MRI Physics

- RF pulse
- T1
- relaxation
- T2
- dephasing
- B0
- precession
- TR (repetition time)
- TE (echo time)

What does an MRI scanner do?

The scanner uses a powerful magnet to align the protons in the hydrogen atoms in your body.

Then a RadioFrequency **pulse** knocks the protons out of alignment.

As the protons start to recover from the radiofrequency pulse, they emit signals.

Depending on the tissues these hydrogen atoms find themselves in, they recover from the RF pulse at different rates.

These different recovery rates result in different amounts of signal associated with each tissue.

And we see these signal differences as contrast

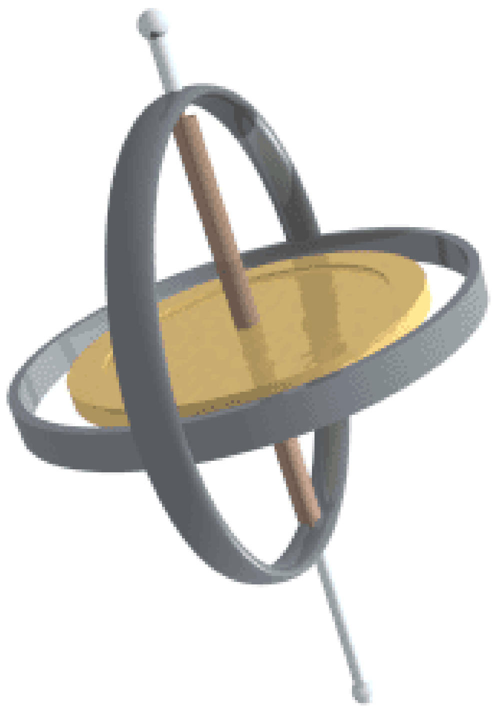
There are all manner of different pulse sequences used to identify different things going on in the tissue.

Let's look at protons in a little more detail.

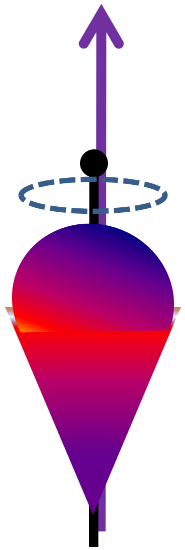
We can characterize 2 important types of signal:
T1 and T2

The 2 kinds of signal, correspond to properties of the hydrogen protons that we manipulate in the scanner.

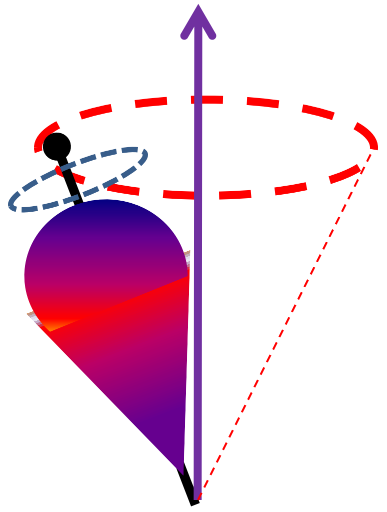
Imagine a proton as a spinning top



Initially, the proton top is spinning almost vertically.
Call the vertical axis "B_0"



As time goes on, our proton top **precesses** around B_0

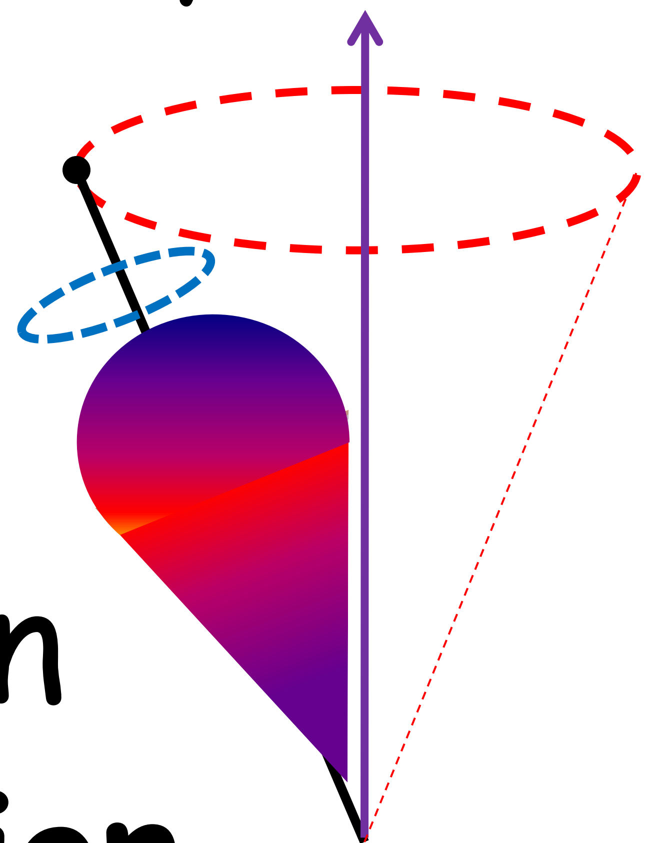


The entire time, the top is

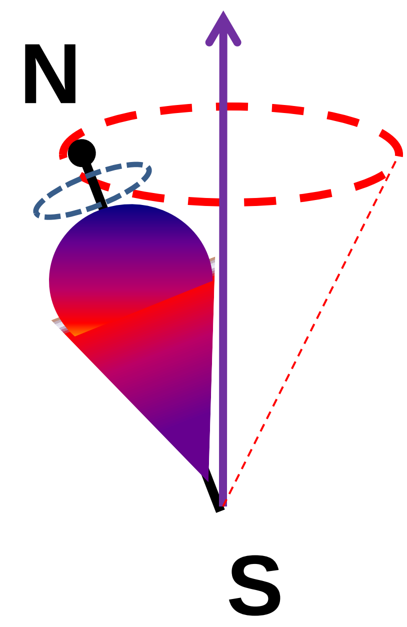
spinning

around its own

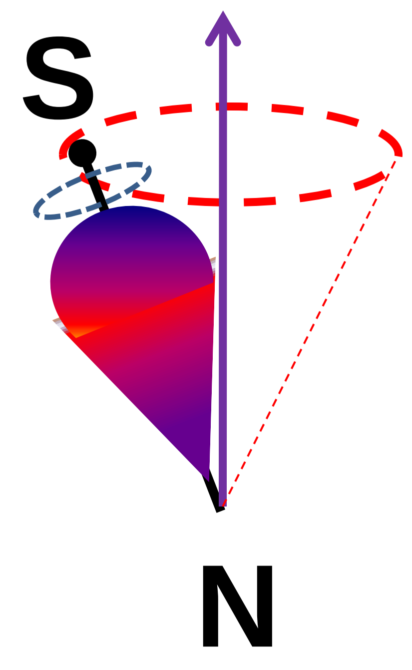
axis of rotation



The proton is a magnet with a North and South pole at either end of the axis of rotation.



