MRI Physics:

Advanced Imaging Topics

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Advanced Image Acquisition Topics

$$Time = T_R \cdot N_y \cdot NA$$

$$Time = T_R \cdot N_y$$

- (Partial Fourier)
- Parallel Imaging (GRAPPA/SENSE/iPAT/ASSET)
- Compressed Sensing
- Simultaneous Multi-Slice Imaging

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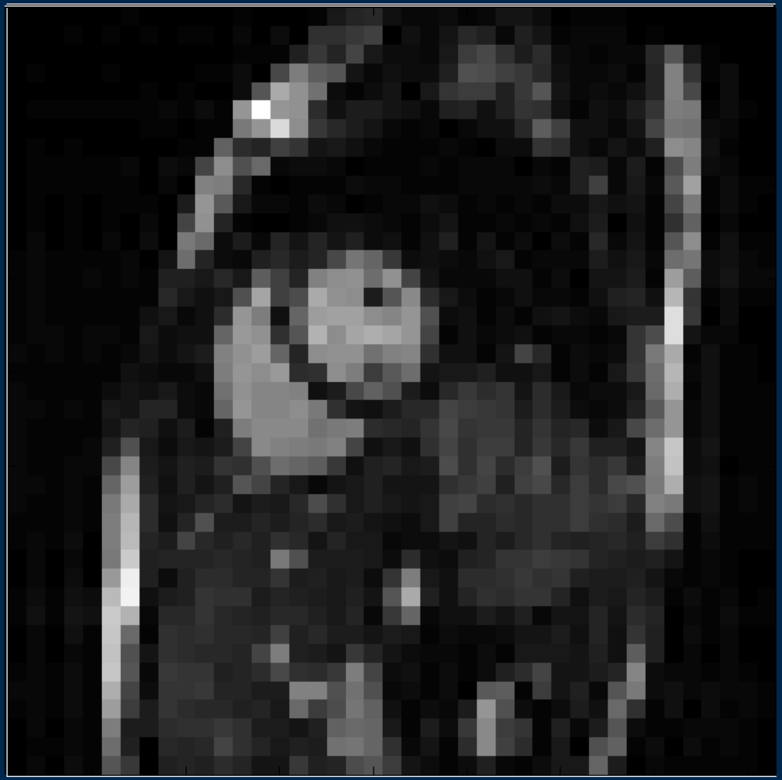
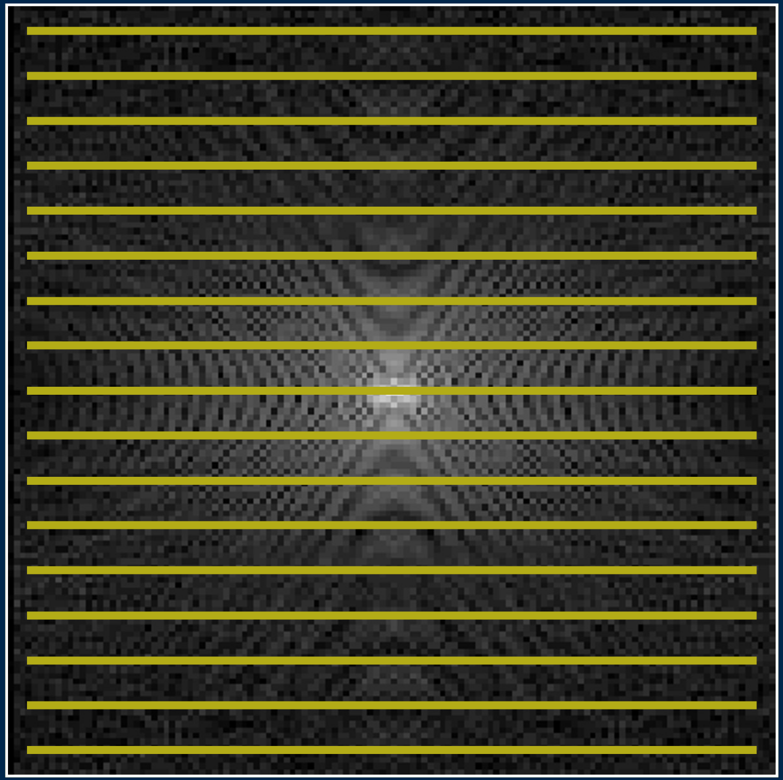
What happens if we reduce the number of lines?





Low resolution scan not useful

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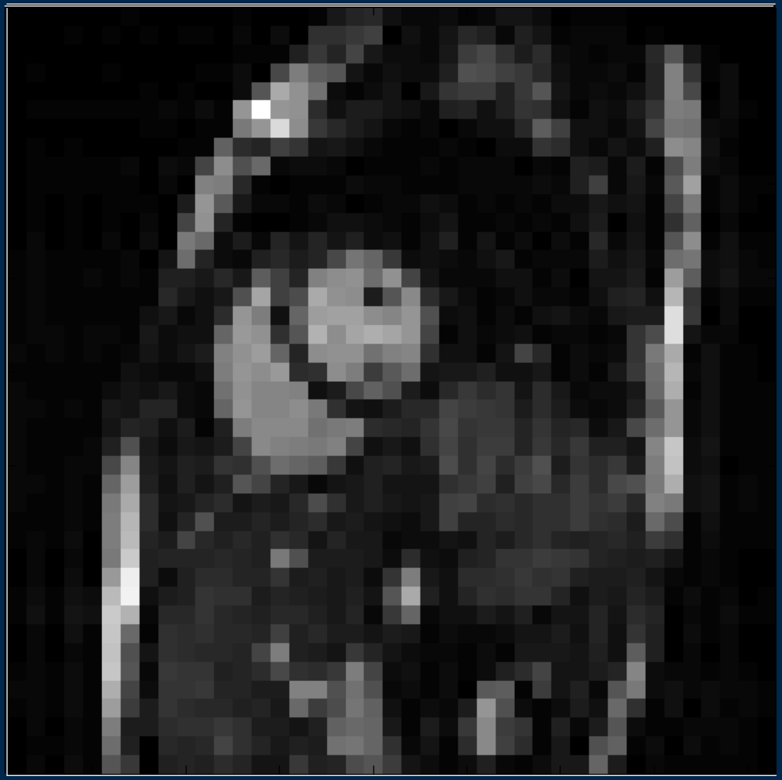
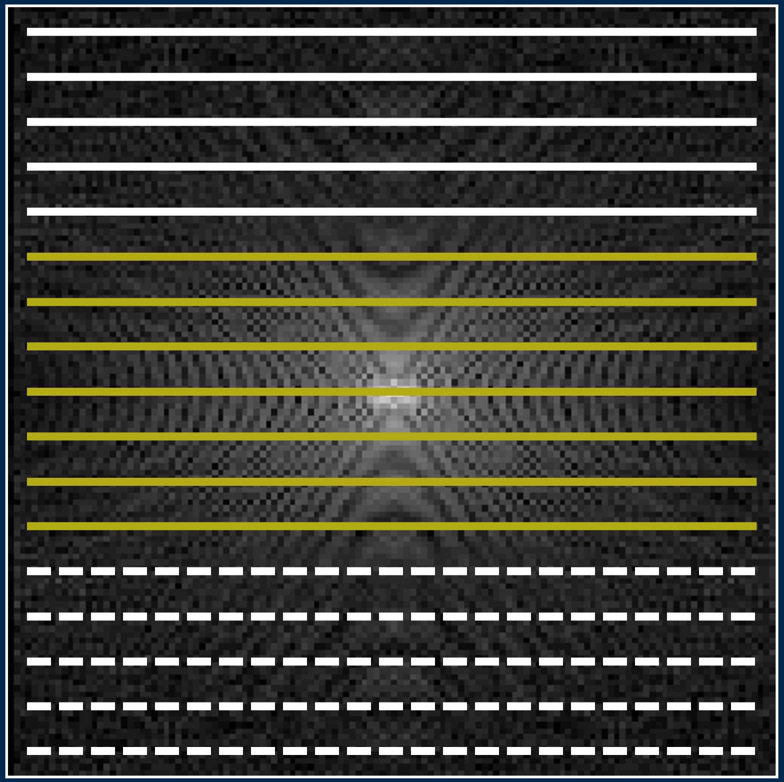
Partial Fourier Reconstruction





