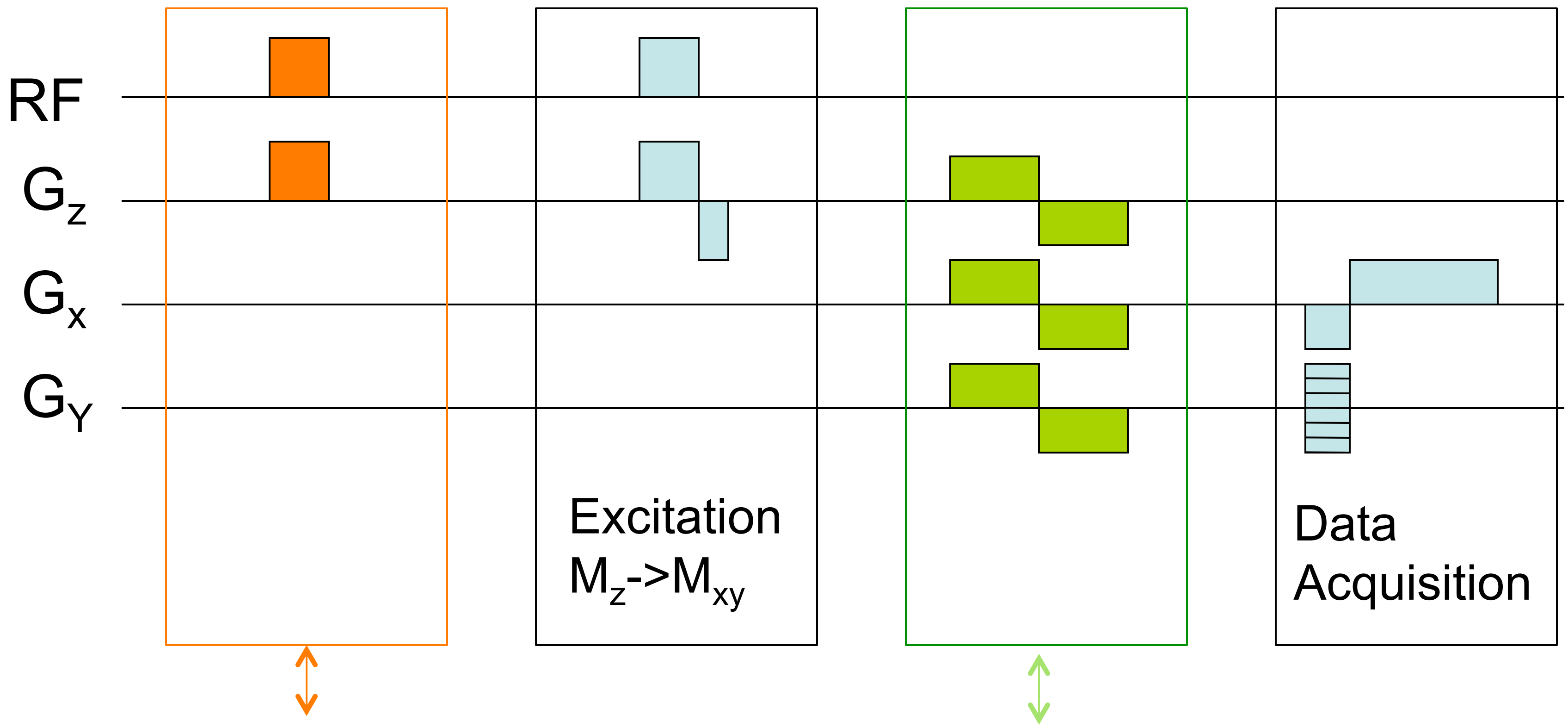
Motion Related Contrast in MRI

Eric Wong

PollEv.com/be278

Motion Encoding



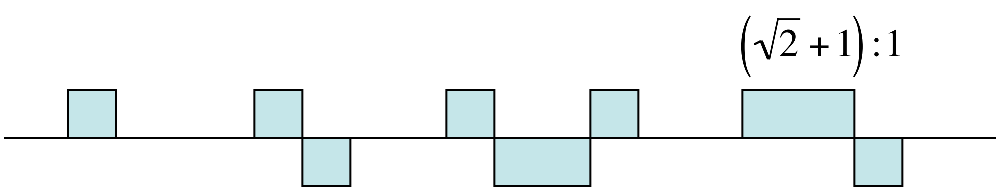
<u>Modify M_Z</u>
- Time of Flight MRA
- Arterial Spin Labeling
- Myocardial Tagging

<u>Modify M_{xy}</u>
- Phase Contrast MRA
- Elastography
- Diffusion Imaging

Encoding M_{XY} for Motion: Phase Contrast

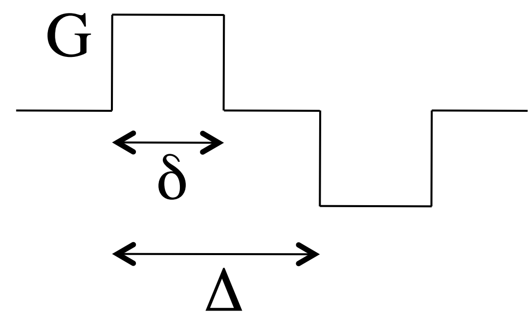
Phase from Motion:

$$\phi(t) = \int \gamma B(t)dt$$
$$= \int \gamma \vec{G}(t) \bullet \vec{r}(t)dt$$
$$= \int \gamma \vec{G}(t)(\vec{r}_0 + \vec{V}t + \ldots)dt$$
$$= \vec{r}_0 \bullet \underbrace{\int \gamma \vec{G}(t)dt}_{\text{Zeroth Moment } (m_0) = k} + \vec{V} \bullet \underbrace{\int \gamma \vec{G}(t)tdt}_{\text{First (flow) Moment } (m_1)} + \ldots$$



$m_0=1$	$m_0=0$	$m_0=0$	$m_0=\sqrt{2}$
$m_1=1$	$m_1=-2$	$m_1=0$	$m_1=0$

Bipolar Gradient:



$$m_1 = \gamma G \delta \Delta$$

How Big can m_1 be?

For: G=4G/cm
δ=Δ=50ms

- π per 6μm
- VENC=velocity for φ=π
- =6μm/50ms=0.12mm/s

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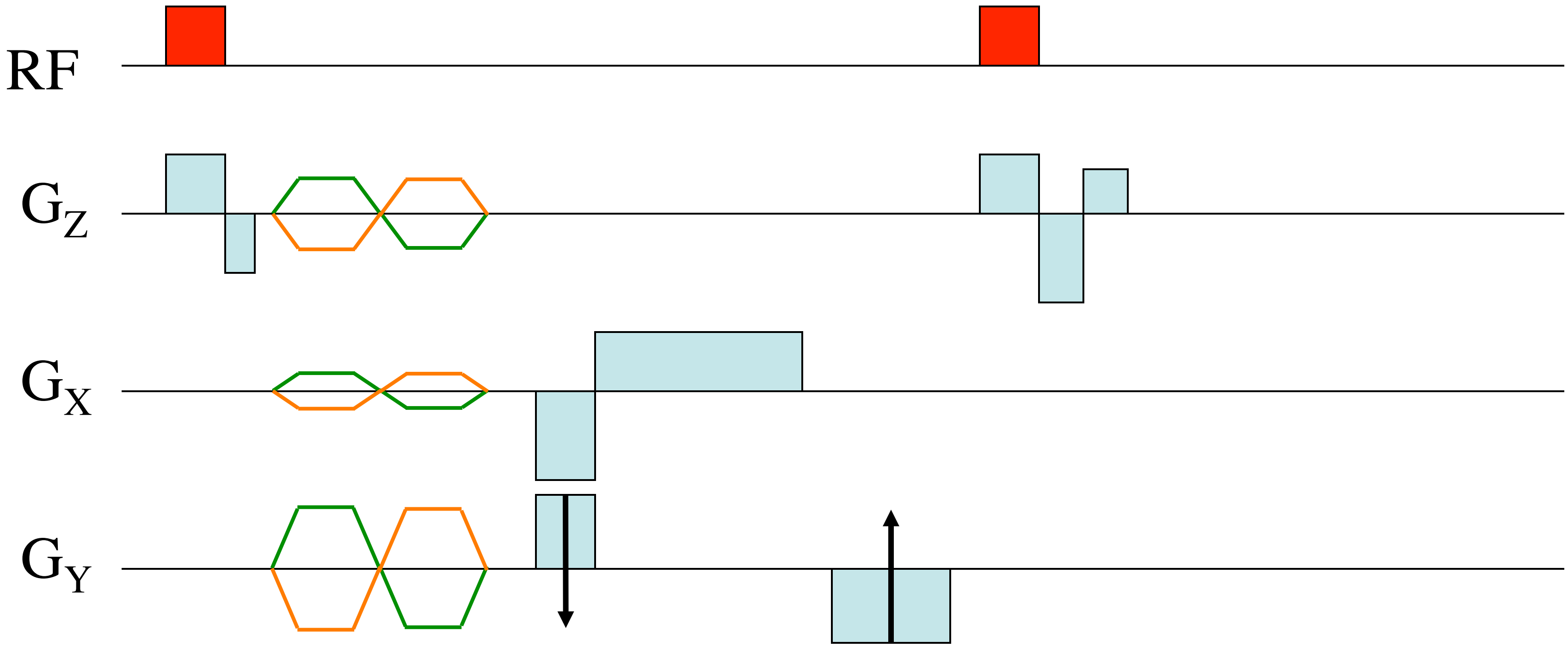
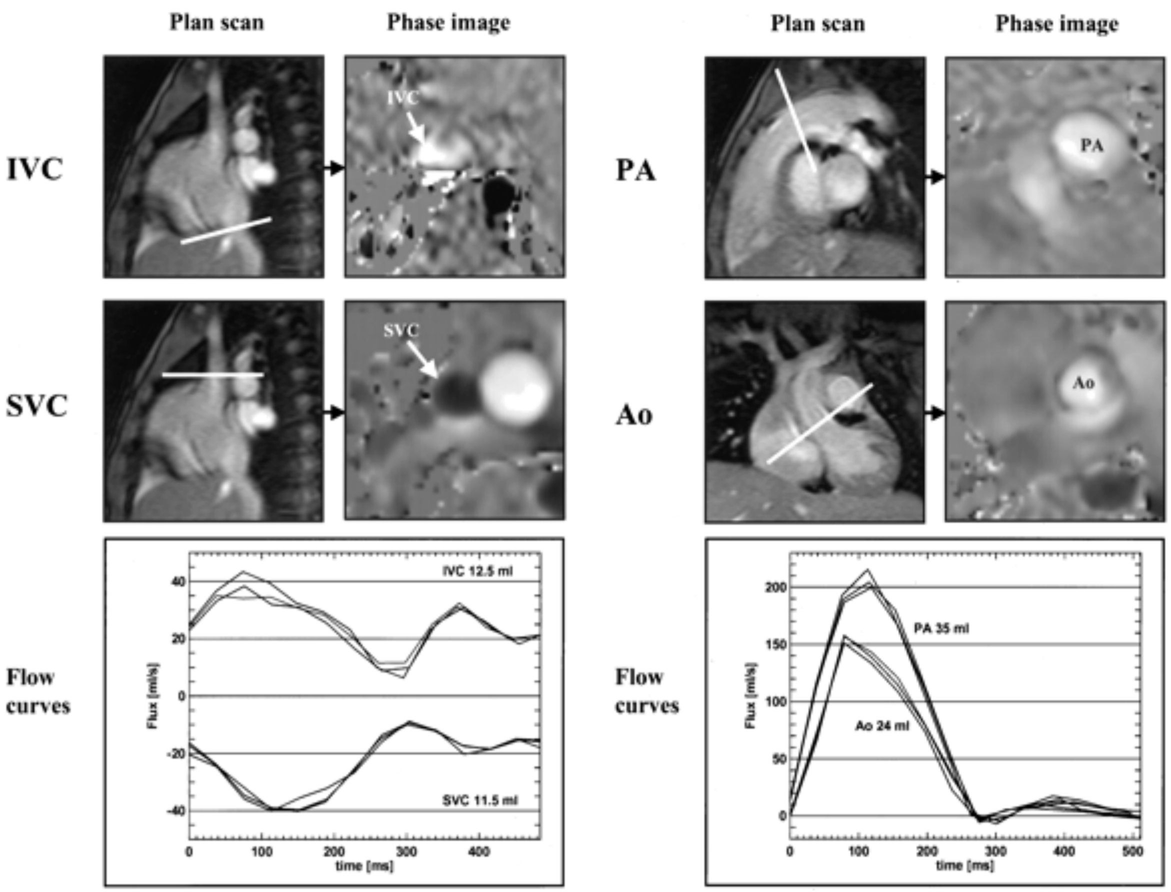
Phase Contrast MRA

