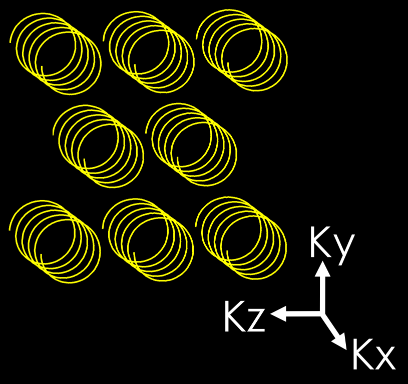
Faster MRI through optimized encoding & reconstruction

Berkin Bilgic

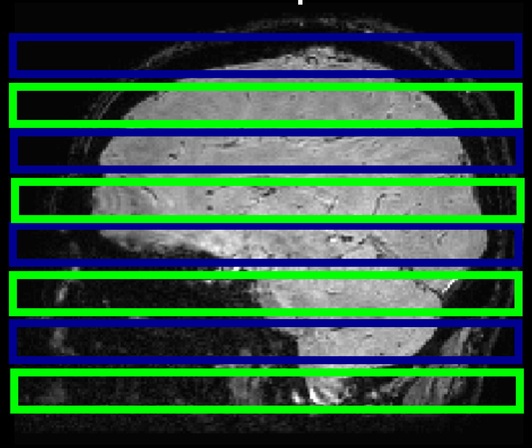
Athinoula A. Martinos Center For Biomedical Imaging
Massachusetts General Hospital
Harvard Medical School
Massachusetts Institute of Technology

MRI is slow & expensive

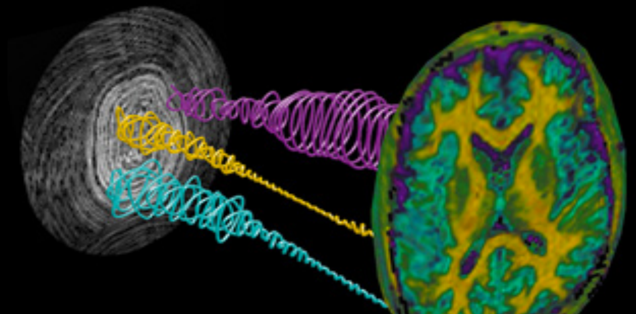
new image encoding



new acquisition

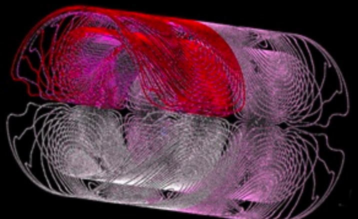


new angle

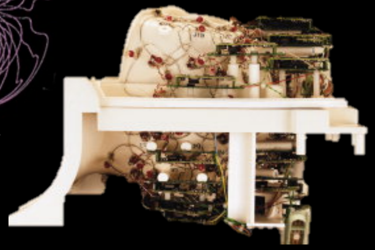


MR fingerprinting

new hardware

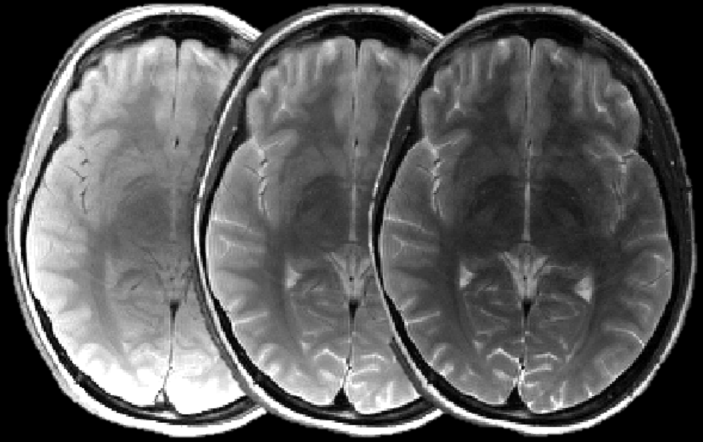


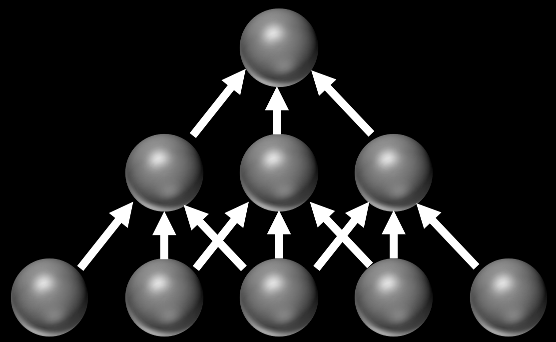
Connectome gradient



64ch coil

new reconstruction





deep learning

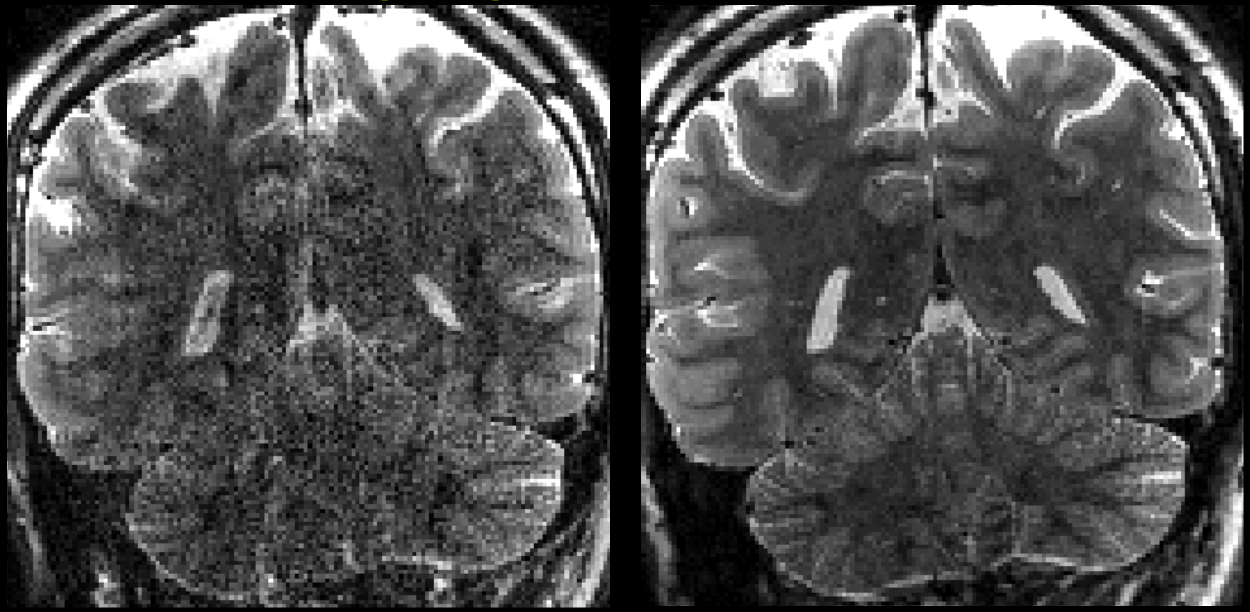
Overview

- Death of 2D: Era of volumetric acquisition
  - Wave-CAIPI: 6 min brain protocol
- Joint image reconstruction
  - Joint LORAKS: faster multi-contrast imaging
- Rapid quantitative imaging
  - 3D MR Fingerprinting
- Machine learning for intractable problems
  - Motion, noise

- Clinical protocol: 2D imaging with thick slices & gaps
- Scan time: 30 min

Conventional 2D imaging

SMS: Wave-CAIPI



5-fold accl

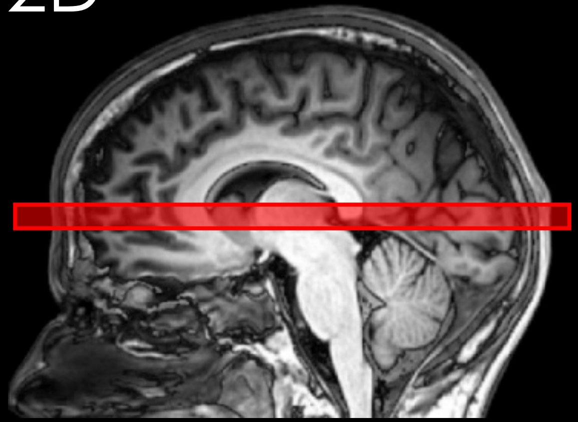
15-fold accl

- We fully harness multi-chan coil to provide 6 min exam
  - whole-brain & high, isotropic resolution
  - more speed & more information

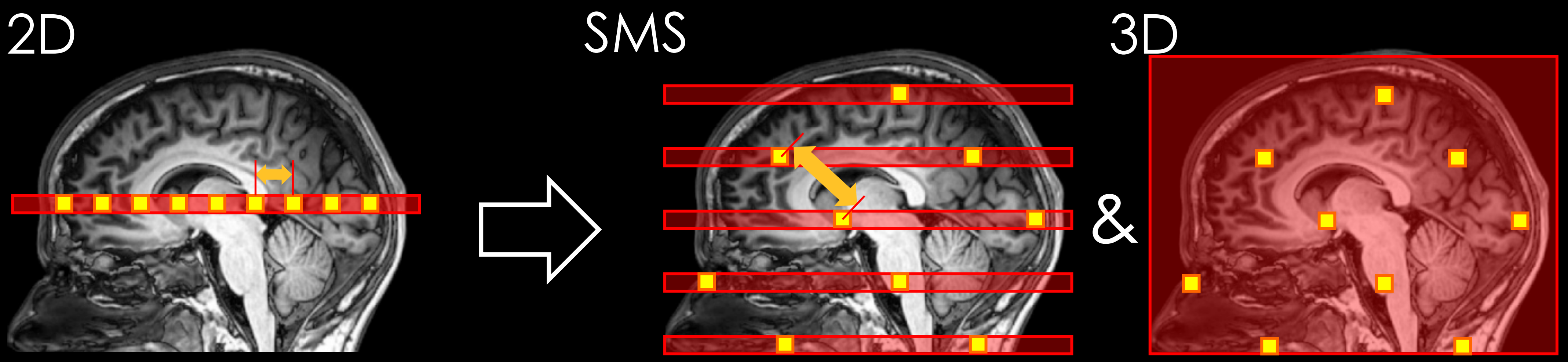
multi-chan coil

Death of 2D: Era of volumetric MRI

2D



Death of 2D: Era of volumetric MRI



- 9-fold Simultaneous MultiSlice (SMS)[1,2] provides 3x SNR gain
- Higher acceleration thru Controlled Aliasing (CAIPI)[3,4]
- Not many excuses to keep using 2D
    - SMS or 3D: depends on application

multi-chan coil

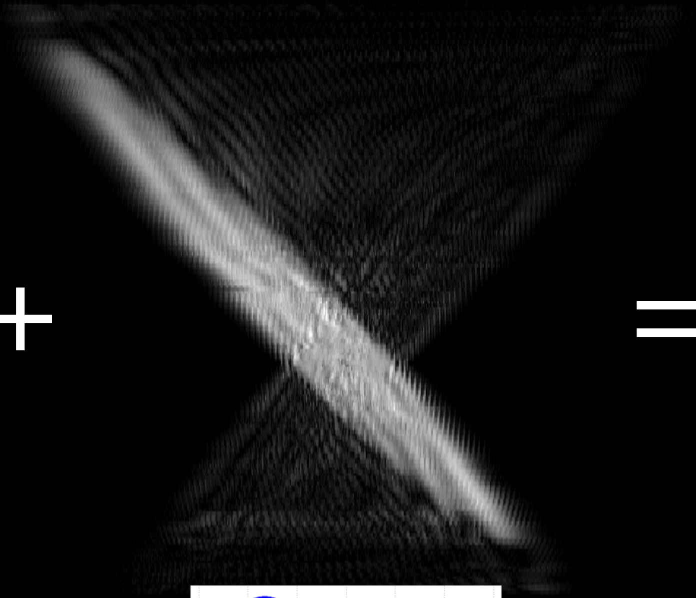
[1] JB Weaver MRM'08
[2] DJ Larkman JMRI'01
[3] FA Breuer MRM'05
[4] K Setsompop MRM'12