Scan time reduced by 10-40%

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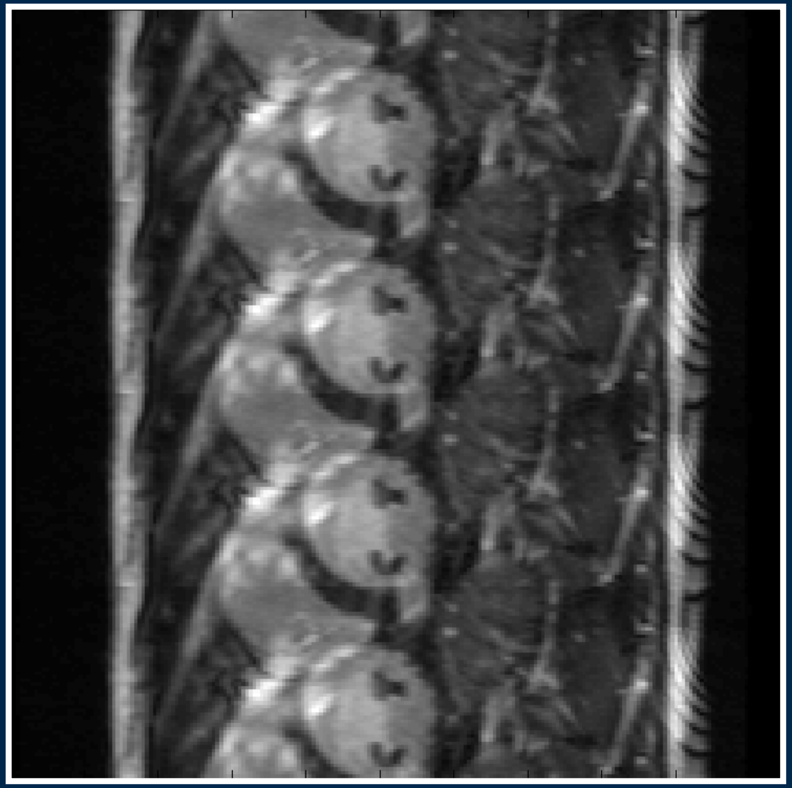
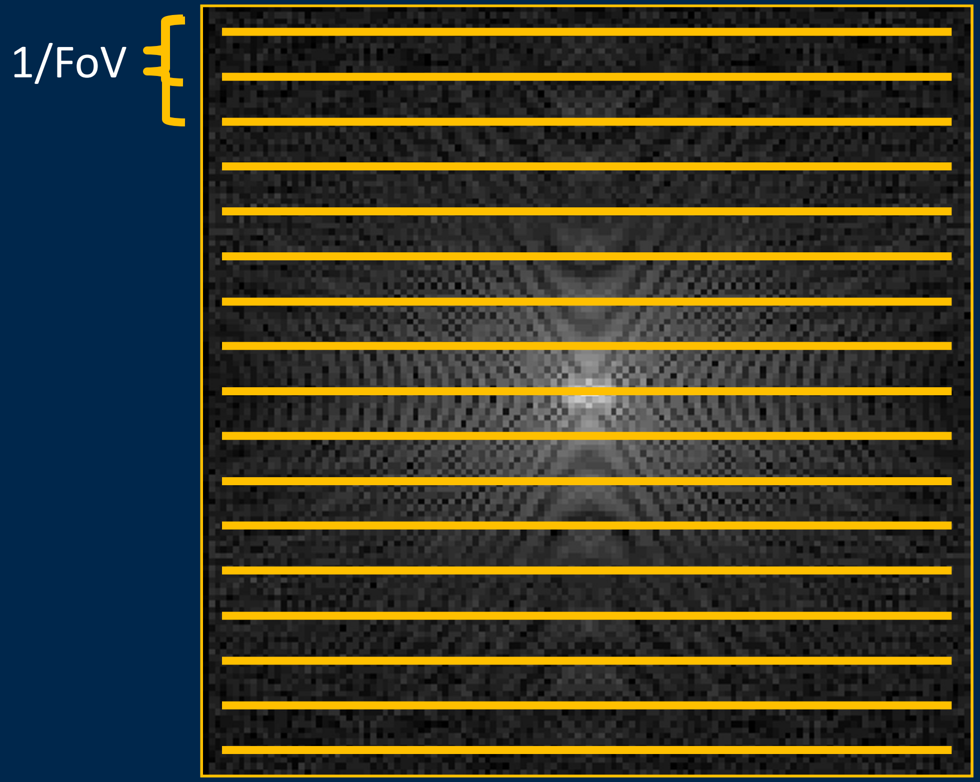
Can we redistribute lines of k-space?



