

New to MRI: simulator to the rescue

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Laptop ready?



New to MRI: simulator to the rescue

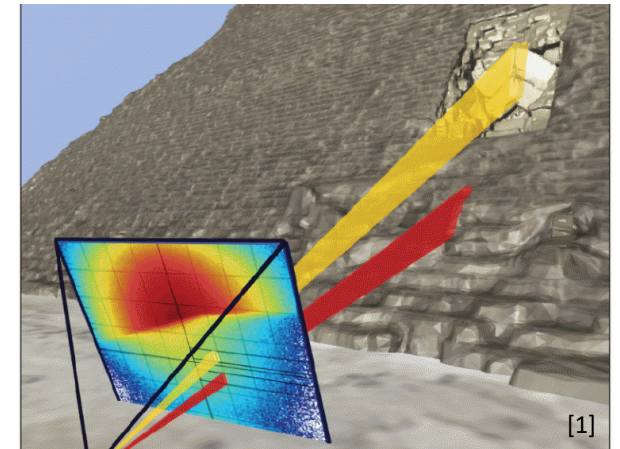
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Background

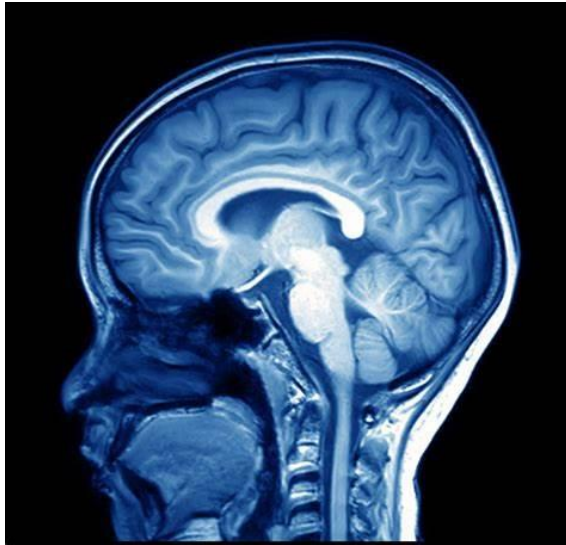
- Nanotechnology
- Muon tomography



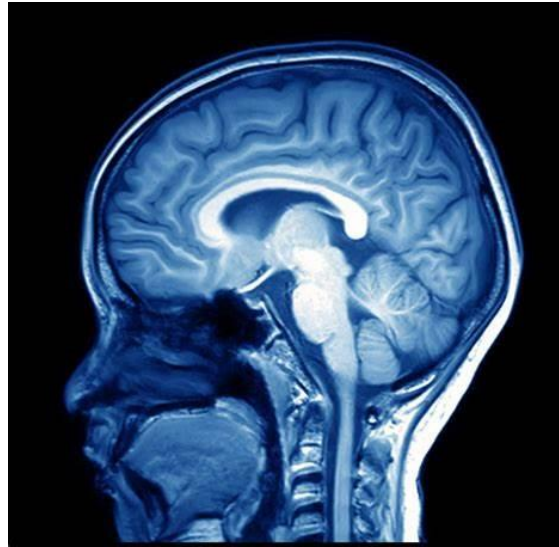
Hello MRI



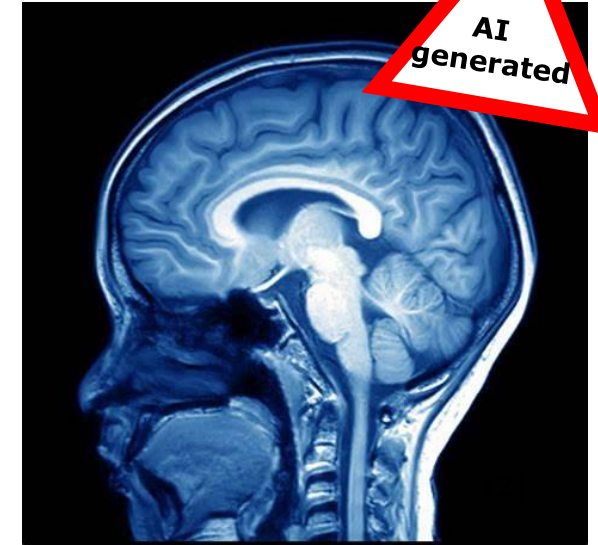
Hello MRI



ESCAPE SE



DANTE



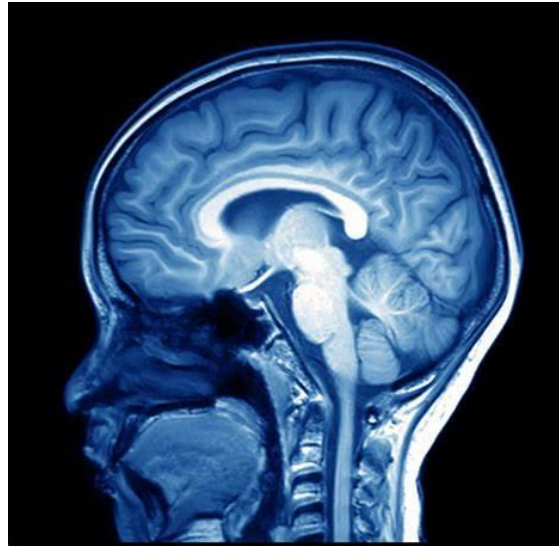
X Æ A-Xii



Hello MRI



ESCAPE SE



DANTE



X Æ A-Xii



Simulator to the rescue



Simulator to the rescue

**Basic MRI physics
(T1, T2* relaxation)**

Basic sequences

**More complicated
sequences**

Going to the scanner



Simulator to the rescue

MRzero, together with pypulseq, is super easy to use and you can try it yourself

■ [03_full_acquisition_simulations/notebooks/New_to_MRI_Simulator_to_the_Rescue/Talk2/](#)

- [ESMRMB_ET03_Mrzero_to_the_rescue_Basic_MRI_Physics.ipynb](#)
- [ESMRMB_ET03_Mrzero_to_the_rescue_Basic_MRI_sequences.ipynb](#)
- [ESMRMB_ET03_Mrzero_to_the_rescue_More_complicated_sequences.ipynb](#)
- [ESMRMB_ET03_Mrzero_to_the_rescue_Going_to_the_scanner.ipynb](#)
- [ESMRMB_ET03_Mrzero_to_the_rescue_HandsOn.ipynb](#)



Simulator to the rescue

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Simulator to the rescue

MRzero, together with pypulseq, is super easy to use and you can try it yourself

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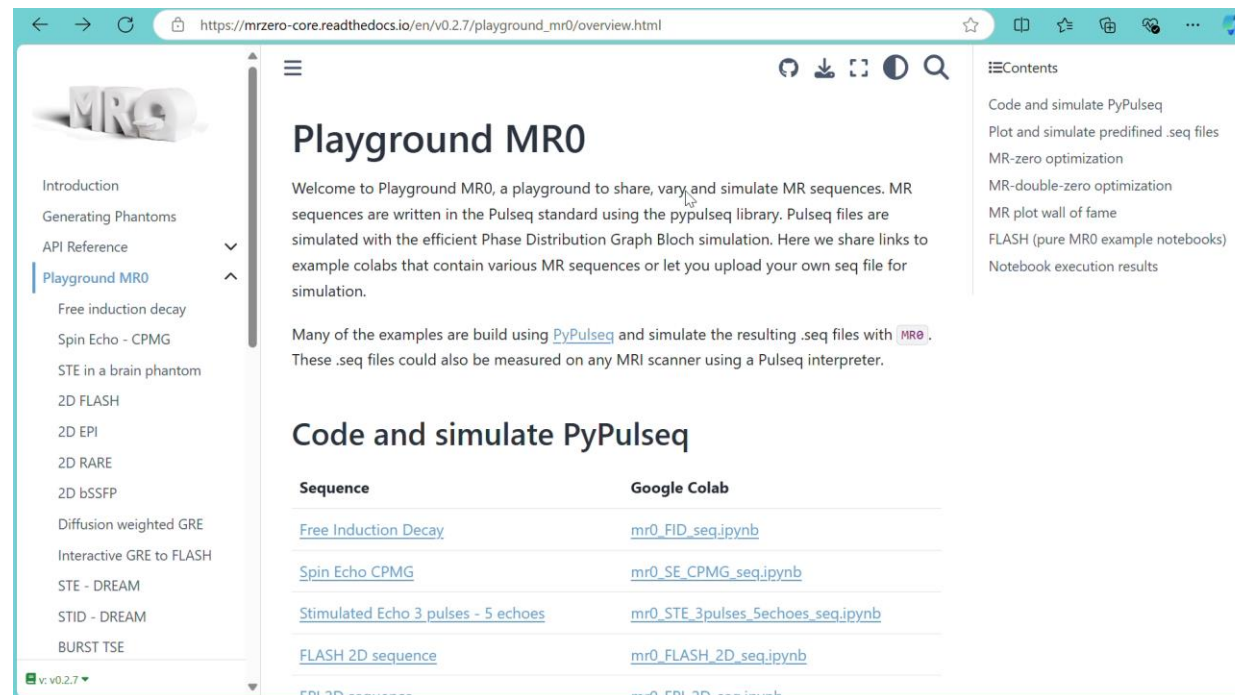
Let's run it together at the end of the session



