



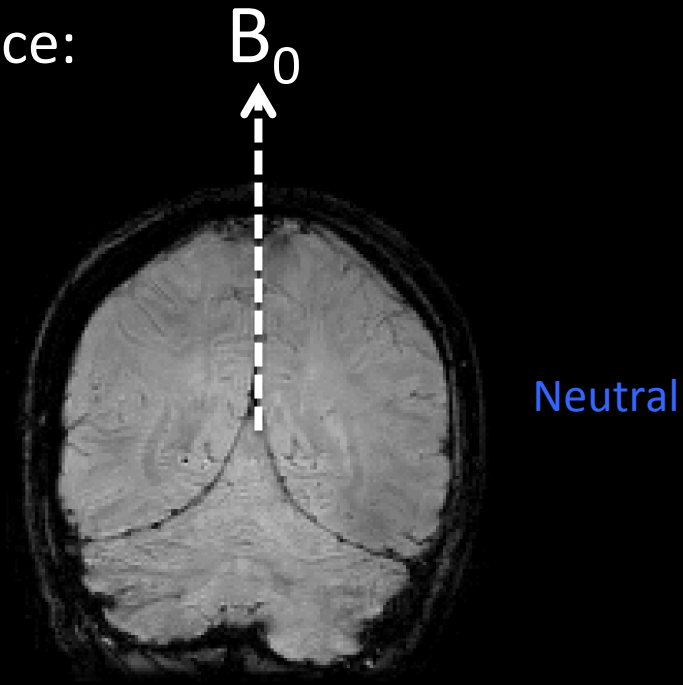
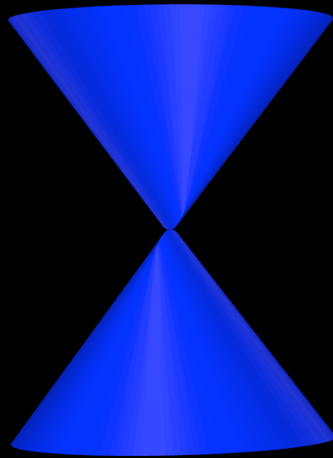
# Rapid Acquisition for Multi-Orientation QSM

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# Multi-orientation susceptibility mapping

- Susceptibility inversion is made difficult by the zeros in the susceptibility kernel  $\mathbf{D}$
- These zeros lie on a conical surface:

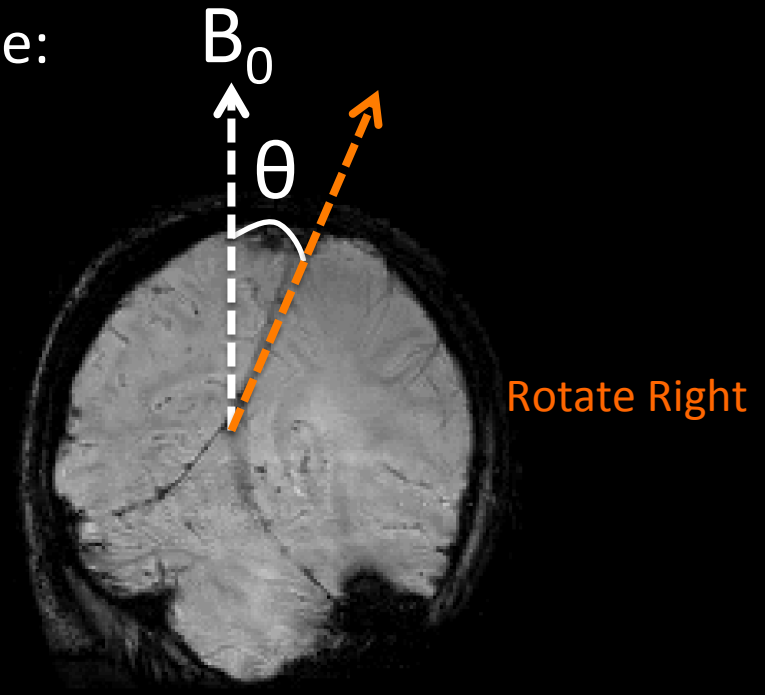


$$\delta = \mathbf{F}^{-1} \mathbf{D} \mathbf{F} \chi$$

$$\mathbf{D} = \frac{1}{3} - \frac{k_z^2}{k_x^2 + k_y^2 + k_z^2}$$

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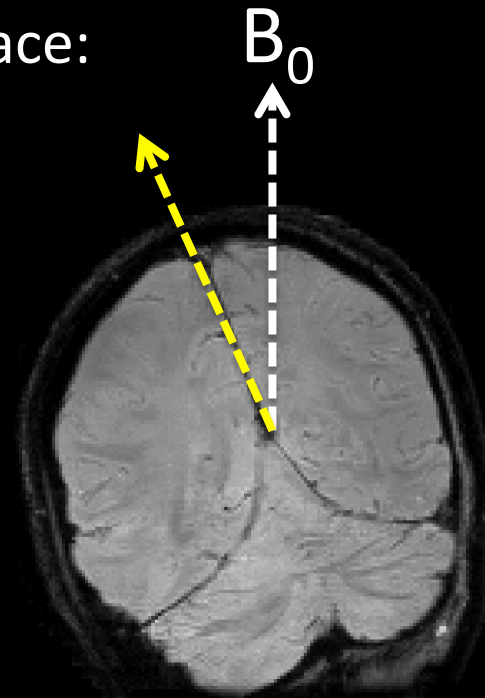
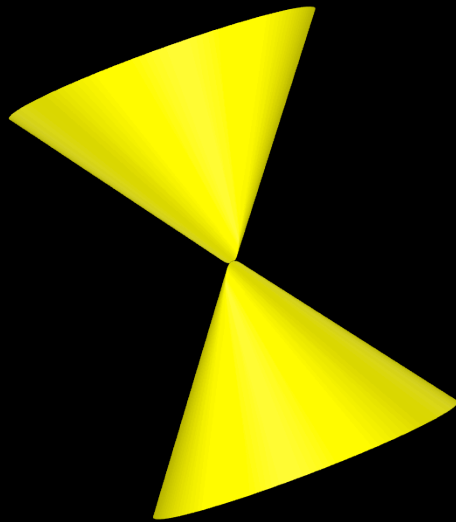


$$\delta_{\theta} = \mathbf{F}^{-1} \mathbf{D}_{\theta} \mathbf{F} \chi$$

$$\mathbf{D}_{\theta} = \frac{1}{3} - \frac{(k_z \cos \theta + k_y \sin \theta)^2}{k_x^2 + k_y^2 + k_z^2}$$

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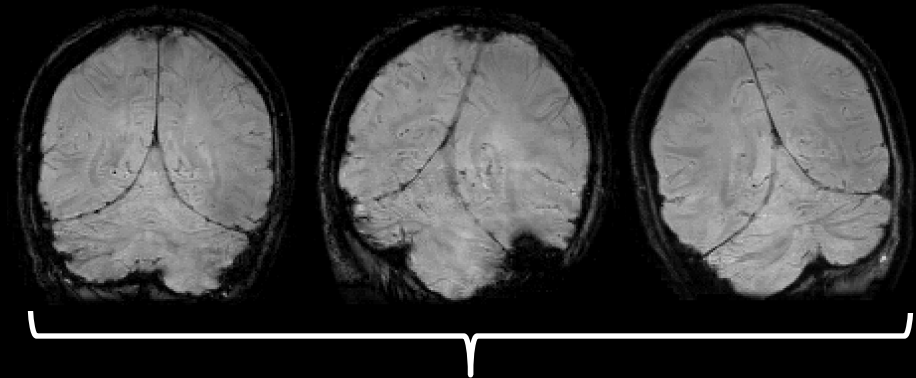
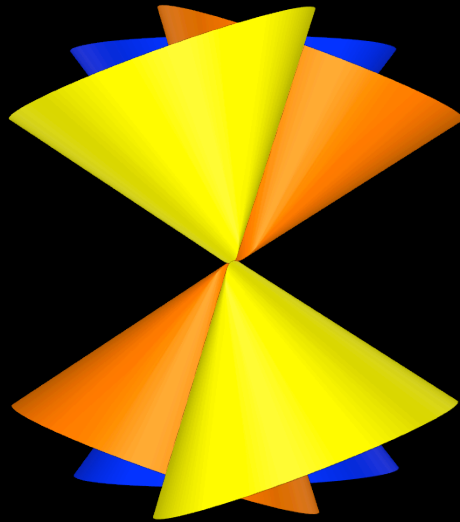
Rotate Left