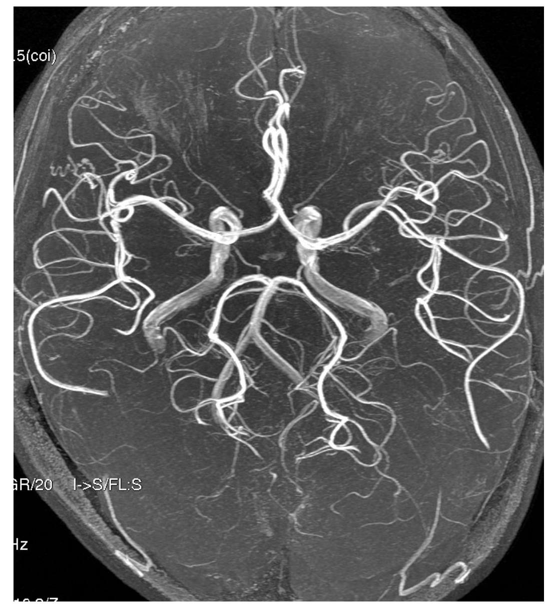


- One image with velocity encoding positive
- One image with velocity encoding negative
- Vector sum of gradients determines direction of encoding
- Display phase difference between images
- Phase difference subtracts out off-resonance and other phase effects

Phase Contrast MRA

- •Phase is proportional to velocity
- •Quantitate velocity from phase images and/or:
- •Construct angiograms by MIP of velocity maps

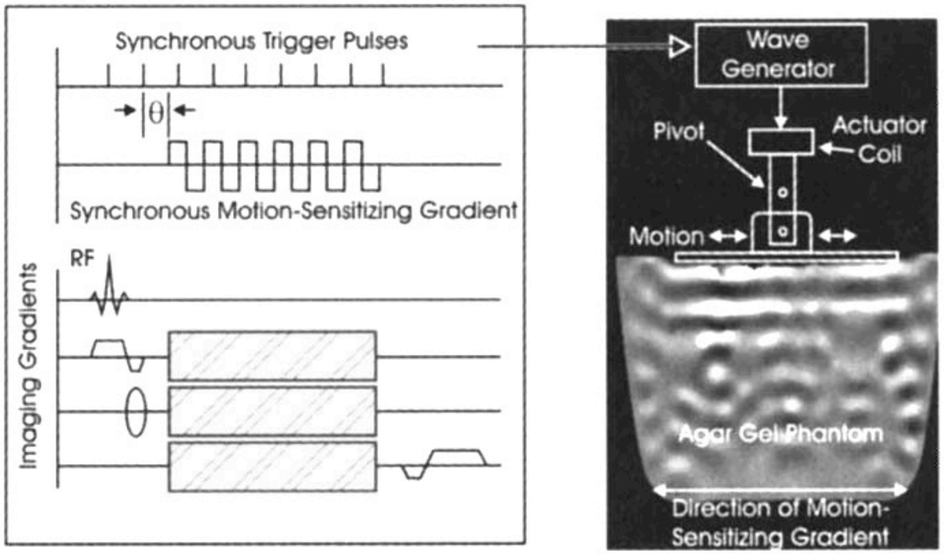




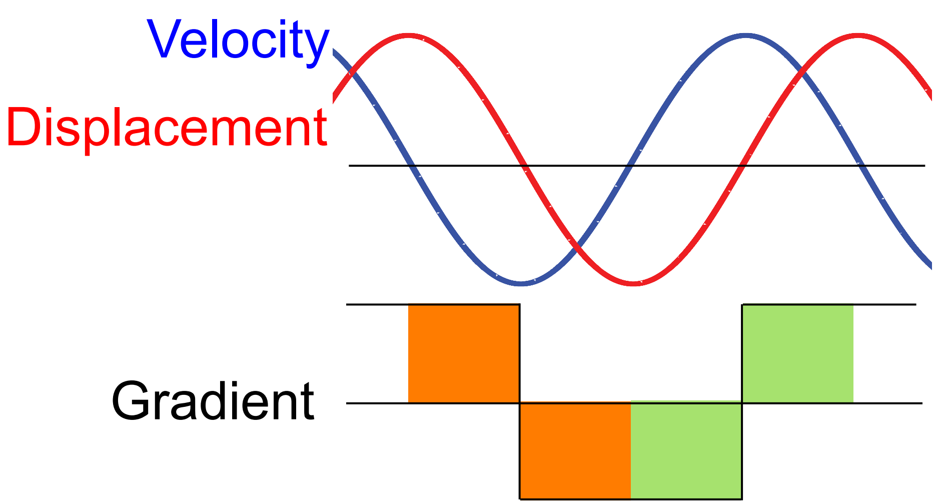
MIP: Maximum Intensity Projection

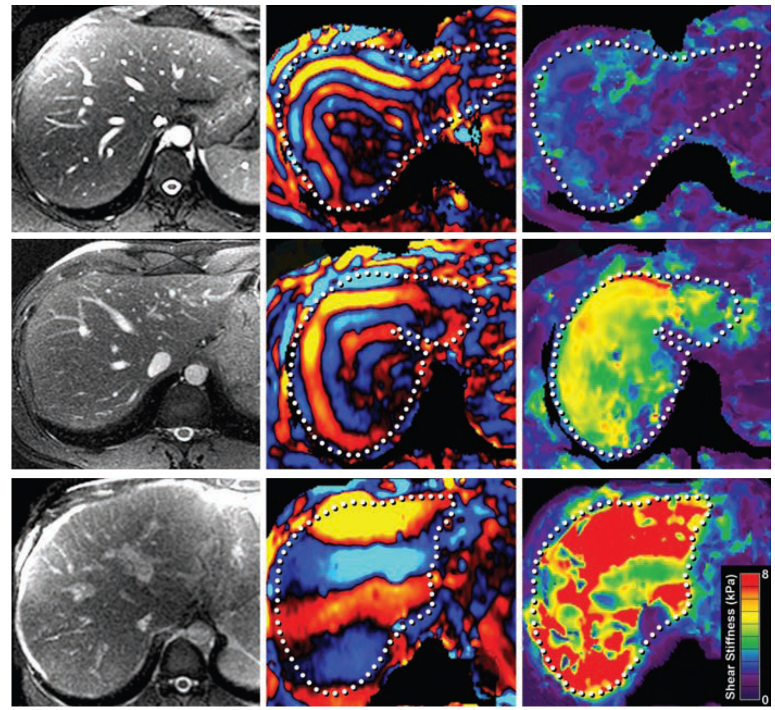
Bushberg: The Essential Physics of Medical Imaging, 2002.

MR Elastography



Muthupillai et al, Nature Medicine 2 (5) 1996





Anatomy Acoustic Waves Stiffness

Taouli et al, *AJR 2009; 193:14–27*

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Diffusion Imaging

Diffusion

- Random walk
- No net displacement -> No net phase shift
- RMS displacement in time *dt* $\propto \sqrt{Ddt}$
- Convolution with Gaussian in image space
- Multiplication by Gaussian in K-space

In 100ms:

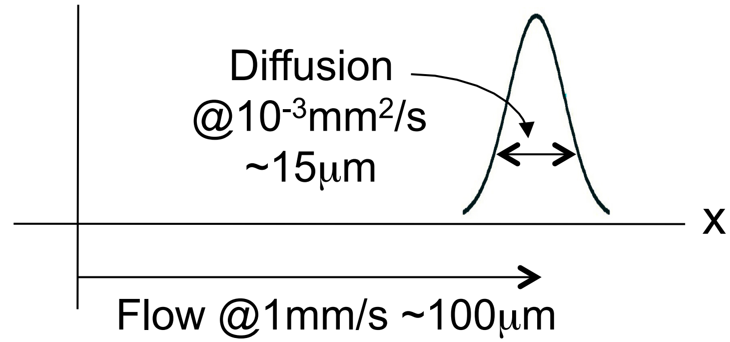
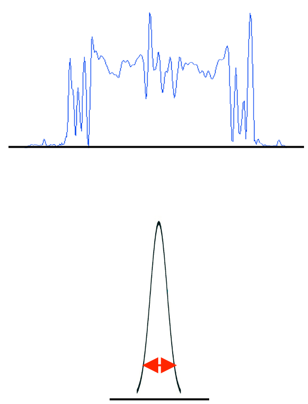
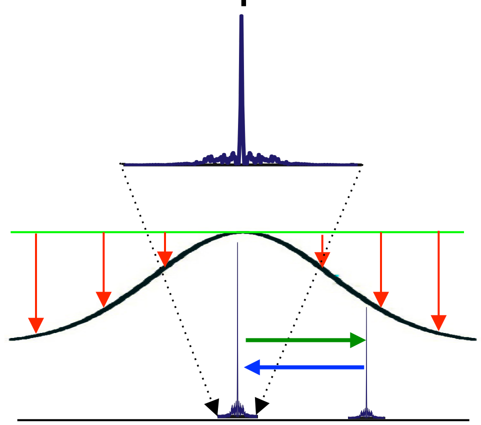


Image Space <—FT—> K-space

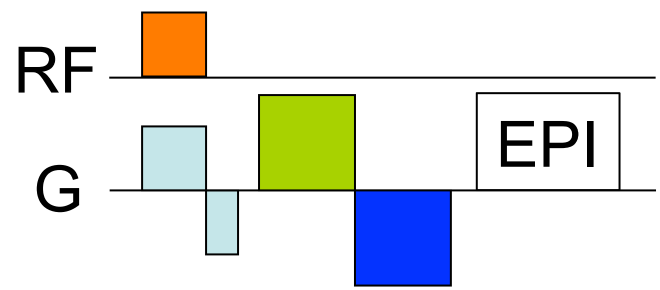


$e^{-x^2/Ddt}$



$e^{-k^2 Ddt}$

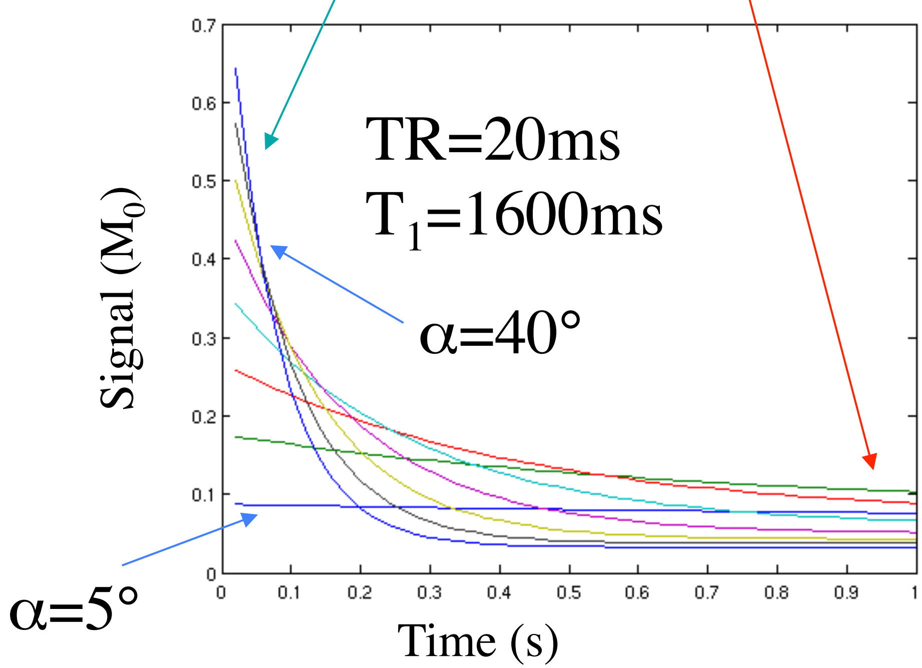
Pulse Sequence



Total Attenuation: $S/S_0 = e^{-D\int k^2 dt} = e^{-bD}$ where: $b \equiv \int k^2 dt$

