Vendor-Neutral Applications for Quantitative MRI Quality Control

Quality Conversations webinar series

December 2nd, 2021

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NeuroPoly Lab, Polytechnique Montreal, Montreal, Quebec, Canada
Montreal Heart Institute, Montreal, Quebec, Canada

INSTITUT DE CARDIOLOGIE DE MONTRÉAL

qMR Lab
Quantitative MRI. Under one umbrella.

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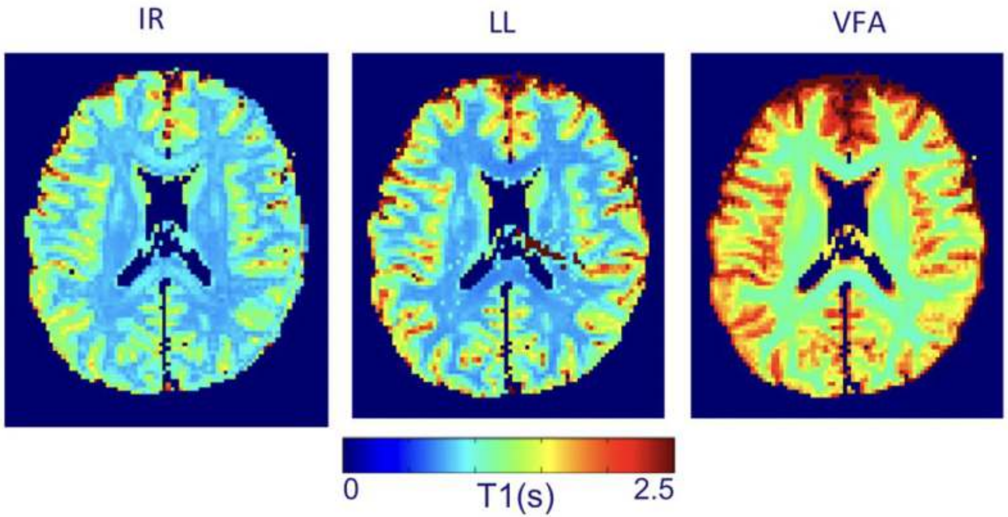
Outline

Part 1: Quantitative MRI, T_1 mapping, and qMRLab

Part 2: A vendor-neutral scanner-to-publication pipeline

Part 3: The ISMRM T_1 Mapping Reproducibility Challenge

Quantitative MRI has a reproducibility problem.



Scientific Note

A Line Scan Image Study of a Tumorous Rat Leg by NMR

I. L. PYKETT and P. MANSFIELD

Department of Physics, University of Nottingham, Nottingham, U.K.

Received 21 *December* 1977, *in final form* 15 *March* 1978

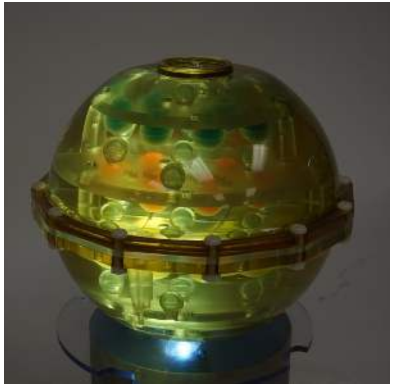
Magnetic Resonance in Medicine 73:514–522 (2015)

On the Accuracy of T_1 Mapping: Searching for Common Ground

Nikola Stikov,[1]* Mathieu Boudreau,[1] Ives R. Levesque,[2] Christine L. Tardif,[3] Joëlle K. Barral,[4] and G. Bruce Pike[1]

Quantitative MRI Community's Response

Quantitative imaging phantoms



ISMRM System Phantom
by CaliberMRI

Open-source software

qMR Lab

Quantitative MRI. Under one umbrella.

Consensus papers on standard protocols

nature protocols

PROTOCOL

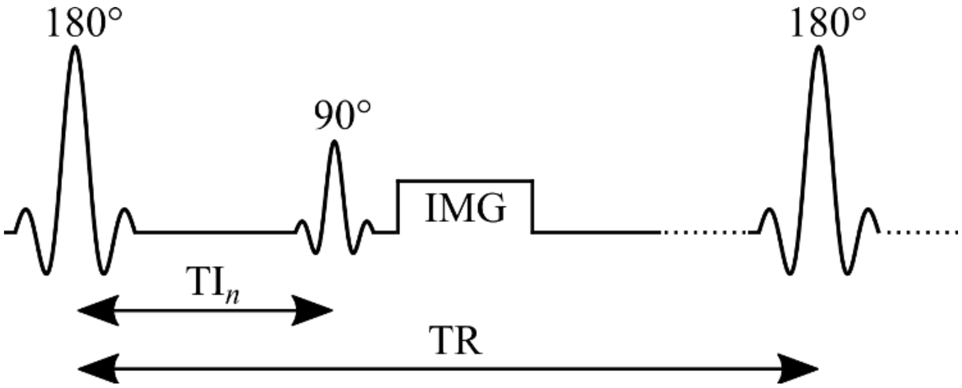
https://doi.org/10.1038/s41596-021-00588-0

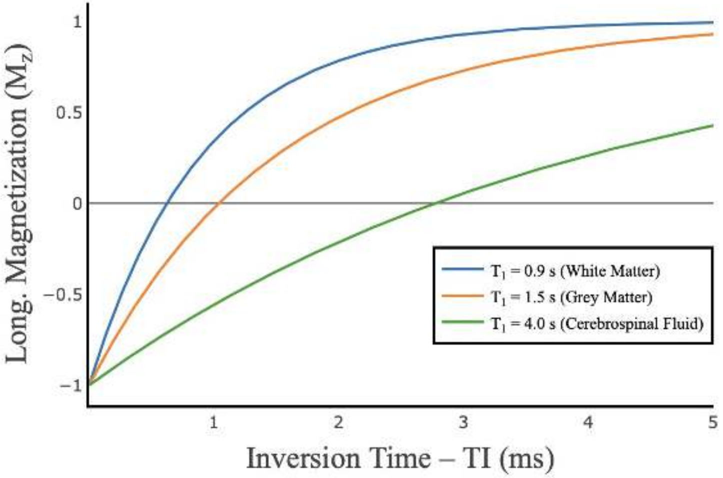
Check for updates

Generic acquisition protocol for quantitative MRI of the spinal cord

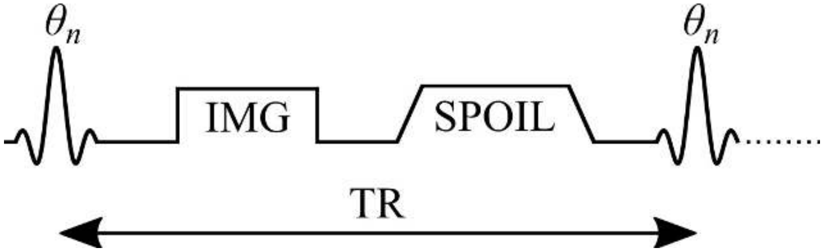
Julien Cohen-Adad[1,2,3], Eva Alonso-Ortiz[1], Mihael Abramovic[4], Carina Arneitz[4], Nicole Atcheson[5], Laura Barlow[6], Robert L. Barry[7,8,9], Markus Barth[10], Marco Battiston[11], Christian Büchel[12], Matthew Budde[13], Virginie Callot[14,15], Anna J. E. Combes[16], Benjamin De Leener[17,18], Maxime Descoteaux[19,20], Paulo Loureiro de Sousa[21], Marek Dostál[22], Julien Doyon[23], Adam Dvorak[24], Falk Eippert[25], Karla R. Epperson[26], Kevin S. Epperson[26], Patrick Freund[27], Jürgen Finsterbusch[12], Alexandru Foias[1], Michela Fratini[28,29], Issei Fukunaga[30], Claudia A. M. Gandini Wheeler-Kingshott[11,31,32], Giancarlo Germani[32], Guillaume Gilbert[33], Federico Giove[29,34], Charley Gros[1,5], Francesco Grussu[11,35], Akifumi Hagiwara[30], Pierre-Gilles Henry[36], Tomáš Horák[37], Masaaki Hori[38], James Joers[36], Kouhei Kamiya[39], Haleh Karbasforoushan[40,41], Miloš Keřkovský[22], Ali Khatibi[23,42], Joo-Won Kim[43], Nawal Kinany[44,45], Hagen Kitzler[46], Shannon Kolind[6,24,47], Yazhuo Kong[48,49,50], Petr Kudlička[37], Paul Kuntke[46], Nyoman D. Kurniawan[5], Slawomir Kusmia[51,52,53], René Labounek[54,55], Maria Marcella Laganà[56], Cornelia Laule[57], Christine S. Law[58], Christophe Lenglet[36], Tobias Leutritz[59], Yaou Liu[60,61], Sara Llufriu[62], Sean Mackey[58], Eloy Martinez-Heras[62], Loan Mattera[63], Igor Nestrasil[36,54], Kristin P. O'Grady[16,64], Nico Papinutto[65], Daniel Papp[1,50], Deborah Pareto[66], Todd B. Parrish[40], Anna Pichiecchio[31,32], Ferran Prados[11,52,67], Àlex Rovira[66], Marc J. Ruitenberg[68], Rebecca S. Samson[11], Giovanni Savini[32], Maryam Seif[27,59], Alan C. Seifert[43], Alex K. Smith[50], Seth A. Smith[16,64], Zachary A. Smith[69], Elisabeth Solana[62], Yuichi Suzuki[39], George Tackley[51], Alexandra Tinnermann[12], Jan Valošek[70], Dimitri Van De Ville[44,45], Marios C. Yiannakas[11], Kenneth A. Weber II[58], Nikolaus Weiskopf[59,71], Richard G. Wise[51,72], Patrik O. Wyss[4] and Junqian Xu[43]

