

Imagerie par Résonance Magnétique & Tomographie par Émission de Positons: **Applications en neuroscience**

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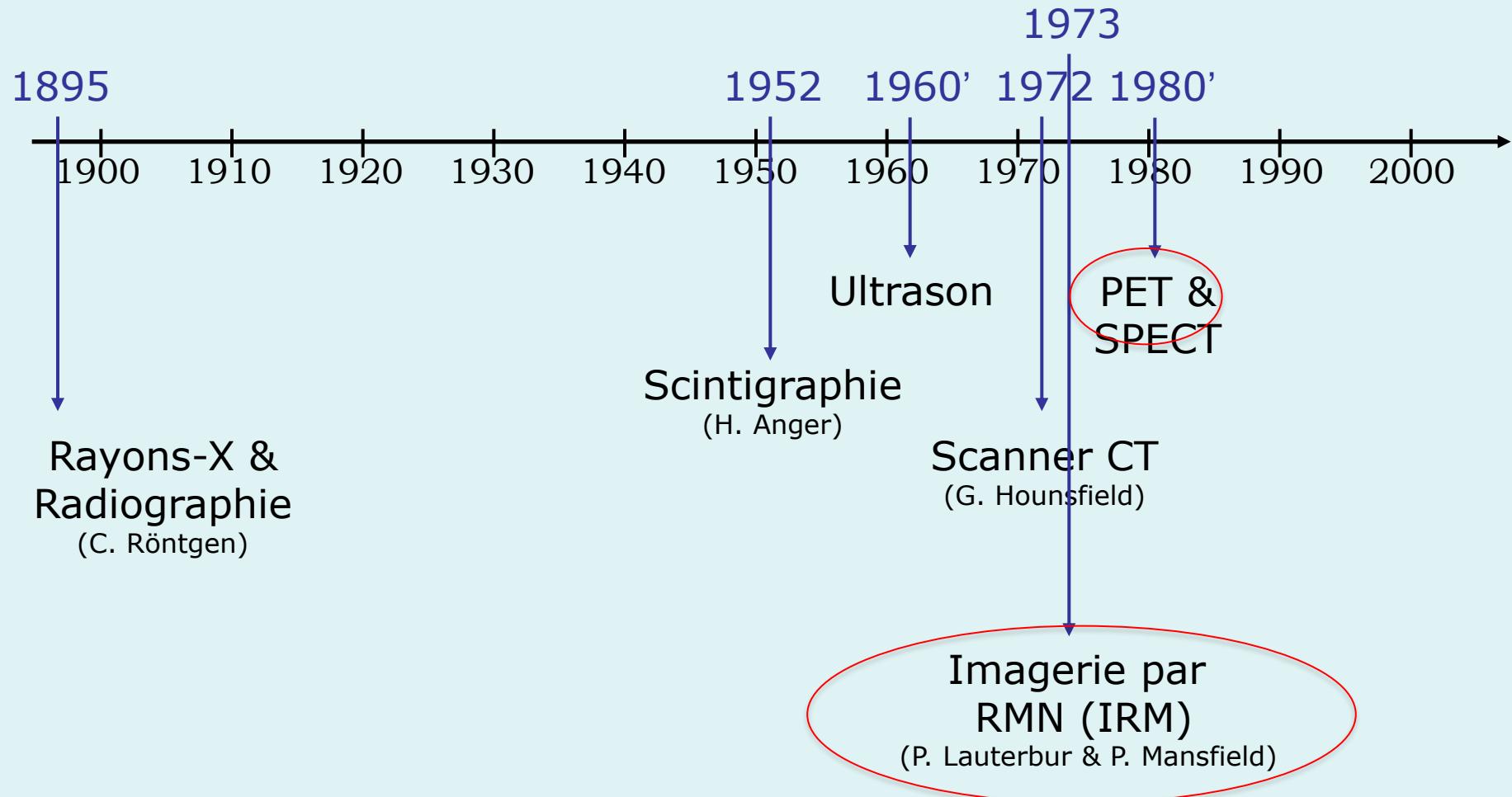
Imagerie médicale

Que peut-on voir **à l'intérieur** du corps humain?

Cela dépend de comment vous le regarder!



Historique



Index

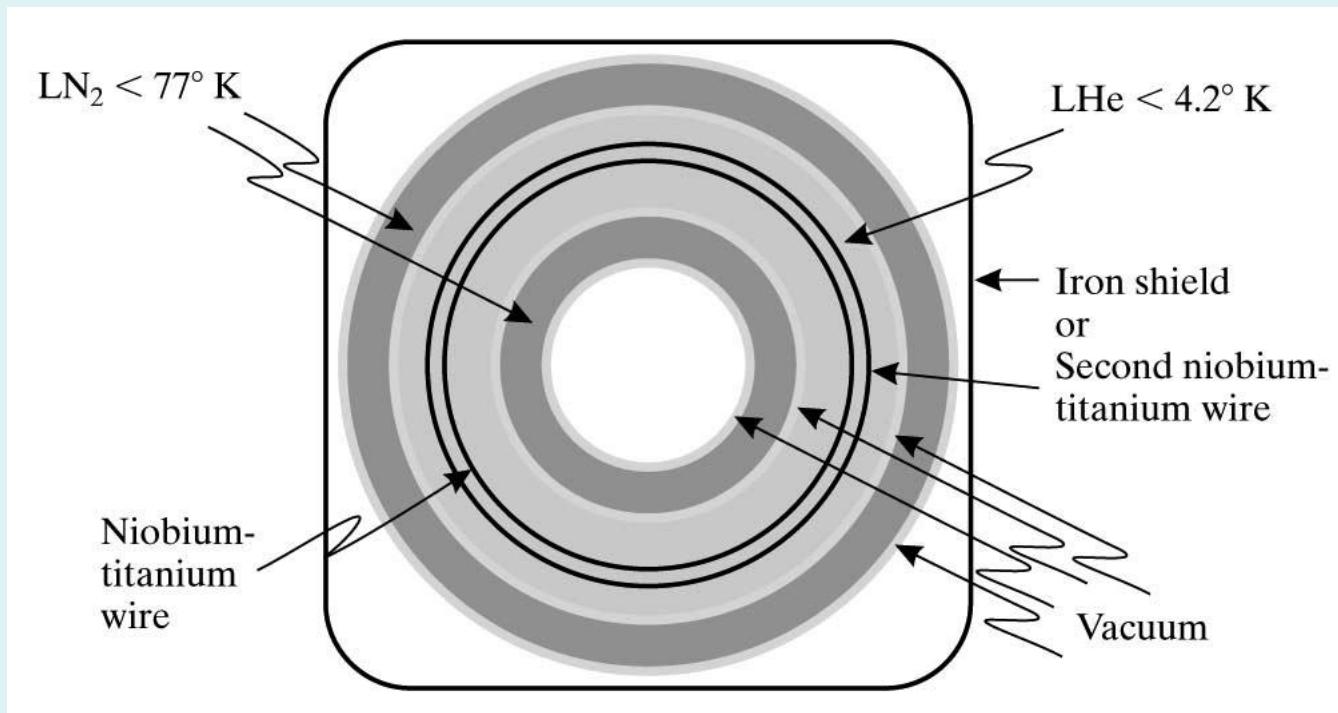
IRM et la TEP en neuroscience

- *Principes de l'IRM et la TEP*
- Application en TEP
- Application en IRM
- Conclusions

Instrumentation

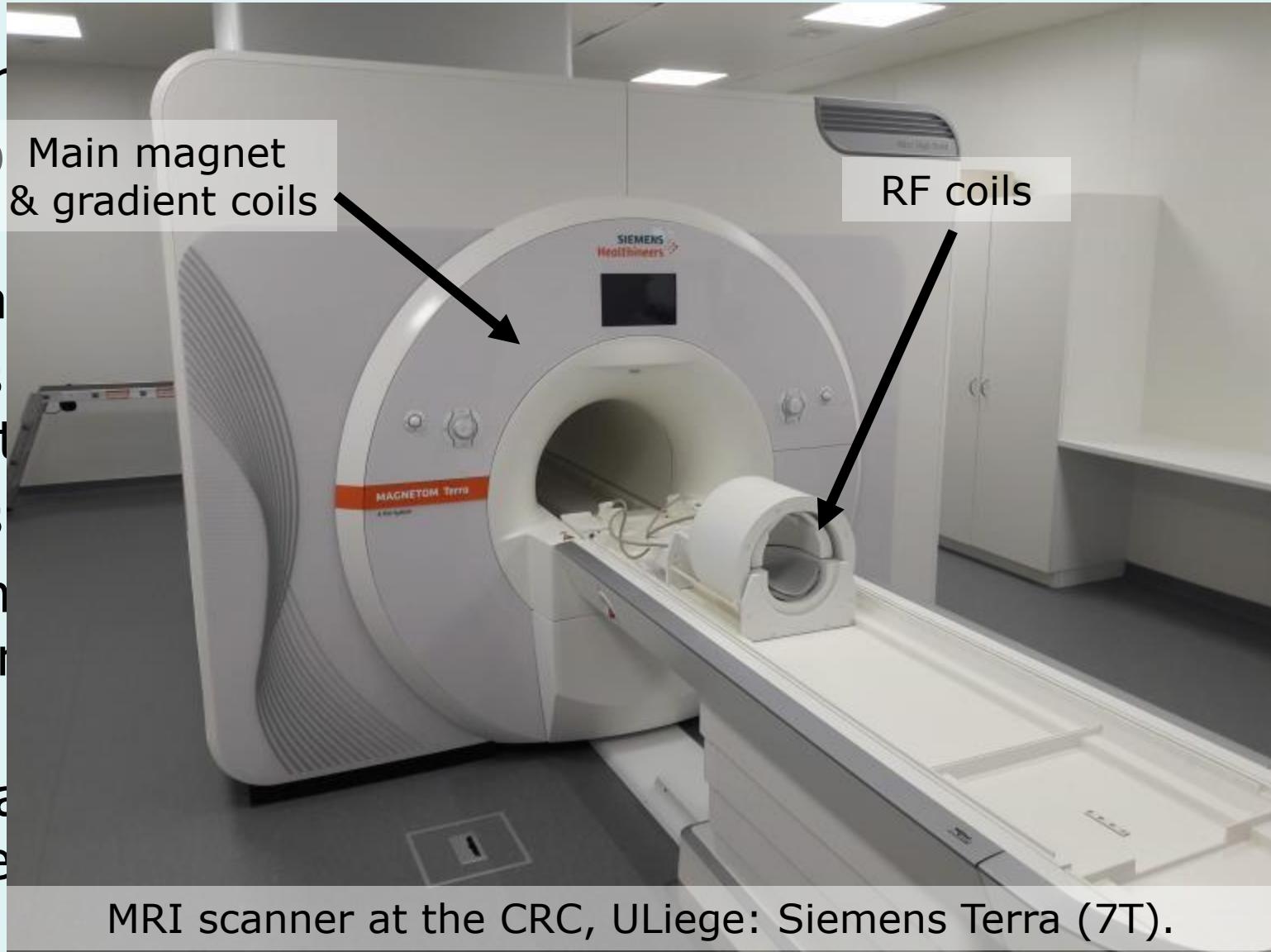
Aimant principal, dans He liquide ($<4.2^\circ\text{K}$):

- bobine supraconductrice
- champ magnétique (1.5T, 3T ou 7T)
- “**JAMAIS**” éteint !



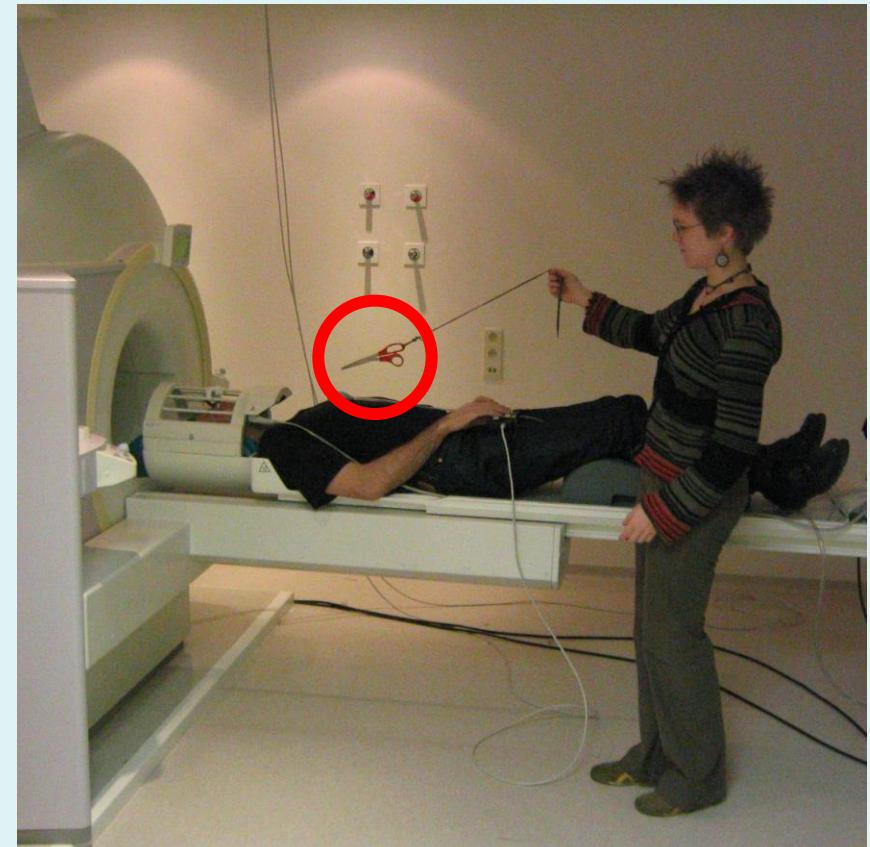
Instrumentation

- 5 éléments principaux
- aimant principal
 - bobines de gradient
 - bobines d'excitation
 - électronique de contrôle
 - console de visualisation et de contrôle

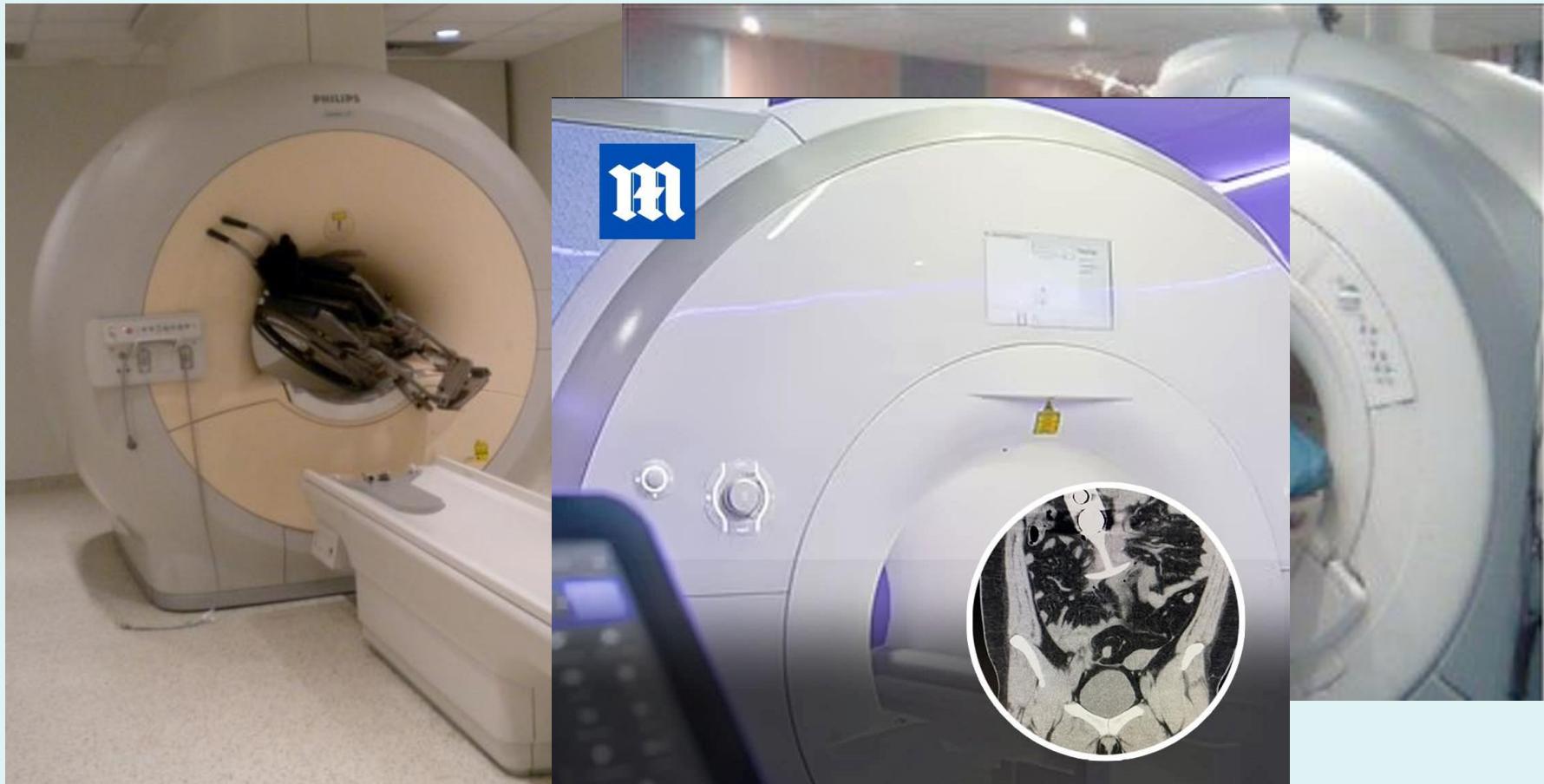


Instrumentation

Danger dû au champ magnétique !!!