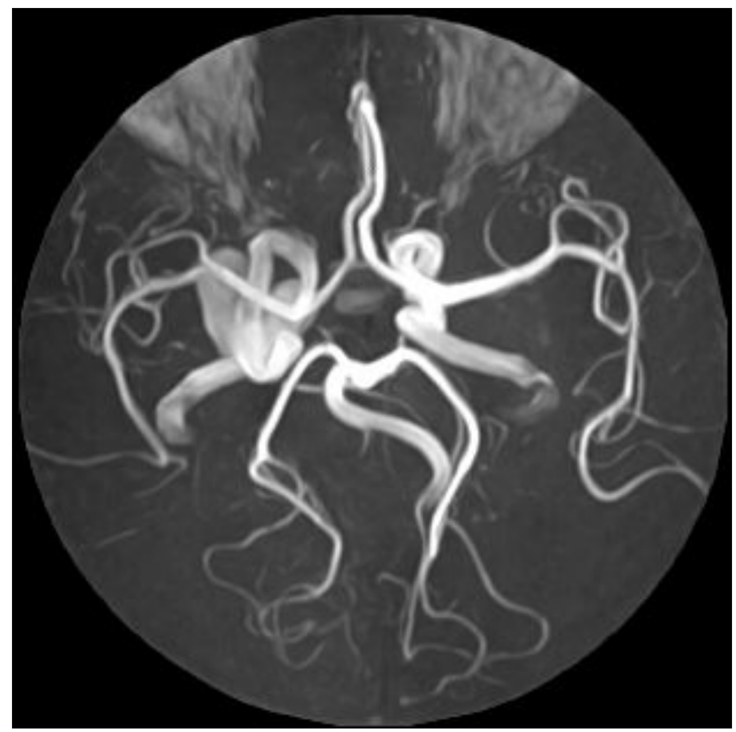
Time of Flight MRA

- Spoiled gradient echo with high flip angle and short TR
- Static magnetization becomes highly saturated
- Relaxed inflowing blood has much higher signal

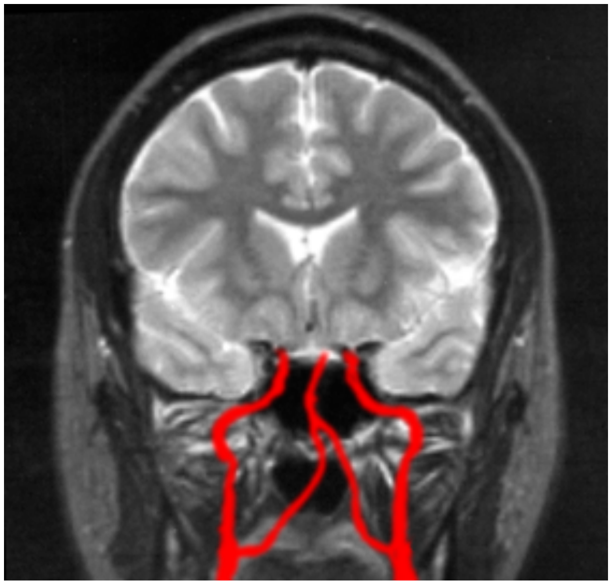


$$M_z(tr) = M_0(1-((1-M_z(tr-1)\cos(\alpha))e^{-TR/T_1}))$$

$$Signal(tr) = M_z(tr)\sin(\alpha)$$

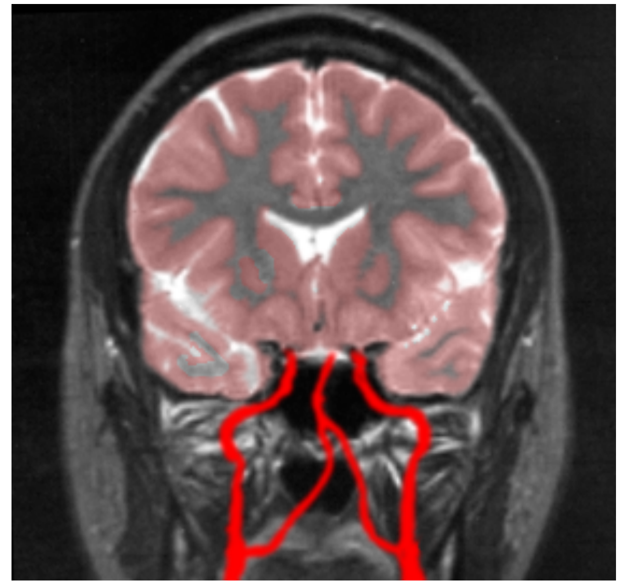


Arterial Spin Labeling



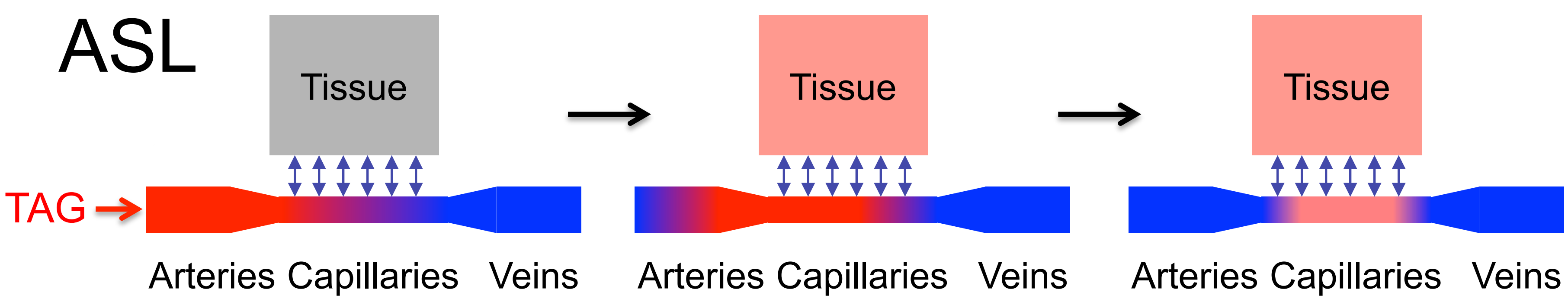
RF

- Using RF pulses, modify (label) the longitudinal magnetization of arterial blood water, typically by inversion.
- Decay constant is T_1 (~1.5s)



- Wait for labeled blood to flow to target tissue
- Measure labeled magnetization in target tissue
- Delivery time is ~1s

Properties of ASL



Advantages:

- Short lived H_2O tracer
  - Fast exchange into tissues
  - Kinetics related only to delivery – No outflow
  - Inherently proportional to perfusion
- Non-Invasive
  - Repeatable indefinitely

Disadvantages:

- Short lived H_2O tracer
  - Strong tradeoff between delivery and T_1 decay
- Low SNR
  - Perfusion is ~$0.01 s^{-1}$