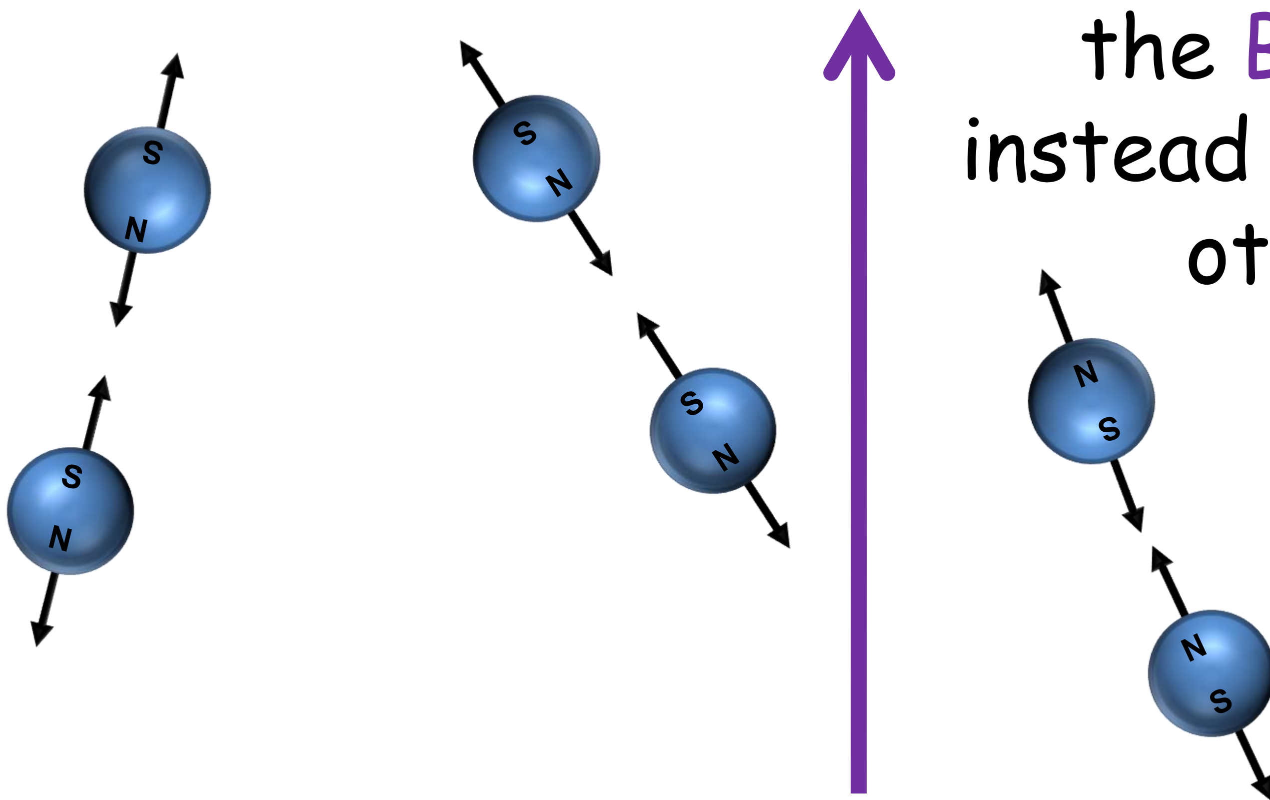
(Or a South and a North pole):



T1: Aligning Protons

Introduce the object to a magnetic field (B_0)…

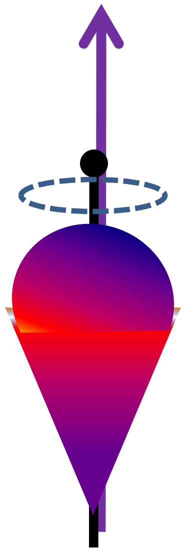
…then the protons' **axes of rotation** relax (align parallel or anti-parallel to the B_0 field, instead of to each other).



Maximum T1 Signal occurs at Alignment

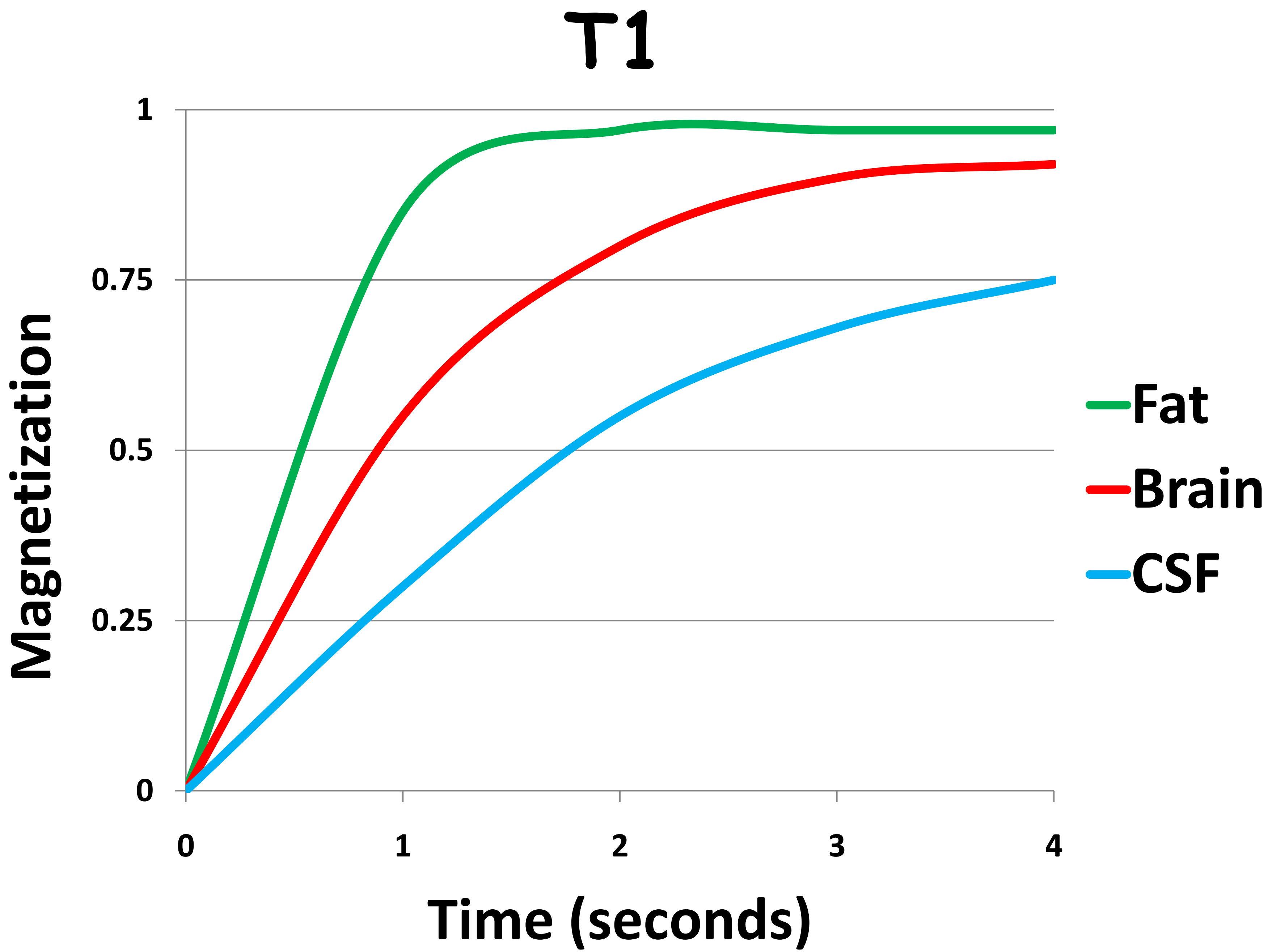
This gives us our first state:

