



Increased SNR by Simultaneous Encoded Complex-Valued Slices with Through-Plane Acceleration in fMRI

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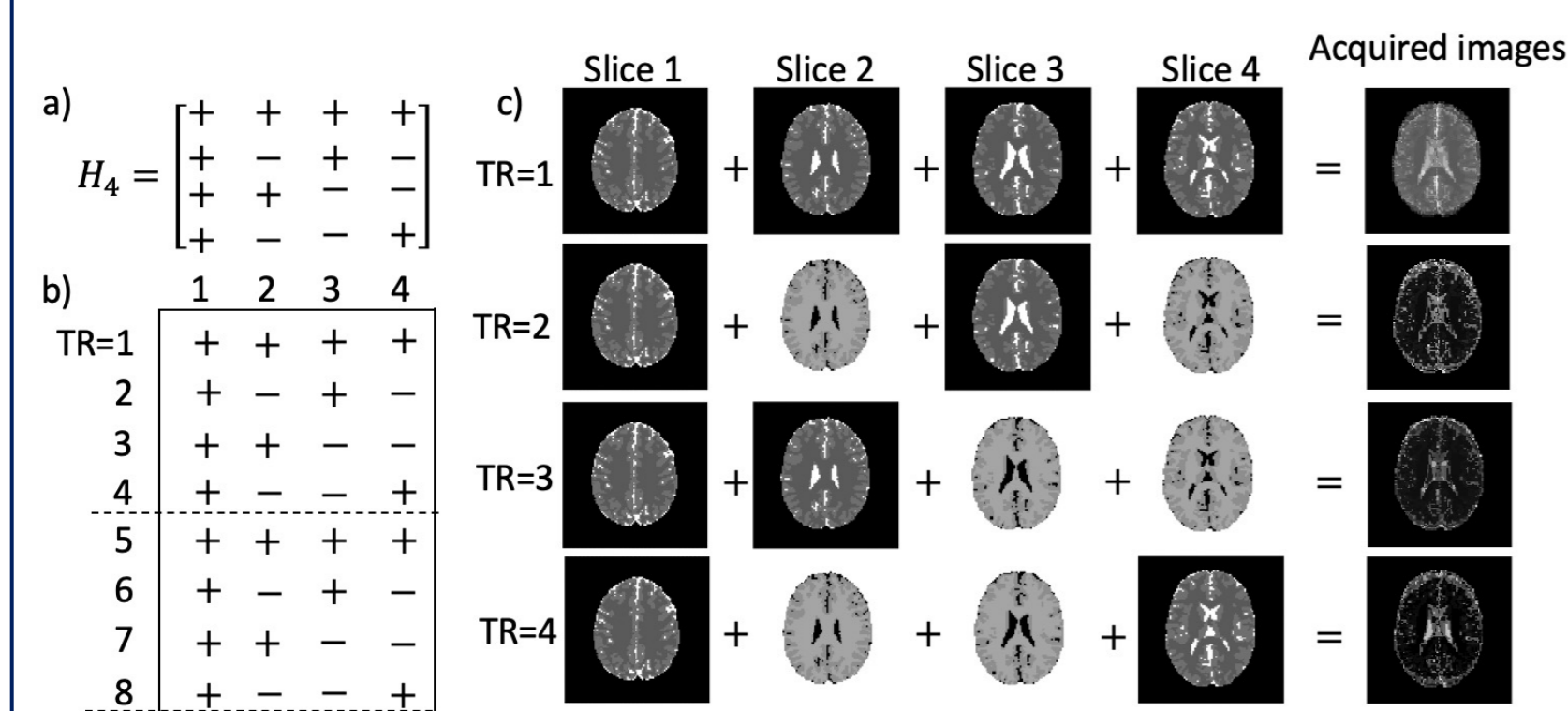
Hadamard Phase Encoding

• The Hadamard Matrix:

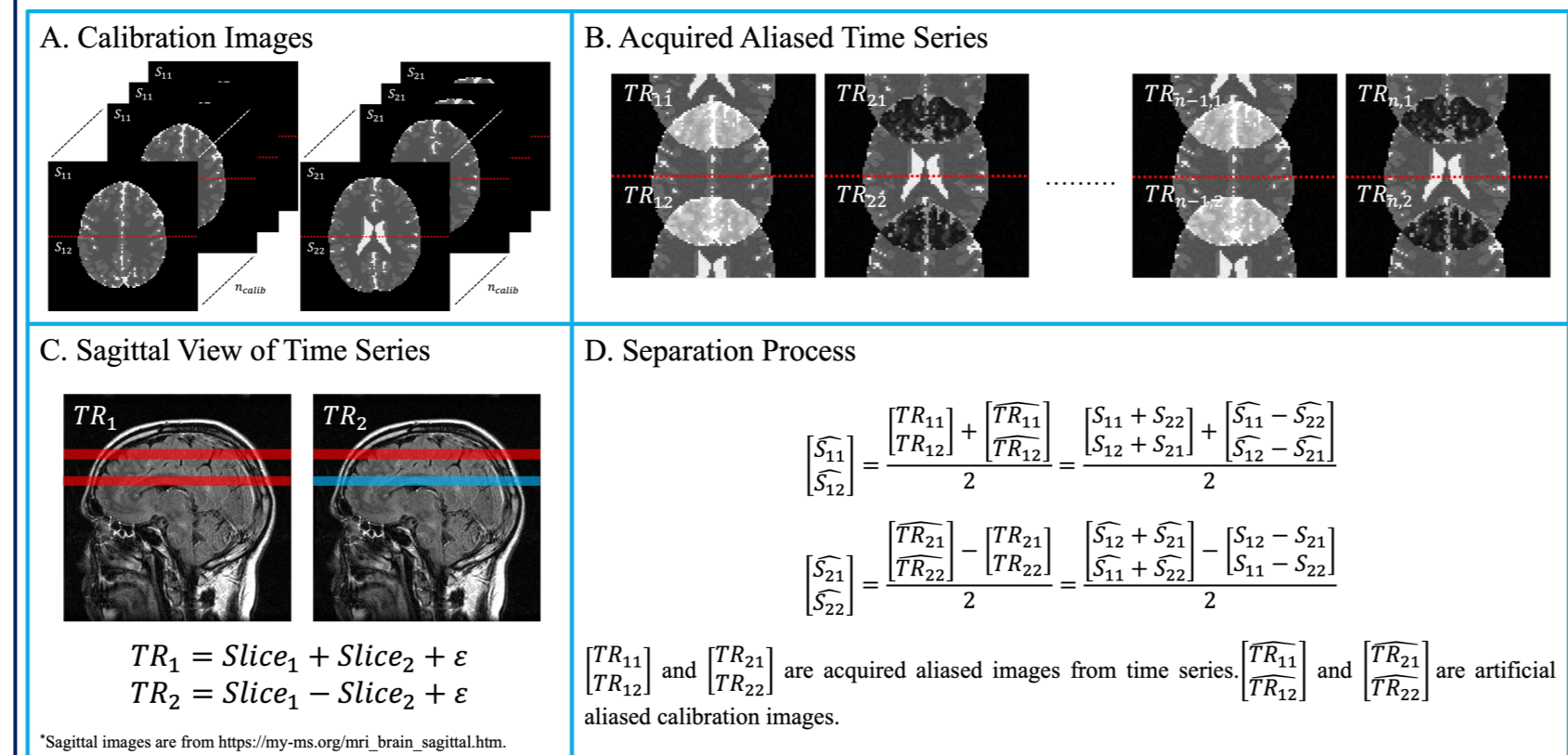
$$H_{2^n} = \begin{bmatrix} H_{2^{n-1}} & H_{2^{n-1}} \\ H_{2^{n-1}} & -H_{2^{n-1}} \end{bmatrix} = H_2 \otimes H_{2^{n-1}}$$