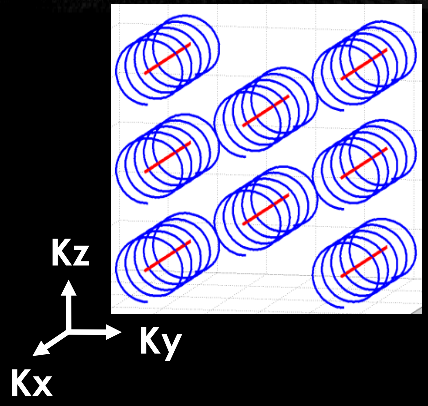
Wave-CAIPI[1]: Controlled Aliasing in 3D

CAIPI

+

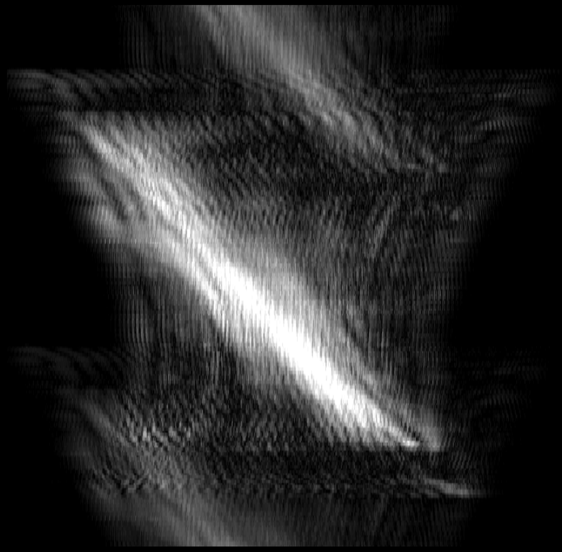
Tailored trajectory





=

Wave-CAIPI



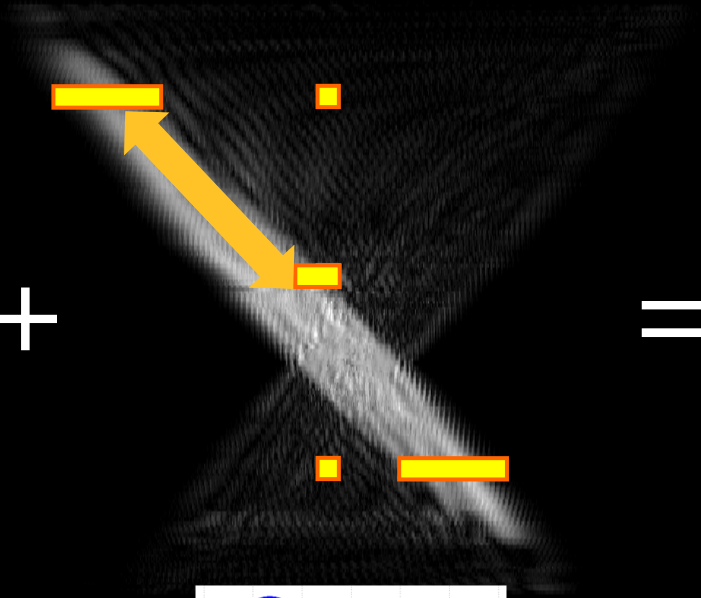
[1] B Bilgic MRM'15

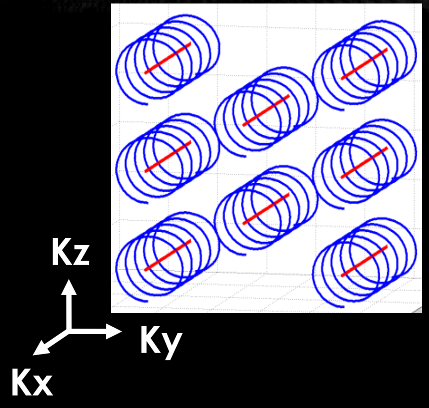
Wave-CAIPI[1]: Controlled Aliasing in 3D

CAIPI

\+

Tailored trajectory

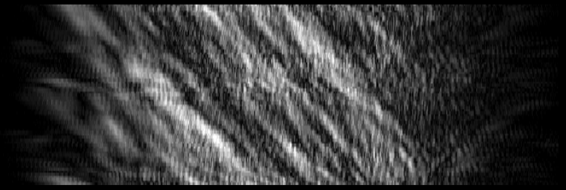




=

Wave-CAIPI

accelerated



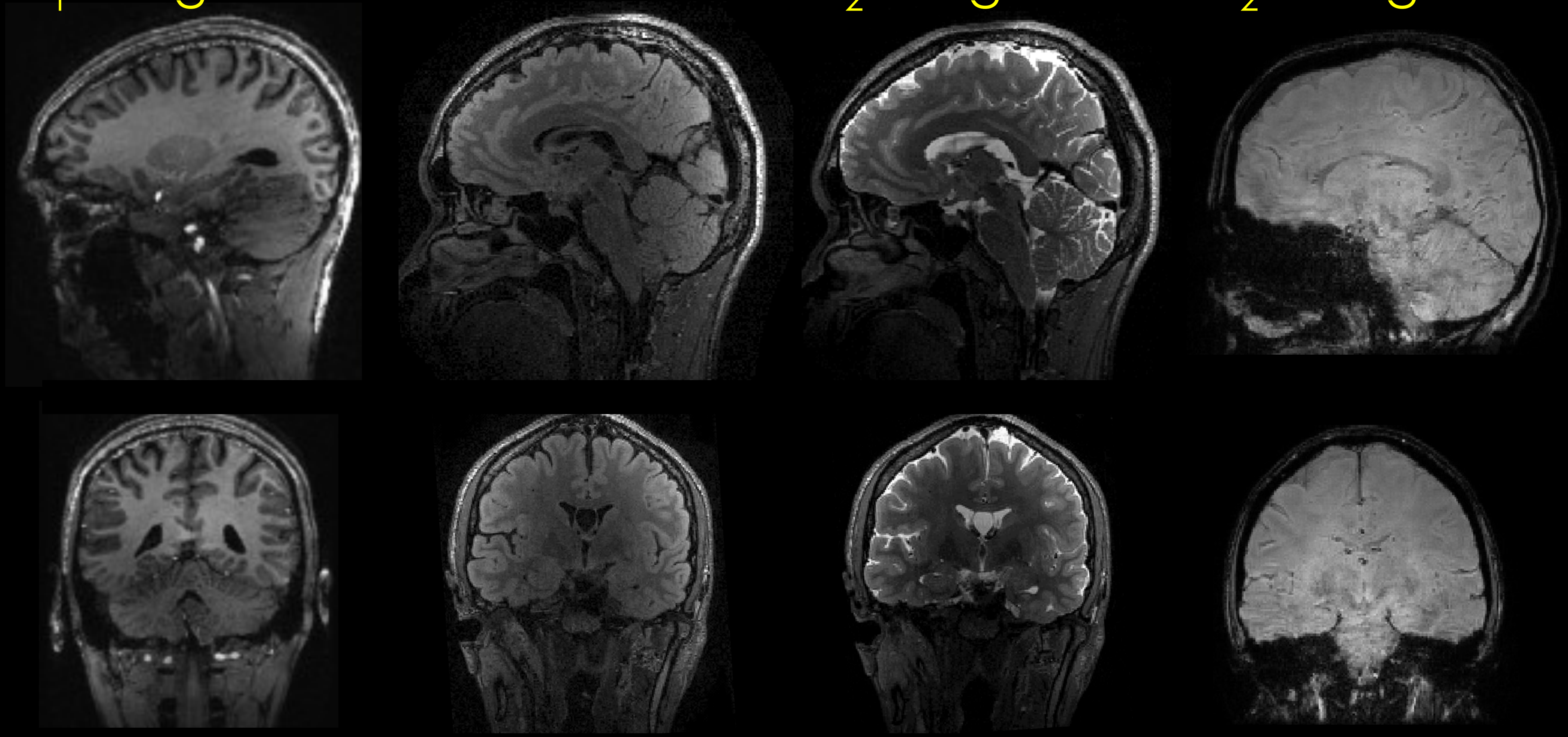
Aliasing is spread in 3D

Image Recon

[1] B Bilgic MRM’15

6 min 1 mm iso brain exam: Wave-CAIPI

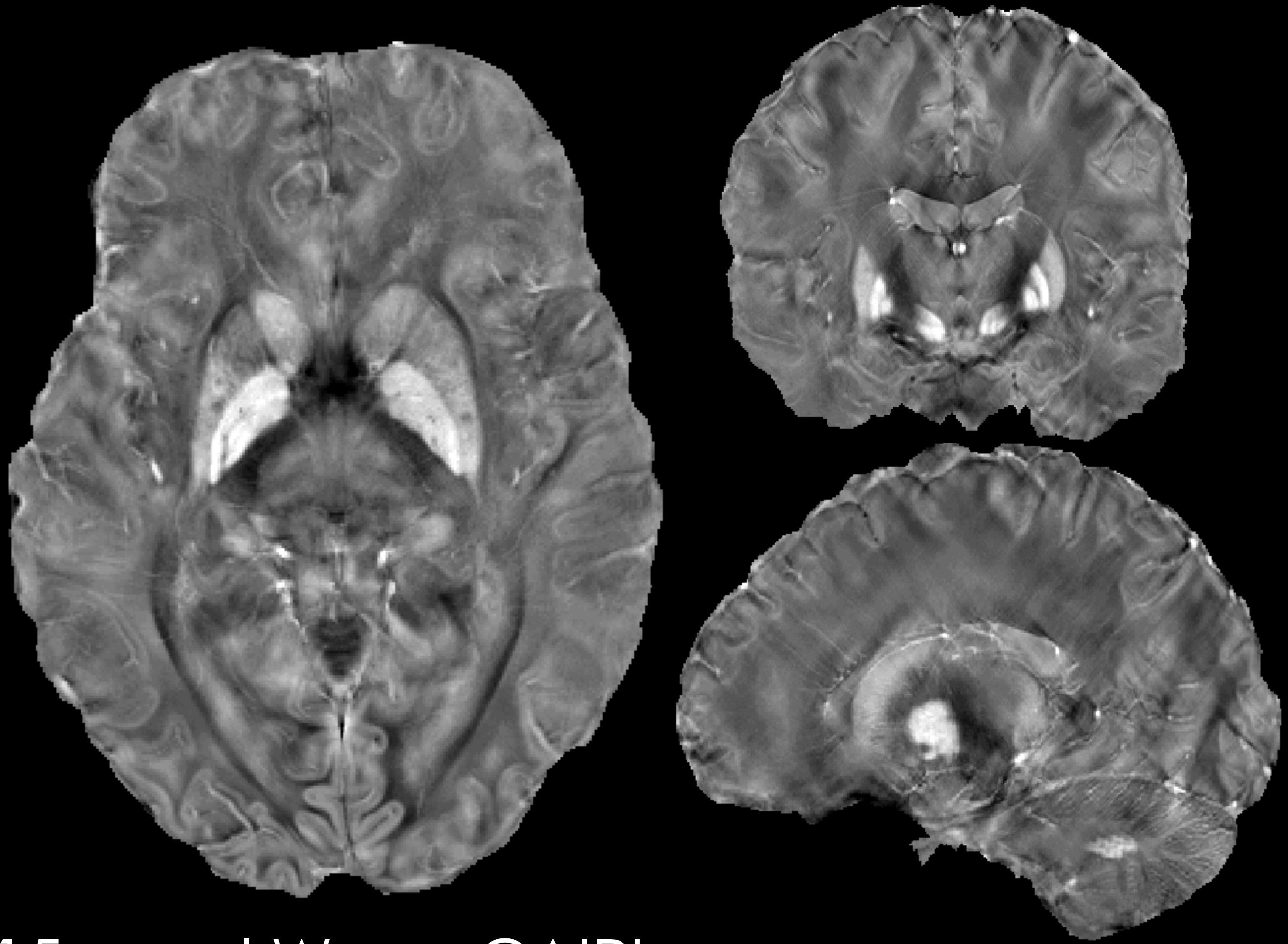
T_1-weighted[1]	FLAIR[2]	T_2-weighted[2]	T_2*-weighted[3]