The proton tops are spinning almost vertically, aligned with “B_0”



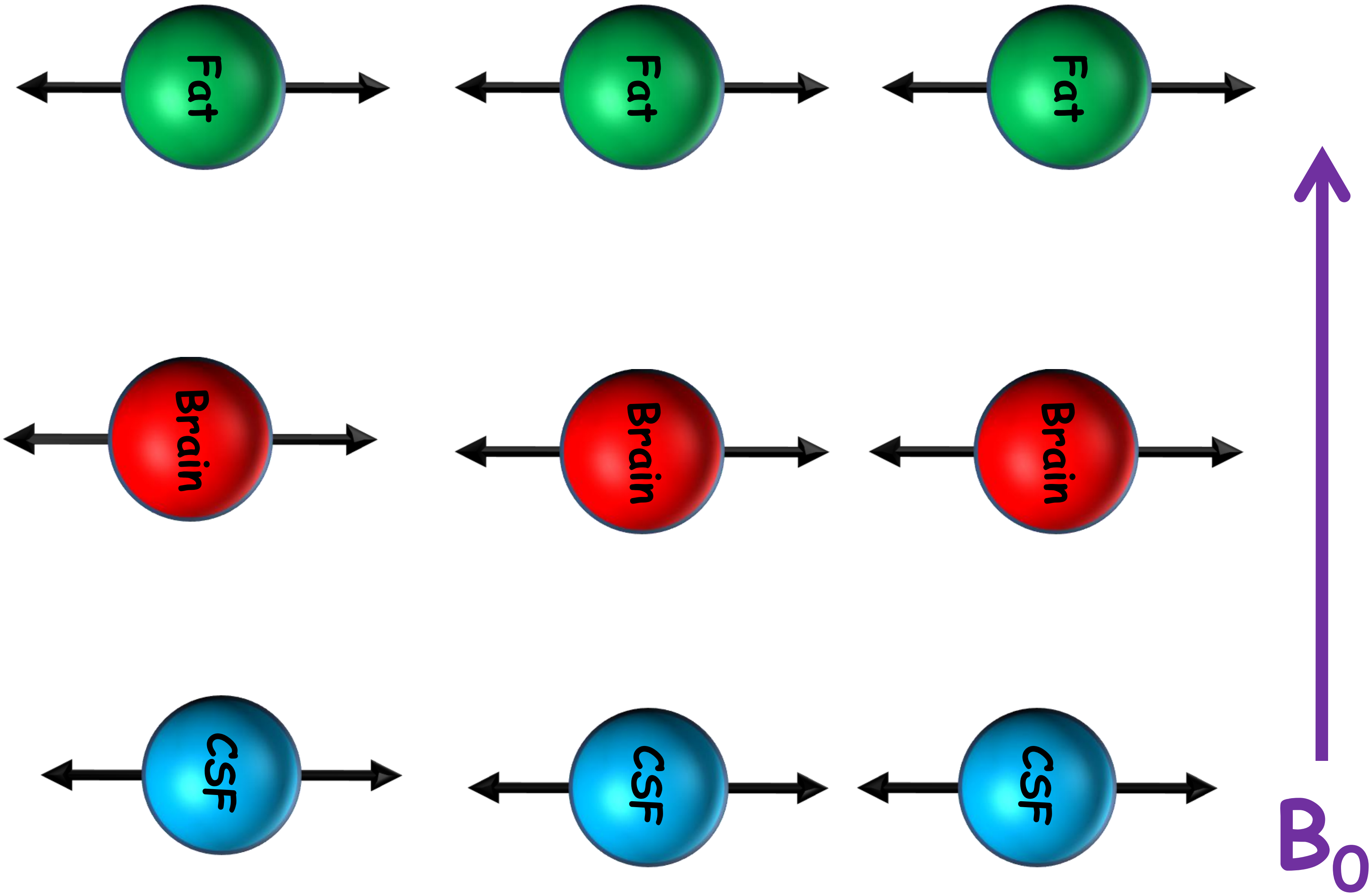
How long does it take for the protons to align to the B_0 field?

Different tissues align at different speeds (which means the number of aligned protons in the tissues differ):

