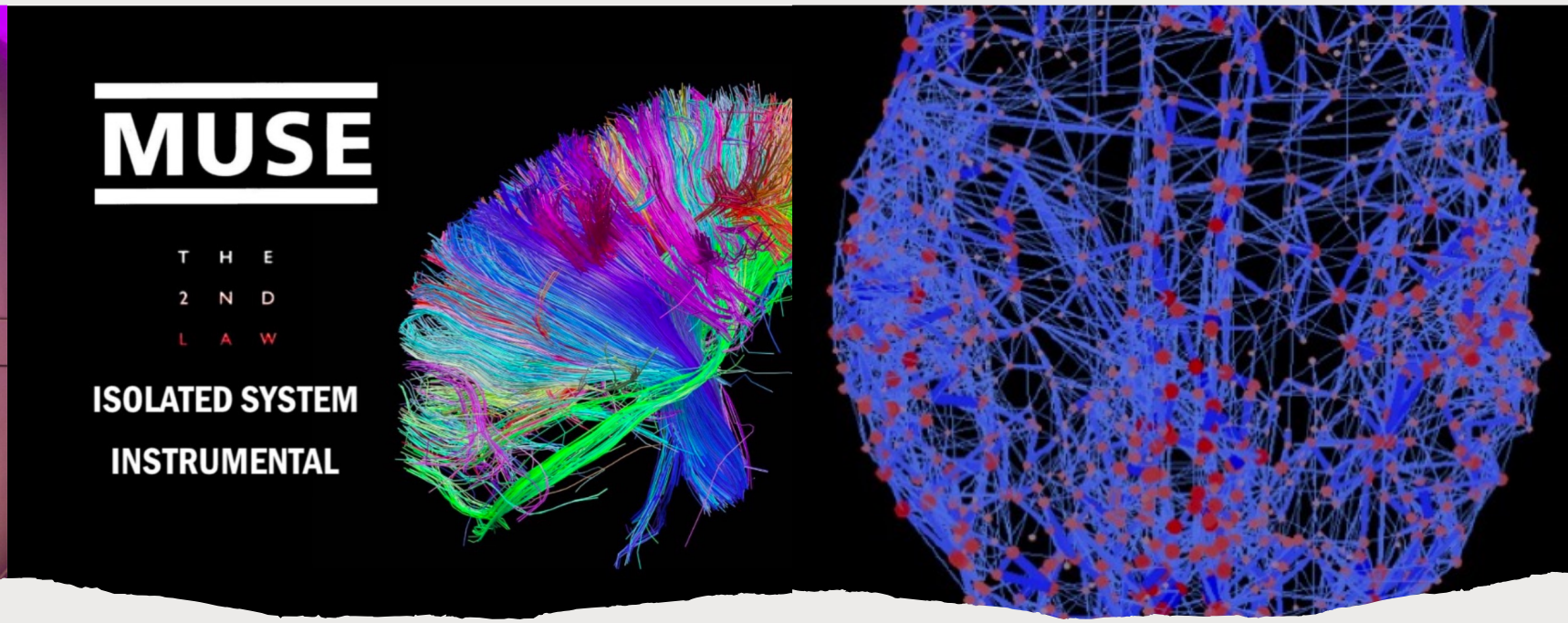
FAST MR IMAGING METHODS

Valerio Zerbi

EPFL and CIBM

CIBM translational MR neuroimaging & spectroscopy, 25.04.2023



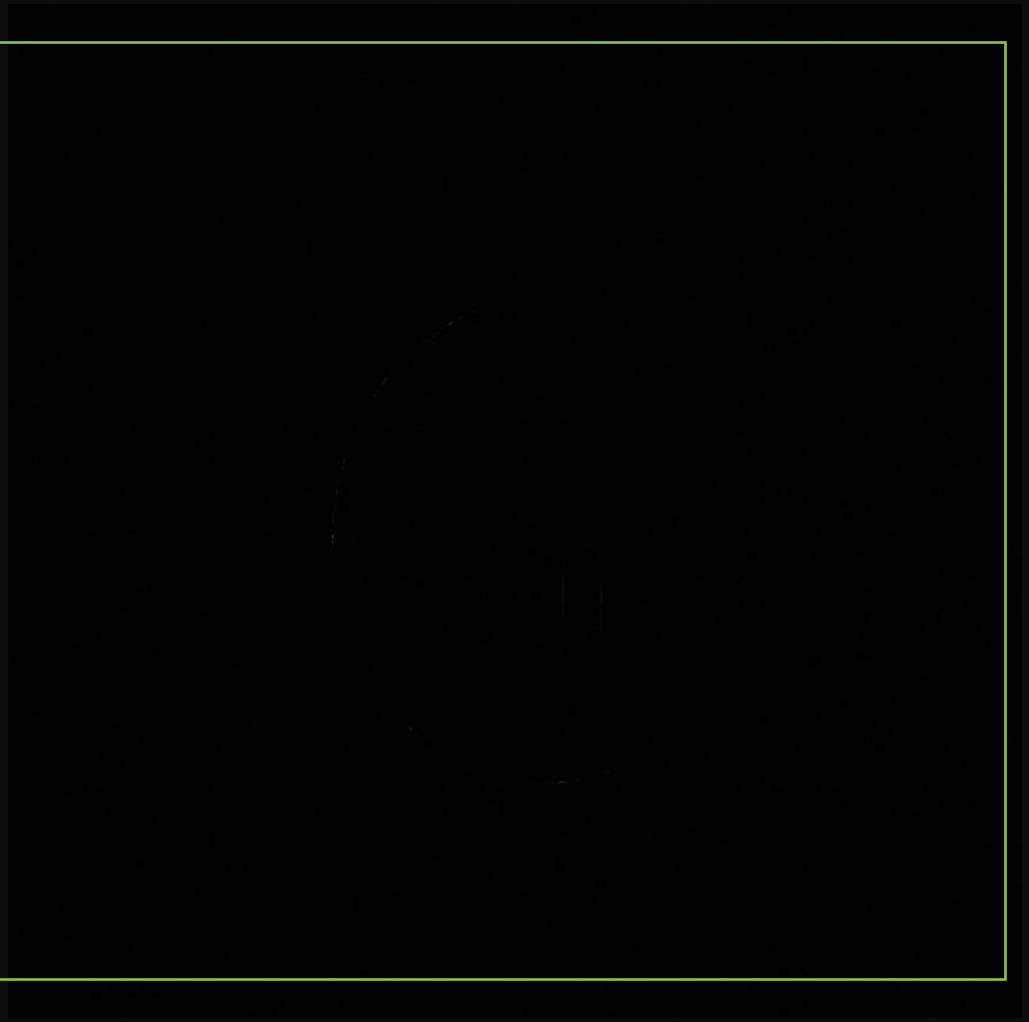
Overview of the afternoon

- **PART1.** Fast MRI, K-Space, Parallel Imaging, and Echo-Planar Imaging, Pros and artifacts (Speaker: Valerio Zerbi)
- **PART2.** Diffusion MRI. MRI sequences and applications of diffusion-weighted imaging (Speaker: Ileana Jelescu)
- **PART 3.** Functional MRI. What is brain function, the BOLD signal, applications of functional imaging, task and resting-state, introduction to large multi-site initiatives (Speaker: Valerio Zerbi)

ULTRA-HD MRI

This is a 100 micron isotropic resolution magnetic resonance imaging (MRI) scan of the human brain on a 7 Tesla MRI scanner

This is a brain specimen. The researchers imaged it for 5 days continuously using a custom-built 31-channel receive array coil.



WHY DO WE NEED FAST IMAGING ACQUISITIONS?

ZE can you make a 5 bullet point on why we need fast MRI acquisitions?

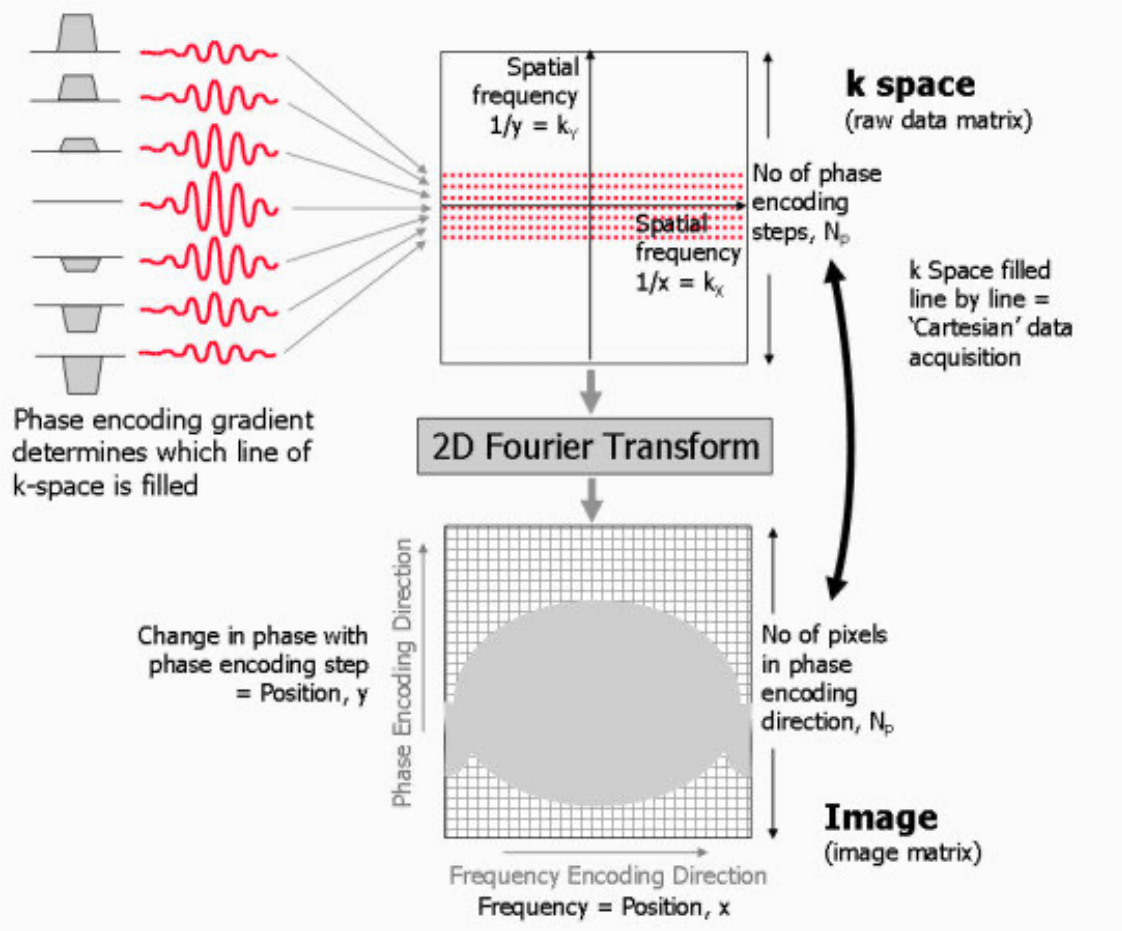
Sure, here are five reasons why fast MRI acquisitions are important:

1. Reducing motion artifacts: Fast MRI acquisitions can reduce motion artifacts caused by patient movement during the scan. This is particularly important when imaging children or patients with conditions that cause involuntary movements.
2. Improving patient comfort: Fast MRI acquisitions can help reduce scan time, which can improve patient comfort and compliance. Patients who are uncomfortable or anxious during MRI scans may move more, which can lead to motion artifacts.
3. Increasing throughput: Fast MRI acquisitions can increase the throughput of MRI scanners, allowing more patients to be imaged in a shorter amount of time. This can be particularly important in busy hospitals or clinics.
4. Enhancing diagnostic accuracy: Fast MRI acquisitions can improve the accuracy of certain MRI exams, such as functional MRI (fMRI), which is used to map brain activity. By reducing the time between stimuli and imaging, fast fMRI acquisitions can provide a more accurate representation of brain activity.
5. Enabling new applications: Fast MRI acquisitions can enable new applications, such as real-time MRI, which can be used to visualize dynamic processes in the body, such as speech or swallowing. Real-time MRI can also be used to guide interventions, such as needle placement during biopsies.

First, a recap from Yesterday..