$$H_1 = [1], H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

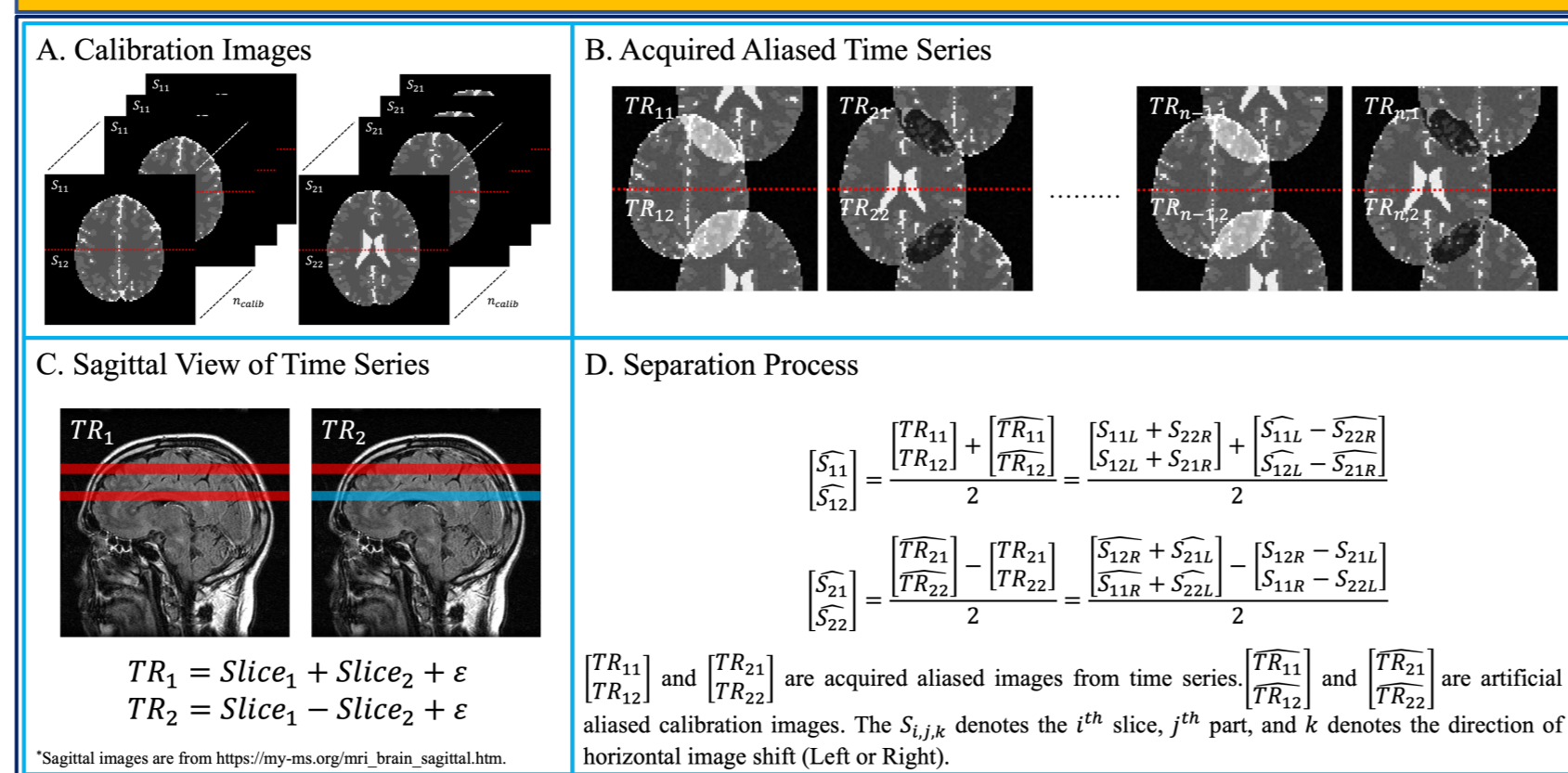
• The Time Series Hadamard Coefficients:



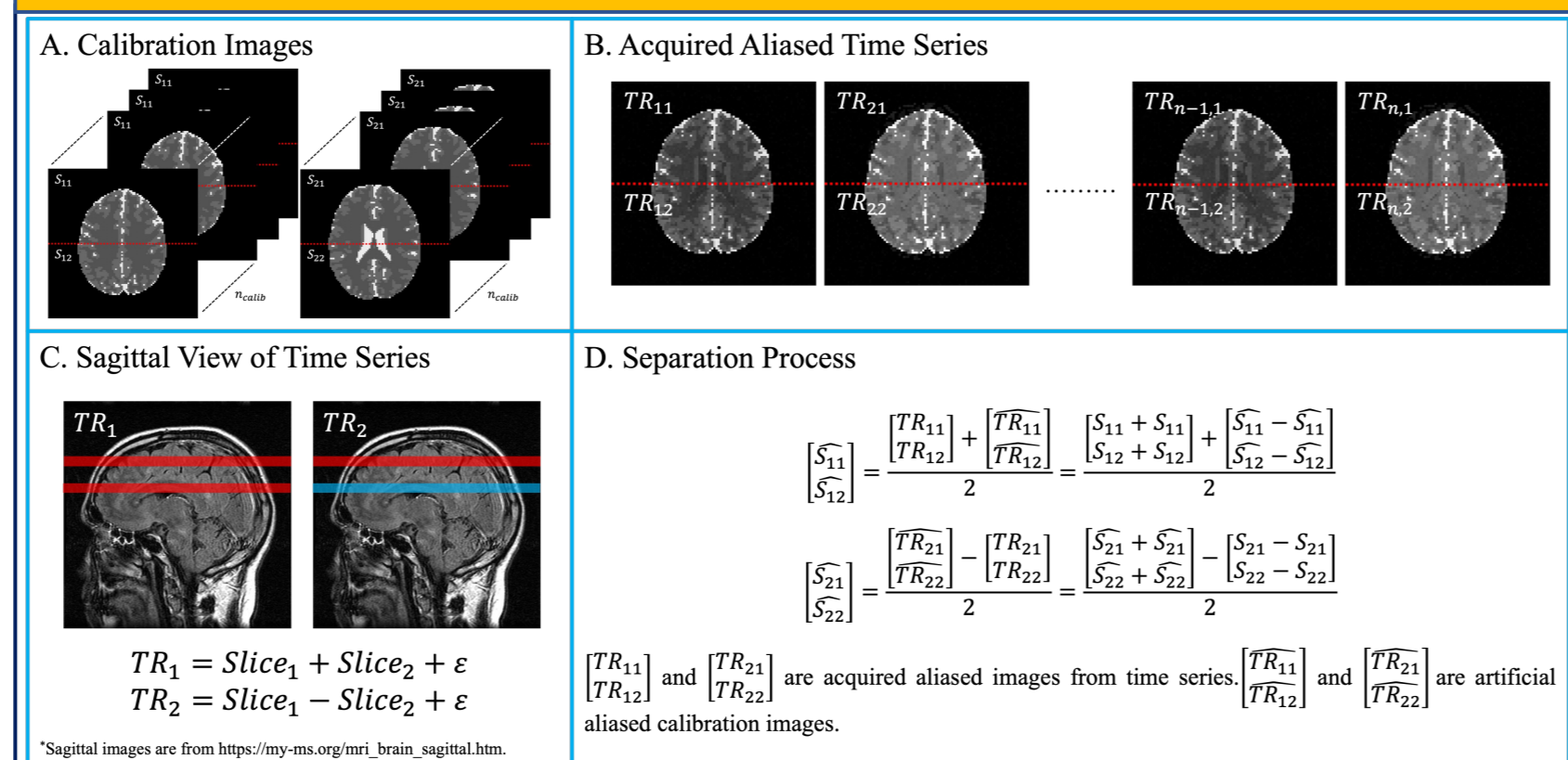
mSPECS-CAIPIRINHA



mSPECS-CAIPIVAT



mSPECS



Separation Model

• In the mSPECS-CAIPI model, the **bootstrap sampling method** and **artificial aliasing of calibration images technique** will be incorporated with the separation equations.