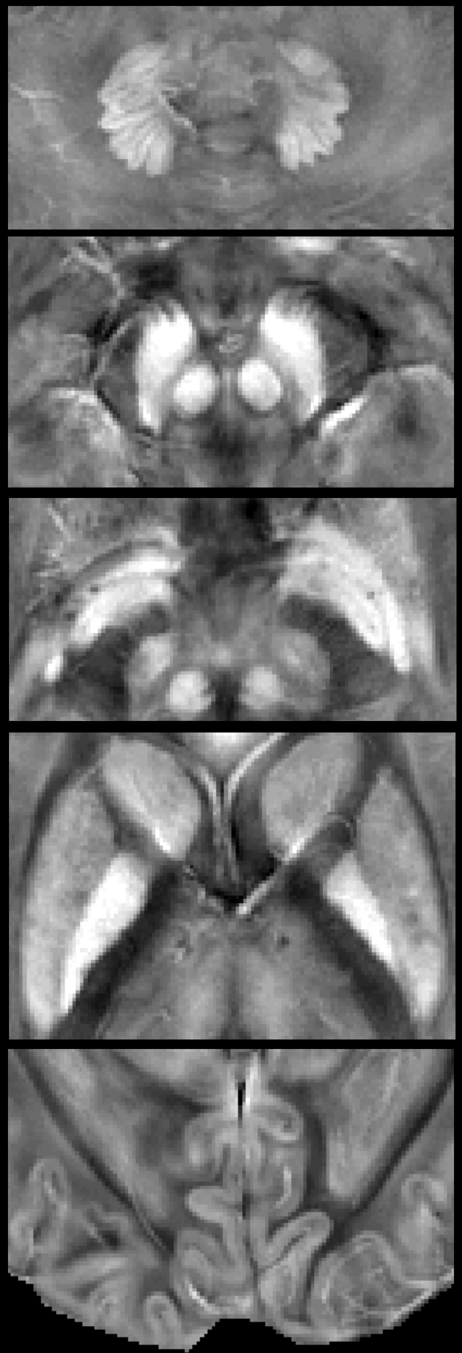


1 min	2 min	1.2 min	1.5 min

[1] D Polak MRM'17

Susceptibility Mapping @ 7T

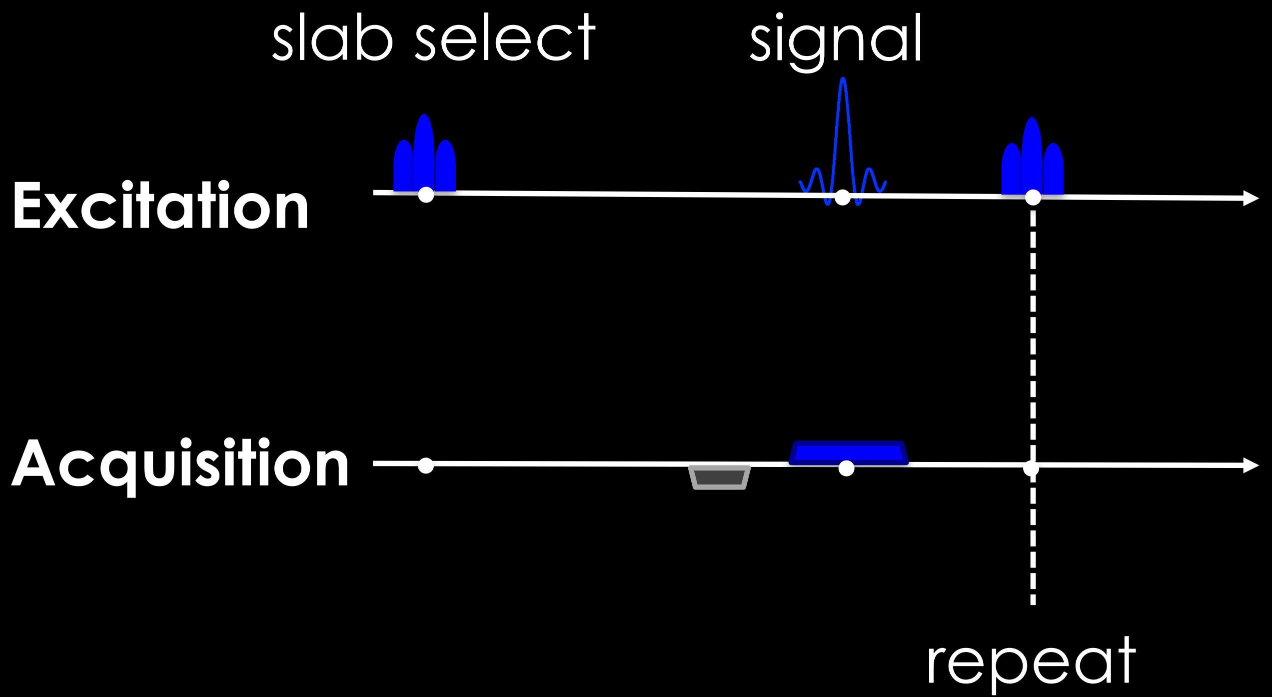


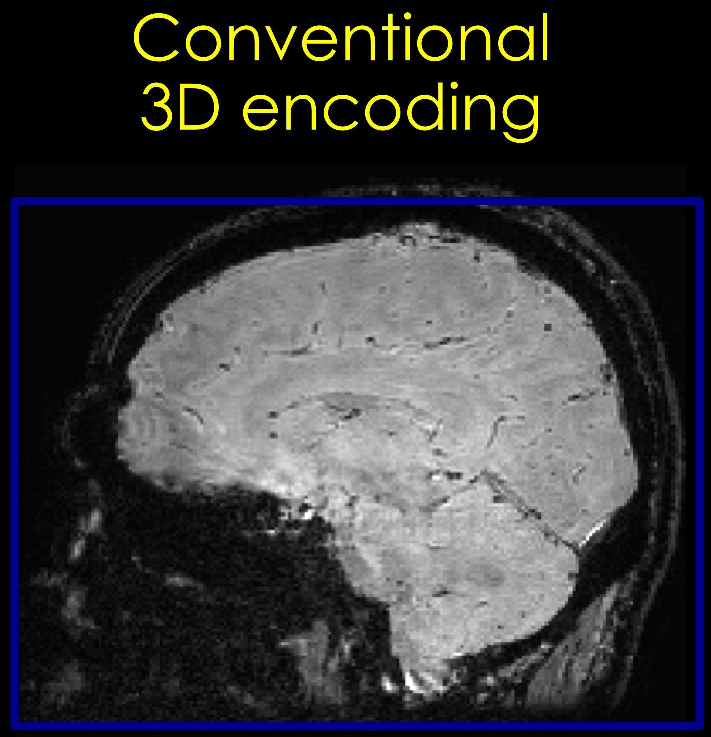


15x accl Wave-CAIPI
500 micron iso Susceptibility Mapping[1]

