Quantitative MRI, practical considerations & applications

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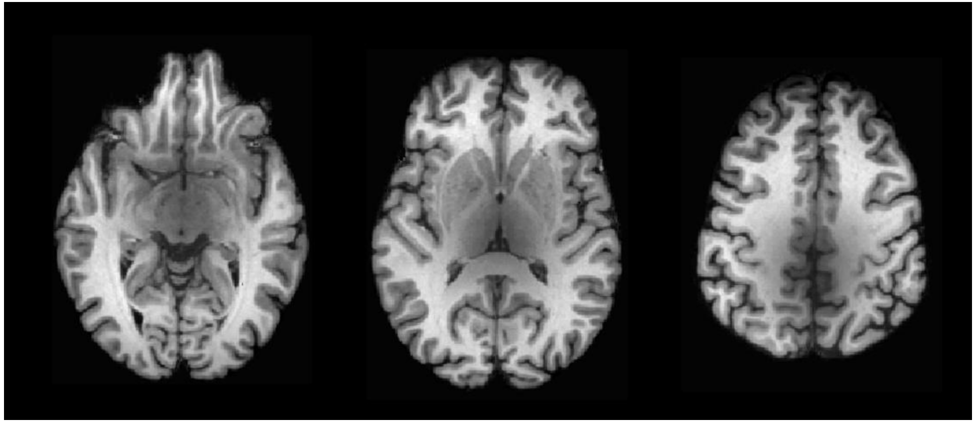
Agenda

- Quantitative MRI
- qMRI application in
  - Multiple sclerosis
  - Alzheimer disease
- Conclusions

Classical vs quantitative MR imaging

SI_{MPRAGE} = f (sequence parameters,
scanner hardware,
physical MRI parameters)



Classical vs quantitative MR imaging

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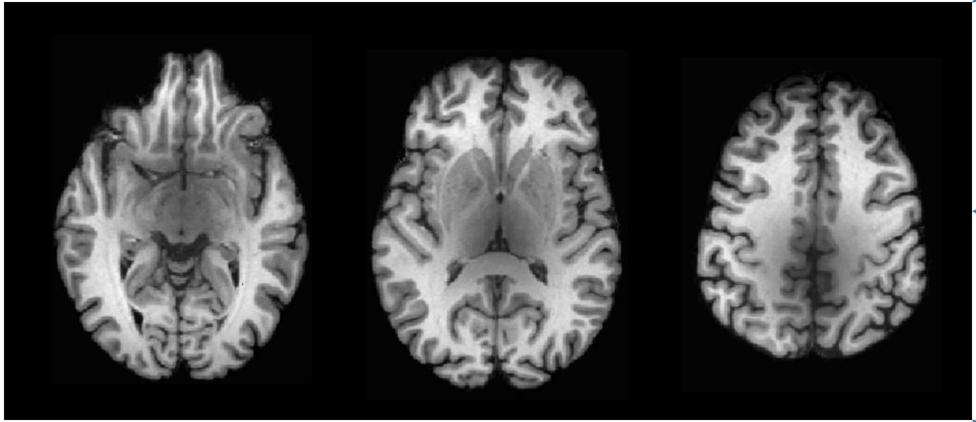
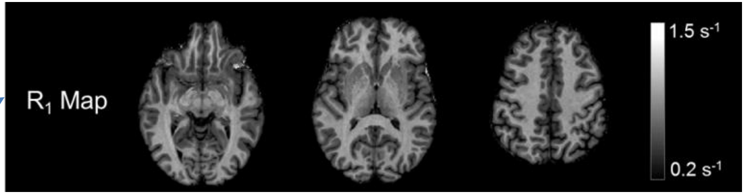
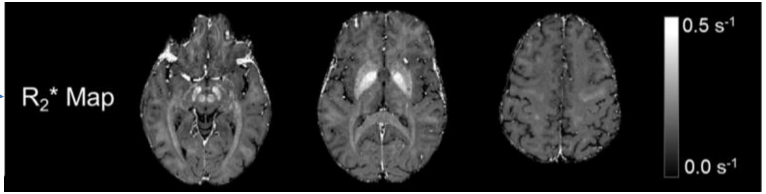


