

Clinical Aspects of Brain Imaging

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המרכז לחקר המוח תל אביב
Tel Aviv Center for Brain Functions



Human Brain Project

Sagol School of
NEURO-SCIENCE
Tel Aviv University

TEL AVIV
UNIVERSITY

The role of brain imaging methods in the clinical practice

Clinical objectives:

Diagnosis and prognosis

Personalized Medicine- treatment decisions

Therapy response assessment

The role of brain imaging methods in the clinical practice

Clinical needs:

Structural information

Functional information

Metabolic information

Tissue characterization

Monitoring plasticity

Neuro-feedback

Guided biopsy



המרכז הרפואי המוח תל אביב
Tel Aviv Center for Brain Functions



1.5T clinical system – Aera



1.5T clinical system – Avanto fit



3T clinical system - Skyra



3T Research system - Prisma

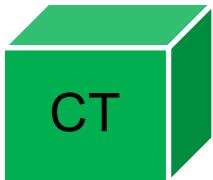


Brain Imaging Methods



X-Ray

Uses computer-processed **x-rays**



Computed Tomography

Uses computer-processed **x-rays**



Magnetic Resonance Imaging

Uses strong **magnetic fields and radiowaves**



Positron Emission Tomography

Detects **gamma rays** emitted indirectly by a tracer



Electroencephalography

Records the brain **voltage fluctuations**

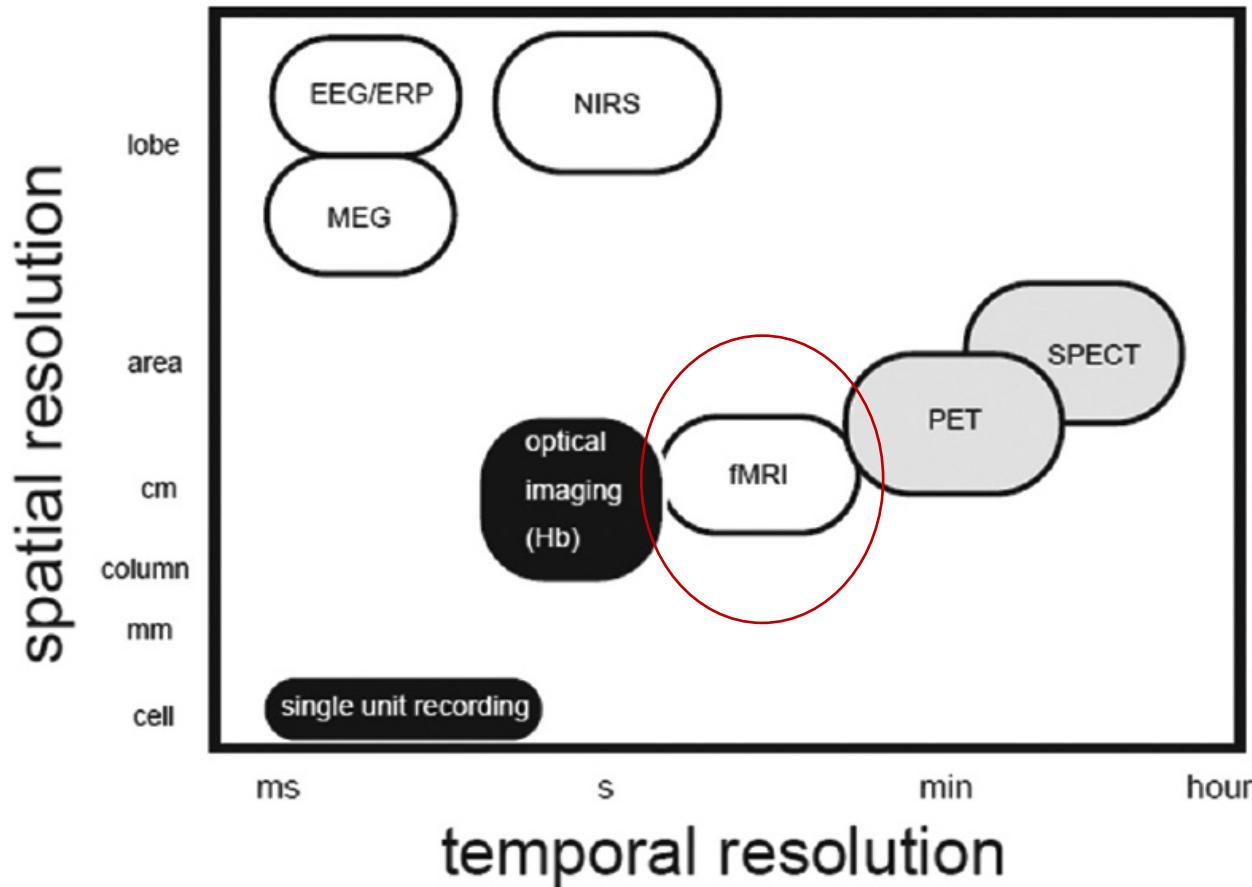


Magnetoencephalography

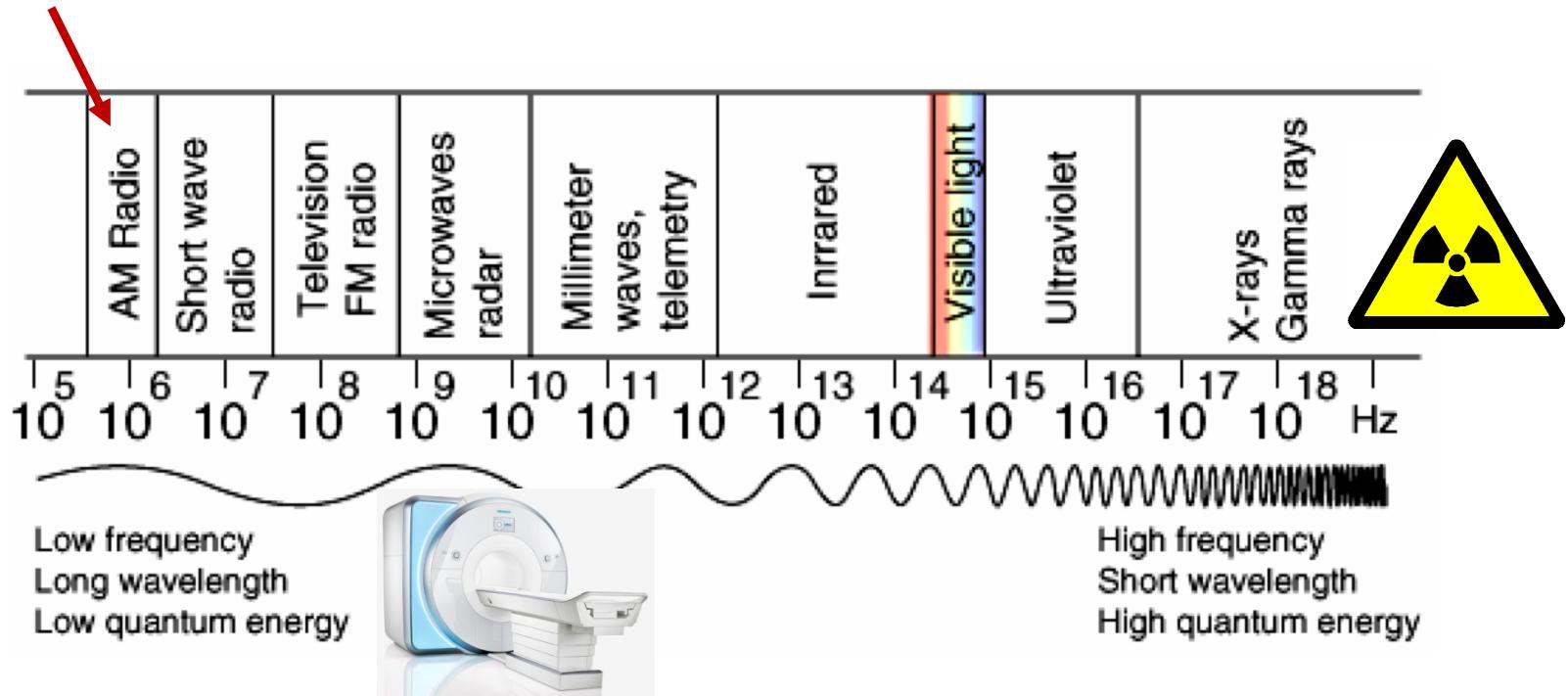
Records the brain **voltage fluctuations**

Brain Imaging Methods

Spatial and temporal resolution



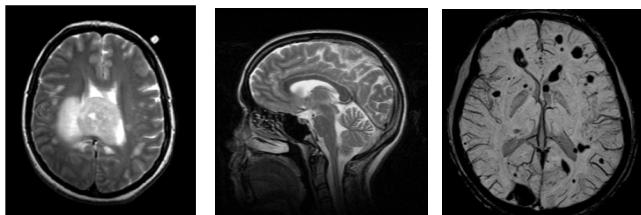
The Electromagnetic Spectrum



Mega Hz - No ionizing radiation!

