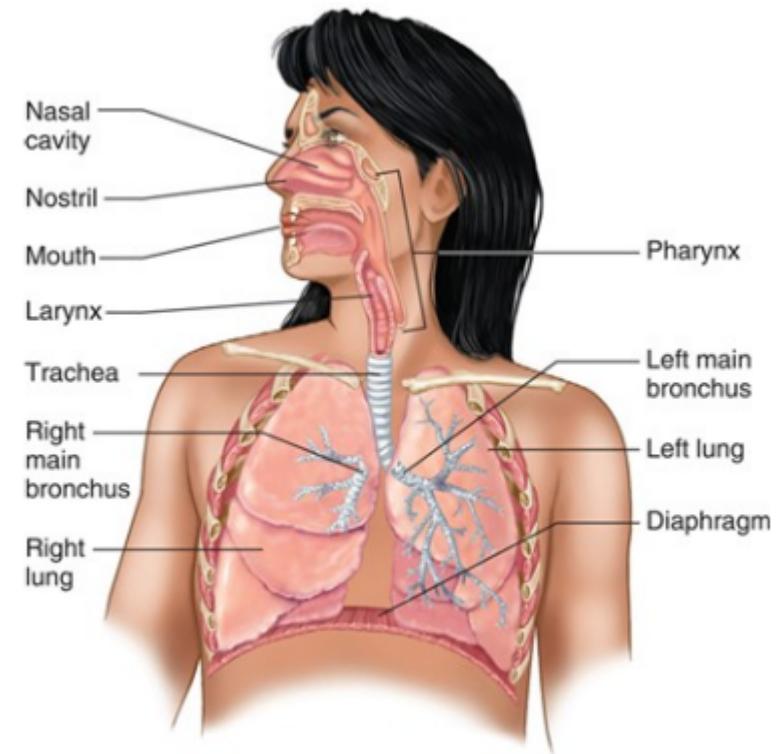


EXPLORING LUNG MICROSTRUCTURE WITH MONTE CARLO

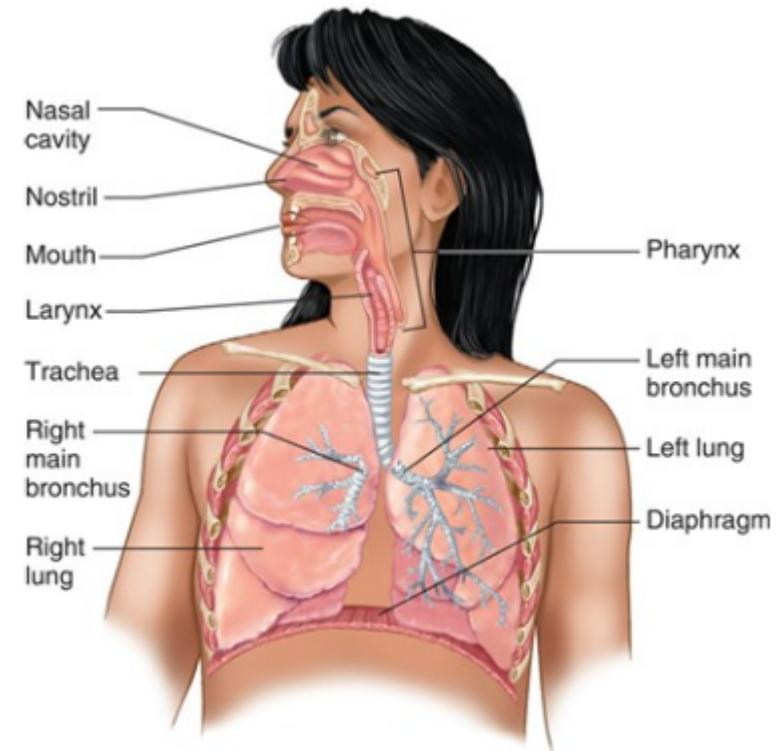
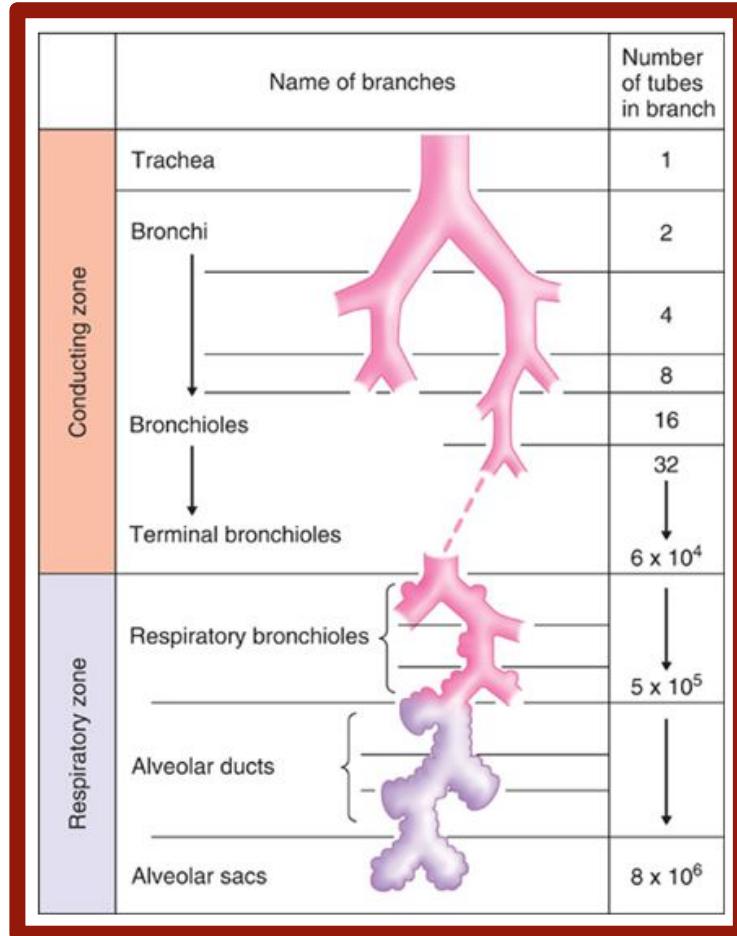
Annie Malkus, PhD, University of Wisconsin-Madison
OSG All Hands Meeting, March 2017, San Diego, CA

LUNG STRUCTURE

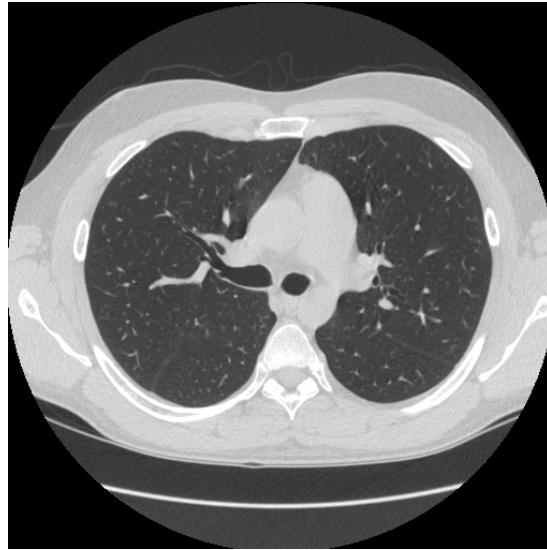
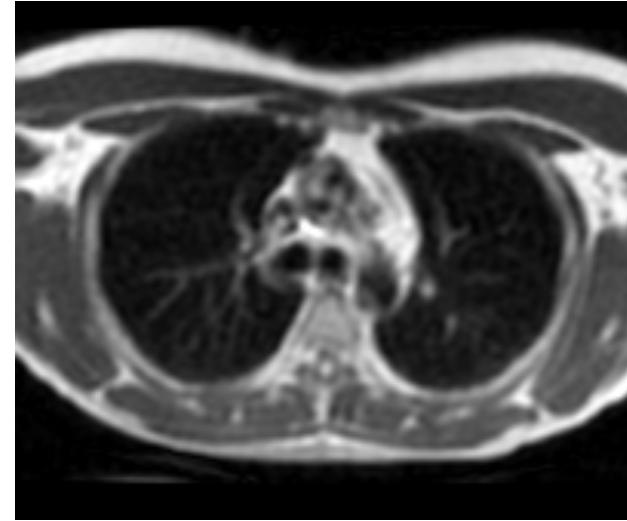
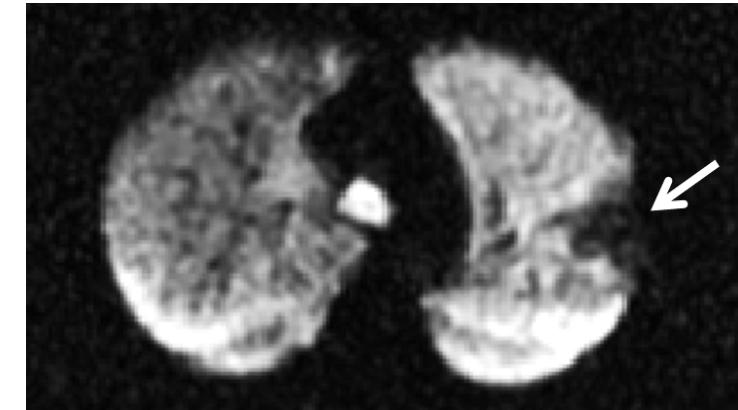


Eric, P. W., Hershel Raff, and Kevin T. Strang. "Vander's Human Physiology, The Mechanism of Body Function." (2014).

LUNG STRUCTURE



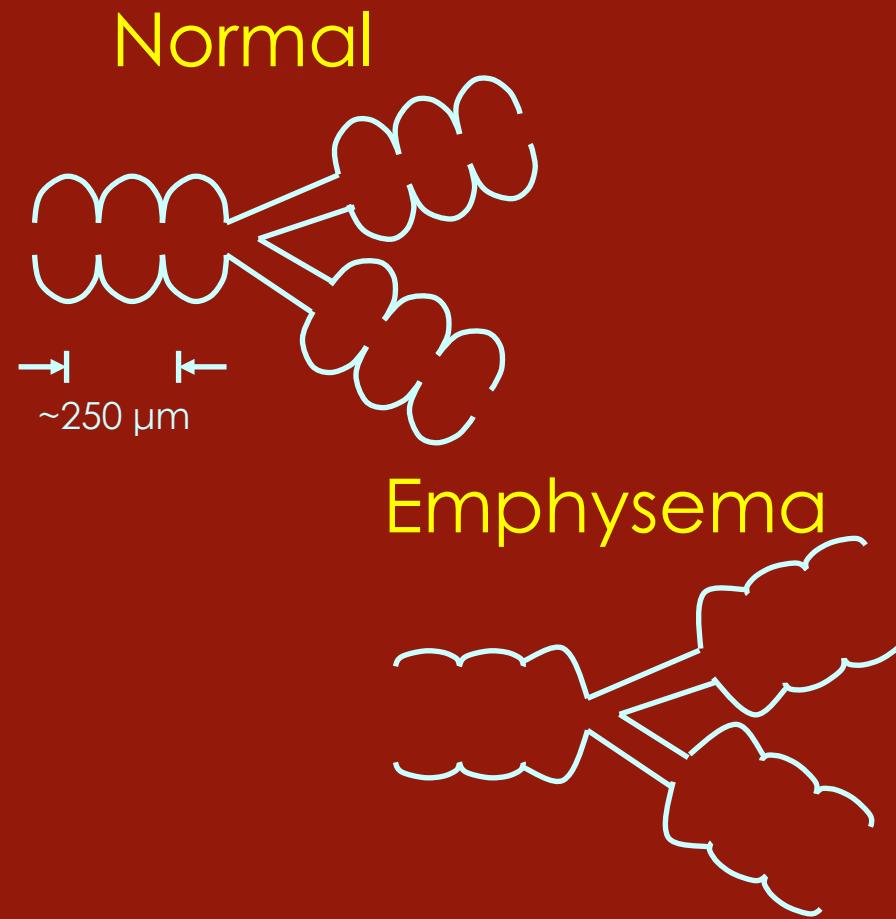
Eric, P. W., Hershel Raff, and Kevin T. Strang. "Vander's Human Physiology, The Mechanism of Body Function." (2014).