R = 2
R = 4



$$3ms \cdot 256 = 768ms$$
$$3ms \cdot 128 = 384ms$$
$$3ms \cdot 64 = 192ms$$

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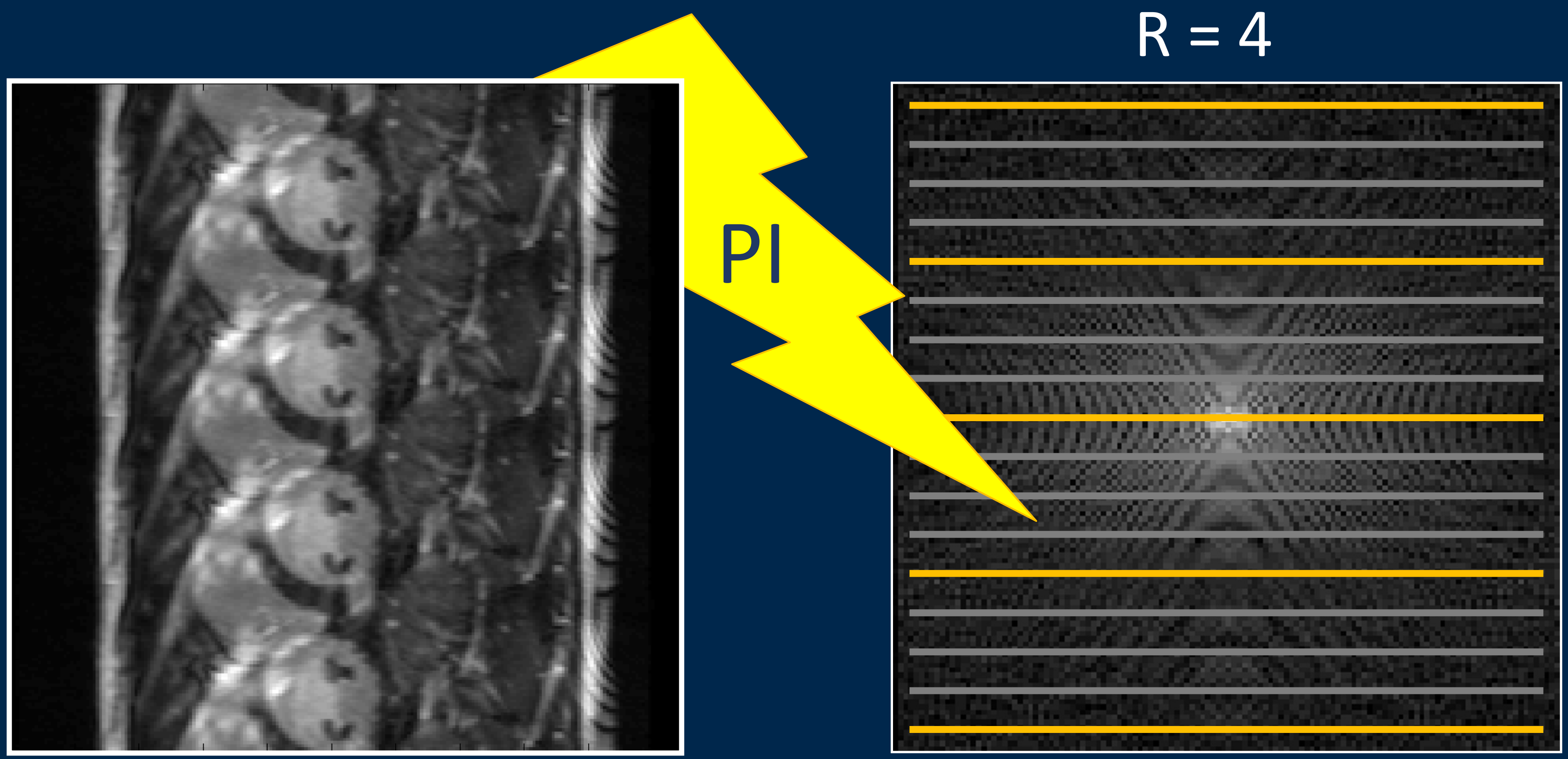
Parallel Imaging can be used to remove aliasing



SENSE/ASSET

GRAPPA / ARC

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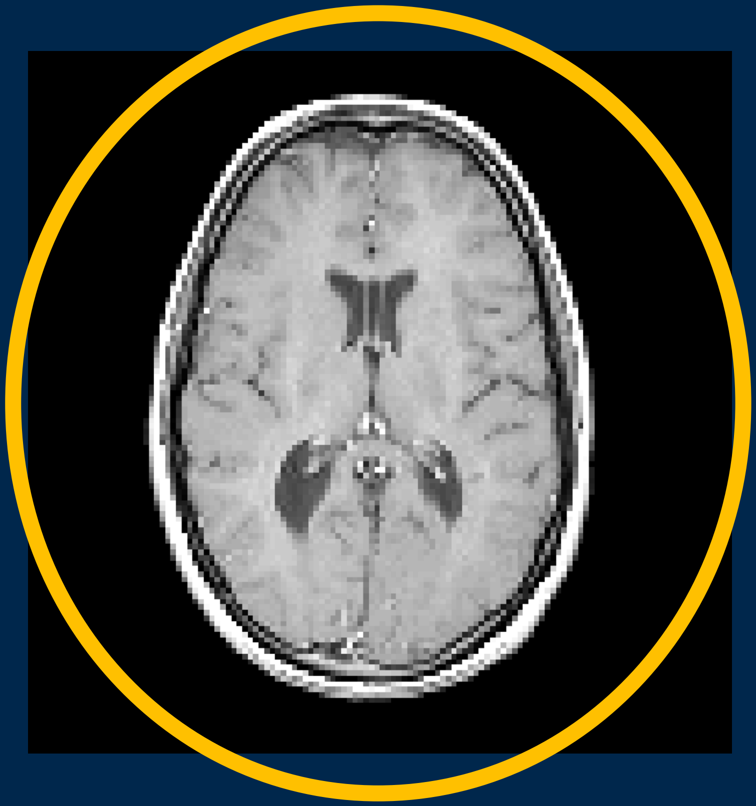
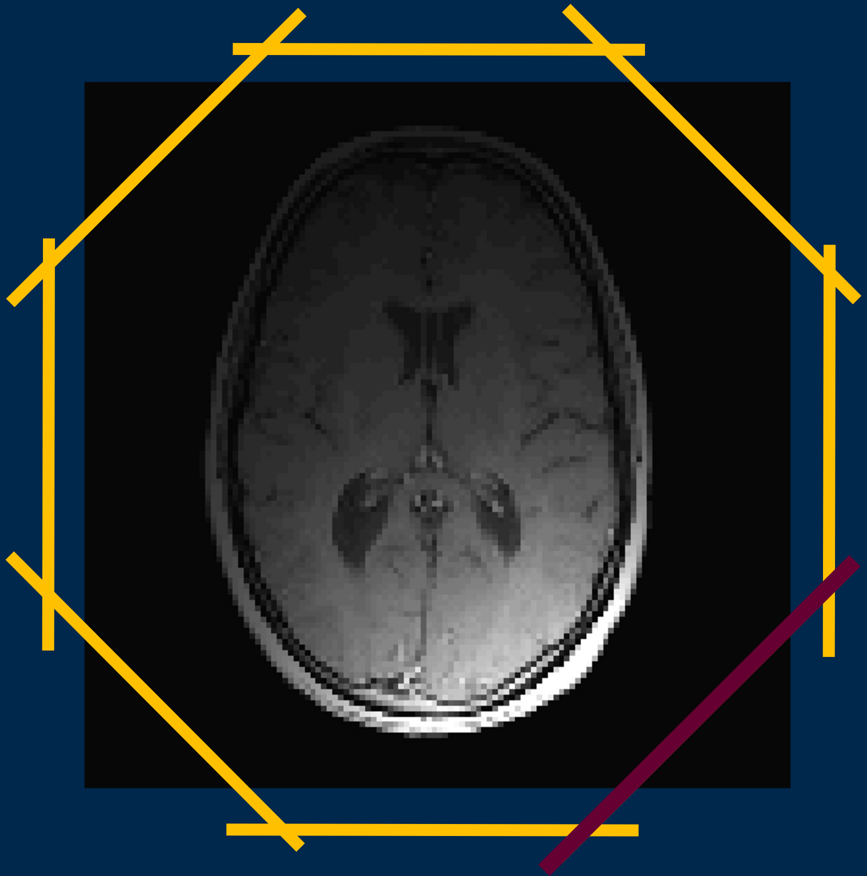
Array of coils provides additional information