The ASL Measurement

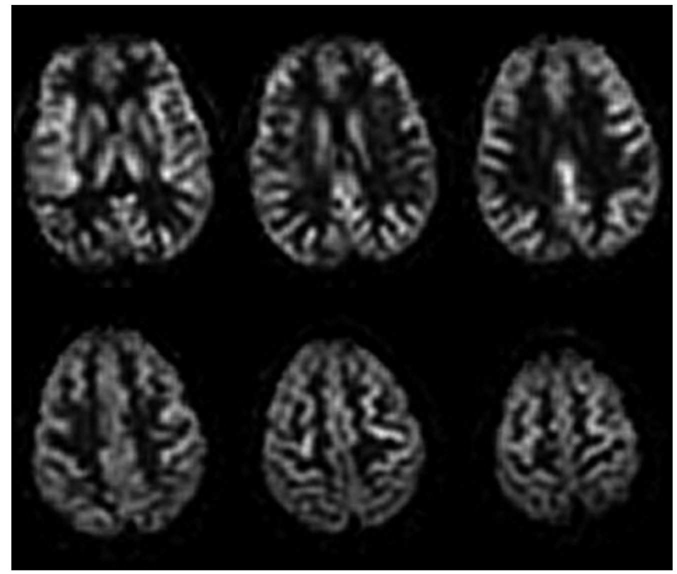
Tag by Magnetic Inversion

delay →

Acquire image of
tissue + tagged blood

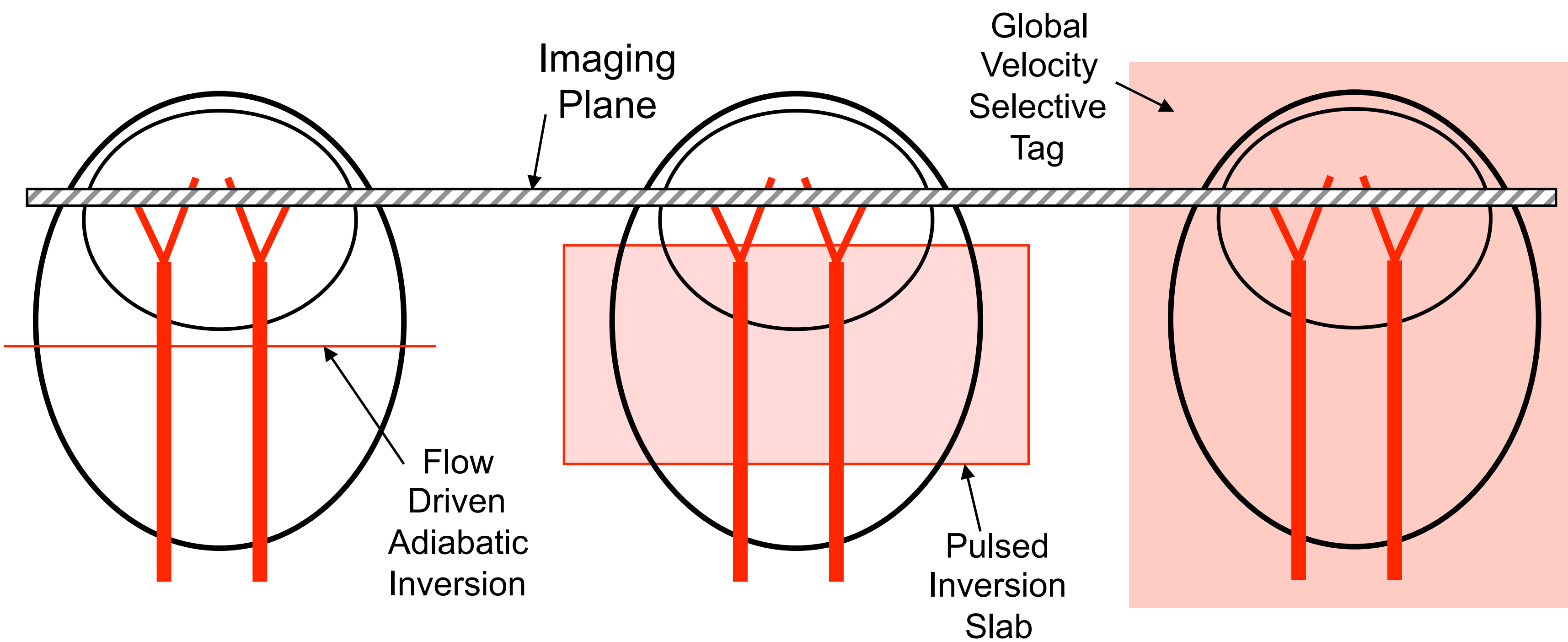
Control

Acquire image of
tissue + relaxed blood

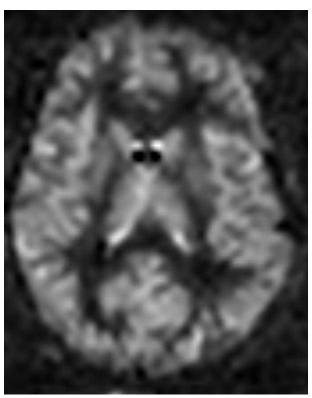


ASL Signal = Control - Tag $\propto$ Perfusion

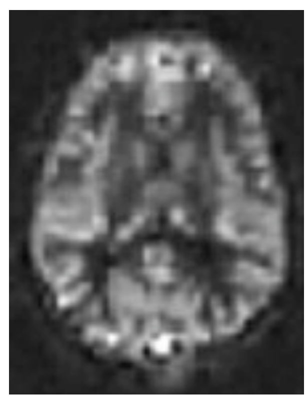
Classes of ASL Labeling Methods



Continuous ASL



Pulsed ASL

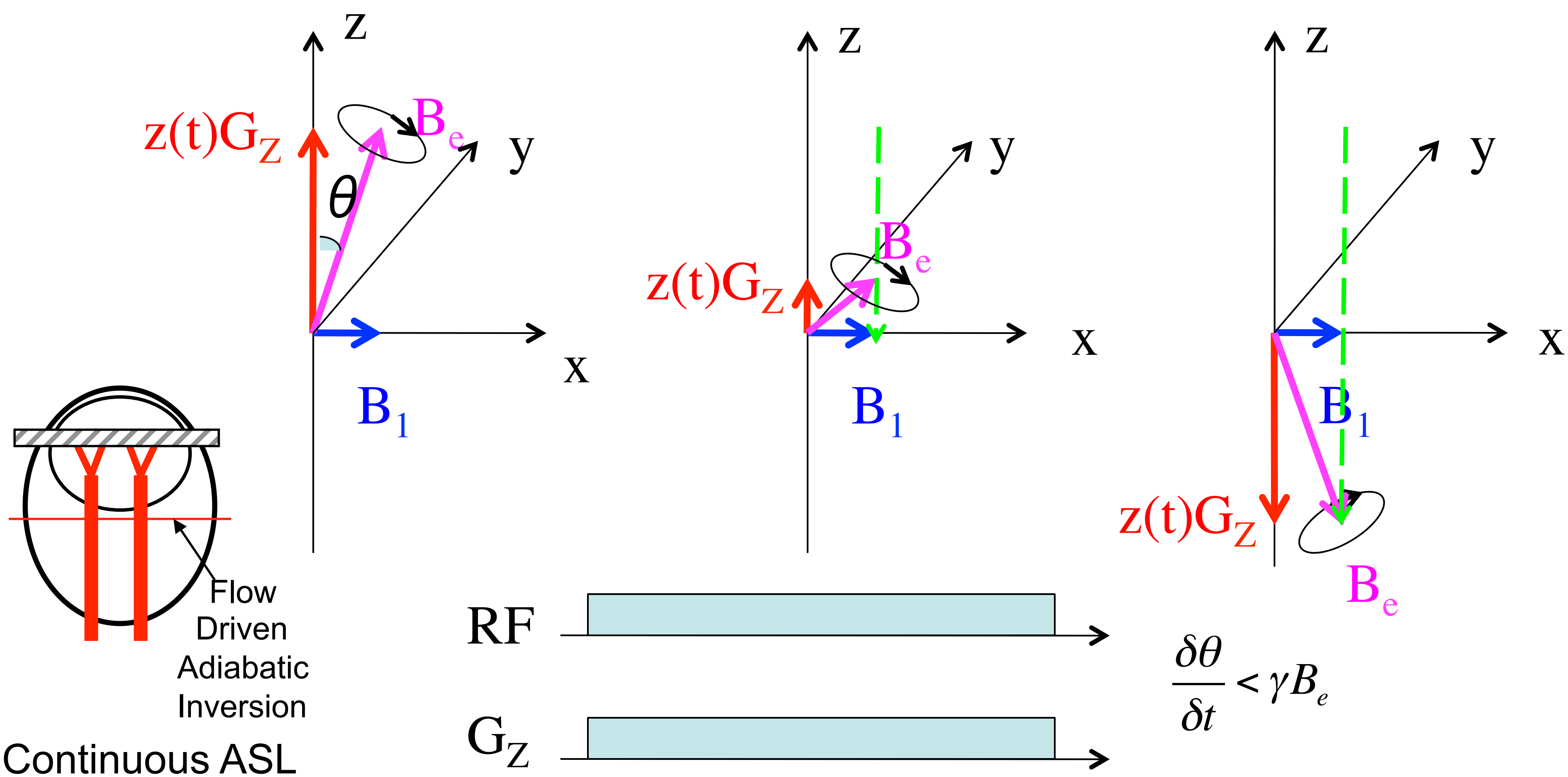


Velocity Selective ASL

CASL: Flow Driven Adiabatic Inversion

Effective field in frame that rotates at ω_L:

$$\vec{B}_e = B_1\hat{i} + z(t)G_Z\hat{k}$$

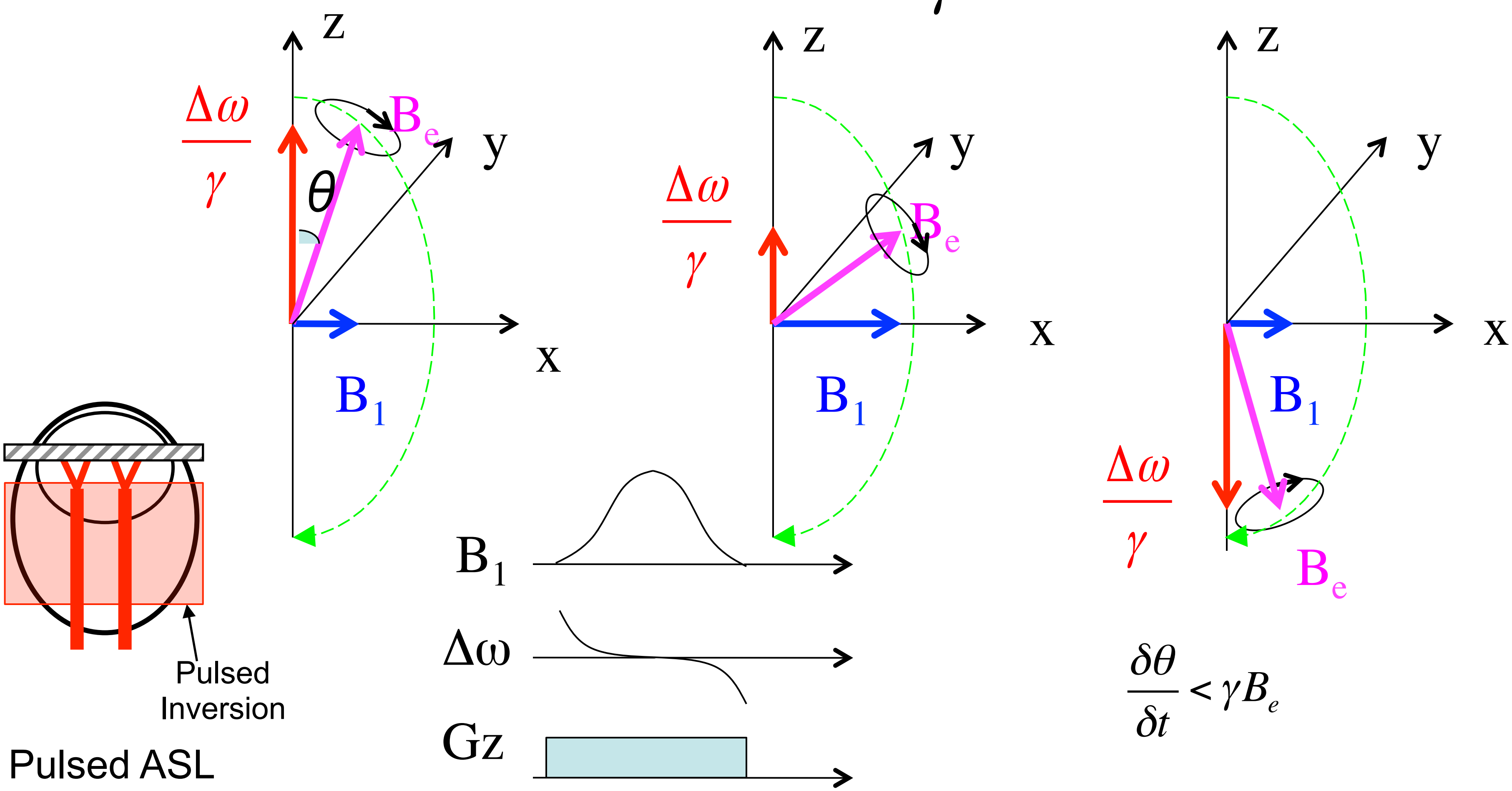


$$\frac{\delta\theta}{\delta t} < \gamma B_e$$

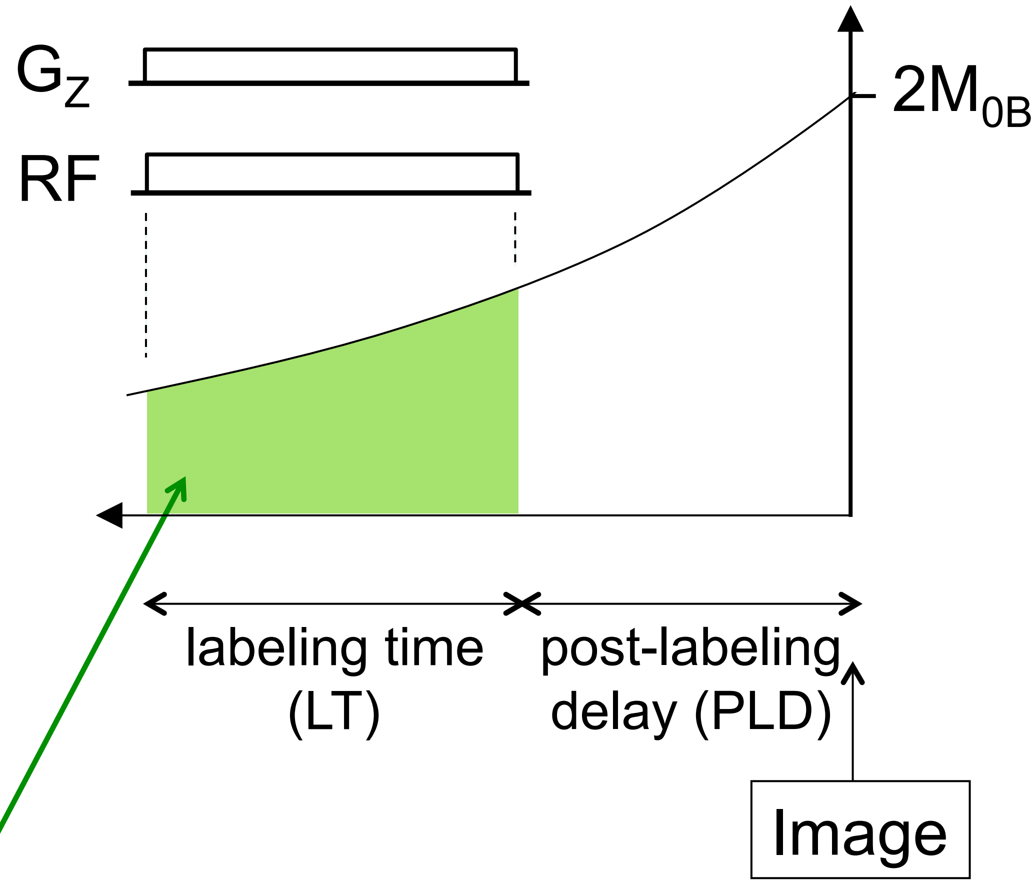
PASL: Pulsed Adiabatic Inversion

Effective field in frame that rotates with pulse:

$$\vec{B}_e = B_1\hat{i} + \frac{\Delta\omega}{\gamma}\hat{k}$$

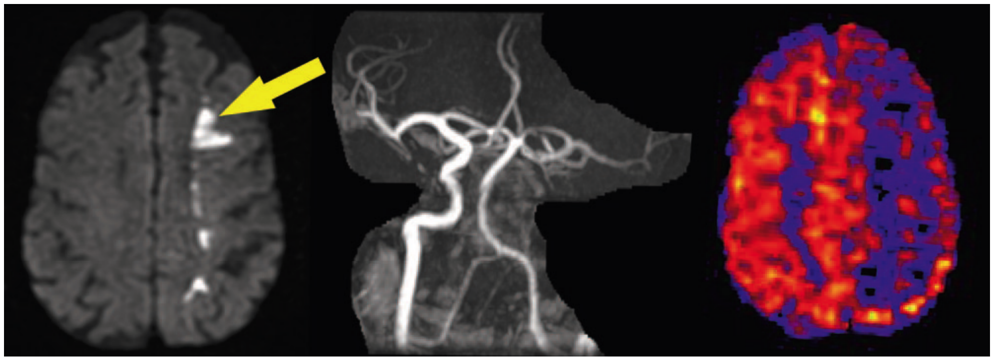


Calculation of CBF

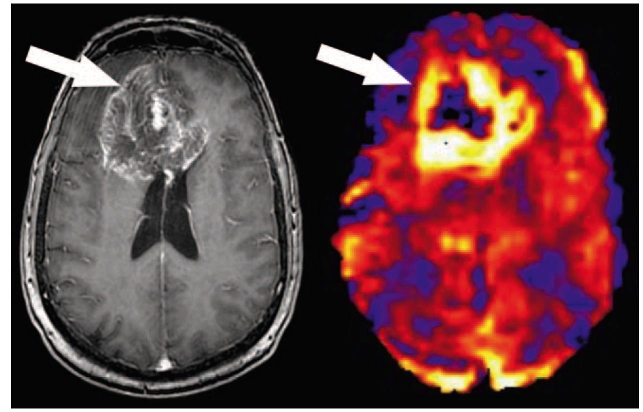


$$\Delta M_Z = (CBF)\,2M_{0B}\int_{PLD}^{PLD+LT} e^{-t/T_1}\,dt$$

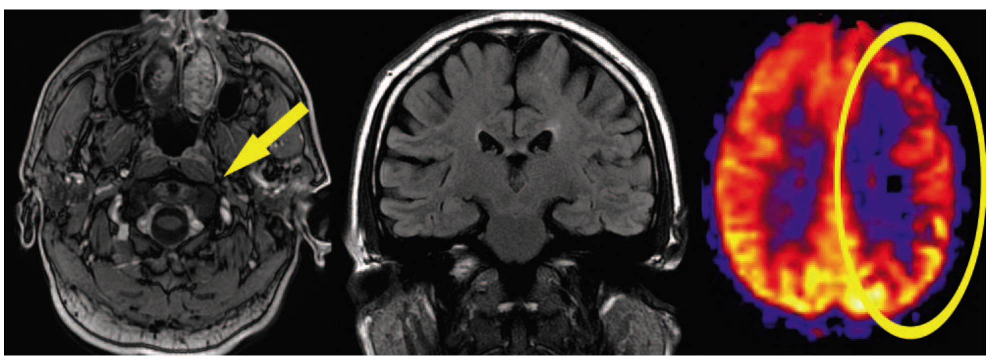
Clinical ASL



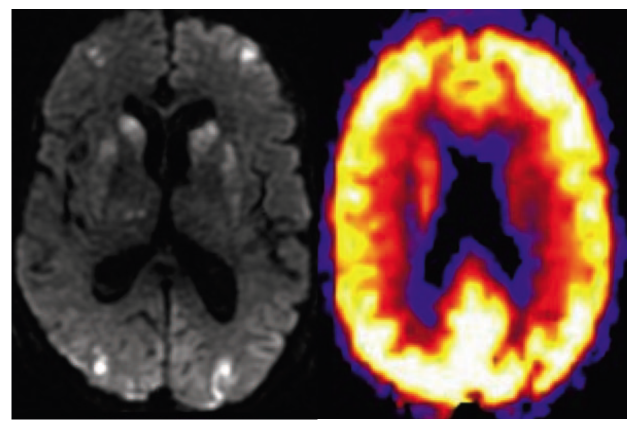
Ischemic Penumbra: Perfusion > Diffusion Mismatch



Glioblastoma Multiforme



LICA Occlusion: Tissue at Risk



Hyperperfusion post anoxia

Wake Forest: Deibler et al, AJNR August 2008

Cardiac MRI - Goals

Metric	**MRI**	**Competing**
Function - Ejection Fraction	Cine	Echocardiography
Function – Contractility	Myocardial Tagging	
Function - Valves	Cine	Echocardiography
Coronary Arteries	Gated TOF	Cardiac Catheterization
Perfusion	Gd Bolus, ASL	SPECT, PET, CT