Structural information

Conventional methods

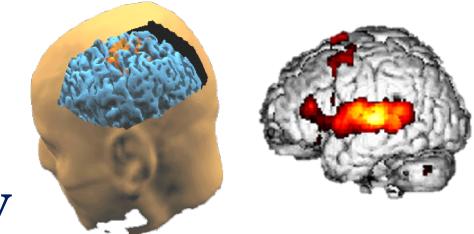


MRI

Functional MRI

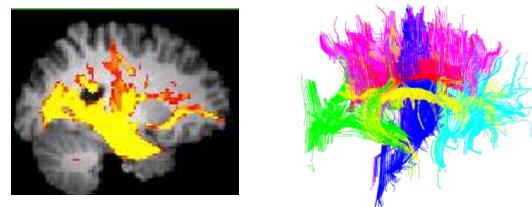
1990 – BOLD

Functional
Imaging (fMRI)



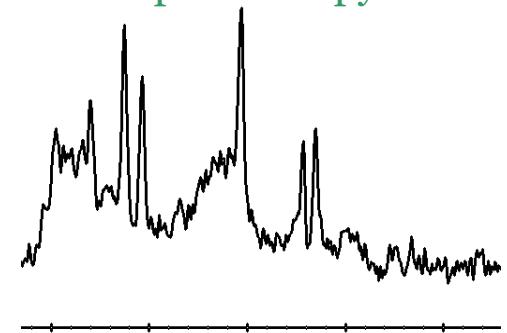
Structural and connectivity information

1994- Diffusion Tensor
Imaging (DTI)



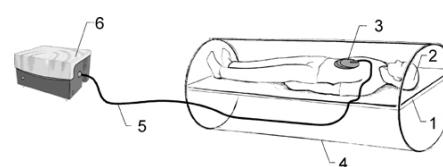
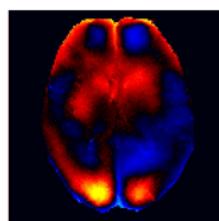
Metabolic information

Spectroscopy



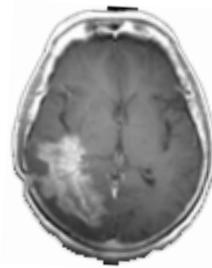
Structural information

MR Electrophraphy



MRI parameters – microstructural properties of the tissue

Post contrast
enhancement



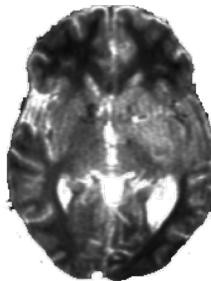
Break down of the BBB

Diffusion
MD, Da, Dr, FA



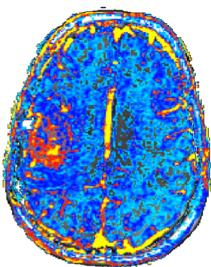
Size of the cells - tissue compartment
Cell size, Myelination, Axonal injury, Fiber organization

Relaxometry
R1, R2, R2*



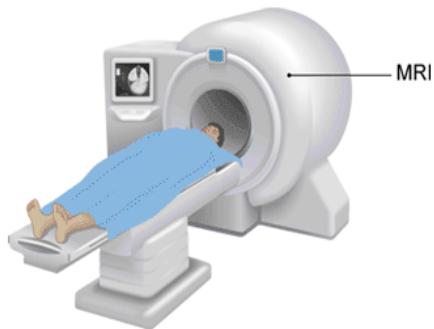
Direct physical characteristic of the tissue
Water content, maturation

Perfusion – DSC& DCE
CBV, CBF, BAT, MTT

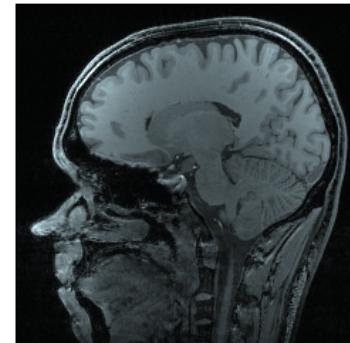
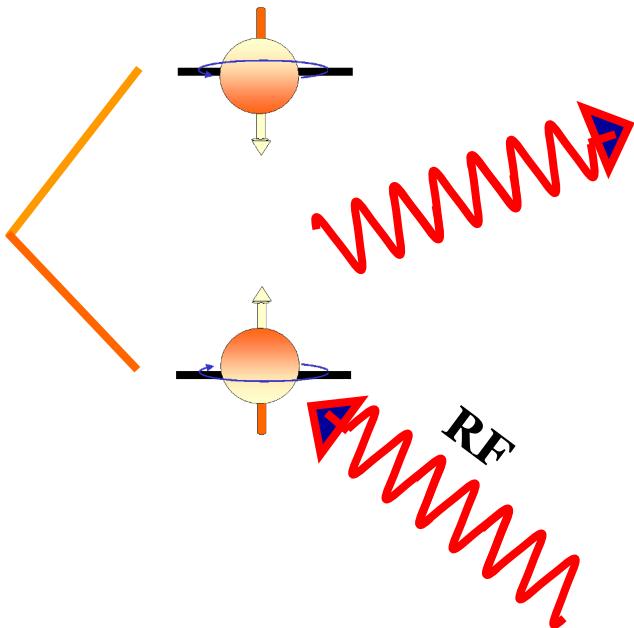
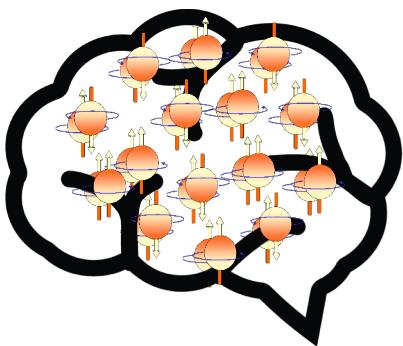


Flow, Blood/plasma volume, Permeability
Bolus arrival time, vessel maturation, VMR

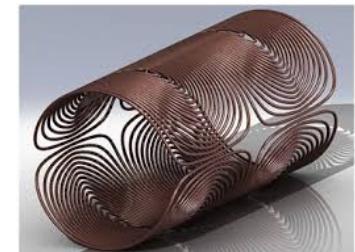
Principles of MRI



With Magnetic Field



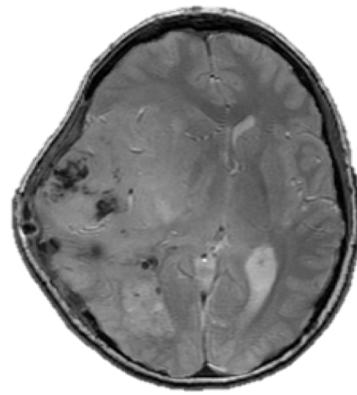
Energy – RF
Gradients are used to encode location



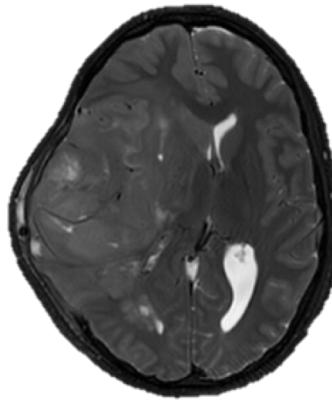
Structural information

Conventional methods

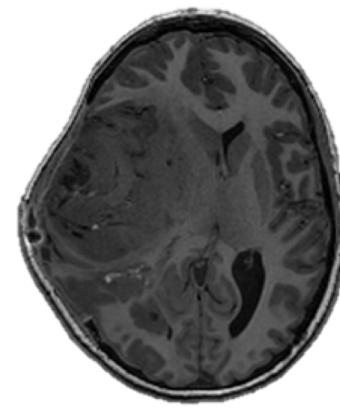
- T₁ Contrast: Short T₁- High Signal
- T₂ Contrast: Long T₂- High Signal
- Proton Density Contrast
- T₂^{*}