• The separation process:

$$y = \begin{bmatrix} a \\ v \end{bmatrix} = \begin{bmatrix} X_A \beta \\ C_A \mu \end{bmatrix} + \begin{bmatrix} \varepsilon \\ \eta \end{bmatrix}$$

$$(X_A)_{\gamma, \delta} = H_{\delta, 1} R_{\gamma, 1} \begin{pmatrix} S_{1,1} \\ \vdots \\ S_{N_c, 1} \end{pmatrix}, \dots, H_{\delta, N_s} R_{\gamma, N_s} \begin{pmatrix} S_{1, N_s} \\ \vdots \\ S_{N_c, N_s} \end{pmatrix}$$

$$(C_A)_{\gamma, \delta} = \overline{H_{\delta, 1} R_{\gamma, 1}} \begin{pmatrix} S_{1,1} \\ \vdots \\ S_{N_c, 1} \end{pmatrix}, \dots, \overline{H_{\delta, N_s} R_{\gamma, N_s}} \begin{pmatrix} S_{1, N_s} \\ \vdots \\ S_{N_c, N_s} \end{pmatrix}$$

• The estimated reconstructed images:

$$\hat{\beta} = (X_A' X_A + C_A' C_A)^{-1} (X_A' a + C_A' v)$$

Simulated Study

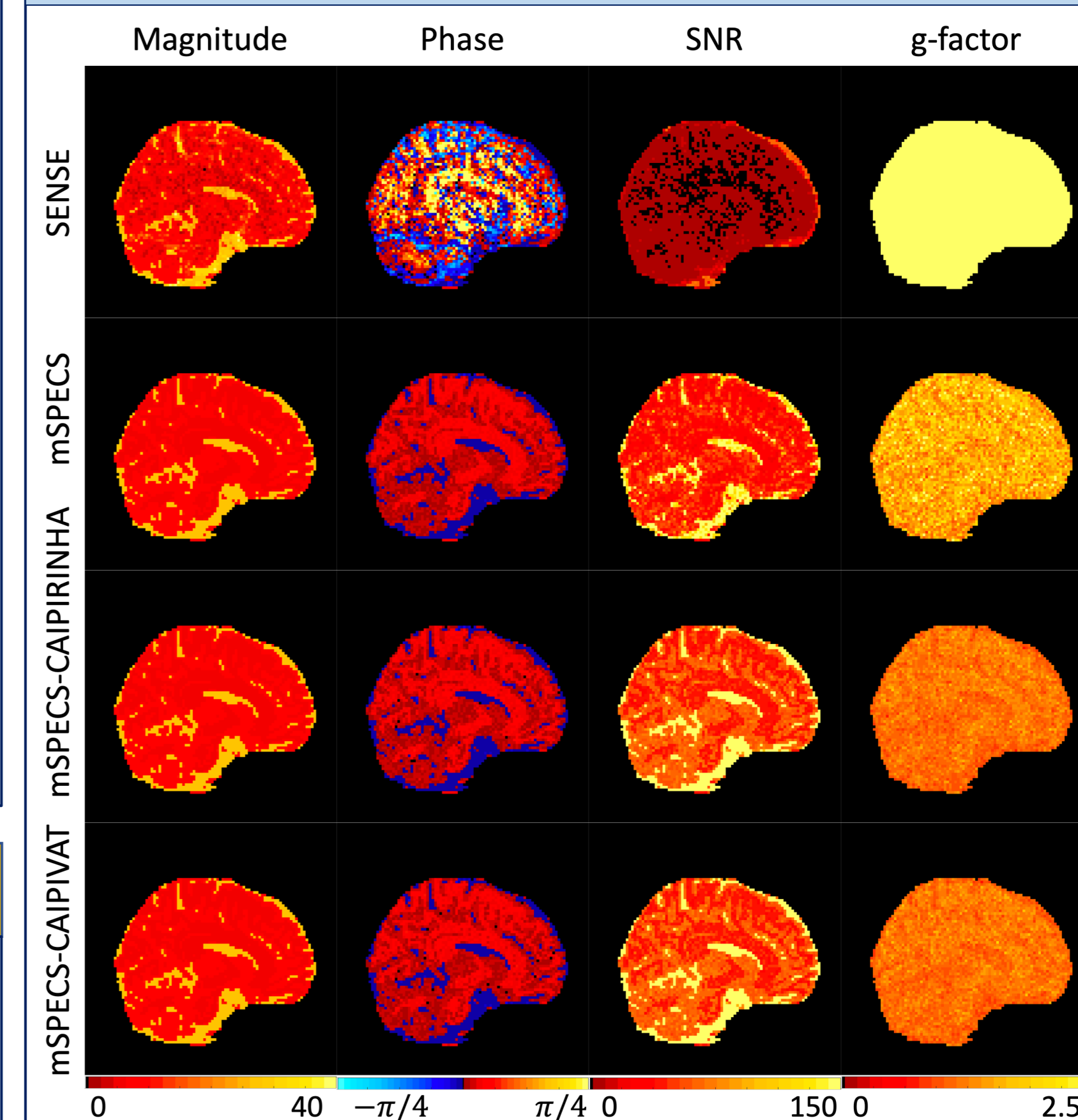
- The total fMRI time series is 640 TRs, first 40 TRs are used as calibration images
- 32 coils sensitivity maps with different phase for different slice
- 8 sagittal brain images with through-plane acceleration of 2, 4, and 8