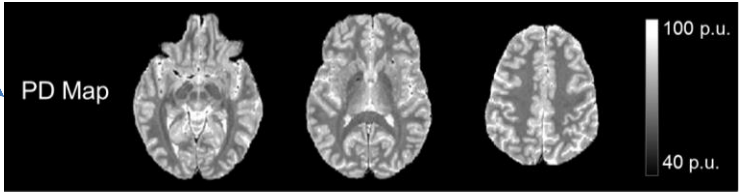
Longitudinal Relaxation Rate



Effective Transverse Relaxation Rate

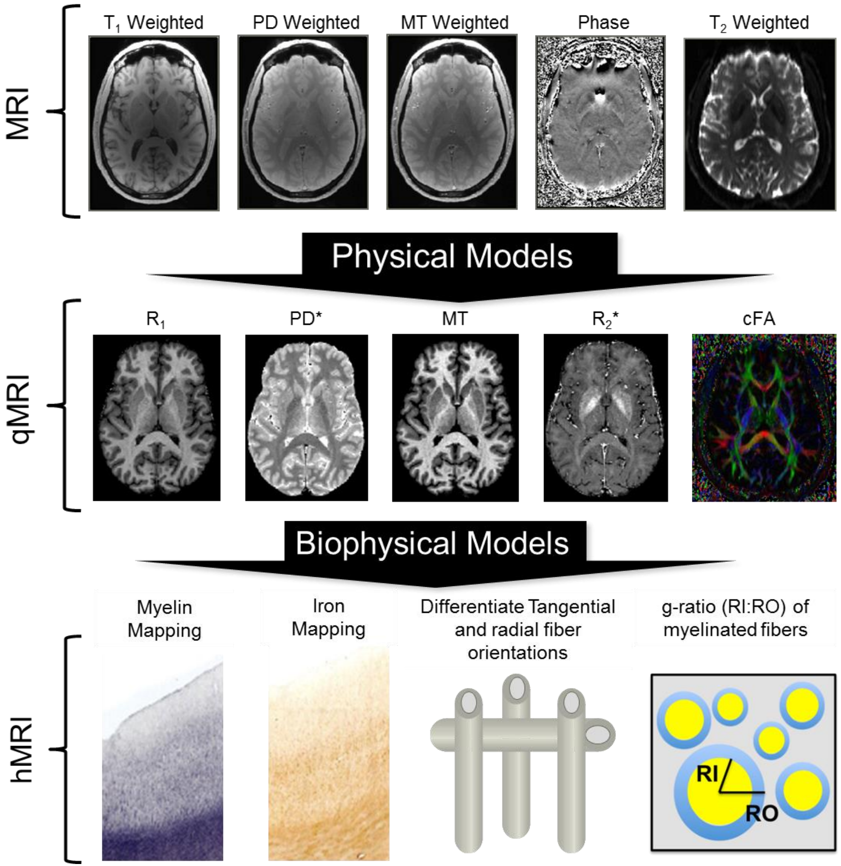


Proton Density



⇒ Quantitative MRI & "Voxel-Based Quantification"

In vivo histology using MRI (hMRI)



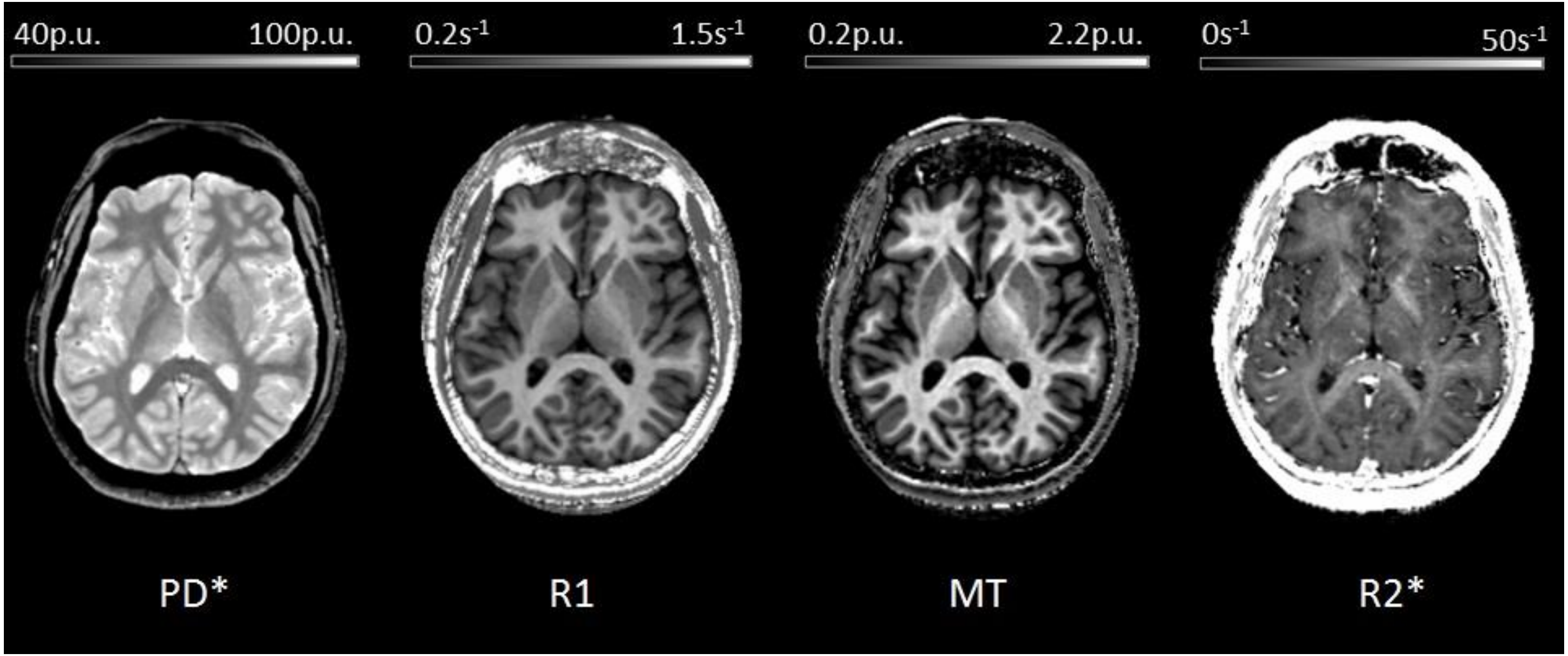
Begin by getting quantitative maps of specific parameters

