Dual-polarity SENSE with calibration data refinement enables robust Nyquist ghost correction on a high-performance gradient system

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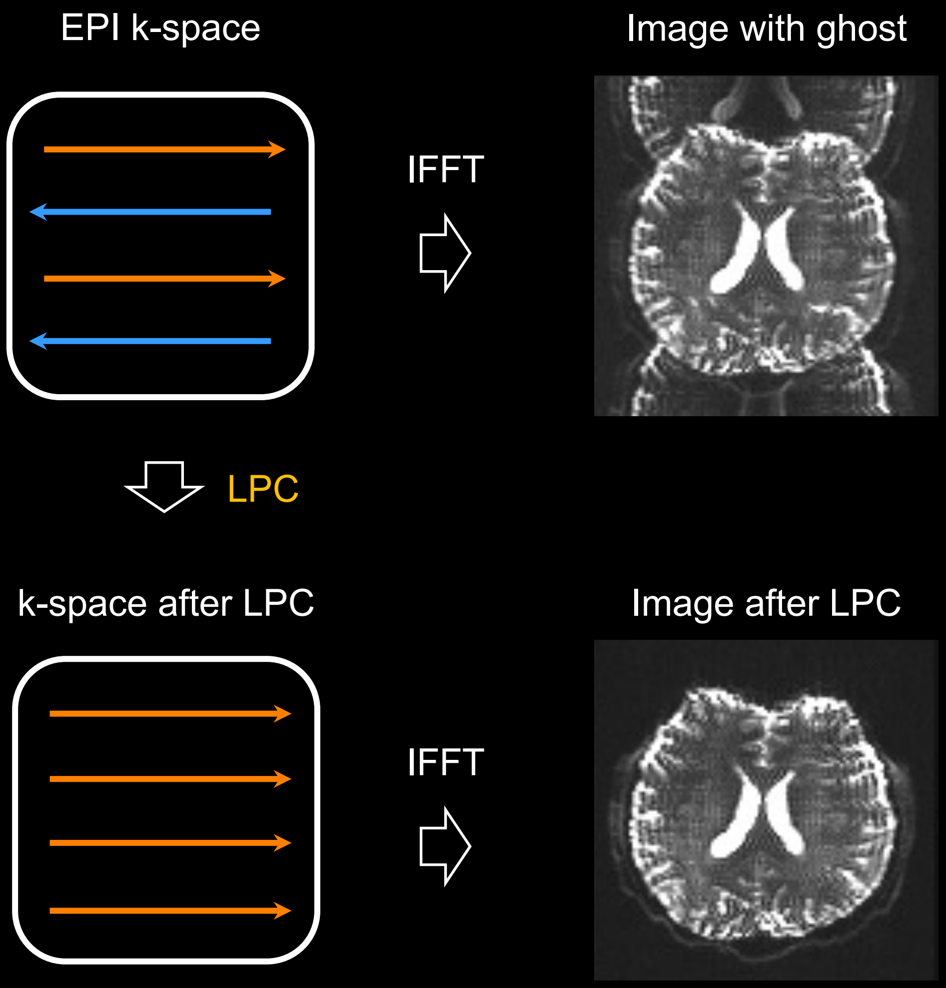
Introduction

Echo-Planer Image (EPI) is prone to Nyquist ghost, because it contains two readout polarities (RO+ and RO-).[1]

Imperfections like gradient delay or Eddy current can cause differences between RO+ and RO-, thus introducing Nyquist ghost.

Linear phase correction (LPC)[2] models the differences as a linear term and corrects it.

However, LPC can fail at scanners with high-performance gradients or ultra-high fields.



[1] Reeder et al. MRM 1997. [2] Feiweier et al. US Patent 2013.

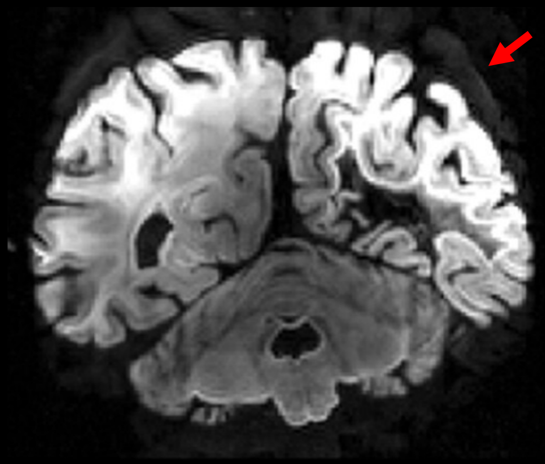
LPC

LPC can fail because of:

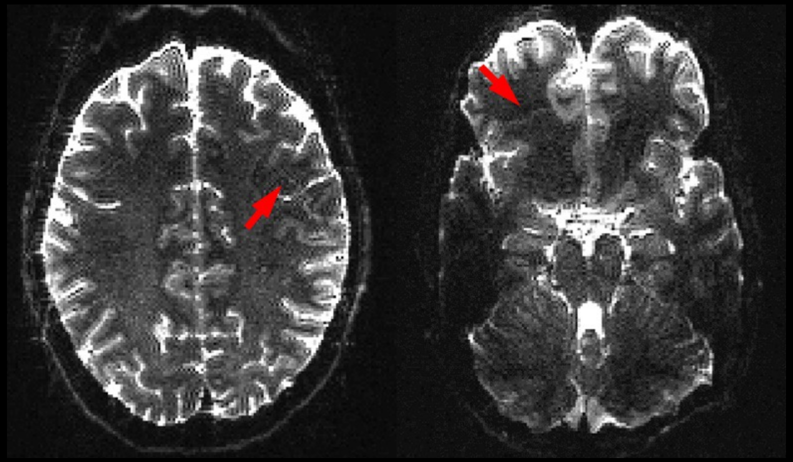
- Severe Eddy currents induced by high slew rate in diffusion encoding gradients.[1]
- Increased B_0-field inhomogeneities in ultra-high fields.[2]

Need some better methods.