Danger!



Woman suffers major injuries after 'mistakenly' wearing a sex toy to an MRI scan

Phénomène de relaxation

Effet macroscopique :

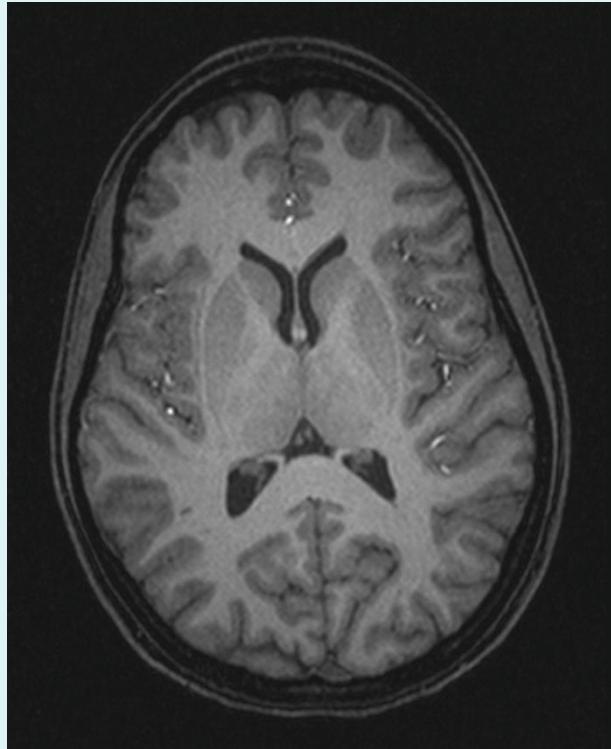
Valeurs typiques de T_1 et T_2 à 1.5 T

Tissus	T_1 (ms)	T_2 (ms)	ρ (%)
LCR	3000	200	100
Graisse	200	90	
MG	750	90	83
MB	500	75	70

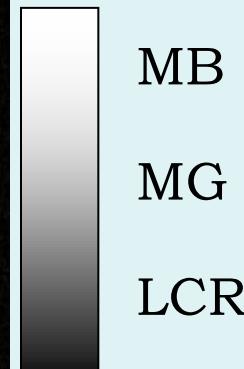
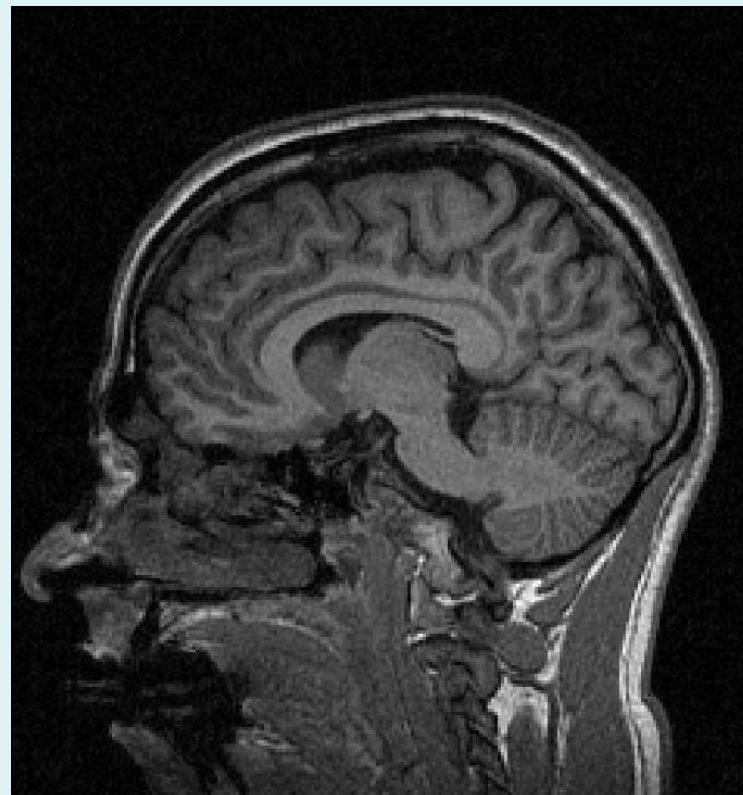
Structurelle classique

Image pondérée en T1

Tissus	T_1 (ms)
LCR	3000
Graisse	200
MG	750
MB	500



TR ~ 500 ms, TE ~ 10 ms



Structurelle classique

Images pondérée en ρ ou T_2

Tissus	T_2 (ms)	ρ (%)
LCR	200	100
Graisse	90	
MG	90	83
MB	75	70



TR = 3370 ms, TE = 112 ms

Médecine nucléaire → TEP

- Modalité d'imagerie utilisant l'*émission* de photons de l'intérieur du corps.
- Radiation ionisante produite par *décroissance radioactive* dans le corps
- *Biodistribution* du *radiotraceur* déterminée par les fonction *physiologiques* et *biochimiques* du corps
⇒ modalité d'imagerie **fonctionnelle**

Instrumentation, cyclotron



→ Production d'isotopes radioactifs

Radionucléides: émetteurs de positons

TABLE 7.1

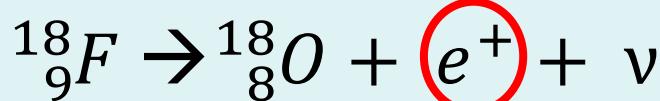
Common Radionuclides in Nuclear Medicine

Positron Emitters			
Z	Nuclide	Half-life	Positron Energy (keV)
6	Carbon-11	20.3 min	326
7	Nitrogen-13	10.0 min	432
8	Oxygen-15	2.1 min	696
9	Fluorine-18	110 min	202
29	Copper-64	12.7 h	656
31	Gallium-68	68 min	1,900
33	Arsenic-72	26 h	3,340
35	Bromine-76	16.1 h	3,600
37	Rubidium-82	1.3 min	3,150
53	Iodine-122	3.5 min	3,100

Source: Wolbarst, 1993.

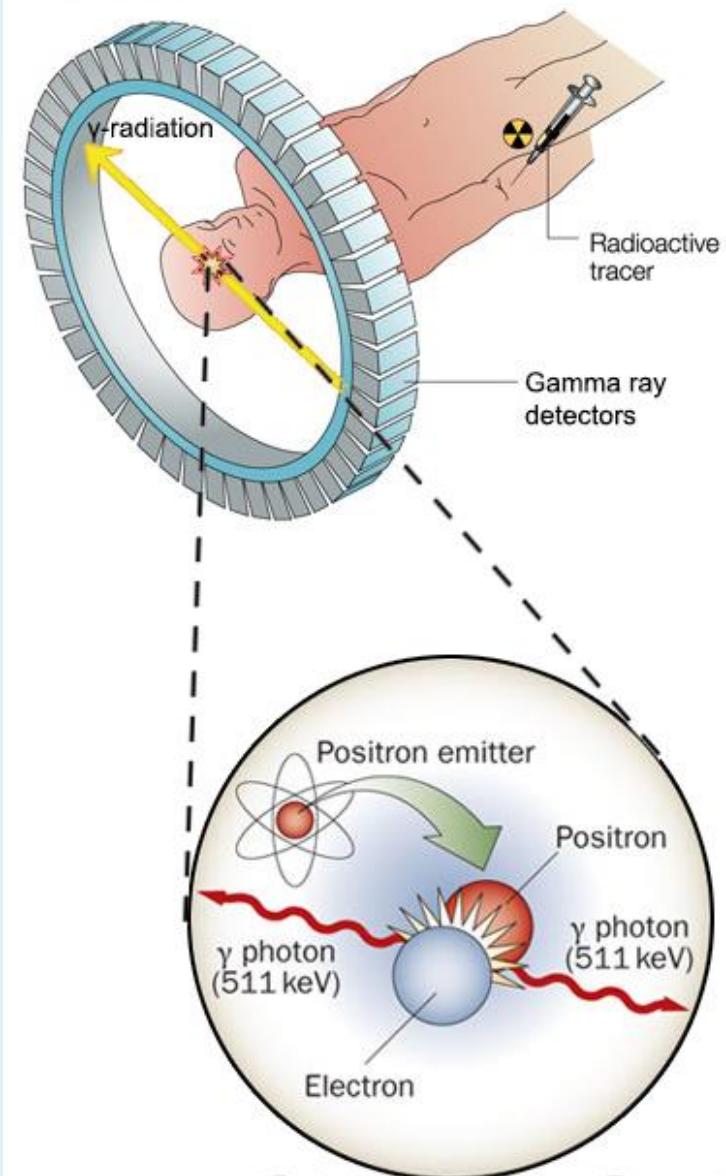
Principe du TEP

Décroissance par positon



- positon émis voyage de quelques *mm*
- rencontre un électron
- annihilation mutuelle
- émission 'back-to-back' de *deux* photons avec énergie 511 keV

511 keV = énergie équivalente à la masse au repos d'un electron/positron par $E = m_0 c^2$



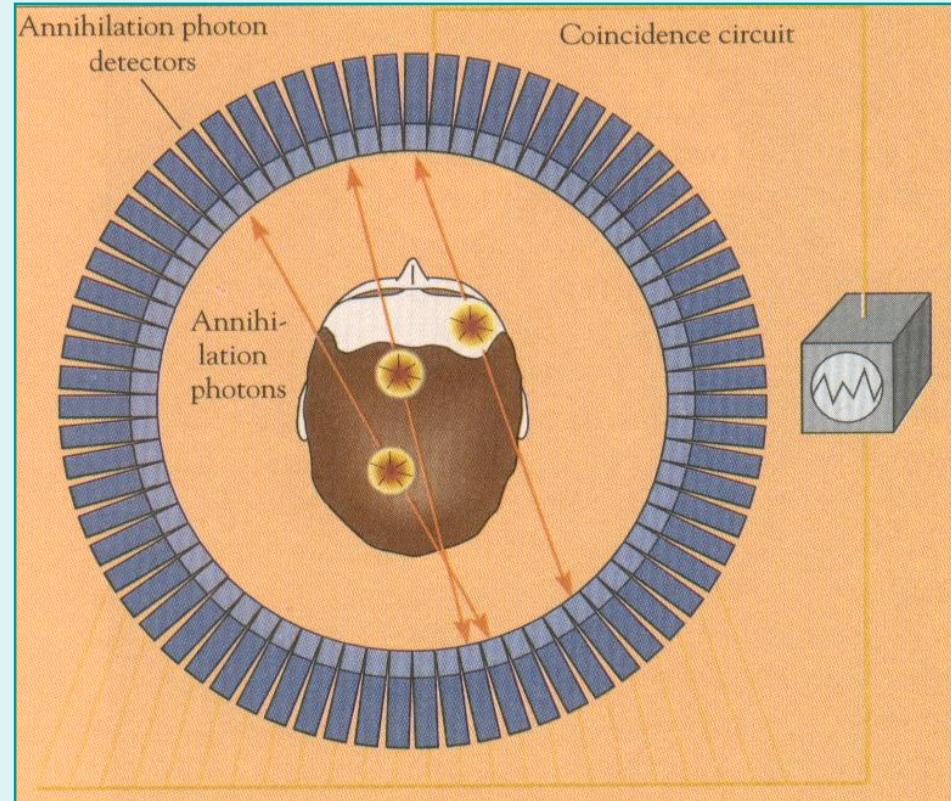
Instrumentation TEP

- Détection simultanée (dans une fenêtre temporelle de ~2-20ns) des 2 photons
⇒ Considéré comme un évènement unique
- Autres detections rejetées
- Pas de collimateur

Un événement

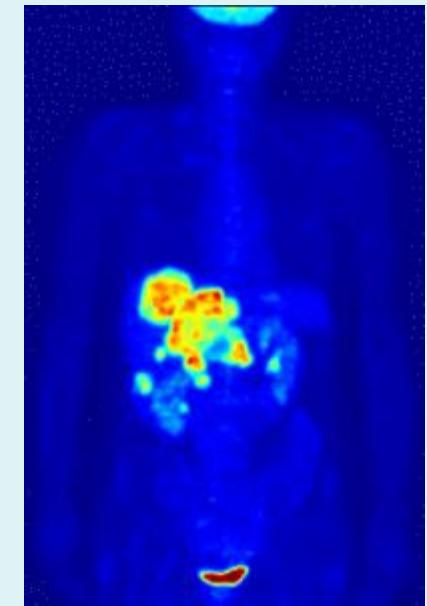
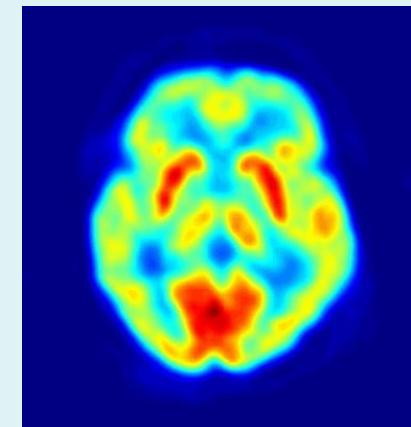
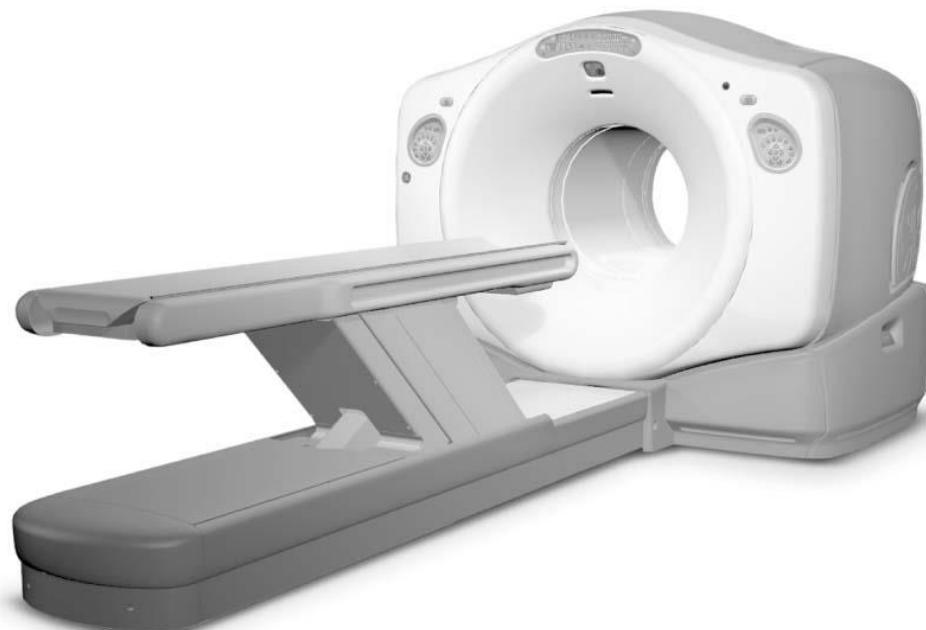
= annihilation le long
de la *ligne de
coïncidence* joignant
2 détecteurs.