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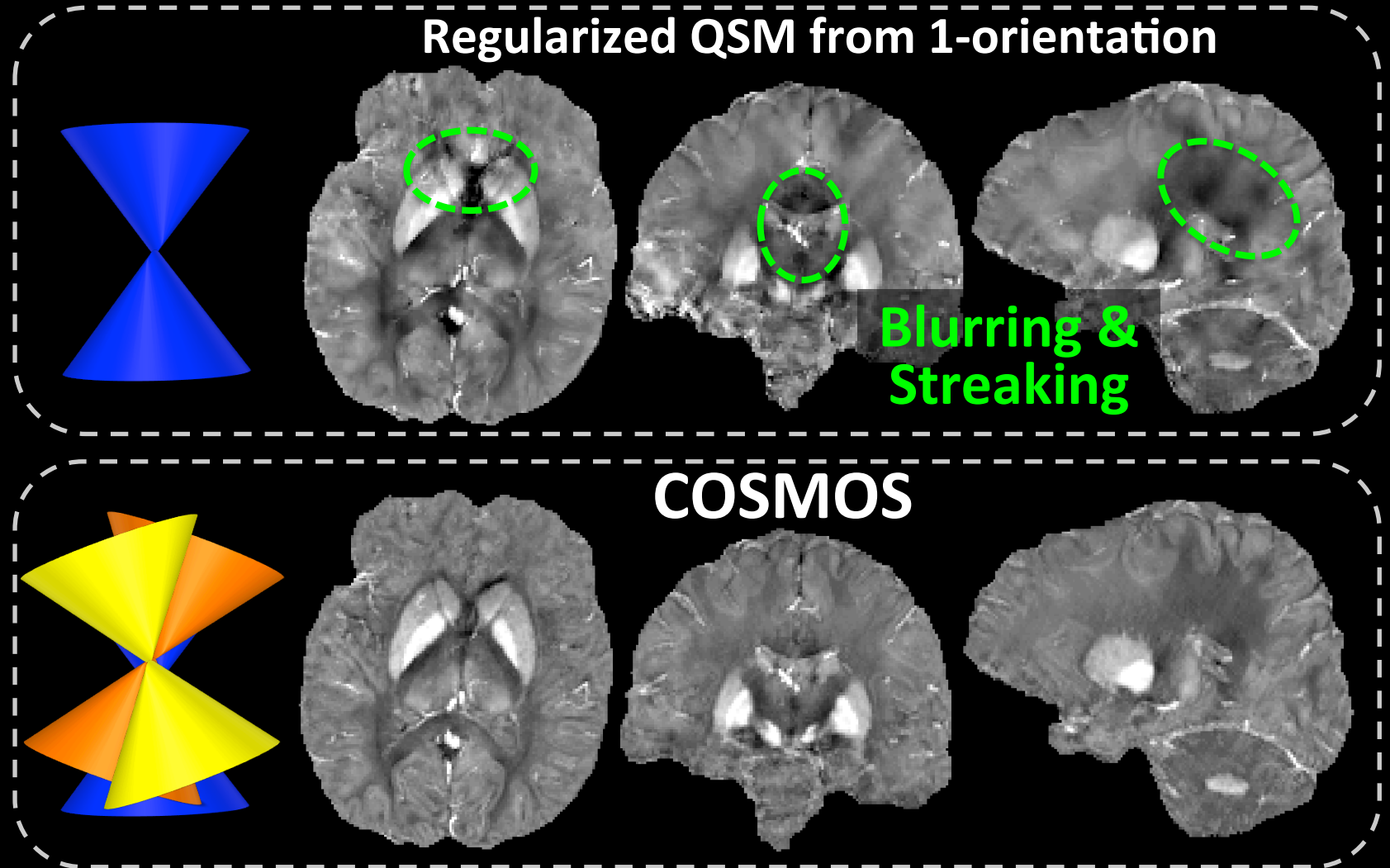