The ultimate target is biological mapping

Weiskopf *et al.*, https://doi.org/10.1097/WCO.0000000000000222

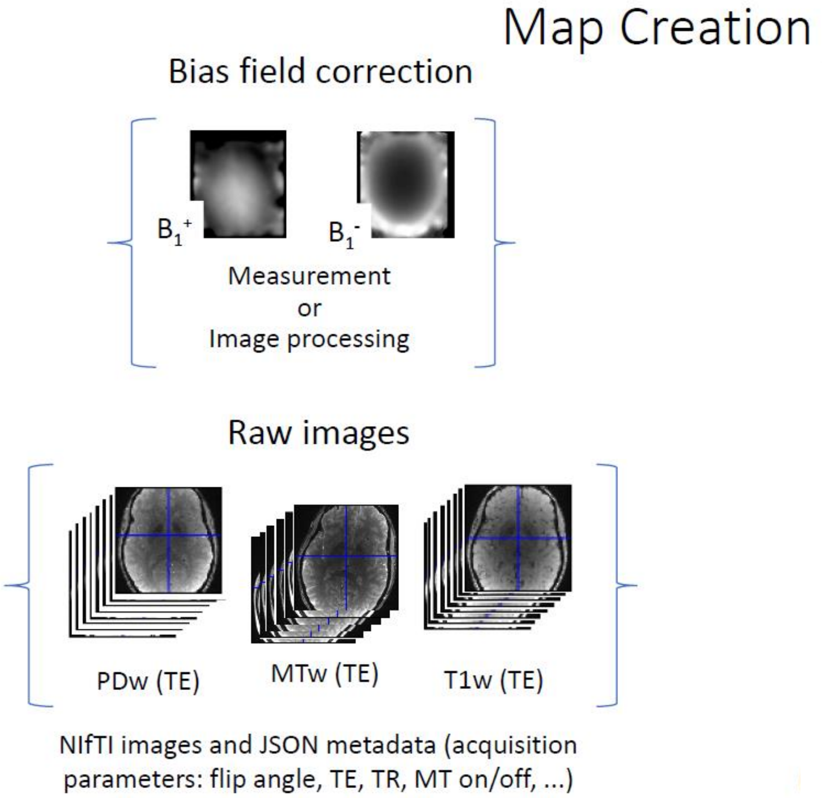
qMRI interpretation as hMRI

Water Content	Water Content; Macromolecules, e.g. myelin; Iron	Macromolecules e.g. myelin	Iron



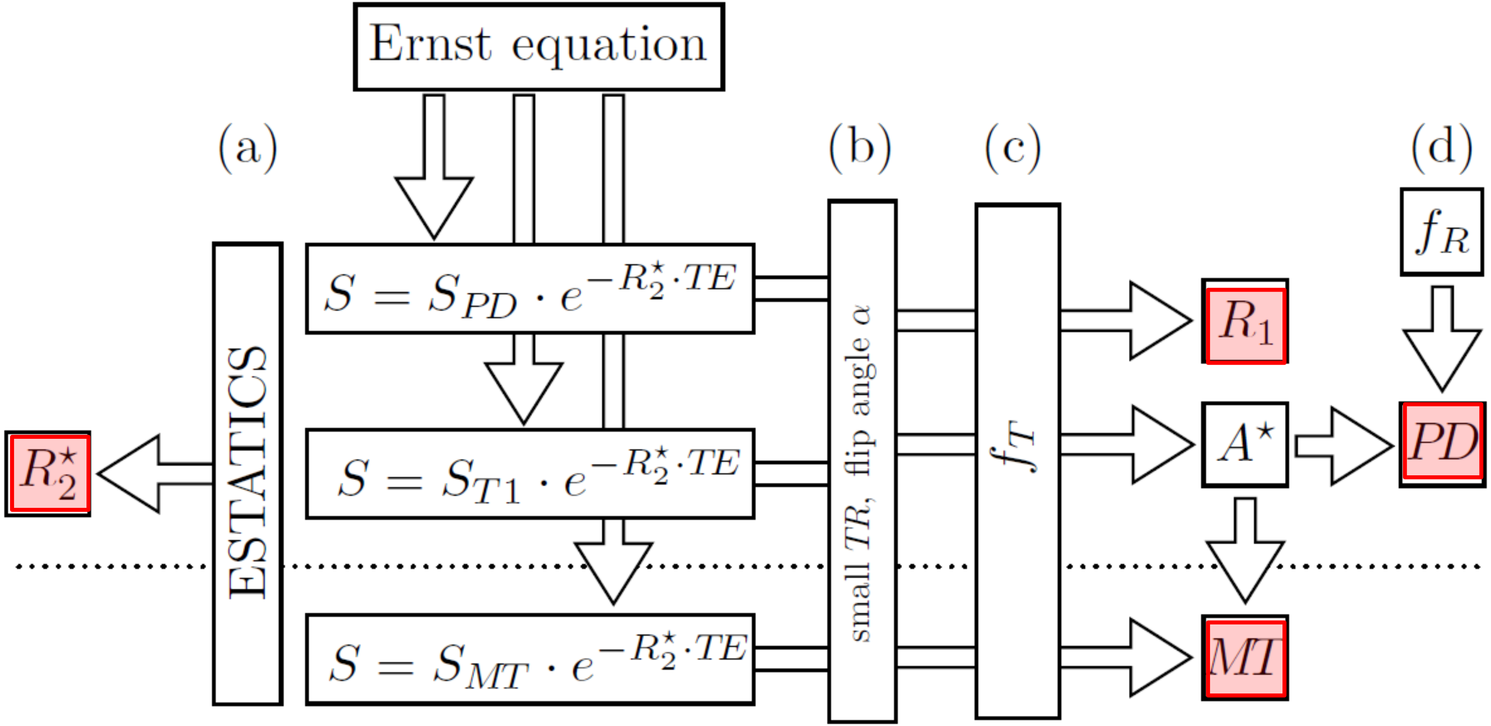
Weiskopf *et al.*, https://doi.org/10.1038/s42254-021-00326-1

