



A Through-Plane Acceleration Approach to Increase SNR of Simultaneous Multi-Slice in FMRI

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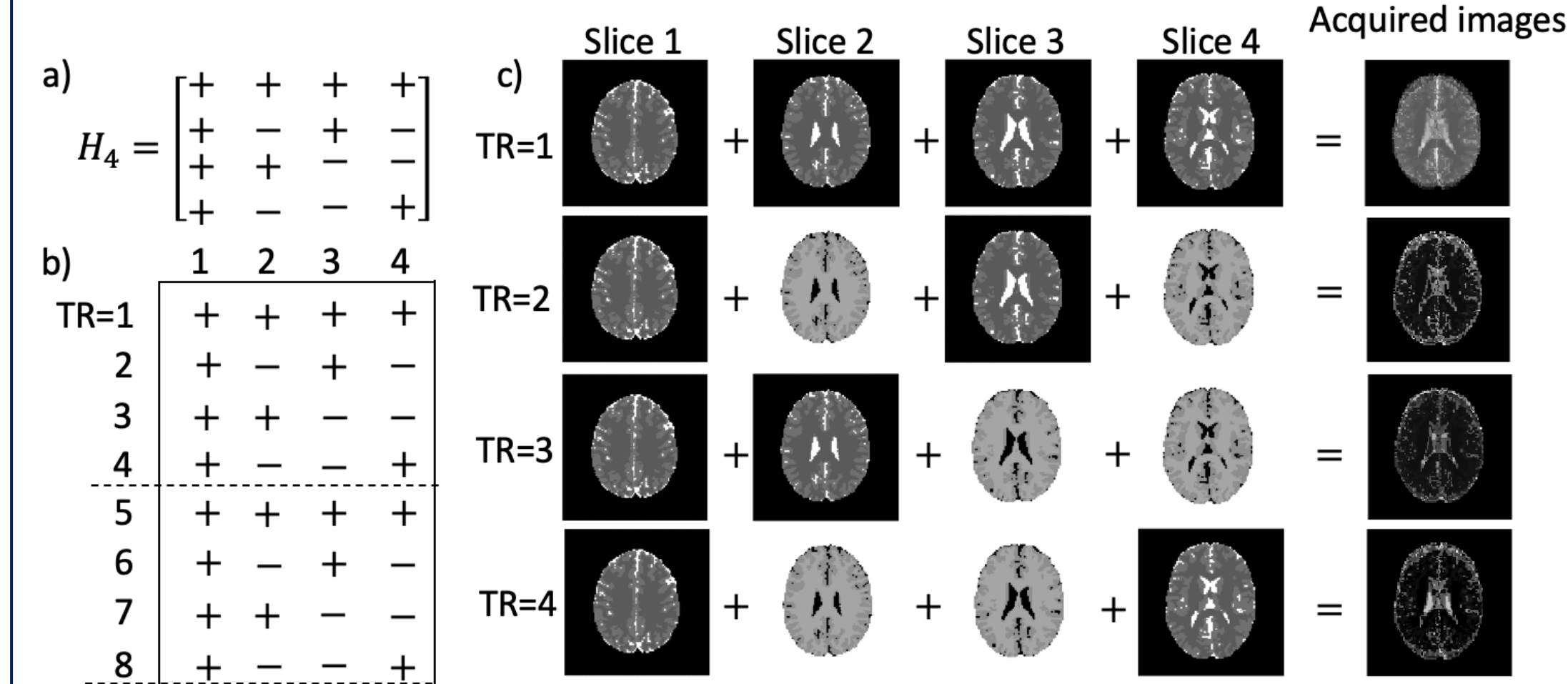
Hadamard Phase Encoding

The Hadamard Matrix:

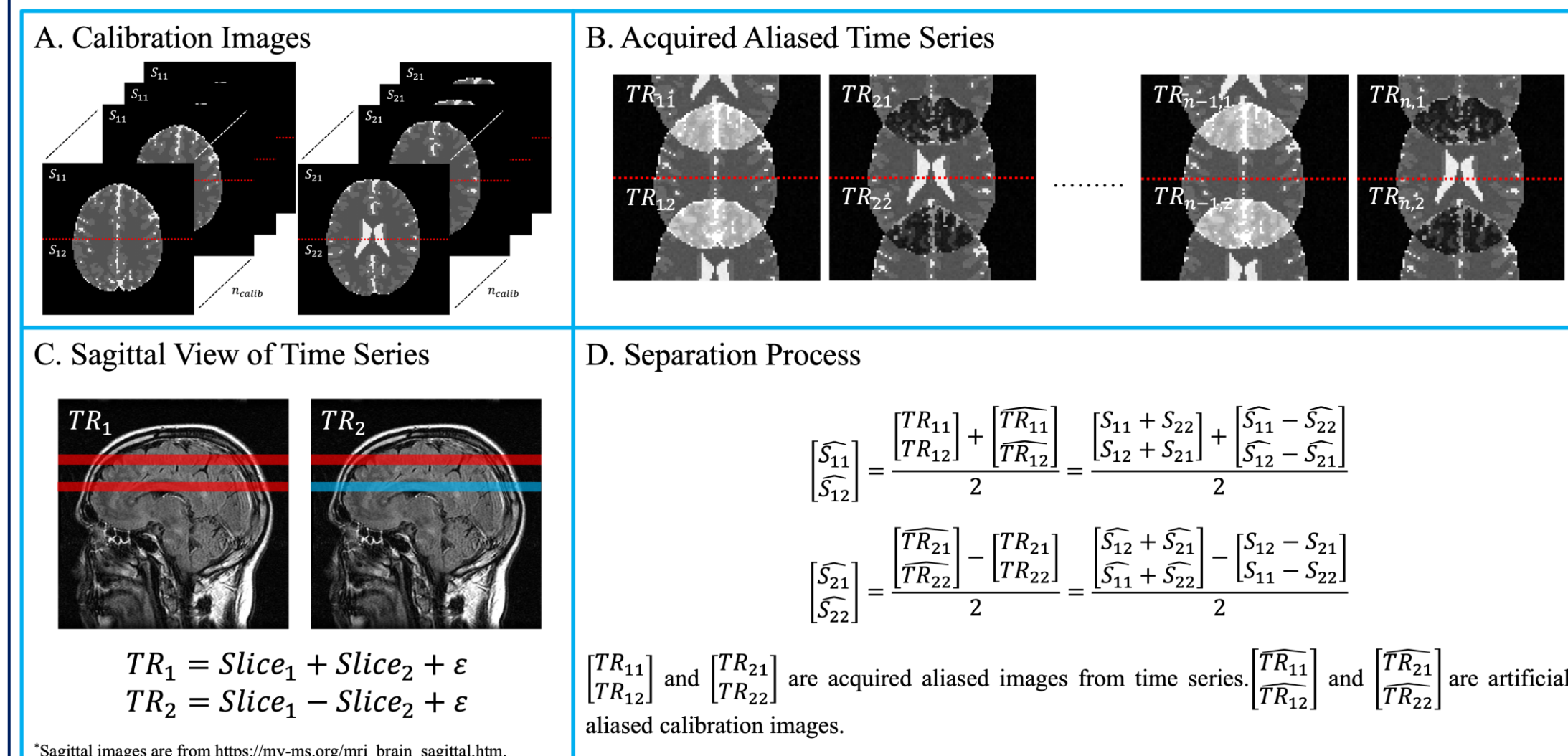
$$H_{2^n} = \begin{bmatrix} H_{2^{n-1}} & H_{2^{n-1}} \\ H_{2^{n-1}} & -H_{2^{n-1}} \end{bmatrix} = H_2 \otimes H_{2^{n-1}}$$

