Reconstruction methods Gridding and Parallel Imaging

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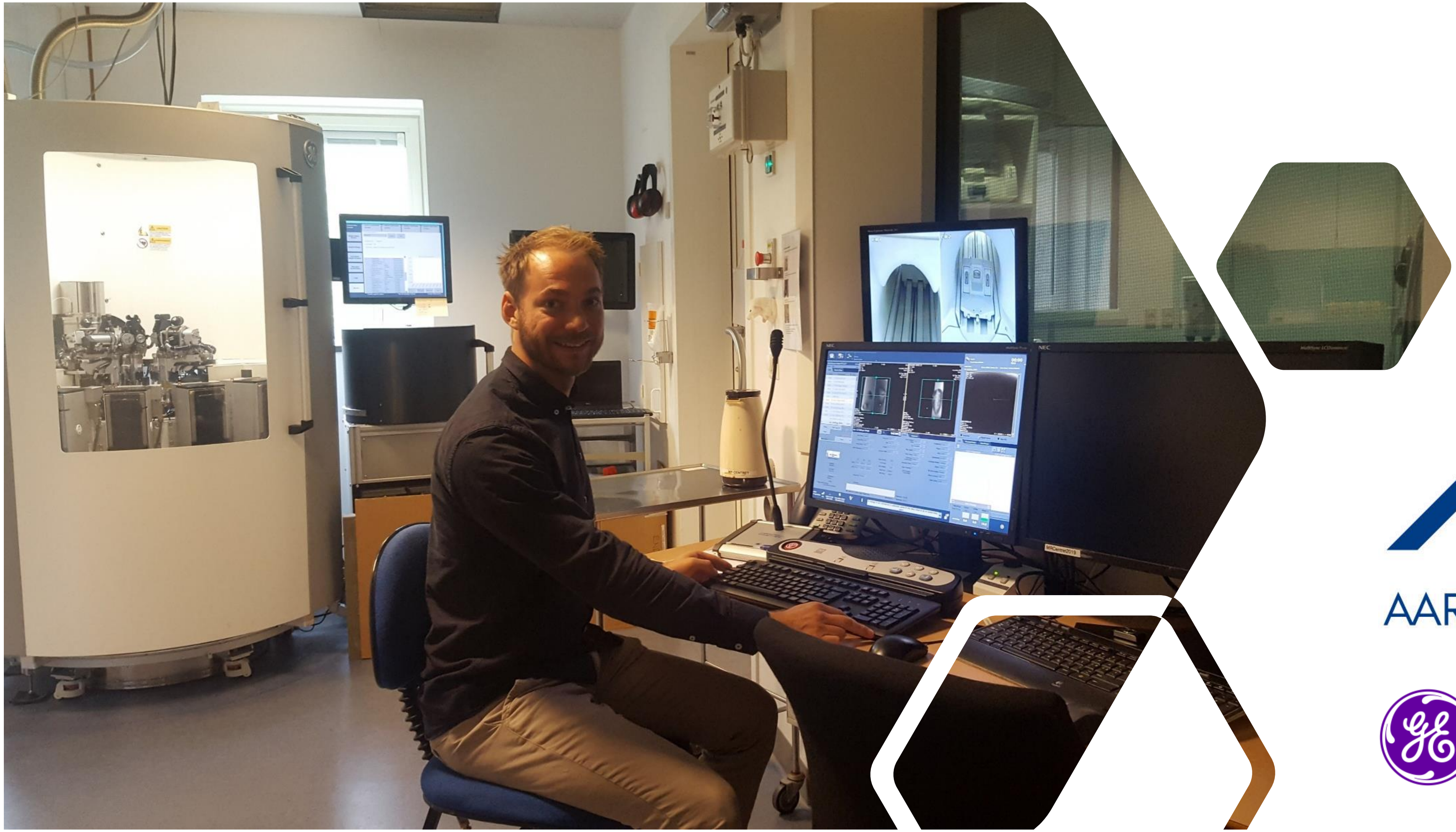
7. October 2024

Disclosures – MR Research Scientist



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GE HealthCare

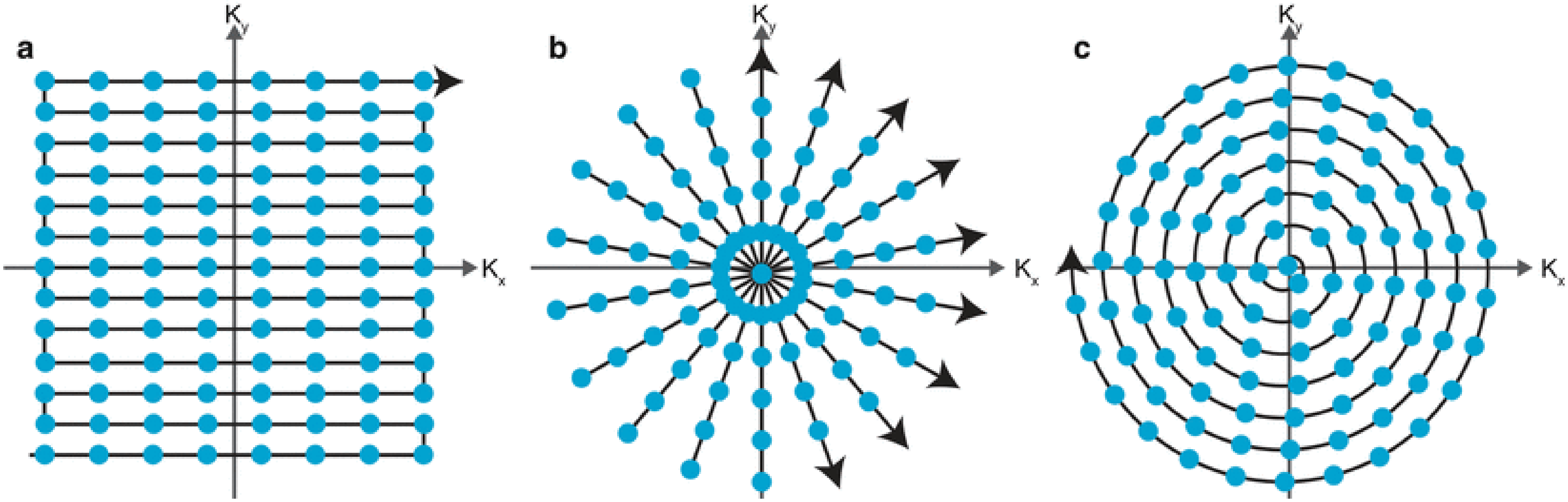
Agenda

- Gridding
  - Non-Cartesian reconstruction
  - K-space resampling
  - Gridding artefacts
  - Oversampling and de-apodization
- Parallel Imaging
  - SENSE | ASSET
  - GRAPPA | ARC
  - Compressed Sensing | HyperSense |Compressed Sense
  - Multiplex |HyperBand | MultiBand | SMS (If time allows)
- Hyperpolarized applications

Gridding

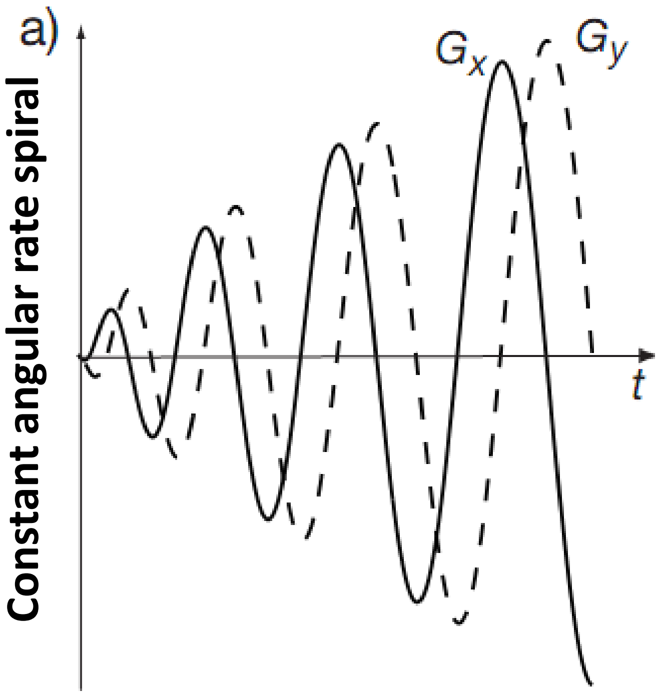
Acquisition trajectories

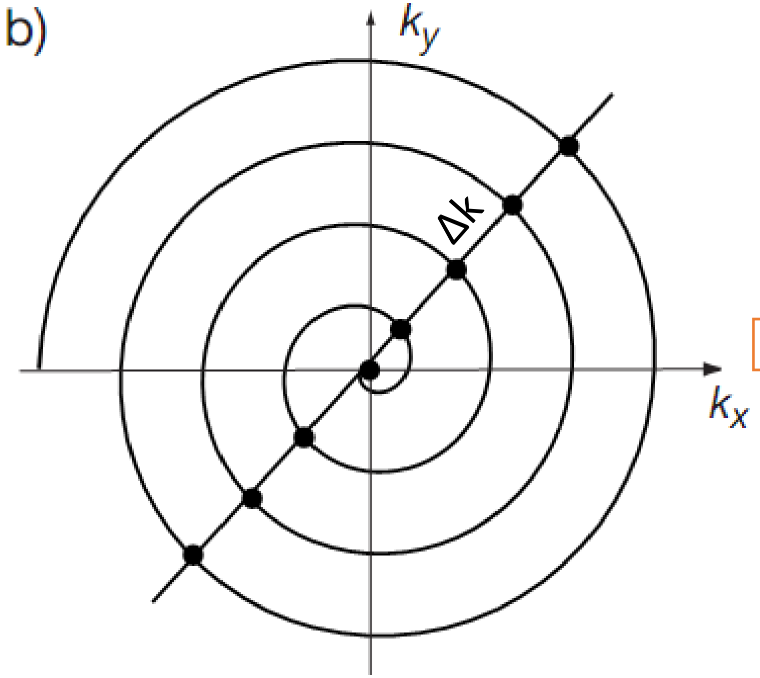
Cartesian **Radial** **Spiral**



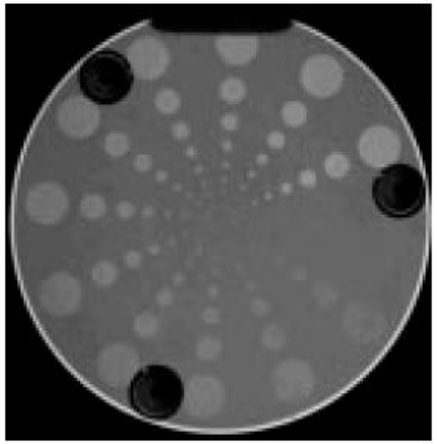
Non-Cartesian Reconstruction

Constant angular rate spiral



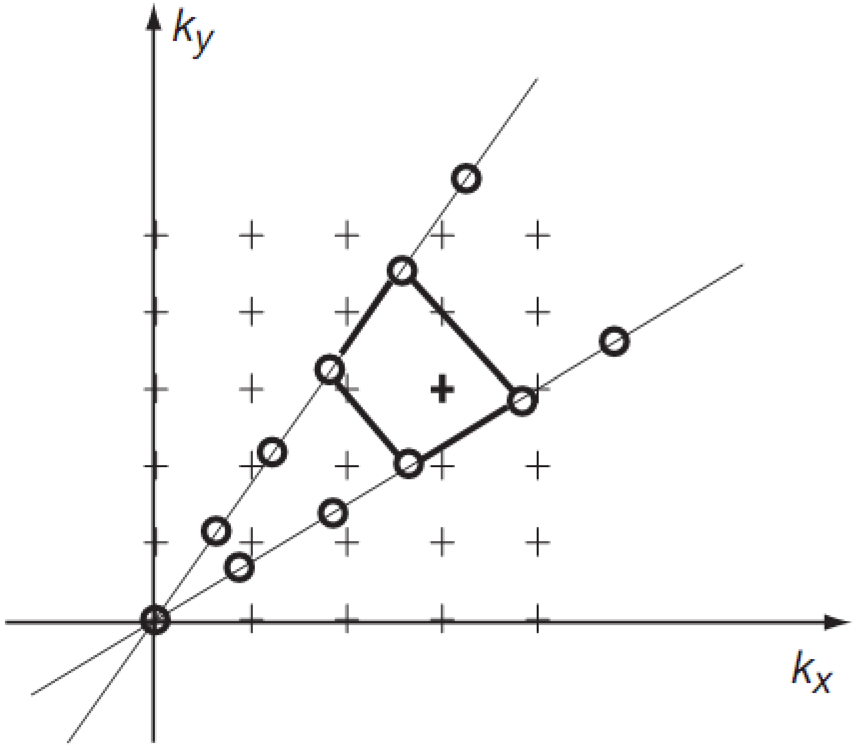


Backprojection

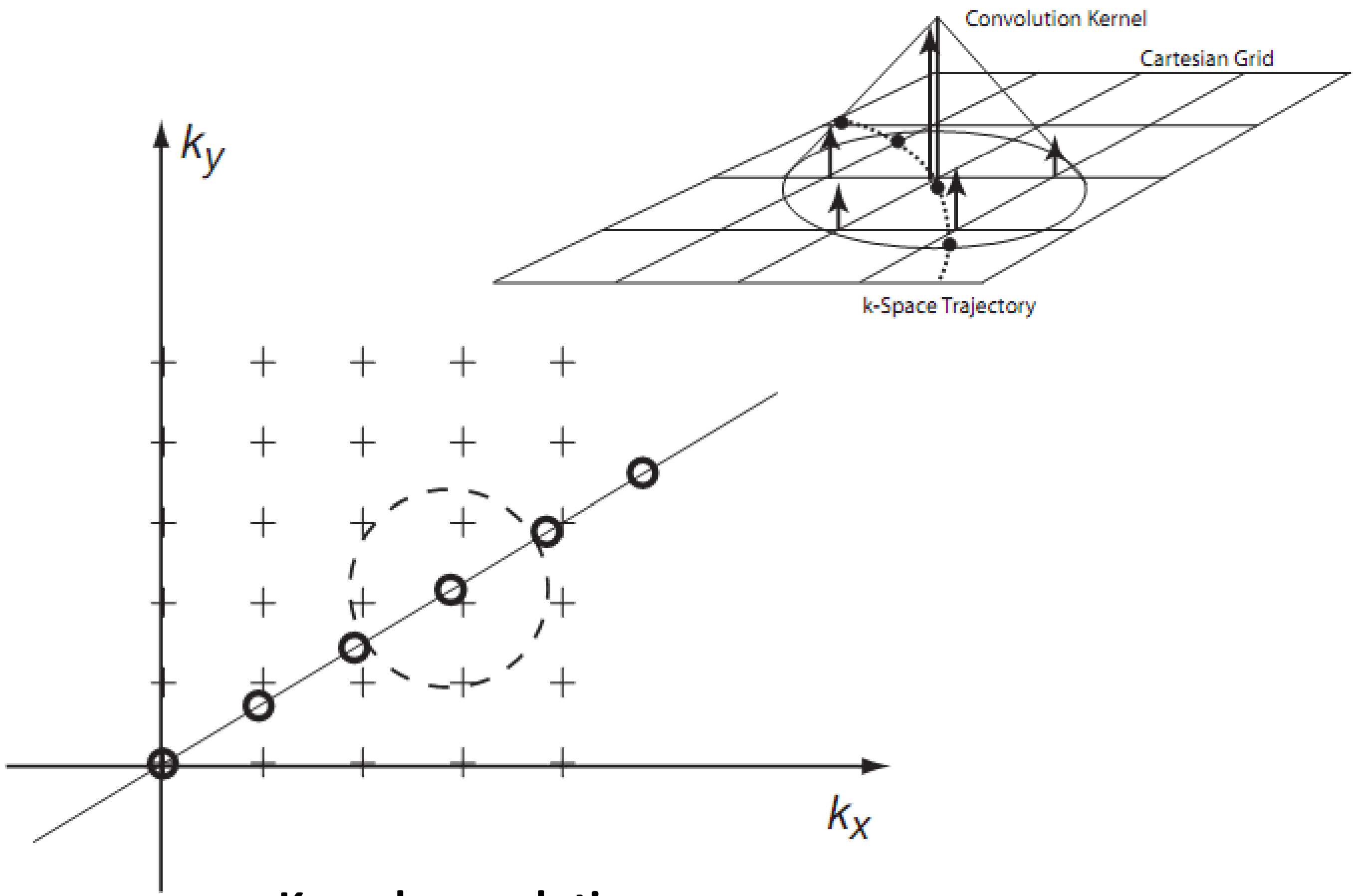


Pauly J, Non-Cartesian Reconstruction, 2005

K-space resampling methods (Gridding)



