Enhanced MRI imaging with spin polarized gases

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MRI depends on the “spin” and “magnetic moments” of the protons in our body

Spin is familiar in macroscopic objects such as planets.

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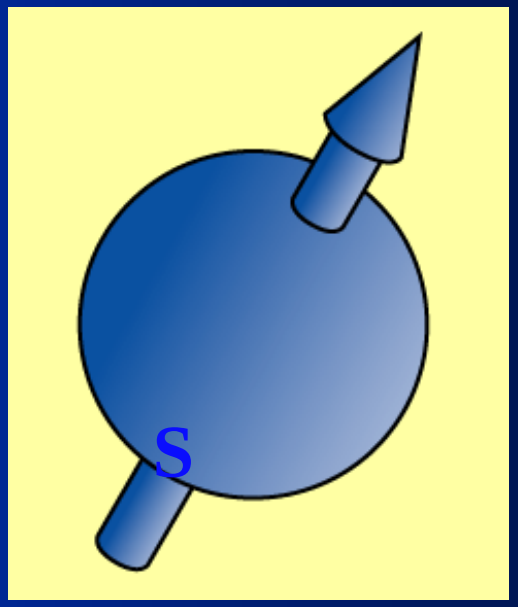
Subatomic particles also behave as if they have spin and an associated magnetic moment.

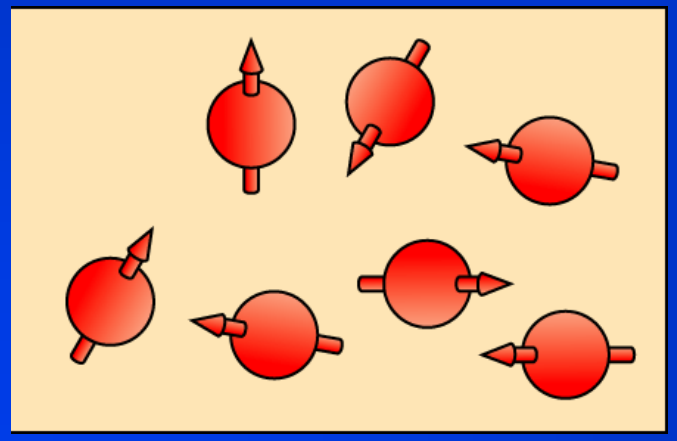


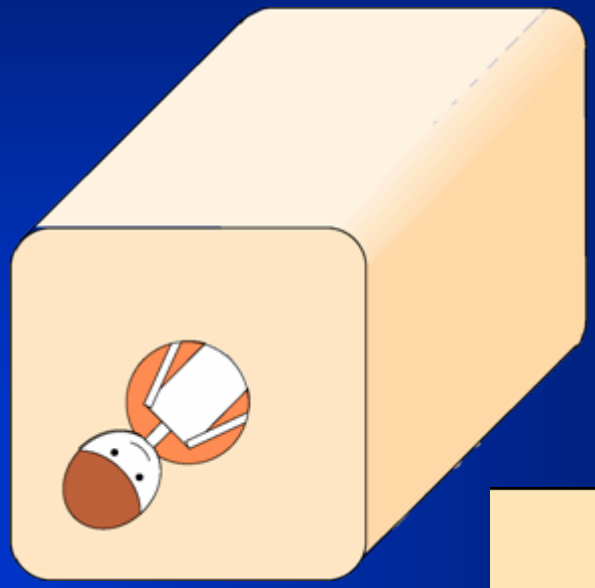
Thus, protons and neutrons behave like little bar magnets.

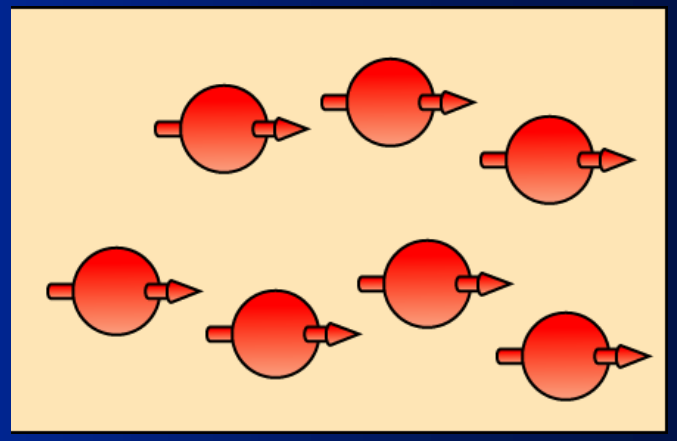
How does MRI work?

STEP #1:

- A large magnetic field aligns the “spins” or magnetic moments of the protons (in hydrogen atoms) in our bodies.