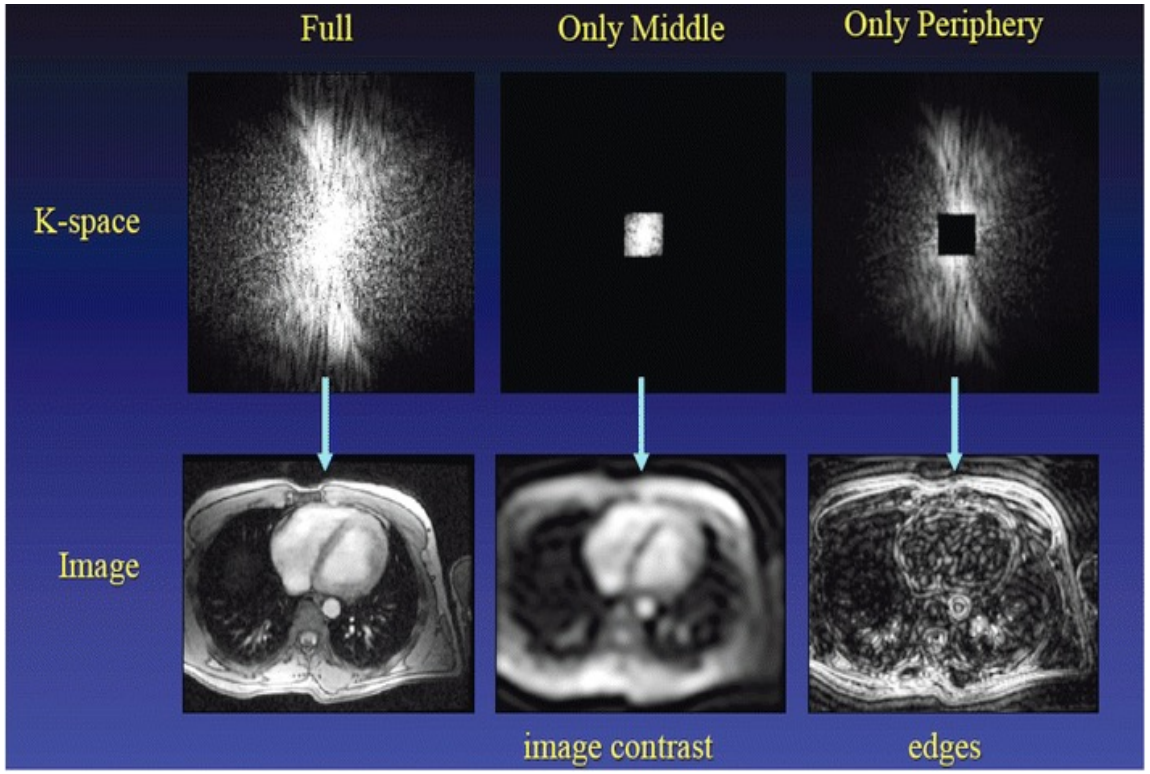
A LOOK BACK AT THE K-SPACE

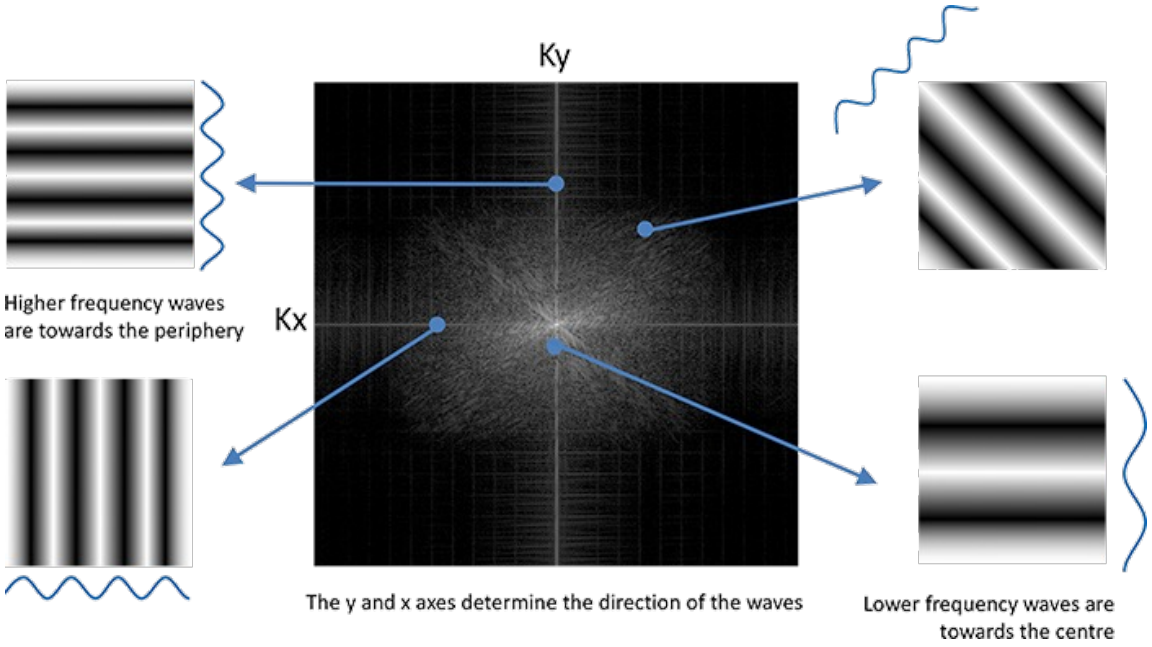
- K-space is the matrix containing the raw data from all the measurement before the Fourier Transformation.
- Rectangular in shape, and has two axes perpendicular to each other
- kX and kY axis represent represent spatial frequencies rather than positions
- Phase encoding gradient determines which line of the k-space is filled
- MR images are obtained by performing 2D-FT of k-space



PROPRIETIES OF THE K-SPACE (1)

Contrast and Resolution





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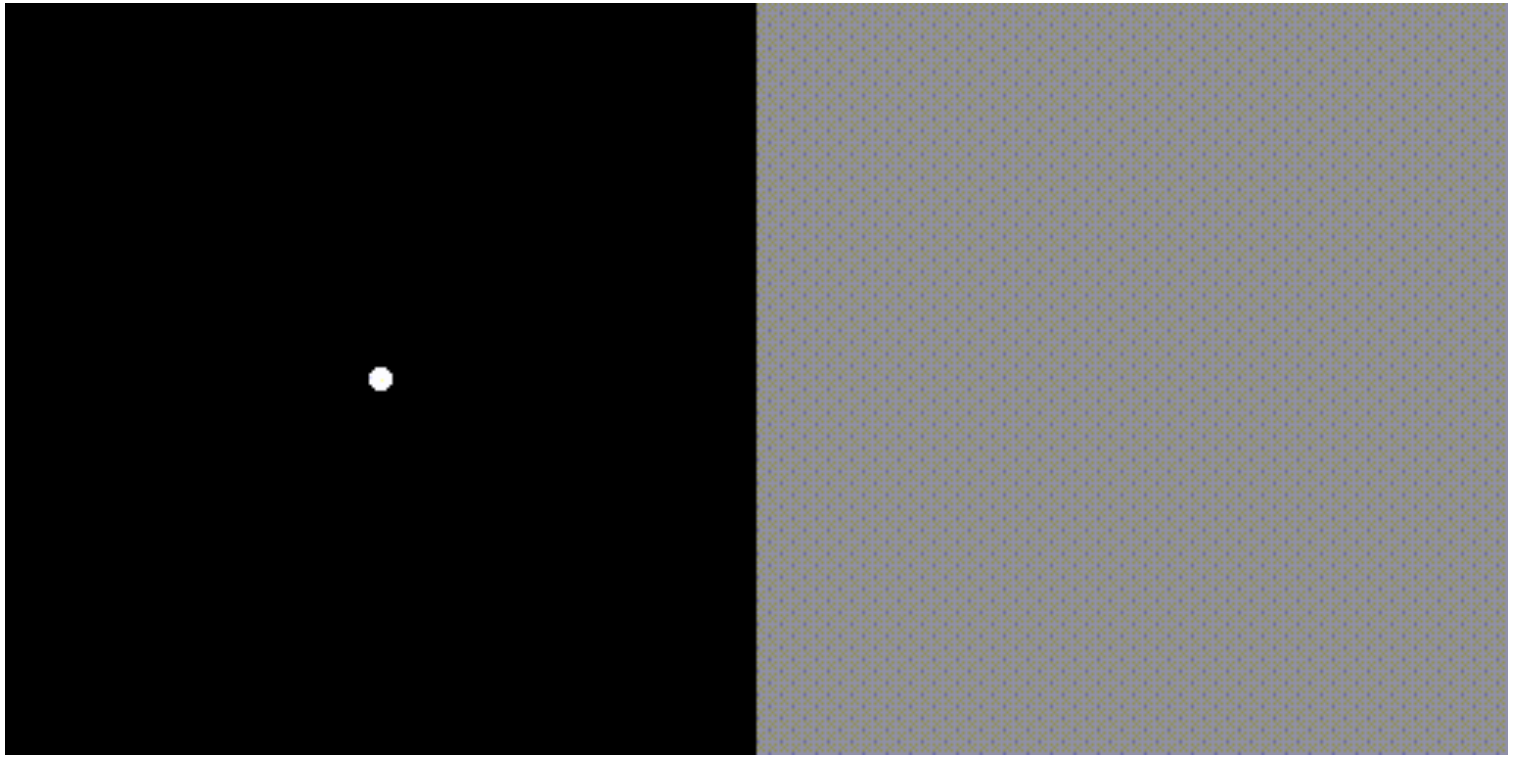
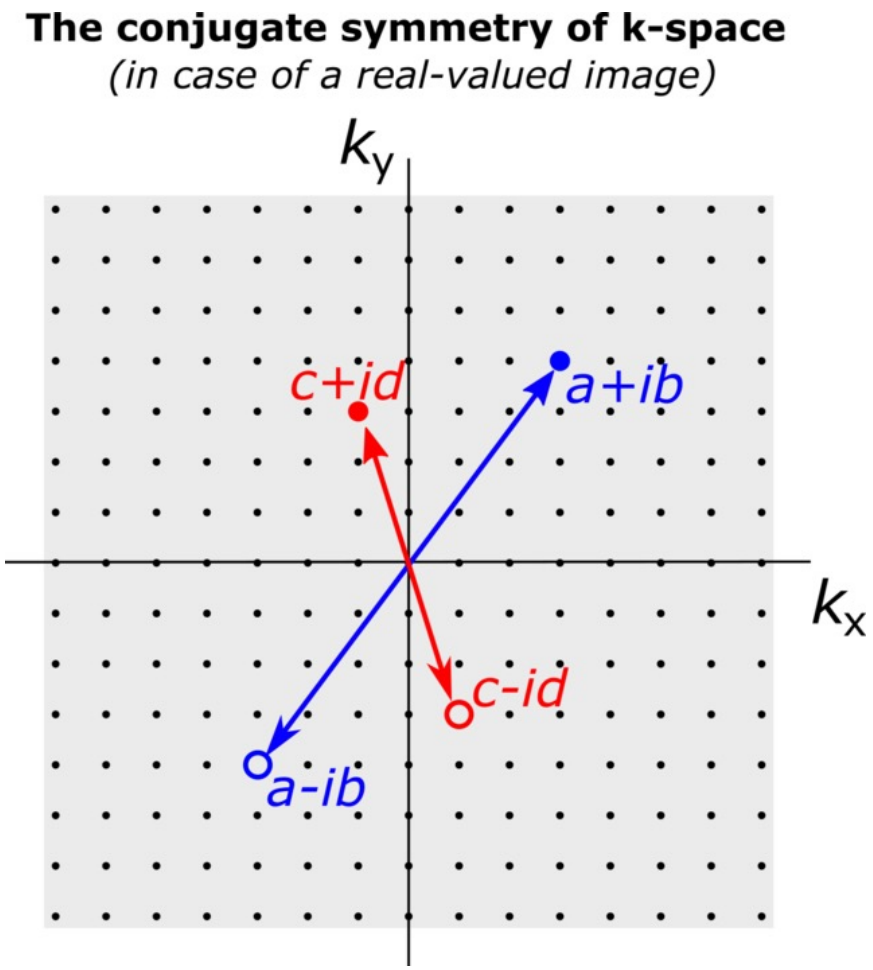


Movie showing spatial frequencies corresponding to various points in *k*-space.
(Courtesy Brian Hargreaves)

PROPRIETIES OF THE K-SPACE (2)

Point Symmetry

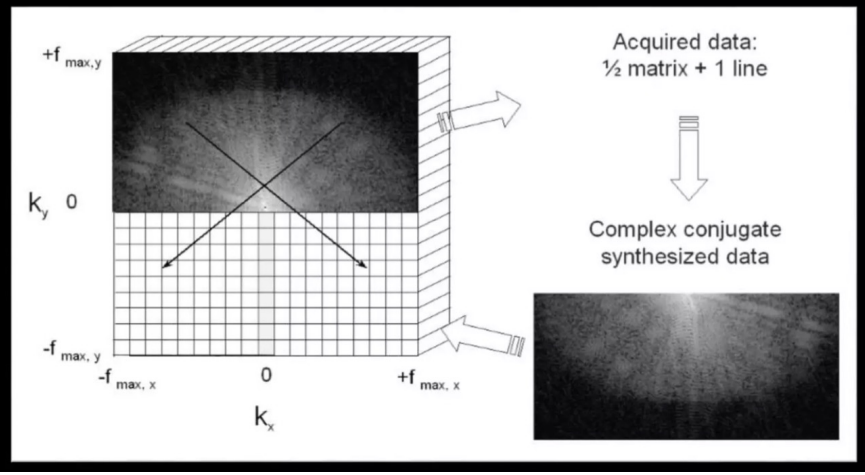


PROPRIETIES OF THE K-SPACE (2)

Q: If the k-space is symmetric, can we just fill half of it and save time?