→ Reconstruction de la
distribution spatiale dans
le corps du patient

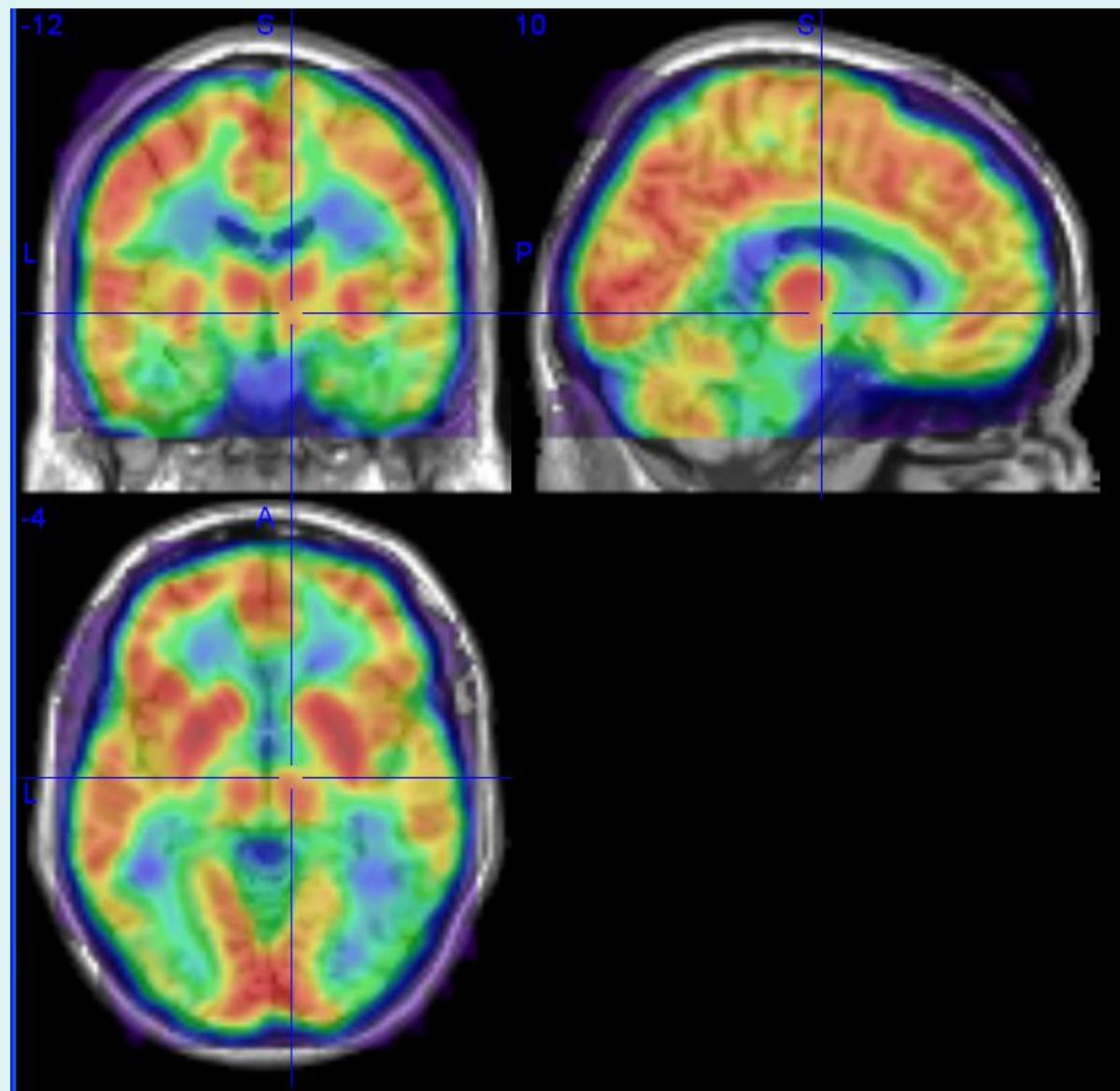


Tomographie par Émission de Positons

- Scanner TEP typique,
- Fluorodésoxyglucose (FDG) = analogue radiopharmaceutique du glucose, marqué au ^{18}F



Combinaison de TEP & IRM structurelle



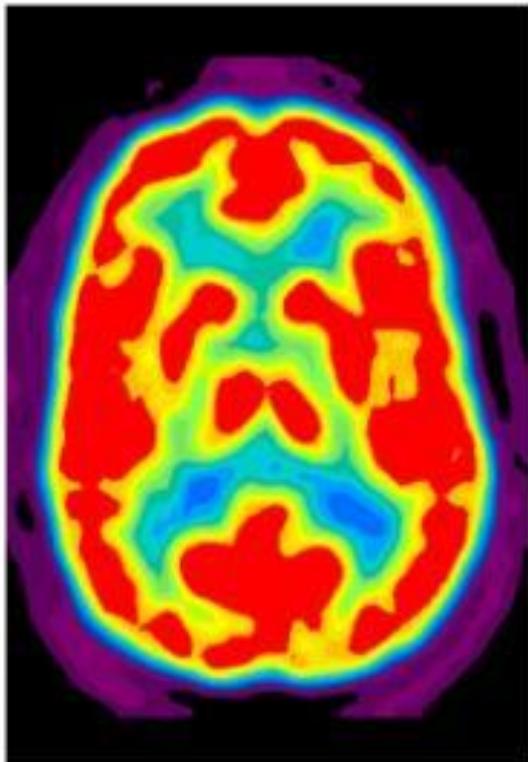
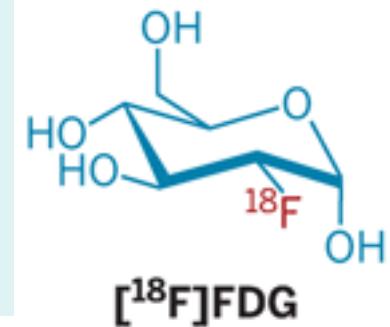
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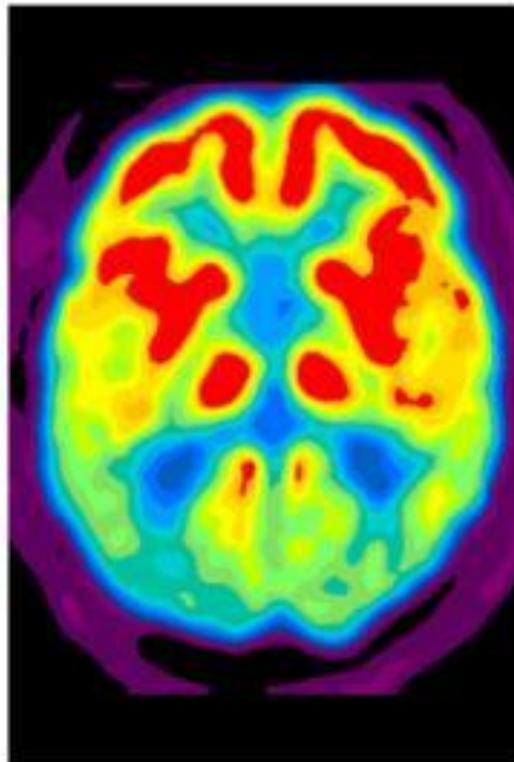
Application de la TEP

Fluorodeoxyglucose (FDG)



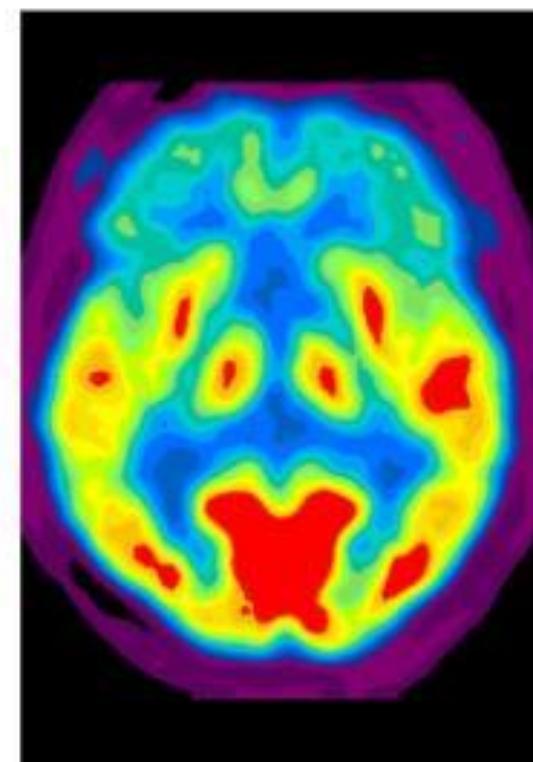
Normal

Consistent metabolic activity throughout the cerebral cortex



Alzheimer's Dementia

Reduced metabolic activity in the temporal and parietal lobes

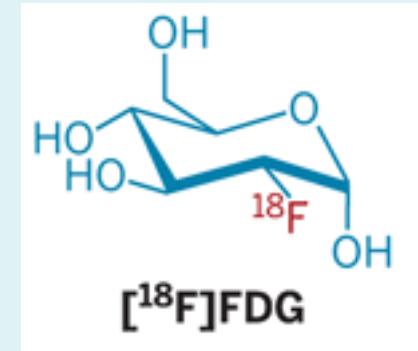
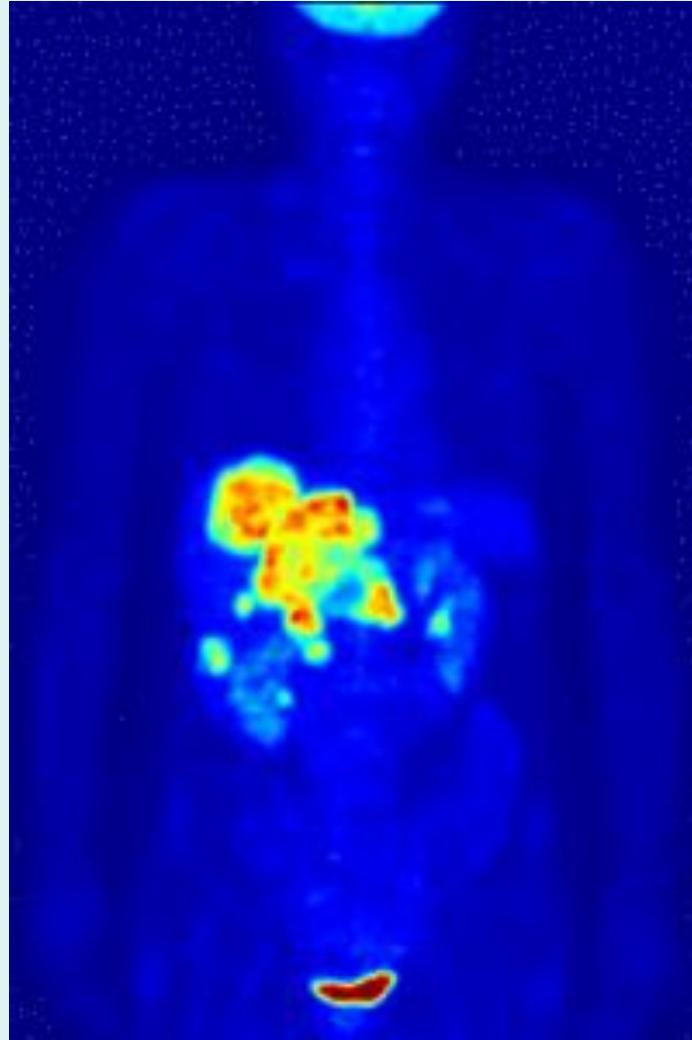


Frontal Lobe Dementia (Pick's Disease)

Reduced metabolic activity in the frontal lobe

Application de la TEP

Fluorodeoxyglucose (FDG)
→ oncologie

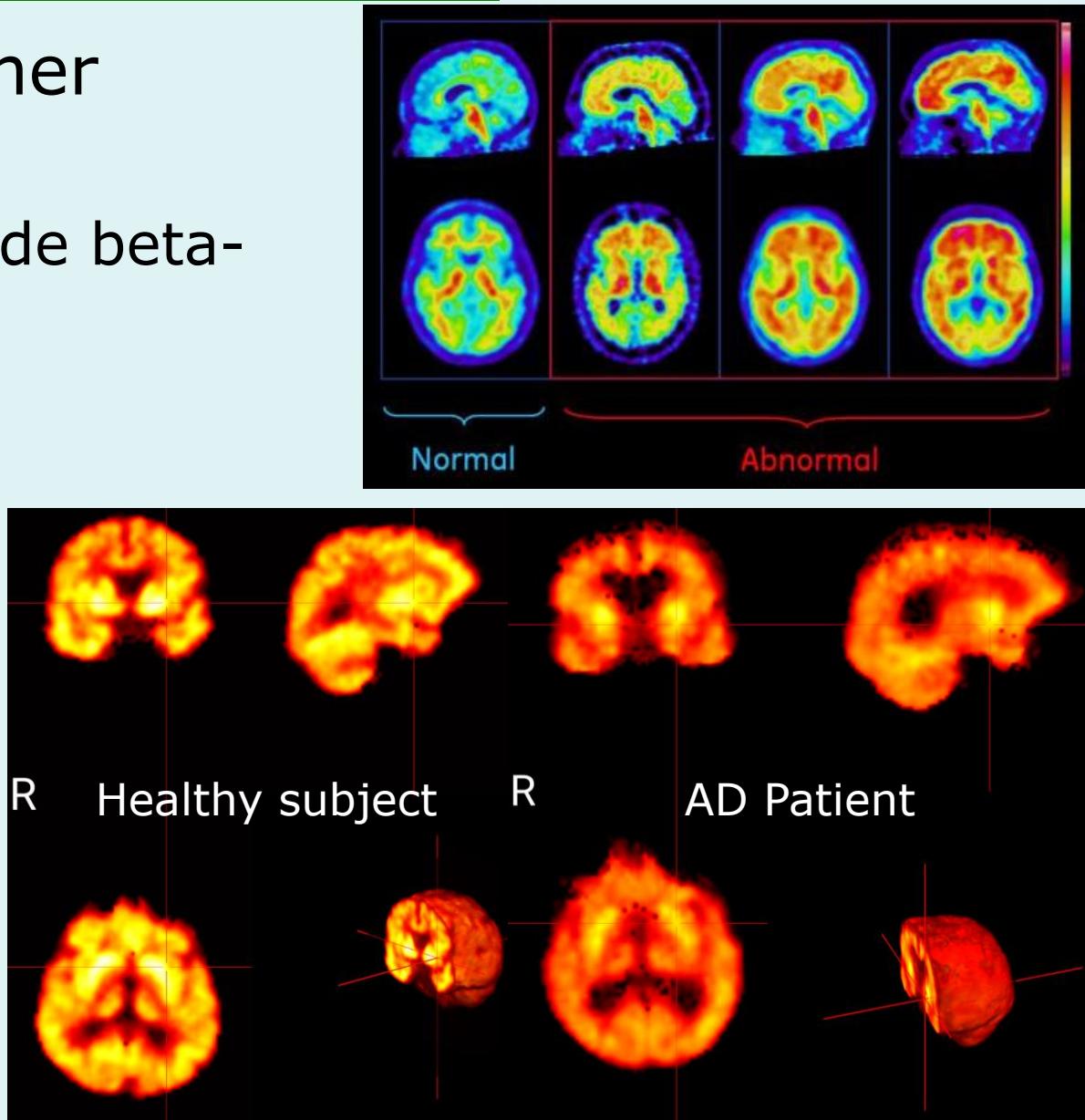


Radiotraceurs au ^{18}F et applications

Maladie d'Alzheimer

- Flutemetamol
→ se lie à la plaque de beta-amiloïde

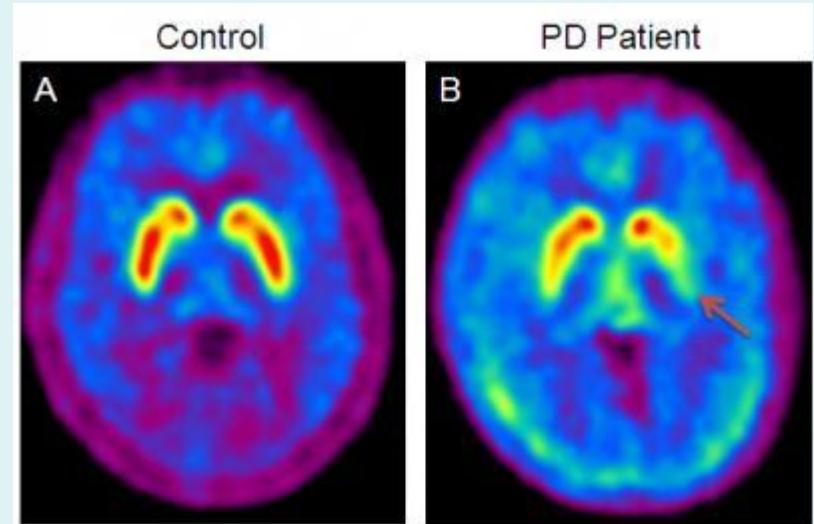
- $[^{18}\text{F}]$ UCB-H
→ se lie à la
“Synaptic Vesicle
Glycoprotein 2A”
(SV2A)
→ marqueur de la
densité
synaptique



