MRI Physics:

Resolution, FoV, Spatial Encoding

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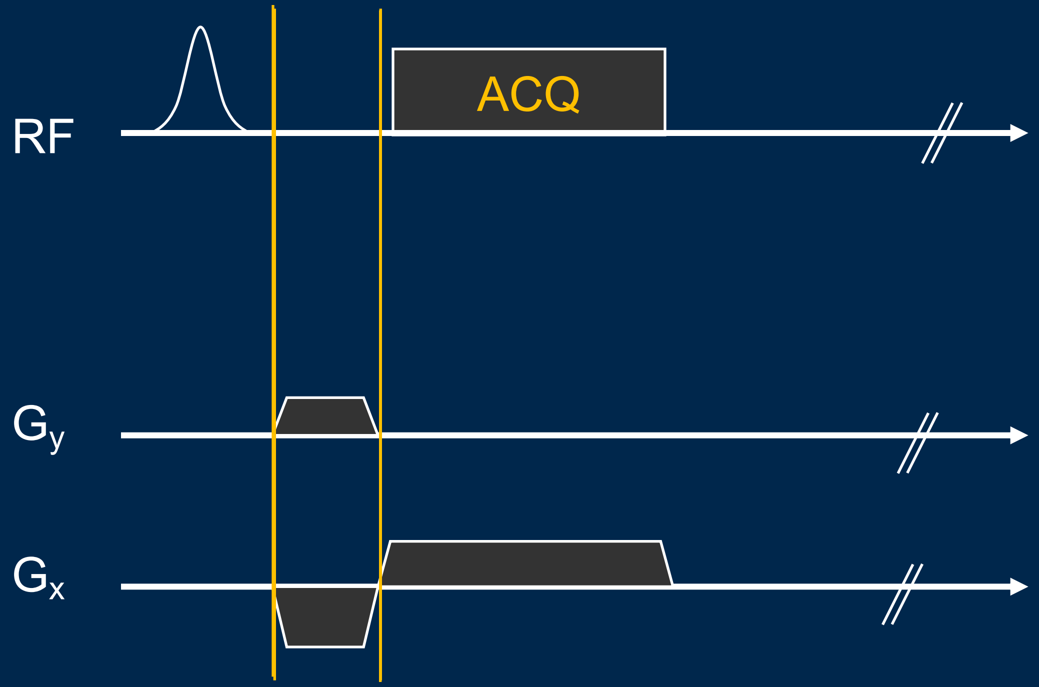
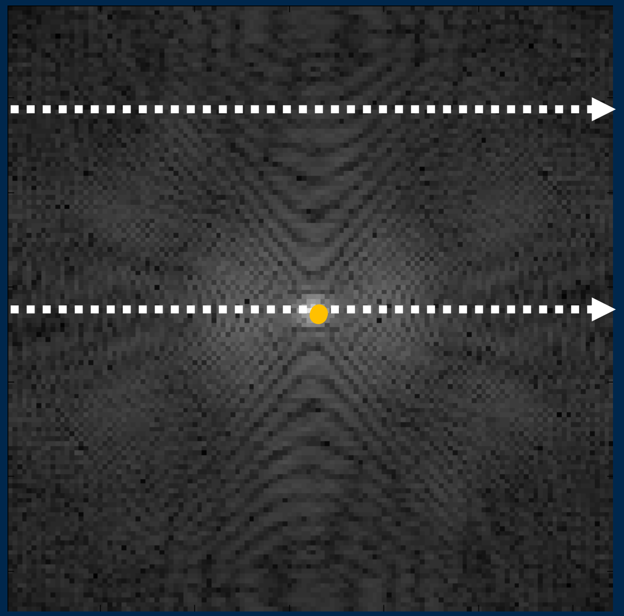
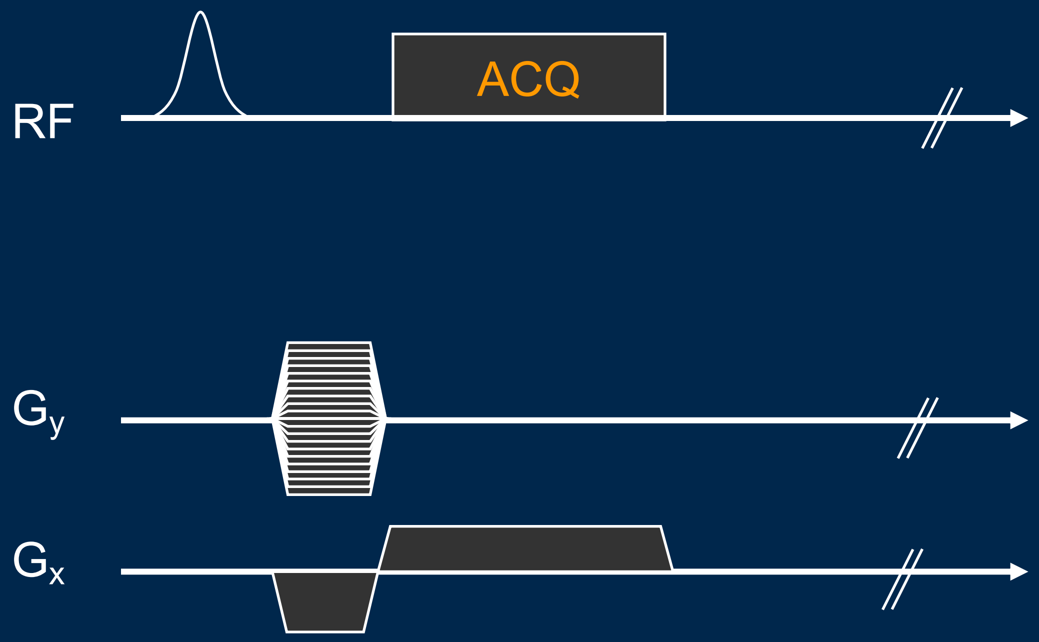
Co-Director of MIITT

Traversal of k-Space with Gradients





Traversal of K-Space with Gradients



k-space Properties

Full K-space

Center Only

Outside Only

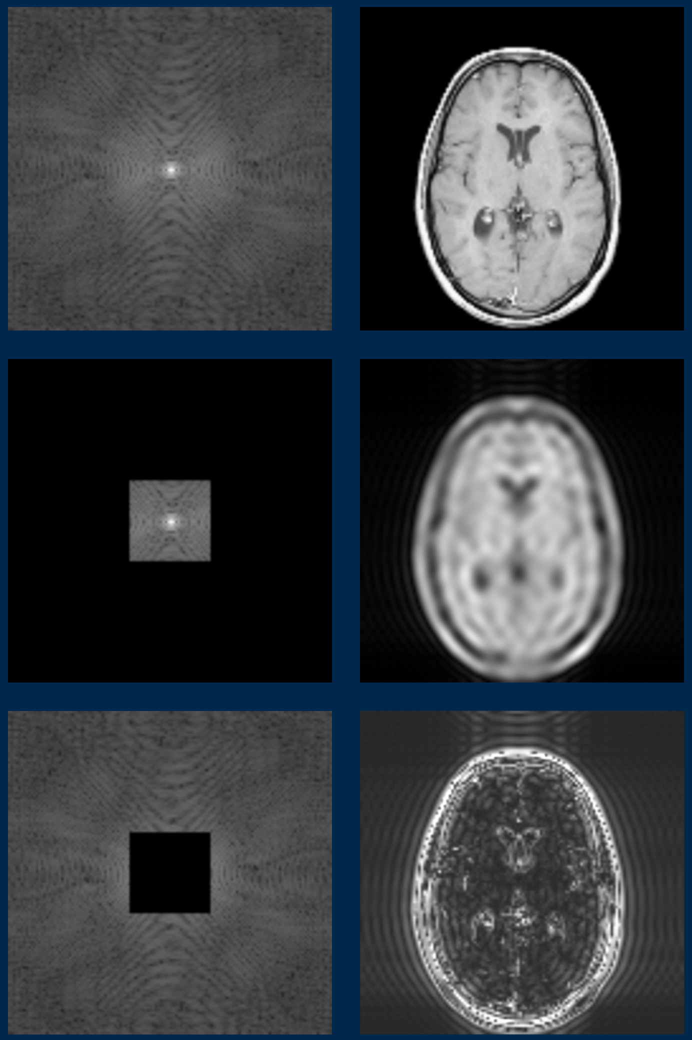
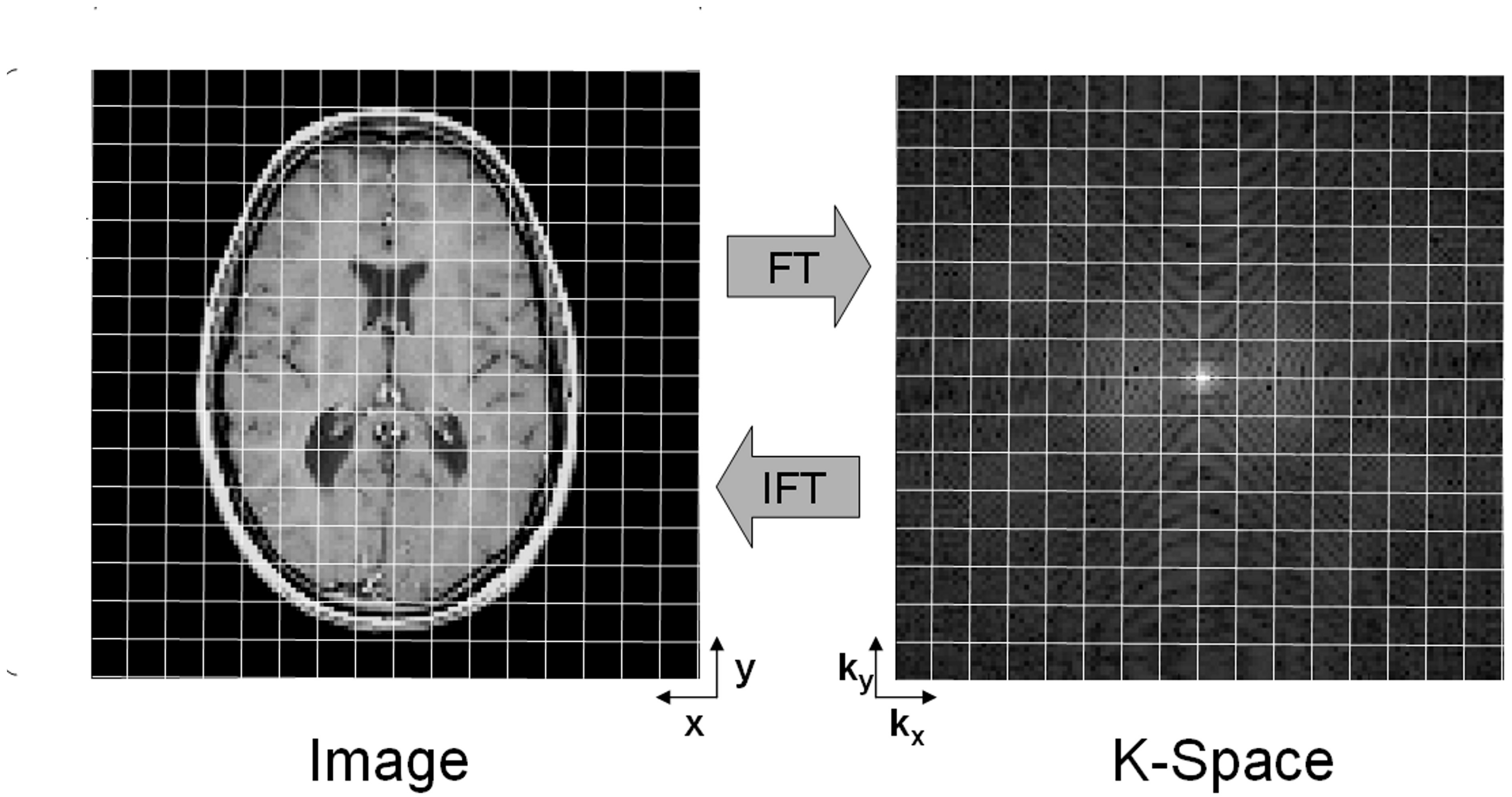