Combine multiple orientations for QSM inversion

- **Undersampling is substantially mitigated**  
Calculation of Susceptibility Through Multiple Orientation Sampling (COSMOS) [1,2]

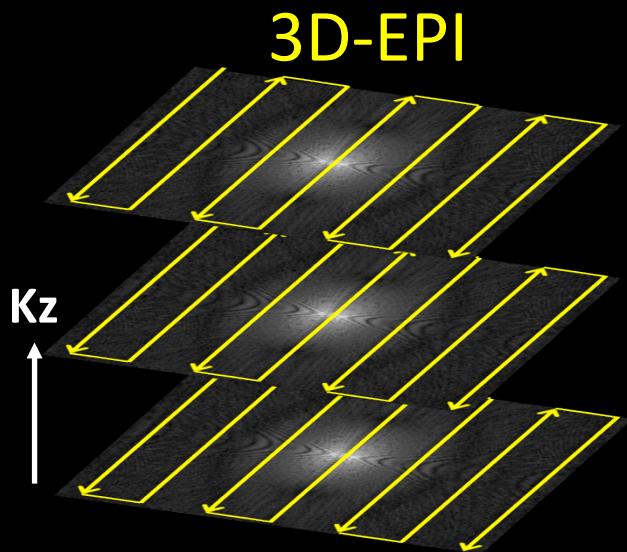
# COSMOS vs. Single-Orientation

- COSMOS yields exquisite susceptibility maps
- **This comes at the expense of substantially increased scan time**



# Rapid Multi-orientation QSM

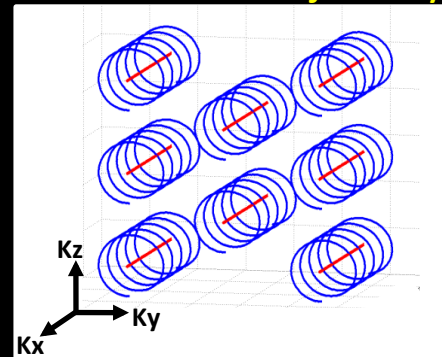
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- **We propose efficient acquisition methods for rapid multi-orientation QSM:**
  - ❖ 3D Echo Planar Imaging (EPI) [1,2]



# Rapid Multi-orientation QSM

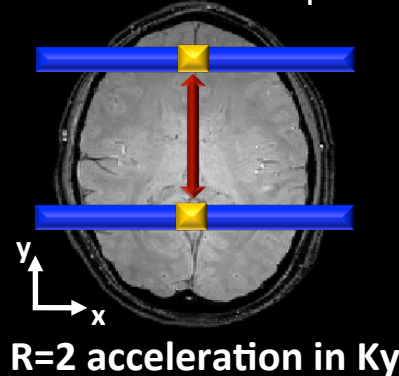
- COSMOS yields exquisite susceptibility maps
- **This comes at the expense of substantially increased scan time**
- We propose efficient acquisition methods for rapid multi-orientation QSM:
  - ❖ 3D Echo Planar Imaging (EPI) [1,2]
  - ❖ 3D GRE with Wave-CAIPI [3]