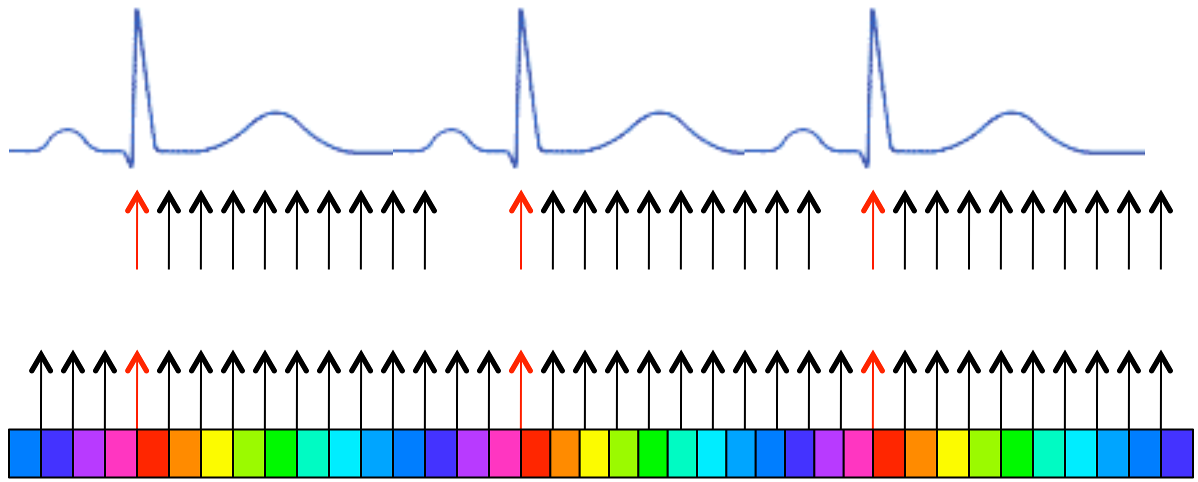
Main Challenge: MOTION

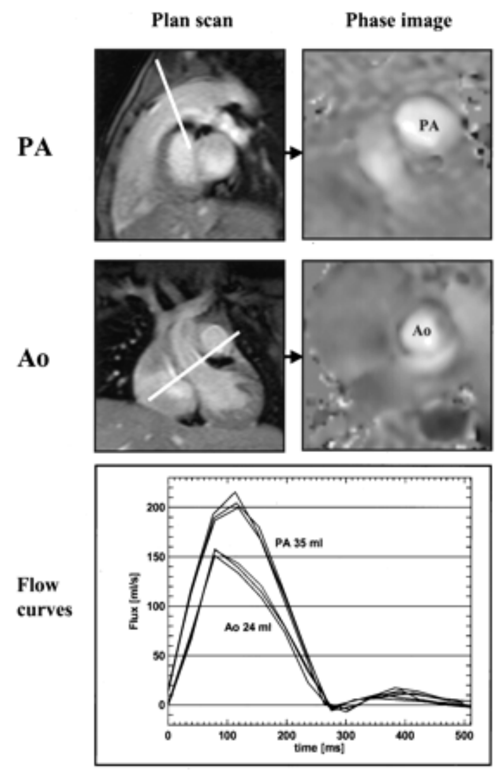
- Beating
- Respiration
- Patient

Gating

Prospective

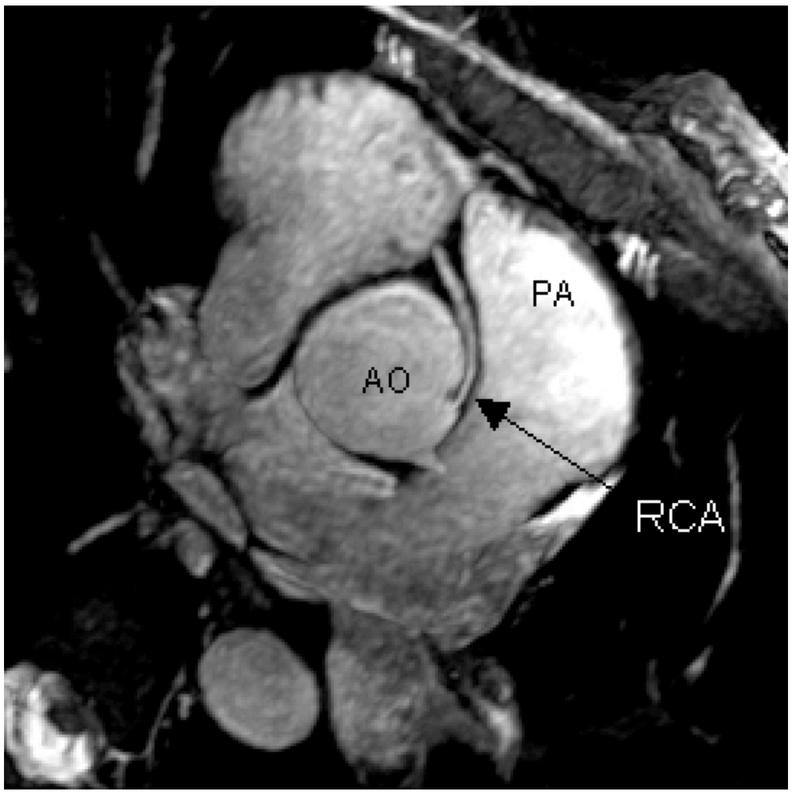
Retrospective

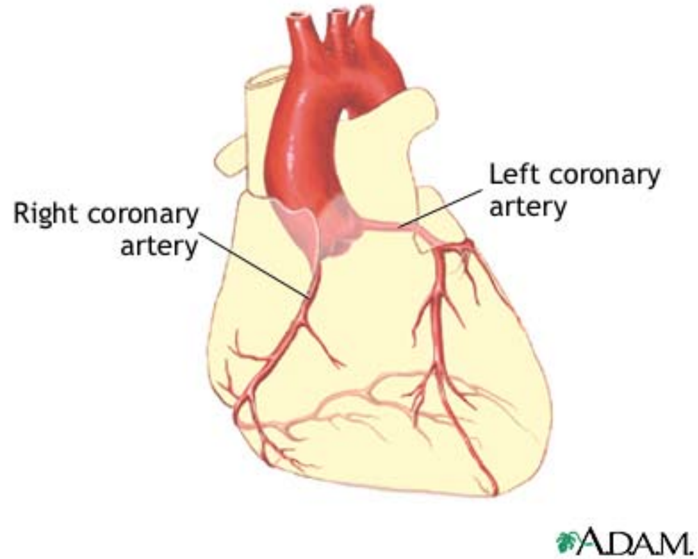


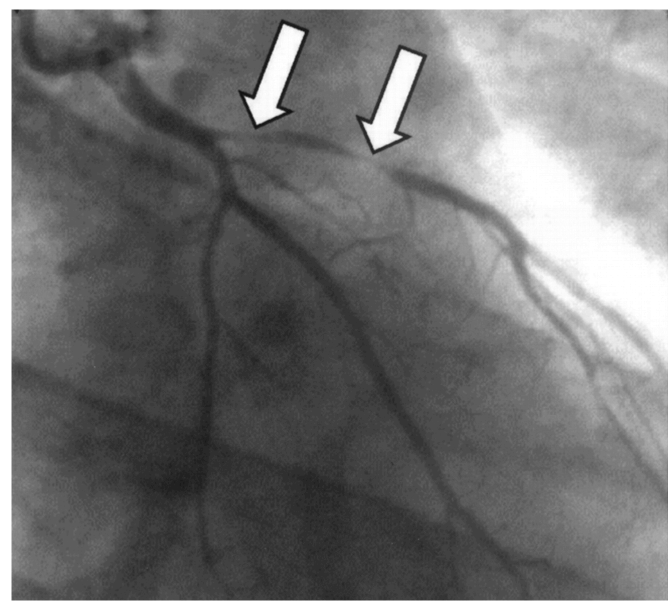


http://youtu.be/BhMFhbcp2Jg

Coronary Arteries

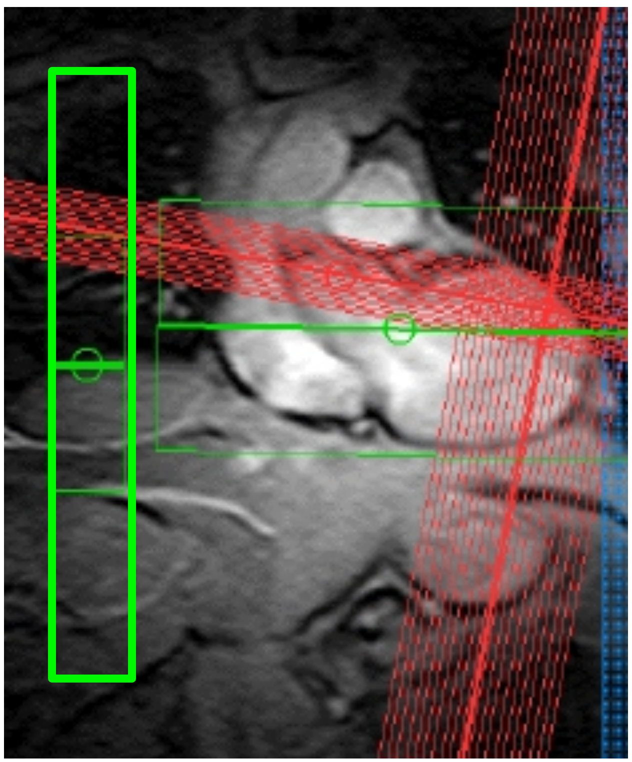


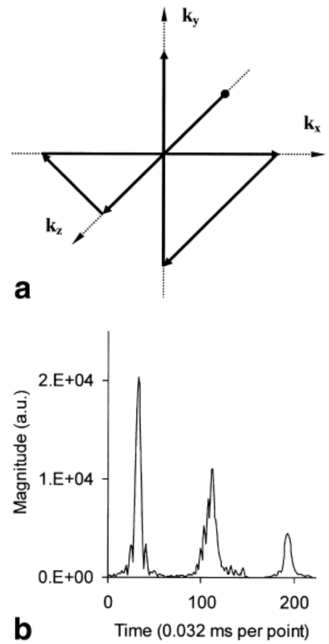