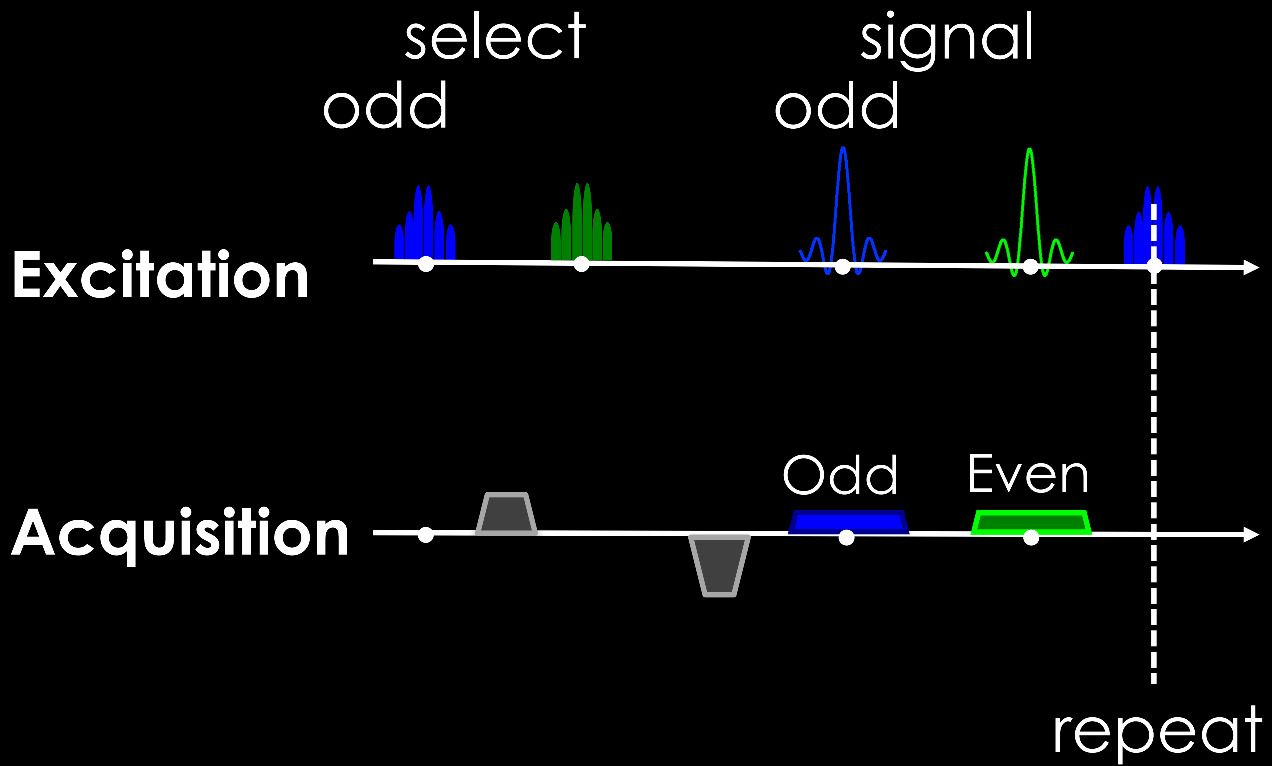
[1] B Bilgic NeuroImage'16

Exploit redundancy in susceptibility acquisition



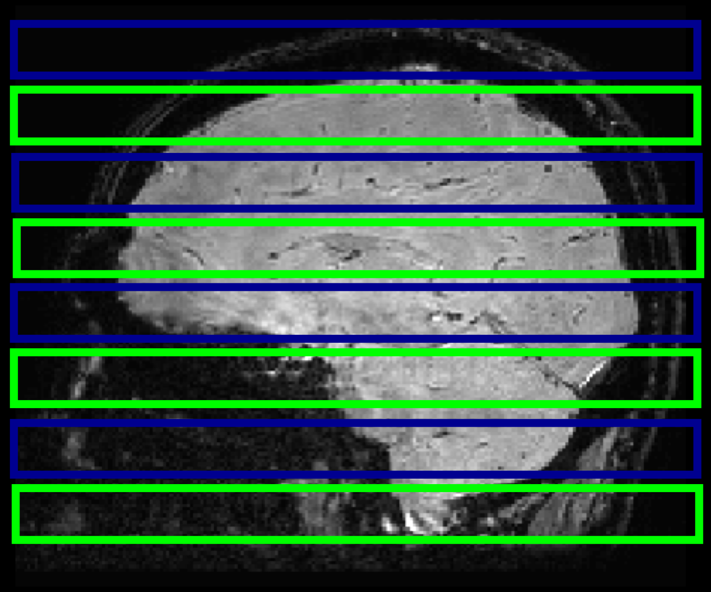


Exploit redundancy in susceptibility acquisition



STIMS[1]

2x extra efficiency



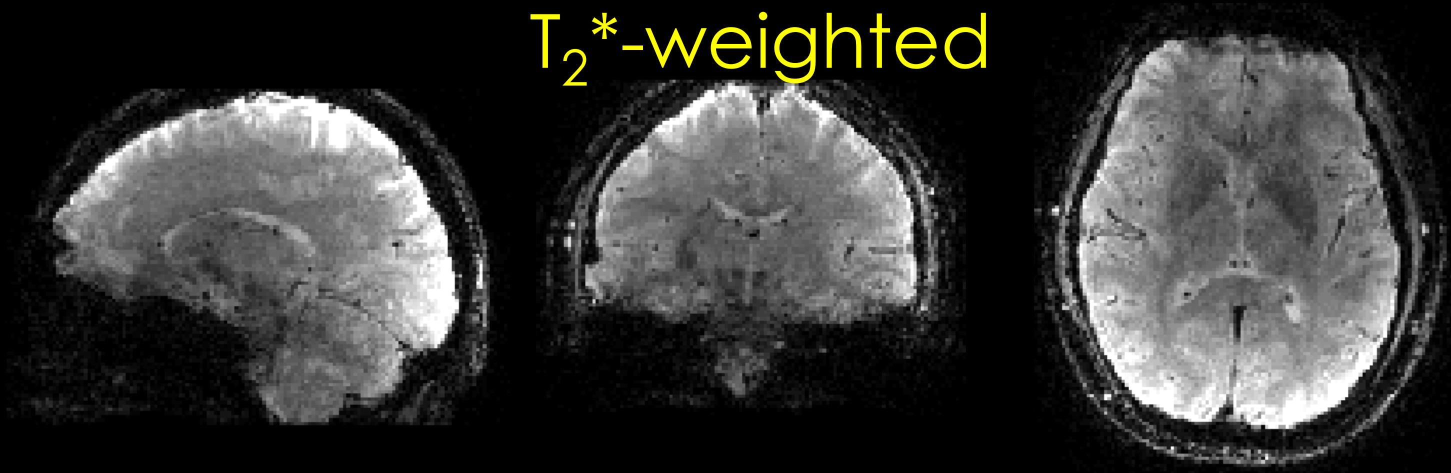
[1] B Bilgic & H Ye NeuroImage'17

30x STIMS accl

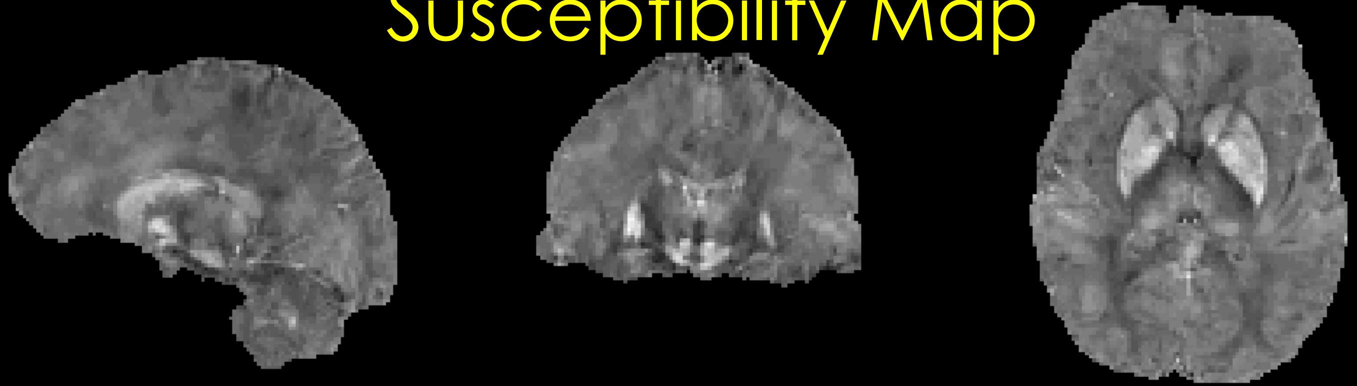
1.5 mm iso in 24 seconds

(2x interleaved, 15x Wave)

T_2*-weighted



Susceptibility Map



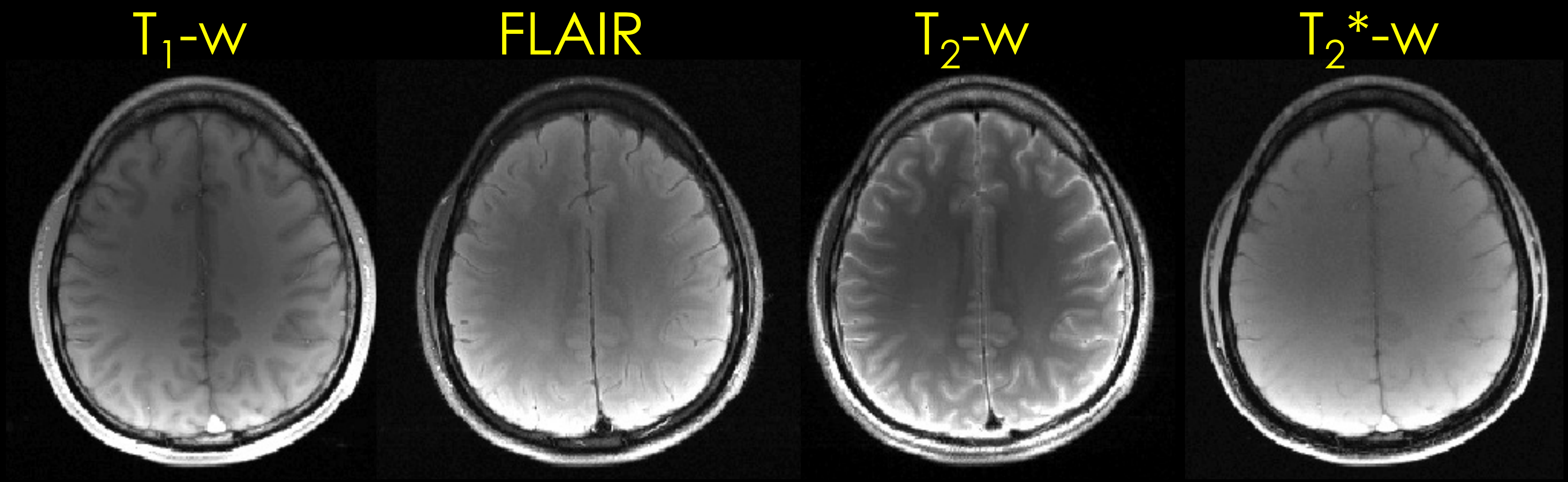
[1] B Bilgic & H Ye NeuroImage'17

Overview

- Death of 2D: Era of volumetric acquisition
  - Wave-CAIPI: 6 min brain protocol
- Joint image reconstruction
  - Joint LORAKS: faster multi-contrast imaging
- Rapid quantitative imaging
  - 3D MR Fingerprinting
- Machine learning for intractable problems
  - Motion, noise

