SIMULTANEOUS MULTISLICE (SMS)

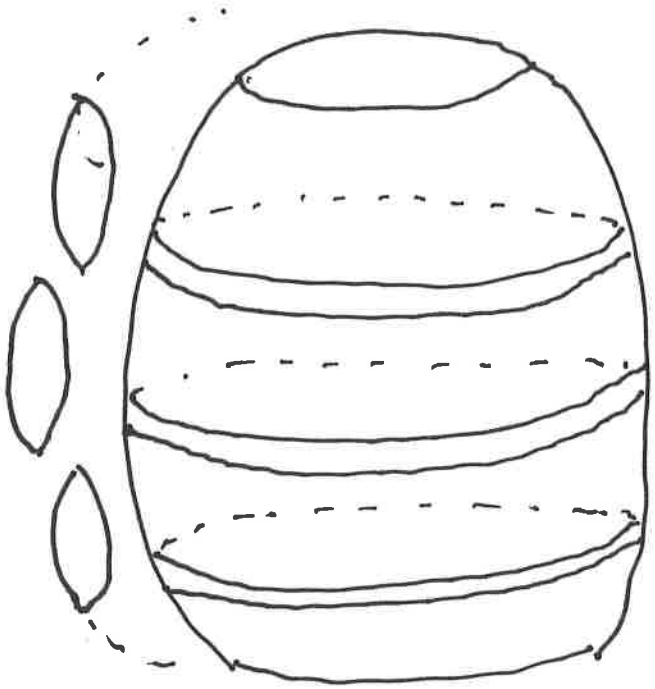
BASIC IDEA

UNDERSAMPLING

RECONSTRUCTION

- SLICE GRAPPA (AND VARIANTS)
- HYBRID SENSE

SMS IDEA



COILS, ALL AROUND

EXCITE MULTIPLE SLICES AT THE SAME TIME

USE COIL SENSITIVITIES TO SORT THEM OUT

WORKS WELL BECAUSE COIL SENSITIVITIES ARE VERY DIFFERENT IF THE SLICES ARE FAR APART

LIMITING CASE, TOP/BOTTOM SLICES ABOVE, ARE COMPLETELY INDEPENDENT. THE COILS THAT SEE ONE DON'T SEE THE OTHER

⇒ NO g-FACTOR LOSS AT ALL!

IN GENERAL, g-FACTOR LOSS MUCH SMALLER THAN THE LOSS FOR IN-PLANE ACCELERATION BY THE SAME FACTOR

3DFT vs 2D Multislice SMS

SMS allows much higher acceleration than 3DFT

3DFT

Transform in readout first

Result is lots of 2D reconstructions

Limits acceleration to 3-4

SMS

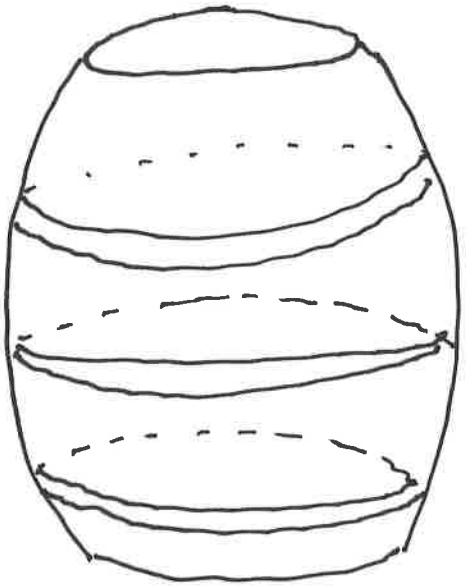
Little g-factor loss in slice direction

Accelerate by 3 or more

Accelerate in slice as usual, 3

Total acceleration 9!