LPC fails @ high slew rate



LPC fails @ 7T

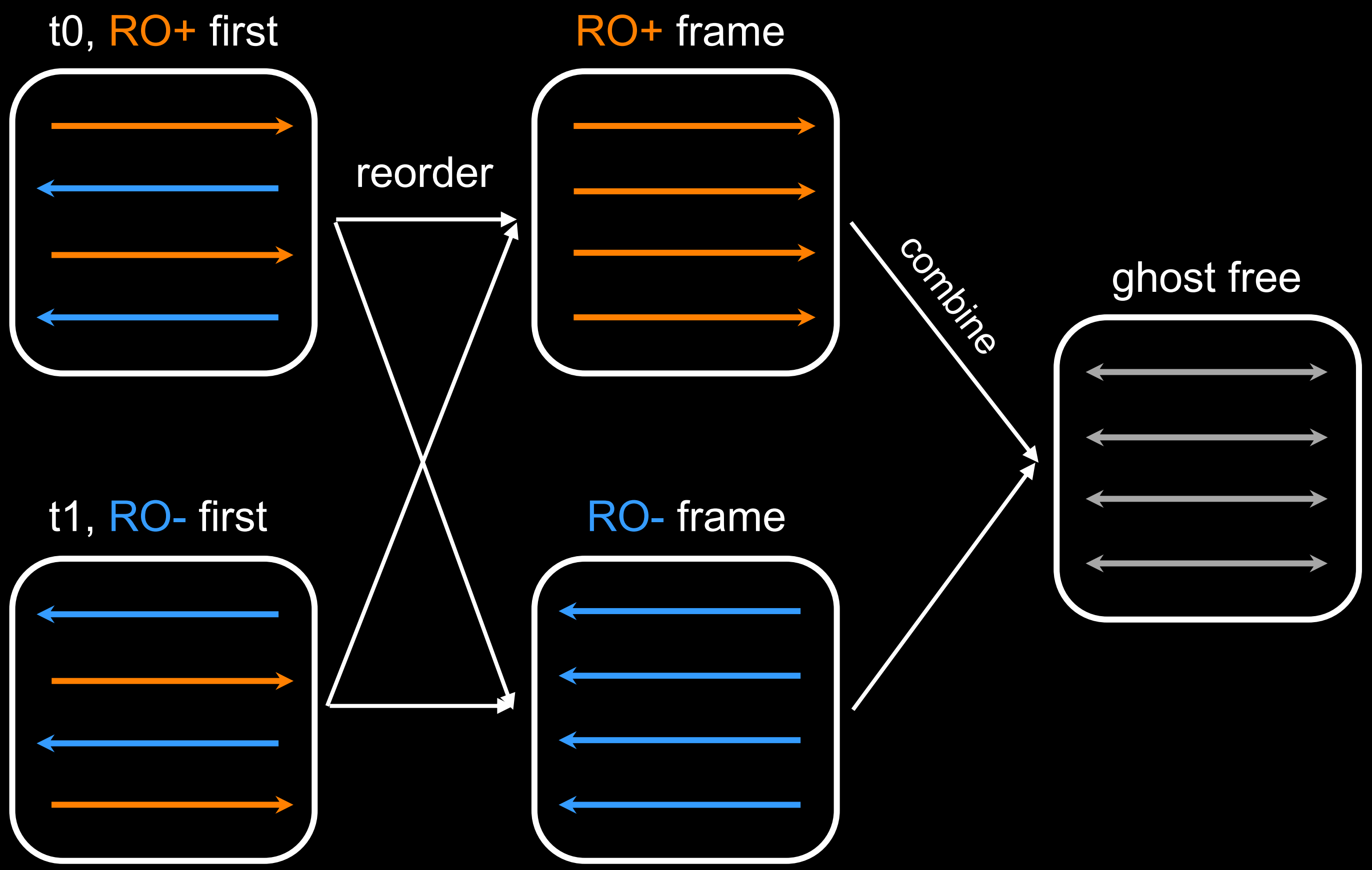


[1] Ramos Llordén et al. MRM 2023. [2] Pan et al. MRM 2023.

