ASLPrep

Outline

1. Perfusion Imaging
2. Arterial Spin Labelling
3. ASLPrep

Perfusion Imaging

Perfusion imaging uses an intravascular tracer and serial imaging to quantify blood flow MRI techniques that to give insights into the perfusion of tissues by blood.

Perfusion imaging techniques

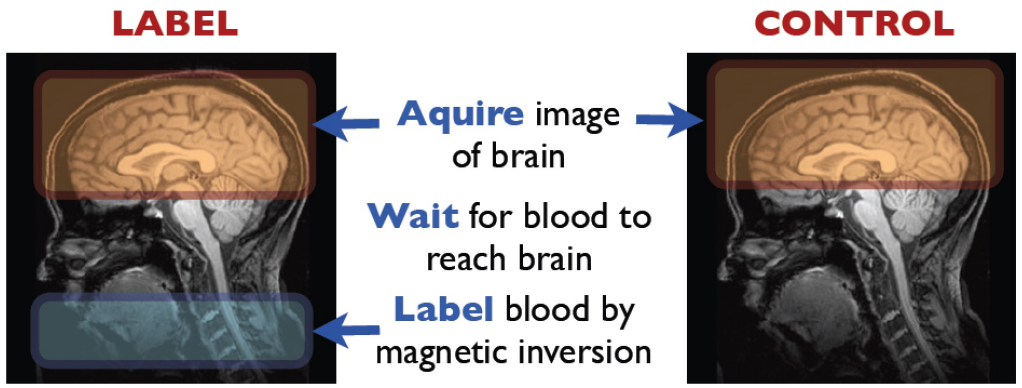
- Dynamic Susceptibility Contrast (DSC)
  - Susceptibility induced signal loss on T2*-weighted sequences
  - Gadolinium-chelate tracer
  - Enhanced signal but not reproducible over time

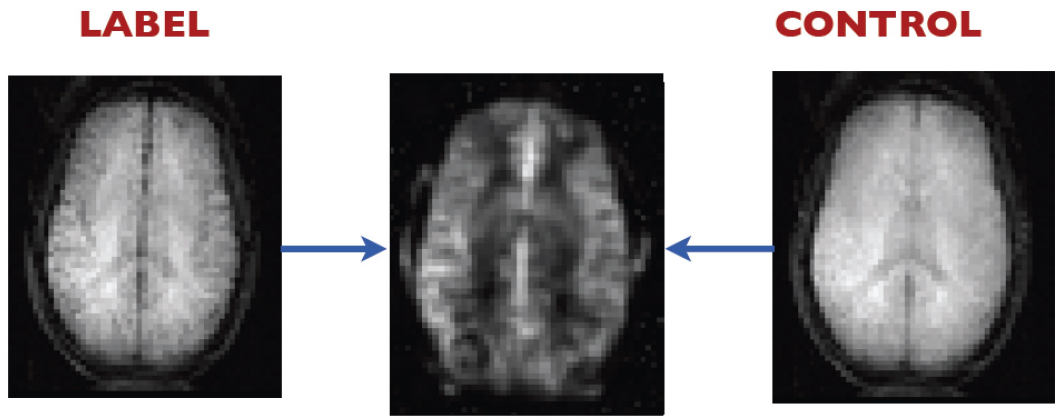
- Dynamic Contrast Enhancement (DCE)
  - Relies on T1 shortening
  - Gadolinium-chelate tracer
  - Enhanced signal but not reproducible over time

- Arterial Spin Labelling (ASL)
  - Spin tagging-magnetic labelled protons
  - No tracer and non-invasive
  - Reproducible over time

Arterial Spin Labelling (ASL)

- Application of magnetic label to water molecules of flowing blood
- No tracer, non-invasive and (highly) reproducible over time





Perfusion is ~60 ml/100g/min = 0.01 s^{-1}
Signal is ~ 1-2%

Arterial Spin Labelling (ASL)

- Application of magnetic label to water molecules of flowing blood
- No tracer, non-invasive and (highly) reproducible over time

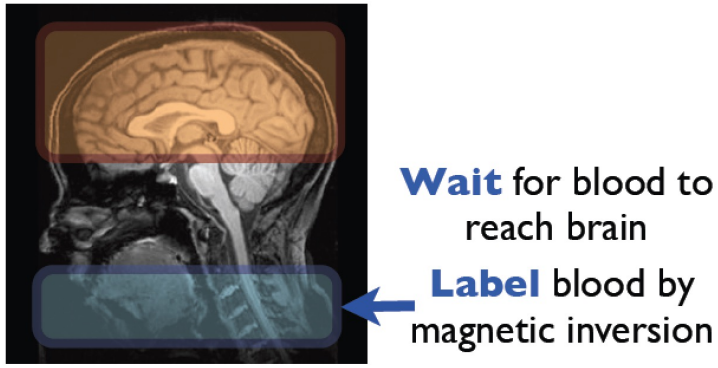
Most common ASL techniques

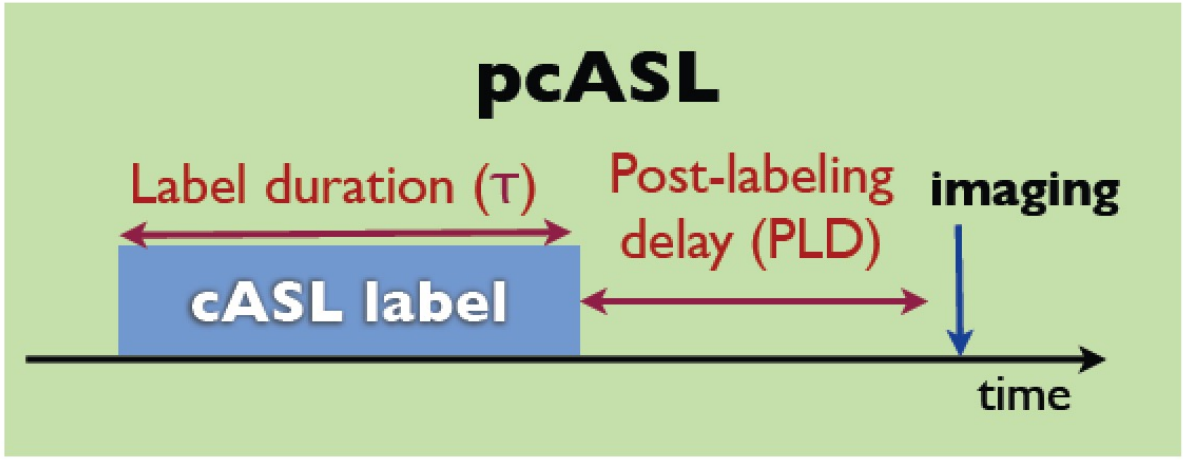
- Pulsed Arterial Spin Label (PASL)
  - short RF pulses > low perfusion sensitivity
- Continuous Arterial Spin Label (CASL)
  - long RF pulses, high sensitivity, too much RF energy
- PseudoContinuous Arterial Spin Label (pCASL)
  - rapidly repeating RF pulses, high efficiency
- Velocity- Selective Arterial Spin Label (VS-ASL)
  - specific velocity range

Arterial Spin Labelling (ASL)

PseudoContinuous Arterial Spin Label (pCASL

- Rapidly repeating gradient and RF pulses with high efficiency
- Low RF energy deposited in subject
- high perfusion sensitivity



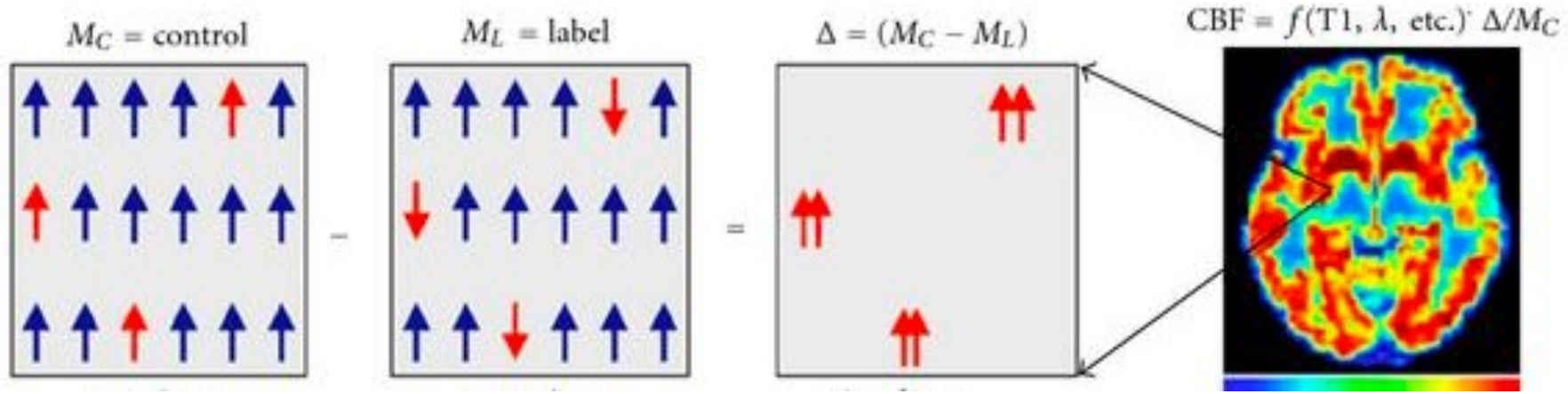


τ= 1500 to 1800 ms
PLD= 1500 to 1800 ms

Arterial Spin Labelling (ASL)