T₂^{*} weighted image



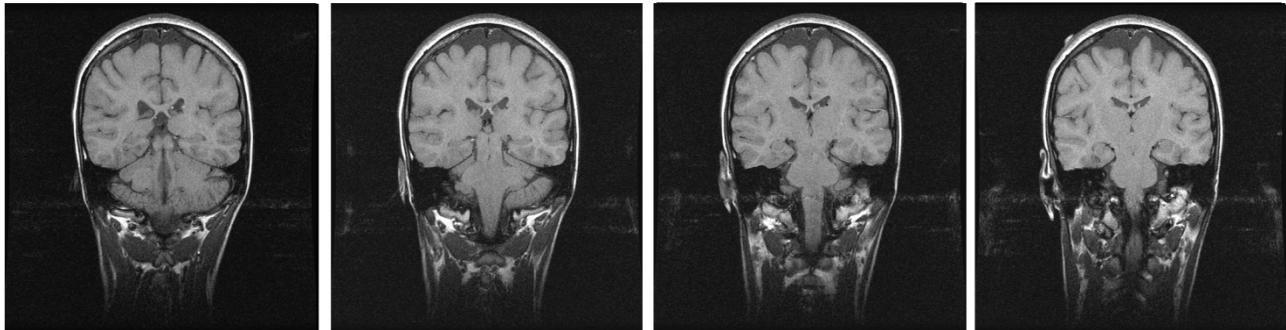
T₂ weighted image



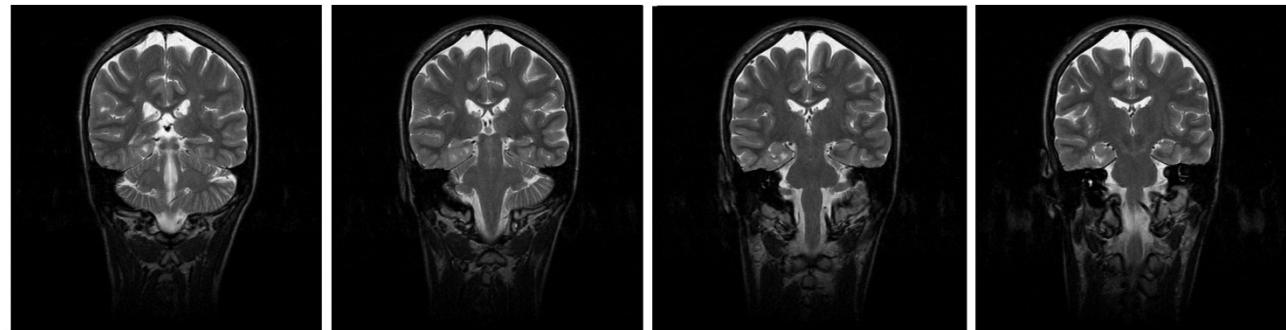
T₁ weighted image

FLAIR

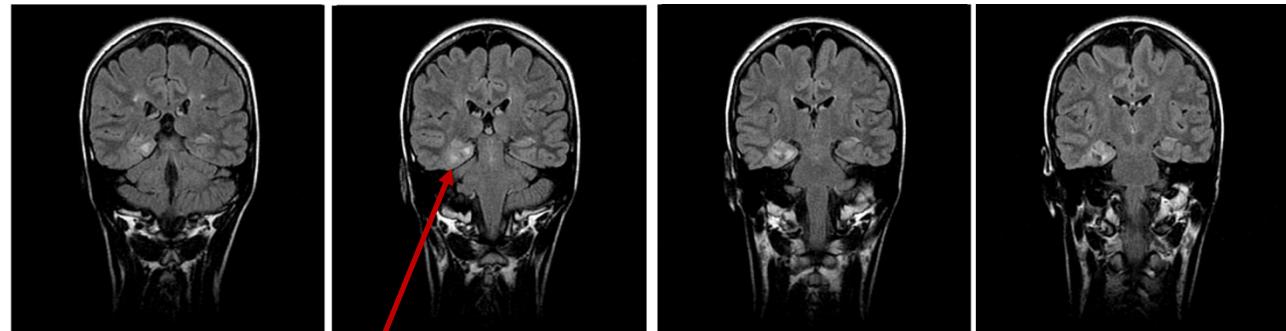
T_1
weighted image



T_2
weighted image



FLAIR



Clinical use:

Structural abnormalities

Lesions / Tumors

Diagnosis, therapy response assessment....