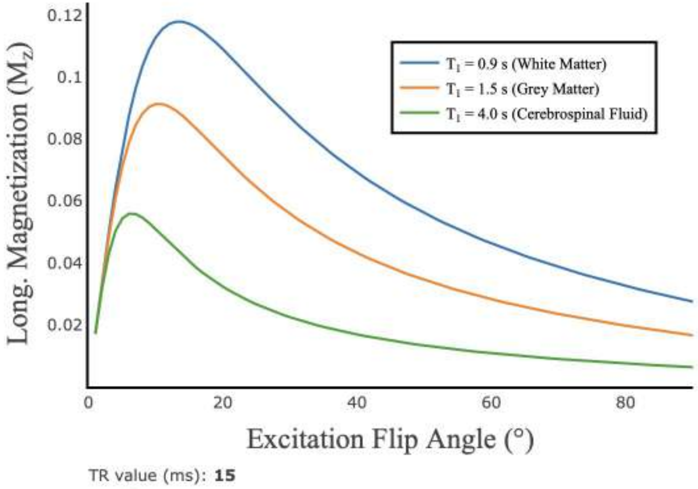
Inversion Recovery





Variable Flip Angle/DESPOT1





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Quantitative T_1 MRI

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ACKNOWLEDGEMENTS

Quantitative T_1 Mapping

This Jupyter Book is a series of interactive tutorials about quantitative T_1 mapping, powered by qMRLab. Most figures are generated with Plot.ly – you can play with them by hovering your mouse over the data, zooming in (click and drag) and out (double click), moving the sliders, and changing the drop-down options. To view the code that was used to generate the figures in this blog post, hover your cursor in the top left corner of the frame that contains the tutorial and click the checkbox "All cells" in the popup that appears.

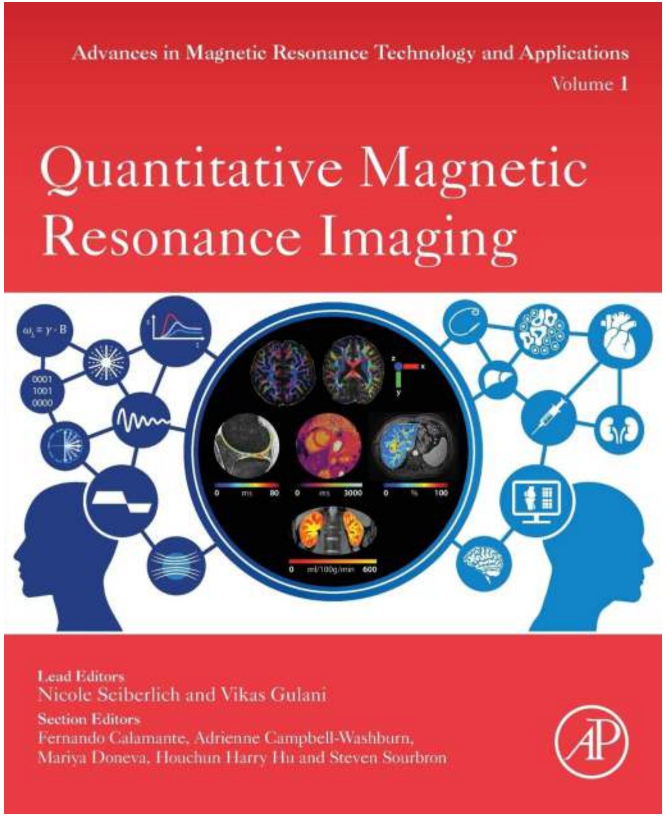
Jupyter Lab notebooks of these tutorials are also available through MyBinder, and inline code modification inside the Jupyter Book is provided by Thebelab. For both options, you can modify the code, change the figures, and regenerate the html that was used to create the tutorial below. This Jupyter Book also uses a Script of Scripts (SoS) kernel, allowing us to process the data using qMRLab in MATLAB/Octave and plot the figures with Plot.ly using Python, all within the same Jupyter Notebook.

Acknowledgements

This work was supported by the Canadian Open Neuroscience Platform (CONP) initiative, the Quebec Bio-Imaging Network (QBIN), and the Montreal Heart Institute Foundation.

〈 | Inversion Recovery 〉

Live demo:
https://qmrlab.org/t1_book/intro



CHAPTER 2

Quantitative T_1 and $T_{1\rho}$ Mapping

Mathieu Boudreau[a,b], Kathryn E. Keenan[c], and Nikola Stikov[a,b]

[a]Montreal Heart Institute, Université de Montréal, Montréal, Canada [b]NeuroPoly Lab, Institute of Biomedical Engineering, Polytechnique Montréal, Montréal, Canada [c]Physical Measurement Laboratory, National Institute of Standards and Technology, Boulder, Colorado

2.1 Introduction

The longitudinal (or spin-lattice) relaxation time (T_1) is one of the fundamental parameters in Magnetic Resonance Imaging (MRI). It characterizes the rate ($R_1 = 1/T_1$) at which longitudinal magnetization recovers to its equilibrium state, which for most tissues can be described by an exponential growth curve [1]. Knowledge of this value is of the utmost importance for many MRI applications, such as pulse sequence design (e.g., optimized signal-to-noise ratio), imaging protocol planning (e.g., improved contrast between tissues), and calibration of other quantitative measurements (e.g., quantitative dynamic contrast enhancement, quantitative magnetization transfer imaging). T_1 is a field-dependent property [2], and also has a temperature dependence [3]. Moreover, it is well-known that many tissue pathologies can be inferred from abnormal T_1 values (e.g., multiple sclerosis lesions, tumors) [4–8].

T_1 mapping has mostly been limited to research applications and is not widely used in clinical imaging protocols. One reason for this is that early T_1 mapping implementations were either very slow (e.g., inversion recovery) or required additional calibration measurements (e.g., variable flip angle, which depends on transmit radiofrequency amplitude maps (B_1^+)). Lack of standardization has also led to a wide range of reported T_1 values when using different methods or scanning at different sites [9]. Recently, however, MRI manufacturers have started adopting rapid techniques such as MP2RAGE (Magnetization Prepared 2 Rapid Acquisition Gradient Echoes) [10] as standard sequences for their scanners, leading to growing interest in adding T_1 maps to clinically-oriented protocols.