CBF quantification

- Using general kinetic model (Detre et al 1992, Buxton and Wang 1998)
- A lot of parameters



$$CBF = \frac{M_c - M_L}{M_c}$$

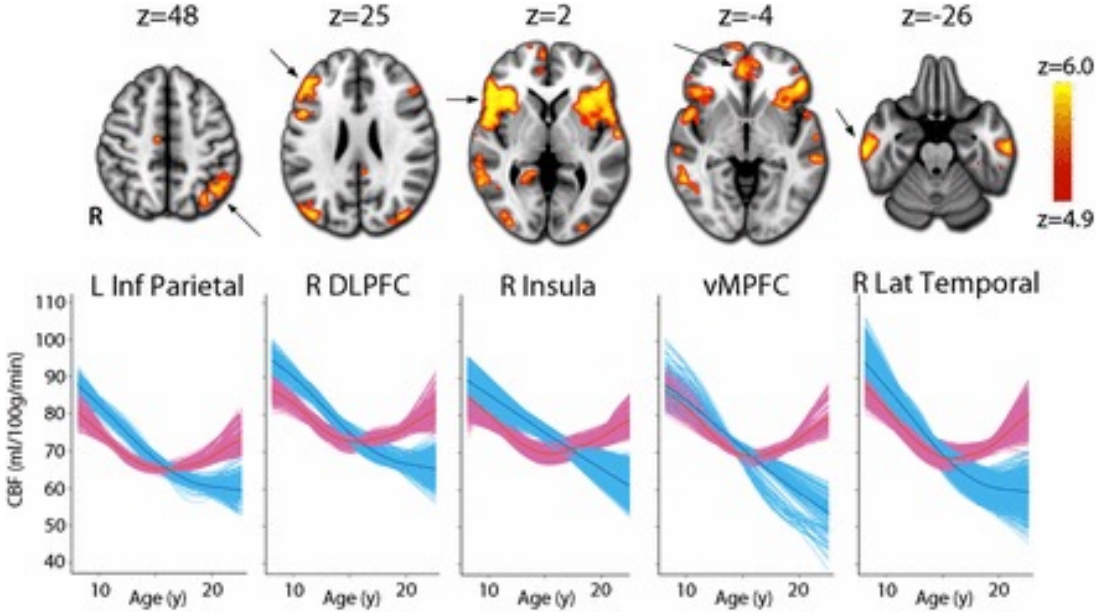
$$CBF = \frac{6000 * \lambda * (SI_C - SI_L) * e^{\frac{PLD}{T1,blood}}}{2 * \alpha * T_{1,b} * SI_{PD} * (1 - e^{-\frac{\tau}{T1,blood}})} \left[\frac{\text{mL}}{100\text{g}}/\text{Min}\right]$$

6000 – conversion factor from mL/g/s to mL/100g/min
SI- signal intensity
ƛ - (blood-brain partition coefficient) = 0.9 ml/g
α - inversion efficiency = 0.85 for pCASL

Arterial Spin Labelling (ASL)

CBF has huge applications in clinics and research

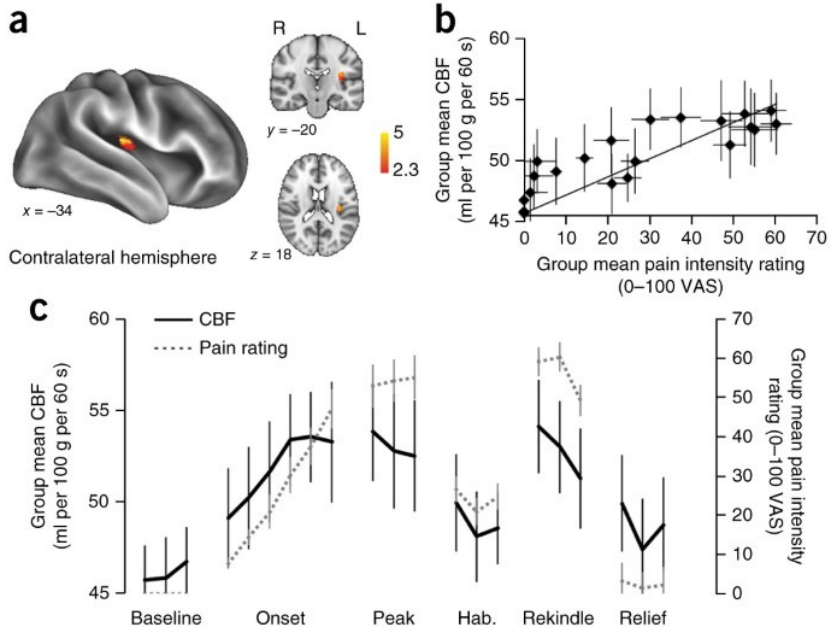
Development and sex differences



Satterthwaite et. al,. 2014, PNAS

patterns of development of cerebral perfusion during adolescence are markedly different in males and females

neural states in human



Segerdahl et. al. 2015 Nature Neuroscience

Contralateral insula showed a strong correlation between absolute CBF and pain ratings

ASLPrep

- *ASLPrep* is built around the same three principles as NiPreps
- **Robustness** - The pipeline adapts the preprocessing steps depending on the input dataset and should provide results as good as possible independently of scanner make, scanning parameters or presence of additional correction scans (such as fieldmaps).
- **Ease of use** - Thanks to dependence on the BIDS standard, manual parameter input is reduced to a minimum, allowing the pipeline to run in an automatic fashion.
- **"Glass box"** philosophy - *ASLPrep* provides visual reports for each subject, detailing the accuracy of the most important processing steps. This, combined with the documentation, can help researchers to understand the process and decide which subjects should be kept for the group level analysis.

ASLPrep

- ASLPrep is written with Python 3.8+ and is based on Nipype.
- It require tools that are not handled by the Python's packaging system :
  - FSL (> version 6.0.3)
  - ANTs (> version 2.2.0)
  - AFNI (> version Debian-16.2.07)
  - C3D (> version 1.0.0)
  - FreeSurfer (> version 6.0.1)
  - connectome-workbench (> version Debian-1.3.2)

Installation

- Within a manually prepared environment (Python 3.8+) this is not recommended
  - Clone the GitHub code: : https://github.com/PennLINC/aslprep
  - Pip install – **pip install aslprep**. https://pypi.org/project/aslprep

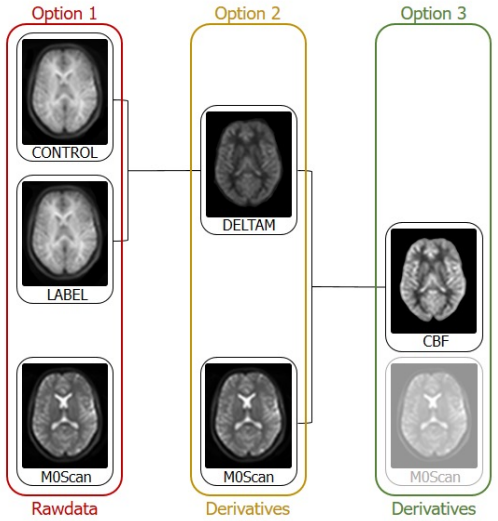
- Using container technologies Docker containers or Singularity containers.
  - More reliable
  - https://hub.docker.com/repository/docker/pennlinc/aslprep/
  - https://aslprep.readthedocs.io/en/latest/docker.html#run-docker

ASLPrep

ASLPrep requires validated BIDS data

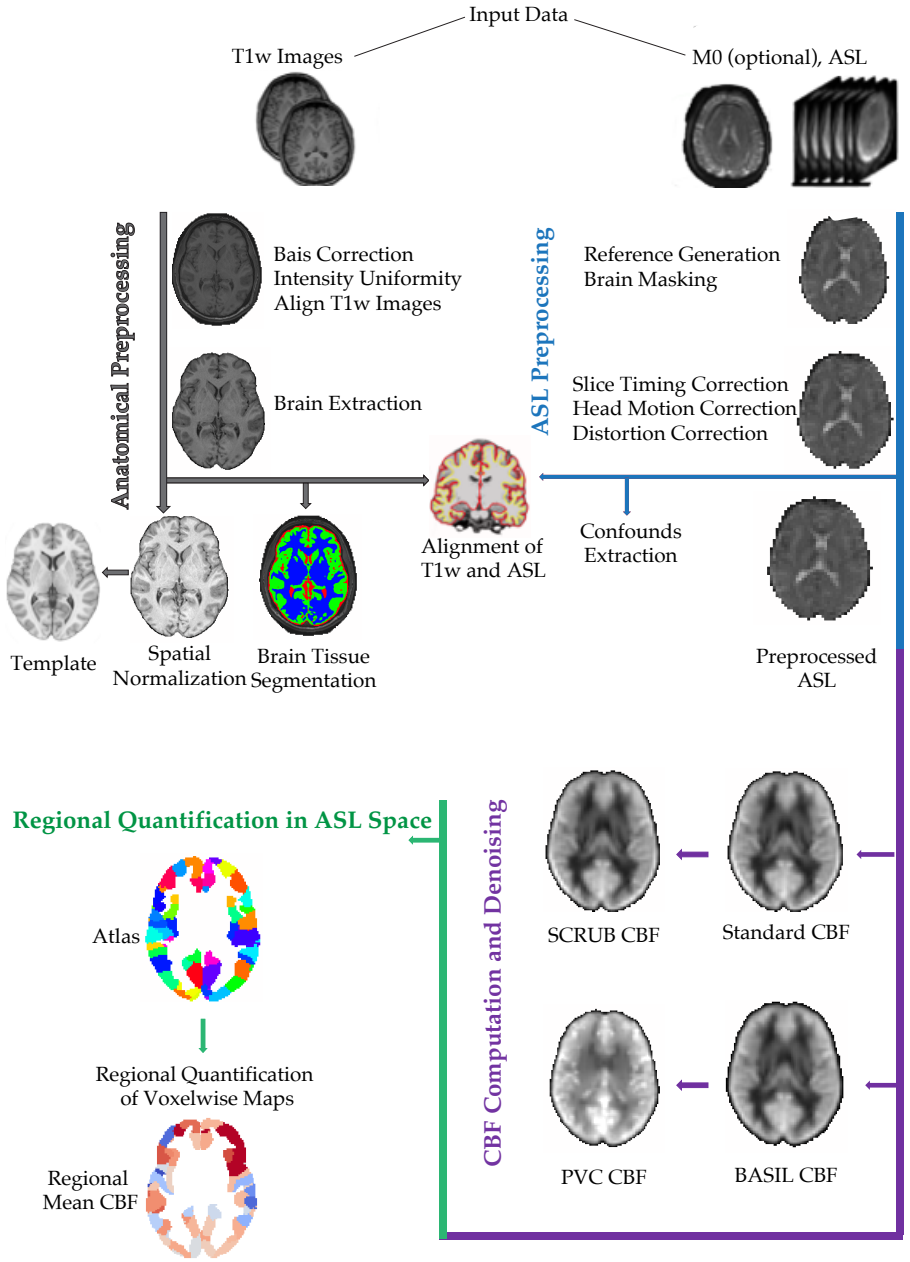
Main inputs required

- T1w image(s),
- ASL data, M0 (optional)