Image Contrast

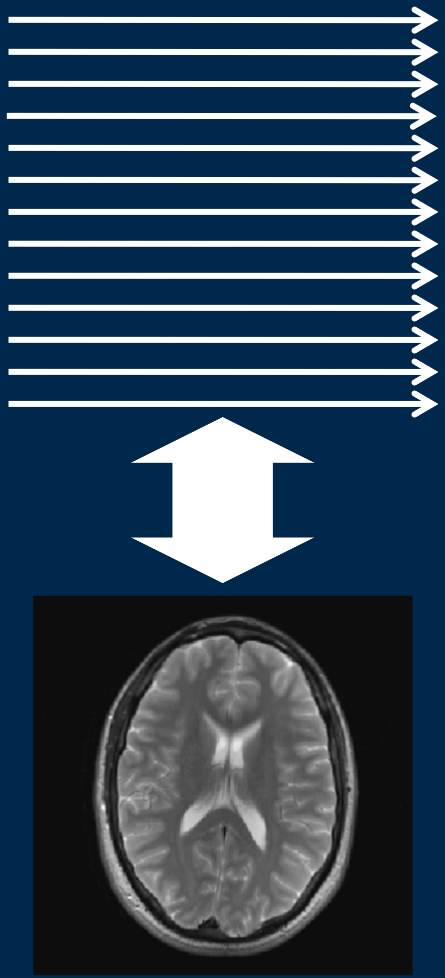
Image Edges

k-space Properties



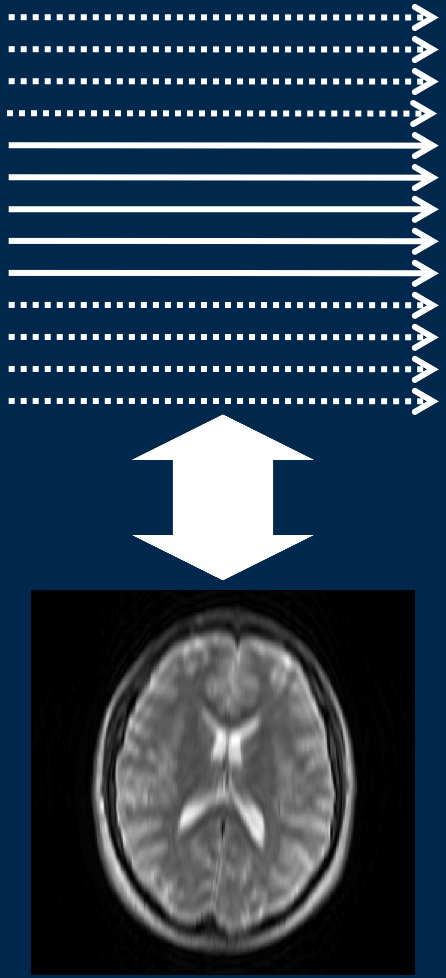
k-space Properties

Big $k_{y,max}$
Small Δk_y spacing



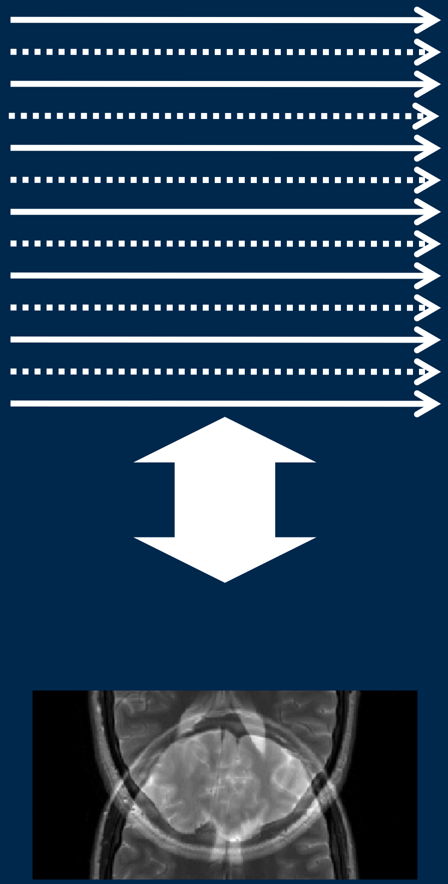
Full FoV
Full Resolution

Small $k_{y,max}$
Small Δk_y spacing



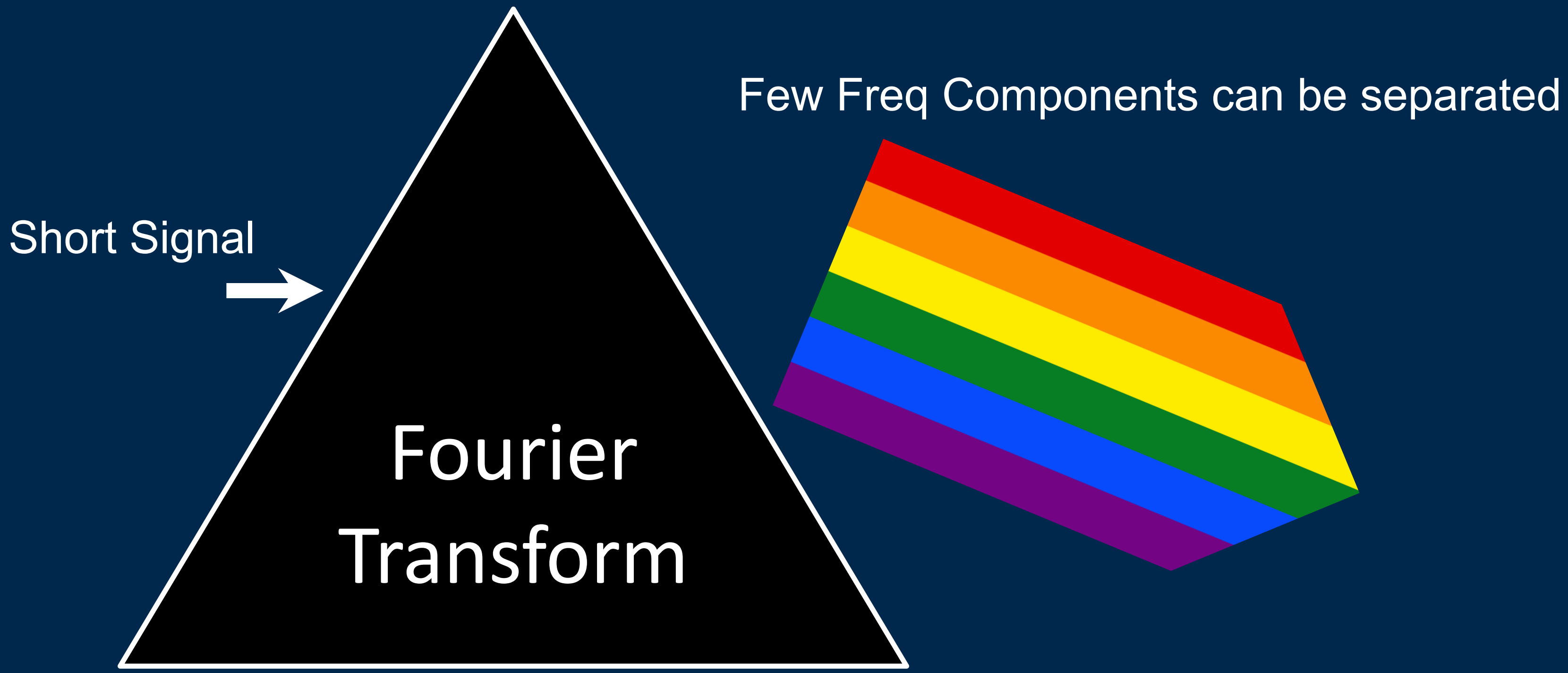
Full FoV
Lower Resolution

Big $k_{y,max}$
Big Δk_y spacing

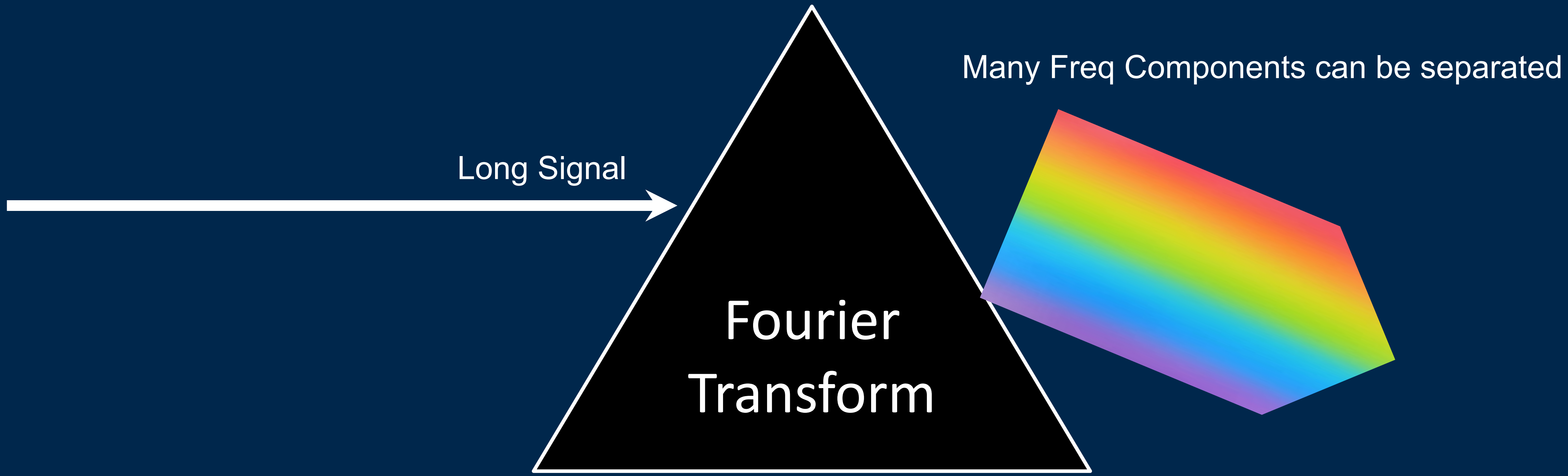


Smaller FoV
Full Resolution

K_{max} → Signal Length → Spatial Resolution



K_{max} → Signal Length → Spatial Resolution



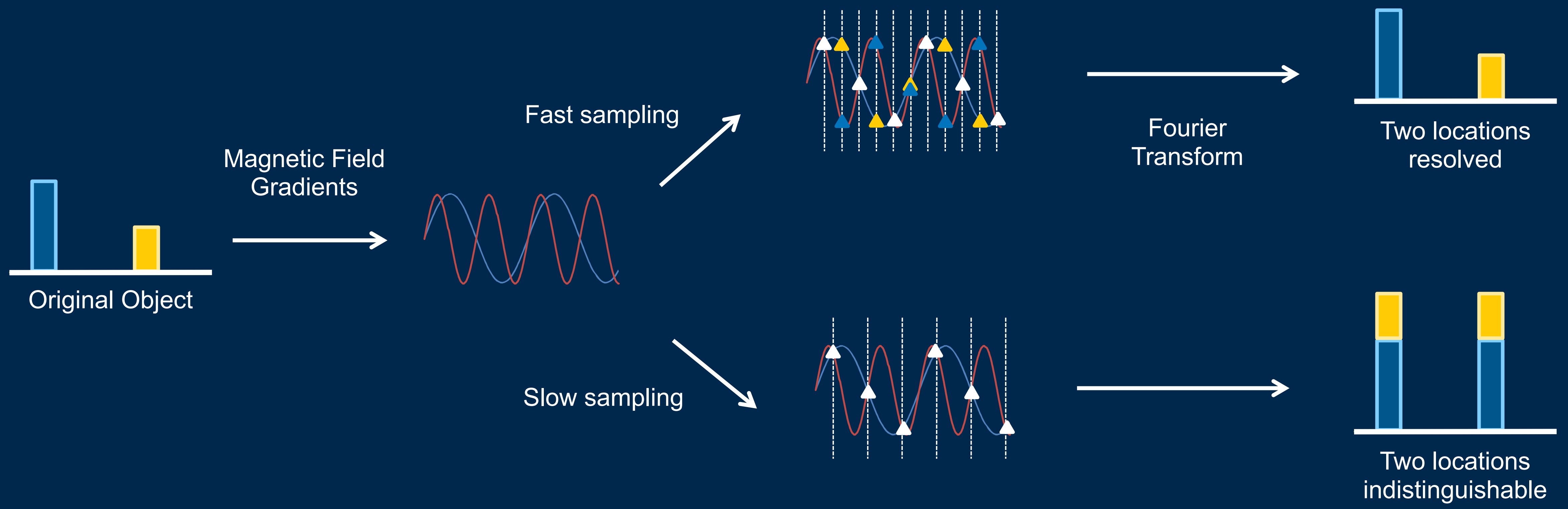
https://www.youtube.com/watch?v=DpeLjY5NGu4

