup coils. An unamplified Wavetek Model 10 function generator was used as the r.f. source, and provided a reference frequency for a 100 kHz lock-in amplifier used in signal detection. For convenience, r.f. pulse timing, gradient control, and data acquisition were handled by a Bruker AMX console.

³He was polarized via spin-exchange with optically pumped Rb using an Opto Power 15 W fiber-coupled laser diode array. Images were taken with a standard FLASH sequence, using 128 concentric phase encode steps and no slice selection or signal averaging. The Larmor frequency of ³He was 67 kHz, corresponding to a field of 20.6 gauss.

Results
At low field, we measured the LP ³He T²* to be greater than 100 msec in rat lungs, which is much longer than the approximately 5 msec T²* observed for guinea pig and human lungs at 2 T and 1.5 T [5,6], respectively. This longer ³He T²* is a result of the reduced effect of magnetic susceptibility heterogeneity at low magnetic fields.

Discussion
We have shown the efficacy of low field imaging of laser-polarized noble gas, in particular for use in biomedical gas-space imaging. The benefits of working at low magnetic fields, such as longer T²* in the lungs, may allow the application of more sophisticated imaging techniques (e.g., EPI) and spectroscopic methods (e.g., time-dependent gas diffusion measurements). While our existing low field MRI system was intended for small scale samples, it is straightforward and inexpensive to build a larger system suitable for animal or human use.

References

Acknowledgments This research was supported by NSF Grant BES-9612237, NASA Grants NAGW-5025 and NAG5-4920, the Whitaker Foundation, and the Smithsonian Institution. We thank J. Moore for preparation of the excised rat lungs. G.P.W. acknowledges support from a NSF Graduate Research Fellowship.