New to MRI: simulator to the rescue

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Laptop ready?

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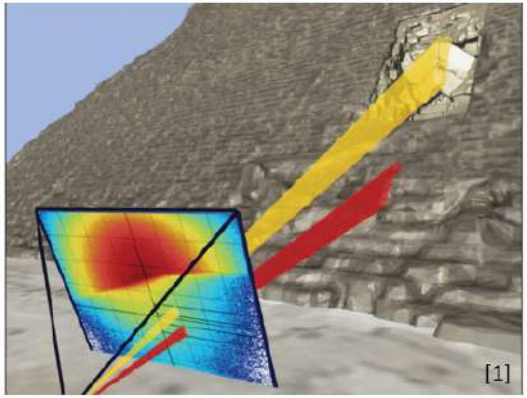
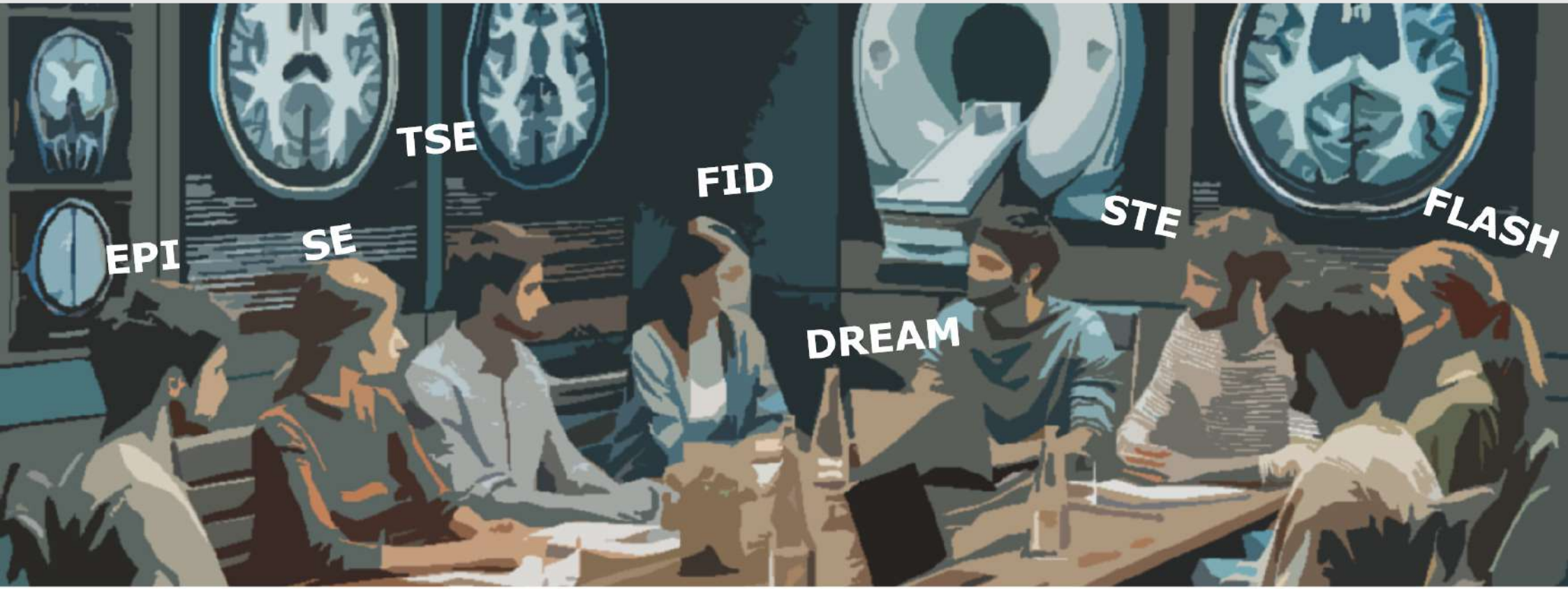
Background

- Nanotechnology
- Muon tomography



Hello MRI



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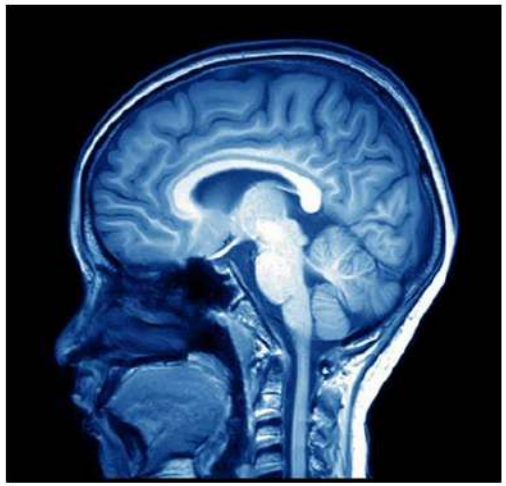
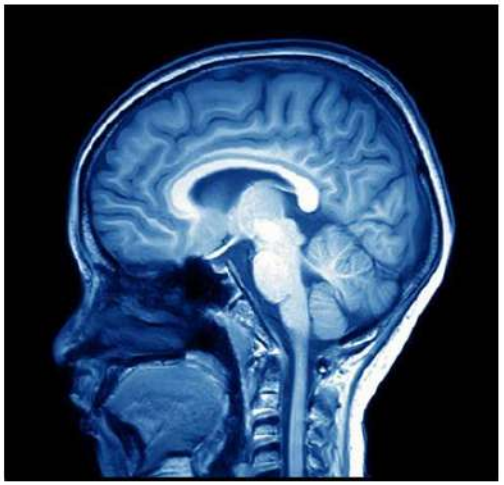
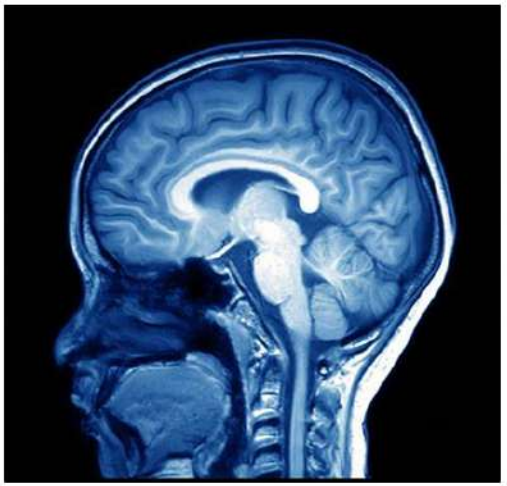