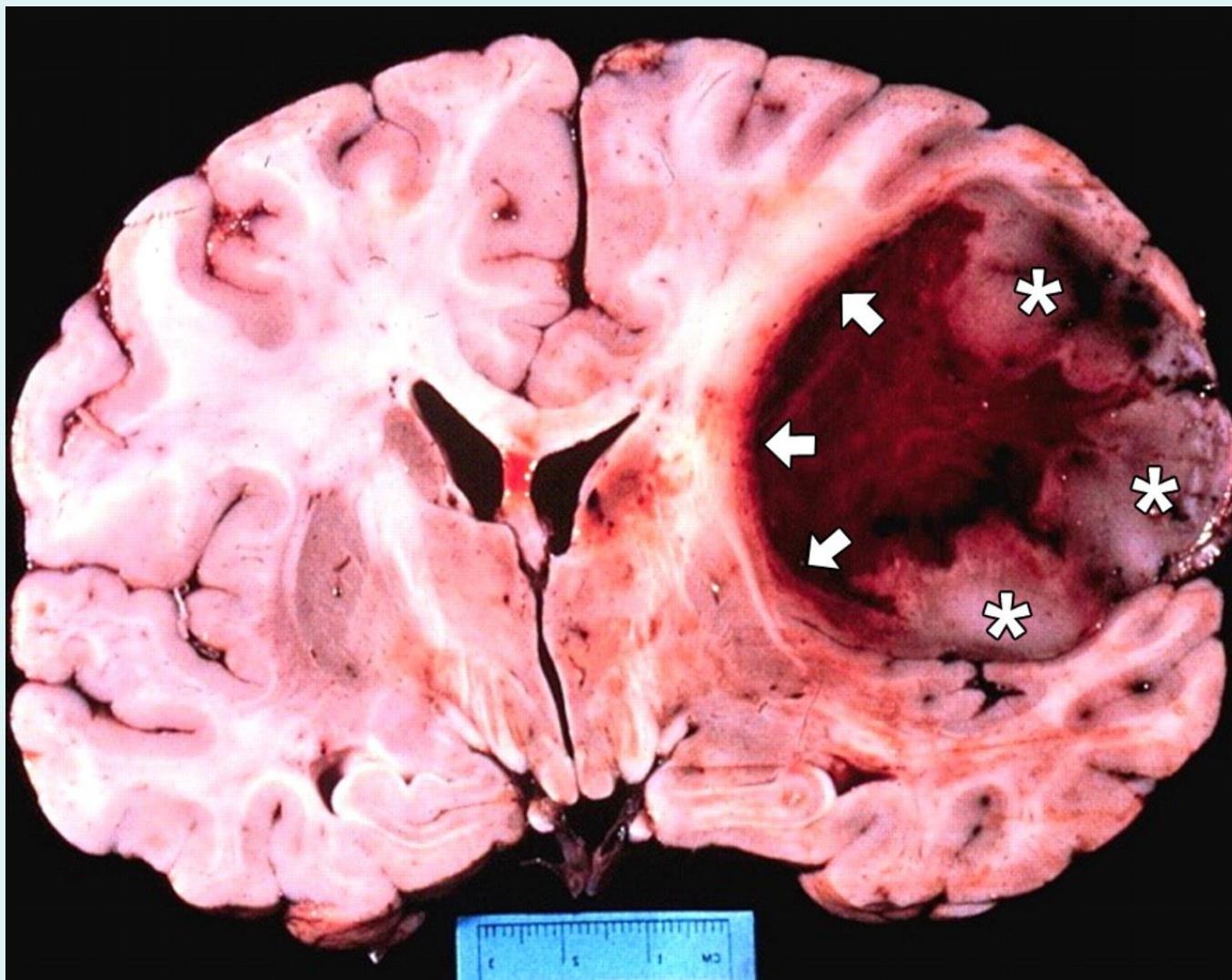
Radiotraceurs au ^{18}F et applications

Maladie de Parkinson

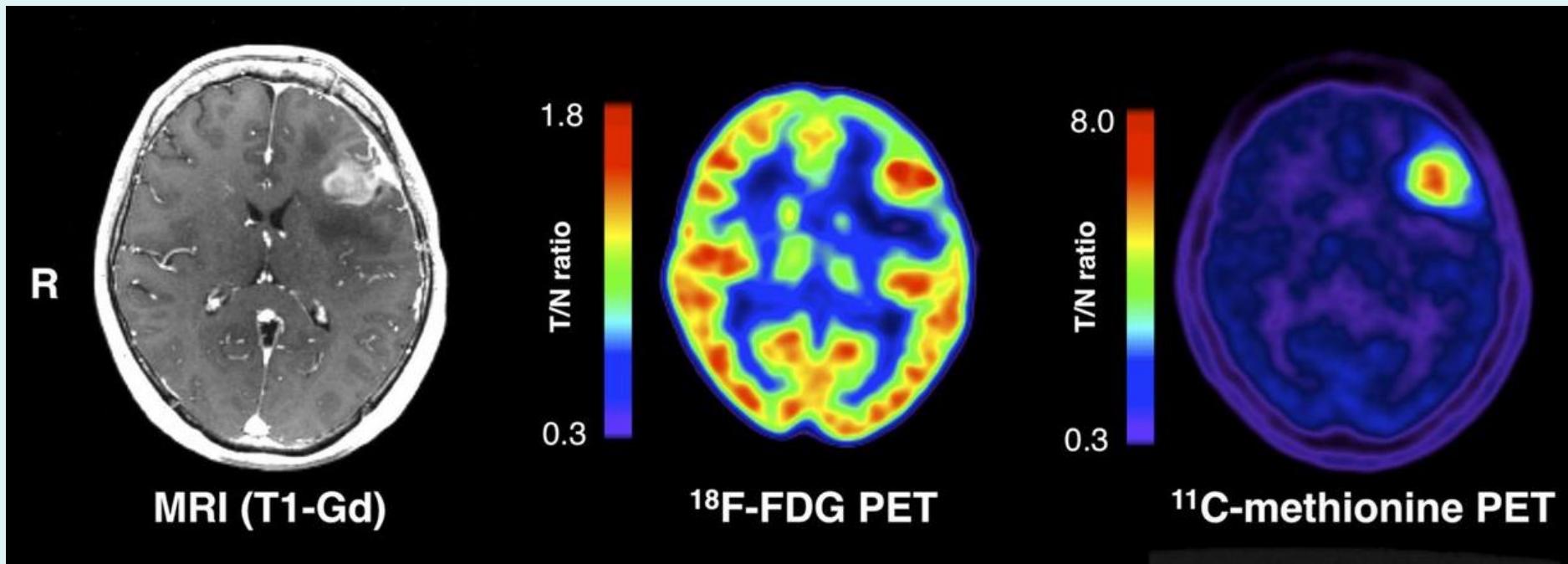
- “Fallypride”
→ antagoniste des récepteurs de dopamine D2/D3 dans le striatum



Glioblastome



PET oncologie



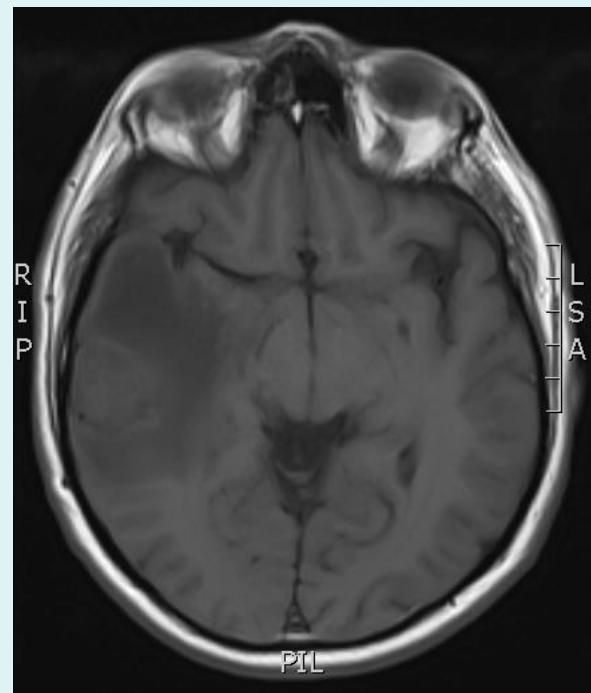
FDG → consommation de glucose
Methionine → production cellulaire (synthèse de protéines)

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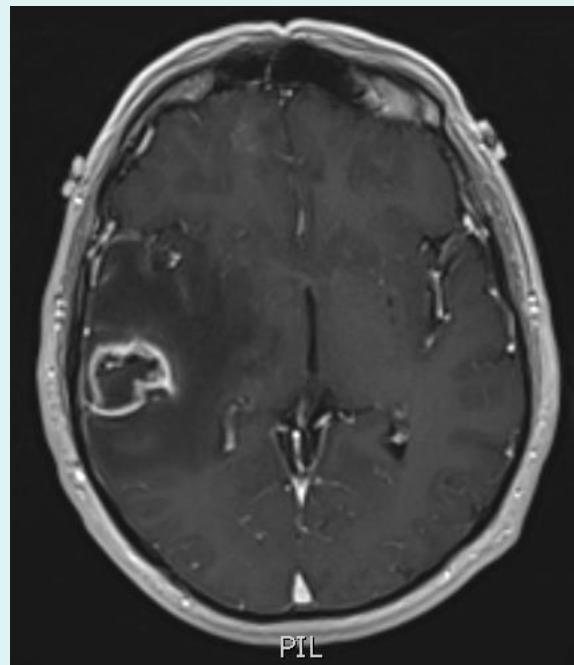
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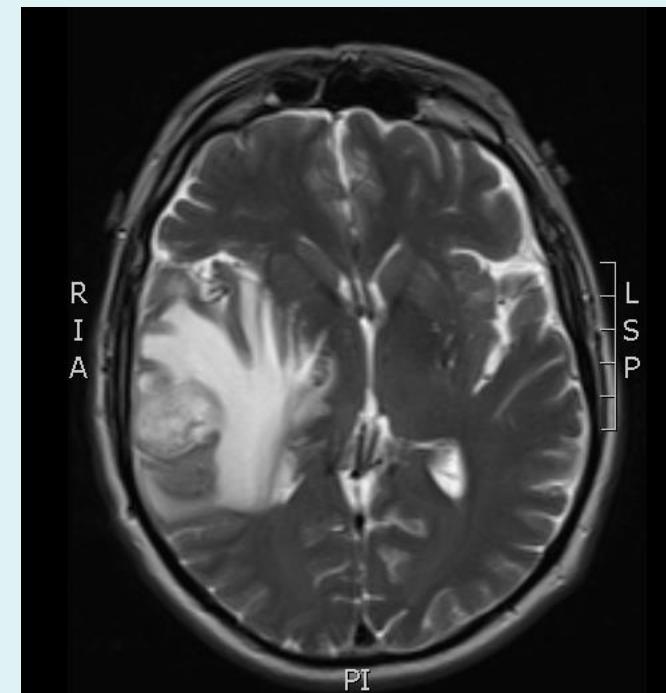
Glioblastome



T1



T1 + Gadolinium



T2

1 seule machine

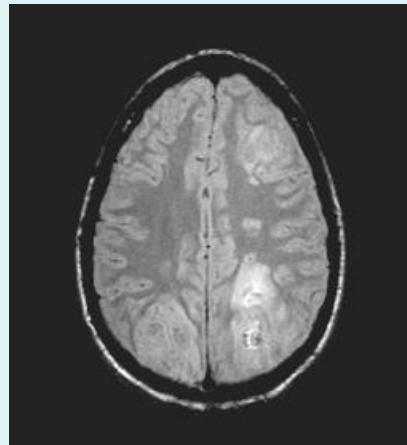
→ différentes séquences d'acquisition

→ différents type d'image, *avec/sans injection*

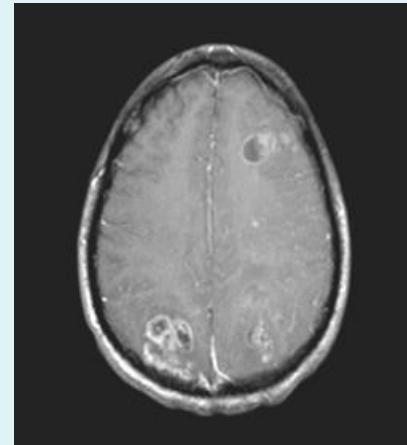
Planning chirurgical

Tumeur : image pondérée en ρ , T_1 ou T_2
+ agent de contraste 'Gadolinium'

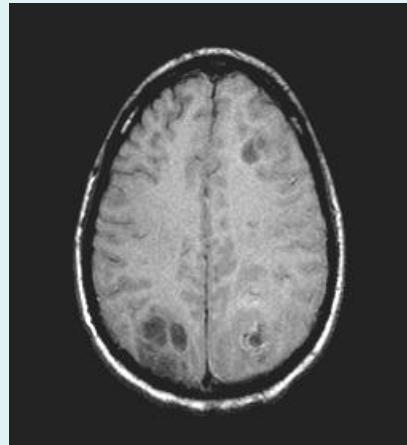
ρ



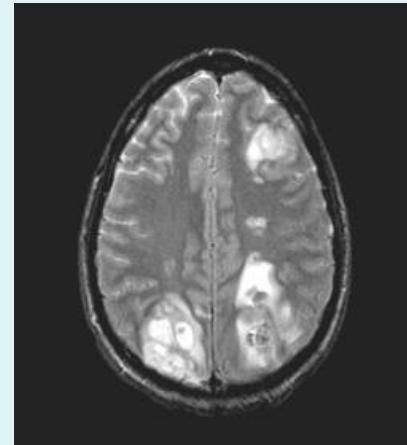
$T_1 + \text{Gd}$



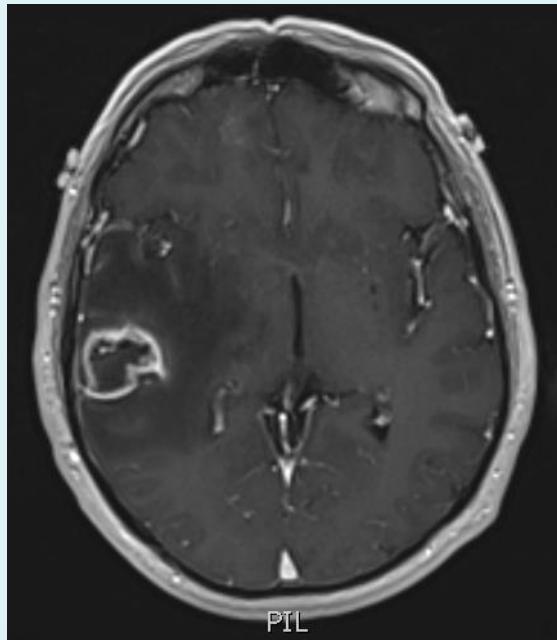
T_1



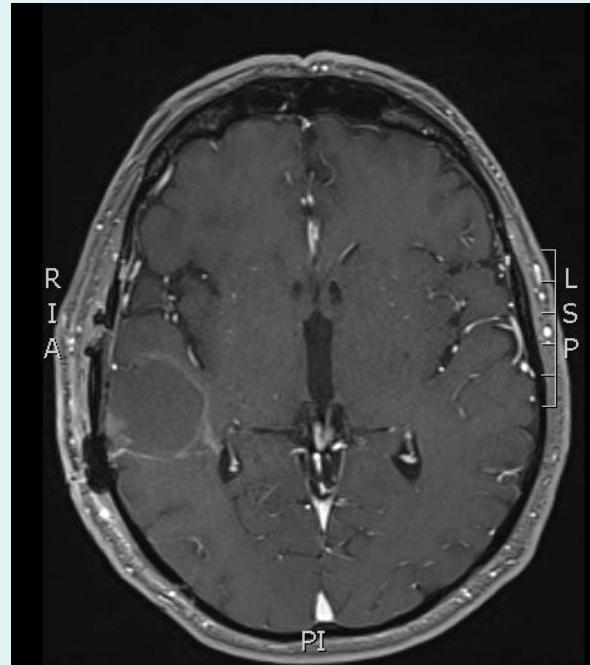
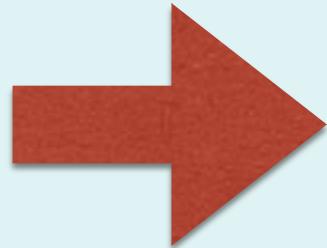
T_2



