Accelerated Diffusion-Weighted Hyperpolarized ^{129}Xe Gas Lung MRI

Fumin Guo[1], Matthew Fox[2,3], Grace Parraga[4,5], and Alexei Ouriadov[3,2]

[1]Sunnybrook Research Institute, University of Toronto, Toronto, Canada,
[2]Lawson Health Research Institute, London, Canada,
[3]Department of Physics and Astronomy, [4]Robarts Research Institute,
[5]Department of Medical Biophysics, Western University, London, Canada

June 4, 2019

Declaration of Relevant Financial Interests and/or Relationships

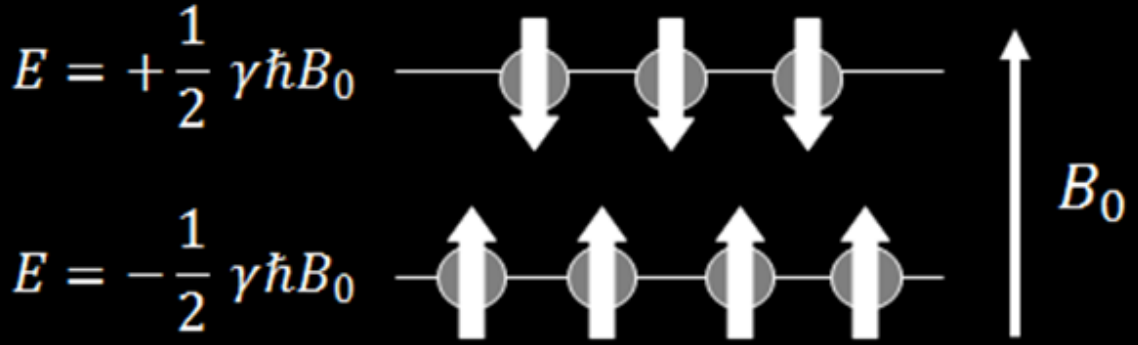
A. Ouriadov and all co-authors:

We have no relevant financial interests or relationships to disclose with regard to the subject matter of this presentation.

Thermal Polarization

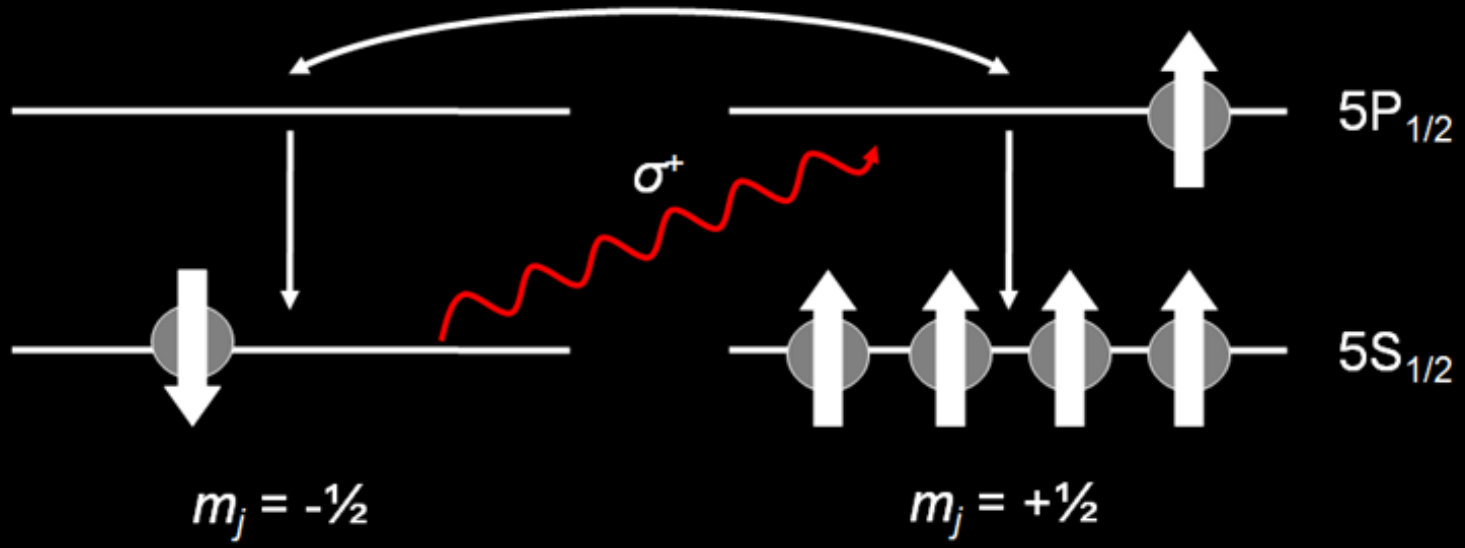
- Nuclei with spin = ½ are placed in an externally applied magnetic field
- Polarization (P) arises from a population difference in energy levels of spin = ½ nuclei

$$P = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$



Spin-Exchange Optical Pumping

- Rubidium electrons are optically pumped into an excited state using circularly polarized laser light
- The electronic polarization of Rb is transferred to the noble gas nuclei via collisions