3:26

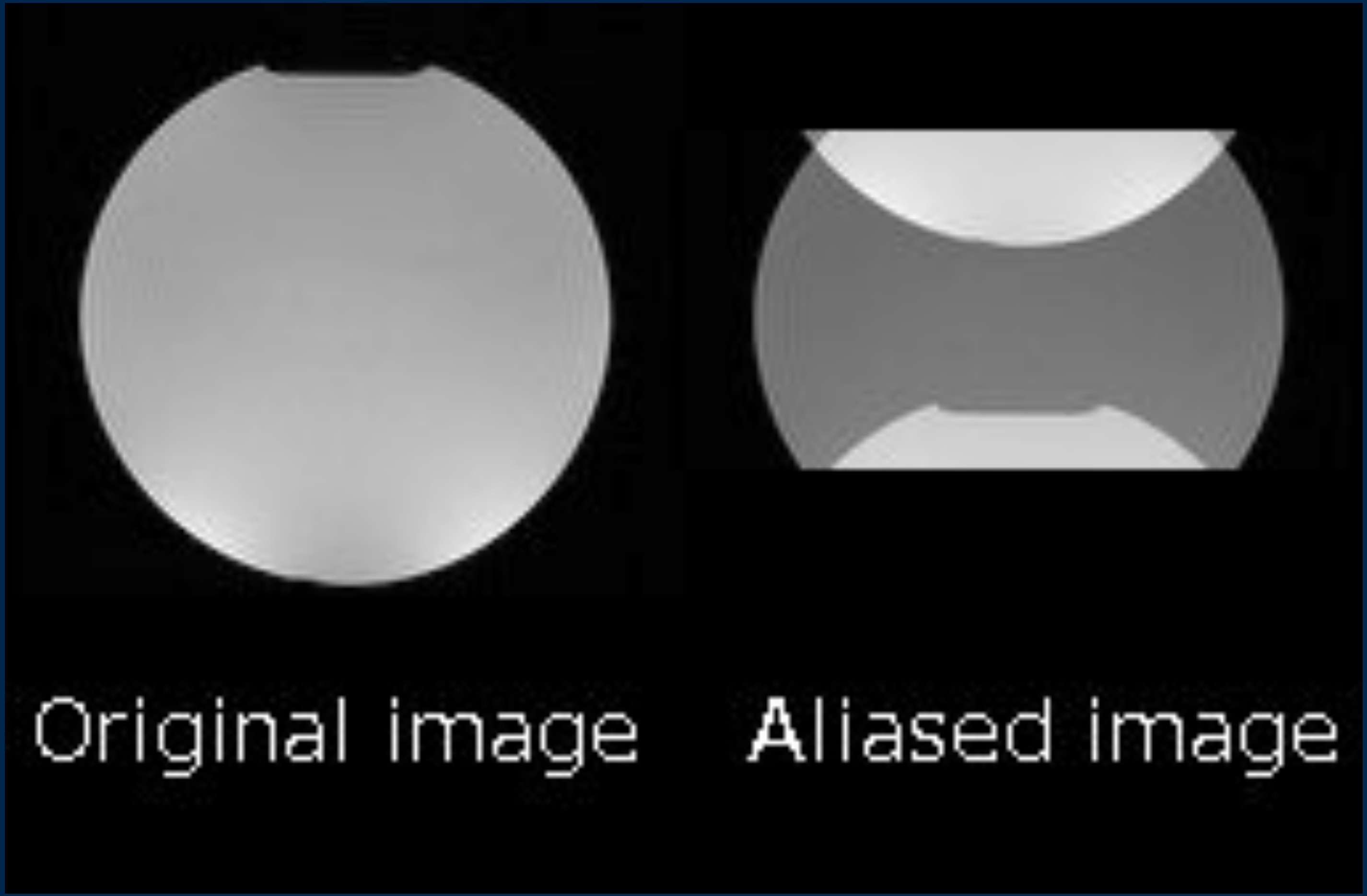
https://www.youtube.com/watch?v=jWIcVP6GRfw

https://www.youtube.com/watch?v=Nyf79SI0U9Q

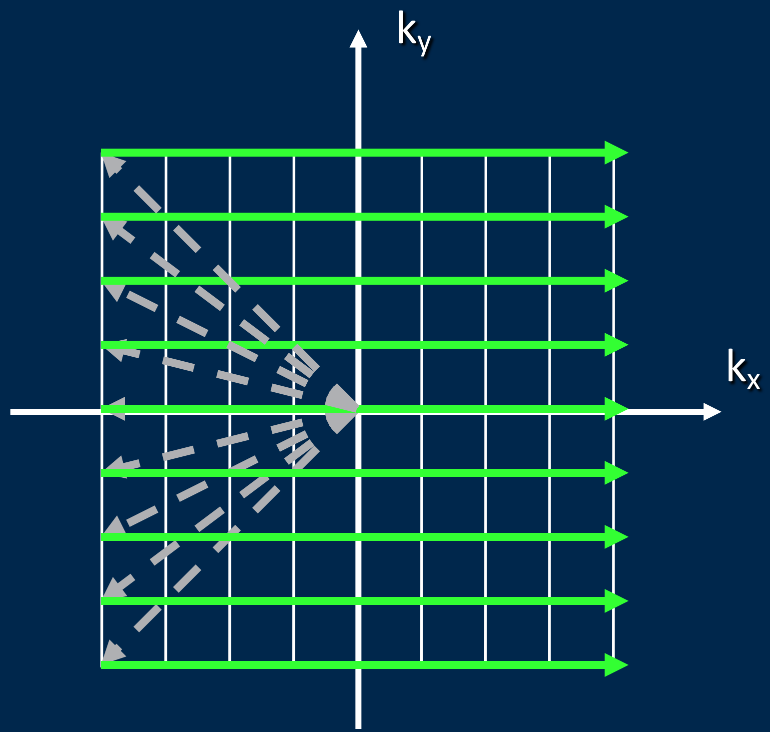
Δk → Line Spacing→ Field-of-View



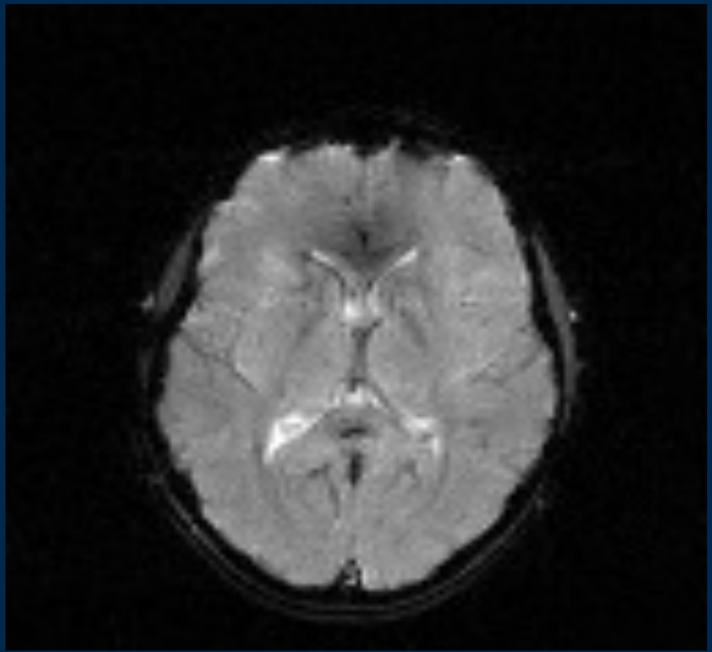
Aliasing Example



Conventional (Spin-Warp) Imaging

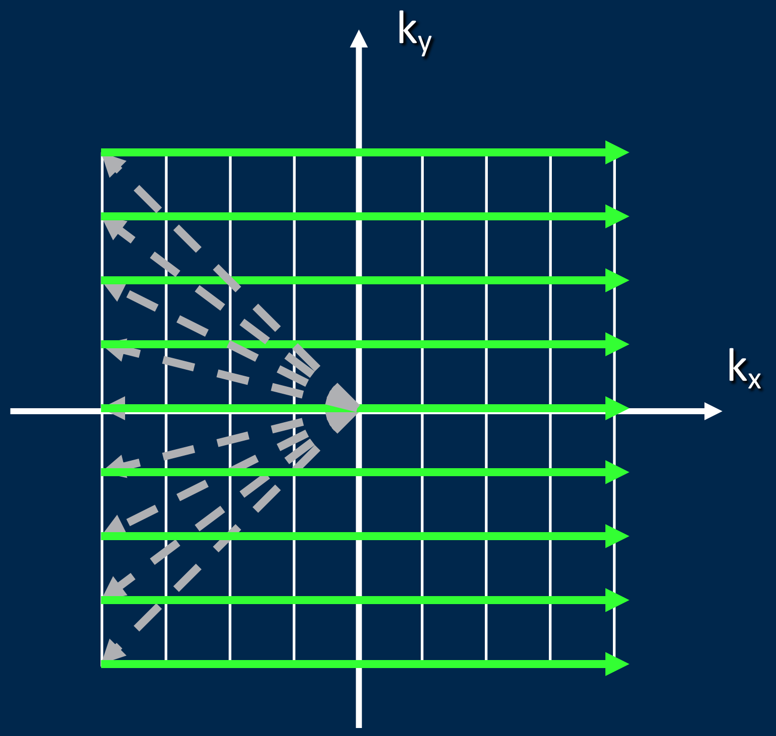


One Line at a Time



128x128 FLASH/SPGR
TR/TE/flip = 50ms/30ms/30º
6.4 sec for single slice
for fMRI

Conventional (Spin-Warp) Imaging



One Line at a Time

- Typically matrix sizes for fMRI
  - 128x64, 128x128
- Acquisition rates
  - 3-10 sec/image
  - 1-4 slices
- Usually best for structural imaging