Chirurgie du glioblastome



Preop



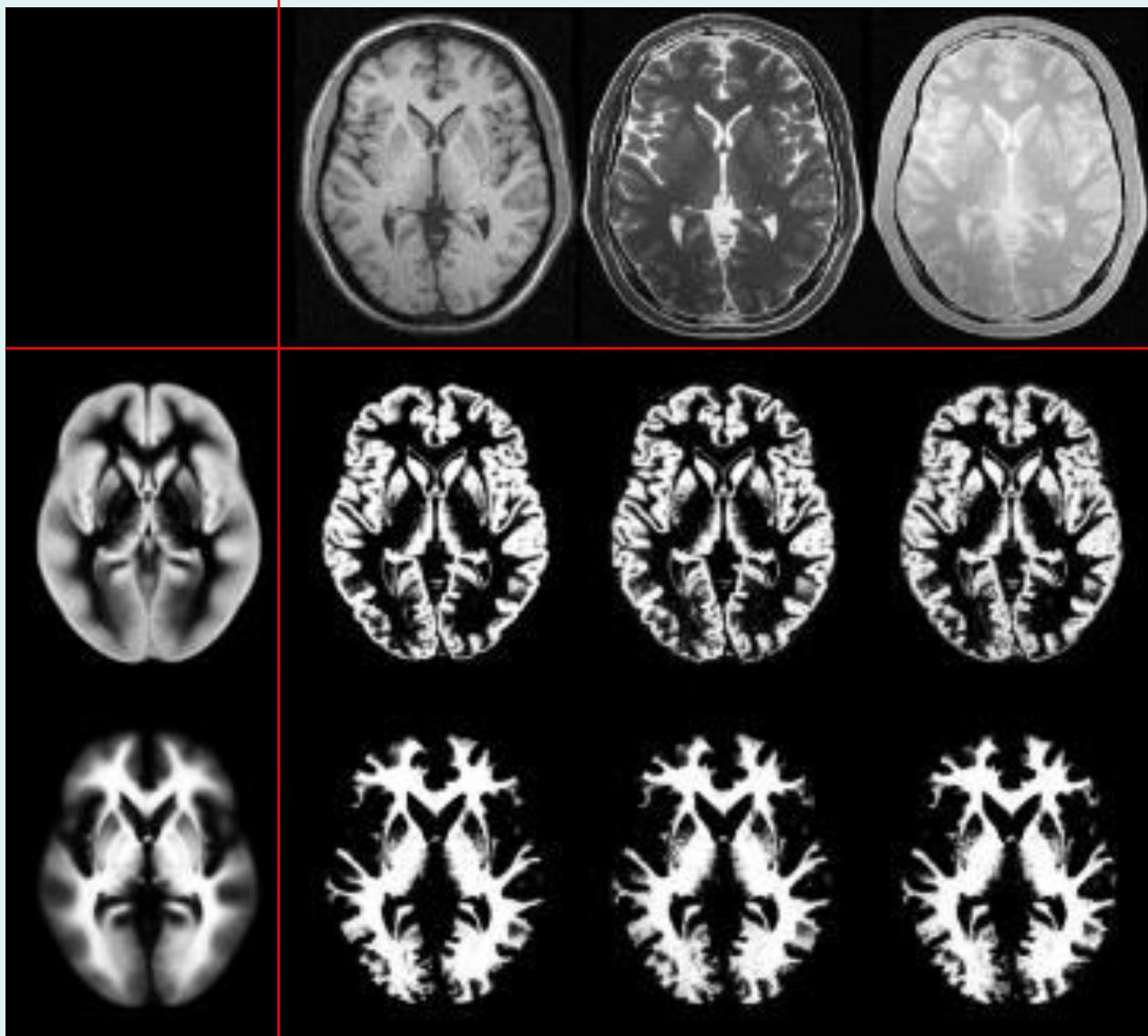
Postop

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IRM et la TEP en neuroscience

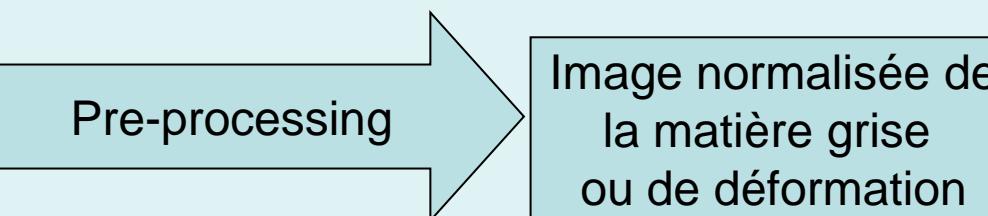
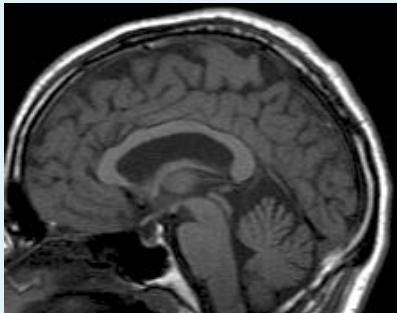
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Segmentation automatique

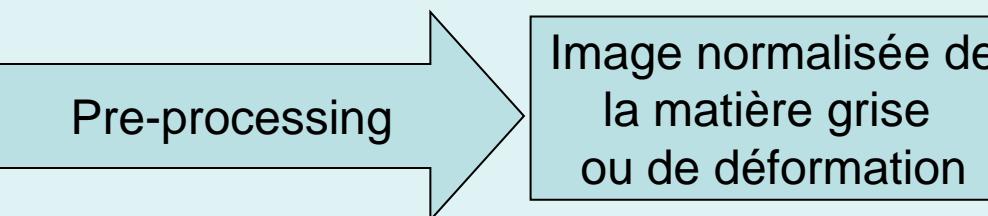
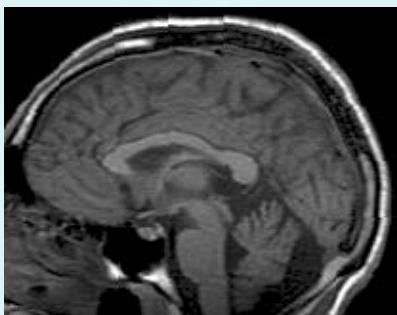


Analyse morphologique

Sujet 1

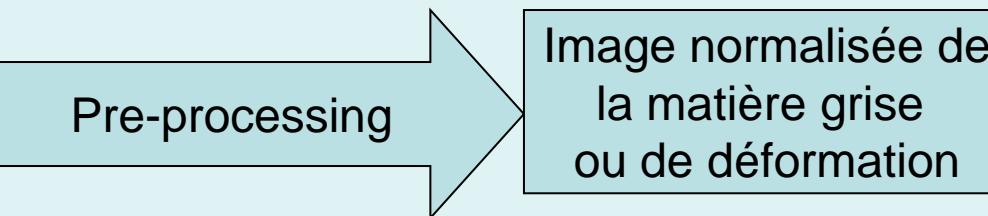
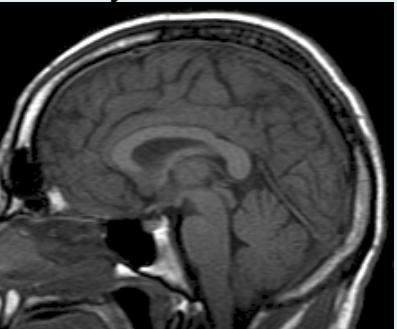


Sujet 2



⋮

Sujet N



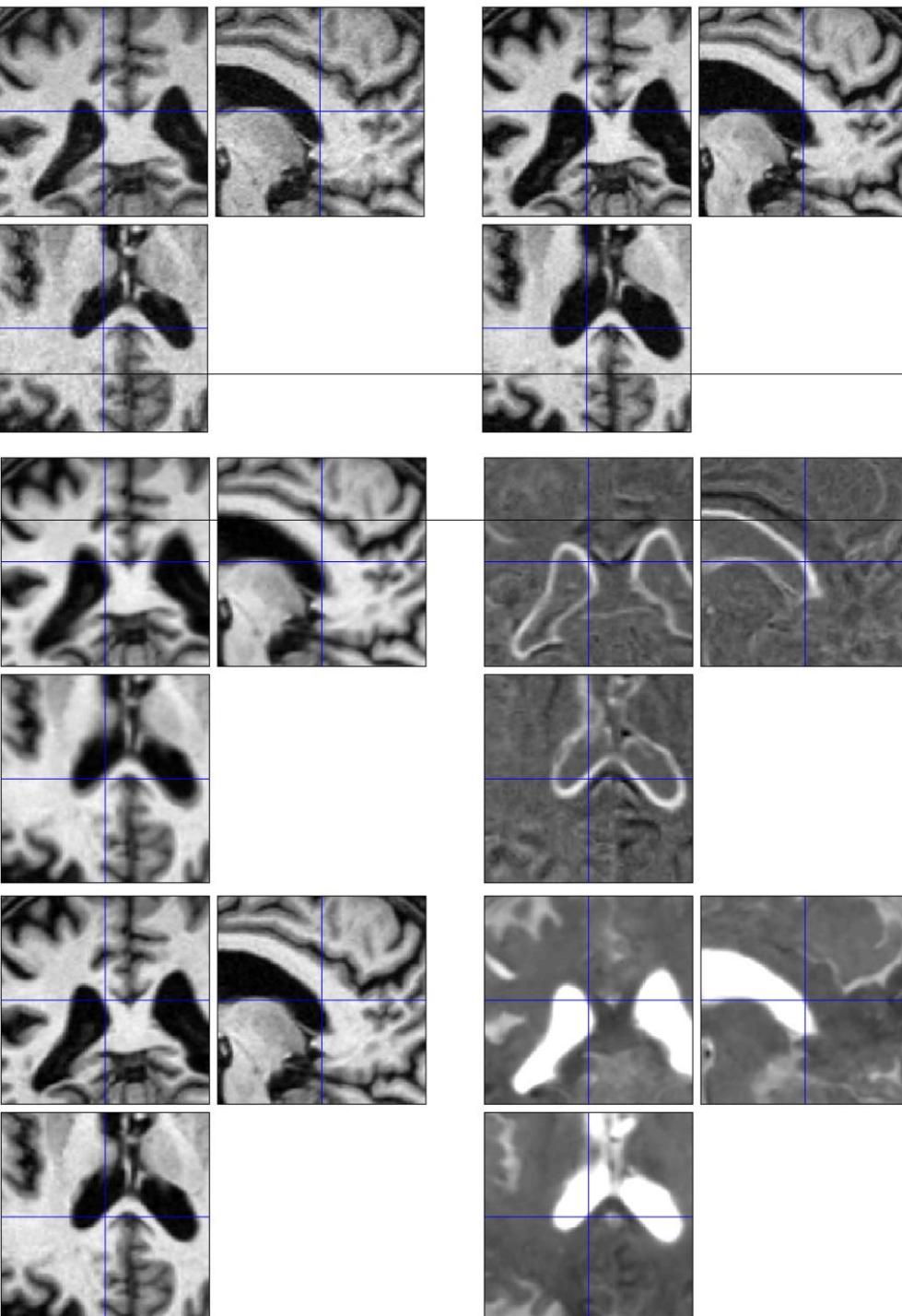
Analyse statistique

Etude longitudinale

2 scans à 6 ans d'écart
(après recalage linéaire)

Moyenne et différence
des images

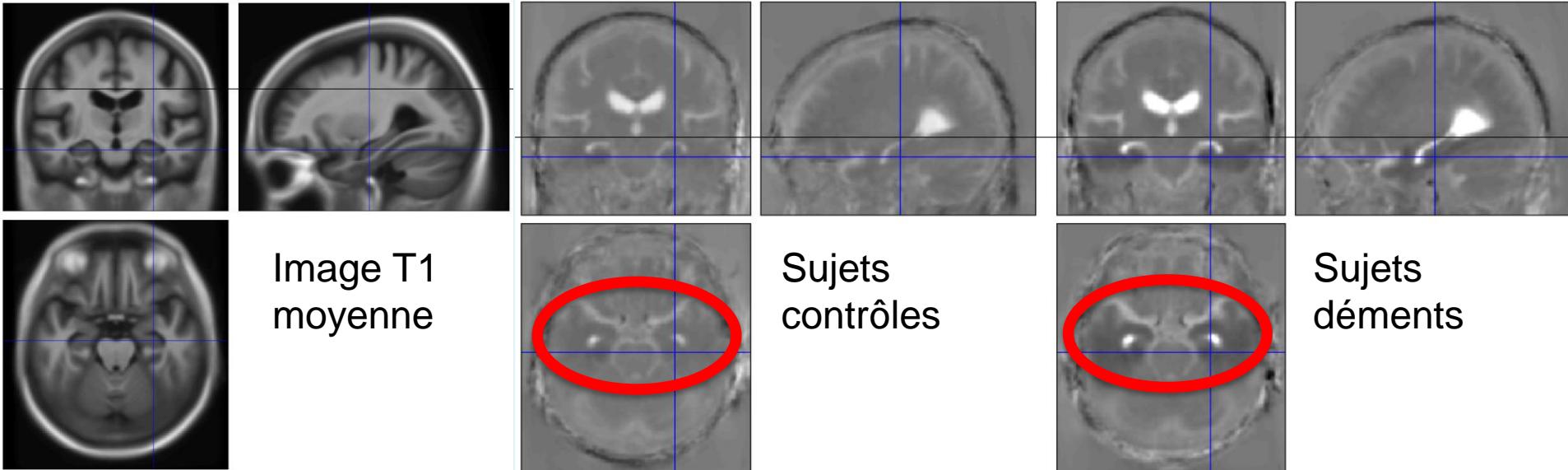
Image moyenne et
carte d'expansion/contraction
(après recalage 'élastique')



Etude longitudinale

- Données de 82 sujets: groupes 'contrôle' et 'dément'
 - Recalage élastique de toutes les données dans un espace anatomique commun
 - Calcul de la moyenne du **taux annuel de déformation** pour chaque sujet
- Comparaison **statistique** des 2 groupes

Plus foncé = réduction plus rapide de la MG!



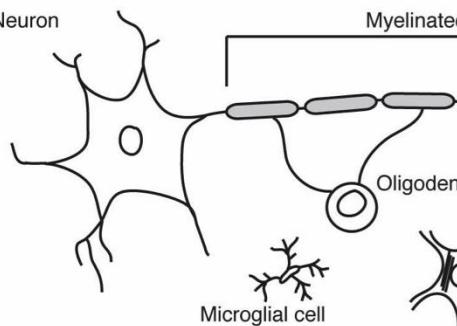
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Structure de la matière blanche