This chapter[a] covers three T_1 mapping techniques (inversion recovery, variable flip angle, MP2RAGE) that represent the fundamental types of methods currently in use (signal recovery, steady-state, dictionary-based). Most other T_1 mapping approaches are variants of these techniques, some of which will also be briefly discussed. Only monoexponential T_1 mapping is covered; although some biexponential longitudinal relaxation behavior has been observed in tissues [11], multiexponential T_1 mapping has not garnered the same level of interest as multiexponential mapping of the

[a]Sections 2.2–2.5 in this book chapter have been previously published under a creative commons license on the qMRLab blog. Visit the original blog posts for interactive versions of the figures: https://qmrlab.org/jekyll/2018/10/23/T1-mapping-inversion-recovery.html.https://qmrlab.org/jekyll/2018/12/11/T1-mapping-variable-flip-angle.html.https://qmrlab.org/2019/04/08/T1-mapping-mp2rage.html.https://qmrlab.org/2019/04/09/T1-mapping-t1rho.html.

Advances in Magnetic Resonance Technology and Applications, Volume 1. ISSN 2666-9099. https://doi.org/10.1016/B978-0-12-817057-1.00004-4

http://bit.ly/2WCMwB7

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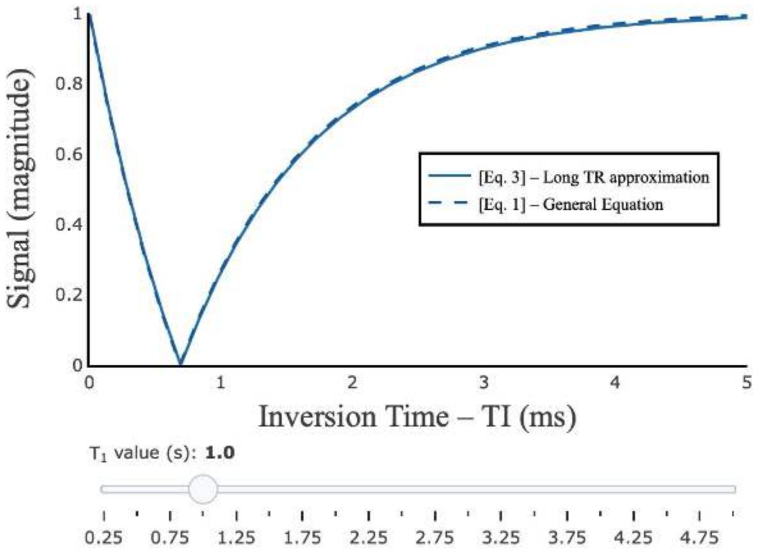
Figure 3. Signal recovery curves simulated using Eq. 3 (solid) and Eq. 1 (dotted) with a TR = 5 s for T_1 values ranging between 0.25 to 5 s.

(View simulation code)

(View plot code)



Live demo:

https://qmrlab.org/t1_book/intro

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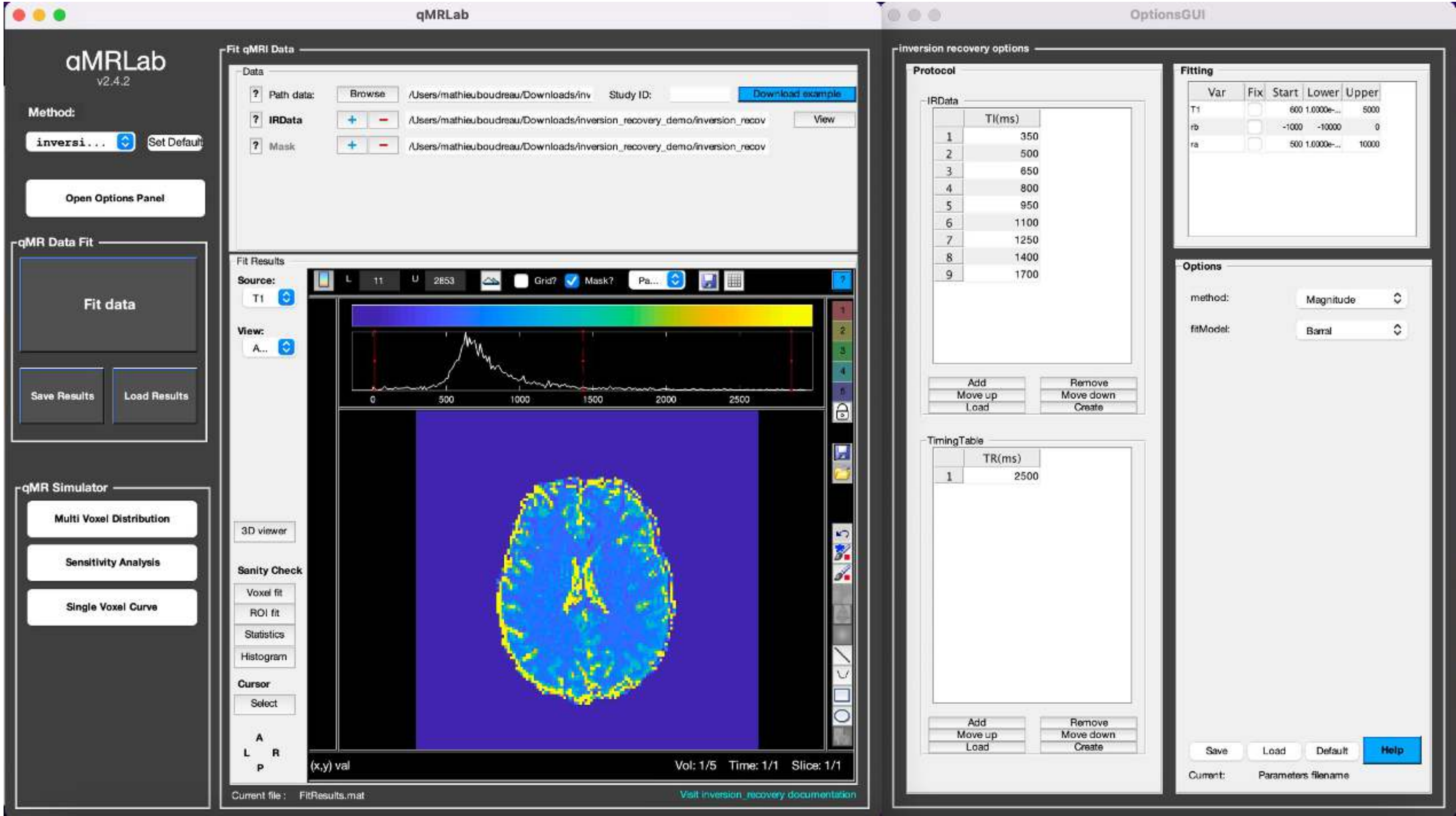

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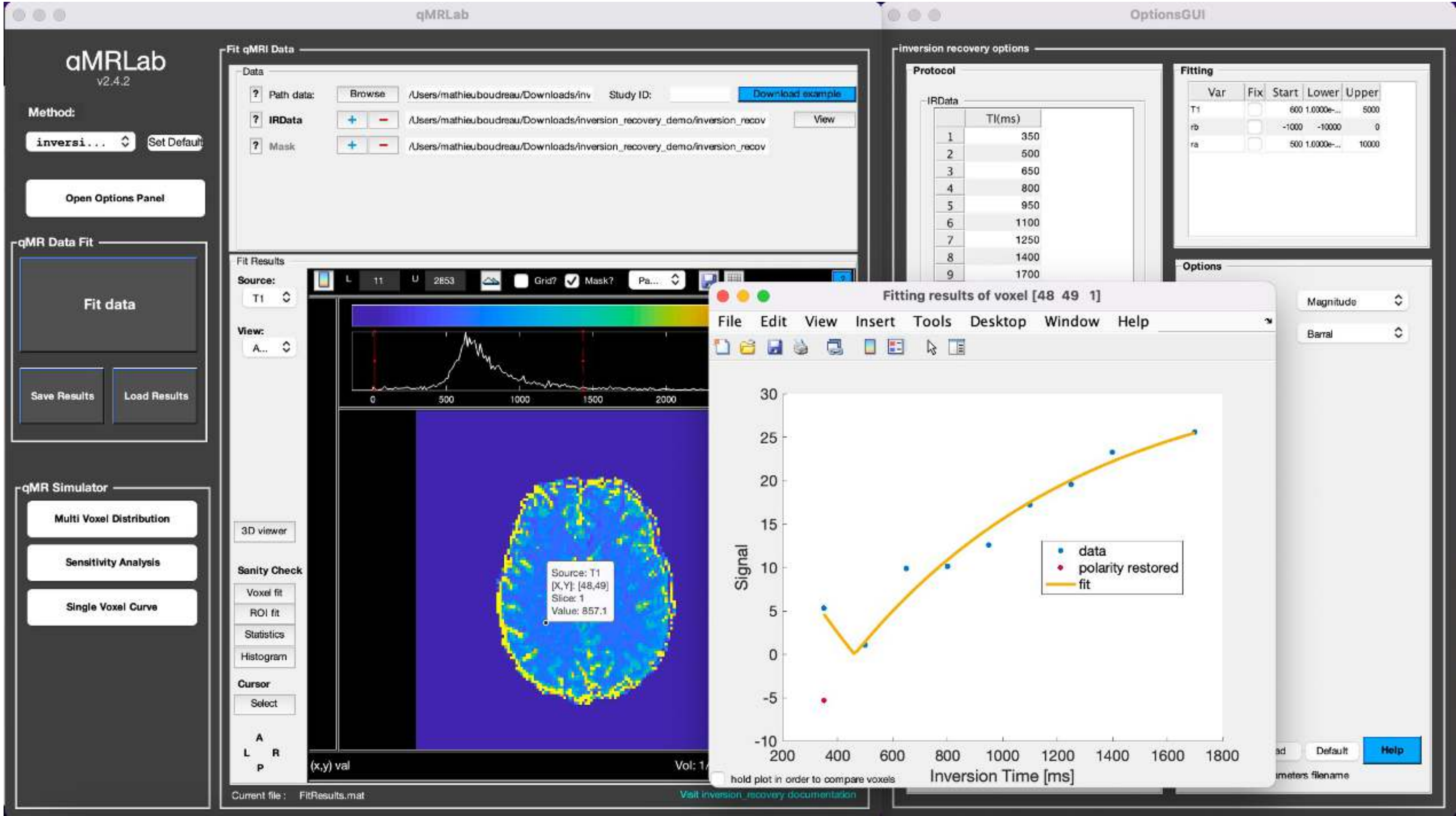