Time-encoded method

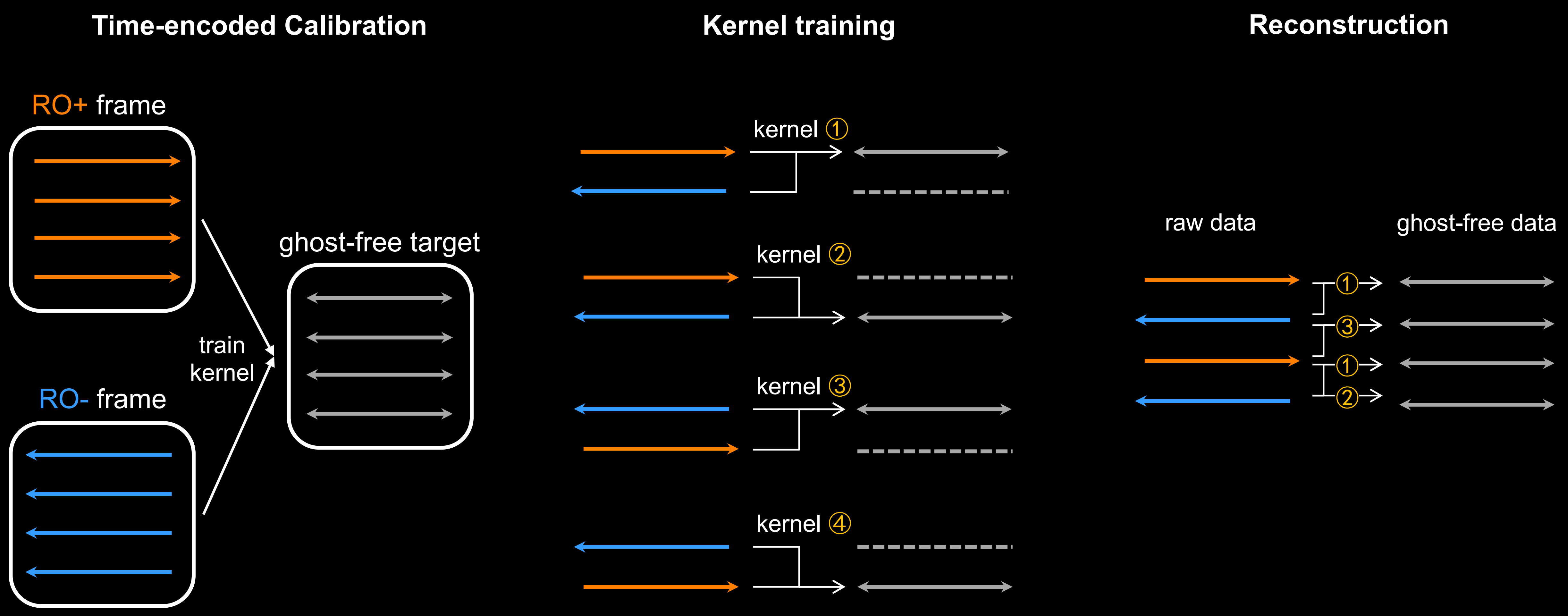
Time-encoded methods capture 2D difference between RO+ and RO-.

It is time-consuming.



[1] Hoge et al. MRM 2010. [2] Xiang et al. MRM 2007.

Dual-polarity GRAPPA (DPG)



[1] Hoge et al. MRM 2016. [2] Hoge et al. MRM 2010

Dual-polarity GRAPPA (DPG)

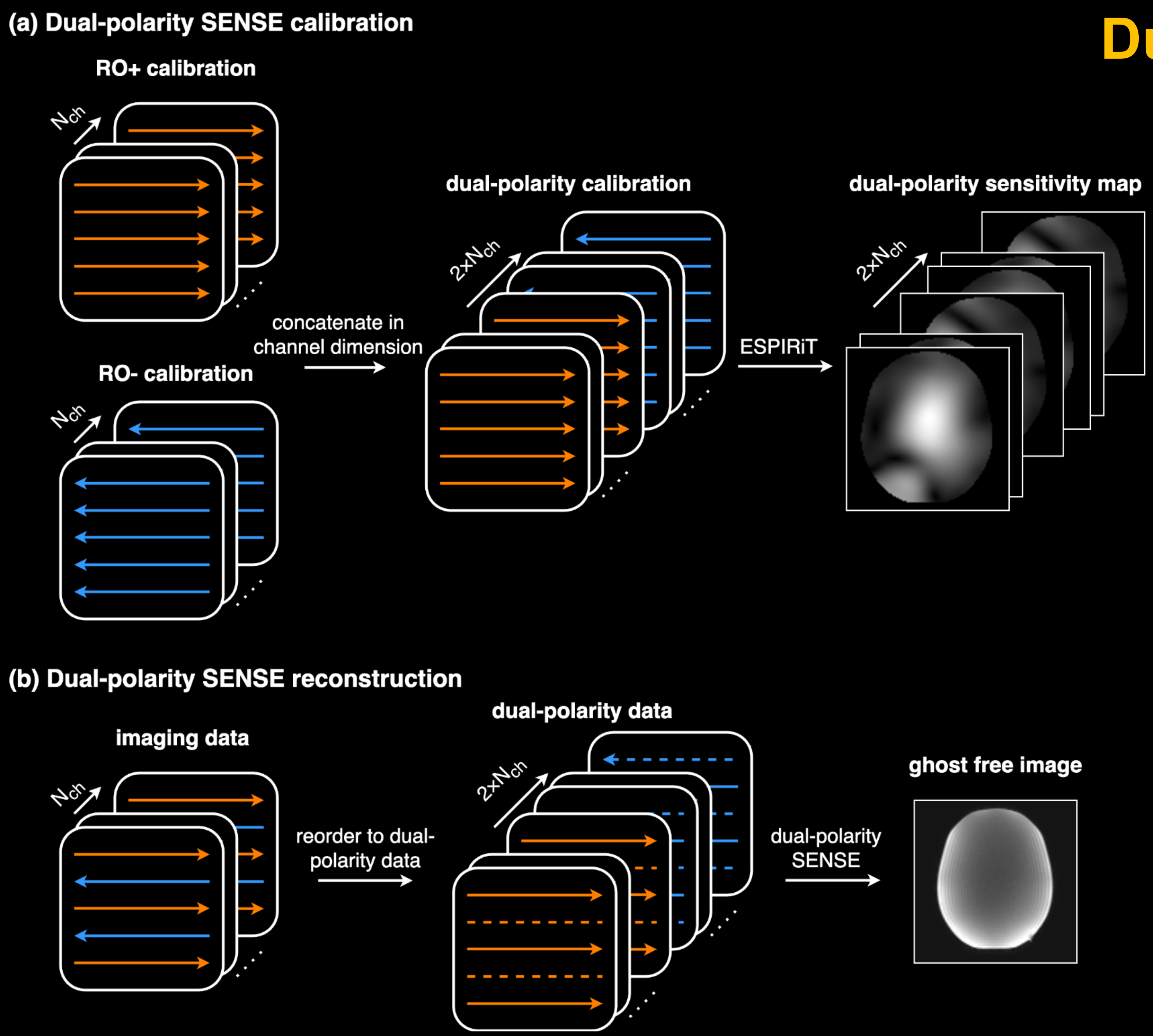
DPG is:

- Originally designed for single-shot EPI.
- GRAPPA-based and cannot lend itself to navigator-free multi-shot diffusion imaging.

Dual-polarity SENSE (DPS):

- SENSE-based regularized reconstruction.

Dual-polarity SENSE (DPS)



DPS utilizes DPG-type calibration.

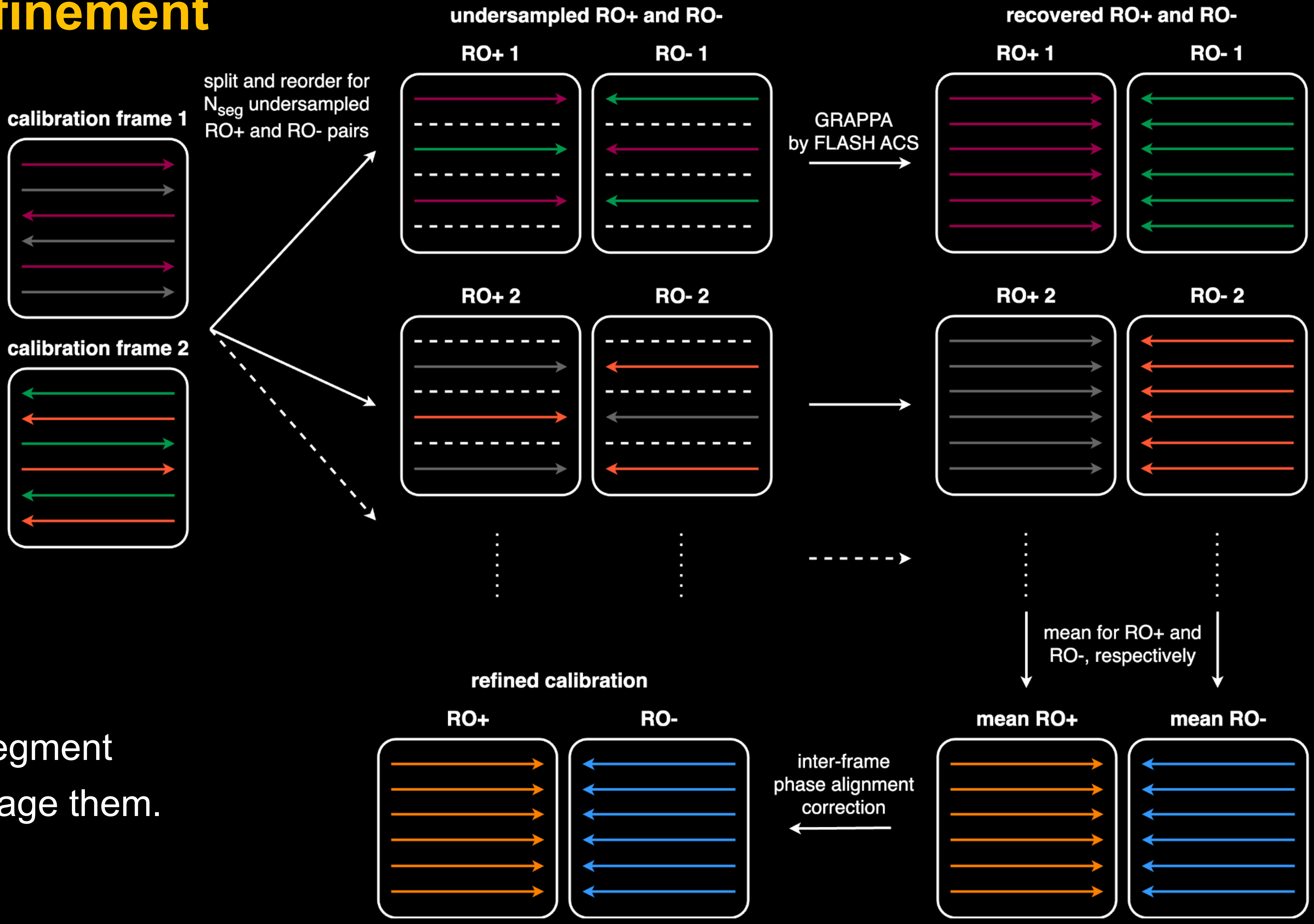
Virtual sensitivity maps is used to capture 2D difference between 2 polarities.