Bilinear interpolation

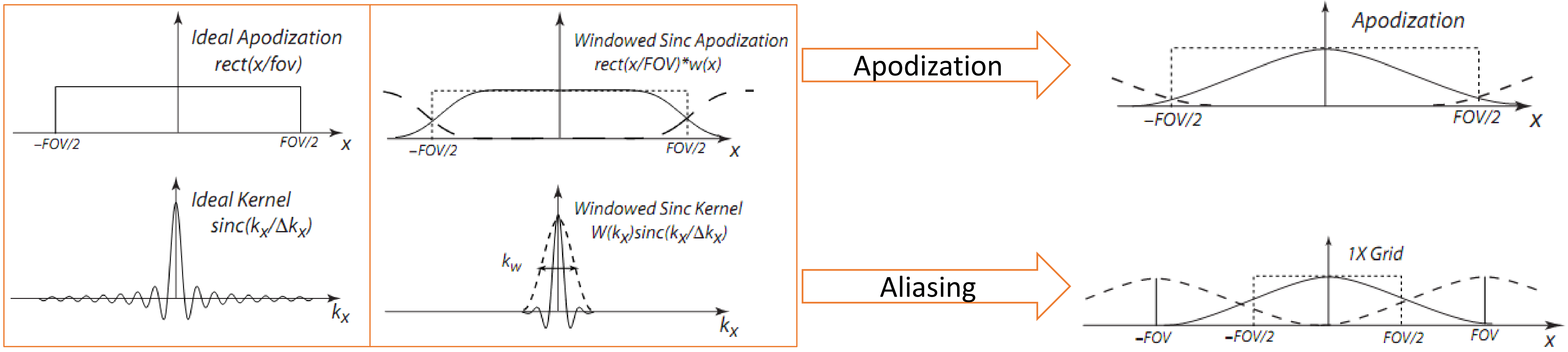


Kernel convolution

Pauly J, Non-Cartesian Reconstruction, 2005

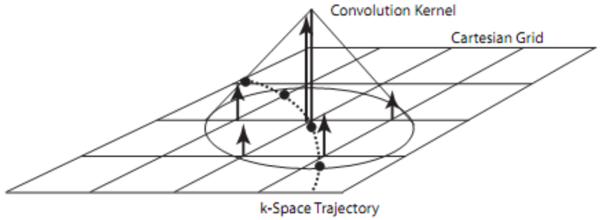
Gridding artifacts

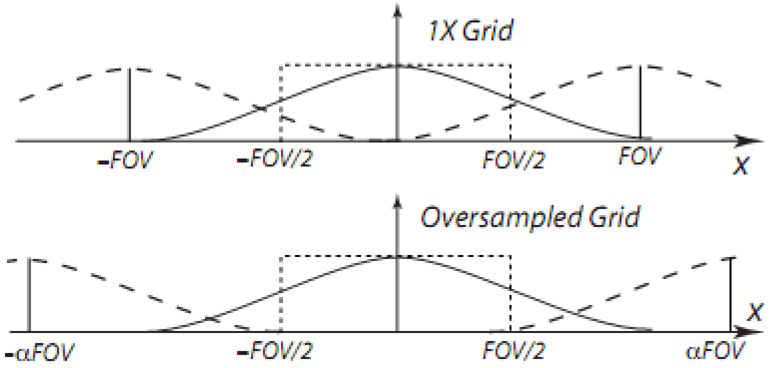
Ideal gridding **Typ. gridding**

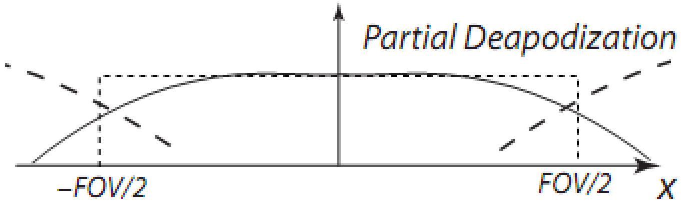


Pauly J, Non-Cartesian Reconstruction, 2005

Reconstruction



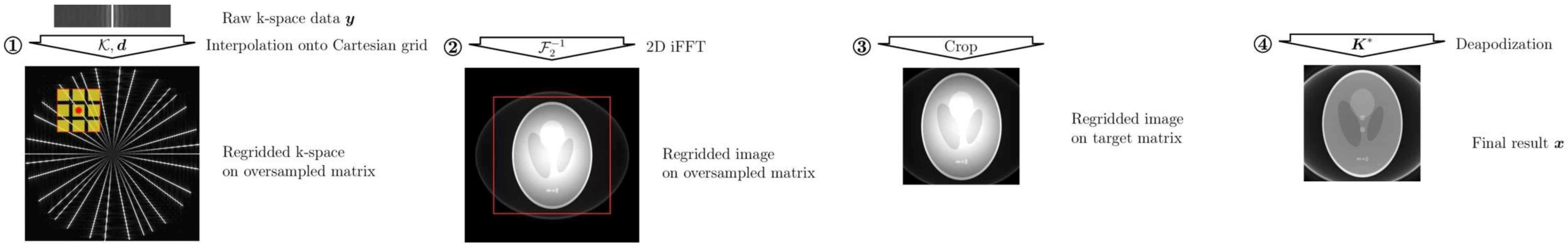




1. Gridding

2 + 3. Oversampling

4. De-apodization

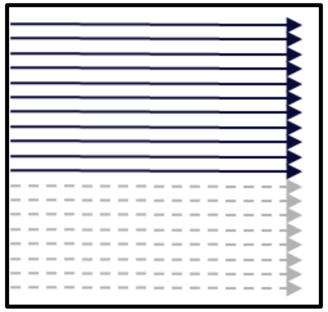


Grimm, Reconstruction Techniques for Dynamic Radial MRI, 2014

Undersampling k-space

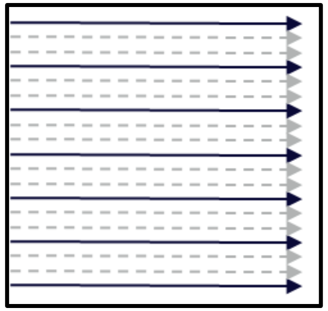
How to accelerate MRI?

- Record half the k-space
  - Half-Fourier

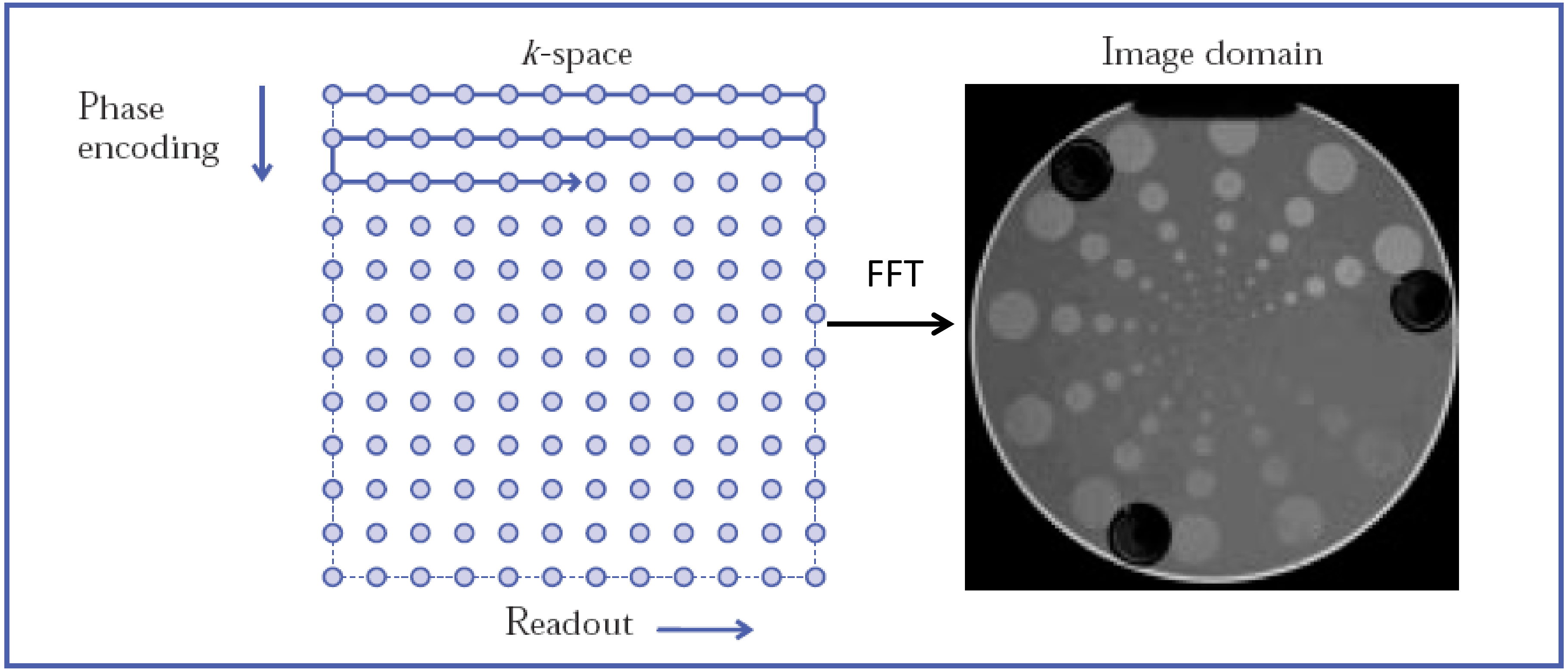


- More k-space points pr excitation
  - FSE, EPI, CUBE/SPACE/VISTA, etc.

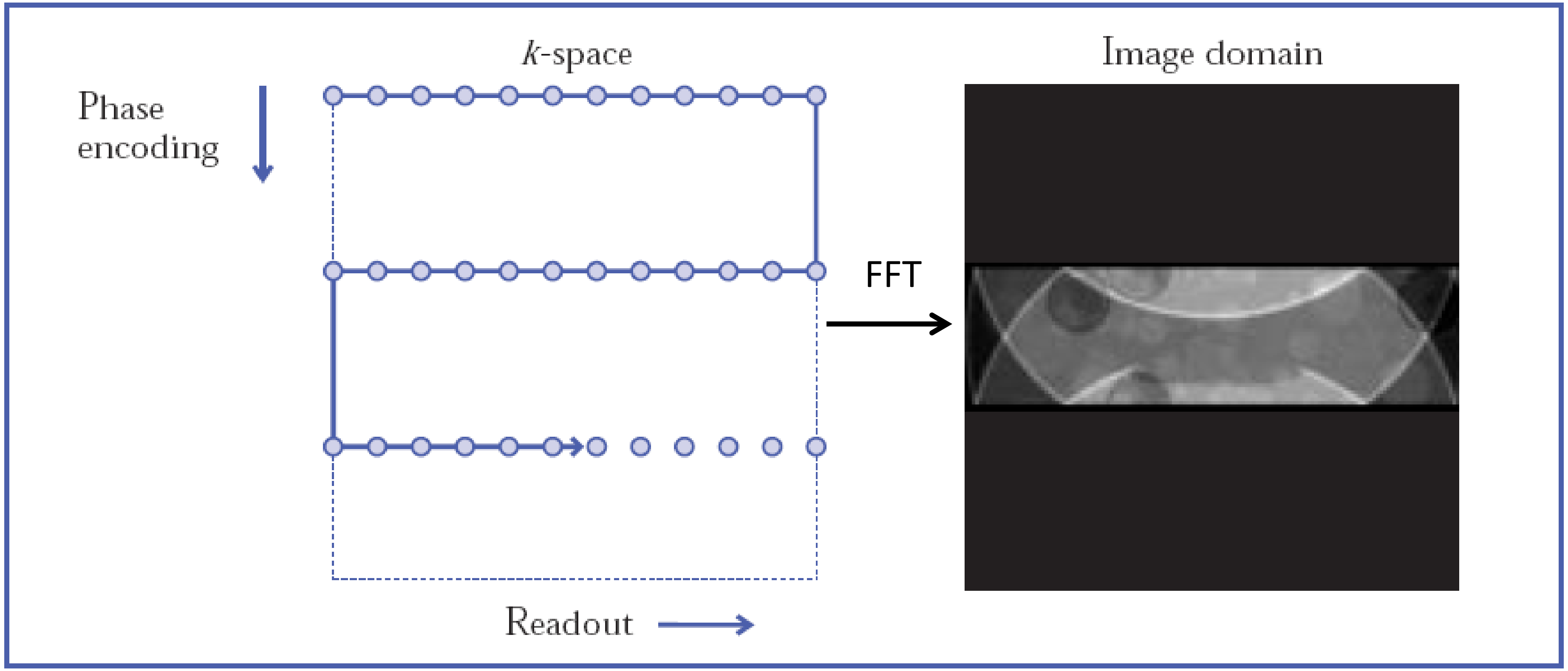
- **Undersampling k-space**
  - SENSE, GRAPPA, Compressed Sensing