Reference

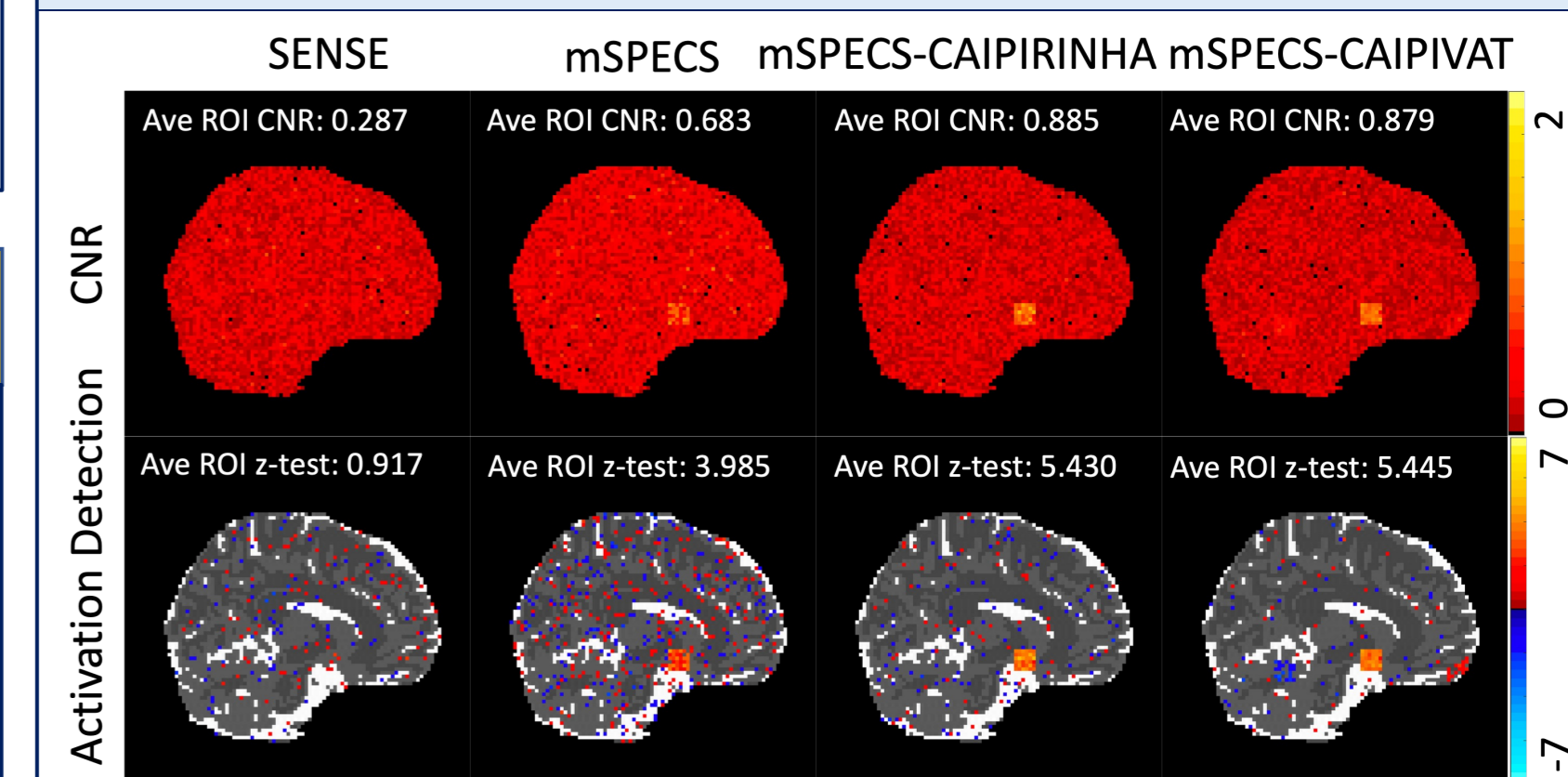
- (1) Breuer FA et al. *Controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) for multi-slice imaging*. Magn Reson Med 2005 Mar;53(3):684-91.
- (2) Kim Min-Oh et al. *MultiSlice CAIPIRINHA Using View Angle Tilting Technique (CAIPIVAT)*. Tomography. 2016 Mar;2(1):43-48.
- (3) Souza SP et al. *SIMA-simultaneous multislice acquisition of MR images by Hadamard-encoded excitation*. J Comput Assist Tomogr 1988;12:1026-1030.
- (4) Rowe DB et al. *A complex way to compute fMRI activation*. Neuroimage. 2004 Nov;23(3):1078-92.

