

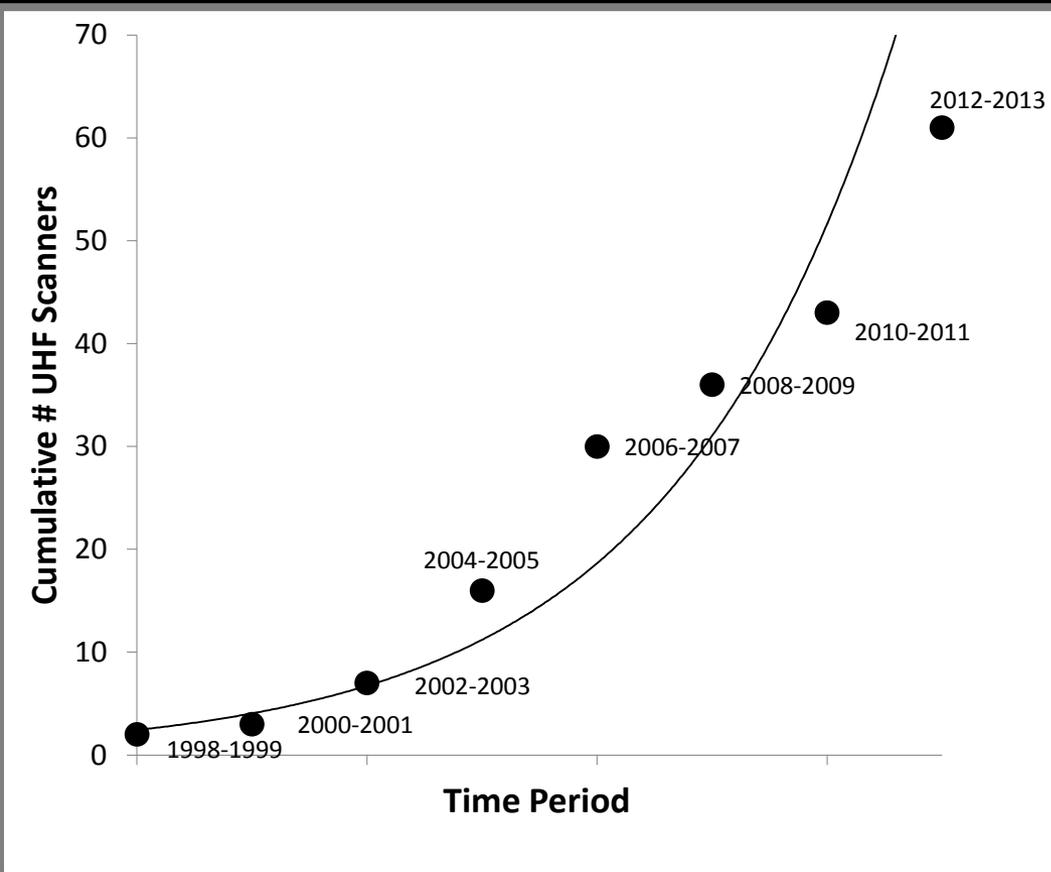
# Imagerie du Cortex à 7 Tesla

Thomas Tourdias

(1) *Service de NeuroImagerie Diagnostique et Thérapeutique, CHU  
Bordeaux, Université de Bordeaux*

(2) *Radiological Sciences Laboratory, Stanford University, CA, USA*

# La « démographie » des aimants 7T



**7T, GE, MR950, Stanford**

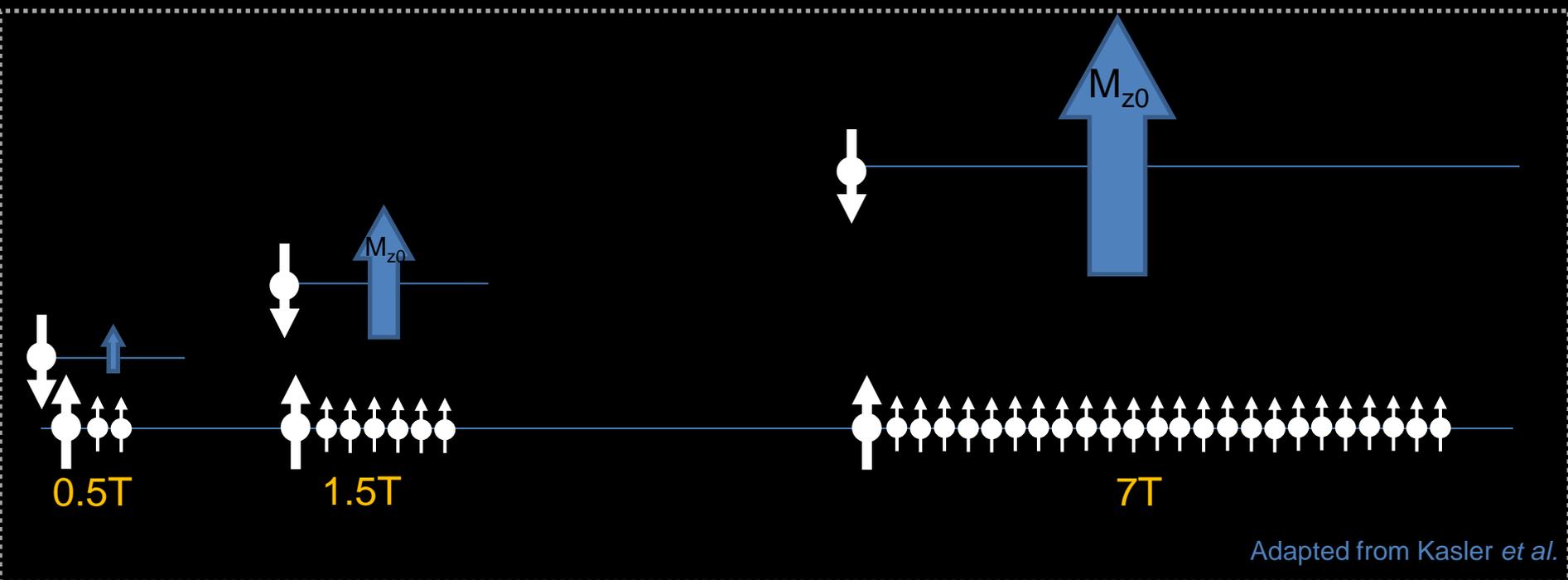
Brian Rutt, Stanford Ultra High Field Program

# Plan:

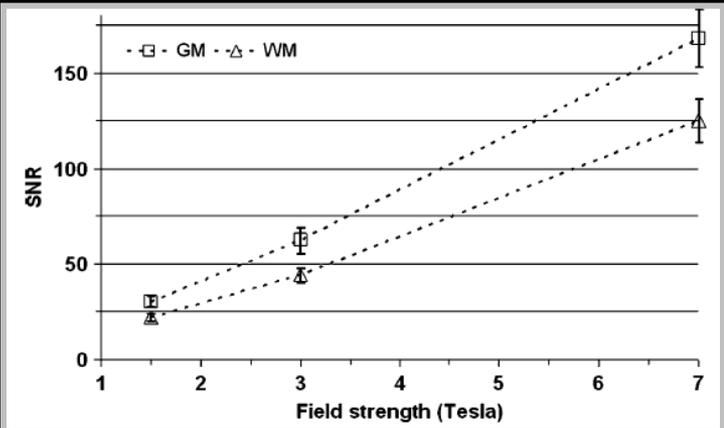
1. Les atouts du 7T pour l'imagerie du cortex
2. Les challenges du 7T pour l'imagerie du cortex
3. Le cortex normal à 7T
  - Micro-anatomie corticale
  - Fonction
4. Applications pathologiques
  - Plaques corticales et sclérose en plaques
  - Segmentation de sous volumes hippocampiques

# Les atouts du 7T pour l'imagerie du cortex :

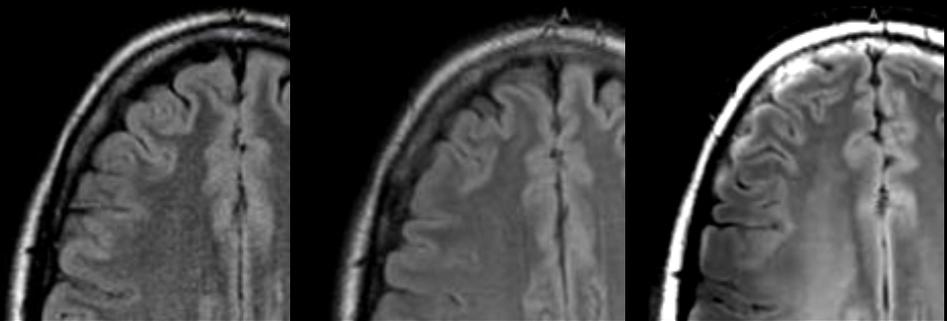
Gain de signal



Adapted from Kasler *et al.*



Zwanenburg *et al.* Eur Radiol 2010; 20:915-922



1.5T

3T

7T

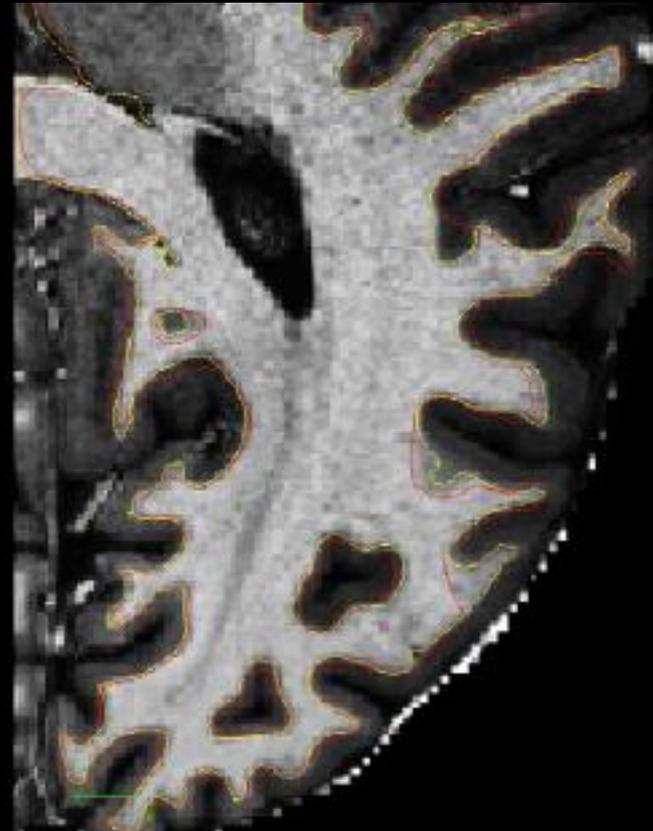
# Les atouts du 7T pour l'imagerie du cortex :

Gain de signal → Gain en résolution spatiale

- Epaisseur corticale  $\approx$  2.5 mm (1 mm à 4 mm)



7T - 1 mm iso

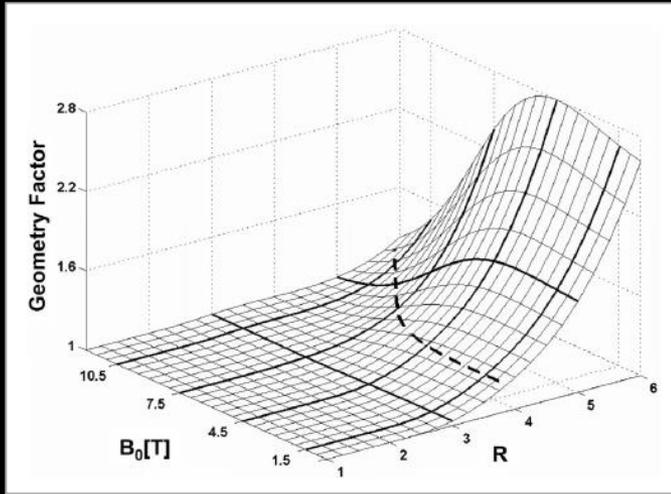


7T - 0.5 mm iso

# Les atouts du 7T pour l'imagerie du cortex :

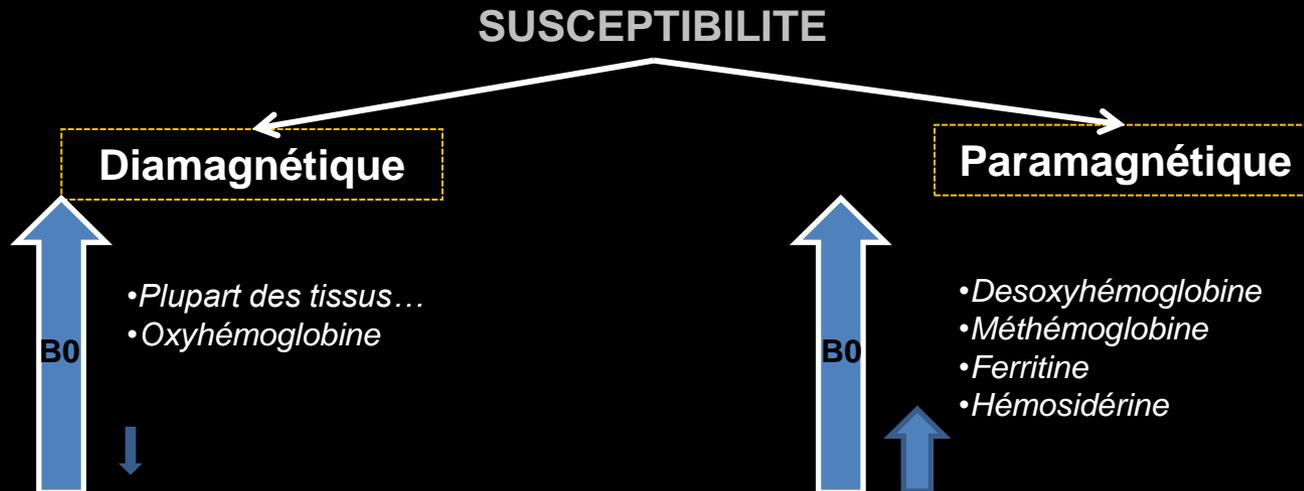
## Imagerie parallèle – Effet de susceptibilité