Brain tumors - diagnosis and grading

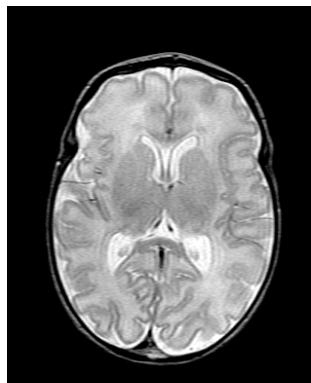
Brain lesion – diagnosis

Structural malformations

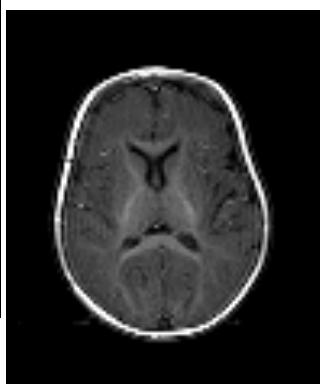
Development / aging

Brain Development

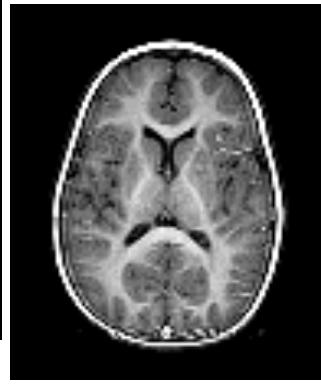
Newborn



6 months



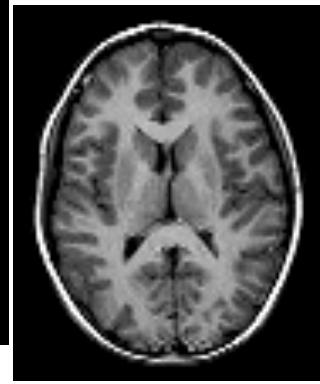
2 years



7 years



12 years



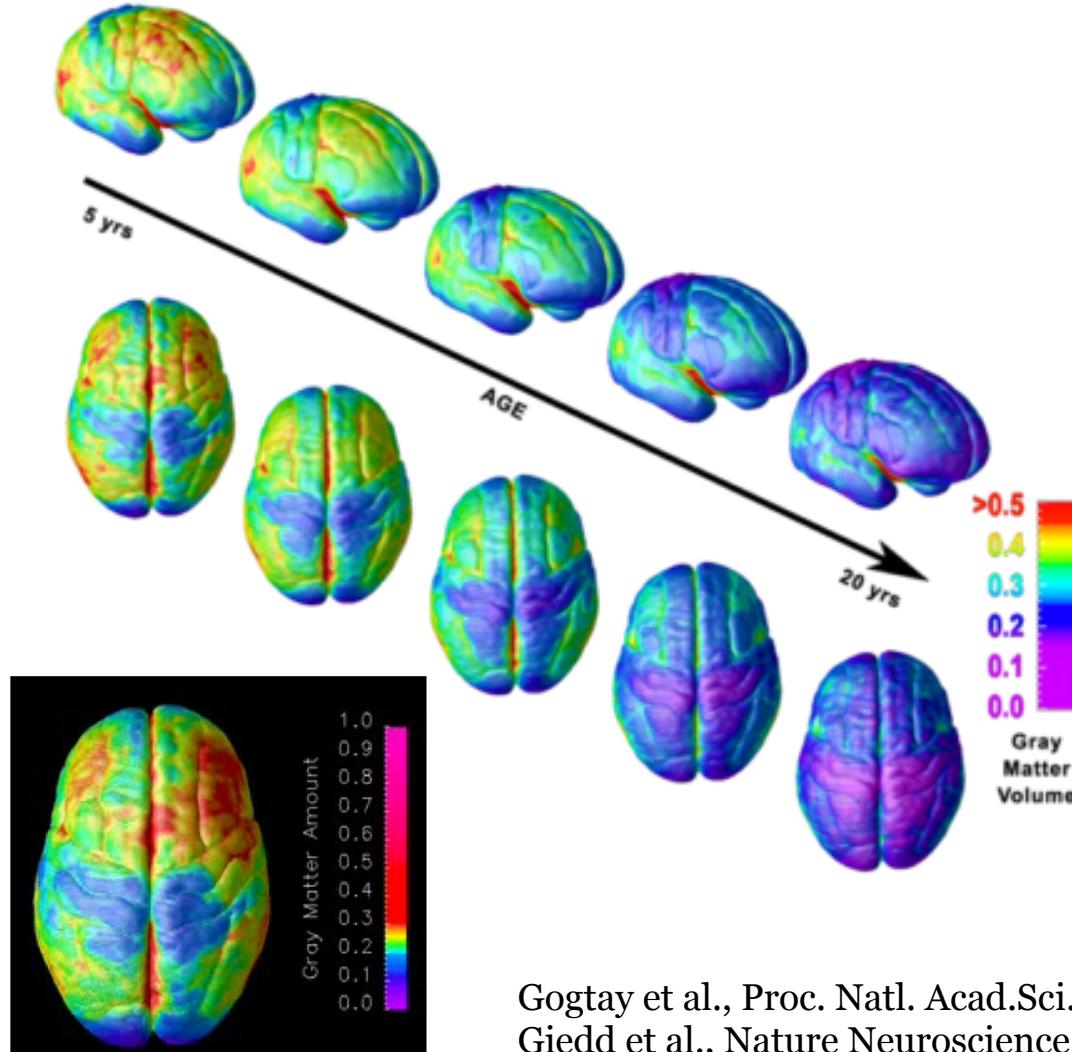
22 years



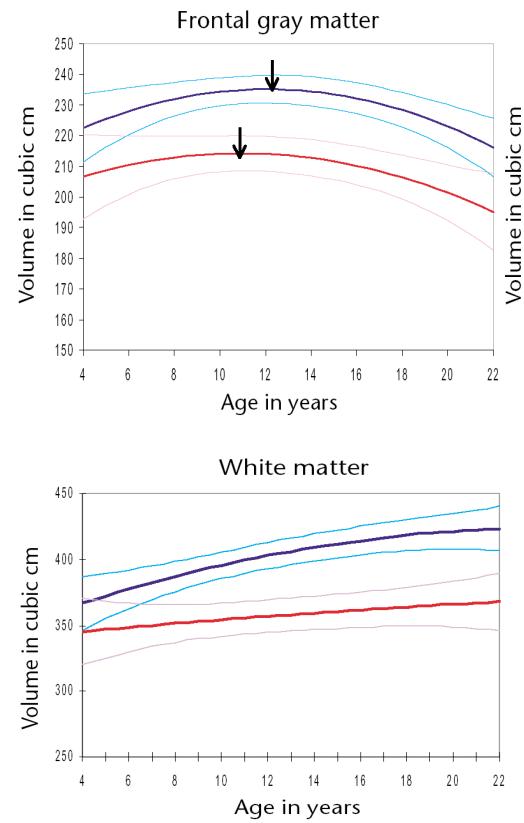
T1 weighted

Normal development –

Regional maturation of cortical thickness: Ages 4-21 years

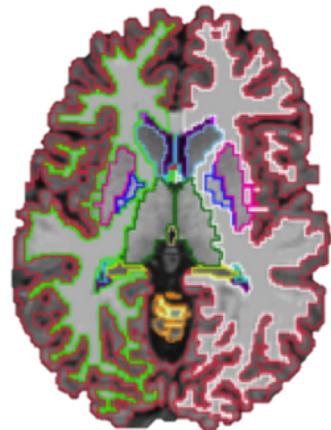


Gogtay et al., Proc. Natl. Acad. Sci. 2004
Giedd et al., Nature Neuroscience, 2: 1999.

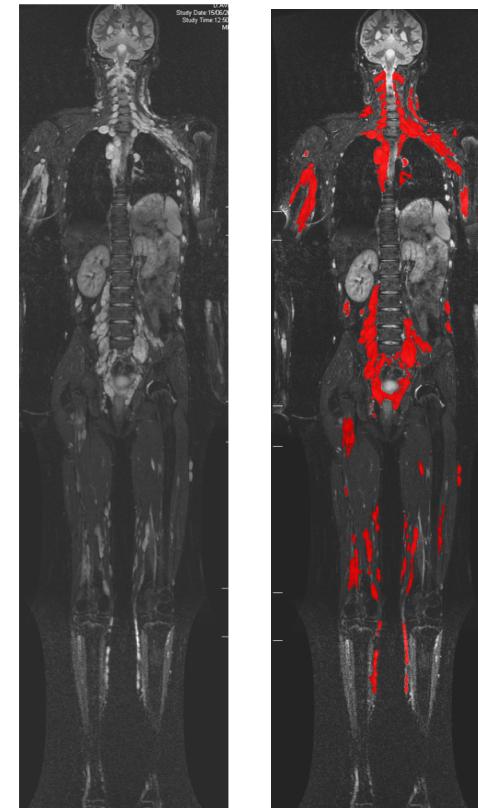
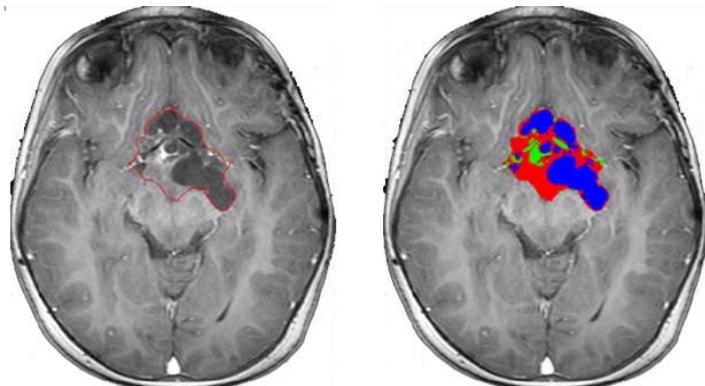


Volumetric measurements

Structural measurements



Lesion volume measurements



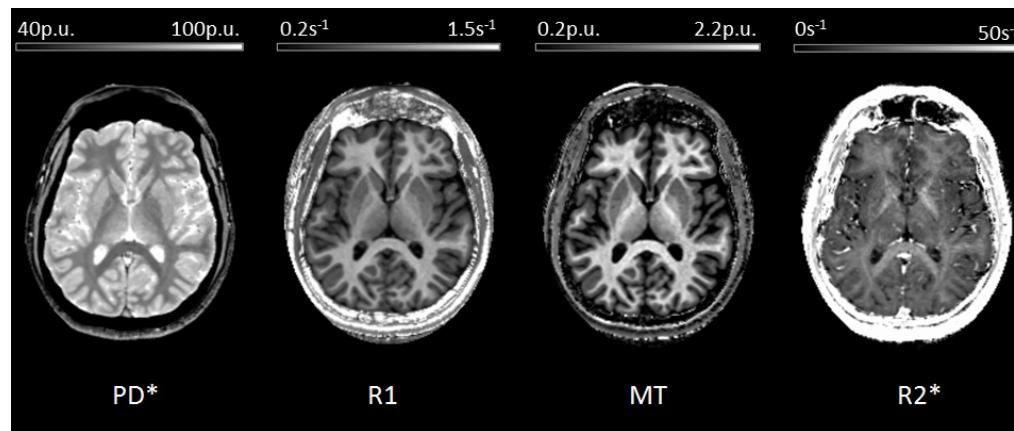
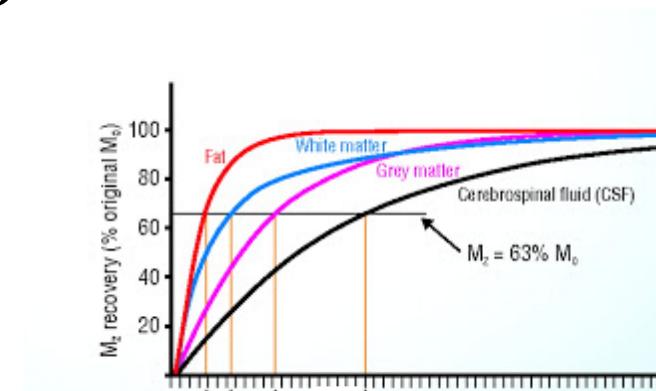
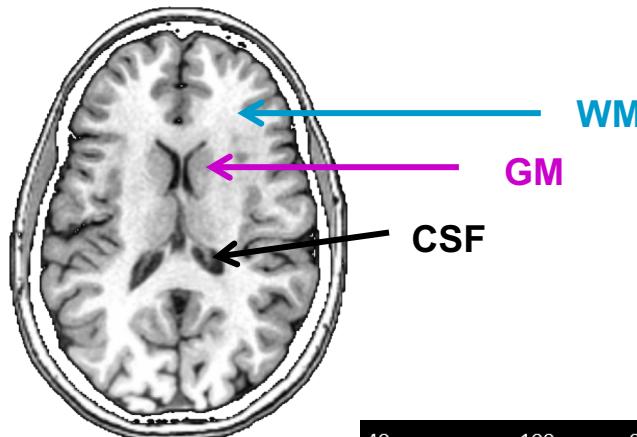
Weizman...Ben Bashat., Med Image Comput Assist Interv. 2010
Weizman...Ben Bashat., CARS 2011

■ Cystic, ■ Solid– Enhancing, and ■ Solid- Non Enhancing

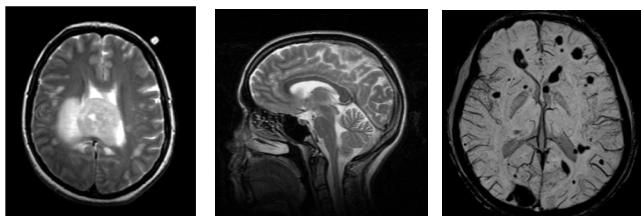
Structural information

Relaxometry methods

Longitudinal (T1) relaxation

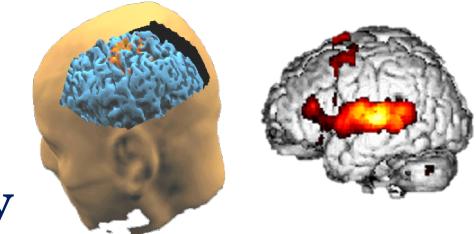


Structural information Conventional methods



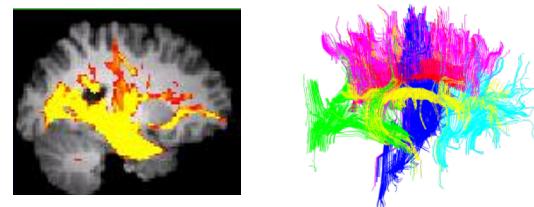
MRI

Functional MRI
1990 – BOLD
Functional
Imaging (fMRI)