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Fundamental Imaging Time

$$Time = T_R \cdot N \cdot NA$$

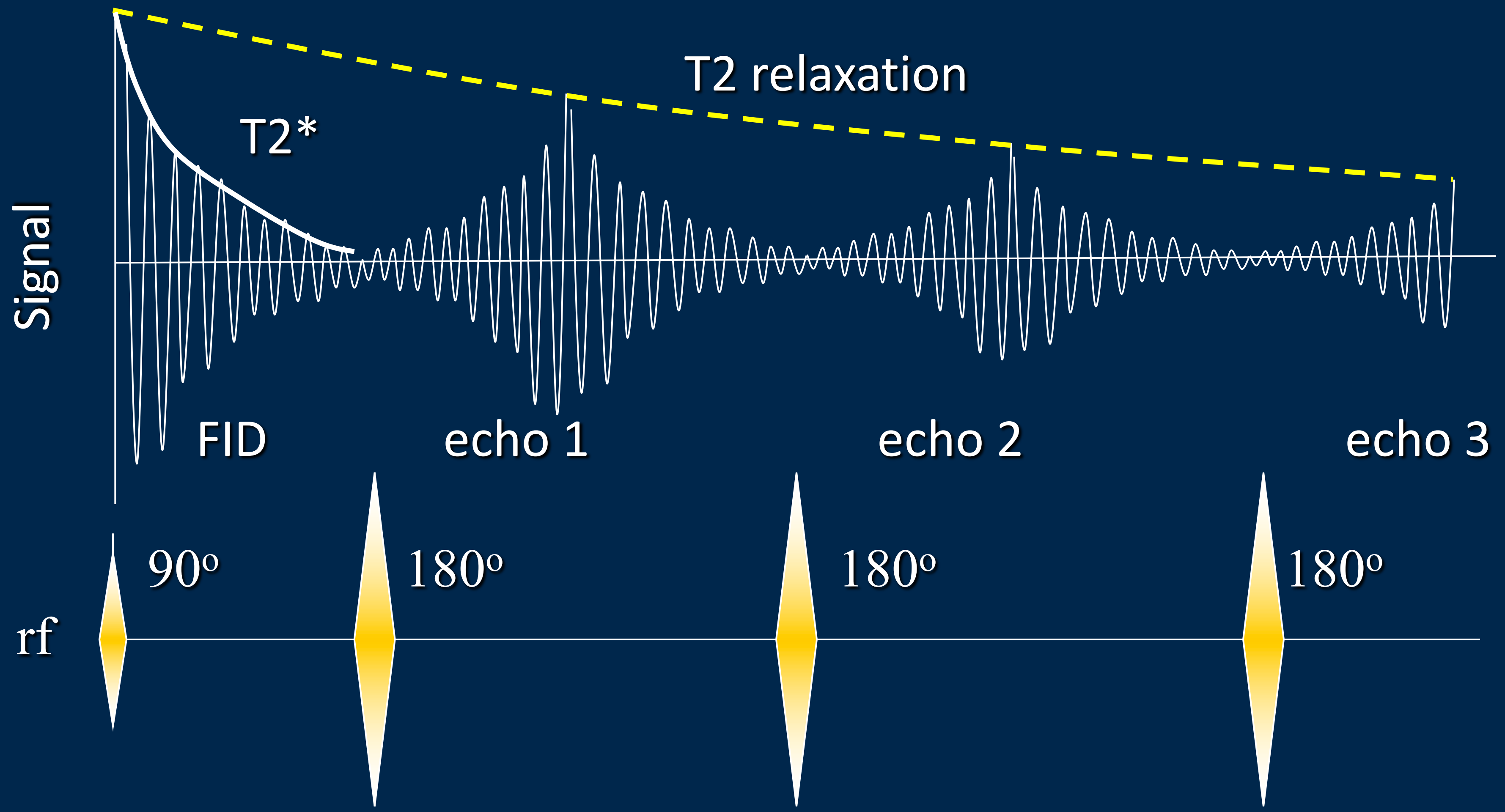
- T_R: Amount of time needed to acquire one line (3 ms – 5 sec)
- N_{PE}: Number of lines to acquire (32 – 512)
- NA: Averages of each line (1 - ∞)

SINGLE SHOT IMAGING

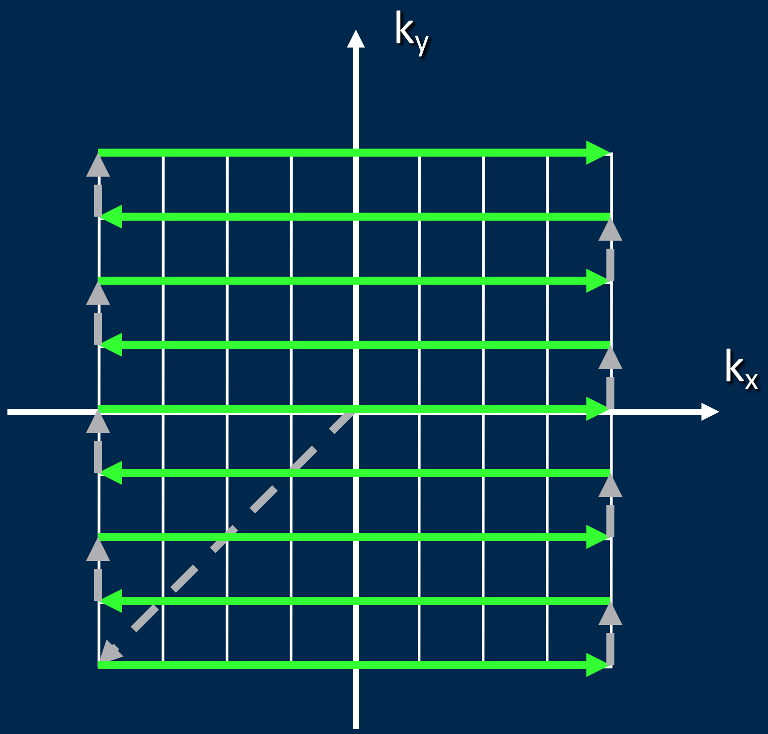
T2 Relaxation

Additional RF pulses to undo T2* factors

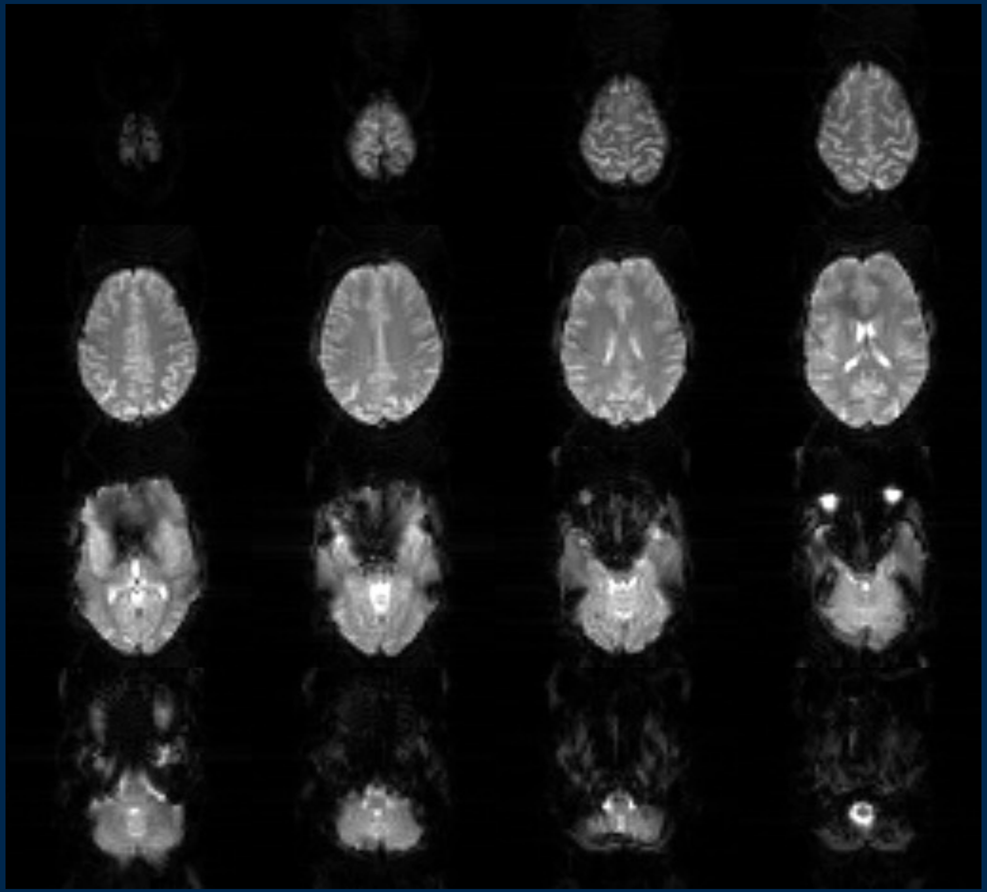
$\Rightarrow$ Multi Spin Echo (MSE)



Echo Planar Imaging (EPI)



Zig-Zag Pattern



Single-shot EPI, TE = 40 ms, TR = 2 s, 20 slices

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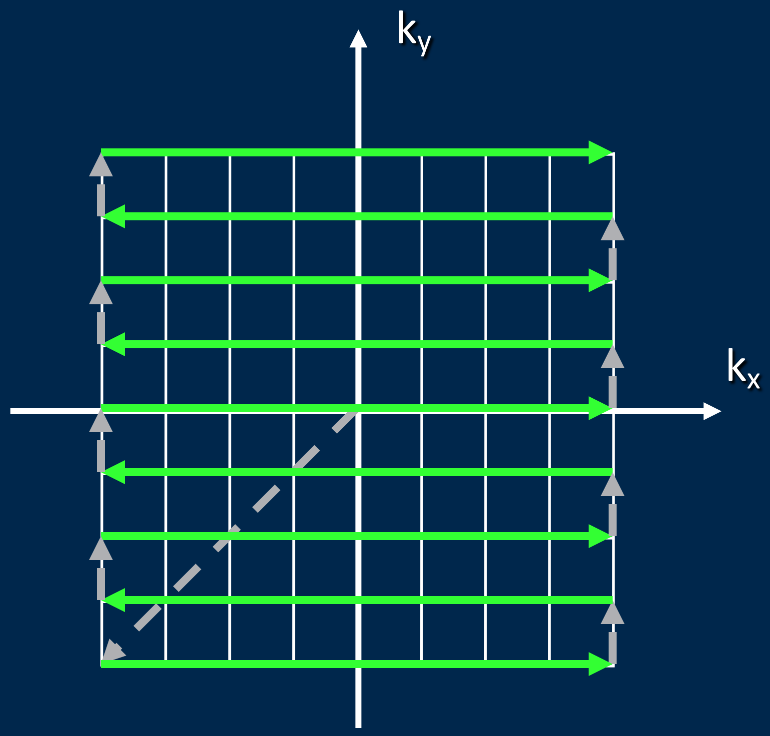
Echo Planar Imaging (EPI)



Zig-Zag Pattern

- Single-shot acquisition
- Typically matrix sizes for fMRI
  - 64x64, 96x96
  - 128x128 interleaved
- Acquisition rates
  - TR = 1-2 sec
  - 20-30 slices
- Suffers some artifacts
  - Distortion, ghosts