### ✓ Meilleures performances de l'imagerie parallèle



Wiesinger et al. MRM 2004; 52:953-964

### ✓ Augmentation de l'effet de susceptibilité: augmentation de l'effet BOLD



# Plan:

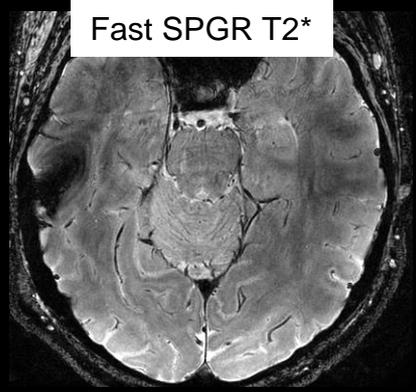
1. Les atouts du 7T pour l'imagerie du cortex
2. Les challenges du 7T pour l'imagerie du cortex



- ↗ SNR
- ↗ Résolution spatiale
- ↗ Performance imagerie parallèle
- ↗ Susceptibilité: ↗ Effet BOLD

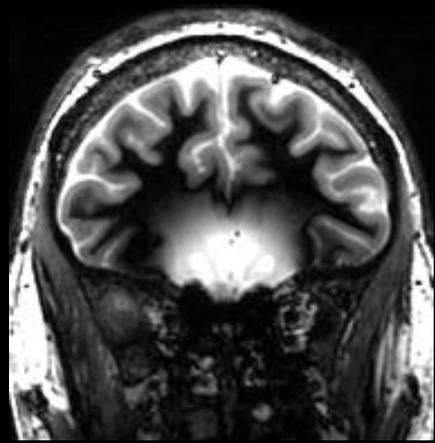
# Les contraintes du 7T

Inhomogénéité de  $B_0$

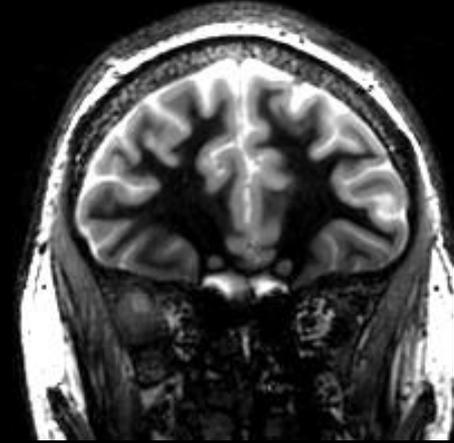


Fast SPGR T2\*

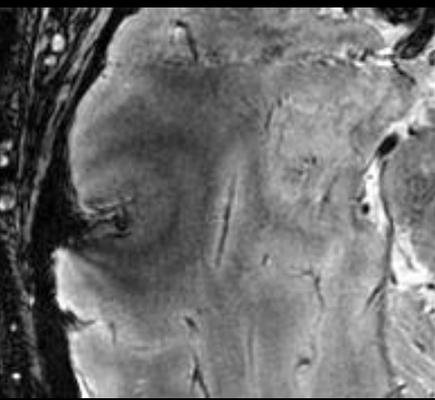
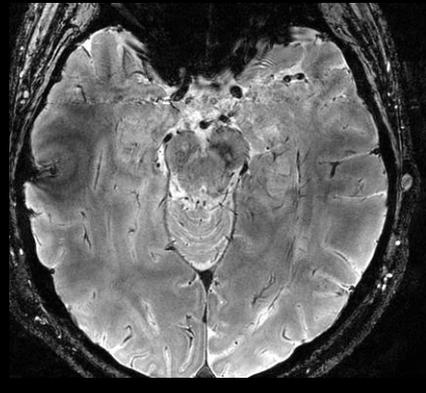
- *Prédomine aux Interfaces Air / Tissue*
- *Importance du «Shim»*



MPRAGE White matter null



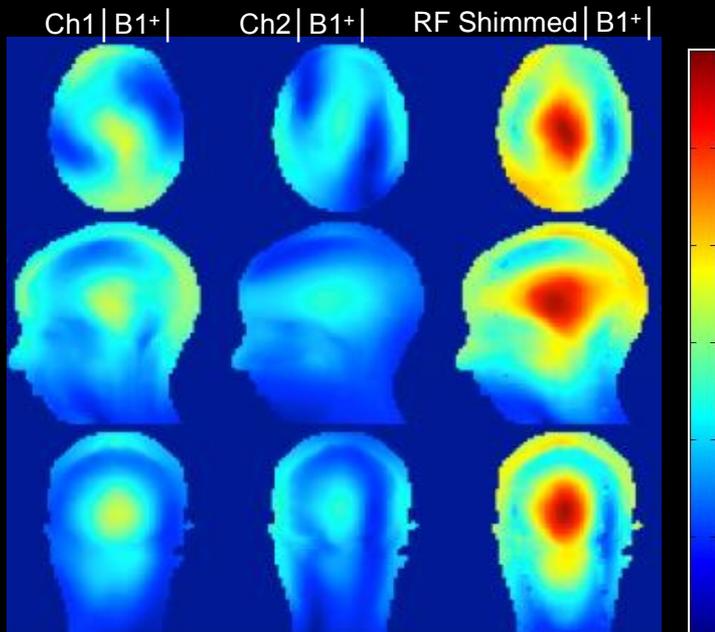
MPRAGE White matter null + Shim



The screenshot shows a software interface for ROI selection and shim calculation. It features three main panels: Transaxial Section (A (Y\_u)), Sagittal Section (S (Z\_u)), and Coronal Section (S (Z\_u)). Each panel displays a brain slice with a red circle indicating the ROI. To the right of each panel is a vertical stack of smaller brain slices, with the slice corresponding to the ROI highlighted in red. The interface includes a status bar at the bottom with the following information: Patient Position: HF/S, Current RMS : 41.49, Predicted RMS : 19.63. There are several buttons: Calculate Shim, Done, ROI Shape, Load MRS ROI, Quit, Angle, Help, Advanced, and Phase Maps.

# Les contraintes du 7T

## Inhomogénéité de $B_1$

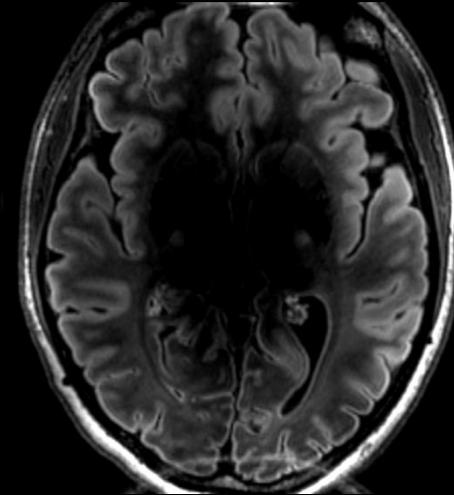


Jonathan Lu, Mehdi Khalighi, Stanford

Coro T2 FSE



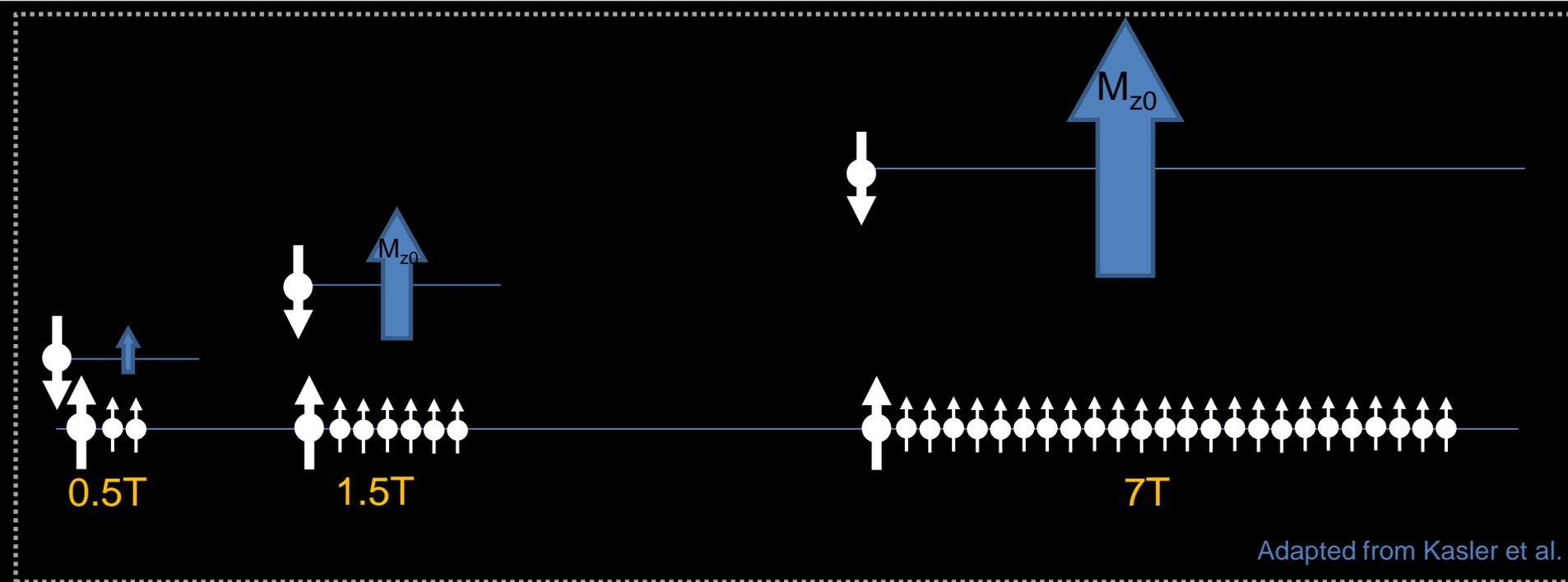
Axial MP FLAIR



- Pulses RF ou séquence " $B_0/B_1$  insensitive": Hyperbolic secant adiabatic pulse
- Compensation des inhomogénéités directe ou lors du post traitement
- Antenne émettrice multicanaux.

# Les contraintes du 7T

Specific Absorbition Rate: SAR



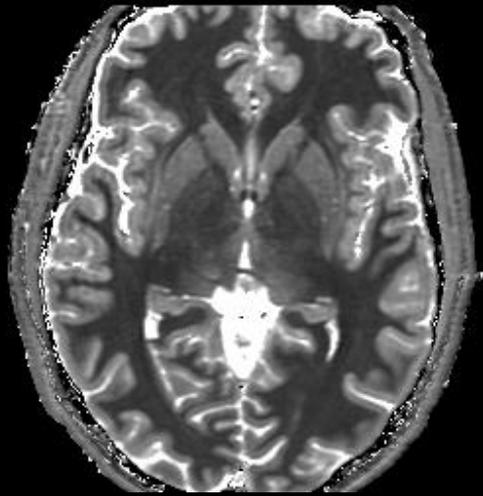
- Pulses RF ou séquence "B0/B1 insensitive": **Hyperbolic secant adiabatic pulse**
- SAR augmente  $\sim B_0^2$
- Surveillance du SAR en temps réel



# Les contraintes du 7T

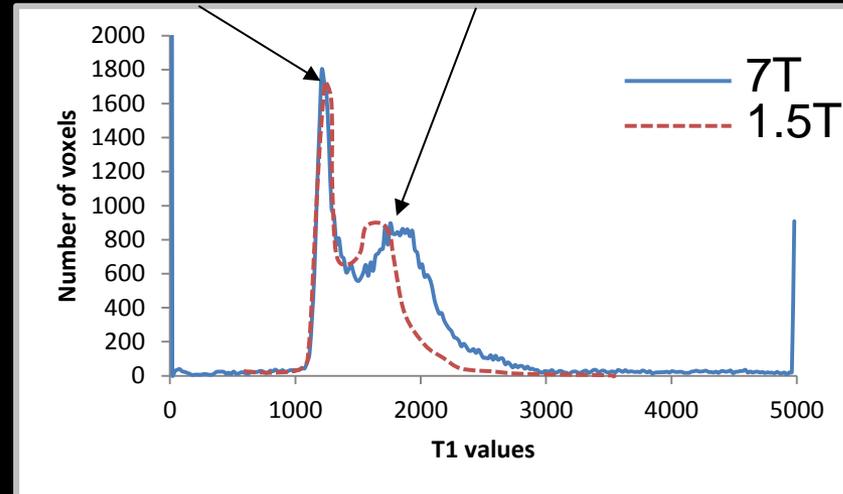
## Modifications des temps de relaxation

- Diminution du T2 et T2\*
- Augmentation des temps de relaxation T1



T1 map IR FSE at 5 TI

SB=650ms      SG=1050ms      LCR=4000ms  
SB=1200ms    SG=2000ms      LCR=4400ms

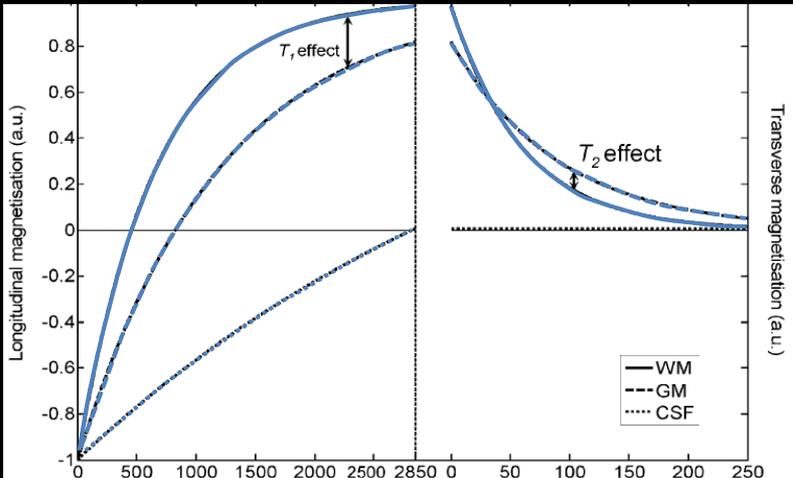
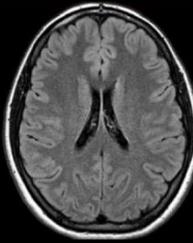