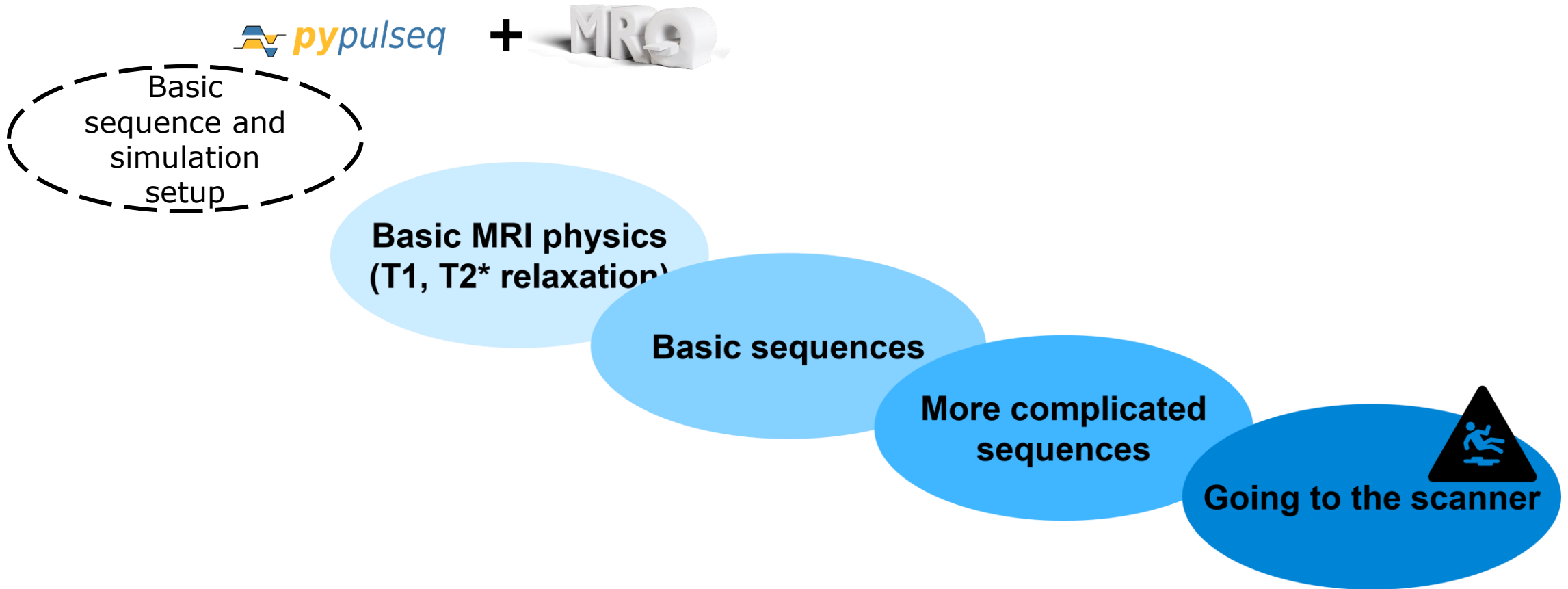
Simulator to the rescue

MRzero, together with pypulseq, is super easy to use and you can try it yourself

More notebooks on the Playground-MR0 website:



Simulator to the rescue



Simulator to the rescue

■ Install libraries

```
!pip install pypulseq==1.4.2  
!pip install MRzeroCore
```

Basic sequence
and simulation
setup



Simulator to the rescue

- Prepare sequence and save as .seq file

```
# Build sequence: T2star relaxation
seqT2star = pp.Sequence()
seqT2star.add_block(rf1, gz)
seqT2star.add_block(gzr)
seqT2star.add_block(adc)
aux_check_timing(seqT2star)
seqT2star.write("FID.seq")
```

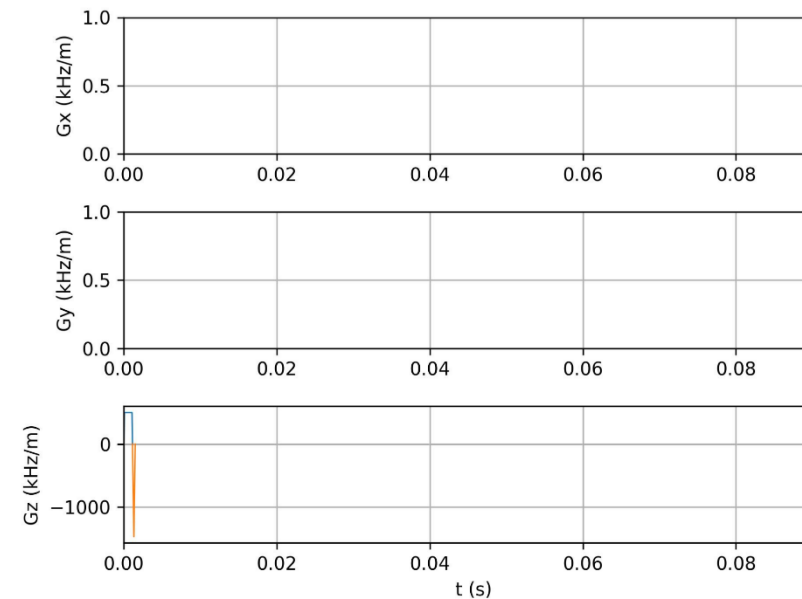
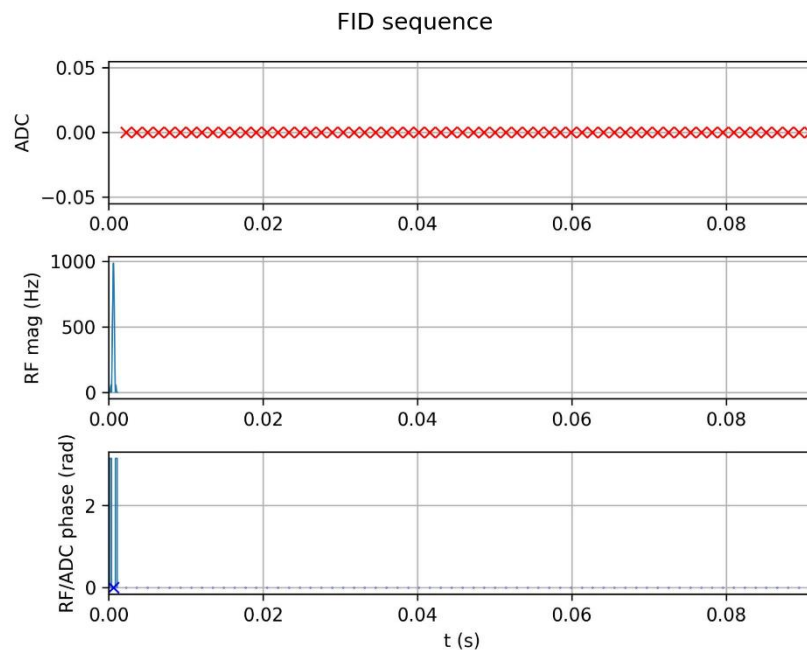
Basic sequence
and simulation
setup



Simulator to the rescue

Basic sequence
and simulation
setup

- Prepare sequence and save as .seq file



Simulator to the rescue

- Load the sequence as an MR-zero sequence object

```
seq0_T2star = mr0.Sequence.import_file('FID.seq')
```