Conventional k-space recording

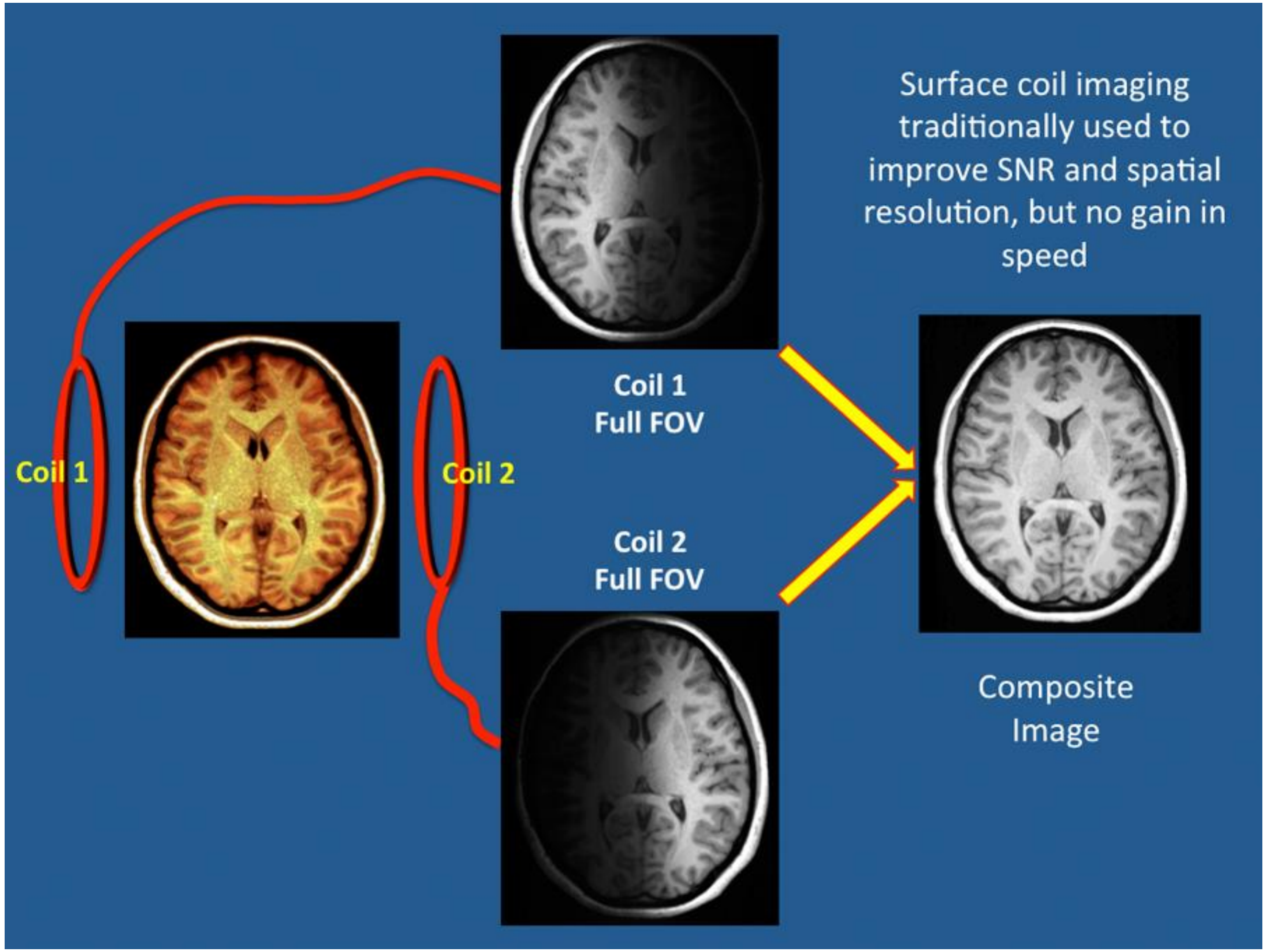


Undersampling of k-space

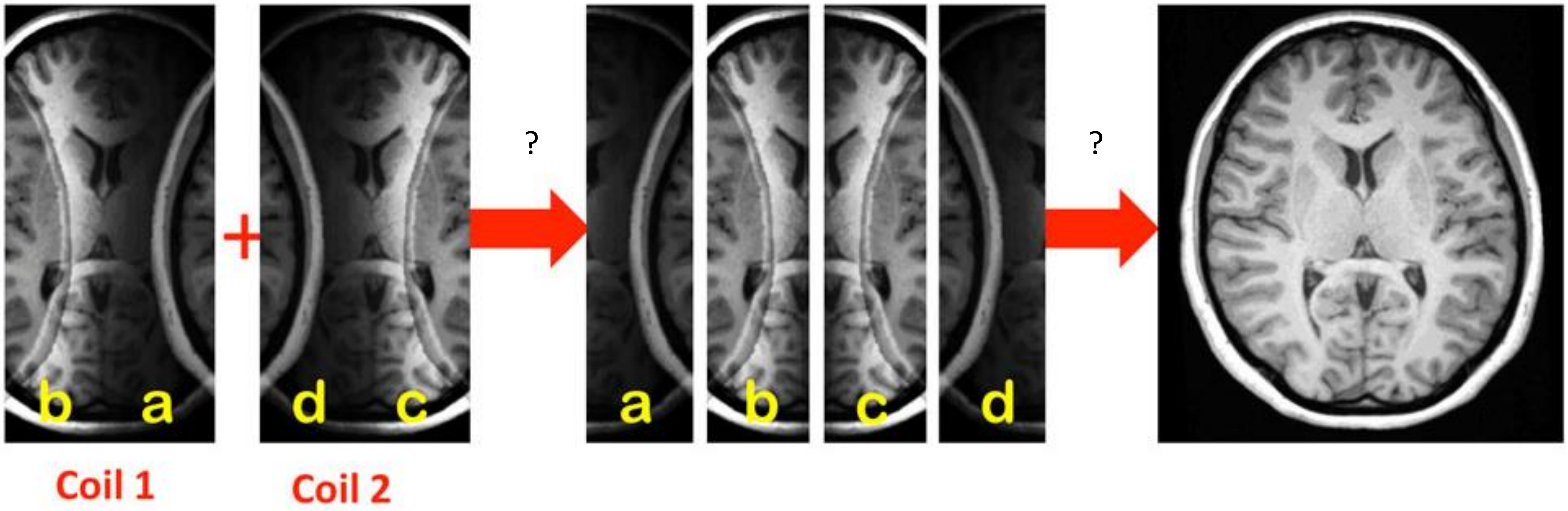


Parallel Imaging

Conventional recording

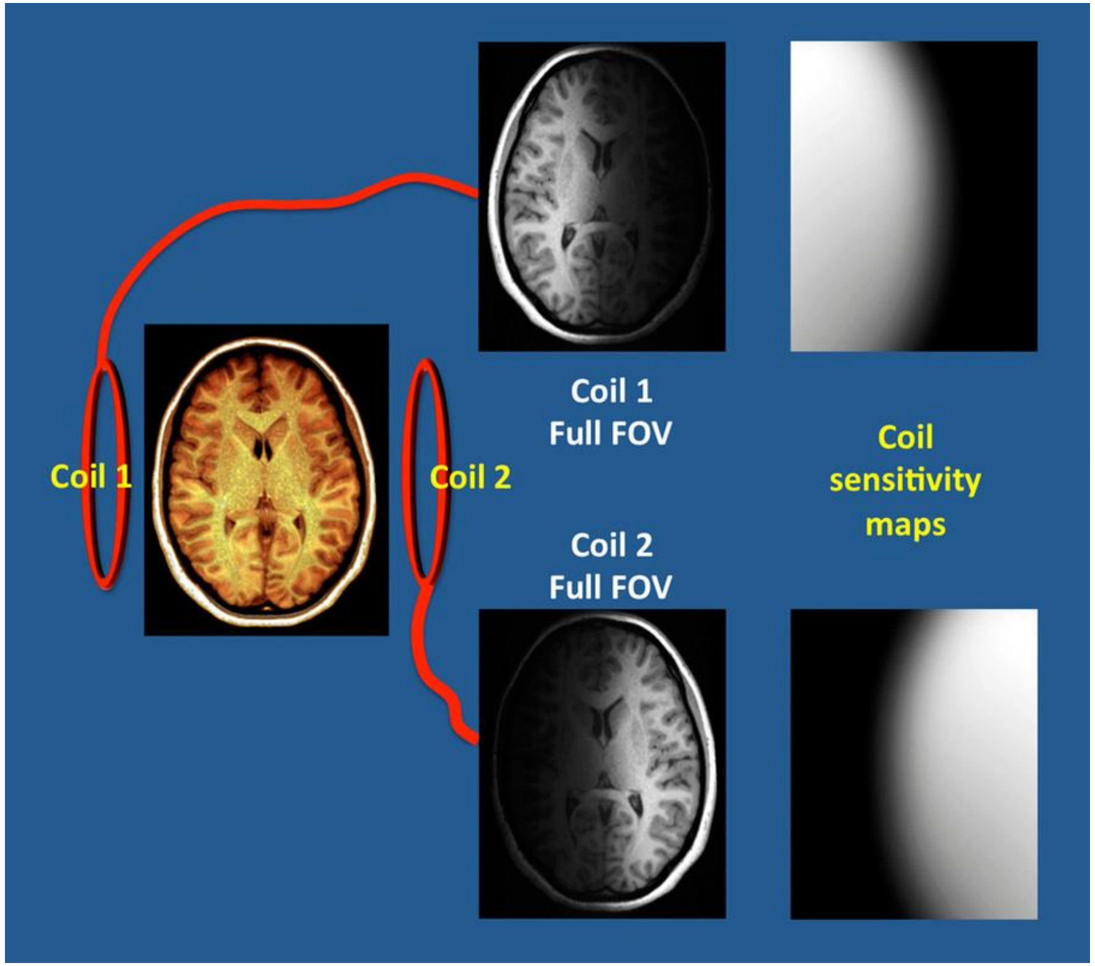


Parallel Imaging – the elements

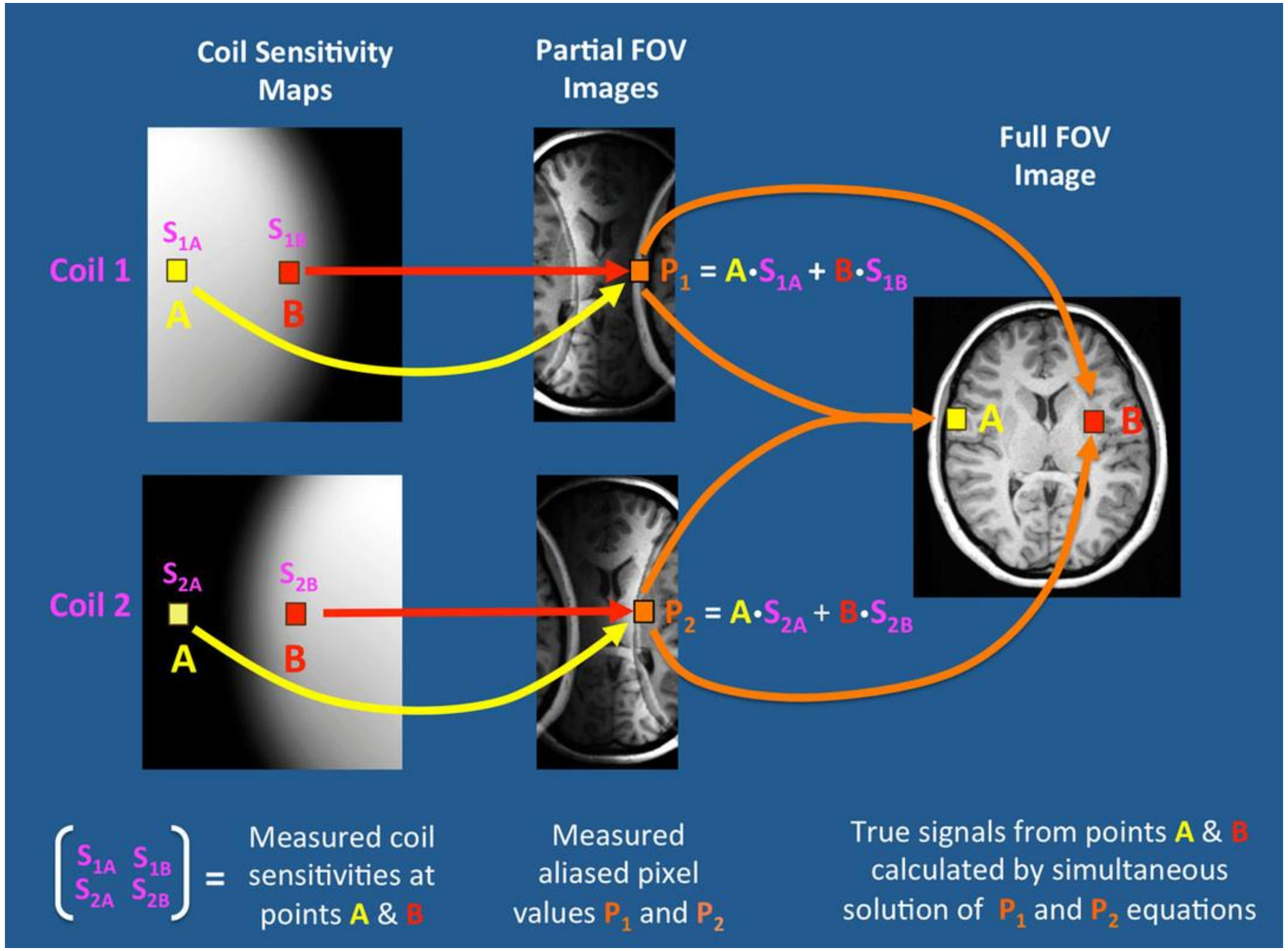


SENSE

SENSE – coil sensitivity profile

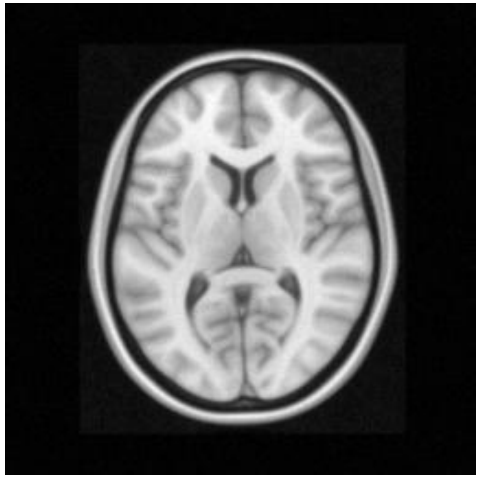


SENSE – linear algebra

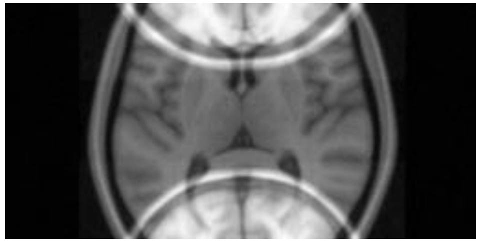


Pruessmann KP, SENSE: sensitivity encoding for fast MRI, MRM, 1999

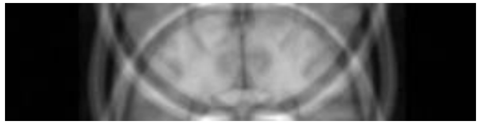
How much can we accelerate?