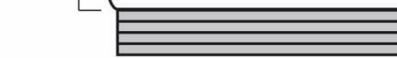
Neuron



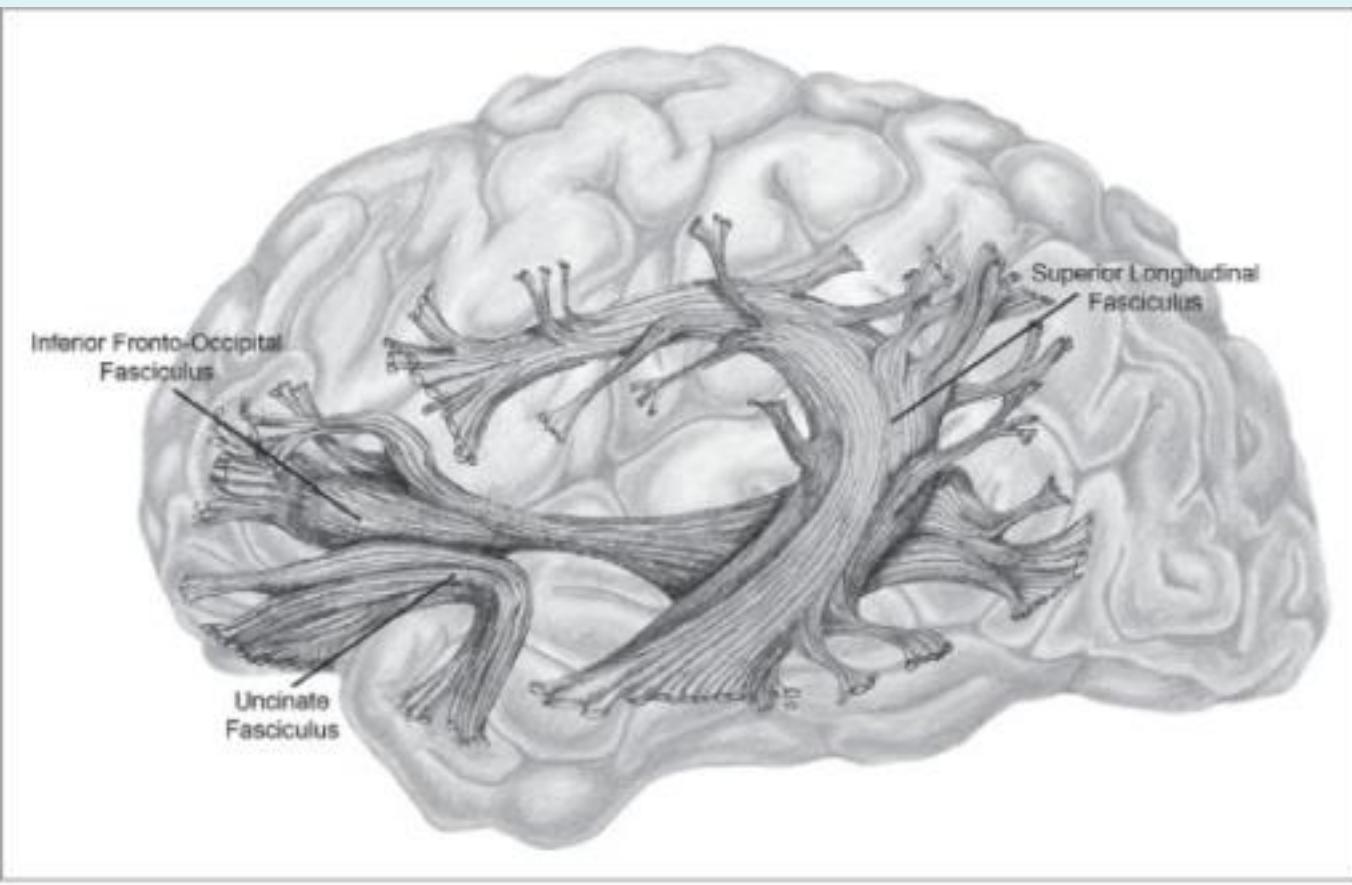
a

Myelin

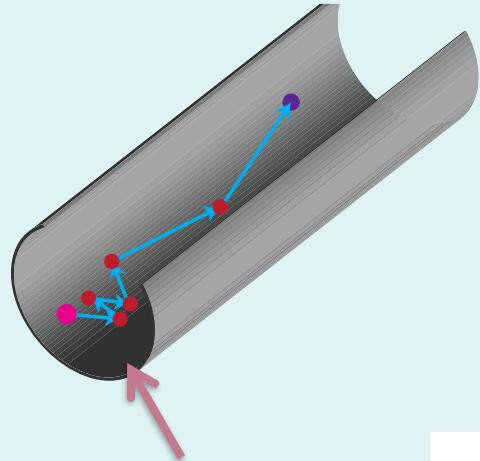
Axon



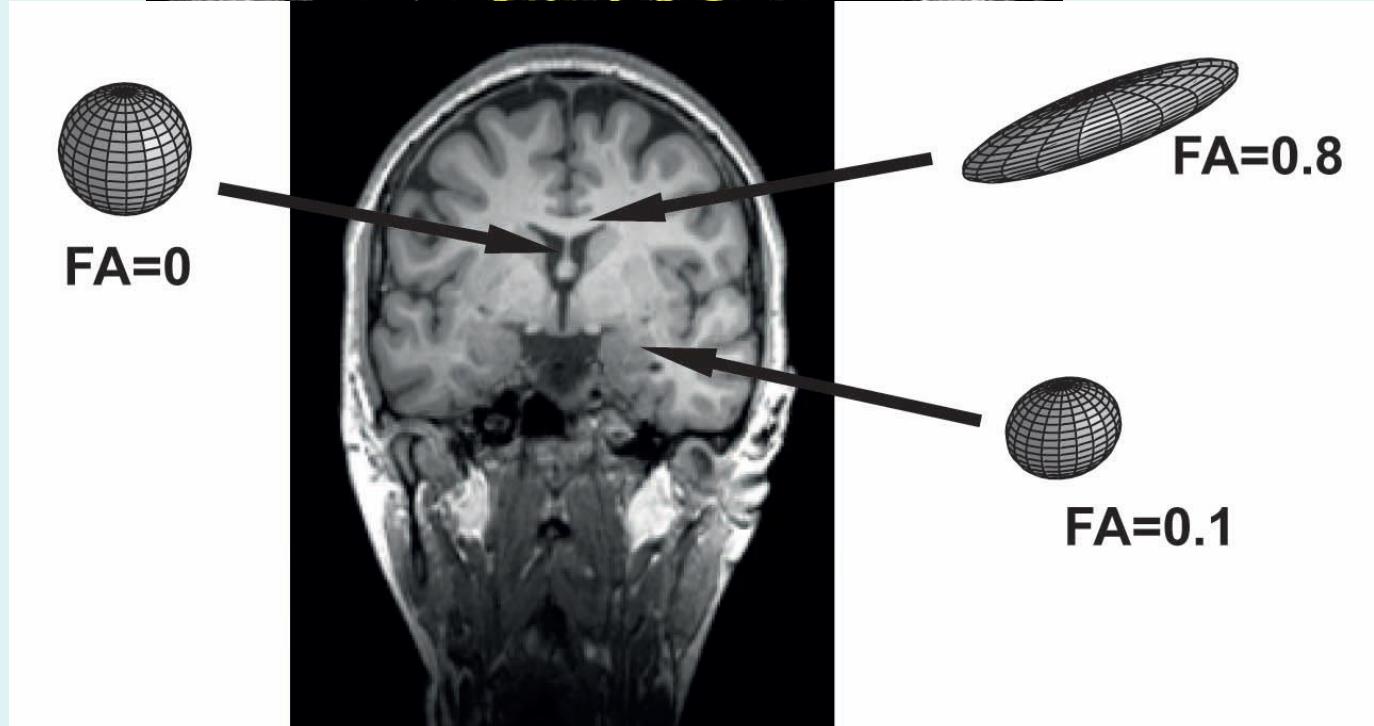
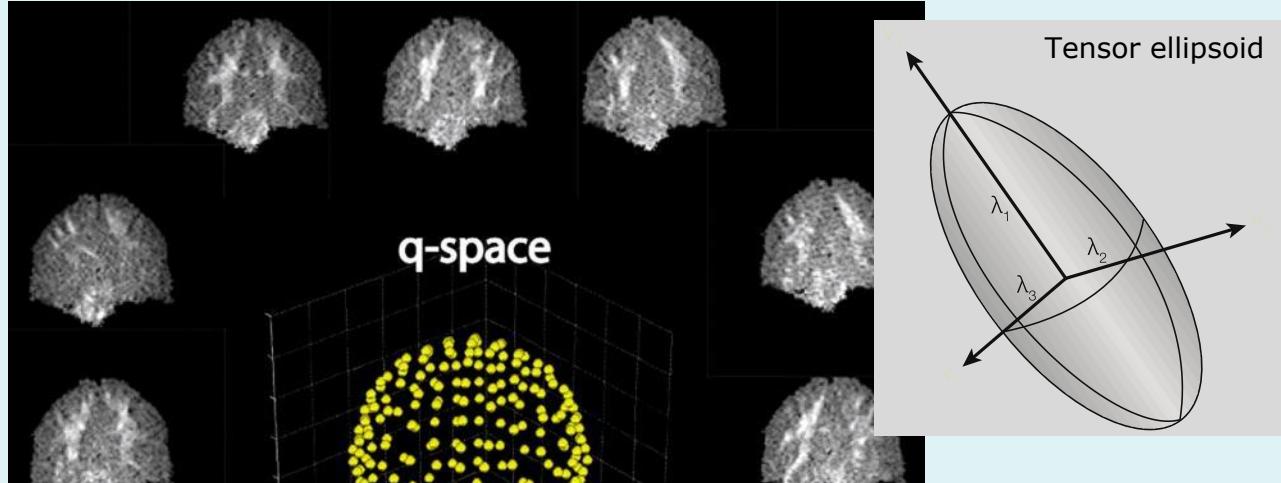
b



Diffusion de l'eau et IRM de diffusion



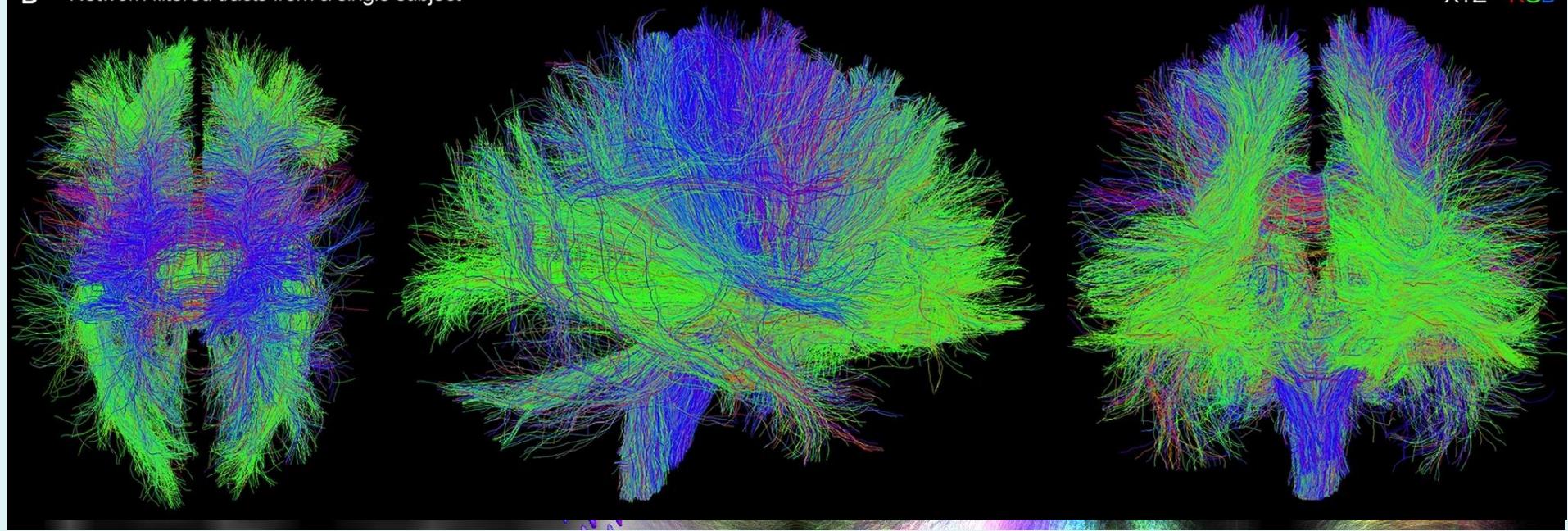
Diffusion
contrainte de l'eau
dans une direction
préférentielle



Tractographie

B Network-filtered tracts from a single subject

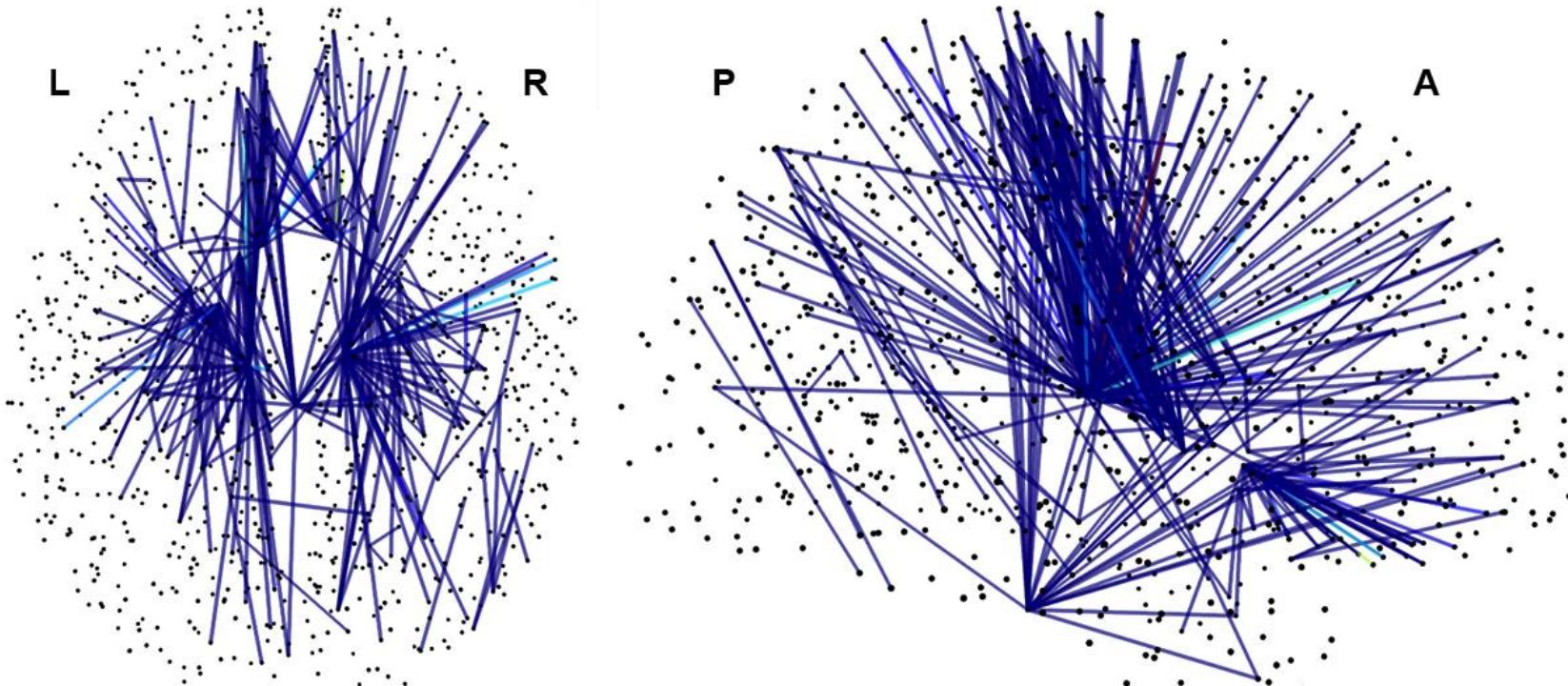
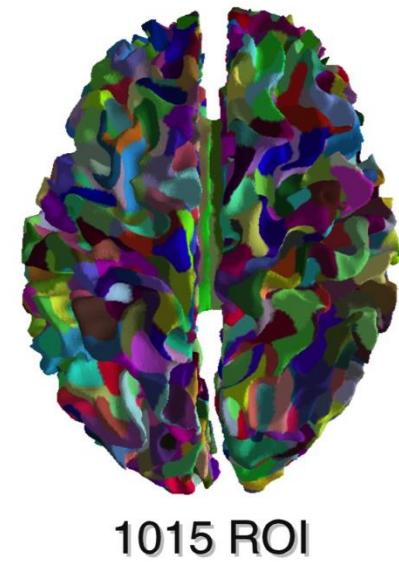
XYZ = **RGB**



Tractographie & connectomique

Groupes génétiquement différents (BDNF)

→ Différence de connectivité structurelle
entre aires cérébrales !



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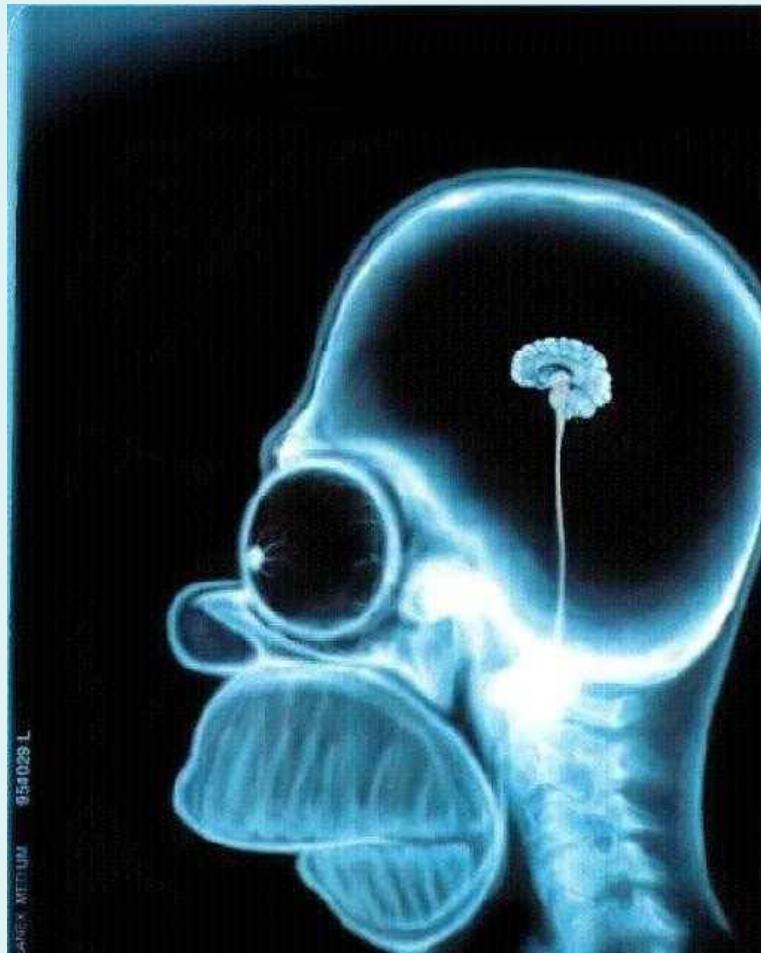
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IRM fonctionnelle