CT**Proton MRI****HP ^3He MRI**

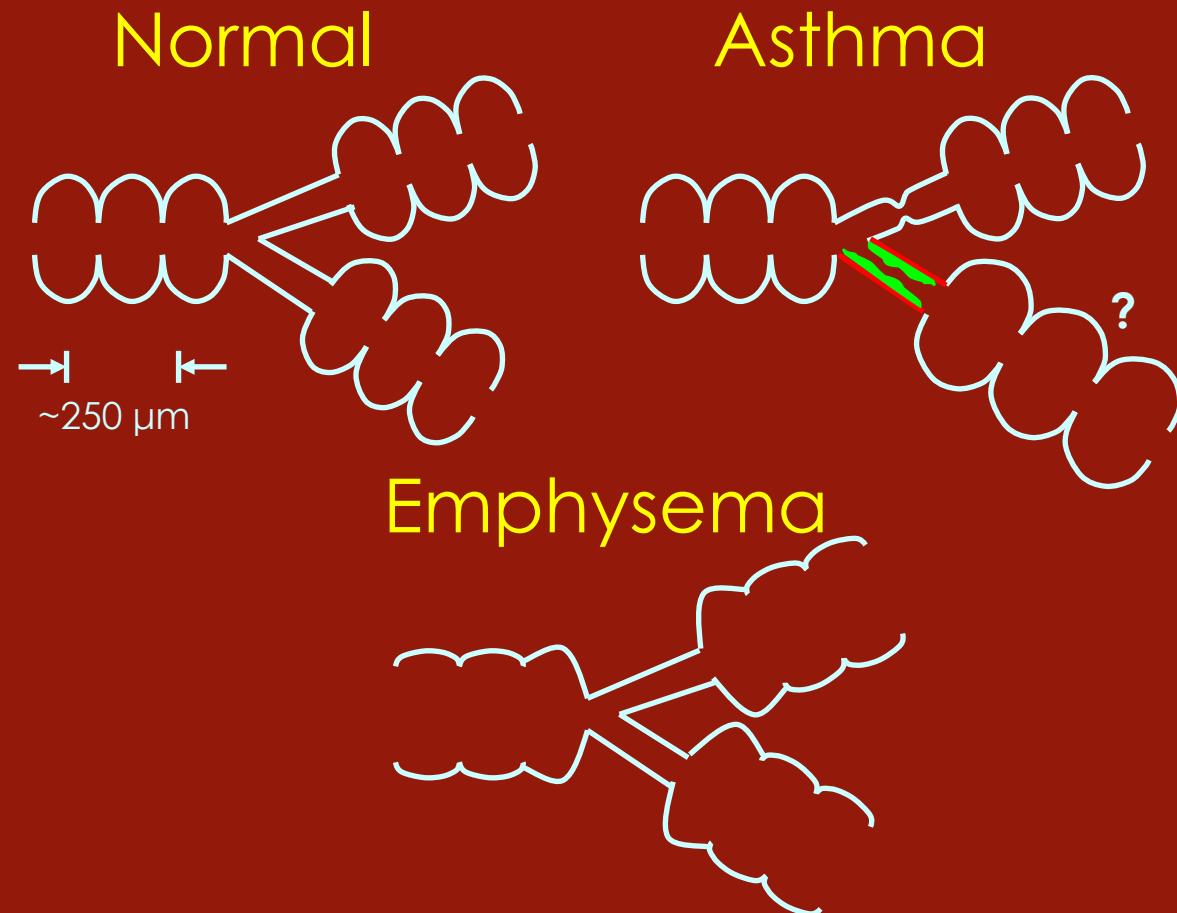
Structure

Function

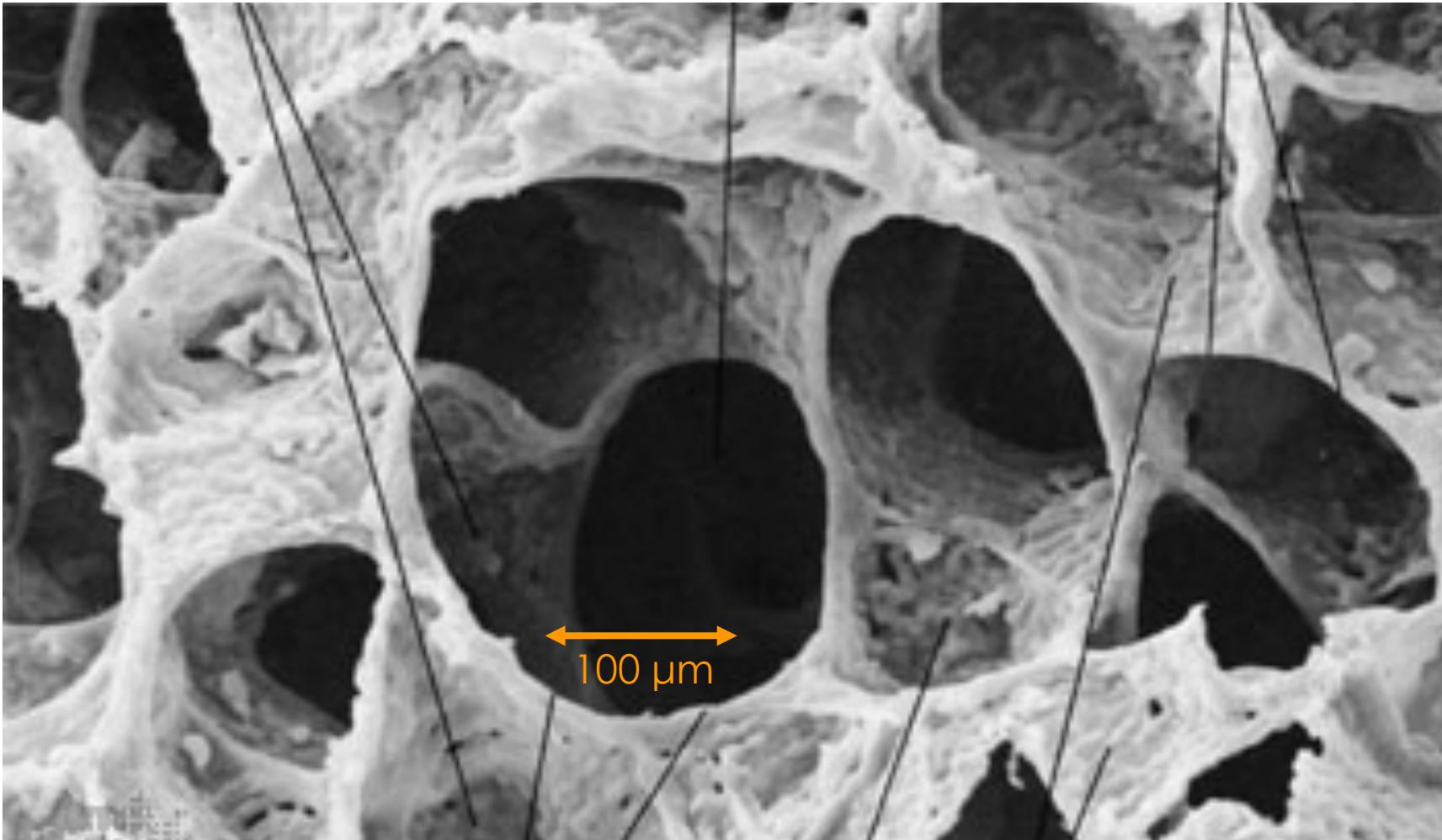
LUNG MICROSTRUCTURE



LUNG MICROSTRUCTURE



LUNG MICROSTRUCTURE



Slide content courtesy of Sean Fain

LUNG MICROSTRUCTURE

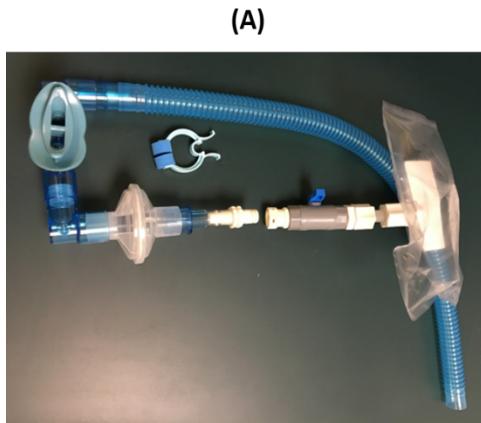
MC can help us probe these scales



MOTIVATION FOR USING HTC

- Structural Imaging
- Functional Imaging
 - Measure microstructural changes
 - Improve scan parameters to probe small airway disease

MATERIAL AND METHODS



(A)



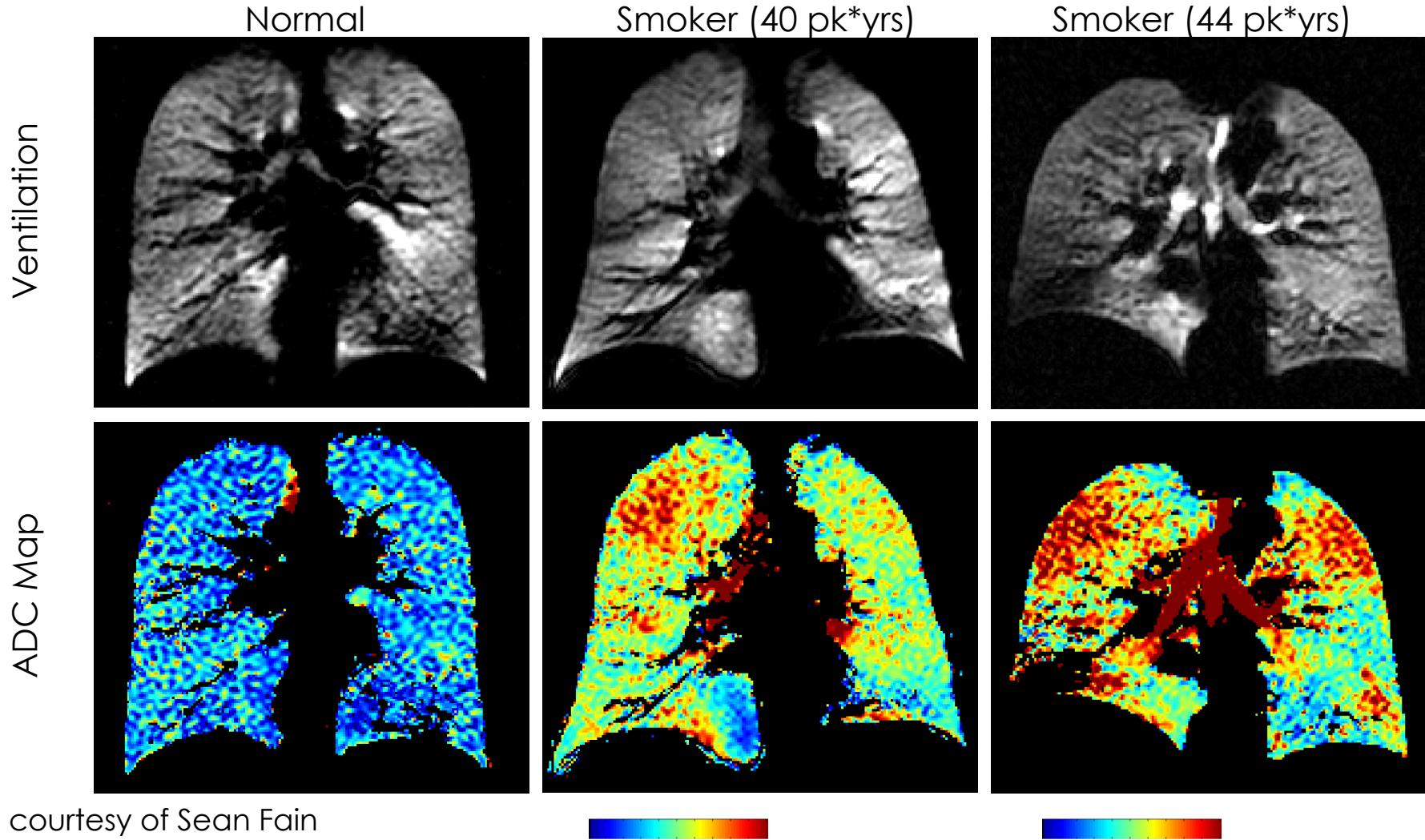
(B)

Breathing apparatus (in action)



Helium
Hyperpolarizer

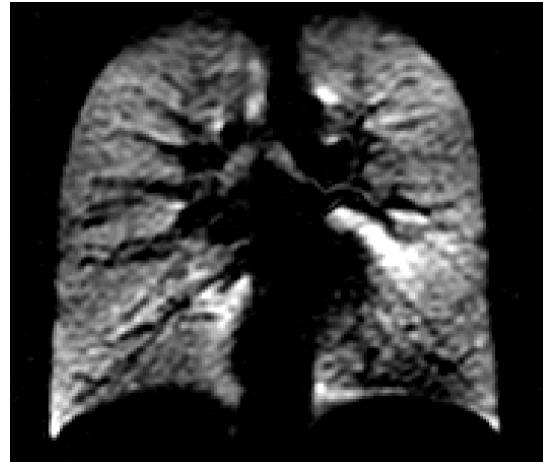
HYPERPOLARIZED GAS



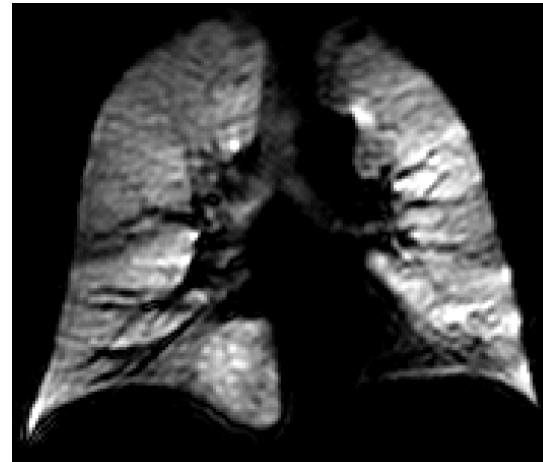
Slide content courtesy of Sean Fain

HYPERPOLARIZED GAS

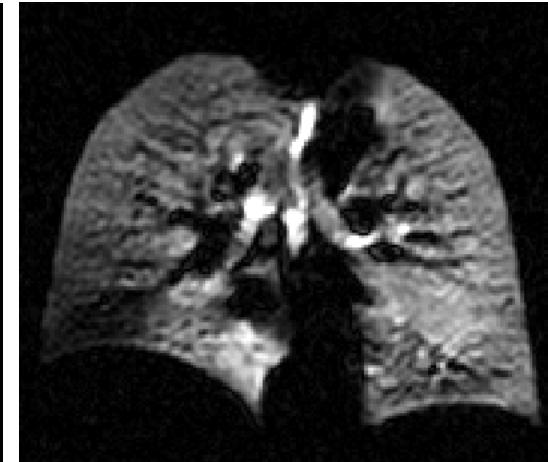
Normal



Smoker (40 pk*yrs)

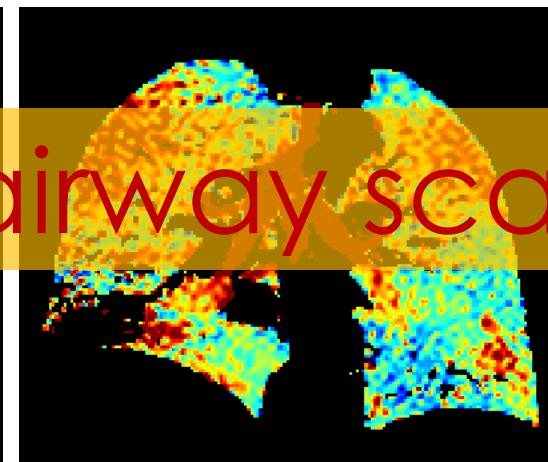
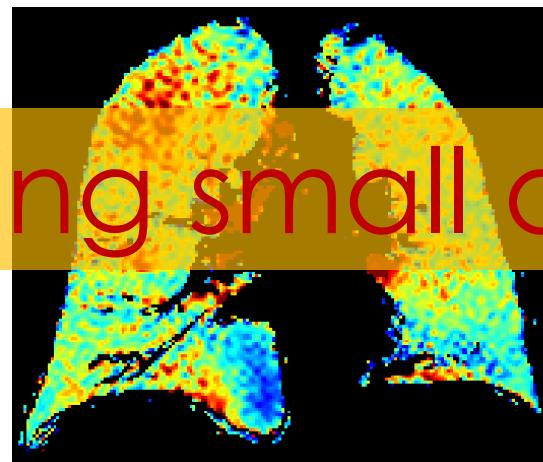
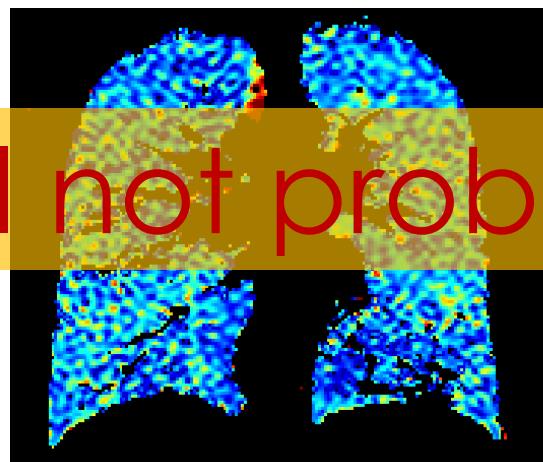


Smoker (44 pk*yrs)



Ventilation

ΔDCT^{app}

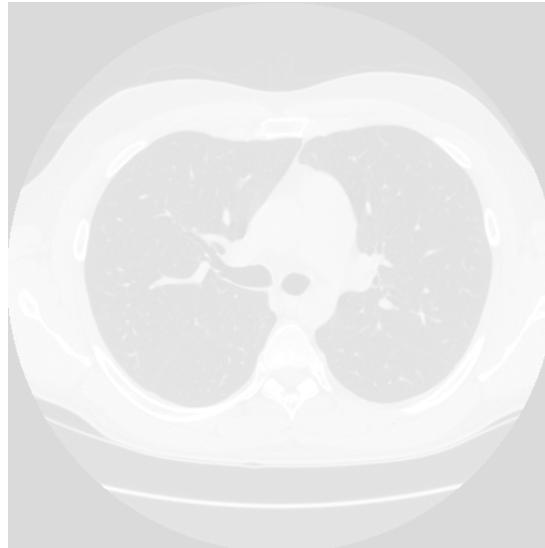


Still not probing small airway scales...

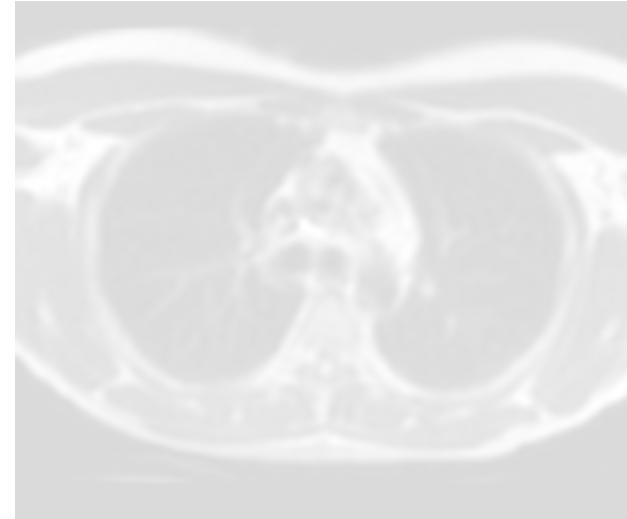
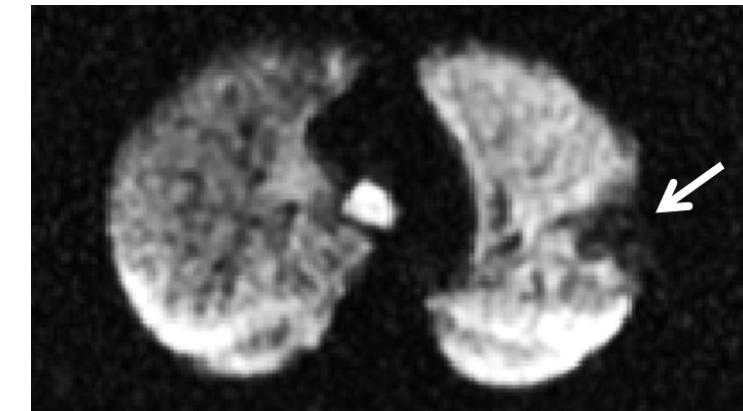
Jin et al. Radiology 2006