ESCAPE SE



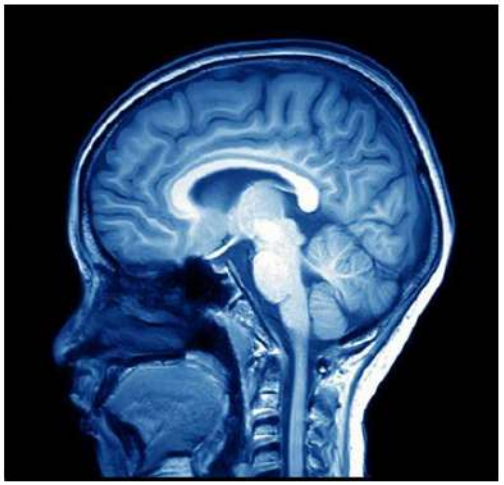
DANTE



X Æ A-Xii

Hello MRI

ESCAPE SE



DANTE

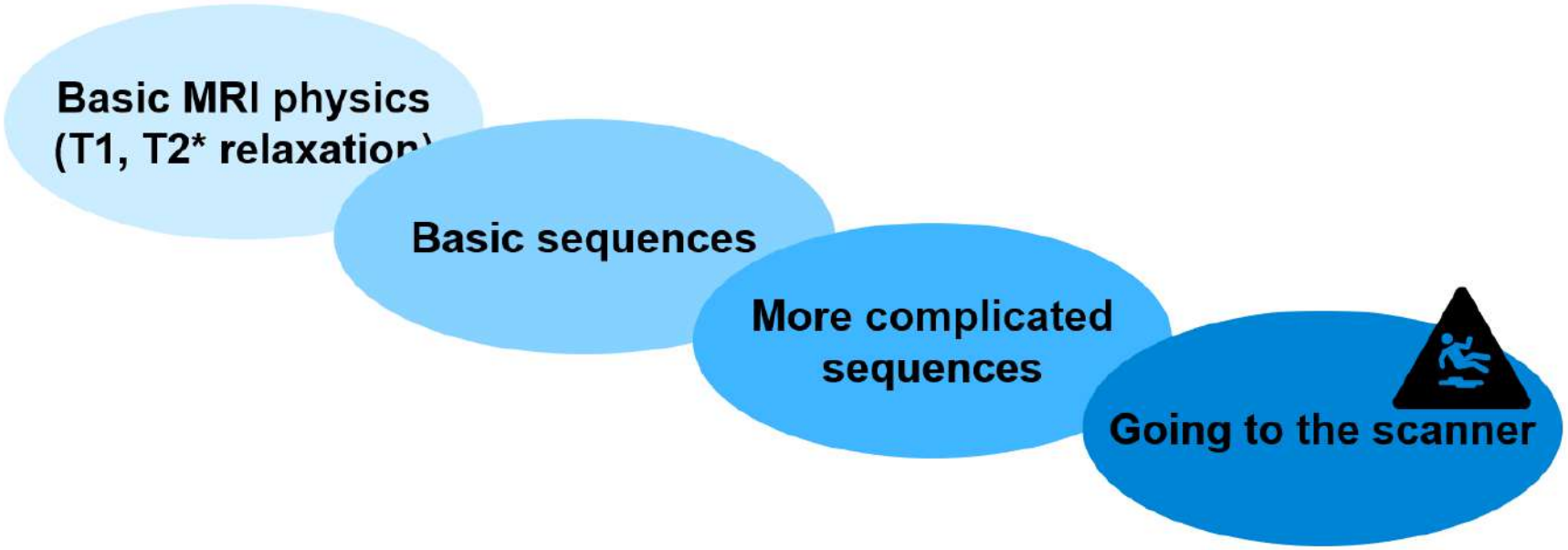
[2]

X Æ A-Xii

Simulator to the rescue

[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

Simulator to the rescue



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**

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

Simulator to the rescue

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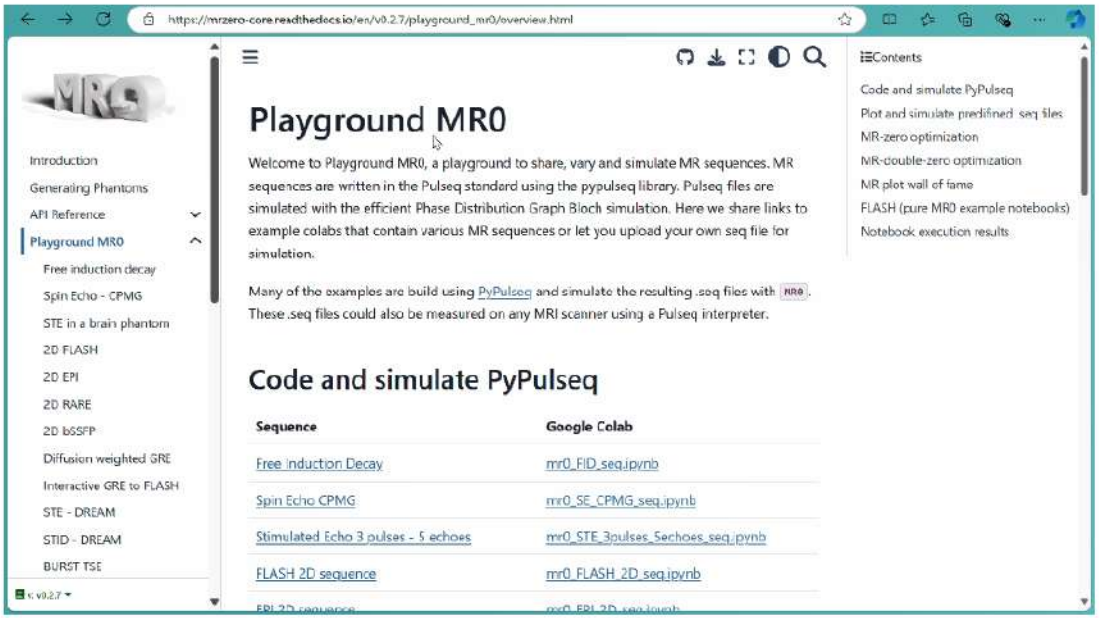
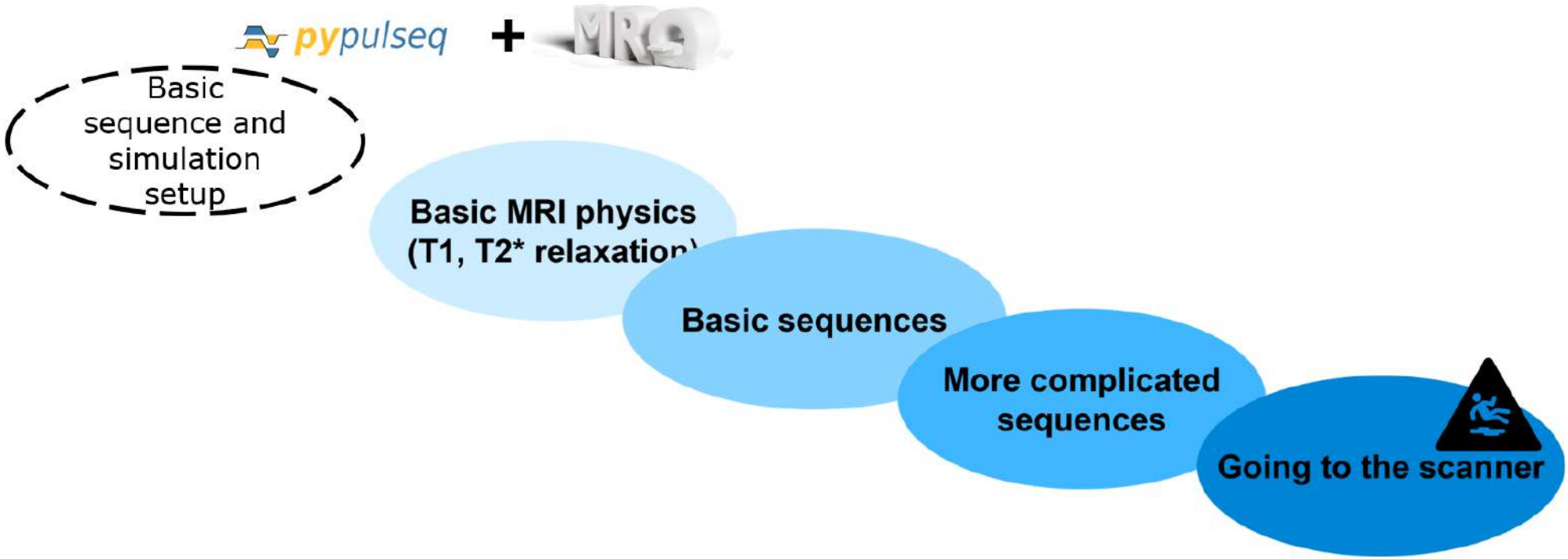
More notebooks on the Playground-MR0 website:



Simulator to the rescue



Simulator to the rescue

Basic sequence and simulation setup

- Install libraries

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

Simulator to the rescue

Basic sequence and simulation setup

- Prepare sequence and save as .seq file

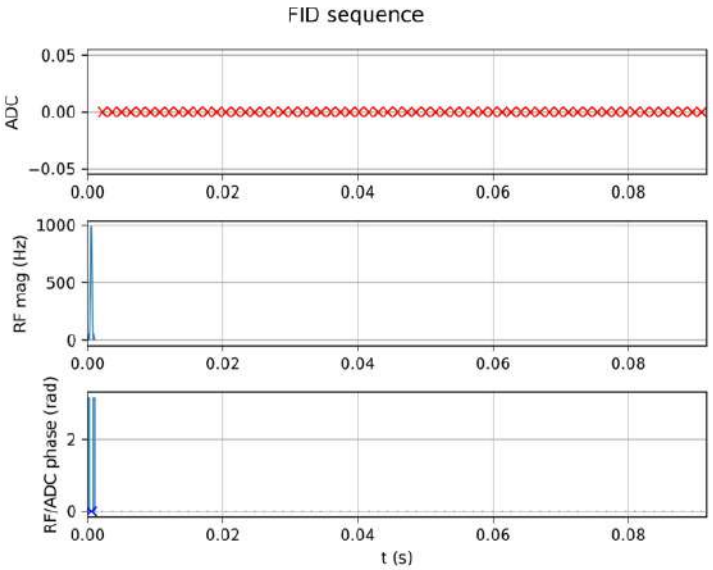
```
# Build sequence: T2star relaxation
seqT2star = pp.Sequence()
seqT2star.add_block(rf1, gz)
seqT2star.add_block(gzr)
seqT2star.add_block(adc)
aux_check_timing(seqT2star)
seqT2star.write("FID.seq")
```

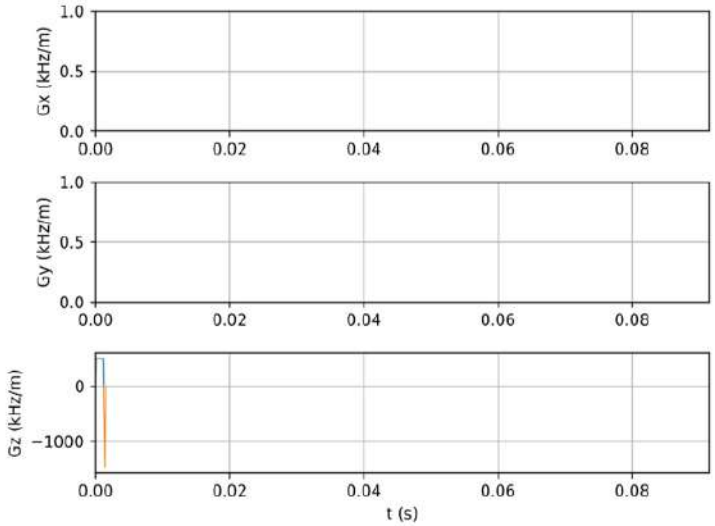
pypulseq

Simulator to the rescue

Basic sequence and simulation setup

- Prepare sequence and save as .seq file





Simulator to the rescue

Basic sequence and simulation setup

- Load the sequence as an MR-zero sequence object

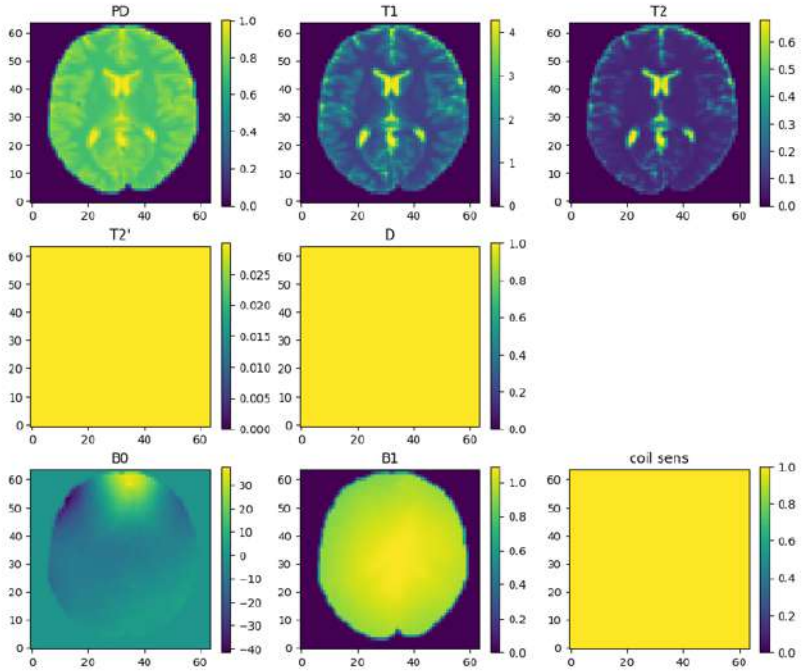
```
seq0_T2star = mr0.Sequence.import_file('FID.seq')
```