- Load a digital phantom

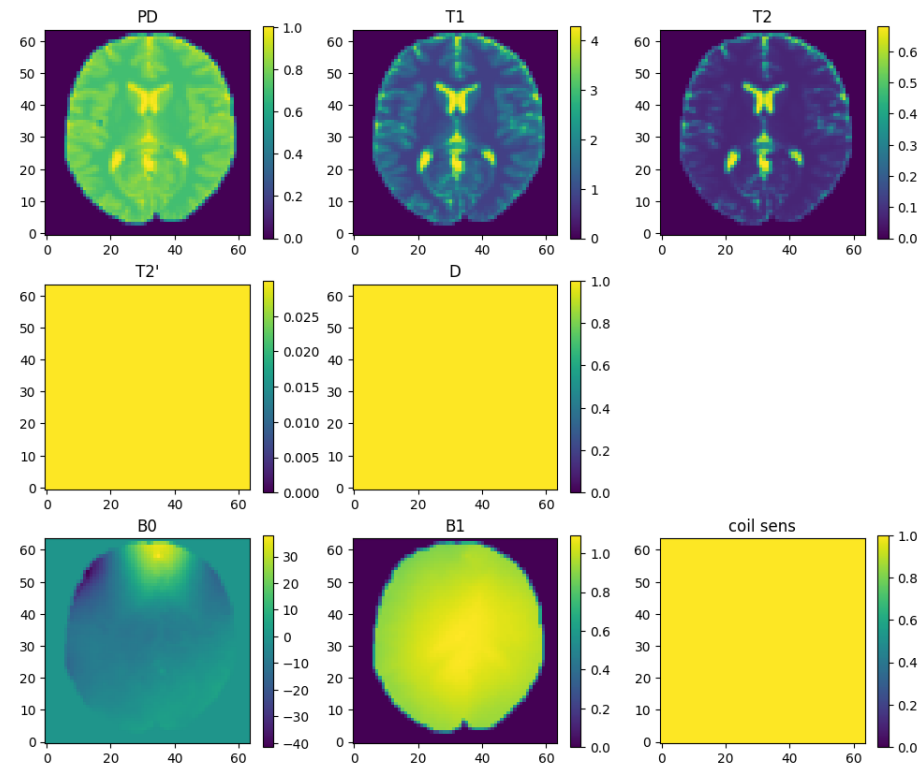
```
sz = [Nread, Nphase]  
phantom = mr0.VoxelGridPhantom.load_mat('numerical_brain_cropped.mat')  
phantom = phantom.interpolate(sz[0], sz[1], 1)  
obj_p = phantom.build()  
phantom.plot()
```

Basic sequence
and simulation
setup



Simulator to the rescue

Basic sequence
and simulation
setup



Simulator to the rescue

**Basic MRI physics
(T1, T2* relaxation)**

- Simulate signal

```
graph_T2star = mr0.compute_graph(seq0_T2star, obj_p, 200, 1e-3)  
signal_T2star = mr0.execute_graph(graph_T2star, seq0_T2star, obj_p)
```