HALF K-SPACE" ACQUISITION

- Only part of k-space is measured.
- The unmeasured points are estimated by conjugate symmetry through the center of k-space.



PARTIAL FOURIER IMAGING

✓The spatial information in either half of the k-space is identical

✓If only half of the data along the Ky is acquired , we can reduce the imaging time

✓It reduce the SNR by a factor of 2,but no loss in spatial resolution

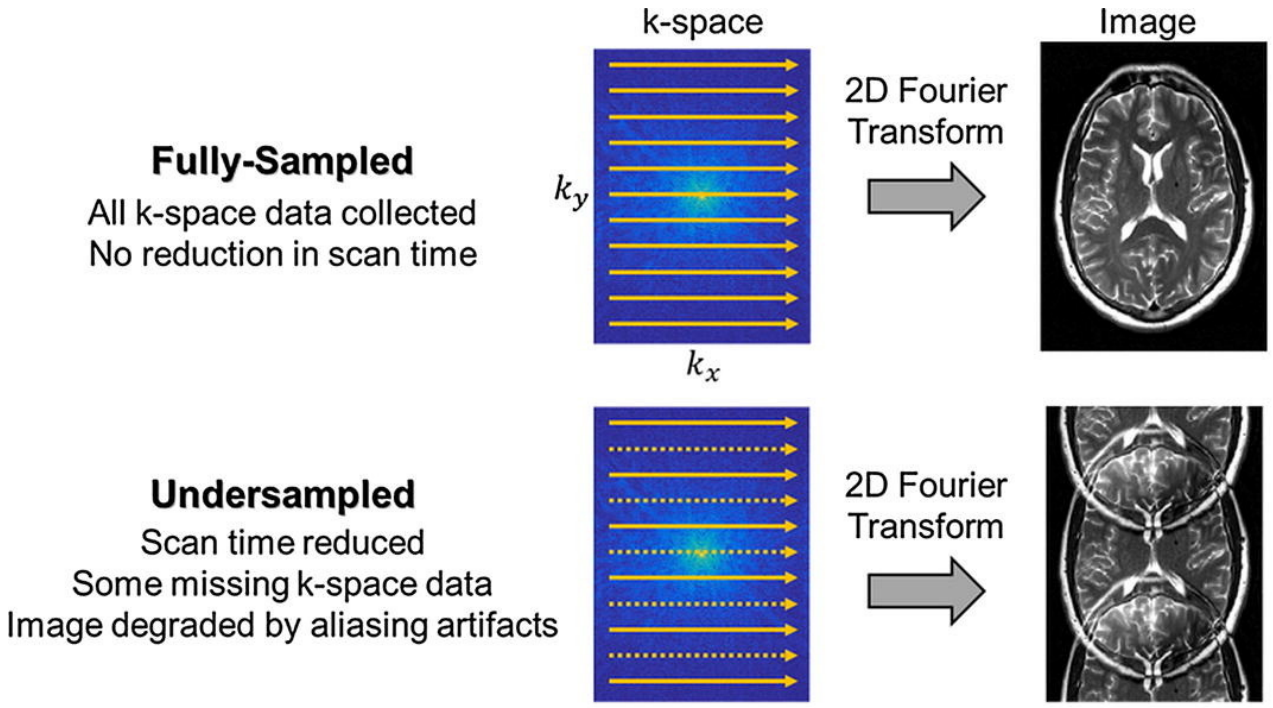
✓Routinely used for time-resolved perfusion & MRA

✓Commonly used in conjunction with HASTE & Balanced SSFP

PROPRIETIES OF THE K-SPACE (2)

Q: If the k-space is symmetric, can we just fill half of it and save time?

A: Yes, but..



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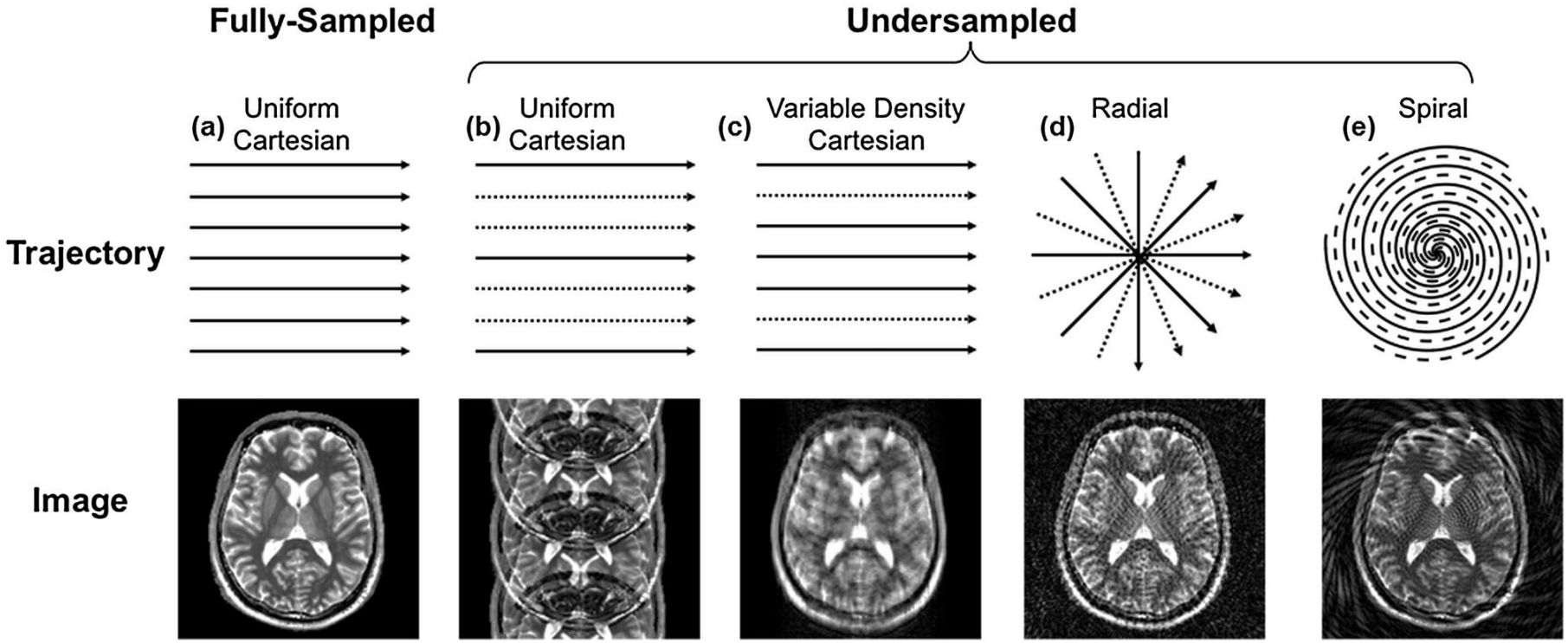
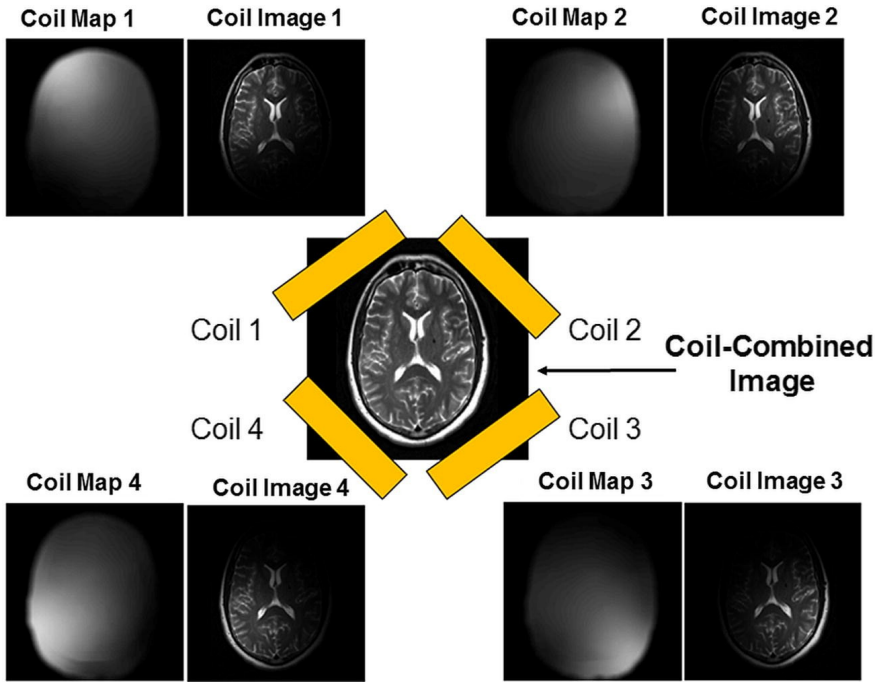


PROPRIETIES OF THE K-SPACE (2)

Q: If the k-space is symmetric, can we just fill half of it and save time?

A: ~~Yes~~, but..if we have more than one receiver coil, we could do **parallel imaging**

No



ELSEVIER

Progress in Nuclear Magnetic Resonance Spectroscopy

Volume 101, August 2017, Pages 71-95

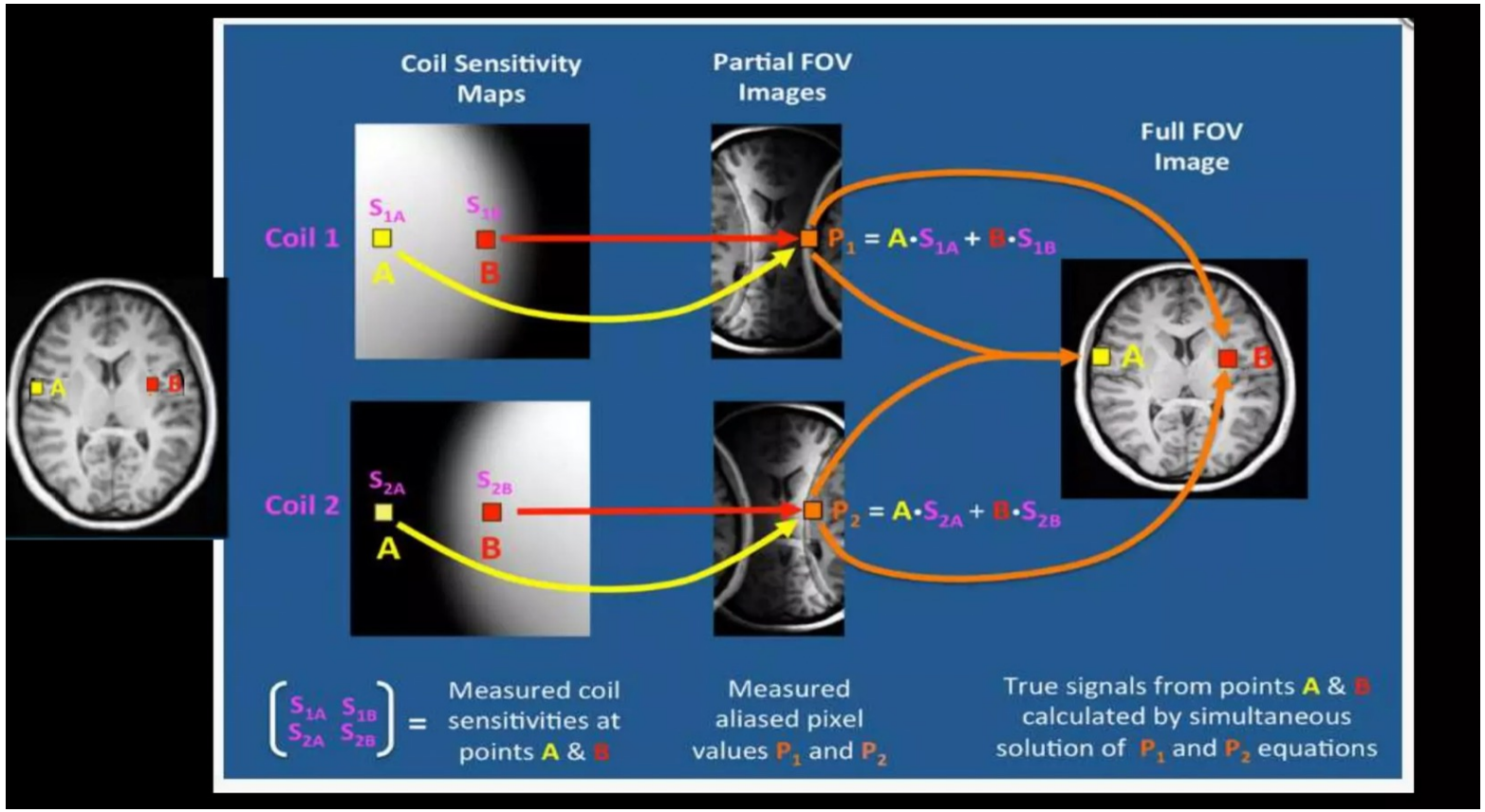
Recent advances in parallel imaging for MRI