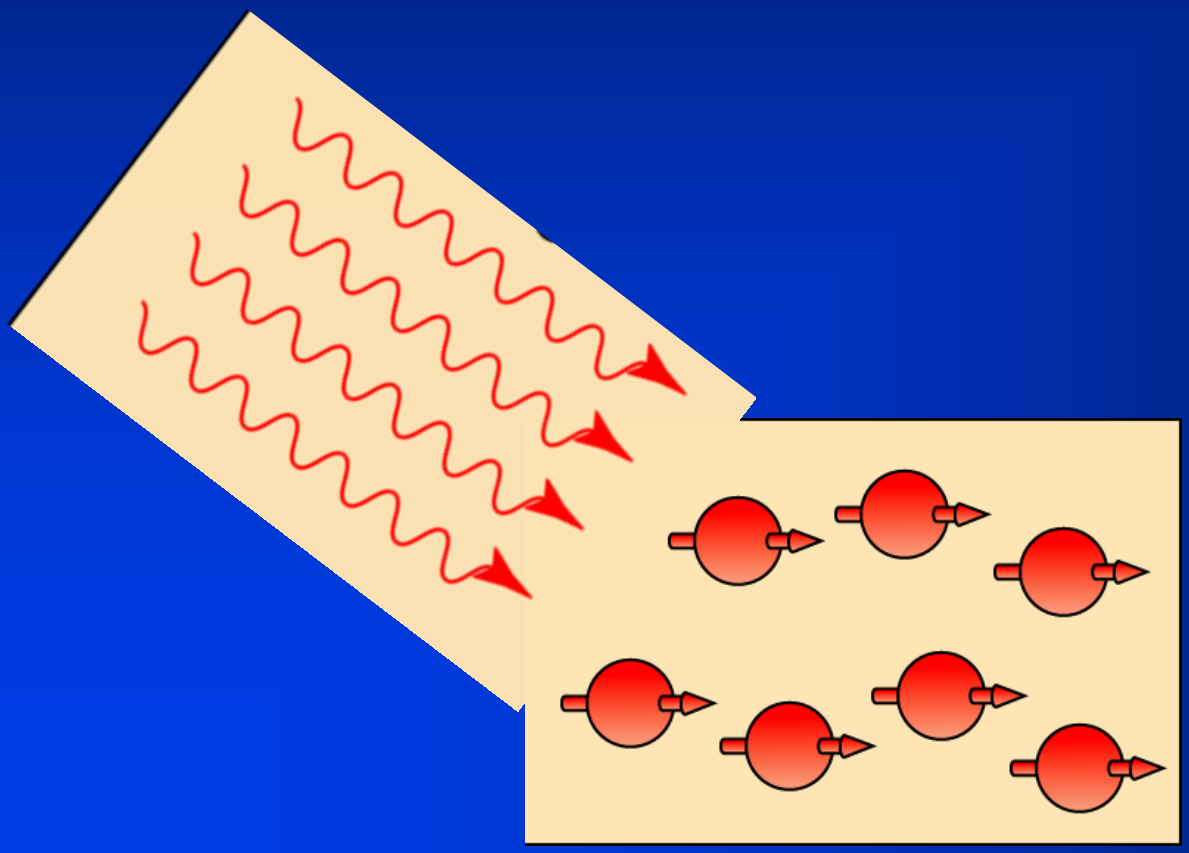


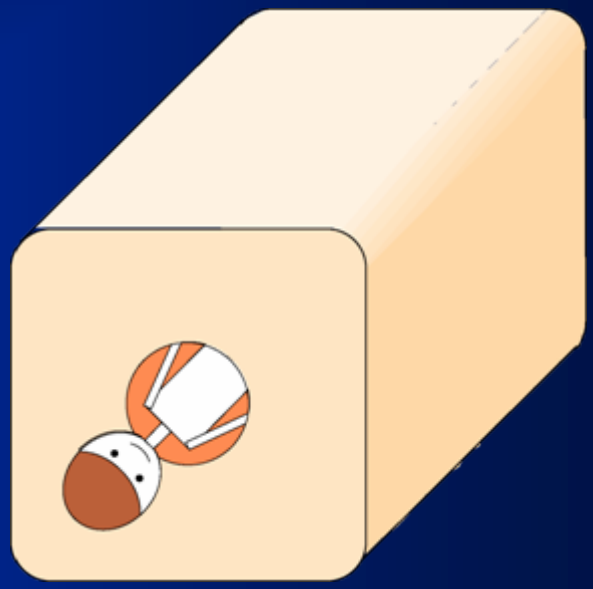


How does MRI work?

STEP #2:

- Radio waves are transmitted into our bodies that make the spins precess.

