- HW 6 DUE TONIGHT AT MIDNIGHT
- PROJECT PROPOSALS DUE NEXT TUESDAY AT MIDNIGHT
- HW 7 WILL BE AVAILABLE BY TOMORROW MORNING, DUE NEXT FRIDAY AT MIDNIGHT
- ADVANCED TOPICS LECTURE WILL COVER "COMPRESSED SENSING" - PLEASE READ PAPER BEFOREHAND! MONDAY 4-5 pm IN ROOM 435

## IMAGING CONSIDERATIONS:

### T2* DECAY:

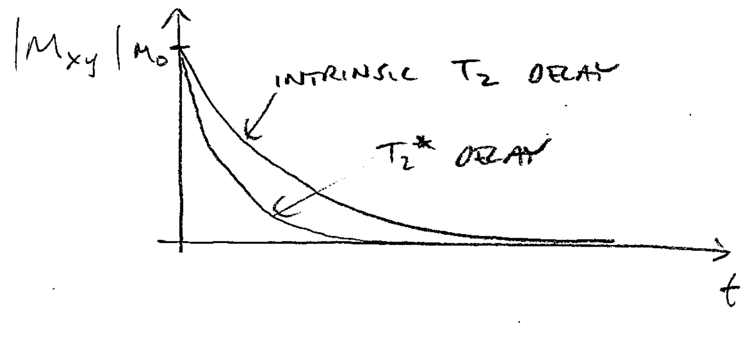
- WE'VE TALKED ABOUT T2 DECAY, AND SAID THAT OUR SIGNAL TYPICALLY DECAYS AS $T_2$.
  - THIS IS ACTUALLY NOT STRICTLY TRUE WHEN WE HAVE INHOMOGENEITY IN OUR MAIN FIELD $B_0$
- ACROSS A VOXEL (OR ANY VOLUME), WE CAN HAVE SLIGHT VARIATIONS IN FREQUENCY, SO:

$$s(t) = \iiint_{x\,y\,z} m(x,y,z)\, e^{-i\omega_E(x,y,z)t}\, e^{-t/T_2(x,y,z)}\, dx\,dy\,dz$$

WHERE:

$$\vec{B} = \left(B_0 + E(x,y,z)\right)\hat{k} \quad \text{AND} \quad \omega_E(x,y,z) = \gamma E(x,y,z)$$

- THIS DEPHASING CAUSES OUR SIGNAL TO DECAY MORE RAPIDLY THAN SIMPLE INTRINSIC T2 DECAY! WE CALL IT "T2*" DECAY



$\boxed{\text{PLAY } T_2^* \text{ SONG}}$

## ECHOES IN MRI:

WE CAN WRITE THE SIGNAL PHASE OF OUR MR SIGNAL AS:

$$\phi(x,y,z,t) = \int_0^t \omega(x,y,z,\tau)\,d\tau$$

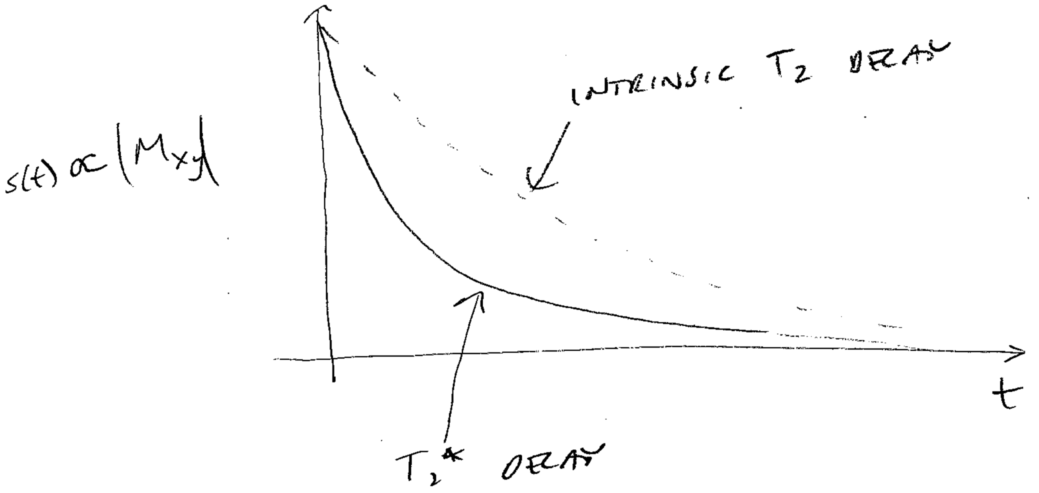
$$\phi(x,y,z,t) = \underbrace{\underbrace{\omega_E(x,y,z)t}_{B_0 \text{ INHOMOGENEITY}} + \underbrace{\omega_{cs}t}_{\text{CHEMICAL SHIFT}}}_{\substack{\text{WE DON'T CONTROL} \\ \text{THESE TERMS} \\ \text{("OFF-RESONANCE")}}} + \underbrace{\gamma\int_0^t \left[G_x(\tau)x + G_y(\tau)y + G_z(\tau)z\right]d\tau}_{\text{GRADIENTS}}$$