Paramètres voire « schéma » de séquence à adapter

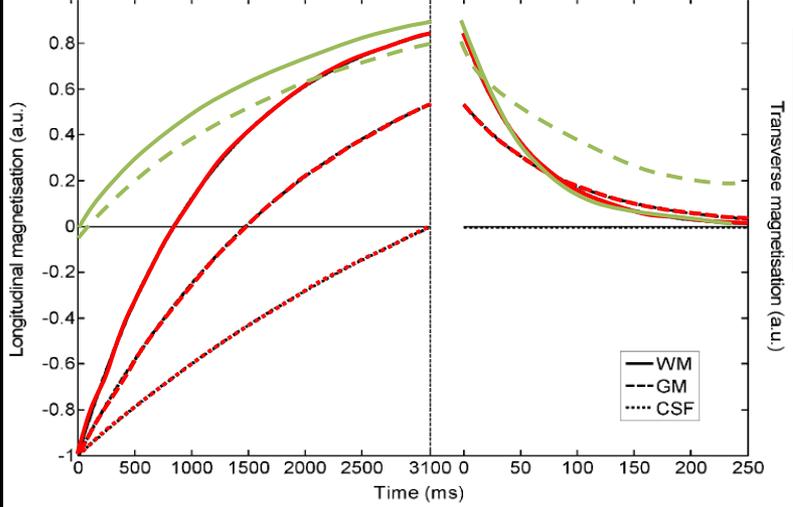
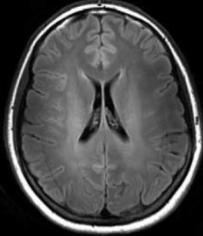
# Les contraintes du 7T

## Modifications des temps de relaxation – Exemple du FLAIR

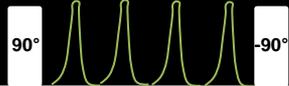
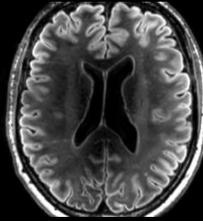
1.5T: FLAIR



7T: FLAIR



7T: MP-FLAIR



Magnetization preparation



# Plan:

1. Les atouts du 7T pour l'imagerie du cortex
2. Les challenges du 7T pour l'imagerie du cortex



↗ SNR  
↗ Résolution spatiale  
↗ Performance imagerie parallèle  
↗ Susceptibilité: ↗ Effet BOLD

↗ Inhomogénéités  $B_0$   
↗ Inhomogénéités  $B_1$   
↗ SAR  
↗ Temps de relaxation  $T_1$  et ↘  $T_2$

# Plan:

1. Les atouts du 7T pour l'imagerie du cortex
2. Les challenges du 7T pour l'imagerie du cortex



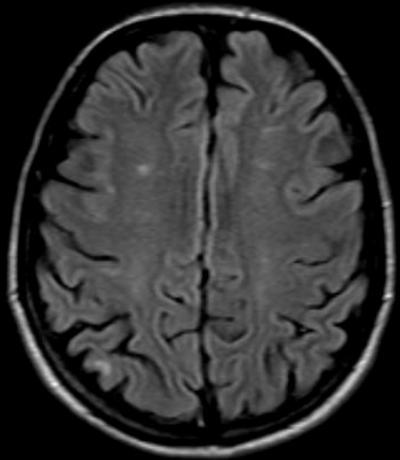
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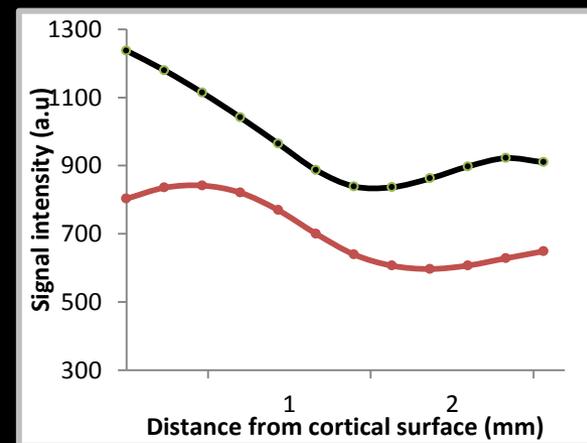
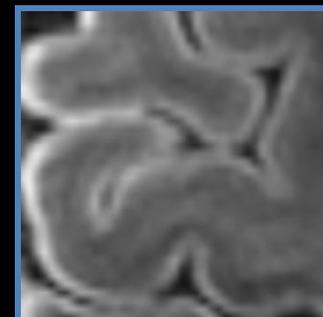
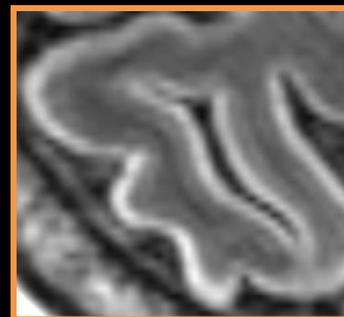
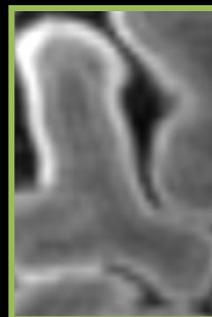
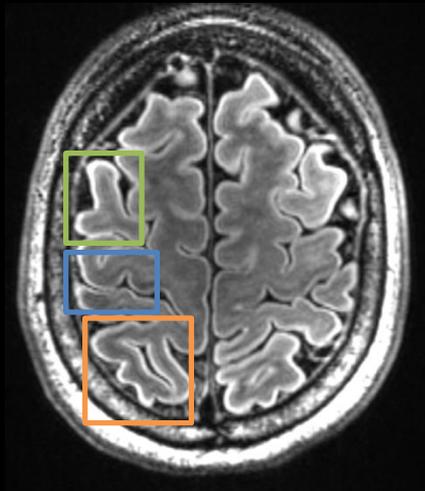
# Le cortex normal à 7T

## Micro-anatomie corticale

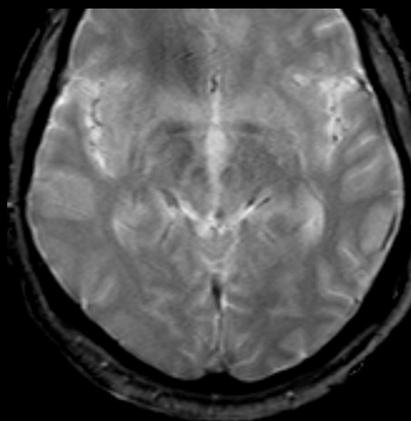
1.5T: FLAIR



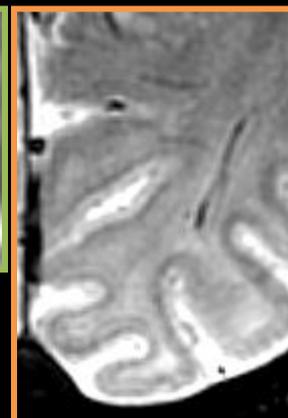
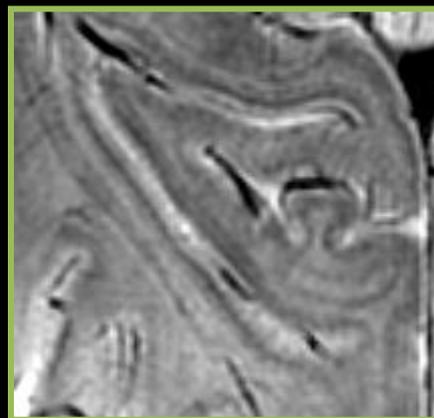
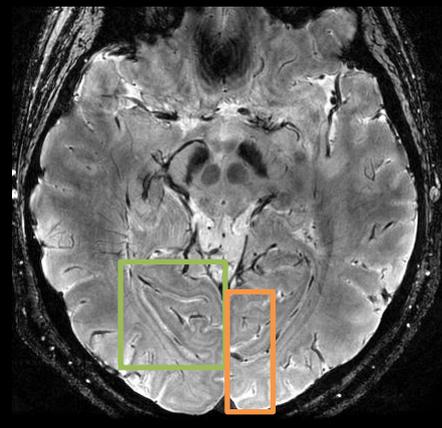
7T: MP-FLAIR



1.5T: T2\*

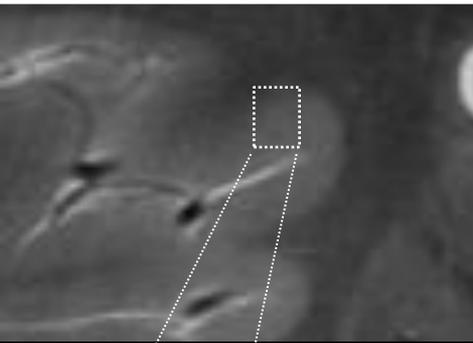


7T: T2\*

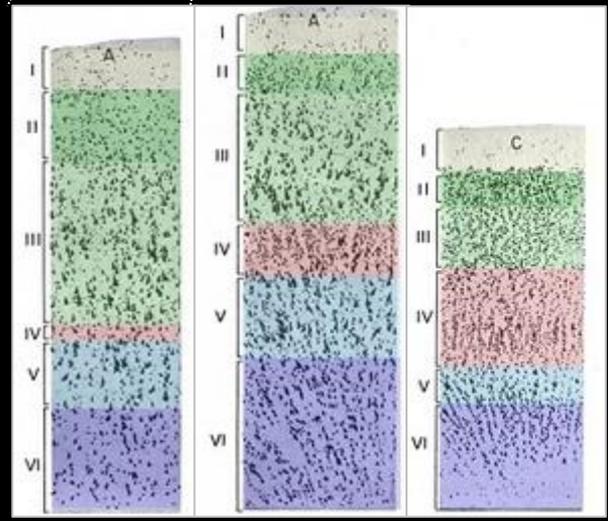
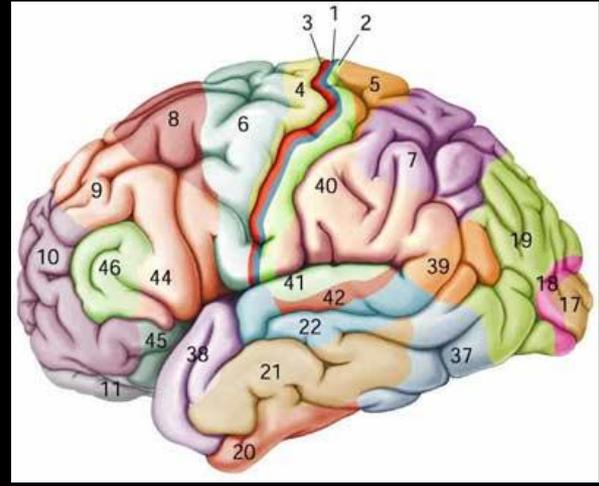
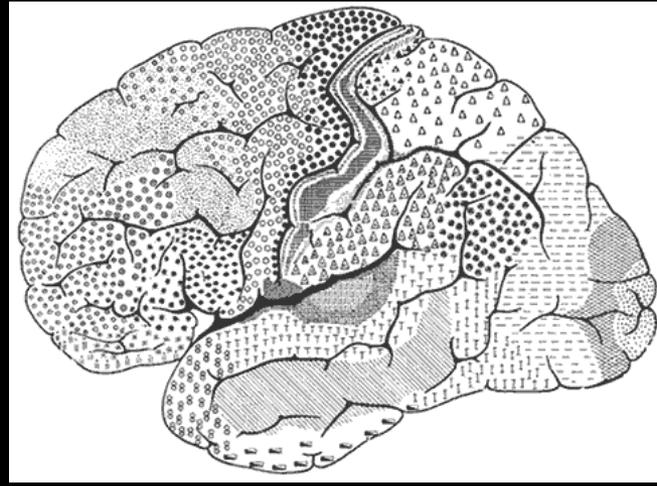