EXCITING MULTIPLE SLICES



EXCITE INDIVIDUAL SLICES WITH:

$$B_{1,1}(t) = B_1(t)\, e^{i\omega_1 t} \qquad \omega_1 = \gamma G z_1$$

$$B_{1,2}(t) = B_1(t)\, e^{i\omega_2 t}$$

$$B_{1,3}(t) = B_1(t)\, e^{i\omega_3 t}$$

EXCITE ALL TOGETHER BY SUMMING

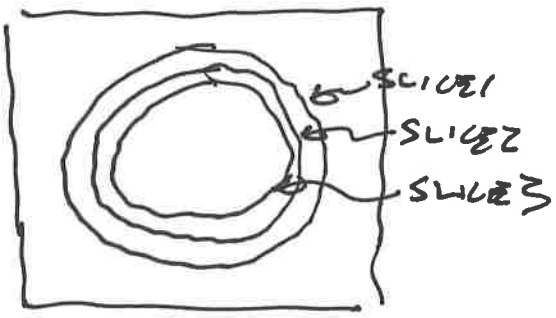
$$B_{1,T}(t) = \sum_k B_{1,k}(t)$$

$$= \sum_k B_1(t)\, e^{i\omega_k t}$$

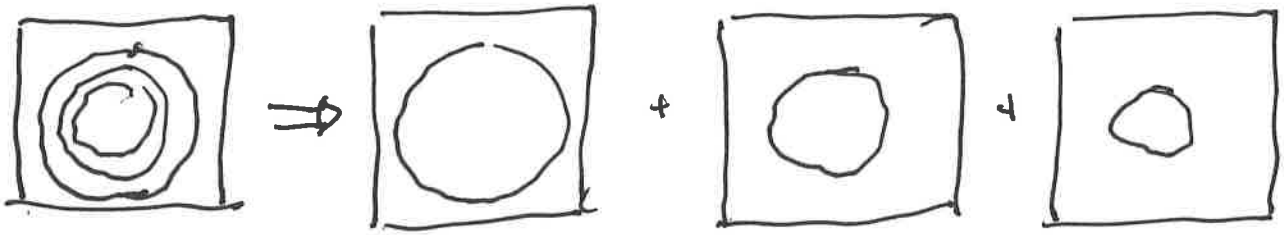
$$= B_1(t)\left(\sum_k e^{i\omega_k t}\right)$$

IF WE HAVE N SLICES, PEAK AMPLITUDE GOES UP BY N, AND POWER BY N^2

IF WE EXCITE WITH THIS AND IMAGE IN X-Y ALL SLICES SUPERIMPOSE



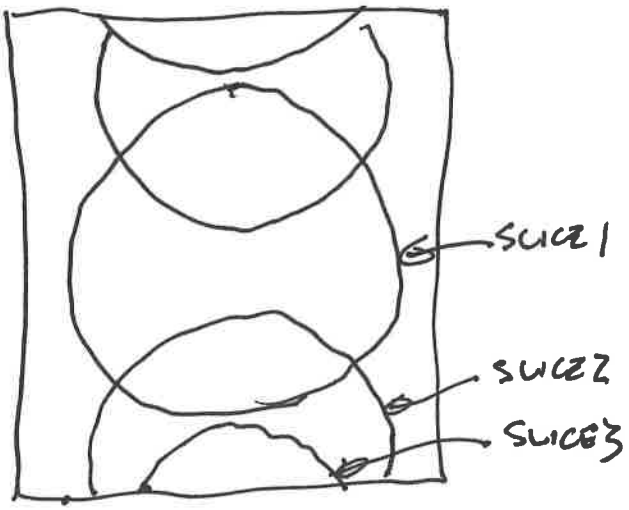
IF WE HAVE ENOUGH PROPERLY SPACED RECEIVE COILS, WE CAN SORT THESE OUT WITH A SENSE RECONSTRUCTION, AS USUAL



WE CAN ACTUALLY DO MUCH BETTER THAN THIS!

IF WE ADD A LINEAR PHASE PROGRESSION IN THE SLICE DIRECTION, WE CAN SHIFT THE SLICES IN THE PHASE ENCODE DIRECTION

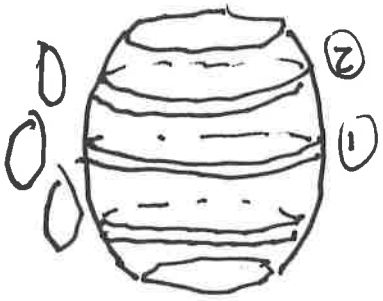
$$\{B_{1,k}(t)\} = \{B_1(t)\left(\sum_{k=1}^{N} \underbrace{e^{j\frac{2\pi}{N}kl}}_{\text{PHASE OFFSET}} \underbrace{e^{j\omega_k t}}_{\text{SLICE POSITION}}\right)\}$$



$\frac{1}{2}$ FOV OFFSET FOR LAST SLICE

WHY IS THIS BETTER?