hMRI toolbox: MPM to quantitative maps



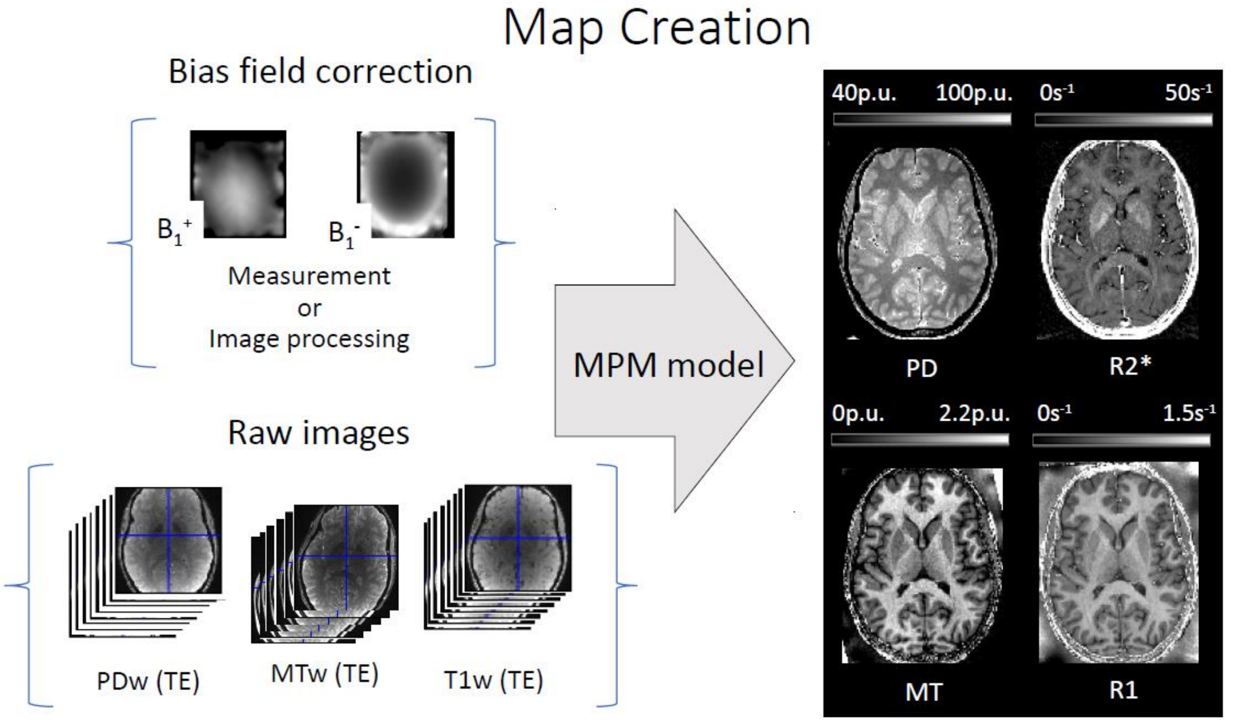
Tabelow *et al.*, https://doi.org/10.1016/j.neuroimage.2019.01.029 & http://hmri.info

Multi-Parameter Mapping (MPM) Protocol



Weiskopf *et al.*, https://dx.doi.org/10.3389%2Ffnins.2013.00095

hMRI toolbox: MPM to quantitative maps



NIfTI images and JSON metadata (acquisition parameters: flip angle, TE, TR, MT on/off, ...)

NIfTI images and JSON metadata (processing parameters & description)

Tabelow *et al.*, https://doi.org/10.1016/j.neuroimage.2019.01.029 & http://hmri.info

Raw data are messy…

qMRI relies on

- multiple series of images (different weighting & field maps)
- specific acquisition parameters (echo times, flip angles,…)

Image Series No.	Sequence Name	Description
4	mfc_seste_b1map_v1e	B_1^+ Mapping Data
5	gre_field_mapping_1acq_rl	B_0 Mapping Magnitude
6	gre_field_mapping_1acq_rl	B_0 Mapping Phase Difference
7	mfc_smaps_v1a_Array	Net Receive Sensitivity Mapping of Array
8	mfc_smaps_v1a_QBC	Net Receive Sensitivity Mapping of Body Coil
9	pdw_mfc_3dflash_v1i_R4	Lower flip angle multi-echo FLASH
Participant moved to new position via primary rotation about z		
10	mfc_smaps_v1a_Array	Net Receive Sensitivity Mapping of Array
11	mfc_smaps_v1a_QBC	Net Receive Sensitivity Mapping of Body Coil
12	mtw_mfc_3dflash_v1i_R4	FLASH acquisition with MT pre-pulse
Participant returned to approximate alignment with the original position		
13	mfc_smaps_v1a_Array	Net Receive Sensitivity Mapping of Array
14	mfc_smaps_v1a_QBC	Net Receive Sensitivity Mapping of Body Coil
15	t1w_mfc_3dflash_v1i_R4	Higher flip angle multi-echo FLASH

Callaghan *et al.*, https://doi.org/10.1016/j.dib.2019.104132

Raw data are messy…

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- hmri_sample_dataset_with_maps
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  - mfc_smaps_v1a_Array_0010
  - mfc_smaps_v1a_Array_0013
  - mfc_smaps_v1a_QBC_0008
  - mfc_smaps_v1a_QBC_0011
  - mfc_smaps_v1a_QBC_0014
  - mtw_mfc_3dflash_v1i_R4_0012
  - pdw_mfc_3dflash_v1i_R4_0009
  - t1w_mfc_3dflash_v1i_R4_0015