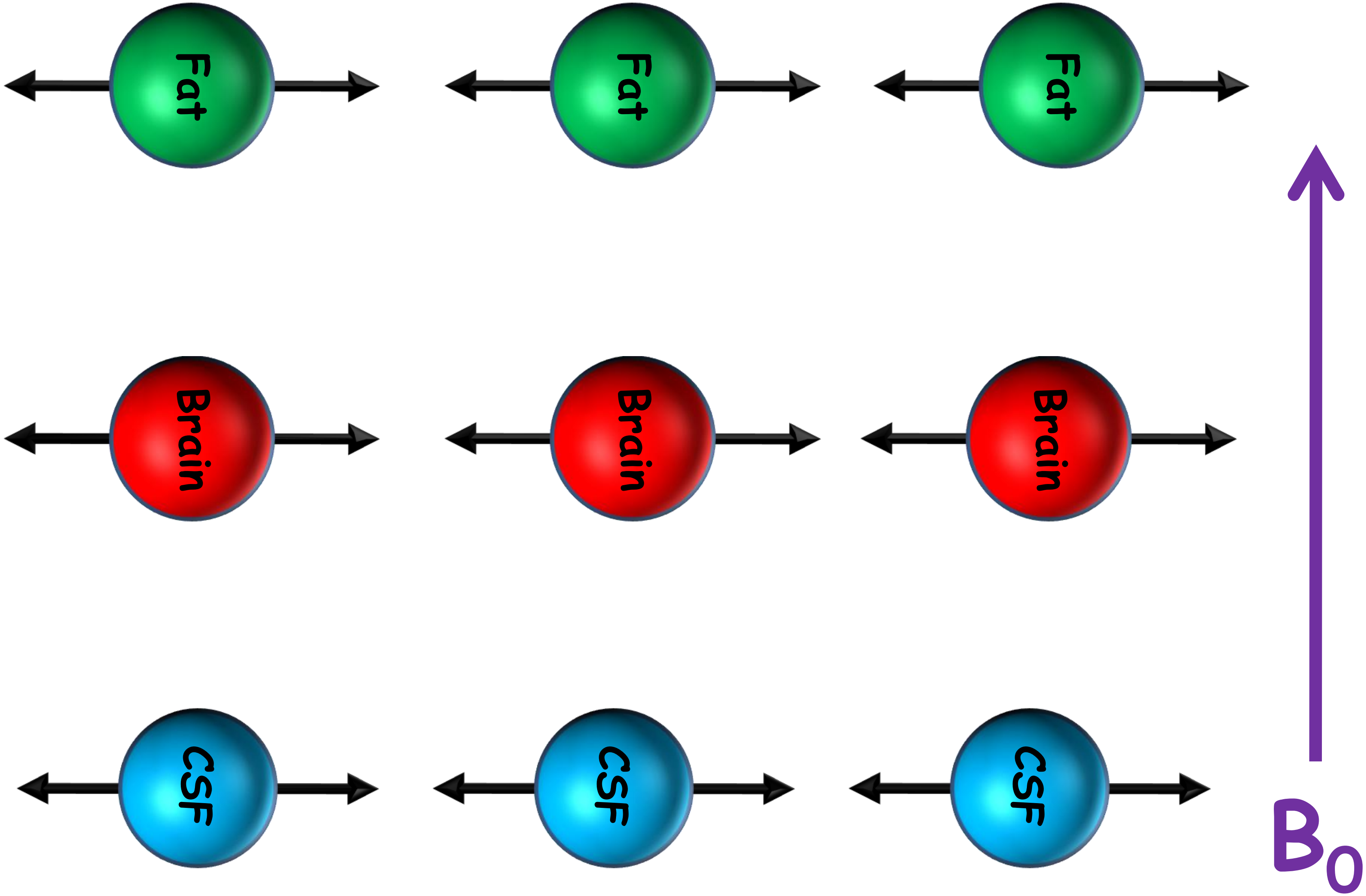

T1
Magnetization
1
0.75
0.5
0.25
0
0
1
2
3
4
Time (seconds)
Fat
Brain
CSF

Wait long enough, and protons in all tissues align to the field, and tissues all have maximum signal*.

*actually, the # of protons that align to B0 is a very small percentage and depends on the magnet strength. For ease of illustration, I pretend it is all or most of the protons that align.


Fat
Fat
Fat
Brain
Brain
Brain
CSF
CSF
CSF
B_0

But, at some intermediate point, fat has the most signal, brain has less, and csf has the least

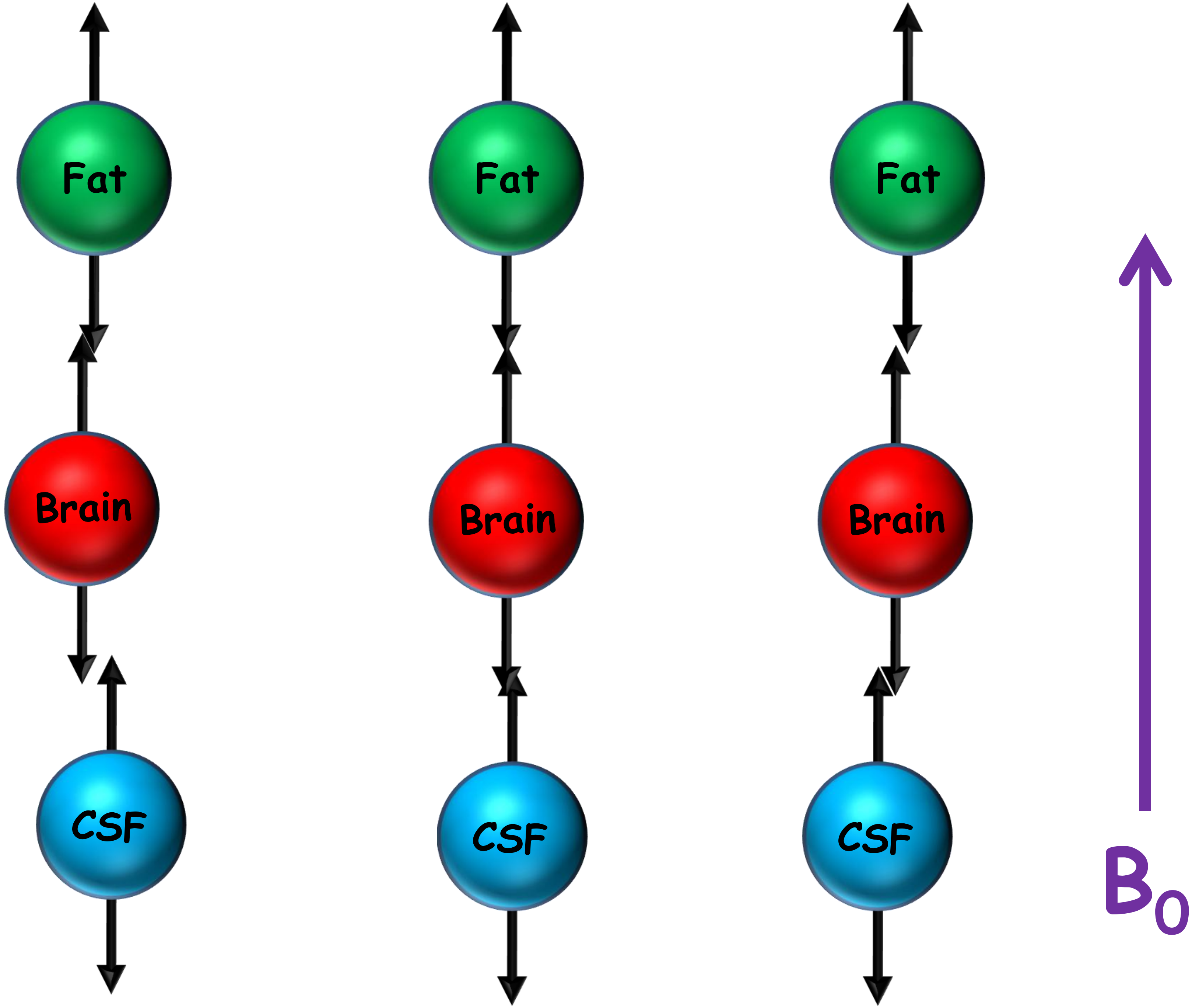

Fat
Fat
Fat
Brain
Brain
Brain
CSF
CSF
CSF
B_0

If we capture this intermediate point, we see maximum tissue contrast.