Spin-Exchange Optical Pumping

^{129}Xe Polarizer, Polarean, USA

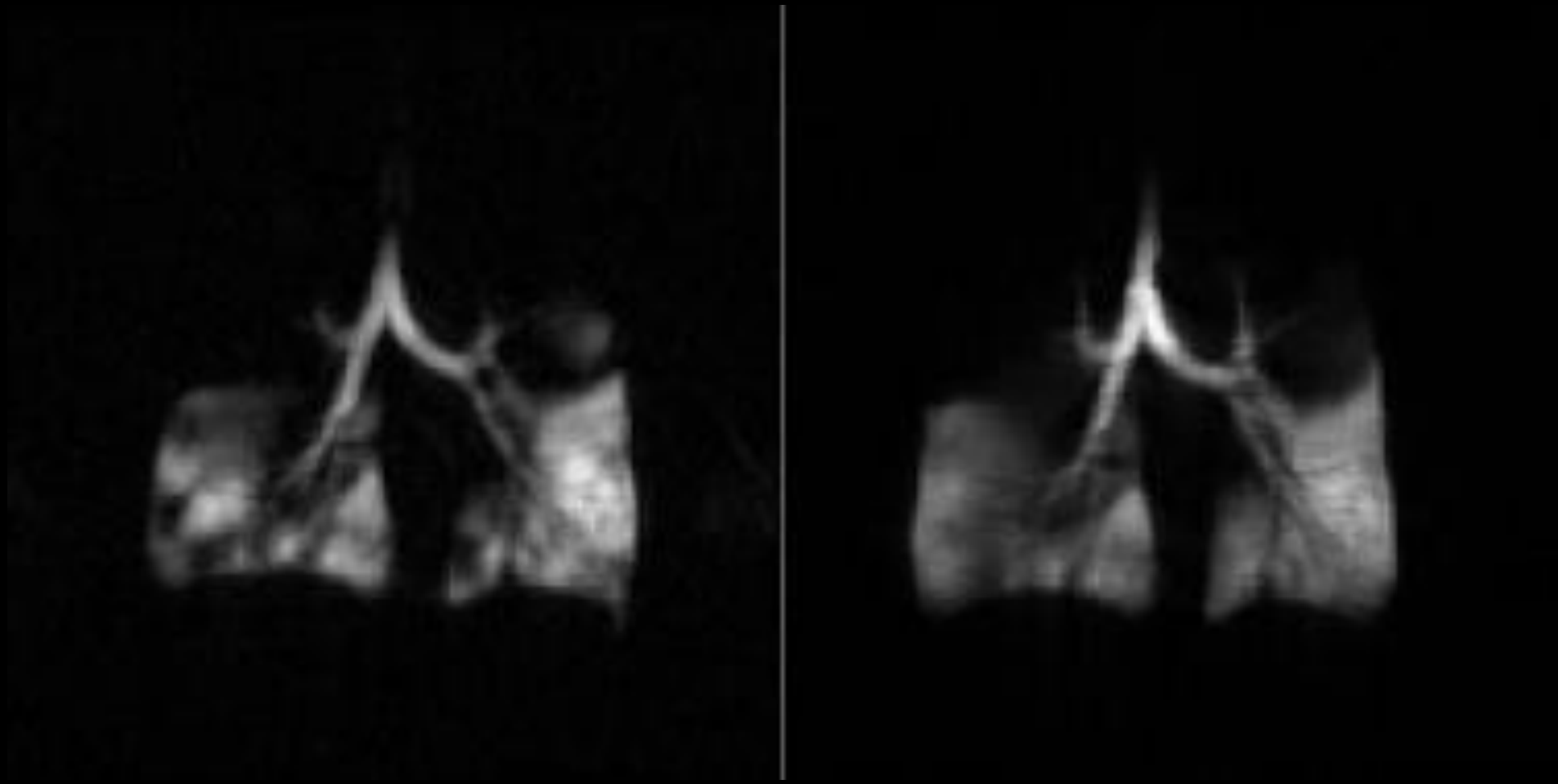
Polarization: 30%

Cryogens required for operation

Production Rate: ~800ml/hour

^{1}H MRI vs Hyperpolarized Gas MRI