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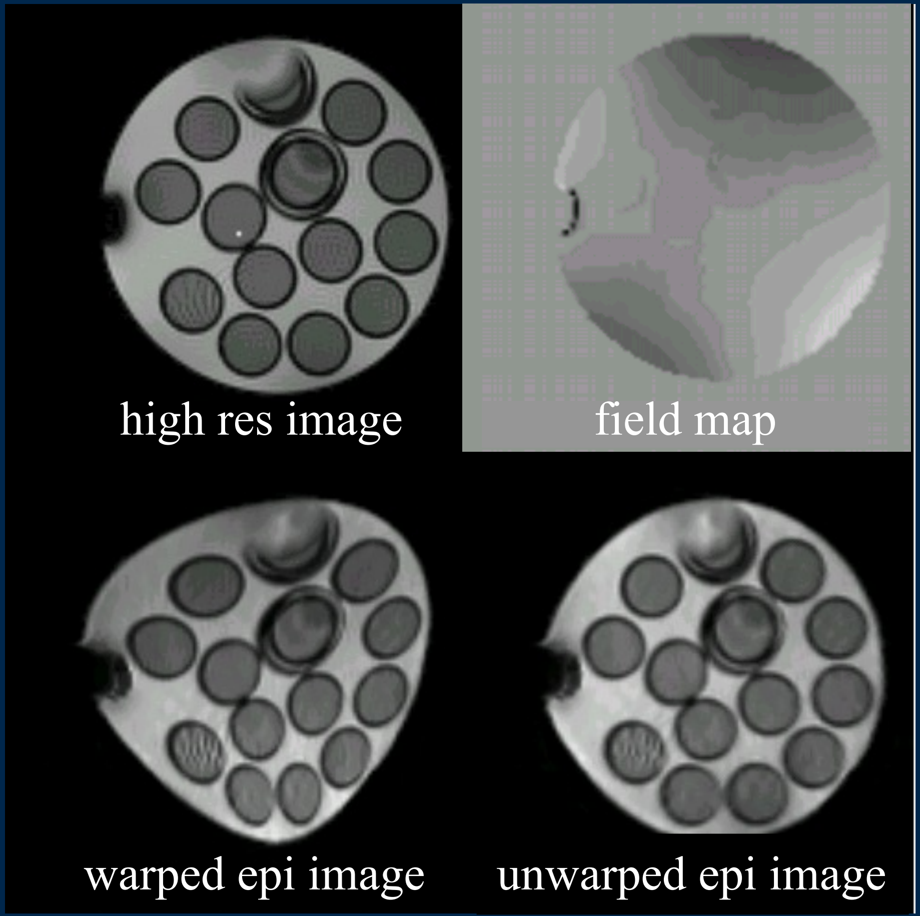
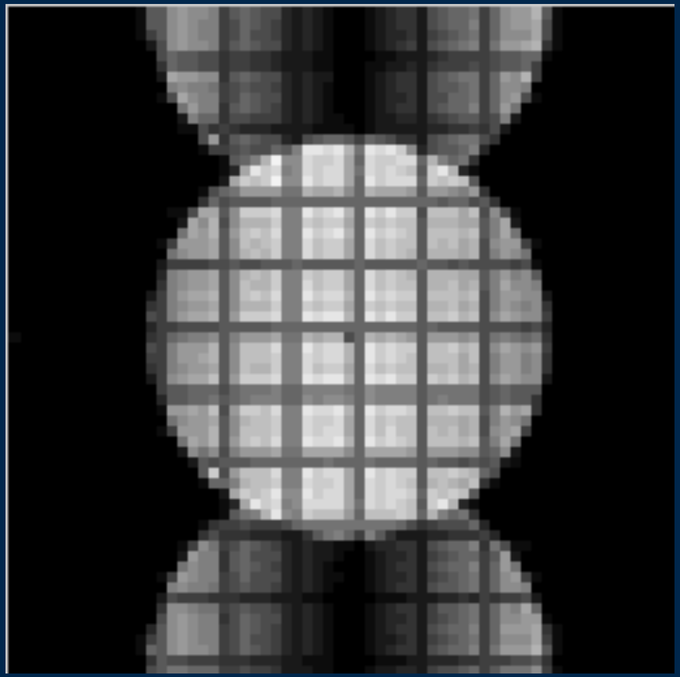
EPI Geometric Distortions