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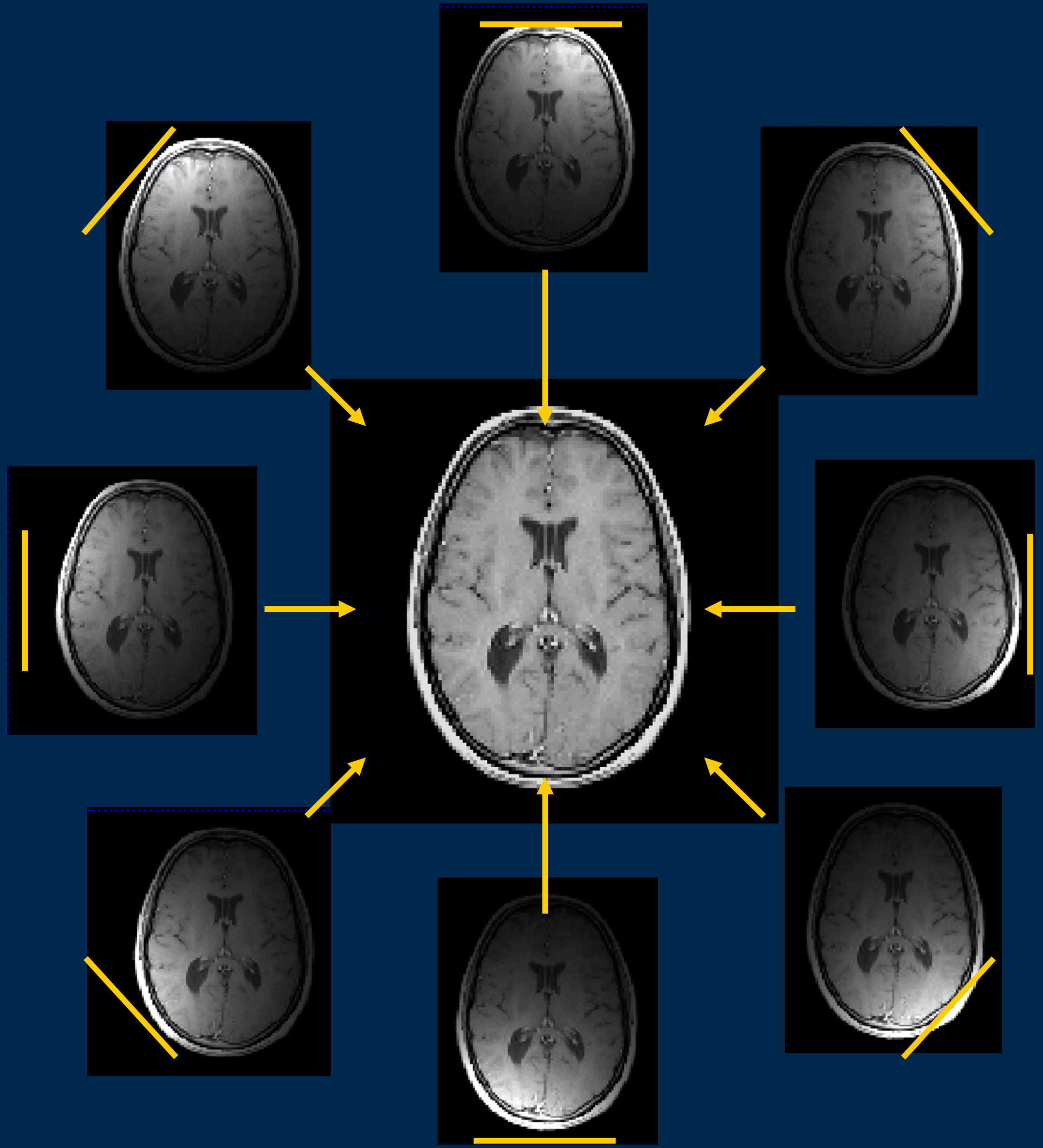
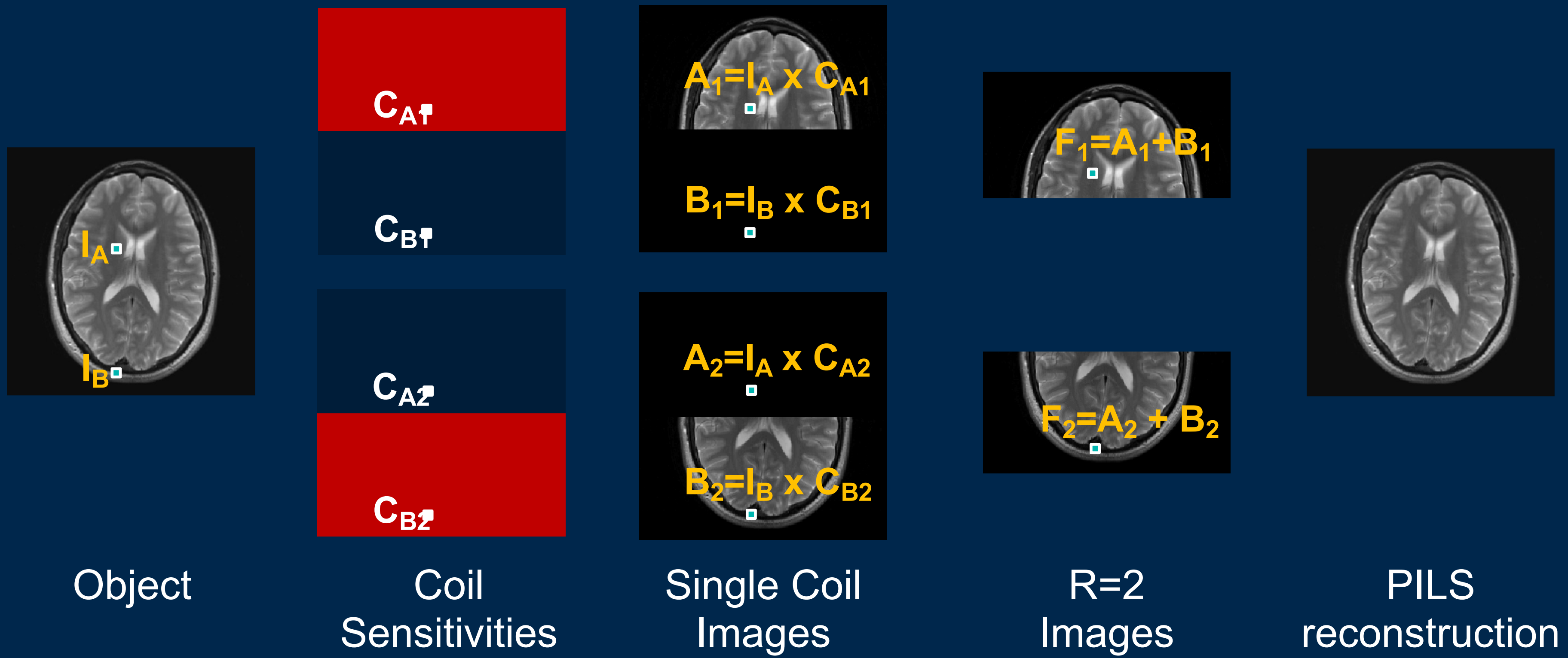
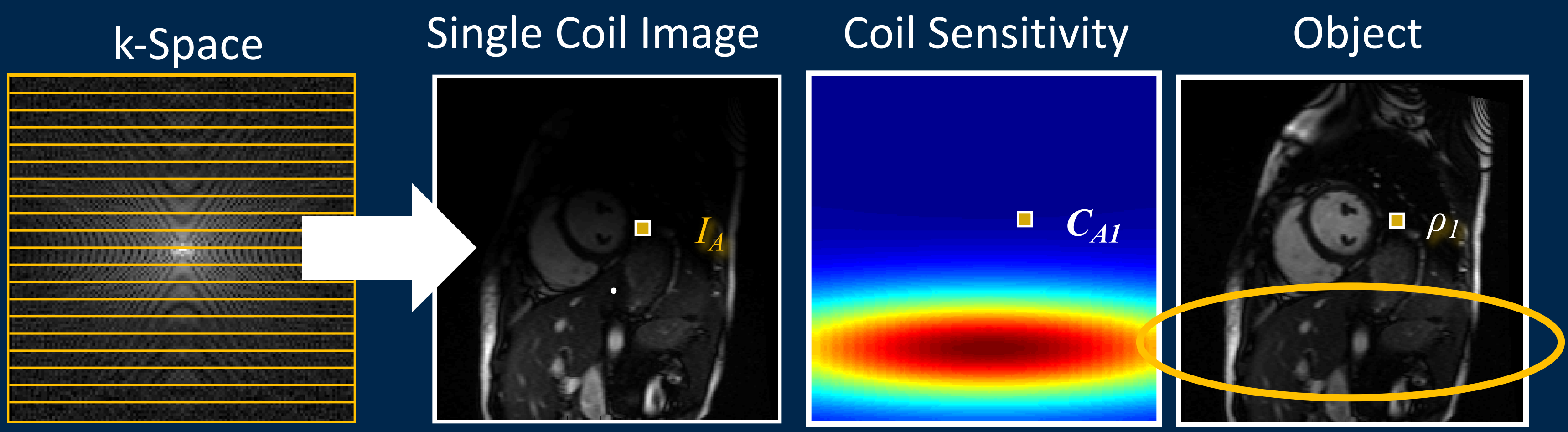
Acquisition using multiple receiver coils