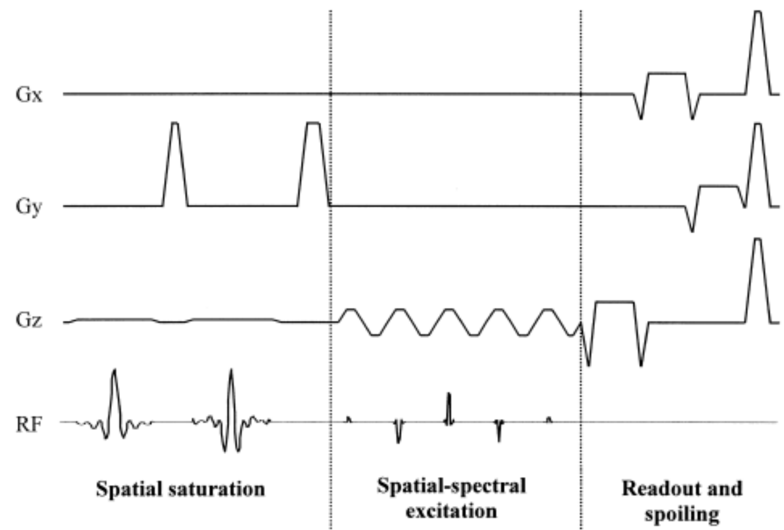


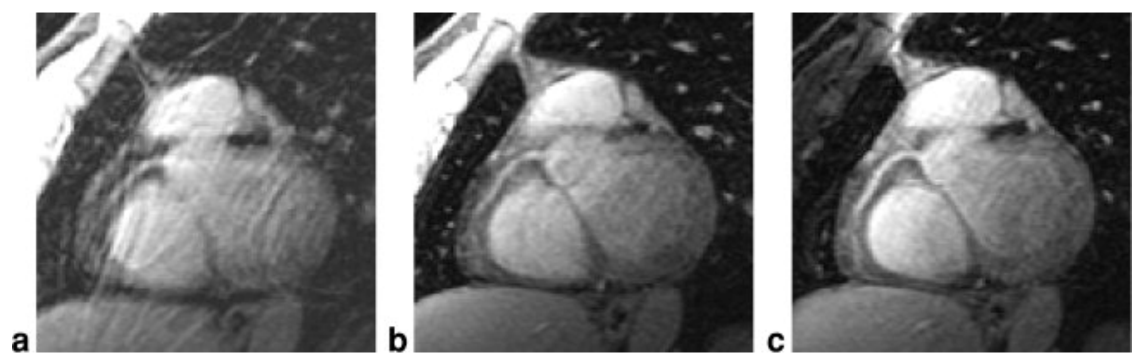
Gating/Navigation

- •Cardiac Gating
- •Respiratory Gating
- •Breath hold
- •Navigation
- •Data filtering









Gated, no nav +diaphragm nav +fat nav

Myocardial Tagging

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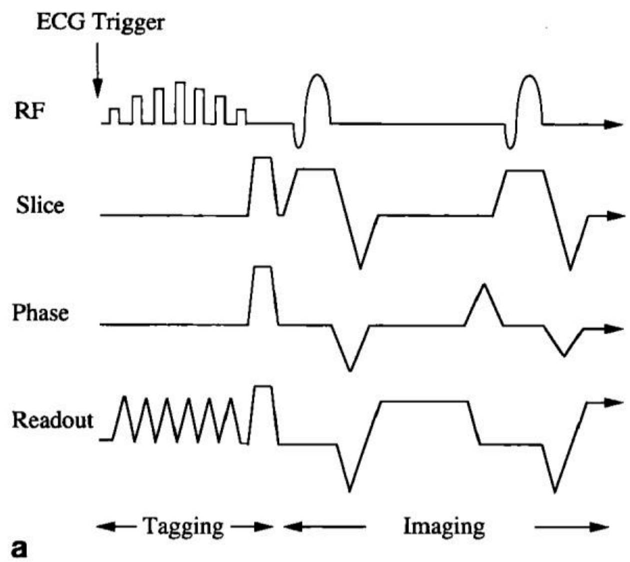
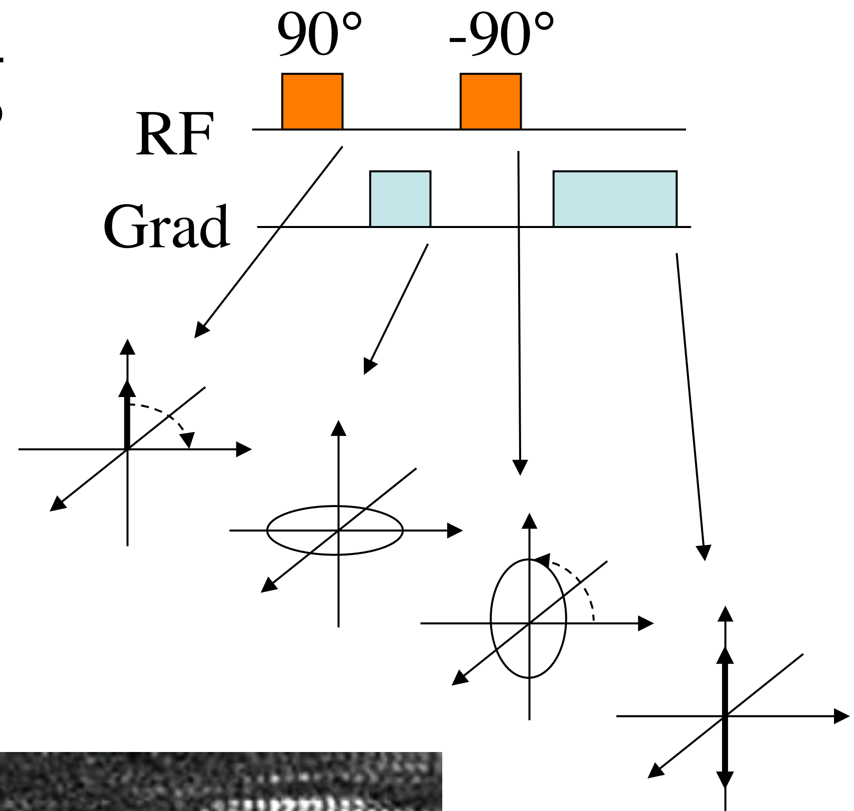
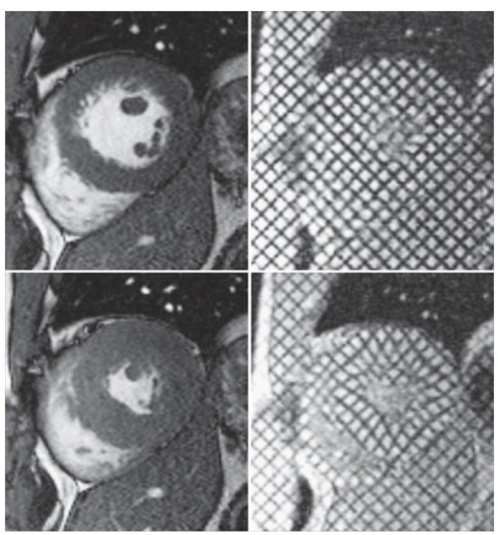
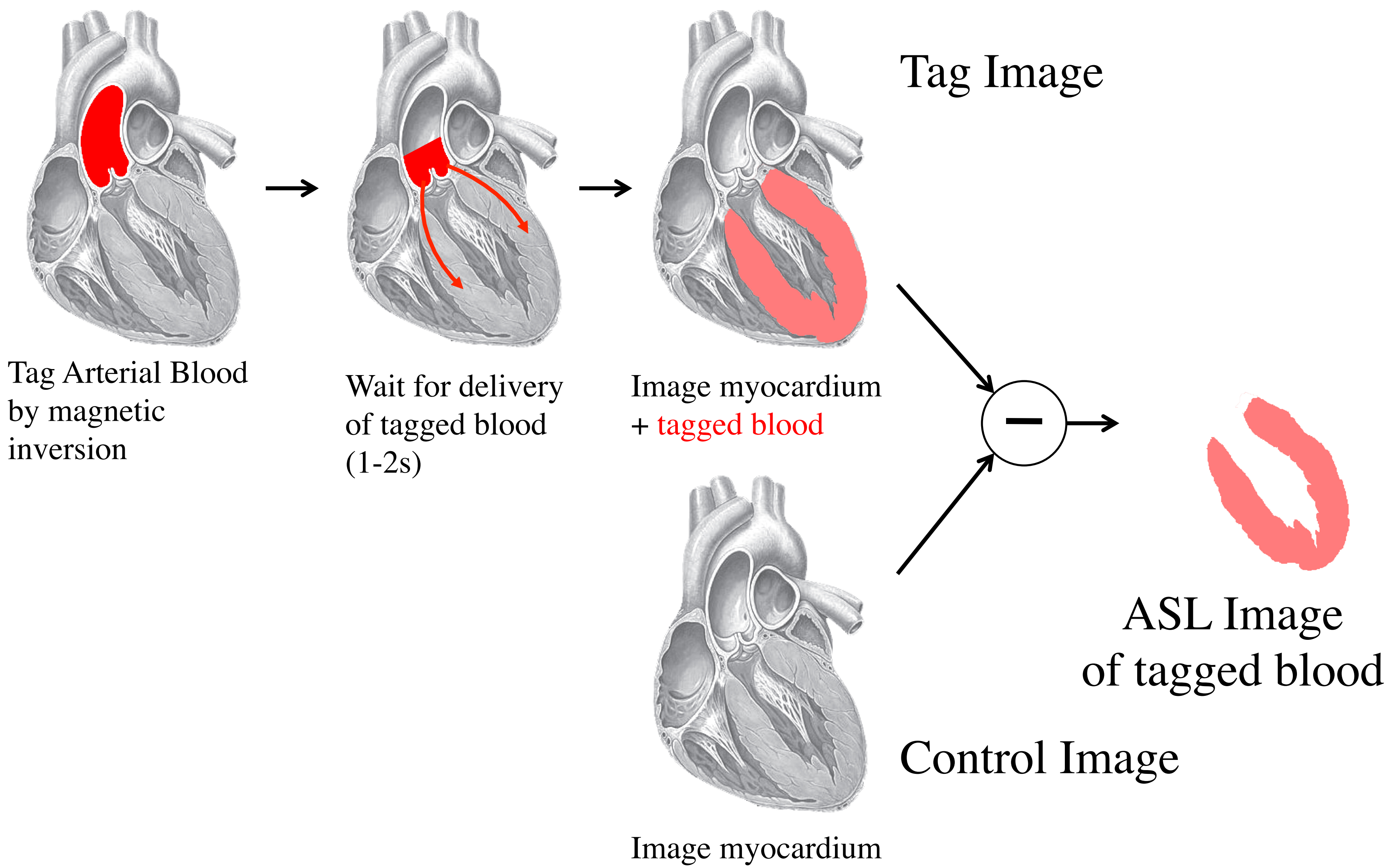




