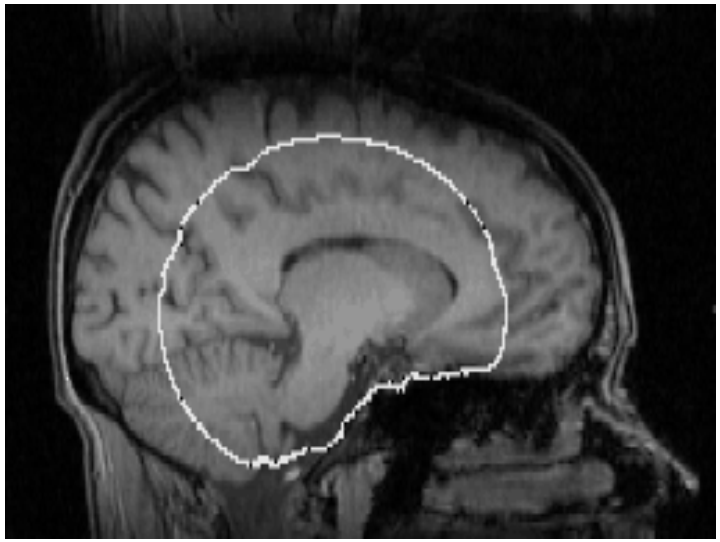
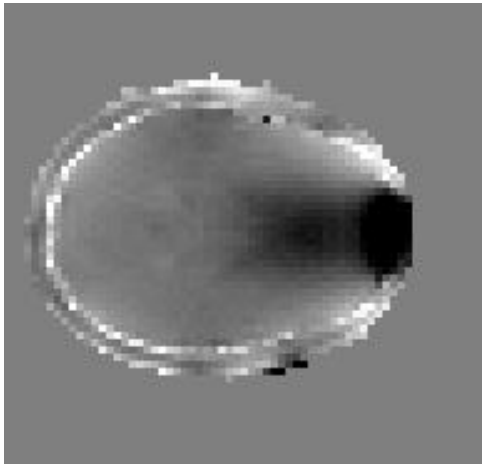
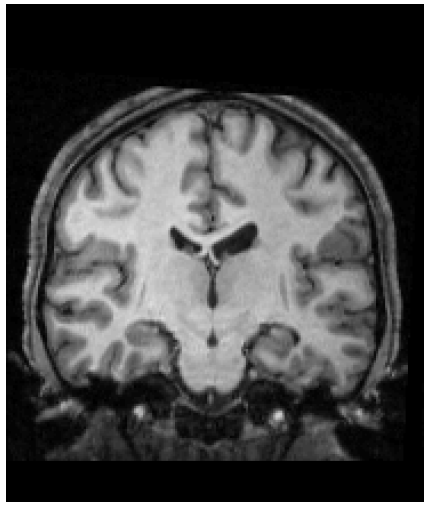
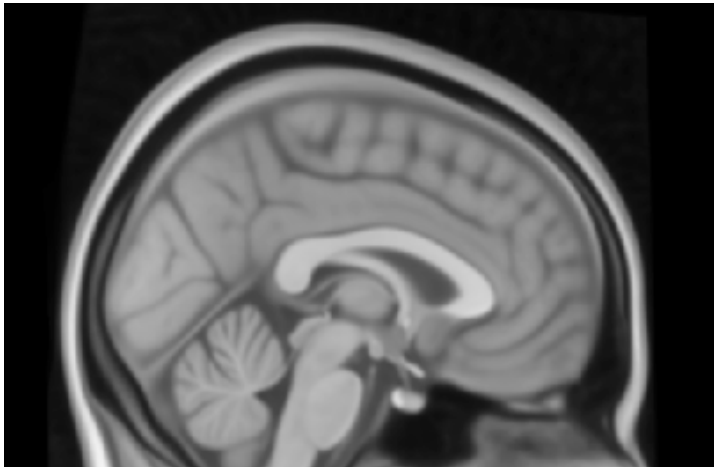
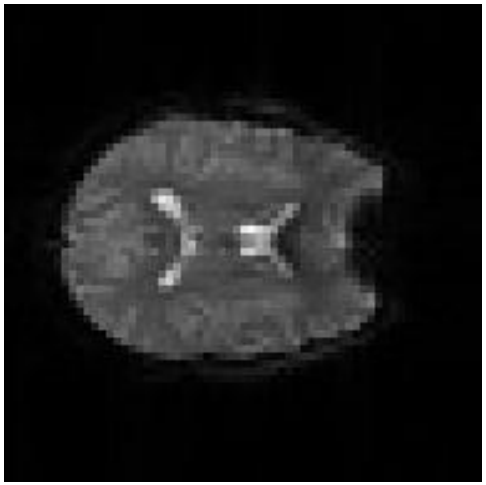
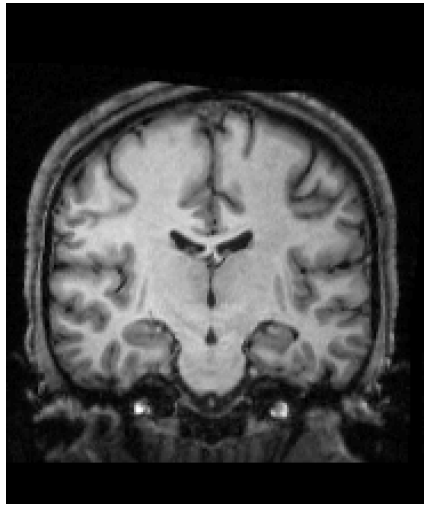
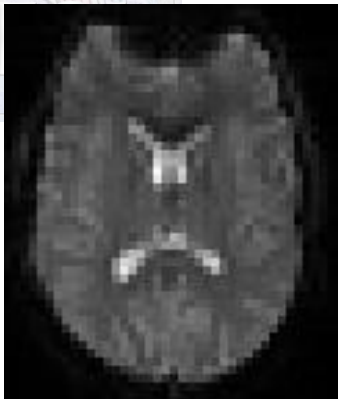
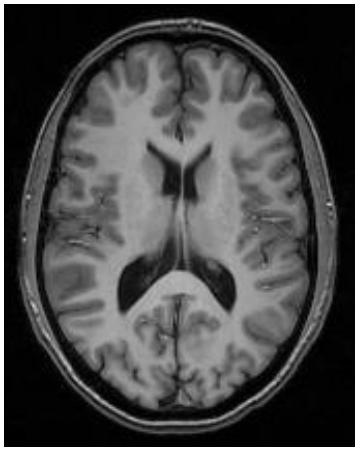
Registration: EPI Distortion Correction and Registration



EPI Distortion Correction



Scenario:

Doing a functional (or diffusion) study

Objective:

Want to correct for distortions in EPI

as otherwise the registrations are inaccurate

Solution:

Fieldmap-based correction using FUGUE/FEAT

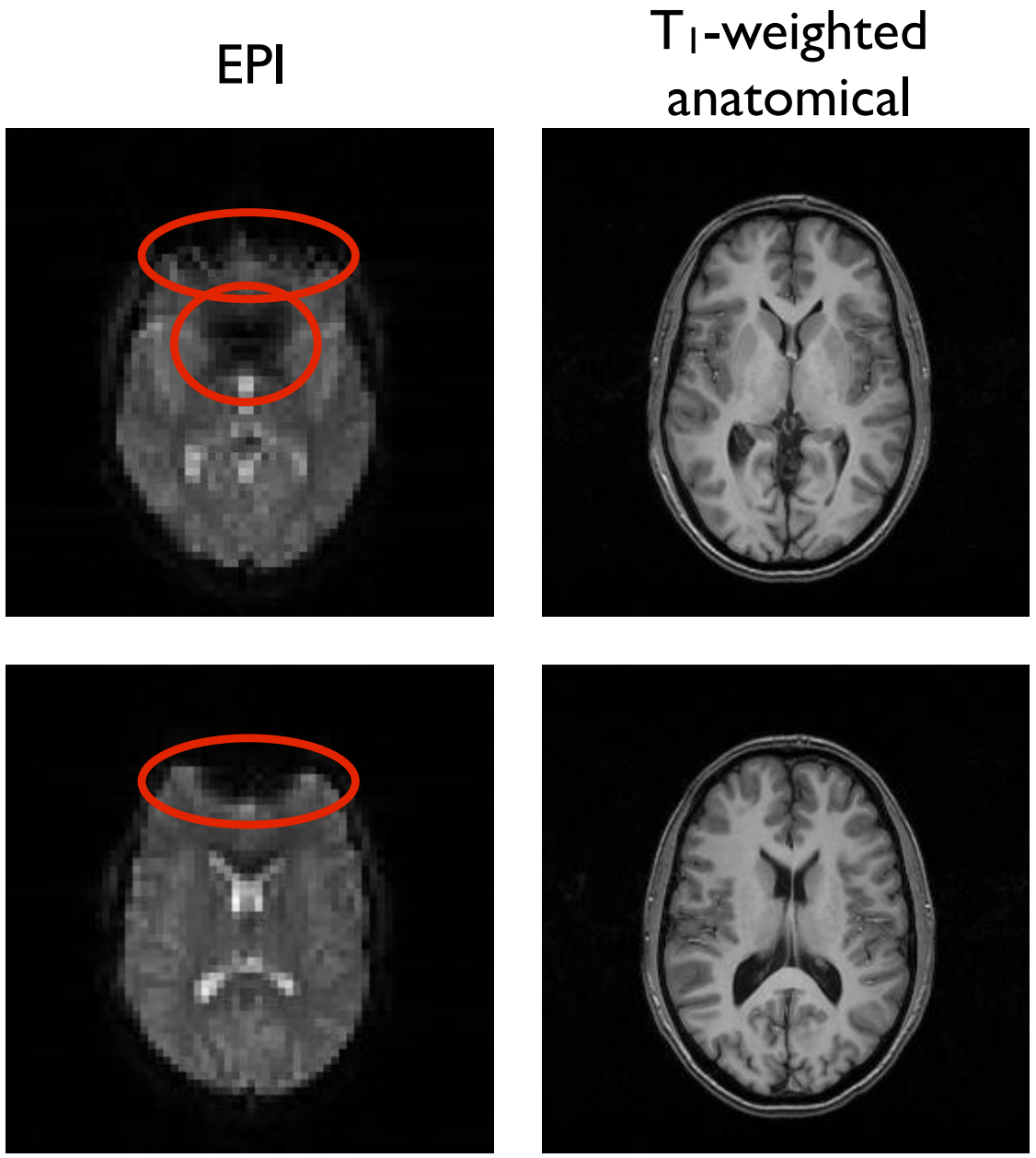
Registration of EPI

Problem:

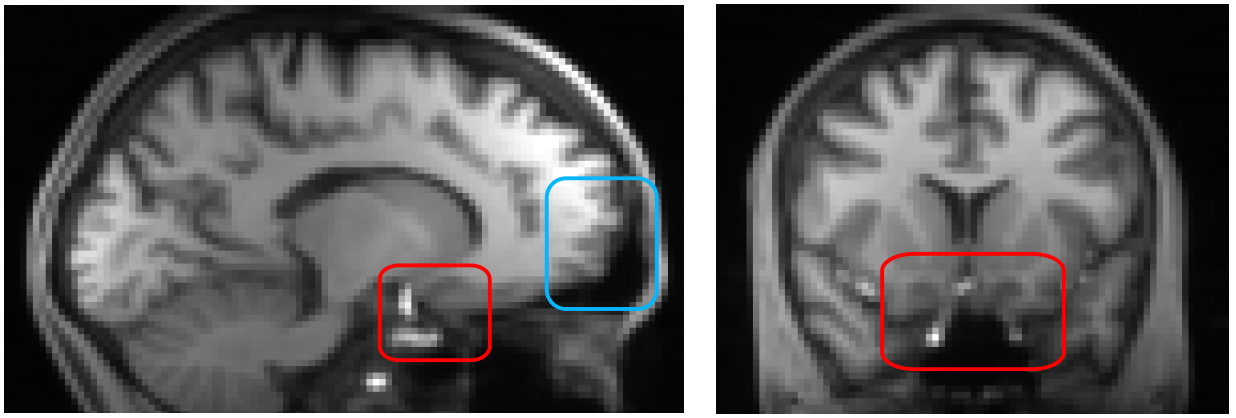
- EPI images distorted and suffer signal loss
- standard registration does not work well

Solution:

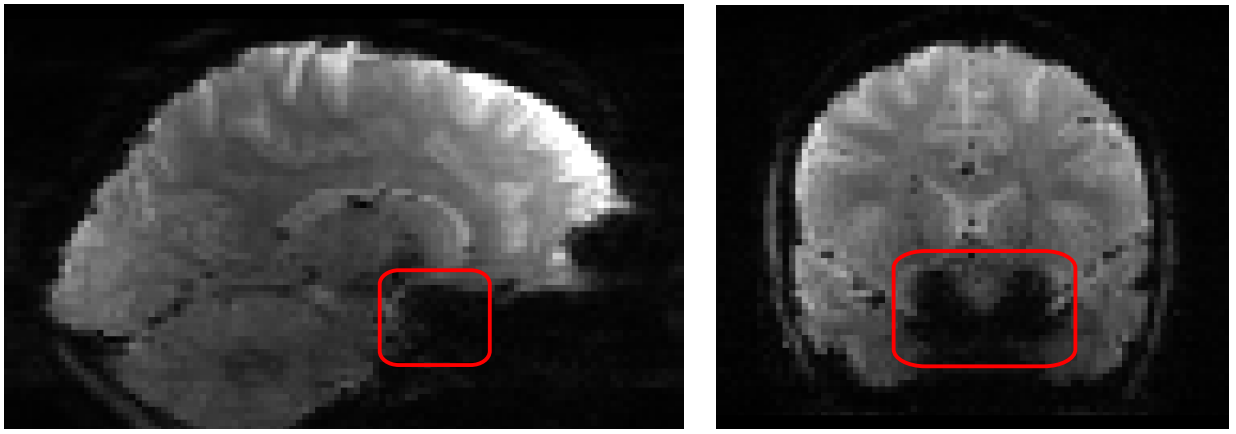
- undo distortion by "unwarping"
- ignore areas of high signal loss
- *needs a* **fieldmap** (special acquisition)



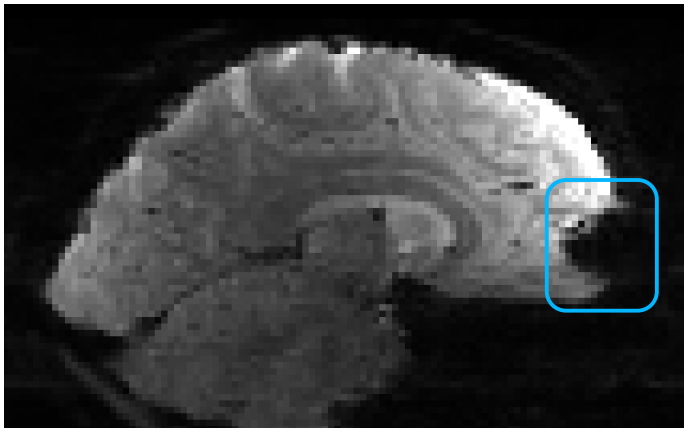
T1-weighted (aligned)