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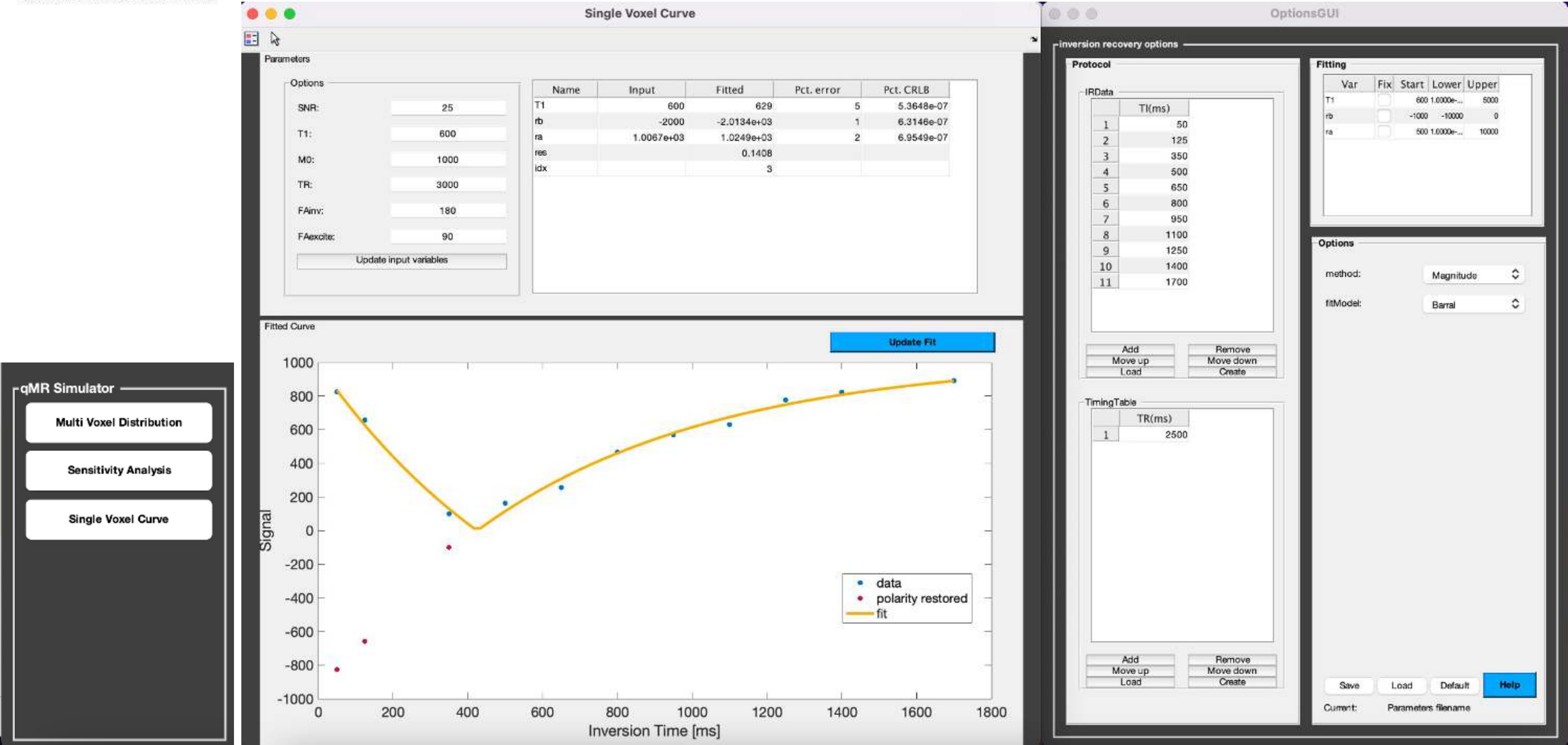


T_1 Mapping Reproducibility Challenge

A joint collaboration between the Reproducible Research and Quantitative MR Study Groups

Challenge Leader: Mathieu Boudreau, PhD

Research Fellow, Montreal Heart Institute

Software Developer, NeuroPoly, Polytechnique de Montréal

ISMRM ONE COMMUNITY FOR CLINICIANS AND SCIENTISTS

Challenge Pitch

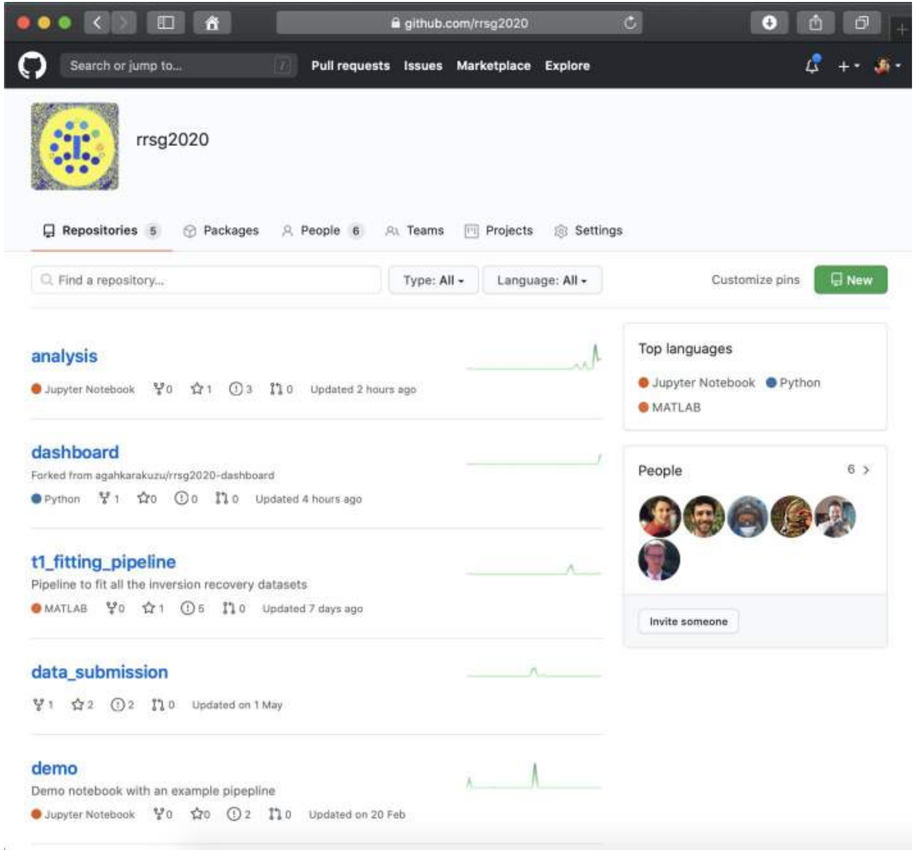
Will an imaging protocol independently-implemented at multiple centers reliably measure what is considered one of the fundamental MR parameters (**T_1**) using the most robust technique (**inversion recovery**) in a standardized phantom (**ISMRM/NIST system phantom**)?