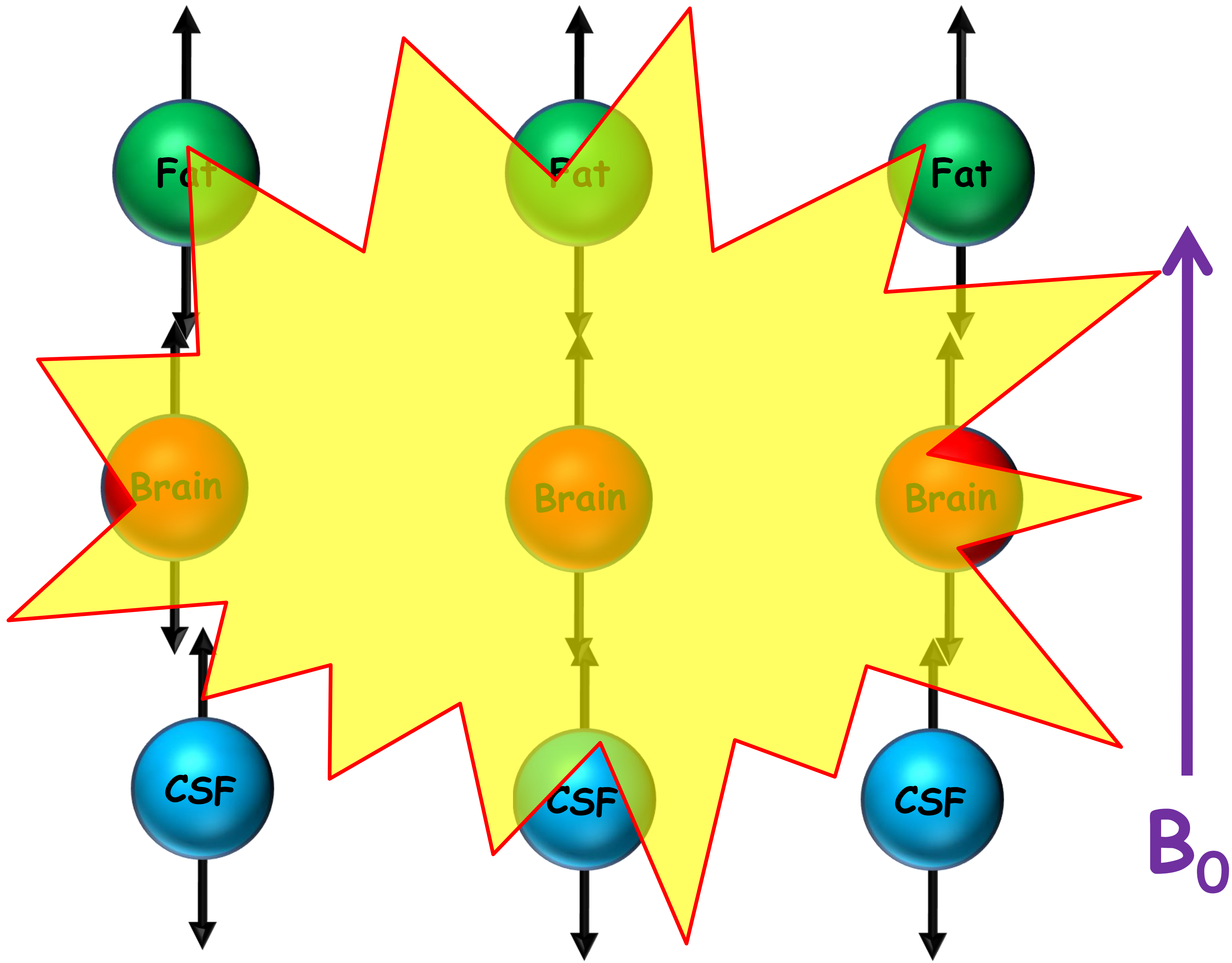
And if we capture signal contrast between tissues, we can make a pretty picture.

How do we do it?

Since we need a few moments in the control room, lets assume we start with a magnetized head (protons are aligned and relaxed).


Fat
Brain
CSF
Fat
Brain
CSF
Fat
Brain
CSF
B_0

Now hit the protons with an exciting RF pulse that knocks them all 90 degrees out of alignment.



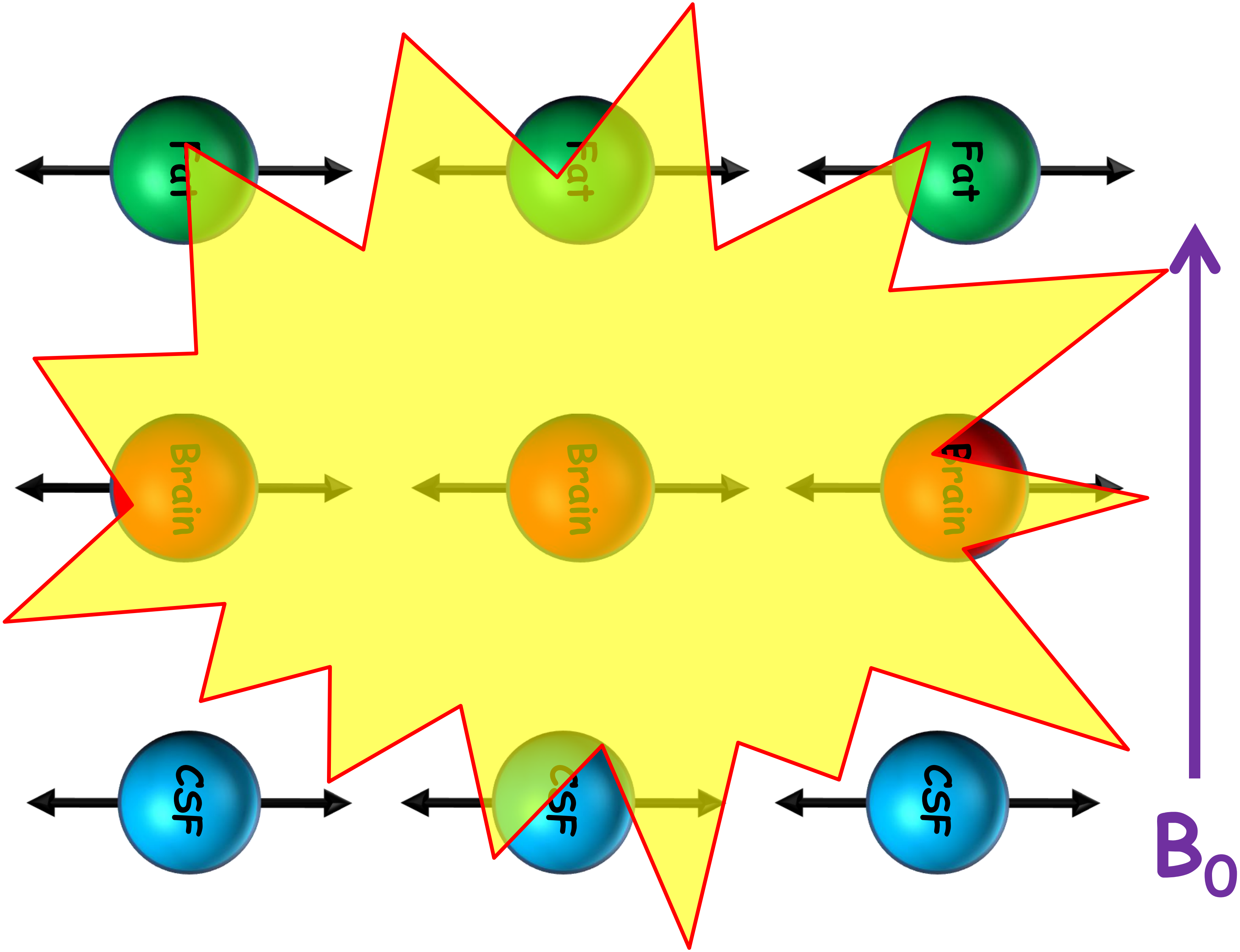
Fat
Fat
Fat
Brain
Brain
Brain
CSF
CSF
CSF
B_0

The excited protons emit a signal.
The amount of signal depends on how many protons in the tissue were magnetized in the first place.

In this first case, the tissues were all fully magnetized beforehand, so they all emit equivalent signal. This means we have no contrast to speak of.

Now we need to do something clever to see contrast between tissues.

The tissues recover magnetization at different rates, but we hit them with a pulse BEFORE they are all fully magnetized.