COIL SENSITIVITIES NOW MUCH DIFFERENT FROM SLICE TO SLICE



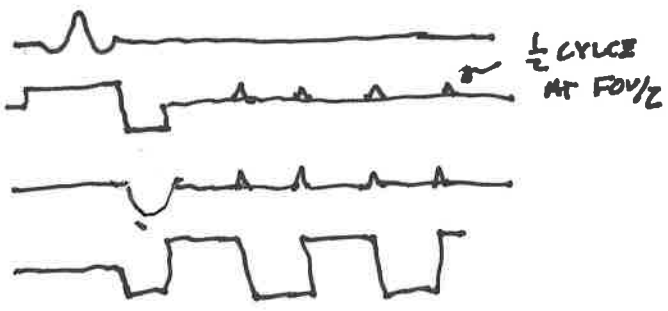
MIDDLE COIL

SLICE 1 SLICE 2

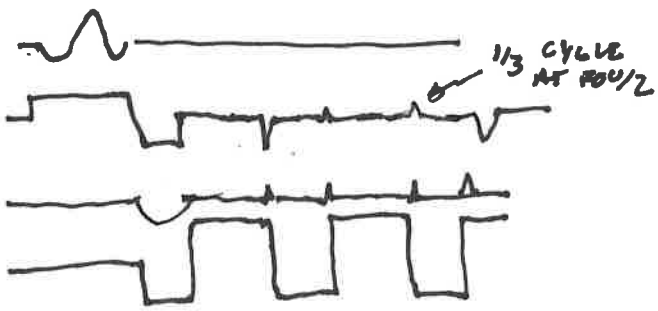
SAME COIL SENSITIVITY SHIFT BY FOV/N FROM ONE SLICE TO NEXT!