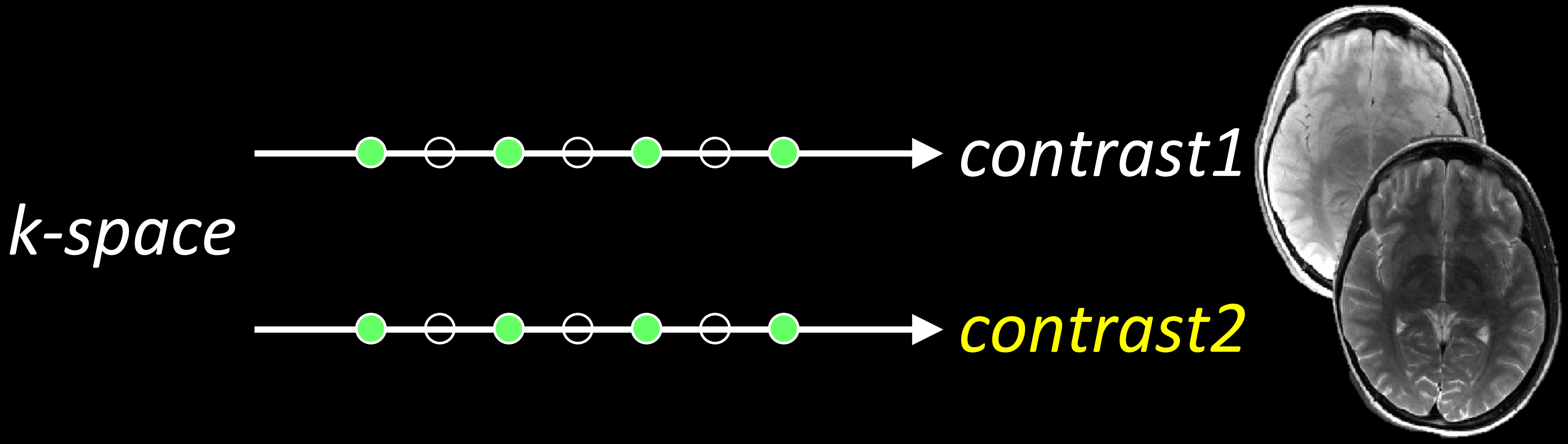
Joint image reconstruction

- Clinical MRI routinely involves multi-contrast acquisition

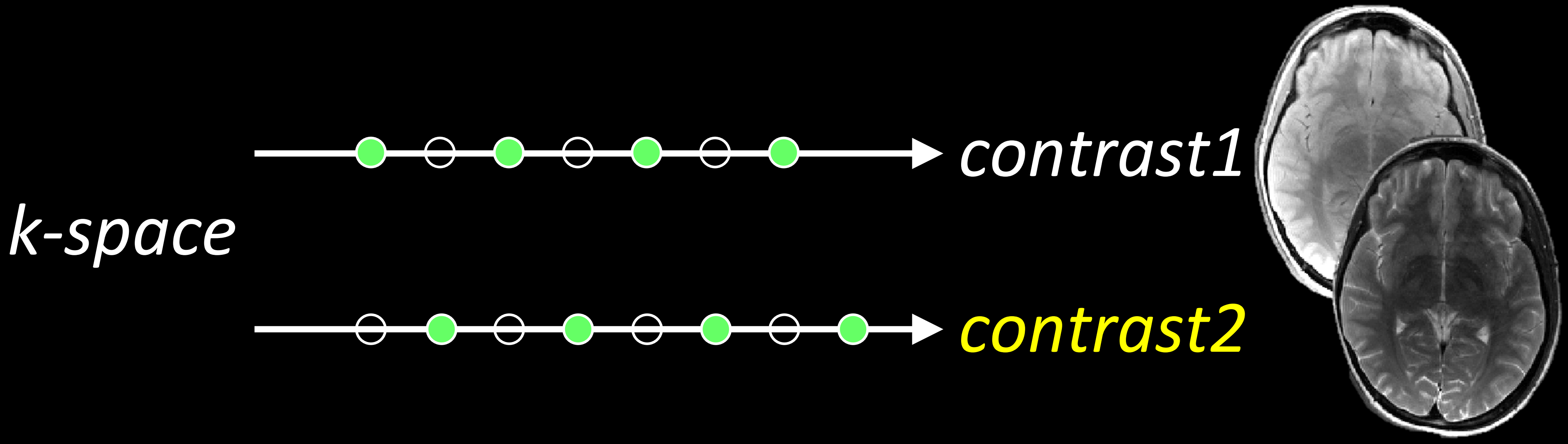


- Design joint acquisition/recon for higher acceleration

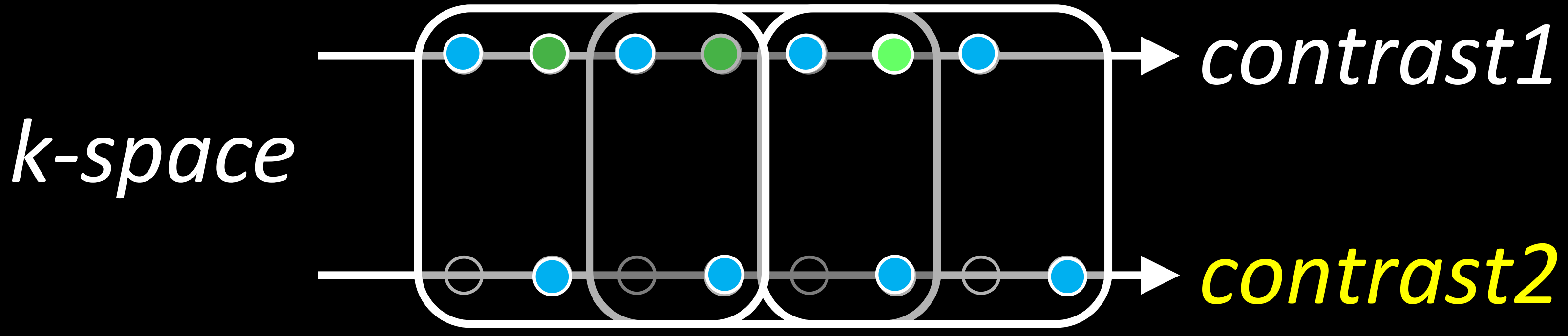
Joint LORAKS

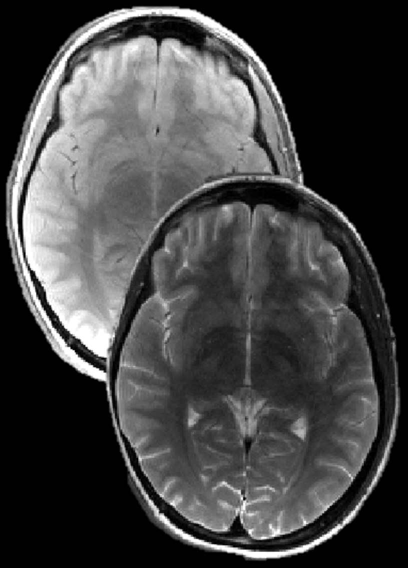


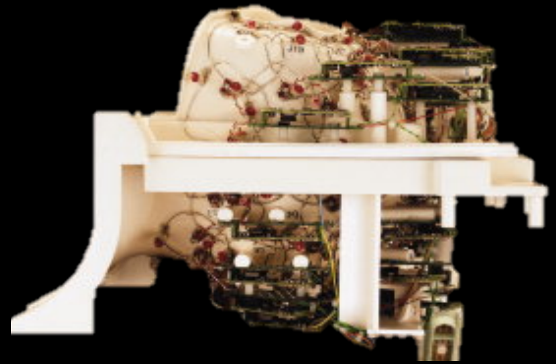
Joint LORAKS



Joint LORAKS



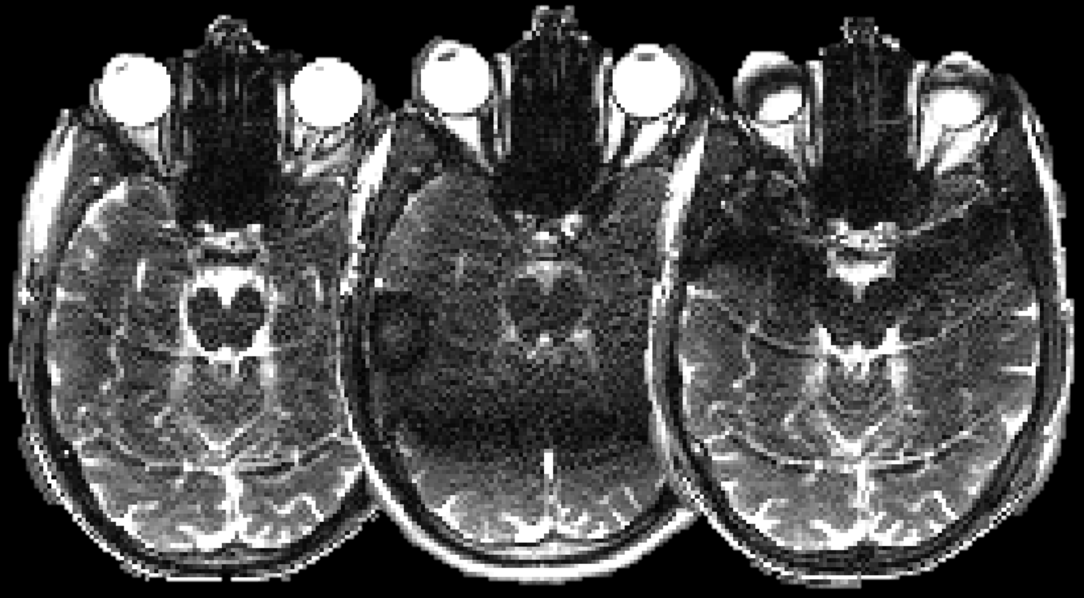




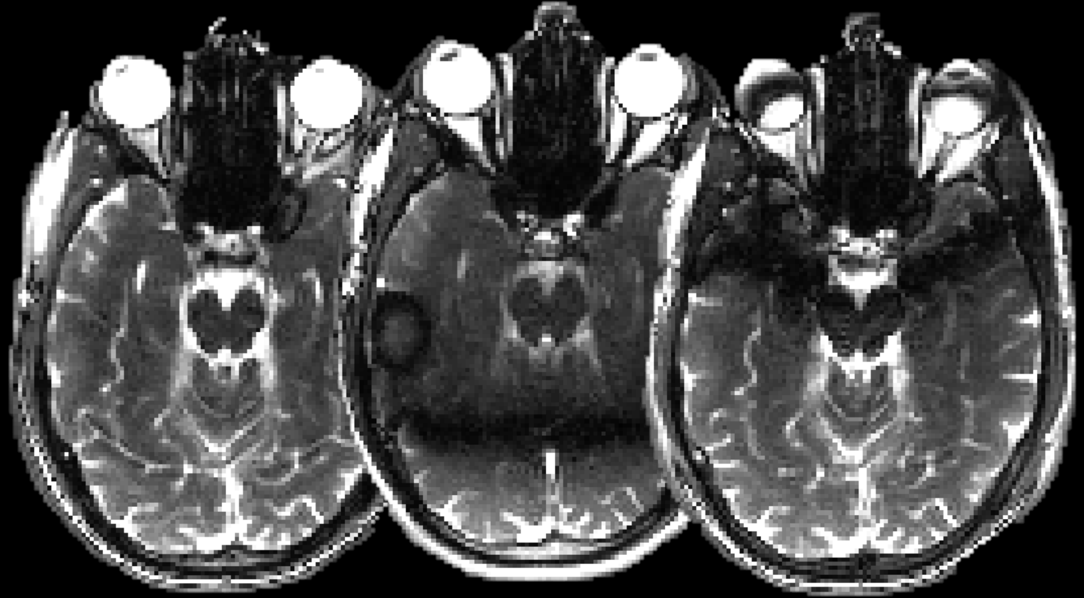
Joint LORAKS[1]

- balanced SSFP with phase-cycling
  - 2D @ 6-fold accl

Standard



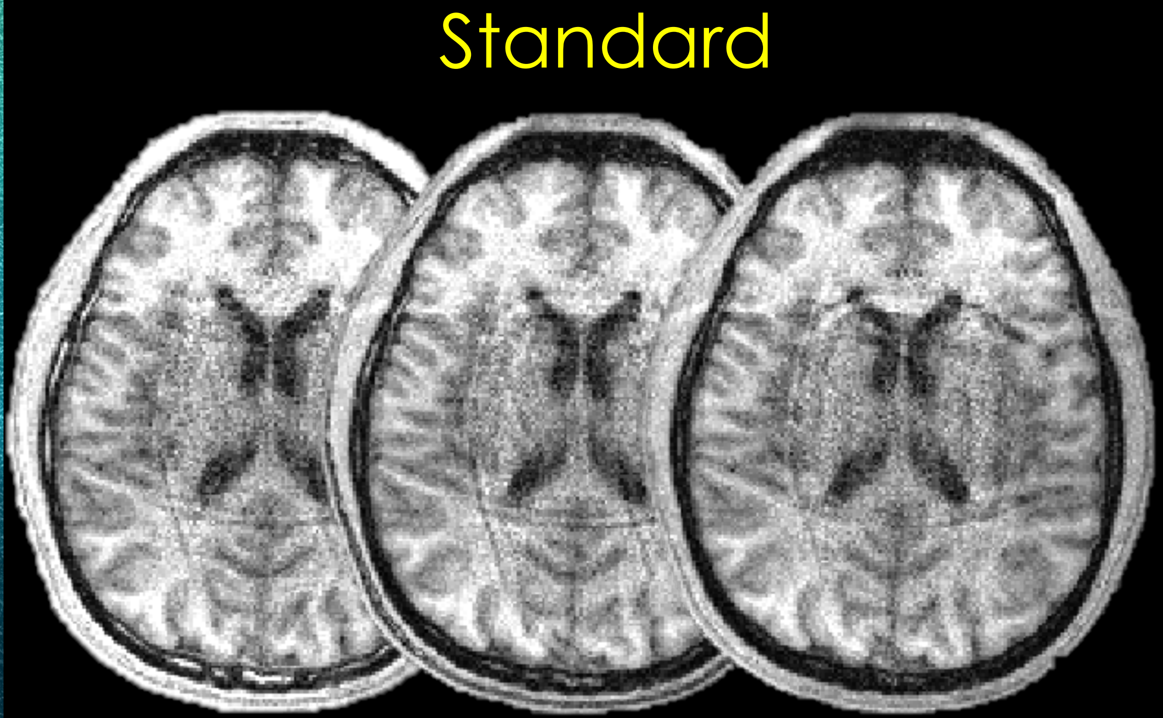
J-LORAKS



[1] B Bilgic & TH Kim MRM, *submitted*

Joint LORAKS[1]