Workflow Stages

1. Anatomical preprocessing
2. ASL preprocessing
3. CBF computation and denoising



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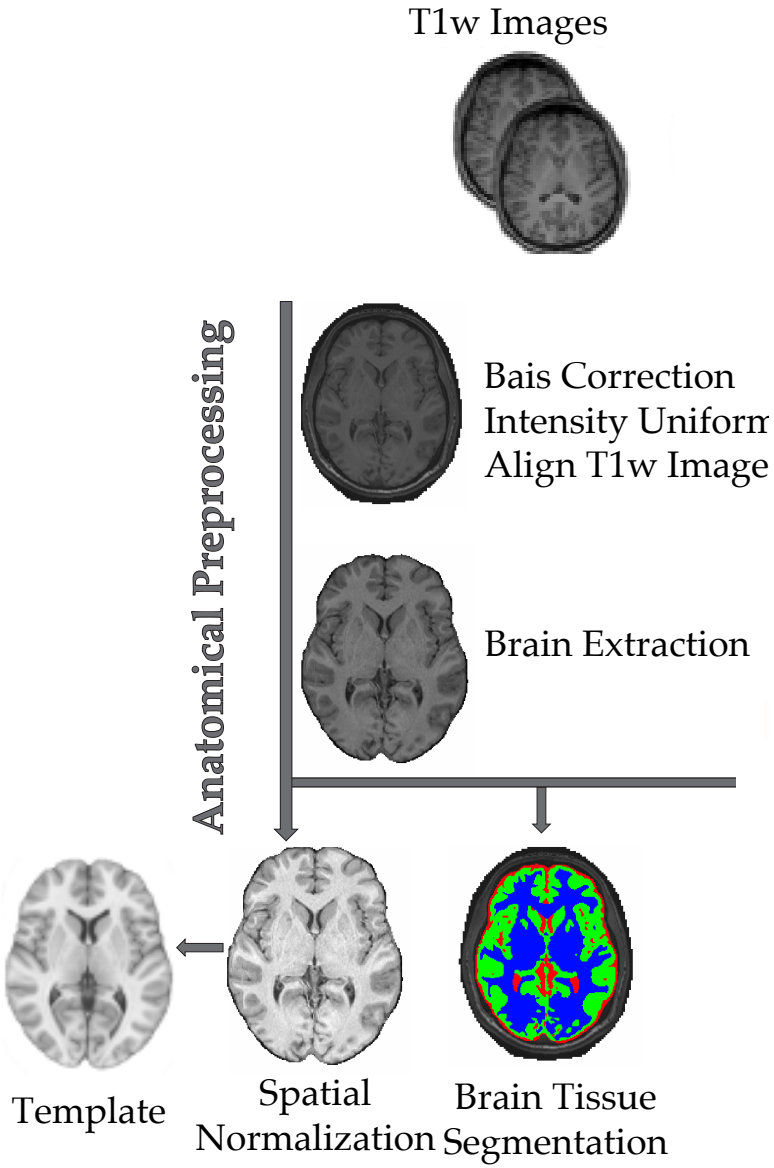
Anatomical preprocessing

- Alignment of T1w images if more than one
- Correction for intensity nonuniformity (N4)

- Atlas-based skull stripping (antsBrainExtraction)
- Brain-tissue segmentation (FAST)

- Spatial normalization to template (many templates to choose from- MNI,PNC,OASIS etc, default: MNI2009)



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ASL Preprocessing

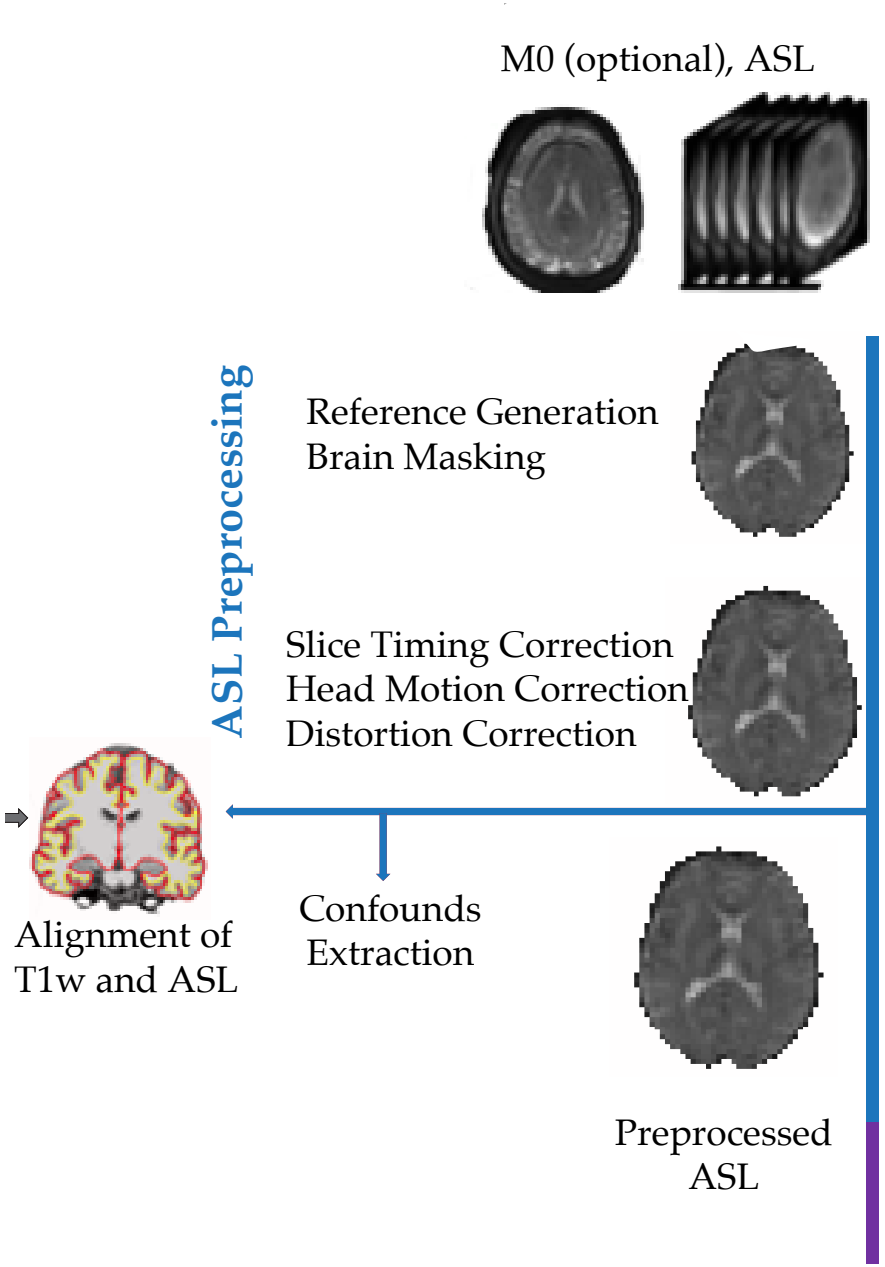
- Generate reference image and brain mask

- Slice timing correction (it can be ignored)
- Head motion estimation

- Distortion correction (it can be ignored)
  - Fieldmap
  - Fieldmapless (SyN)

- Alignment of T1w and ASL

- Extraction of confounds parameters:
  - six motion parameters,
  - dvars, std-dvars



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CBF computation and denoising

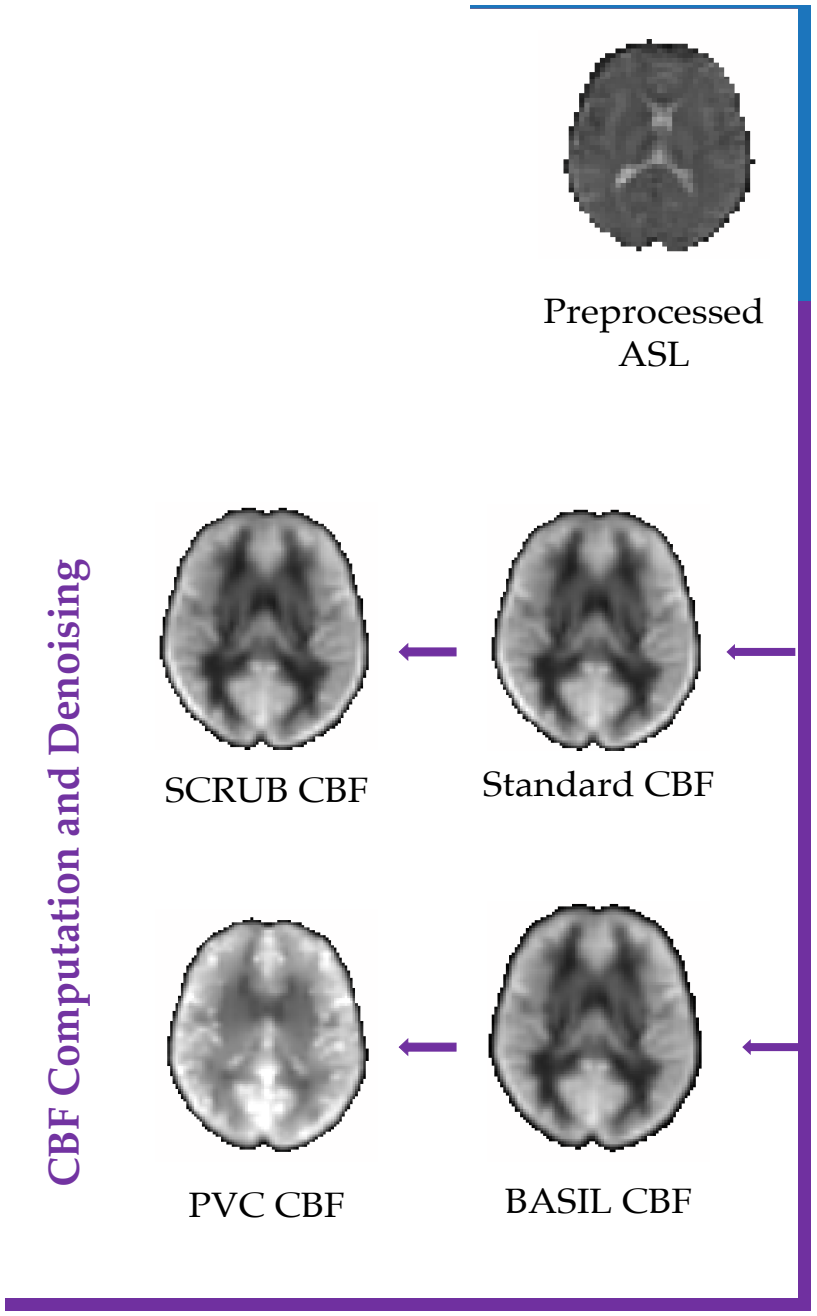
- Extract the ASL tag-control label and ASL parameters
- Align M0 and ASL, use average control if M0 is absent