Hyperpolarized Gas MRI

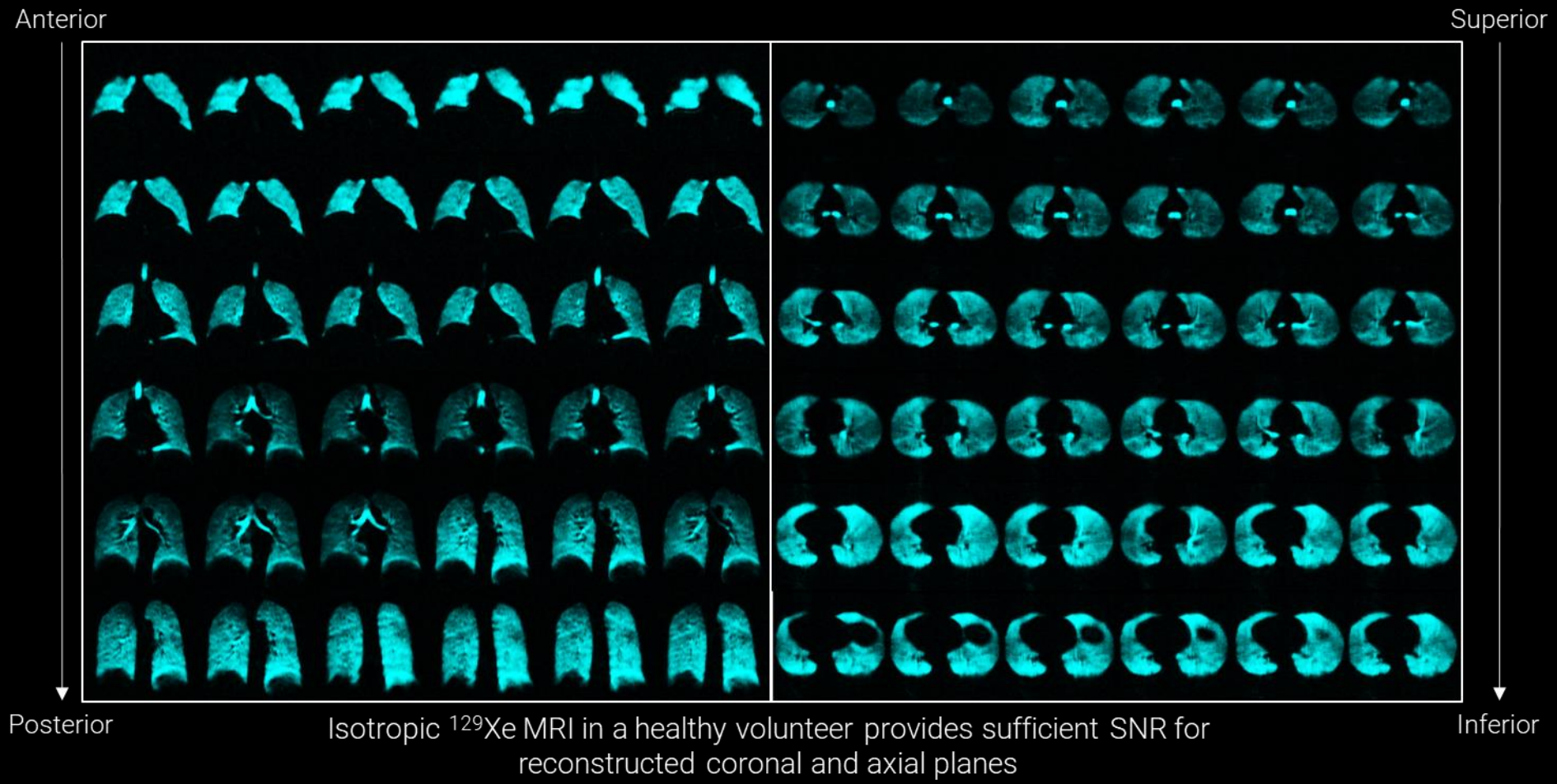


Helium-3 **Xenon-129**

Kirby M. et al. Radiology 265, 600-610, (2012)

^{129}Xe MRI Hardware

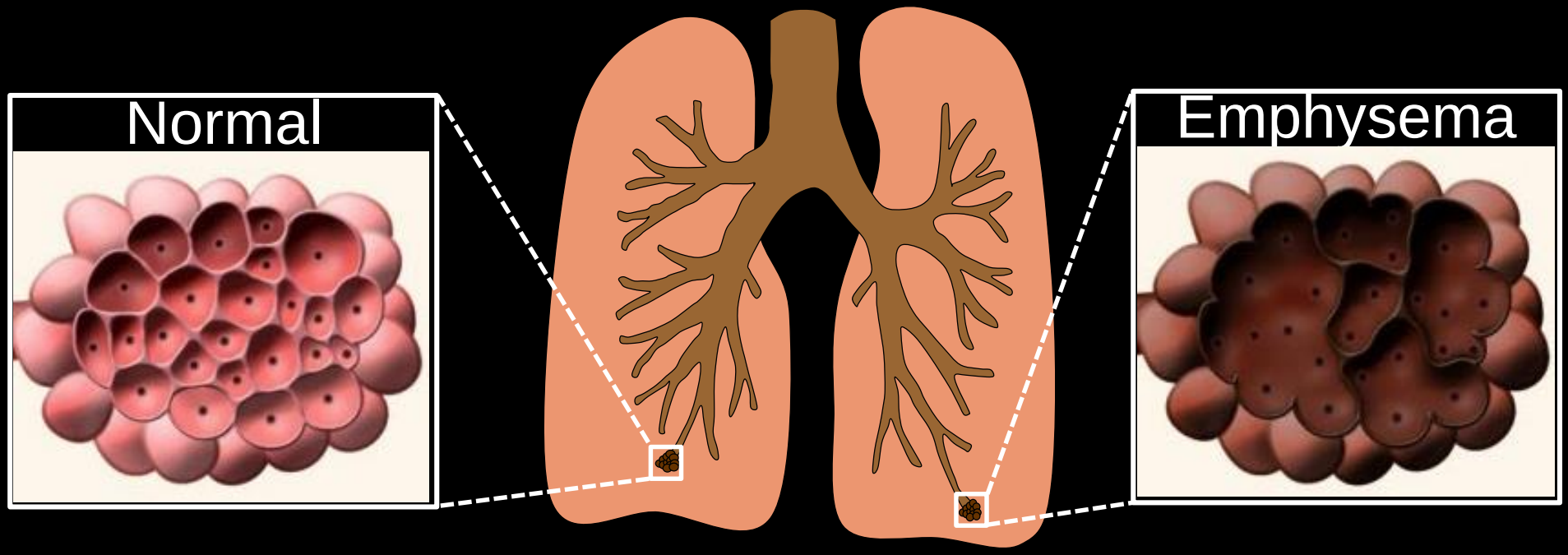
Single Breath-hold Isotropic ^{129}Xe MRI