- Multi-contrast T_1-weighted
  - 3D @ 16-fold accl



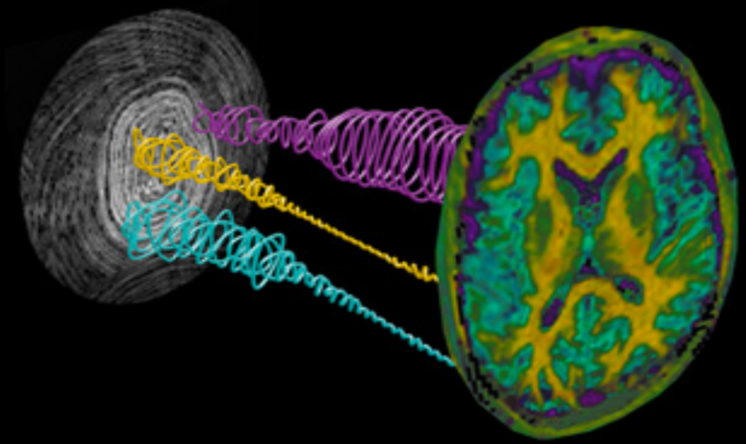
[1] B Bilgic & TH Kim MRM, *submitted*

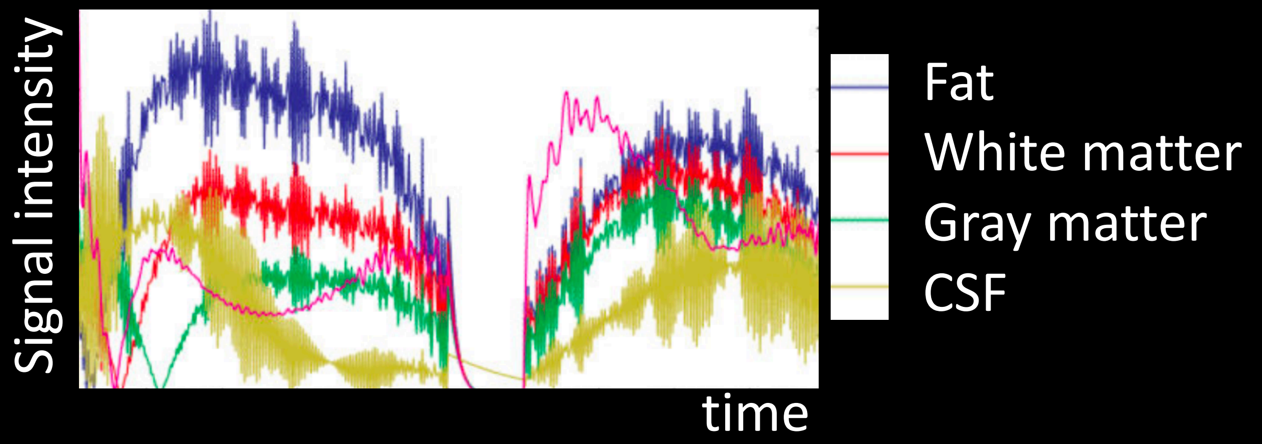
Overview

- Death of 2D: Era of volumetric acquisition
  - Wave-CAIPI: 6 min brain protocol
- Joint image reconstruction
  - Joint LORAKS: faster multi-contrast imaging
- Rapid quantitative imaging
  - 3D MR Fingerprinting
- Machine learning for intractable problems
  - Motion, noise

MR Fingerprinting[1]

- MRF collects data in a randomized way, each tissue has unique fingerprint



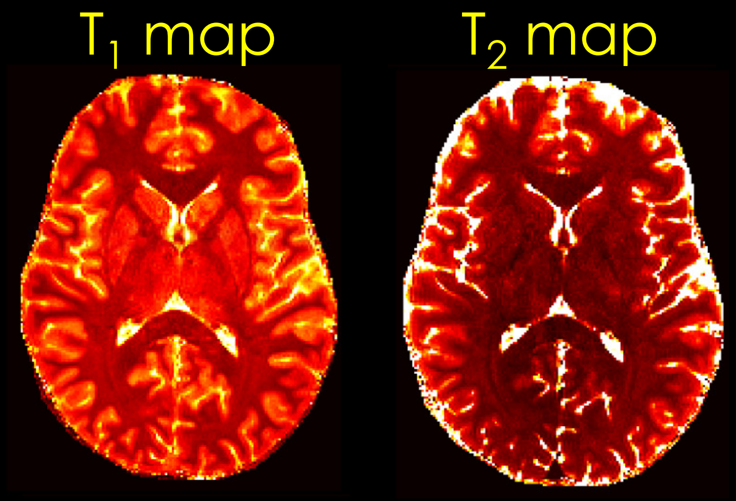


- Rethink acquisition/recon:
  - Simulate all possible fingerprints
  - Match acquired random data to dictionary

[1] D Ma Nature'13

MR Fingerprinting[1]

- Physics based recon provides *quantitative* T_1, T_2 maps

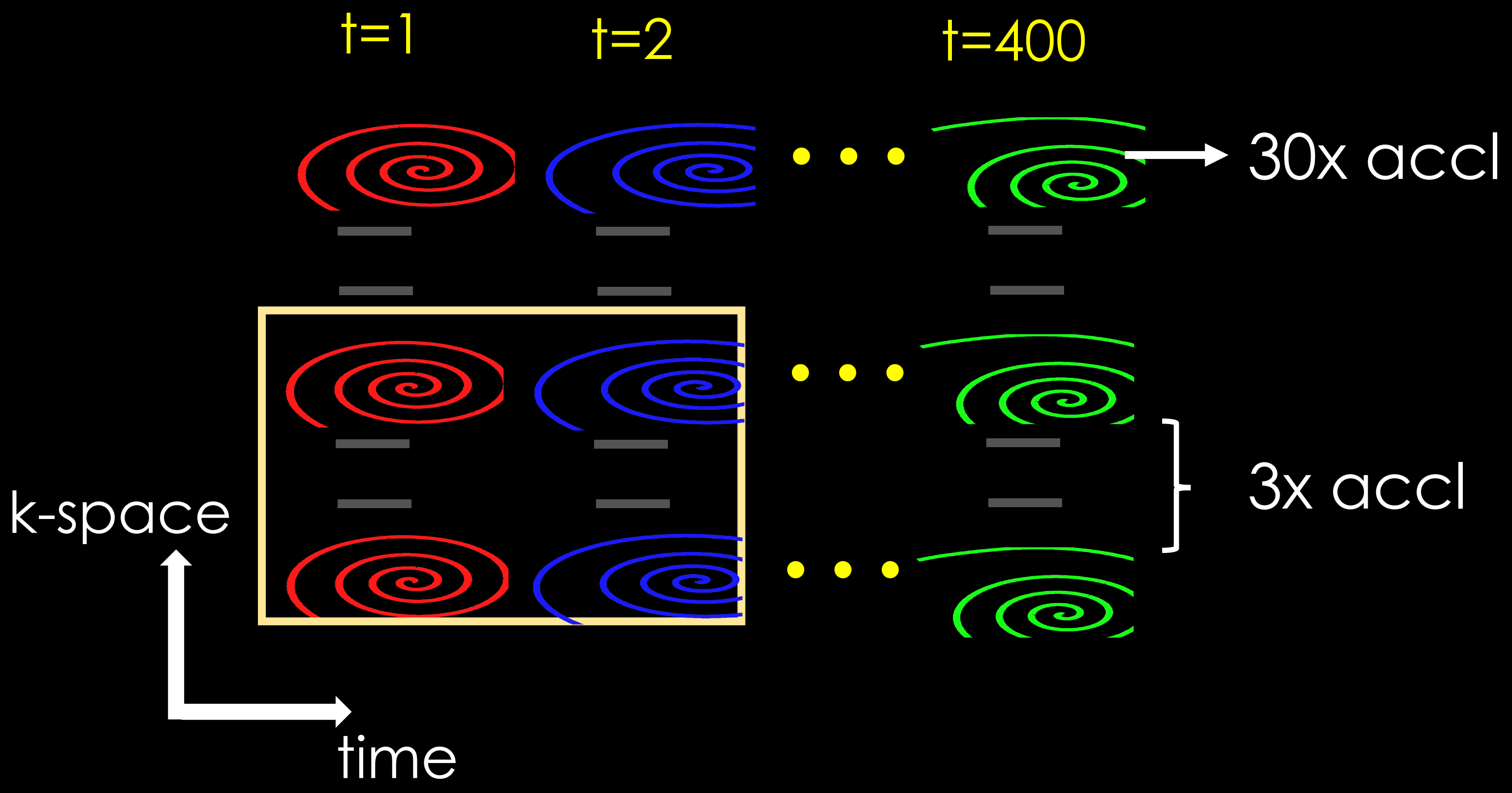


- Fast for single slice: 10 sec
- Whole-brain: **30 min**
- SNR of 2D **insufficient** for high-res

[1] D Ma Nature'13

3D MRF[1]