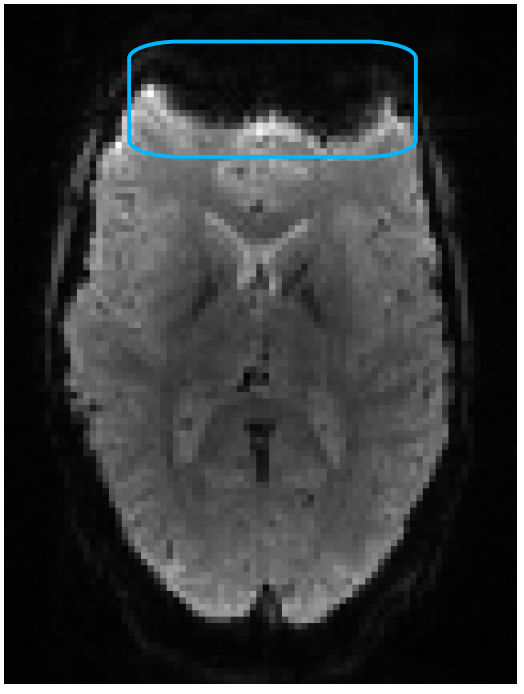


Signal Loss



Distortion



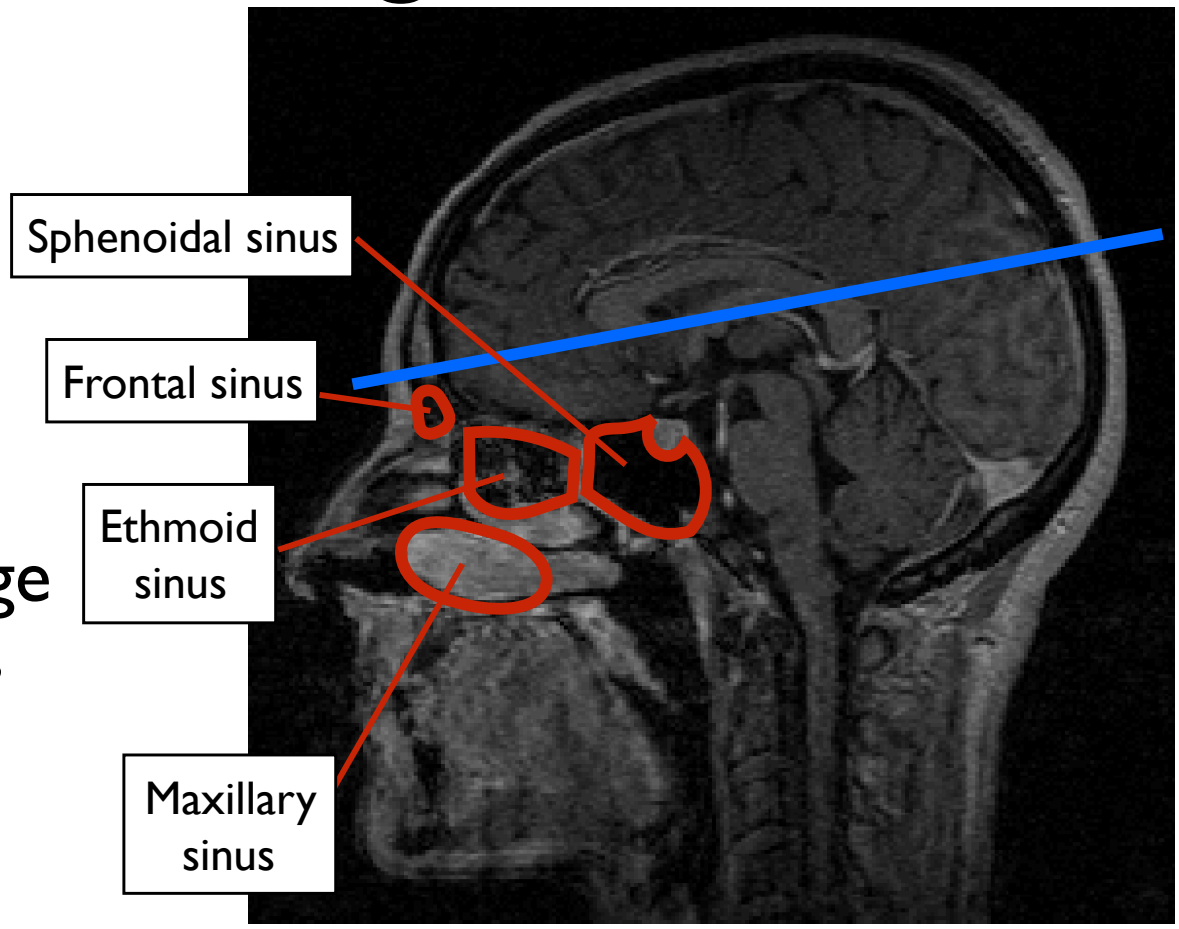


B_0 Field Inhomogeneities

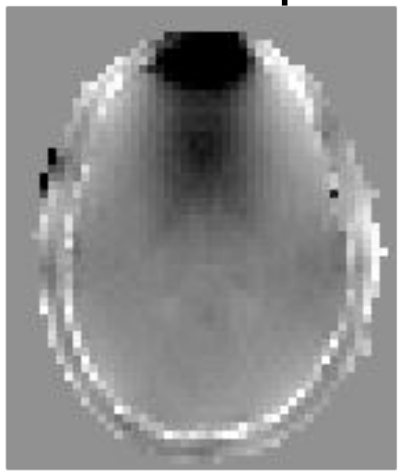
EPI is very sensitive to any deviations from a perfectly uniform B_0 field

Air-tissue interfaces cause magnetic disturbances

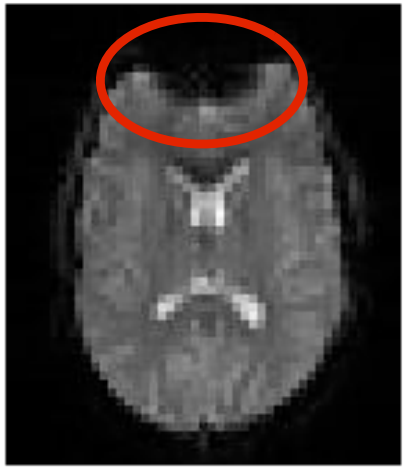
A separate ***fieldmap*** image measures the B_0 deviations



fieldmap

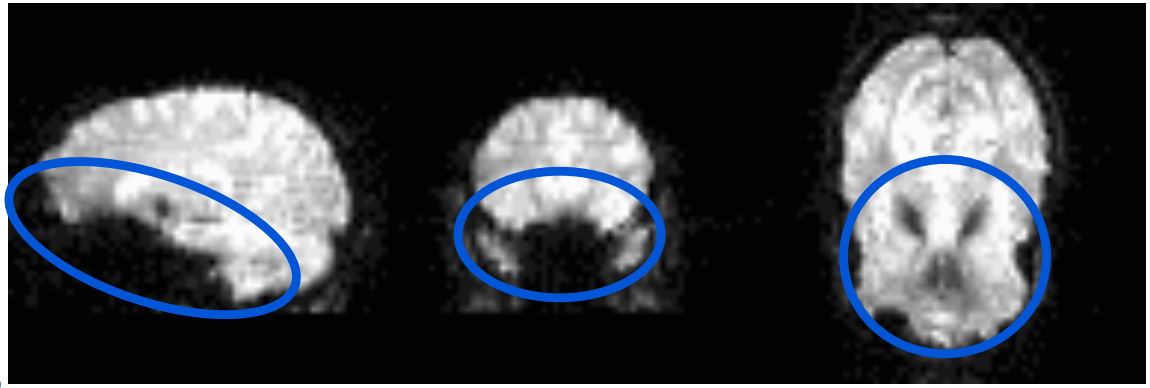


EPI



distortion

signal loss



Courtesy of D. Greve, MGH

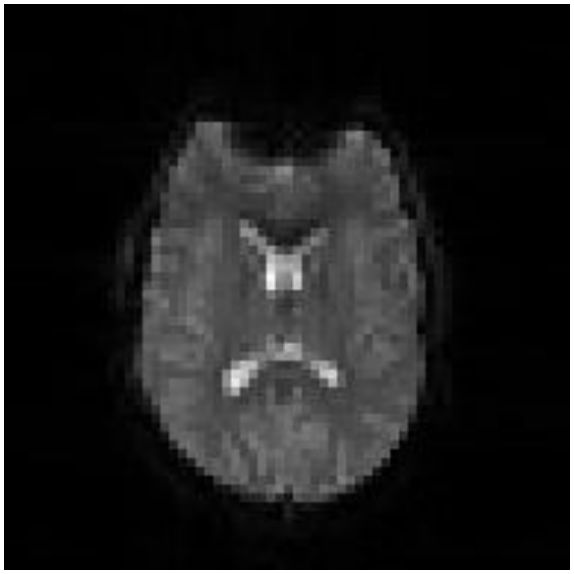
Using Fieldmaps

From the fieldmap image we get:

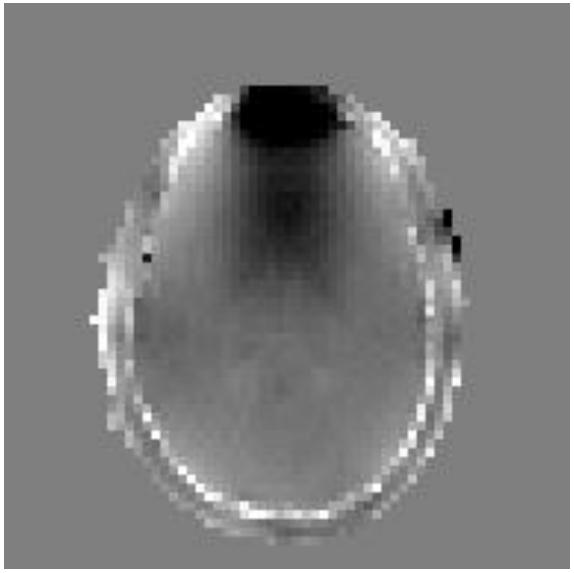
Magnitude of spatial distortions
(phase-encode direction only)
Estimate of signal loss