$\Uparrow$ WE CONTROL THIS TERM

WE ARE GOING TO TALK ABOUT TWO TYPES OF "ECHOES" IN MR IMAGING:

① **GRADIENT ECHOES:** "ECHOES" IN THE SIGNAL FROM UNDOING PHASE SHIFTS FROM GRADIENT FIELDS

② **SPIN ECHOES:** ECHOES IN SIGNAL FROM UNDOING PHASE SHIFTS (OR DEPHASING) FROM $B_0$ INHOMOGENEITY AND GRADIENT FIELDS

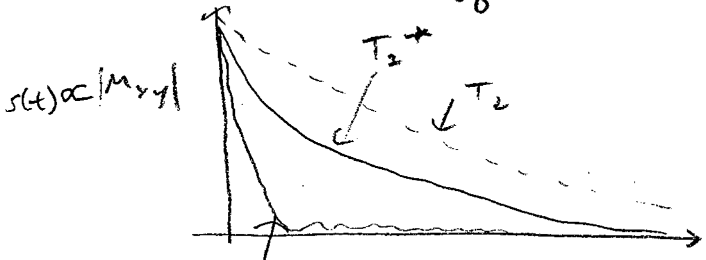


- WITH NO GRADIENTS ON, WE GET $T_2^*$ DECAY.

- WHAT HAPPENS TO SIGNAL WHEN WE TURN GRADIENTS ON?

SIGNAL "DEPHASES", AND DECAYS RAPIDLY, SINCE:

$$\phi(x,y,z,t) = \gamma \int_0^t \left[ G_x(\tau)x + G_y(\tau)y + G_z(\tau)z \right] d\tau$$

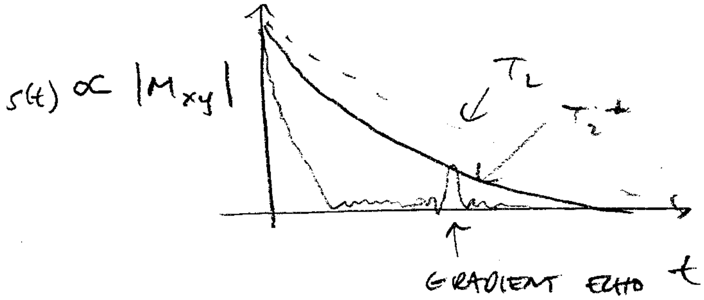


POSSIBLE ACTUAL SIGNAL AS WE TRAVERSE K-SPACE

- WHAT HAPPENS WHEN:

$$\phi(x,y,z,t) = 0 \,? \Longleftarrow \boxed{\text{"GRADIENT ECHO"}}$$

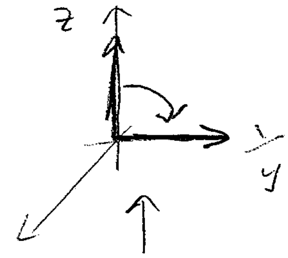
- WE ARE BACK AT THE CENTER OF K-SPACE! ANY LINEAR PHASE ACROSS OUR OBJECT DUE TO GRADIENTS IS UNDONE!



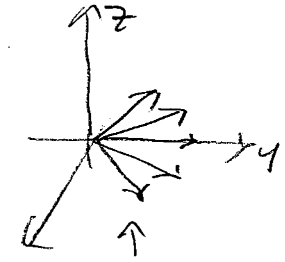
- TECHNICALLY, A GRADIENT ECHO ONLY OCCURS WHEN WE CROSS THE CENTER OF K-SPACE, BUT IT IS COMMON TO REFER TO A CROSSING IN THE READOUT DIRECTION (i.e, $k_x = 0$ FOR 2DFT IMAGING) AS A GRADIENT ECHO AS WELL.

## SPIN ECHOES:

- NOW CONSIDER THE SPINS IN A VOLUME. $T_2^*$ DECAY HAPPENS FROM DEPHASING DUE TO OFF-RESONANCE SOURCES.



AFTER TIP, EVERYONE IS IN PHASE

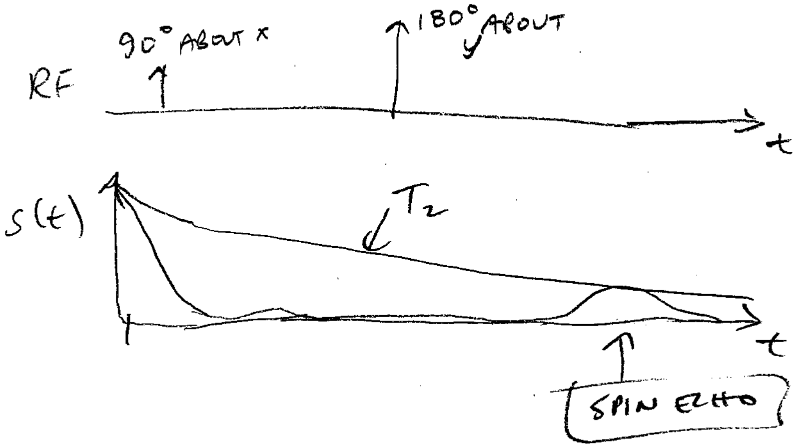


OVER TIME, SPINS SPREAD OUT!! (DEPHASE)