# Le cortex normal à 7T

Micro-anatomie corticale



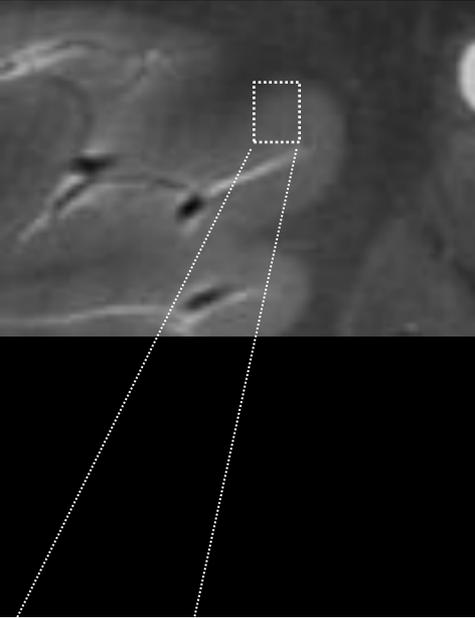
## Aire de Brodmann: Cytoarchitecture



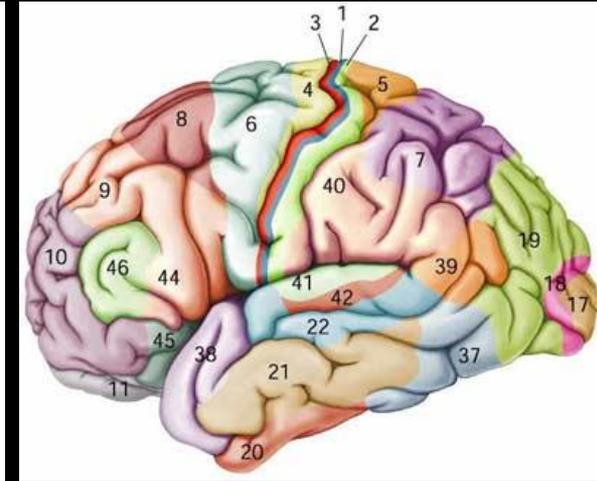
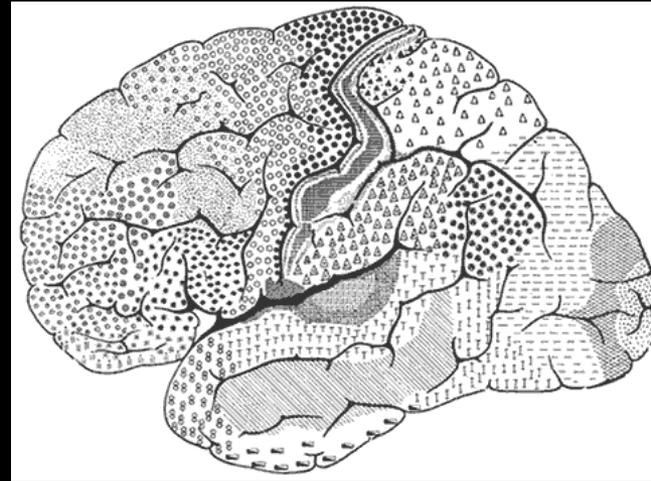
Cytoarchitecture

# Le cortex normal à 7T

Micro-anatomie corticale



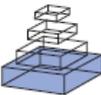
## Aire de Brodmann: Cytoarchitecture



frontiers in  
**HUMAN NEUROSCIENCE**

**PERSPECTIVE ARTICLE**

published: 18 February 2011  
doi: 10.3389/fnhum.2011.00019



Microstructural parcellation of the human cerebral cortex – from Brodmann's post-mortem map to *in vivo* mapping with high-field magnetic resonance imaging

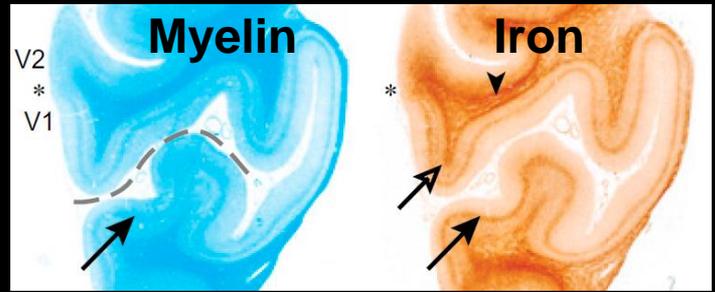
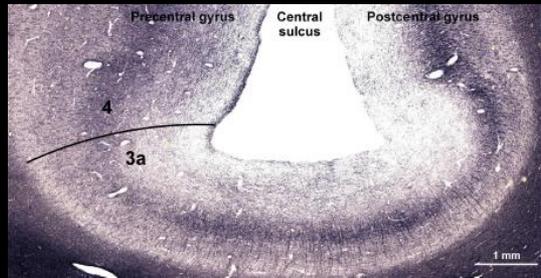
**Stefan Geyer\***, Marcel Weiss, Katja Reimann, Gabriele Lohmann and Robert Turner

Department of Neurophysics, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

# Le cortex normal à 7T

## Micro-anatomie corticale

- ↗ SNR
- ↗ Résolution spatiale
- ↗ Performance imagerie parallèle
- ↗ Susceptibilité: ↗ Effet BOLD



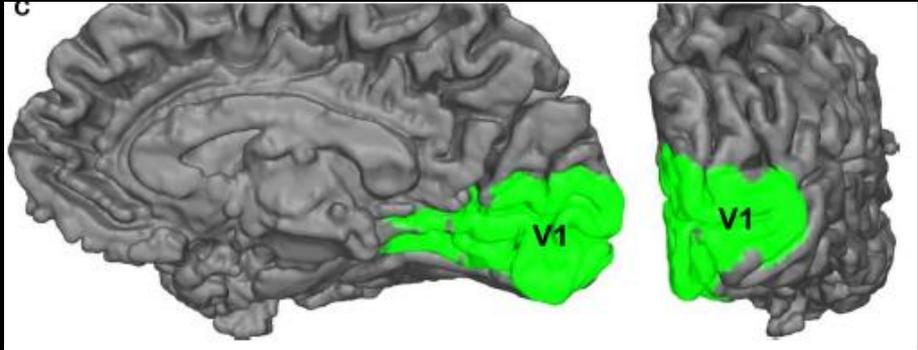
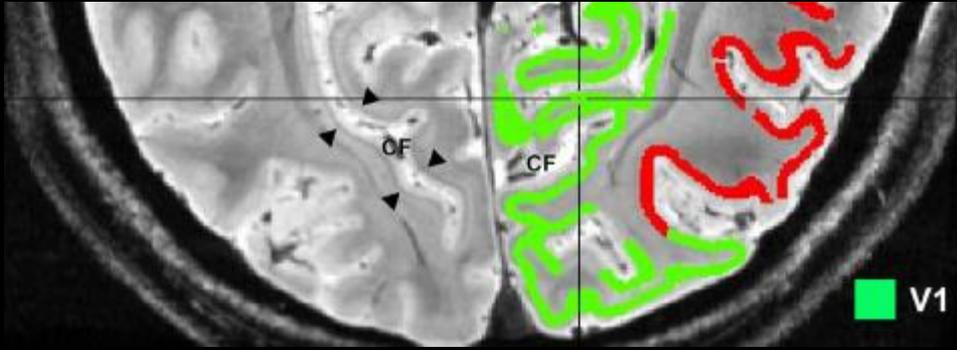
Fukunaga et al. PNAS 2010; 107:3834-39

$T_2^*$  mapping and  $B_0$  orientation-dependence at 7 T reveal cyto- and myeloarchitecture organization of the human cortex

J. Cohen-Adad <sup>a,b,\*</sup>, J.R. Polimeni <sup>a,b</sup>, K.G. Helmer <sup>a,b</sup>, T. Benner <sup>a,b</sup>, J.A. McNab <sup>a,b</sup>, L.L. Wald <sup>a,b,c</sup>, B.R. Rosen <sup>a,b</sup>, C. Mainero <sup>a,b</sup>

<sup>a</sup> A.A. Martinos Center for Biomedical Imaging, Dept. of Radiology, Massachusetts General Hospital, Charlestown, MA, USA  
<sup>b</sup> Harvard Medical School, Boston, MA, USA  
<sup>c</sup> Harvard-MIT Division of Health Sciences and Technology, MIT, Cambridge, MA, USA

Neuroimage 2012



Geyer et al. Front in Hum Neurosci 2011; 18:5

# Le cortex normal à 7T

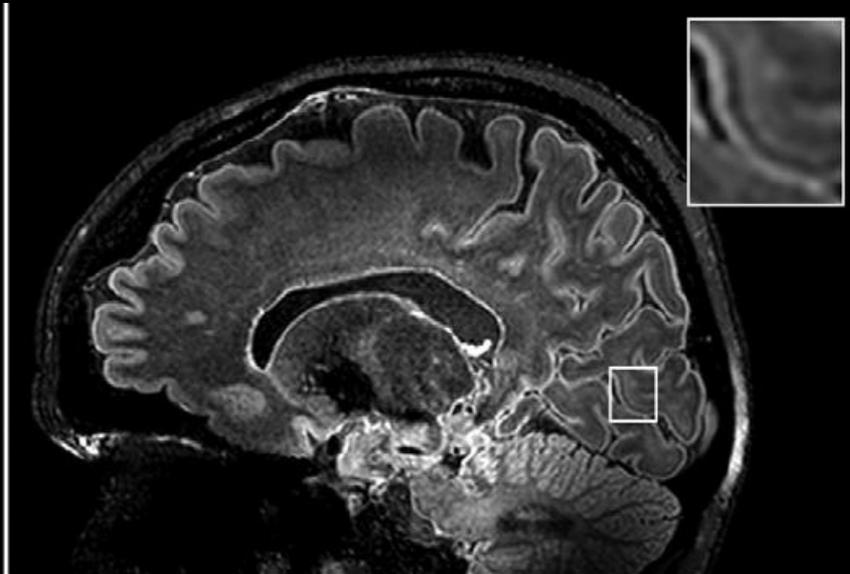
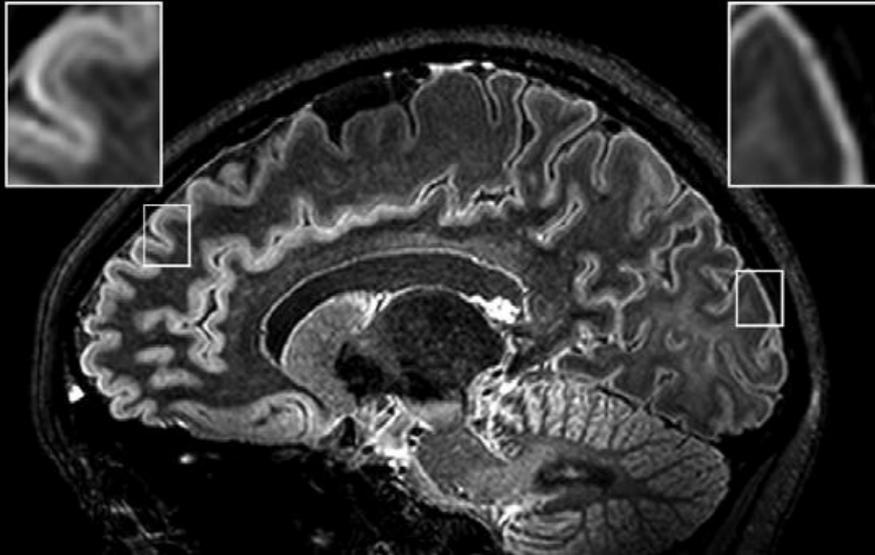
Micro-anatomie corticale

Radiology

Jaco J. M. Zwanenburg, PhD  
Jeroen Hendrikse, MD, PhD  
Peter R. Lujtjen, PhD

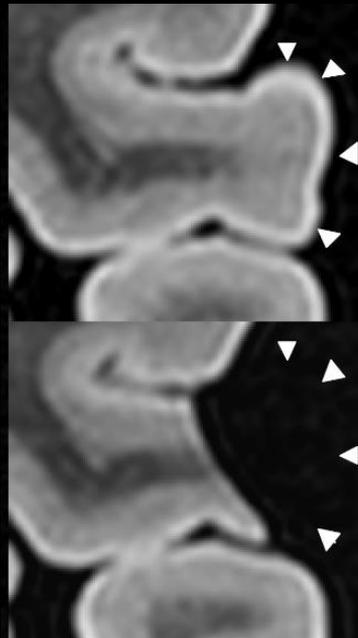
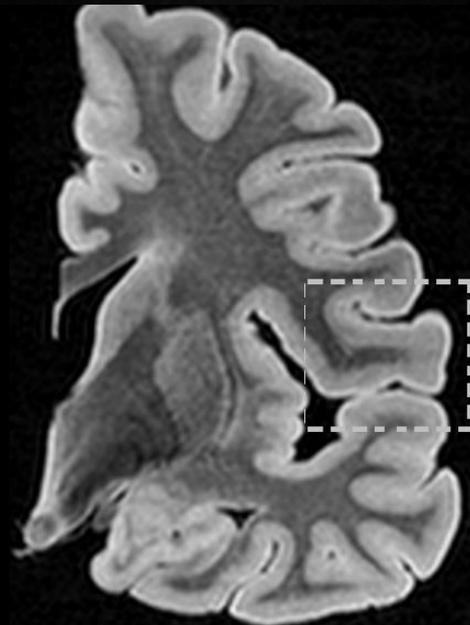
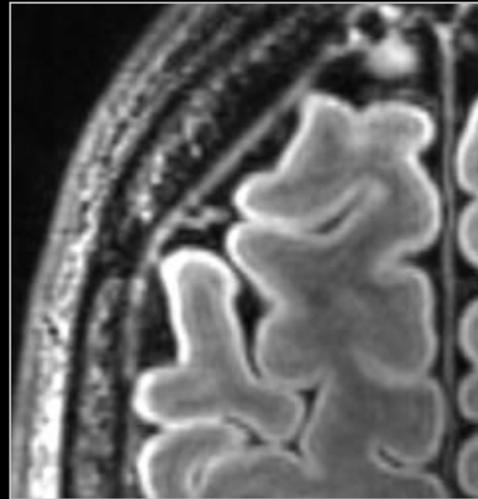
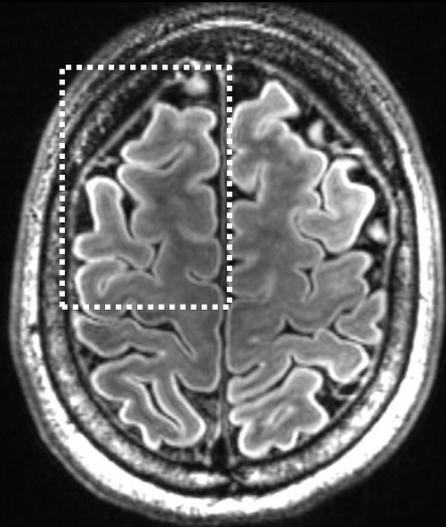
## Generalized Multiple-Layer Appearance of the Cerebral Cortex with 3D FLAIR 7.0-T MR Imaging<sup>1</sup>

*Radiology*: Volume 262: Number 3—March 2012 • [radiology.rsna.org](http://radiology.rsna.org)



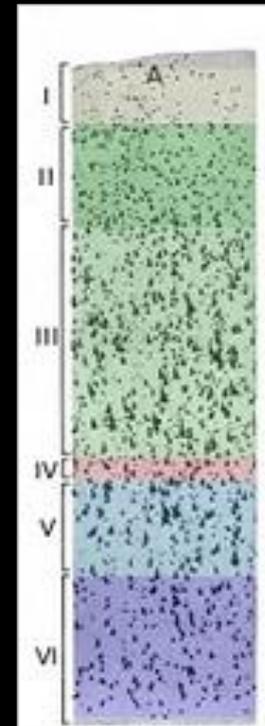
# Le cortex normal à 7T

## Micro-anatomie corticale



### Liseré périphérique hyperintense

- Artefact ?
- Méninges ?
- Couche corticale externe (Couche I) ?