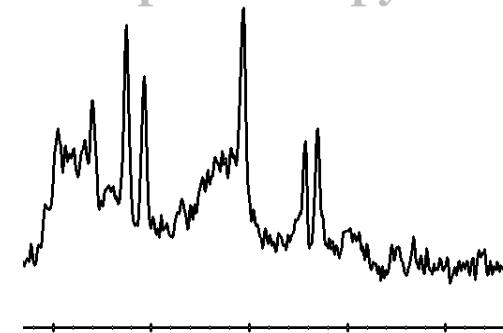


Structural and connectivity information

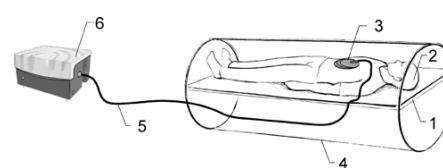
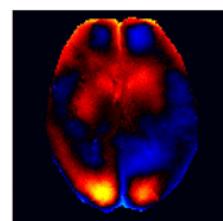
1994- Diffusion Tensor
Imaging (DTI)



Metabolic information
Spectroscopy



Structural information MR Electrogaphy



Structural and connectivity information

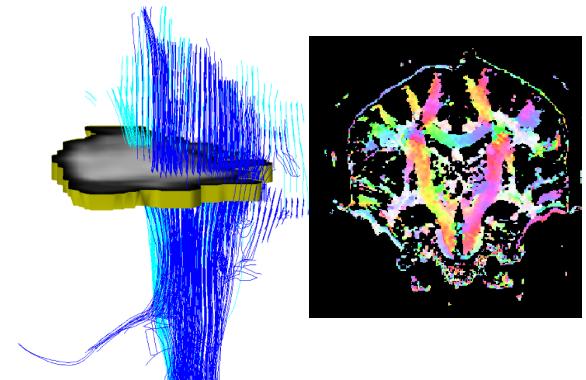
I. Conventional Diffusion Imaging

- ◆ Hypoxic Ischemic Injury
- ◆ Differentiation between lesions



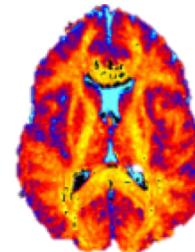
II. Diffusion Tensor Imaging - DTI

- ◆ Structural anisotropy
- ◆ Structural connectivity



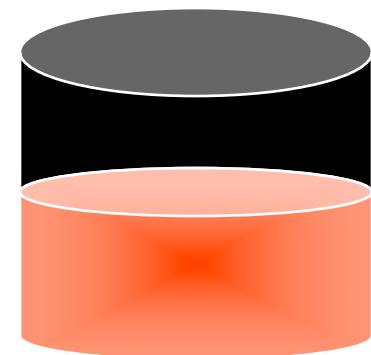
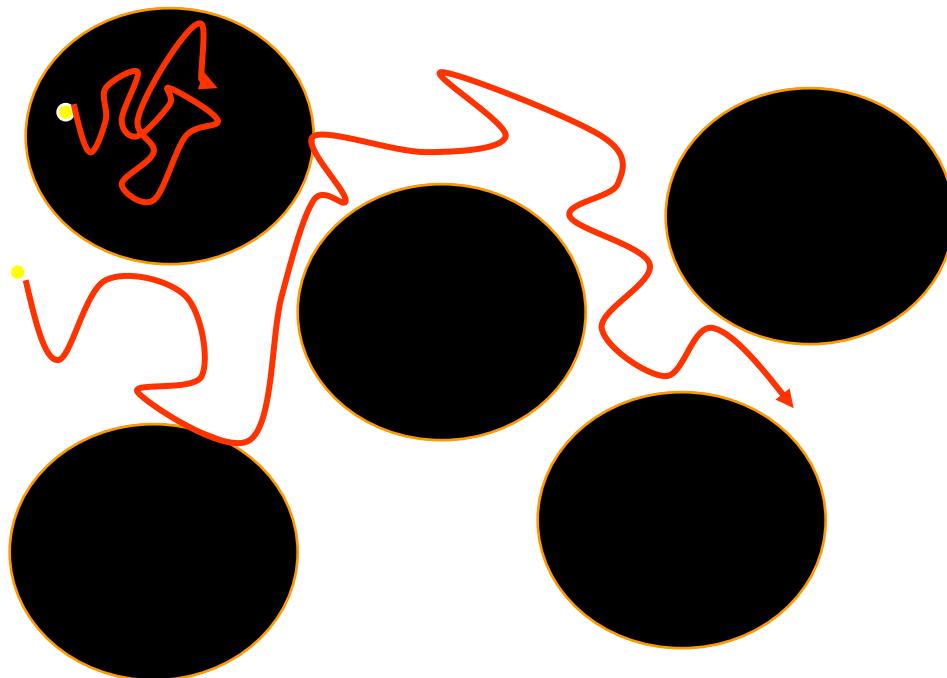
III. Advanced diffusion methods

- ◆ White Matter disorders
- ◆ Developmental delay
- ◆ Structural connectivity



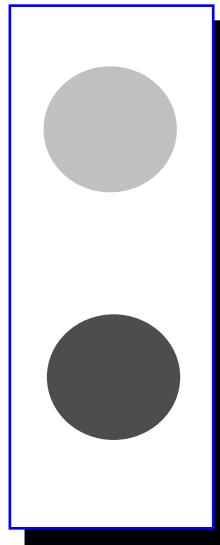
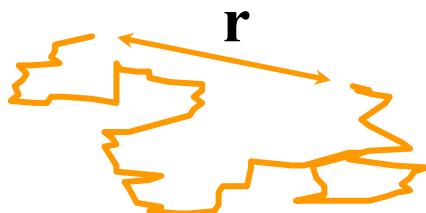
Diffusion Imaging

In cellular tissue the diffusion is
Influenced by cellular compartments



Diffusion Imaging

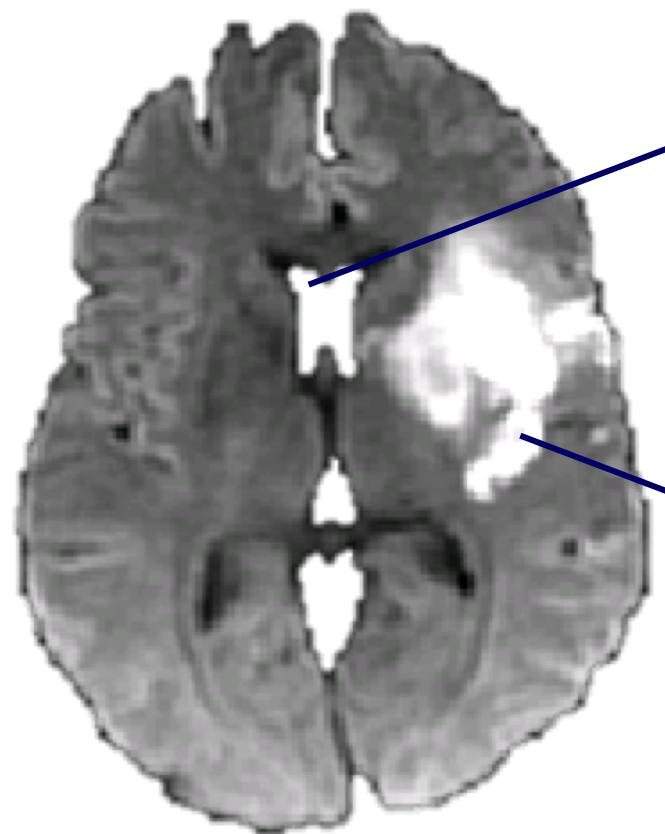
- The Measurement of mean displacement of water molecules
- Signal intensity in the image depends on displacement during the diffusion time