Imaging Protocol

Pulse sequence	Spin-echo inversion recovery
Repetition time	2550 ms
Inversion times	50, 400, 1100, 2500 ms
Echo time	14 ms
In-plane resolution	1 mm x 1 mm
Slice thickness	2 mm

Barral, J.K., Gudmundson, E., Stikov, N., Etezadi□Amoli, M., Stoica, P. and Nishimura, D.G. (2010), *A robust methodology for in vivo T_1 mapping.* Magn. Reson. Med., 64: 1057-1067.

Data Processing:
Collaborative coding & analysis



www.github.com/rrsg2020

Summary of Submissions
Datasets

Total # of submissions: **19**

CaliberMRI/NIST phantom

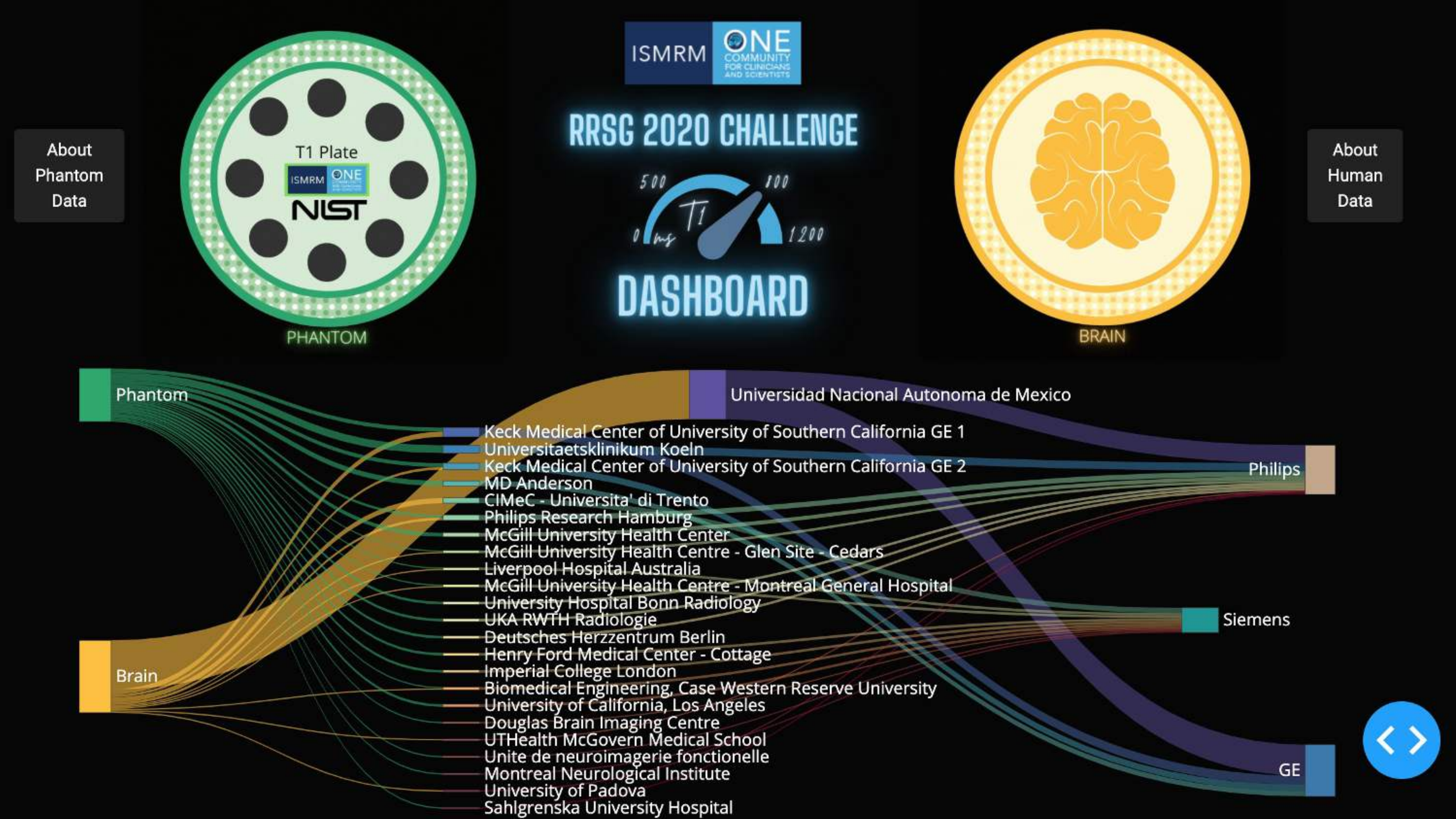
- # of T_1 datasets: **41**

Human subjects

- # of T_1 datasets: **56**

All at **3.0 T** (except for one phantom @**350 mT**)

Vendors: **GE, Philips, Siemens**.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Universitaetsklinikum Koeln
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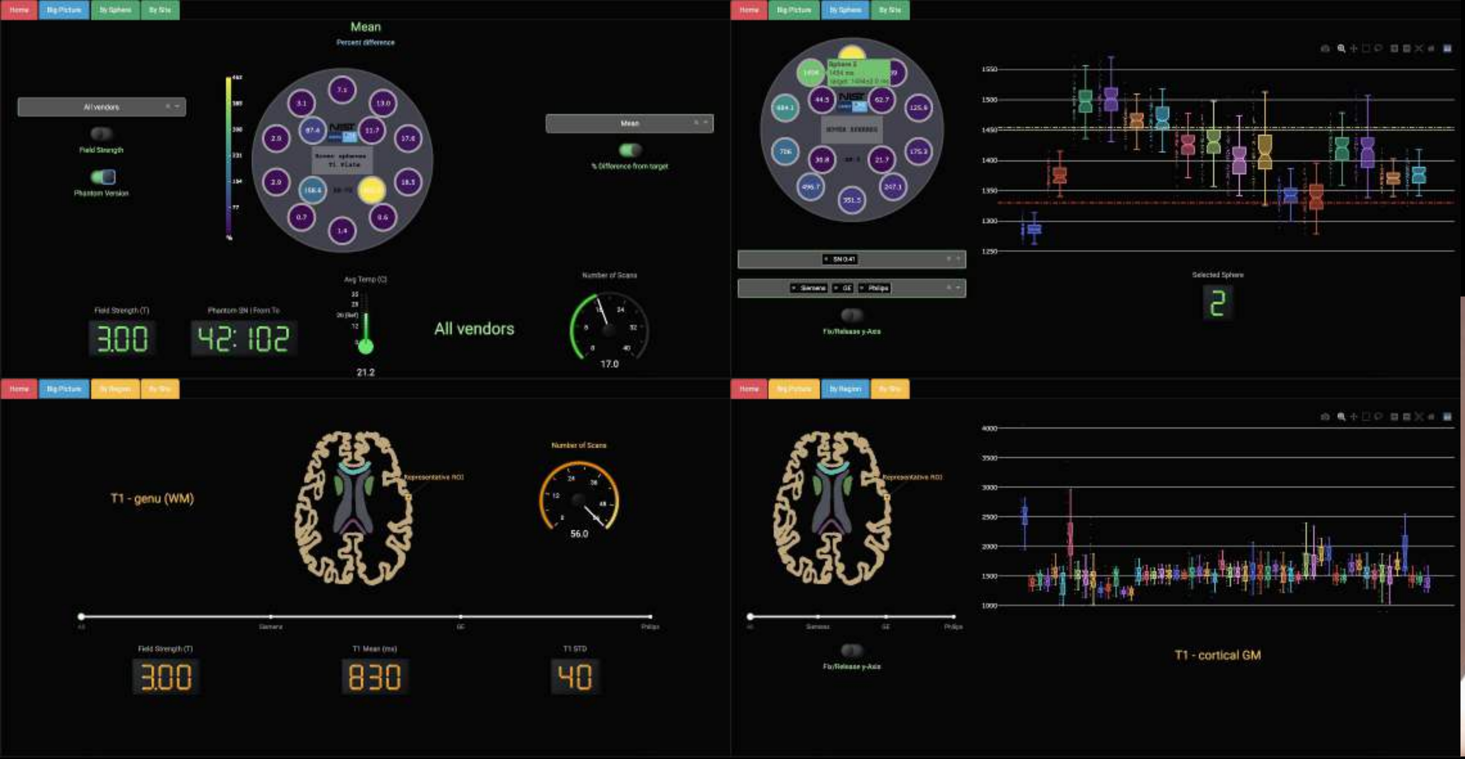
Liverpool Hospital Australia
McGill University Health Centre - Montreal General Hospital
University Hospital Bonn Radiology
UKA RWTH Radiologie
Deutsches Herzzentrum Berlin
Henry Ford Medical Center - Cottage
Imperial College London
Biomedical Engineering, Case Western Reserve University
University of California, Los Angeles
Douglas Brain Imaging Centre
UTHealth McGovern Medical School
Unite de neuroimagerie fonctionelle
Montreal Neurological Institute
University of Padova
Sahlgrenska University Hospital
Philips
Siemens
GE