R = 1



R = 2

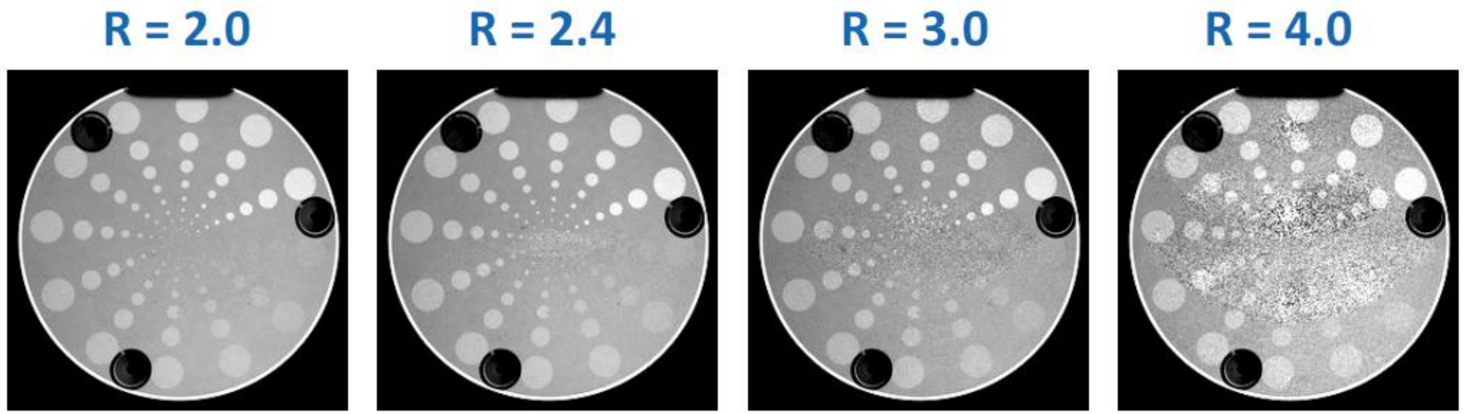


R = 3

R = 4

R = 5

Parallel Imaging and g-factor



$$SNR^{SENSE} = \frac{SNR^{Full}}{\sqrt{R} \cdot g(\vec{x})}$$

$$g(\vec{x}) = \sqrt{\left(E^H E\right)_{i,i} \left(\left(E^H E\right)^{-1}\right)_{i,i}} \geq 1$$

Pruessmann KP, SENSE: sensitivity encoding for fast MRI, MRM, 1999

SENSE – SNR vs time

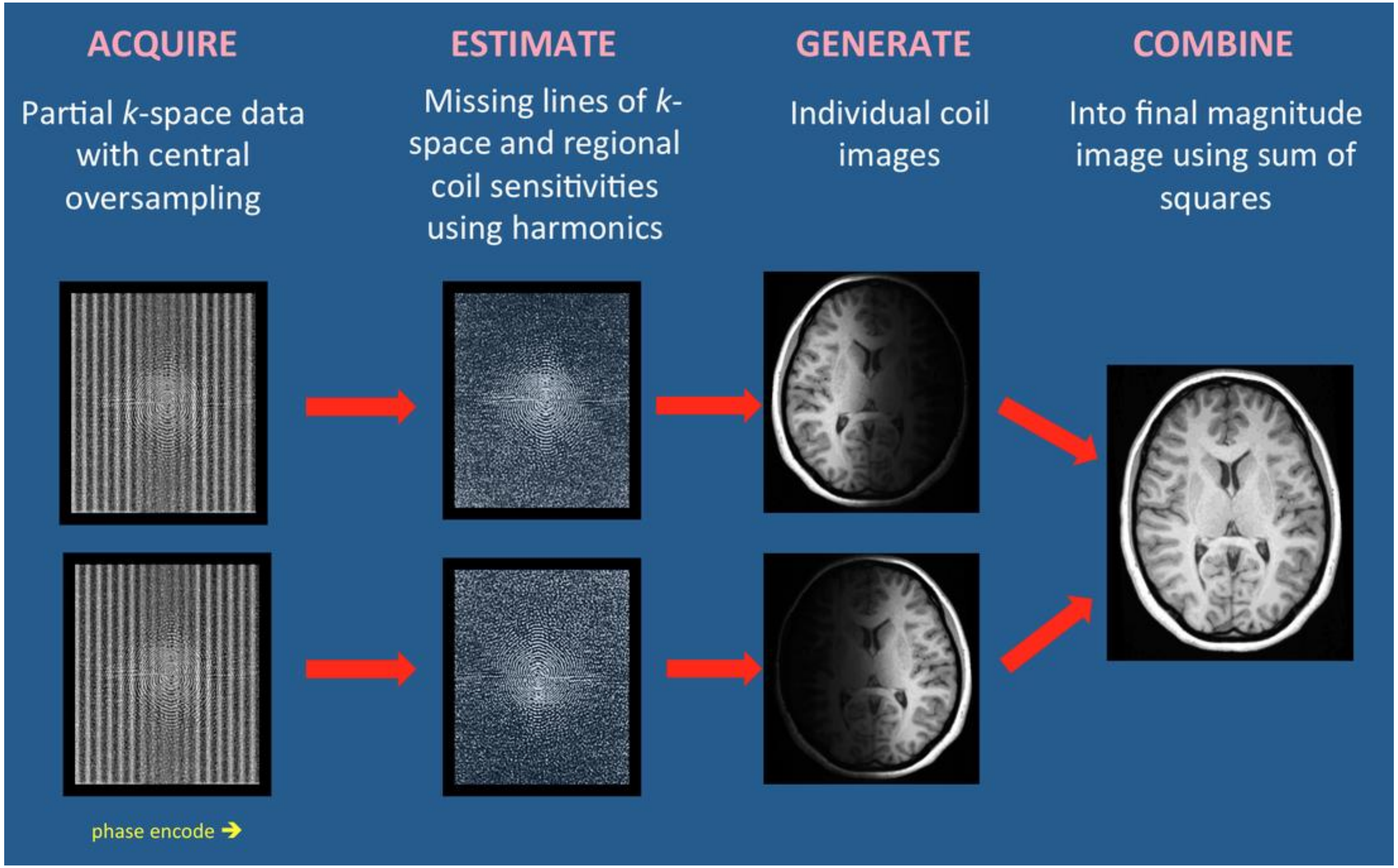
Conventional (TA 84 sec) | ***R* = 2** (TA 44 sec) | ***R* = 3** (TA 32 sec) | ***R* = 4** (TA 24 sec)

GRAPPA

GRAPPA – interpolation in k-space

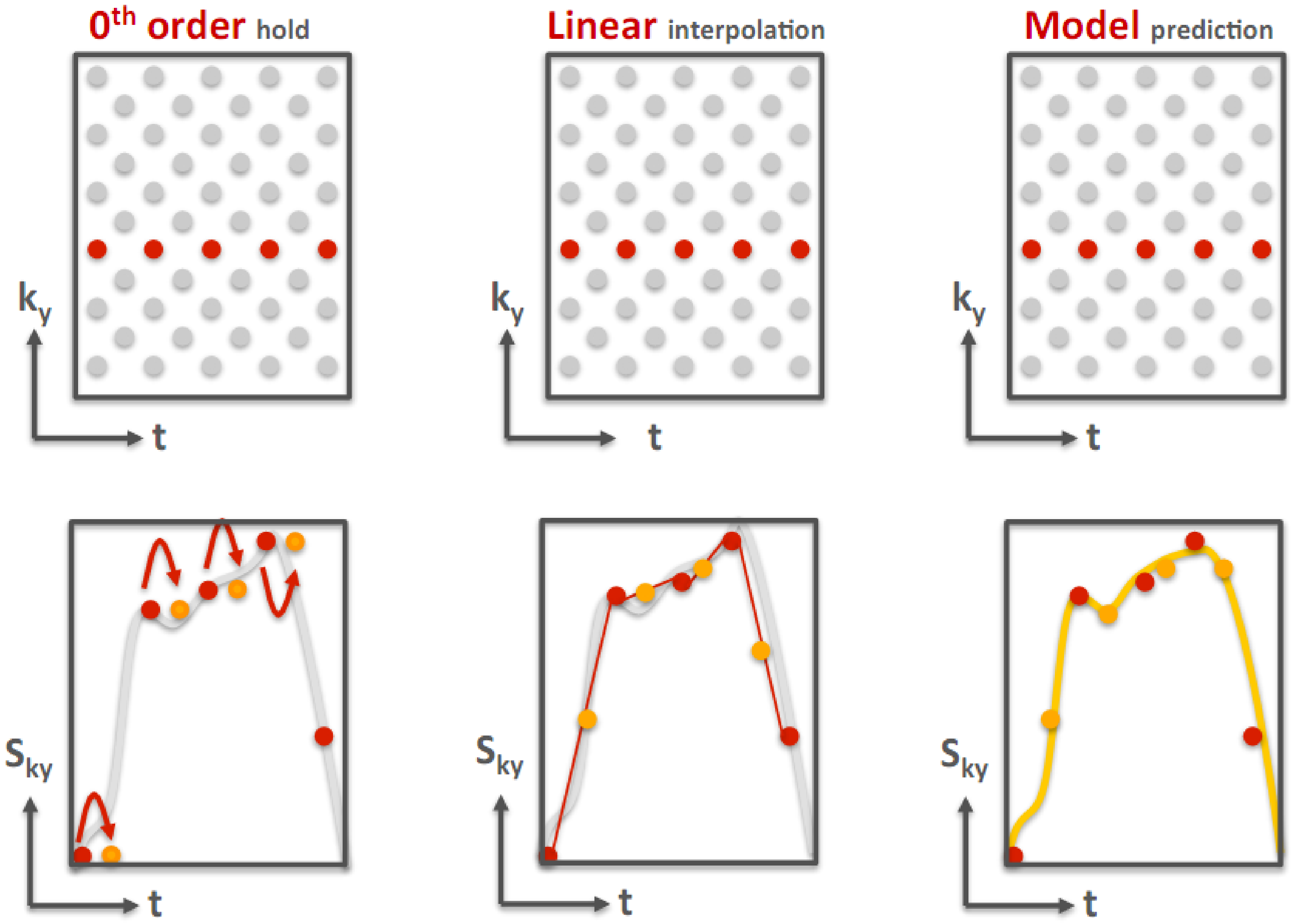
Coil 1

Coil 2

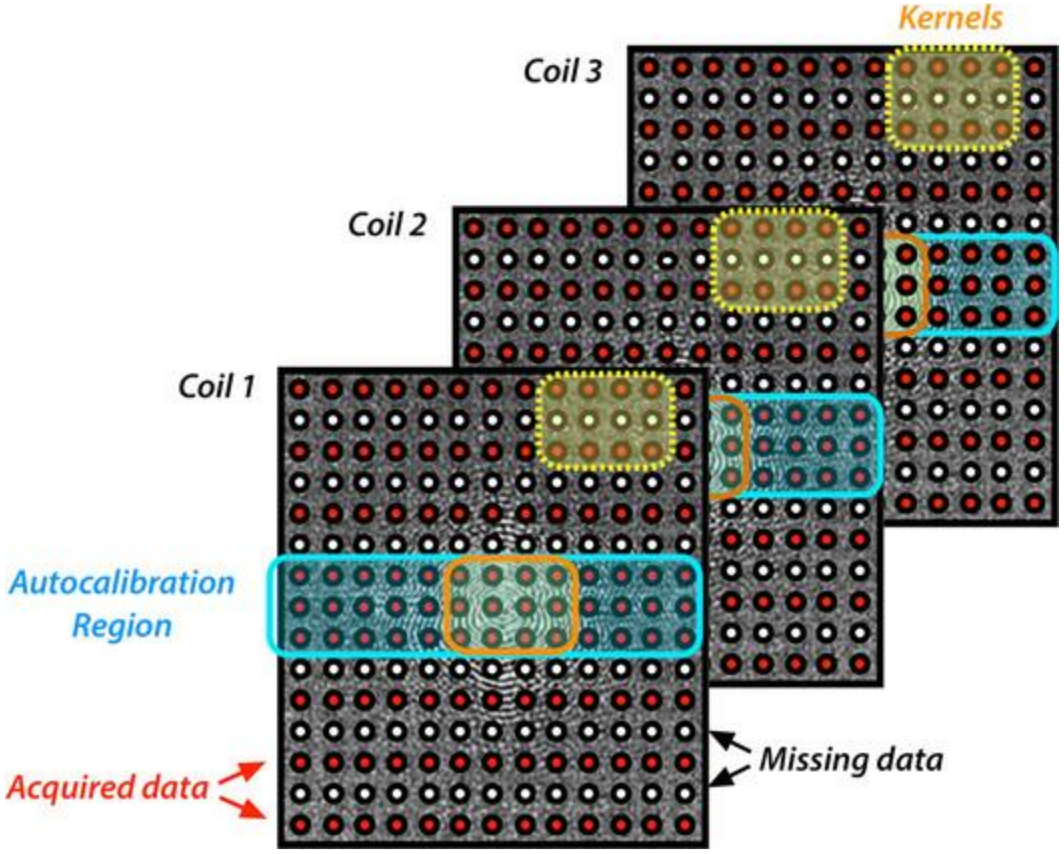


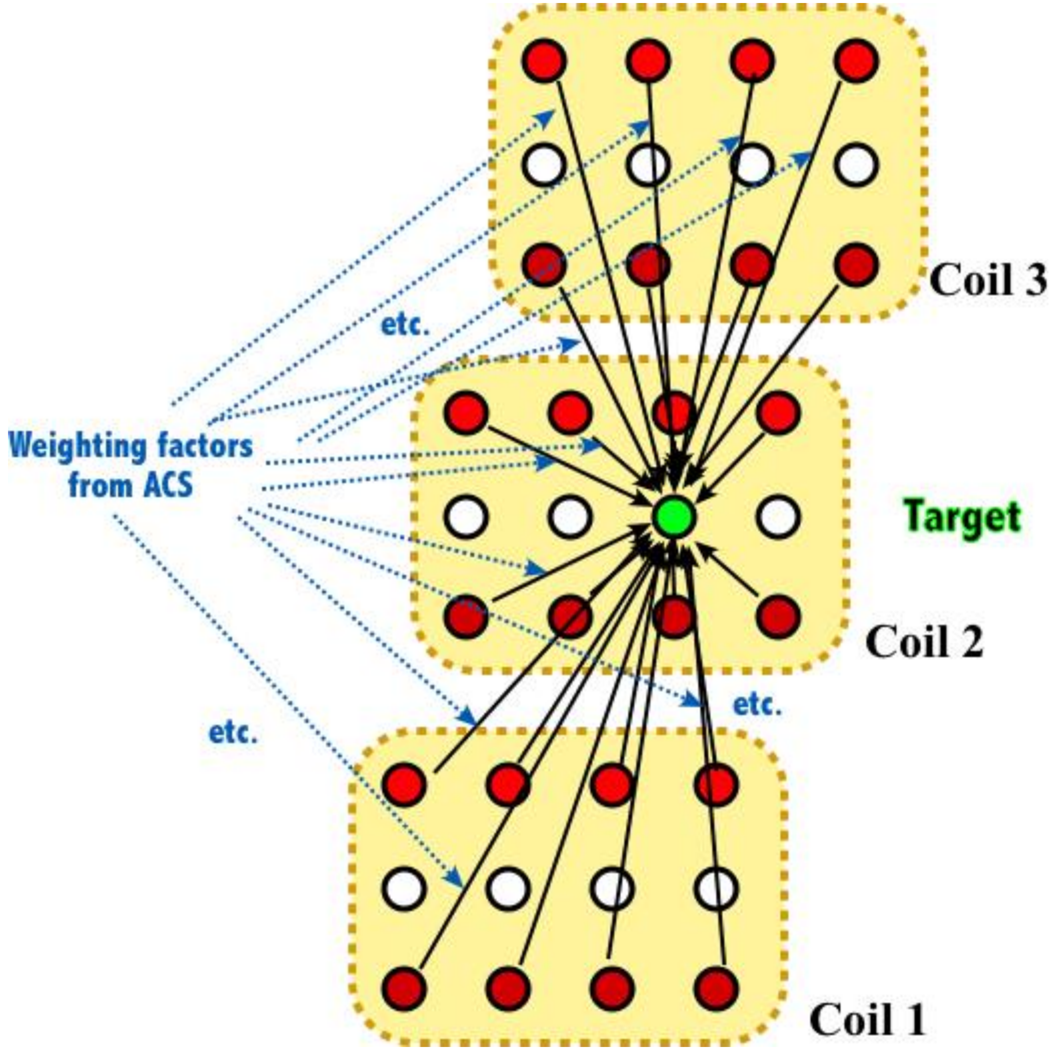
Grisworld MA, Generalized autocalibrating partially parallel acquisitions (GRAPPA), MRM, 2002

How to interpolate k-space?