Only takes a few minutes to acquire one fieldmap - and it *massively* improves registration

Need a new fieldmap for each scanning session as it changes
(e.g. it depends on head orientation)



EPI



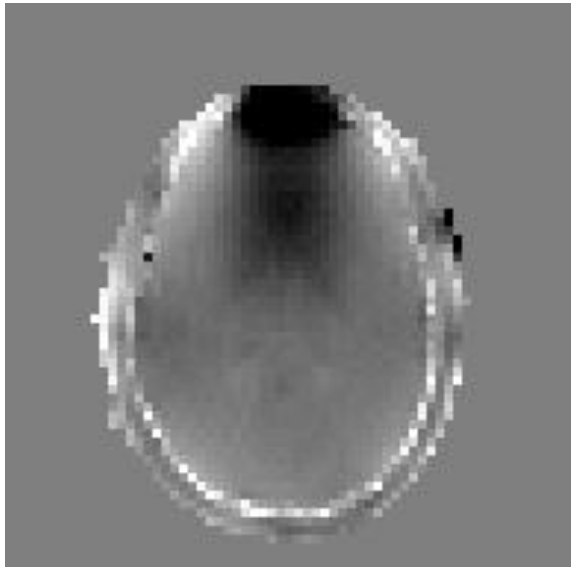
B_0 Fieldmap

Unwarping with Fieldmaps

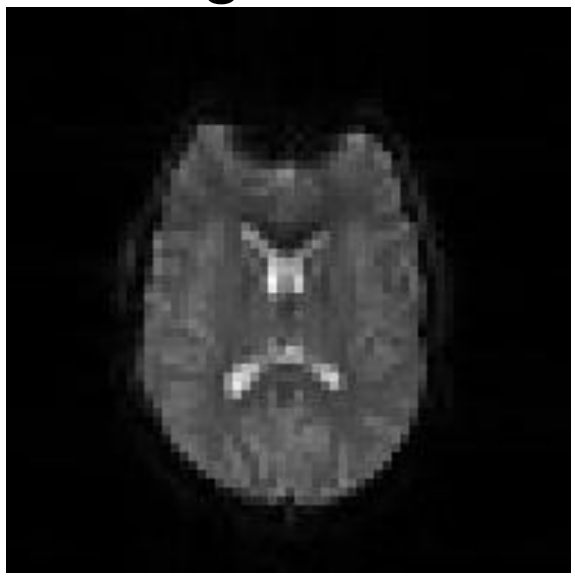
Used to improve **registration** of EPI and structural scan

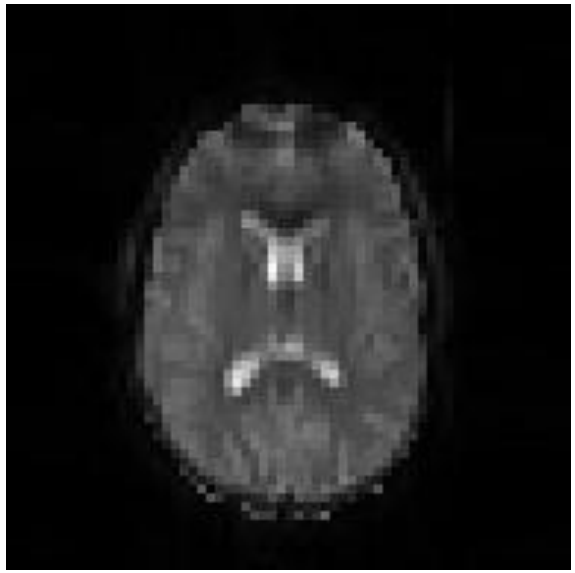
It **does not** restore signal in the frontal lobe

Fieldmap



Original EPI





Unwarped EPI

Unwarping with Fieldmaps

Used to improve **registration** of EPI and structural scan

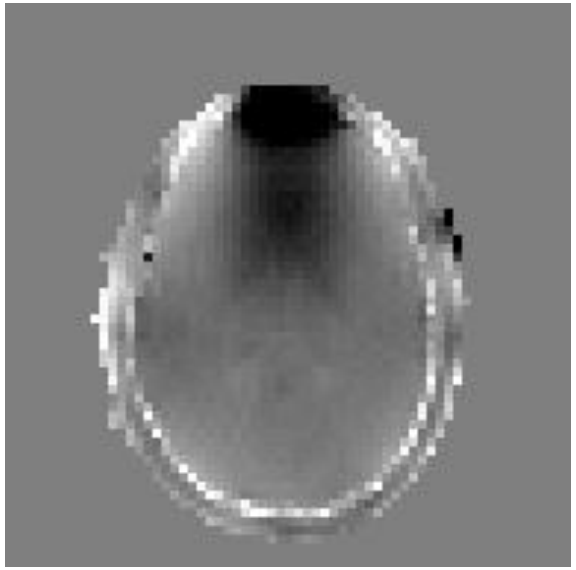
It **does not** restore signal in the frontal lobe

It **does not** do anything about motion correction

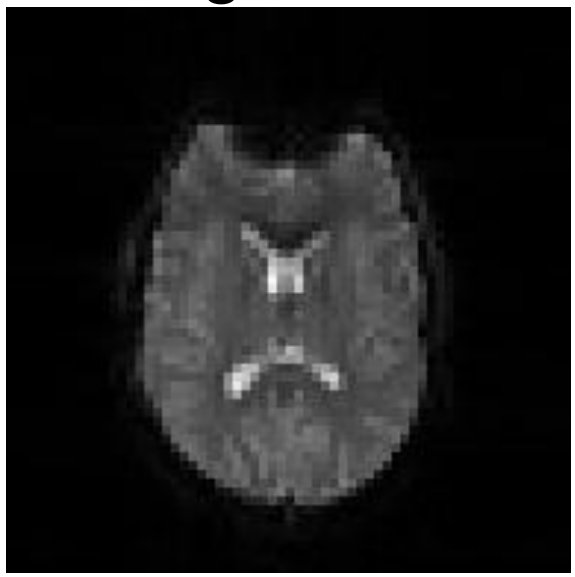
It **does** use fieldmap image to calculate distortion and "unwarp" EPI

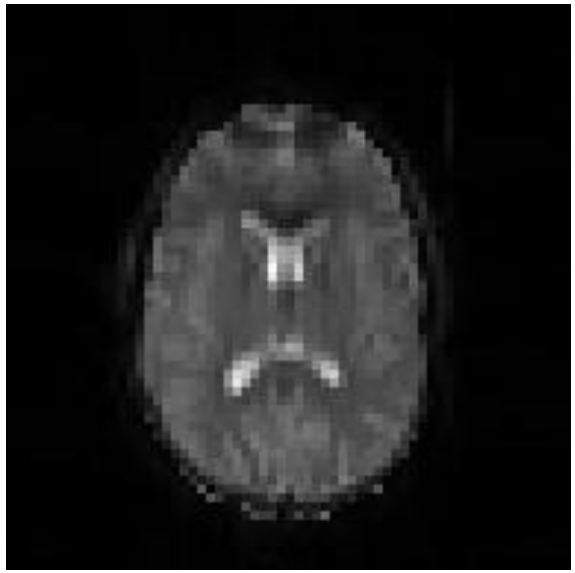
It **does** deweight areas with substantial signal loss *in the registration*

Fieldmap



Original EPI





Unwarped EPI

Fieldmap Acquisition

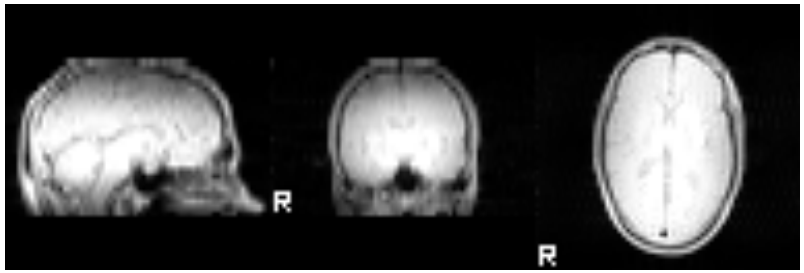
Fieldmaps are becoming standard sequences