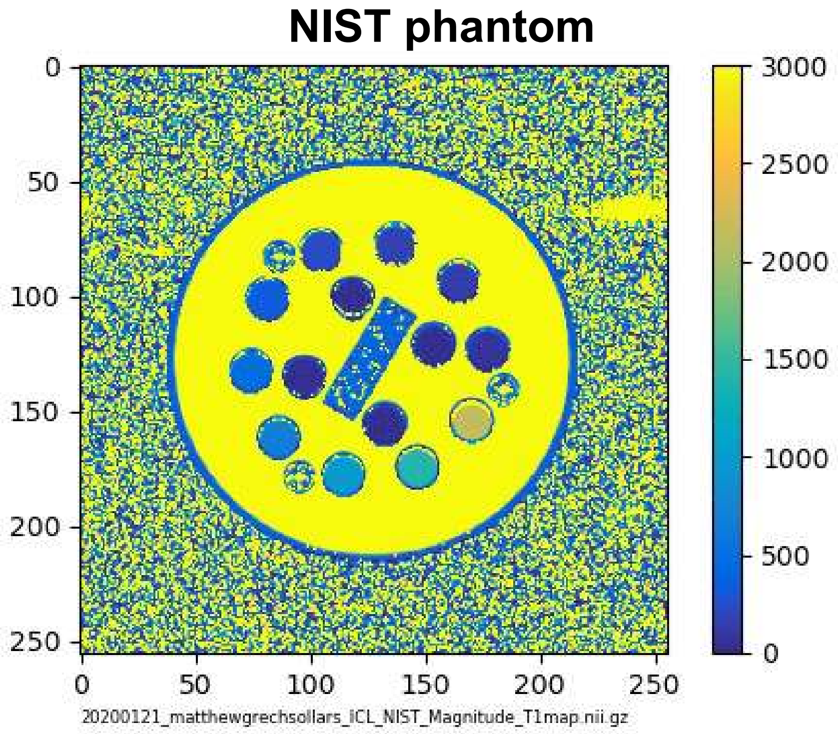


Agah Karakuzu

http://rrsg2020.herokuapp.com/

Work In Progress

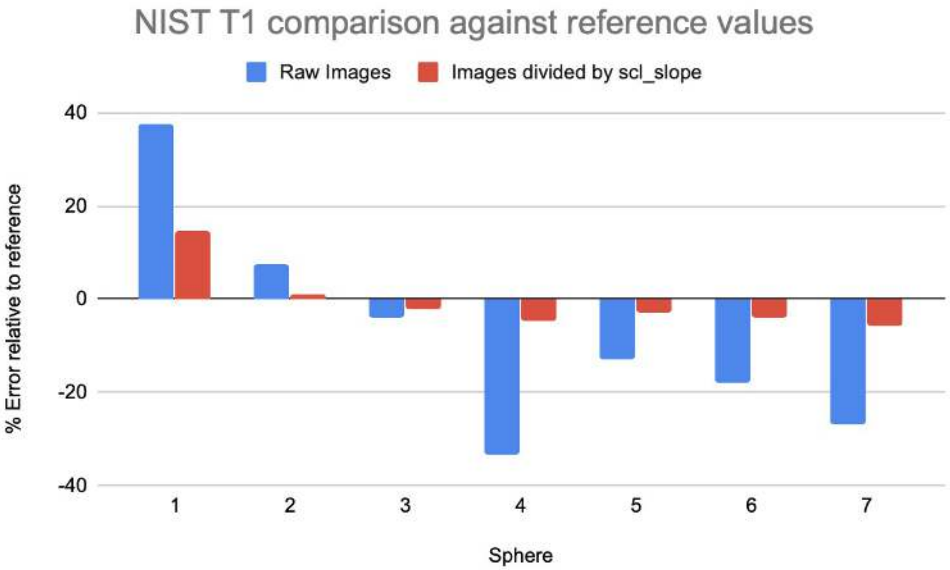
Raw T_1 Maps



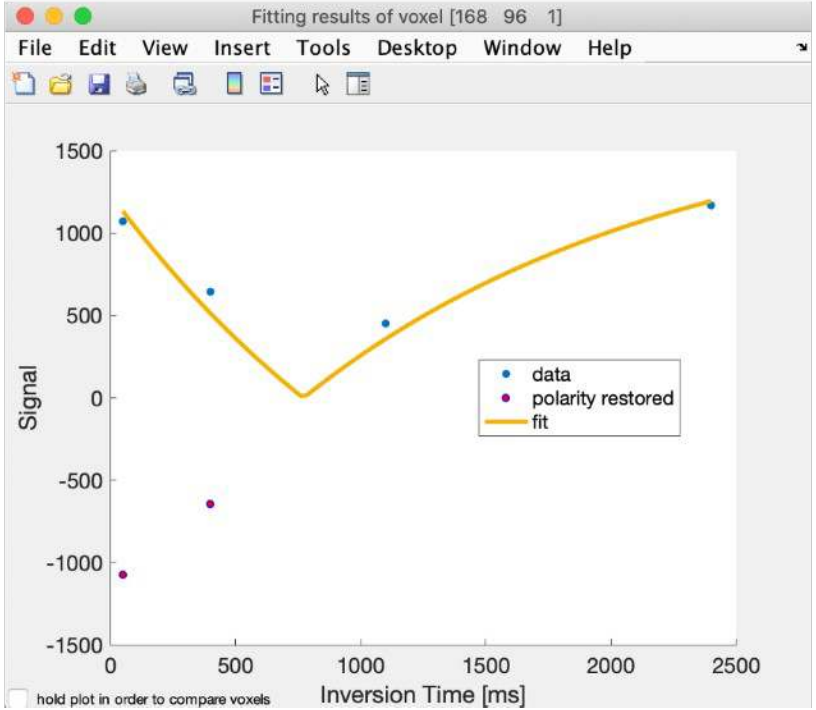
https://github.com/rrsg2020/t1_fitting_pipeline
https://github.com/rrsg2020/analysis/blob/master/01-wholedataset_gif_NIST.ipynb