Isotropic ^{129}Xe MRI in a healthy volunteer provides sufficient SNR for reconstructed coronal and axial planes

Barker A, et all, ISMRM 2019

Emphysema: Pathology

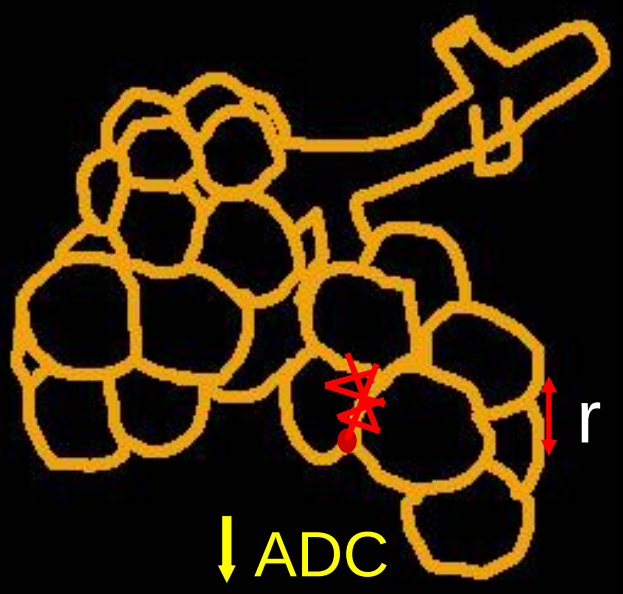


Evaluating Emphysema

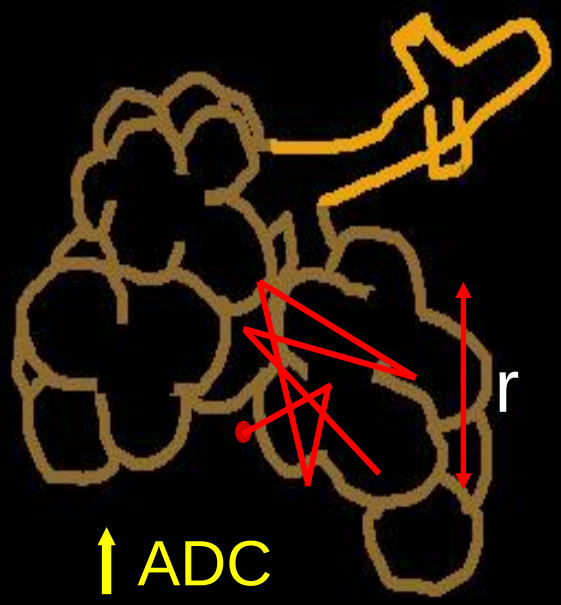
- Spirometry and Plethysmography
- Computed Tomography
- Diffusion-Weighted (DW) Hyperpolarized Gas MRI