**Slow diffusion
Restricted diffusion?**

**Fast diffusion
“Free” diffusion**

Clinical applications: Ischemic stroke



Fast diffusion : Large Signal Decay
Hypointensity

Slow diffusion: Smaller Signal Decay
Hyperintensity

Ischemic stroke

DWI

FLAIR

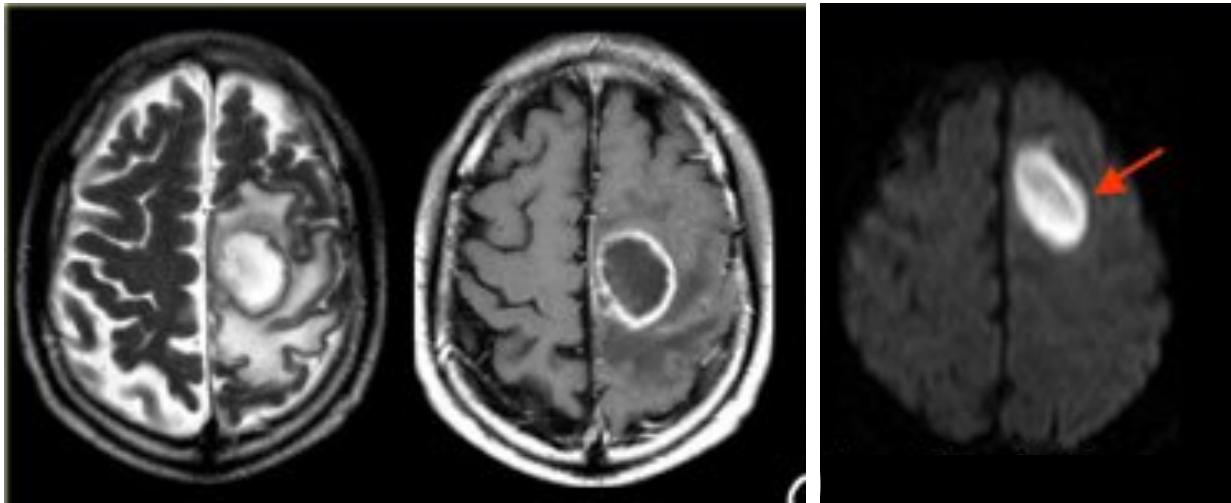
2 hrs

10 hrs

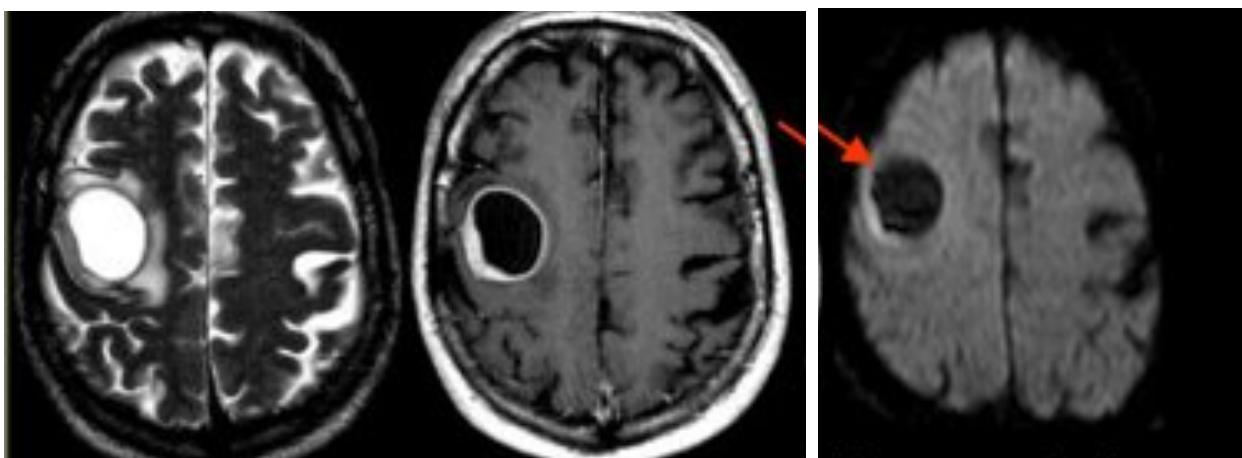
36 hrs

Brain Lesions

Brain abscess

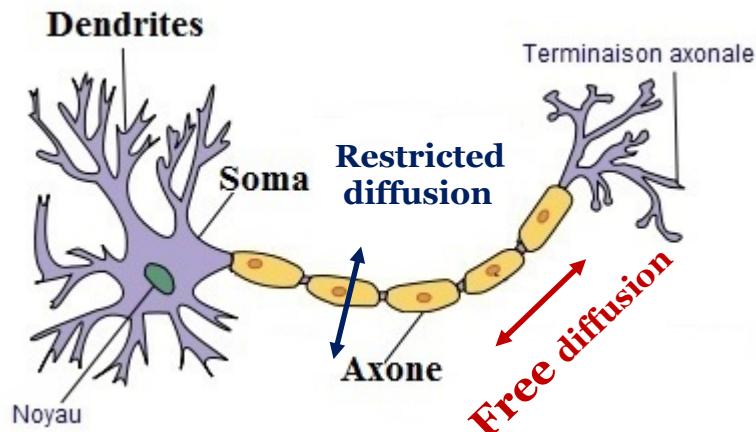


Brain metastatic lesion with necrotic core



Anisotropy of brain diffusivity

In the brain, diffusion is not isotropic



Fractional Anisotropy (FA) (0-1)

$$FA = \frac{\sqrt{3}}{\sqrt{2}} \frac{\sqrt{(\lambda_1 - \lambda)^2 + (\lambda_2 - \lambda)^2 + (\lambda_3 - \lambda)^2}}{\sqrt{\lambda_1^2 + \lambda_2^2 + \lambda_3^2}}$$

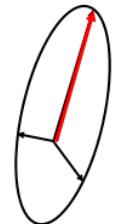
Mean diffusivity

$$\frac{S(TE)}{S_0} = \exp \left[-\gamma^2 G^2 \delta^2 \left(\Delta - \frac{\delta}{3} \right) D \right]$$

$$MD = (\lambda_1 + \lambda_2 + \lambda_3)/3$$

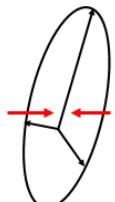
Axial diffusivity (Da)

$$Da = \lambda_1$$

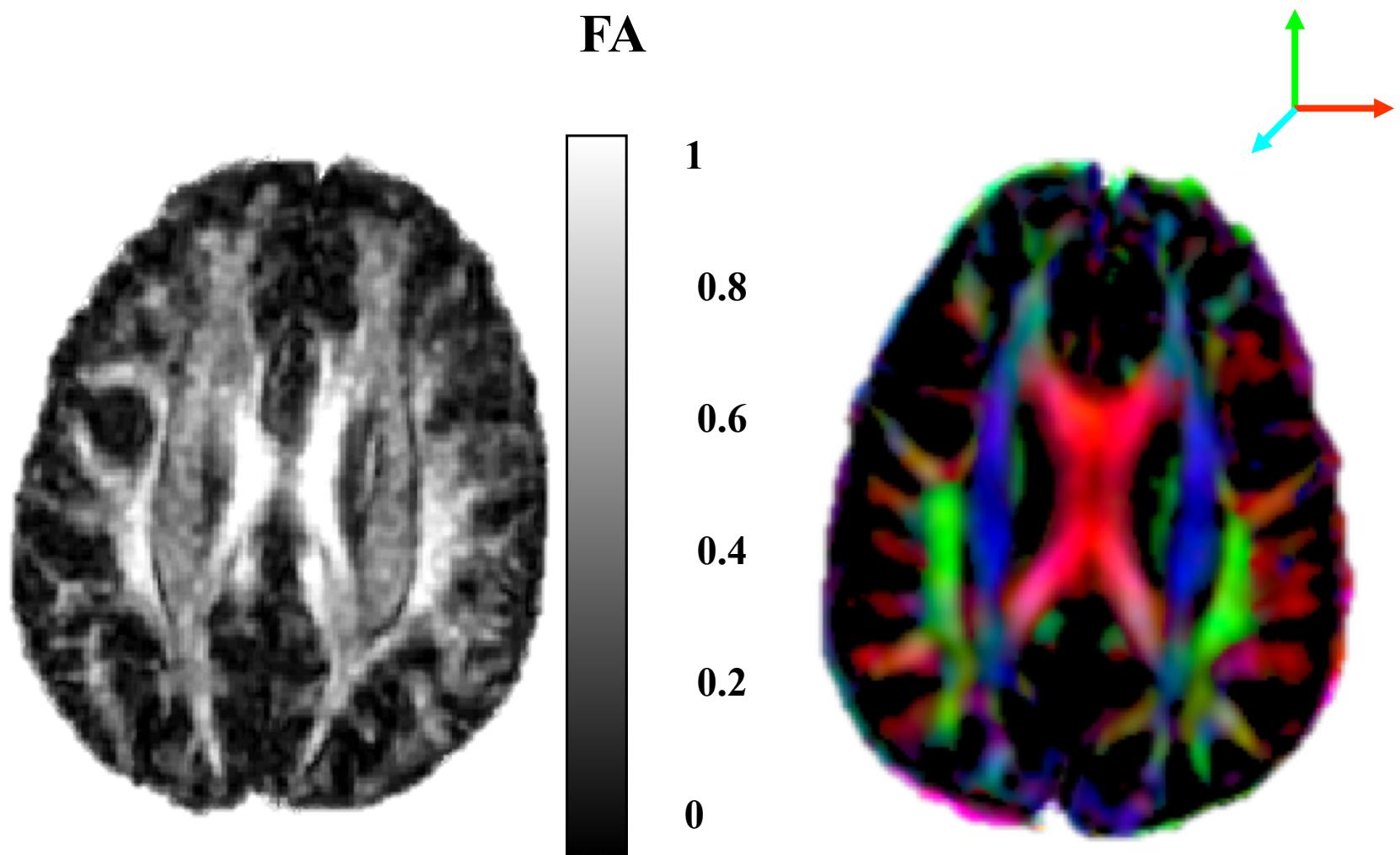


Radial diffusivity (Dr)