CT



Proton MRI

HP ^3He MRI

Structure

Function

MAGNETIZATION ACCUMULATES PHASE
BASED ON STRENGTH OF MAGNETIC FIELD

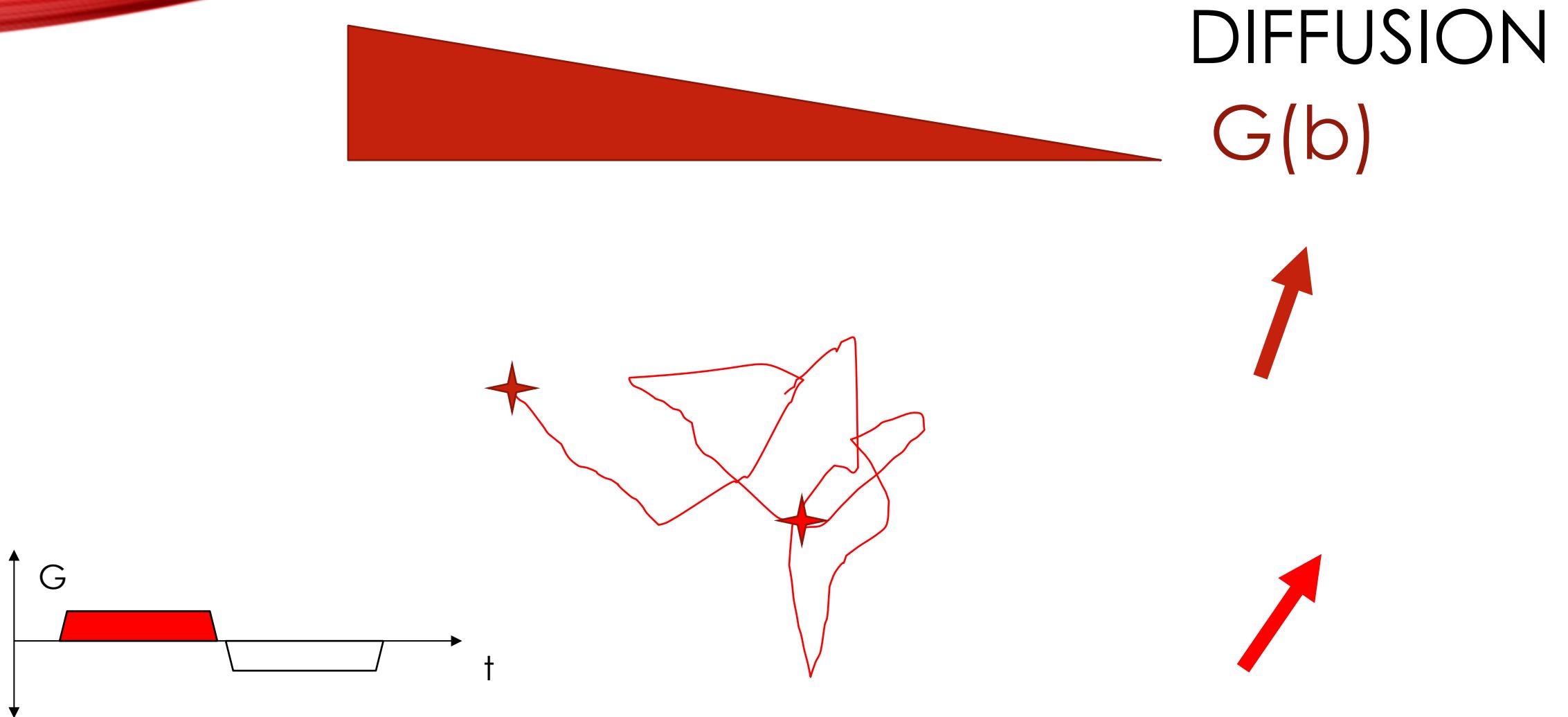
$$\omega = -\gamma B_0$$

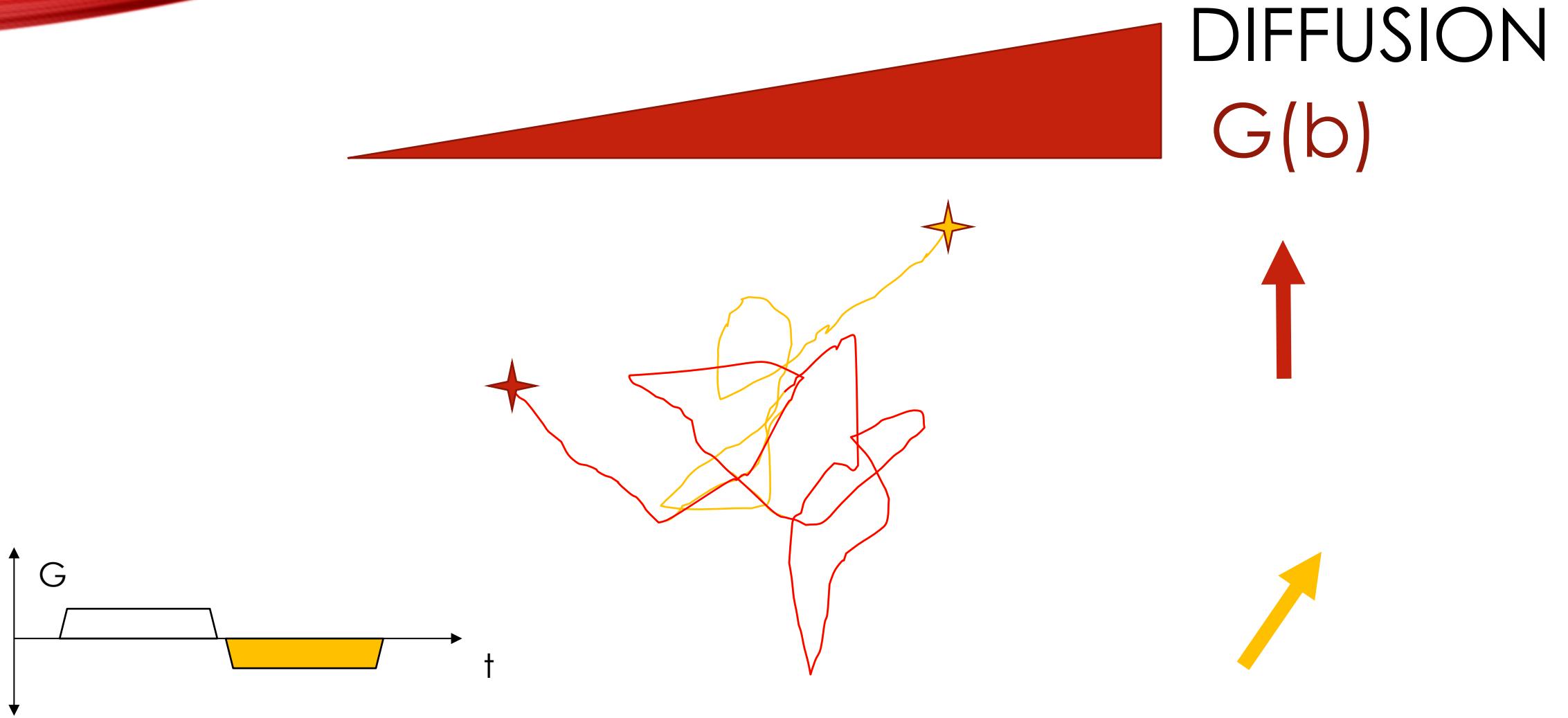
MAGNETIZATION ACCUMULATES PHASE
BASED ON STRENGTH OF MAGNETIC FIELD

This is how we probe small airway scales...