DW Hyperpolarized Gas MRI

Healthy



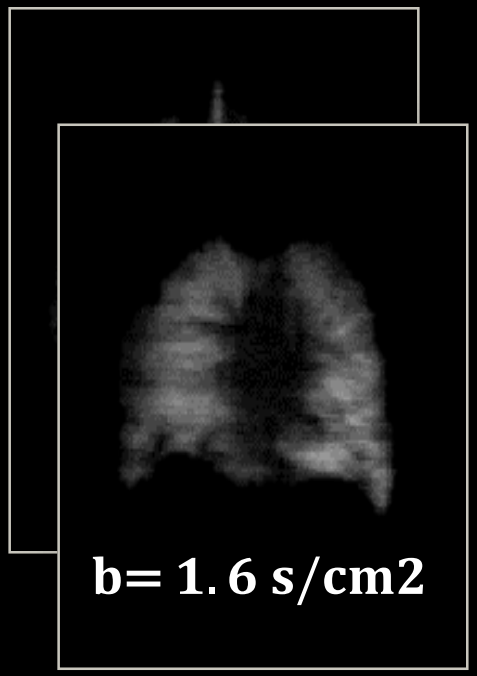
Emphysema



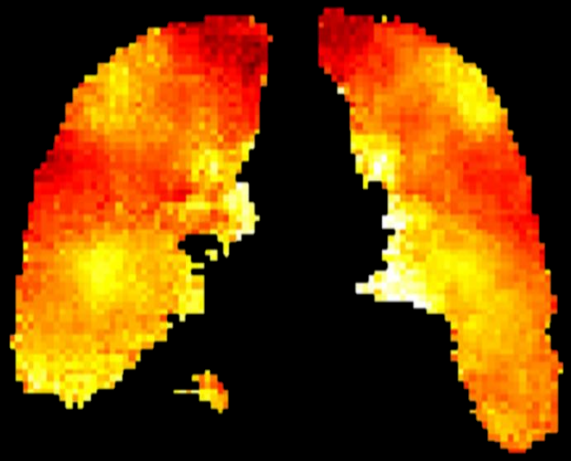
$$ADC = \frac{r^2}{2t}$$

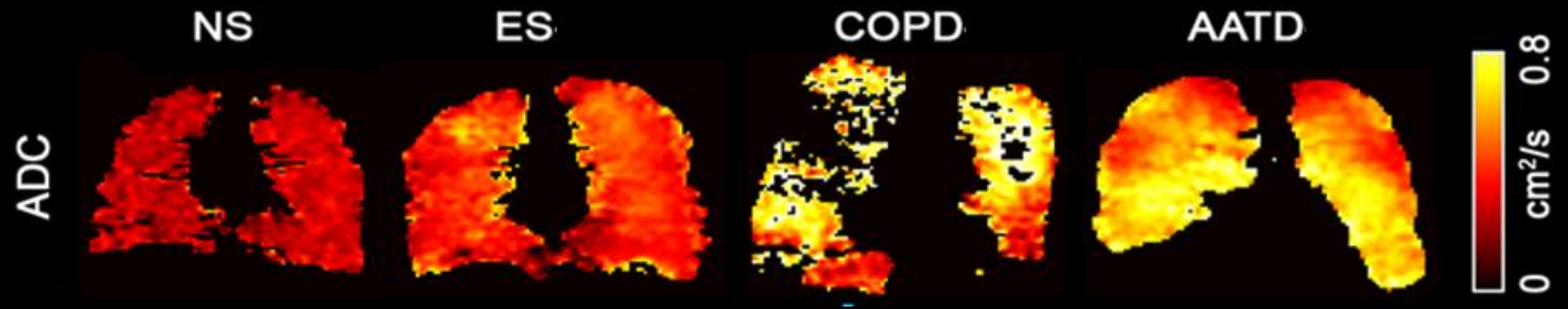
ADC = apparent diffusion coefficient
r = distance the helium atoms diffuse
t =diffusion time

DW Hyperpolarized Gas MRI



$$S(b) = S_0 exp(-bADC)$$





[1]**Ouriadov A**, *et all, Magn Reson Med 2018; 79: 439-448.*

Limitations to DW Hyperpolarized Gas MRI

- A stretched exponential method[3] (SEM) combined with under-sampling (compressed sensing) in the imaging and diffusion directions[4] was proposed for the evaluation of hyperpolarized gas multiple b-value diffusion-weighted MRI.
- The major advantage of this method is the possibility to significantly speed up the data acquisition using acceleration factors (AF) between 7 and 10.[4]

[2]*Ouriadov A. et al. Magn Reson Med (2012)*
[3]*Chan H. F. et al. Magn Reson Med, (2016).*
[4]*Abascal J. F. A. et al. ArXiv, (2017)*

Research Objective

To develop the accelerated SEM-based ^{129}Xe MRI approach and generate hyperpolarized gas MRI-based emphysema biomarkers in a small group of young healthy volunteers and Alpha-1 Antitrypsin Deficiency subjects.

Research Hypothesis

Accelerated (7 folds faster) methods can be developed to provide whole lung hyperpolarized gas MRI-based emphysema biomarkers including static-ventilation, T_2*, ADC and morphometry maps in a single 16 sec breath-hold.

Methods: MRI Protocol

3.0 T Discovery MR750 (GEHC)

	Hyperpolarized ^{129}Xe MRI
Pulse Sequence Parameters	**Accelerated 2D Gradient Echo DW** Short-TE/TE/TR/FA/BW = 2ms/10ms/5ms/4°/31.25kHz Matrix Size = 128x20, Acceleration Factor = 7 Diffusion time (Δ) = 5.2ms *b*-values =0, 0, 12, 20, 30, 45.5 s/cm^2 FOV =40x40cm^2, 8 slices, 30 mm slice thickness
Dose	 
Coil	CMRS flexible transmit/receive chest coil

Methods: Image Analysis

Diffusion Attenuated MR Signal in SEM:

$$S(b) = \mathrm{S}_0 \exp(-\boldsymbol{b} \bullet \mathrm{DDC})^{\alpha},$$

$$where \quad \mathrm{DDC} = \text{diffusivity}, \quad \alpha = \text{heterogeneity index};$$

and mean diffusion length $(\mathrm{Lm_D}) = (2\,\Delta\,\langle \mathrm{DDC} \rangle)^{1/2}$

The SEM was extended[4,5] to provide clinically-relevant biomarkers of emphysema, such as mean linear intercept (L_m)[6] for ^{129}Xe:

$$\mathrm{L_m} = -562\,\mu\mathrm{m} + 4.3 \cdot \mathrm{Lm_D} \cdot \sqrt{\frac{\mathrm{D_0^{He}}\,\Delta_{\mathrm{He}}}{\mathrm{D_0^{Xe}}\,\Delta_{\mathrm{Xe}}}}$$

$\mathrm{D_0^{He}} = 0.83\ \mathrm{cm^2/s}$[7]