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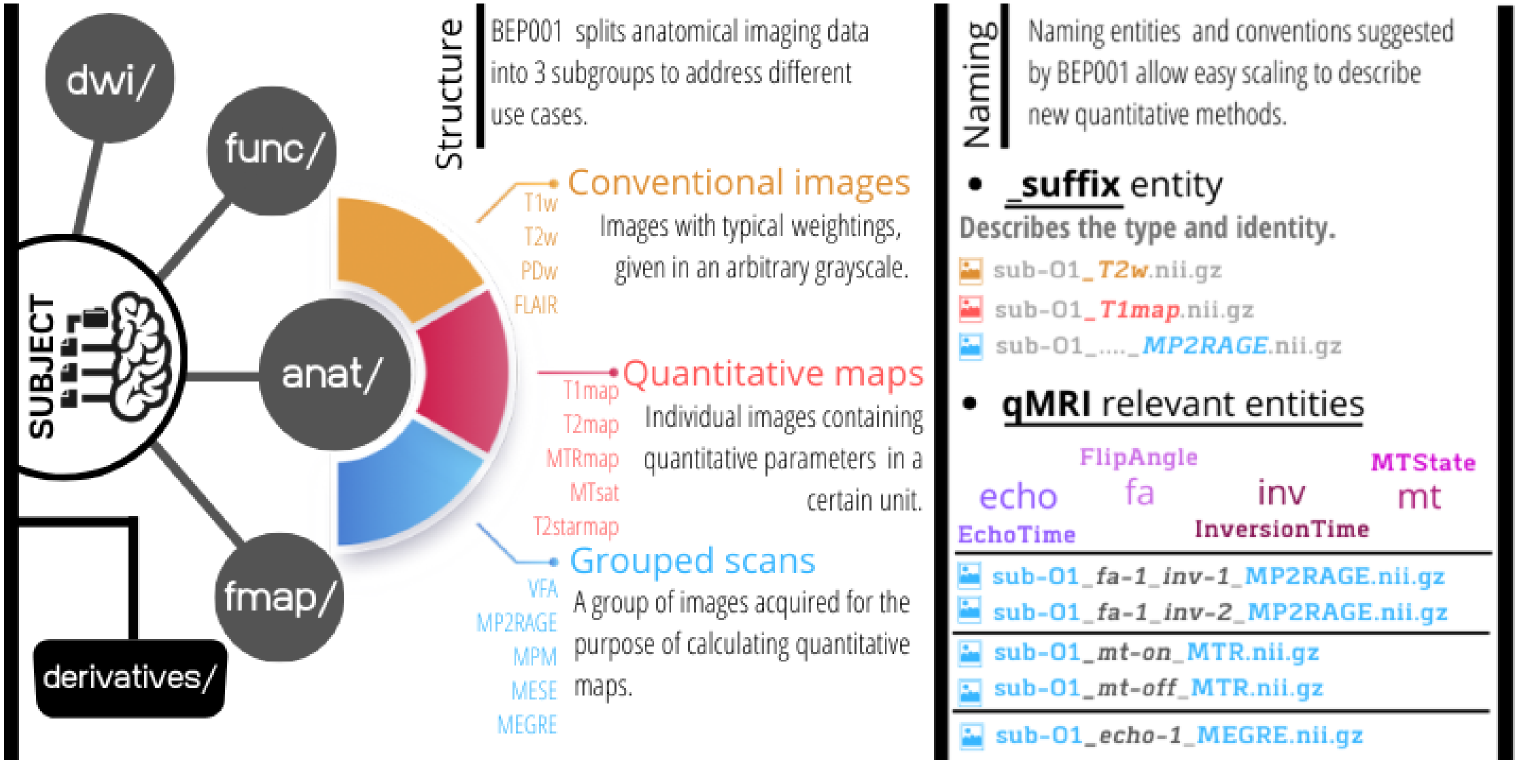
Callaghan *et al.*, https://doi.org/10.1016/j.dib.2019.104132

BIDS, with qMRI extension…

Brain Imaging Data Structure



Karakuzu *et al.*, https://doi.org/10.1101/2021.10.22.21265382 & https://bids.neuroimaging.io/

Raw data sorted…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      "history": []
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"BIDSme" tool

Beliy *et al.*, https://doi.org/10.21105/joss.05575 &
https://github.com/CyclotronResearchCentre/bidsme

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  - anat

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- sub-01
  - anat
  - fmap

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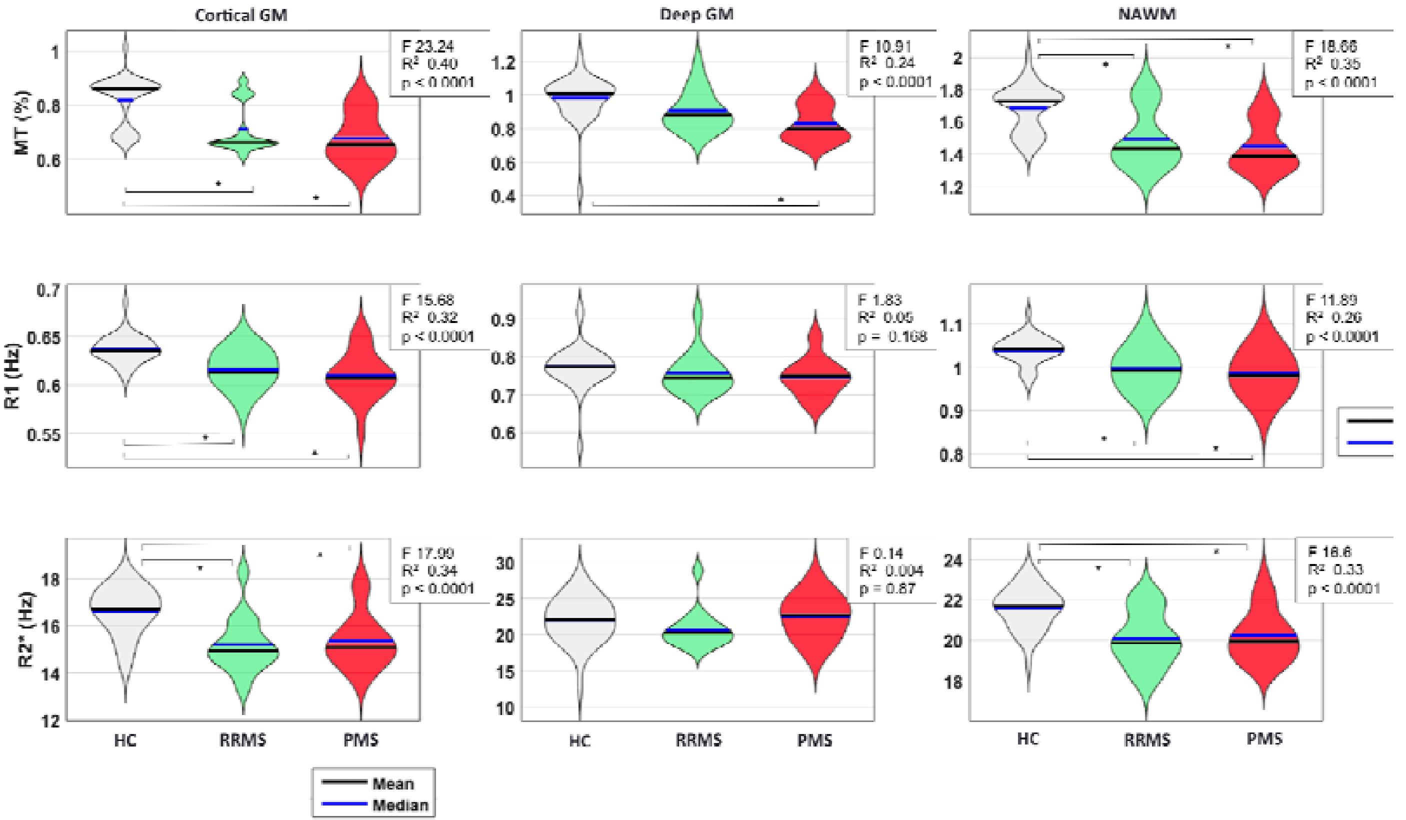
qMRI application in multiple sclerosis (MS)