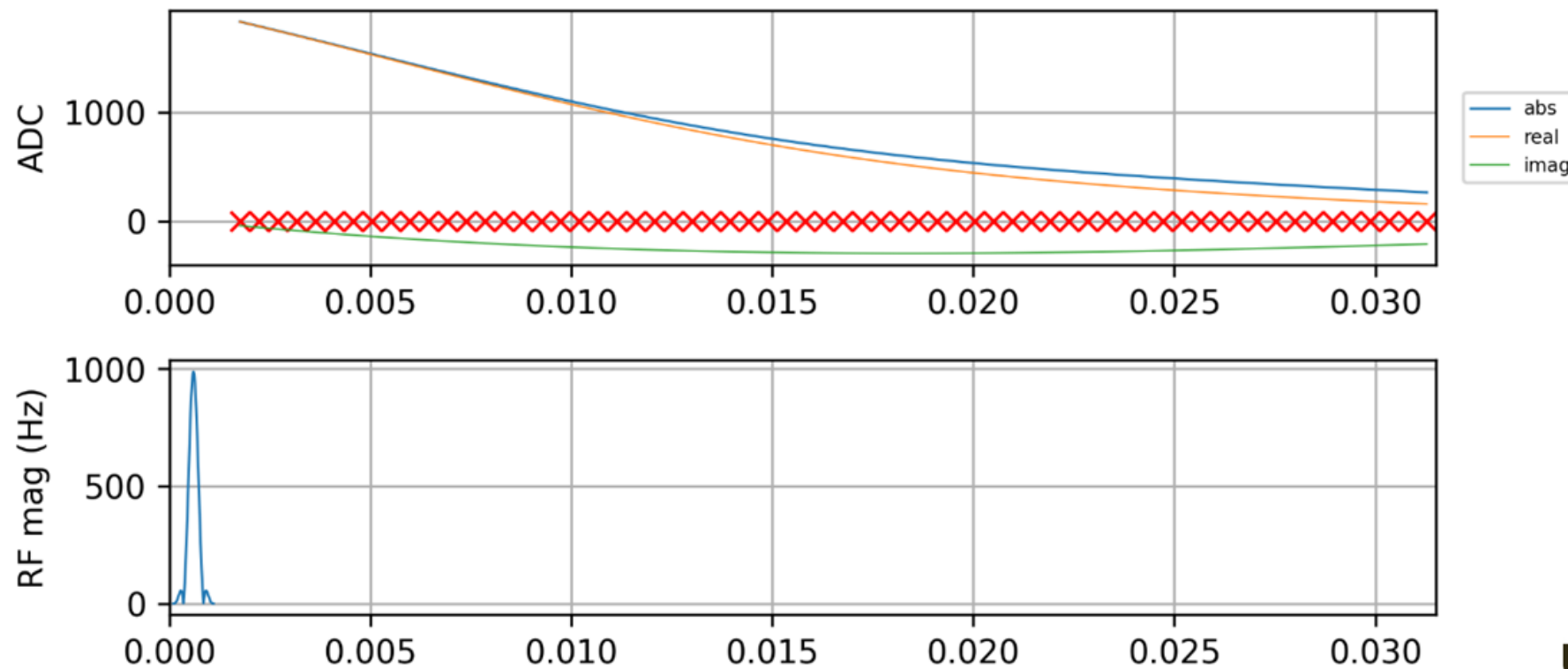


Simulator to the rescue

**Basic MRI physics
(T1, T2* relaxation)**

■ Simulate signal

FID signal

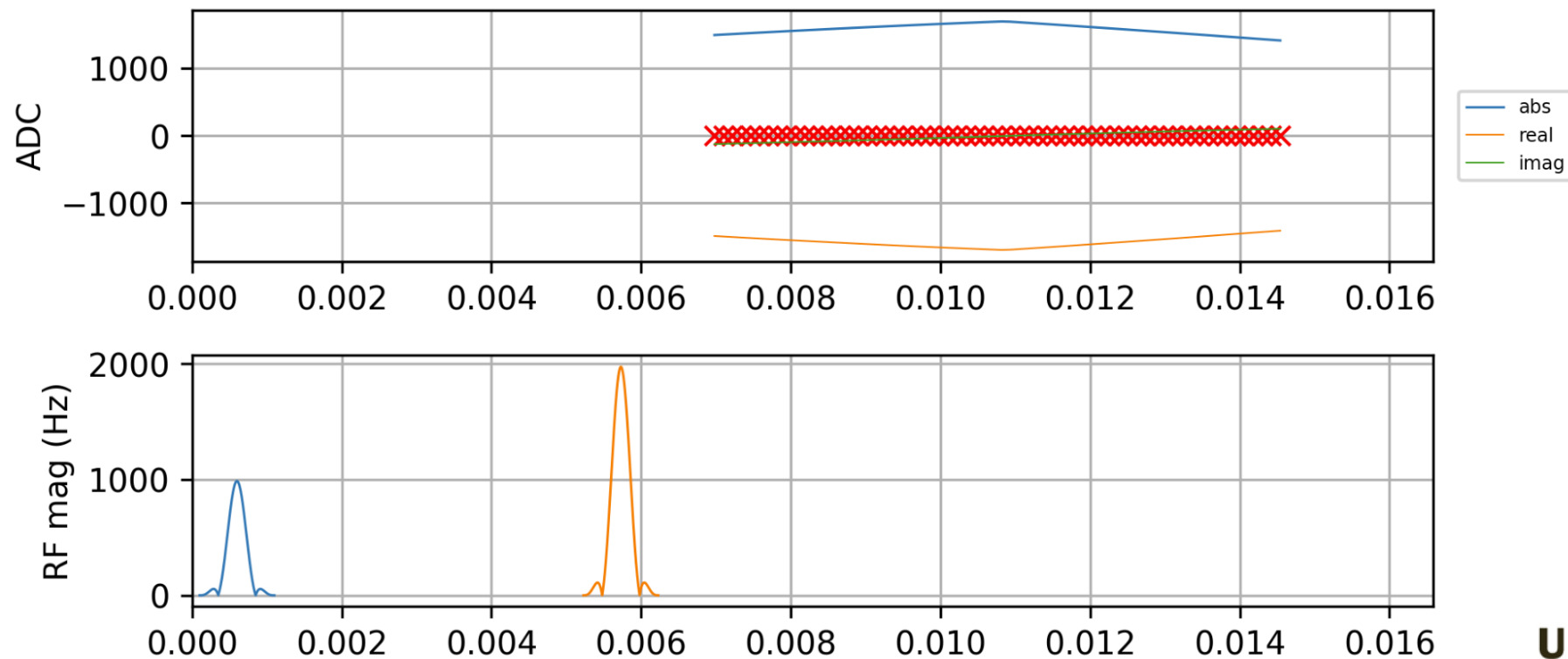


Simulator to the rescue

**Basic MRI physics
(T1, T2* relaxation)**

■ Simulate signal

SE signal



Simulator to the rescue

Basic sequences

■ Simulate

```
signal_EPI = mr0.execute_graph(graph_EPI, seq0_EPI, obj_p)
```

■ Reconstruct image from signal

```
# kspace reordering
kspace_EPI = torch.reshape((signal_EPI), (Nphase, Nread)).clone().t()
kspace_EPI[:,0::2] = torch.flip(kspace_EPI[:,0::2],[0] )[:,:]

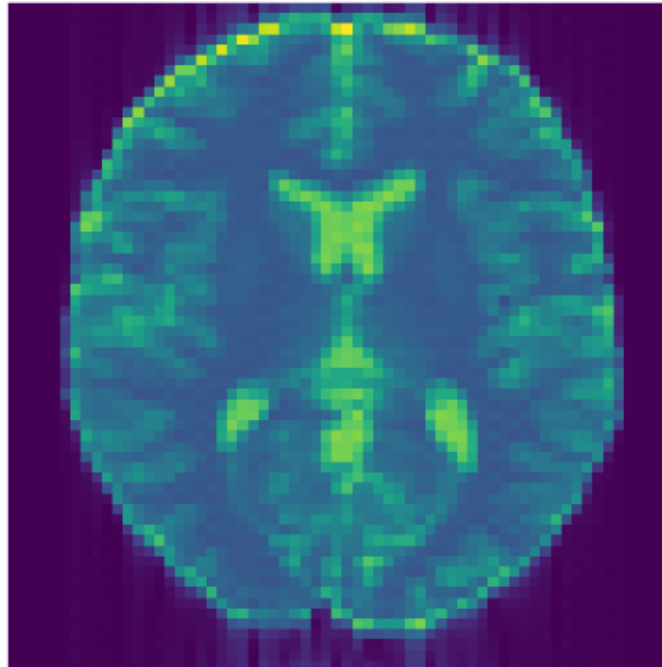
# FFT
spectrum_EPI = torch.fft.fftshift(kspace_EPI)
image_EPI = torch.fft.fft2(spectrum_EPI)
image_EPI = torch.fft.ifftshift(image_EPI)
```



Simulator to the rescue

Basic sequences

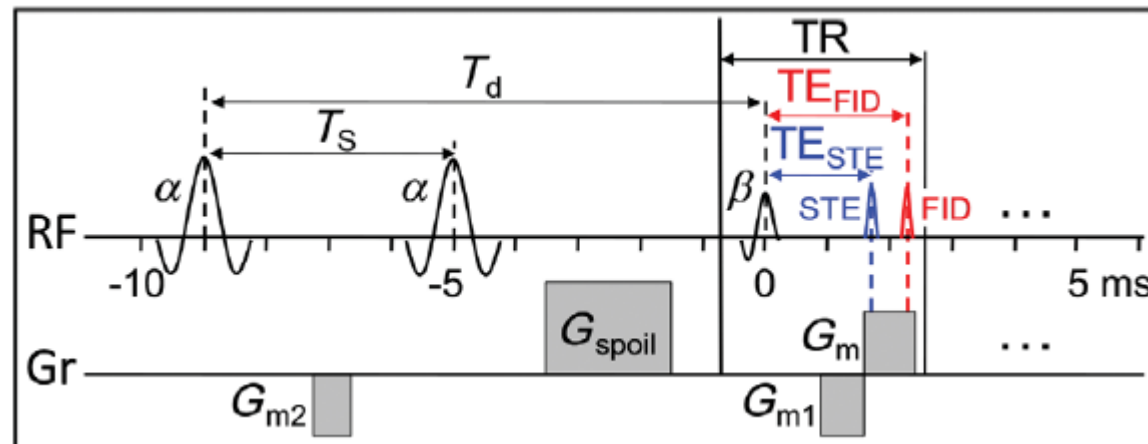
Magnitude EPI



Simulator to the rescue

More complicated sequences

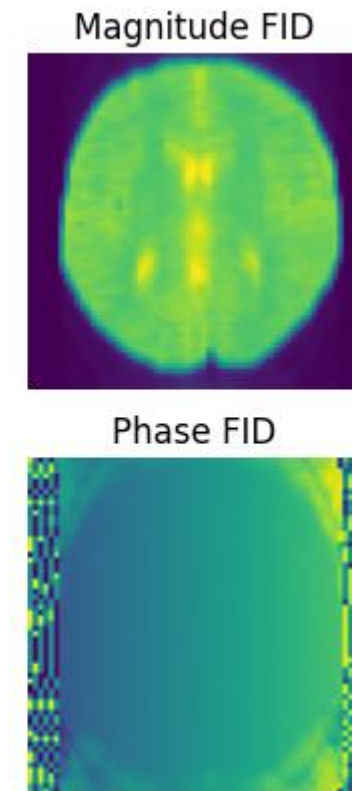
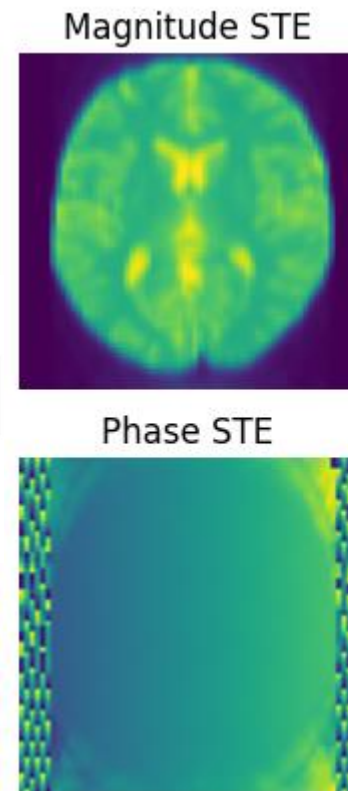
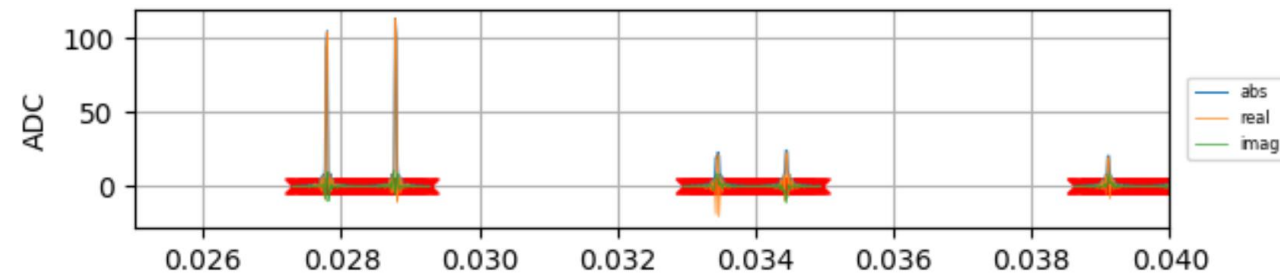
■ DREAM – B1, B0, TxRx mapping sequence