SENSE-type reconstruction.

Need high-quality calibration data.

[1] Uecker et al. MRM 2014.

Calibration refinement



Reconstruct each segment separately and average them.

[1] Chang et al. Proc ISMRM 2019.

Experiments

Connectome 2.0

3T, G_{max} = 500 mT/m, S_{max} = 600 T/m/s

- Single-shot EPI (ssEPI)
- Phantom and in vivo experiments.
- Test calibration refinement.
- Compare DPS with LPC+GRAPPA and DPG.

Terra.X

7T, G_{max} = 130 mT/m, S_{max} = 250 T/m/s

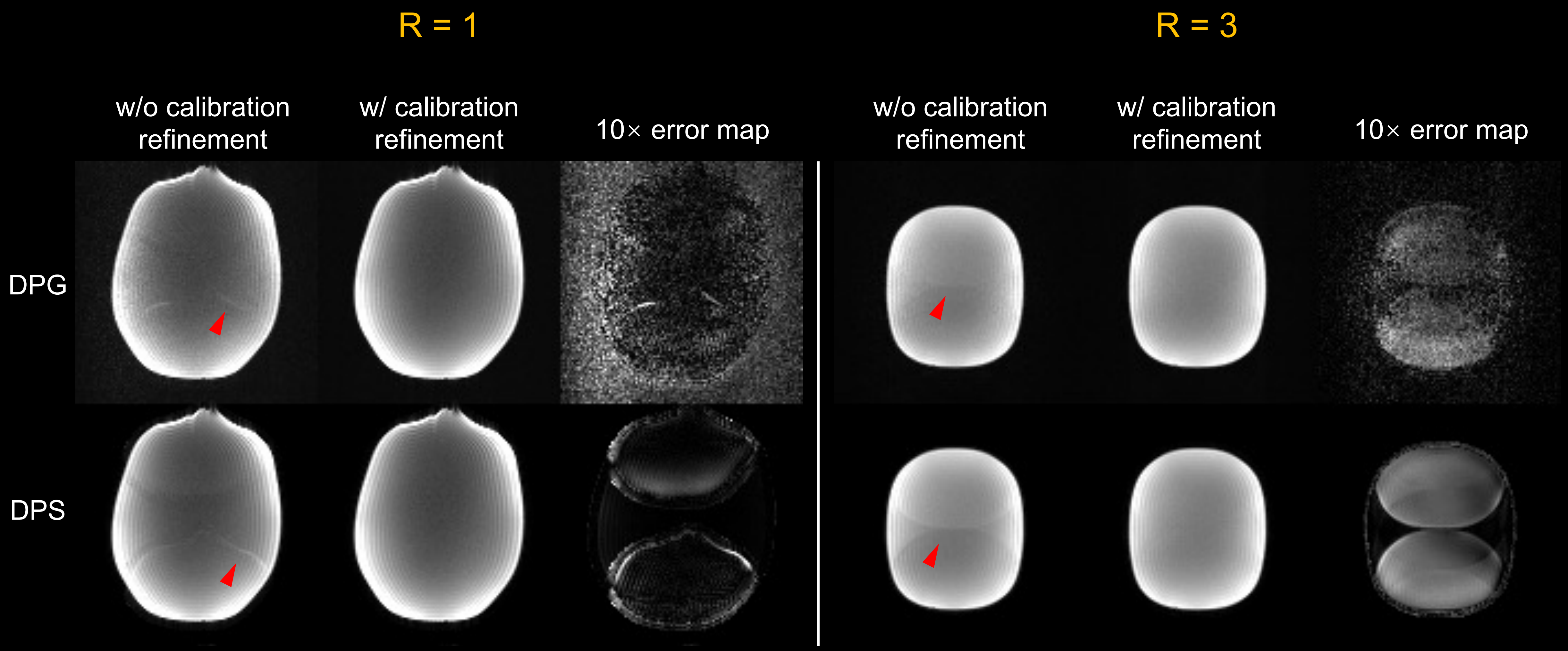
- Interleave EPI (iEPI)
- In vivo experiments.
- Compare DPS with LPC+SENSE and DPG*.

* We used DPG to reconstruct each shot and averaged the results.

[1] Huang et al. NeuroImage 2021. [2] Layton et al. MRM 2016.