Only takes a few minutes to acquire - best either immediately before or after EPI scans (but this is not crucial)

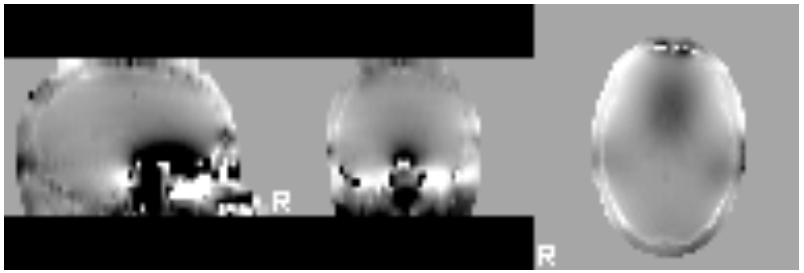
Four main types of acquisitions:

- Gradient Echo ✔
- Asymmetric Spin Echo ✔
- EPI ✘ Distortion & Signal Loss
- Blip-reversed b=0 pair (EPI) ✔

Each based on a pair of images with different TE (*record* these TE values)



Magnitude part of fieldmap

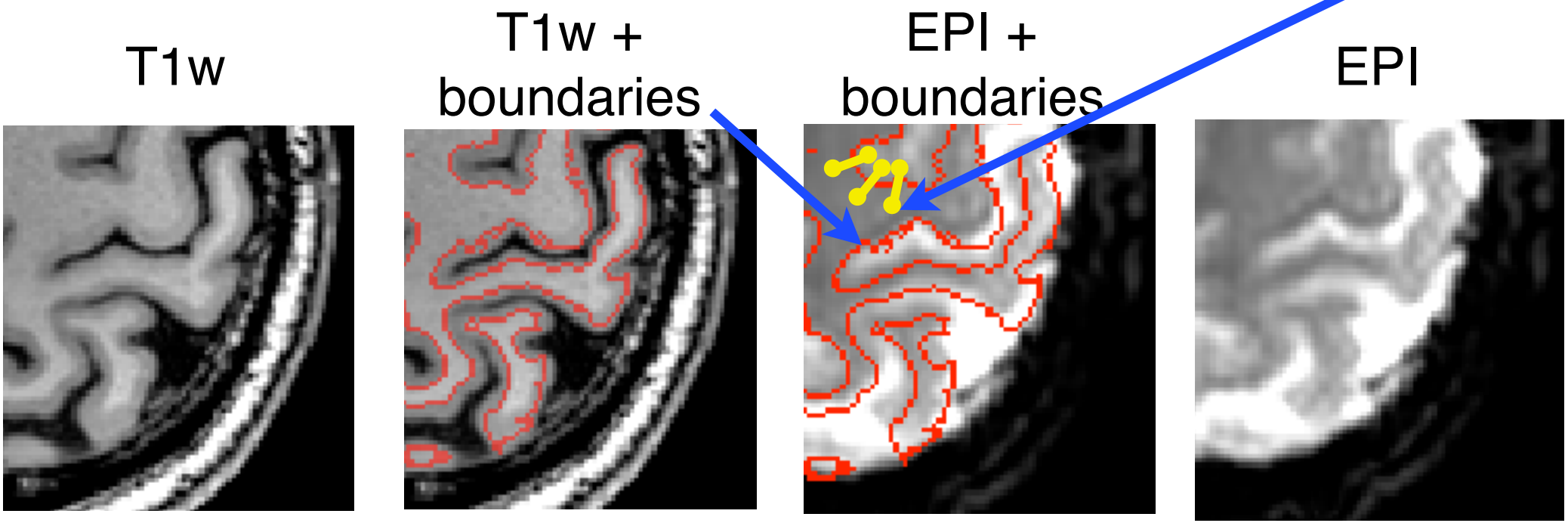


Phase difference of images

Crucially requires the *phase information* (not only the magnitude, unlike the vast majority of other images)

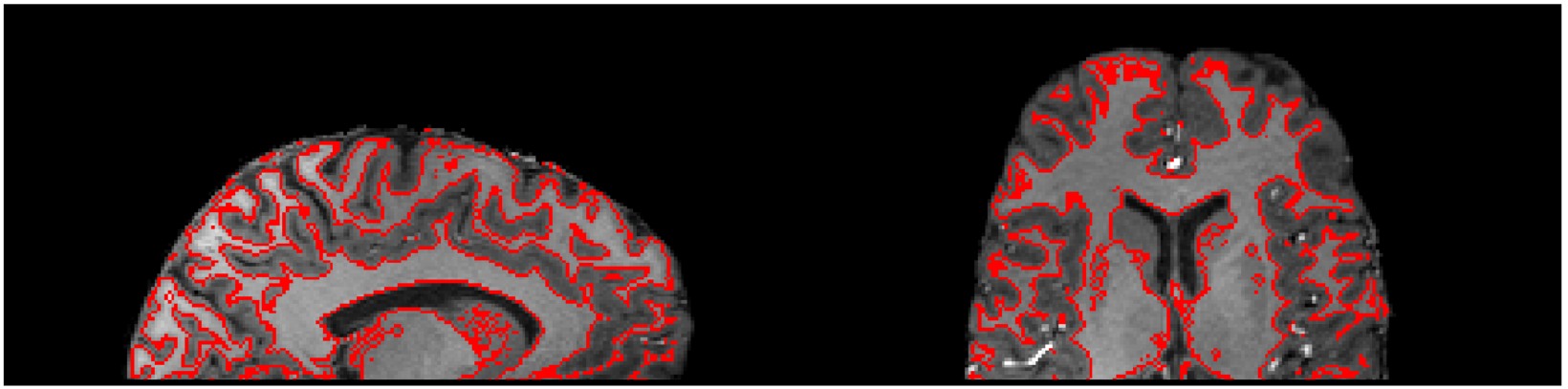
Boundary-Based Registration (BBR)

- *EPI to structural registration* (Greve & Fischl, NeuroImage, 2009)
  - incorporates ***fieldmap*** correction (previously FUGUE)
  - used in FEAT (B0 unwarping)
- Uses ***white-matter boundaries*** (via T1w segmentation)
  - Need good structurals (not too much bias field)
  - Also ***requires anatomical contrast in the EPI***
  - Driven by intensity difference across boundary (samples)
- More robust to pathologies and artefacts in EPI