Jesse Hamilton [a], Dominique Franson [a], Nicole Seiberlich [a b]

Multiple surface coils may be used to detect the MR signal, and their individual outputs are combined into one aggregate complex signal that is digitized and processed into the final image

PARALLEL IMAGING AT A GLANCE

Acquire, Reconstruct and Unfold



SENSE, ASSET, GRAPPA, ARC, …

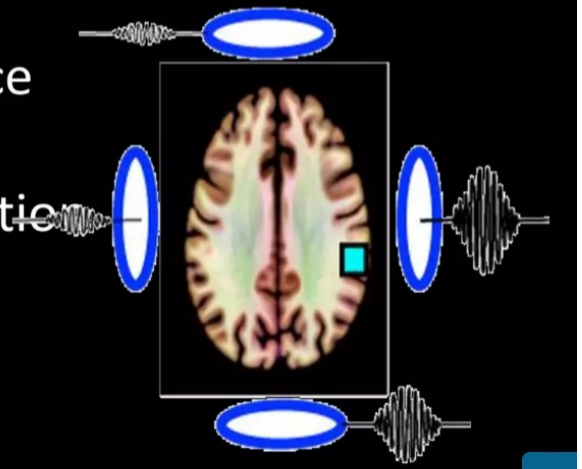
PARALLEL IMAGING AT A GLANCE

Acceleration factor (R)

If we have M coil elements covering the FOV, we can skip up to [M-1] lines for each line in k-space .

This can be fractional as well:

$$R = \frac{\text{no of phase-encodes to cover k-space}}{\text{no of phase-encodes used in acquisition}}$$

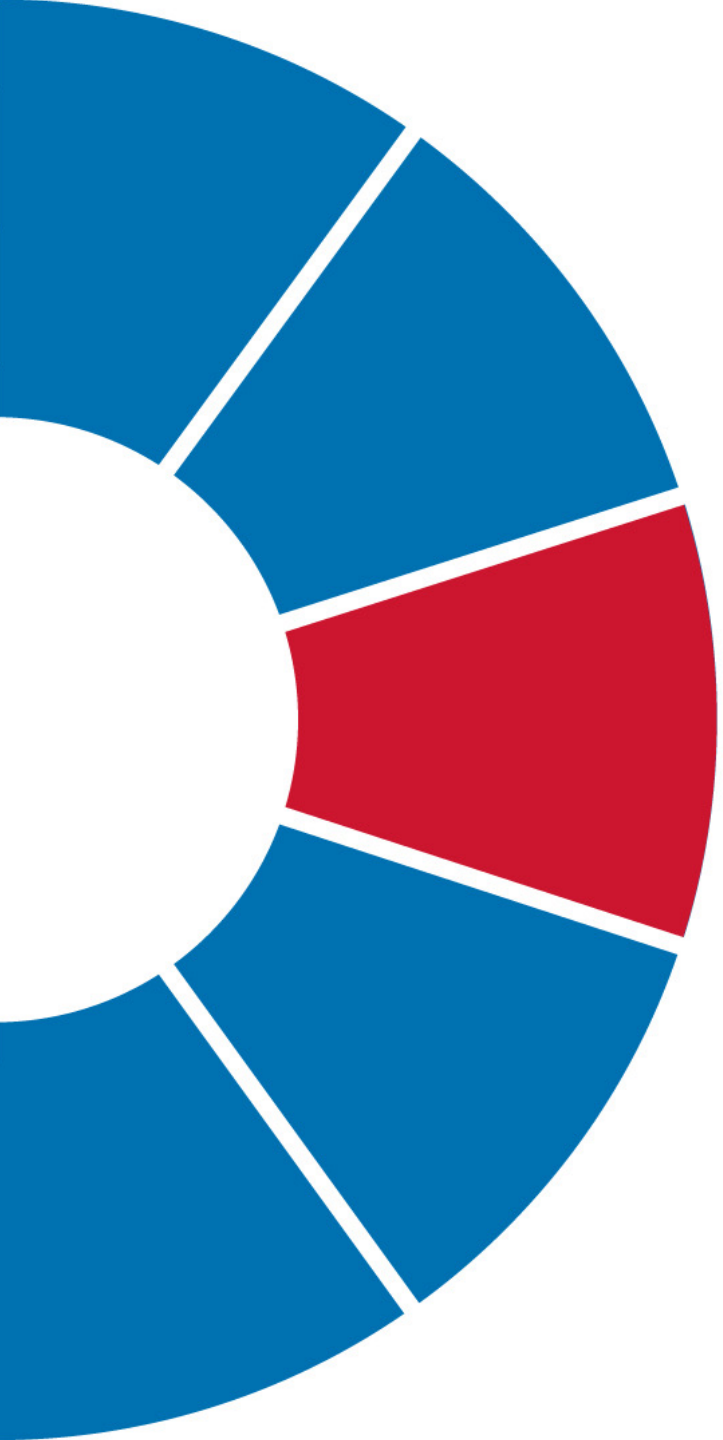


iPAT factor (Siemens)
ASSET factor (GE)
SENSE factor (Philips)

BUT…

$$SNR_{accelerated}(x,y) = \frac{SNR_{full}(x,y)}{g(x,y)\sqrt{R}}$$

AND…

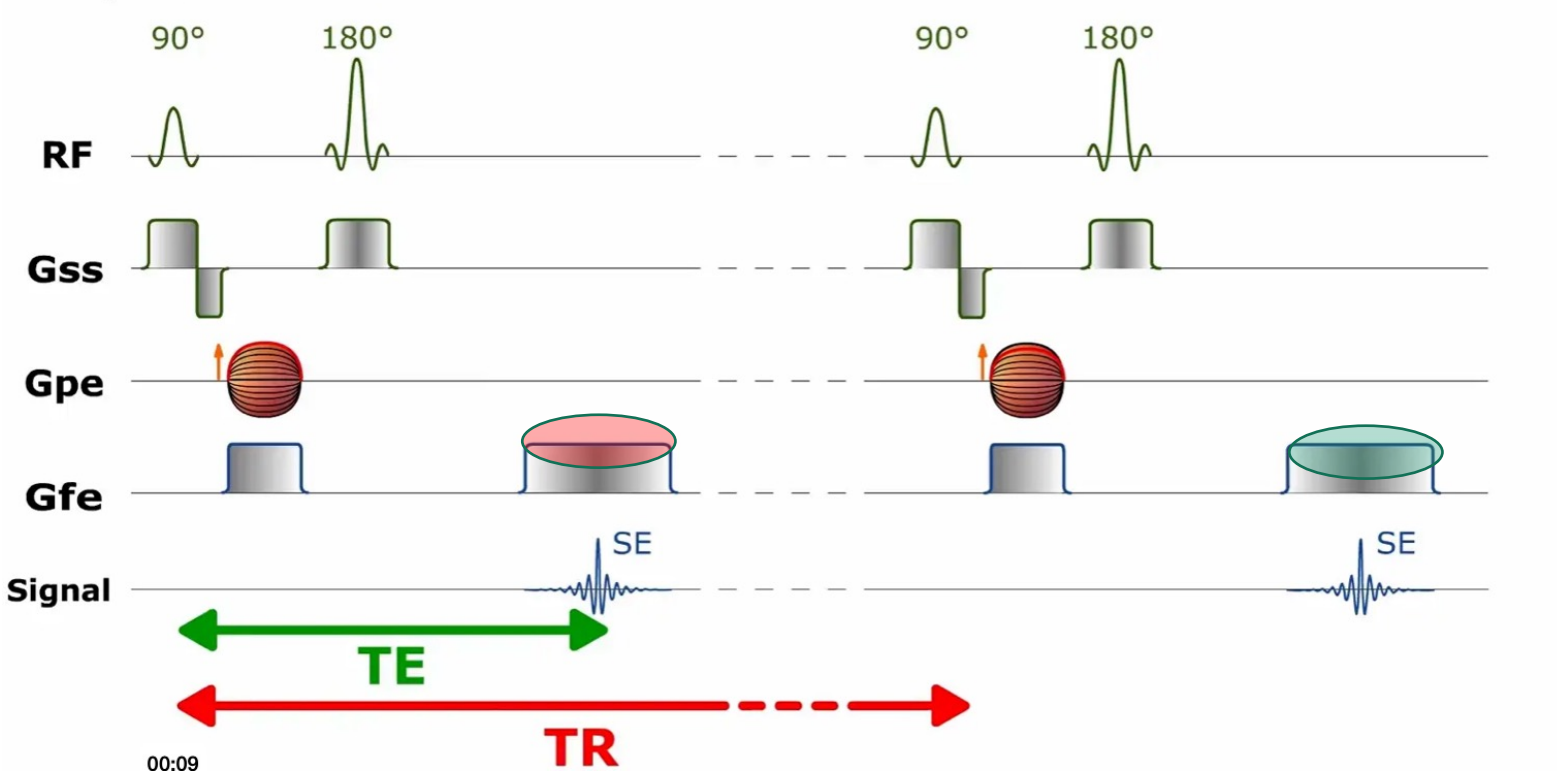


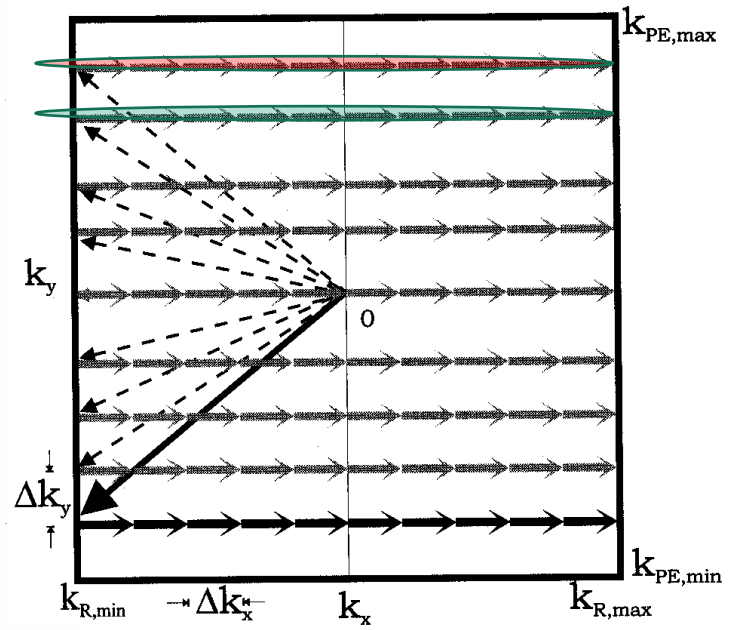
ECHO PLANAR IMAGING (EPI)