- 35 MS patients (14 RRMS, 21 PMS) & 36 matched controls
- qMRI data + FLAIR
- Processing:
  - "unified segmentation with lesion"
  - tissue-weighted smoothing
  - population GM mask

Application in MS: healthy tissues **global** changes

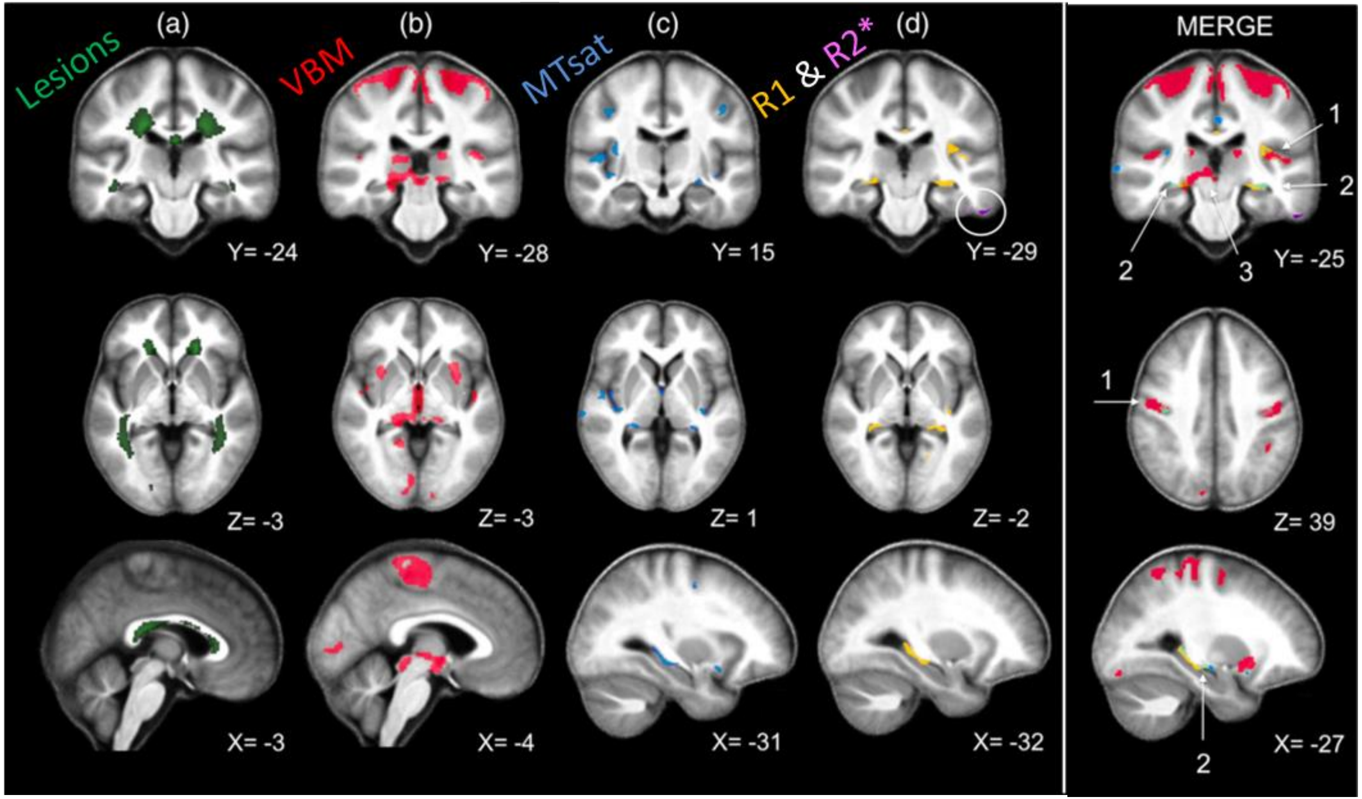
- 35 MS patients (14 RRMS, 21 PMS) & 36 matched controls
- qMRI data + FLAIR
- Processing:
  - "unified segmentation with lesion"
  - tissue-weighted smoothing
  - population GM mask
- GM-specific global comparison of
  - MTsat, R1 & R2*
  - Across HC vs. RRMS vs. PMS



Lommers *et al.*, https://doi.org/10.1016/j.nicl.2019.101879

Application in MS: healthy tissue **voxel-wise** analysis

- 35 MS patients (14 RRMS, 21 PMS) & 36 matched controls
- qMRI data + FLAIR
- Processing:
  - "unified segmentation with lesion"
  - tissue-weighted smoothing
  - population GM mask
- GM-specific voxel-wise comparison of
  - MTsat, R1 & R2* (VBQ)
  - GM density (VBM)
  - HC > MS



⇒ 3 different patterns: Primary Neocortical Regions (1), Hippocampus (2), Deep Gray Matter Nuclei (3)