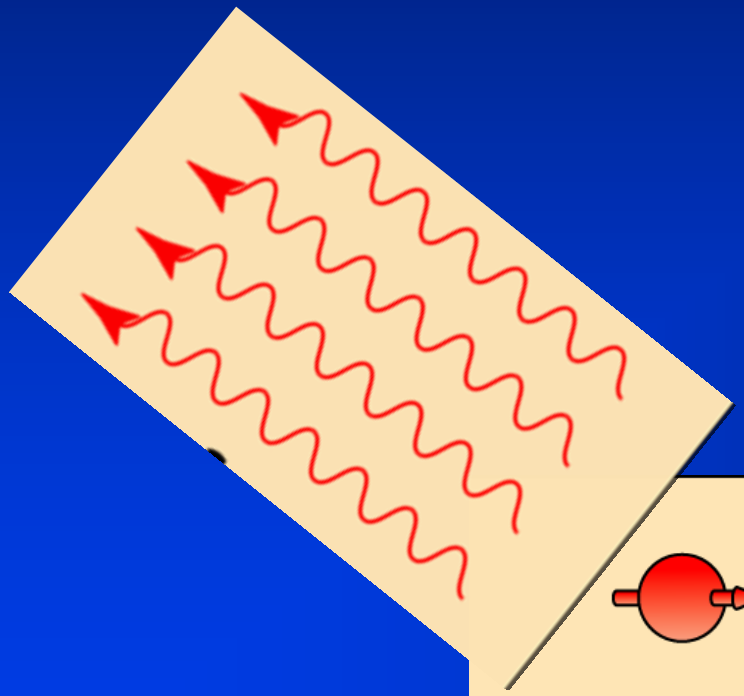


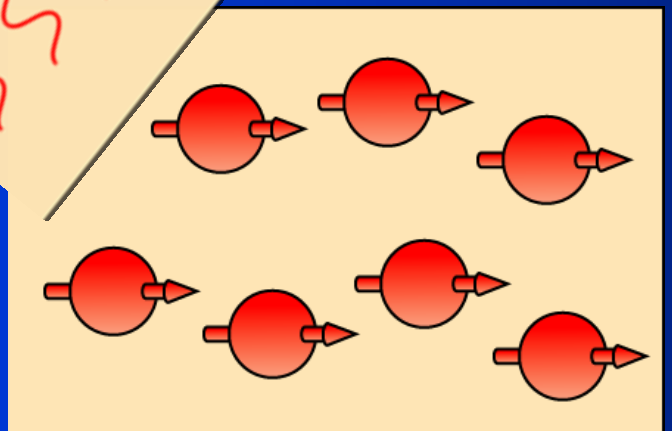


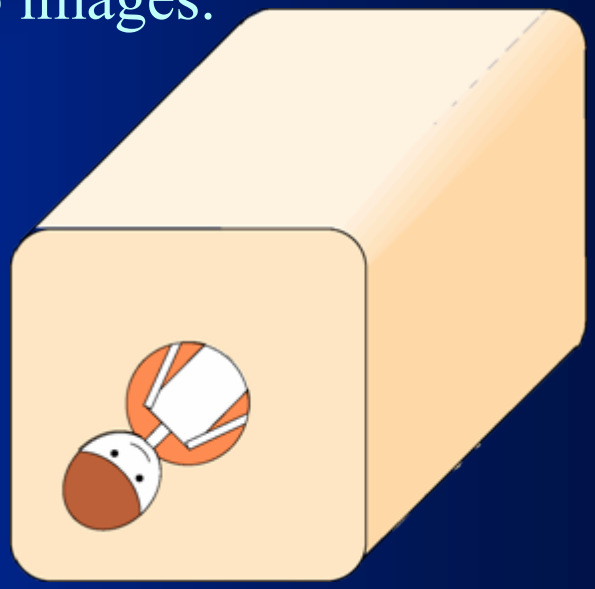
How does MRI work?

STEP #3:

- Radio waves are re-emitted from our bodies and detected by receivers.
- Computers reconstruct these signals into images.







How do Laser-polarized noble gases help MR?