- Compute CBF with general kinetic model
- Denoise by Sudipto’s SCORE and SCRUB

- Compute CBF with FSL’s BASIL including spatial regularization
- Partial volume correction (PVC) of CBF

- SCORE, SCRUB and PVC use brain tissue segmentation

- ROI quantification with different atlases
- Normalization to T1w and template space (optional)



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Quality control measures

- Motion summary measures (FD and relRMS)
- Registration quality indices
  Normalization quality indices
- Quality evaluation index
- Mean CBF within tissue classes (GM,WM, and ratio)
- Percentage of negative voxels

ASLPrep

Visual reports

Summary

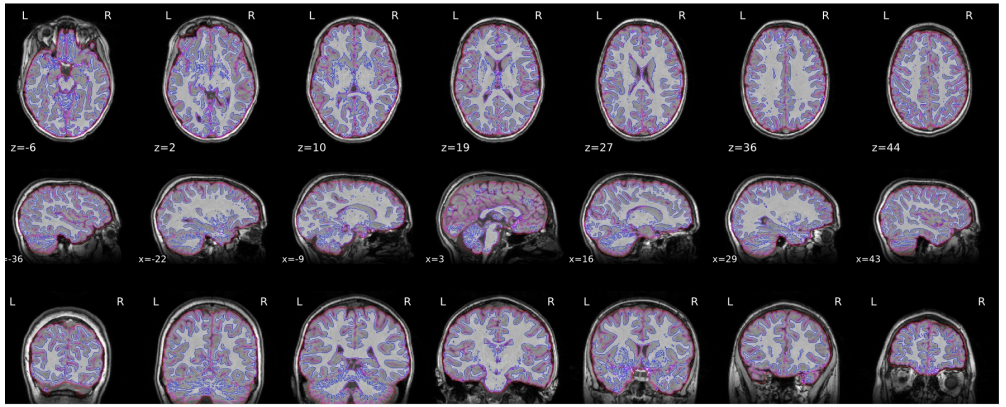
- Subject ID: 20197
- Structural images: 1 T1-weighted (+ 1 T2-weighted)
- ASL series: 1
  - Task: rest (1 run)
- Standard output spaces: MNI152NLin2009cAsym
- Non-standard output spaces: anat, func
- FreeSurfer reconstruction: Not run

Anatomical

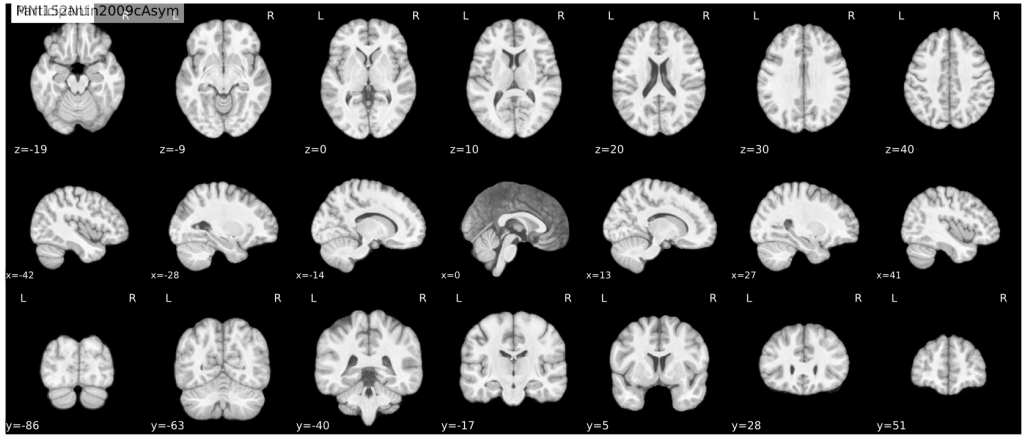
Anatomical Conformation

- Input T1w images: 1
- Output orientation: RAS
- Output dimensions: 192x256x160
- Output voxel size: 0.94mm x 0.94mm x 1mm
- Discarded images: 0

Brain mask and brain tissue segmentation of the T1w



Spatial normalization of the anatomical T1w reference



ASLPrep

Visual reports

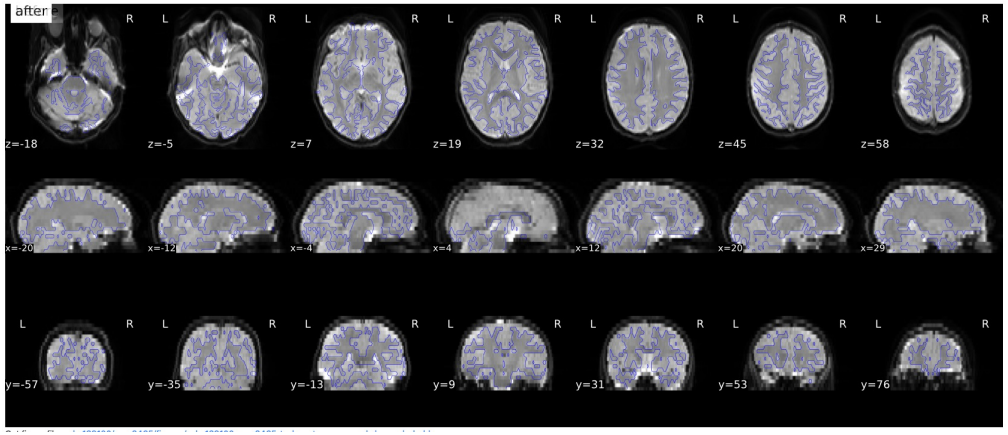
Arterial Spin Labelling

Reports for: session 11245, task rest.

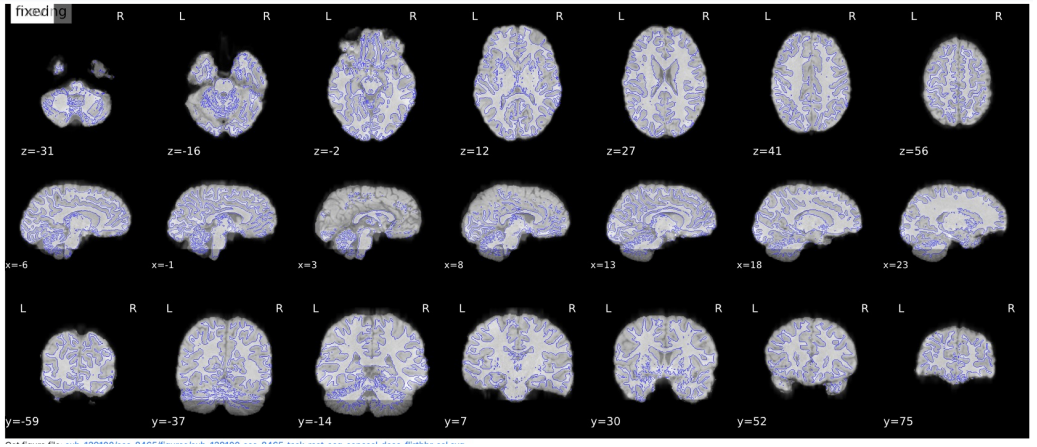
Summary

- Repetition time (TR): 4s
- Phase-encoding (PE) direction: MISSING - Assuming Anterior-Posterior
- Slice timing correction: Not applied
- Susceptibility distortion correction: None
- Registration: FreeSurfer `bbregister` (boundary-based registration, BBR) - 6 dof
- Confounds collected: std_dvars, dvars, framewise_displacement, trans_x, trans_y, trans_z, rot_x, rot_y, rot_z
- Non-steady-state volumes: 0
- Motion summary measures: FD : 0.1705, relRMS: 0.0015
- Coregistration quality: Dice Index: 0.997, Jaccard Index: 0.994, Cross Cor.: 0.9963, Coverage: 1.0
- Normalization quality: Dice Index: 0.9633, Jaccard Index: 0.9292, Cross Cor.: 0.9545, Coverage: 0.9847
- Quality evaluation index : cbf: 0.7475,score: 0.7466,scrub: 0.7964, basil: 0.7519, pvc: 0.7791
- Mean CBF (mL 100/g/min) : GM CBF: 71.95, WM CBF: 64.79, GM/WM CBF ratio: 1.11
- Percentage of negative voxel : cbf: 0.58, score: 0.59, scrub: 0.23, basil: 0.0, pvc: 0.0