- 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()
```

Simulator to the rescue

Basic sequence and simulation setup



Simulator to the rescue

Basic MRI physics (T1, T2* relaxation)

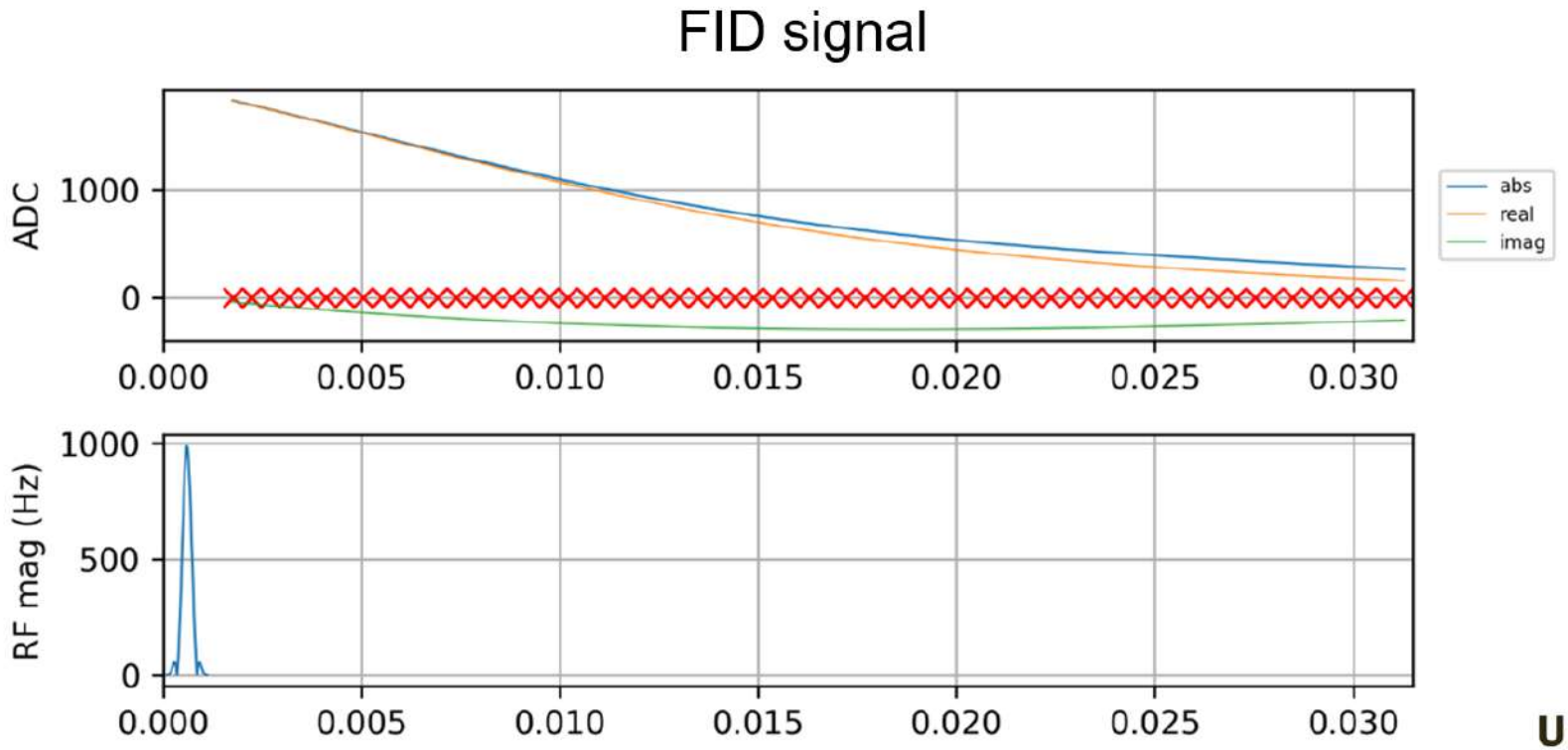
- Simulate signal

```
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



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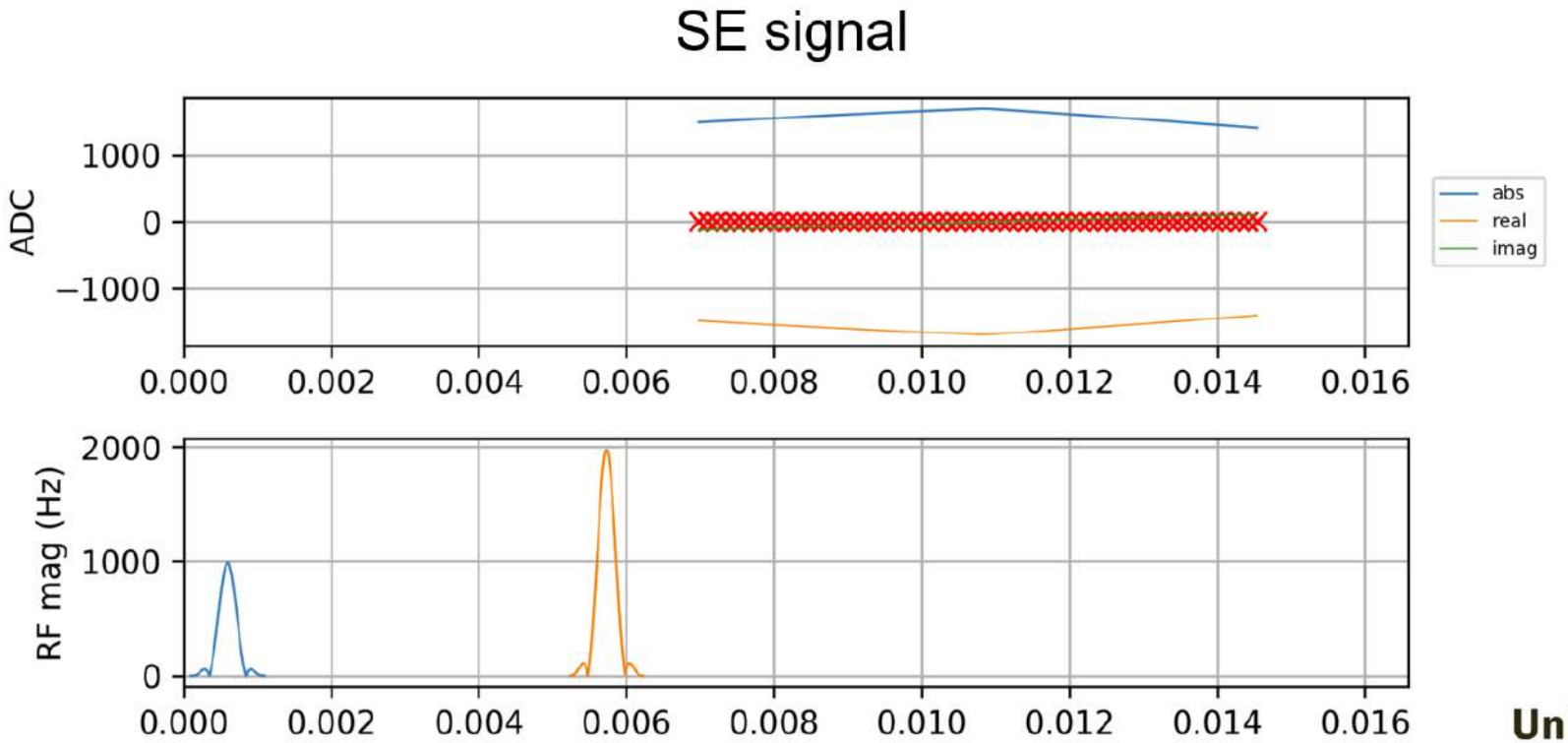