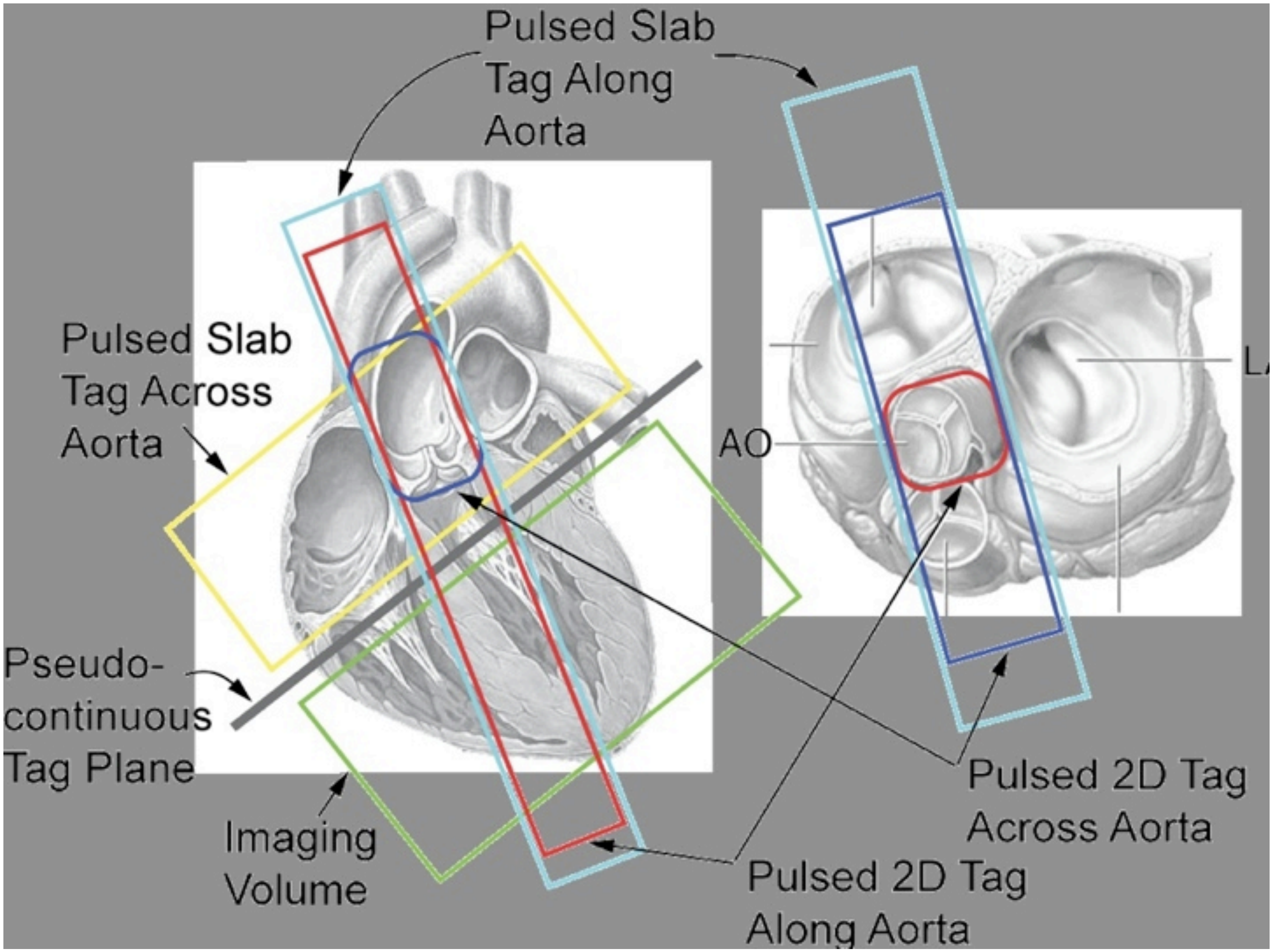


http://www.med-ed.virginia.edu/courses/rad/cardiacmr/Techniques/Tagging.html

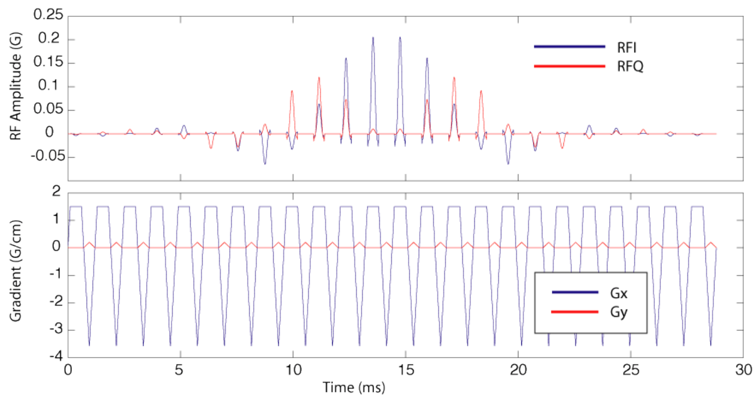
Arterial Spin Labeling

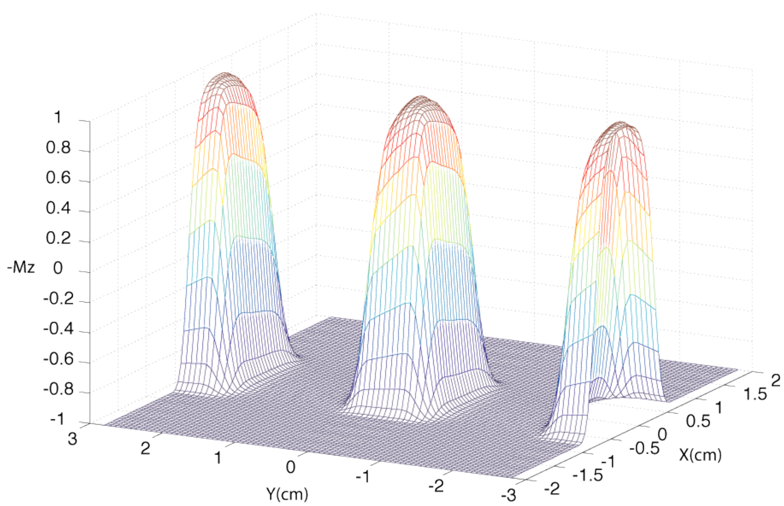


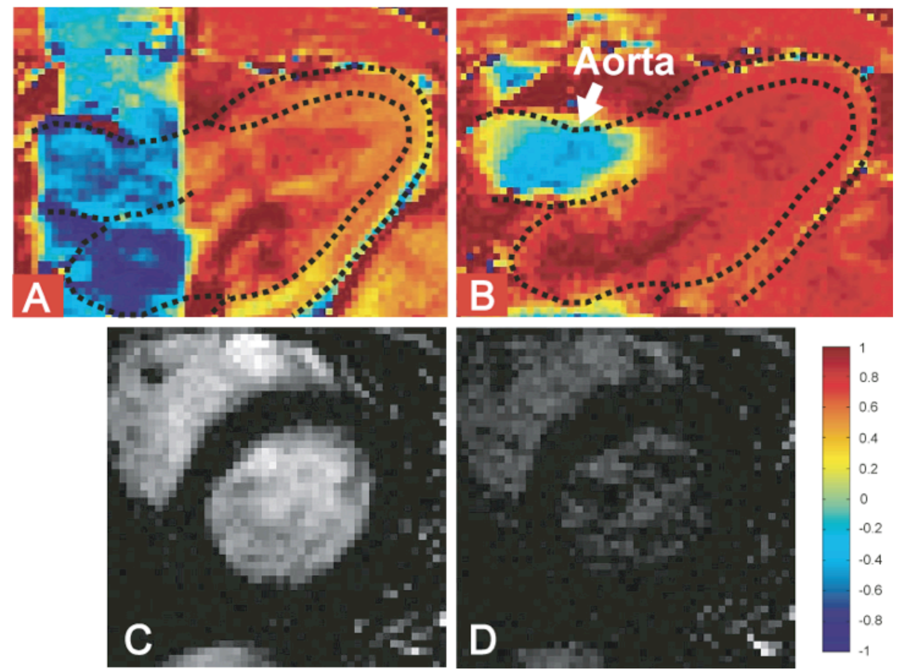
ASL Tagging Schemes

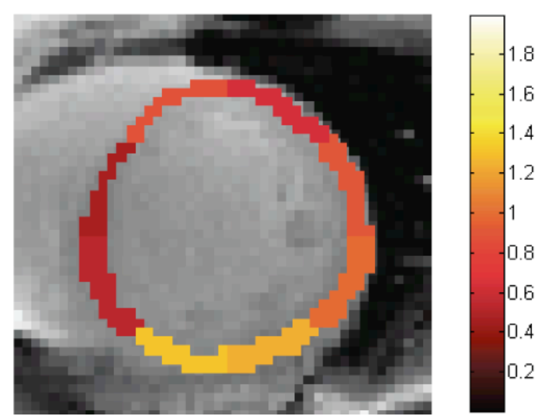


2D Pulsed Tagging

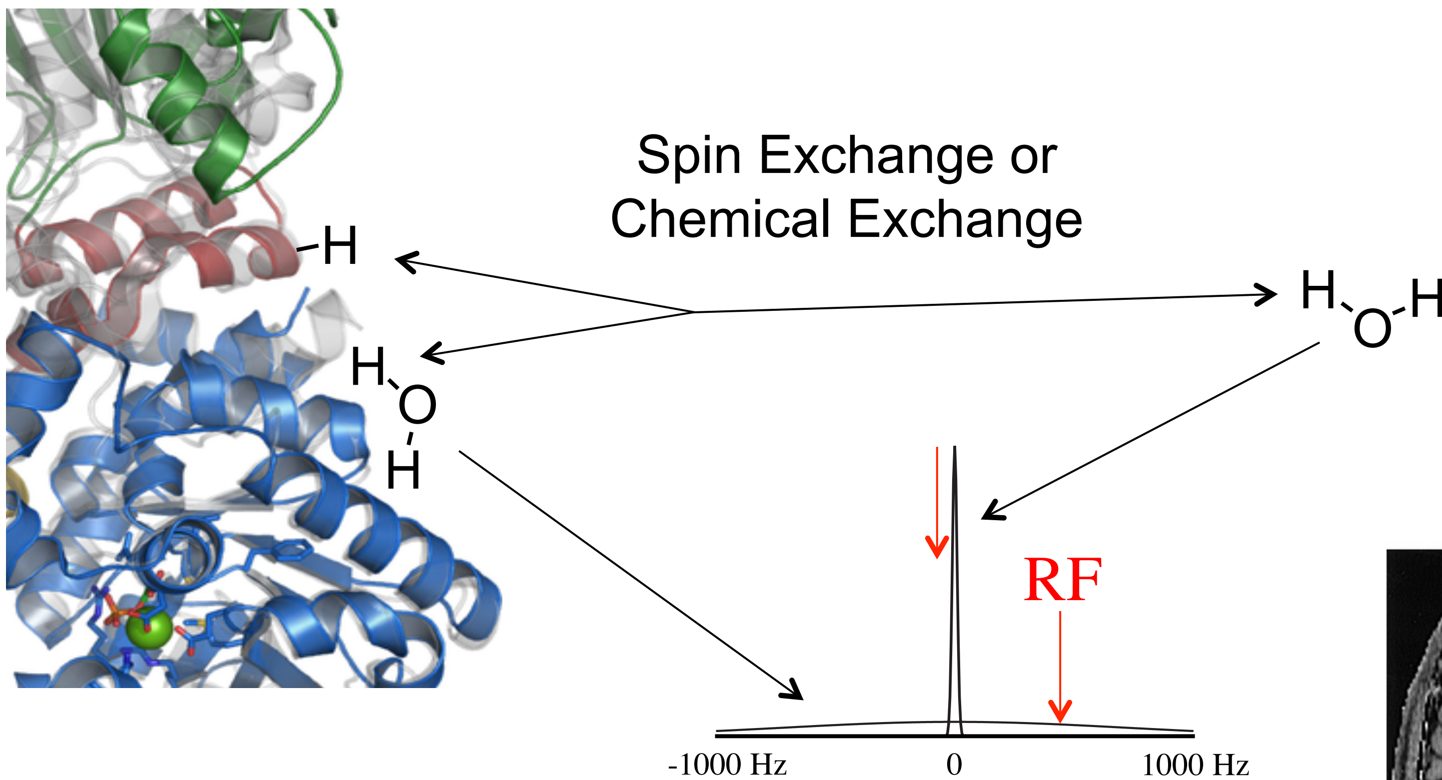








Magnetization Transfer



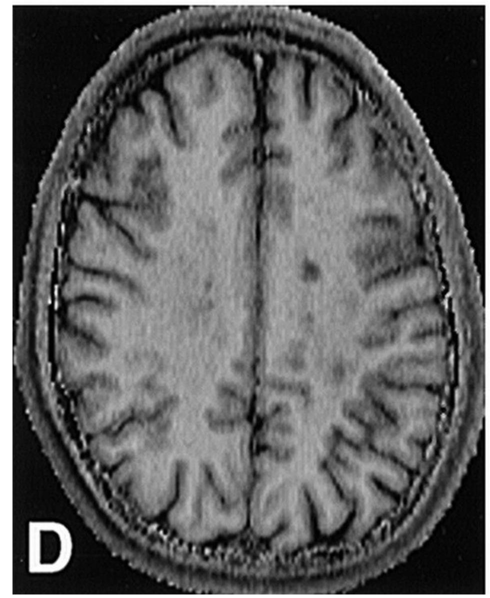
MT Ratio

Image Credit: http://commons.wikimedia.org/wiki/File:Conformational_states_of_PPDK.png

Magnetization Transfer: Applications

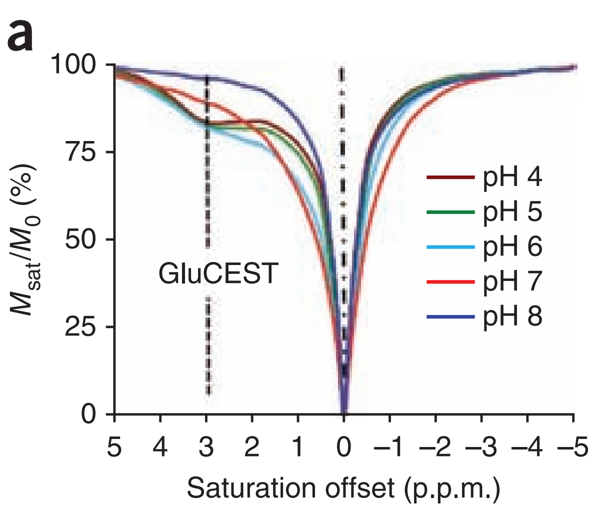
Static tissue suppression for MRA

Henkelman et al, *NMR Biomed*. 2001;14:57–64



Lesion detection in MS

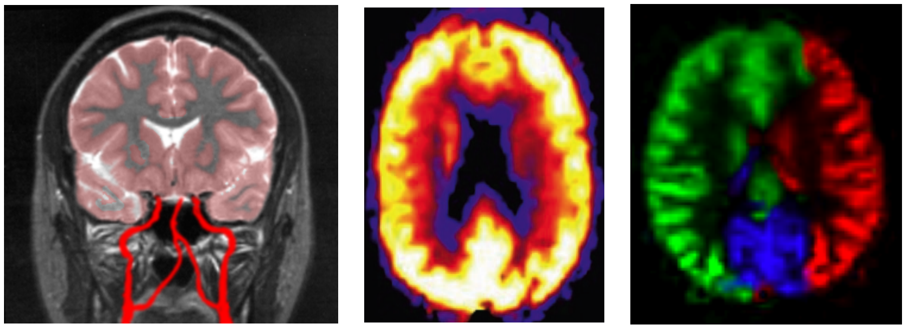
Pike G B et al. Radiology 2000;215:824-830



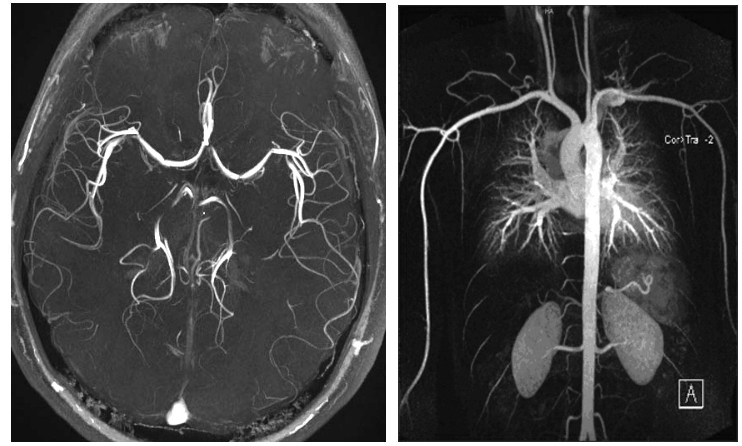
CEST:
Chemical Exchange
Saturation Transfer

Cai et al. Nature Medicine **18**, 302–306 (2012)
doi:10.1038/nm.2615

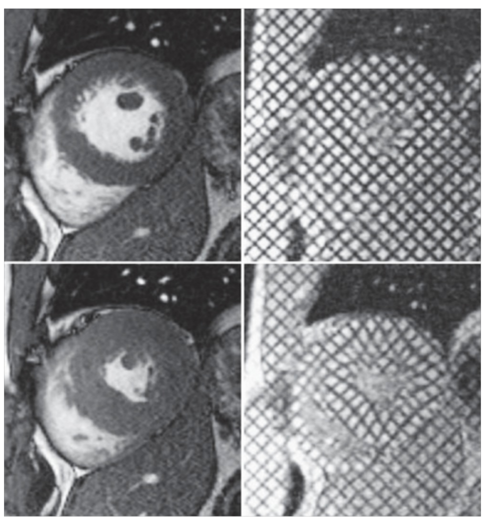
Summary



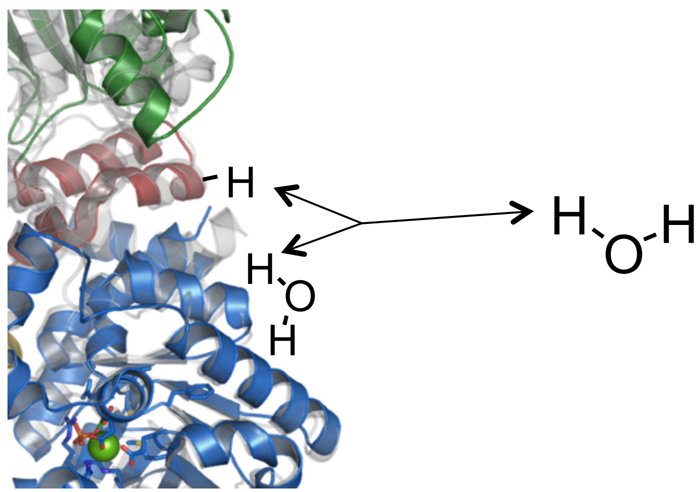
ASL: 10cm, T_1



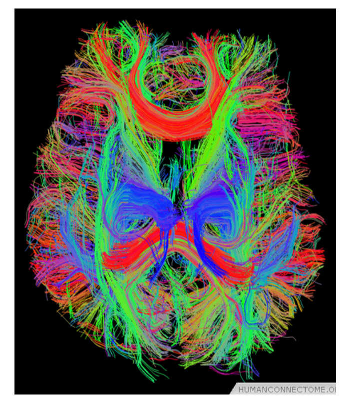
MRA: TOF 1cm, T_1; PC 1mm, T_2



Tagging: 1cm, T_1



MT: 1ηm, T_1



Diffusion: 10μm, T_2