Susceptibility distortion correction



Alignment of asl and anatomical MRI data



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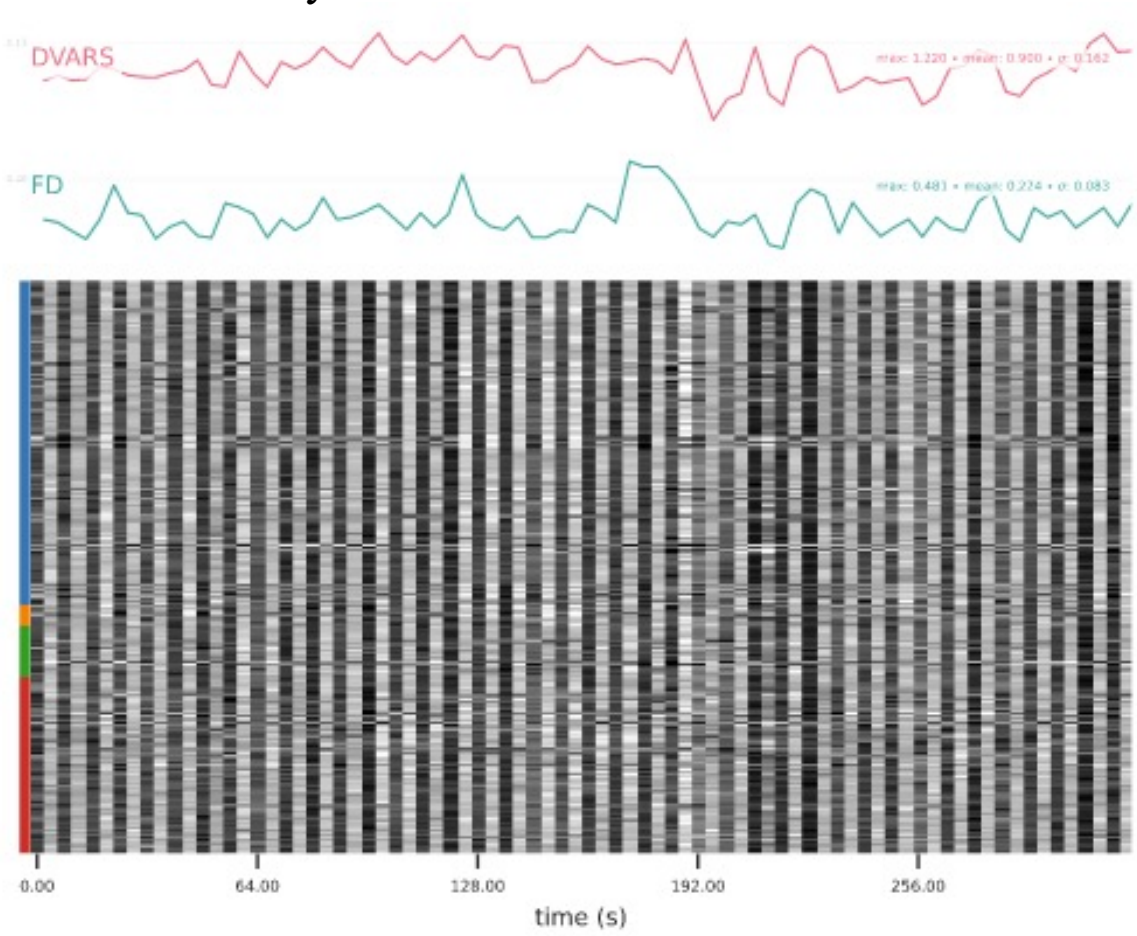
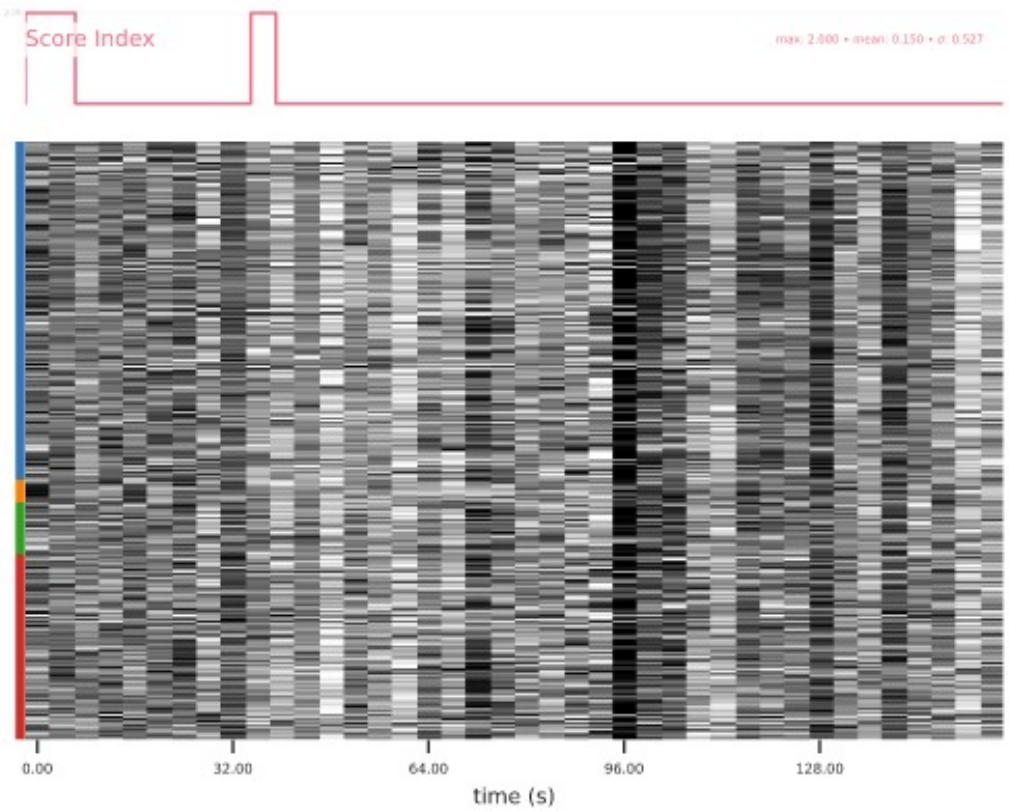
Visual reports

ASL Summary



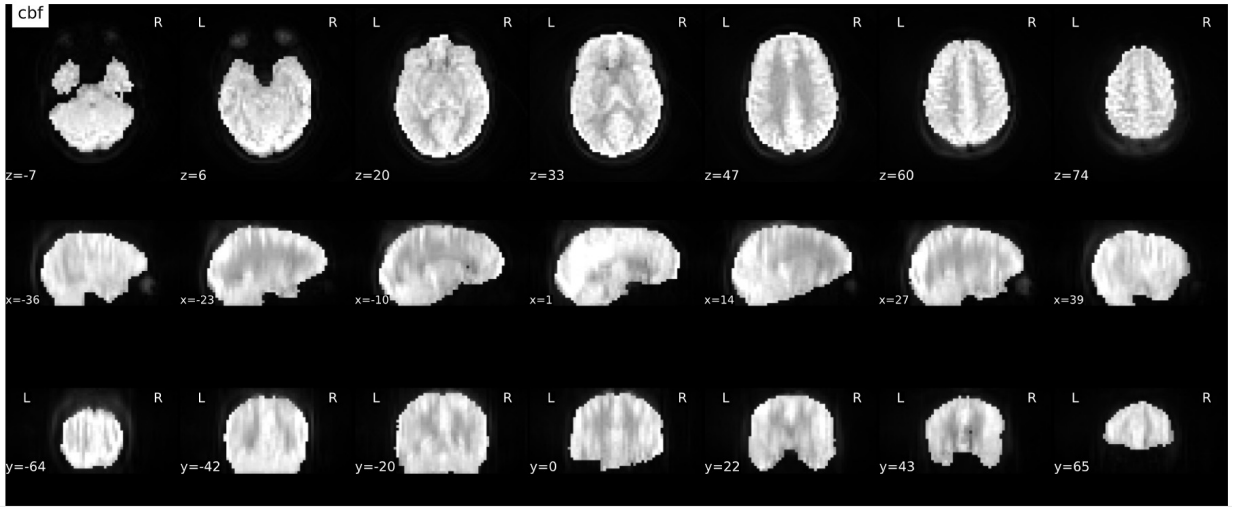
CBF Summary
With volume index deleted by SCORE