Easy Parallel Imaging (PILS)



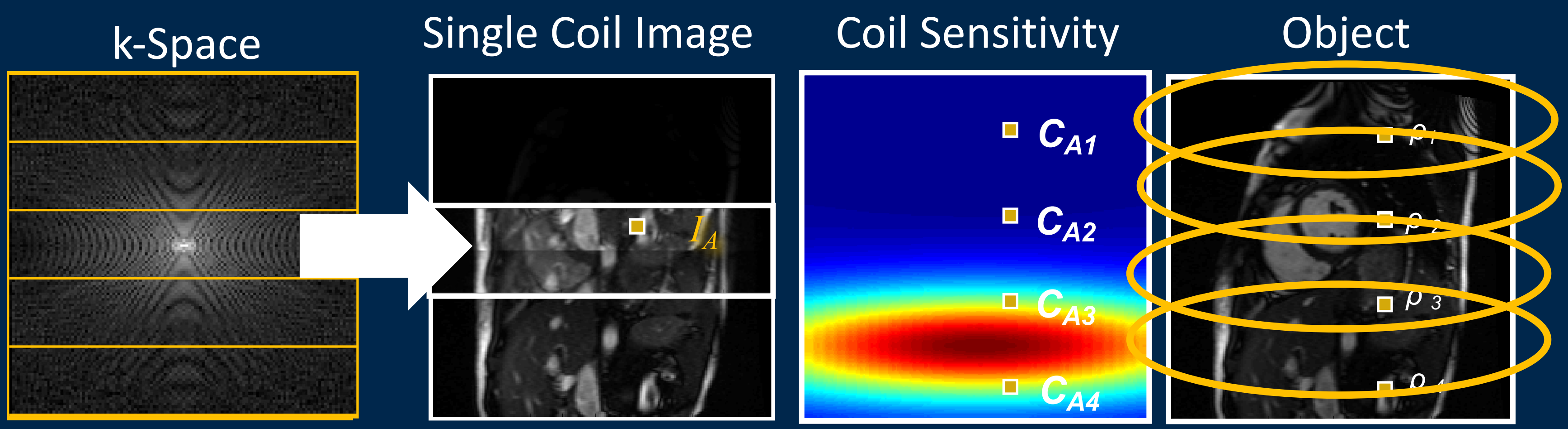
SENSitivity Encoding (SENSE)



$$I_A = C_{A1} \cdot \rho_1$$

Pruessmann KP, et al. Magn Reson Med 1999:42:952-962.

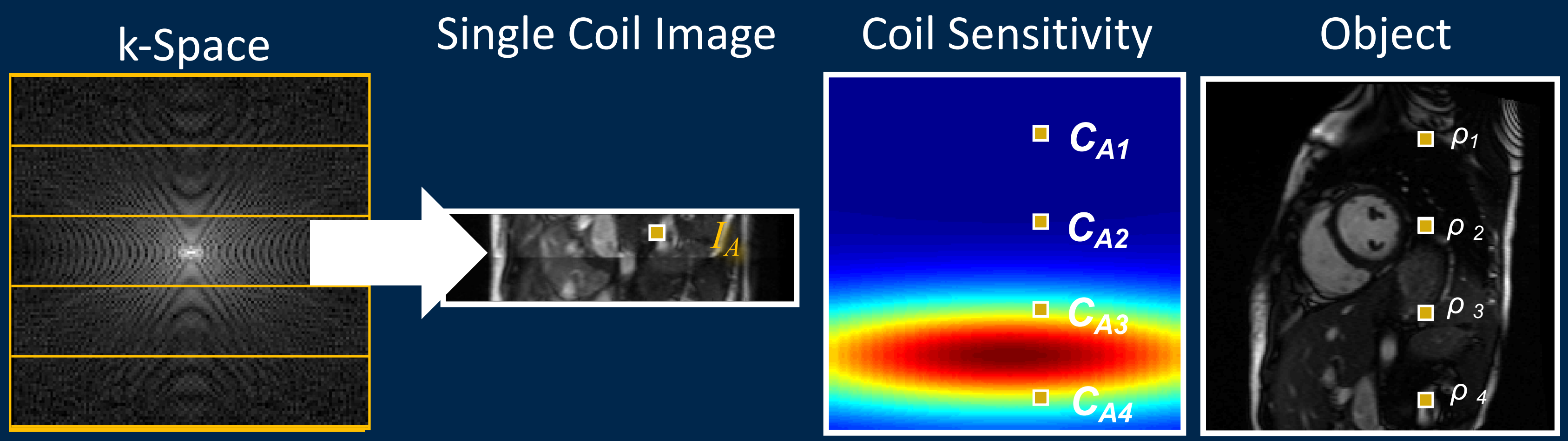
SENSitivity Encoding (SENSE)