Simulator to the rescue

Basic sequences

- Simulate

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

- Reconstruct image from signal

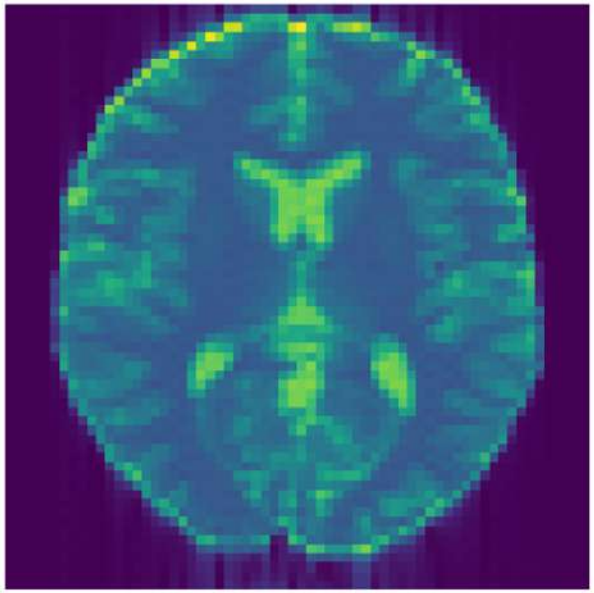
```
# kspace reordering
kspace_EPI = torch.reshape((signal_EPI), (Nphase, Nread)).clone().t()
kspace_EPI[:,0::2] = torch.flip(kspace_EPI[:,0::2],[0] )[:,:]

# 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

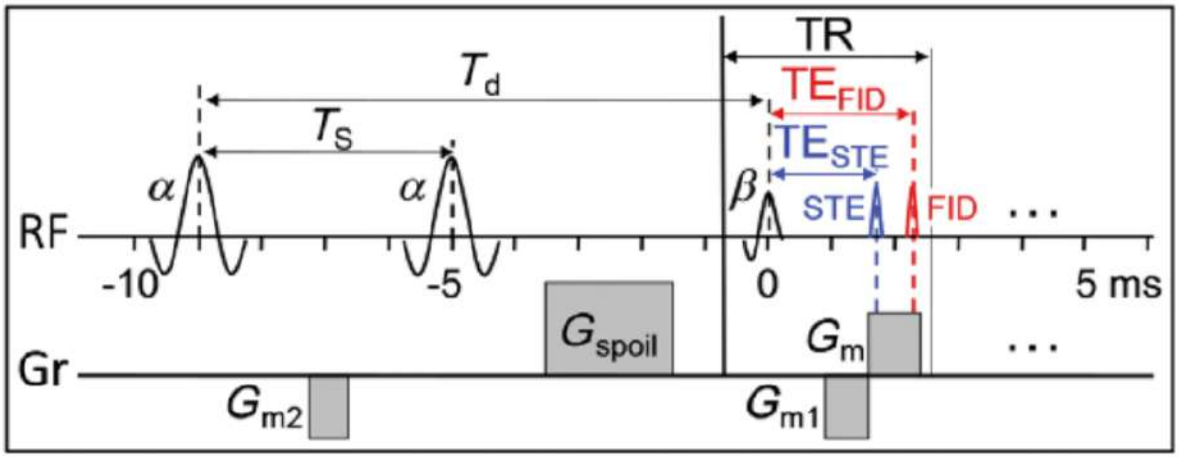
Basic sequences

Magnitude EPI



Simulator to the rescue

More complicated sequences

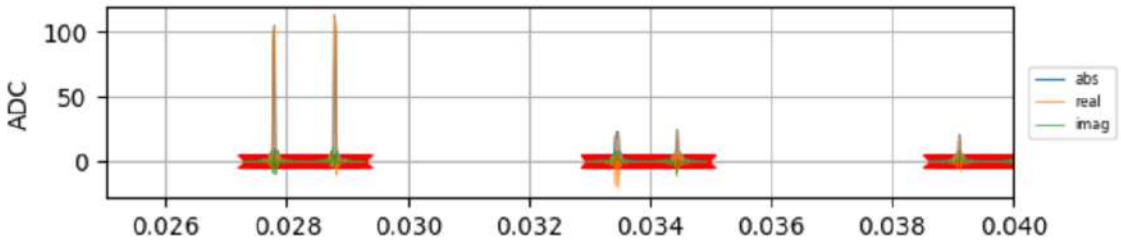


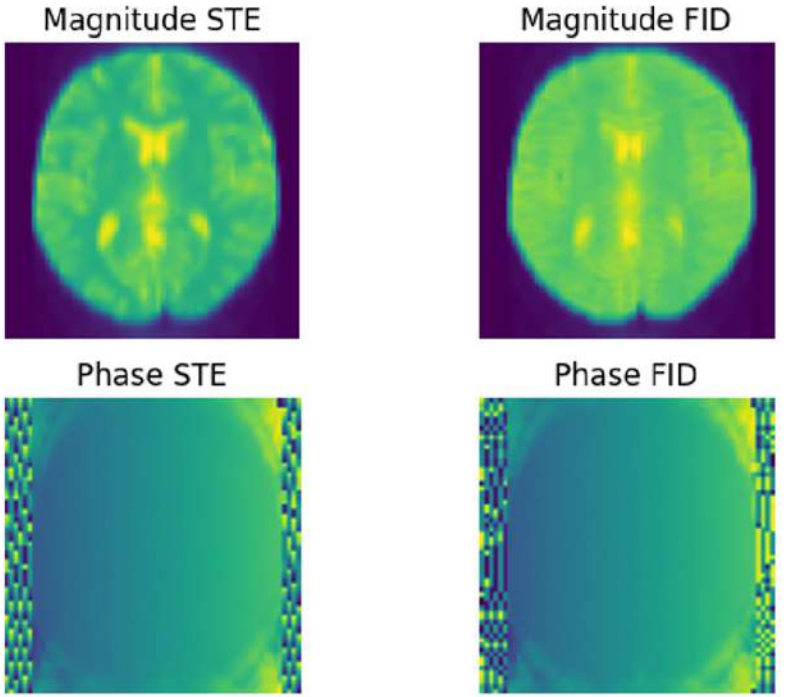
[4] Nehrke, K., Börnert, P. (2012). DREAM—a novel approach for robust, ultrafast, multislice B1 mapping. https://doi.org/10.1002/mrm.24158

Simulator to the rescue

More complicated sequences