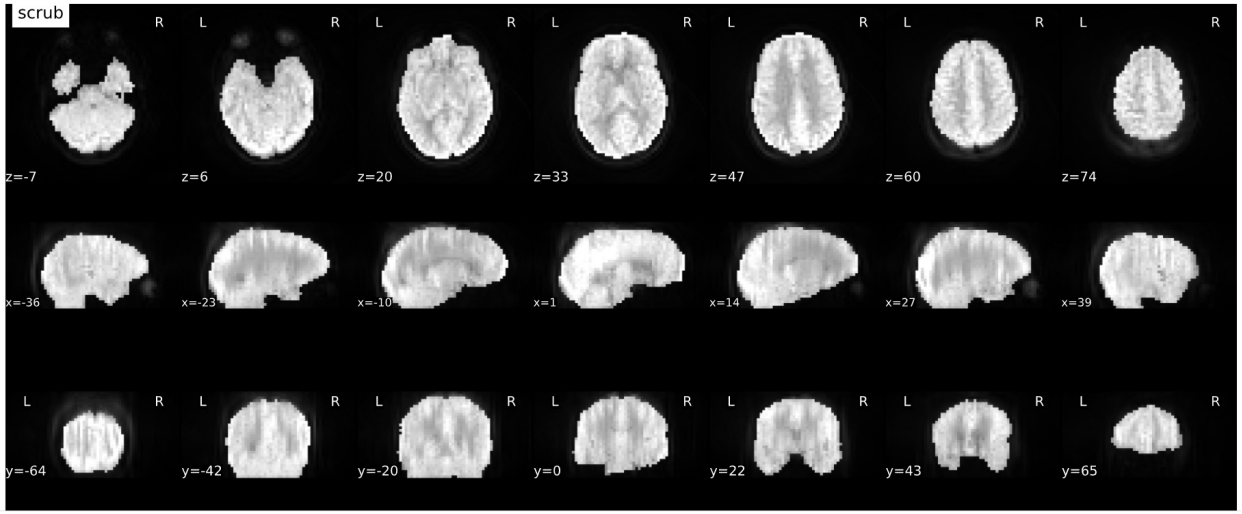
ASLPrep

Visual reports

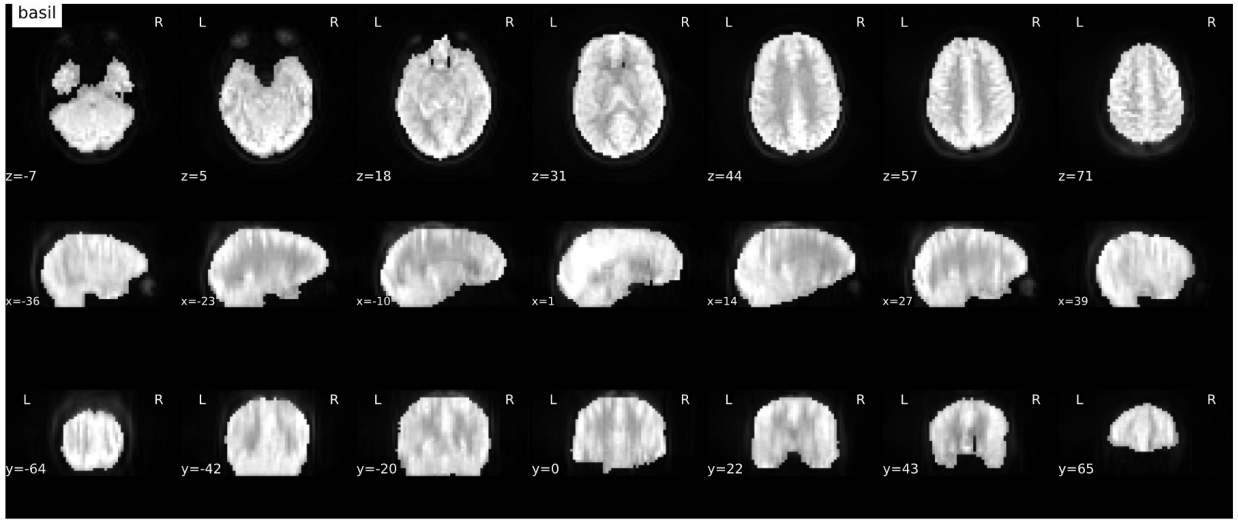
CBF map



SCRUB CBF map



BASIL CBF map



ASLPrep

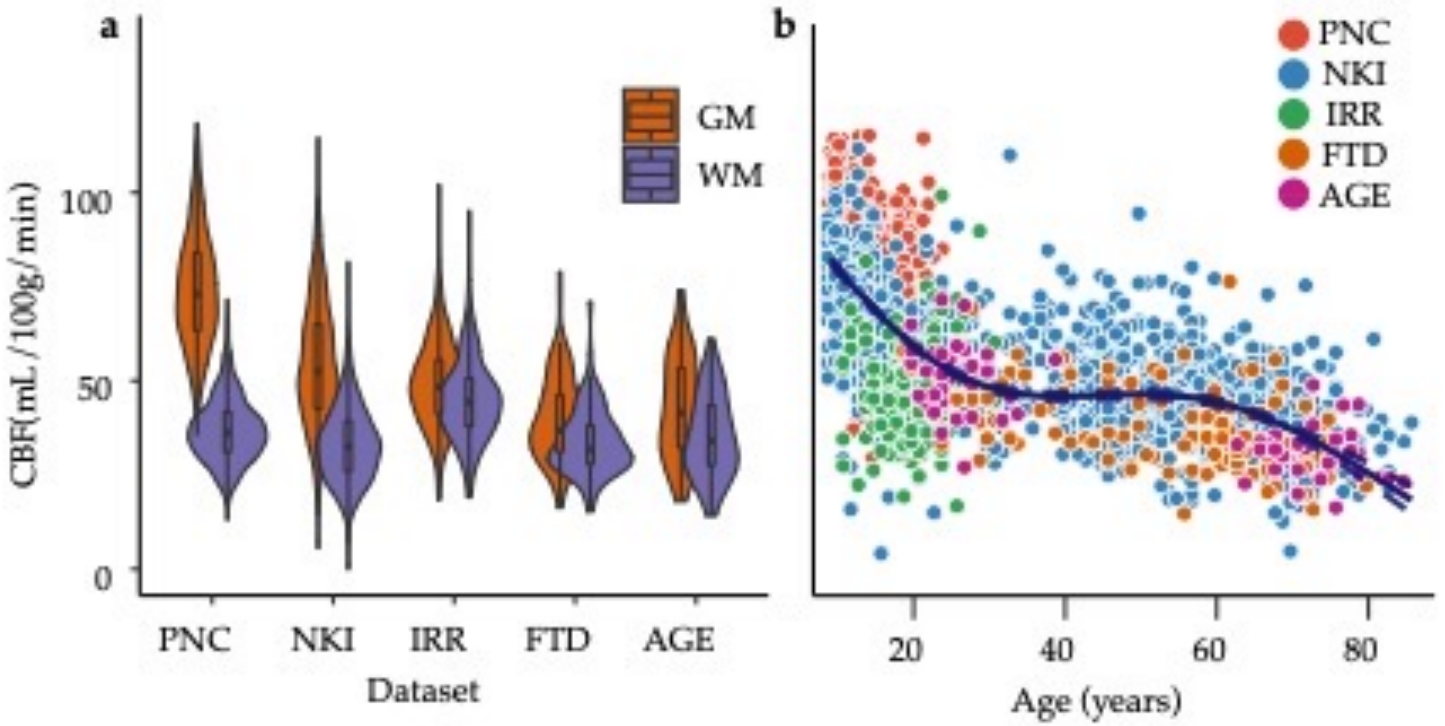
- Application of ASLPrep on large datasets
  3,218 total scans, 1697 females; age=26.43±19.51 years old
- Different scanning parameters and data types
- Pure raw ASL Data and M0 scan – IRR
- Pure raw ASL data only – NKI, PNC and AGE
- Derivatives data - FTD

Datasets	Number of scans processed	Number of scans passing QA
IRR	163	154
PNC	1515	1481
NKI	1367	1242
AGE	63	57
FTD	110	109

ASLPrep

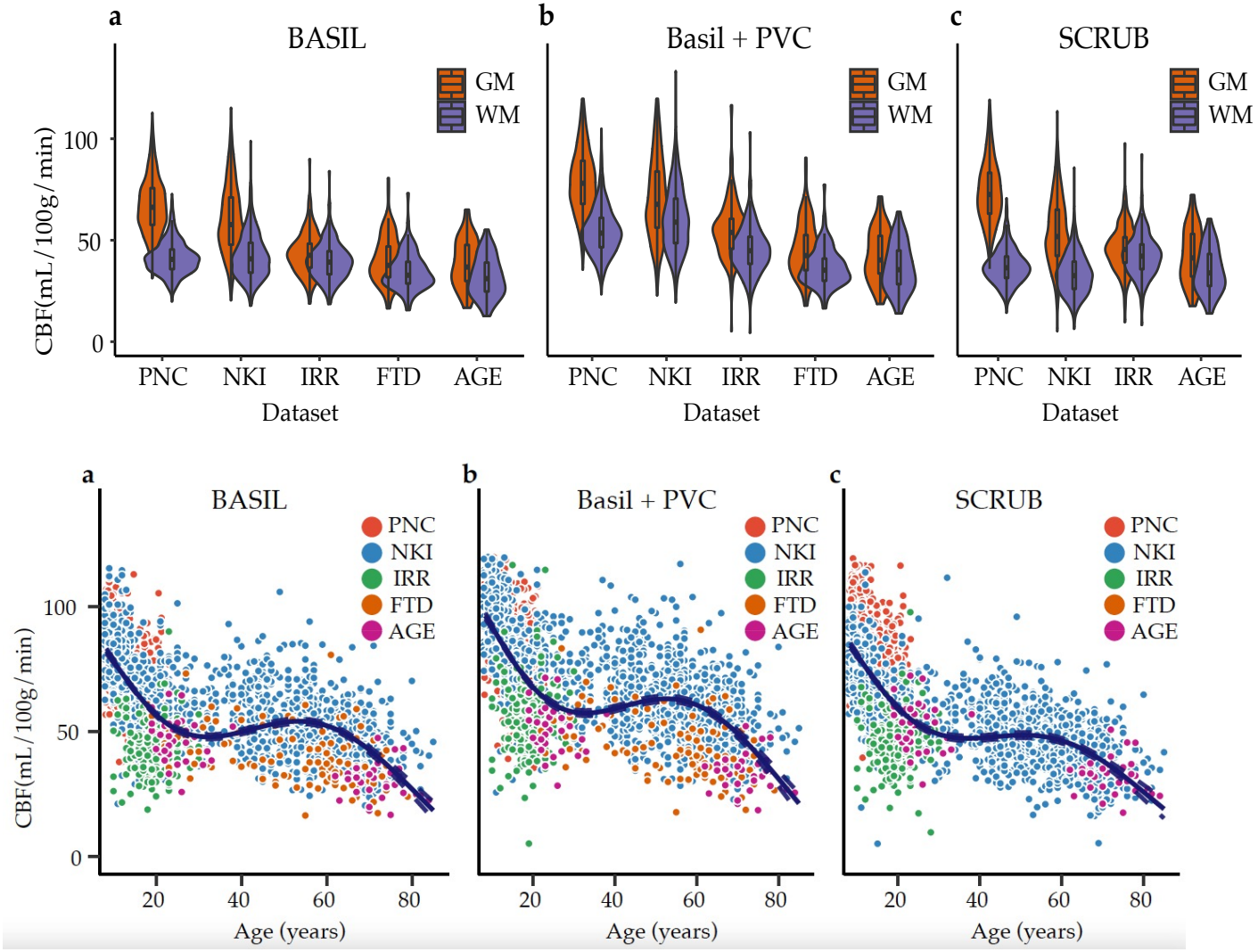
Highly reproducible across datasets

- Distinction between gray matter and white matter CBF
- Nonlinear decline of CBF over the lifespan