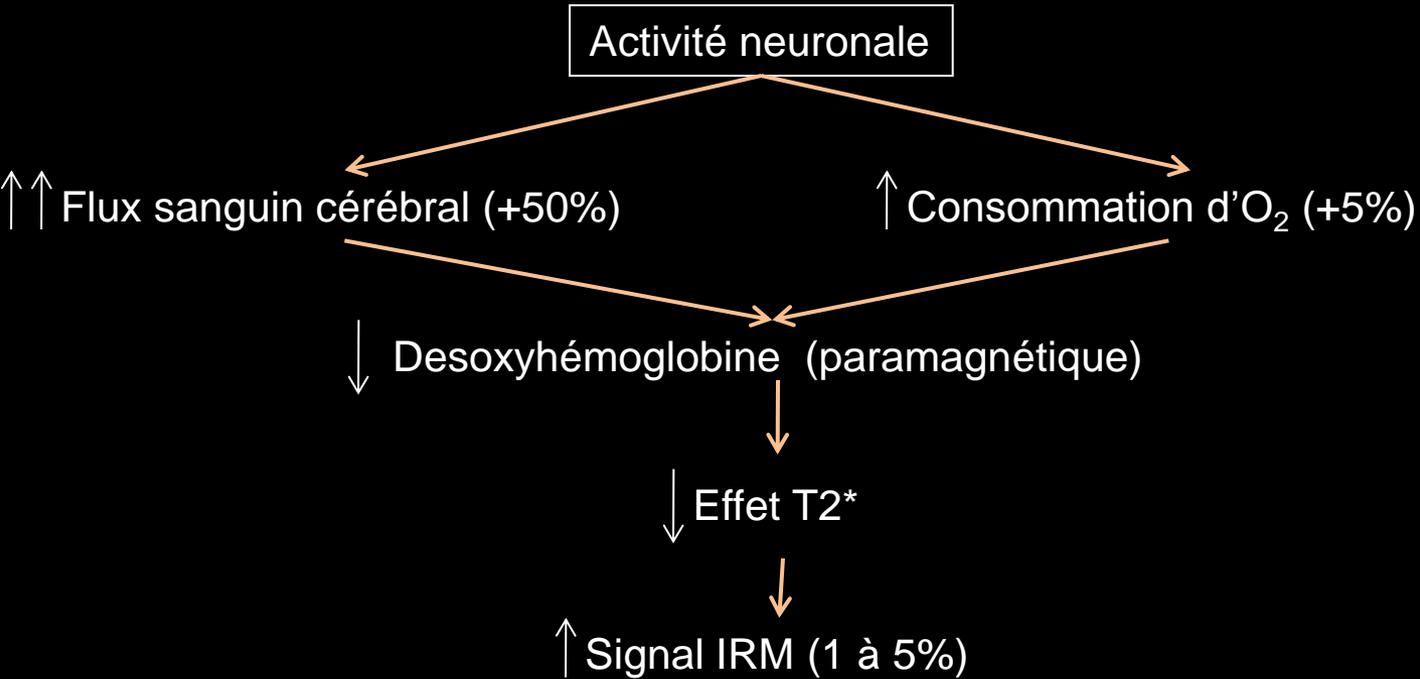


# Plan:

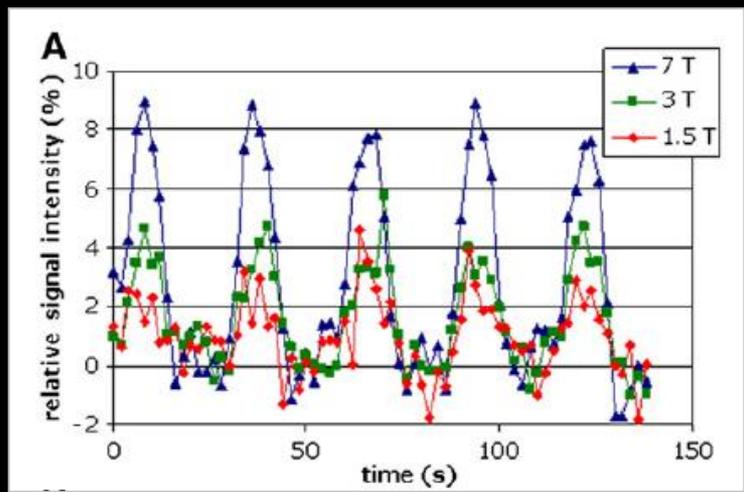
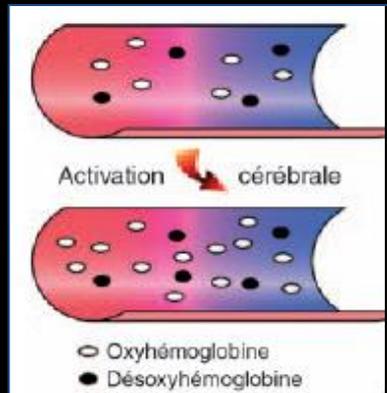
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# Le cortex normal à 7T

IRM fonctionnelle ultra haute résolution

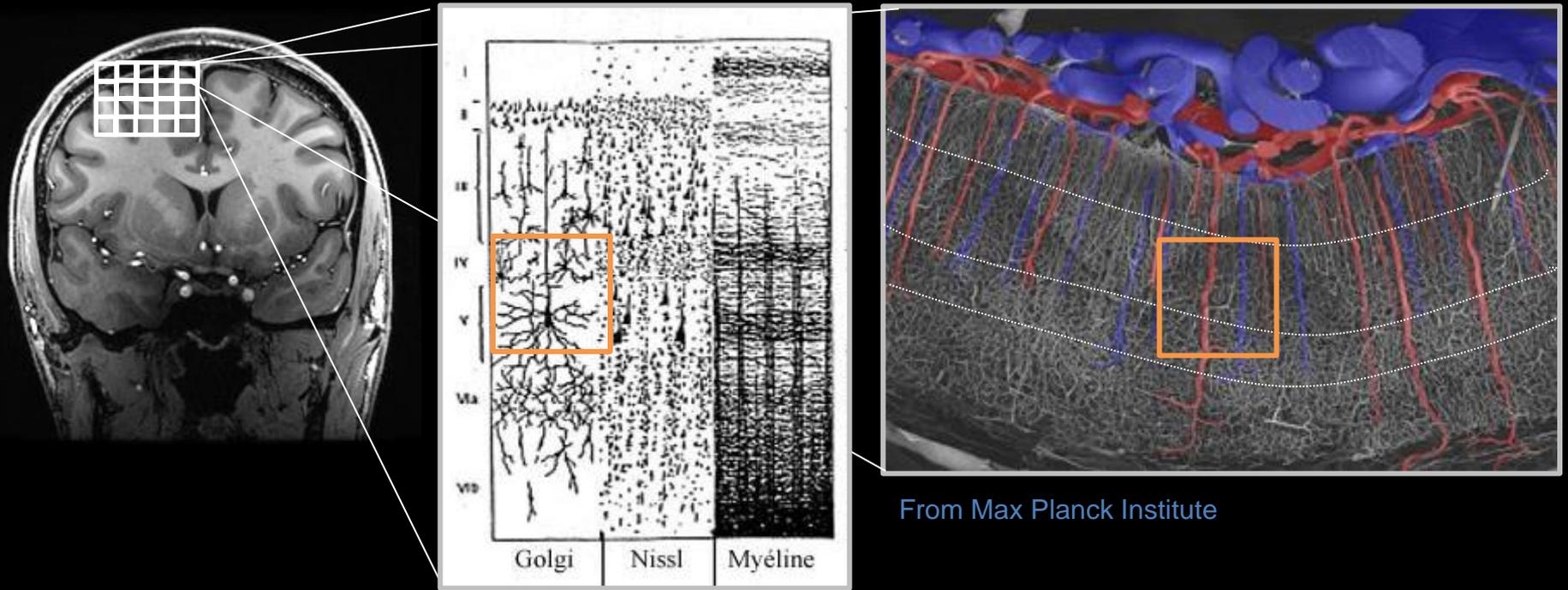


## Couplage neuro-vasculaire



# Le cortex normal à 7T

IRM fonctionnelle ultra haute résolution



IRMf jusqu'à une résolution laminaire : meilleure spécificité du signal BOLD

# Le cortex normal à 7T

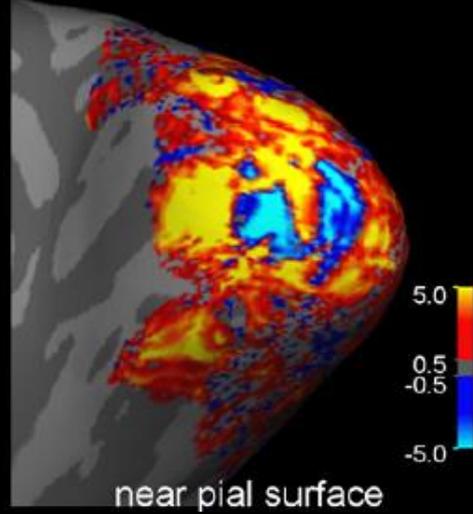
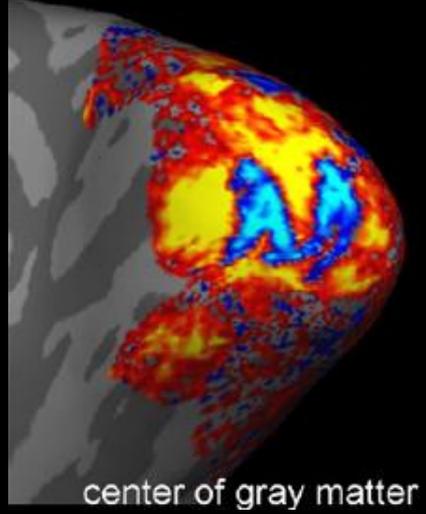
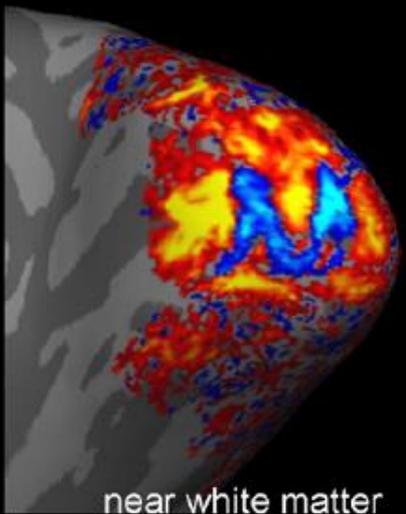
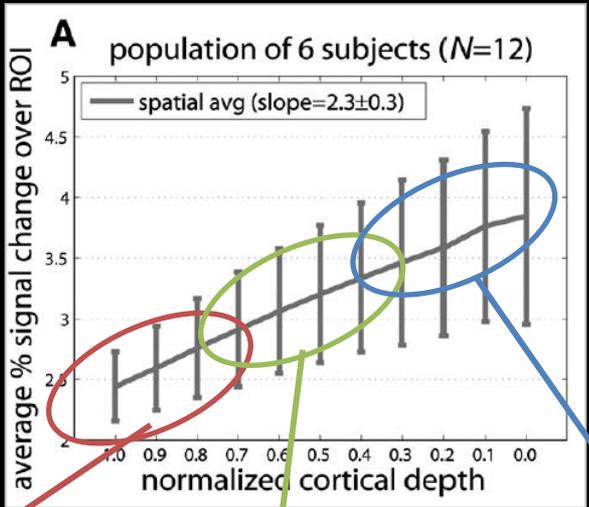
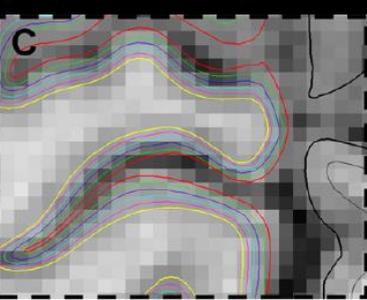
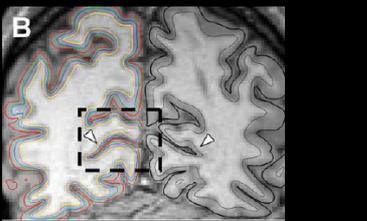
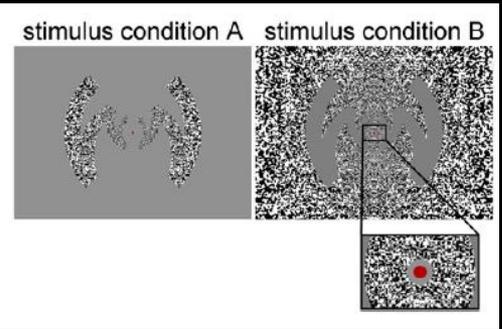
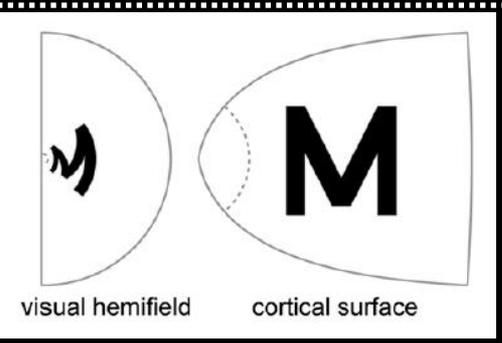
## IRM fonctionnelle ultra haute résolution