Simulated Results

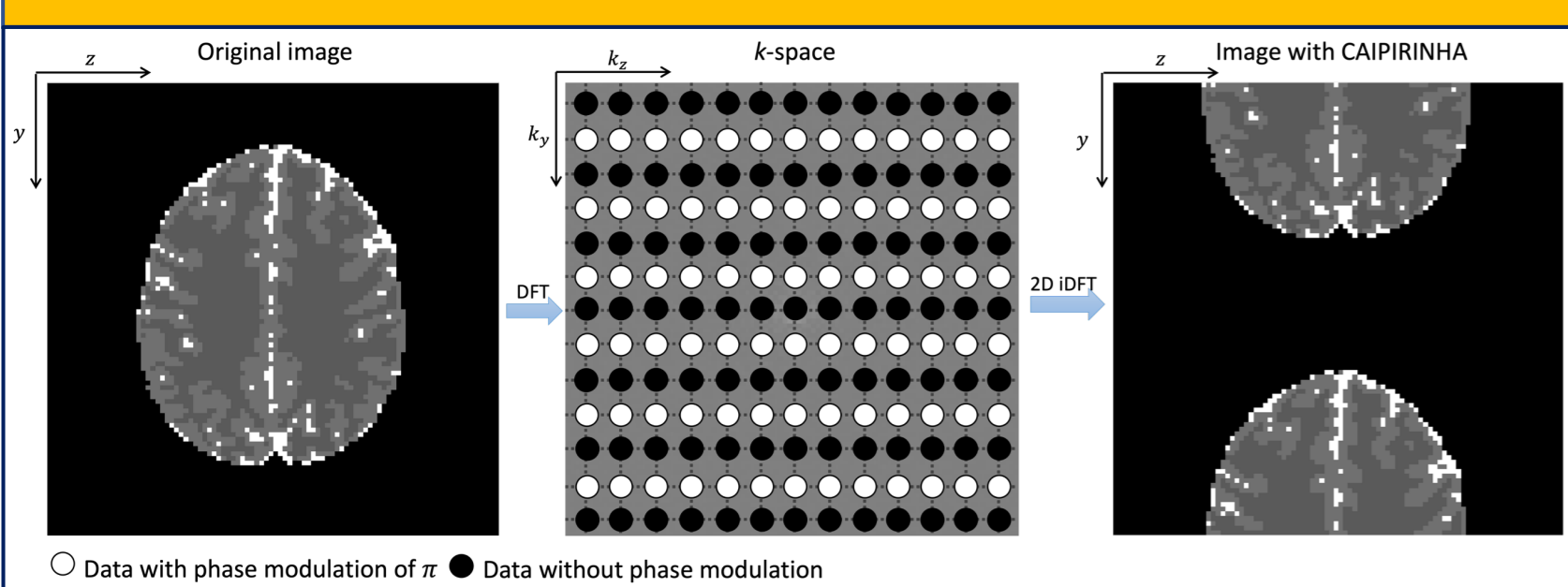
Resting State Simulated Results



Activation Simulated Results



CAIPIRINHA



CAIPIVAT