Conventional MR

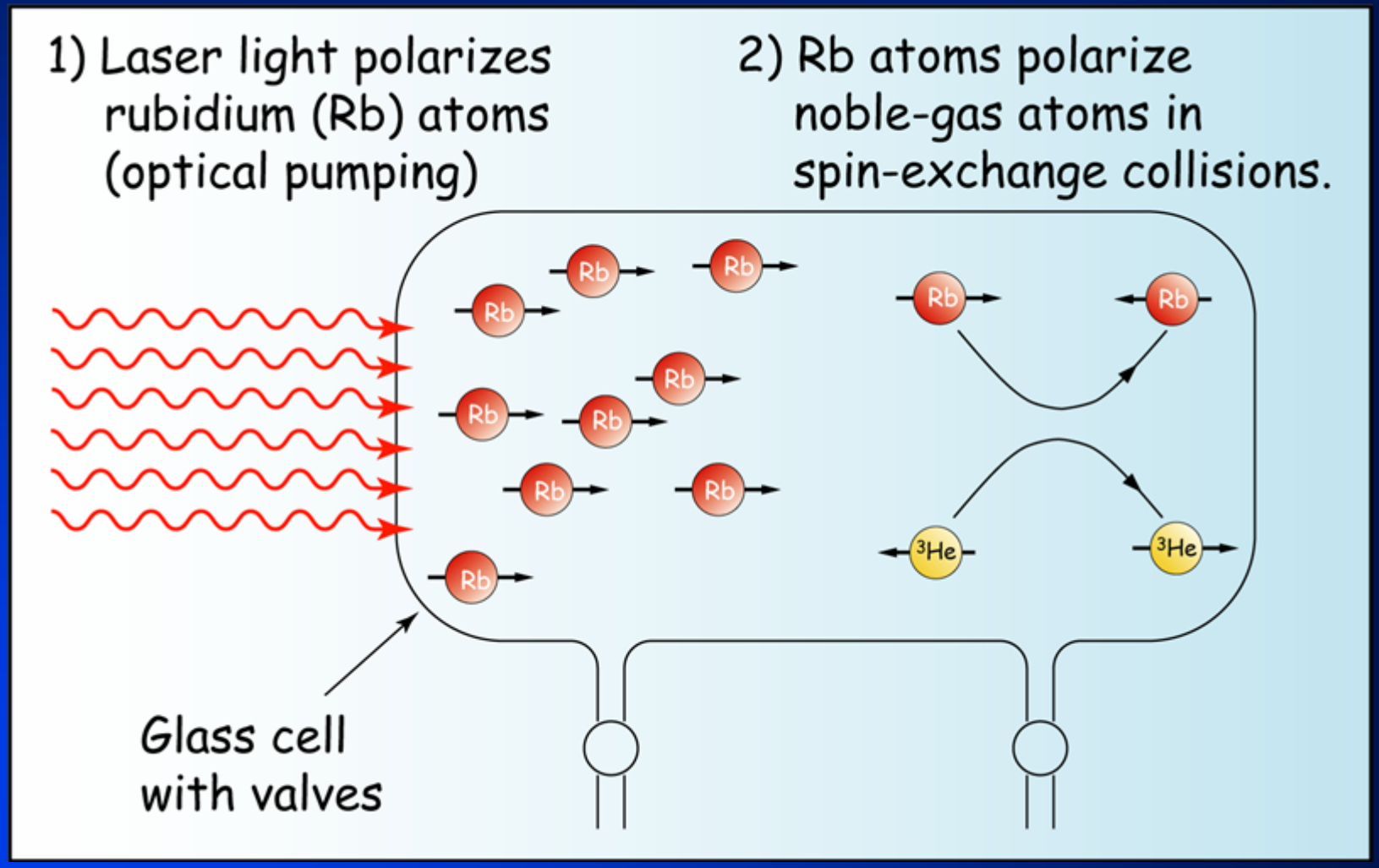
- Signal comes from proton spins in water
- Protons are polarized by large magnetic field.
- The polarization $\approx 10^{-6}$ is due to the thermal Boltzmann distribution

MR using laser-polarized noble gases:

- The signal comes from laser-polarized noble gases such as ^{3}He or ^{129}Xe
- Polarizations are 5-50%

  (up to 100,000 bigger!)
- Great for imaging lungs

Spin-exchange optical pumping: a laser technique to polarize noble gases such as ^{3}He and ^{129}Xe