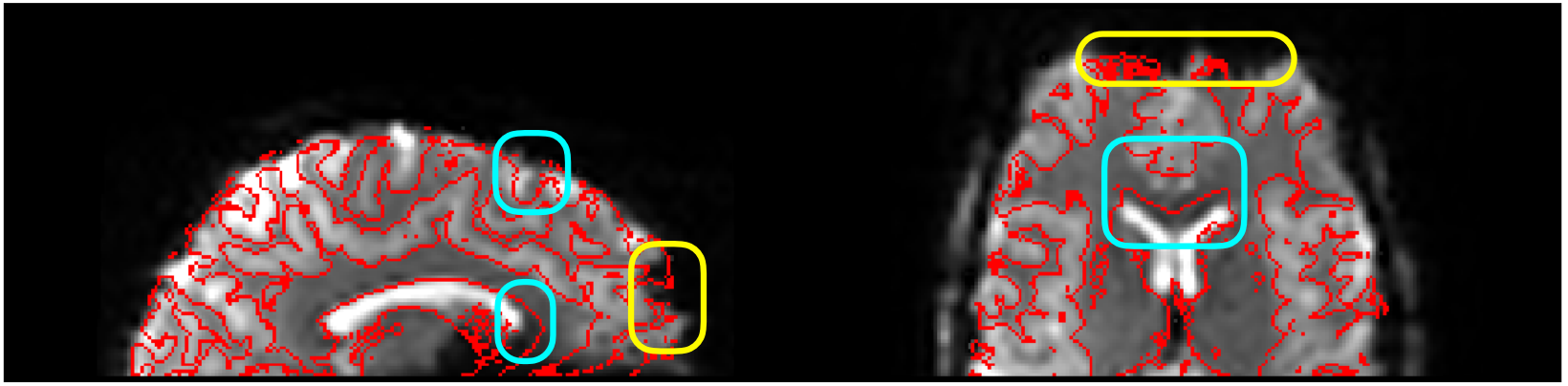


Distortion Correction

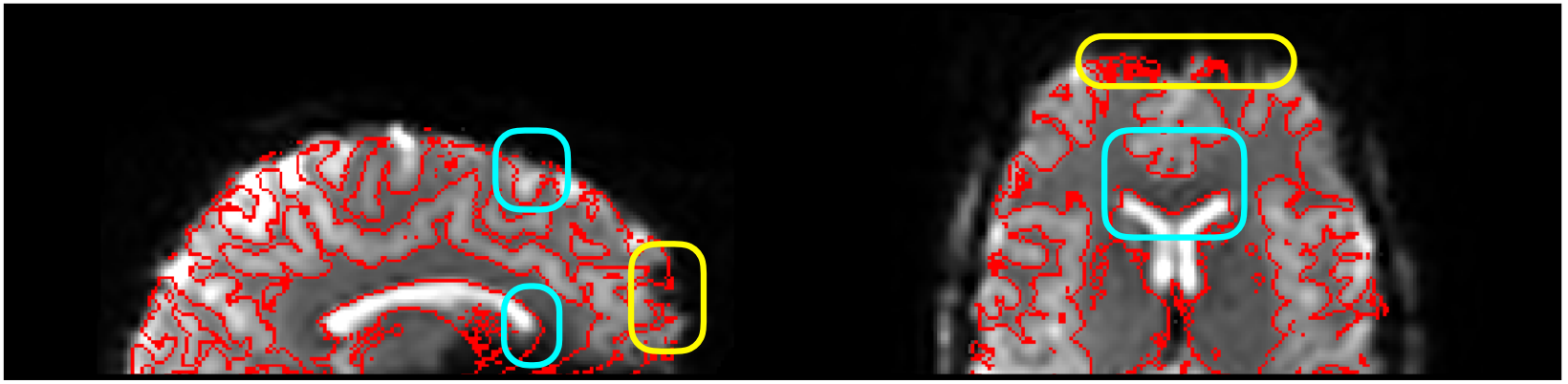
Structural Image



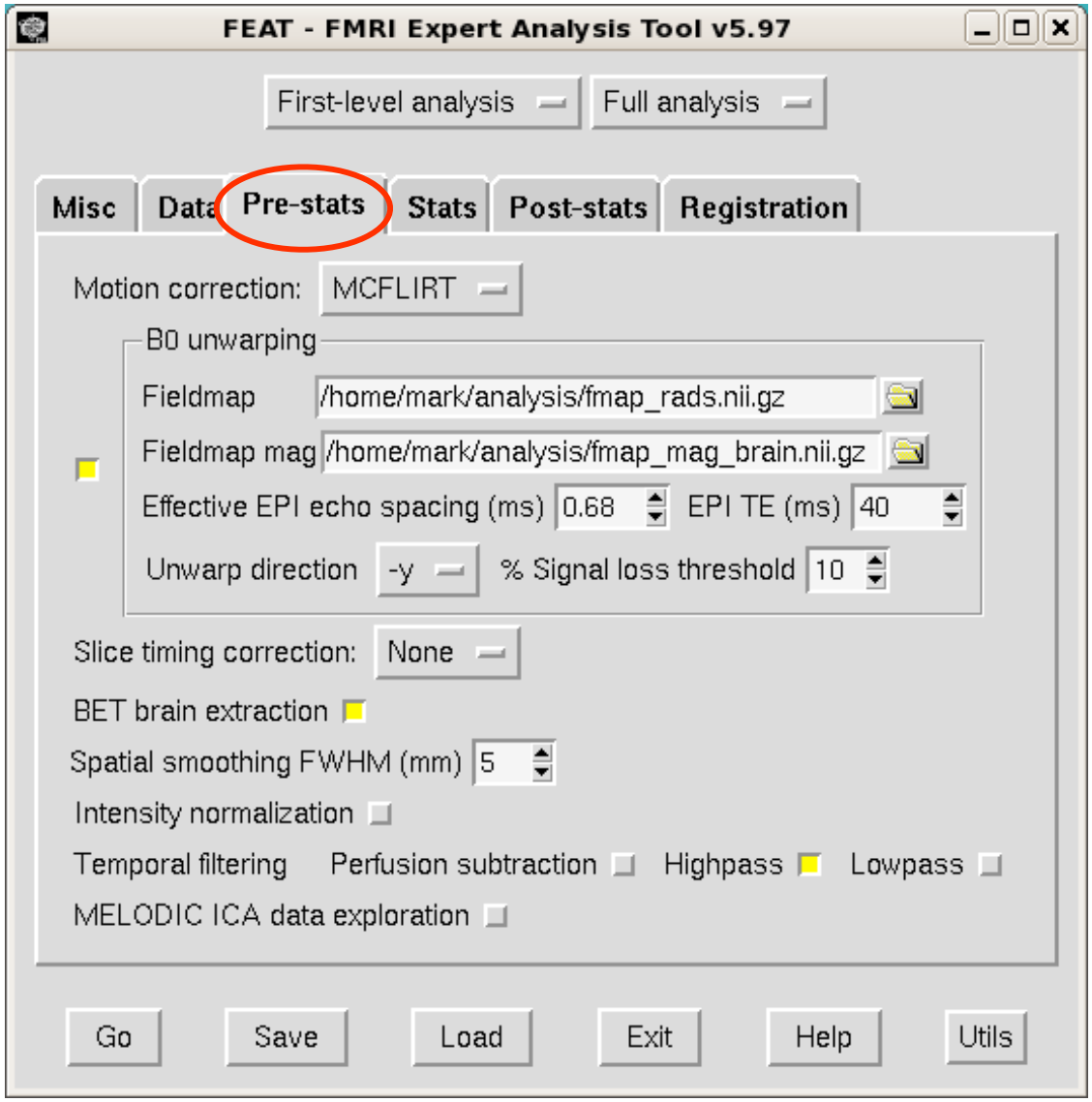
Registration without Distortion Correction