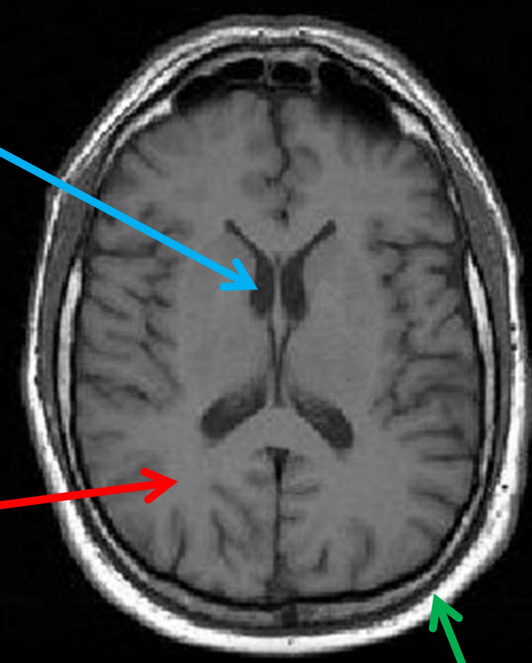


Fat
Fat
Fat
Brain
Brain
Brain
CSF
CSF
CSF
B_0

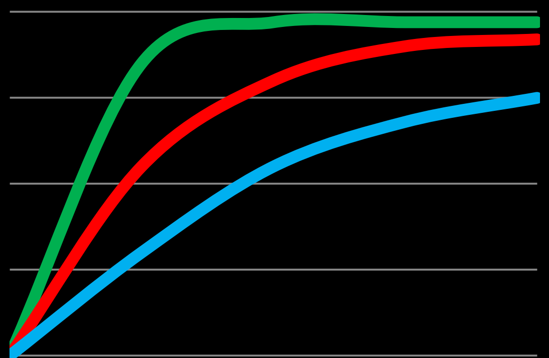
Now the tissues emit signals of different strengths.

T1

CSF aligns very slowly,
has the least signal,
is the third brightest



Brain aligns more slowly,
has less signal,
is the second brightest



Fat aligns fastest,
has the most signal,
is the brightest

For a T1-weighted image, we wait a short time (300-500 ms) between pulse repetitions.

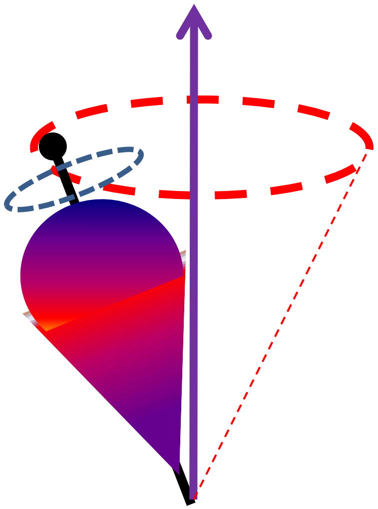
This is called the TR (repetition time).

We wait a short time, because we do NOT want the tissues to fully remagnetize.

Then, what's T2?

T2 is about in-phase precession

This is precession:

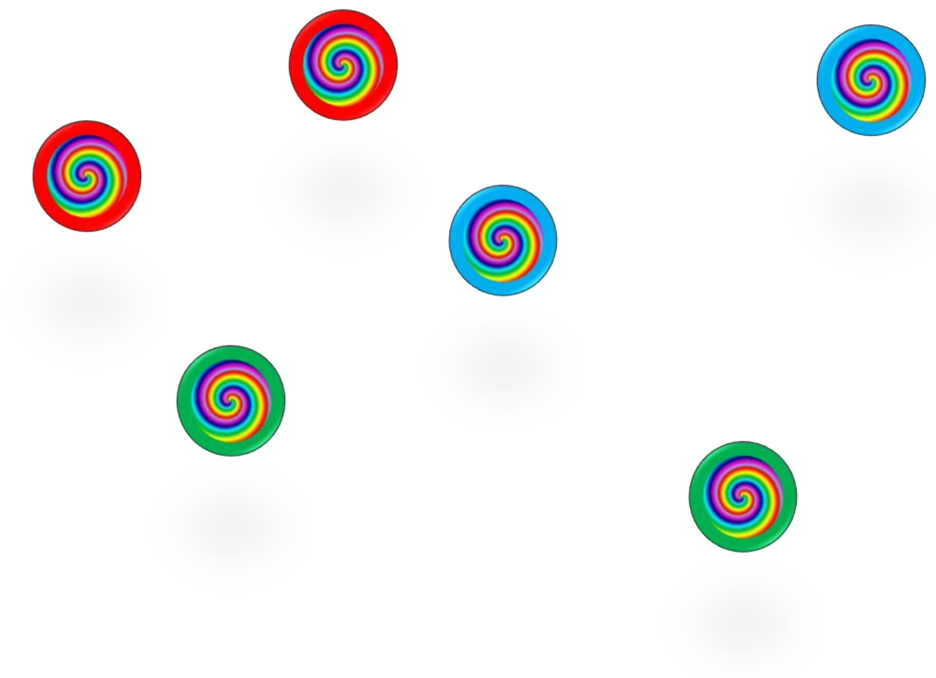


What is in-phase precession?

Imagine that we have lots of protons, and we've just hit them with an RF pulse.

They are precessing together

In-phase precession: View from above

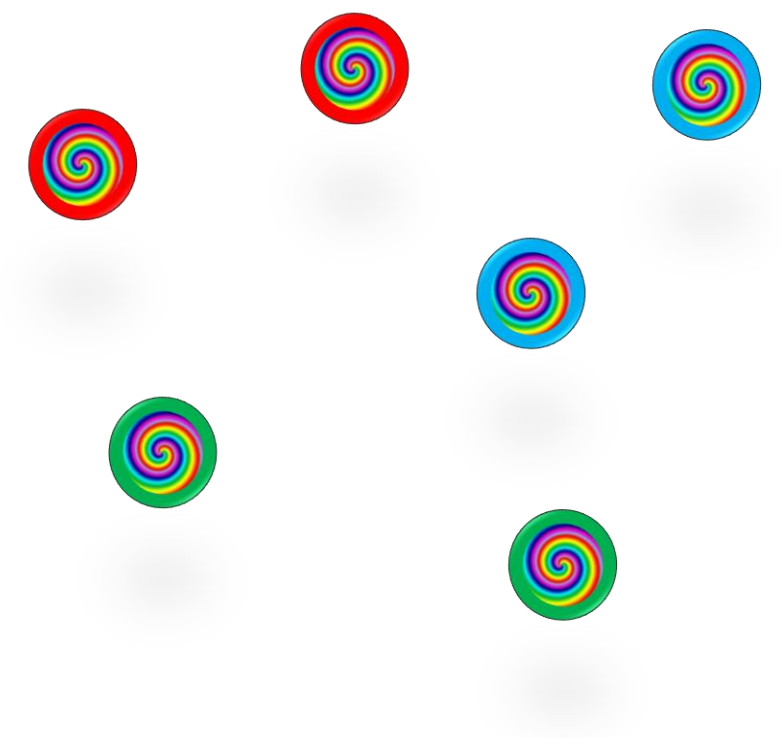


In-phase precession is maximized right after the radio frequency pulse

But precession slowly gets out of phase, because the magnetic field in inhomogeneous

The rate of dephasing depends on the tissues, because some tissues are more regular (homogeneous)