- DREAM – B1, B0, TxRx mapping sequence





[5] Baum, T. https://mrzero-core.readthedocs.io/en/v0.2.7/playground_mr0/mr0_DREAM_STE_seq.html#dream-ste-seq

Simulator to the rescue

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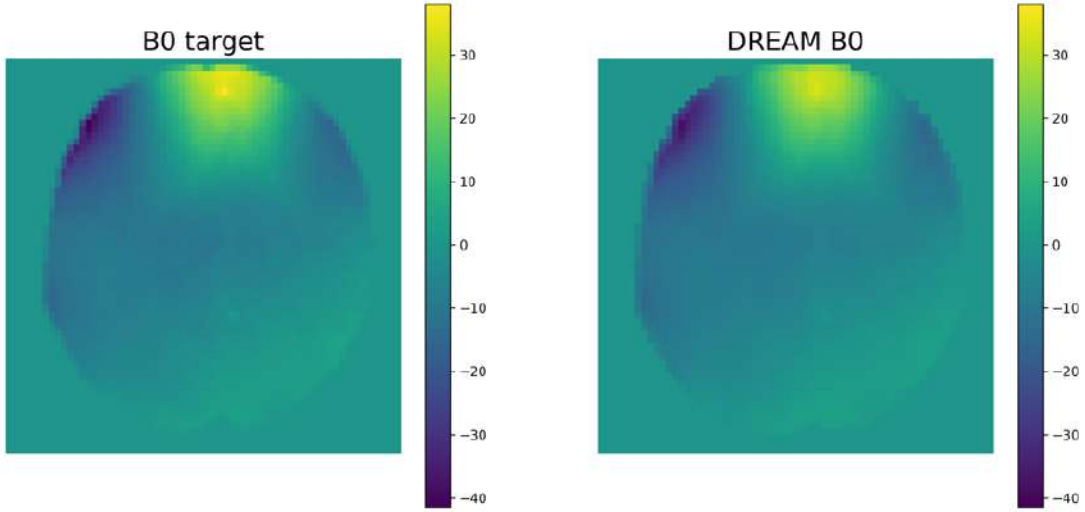

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Simulator to the rescue

- Problem number #1

Simulator to the rescue

- Problem number #1

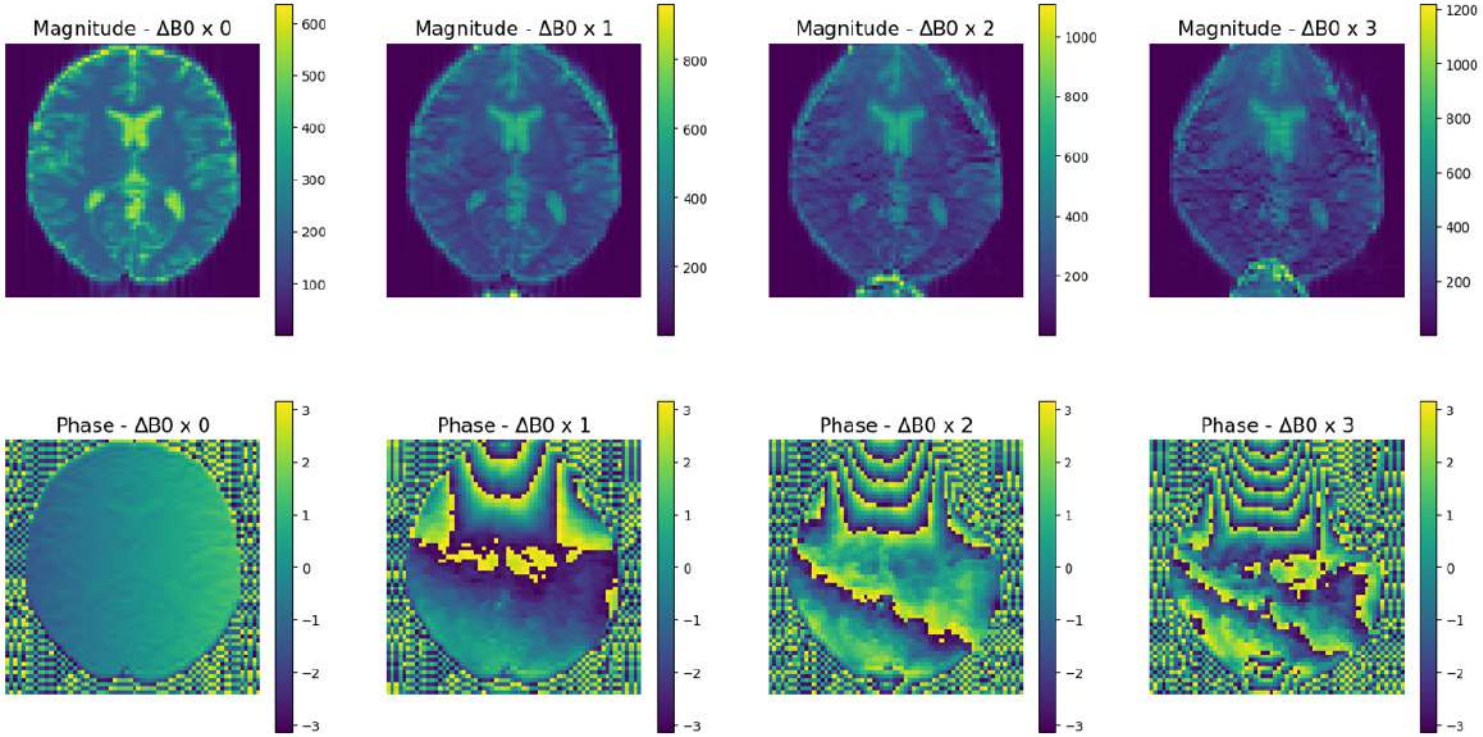
Time to code:

03_full_acquisition_simulations/notebooks/New_to_MRI_Simulator_to_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

Simulator to the rescue

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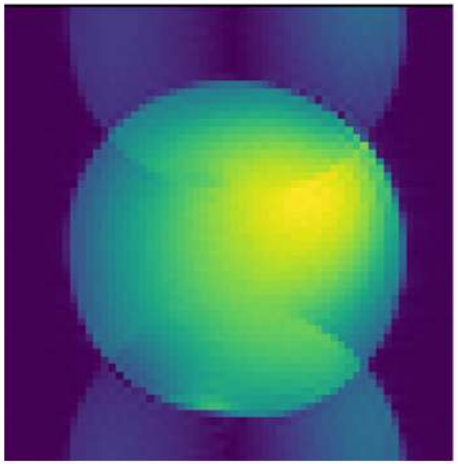
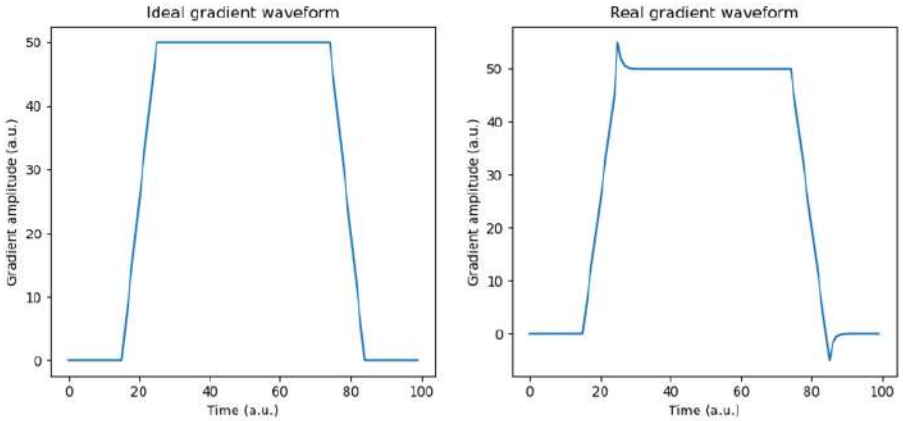


Simulator to the rescue