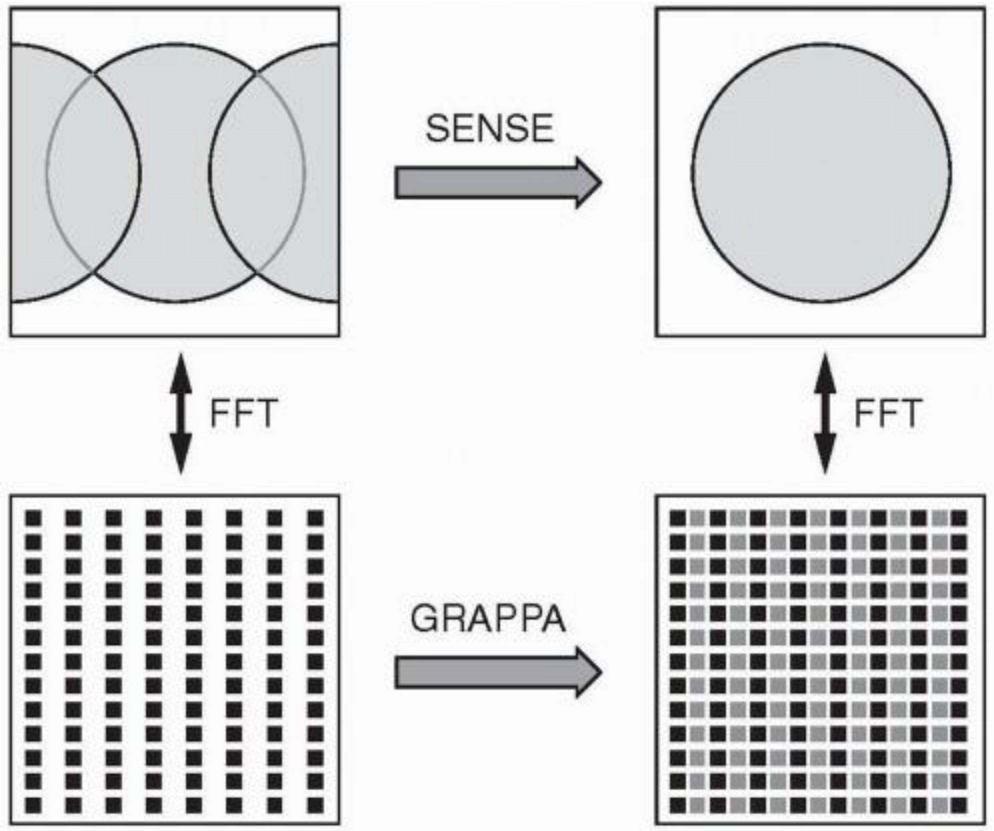


GRAPPA – interpolation in k-space





SENSE vs GRAPPA



SENSE: Coils sensitivity profiles, reconstruction in image domain.
GRAPPA: Interpolation of k-space, reconstruction in k-space.

Parallel Imaging - applications

- Performing fast scans and thereby reducing motion artifacts
- Completion of scan in a breath hold
- Higher temporal resolution for dynamic scans
- Reduction of susceptibility artifacts by EPI sequences
- Higher spatial resolution at the same scan time
- Fewer RF pulses and thus reduction of SAR
- SENSE (image) or GRAPPA (k-space) method

Compressed Sensing

Compressed Sensing

1. K-space sampling

    Undersampling + incoherent sampling

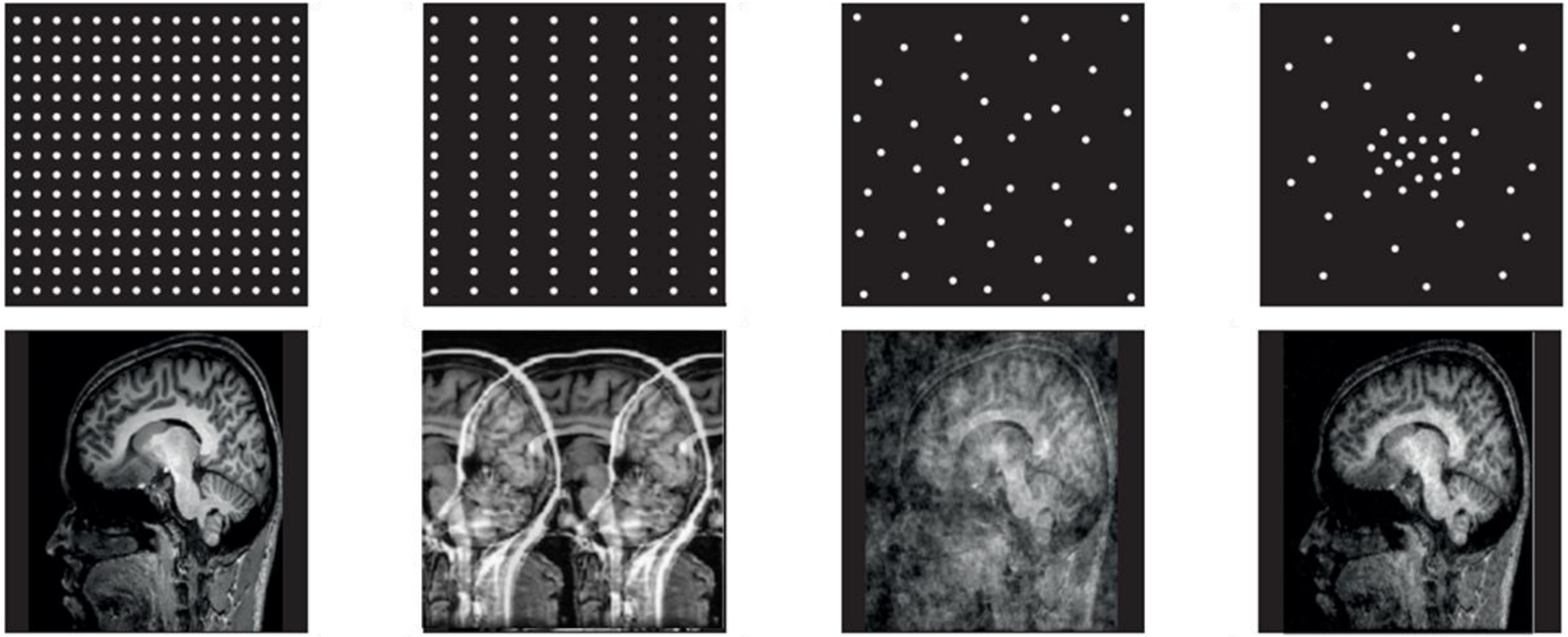
2. Wavelet transformation

    Sparsity in data

    Filtering

3. Iterative reconstruction

1. K-space samling



All samples

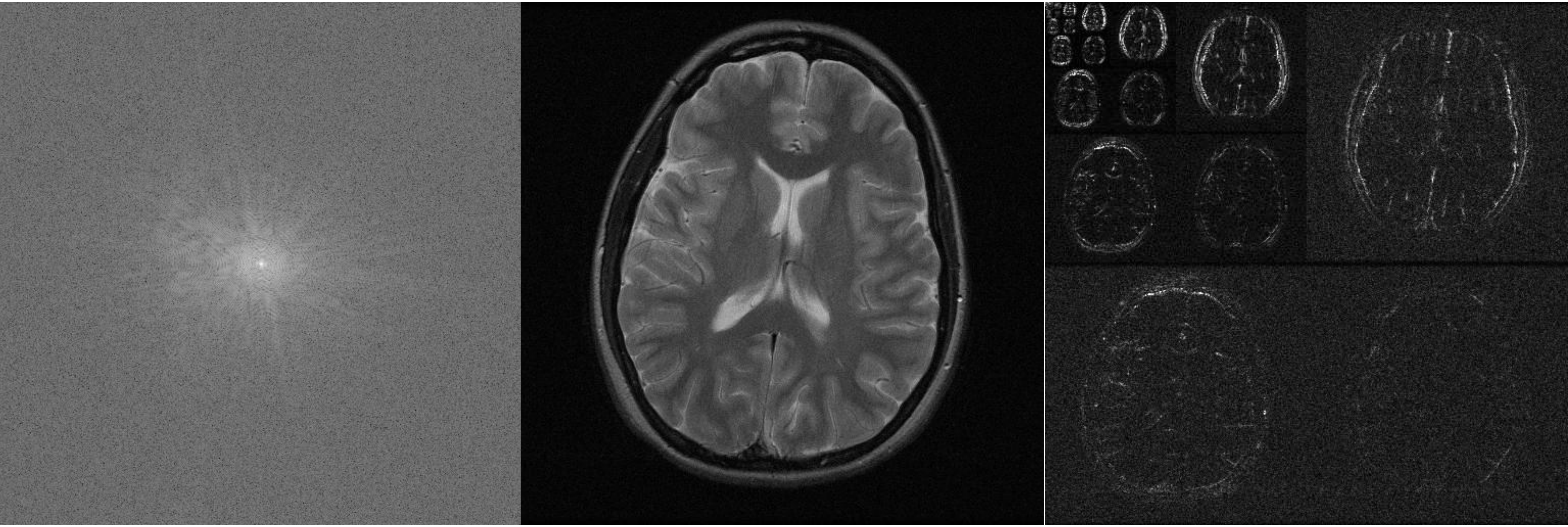
Uniform Undersampling

”Incoherent” Undersampling

”Incoherent” Undersampling, Increased density at centre

Lustig M., et.al. Sparse MRI: The application of Compressed Sensing for Rapid MR Imaging. Magn Reson Med. 2007, 58:1182-95

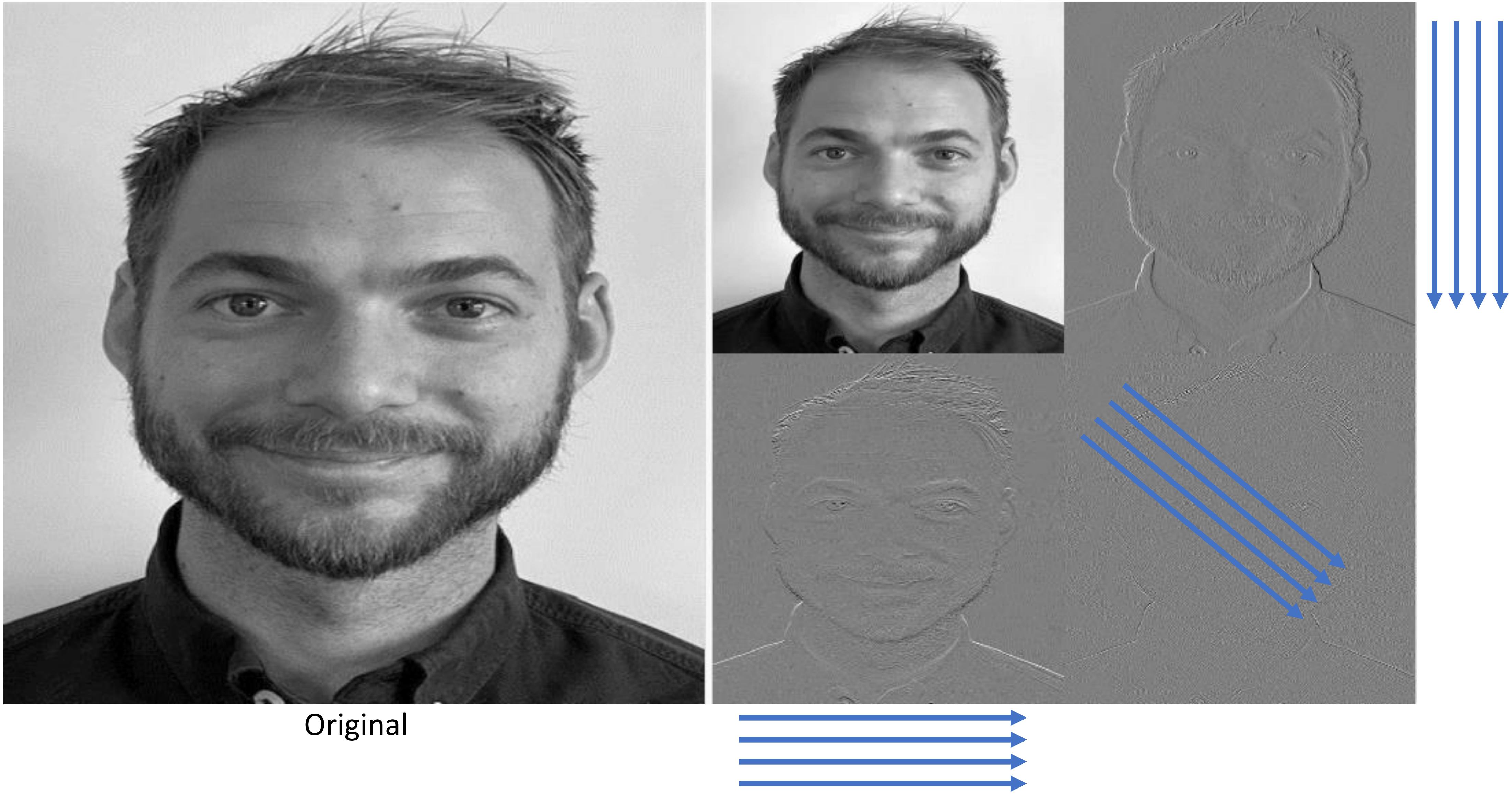
2. Wavelet transformation



k-space | Image domain | Wavelet

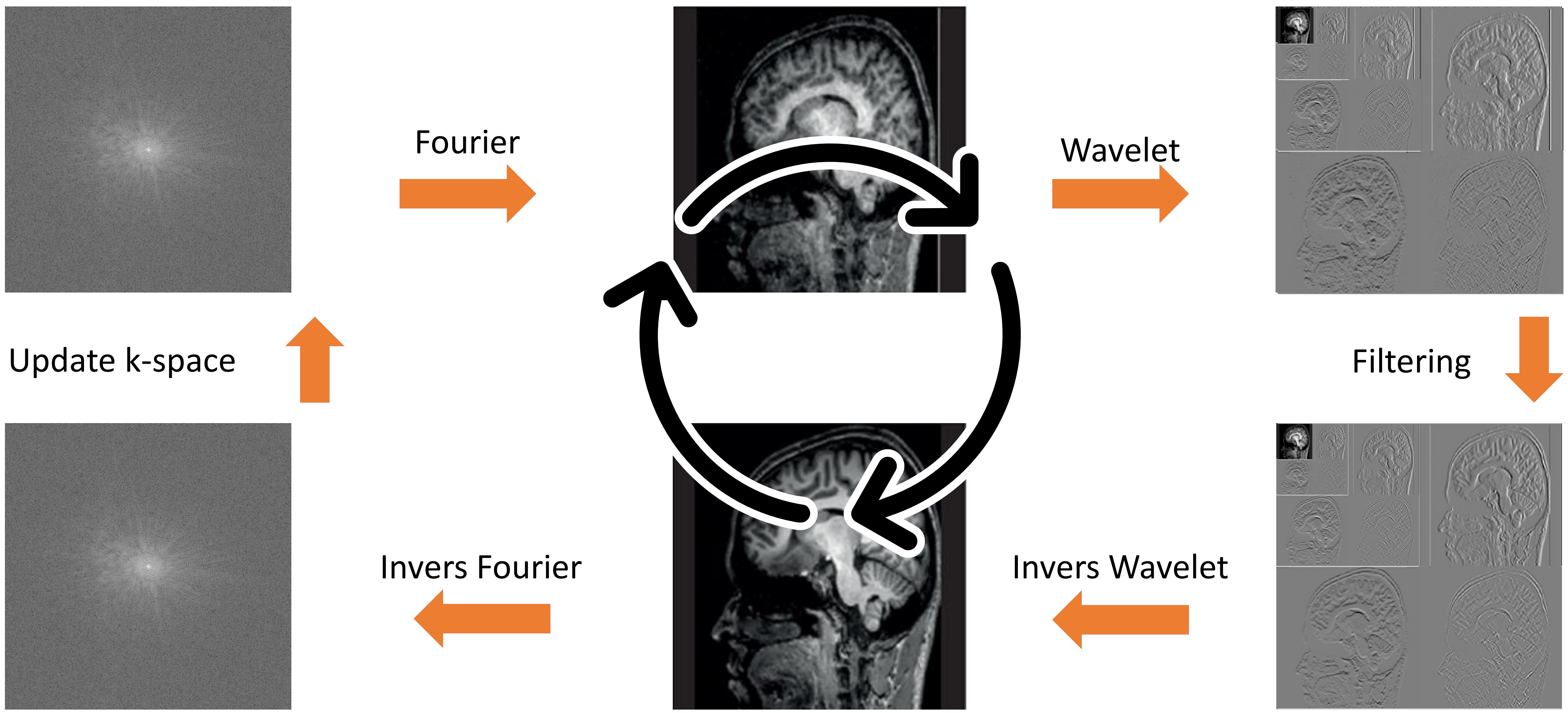
Uecker M., et.al. Software Toolbox and Programming Library for Compressed Sensing and Parallel Imaging. *ISMRM Workshop on Data Sampling and Image Reconstruction*. Sedona, 2013