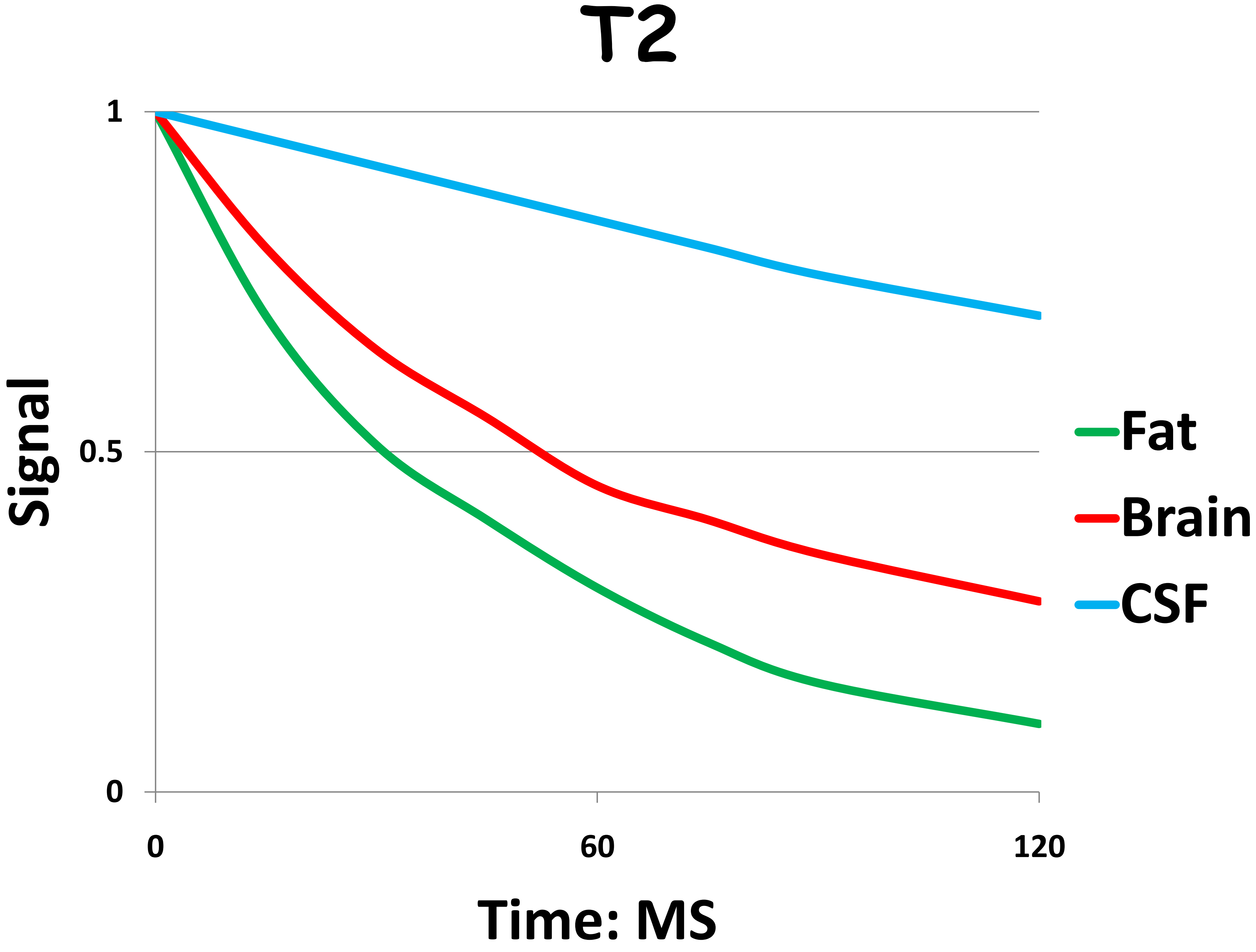
Dephasing:



Uniform tissues, like CSF, stay in-phase longest.

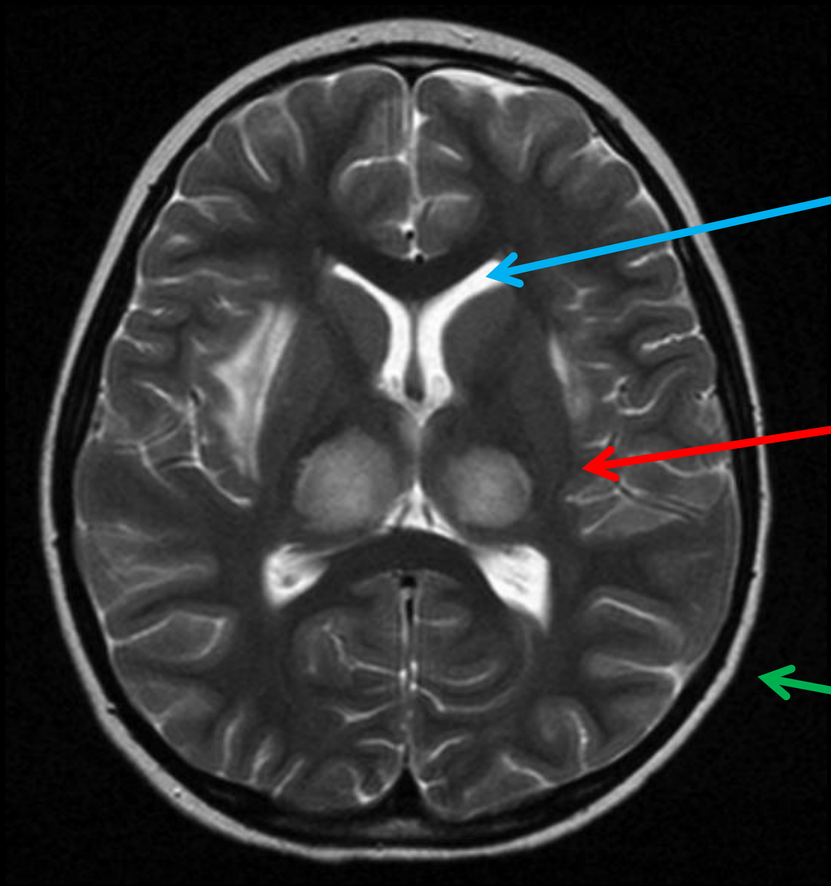
Brain dephases more quickly.

Fat dephases the fastest.



T2
1
0.5
0
0
60
120
Signal
Time: MS
Fat
Brain
CSF

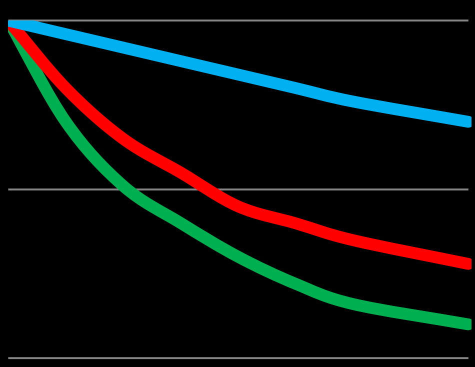
In-phase protons have more T2 signal.