Lommers *et al.*, http://dx.doi.org/10.1002/hbm.25274

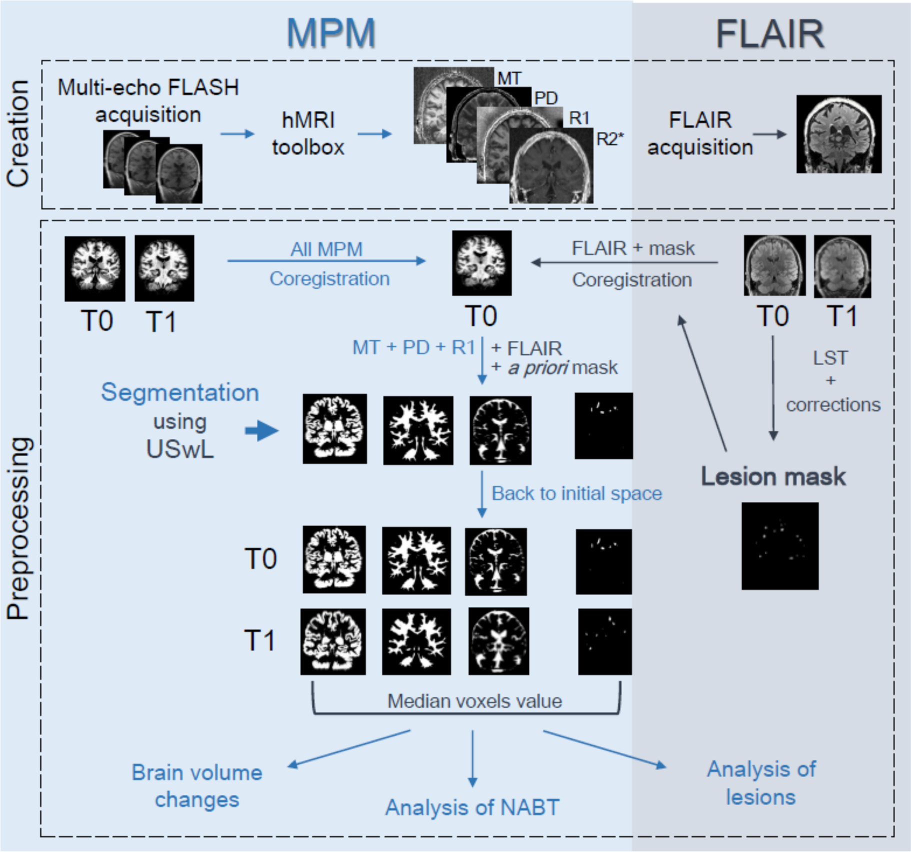
Longitudinal qMRI analysis in MS

Data

- 17 MS patients (11 RRMS, 6 PMS),
  - scanned twice over 1-5 years (T0 & T1), on average 2.5 years
  - 13 patients with disease-modifying treatments (11 RRMS, 6 PMS)
- qMRI & FLAIR images

Processing

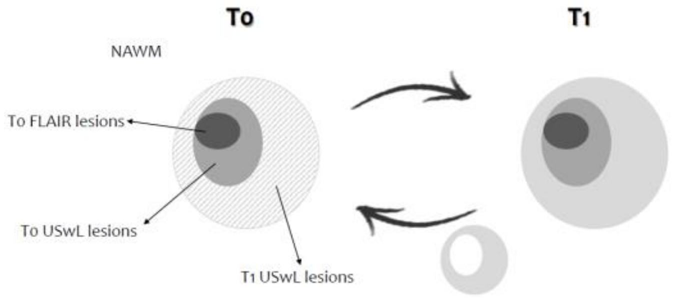
- FLAIR derived mask + qMRI-USwL multichannel segmentation
  → normal appearing tissues (NAWM, NACGM, NADGM) & lesion
- Spatial alignment to T0
- Extract volumes & tissue preperties



Vandeleene *et al.*, https://doi.org/10.1002/brb3.2923

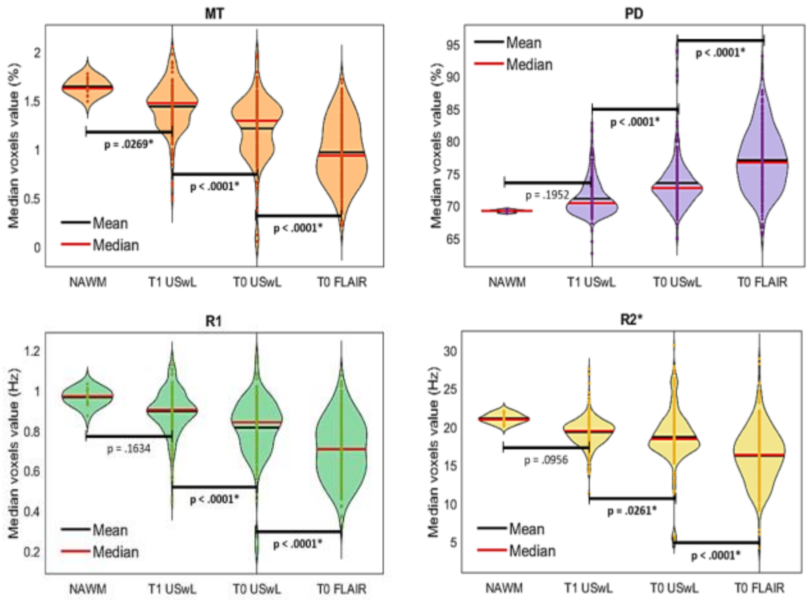
Longitudinal qMRI analysis in MS

- Significant longitudinal effects
  - (Relative) lesion volume increase
  - Rate of change for some qMRI values in NA tissues, associated to clinical status



- FLAIR hyper-intensity lesions
  < US-w-Lesion qMRI detected lesions
  ⇒ 3 “lesional tissue” types in WM
  - Clinical lesion (FLAIR hyp-int) at T0
  - Peripheral lesion (qMRI USwL) at T0
  - Peripheral lesion (qMRI USwL) at T1