Simulator to the rescue

More complicated sequences

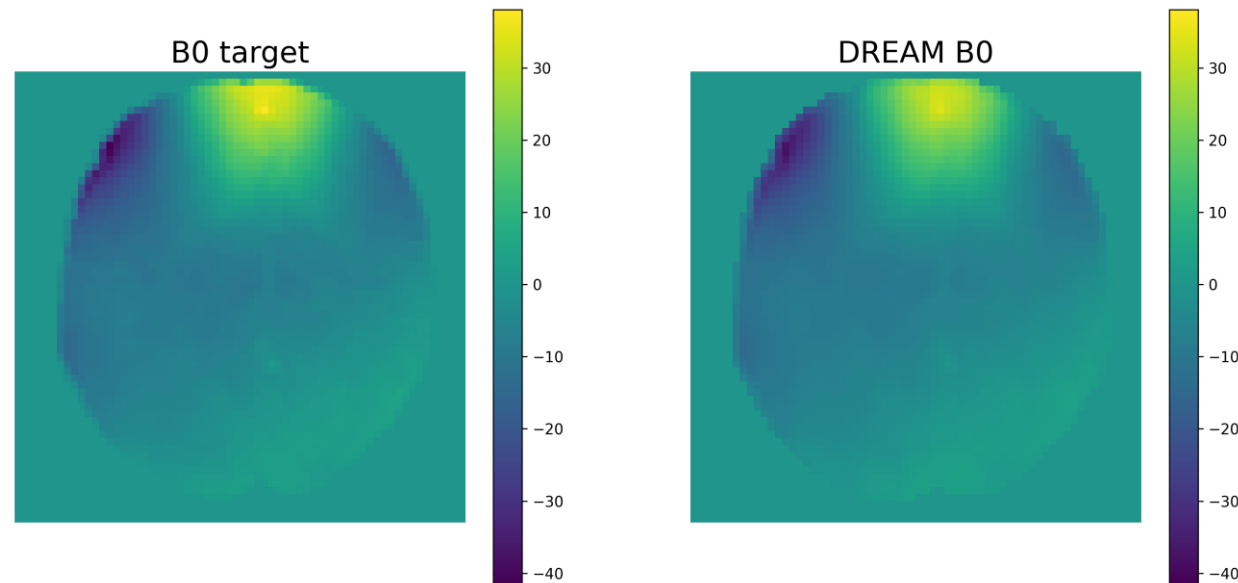
■ DREAM – B1, B0, TxRx mapping sequence



Simulator to the rescue

**More complicated
sequences**

- DREAM – B1, B0, TxRx mapping sequence



Simulator to the rescue



■ Problem number #1

https://mriquestions.com/echo-planar-imaging.html

QUESTIONS AND ANSWERS IN MRI

distortion 0/0

Echo-Planar Imaging (EPI)

What is echo-planar imaging (EPI)? Is this the same as Fast Spin Echo (FSE)?

- A rapid GRE or SE technique where an entire 2D planar image is acquired in a single (or small number) of excitations
- An FSE sequence with high ETL like HASTE might be considered a "multi-shot" EPI

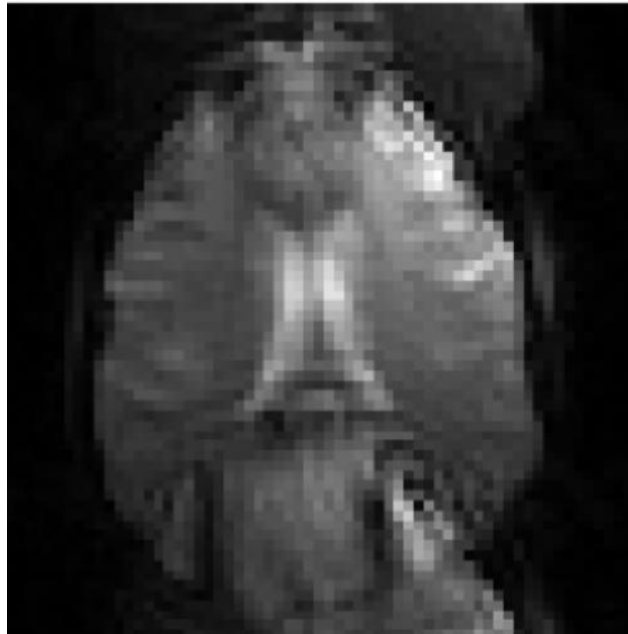


Simulator to the rescue



Going to the scanner

■ Problem number #1



Simulator to the rescue



Going to the scanner

■ Problem number #1

Time to code:

**03_full_acquisition_simulations/notebooks/New_to_MRI_Simulator_t
o_the_Rescue/Talk2/**

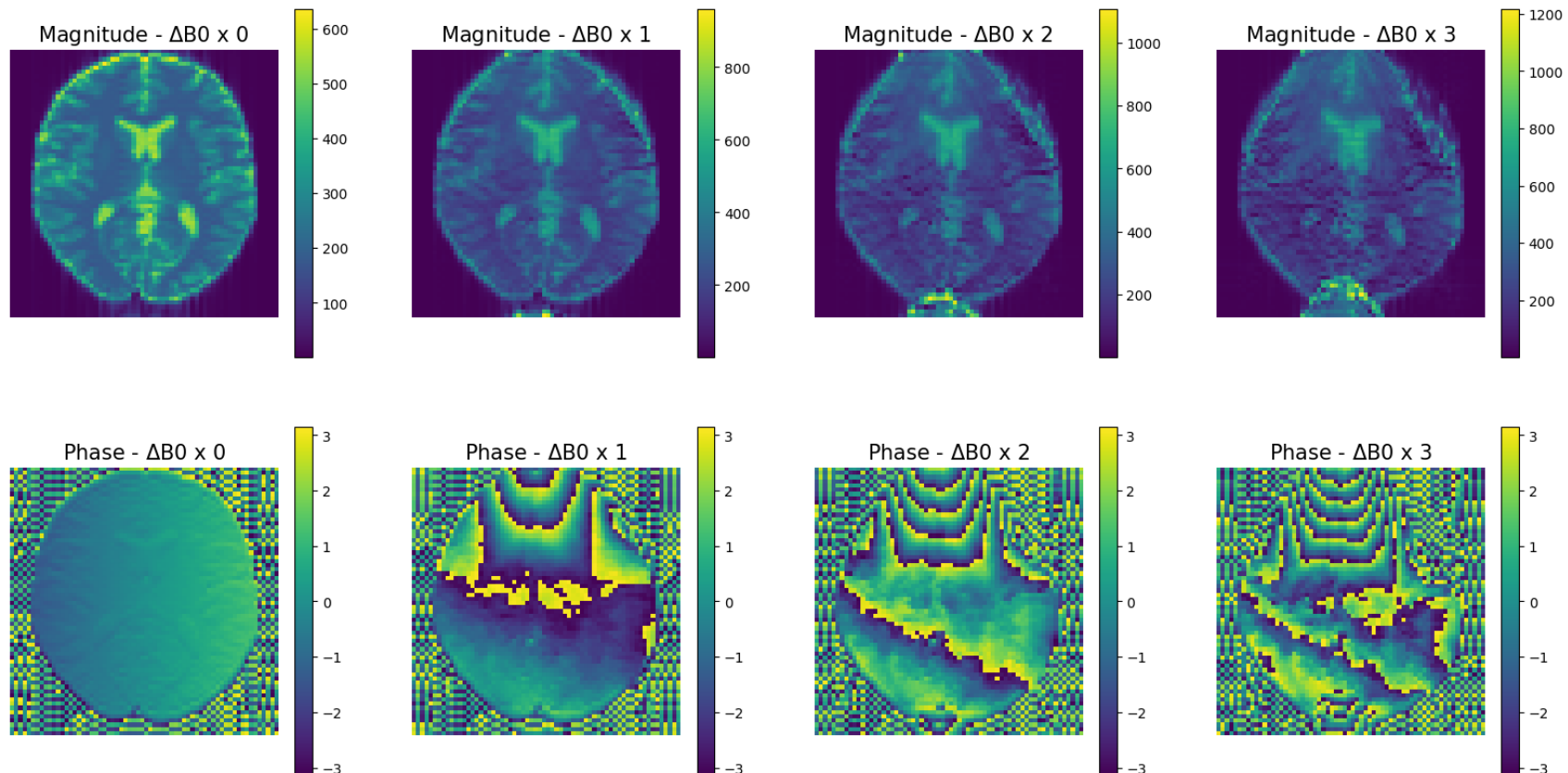
ESMRMB_ET03_Mrzero_to_the_rescue_HandsOn.ipynb



Simulator to the rescue



■ Problem number #1



Simulator to the rescue



■ Problem number #2

The screenshot shows a web browser at <https://mriquestions.com/echo-planar-imaging.html>. The page has a dark blue sidebar with the text 'QUESTIONS AND ANSWERS IN MRI'. The main content area has a search bar with 'ghosts' entered, showing '0/0' results. Below the search bar, the heading 'Echo-Planar Imaging (EPI)' is displayed in orange. Underneath, a blue text block asks: 'What is echo-planar imaging (EPI)? Is this the same as Fast Spin Echo (FSE)?'. To the right, a blue box contains two bullet points: '• A rapid GRE or SE technique where an entire 2D planar image is acquired in a single (or small number) of excitations' and '• An FSE sequence with high ETL like HASTE might be considered a “multi-shot” EPI'.