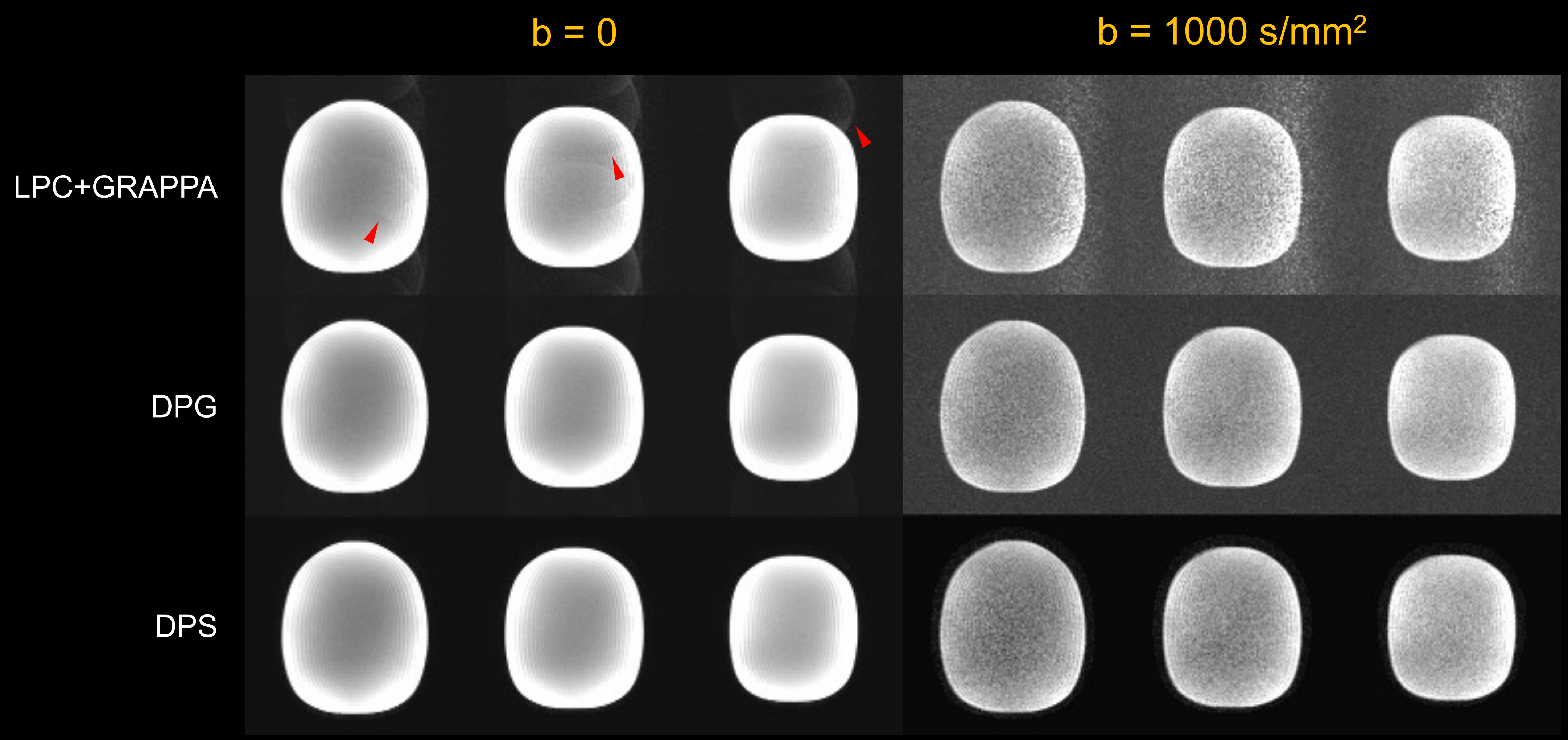
ssEPI, phantom @Connectome 2.0

- 2 mm isotropic



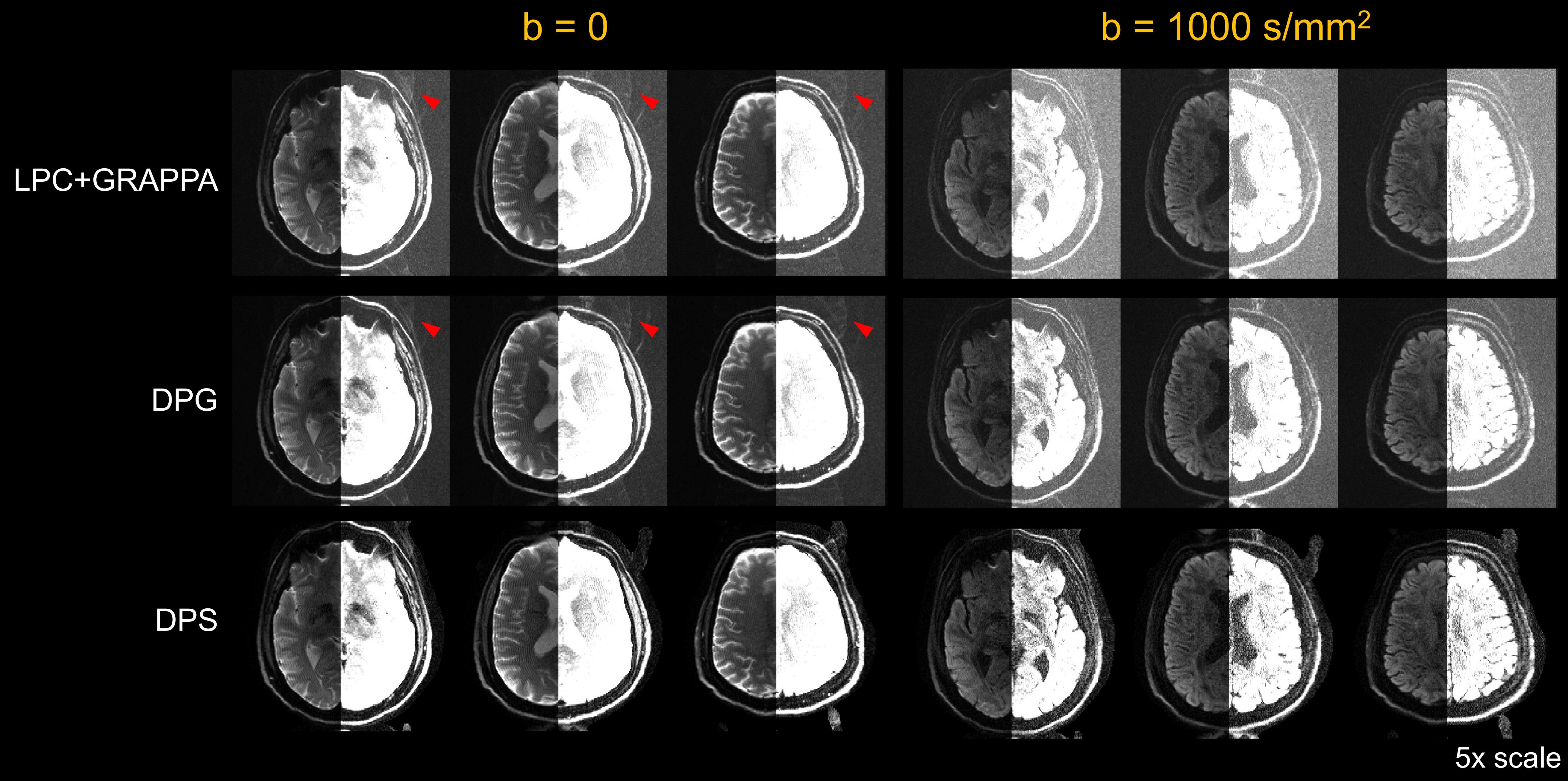
ssEPI, phantom @Connectome 2.0

- R = 2, 2 mm isotropic



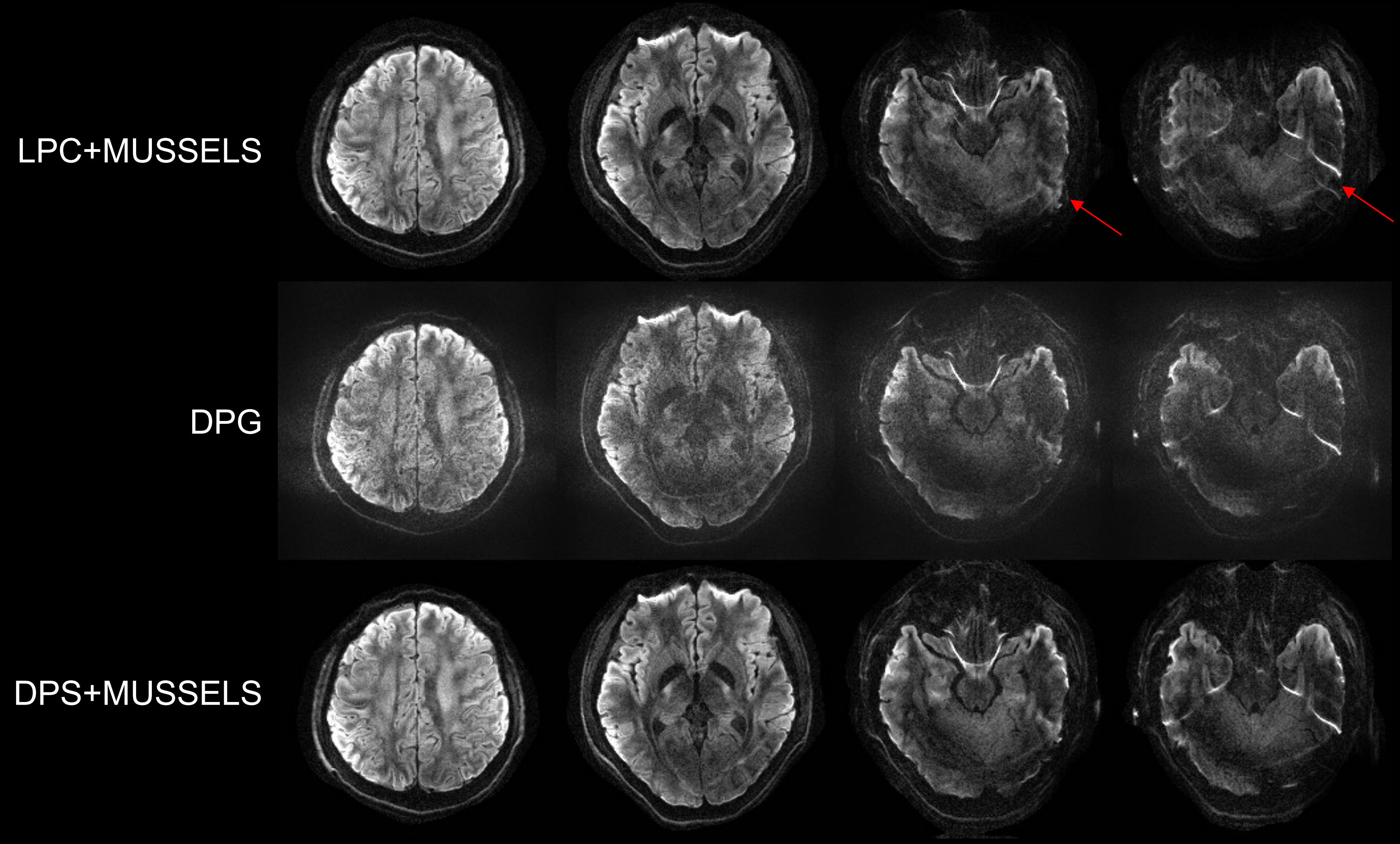
ssEPI, in vivo @Connectome 2.0

- $R = 2$, $1 \times 1 \times 4$ mm^3
- pF = 6/8
- ESP = 0.57 ms



iEPI, in vivo @Terra.X

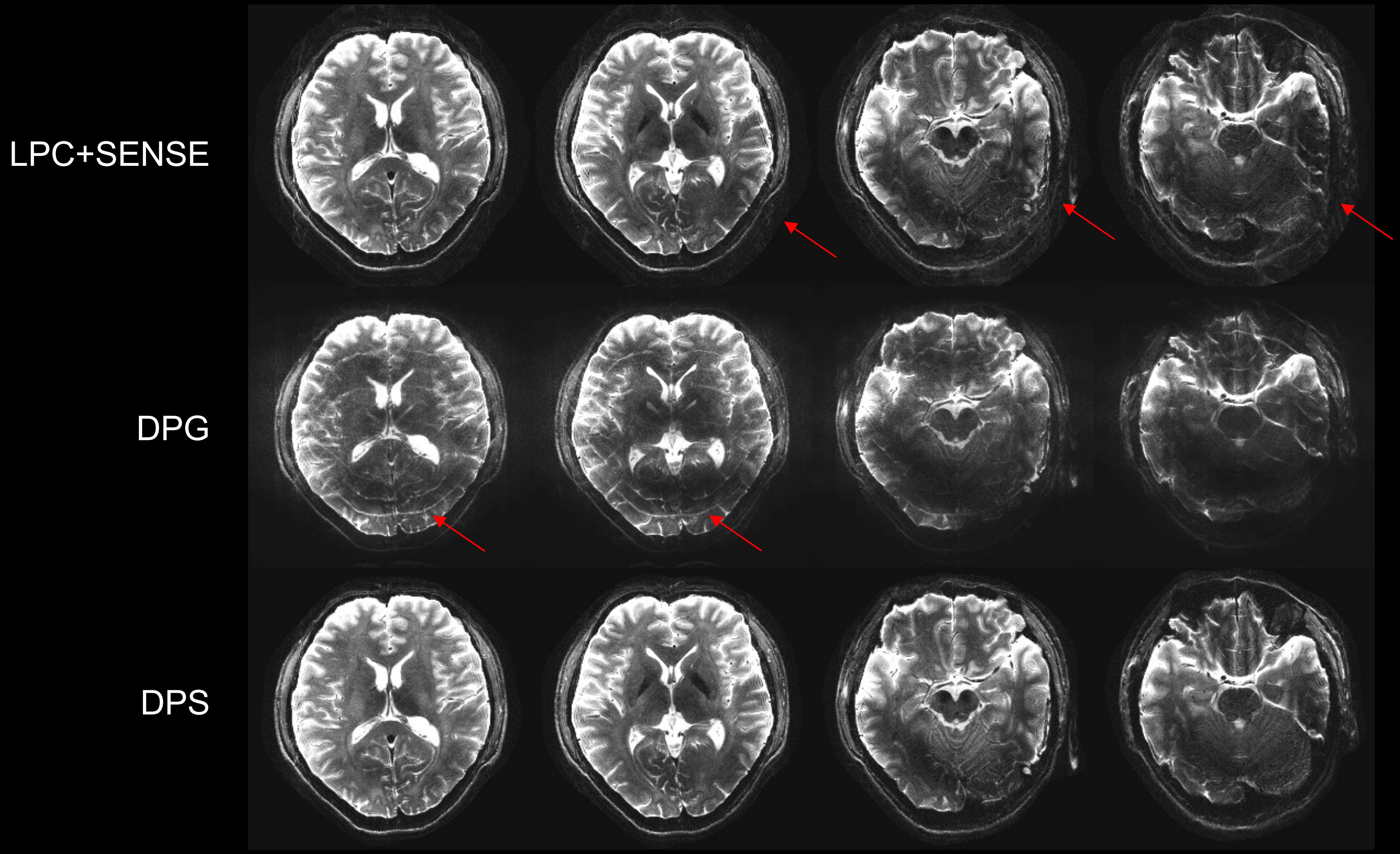
- shot = 3
- R = 6 for each shot
- $1 \times 1 \times 4$ mm^3
- b = 1000 s/mm^2



[1] Mani et al. MRM 2017.

iEPI, in vivo @Terra.X

- shot = 4
- R = 8 for each shot
- $0.82 \times 0.82 \times 4.1$ mm^3
- b = 0



Discussion and Conclusion

- We proposed dual-polarity SENSE (DPS), a sense-based method for EPI Nyquist ghost correction.
- We tested the method by phantom and in vivo experiments on scanners with high-performance gradients or ultra-high fields.
- In the ssEPI experiments, DPS outperformed LPC and offered comparable results to the state-of-the-art DPG.
- In the iEPI experiments, DPS outperformed LPC and could be used for data with large acceleration factors where DPG would fail.

- Take more experiments
- Test iEPI on Connectome 2.0.

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