SLICE SHIFTING DONE HERE WITH RF SET OF N PULSES

SIMILAR EFFECT CAN BE PRODUCED WITH GRADIENT BLIPS



CAIPI

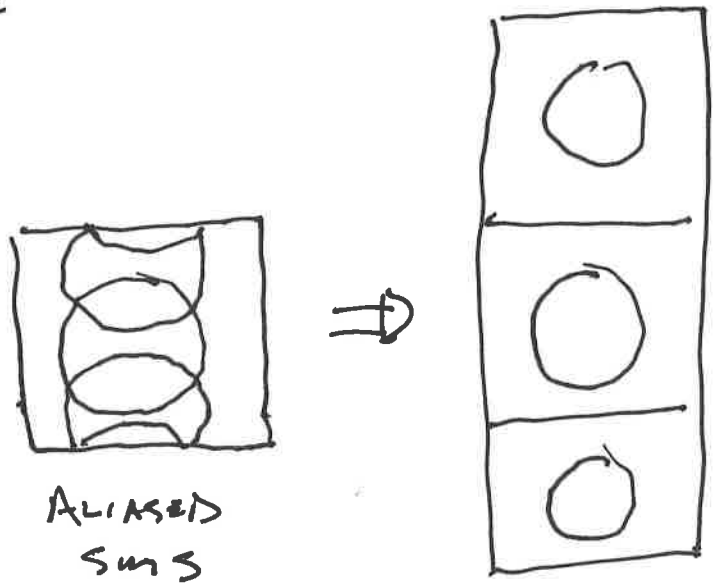


BLIPPED CAIPI

CAIPIRHINA

RECONSTRUCTION

WE CAN CONSIDER THE SMS IMAGE TO BE AN ALIASED VERSION OF A LARGE FOV IMAGE

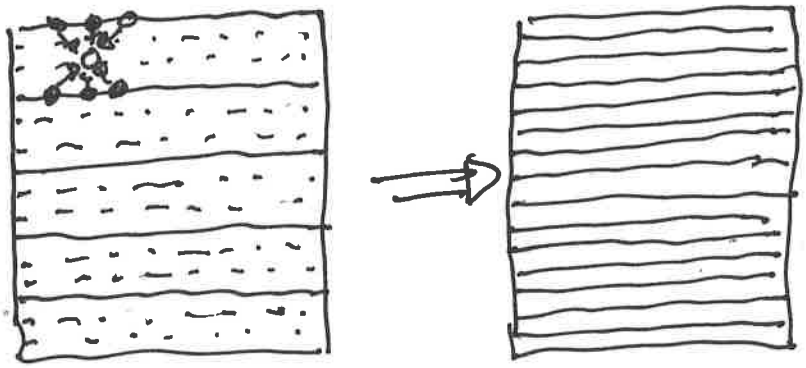


ALIASED SMS

(POMP GLOUER)

RECONSTRUCTION IS JUST PARALLEL IMAGING!

GRAPPA IS A COMMON CHOICE



UNDERSAMPLED BY 3

SMS IS POMP + PI!

MANY VARIATIONS

CLASSICAL GRAPPA — HAS PROBLEMS WITH PHASE DISCONTINUITIES AT EDGE OF FOV

SLICE GRAPPA

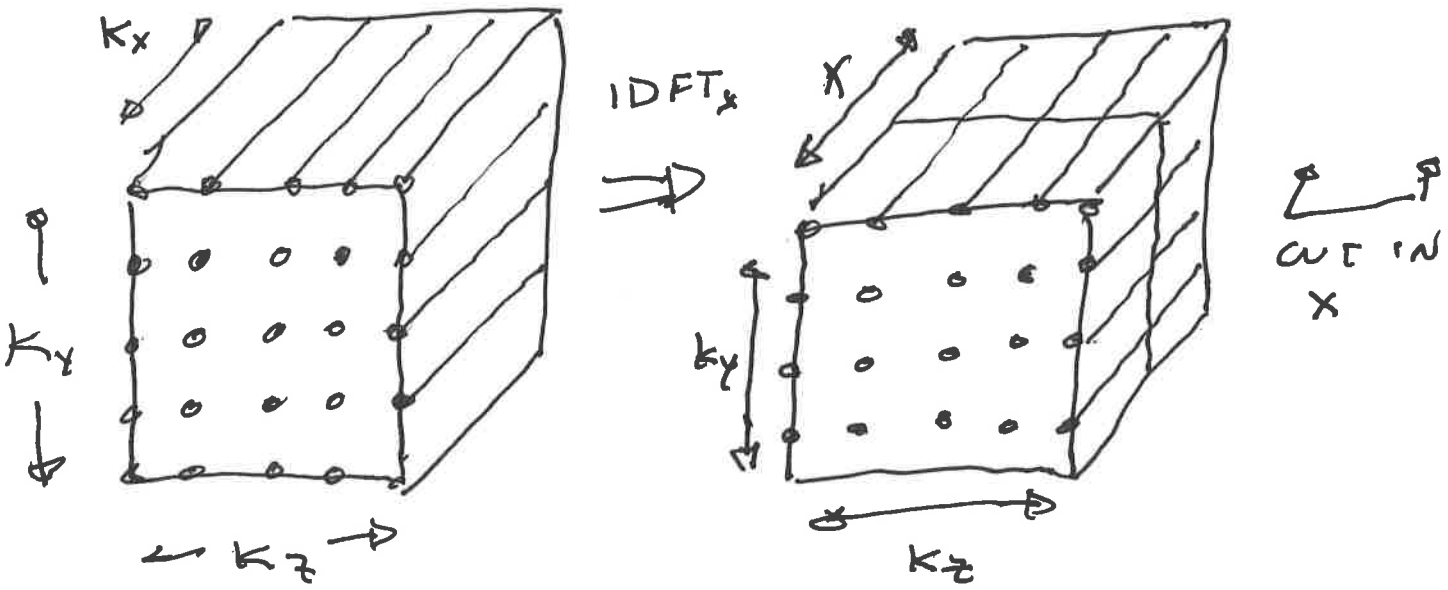
- INITIAL FULL SINGLE SLICE IMAGES FOR EACH SLICE
- COMPUTE A KERNAL DEPENDANT ON ALL SLICES TO RECONSTRUT EACH SLICE (N KERNELS)
- OPERATES ON ALIASED COIL DATA
- COMPLETELY SYNTHESIZES NEW DATA FOR EACH SLICE
- GOOD SNR, HIGH LEAKAGE BETWEEN SLICES