Wave-CAIPI trajectory



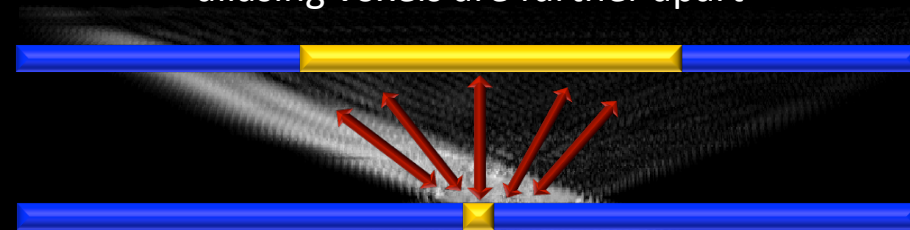
## Normal GRE

two voxels collapse



## Wave-CAIPI

aliasing voxels are further apart



Aliasing voxels are spread out to increase the variation in coil sensitivity profiles:

**Improved G-Factor**



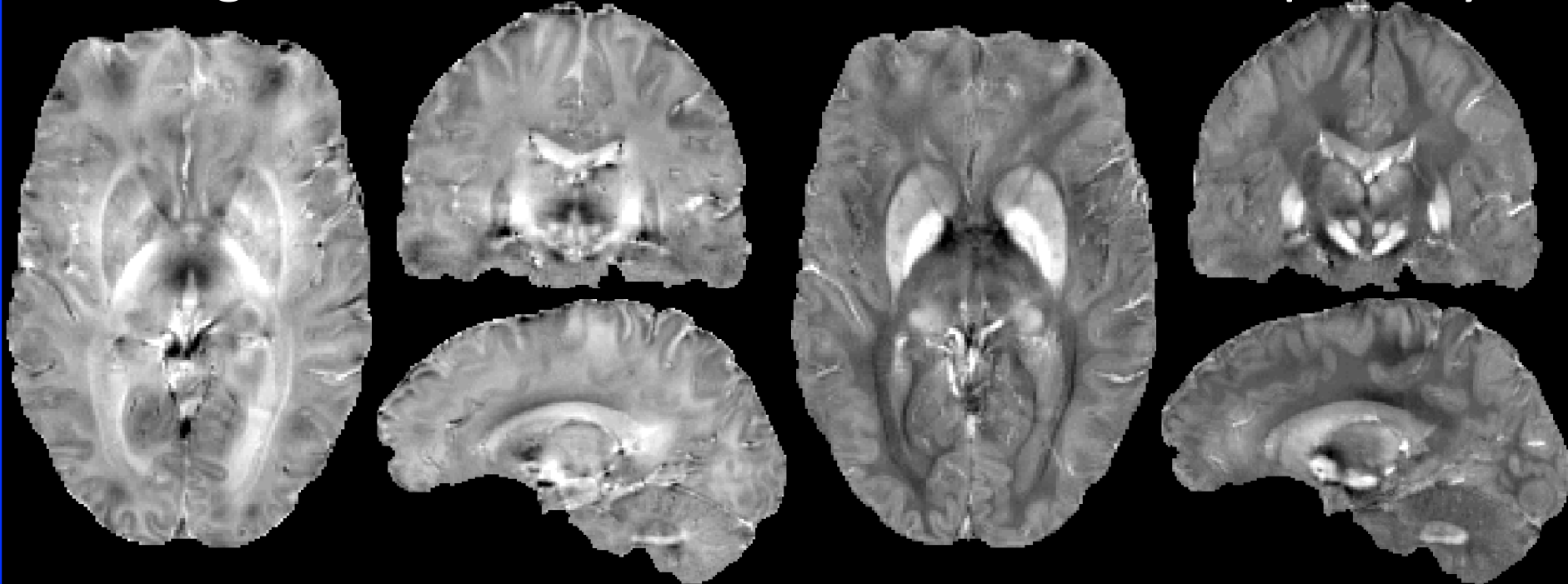
$R_{\text{inplane}}=3$  @ 3 Tesla  
FOV=230×230×176  
TR/TE = 69/30 ms  
4 avg / orientation