CSF has lots of T2 signal

Brain tissue has less T2 signal

Fat has the least T2 signal

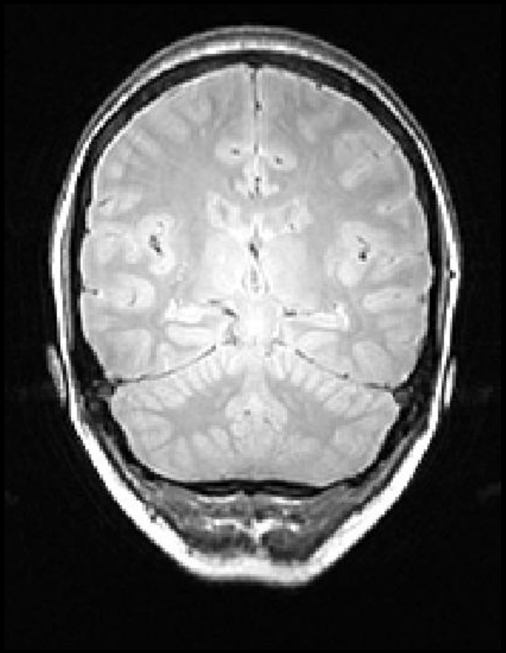


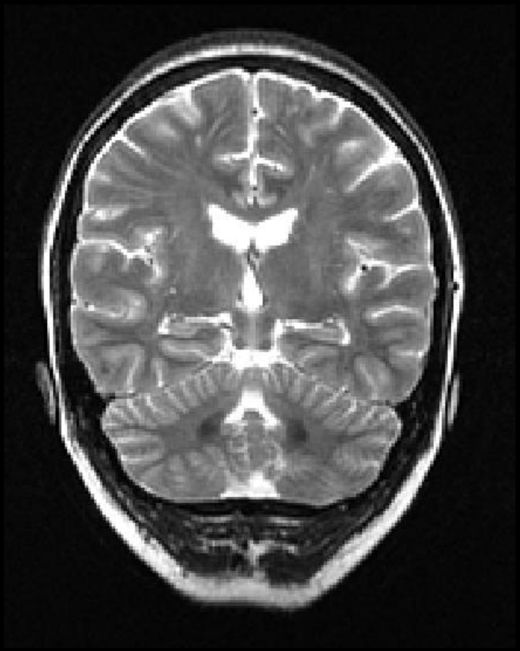
Dephasing occurs at different rates for different tissues

So, the longer we wait, the more phase related contrast we see.

TE=17 ms: More signal, but less contrast

TE=102 ms: Less signal, but more contrast





Time

Summary

T1 is the time it takes protons to relax back into alignment with B_0

T2 is the dephasing.

TE (echo time) is the time between the RF pulse and signal collection.

Every tissue has its own T1 and T2 value.

By choosing the right machine timing and flip angles, you can **weight** an image contrast by mostly T1 effects or mostly T2 effects.

- T1 contrast results by imaging with a short TR relative to the longest tissue T1 and a short TE relative to tissue T2 (to reduce T2 contributions to the contrast)

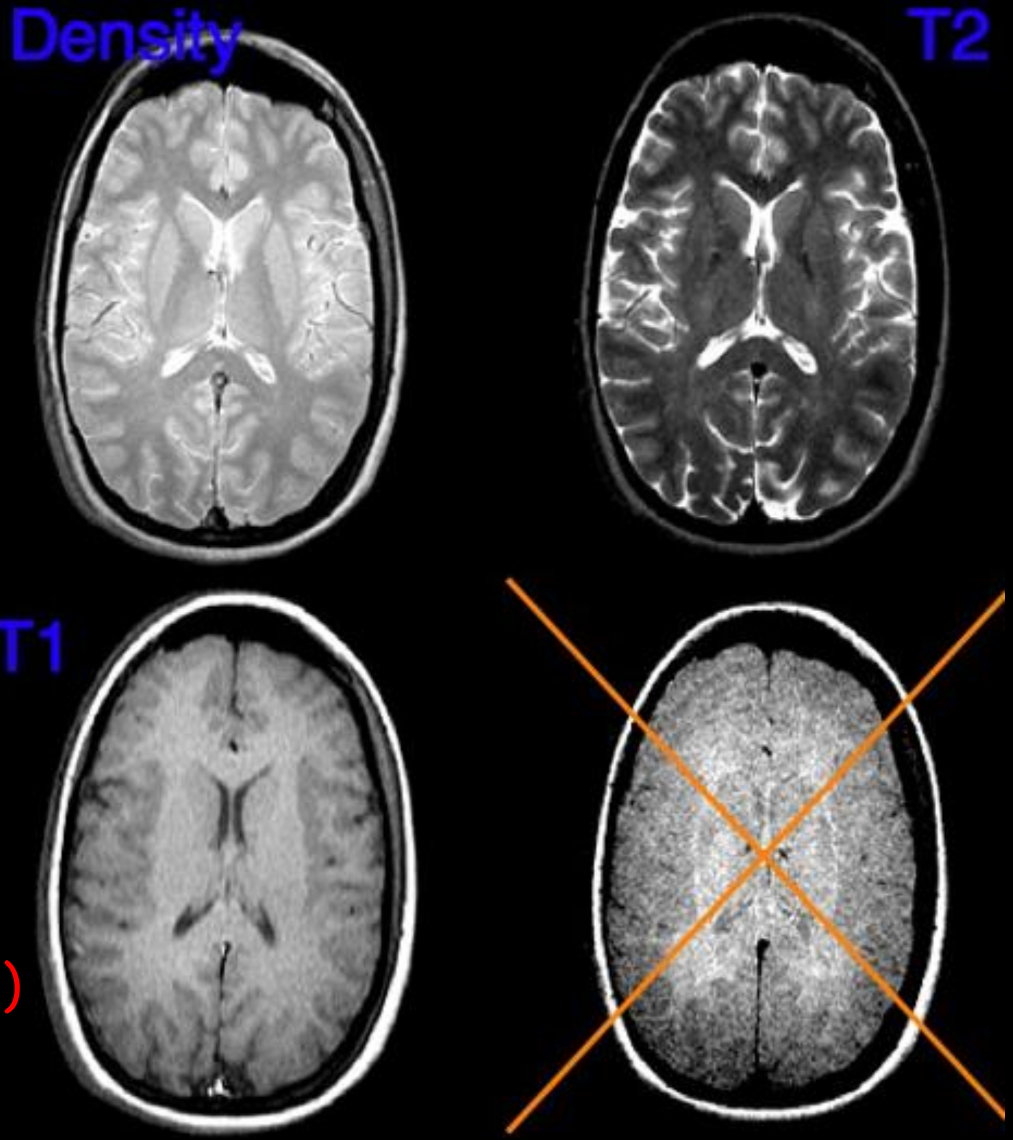
- A T2 weighted image uses a long TR compared to the tissue T1 (to reduce T1 contribution to the contrast)…at least 3 times as long as the longest T1! TE must be between the longest and shortest tissue T2s of interest.

From Mark Cohen’s 2007 podcast

Long
(2-3 s)

TR

Short
(300-500 ms)



Short
(10-20 ms)

TE

Long
(~100 ms)

- RF pulse
- T1
- relaxation
- T2
- dephasing
- B0
- precession
- TR (repetition time)
- TE (echo time)