- Improved SNR enables high-res
- 4D Joint Recon: across space & time



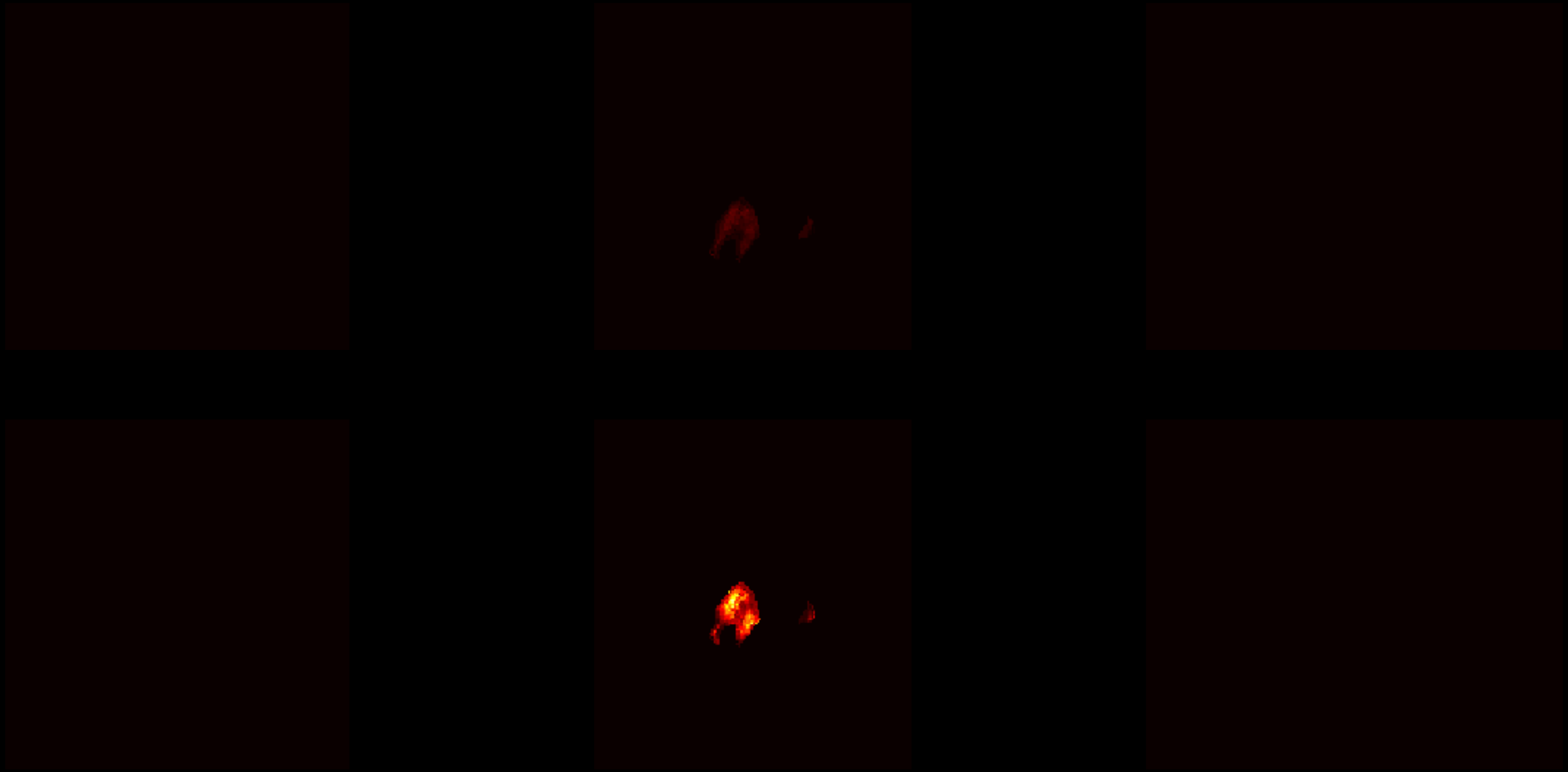
Massive 90x accl

[1] C Liao & B Bilgic NeuroImage'17

Whole-brain MRF @ 1mm iso in 7.5 min

T_1 map

T_2 map

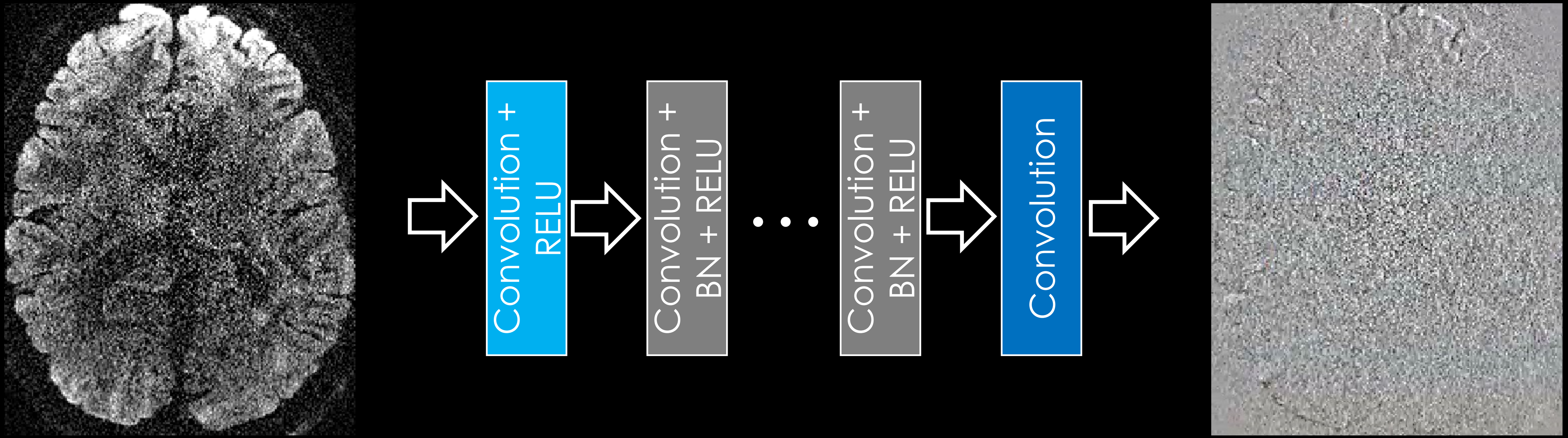


Overview

- Death of 2D: Era of volumetric acquisition
  - Wave-CAIPI: 6 min brain protocol
- Joint image reconstruction
  - Joint LORAKS: faster multi-contrast imaging
- Rapid quantitative imaging
  - 3D MR Fingerprinting
- Machine learning for intractable problems
  - Motion, noise

ML for intractable problems

- When things are too difficult to model
    - Noise physiological / thermal
    - Motion
- Deep residual learning: easier to learn the artifact