### Laminar analysis of 7 T BOLD using an imposed spatial activation pattern in human V1

Jonathan R. Polimeni <sup>a,\*</sup>, Bruce Fischl <sup>a,b</sup>, Douglas N. Greve <sup>a</sup>, Lawrence L. Wald <sup>a,c</sup>

<sup>a</sup> Athinoula A. Martinos Center for Biomedical Imaging, Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Bldg 149 Thirteenth St., Suite 2301, Charlestown, MA 02129, USA  
<sup>b</sup> Computer Science and Artificial Intelligence Laboratory (CSAIL), Massachusetts Institute of Technology, Cambridge, MA, USA  
<sup>c</sup> Harvard-MIT Division of Health Sciences and Technology, Massachusetts Institute of Technology, Cambridge, MA, USA

Neuroimage 2010



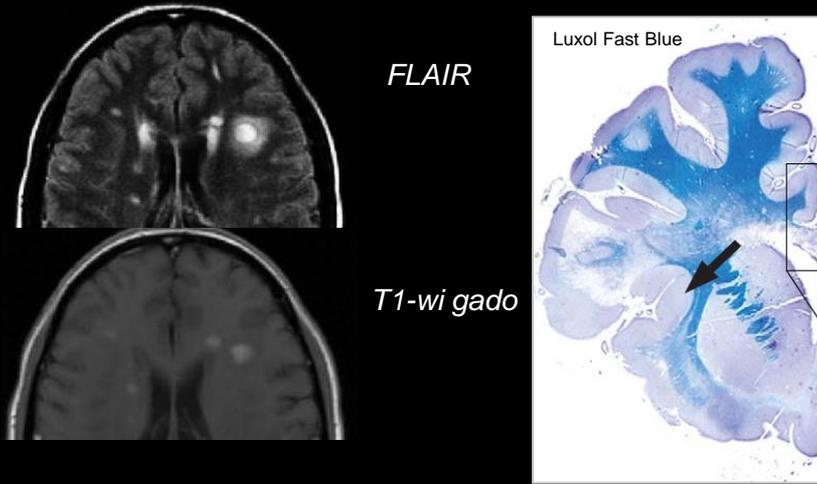
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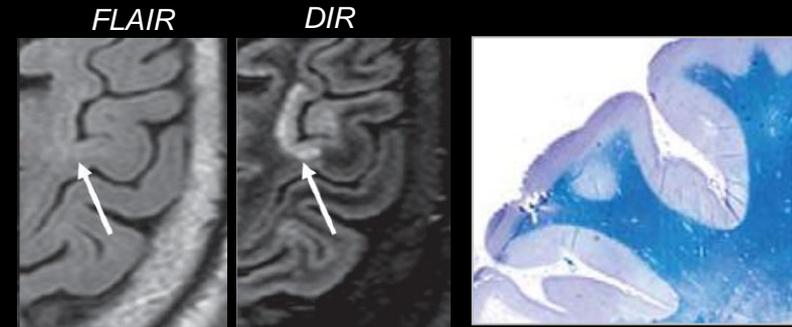
# Sclérose en plaque et atteinte corticale

Difficultés à 1.5T et 3T

## Atteinte de la Substance Blanche



## Atteinte de la Substance Grise



Calabrese *et al.* *Nature Review Neurology* 2010; 6:438-44

## Lésions corticales

- Petite taille
- Volume partiel (LCR)
- Faible contenu en myéline de la SG adjacente
- Moins d'inflammation que dans les lésions de la SB
- Absence de rupture de la BHE

Pb. de résolution spatiale

Pb. de résolution en contraste

## Double Inversion Récupération (DIR) à 1.5T et 3T

- Accord complet inter lecteurs ~ 20%
- Sensibilité ~ 18%

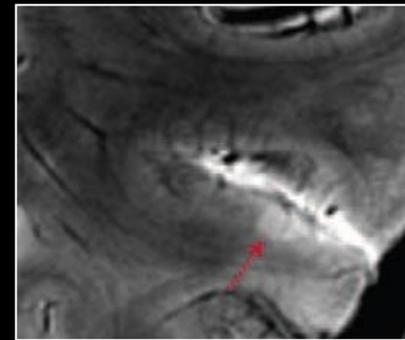
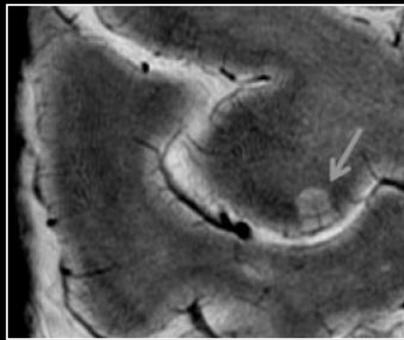
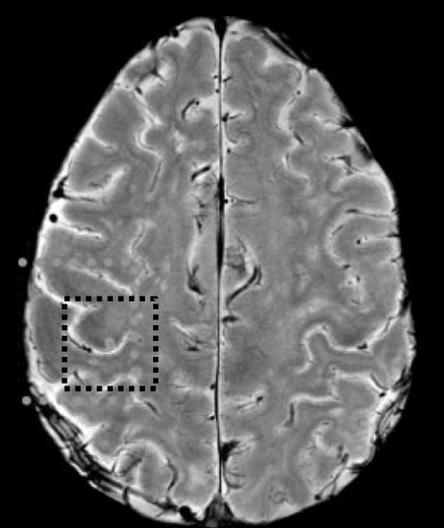
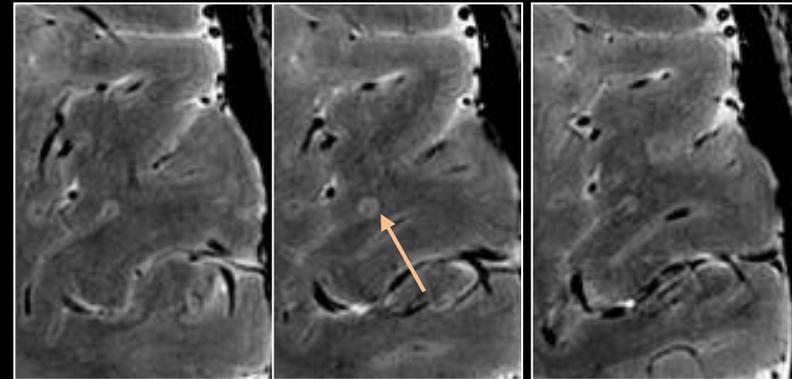
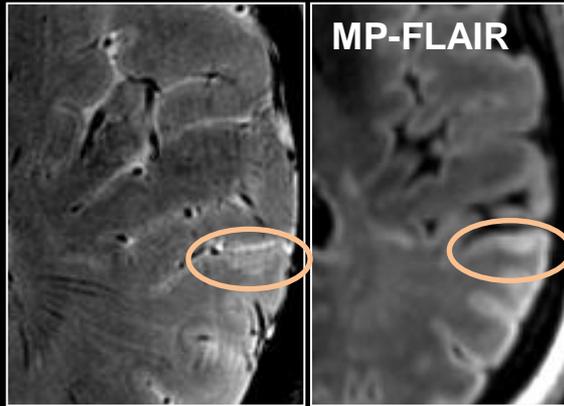
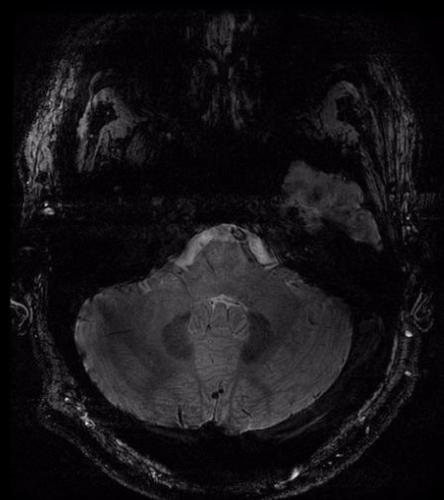
Geurts *et al.* *Neurology* 2011; 76:418-24

Steewann *et al.* *Neurology* 2012; 78:302-8

# Sclérose en plaque et atteinte corticale

Apport potentiel du 7T – séquence T2\*

FAST SPGR T2\* - 0.46 x 0.46 x 1.2mm - 91 slices (supra tentorial brain) - ≈8 min

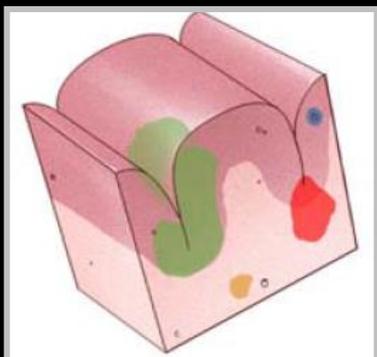


Metcalf *et al.* J Neuroimaging 2010; 20:141-47

Mainero *et al.* Neurology 2009; 73:941-48

# Sclérose en plaque et atteinte corticale

Apport potentiel du 7T – séquence T2\*



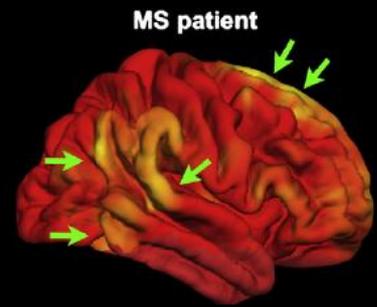
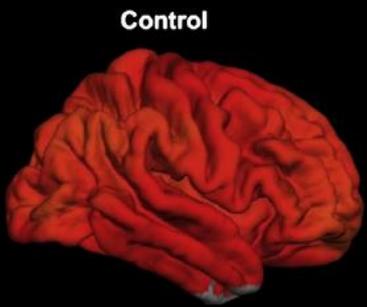
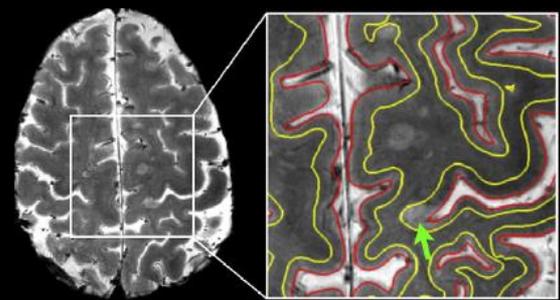
	7-T MRI		Pathology (study 1'), %	Pathology (study 2'), %
	%	(n)		
All types	100	(199)	100	100
Type I	36.2	(72)	34	38
Type II	13.6	(27)	16	18
Type III/IV	50.2	(100)	50	44

Lucchinetti *et al.* NEJM 2011; 365:2188-97

Mainero *et al.* Neurology 2009; 73:941-48

	3T – DIR	7T- FLASH T2*
Nombre de lésions corticales	N=18	N=88
Reproductibilité inter observateur (k)	K=0.12	K=0.97

Nielsen *et al.* JMRI 2012; 35:537-42

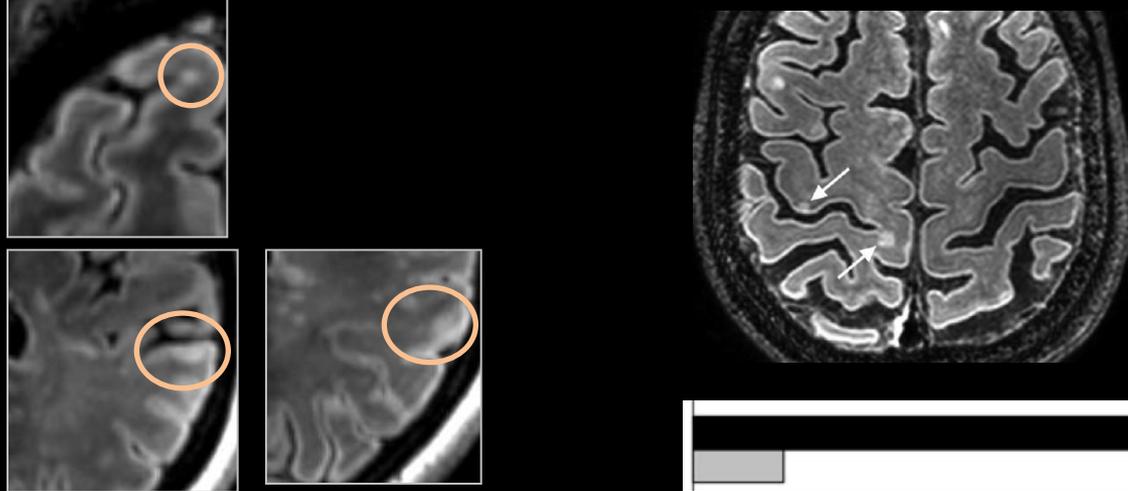


Cohen-Adad *et al.* Neuroimage 2011; 57:55-62

# Sclérose en plaque et atteinte corticale

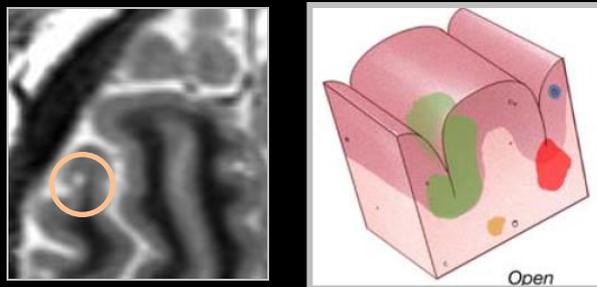
Apport potentiel du 7T – séquences avec suppression tissulaire