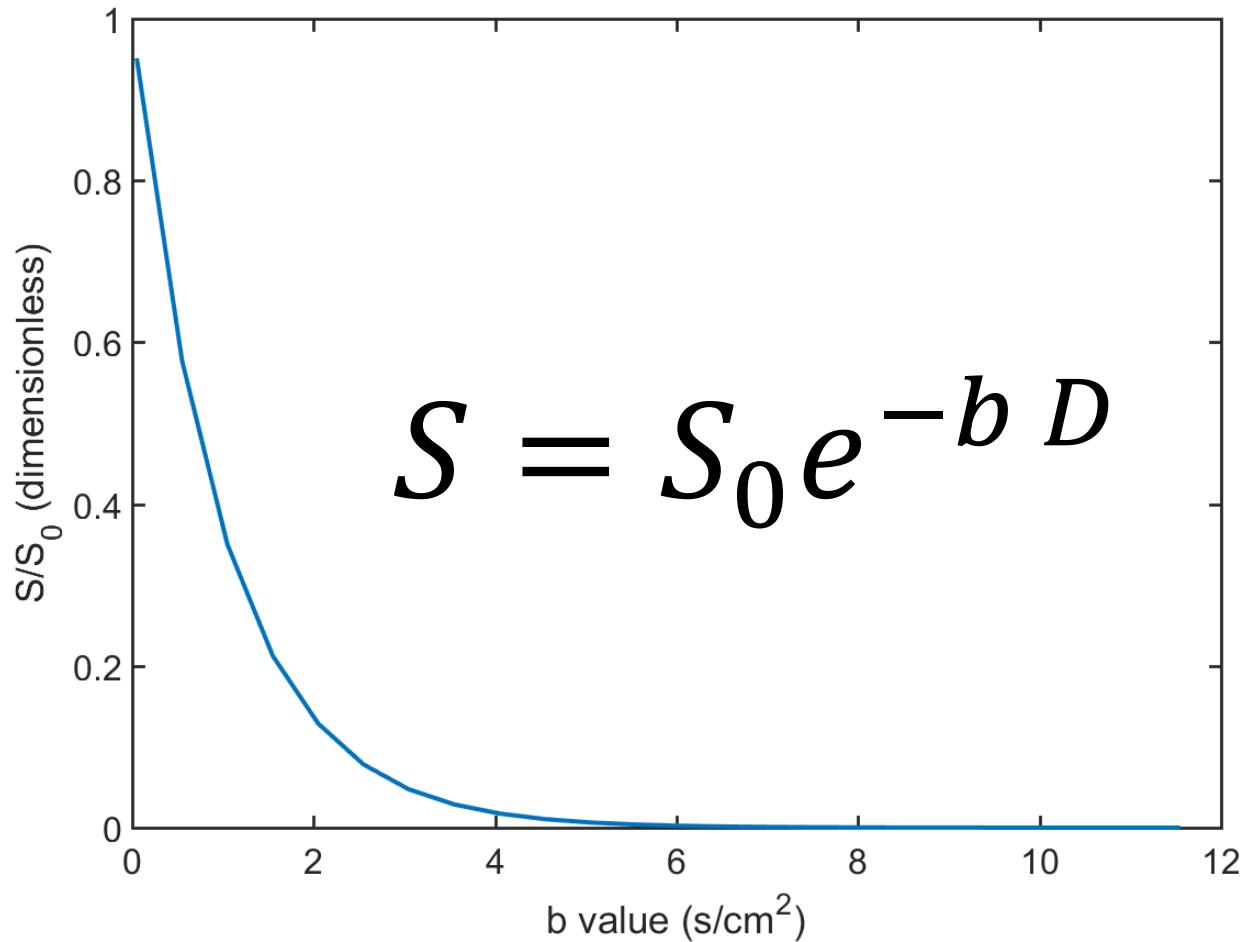
DIFFUSION



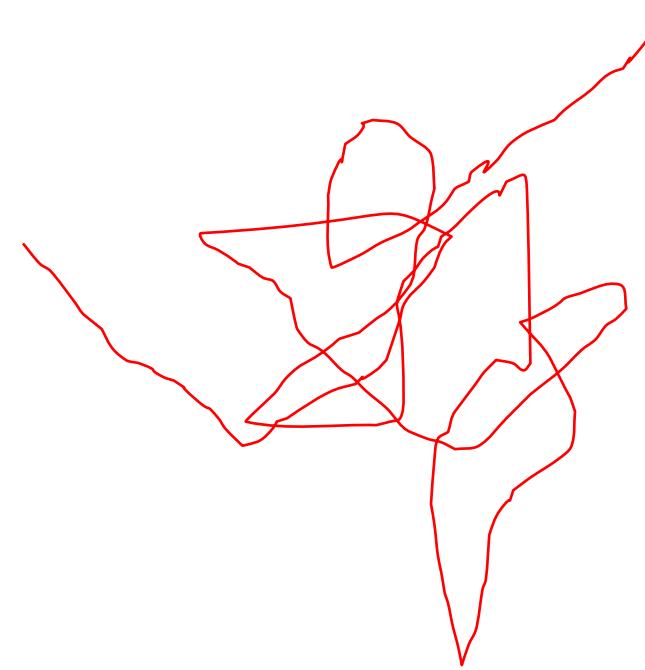


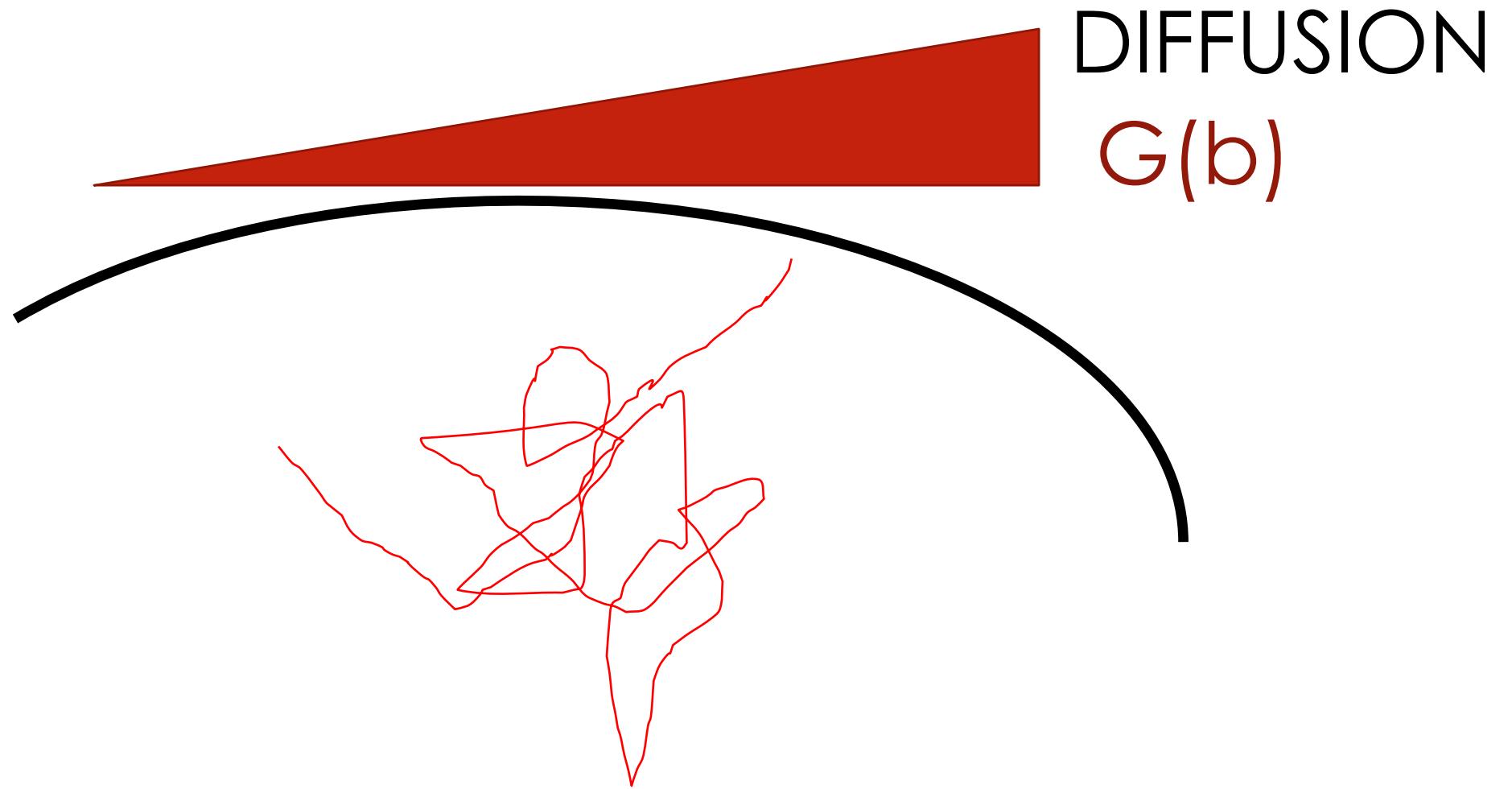


DIFFUSION

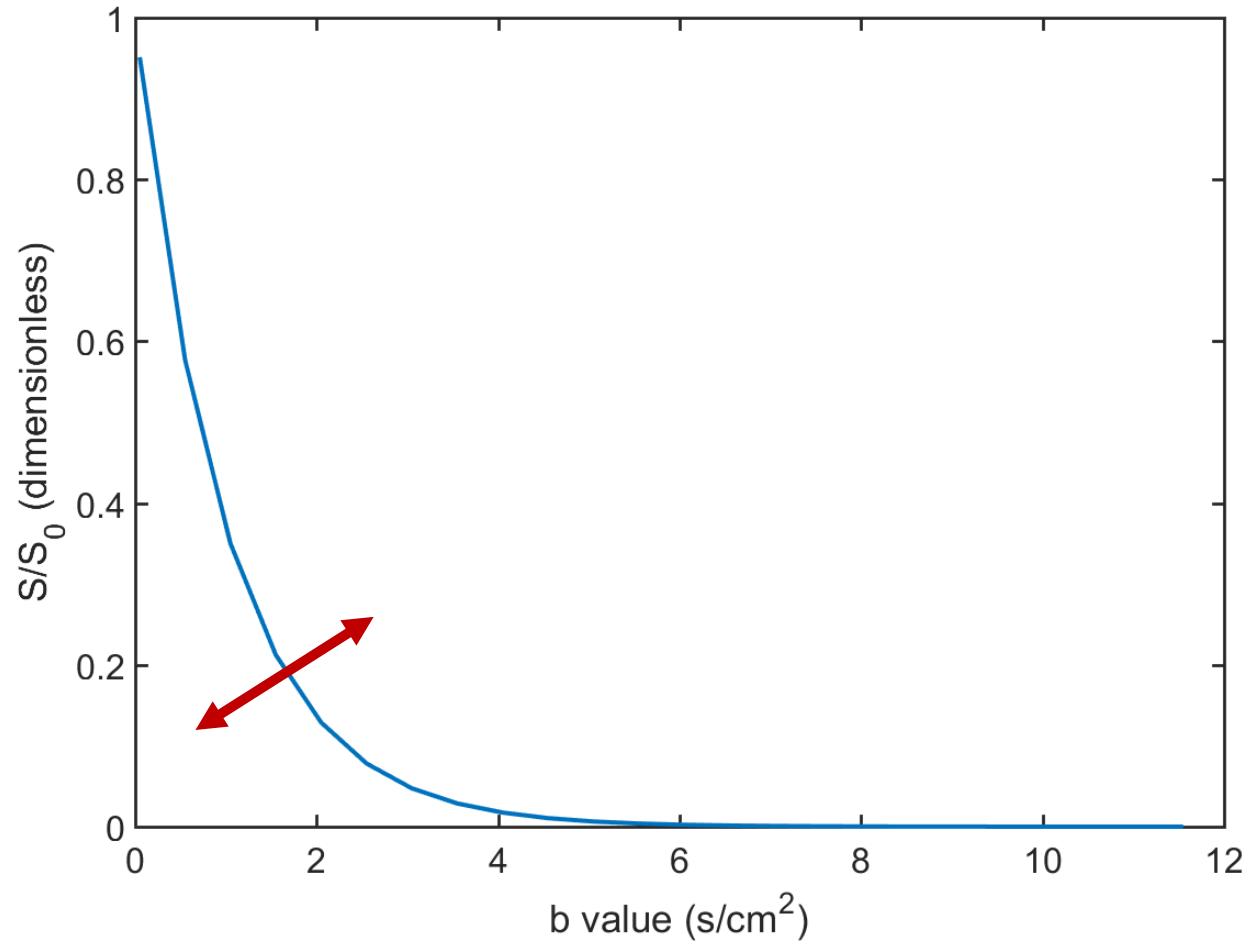


DIFFUSION
 $G(b)$

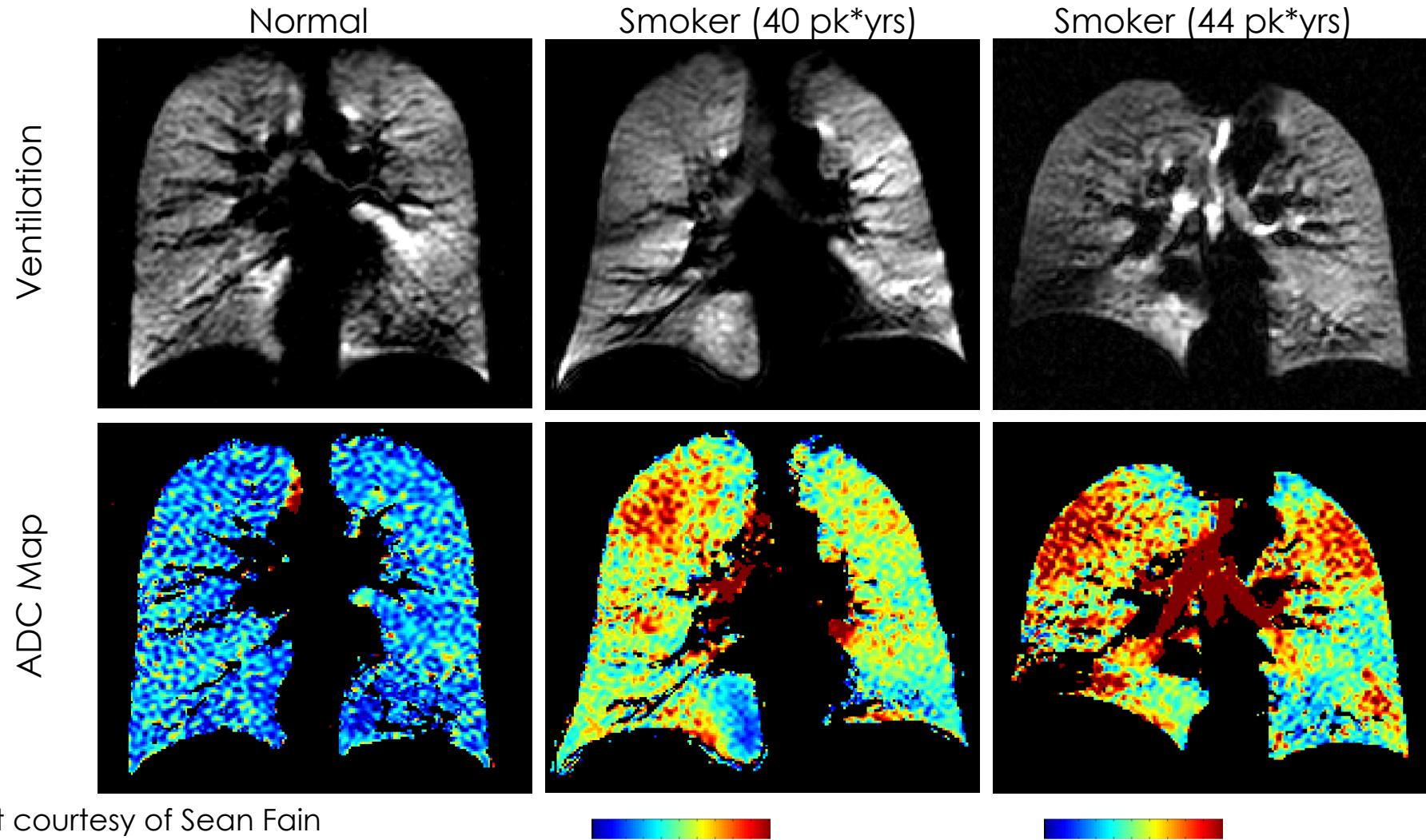




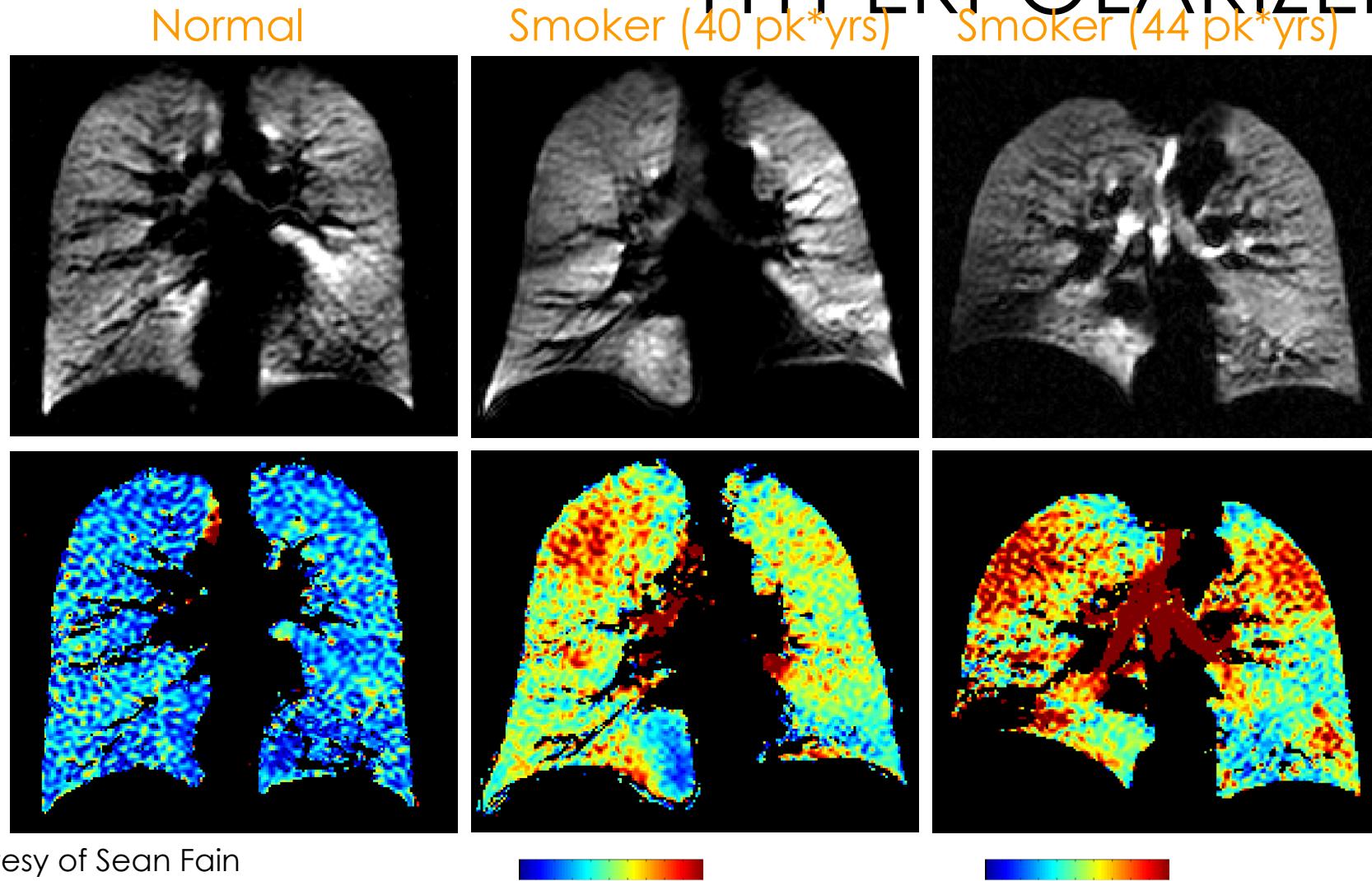
DIFFUSION



HYPERPOLARIZED GAS



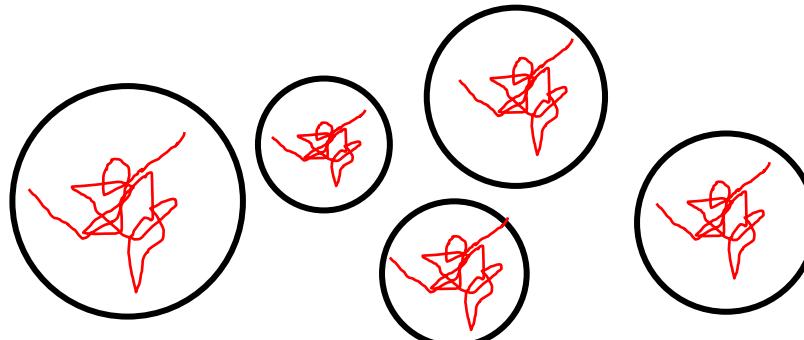
HYPERPOLARIZED GAS



Fain et al. Radiology 2006

HOW WE USE MC TO MAKE MEASUREMENTS IN MR

- Run simulations over scales in regime of interest



HOW WE USE MC TO MAKE MEASUREMENTS IN MR

- Run simulations over scales in regime of interest
- Compute signal with the experiment's actual scan parameters



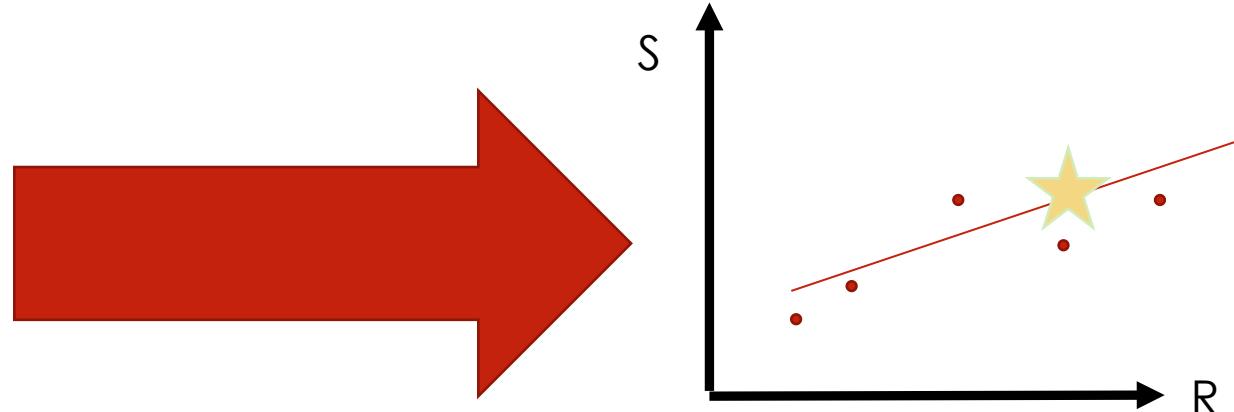
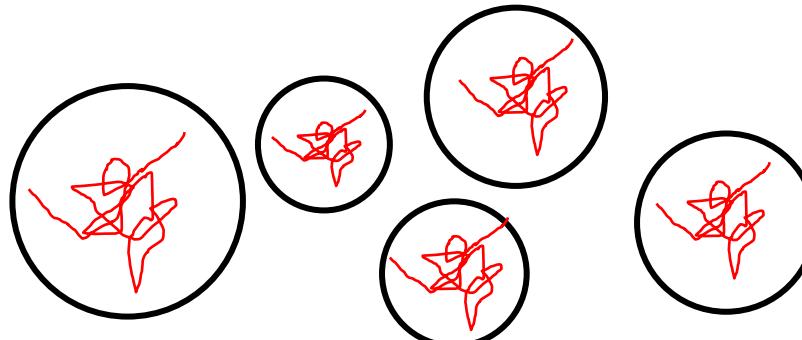
HOW WE USE MC TO MAKE MEASUREMENTS IN MR

- Run simulations over scales in regime of interest
- Compute signal with the experiment's actual scan parameters
- Fit MC to model