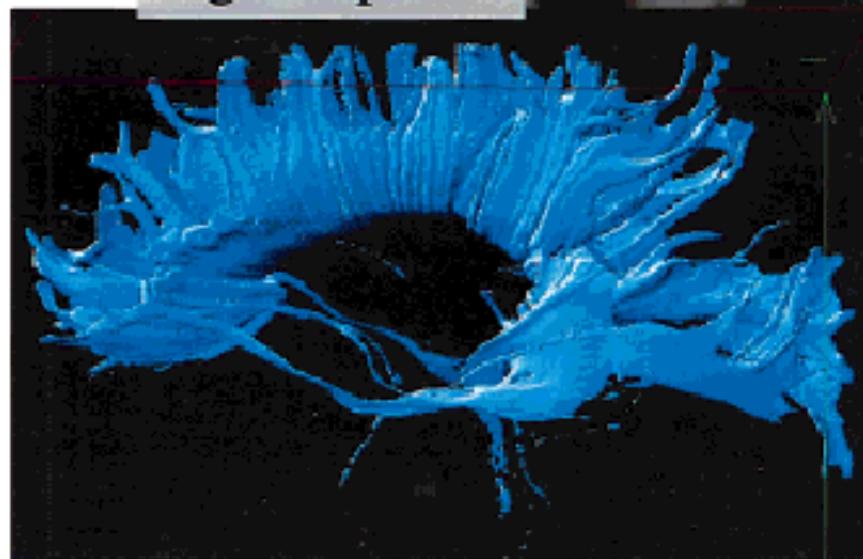
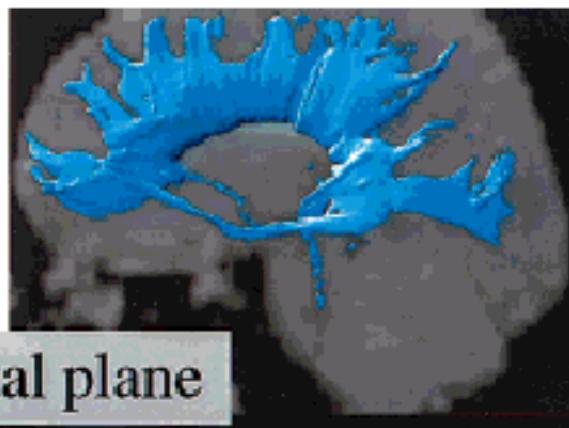
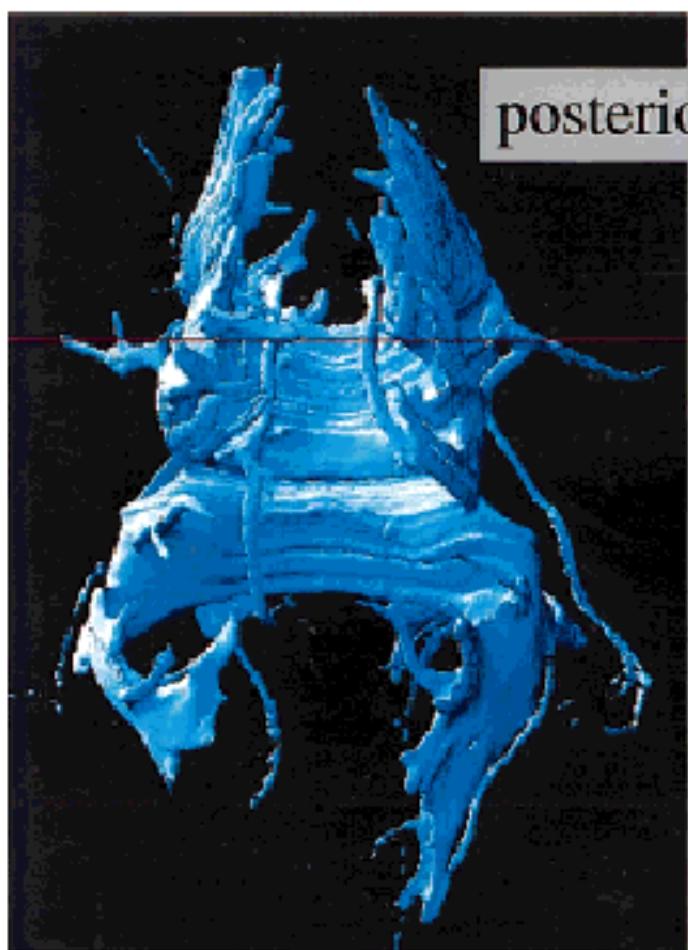
$$Dr = (\lambda_2 + \lambda_3)/2$$



Diffusion Tensor Imaging - DTI

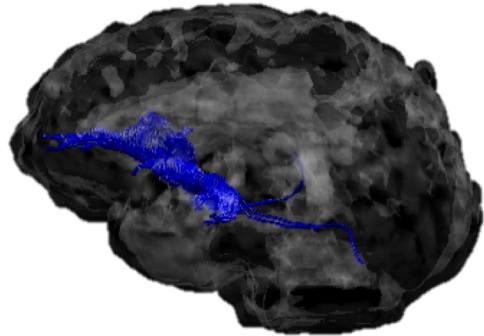


3D White Matter Directionality → Tractography

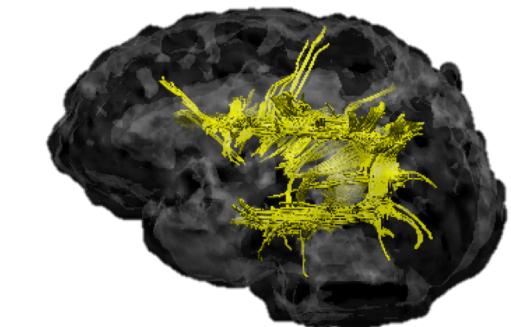
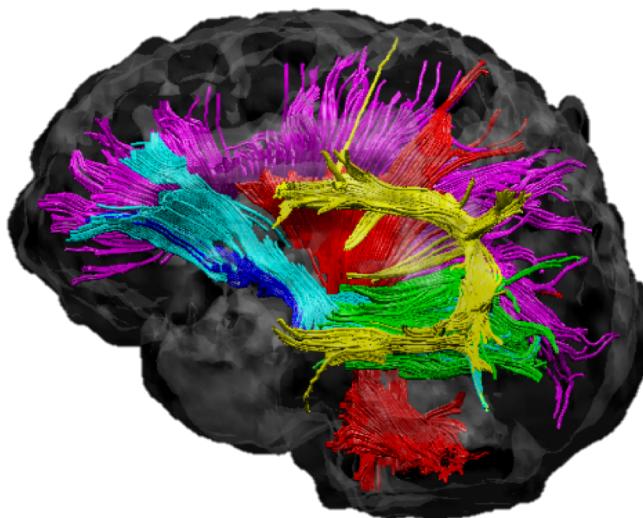


P.J. Basser, et-al, Magn Reson Med, 2000.