MP-FLAIR – 0.8 x 0.8 x 0.8mm - 200 slices (whole brain) - ≈ 5:40 min



de Graaf *et al.* Eur Radiol 2012; [Epub ahead of print]

MPRAGE with WM suppression - 0.8 x 0.8 x 0.8mm - 200 slices (whole brain) - ≈8 min

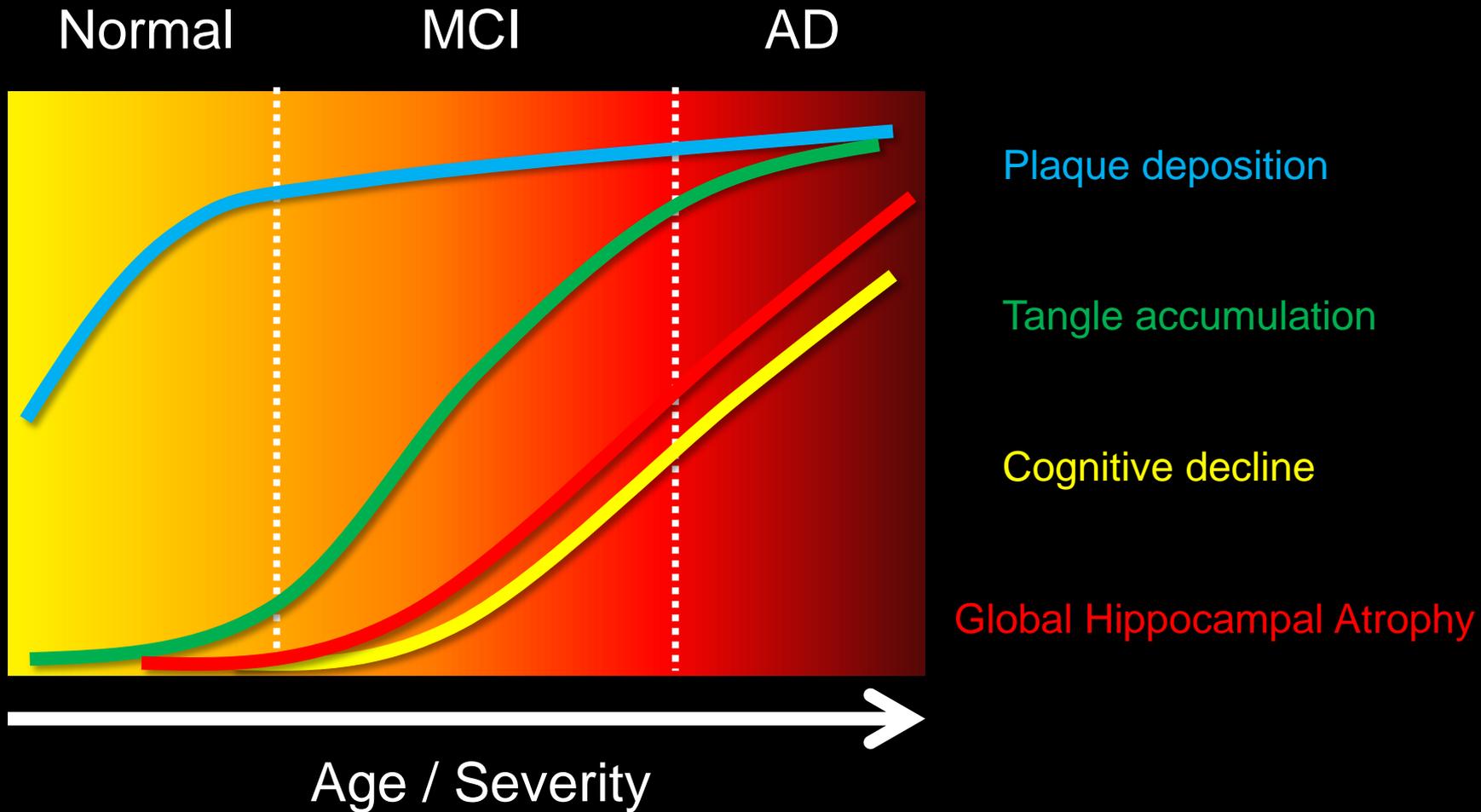


# Plan:

1. Les atouts du 7T pour l'imagerie du cortex
2. Les challenges du 7T pour l'imagerie du cortex
3. Le cortex normal à 7T
  - Micro-anatomie corticale
  - Fonction
4. Applications pathologiques
  - Plaques corticales et sclérose en plaques
  - Segmentation de sous volumes hippocampiques

# Maladie d'Alzheimer

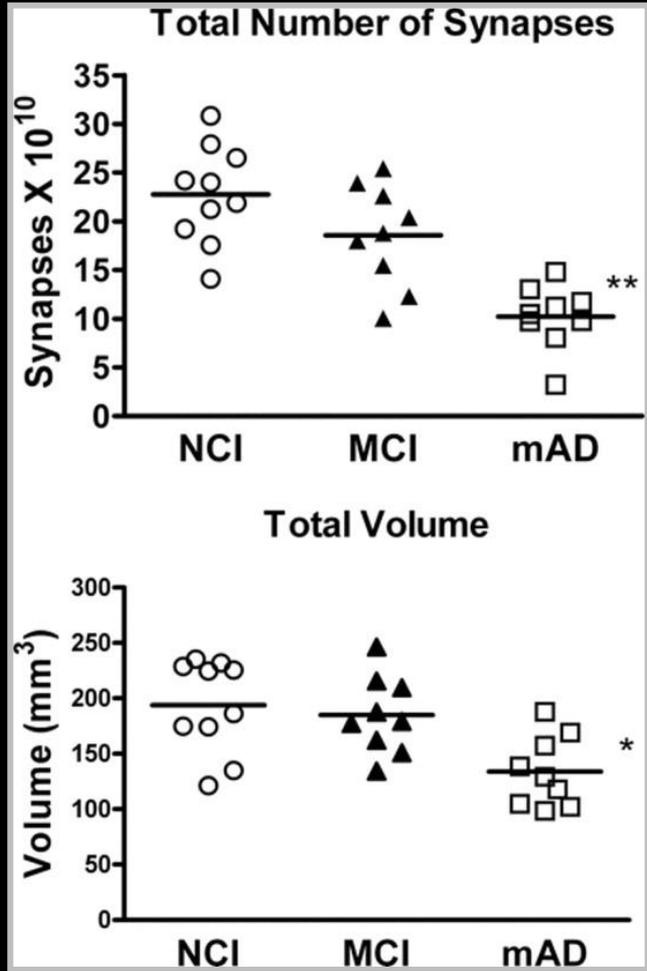
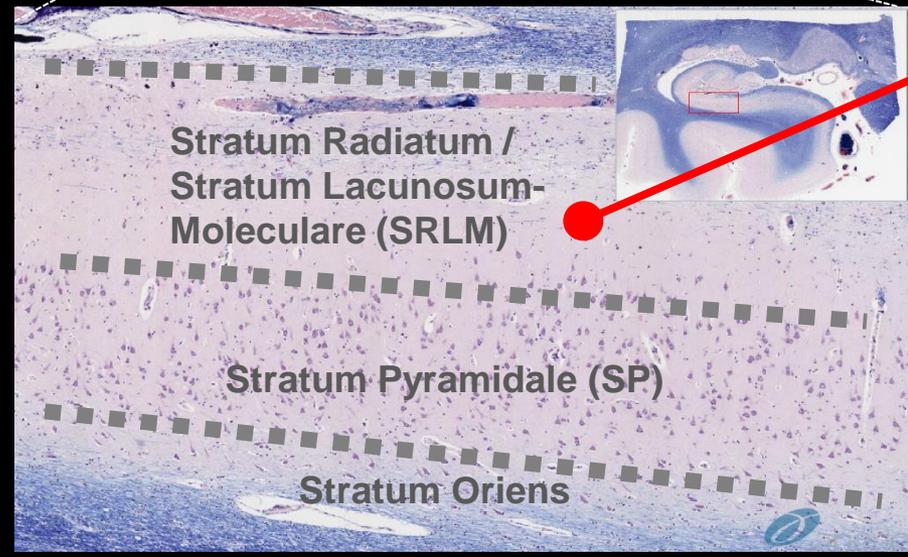
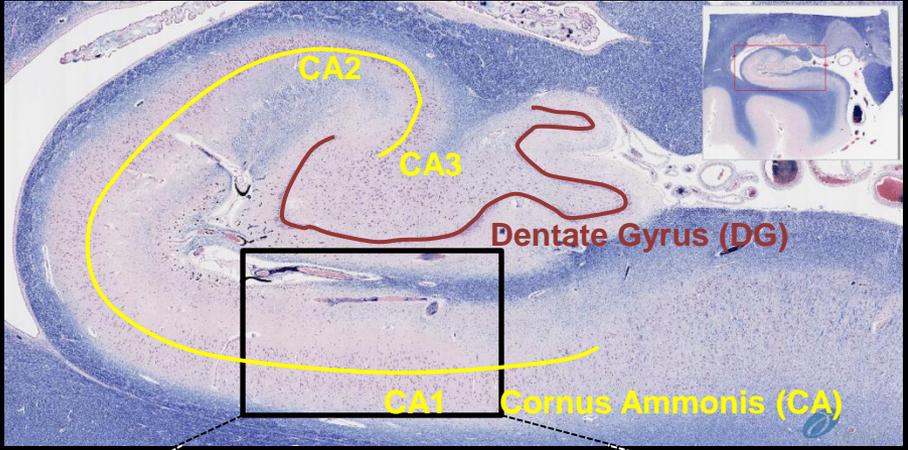
Hypothèse temporelle



*Une atteinte « locale » plus précoce que l'atteinte « globale »*

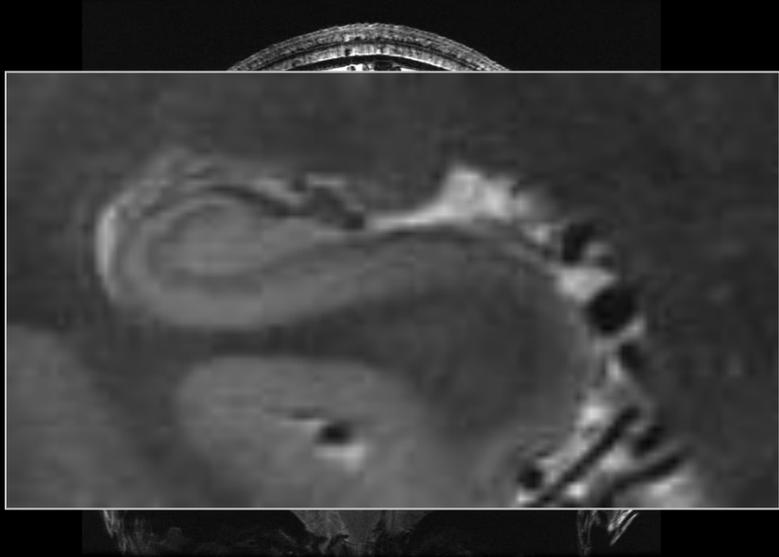
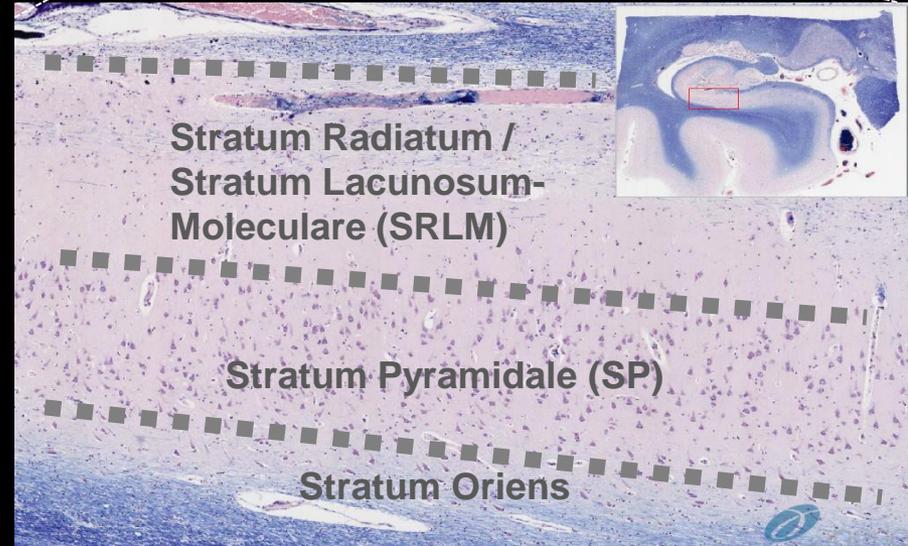
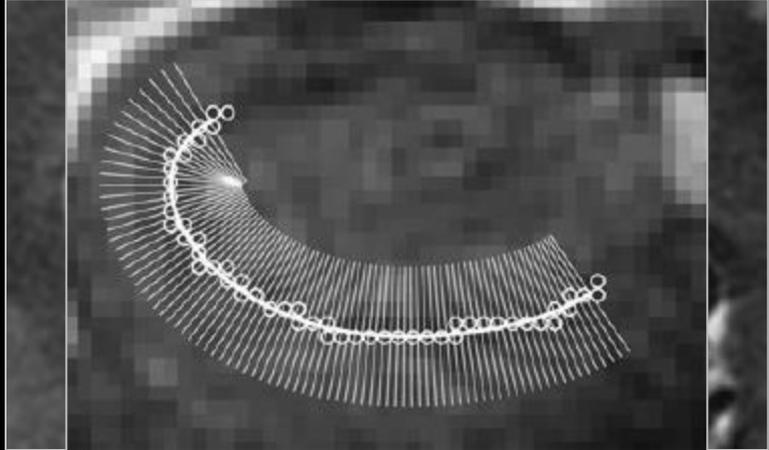
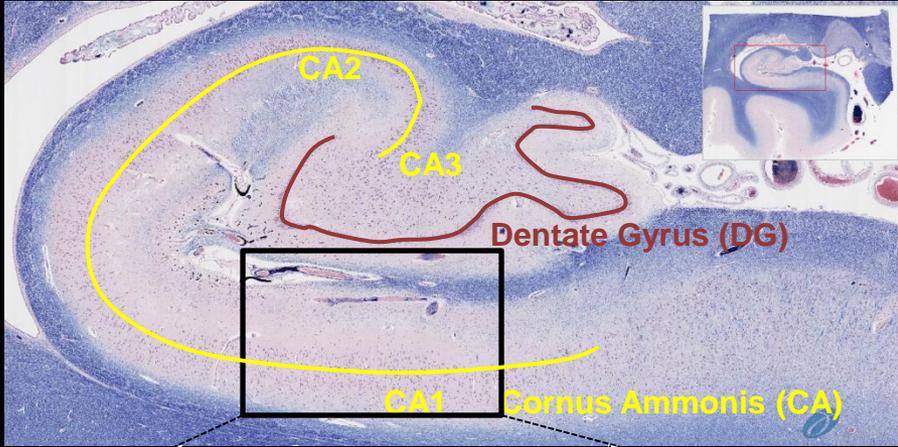
# Maladie d'Alzheimer