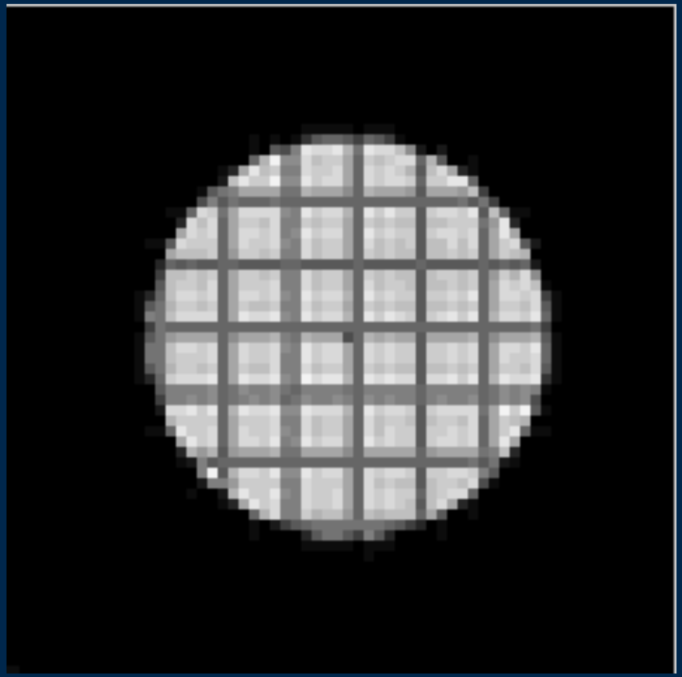


Jezzard and Balaban, MRM 34:65-73 1995

Courtesy of P. Jezzard

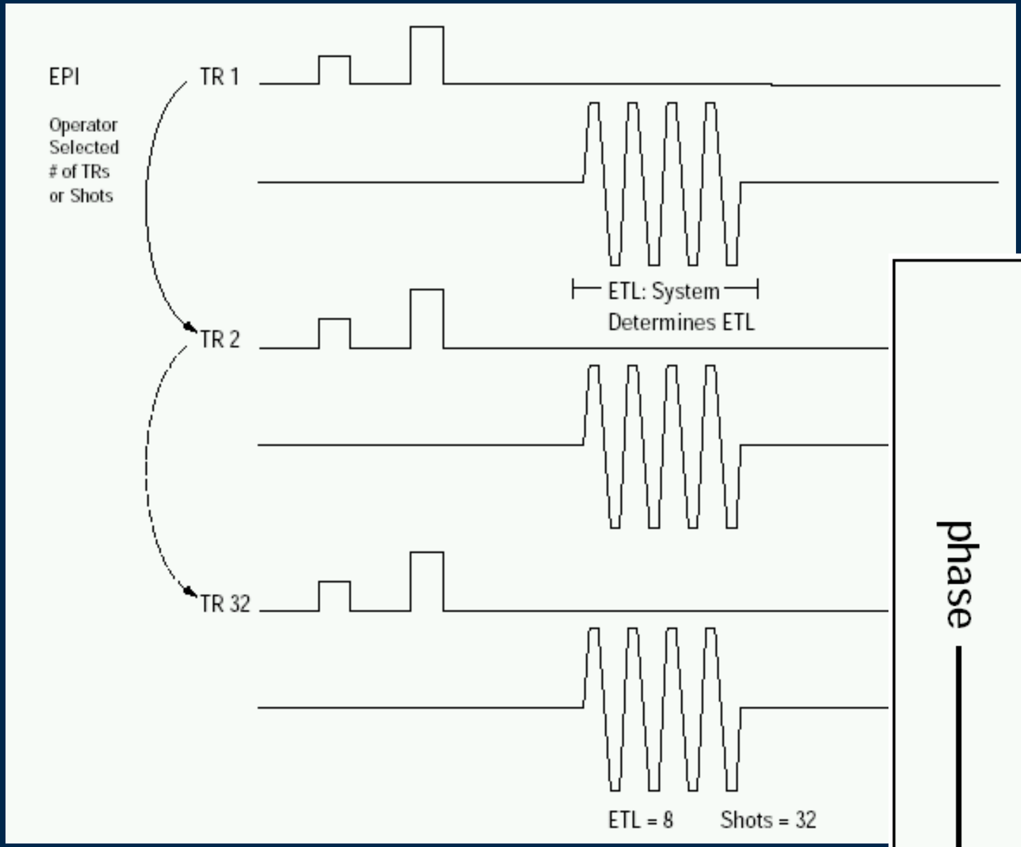
EPI Nyquist Ghost

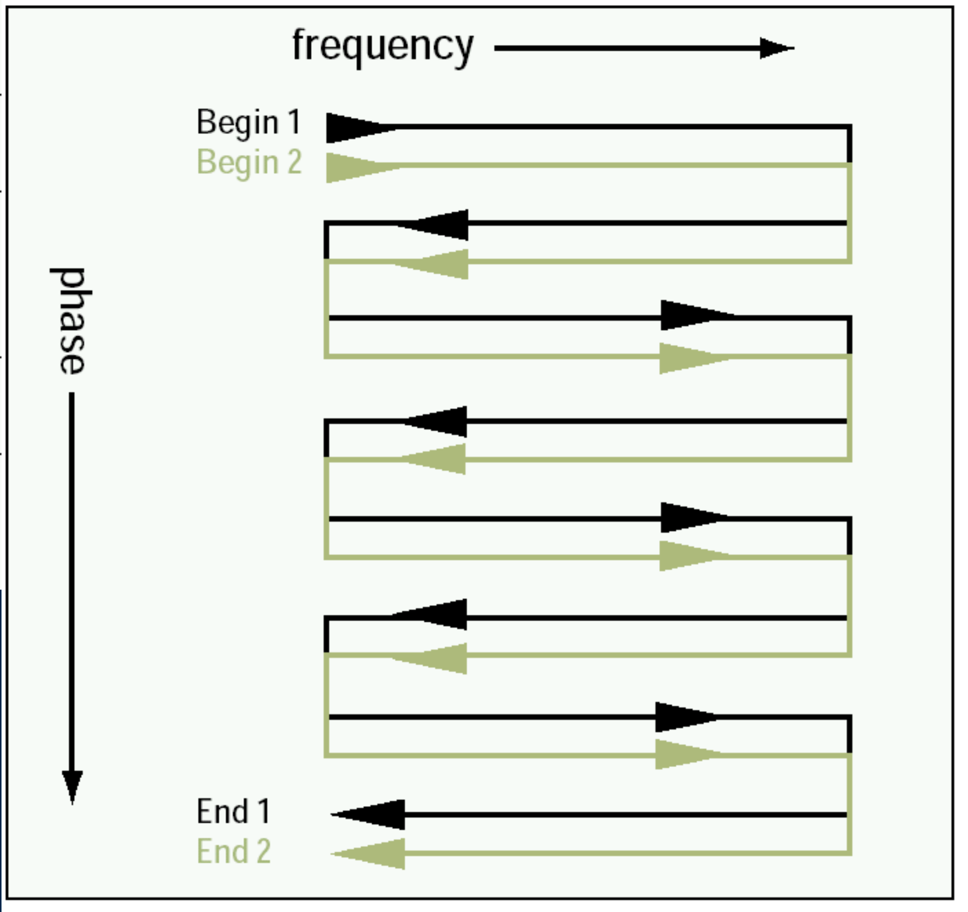




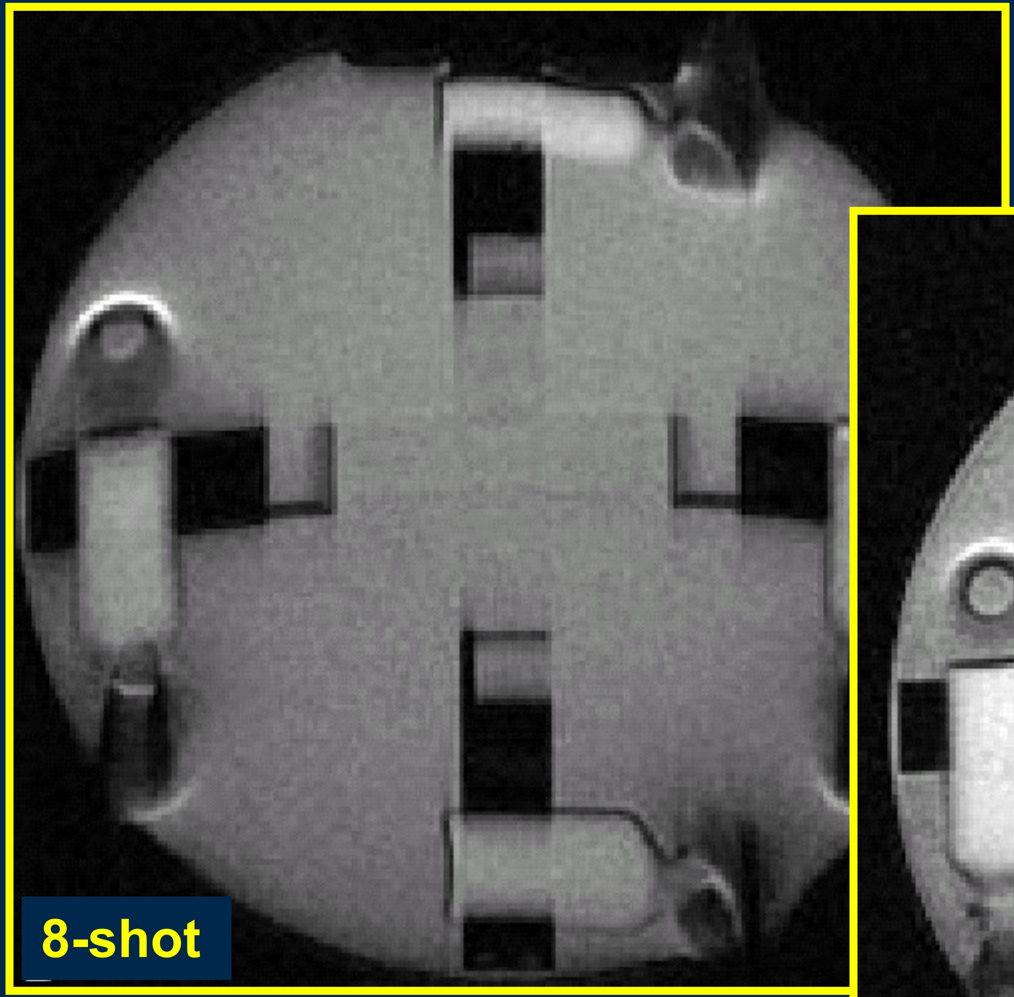
Courtesy of P. Jezzard

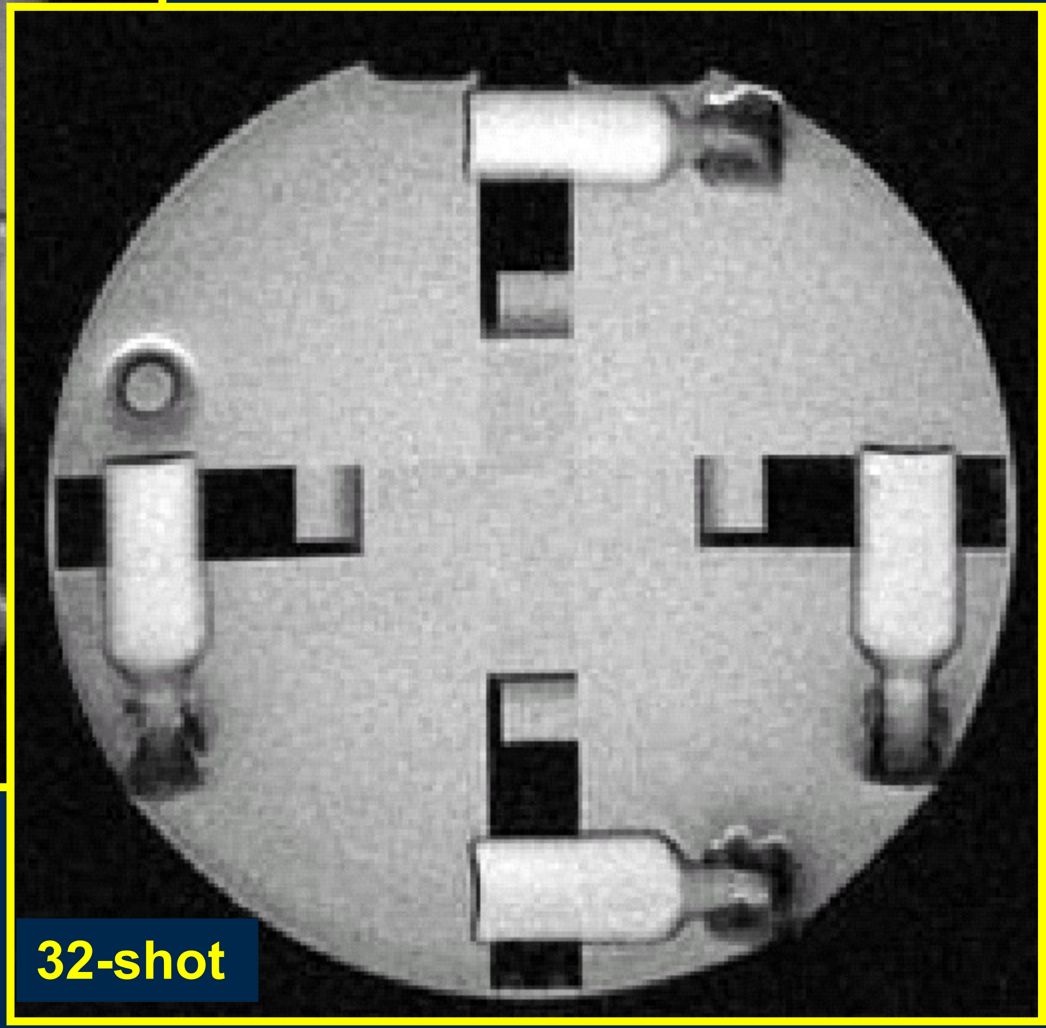
2D Echo Planar Imaging (EPI) → "Multi-Shot"





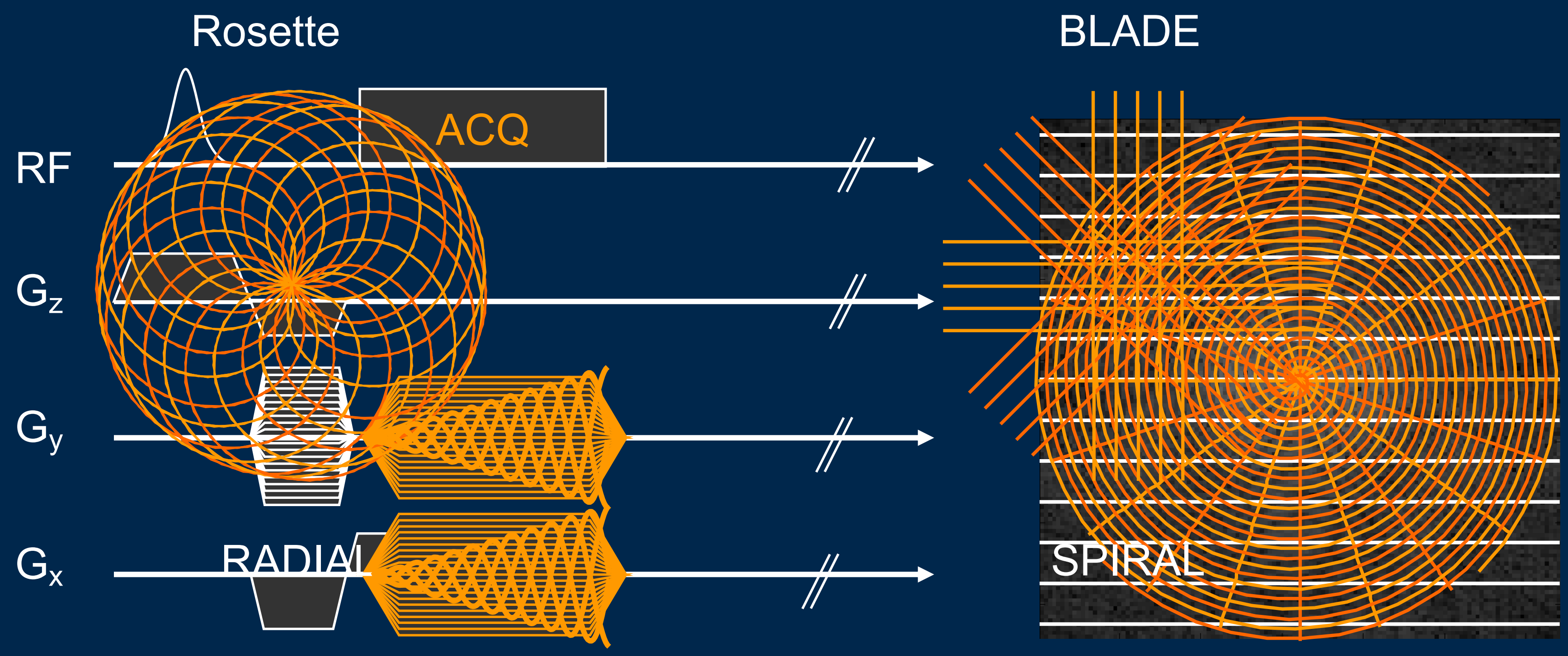
Multi - Shot EPI: Increase #-shots to reduce geometric / signal distortions, but scans are longer





Non-Cartesian Imaging

Cartesian Imaging



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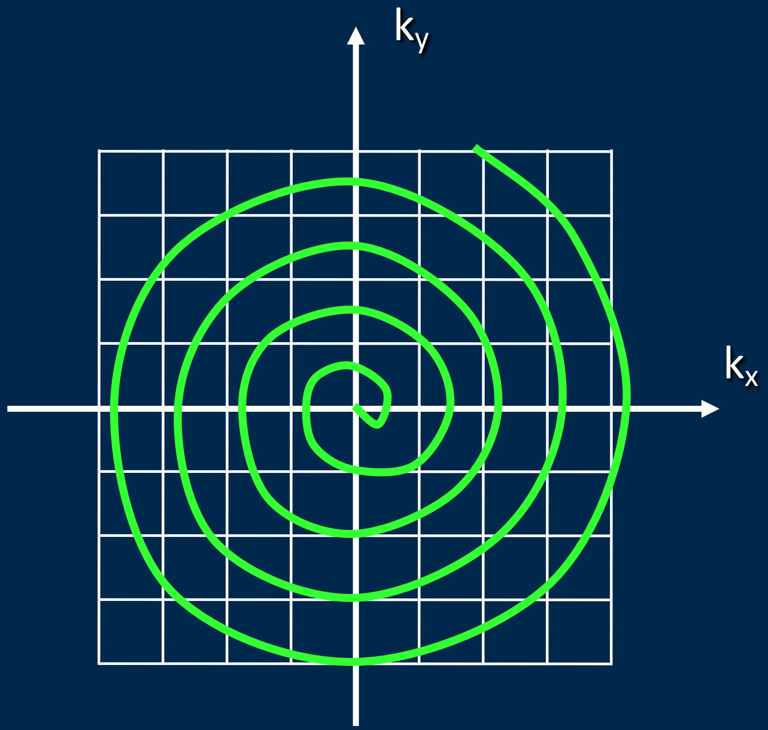
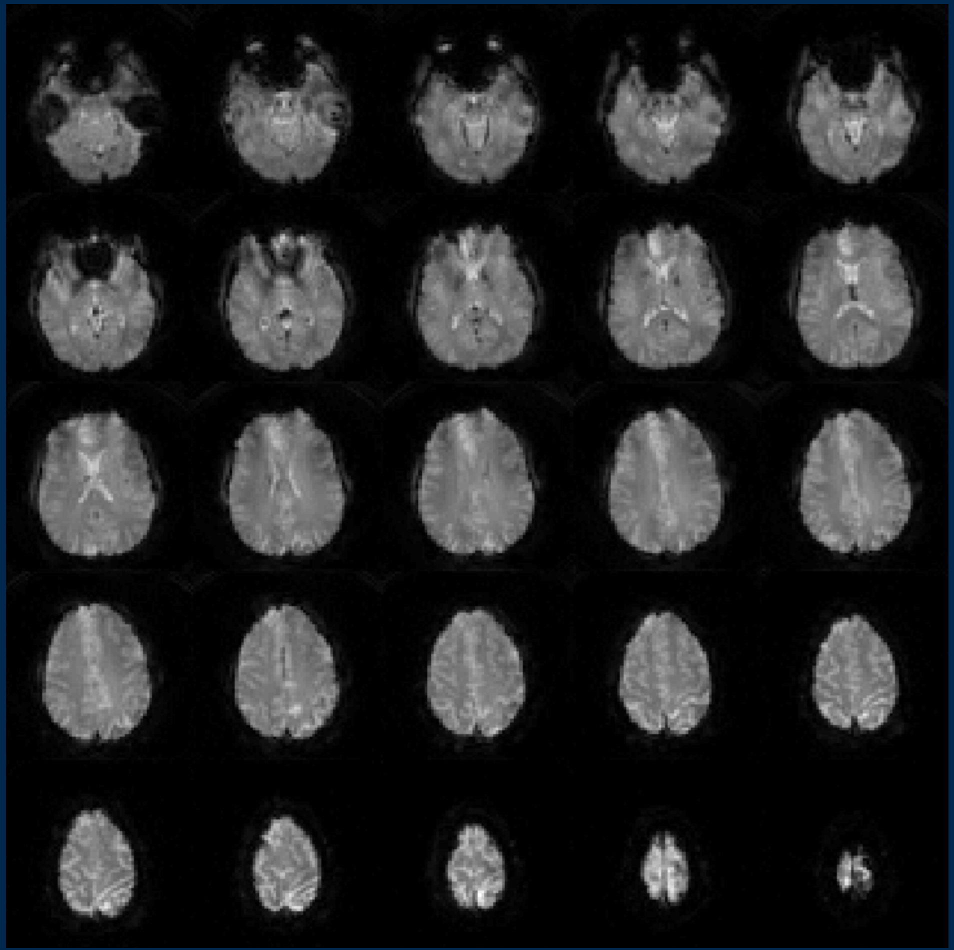
Spiral Imaging