Work In Progress

Quality Control

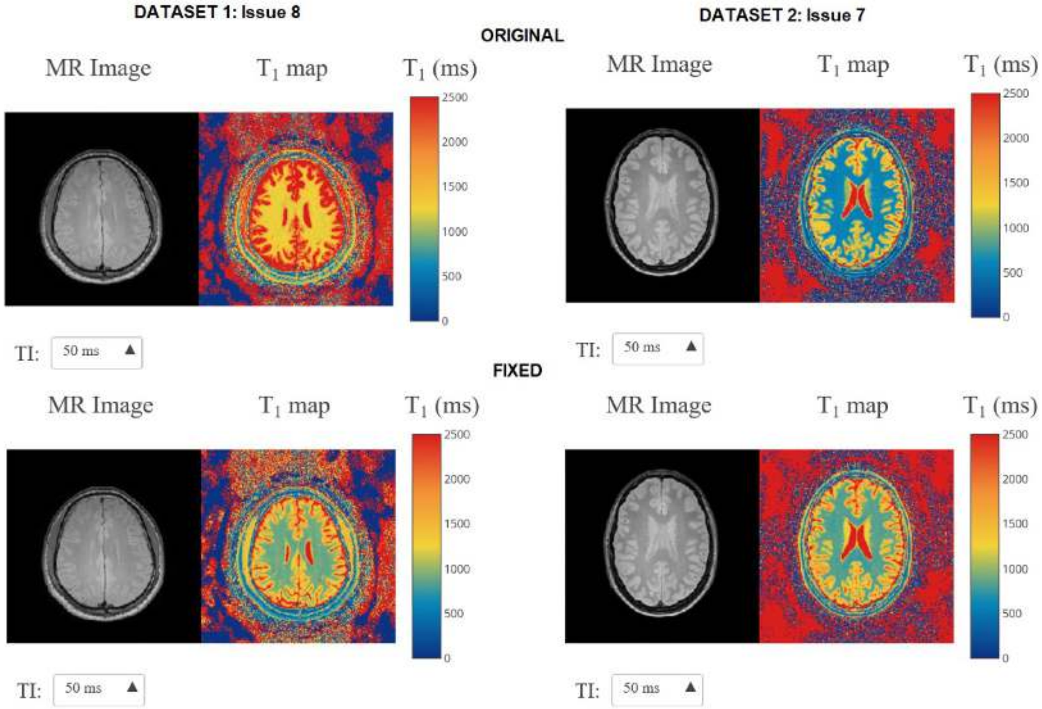


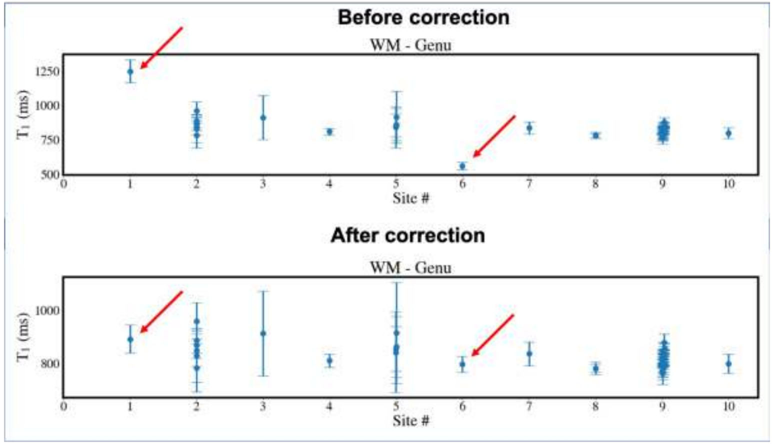
Raw images



Work In Progress

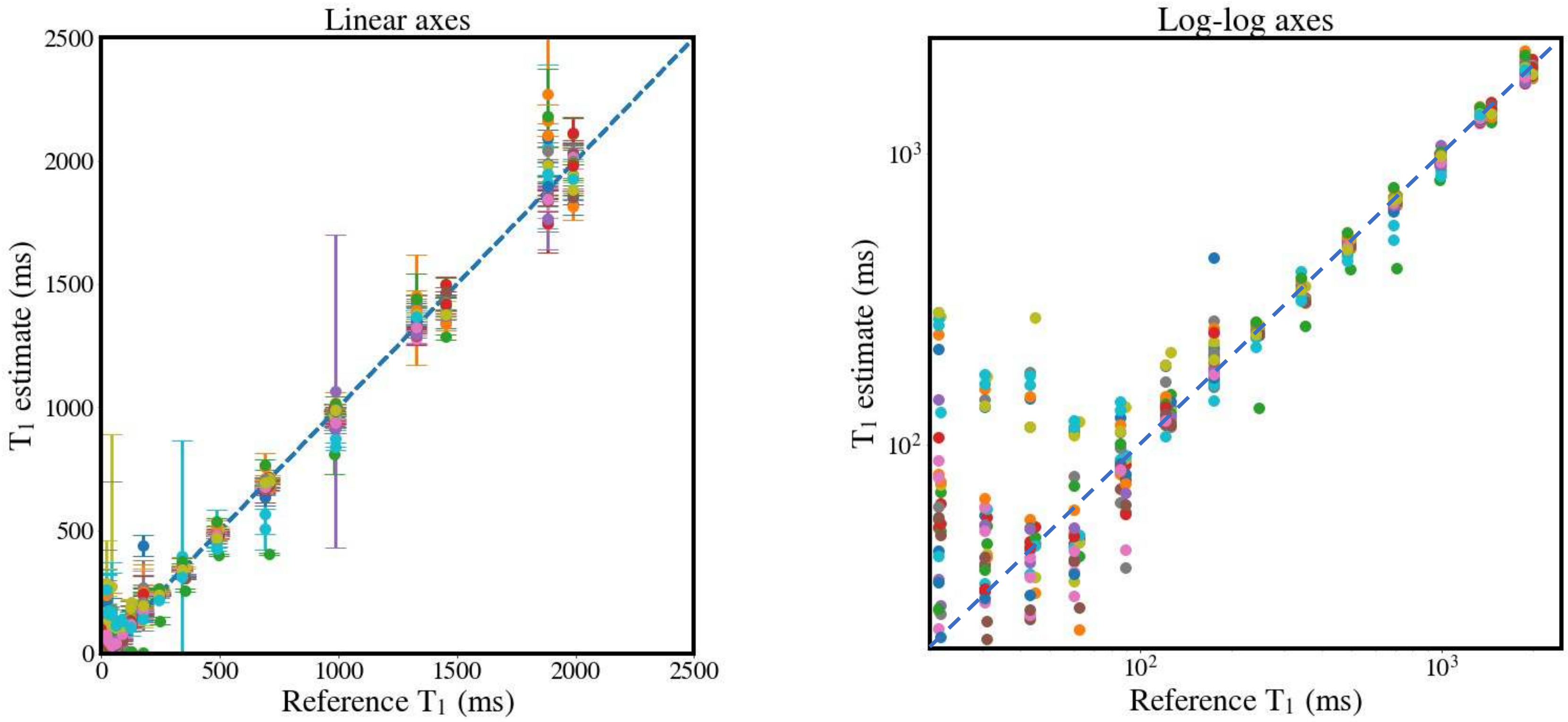
Quality Control





Work In Progress

Phantom: All Datasets



https://github.com/rrsg2020/analysis/blob/master/04_alldatasets_scatter_NIST.ipynb