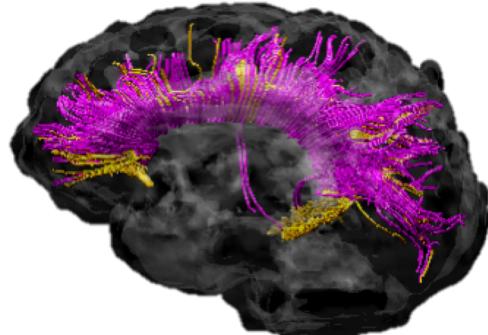
DTI - Tractography



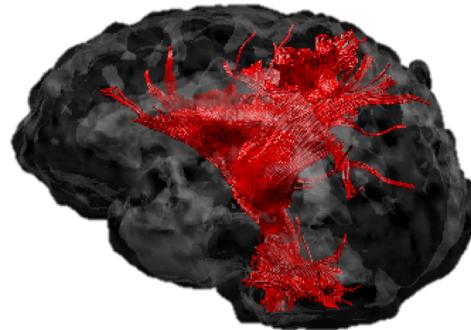
Uncinate Fasciculus



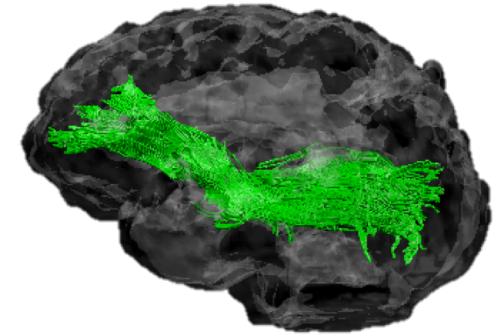
Superior Longitudinal
Fasciculus



Corpus Callosum &
Cingulum



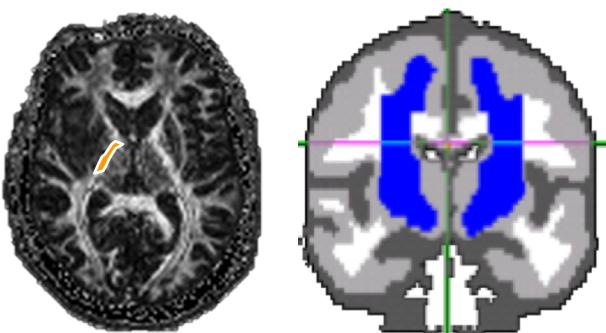
Corona Radiata



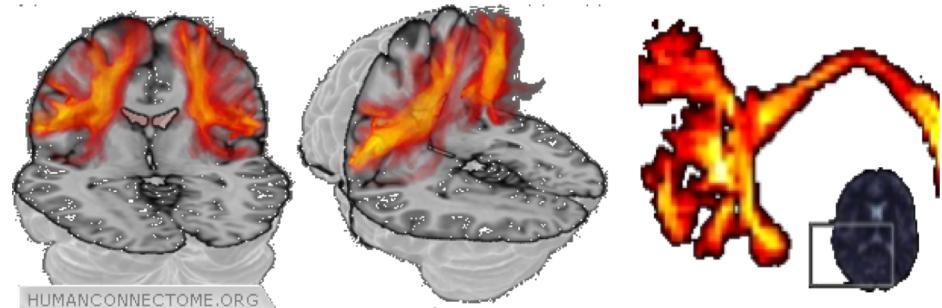
Inferior Longitudinal
Fasciculus

DTI – Analysis methods

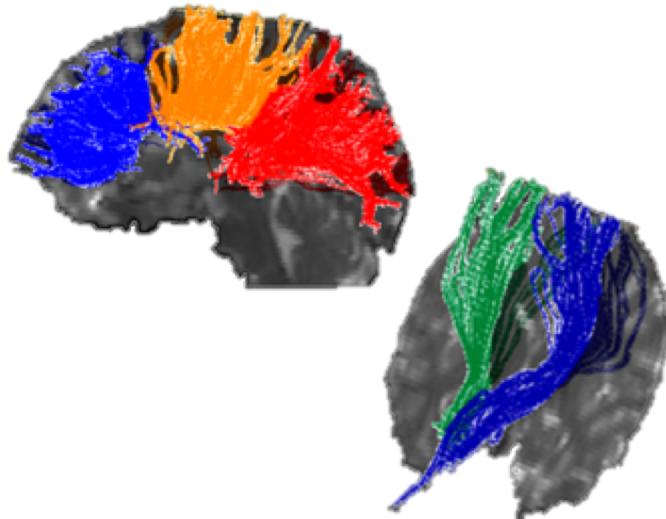
Volume / area of interest



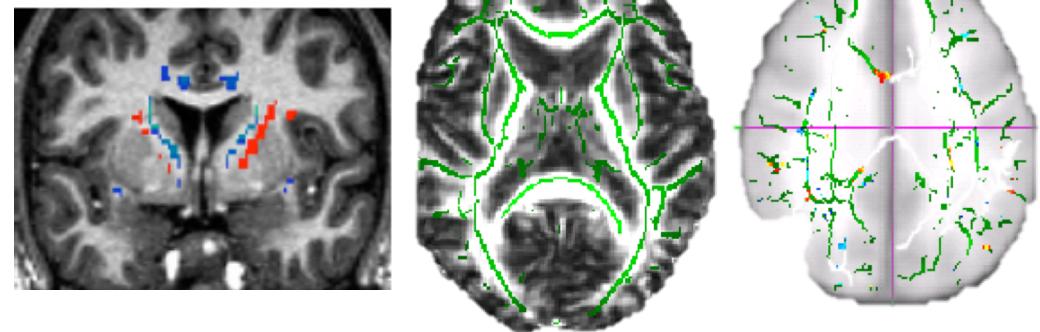
Probabilistic Tractography



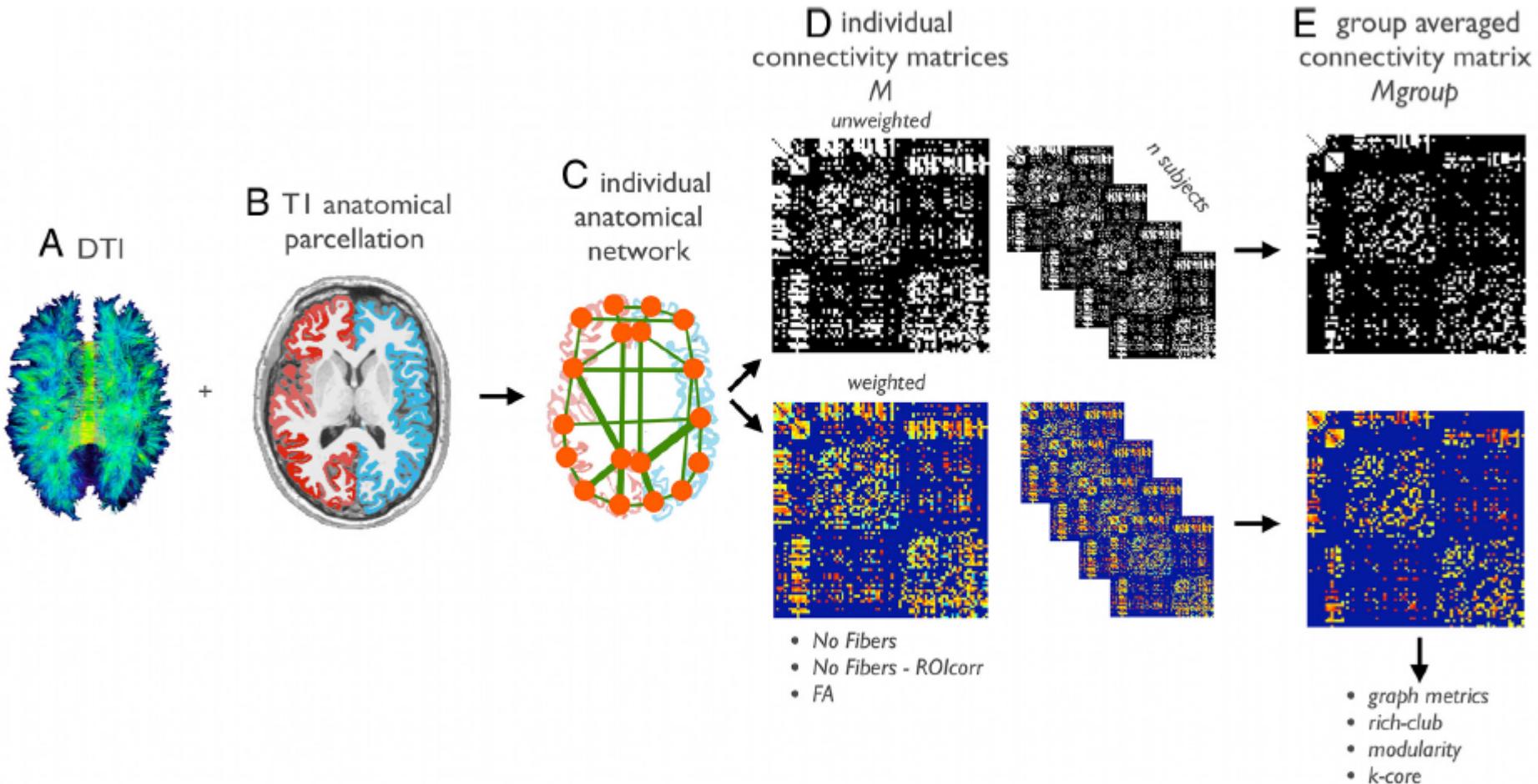
Streamline Tractography



Voxel based / TBSS - Tract-Based Spatial Statistics



DTI – Networks Analysis



Van den Heuvel and Sporns, The Journal of Neuroscience, 2011