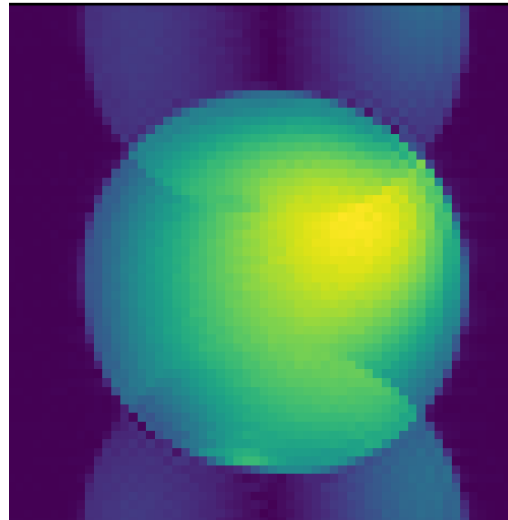


Simulator to the rescue



Going to the scanner

■ Problem number #2

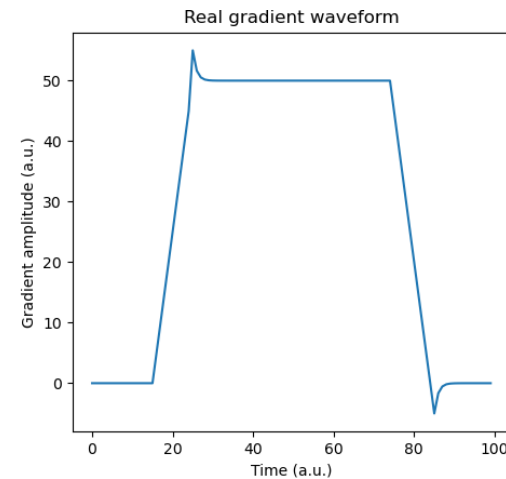
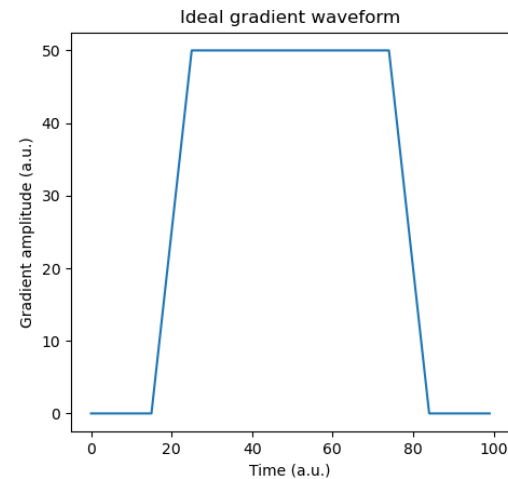


Simulator to the rescue



Going to the scanner

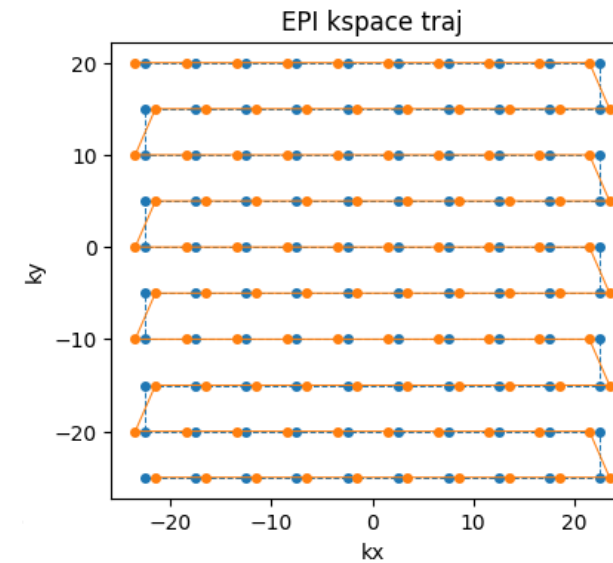
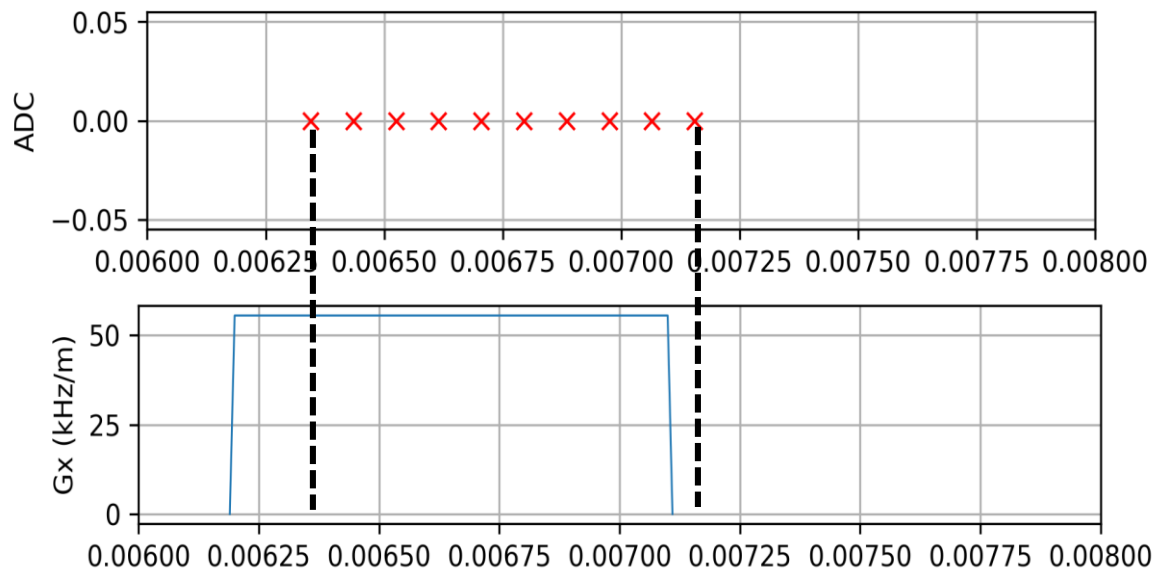
■ Problem number #2