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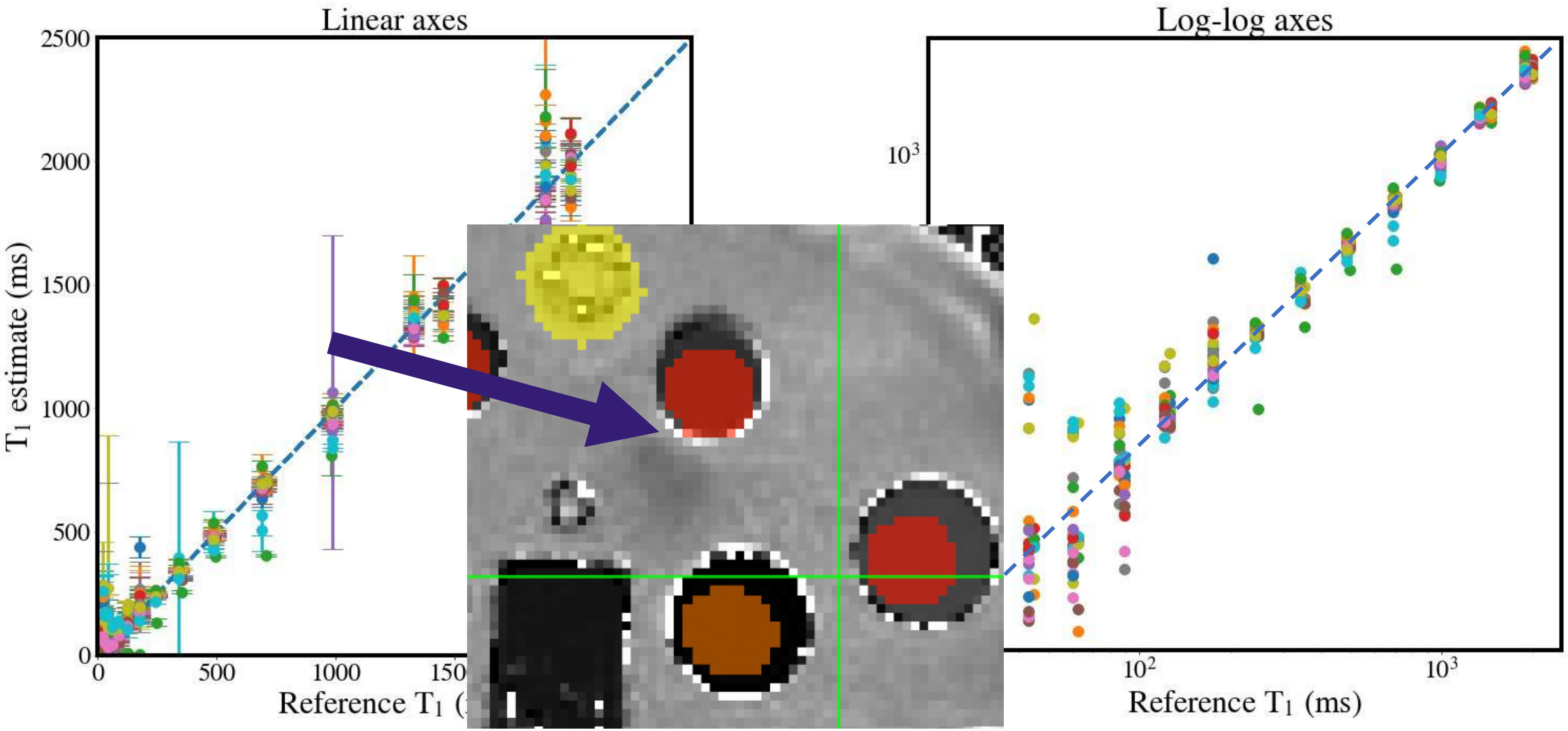
Quality Control



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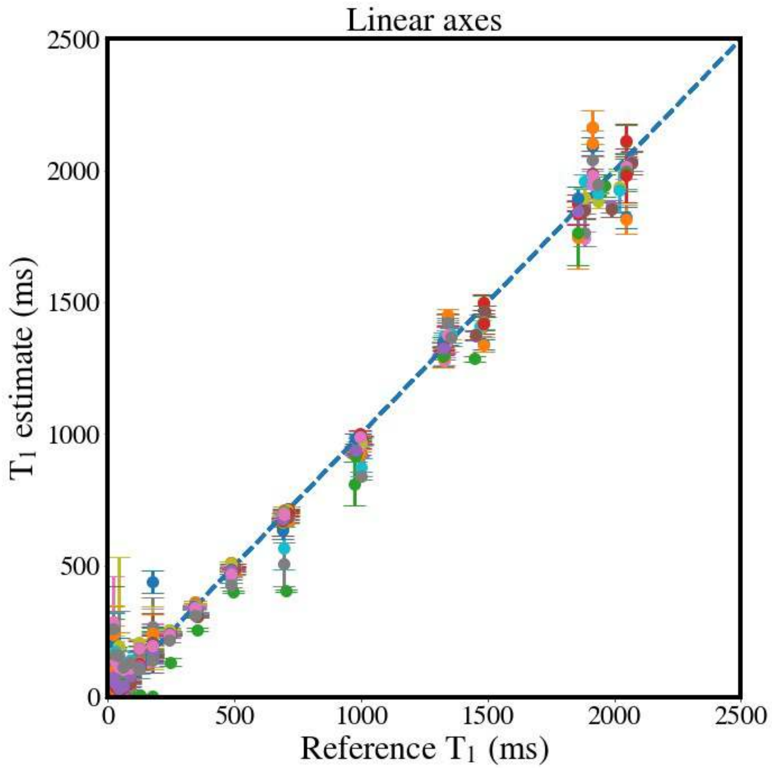
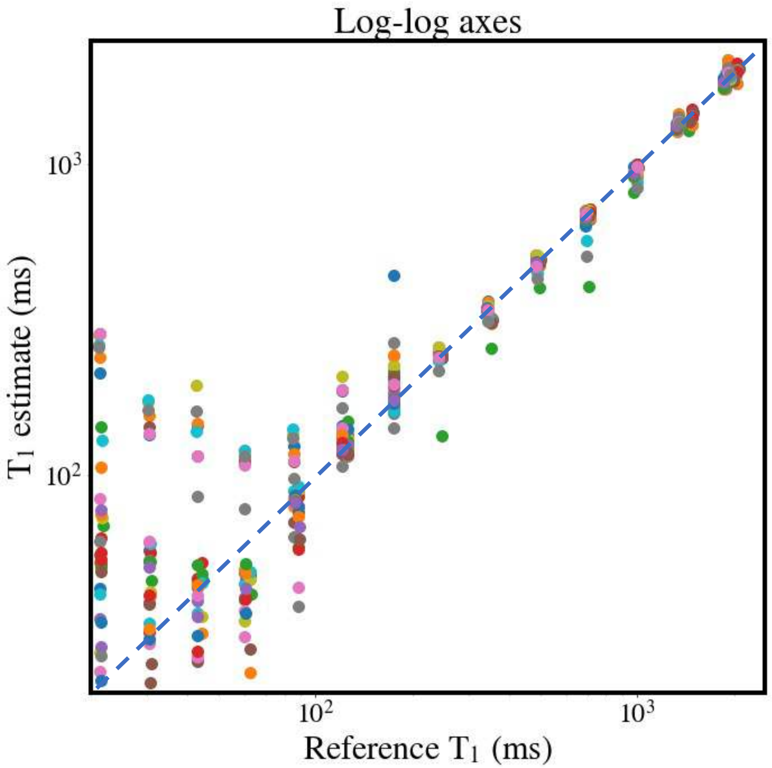
Work In Progress

Phantom: All Datasets

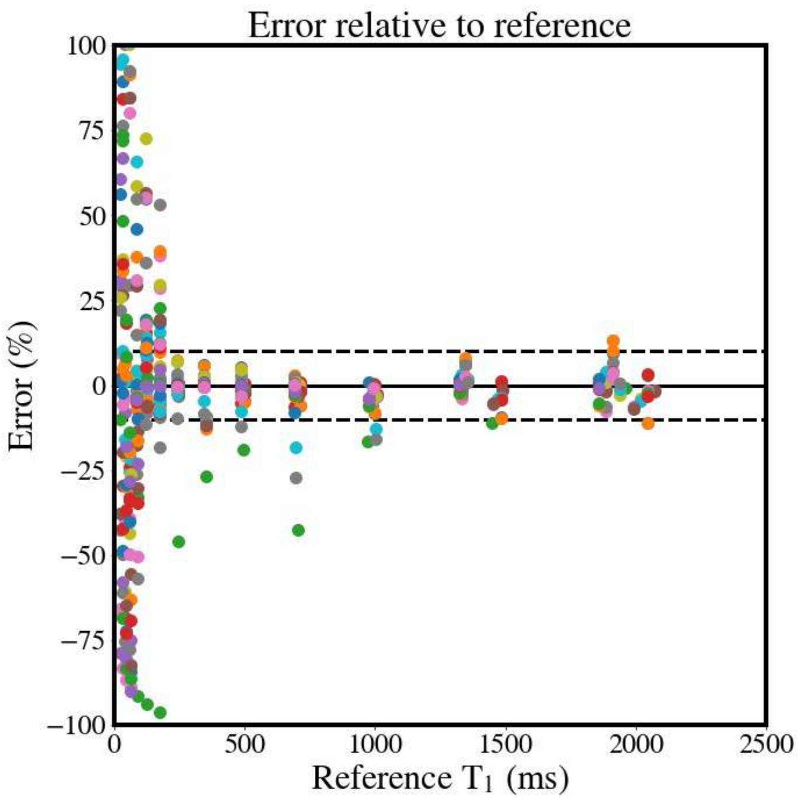




https://github.com/rrsg2020/analysis/blob/master/04_alldatasets_scatter_NIST.ipynb

Work In Progress

Phantom: All Datasets



https://github.com/rrsg2020/analysis/blob/master/04_alldatasets_scatter_NIST.ipynb

Challenge Participants
(NIST phantom data)

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Zydrunas Gimbutas

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