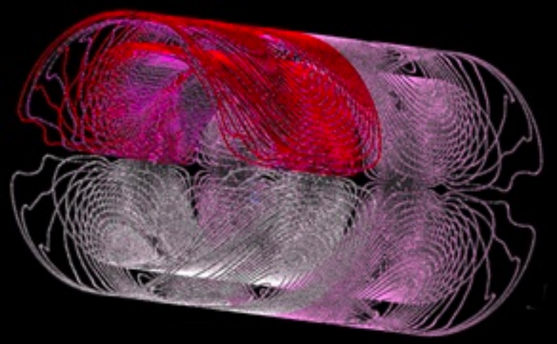


Noisy image

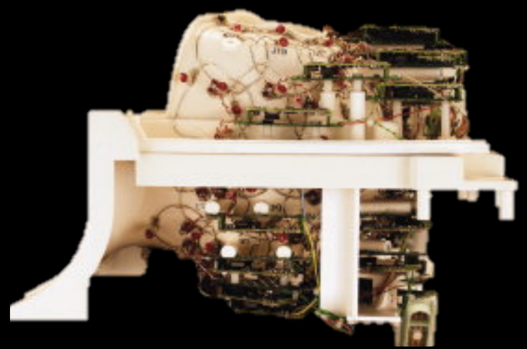
Artifact only

gSlider[1]: 660 micron diffusion MR

- 3D encoding for gray matter diffusion



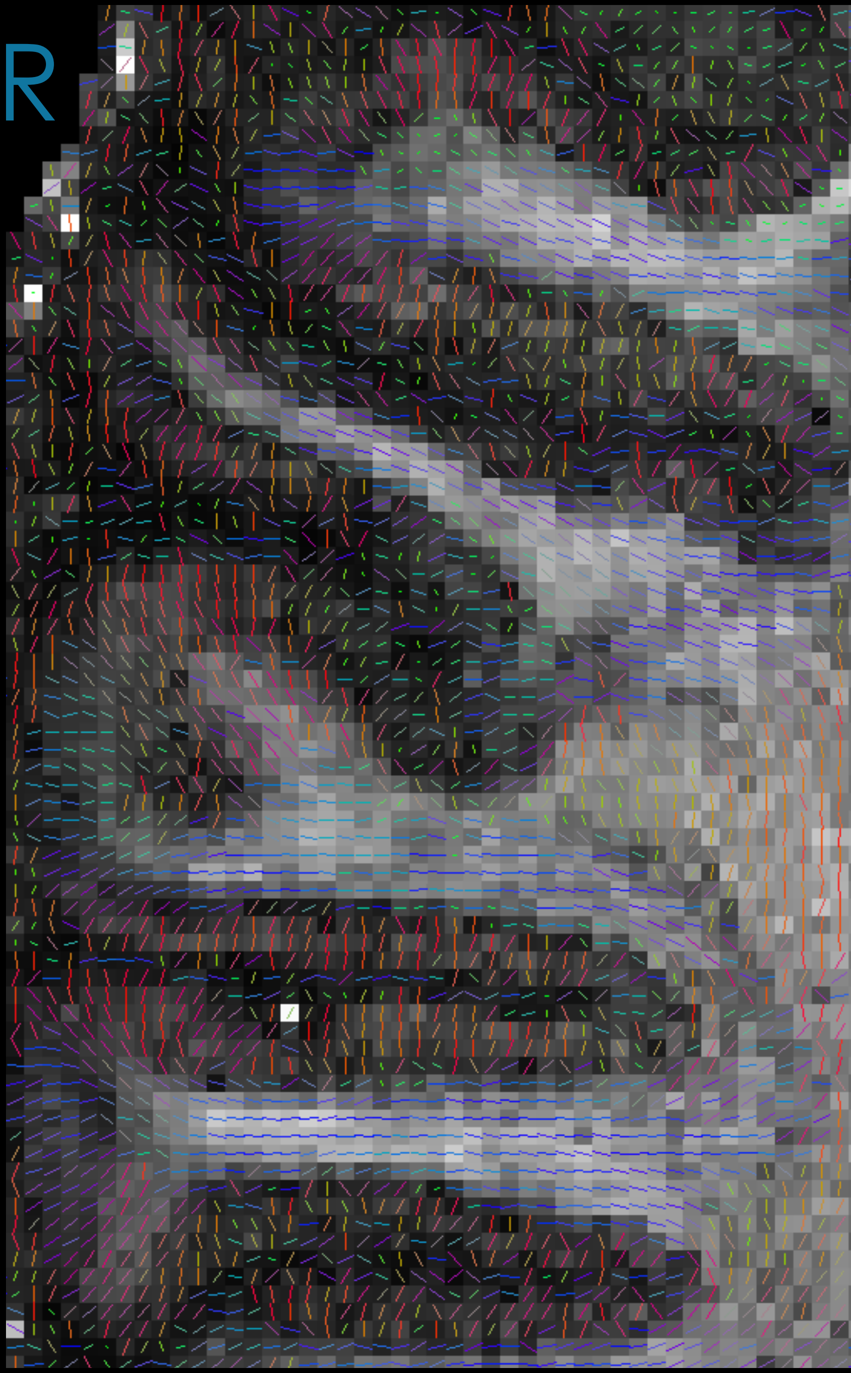
Connectome gradient



64ch coil

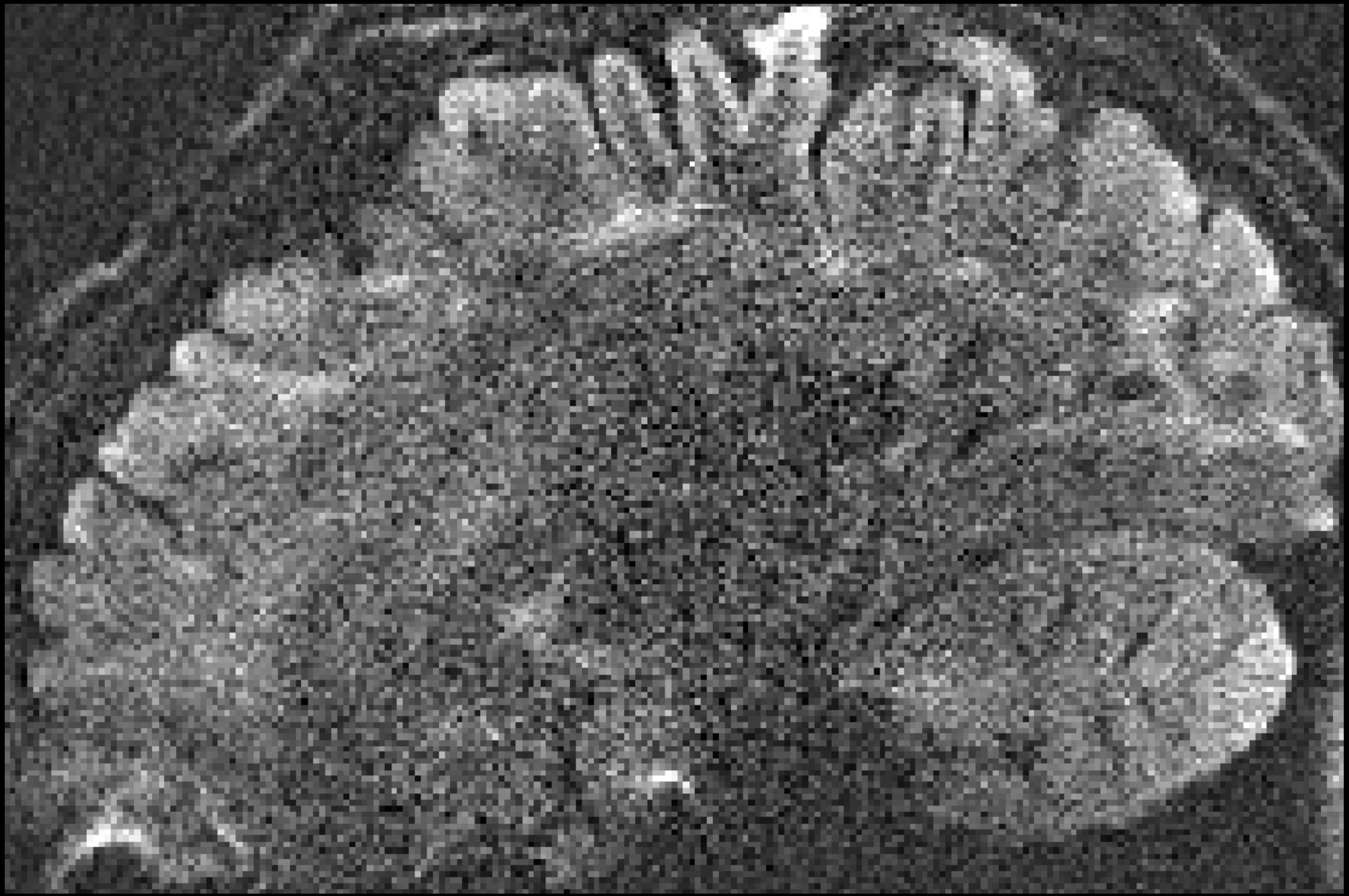
- Physics dictate: 1 hour scan
- Beat physics:

reduce thermal noise & scan time



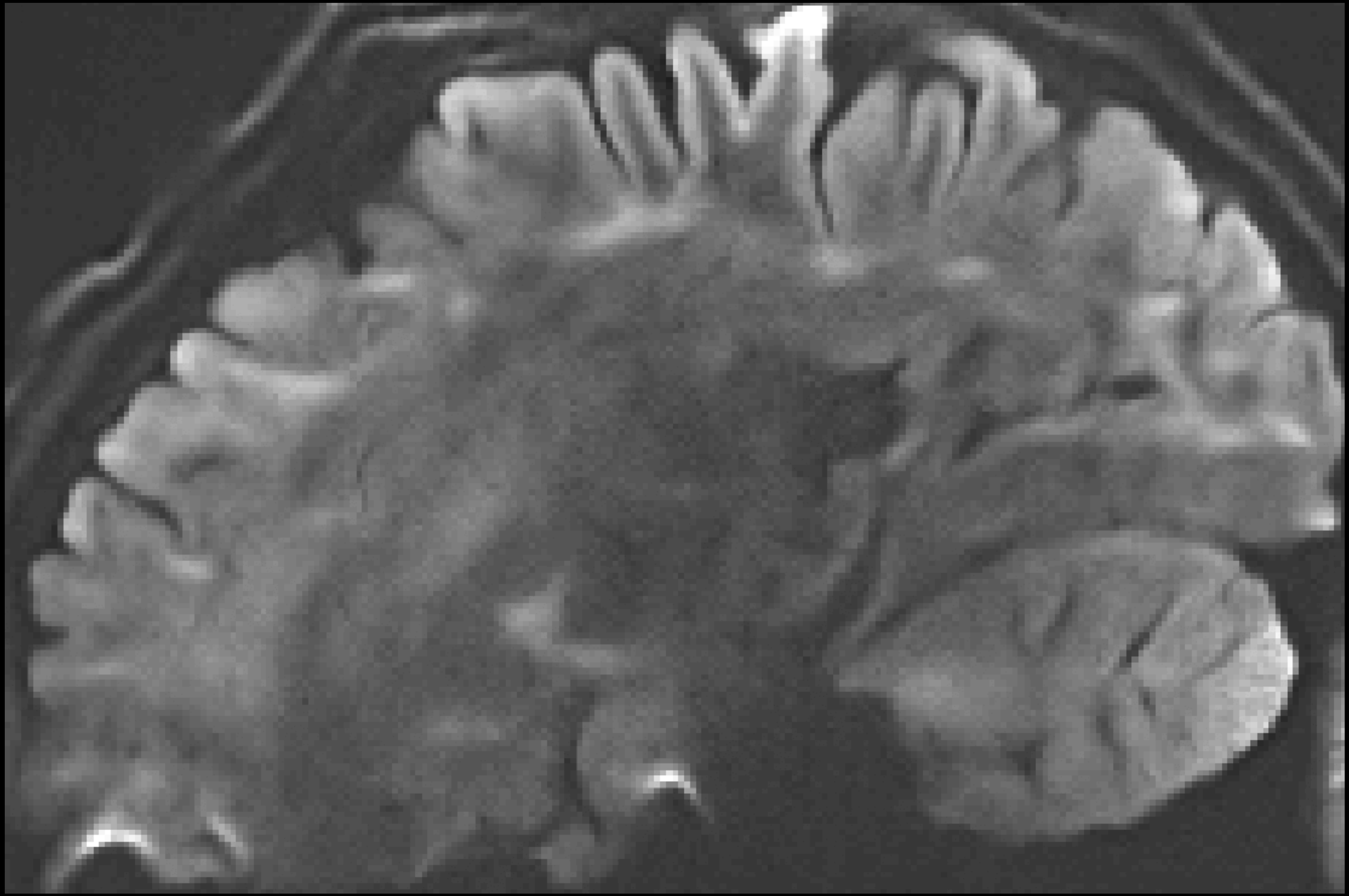
[1] K Setsompop MRM'17

gSlider[1]: 660 micron diffusion MR



[1] K Setsompop MRM'17

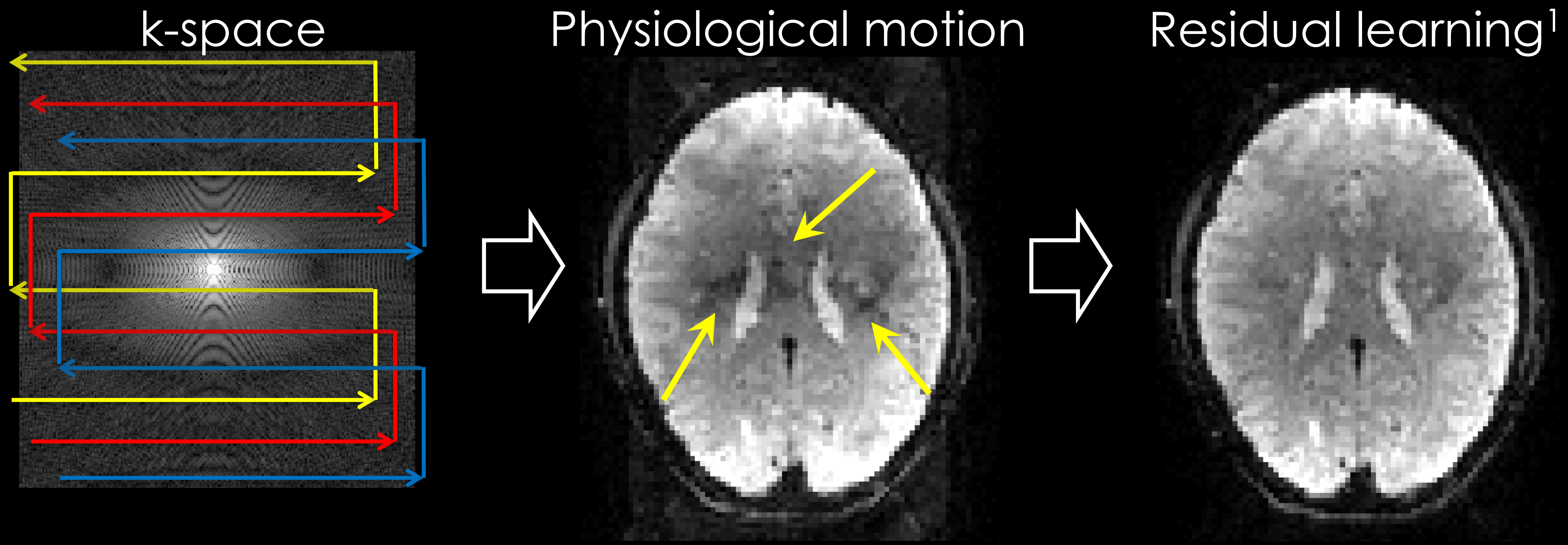
Deep Residual Learning[1]



[1] B Bilgic, *unpublished*

Multi-shot Echo Planar Imaging

- Multi-shot EPI is extremely efficient
- Combining shots is prohibitively hard



[1] B Bilgic, *unpublished*

Motion Correction

- Learn motion artifacts from Alzheimer’s patients’ scans
- Apply network to unseen motion:

Motion Correction

- Learn motion artifacts from Alzheimer's patients' scans
- Apply network to unseen motion:

Residual learning[1]

[1] B Bilgic, *unpublished*

Motion Correction

- ML: initialize physics-based recon
- TAMER: use redundancy in multi-channel coil

TAMER[1]

[1] M Haskell, ISMRM'16

Thank you for your attention!

- Questions / comments:
  berkin@nmr.mgh.harvard.edu
- Code / data:
  martinos.org/~berkin
- Thanks to:

Athinoula A. Martinos Center For Biomedical Imaging

K Setsompop
SF Cauley
C Liao
LL Wald
JR Polimeni
MK Manhard
SH Han
F Wang
M Haskell

Zhejiang University 1897

H Ye
Z Wu

USC University of Southern California

J Haldar
TH Kim

Stanford

E Gong

SIEMENS

D Polak
Y Chang
H Bhat

Boston Children's Hospital

BA Gagoski

NANOTEC

I Chatnuntawech