- Problem number #2



Simulator to the rescue

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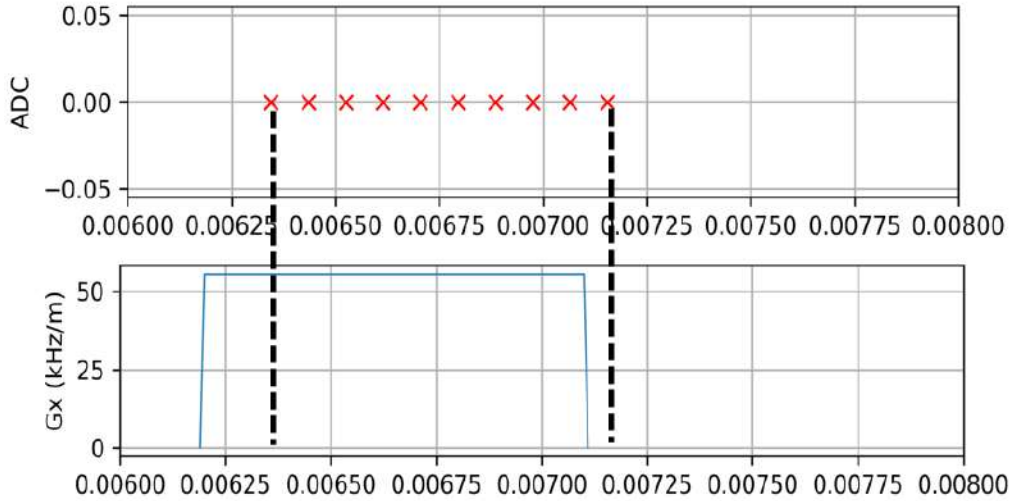

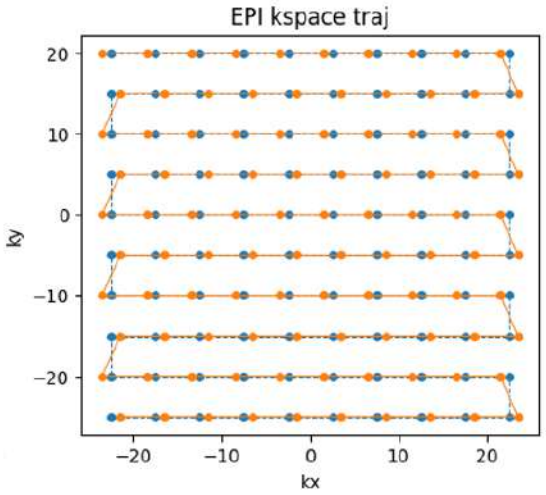

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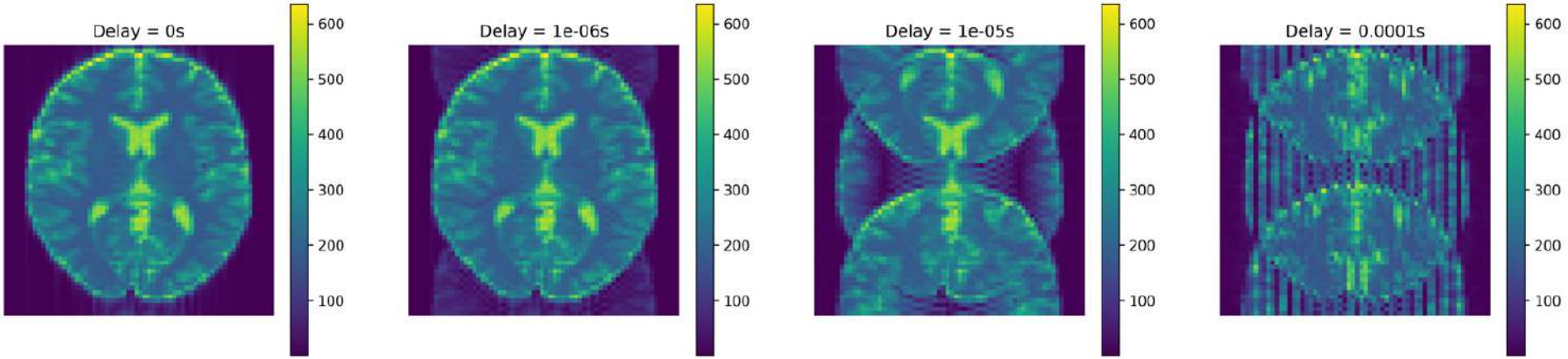

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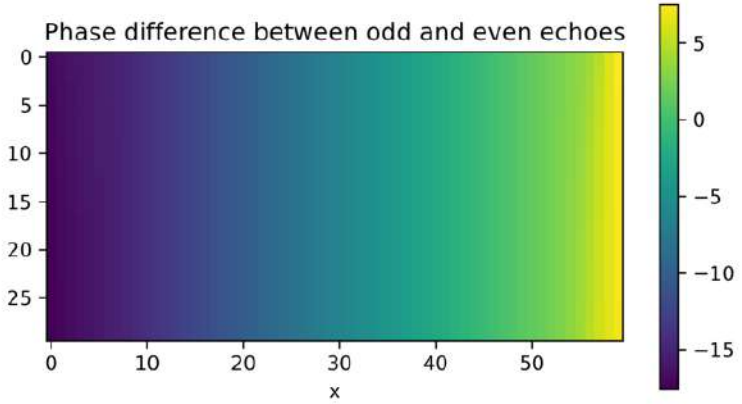
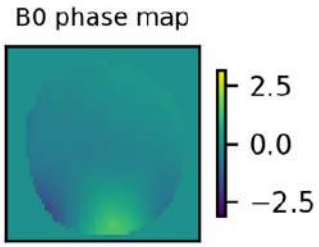
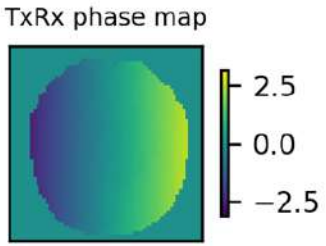


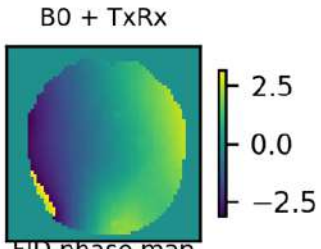
Time delay = linear phase factor

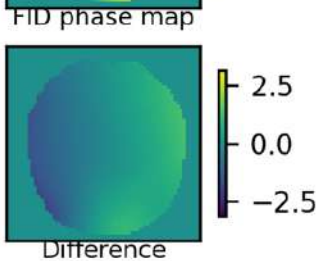
Simulator to the rescue

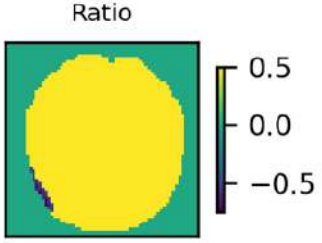
- Problem number #3

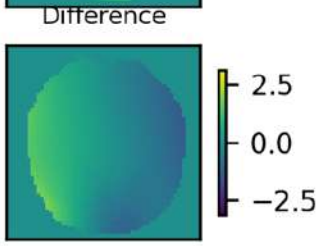






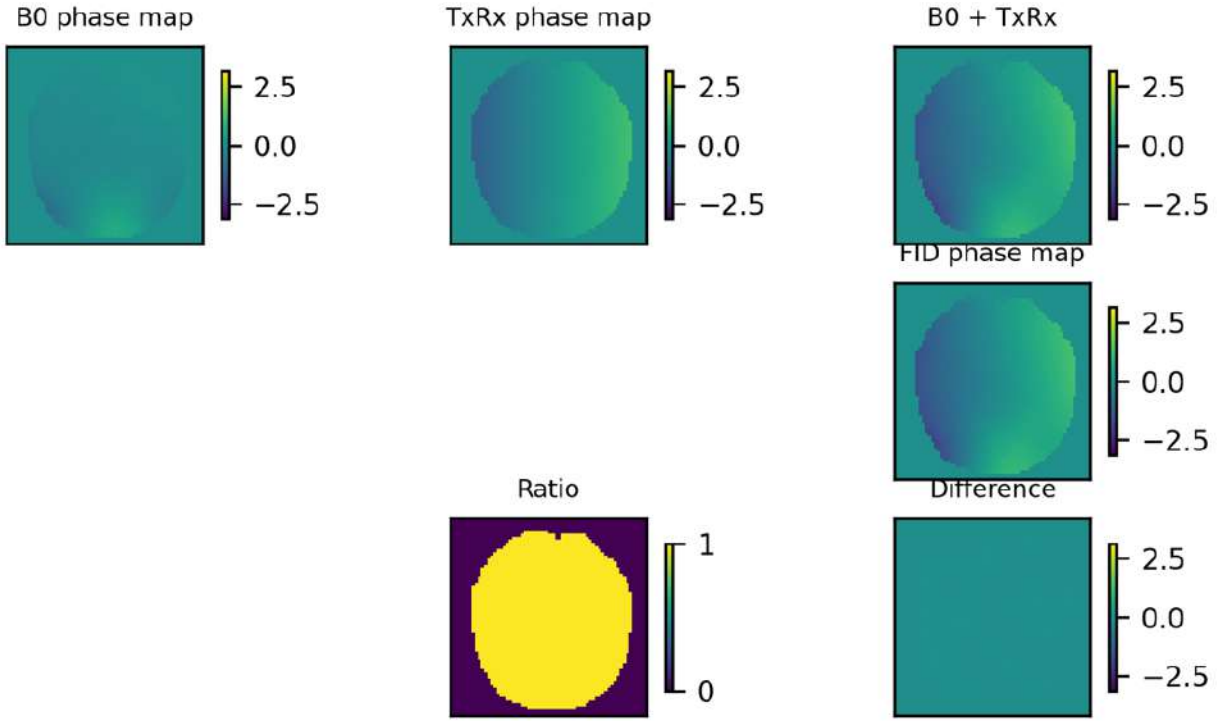






Simulator to the rescue

- Problem number #3