IRM structurelle

→ anatomie du cerveau

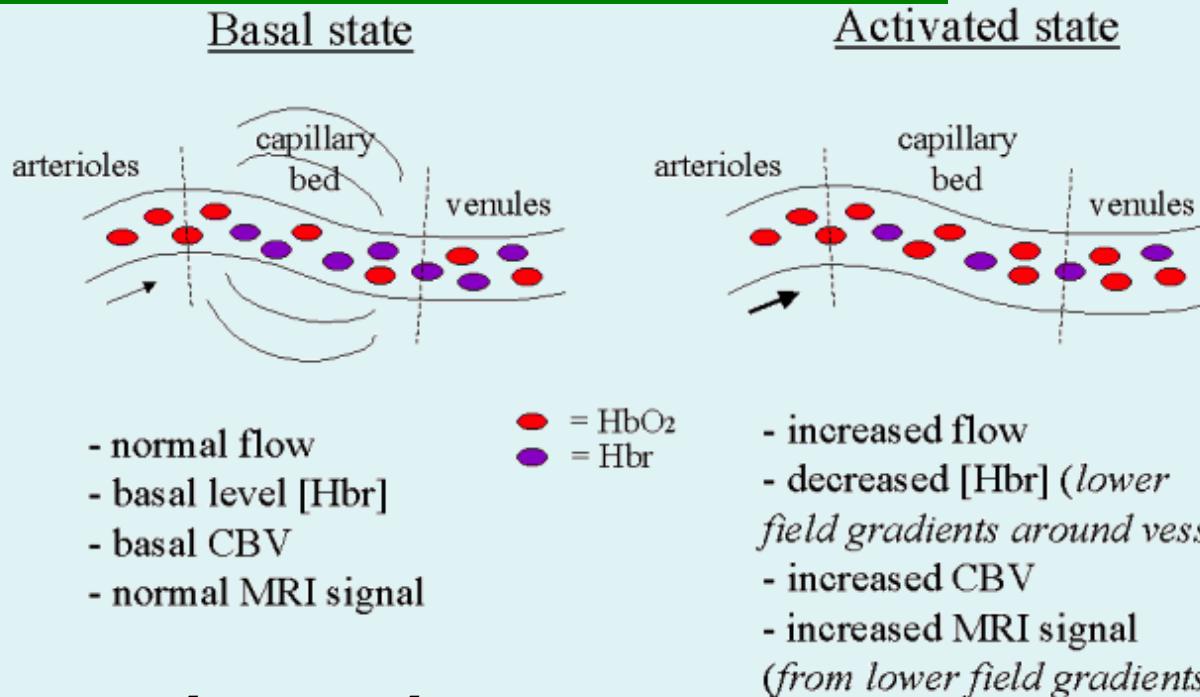


IRM fonctionnelle

→ fonctions du cerveau



Réponse BOLD



Susceptibilité magnétique

→ champs magnétique effectivement perçu dans le tissus :

$$\mathbf{B}_{\text{eff}} = (1+\chi) \mathbf{B}_0$$

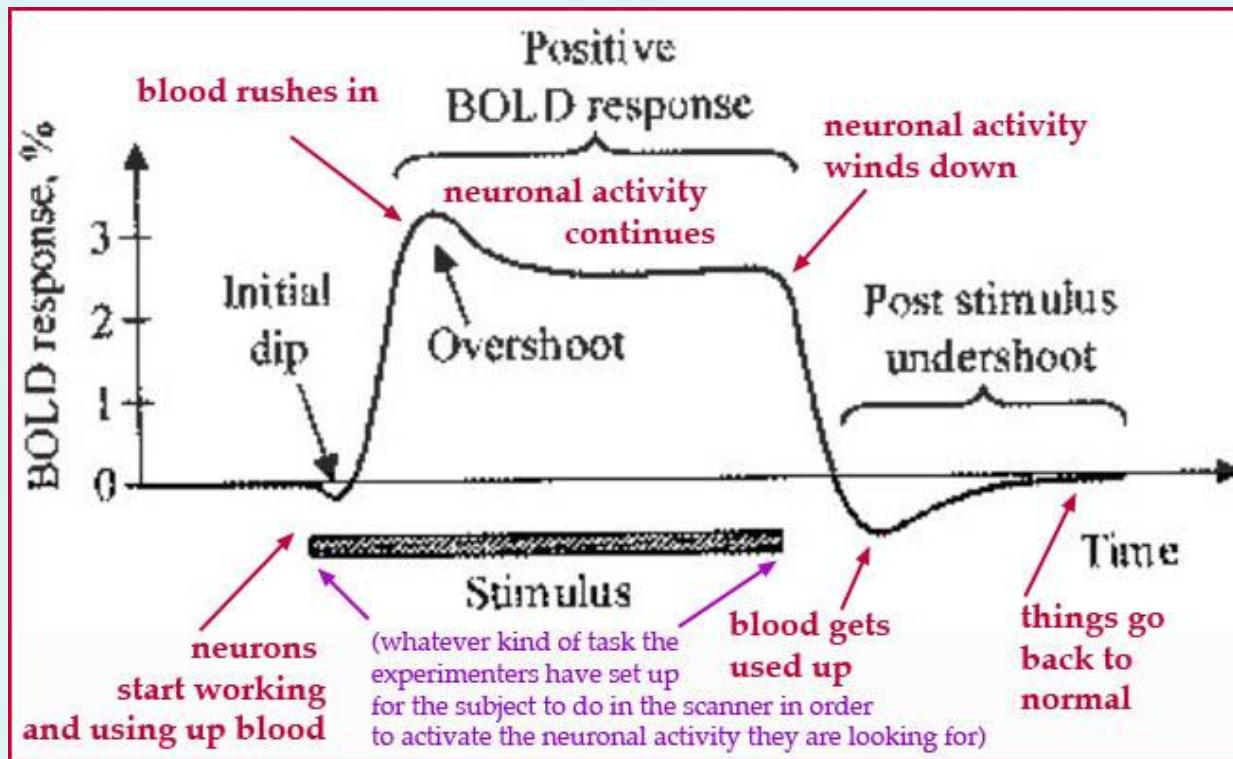
Et propriétés magnétique de l'haemoglobin

- deoxyhaemoglobin : paramagnetique ($\chi > 0$)
- oxyhaemoglobin : légèrement diamagnetic ($\chi < 0$)

Réponse BOLD

Régions **activées** :

- augmentation du flux de sang oxygéné [oxyHb] ↑
- [déoxyHb] ↓
- réduction de la perte de signal = augmentation du signal

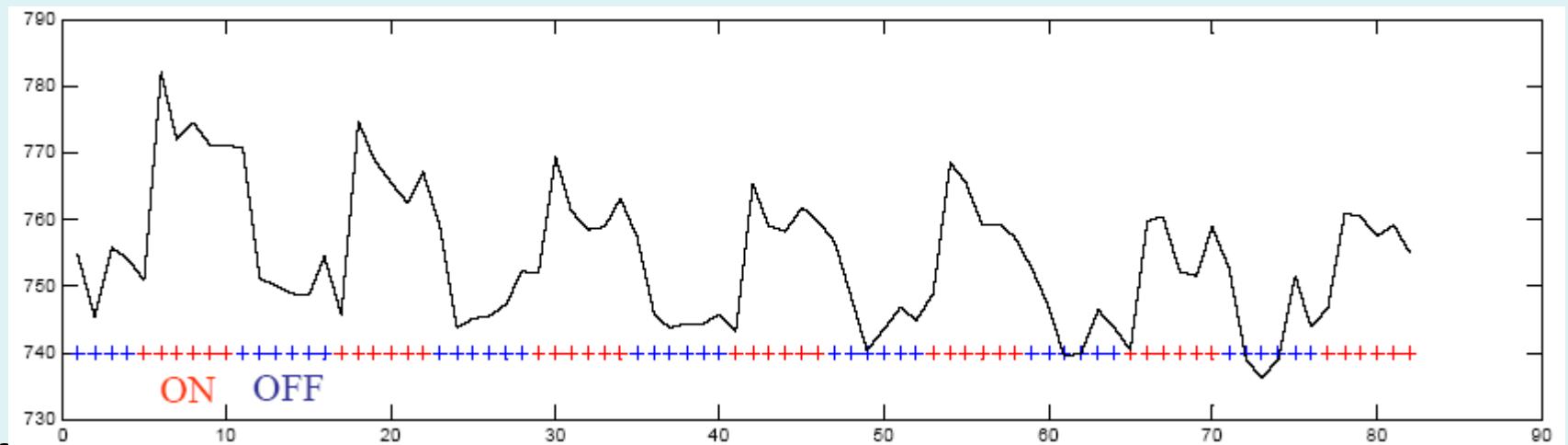


Exemple d'expérience

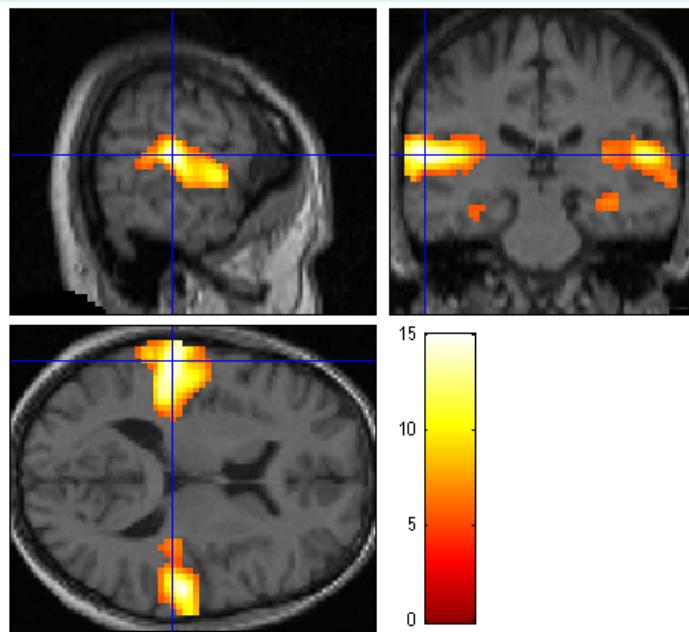
Stimuli: 'écoute passive de mots' vs. 'repos'



Réponse BOLD dans le cortex auditif:



Cartographie Paramétrique Statistique

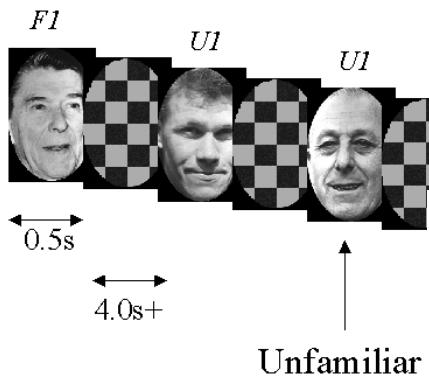


p-values adjusted for search volume

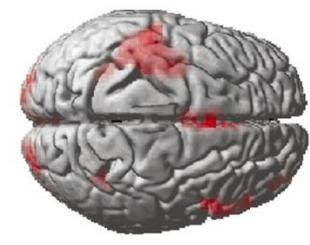
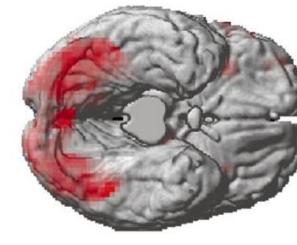
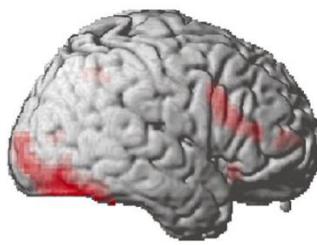
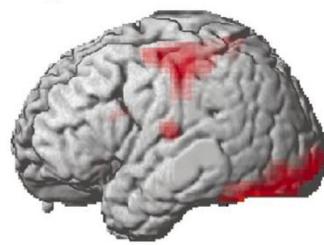
set-level		cluster-level				peak-level					mm mm mm		
p	c	$P_{\text{FWL-corr}}$	$q_{\text{FDR-corr}}$	k_c	p_{uncorr}	$P_{\text{FWL-corr}}$	$q_{\text{FDR-corr}}$	T	(Z_{ε})	p_{uncorr}	x	y	z
0.000	10	0.000	0.000	791	0.000	0.000	0.000	15.04	Inf	0.000	-60	-28	11
						0.000	0.000	14.15	Inf	0.000	-48	-34	14
						0.000	0.000	12.60	Inf	0.000	-66	-10	2
						0.000	0.000	14.77	Inf	0.000	57	-22	11
						0.000	0.000	13.31	Inf	0.000	63	-10	-1
						0.000	0.000	8.39	7.00	0.000	57	-40	5
						0.000	0.003	6.84	5.99	0.000	36	-28	-13
						0.000	0.013	6.41	5.69	0.000	54	-1	44
						0.001	0.003	0.089	5.87	0.000	-33	-31	-19
						0.007	0.013	0.311	5.50	0.000	-45	41	5
						0.010	0.016	0.359	5.44	0.000	-63	-55	-7
						0.010	0.036	0.788	5.20	0.000	-54	-4	47
						0.023	0.452	1	0.452	0.000	45	-43	35
						0.023	0.452	1	0.452	0.000	48	26	20

Autre expérience

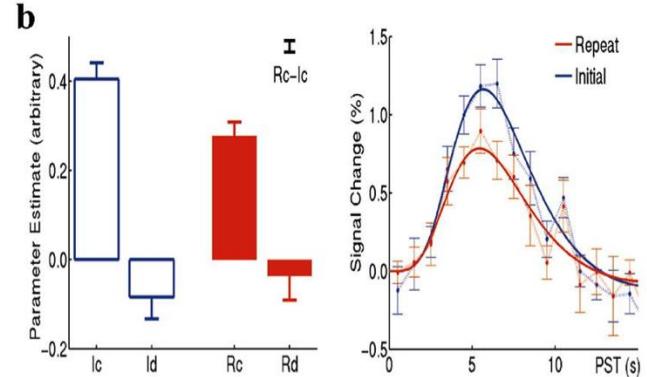
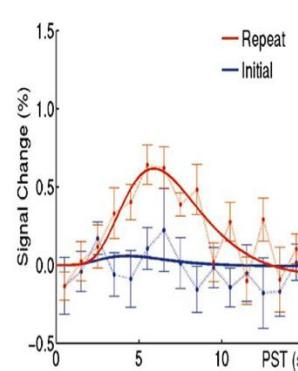
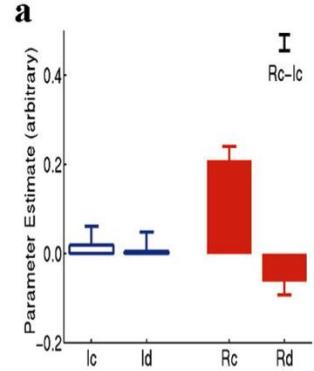
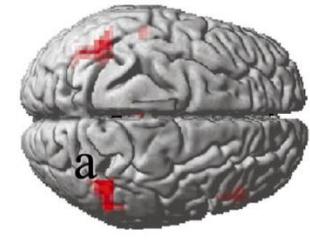
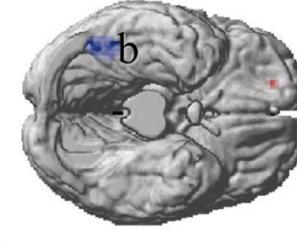
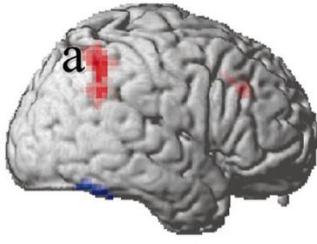
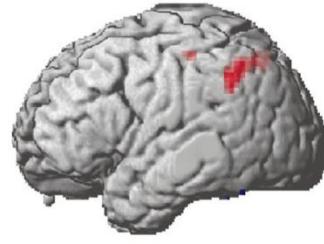
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Reconnaissance de visages



Repeat - Initial



(Henson et al,
NI, 2002)