Let’s hear the words of a Nobel Price winner

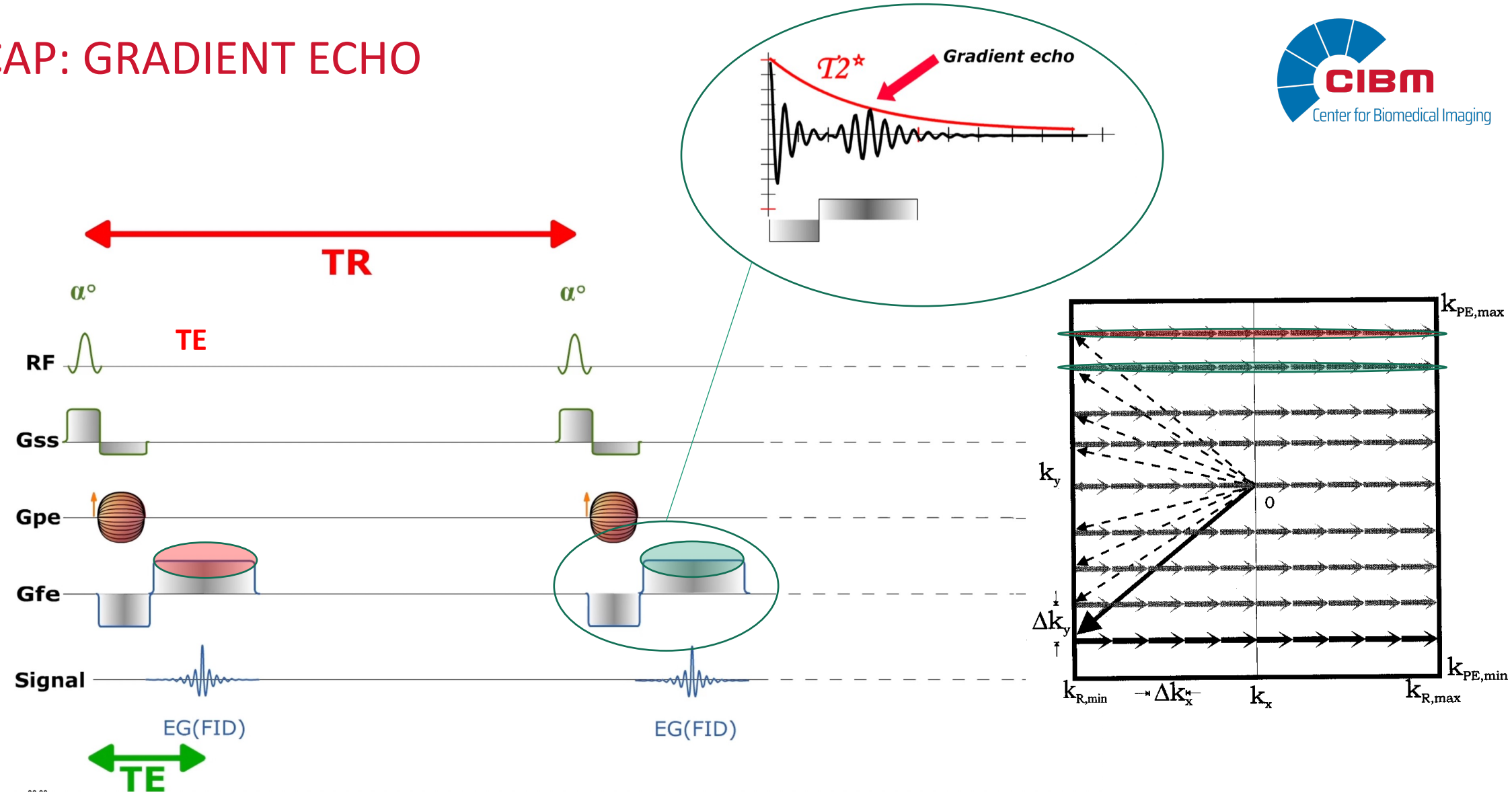
Sir Peter Mansfield, 2003 Nobel Prize in Physiology and Medicine

RECAP: SPIN ECHO

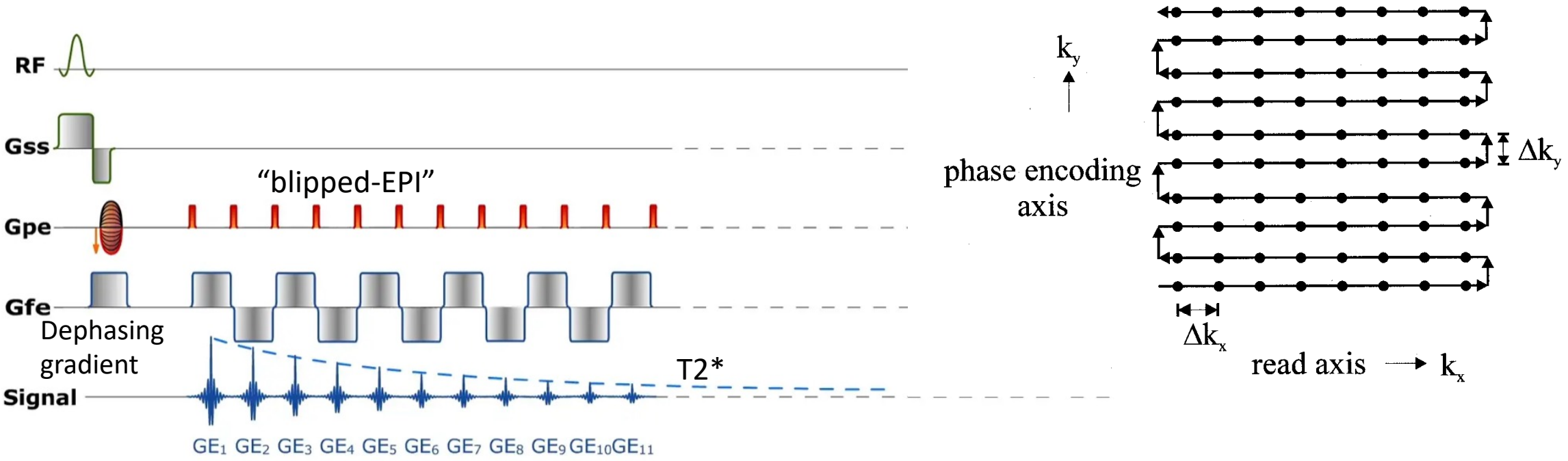




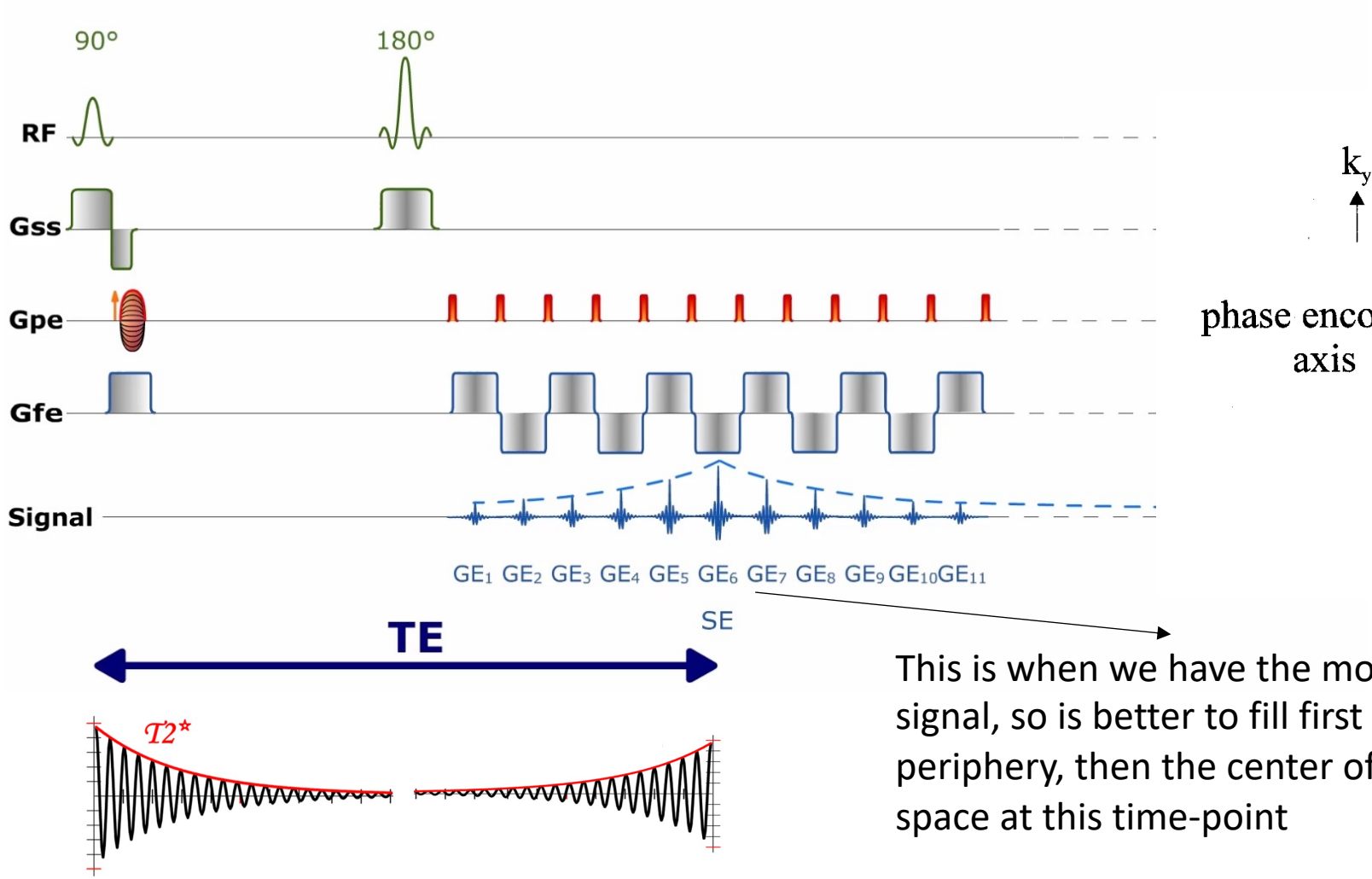
RECAP: GRADIENT ECHO

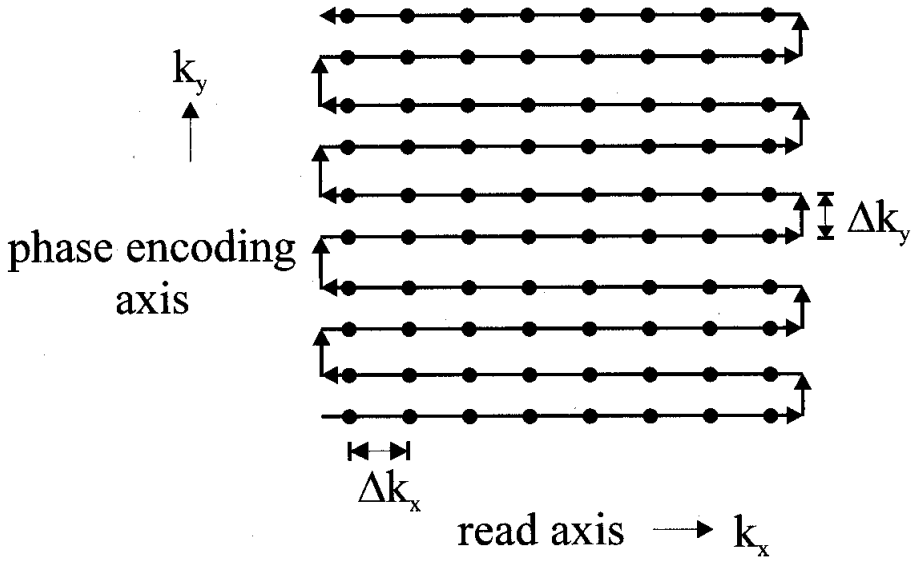


GRADIENT ECHO PLANAR IMAGING (GE-EPI)

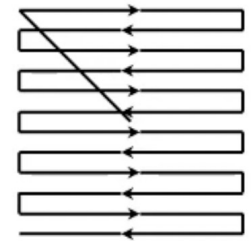


SPIN ECHO PLANAR IMAGING (SE-EPI)