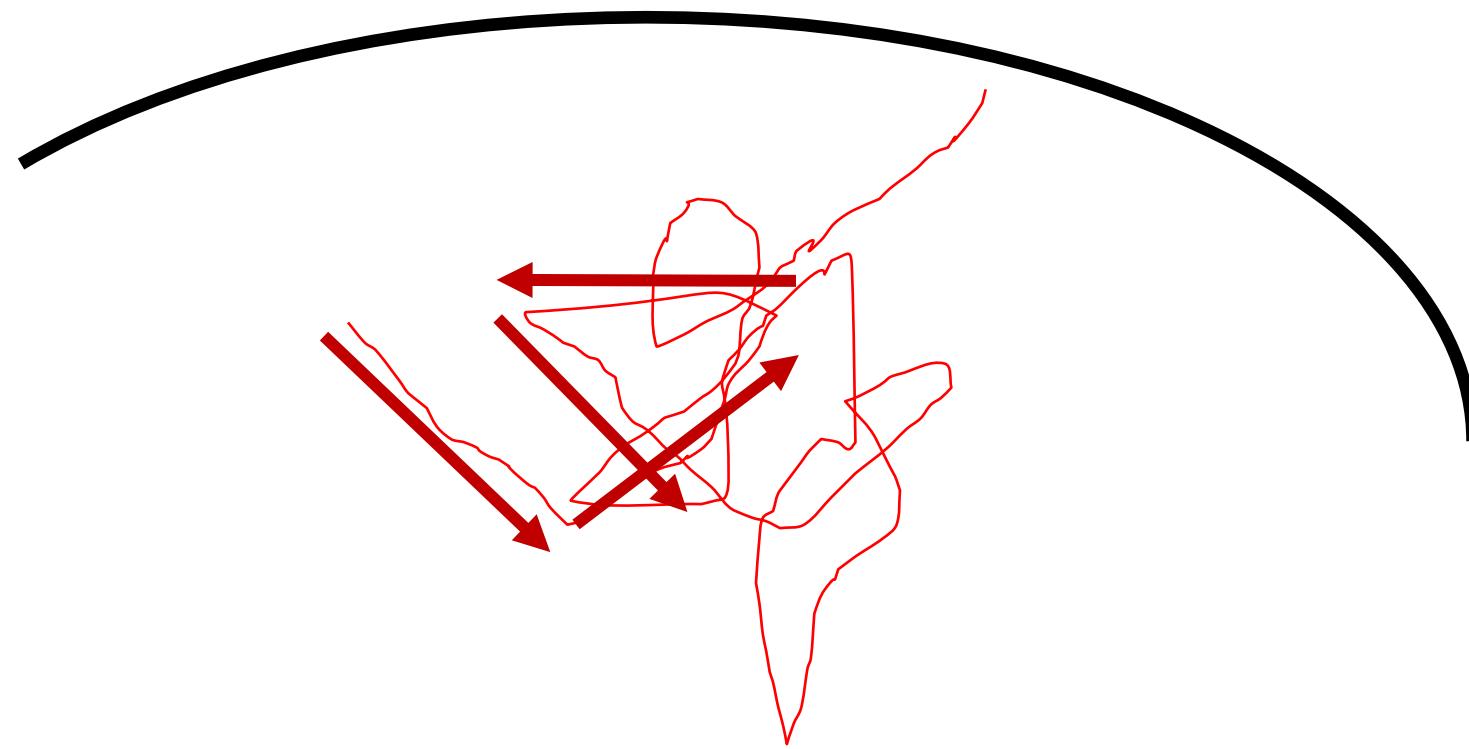


HOW WE USE MC TO MAKE MEASUREMENTS IN MR

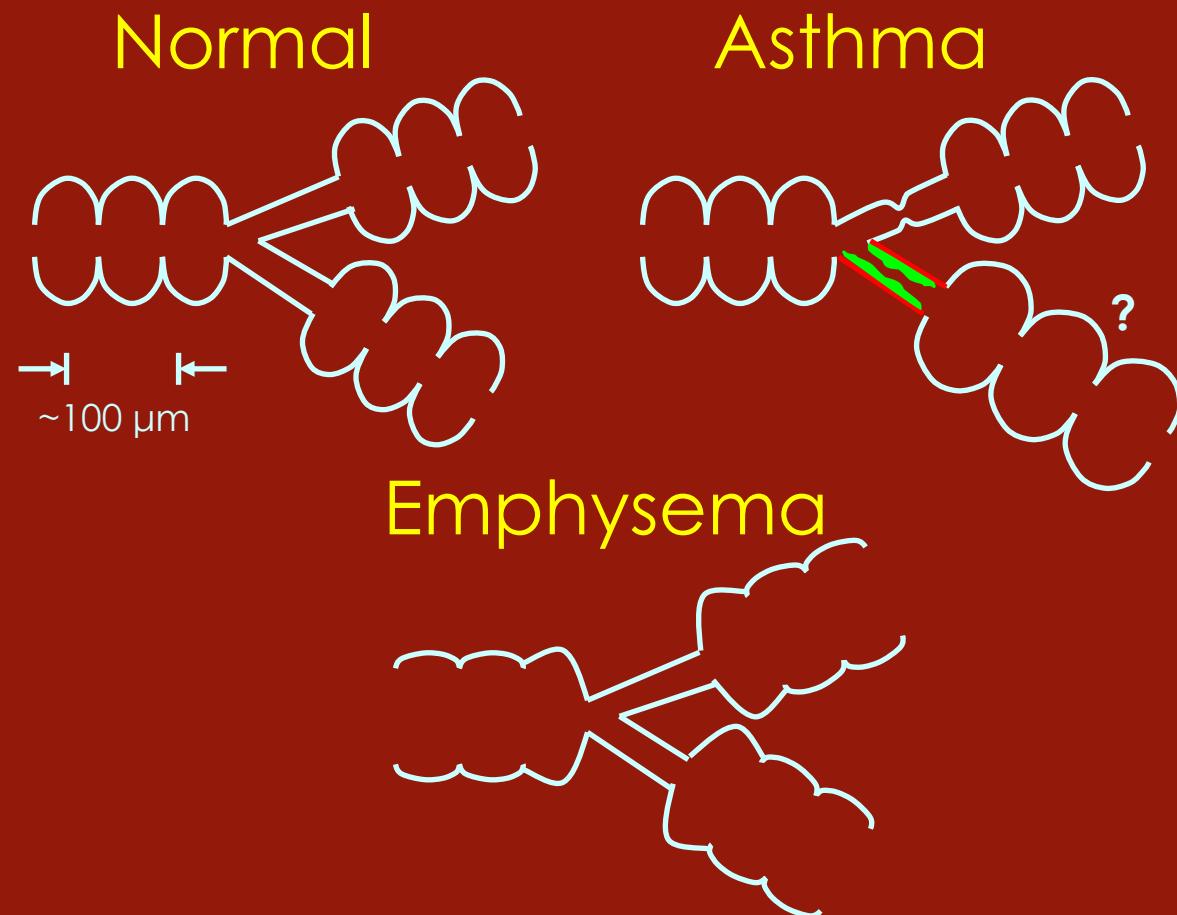
- Run simulations over scales in regime of interest
- Compute signal with the experiment's actual scan parameters
- Fit MC to model
- Compare data to model



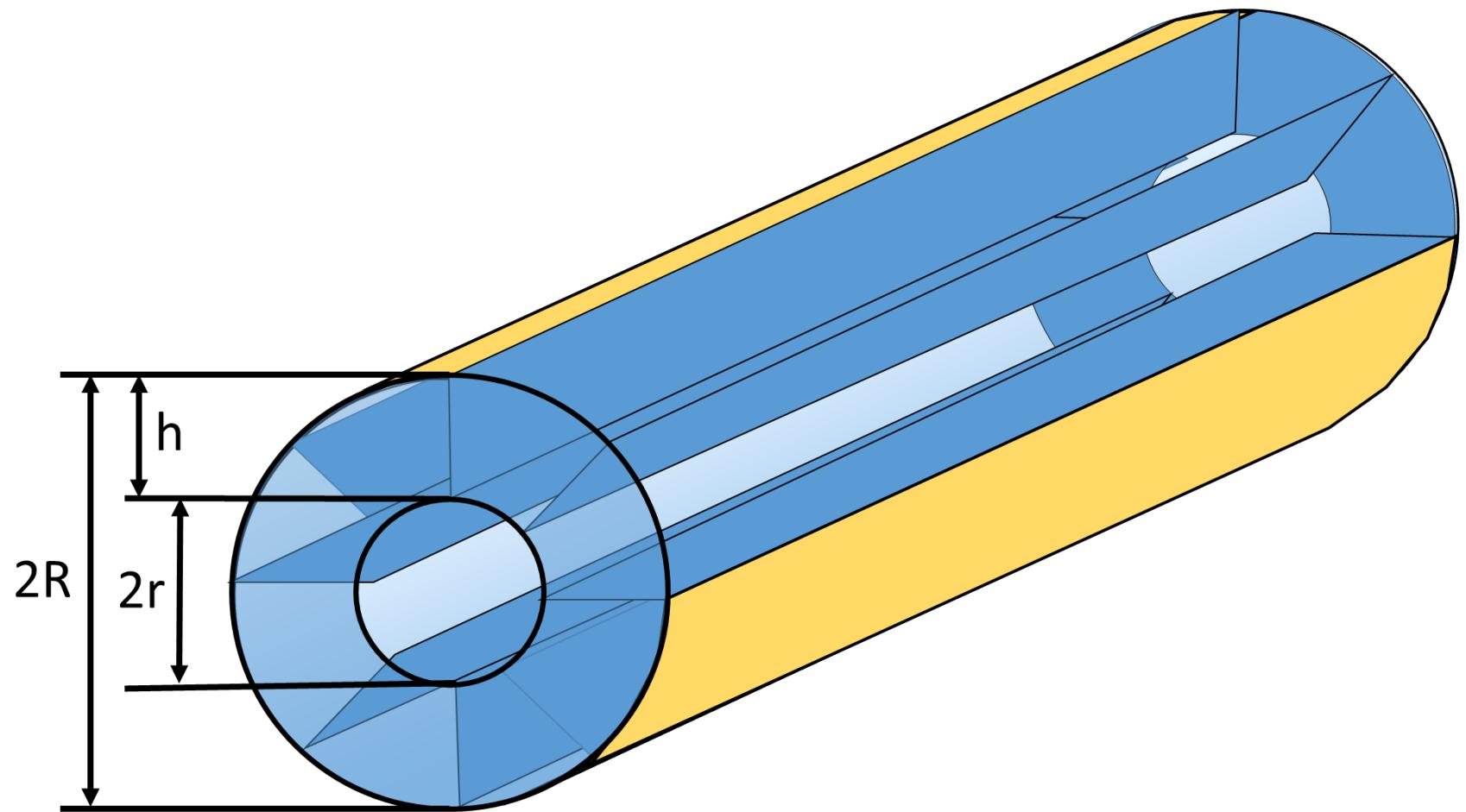
DIFFUSION—MONTE CARLO (MC)