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

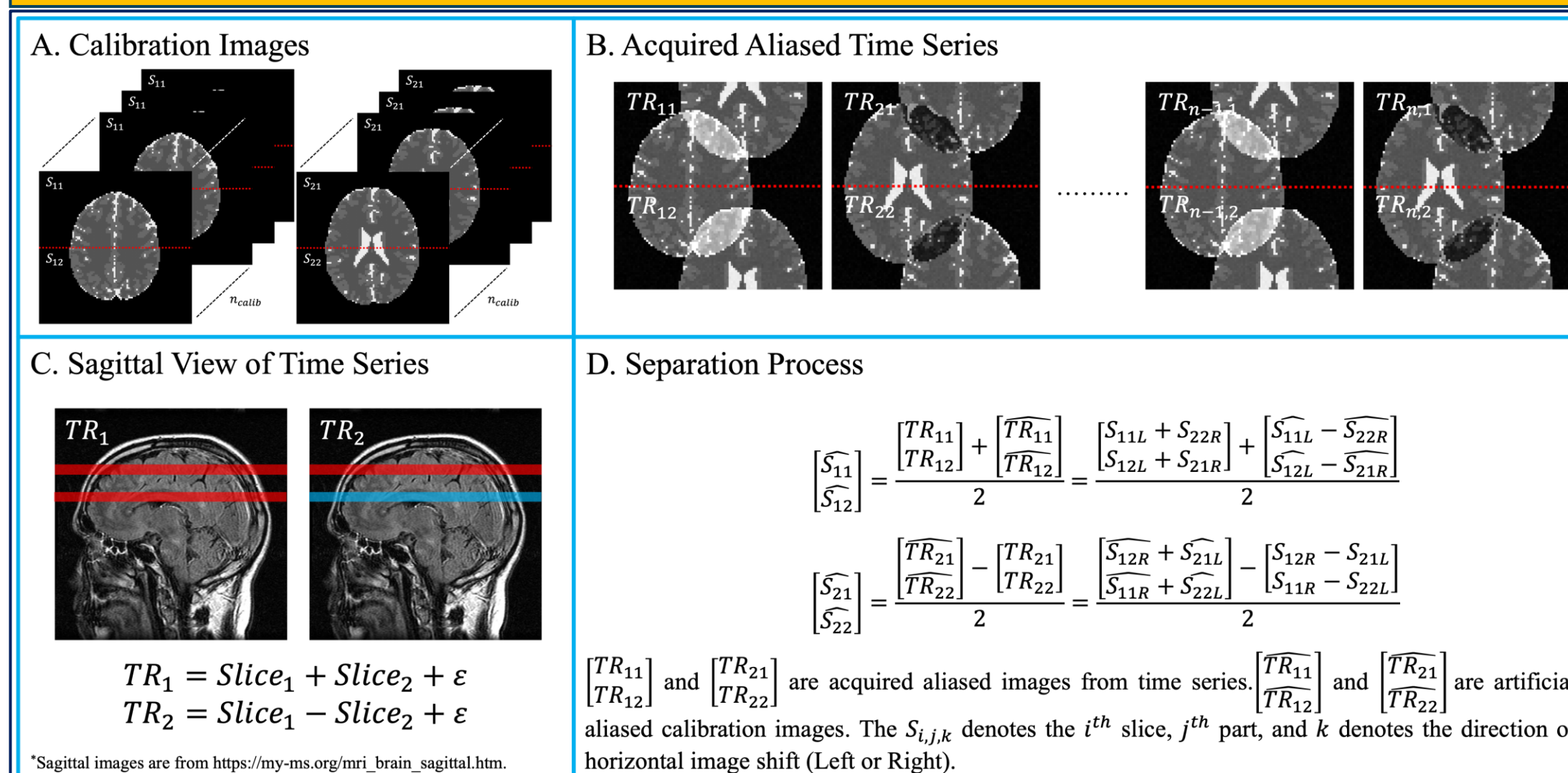
The Time Series Hadamard Coefficients:



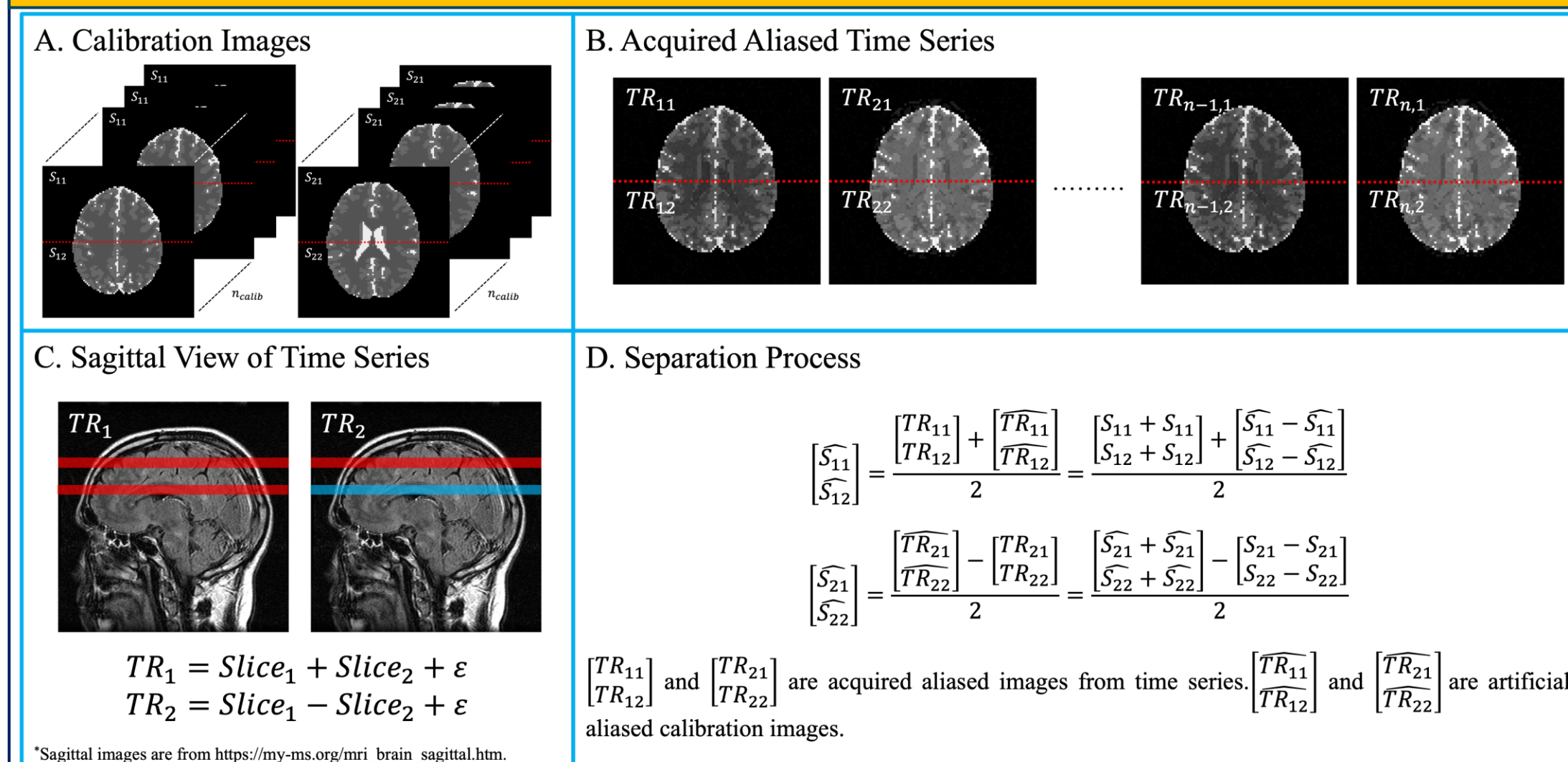
mSPECS-CAIPIRINHA



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:

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

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

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

The estimated reconstructed images:

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

Simulated Study

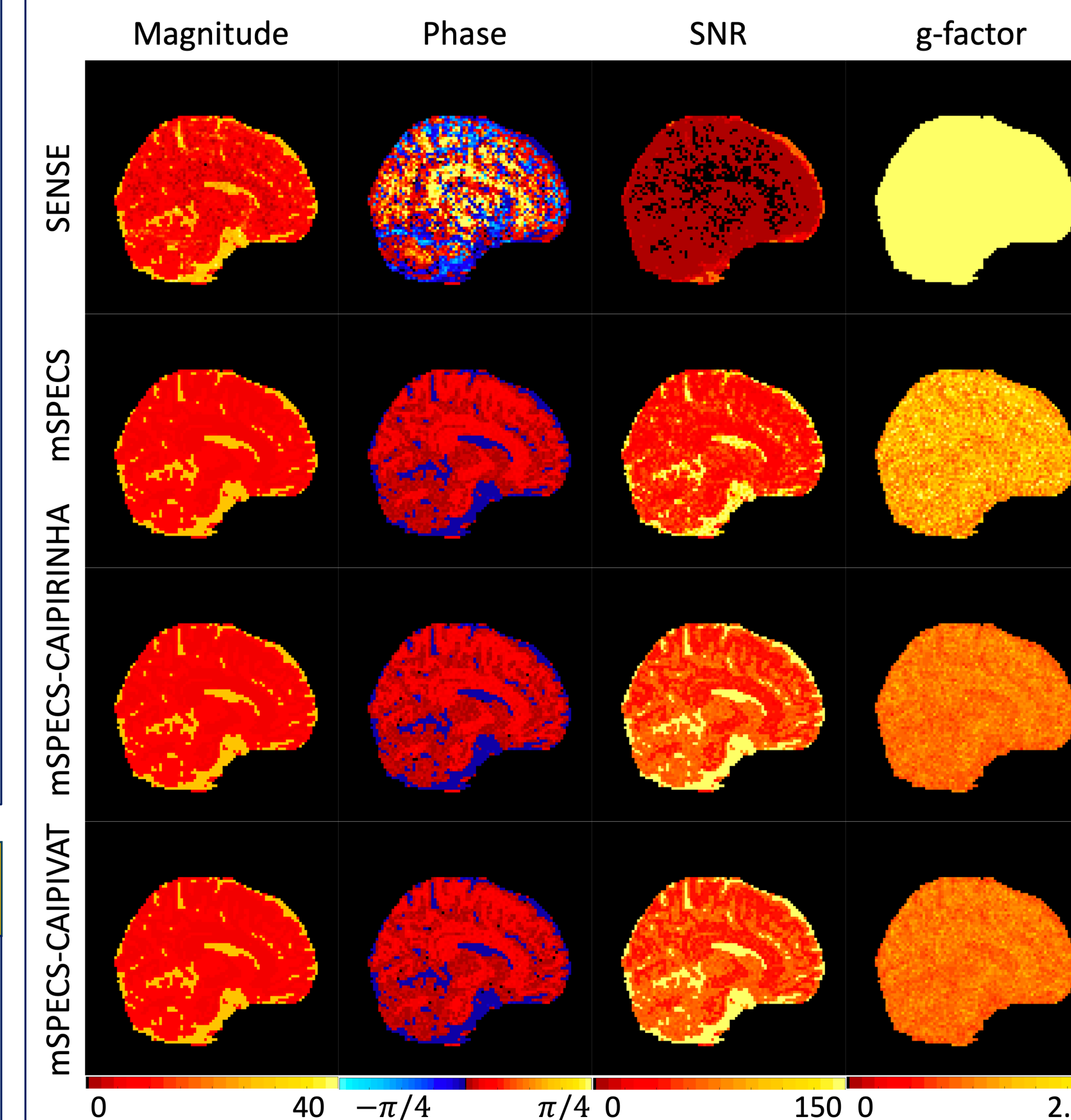
- The total fMRI time series is 640 TRs, first 40 TRs are used as calibration images
- 32 coils sensitivity maps with different phase for different slice
- 8 sagittal brain images with through-plane acceleration of 2, 4, and 8