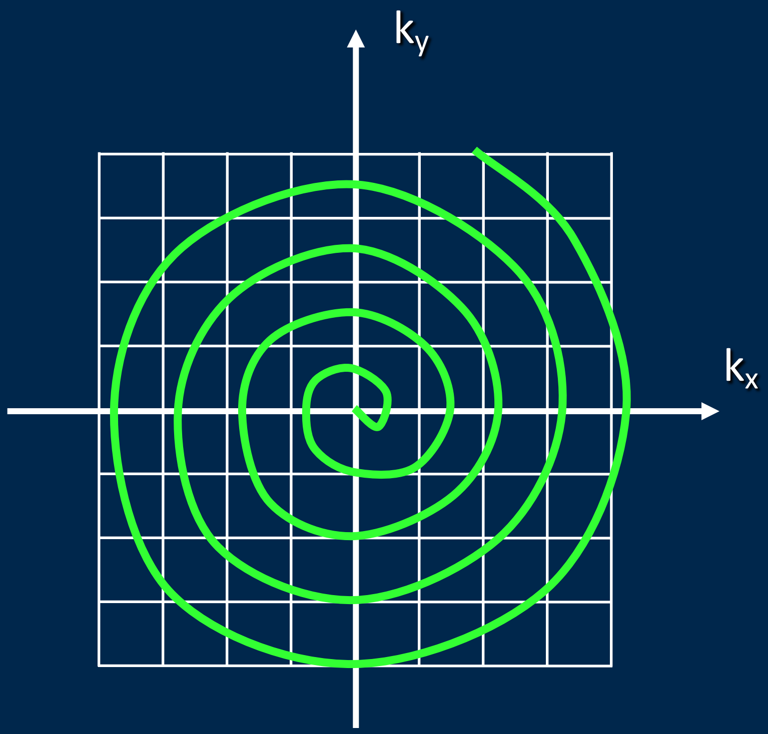


Spiral Pattern



Single-shot spiral, TE = 25 ms, TR = 2 s, 32 slices

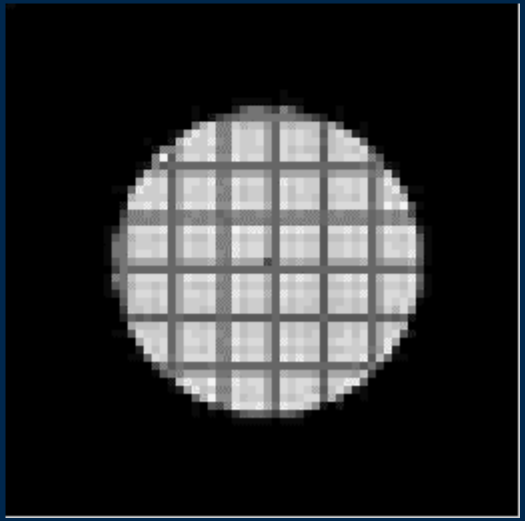
Spiral Imaging



Spiral Pattern

- Single-shot acquisition
- Typically matrix sizes for fMRI
  - 64x64, 96x96
  - 128x128 interleaved
- Acquisition rates
  - TR = 1-2 sec
  - 20-40 slices
- Suffers some artifacts
  - Blurring

Spiral Off-Resonance Distortions



perfect shim

poor shim

Courtesy of P. Jezzard

Single-shot Imaging

- Single-shot imaging is an extremely rapid and useful class of imaging methods for fMRI
- It does, however, require high performance hardware. Why?
  - In spin-warp, we acquire a small piece of data for an image with each RF pulse
  - In EPI and spiral, we try to acquire all of the data for an image with a single RF pulse

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Single-shot Imaging

- Need powerful gradient amps
- Limitations:
  - Peripheral nerve stimulation
  - Acoustic noise
  - Increased image noise
  - Heating and power consumption in gradient subsystem
- Other issues:
  - Limited spatial resolution
  - Image distortions
  - Some limits on available contrast

Goals of Image Acquisition

- Acquire 2D (or 3D) Fourier data
- Acquire samples finely enough to prevent aliasing (FOV)
- Acquire enough samples for the desired spatial resolution (Dx)
- Acquire images with the right contrast
- Do it fast as possible
- Do it without distortions and other artifacts

MRI Physics:

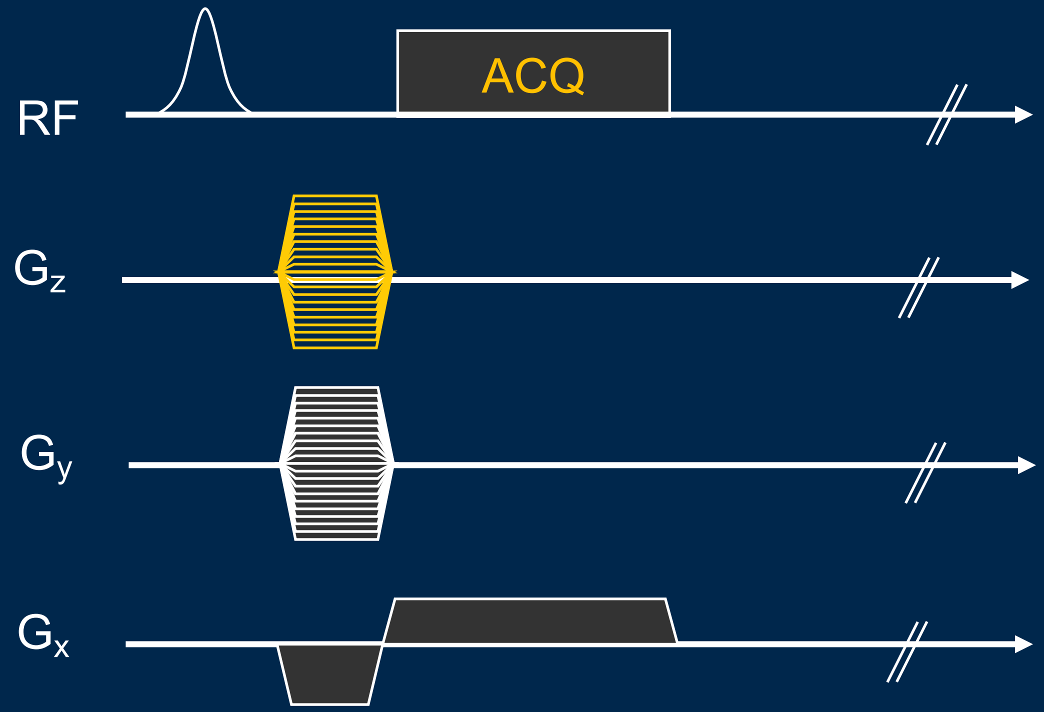
Encoding the 3rd Dimension

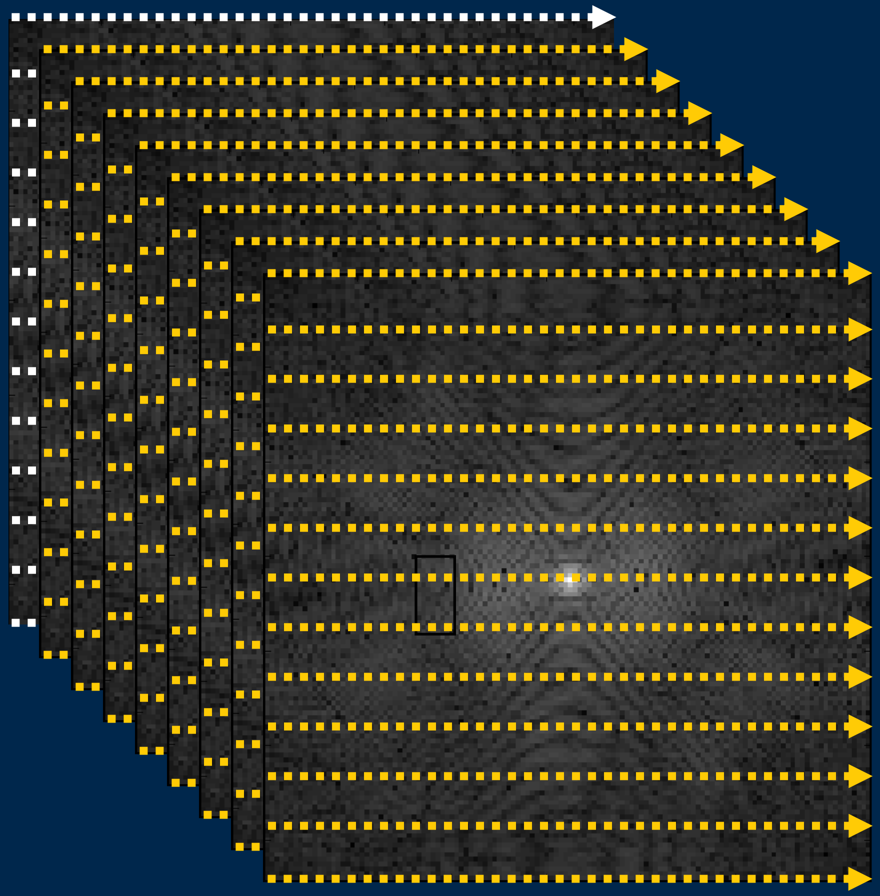
Nicole Seiberlich
Associate Professor, Radiology
Co-Director of MIITT

The 3rd Dimension

- We've talked about 1D and 2D imaging, but the head is 3D!!
- Solution #1 – 3D Imaging
  - Acquire data in a 3D Fourier domain
  - Image is created by using the 3D Fourier transform
- Solution #2 – Slice Selection
  - Excite a 2D plane and do 2D imaging
  - Most common approach