ASLPrep

Highly reproducible across datasets



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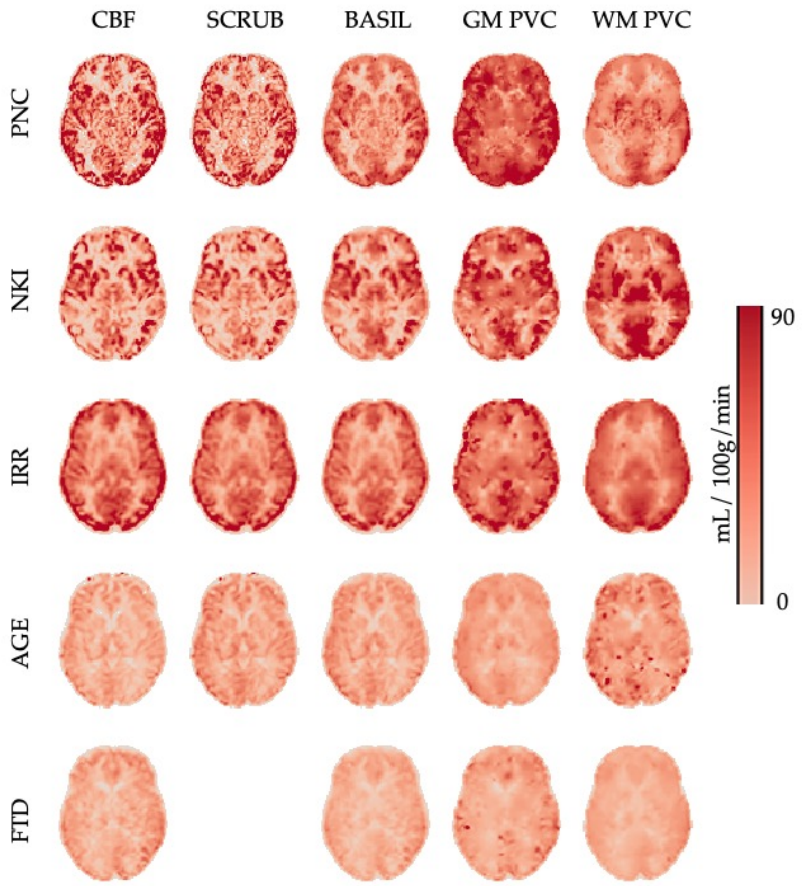
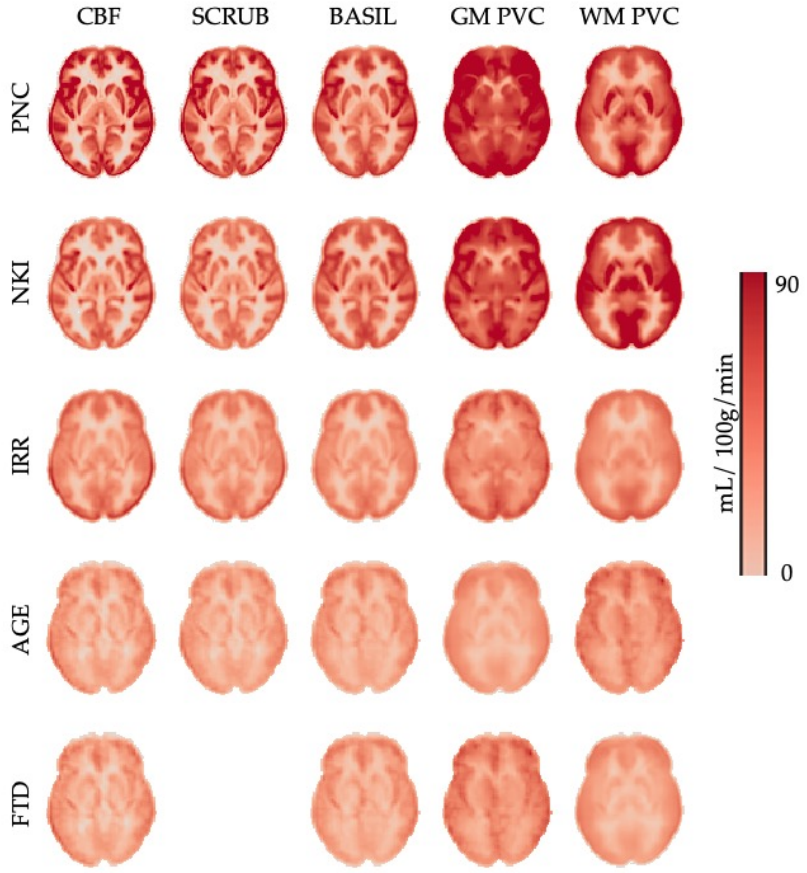
CBF Maps

Example one single subject



Average over all the subjects



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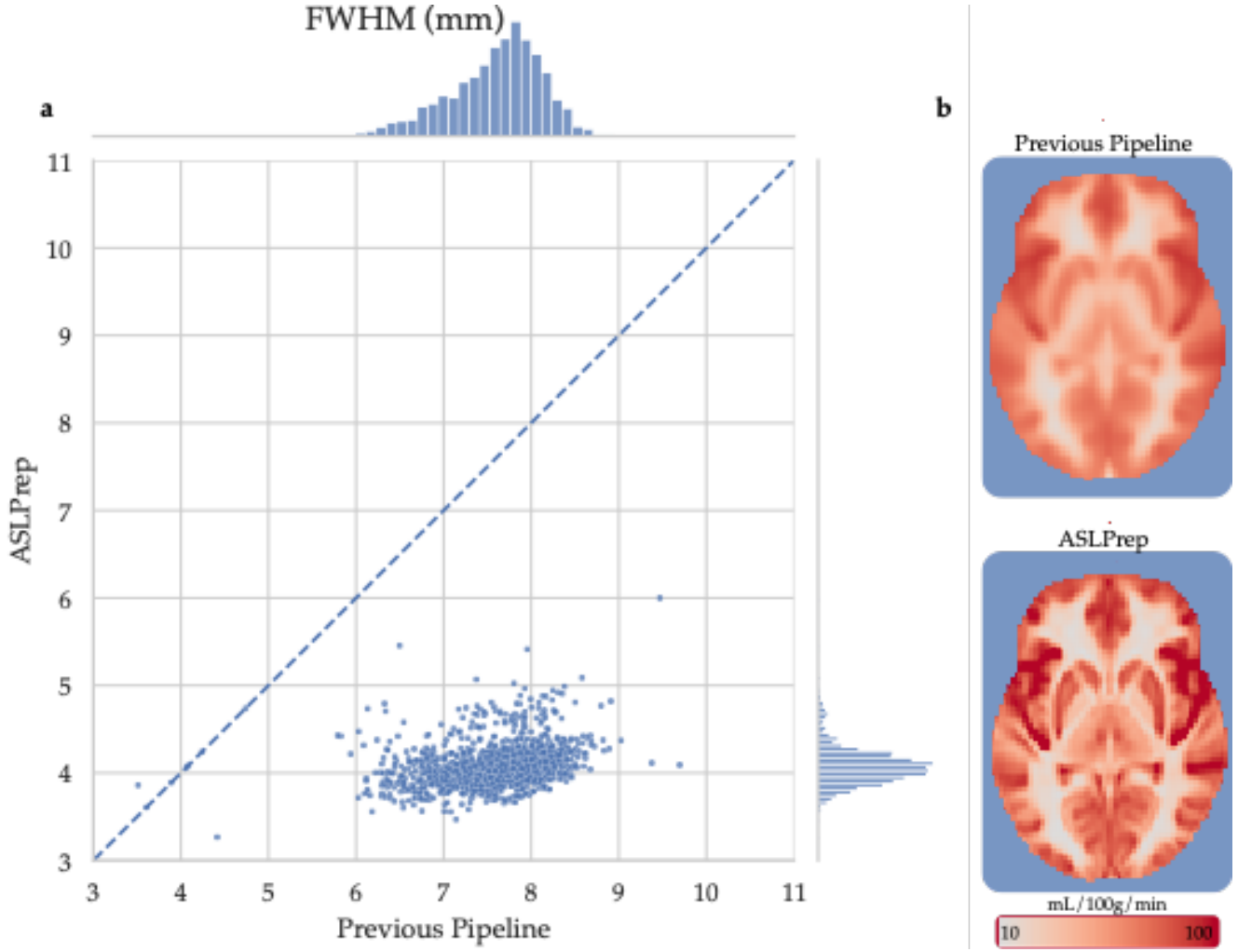
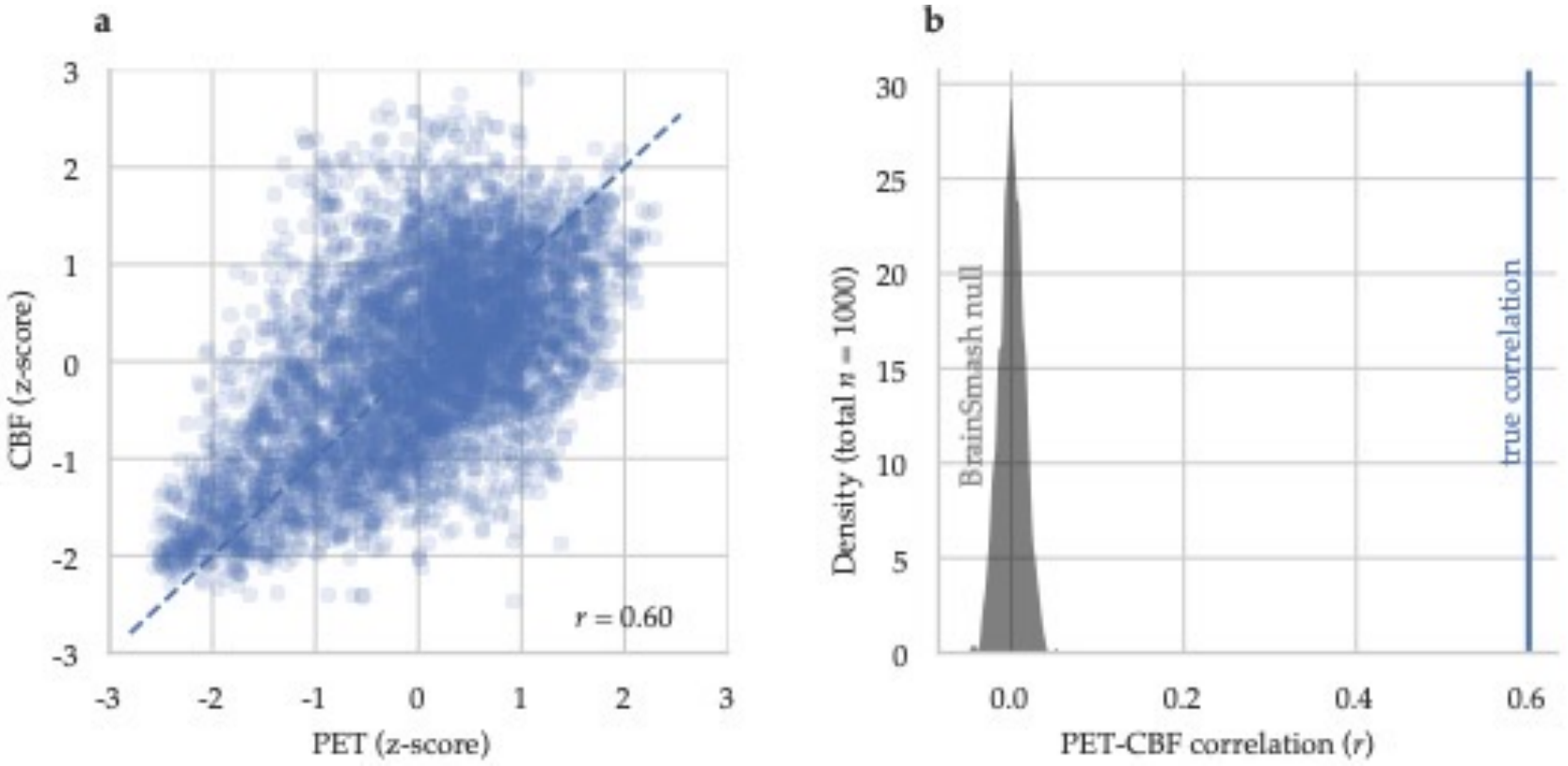
ASLPrep preserved anatomical detail and reduced blurring