Simulator to the rescue



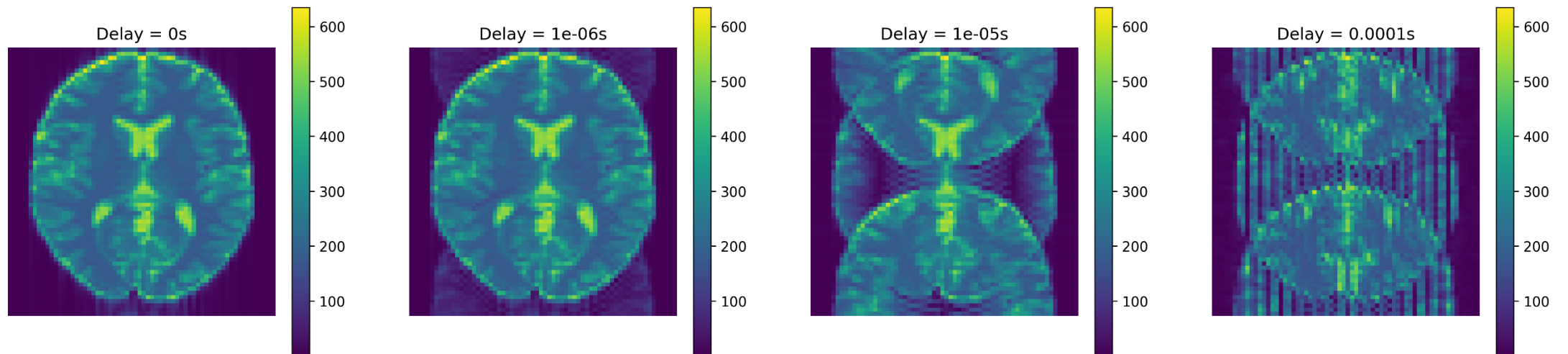
■ Problem number #2



Simulator to the rescue



■ Problem number #2

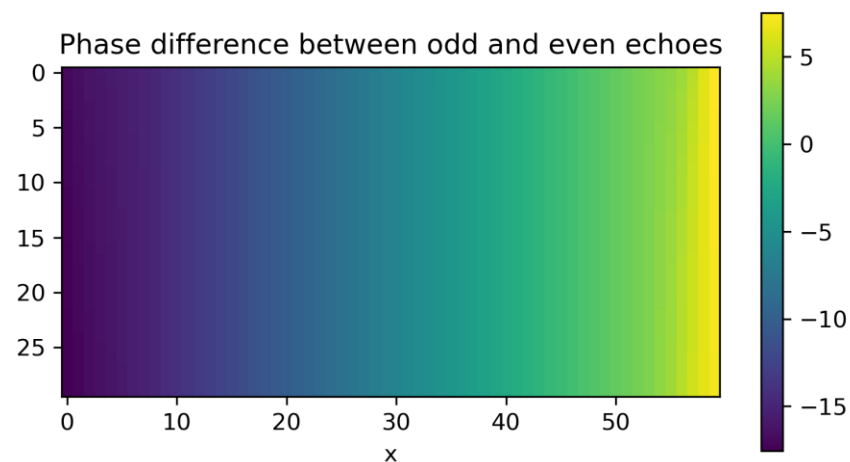


Simulator to the rescue



Going to the scanner

■ Problem number #2



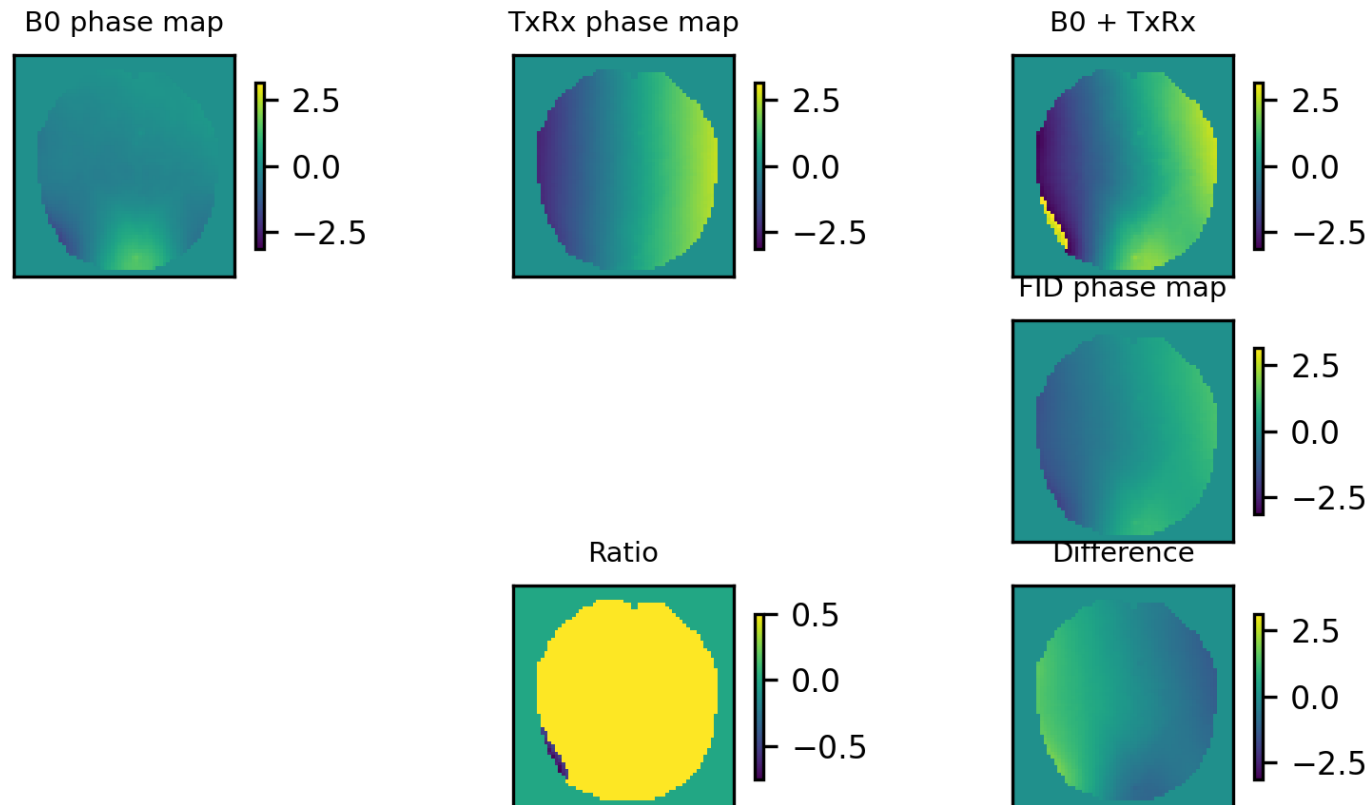
Time delay = linear phase factor



Simulator to the rescue



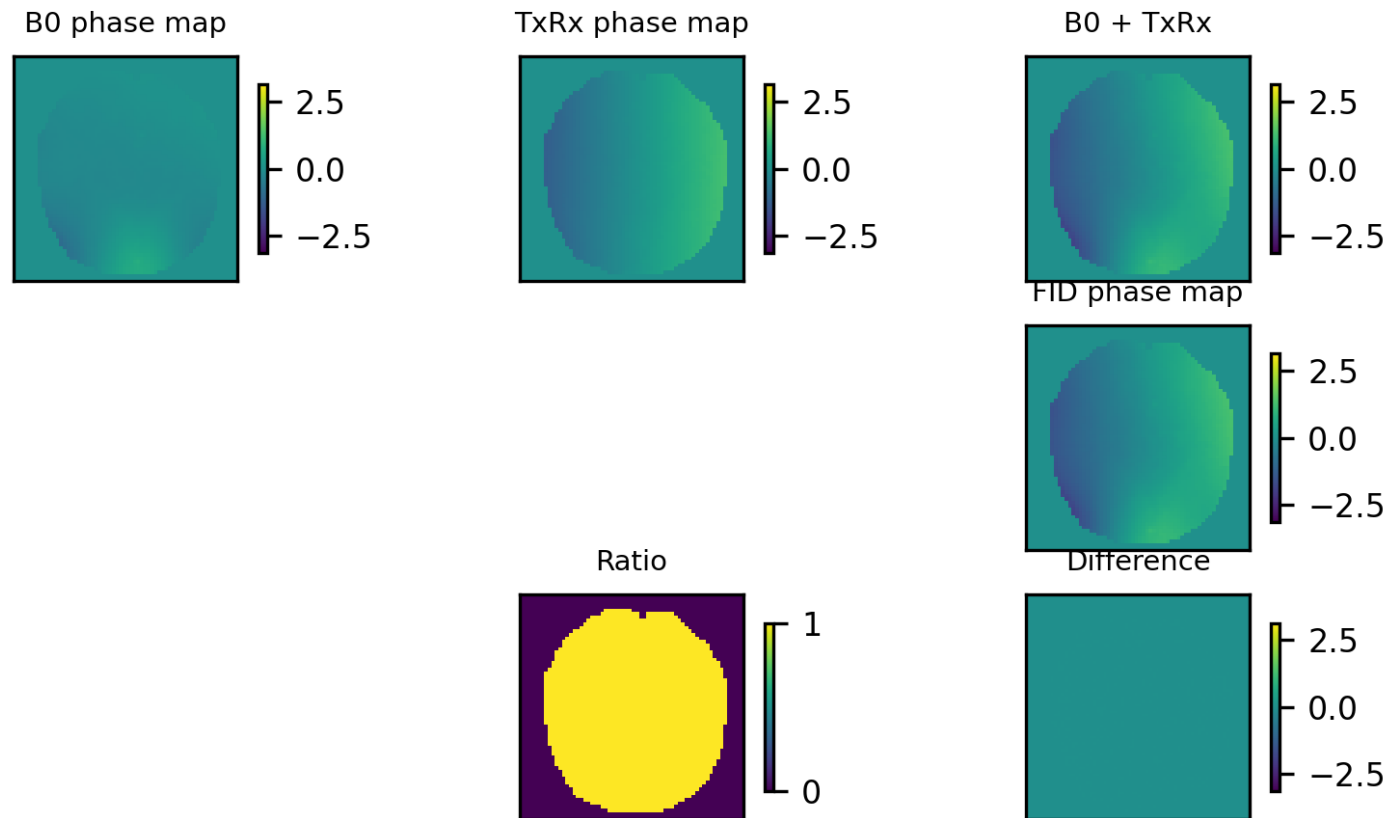
■ Problem number #3



Simulator to the rescue



■ Problem number #3



Simulator to the rescue

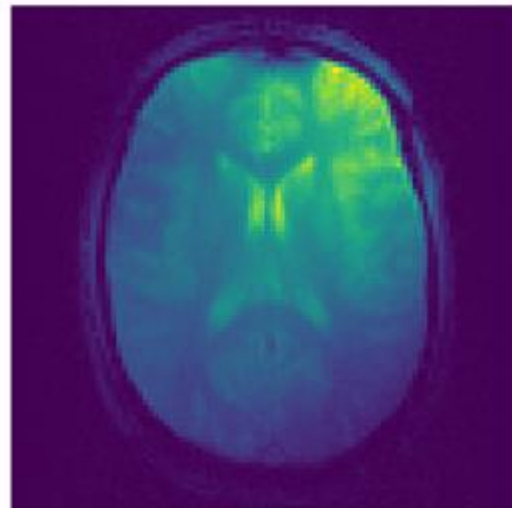


Going to the scanner

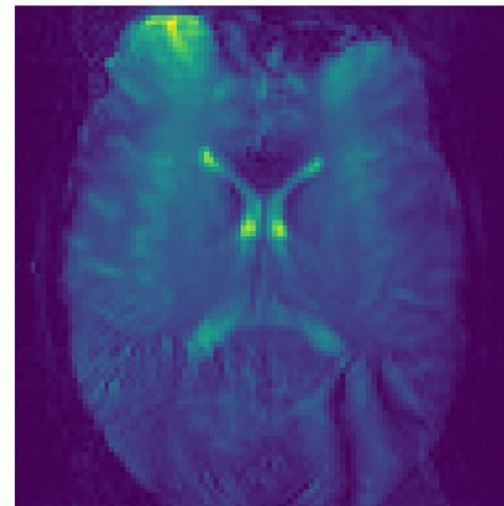
■ Problem number #4

Just a few weeks ago...looking to have the same FOV for a FLASH and EPI

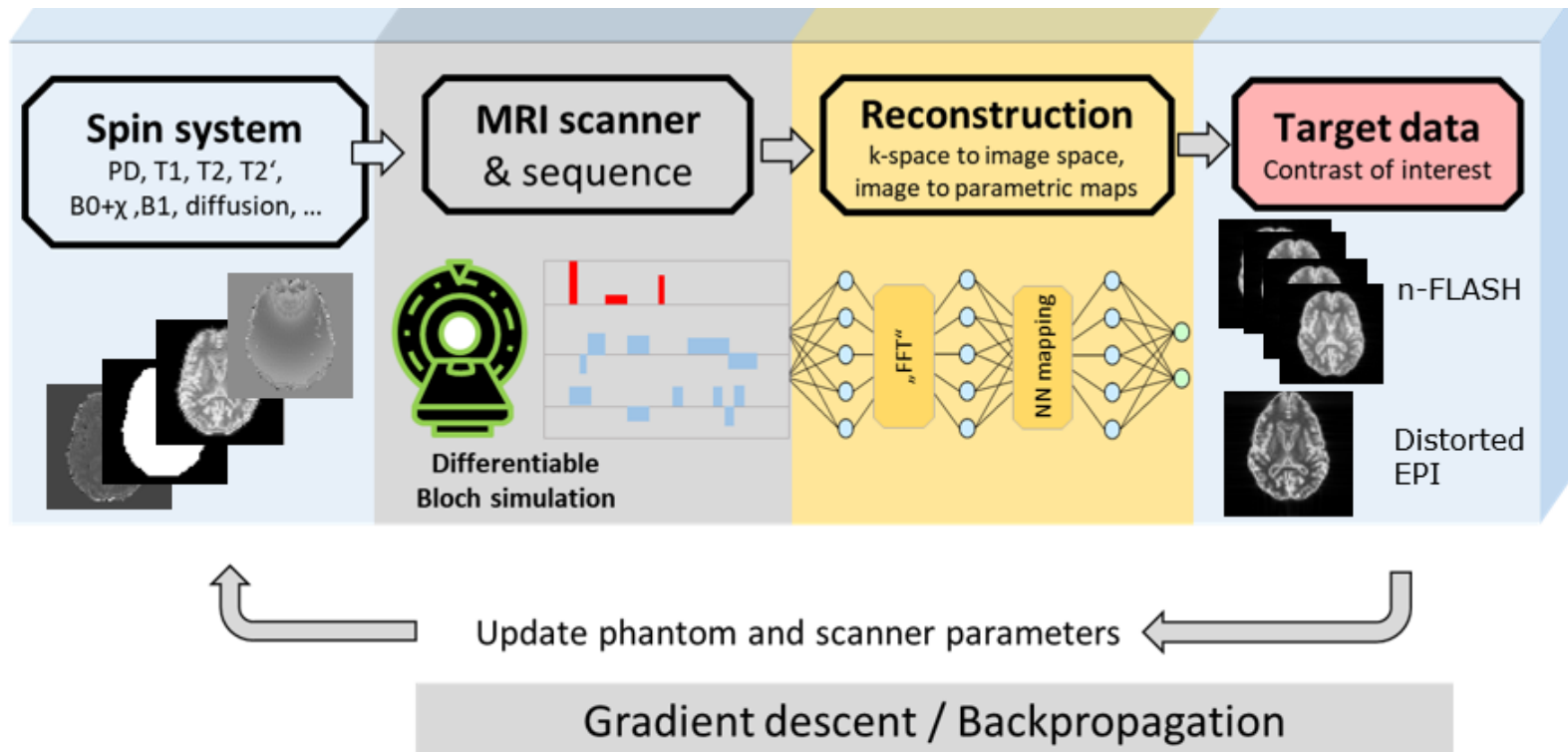
FLASH



EPI



You can do this and much more



You can do this and much more

- Determine the best readout for transient state
- Test the effect of more dummy pulses and variable flip angles
- Optimize sequences
- Jointly reconstruct different readout images
- Perform parameter quantification
- Optimize kT-points for pTx

**Visit the UKER
posters to learn
more**

**0011, 0112, 0113,
0421, 0422, 0423,
0456, 0483, 0484**



Conclusion