$$I_A = C_{A1} \cdot \rho_1 + C_{A2} \cdot \rho_2 + C_{A3} \cdot \rho_3 + C_{A4} \cdot \rho_4$$
$$I_B = C_{B1} \cdot \rho_1 + C_{B2} \cdot \rho_2 + C_{B3} \cdot \rho_3 + C_{B4} \cdot \rho_4$$
$$I_C = C_{C1} \cdot \rho_1 + C_{C2} \cdot \rho_2 + C_{C3} \cdot \rho_3 + C_{C4} \cdot \rho_4$$
$$I_D = C_{D1} \cdot \rho_1 + C_{D2} \cdot \rho_2 + C_{D3} \cdot \rho_3 + C_{D4} \cdot \rho_4$$

Pruessmann KP, et al. Magn Reson Med 1999:42:952-962.

SENSitivity Encoding (SENSE)

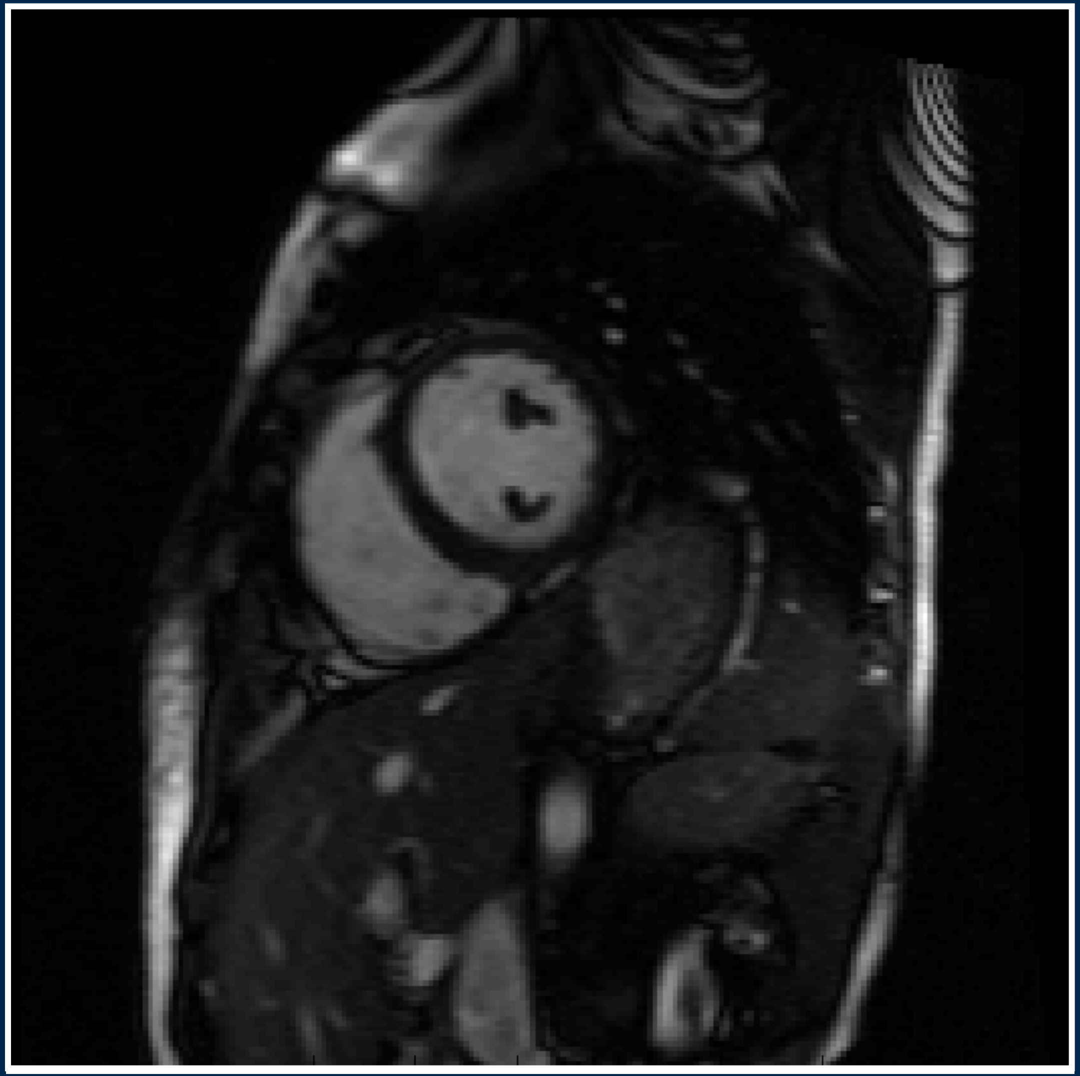


$$\vec{I} = \hat{C} \cdot \vec{\rho}$$

$$\hat{C}^{-1} \cdot \vec{I} = \vec{\rho}$$

Pruessmann KP, et al. Magn Reson Med 1999:42:952-962.

SENSitivity Encoding (SENSE)



$$\hat{C}^{-1} \cdot \vec{I} = \vec{\rho}$$

Parallel Imaging

- In the lecturer's opinion, parallel imaging is very useful for structural imaging, but only moderately useful for fMRI

- Pros:
  - Higher spatial resolution
  - Some reduction of distortions

- Cons:
  - Reduced SNR
  - Minimal increase in temporal resolution (in fMRI)

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Simultaneous Multi-Slice Imaging

- Basic Idea: Use coil localization information to separate two or more overlapping slices
- Similar to parallel imaging
- References:
  - Larkman, et al. *J. Magn. Reson. Imaging* 2001; **13**: 313-317.
  - Moeller, et al. *Magn. Reson. Med.* 2009; **63**:1144–1153.
  - Setsompop, et al. *Magn. Reson. Med.* 2012; **67**:1210–1224.