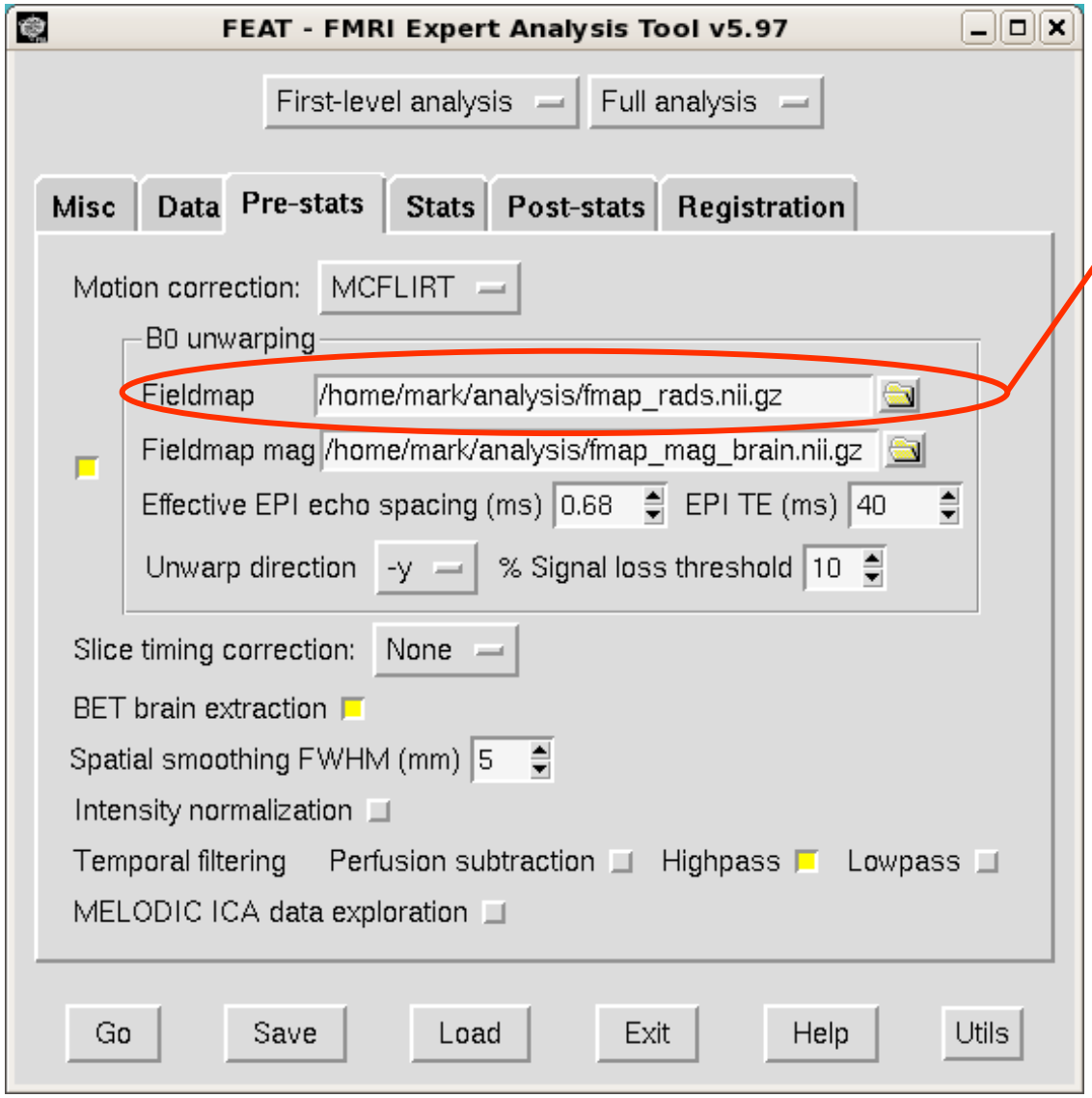
Registration with Distortion Correction



Distortion Correction within FEAT

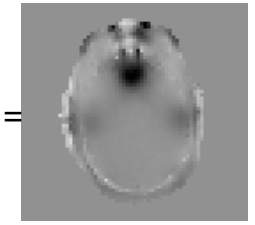


Distortion Correction within FEAT



Fieldmap in rad/s

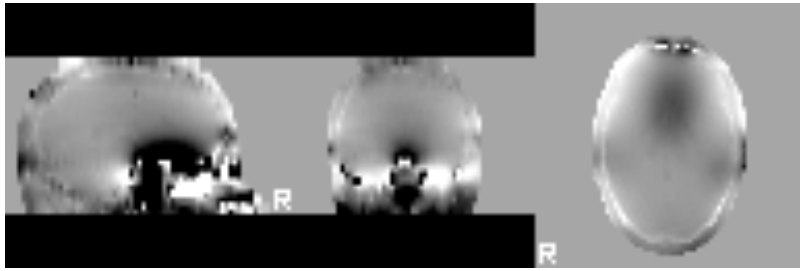
/ TE difference (sec) =



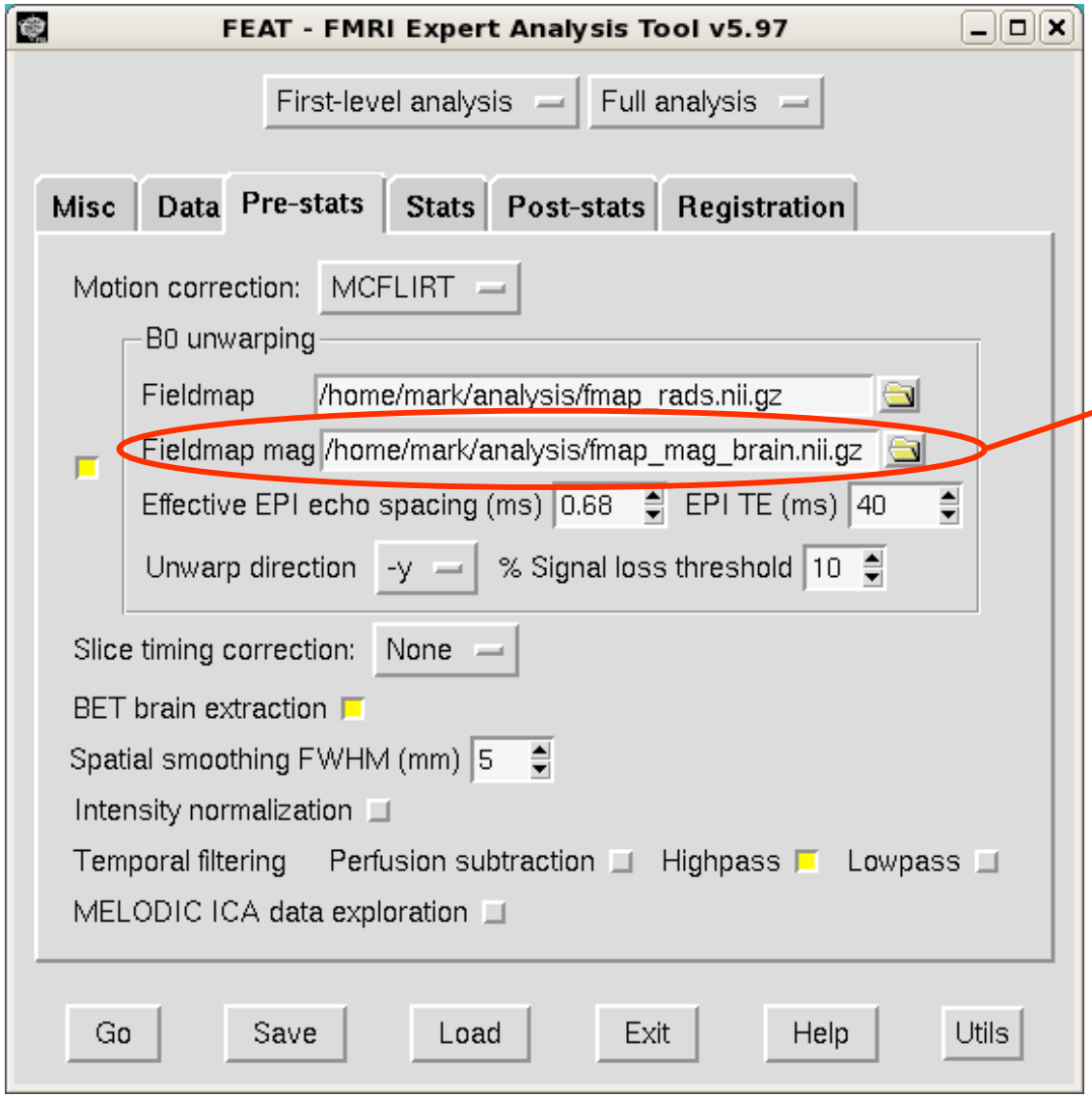
Phase difference (rad)

B_0 Field (rad/s)

Need to prepare the fieldmap image: *Fsl_prepare_fieldmap* (for Siemens)