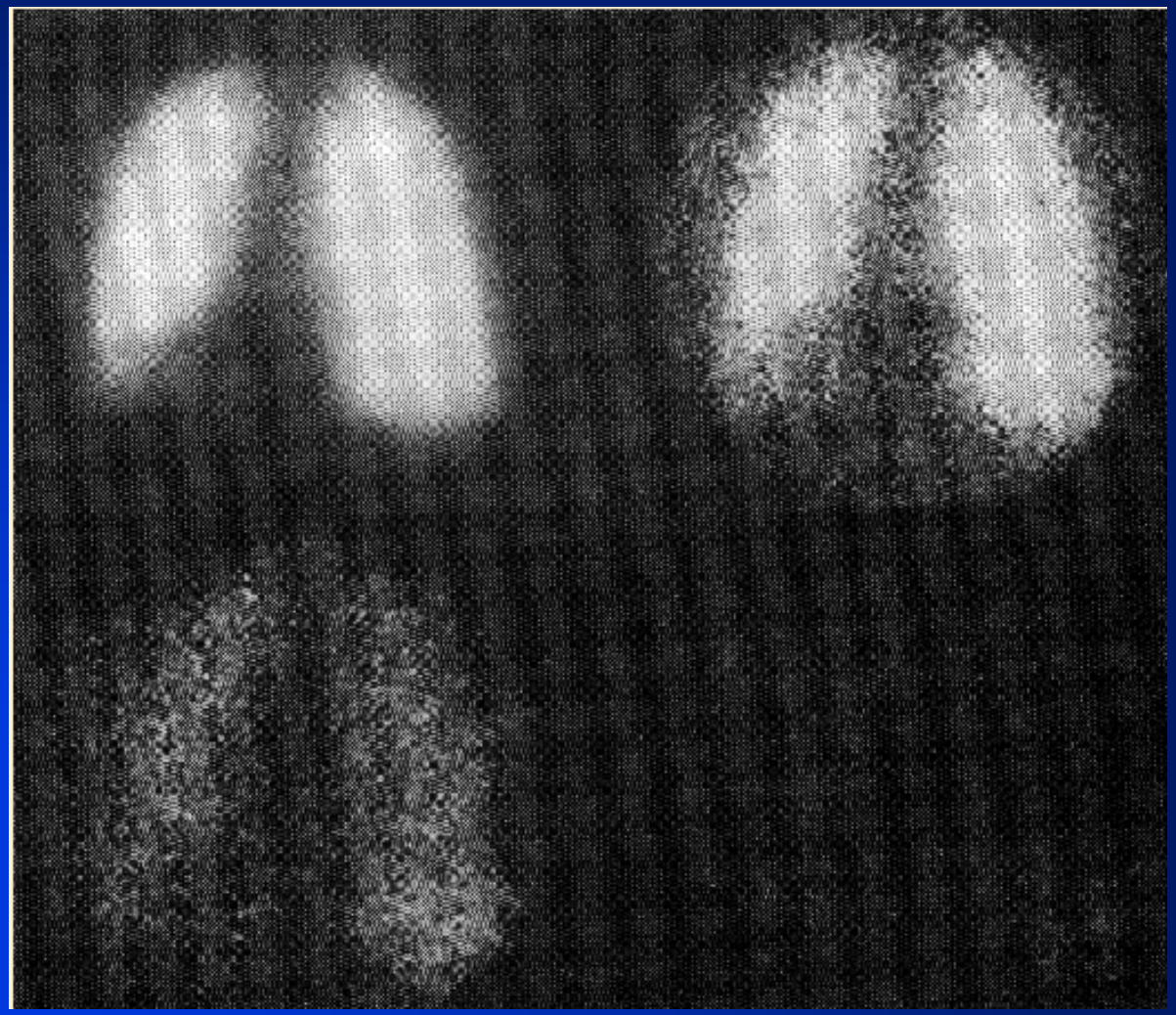
The polarized noble gas is inhaled to make a pulmonary MRI

Noble gas is transported from polarizer to the patient in a small bag.

Patient inhales noble gas just prior to the scan.

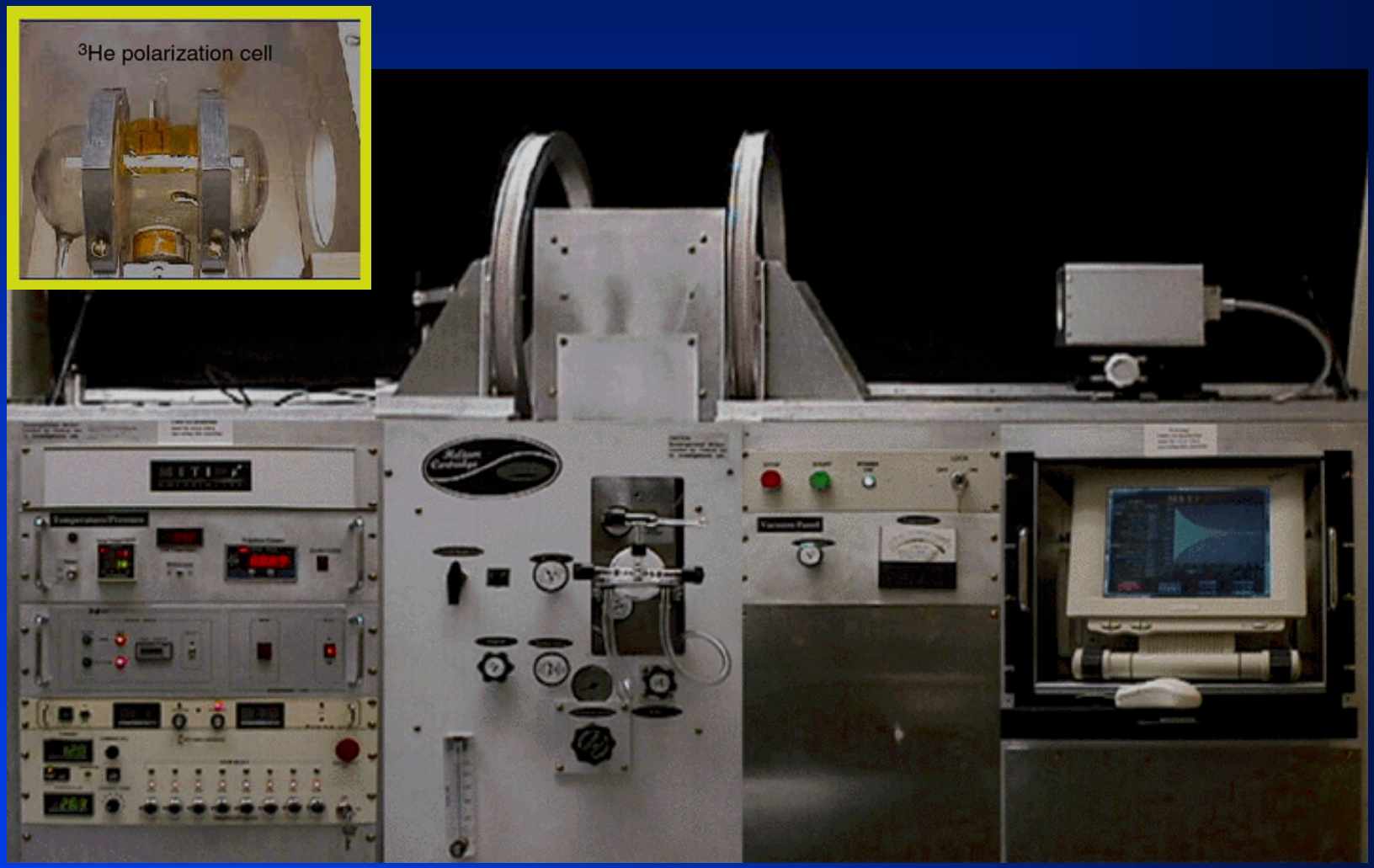
Why bother?