Traversal of k-Space with Gradients





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Fundamental Imaging Time

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

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

- T_R: Amount of time needed to acquire one line (3 ms – 5 sec)
- N_y: Number of lines to acquire (32 – 512)
- NA: Averages of each line (1 - ∞)
- 2D Scan Time ~ 3 ms x 256 lines x 1 average = 768 ms
- 3D Scan Time ~ 3 ms x 256 lines x 256 lines x 1 average = ***196 s***

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Fundamental Imaging Time

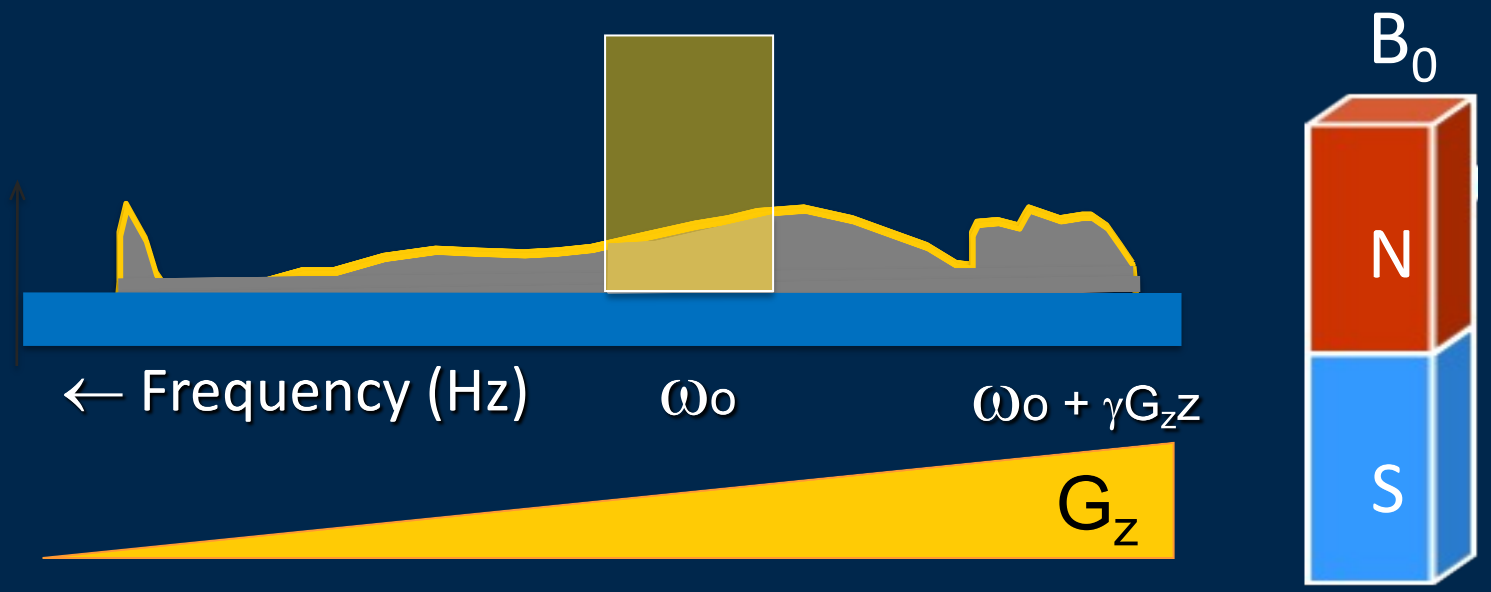
$$Time = T_R \cdot N_y \cdot NA$$

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

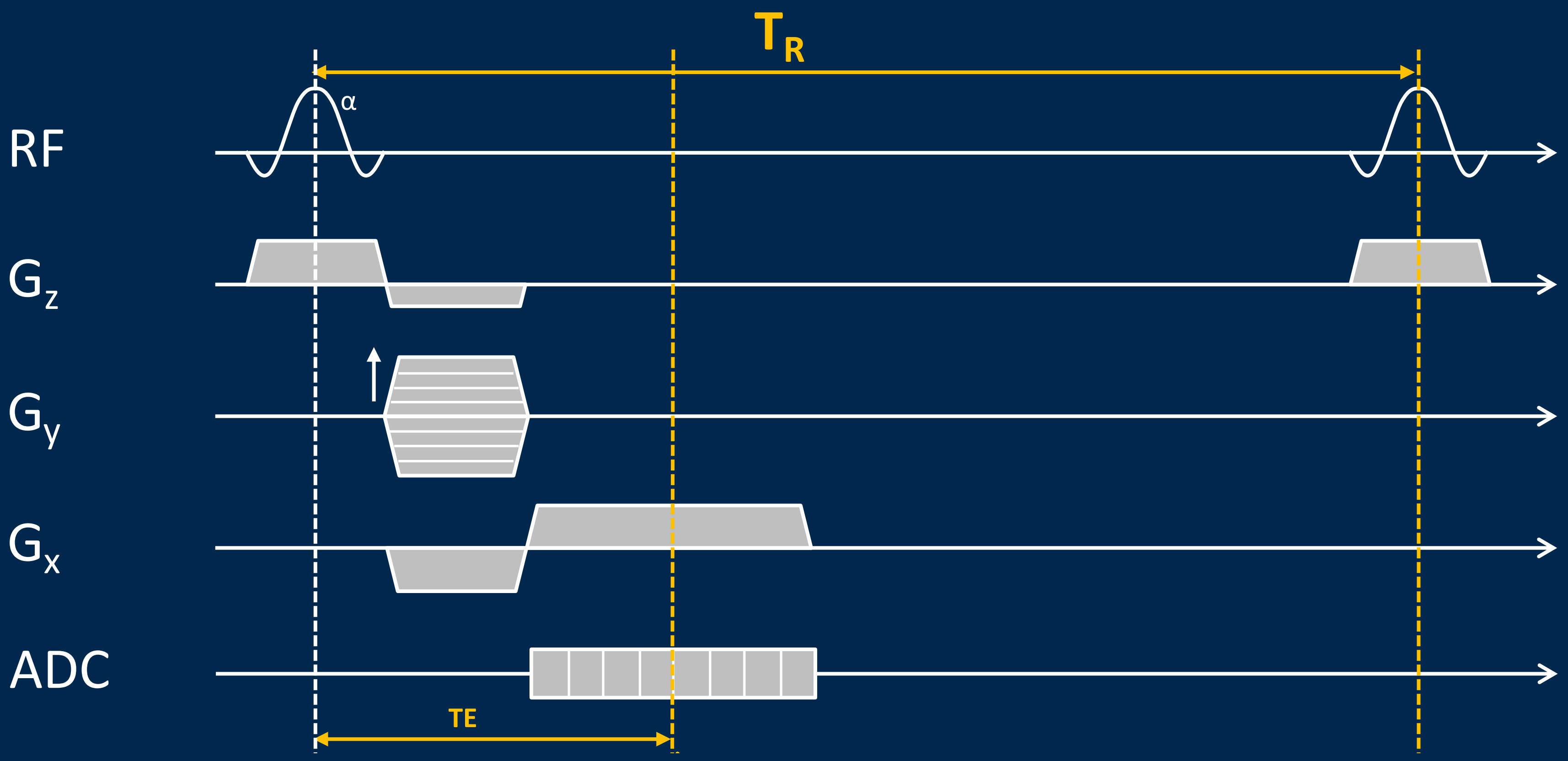
- Long Scan!!
- No chance to follow rapid temporal dynamics (fMRI)
- Motion artifacts

Slice Selection

- The 3rd dimension is localized during excitation
  - "Slice selective excitation"
- Makes use of the resonance phenomenon
  - Only "on-resonant" spins are excited



Pulse Sequence



Fundamental Imaging Time

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

$$Time = T_R \cdot N_y \cdot NA \cdot \text{Slices}$$

- Shorter scans / slice
- Lots of slices = long scan time

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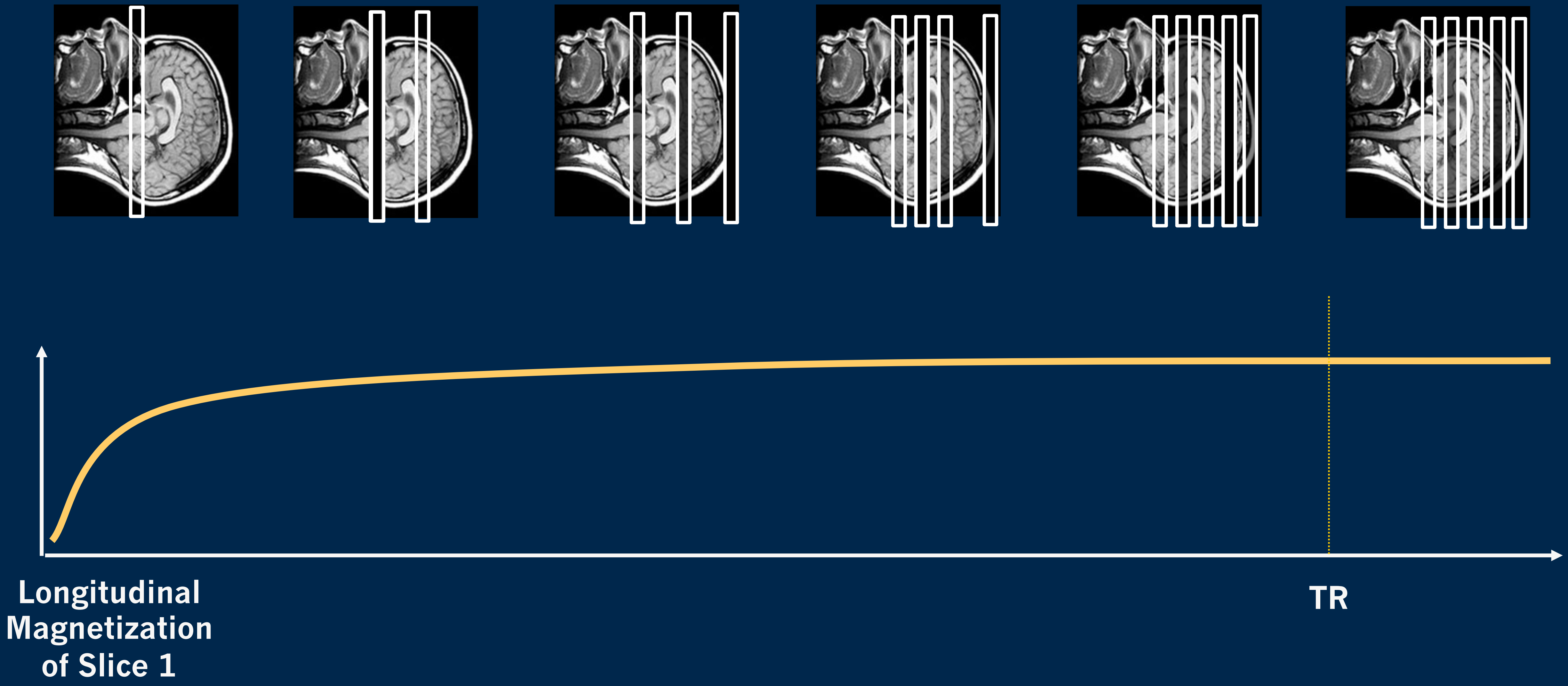
Interleaved Multi-Slice 2D Spin Echo MRI



Summary

- Acquisition of all of k-space is what causes scans to be long
- Spin Warp / Spin Echo sequences can be long
- Turbo Spin Echo used to collect multiple echoes after one excitation → T2 Weighted
- Echo Planar Imaging used to collect multiple echoes after one excitation → T2* Weighted
- MRI data can be collected in 3D
- Most MRI scans are 2D using slice selection
- Interleaved slices can be collected to shorten scan time