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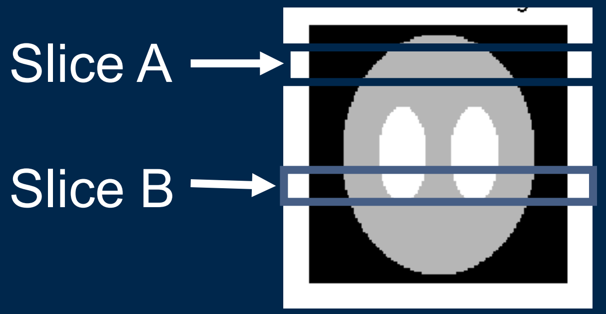
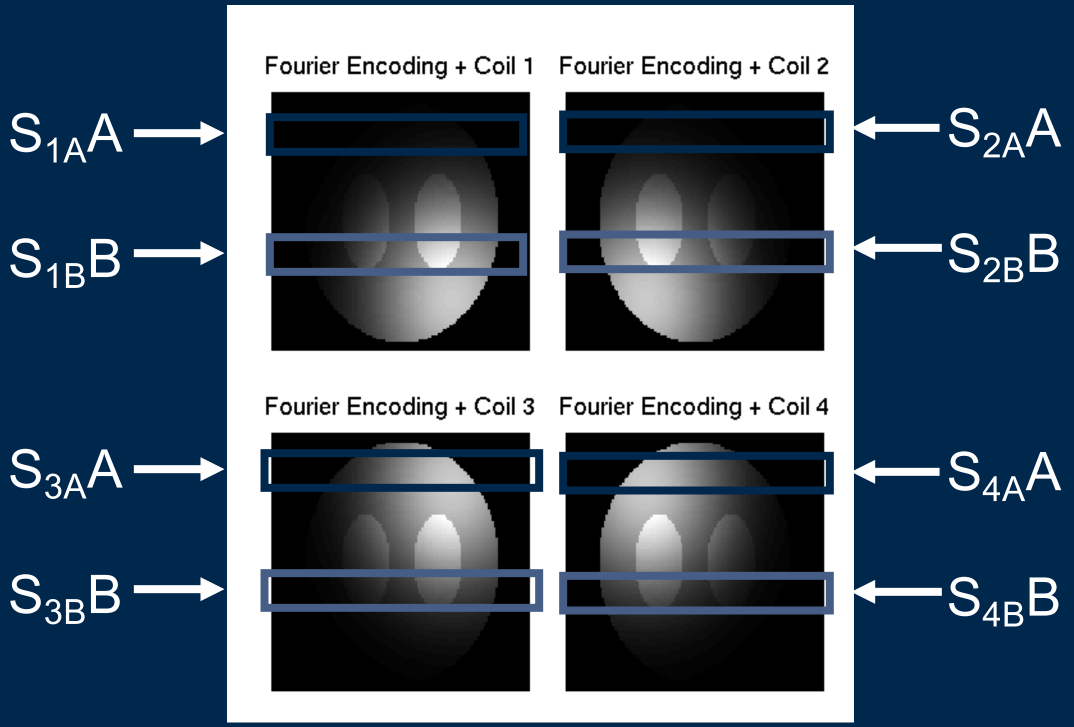
Simultaneous Multi-Slice Imaging – An Example

2 Slices
Volume Coil



2 Slices
Array Coil



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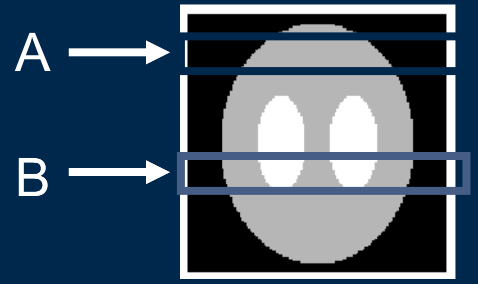
Simultaneous Multi-Slice Imaging – An Example

- Same basis equations as parallel imaging
- Operates on slices that overlap instead of aliases of a single slice
- Can be combined with parallel imaging

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} S_{1A} & S_{1B} \\ S_{2A} & S_{2B} \\ S_{3A} & S_{3B} \\ S_{4A} & S_{4B} \end{bmatrix} \begin{bmatrix} A \\ B \end{bmatrix}$$



Simultaneous Multi-Slice Imaging

- Really quite useful for single shot imaging applications like fMRI and diffusion tensor imaging (DTI)

- Pros:
  - Increase in temporal resolution (2x-8x!)
  - Allows for thinner slices
  - Faster acquisition reduced effects of physio noise