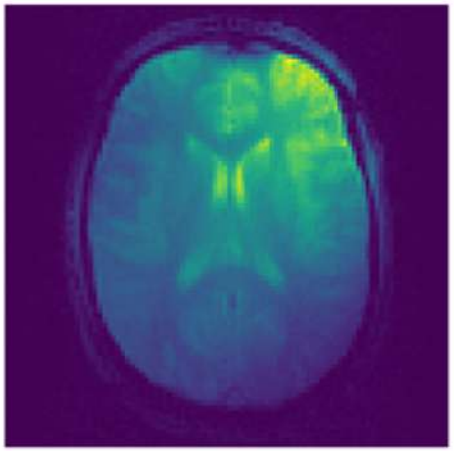


Simulator to the rescue

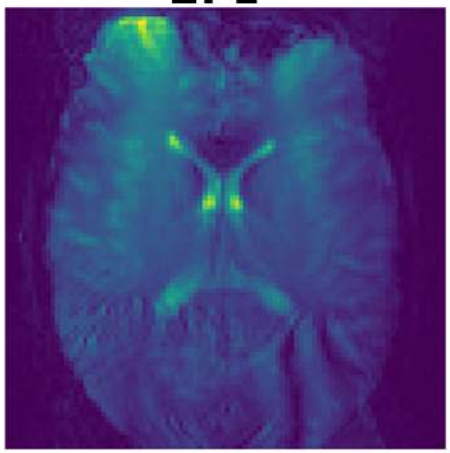
- Problem number #4

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

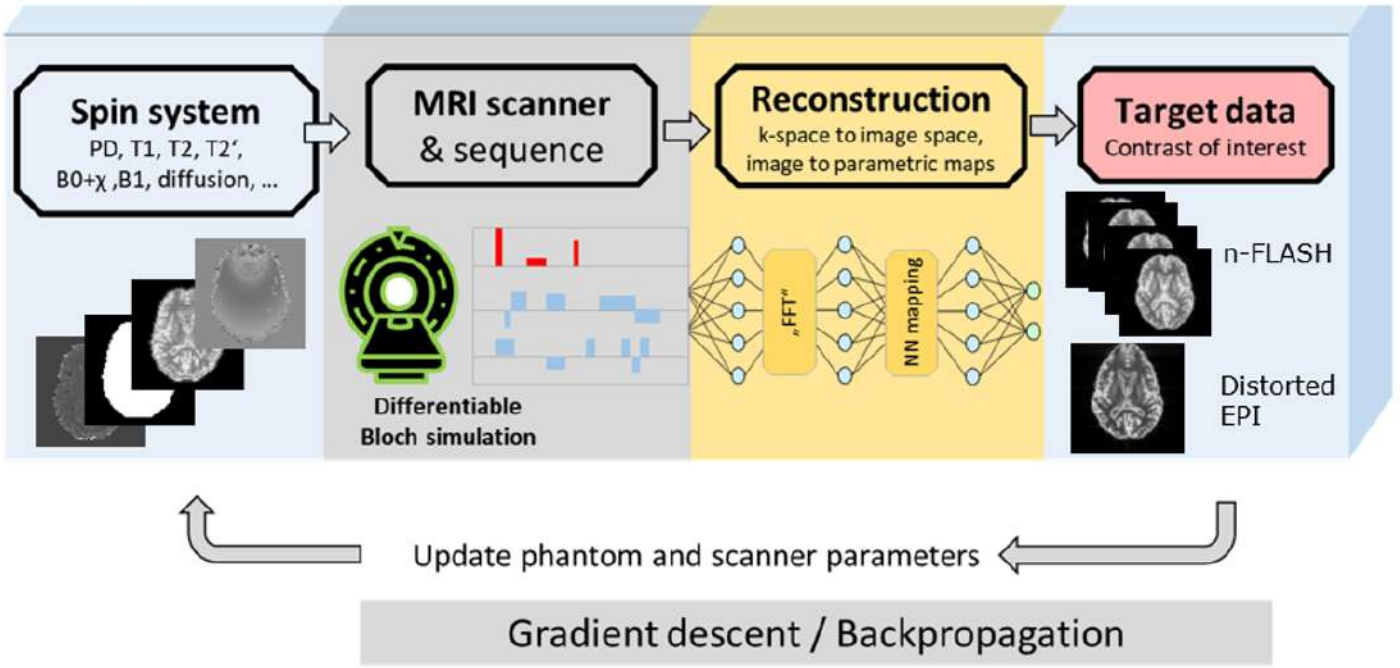
FLASH



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 variale flip angles
- Optimize sequences
- Jointly reconstruct different readout images
- Perform parameter quantification
- Optimize kT-points for pTx

You can do this and much more

- Determine the best readout for transient state
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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 pulseq course
  - Hands-on MR Physics with Pulseq, 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

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