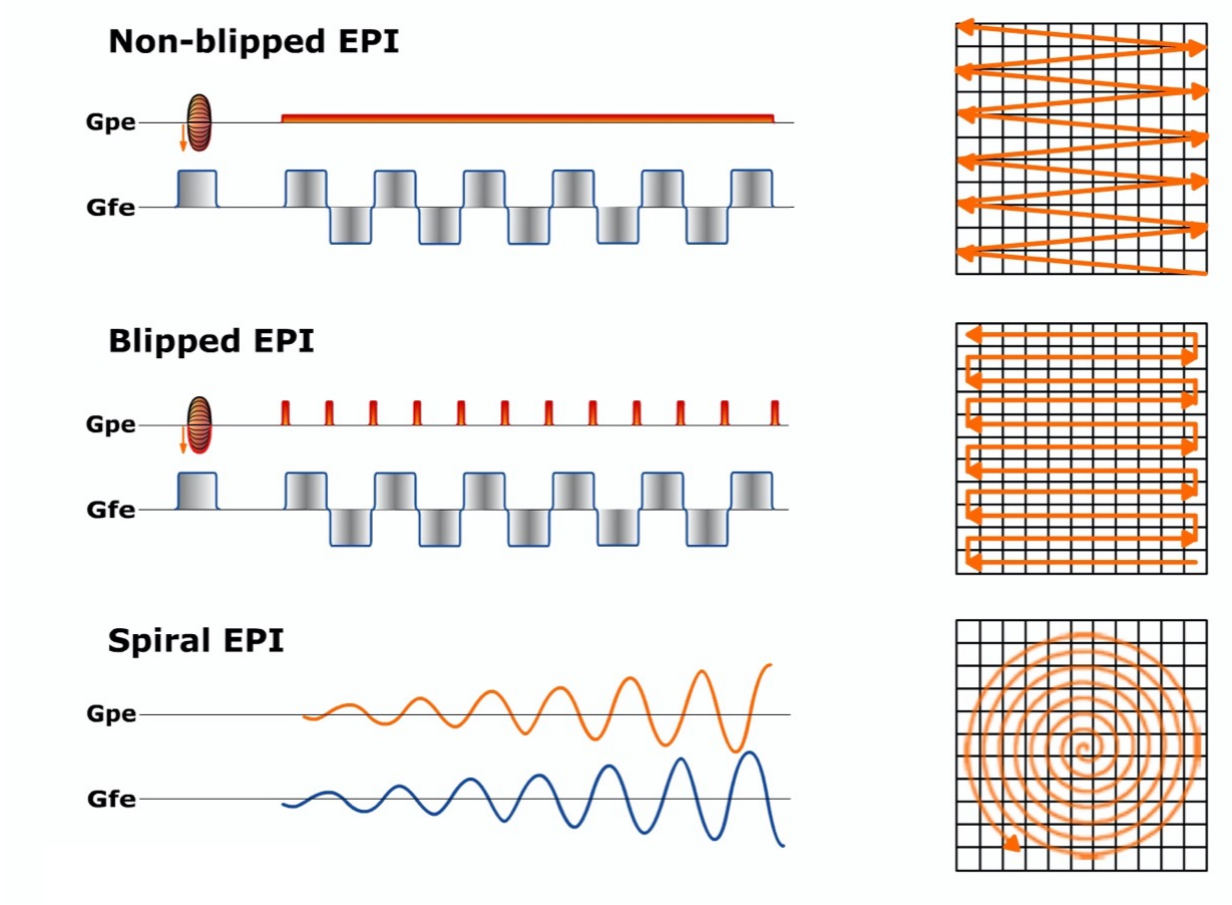


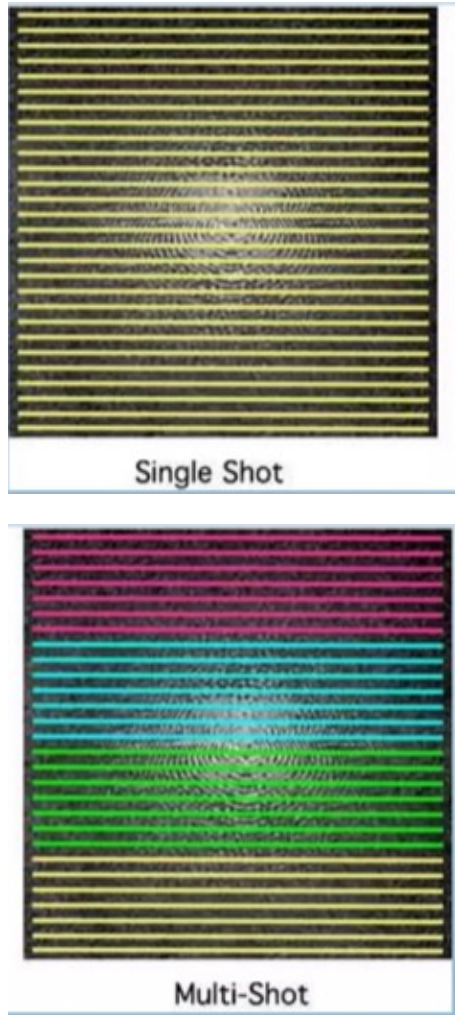


This is when we have the most signal, so is better to fill first the periphery, then the center of K-space at this time-point



K-SPACE EPI TRAJECTORIES





Noise in the MRI

- An EPI (Echo Planar Imaging) sequence in MRI is typically louder than a conventional GE (Gradient Echo) scan
- During an EPI sequence, the magnetic gradients are rapidly switched to fill multiple lines of K-space within a single acquisition. This produces a series of rapidly repeating ”blips" which can be quite loud and jarring for the patient. Additionally, the EPI sequence is often used in studies that involve rapid image acquisition over time. This means that the ”blips" may be more frequent and intense than in a typical GE scan.
- In contrast, a GE scan typically uses a slower and more gradual gradient switching pattern to acquire the imaging data. This can result in a quieter scanning experience for the patient.

Summary: EPI and K-Space (1/2)

Basics

- The echo planar is the fastest acquisition method in MRI (100ms / slice)
- It is based on:
  - an excitation pulse, possibly preceded by magnetization preparation
  - continuous signal acquisition in the form of a gradient echo train, to acquire total or partial k-space (single shot or segmented acquisition)
  - readout and phase-encoding gradients adapted to spatial image encoding, with several possible trajectories to fill k-space

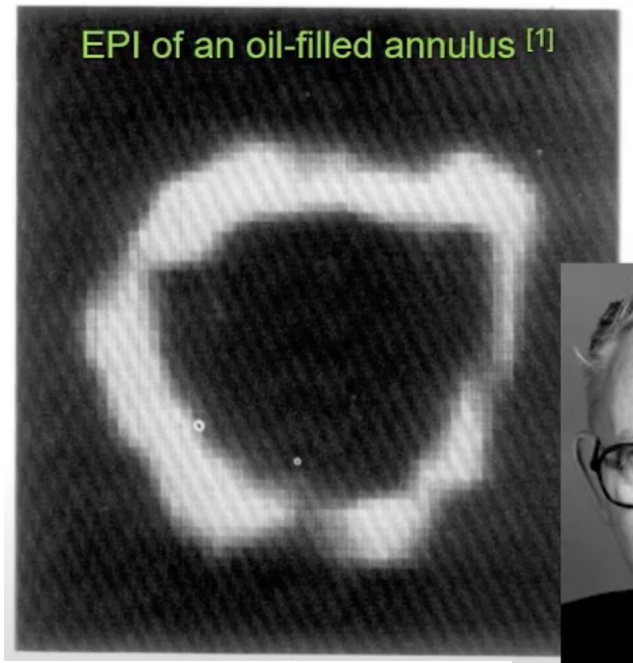
Contrasts

- GE-EPI: single RF excitation pulse -> T2* weighting
- SE-EPI: pair of 90° - 180° pulses (spin echo type) -> T2 weighting

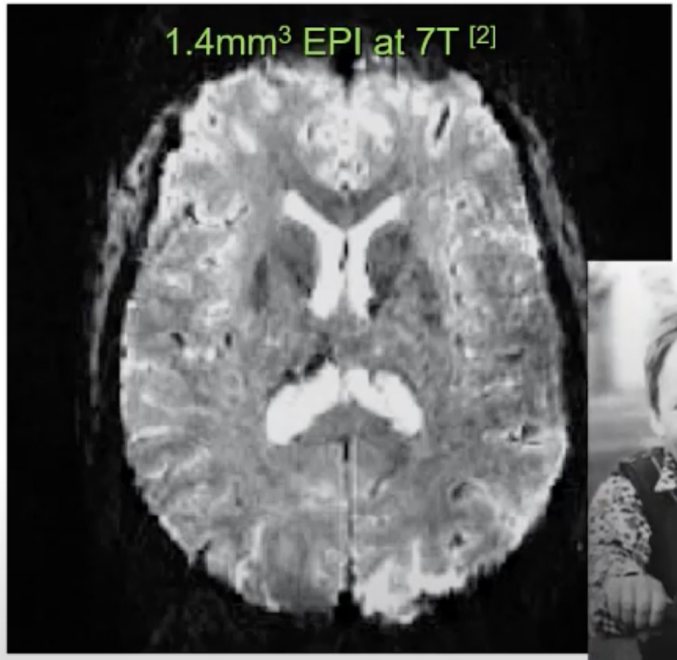
Summary: EPI and K-Space (2/2)

- In the case of an alternating gradient, k-space will be scanned from left to right and back, with each echo.
- Echoplanar sequences demand intense, high-performance gradients (for fast signal readout), with short ascent times (because of frequent gradient-switching).
- Imaging of rapidly changing physiological processes becomes possible!

TODAY EPI IS A WORKHORSE..



Sir Peter Mansfield

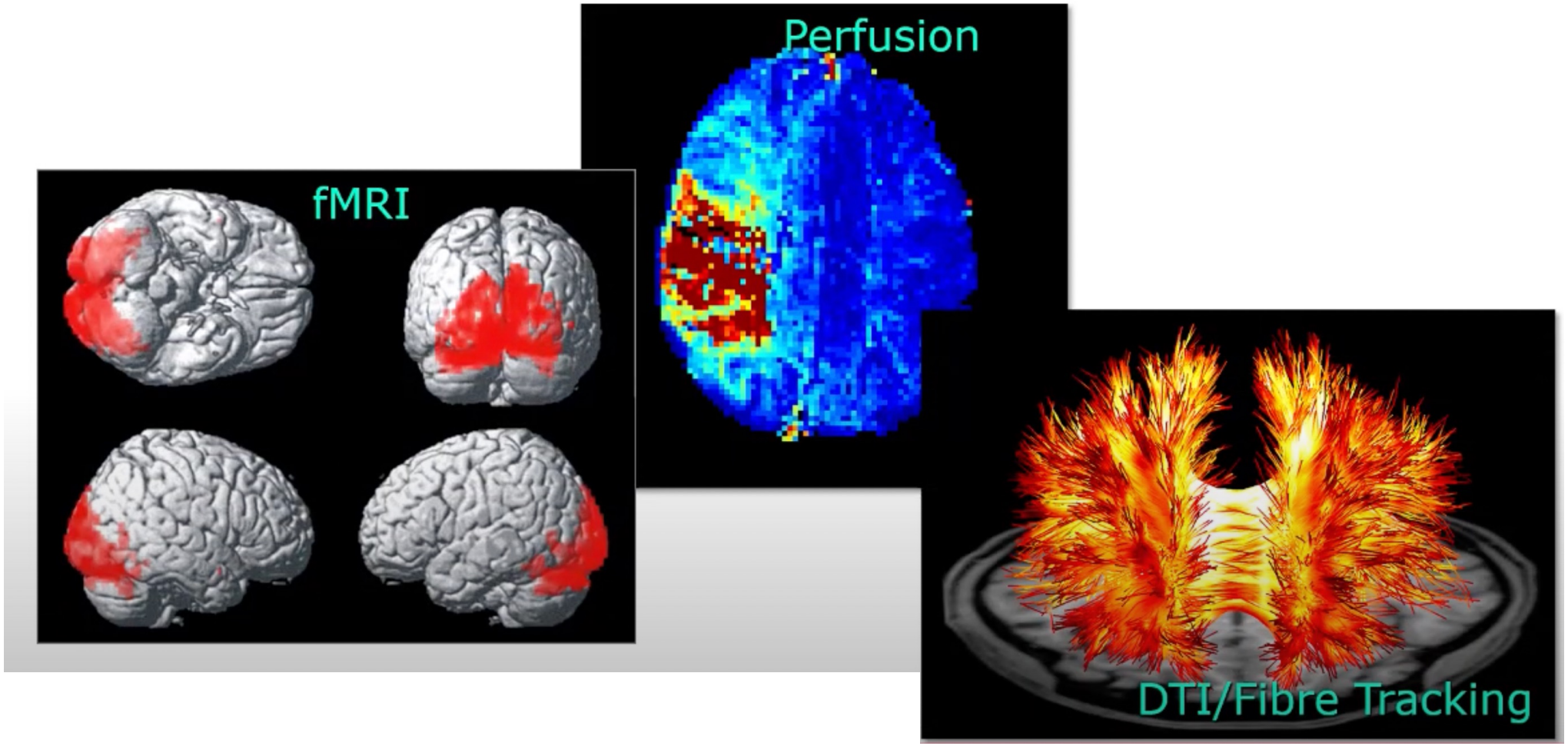


Maxim Zaitsev, Ph.D.

[1] Mansfield and Pykett "Biological and medical imaging by NMR" JMR 29,355-73 (1978)
[2] Speck O, Stadler J, Zaitsev M. "High resolution single-shot EPI at 7T" MAGMA 21:73-86 (2008).

https://www.youtube.com/watch?v=RkmoLqRkpMs&t=188s

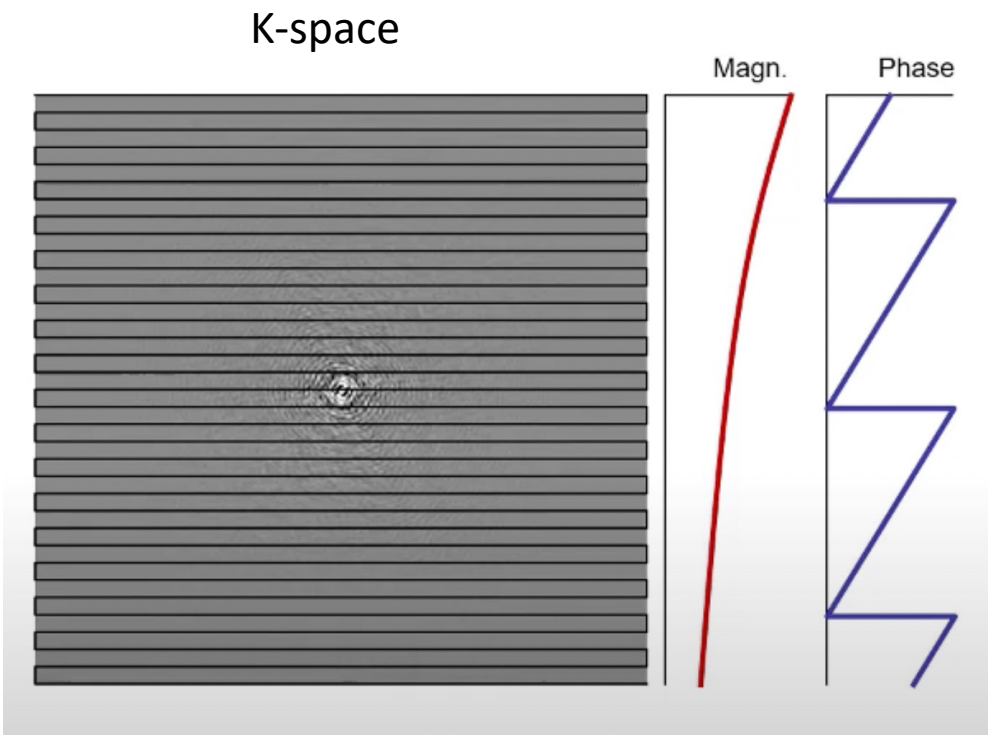
TODAY EPI IS A WORKHORSE..