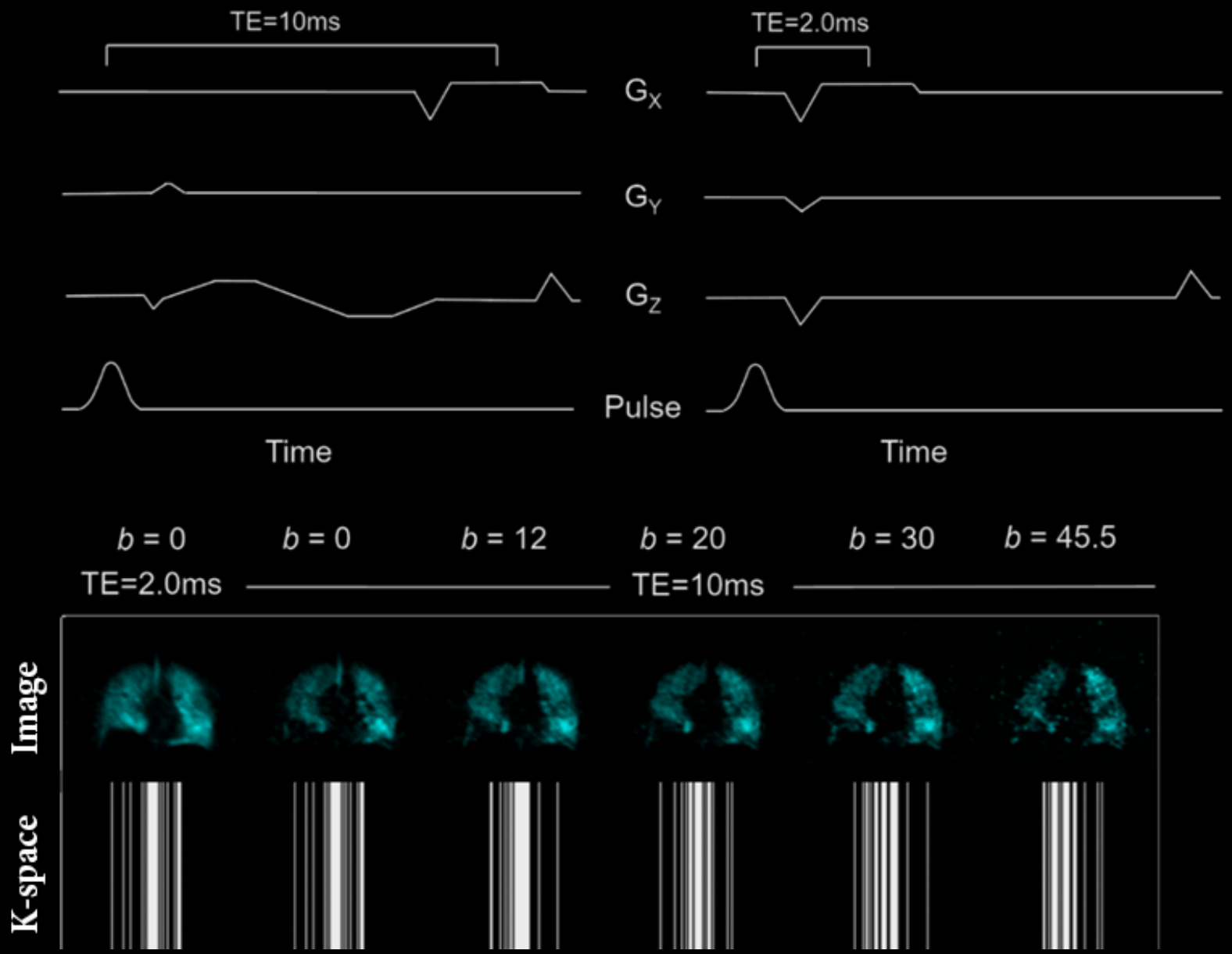
$\mathrm{D_0^{Xe}} = 0.22\ \mathrm{cm^2/s}$[7]