2. Wavelet transformation (components)



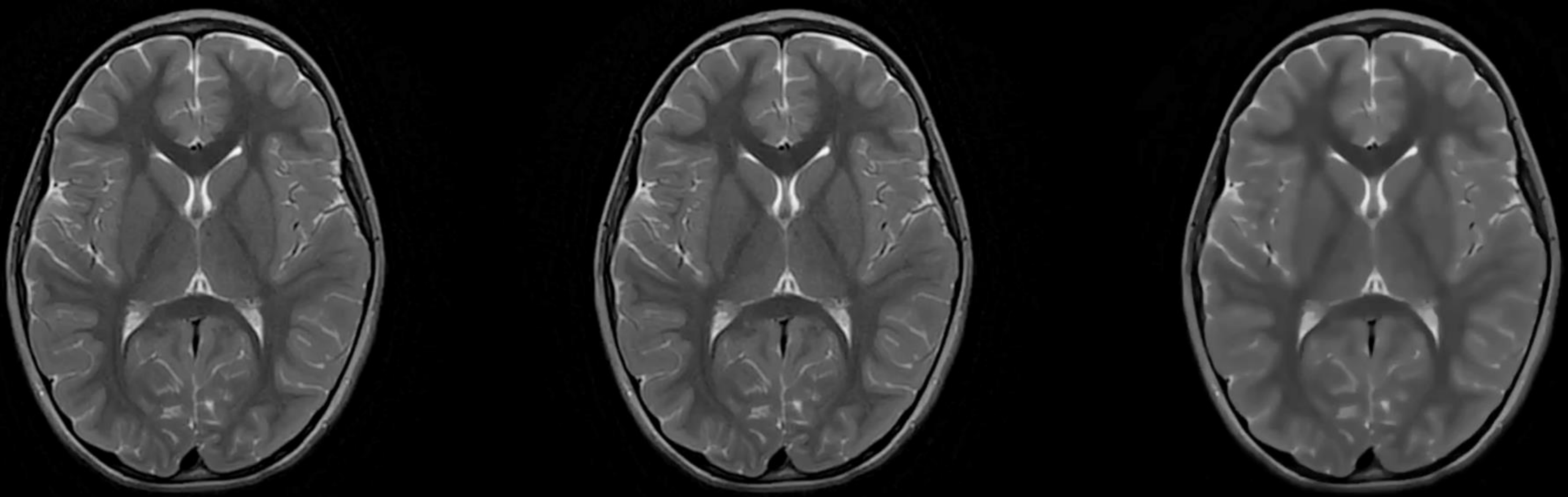
Original

3. Iterative reconstruction



Encoding, De-noising, & Sparsity-enforcing regularization

Original | CS image good | CS image bad



$$\hat{x} = \arg\min \{ \|Ex - y\|_2^2 + \Lambda \|Tx\|_1 \}$$

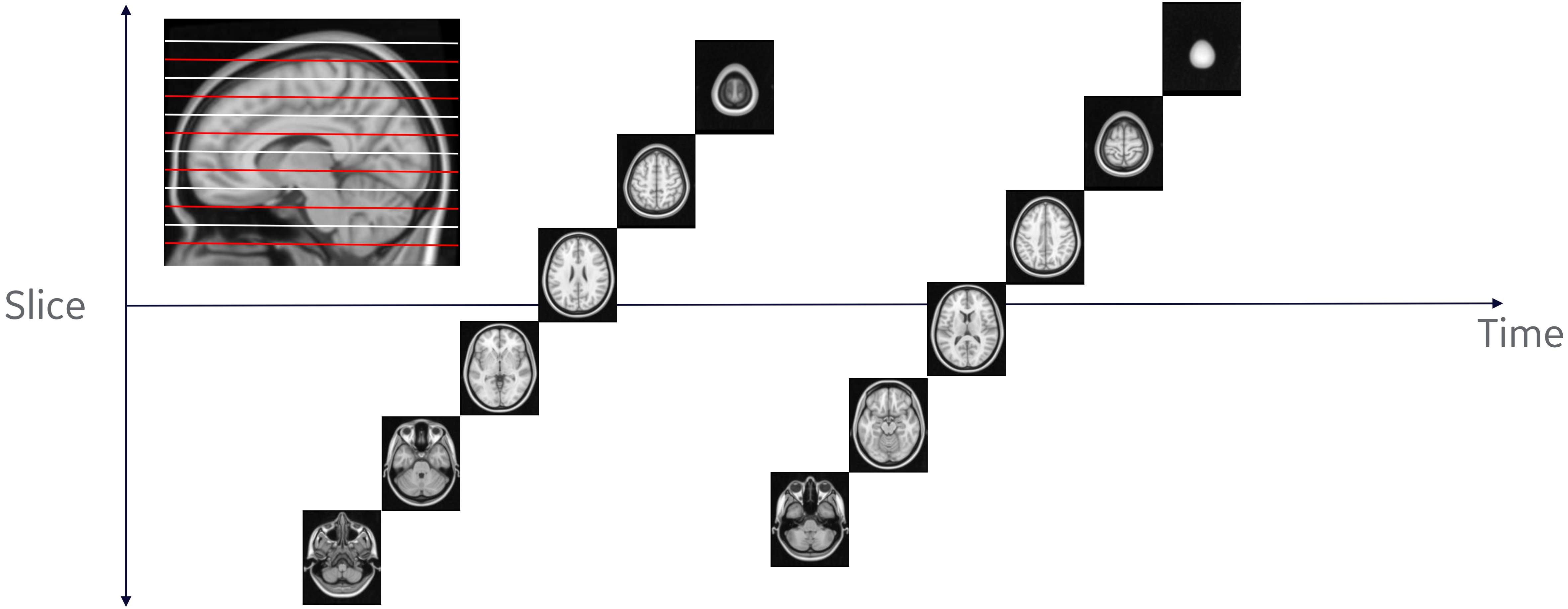
Knoll F., et.al. Second Order Total Generalized Variation (TGV) for MRI. Magn Reson Med. 2011;65(2):480-491

Compressed Sensing - applications

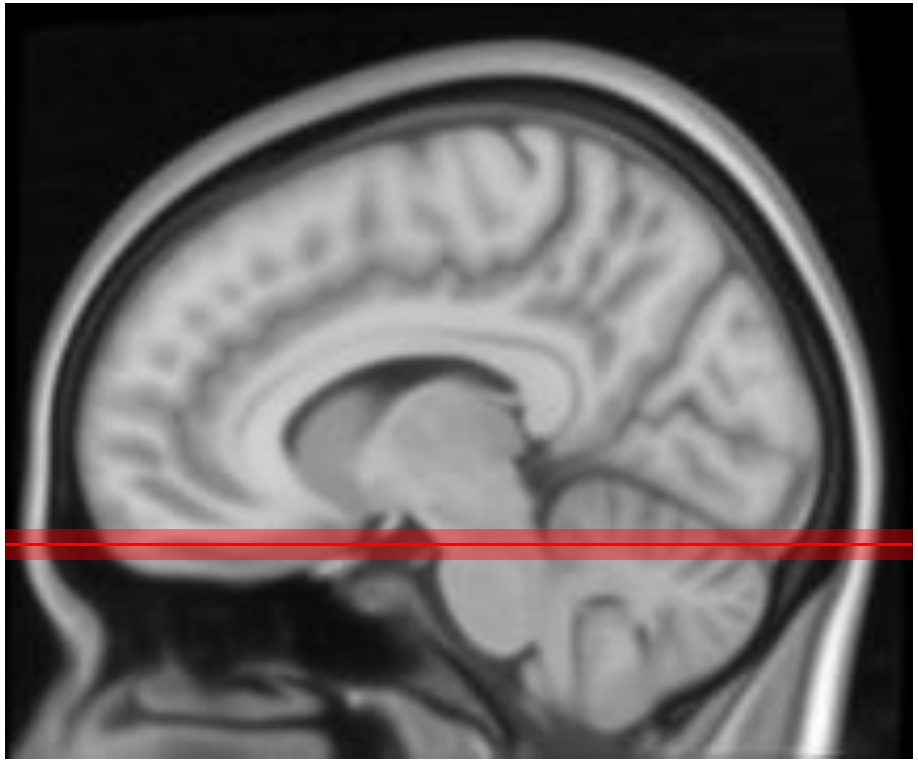
- Faster image acquisition
- Better image quality
- Can be used for all anatomical areas
- Can be used in both 2D and 3D sequences, but not EPI
- Faster breath hold / dynamic images