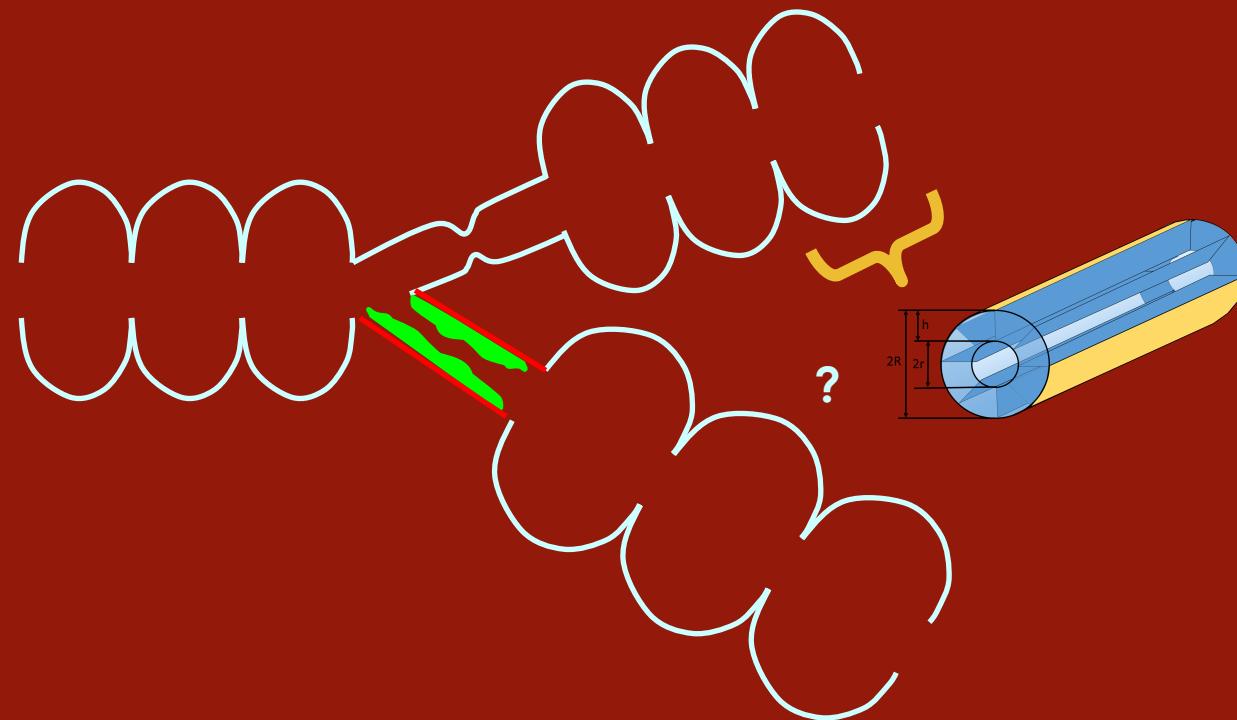
LUNG MICROSTRUCTURE



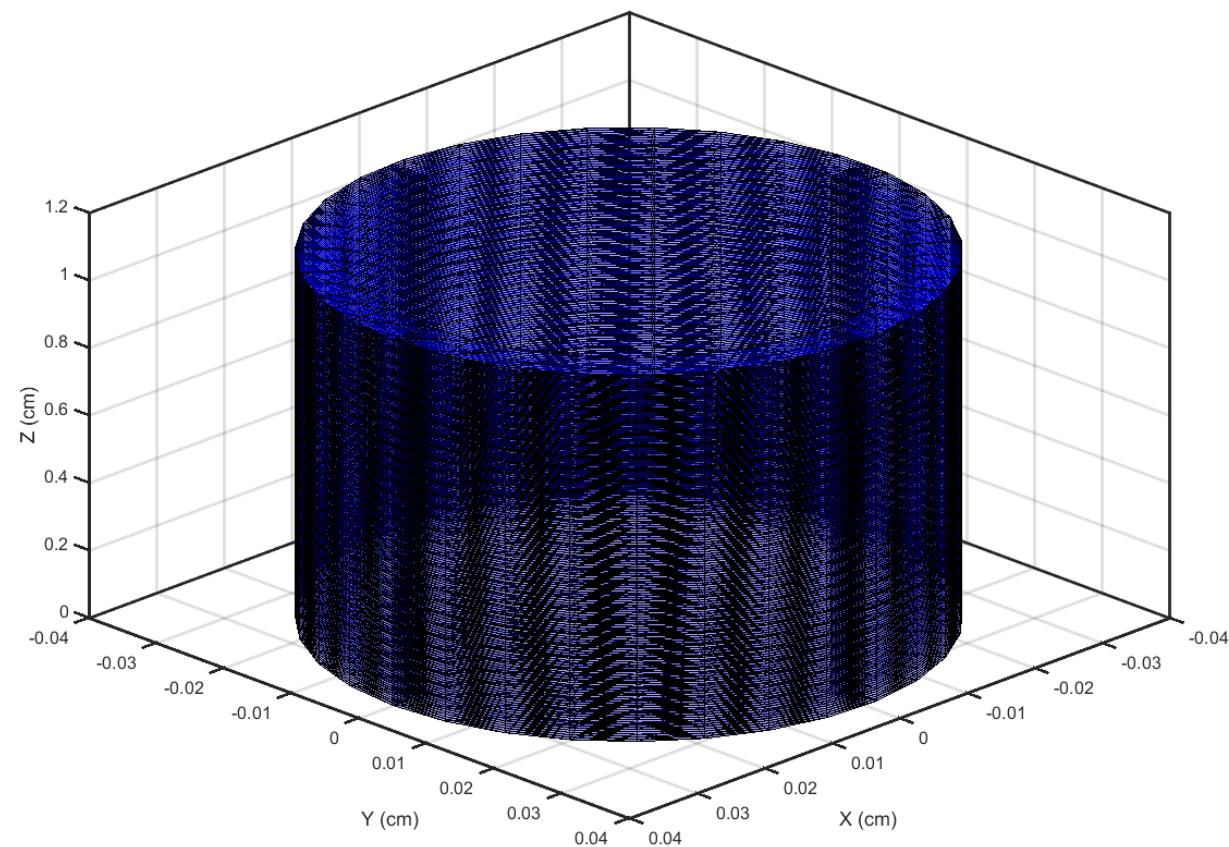
LUNG MICROSTRUCTURE



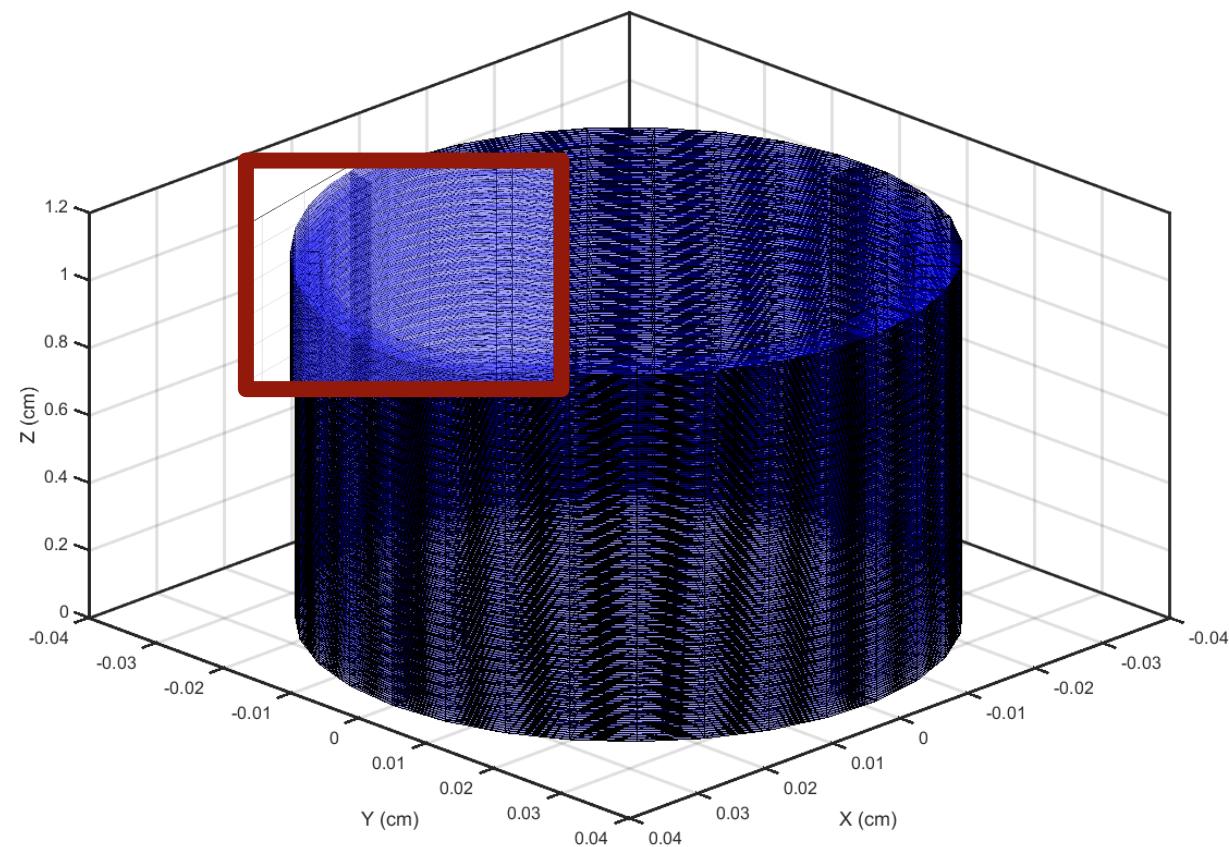
LUNG MICROSTRUCTURE



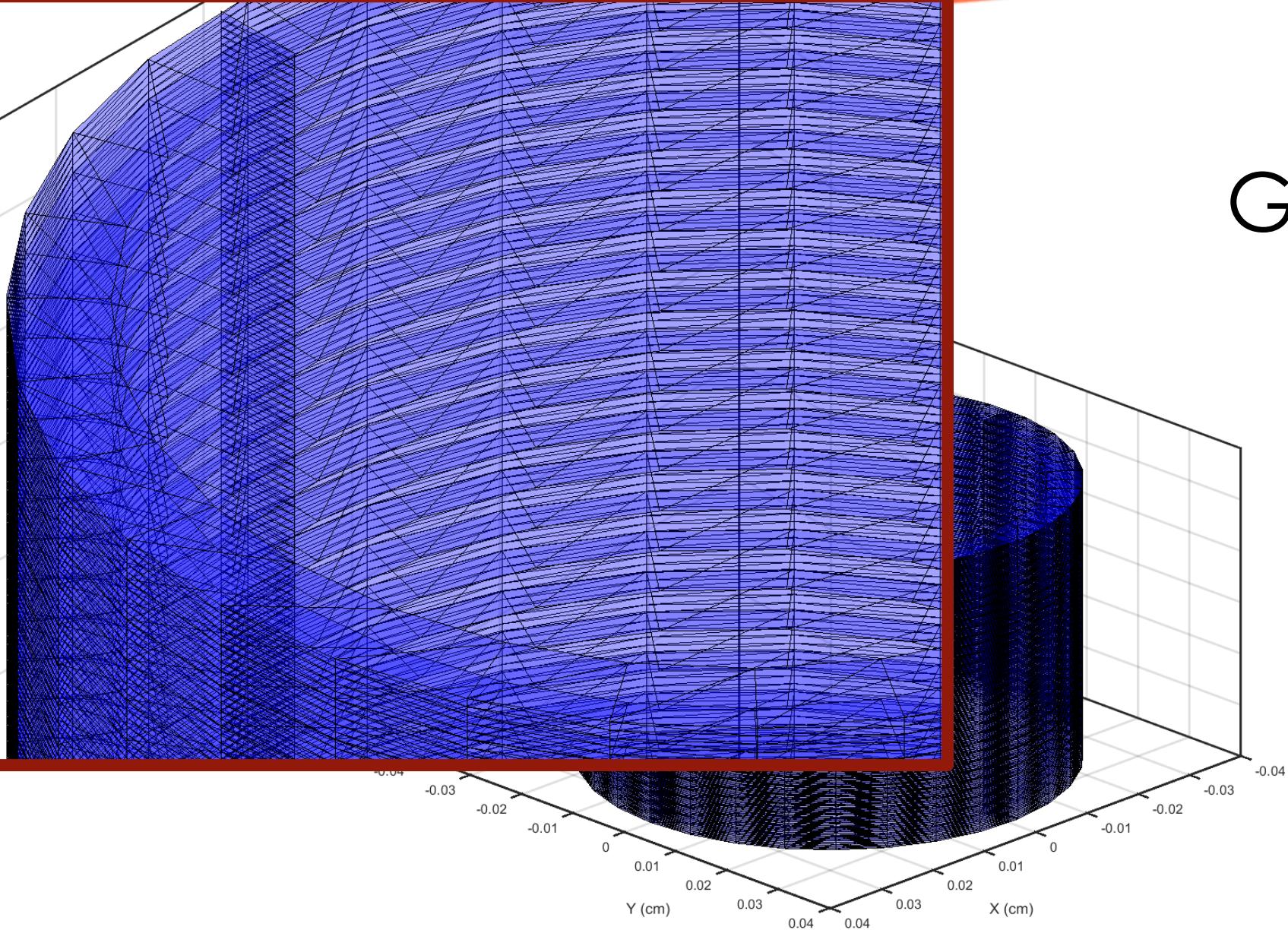
GEOMETRY



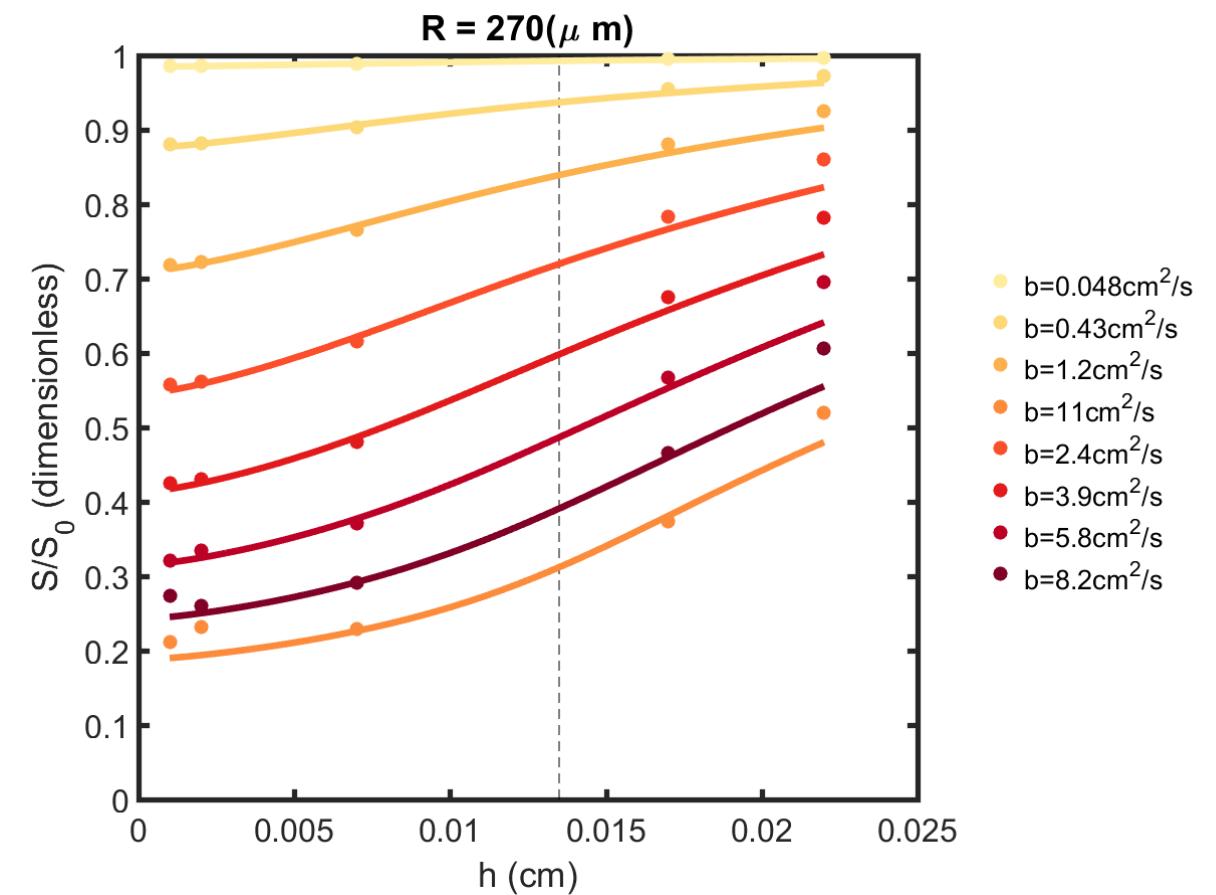
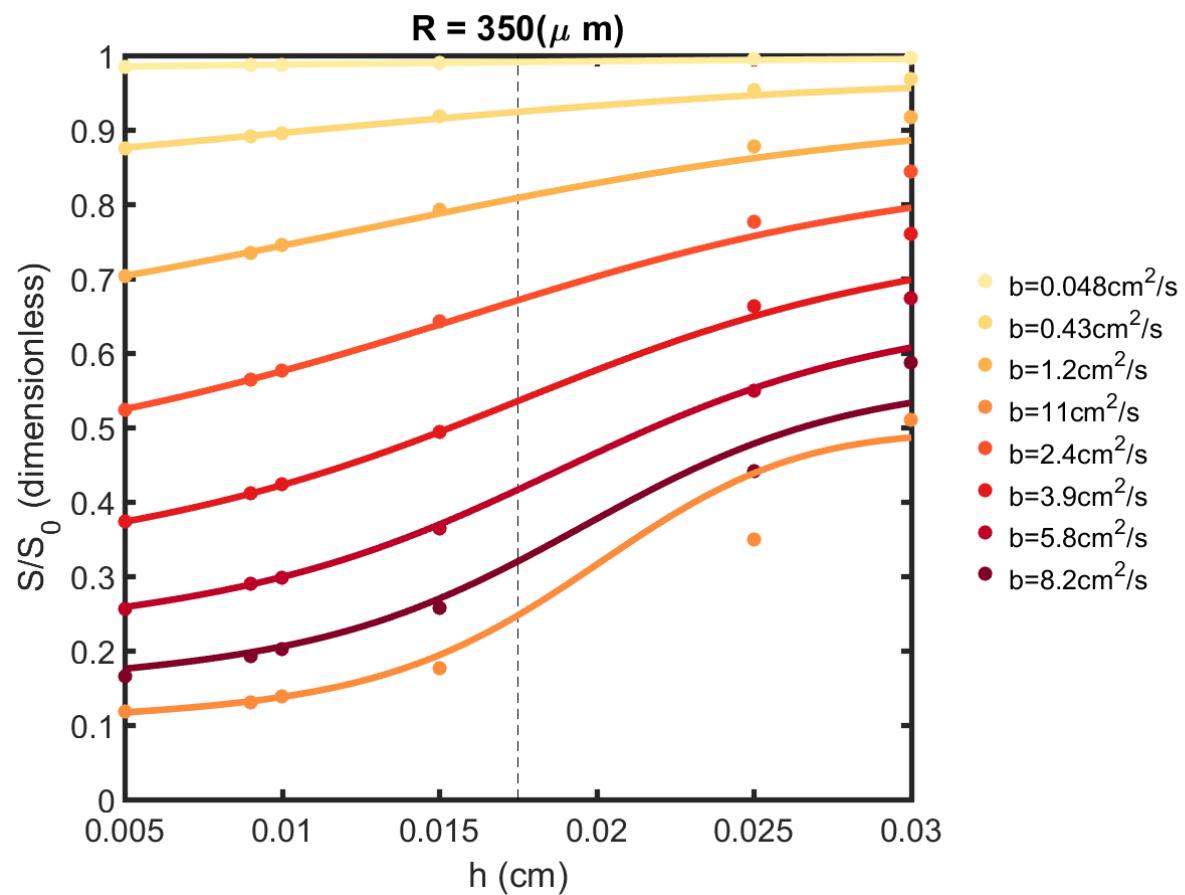
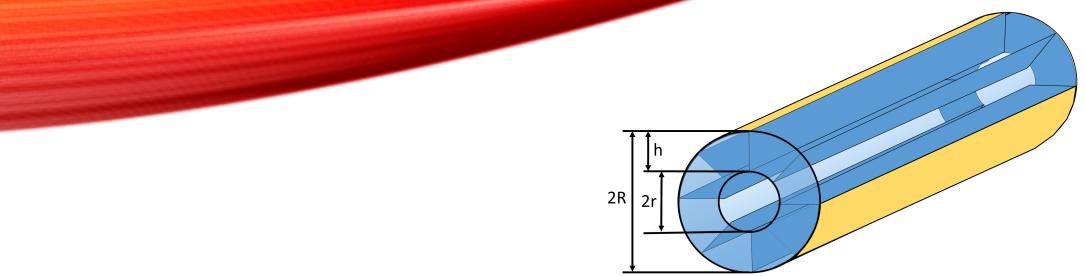
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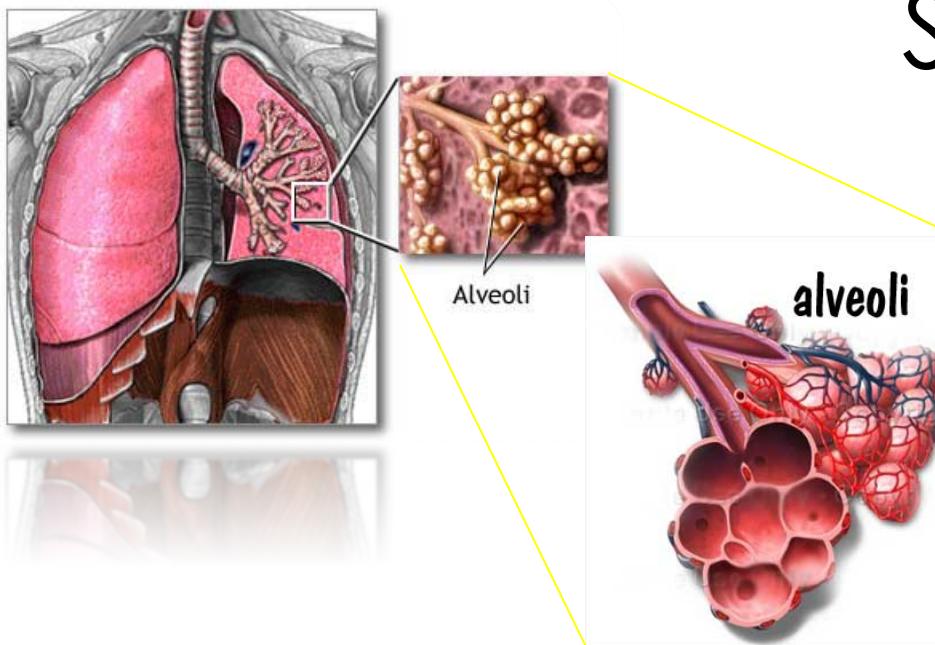
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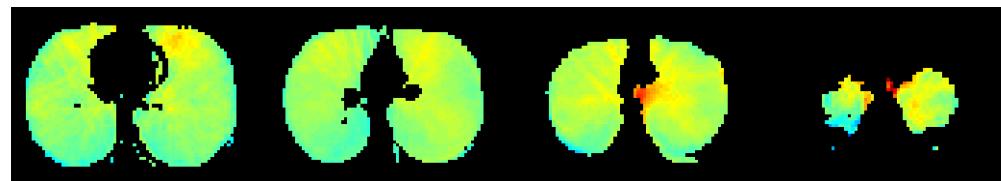
SEQUENCE ANALYSIS



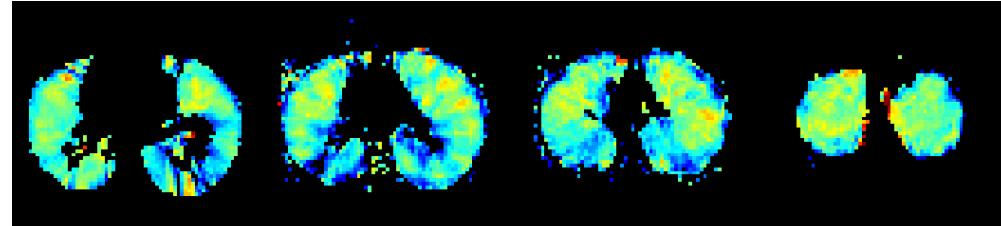
SEQUENCE ANALYSIS



No asthma or
HRV/wheeze



Asthma &
HRV/wheeze



SUMMARY

- Hyperpolarized Gas MR can show structure of lungs
- Diffusion imaging with hyperpolarized gas can reveal microstructural changes important to gas exchange
- MC can guide optimization of scans to be sensitive to specific dimensions of interest in asthma and COPD.