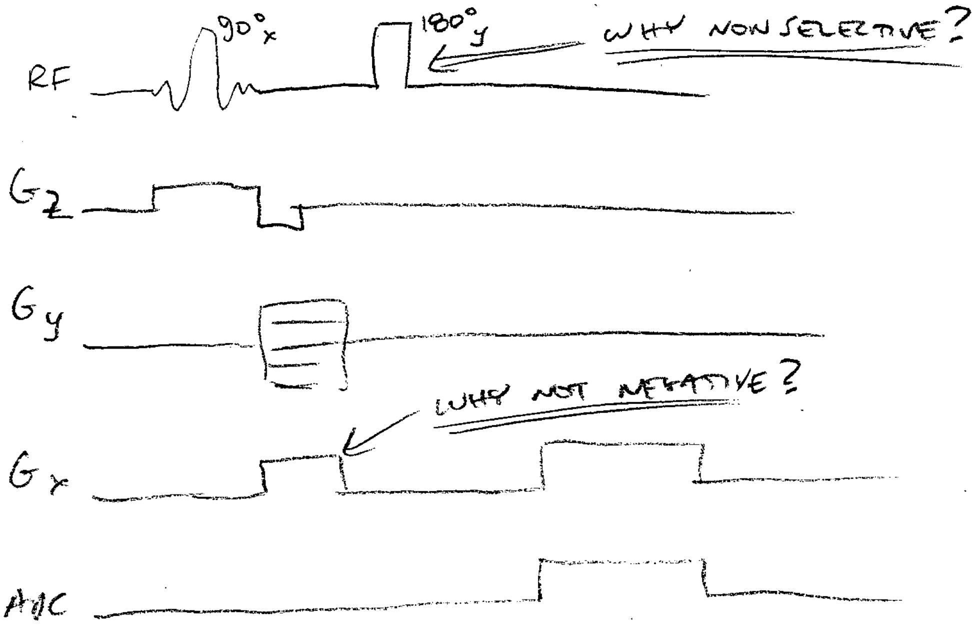
⟸ IN ROTATING FRAME!

- WHAT HAPPENS IF, SOME TIME AFTER OUR INITIAL TIP, WE DO A 180° FLIP AROUND THE Y-AXIS ??

FORM A **"SPIN ECHO"** !



## 2DFT "SPIN ECHO" SEQUENCE:



## NOISE CONSIDERATIONS:

- RECALL: $$\text{SNR} \equiv \frac{\text{SIGNAL AMPLITUDE}}{\text{STD. DEV. OF NOISE}}$$

$$\text{CNR} \equiv \frac{\text{SIGNAL DIFFERENCE}}{\text{STD. DEV. OF NOISE}}$$

## SOURCES OF NOISE:

- UNLIKE CT, WE MODEL AS GAUSSIAN-DISTRIBUTED AND ADDITIVE.

- MAIN SOURCE IS THERMAL NOISE ARISING FROM THE BROWNIAN MOTION OF ELECTRONS IN A CONDUCTOR, WHICH GENERATES RANDOM ELECTRICAL FLUCTUATIONS.
  - THIS IS CALLED "JOHNSON NOISE" OR "RESISTIVE NOISE".

- TWO SOURCES:

  IDEALLY ONLY INDUCTIVE COUPLING, SO INDUCTIVE LOSSES DUE TO "MAGNETIC RESISTANCE"

  ① RESISTANCE $R_c$ OF THE RECEIVER COIL

  ② RESISTANCE $R_s$ OF THE SAMPLE AS SEEN BY THE RECEIVER COIL.

- POWER SPECTRAL DENSITY IS GIVEN BY:

$$N(f) = 4\underset{\substack{\uparrow \\ \text{BOLTZMANN'S} \\ \text{CONSTANT}}}{k}\overset{\substack{\text{ABSOLUTE TEMP.} \\ \downarrow}}{T} R \Leftarrow \text{RESISTANCE}$$

TOTAL NOISE POWER WITHIN A BANDWIDTH $\Delta f$ IS THEN GIVEN BY:

$$4kTR\Delta f$$

- IN MRI, "BODY" NOISE TYPICALLY DOMINATES OVER RECEIVER COIL NOISE.

TUESDAY: $$\text{SNR} \propto (\Delta x)(\Delta y)(\Delta z)\sqrt{\text{TOTAL READOUT TIME}}\; f(\rho, T_1, T_2)$$