Reference

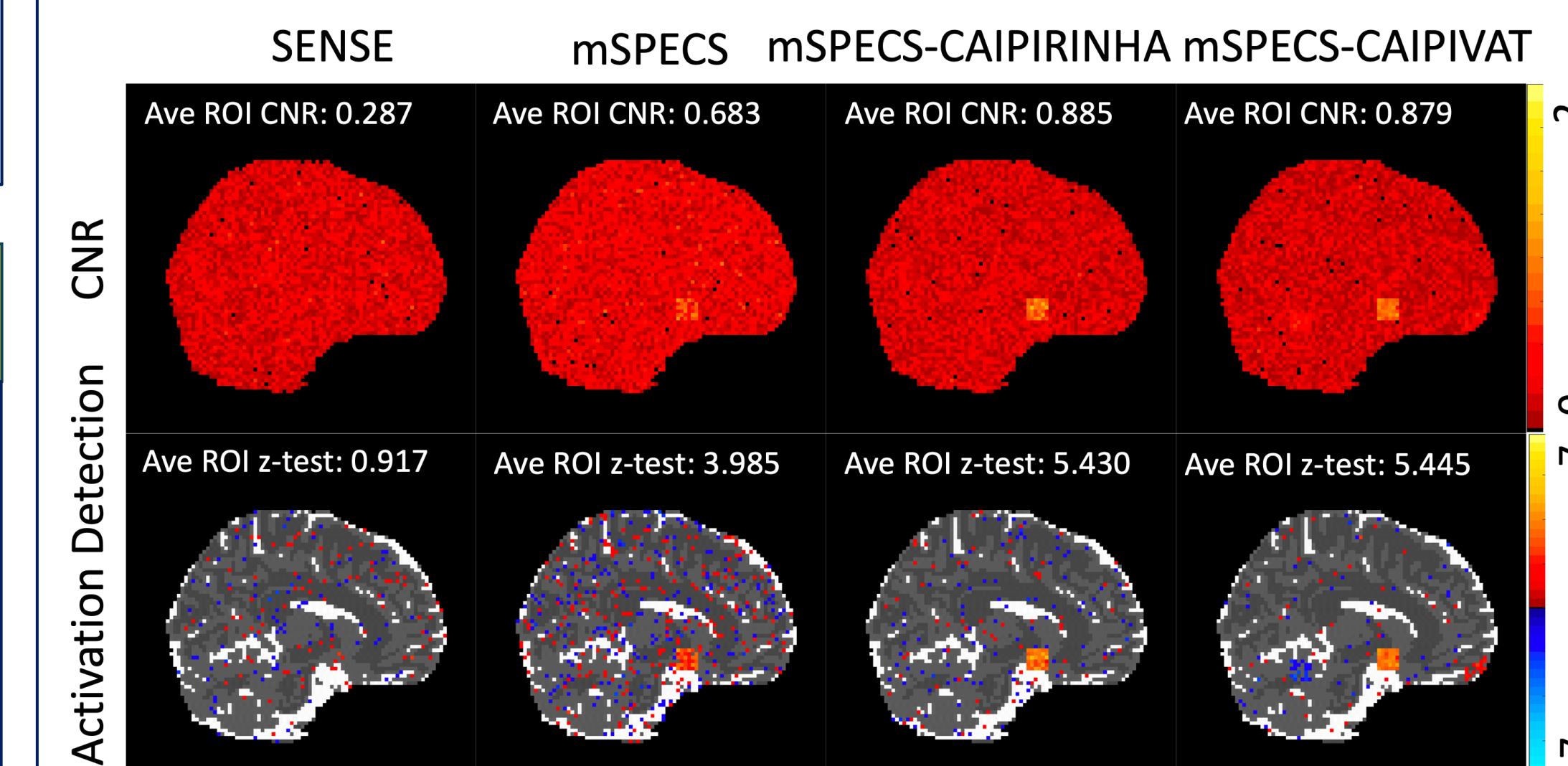
- Breuer FA et al. *Controlled aliasing in parallel imaging results in higher acceleration (CAIPIRINHA) for multi-slice imaging*. Magn Reson Med 2005 Mar;53(3):684-91.
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Simulated Results