Current state of the art is a nuclear medicine scan using a radioactive isotope such as ^{133}Xe



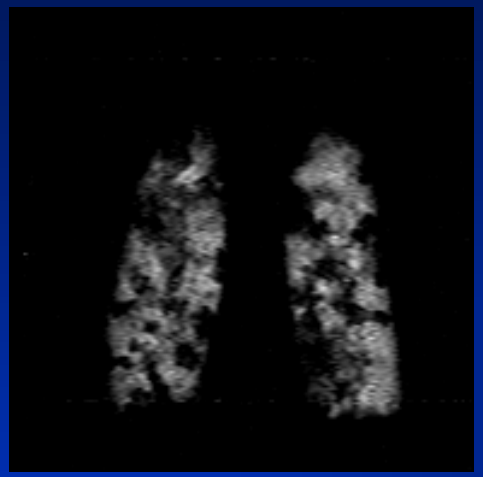
MRI using laser-polarized noble gas greatly improves resolution

“User friendly” noble-gas polarizer greatly simplifies the technique



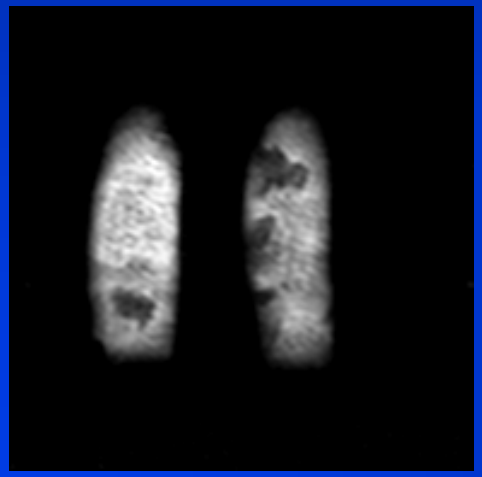
Routine polarization of noble gases make serious clinical studies a practical reality.

Healthy normal subject

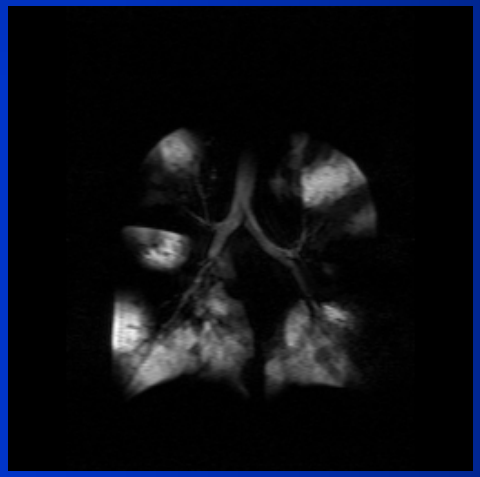


Smoker

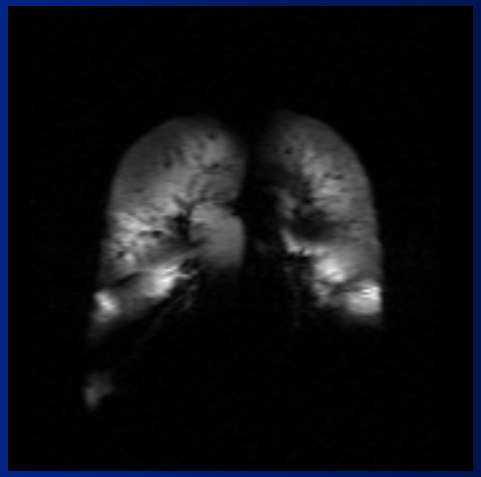
Emphysema



Asthma



Cystic Fibrosis



α_1 antitrypsin def.