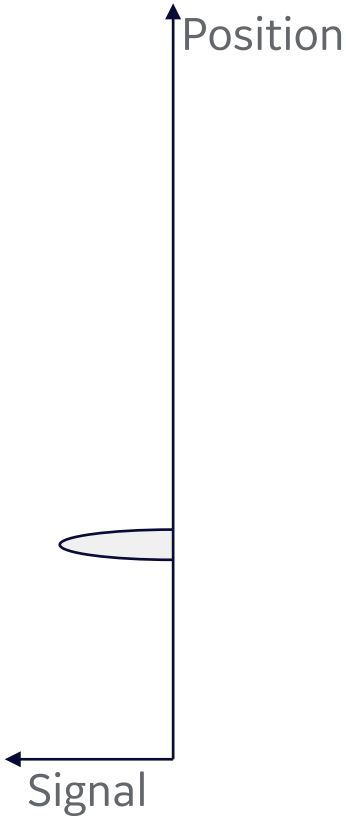
Multiplex

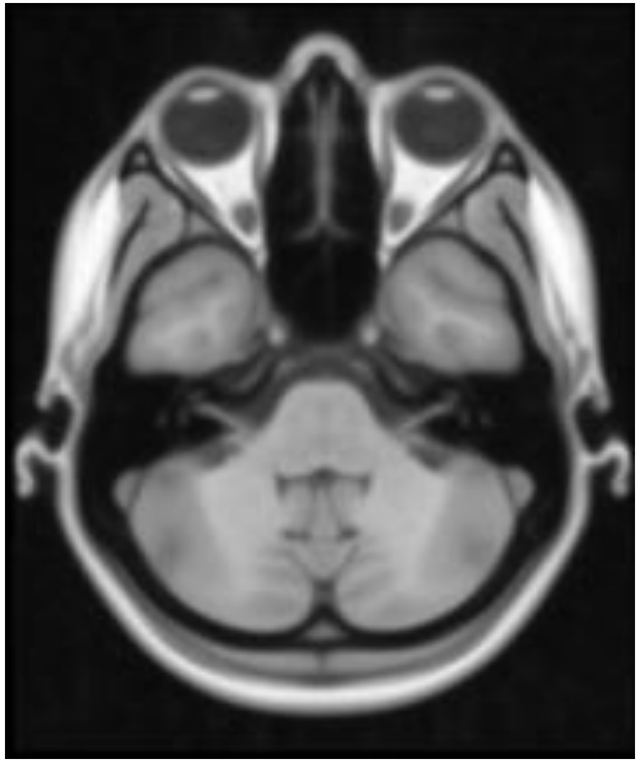
Conventional interleaved acqusition



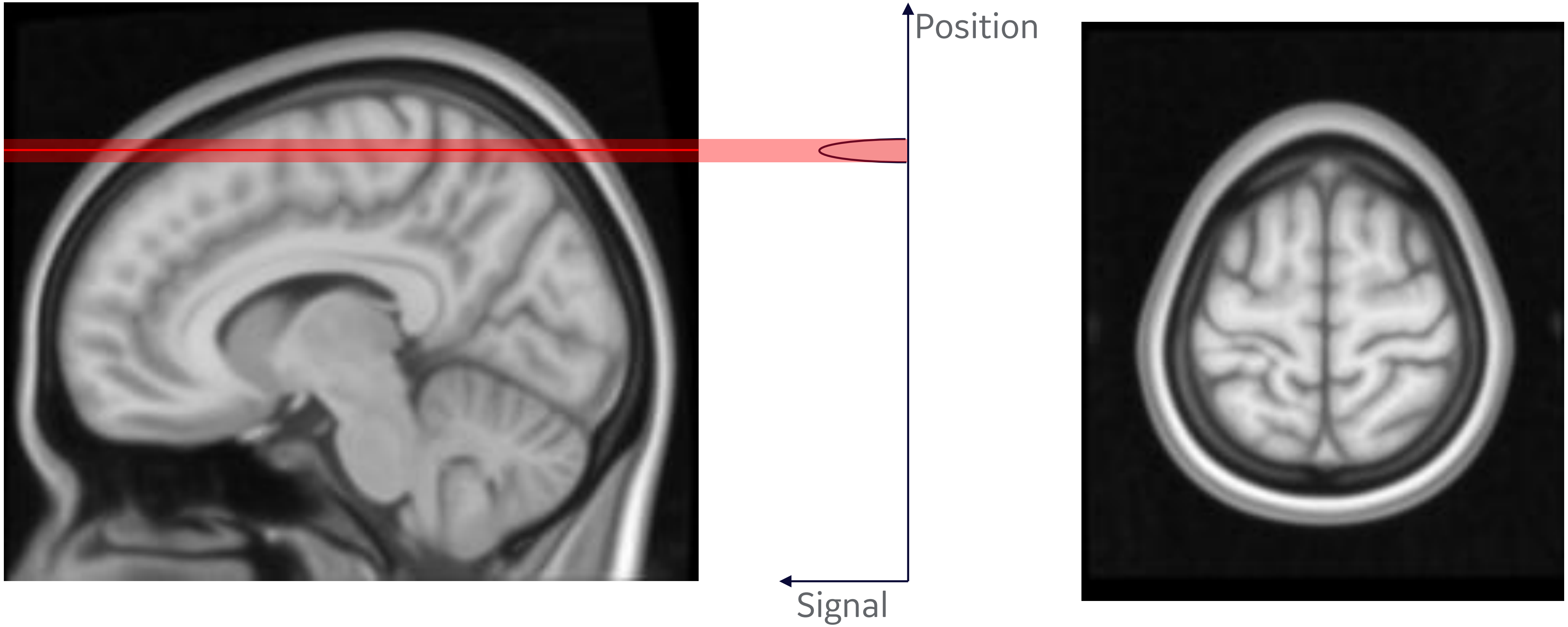
Conventional acqusition



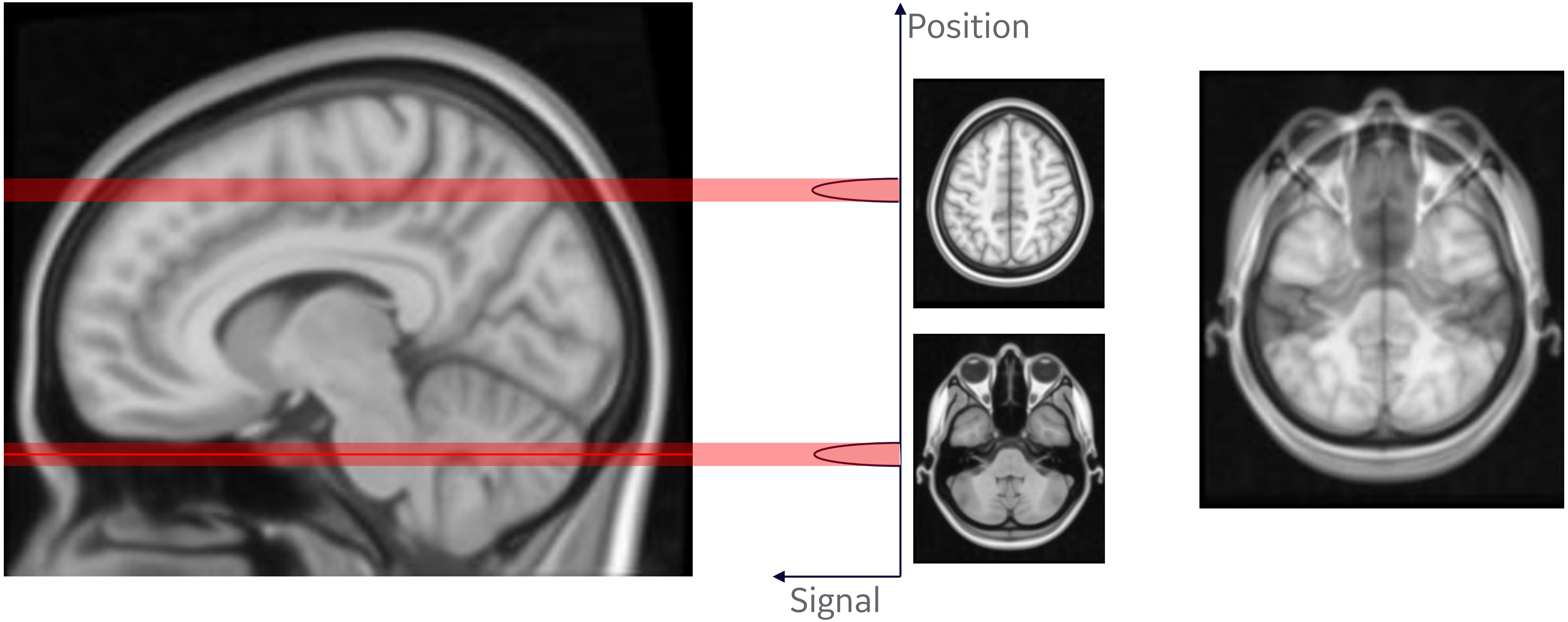




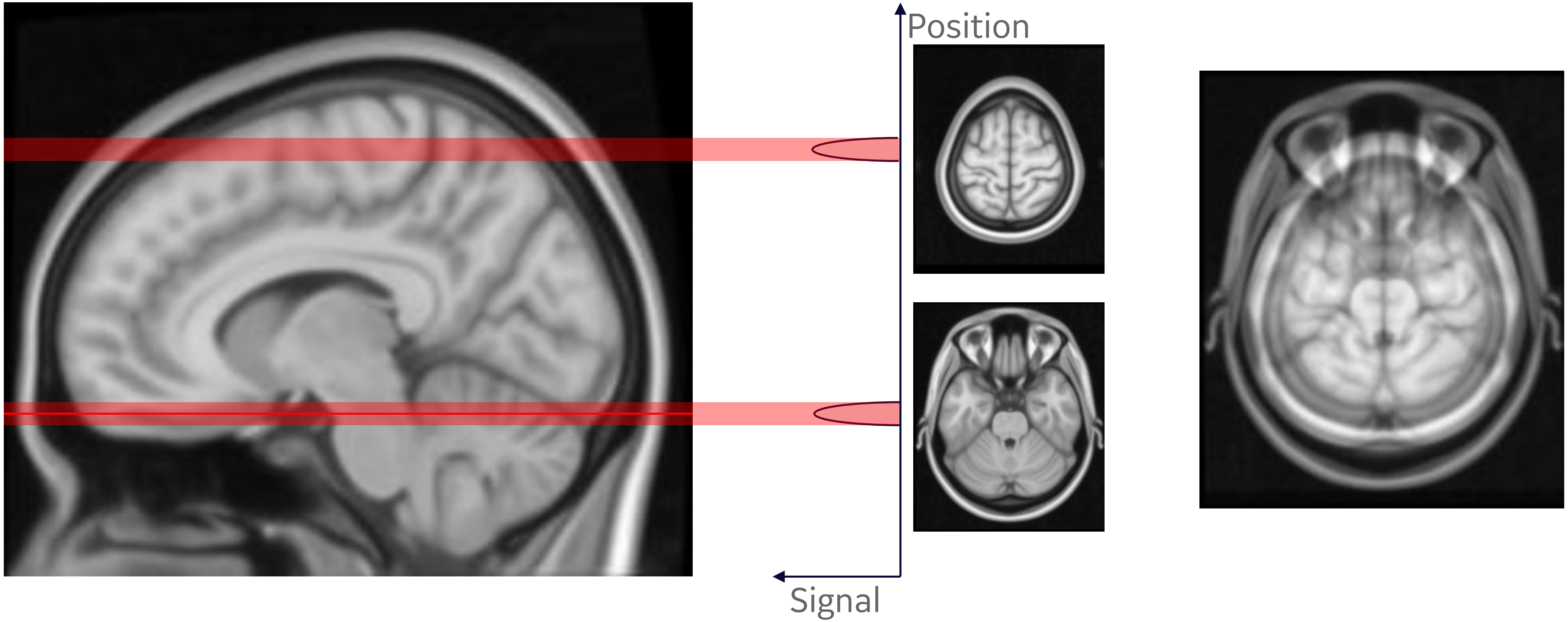
Conventional acqusition



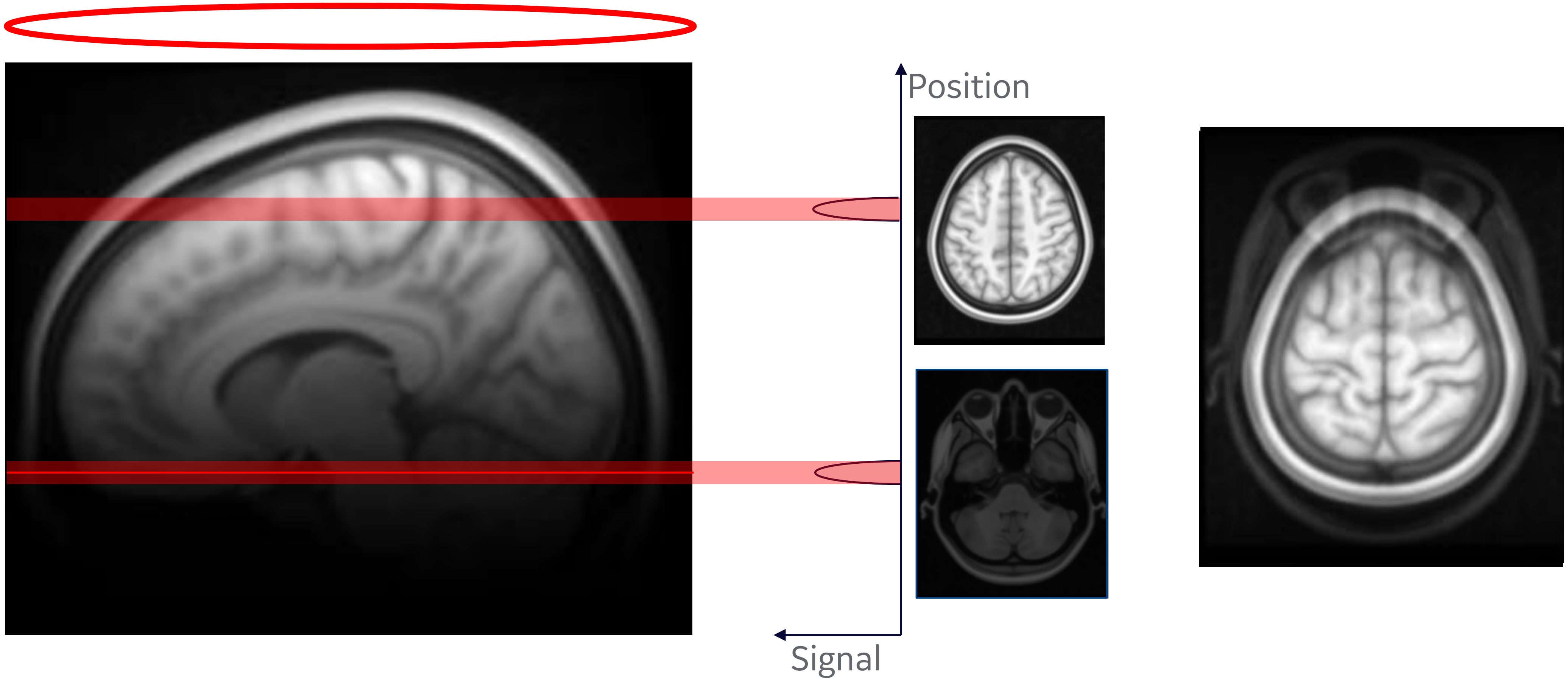
Multiplex acqusition



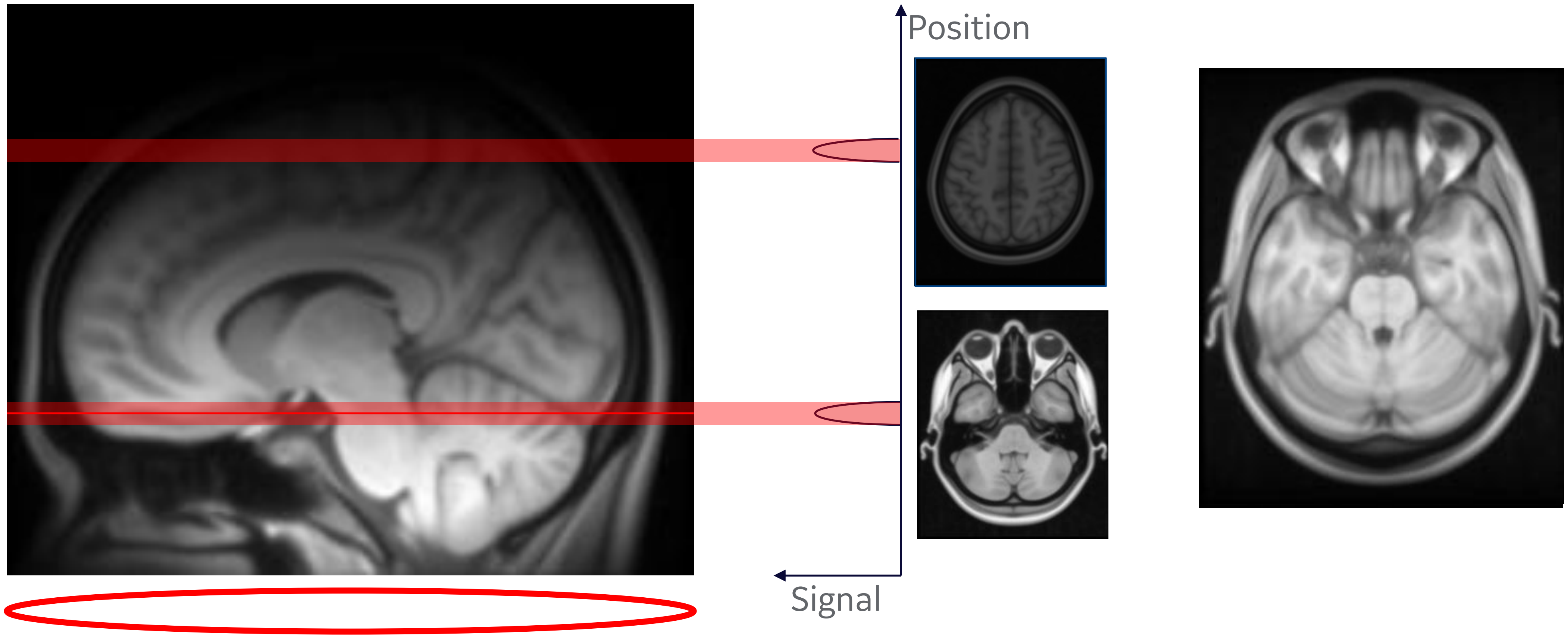
Multiplex acqusition



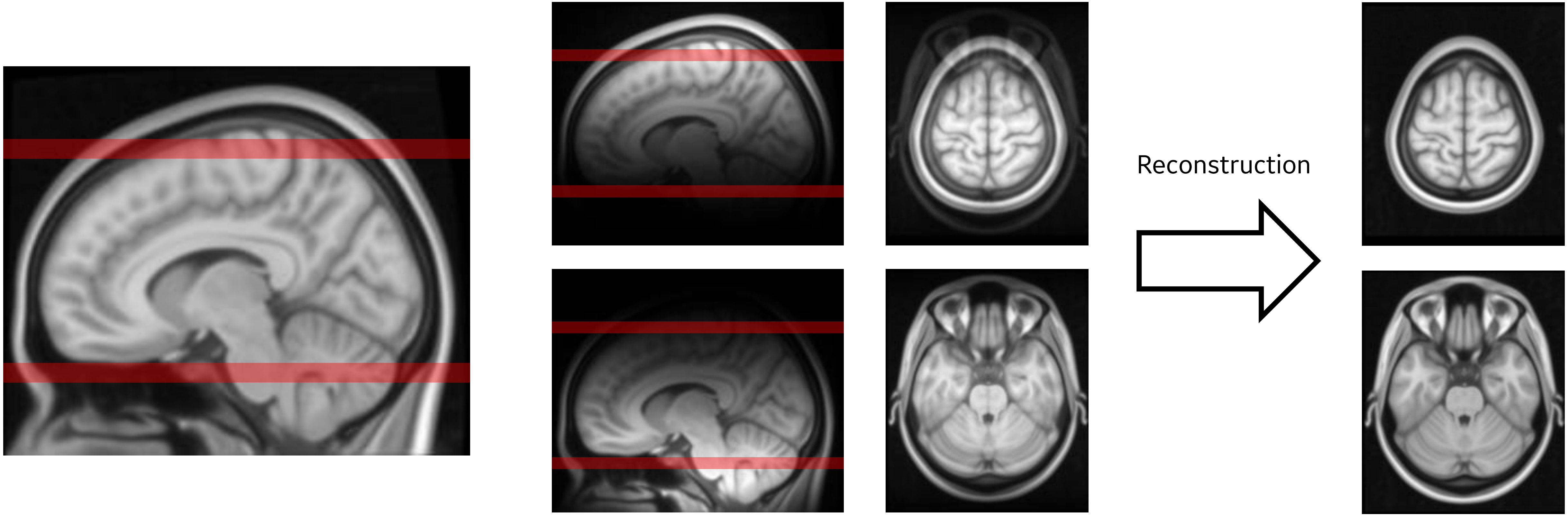
Coil element no. 1



Coil element no. 2

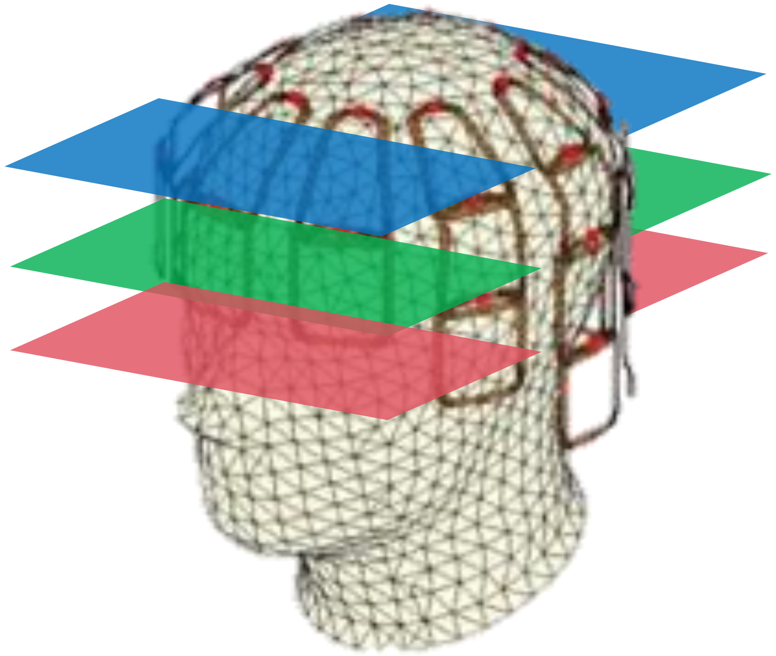


Coil element no. 1 + no. 2



Multiplex - applications

- More slices per. excitation
- Uses coil sensitivity for separation
- 1.5-3 acceleration without loss of SNR
- Can be combined with Parallel Imaging
- Reduces scan time by e.g.:
  - Multiple slices
  - Fewer NEX
  - Fewer recordings