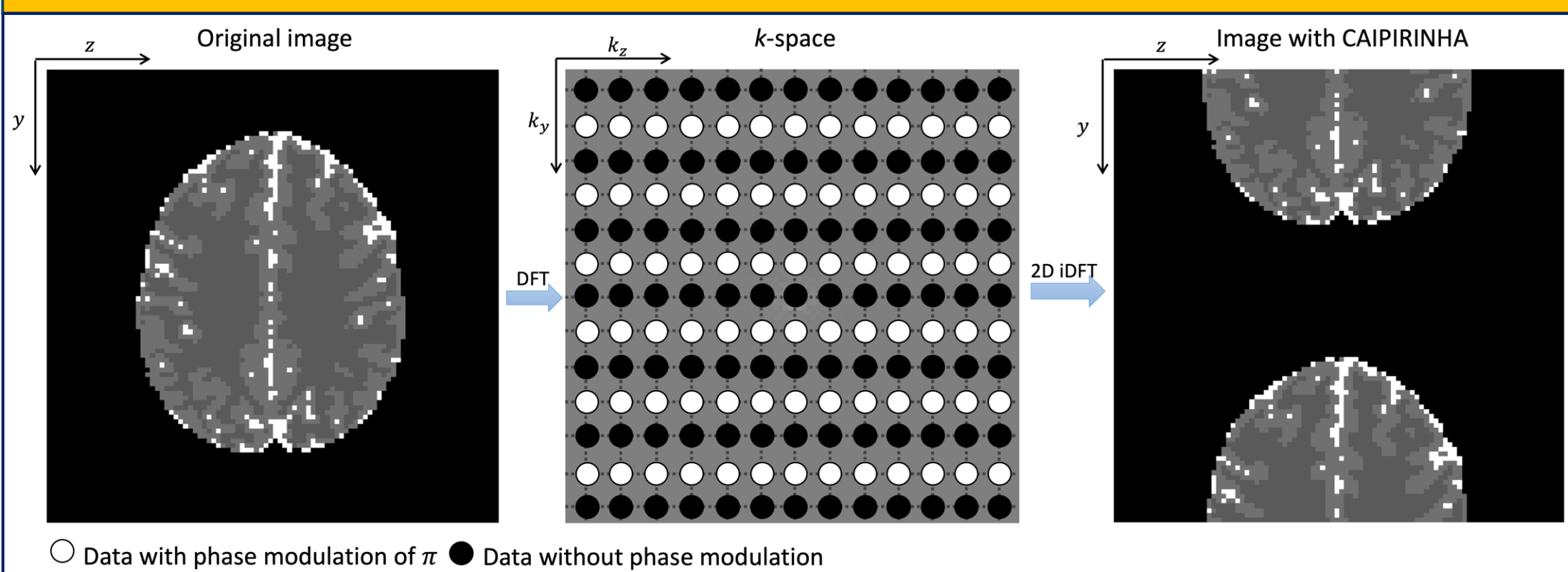
Resting State Simulated Results



Activation Simulated Results



CAIPIRINHA



CAIPIVAT