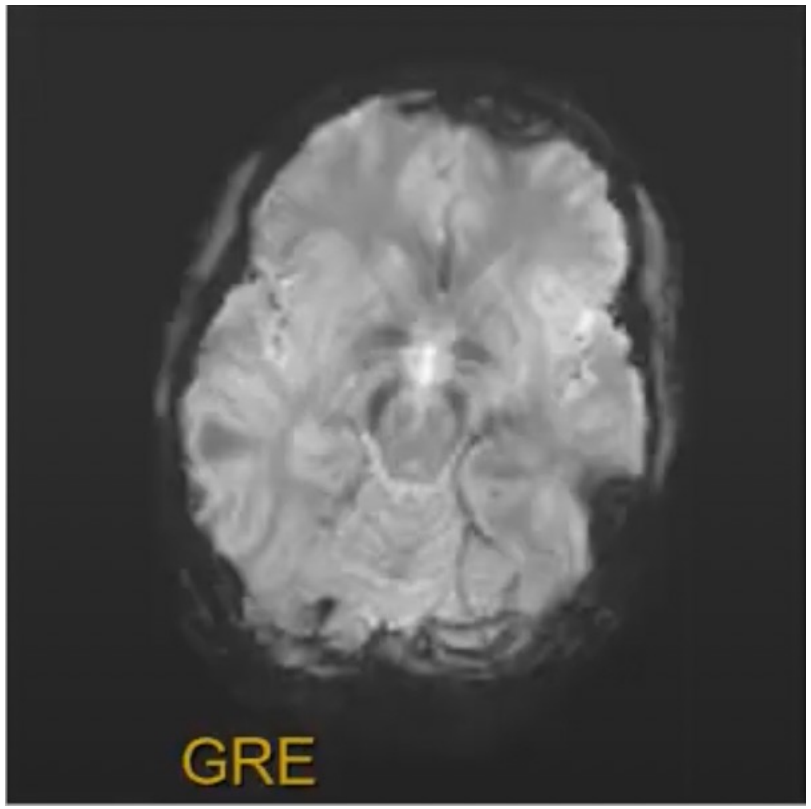

Fast MR imaging comes at a price..

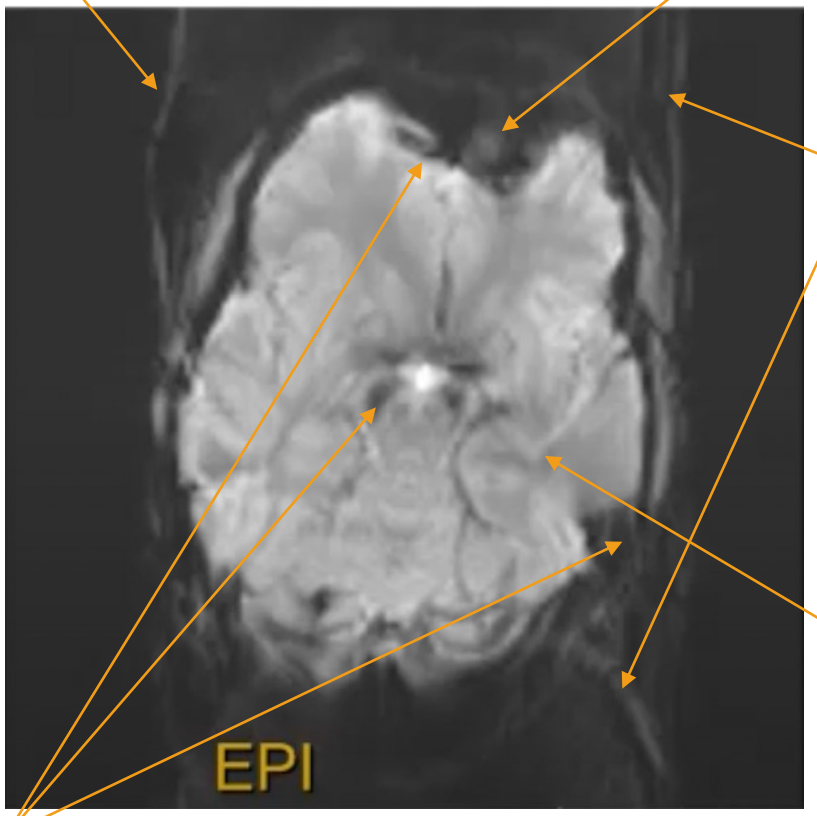
ARTIFACTS OF EPI

- Single shot is fast but **not instantaneous**
  - Signal evolves during the readout
- Alternating readout polarity
  - Susceptible to gradient and receiver imperfections
- 2D Fourier reconstruction
  - Perfect encoding?
  - Deviations lead to artifacts



ARTIFACTS OF EPI





Chemical Shift Artifact

Geometric Distortions

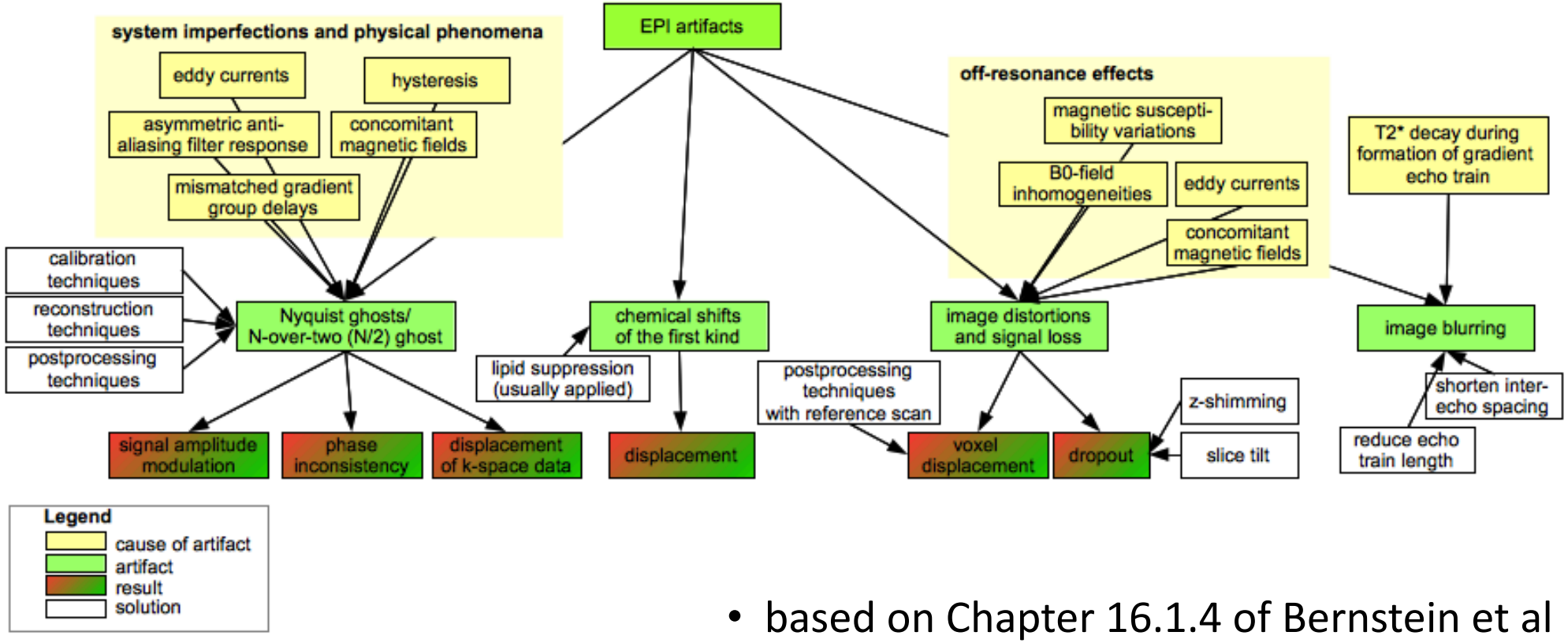
Ghosting

Contrast Variation

Signal Dropout

Poor Resolution

ARTIFACTS OF EPI

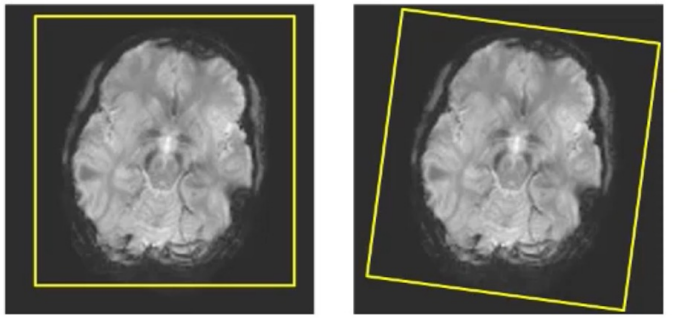


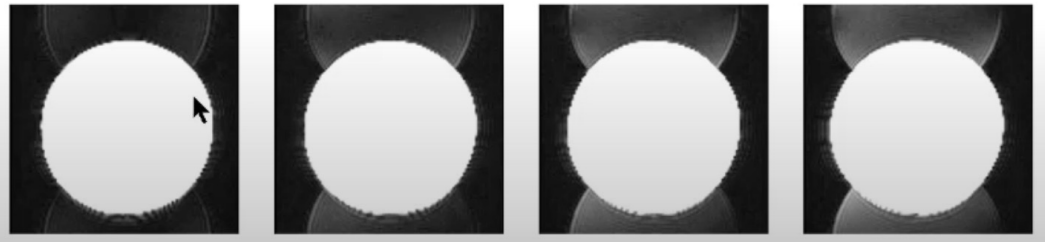
- based on Chapter 16.1.4 of Bernstein et al (2004) *Handbook of MRI sequences*.

ARTIFACTS OF EPI

Ghosting: practical advice #1

- For RO use pure gradient
  - Avoid double-oblique slices
  - No in-plane rotation