ASLPrep

- Good alignment between CBF quantified using ASLPrep and a commonly used PET atlas



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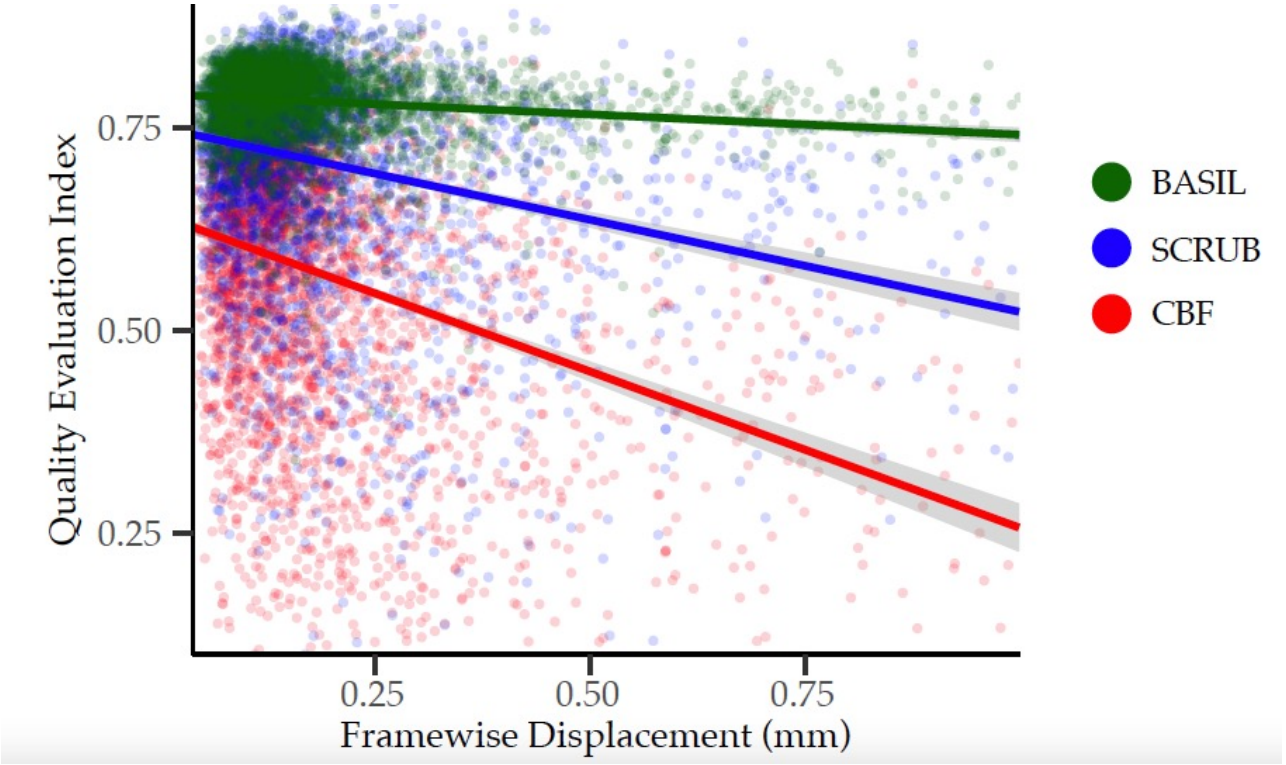
Impact of in-scanner motion on data quality

Quality evaluation index (QEI)

- CBF map's similarity with the structural tissues,
- CBF spatial variability within each tissue class (GM, WM),
- The percentage of negative voxels within the GM mask



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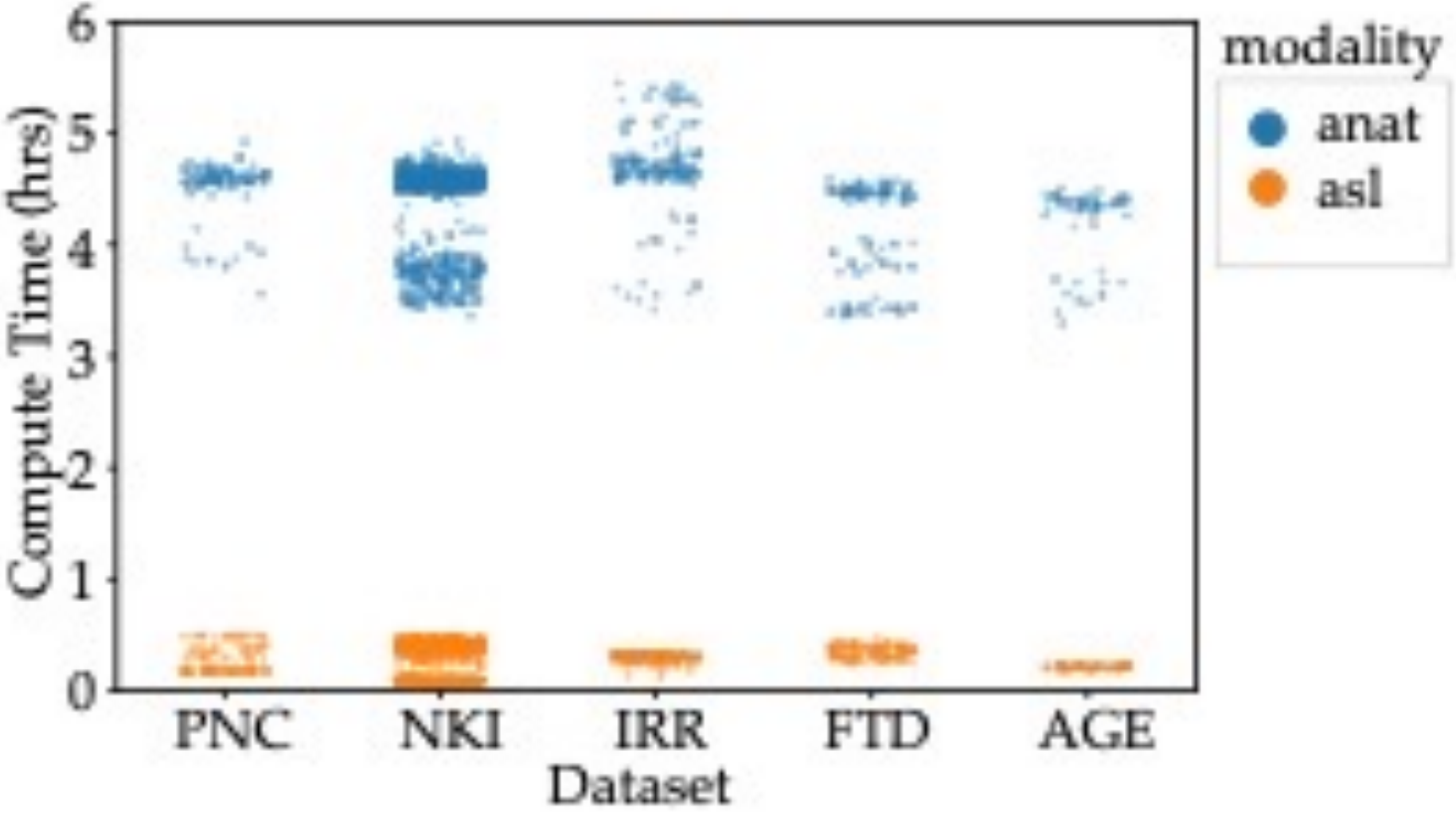
Anatomical processing take longer time



Thank you very much!!!

Many thanks

Matt and Max (M and M)

PennLinc, BBL,

Everyone!