- MR-zero is a great simulation tool for introduction to MRI.
- Integrated with pypulseq, it allows easy and fast sequence simulation.
- Its full diferentiability allows end-to-end optimization.



Conclusion

- There are several opportunities to get started throughout the year:
 - MRTwin course at FAU
 - ISMRM 2023 pulseseq course
 - Hands-on MR Physics with Pulseseq, Freiburg 2024



References

- [1] Morishima, K., Kuno, M., Nishio, A., et al. (2017). Discovery of a big void in Khufu's Pyramid by observation of cosmic-ray muons. *Nature*, 552, 386–390. <https://doi.org/10.1038/nature24647>
- [2] Farhat, A. (n.d.). AI-generated image of Elon Musk as a baby. Twitter. Retrieved from <https://twitter.com/alifarhat79>
- [3] Endres, J., Weinmüller, S., Dang, H. N., & Zaiss, M. (2024). Phase distribution graphs for fast, differentiable, and spatially encoded Bloch simulations of arbitrary MRI sequences. *Magnetic Resonance in Medicine*. <https://doi.org/10.1002/mrm.30055>
- [4] Nehrke, K., Börnert, P. (2012). DREAM—a novel approach for robust, ultrafast, multislice B1 mapping. <https://doi.org/10.1002/mrm.24158>
- [5] Baum, T. https://mrzero-core.readthedocs.io/en/v0.2.7/playground_mr0/mr0_DREAM_STE_seq.html#dream-ste-seq