Imaging with Xe-129

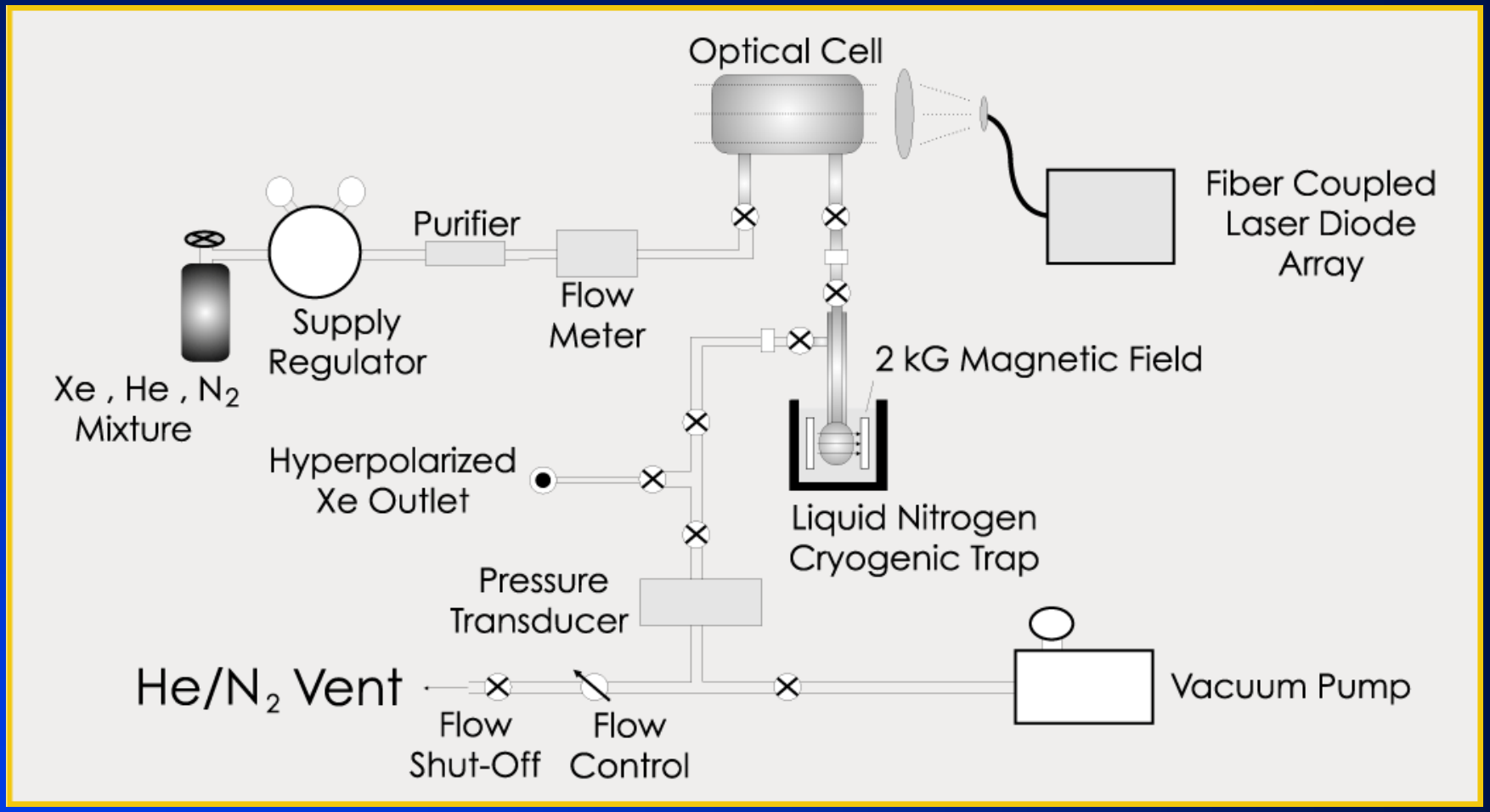
- Much more plentiful on the earth, but …..

- Xe-129 has an isotopic abundance of 26%
- The magnetic moment is about 1/4 that of He-3
- It is trickier to polarize

Why is it trickier to polarize?

- There is much less cumulative experience polarizing Xe-129
  - Polarization techniques for He-3 have been extensively developed for polarized nuclear targets.
- It is a powerful depolarizing agent for alkali-metal vapors
  - This means you need more laser power to maintain high polarization.

One approach to polarizing ^{129}Xe, the "flomaster"



Works pretty well, but polarizations are about 5-18% for liter type quantities of gas.

What can you do with an FEL?

Michelle indicated that at 795 nm, a power of 1kW and a bandwidth of 320 GHz is conservative.