ACKNOWLEDGEMENTS

Lung Group:

- Sean Fain, PhD
- Scott Nagle, MD, PhD
- Bob Cadman, PhD
- Wei Zha, PhD
- Andrew Hahn, PhD
- David Mummy, MS
- Jeffrey Kammerman
- Luis Torres
- Katie Banowetz

UW Collaborators:

- Kai Ludwig, MS
- Erin Adamson, MS

UW Staff:

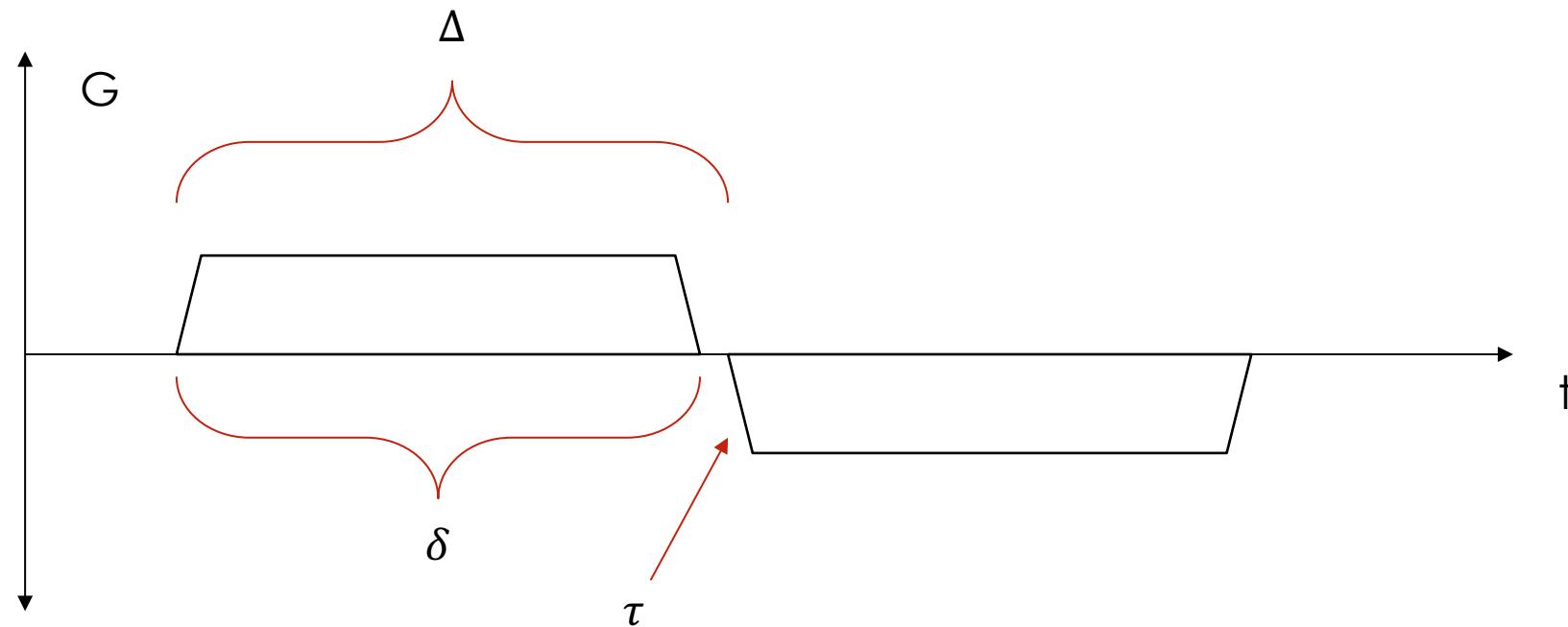
- Gina Crisafi
- Jan Yakey, RN, CCRC
- Kelli Hellenbrand
- Jenelle Fuller
- Sara John
- Molly Ellertson

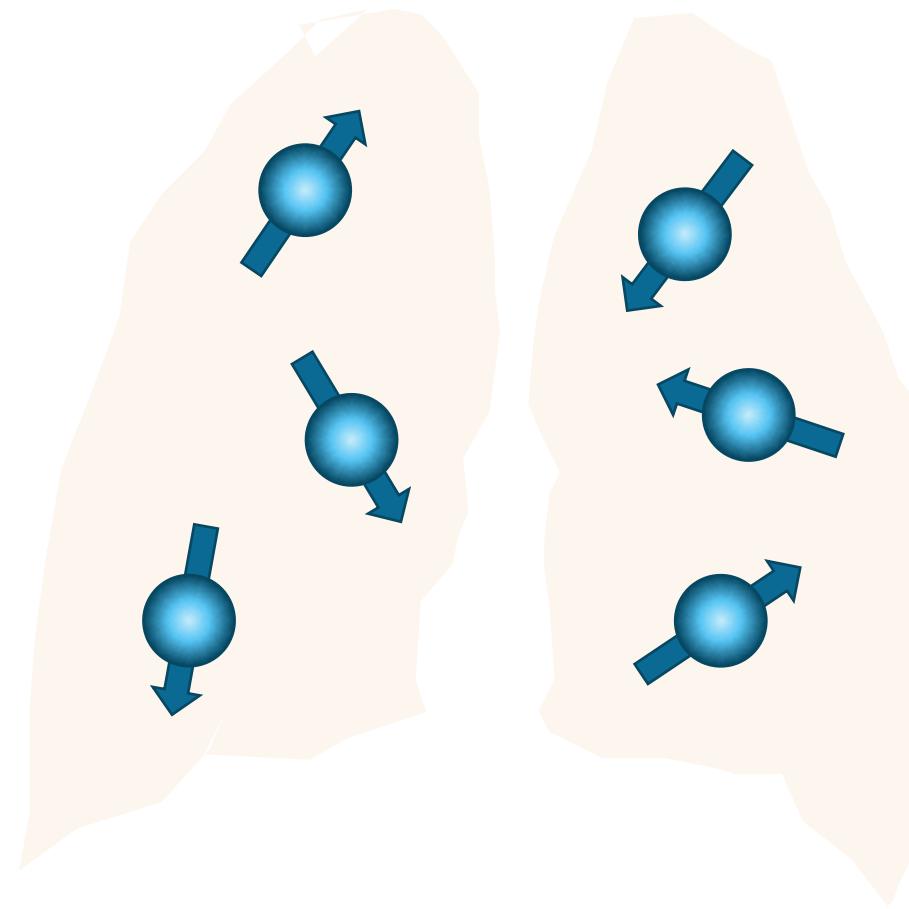
This project was supported in part by grant UL1TR000427 to UW ICTR from NIH/NCATS

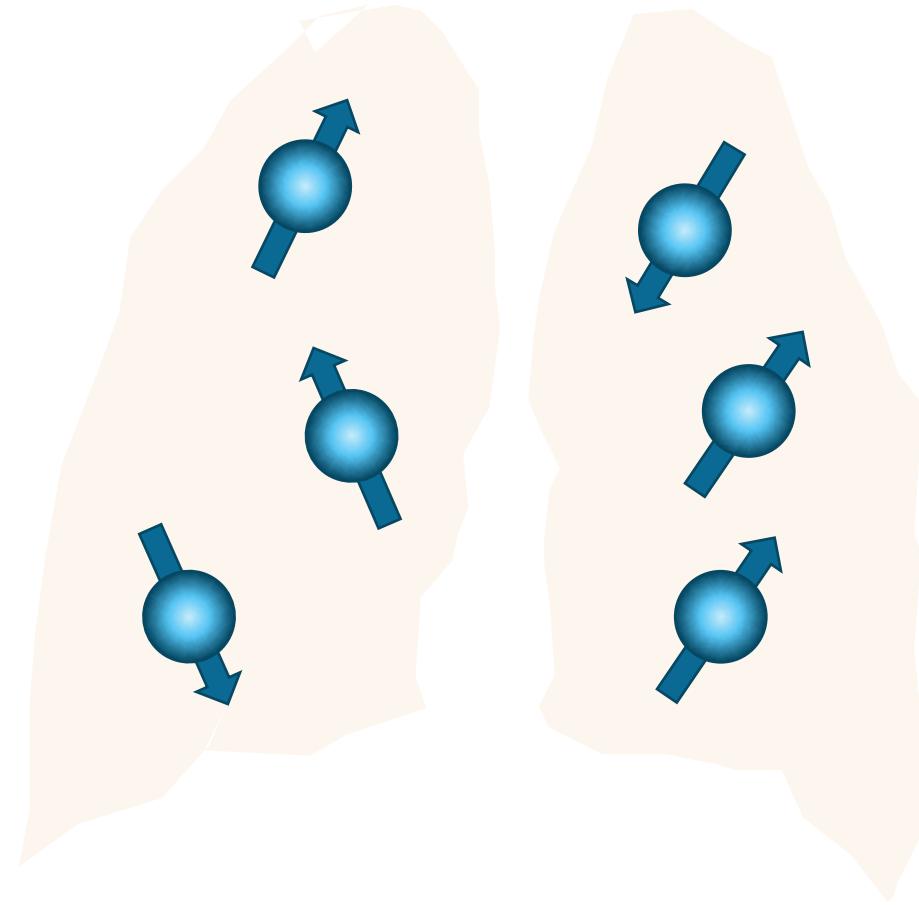
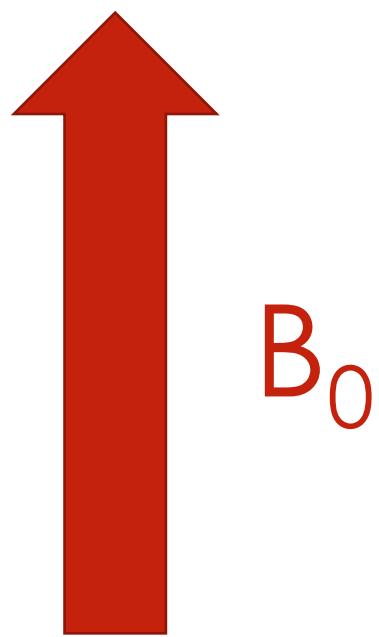
DIFFUSION MC

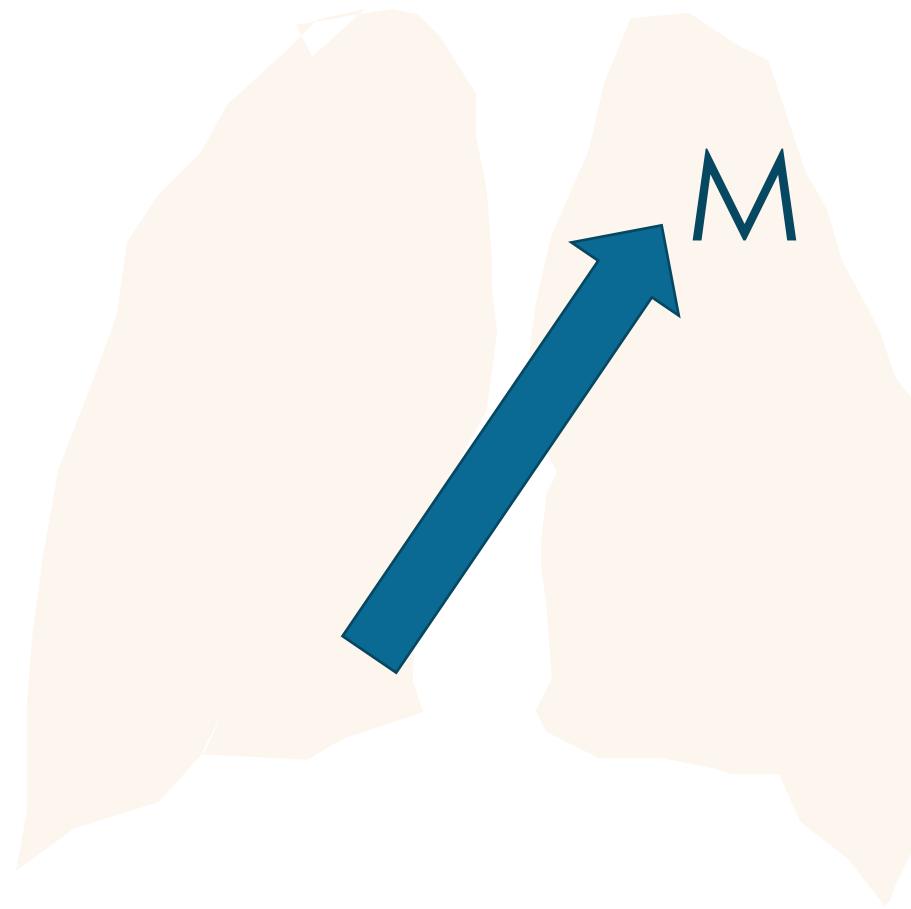
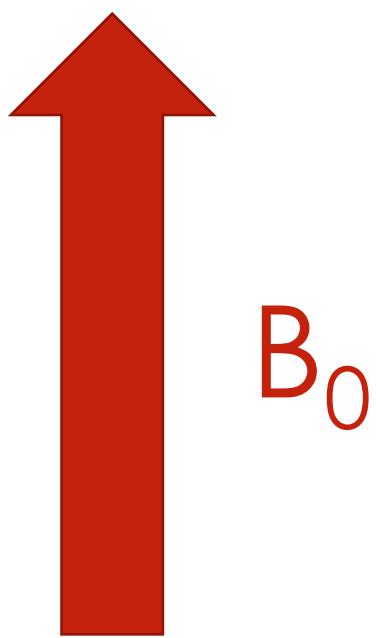
- Matlab
 - Build geometry
 - Populate with particles
- C++
 - Random walks
- $10^6\text{-}10^7$ particles
- $\sim 10^3$ time steps
- 1000 jobs at a time
- Several hours