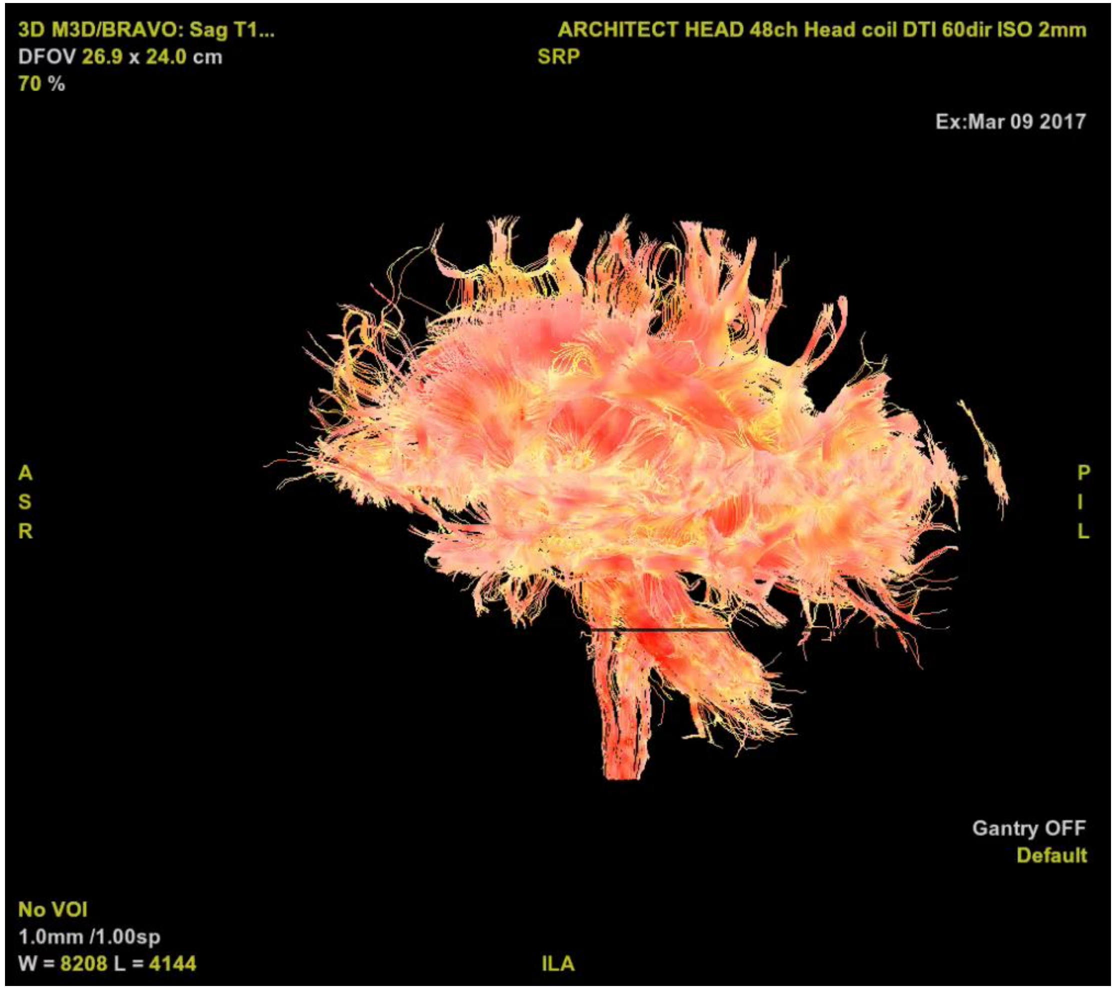


Mulitplex – why in diffusion?

- Multiple shells (b-values)
- Scan efficiency
- Higher resolution
- Isotropic solution
- Thinner slices
  - All in one TR
  - Larger z-FOV

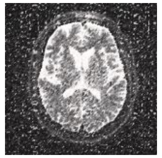
SIGNA™ Architect 3.0T
48 channel Head coil
b-value 1000
HyperBand factor = 2
ARC = 2
Voxels = 2.00mm isotropic
Number of diffusion directions = 60
Number of b-0 volumes = 8

Total scan time = 8 minutes



Hyperpolarized applications

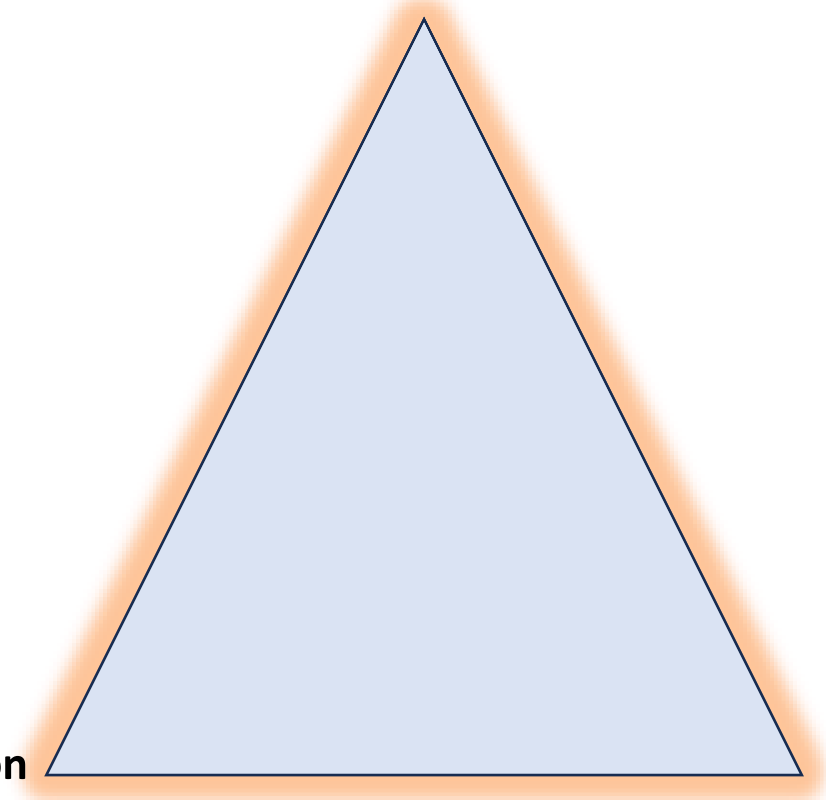
Hyperpolarized applications



SNR

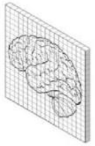
Thermal polarisation

$$\text{SNR} \propto \frac{\Delta \text{V}}{\sqrt{\text{BW}}}\sqrt{\text{N}}$$



Hyperpolarisation

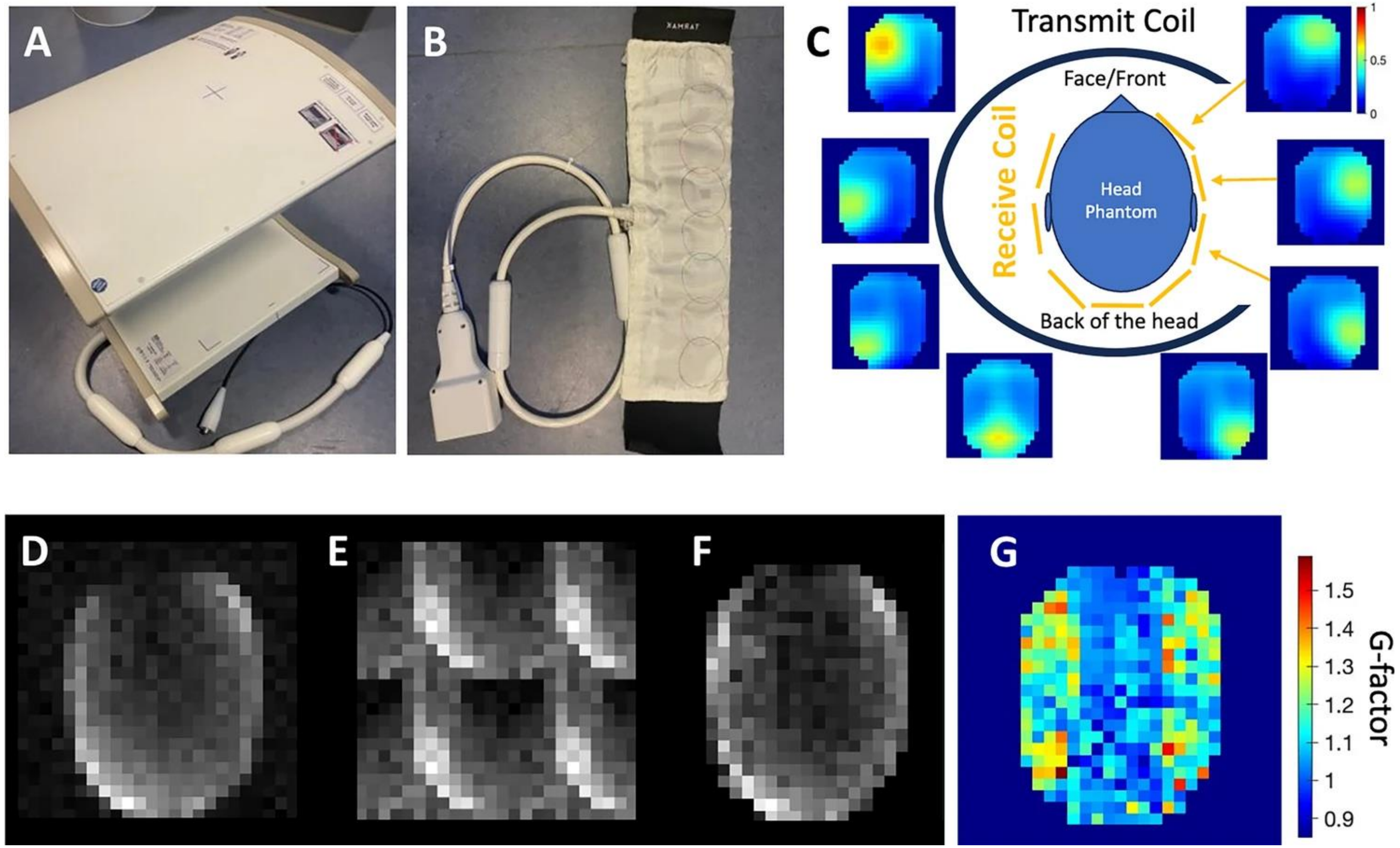
$$\text{SNR} \propto \frac{\Delta \text{V}}{\sqrt{\text{BW}}\sqrt{\text{N}}} \frac{1-\cos^{N}(\alpha)}{1-\cos(\alpha)}$$



Resolution (ΔV)

Scan time (N)

SENSE w. 23Na map in HP 13C imaging

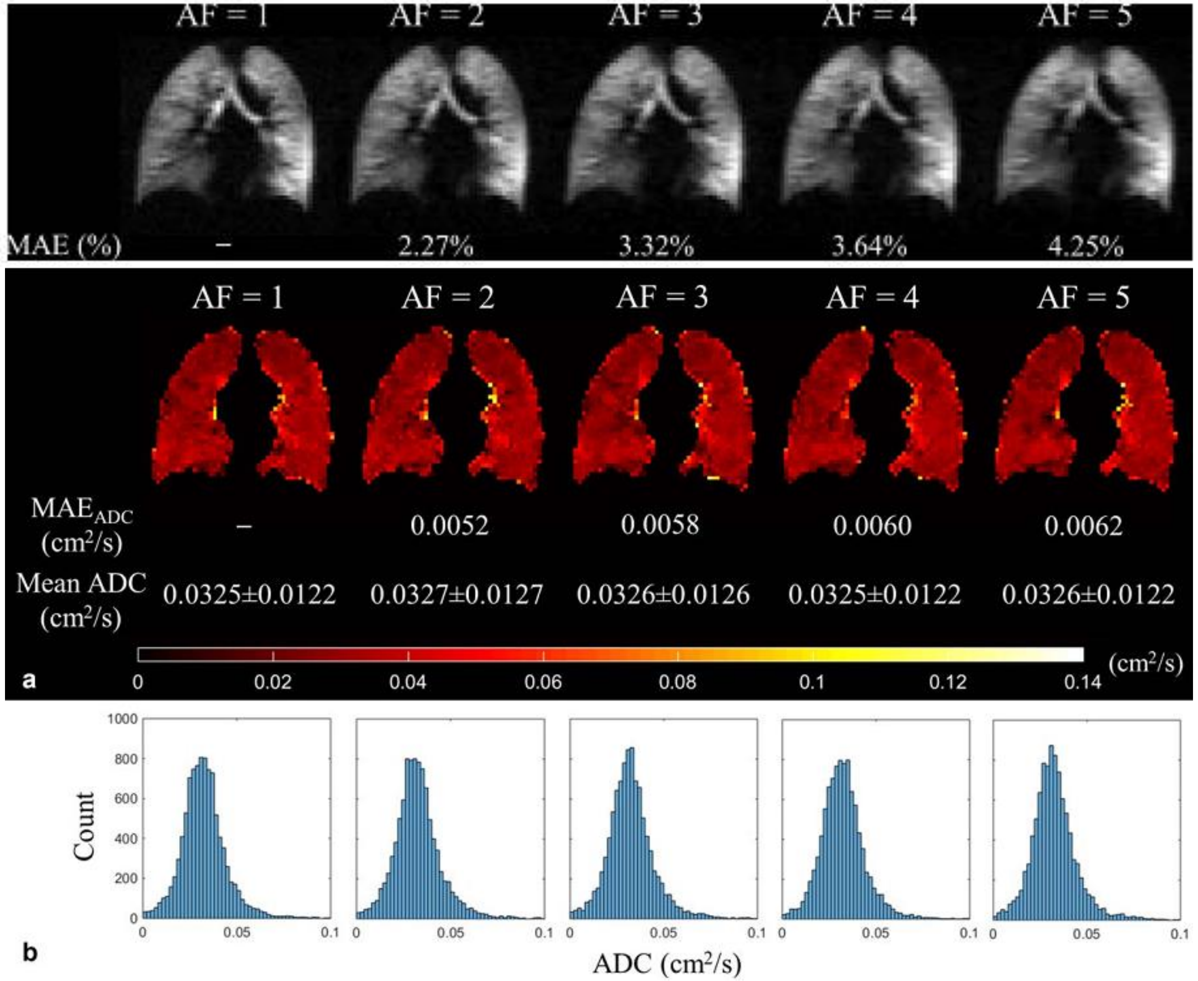


Coil-element sodium sensitivity maps

(**D**) Fully sampled ^{13}C image. (**E**) Under sampled ^{13}C image. (**F**) Under sampled SENSE reconstructed image.

Enabling SENSE accelerated 2D CSI for hyperpolarized carbon-13 imaging, Shinozaki A, Sci Reps, 2024

Compressed sensing to facilitated single-breath 3D multiple b-value 129Xe DW-MRI acquisitions



3D Diffusion-Weighted 129Xe MRI for Whole Lung Morphometry, Chang H, MRM, 2018

Moesgaard Forest, Aarhus