## Couche synaptique de CA1



# Maladie d'Alzheimer

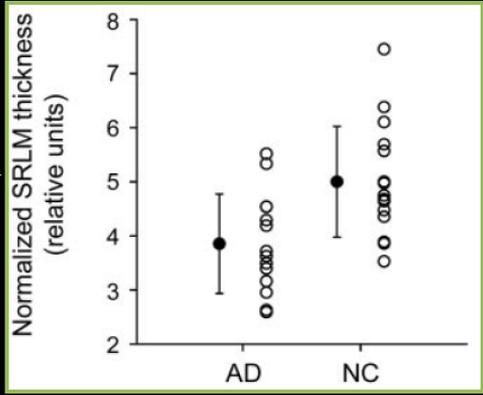
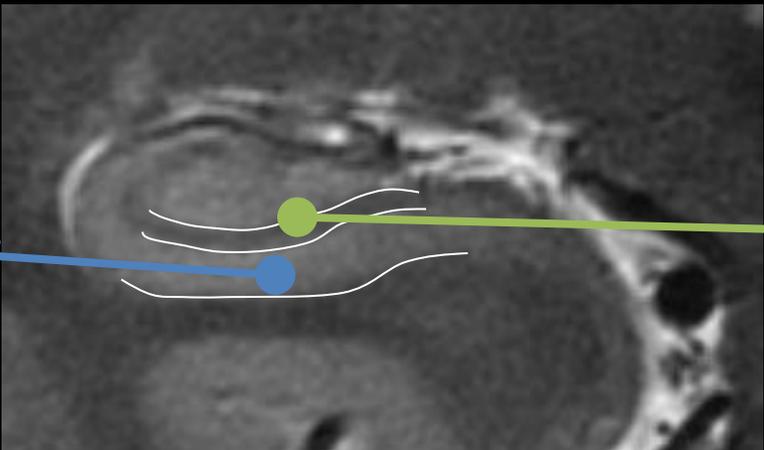
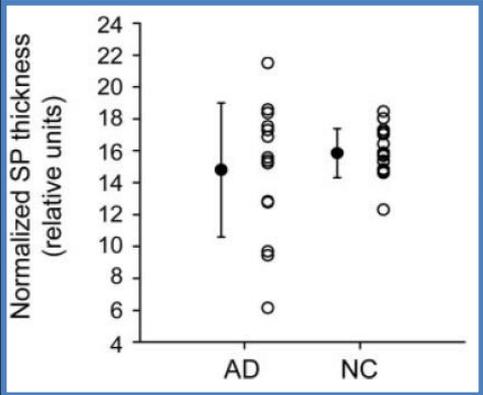
## Couche synaptique de CA1



T2 FSE - 0.2 x 0.2 x 1.5mm – Gating respiratoire - ≈10 min

# Maladie d'Alzheimer

## Couche synaptique de CA1

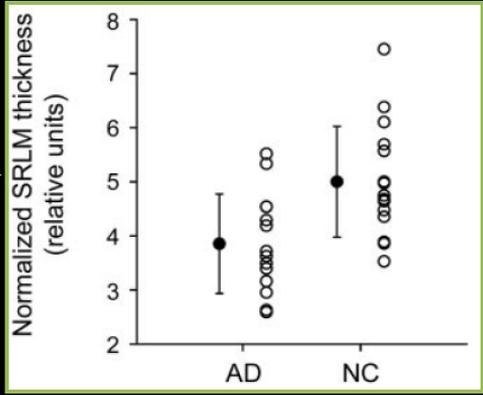
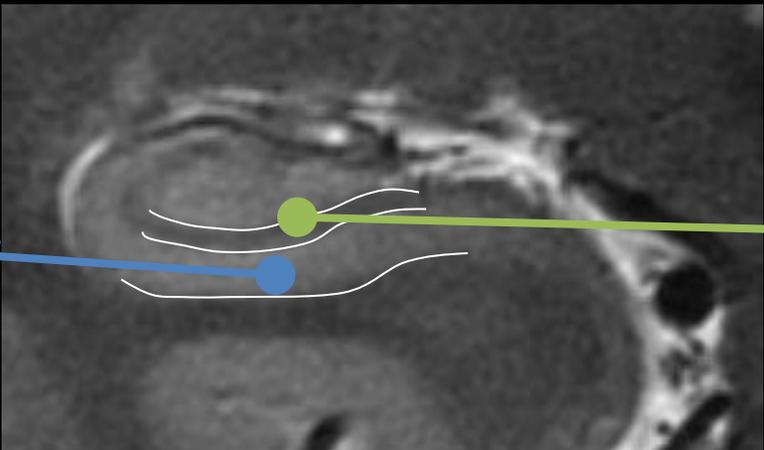
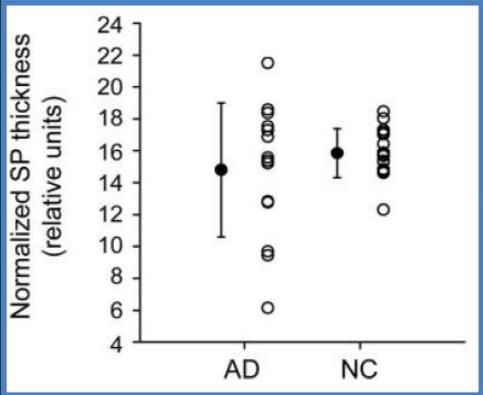


	AD (n = 14)	NC (n = 16)	P
Age	66 ± 8	67 ± 5	0.56
Normalized Total Hippocampal Volume	4.5 ± 1	5.1 ± 0.6	0.15
Normalized CA1-SRLM thickness	3.9 ± 0.9	5.0 ± 1	0.003
Normalized CA1-SP thickness	14.8 ± 4.2	15.9 ± 1.5	0.8
Absolute CA1-SRLM thickness (mm)	0.43 ± 0.1	0.58 ± 0.1	0.001
Absolute CA1-SP thickness (mm)	1.7 ± 0.5	1.8 ± 0.2	0.19

Kerchner *et al.* Neuroimage 2012; 63:194-202  
 Kerchner *et al.* Neurology 2010; 75:1381-87

# Maladie d'Alzheimer

## Couche synaptique de CA1

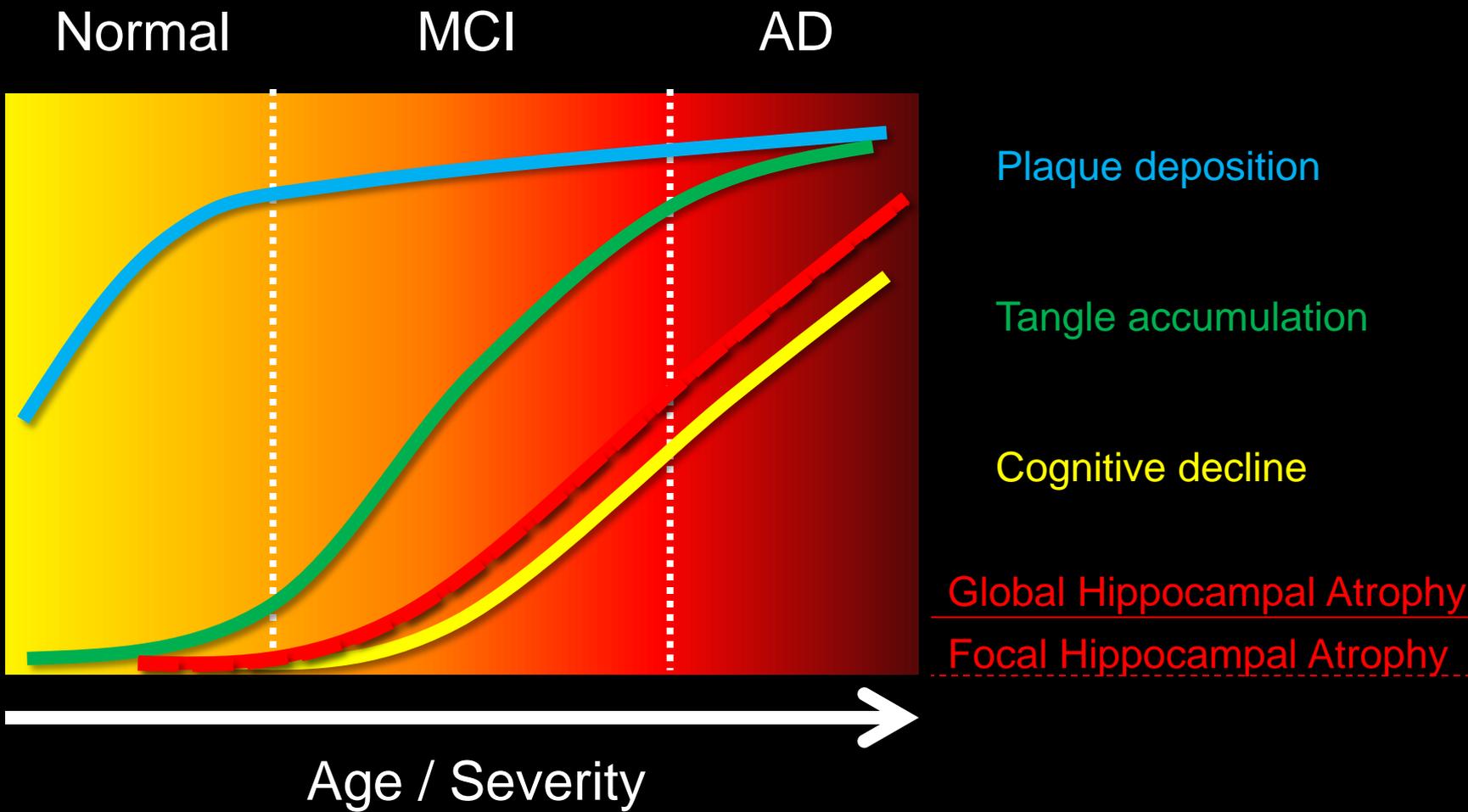


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Absolute CA1-SP thickness (mm)	1.7 ± 0.5	1.8 ± 0.2	0.19

Kerchner *et al.* Neuroimage 2012; 63:194-202  
 Kerchner *et al.* Neurology 2010; 75:1381-87

# Maladie d'Alzheimer

Hypothèse temporelle



# Conclusion

**Un outil pour une meilleure compréhension du cortex normal**

**Et pathologique...**

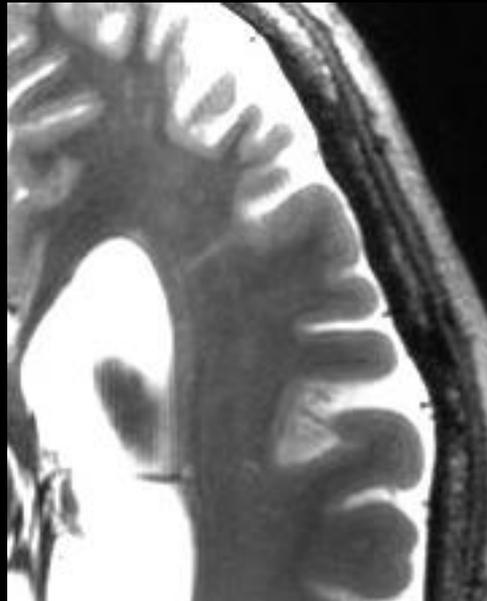
**SEP**

**Alzheimer et hippocampe**

**Sclérose mésiale**

**Dysplasie corticale focale**

....



➤ **Radiological Sciences Laboratory : “Ultra high Field Program”**

Brian Rutt

Manoj Saranathan

Ives Levesque

Michael Zeineh

Jaon Su

Medhi Khalighi

Jennifer Mcnab

Simone Winkler

➤ **Neurology departments**

Geoff Kerchner

May Han



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