## 3D-EPI QSM from 3 orientations

1 mm iso,  $T_{\text{acq}}=3.3\text{min}$

Avg Tissue Phase

COSMOS Susceptibility



max intensity projection over 3mm

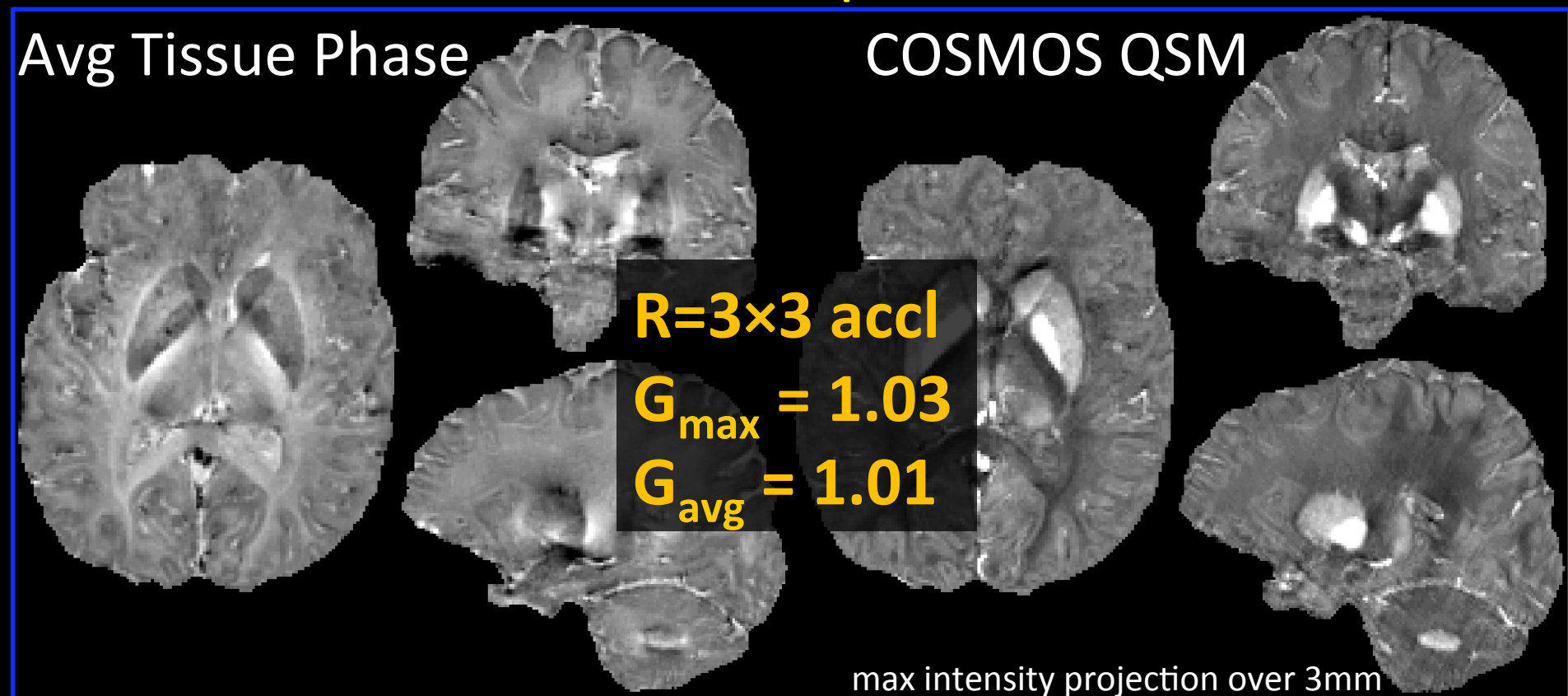
R=3x3 @ 3 Tesla  
FOV=240x240x192  
TR/TE = 40/30 ms

# Wave-CAIPI QSM from 3 orientations

1 mm iso,  $T_{acq} = 10.3\text{min}$

Avg Tissue Phase

COSMOS QSM



$R=3 \times 3$  accl

$G_{max} = 1.03$

$G_{avg} = 1.01$

max intensity projection over 3mm

R=5×3 @ 3 Tesla  
FOV=255×255×180  
TR/TE = 35/25 ms

Wave-CAIPI R=5×3 accl  
1.1mm iso,  $T_{acq}$ =90sec