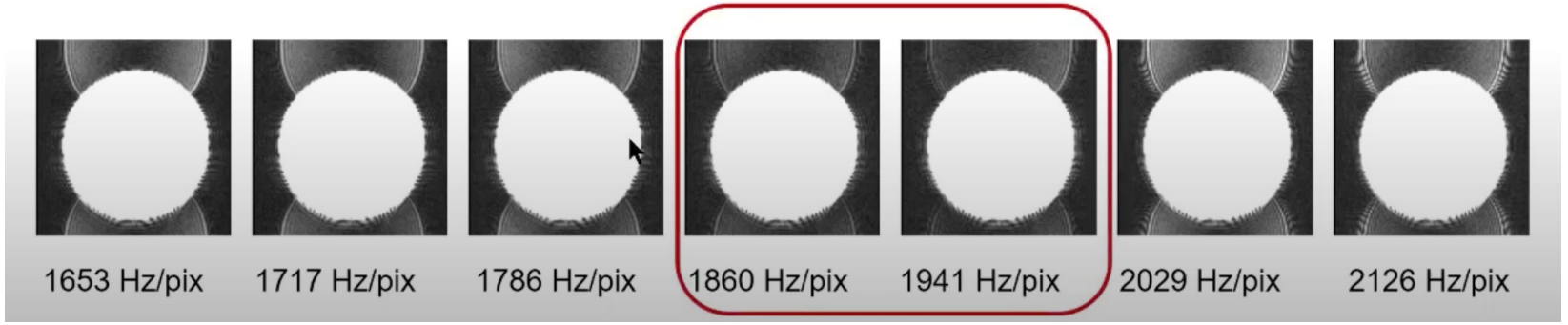




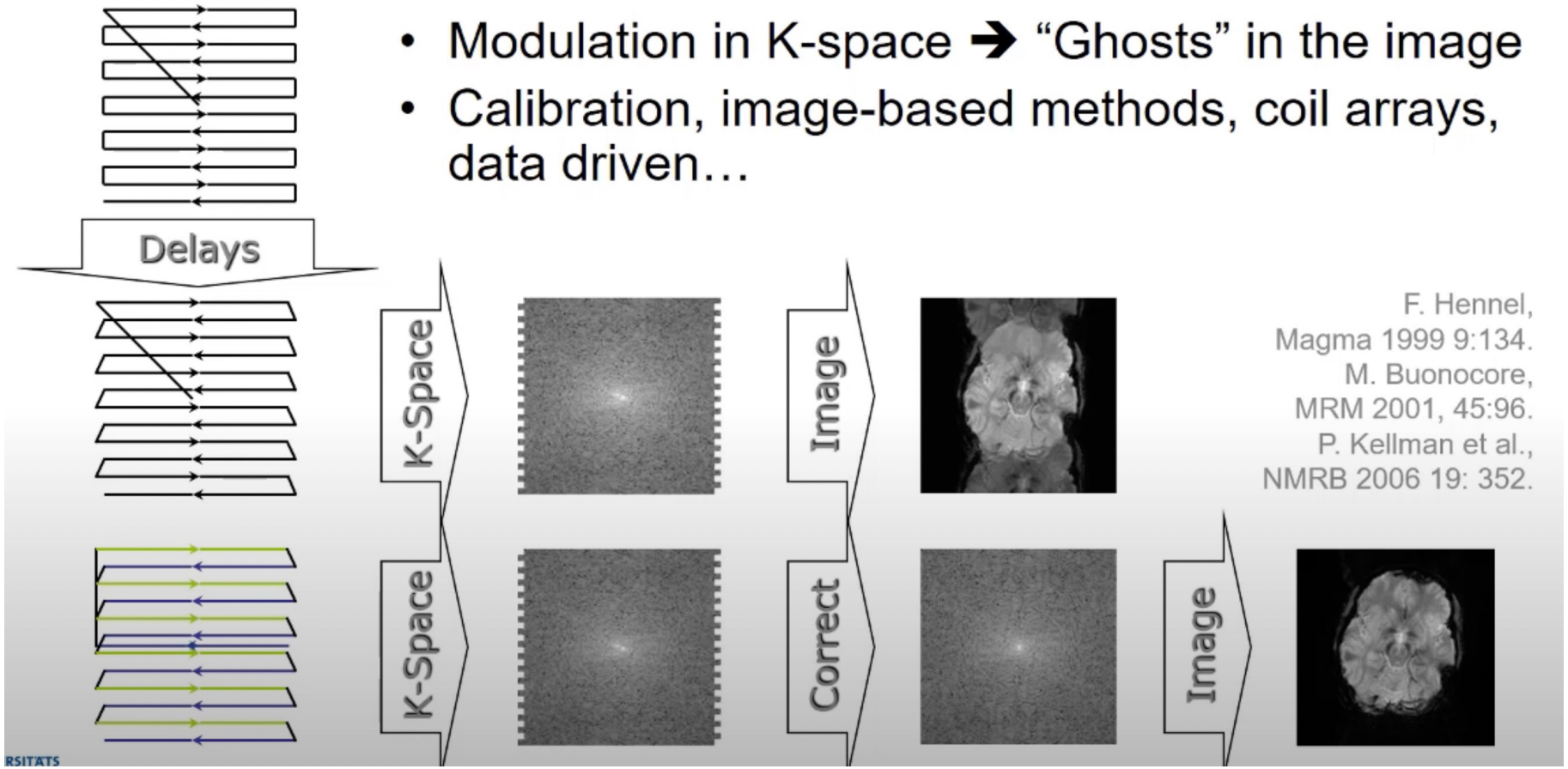
ARTIFACTS OF EPI

Ghosting: practical advice #2

- Optimize readout bandwidth / echo spacing
- Check “step left / step right”

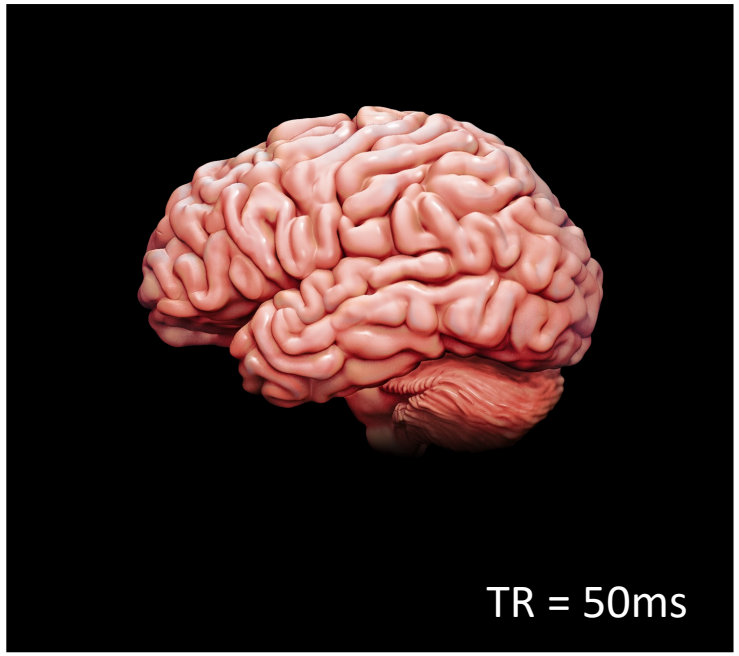


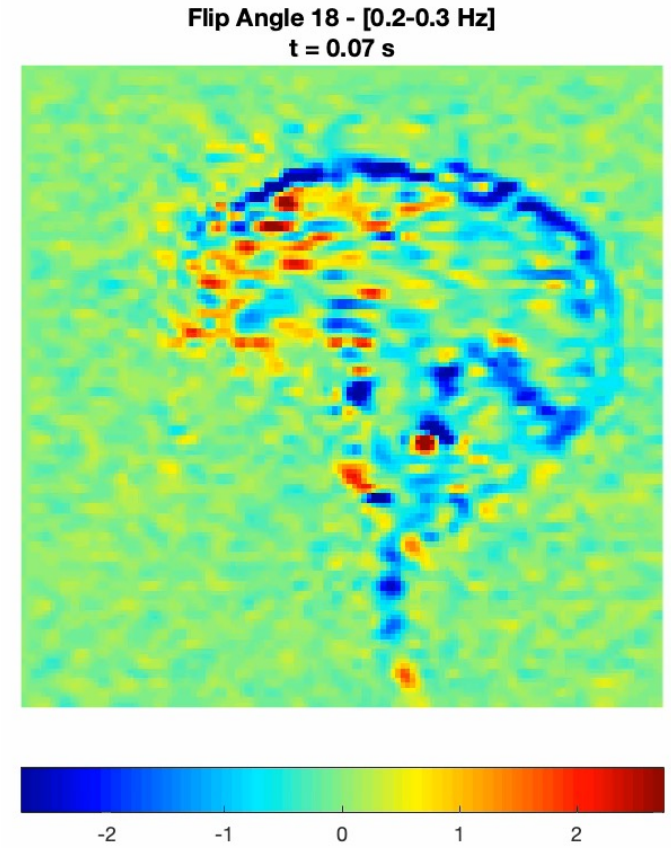
ARTIFACTS OF EPI



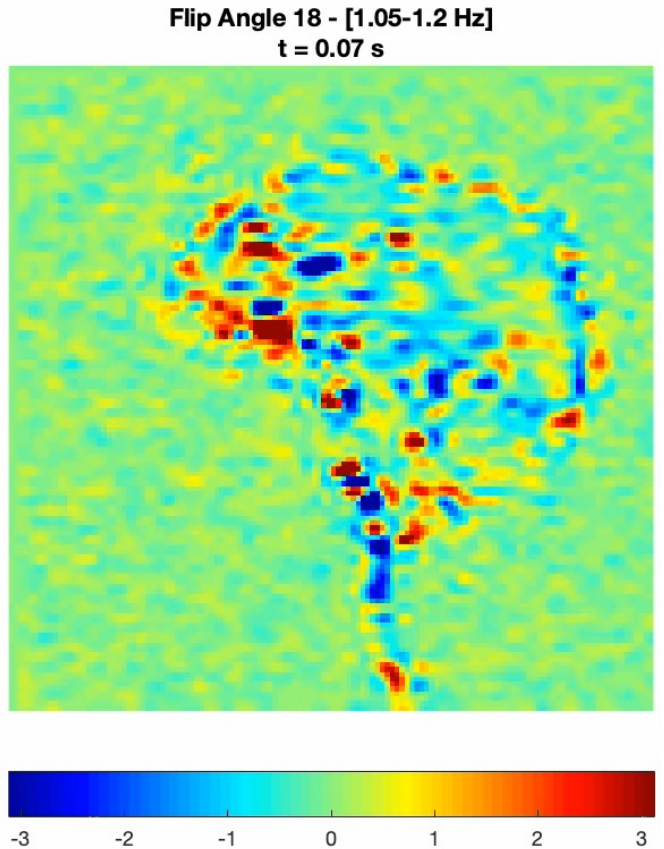
- Modulation in K-space ➔ “Ghosts” in the image
- Calibration, image-based methods, coil arrays, data driven…

HOW FAST CAN WE GO?





Breathing frequency



Heart-rate frequency

CIBM
Center for Biomedical Imaging

THANK YOU FOR YOUR ATTENTION

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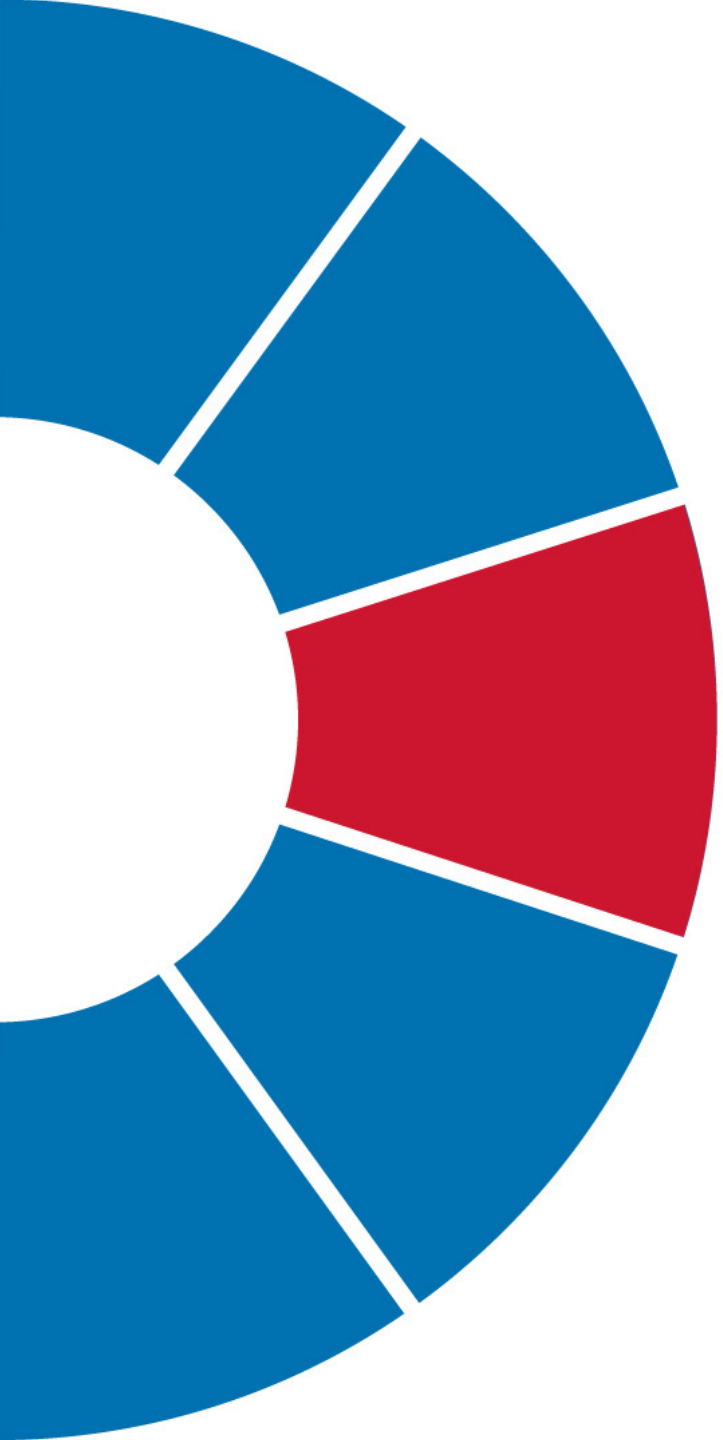

FOR ANY QUESTIONS YOU MAY HAVE,

PLEASE WRITE AT:

VALERIO.ZERBI@EPFL.CH