ImagéSanté 2025

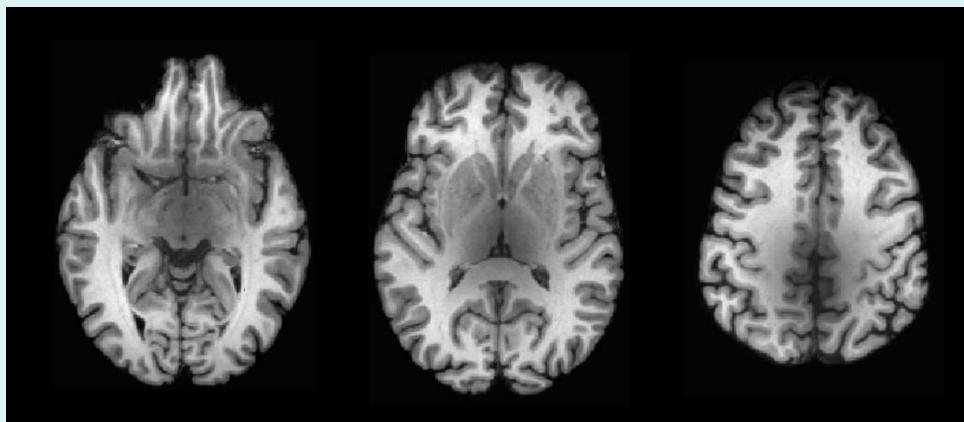
Index

IRM et la TEP en neuroscience

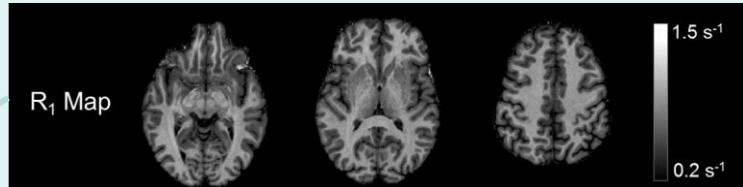
- Principes de l'IRM et la TEP
- Application en TEP
- *Application en IRM*
 - Imagerie structurelle
 - Imagerie par diffusion
 - Imagerie fonctionnelle
 - *Imagerie quantitative*
- Conclusions

IRM quantitative

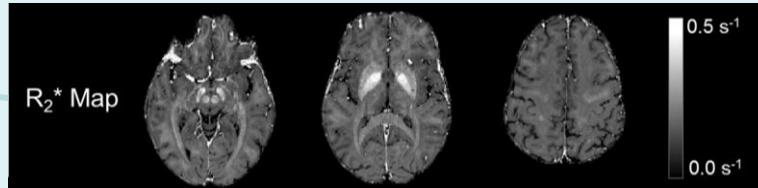
$SI_{MPRAGE} = \text{fonction(}$
paramètre de la séquence,
scanner/hardware,
paramètre IRM physique)



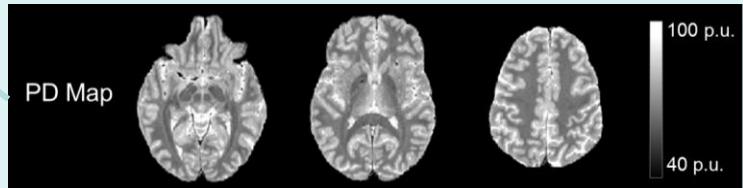
Taux de Relaxation Longitudinale



Taux Effectif de Relaxation Transverse



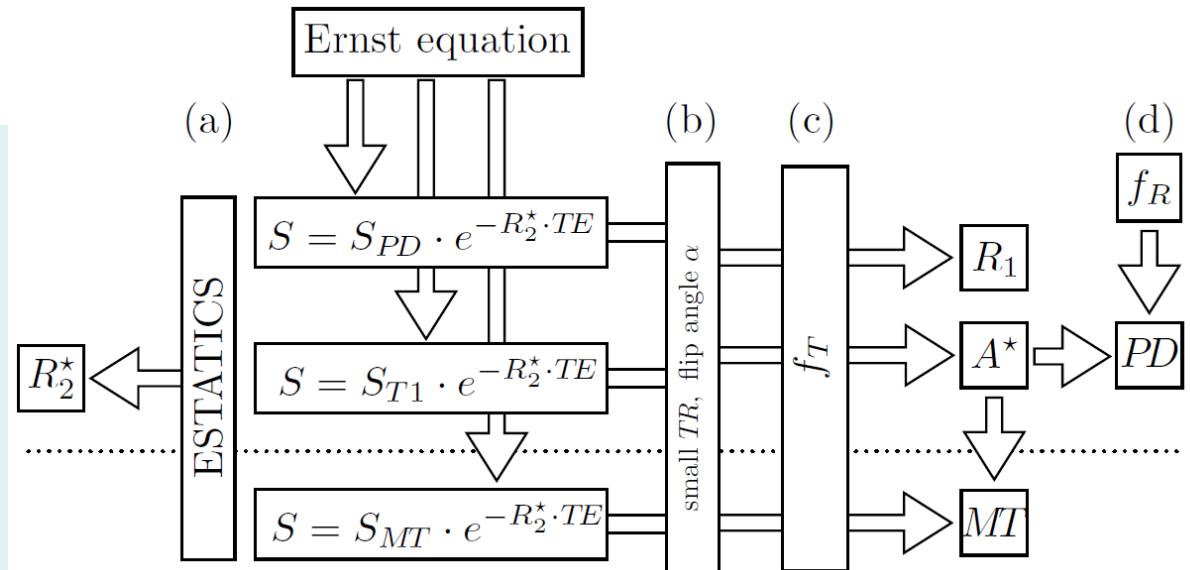
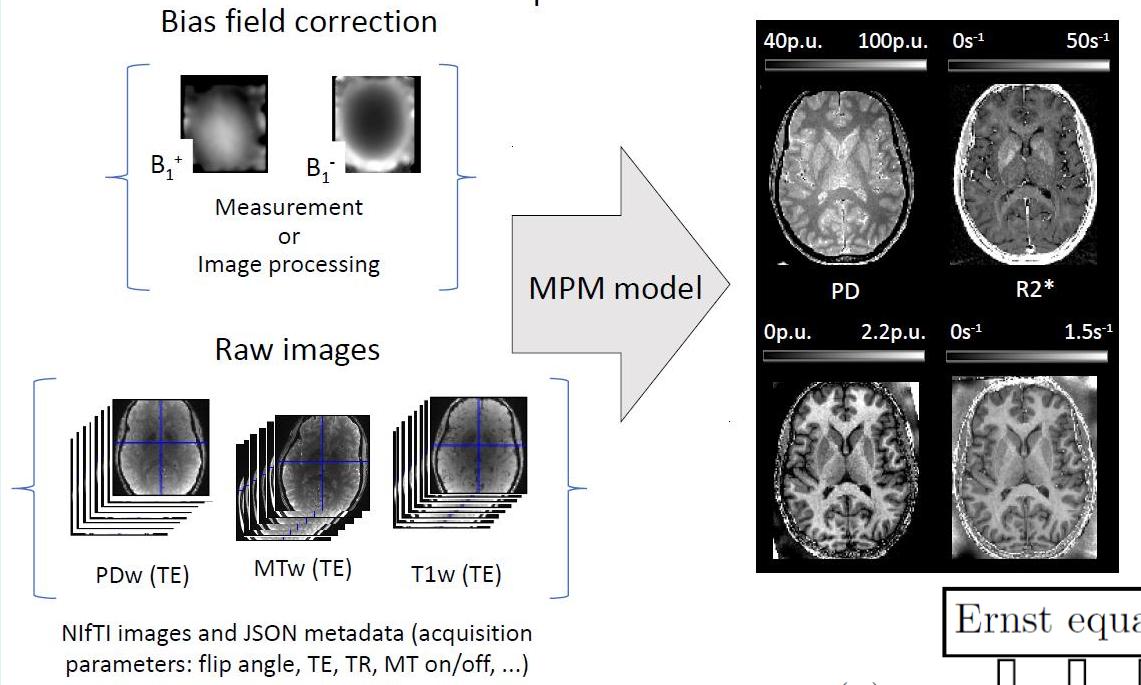
Densité de Proton



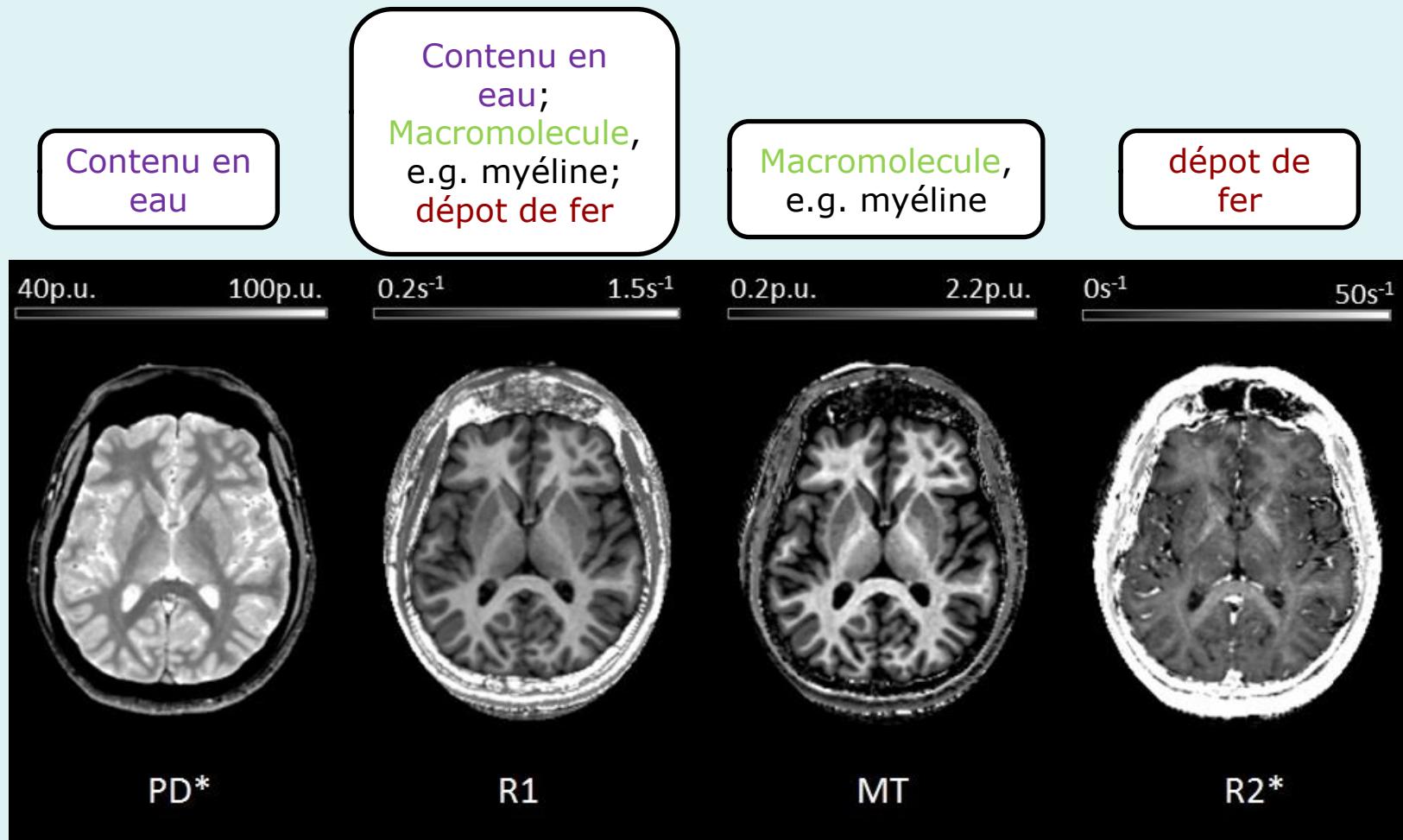
⇒ IRM Quantitative &
“Voxel-Based Quantification”

IRM quantitative

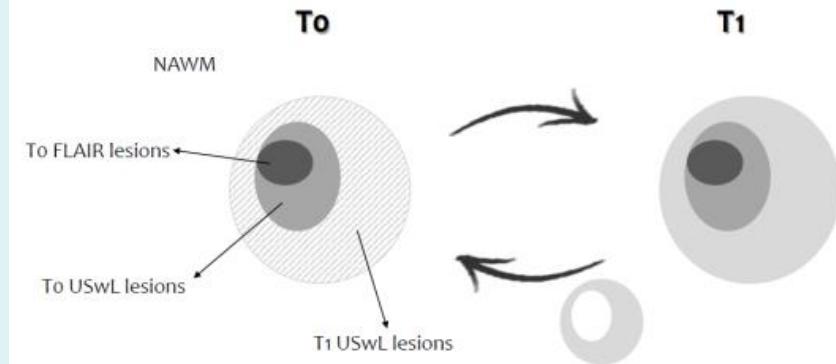
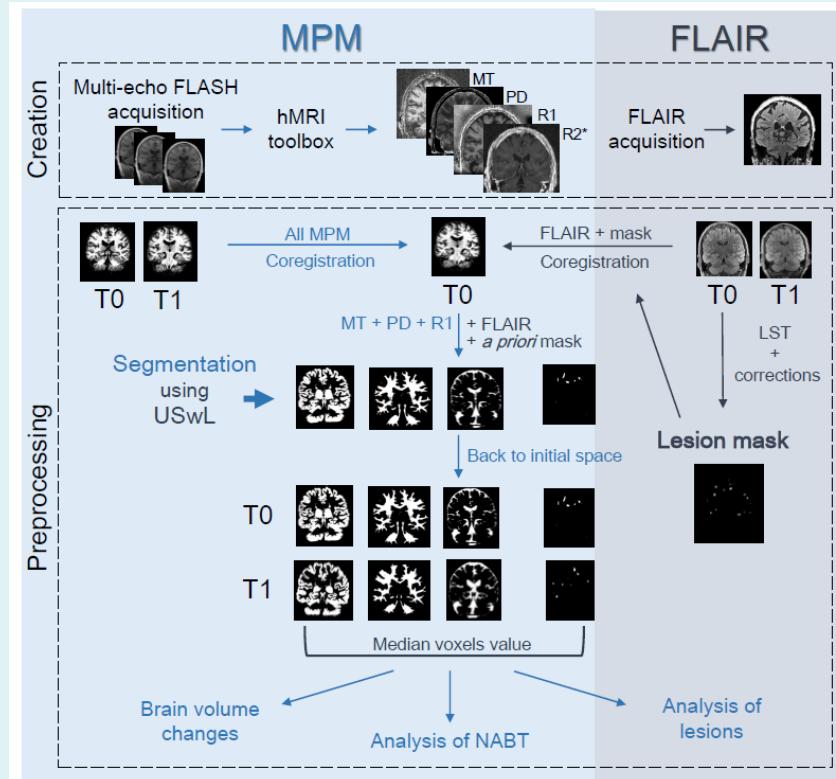
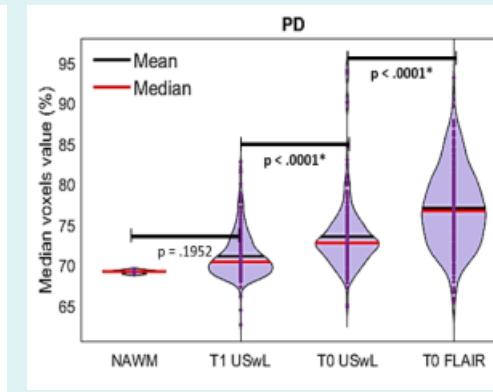
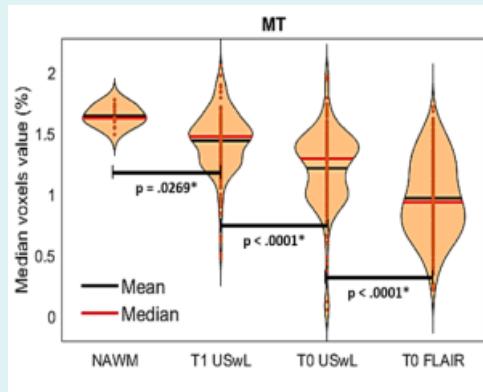
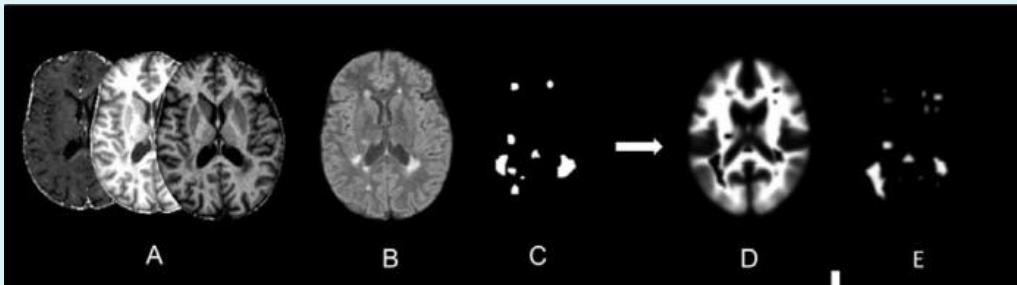
Map Creation



Interprétation de l'IRM quantitative



IRM quantitative & sclérose en plaque



Index

IRM et la TEP en neuroscience

- Principes de l'IRM et la TEP
- Application en TEP
- Application en IRM
- *Conclusions*

PET & IRM

- Domaine pluridisciplinaire: technologie et neuroscience
- Grands nombres d'applications possibles en recherche *fondamentale* et *clinique*
- Développements techniques et méthodologiques toujours en cours!
 - ➔ validation pour applications en « routine clinique » (dans le futur)
- Besoin de personnel compétent pour « piloter » les machines



Questions ?