- Cons:
  - Small increase in noise, artifact from imperfect decoding of slices

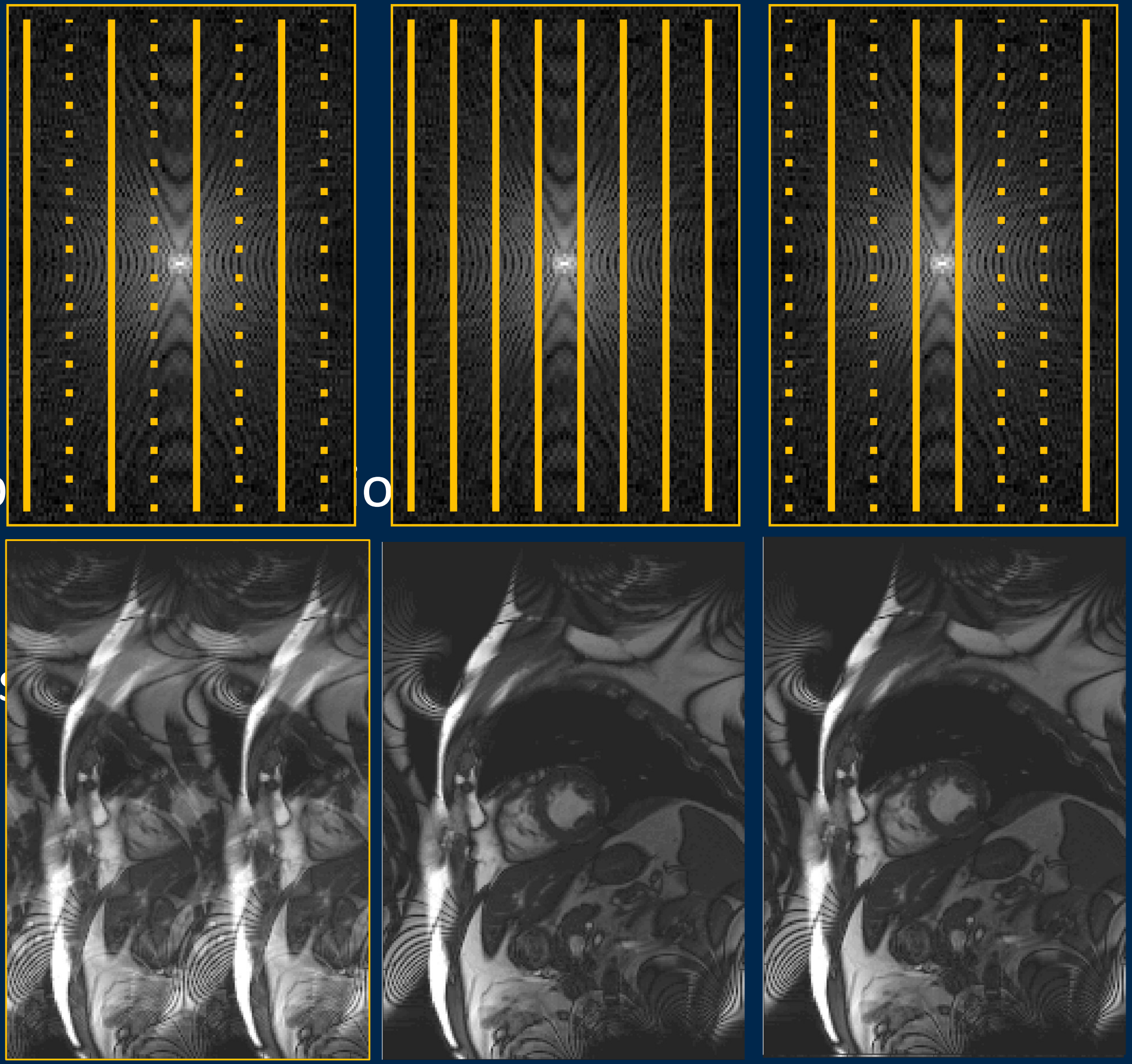
The Idea of Compressed Sensing

Rapidly collect undersampled data

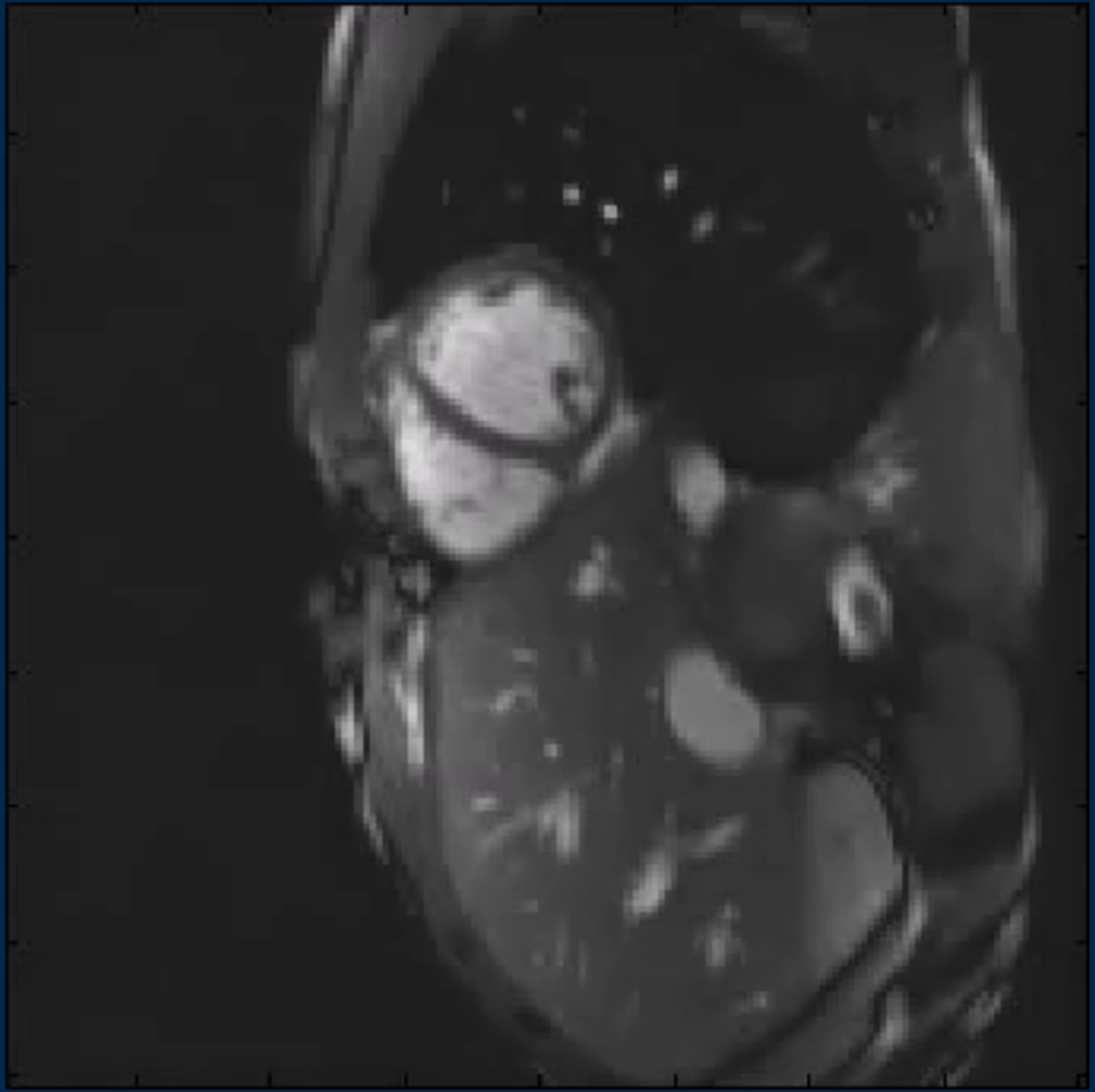
Aliasing artifacts look like noise

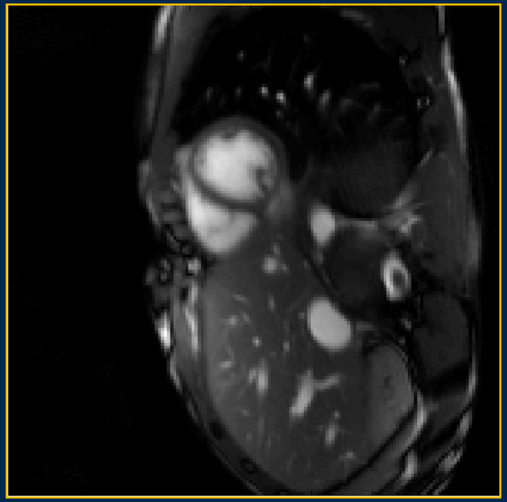
Separate “noise” from true signal using a p

Images should be “sparse” or trans



Sparse Images: Cardiac Imaging





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Sparse Images: Cardiac Imaging

Goal: Make image sparse + consistent with data

$$\text{minimize} \quad \|\Psi x\|_1$$
$$\text{s.t.} \quad \|Fx - y\|_2 \leq \varepsilon$$

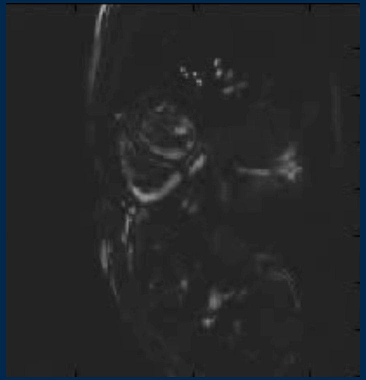
Sparsifying Transform

Image

Fourier Transform

k-Space Data

Find an image x that is:



1) Sparse in the transform domain (prior information)

2) And also consistent with the data that was collected

Lots of different sparsifying transforms, iterative techniques, ways to balance between data and a priori info, etc

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Compressed Sensing

- Jury still out for utility in fMRI

- Pros:
  - Increase in temporal resolution (2x-8x!)
  - Faster acquisition reduced effects of physio noise

- Cons:
  - Loss of small/low SNR features

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Summary

- Fast imaging is essential in MRI
- Skipping lines of k-space one way to speed up data collection
- Aliasing artifacts must be removed
- Parallel Imaging, Simultaneous Multi-Slice Imaging, Compressed Sensing, etc.…
- Active area of research

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