- Consider a 58 mm sphere containing 5 atmospheres of Xe-129.
  - This is just the simpler approach used with He-3 with a REALLY BIG LASER
- With 320 GHz, we would naively expect a polarization of 60 - 70%
- With 50 GHz, we would naively expect a polarization of 70 - 80 %.

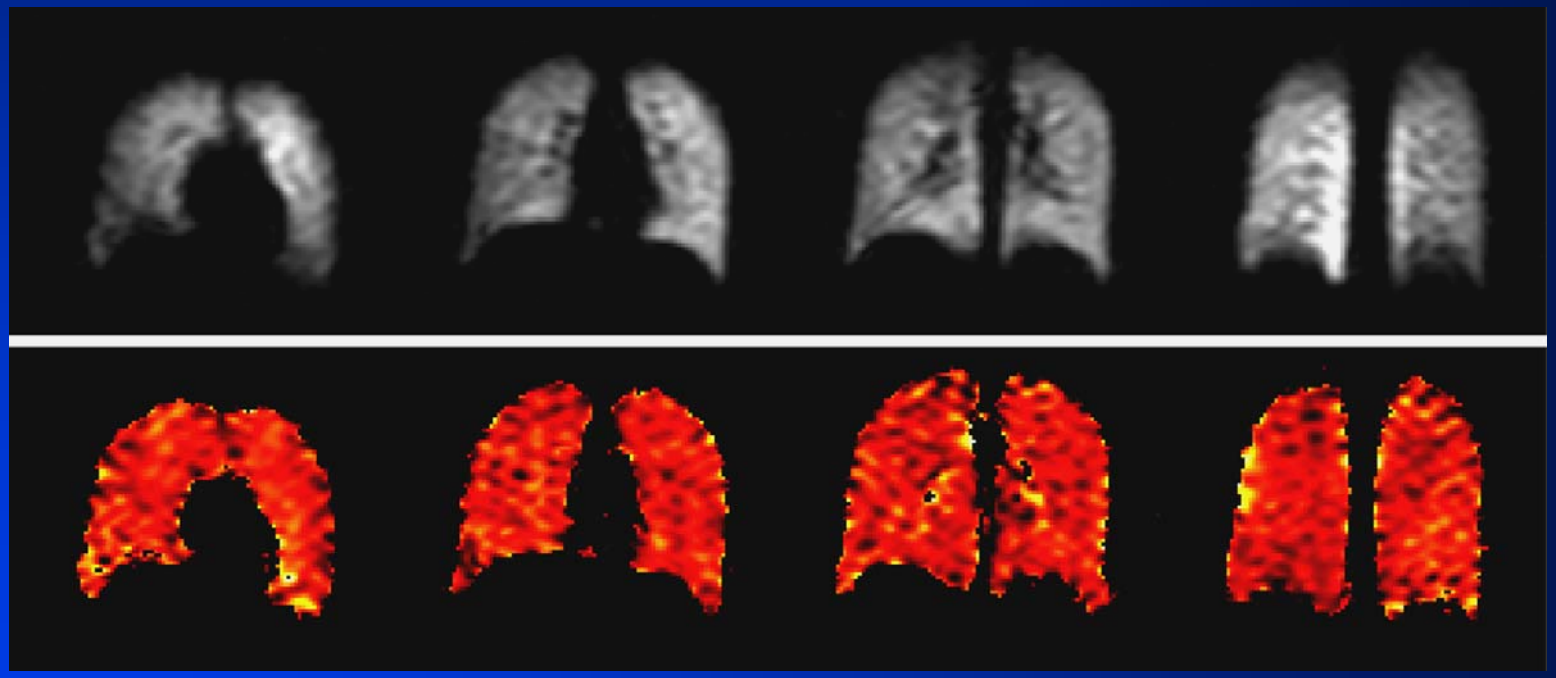
The basic strategy

- Polarize sealed 58 mm spheres containing 0.5 atmosphere-liters of Xe-129
- Store the spheres in liquid He once they are polarized (relaxation times are several weeks with a 1 kG field).
- In principle, one could polarize around 60 doses/hour
- Transport the polarized Xe-129 all over the world.
- At $1200/hour, that would be around $20/dose.
- For comparison, the unpolarized isotopically enriched Xe-129 costs around $300/liter.

Applications using ^{129}Xe:

Since Xe is heavier than He, ADC maps are sensitive to shorter distance scales

The first human ADC maps made using ^{129}Xe



Upper panel: one of several diffusion weighted images.
Lower panel: ADC map of several coronal slices.

Summary

- Noble-gas imaging using ^{3}He has established itself as a robust tool for studying the lung.
- With limited supplies of He-3, Xe-129 will need to be the gas of choice if the technique becomes widespread.
- The FEL allows the study of polarization technology at power levels that were previously unavailable.
- If $1200/hour is feasible, it is likely to be cost effective.