SPLIT-SLICE GRAPPA

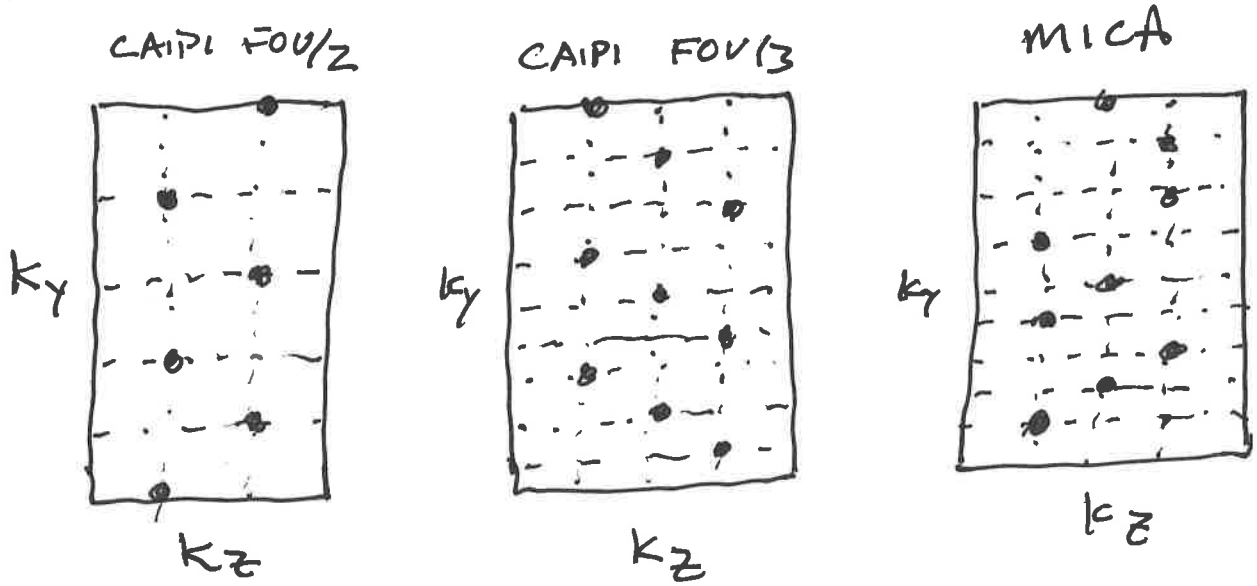
- SAME IDEA AS SLICE GRAPPA
- KERNELS DESIGNED TO NULL OUT OTHER SLICES

HYBRID SENSE

- TRANSFORM IN READOUT $\Rightarrow$ HYBRID SPACE
- SOLVE PI PROBLEM IN k_y-k_z FOR EACH x
- ANALYTIC EXPRESSION FOR g



k_y - k_z SAMPLING



MICA (MULTISLICE WITH INCOHERENT ALIASING)

WORKS BETTER FOR LARGE NUMBER OF SLICES

FOR N SMALL (< 6-8) DOESN'T MATTER TOO MUCH

HYBRID SENSE RECONSTRUCTION

FULLY SAMPLED CALIBRATION IMAGES
  FOR EACH SLICE

ESTIMATE COIL SENSITIVITIES

SENSE RECONSTRUCTIONS
  TRANSFORM IN READOUT
  RECONSTRUCT ALIASED y-z IMAGES
    FOR EACH x
  SENSE RECONSTRUCTIONS FOR EACH x

GRAPPA IS AN ALTERNATIVE, OR ANY OTHER
  PI METHOD

SENSE IS NICE BECAUSE WE CAN
  COMPUTE g-FACTOR MAPS

PRACTICAL ISSUES

OFTEN USED WITH EPI
  SLICE DEPENDENT DELAYS, EDDY CURRENTS
  MUST BE INCLUDED IN RECON
RF PEAK POWER AND FIDELITY