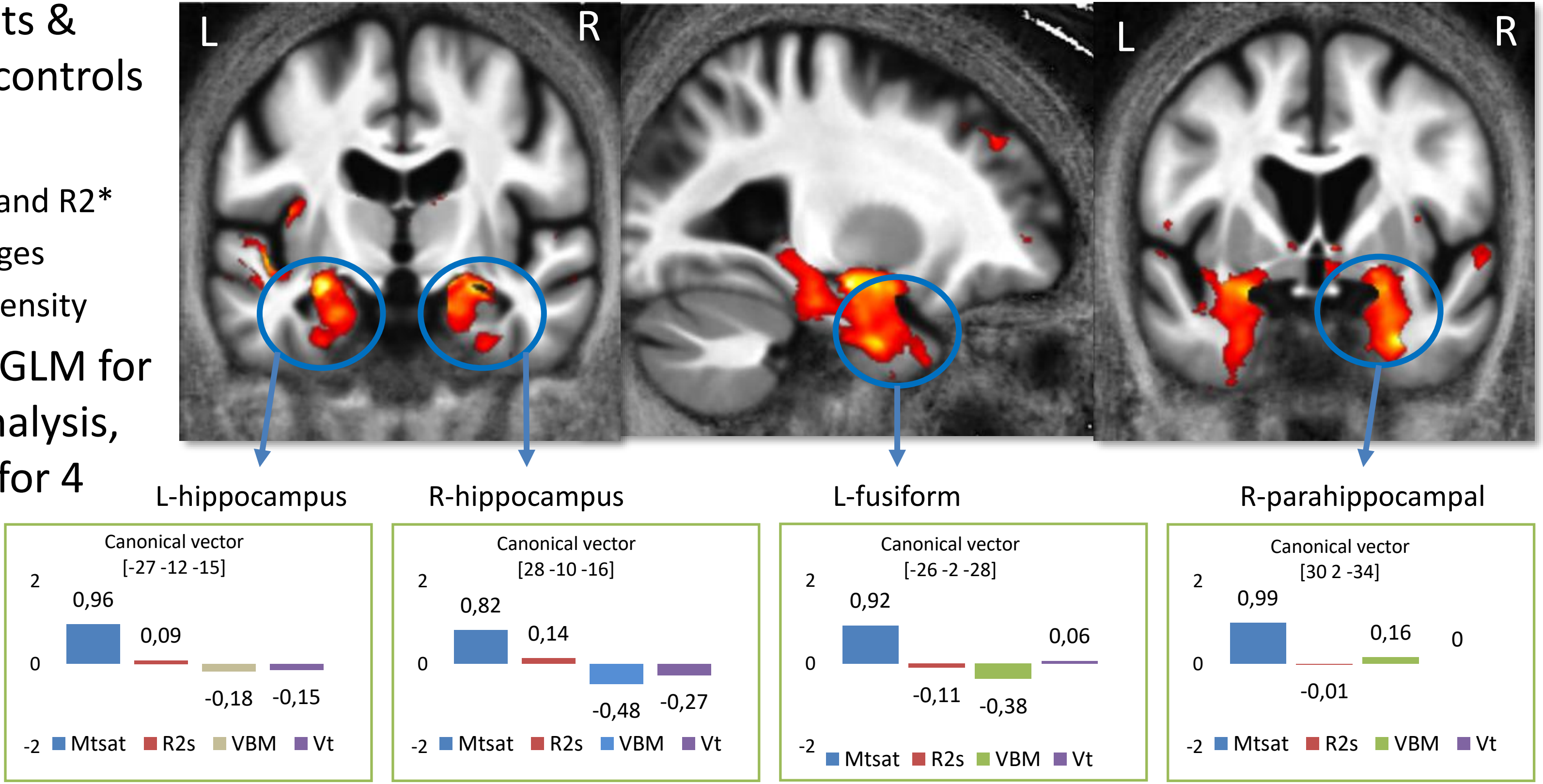
  + Normal appearing WM



Vandeleene *et al.*, https://doi.org/10.1002/brb3.2923

Application in Alzheimer disease

- 24 AD patients & 19 matched controls
- Data
  - qMRI : Mtsat and R2*
  - SV2A PET images
  - Grey matter density
- Multivariate GLM for voxel wise analysis, i.e. 1 mGLM for 4 modalities!



Moallemian *et al.*, http://dx.doi.org/10.1002/hbm.25274

Conclusions

- Morphometry still useful but…
- qMRI biomarkers
  - enhance specificity
  - disentangle effects via multi-modal quantification
  - reproducible across scanner
- getting closer to *in vivo* histology using MRI
  - follow tissue changes w/o (or before…) volume changes
  - (explore structure/function relationships)
- hMRI toolbox (SPM12 add-on) to create & process maps

Perspectives

- Improve MRI acquisition sequence:

  speed, SNR, resolution, different scanners, 3T & 7T,…

- Improve image reconstruction & processing:

  noisy voxels, automatization, data & meta-data organization (BIDS),…

- Linking to neuro-biological tissue properties:

  combining with PET, clinical applications,…

CRC references

- N. Beliy et al., *BIDSme, a user friendly open-source python toolkit to "bidsify" source-level neuroimaging data-sets to BIDS-conformed*.
  2019, https://github.com/CyclotronResearchCentre/bidsme &
  2023, https://doi.org/10.21105/joss.05575
- E. Lommers et al., *Multiparameter MRI quantification of microstructural tissue alterations in multiple sclerosis.* 2019, https://doi.org/10.1016/j.nicl.2019.101879
- E. Lommers et al., *Voxel-Based quantitative MRI reveals spatial patterns of grey matter alteration in multiple sclerosis*. 2021, http://dx.doi.org/10.1002/hbm.25274
- N. Vandeleene et al., *Using quantitative MRI to characterize cerebral damage in multiple sclerosis: a longitudinal study.* 2023, https://doi.org/10.1002/brb3.2923
- S. Moallemian et al., Multimodal imaging of microstructural cerebral alterations and loss of synaptic density in Alzheimer's disease. 2023, https://doi.org/10.1016/j.neurobiolaging.2023.08.001

Some qMRI/hMRI references

- Toolbox, http://hmri.info & https://doi.org/10.1016/j.neuroimage.2019.01.029
- MPM protocol, https://dx.doi.org/10.3389%2Ffnins.2013.00095
- hMRI review, https://doi.org/10.1097/WCO.0000000000000222
- Multi-centre study, https://doi.org/10.3389/fnins.2013.00095
- Ageing studies, https://doi.org/10.1016/j.neuroimage.2011.01.052 and https://doi.org/10.1016/j.neurobiolaging.2014.02.008
- Example dataset, https://doi.org/10.1016/j.dib.2019.104132
- qMRI-BIDS, https://doi.org/10.1038/s41597-022-01571-4

Thank you for your attention!

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the international hMRI teams

LIÈGE université
GIGA