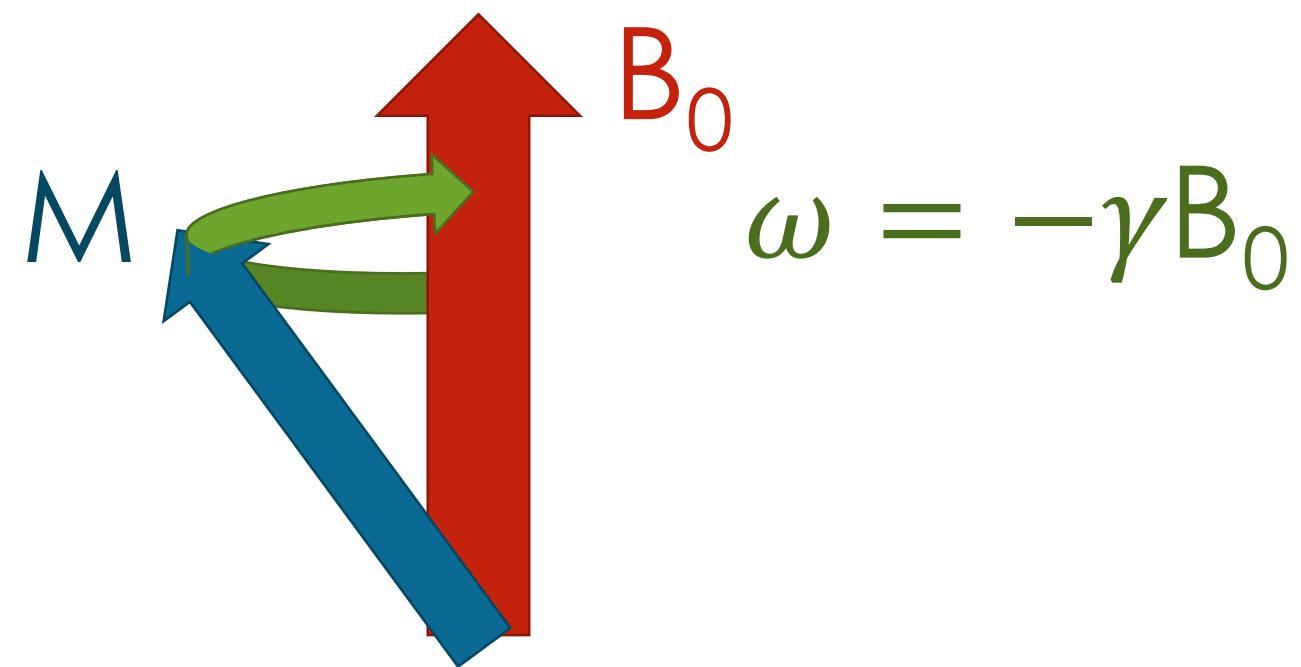
DIFFUSION

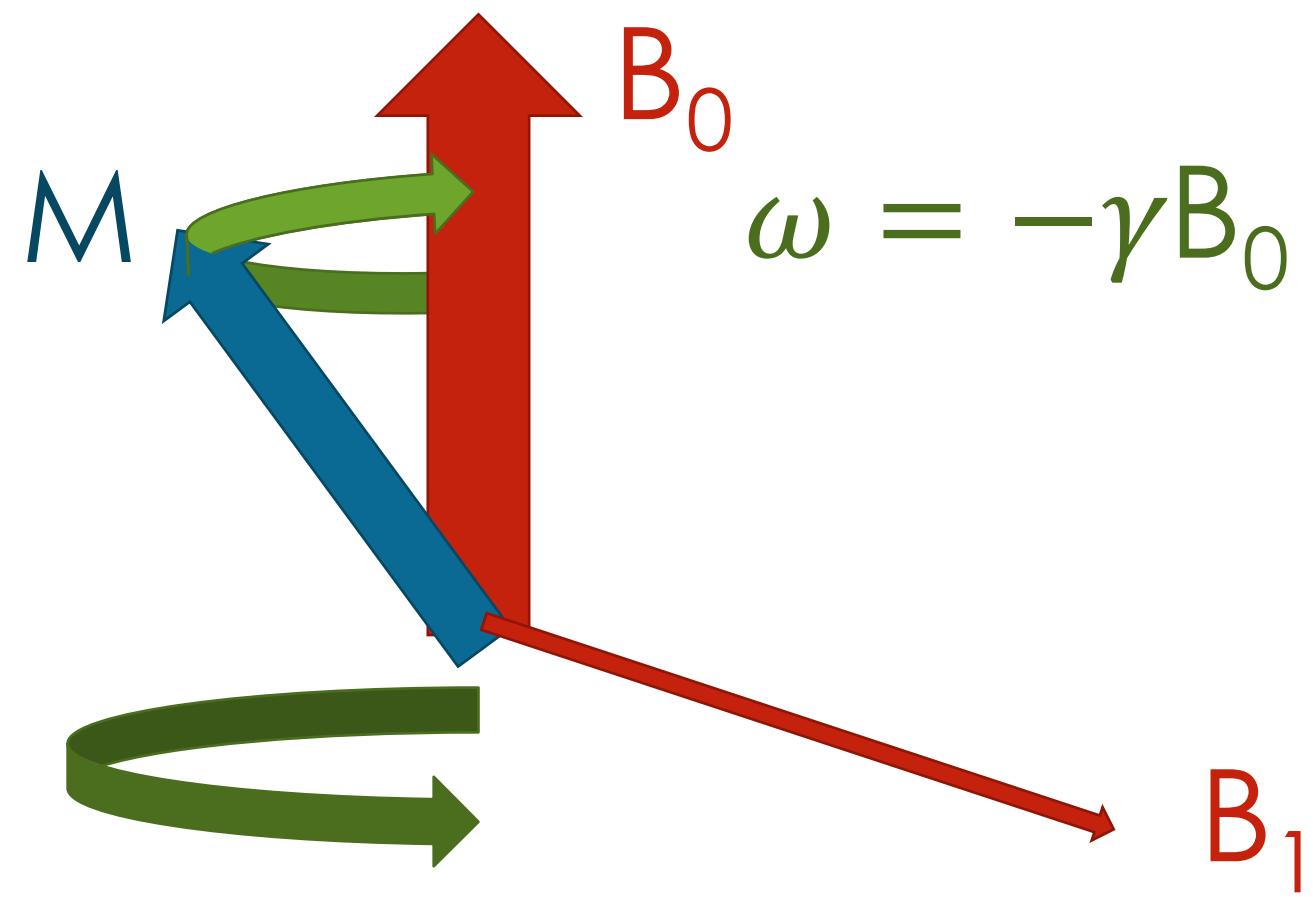


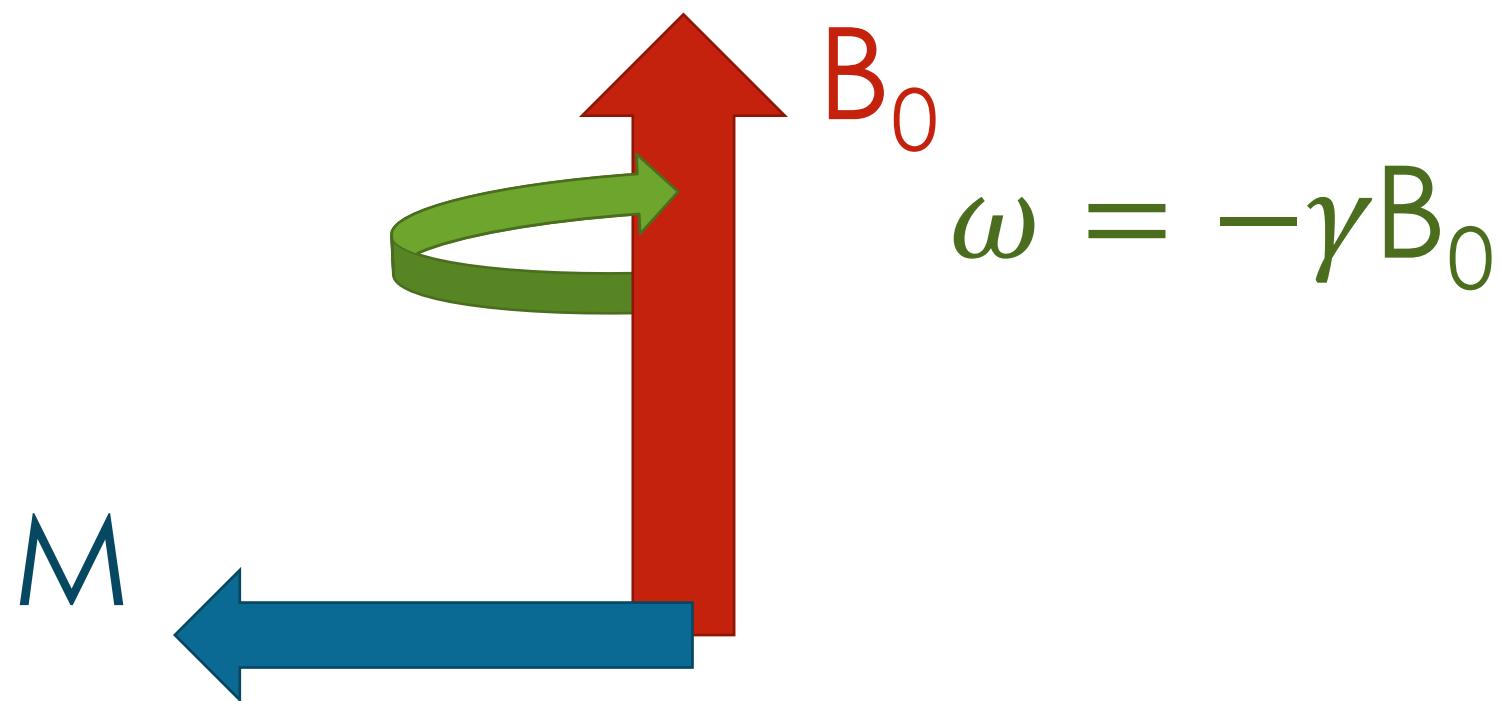


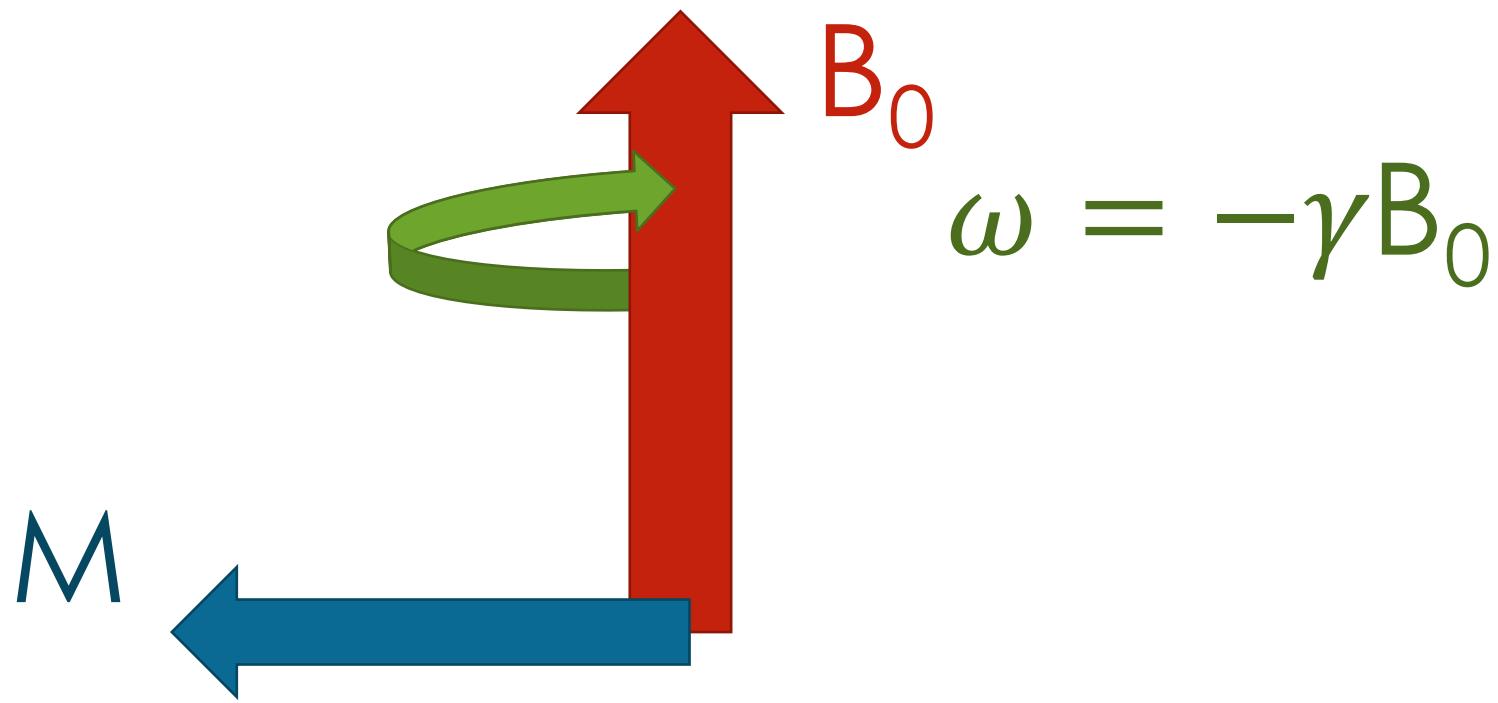
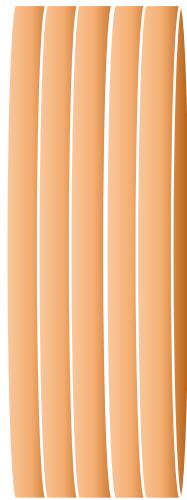




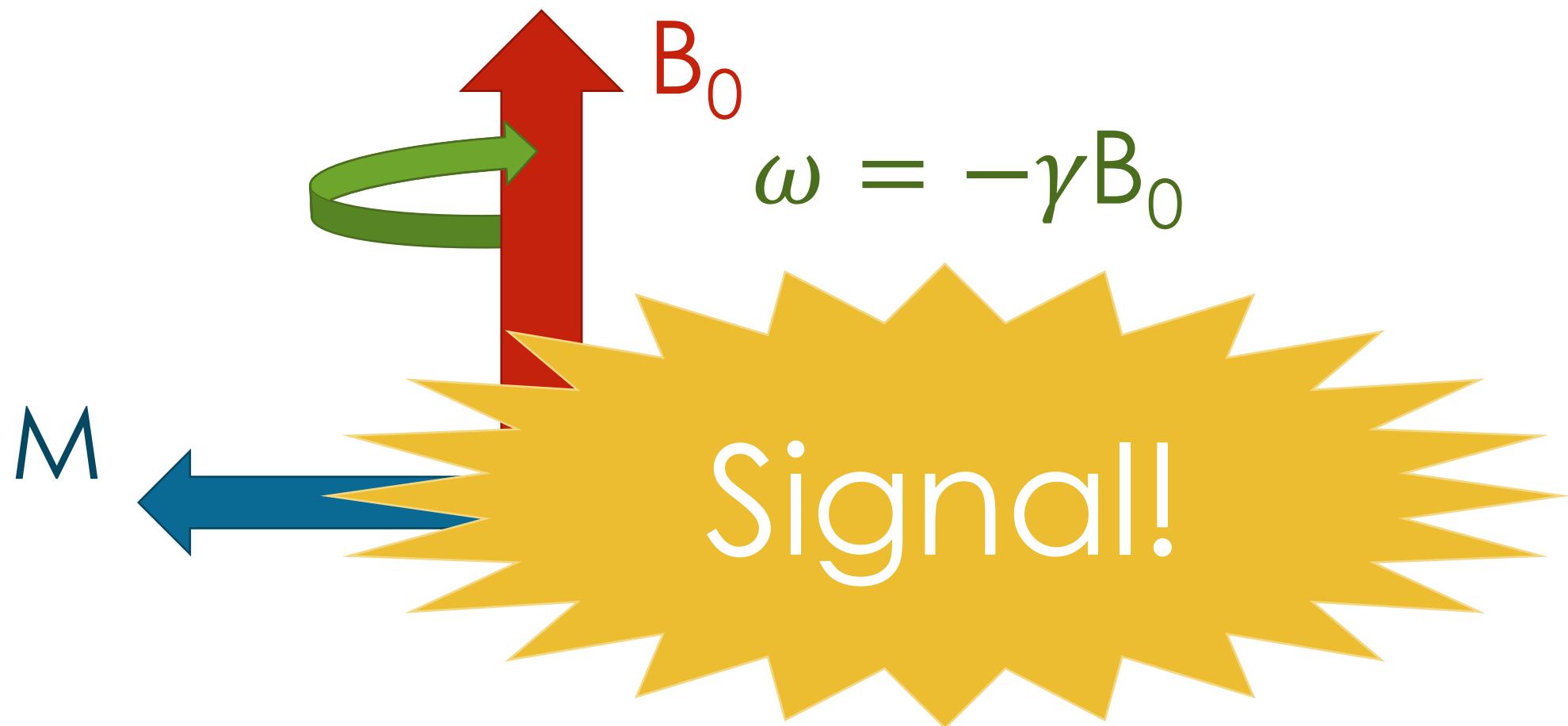
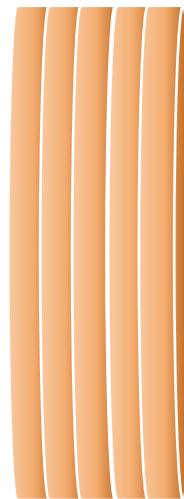


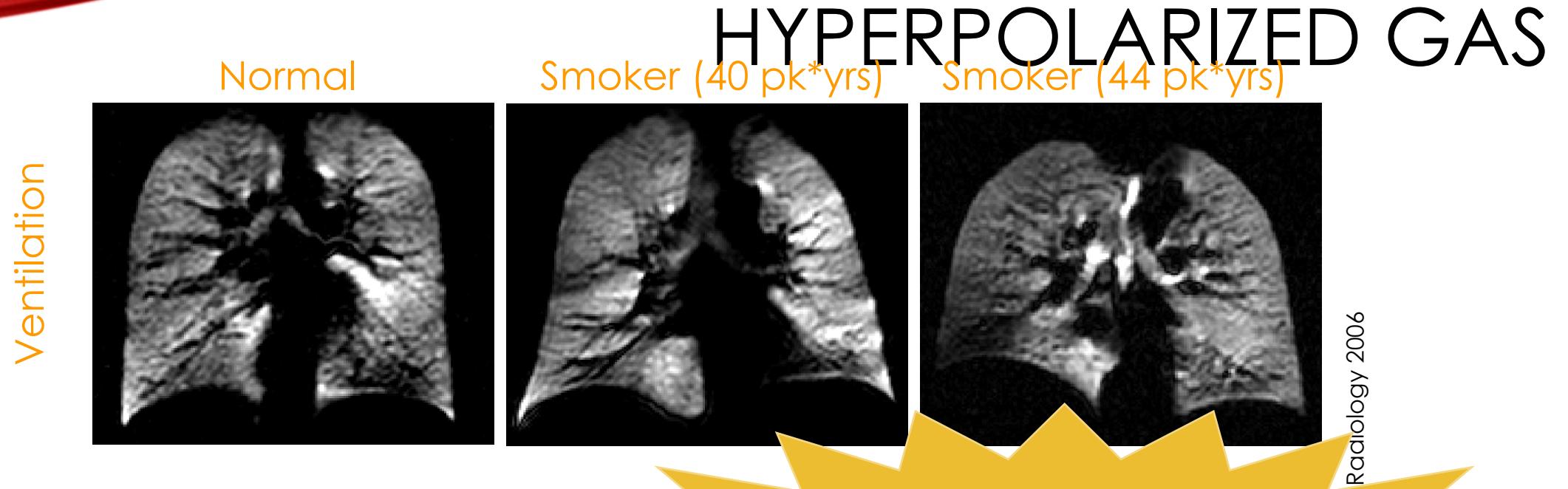






$$\omega = -\gamma B_0$$





Signal!