$\Delta_{\mathrm{He}} = 1.46\ \mathrm{ms}$

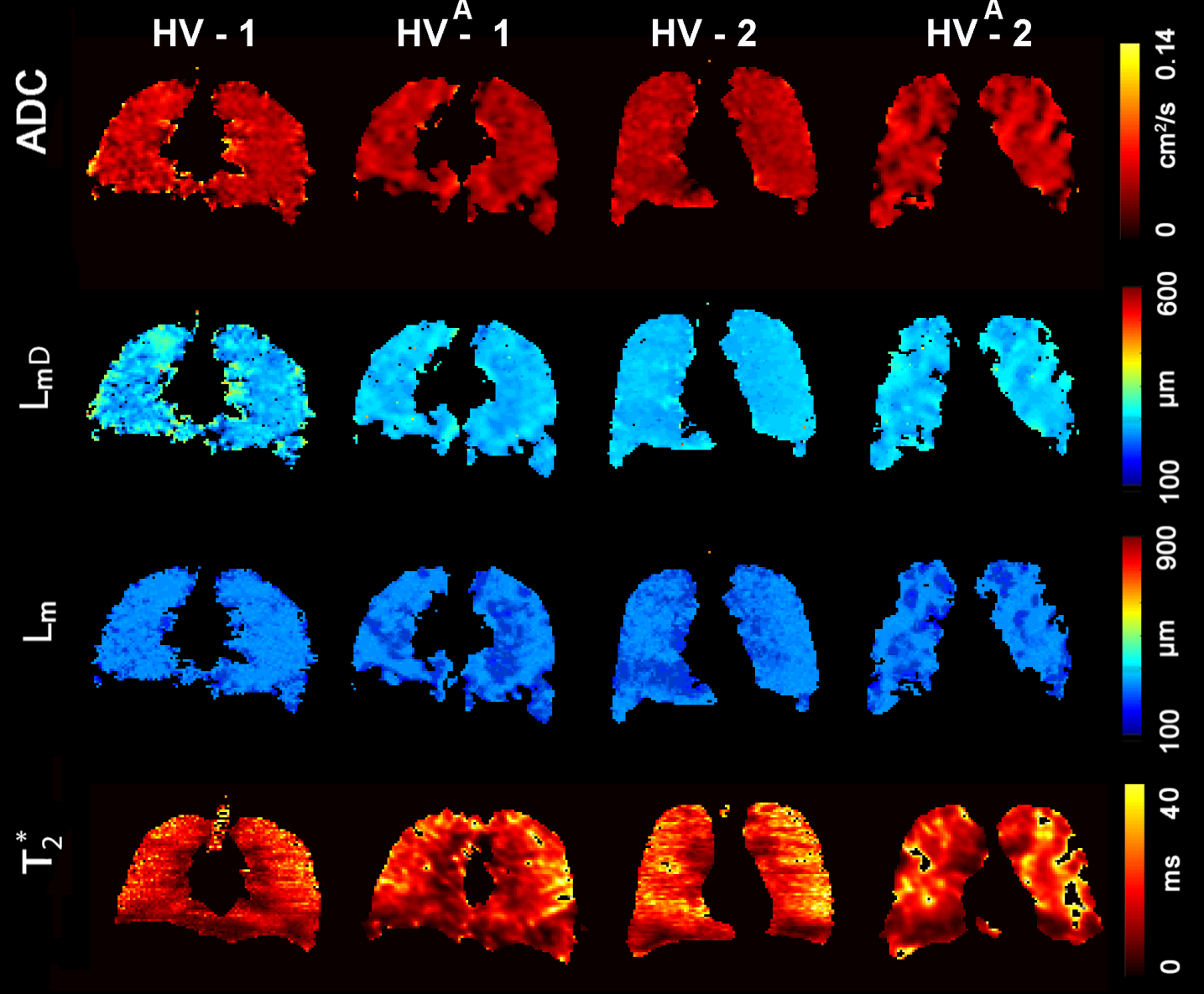
$\Delta_{\mathrm{Xe}} = 5.2\ \mathrm{ms}$

[4] *Ouriadov A. et al. Magn Reson Med (2017)*
[5] *COuriadov. et al. ISMRM, (2016).*
[6] *Yablonskiy D. A. et al. J Appl Physiol 107, 1258-1265, (2009).*
[7] *Kirby M. et al. Radiology 265, 600-610, (2012)*

Methods: Pulse Sequence

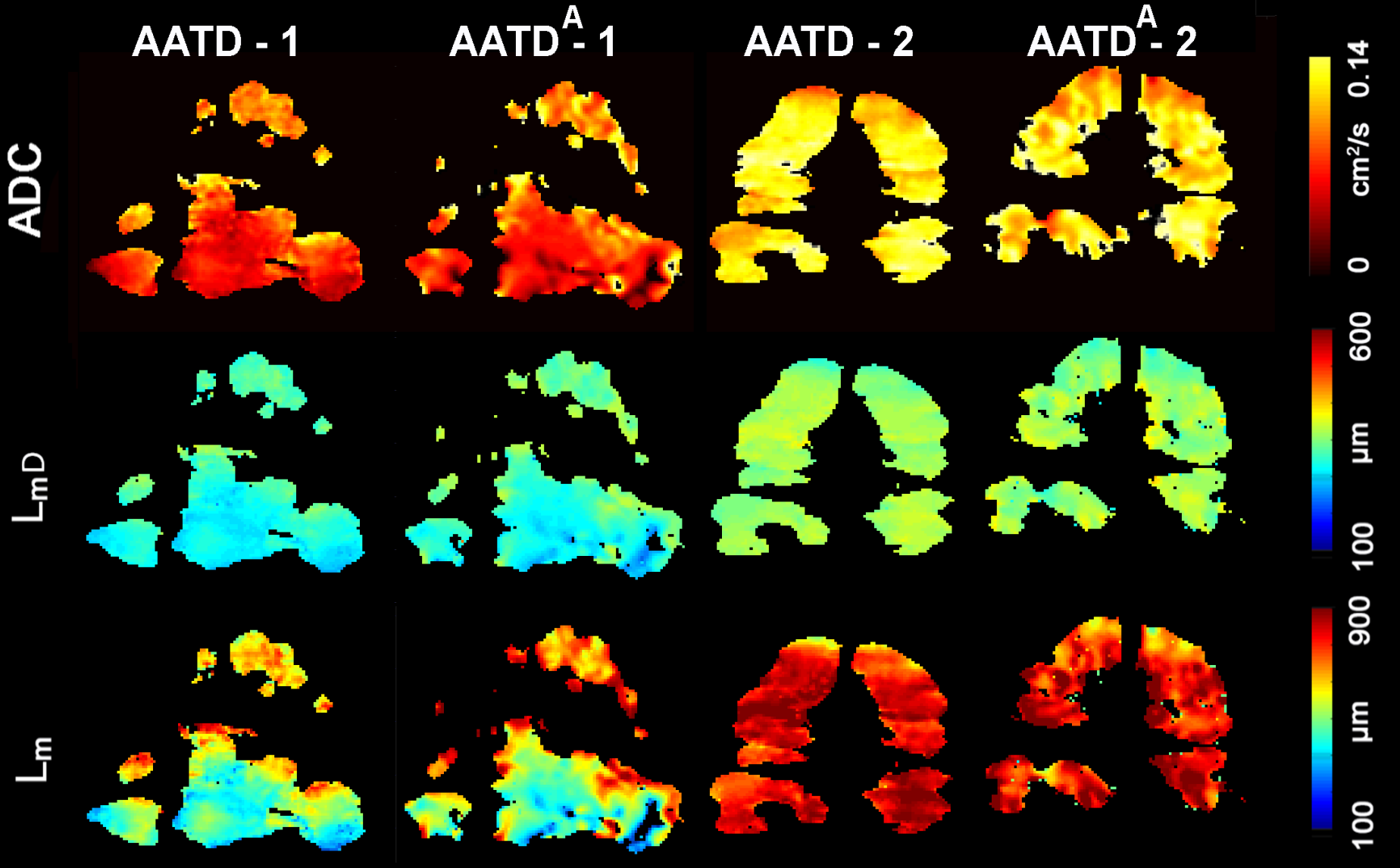


Results: Accelerated ^{129}Xe MRI



Ouriadov A, et all, Submitted to Magn Reson Med

Results: Accelerated ^{129}Xe MRI



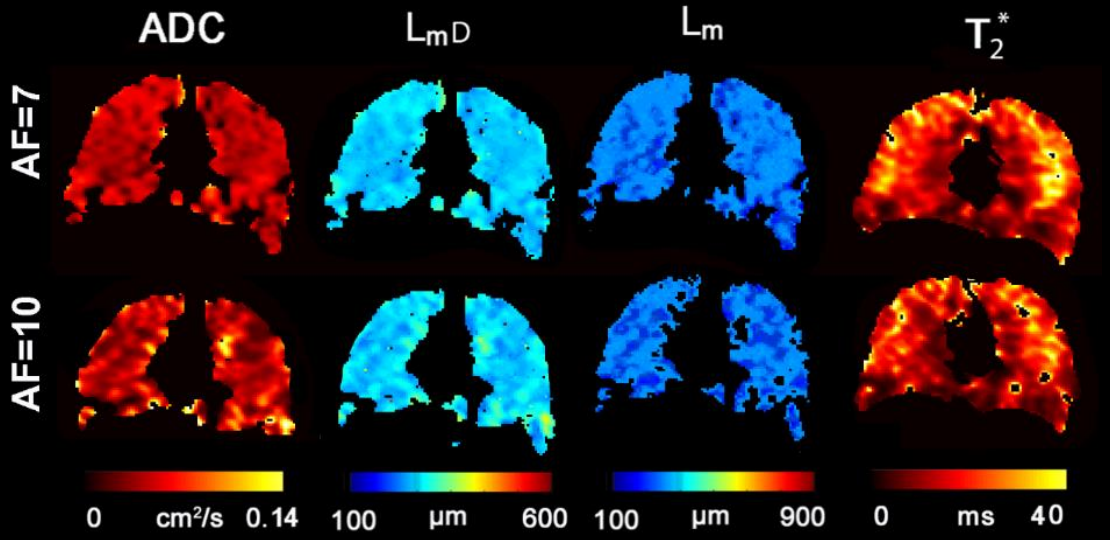
Ouriadov A, et all, Submitted to Magn Reson Med

Conclusions

- **Accelerated ^{129}Xe MRI provides a way to generate alveolar morphometry estimates to regionally characterize emphysema and airspace enlargement in patients with AATD in a single 16 sec breath-hold scan**

- **The Signal-to-Noise Ratio (35-40) of the short-TE image was more than adequate for the calculation of the Ventilation Defect Percentage which may be simultaneously generated with T_2*, ADC and L_m values in a single rapid breath hold**

- **This is the first in patient demonstration of this acceleration (7x) method for ^{129}Xe and it suggests that the acceleration factors of 10 fold are possible. It will help retain resolution, maintain high number of b-values**



Ouriadov A, et all, ISMRM 2019

Translating ^{129}Xe MRI Across Canada

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Robarts Research Institute
Toronto ON:
The Hospital for Sick Children
Hamilton ON:
Firestone Institute for Respiratory Health
St. Joseph's Healthcare
Thunder Bay ON:
Thunder Bay Regional Research Institute
Montreal QC:
CHU Sainte-Justine
Université de Montreal
Vancouver BC:
The Institute of Heart and Lung Health
St. Paul's Hospital

Western UNIVERSITY · CANADA

LAWSON HEALTH RESEARCH INSTITUTE

London Lung Imaging Research Team

Western Science

Physics & Astronomy

robarts RESEARCH