Distortion Correction within FEAT

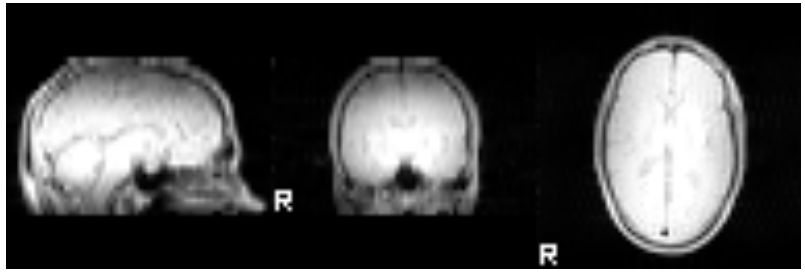


Input file = brain extracted file ...
but also needs to find original*

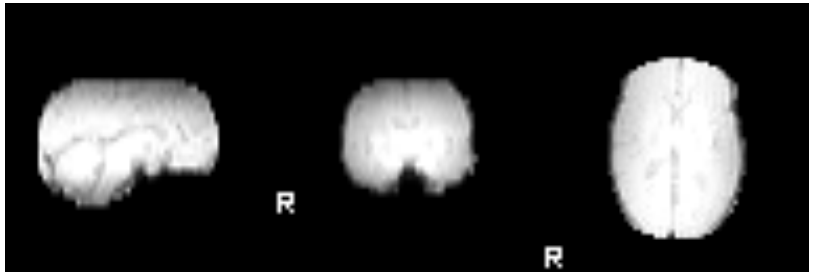
Fieldmap in rad/s

Fieldmap Magnitude

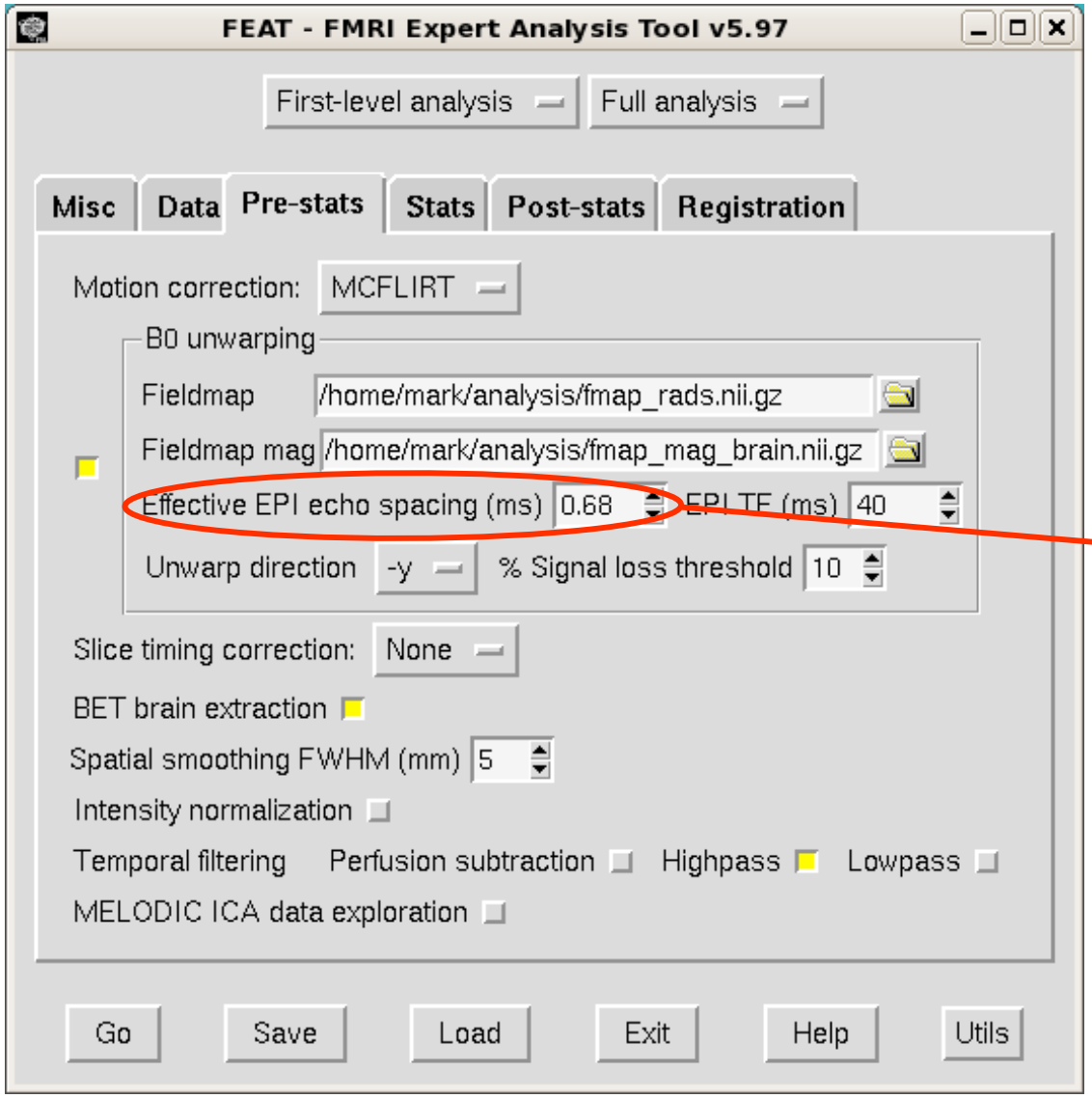
... needs this ...



... and aggressive BET (leave **no** non-brain) for best performance



Distortion Correction within FEAT



Divide value by any acceleration factor

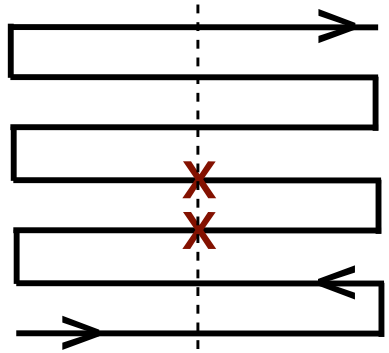
Fieldmap in rad/s

Fieldmap Magnitude

EPI echo spacing (ms)

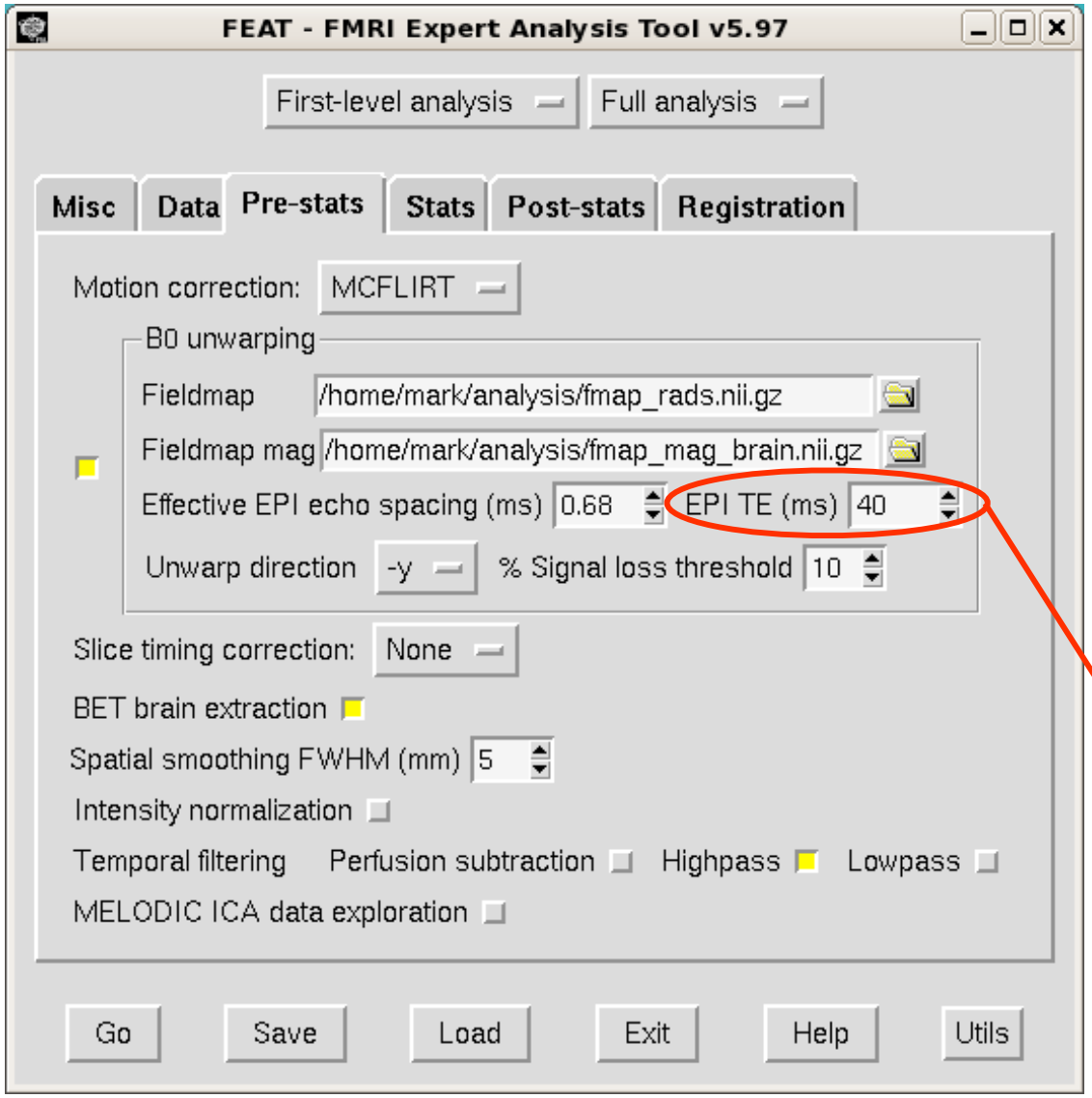
Also called dwell time

Normally about 0.5-0.7ms



Time between echos in k-space

Distortion Correction within FEAT



Fieldmap in rad/s

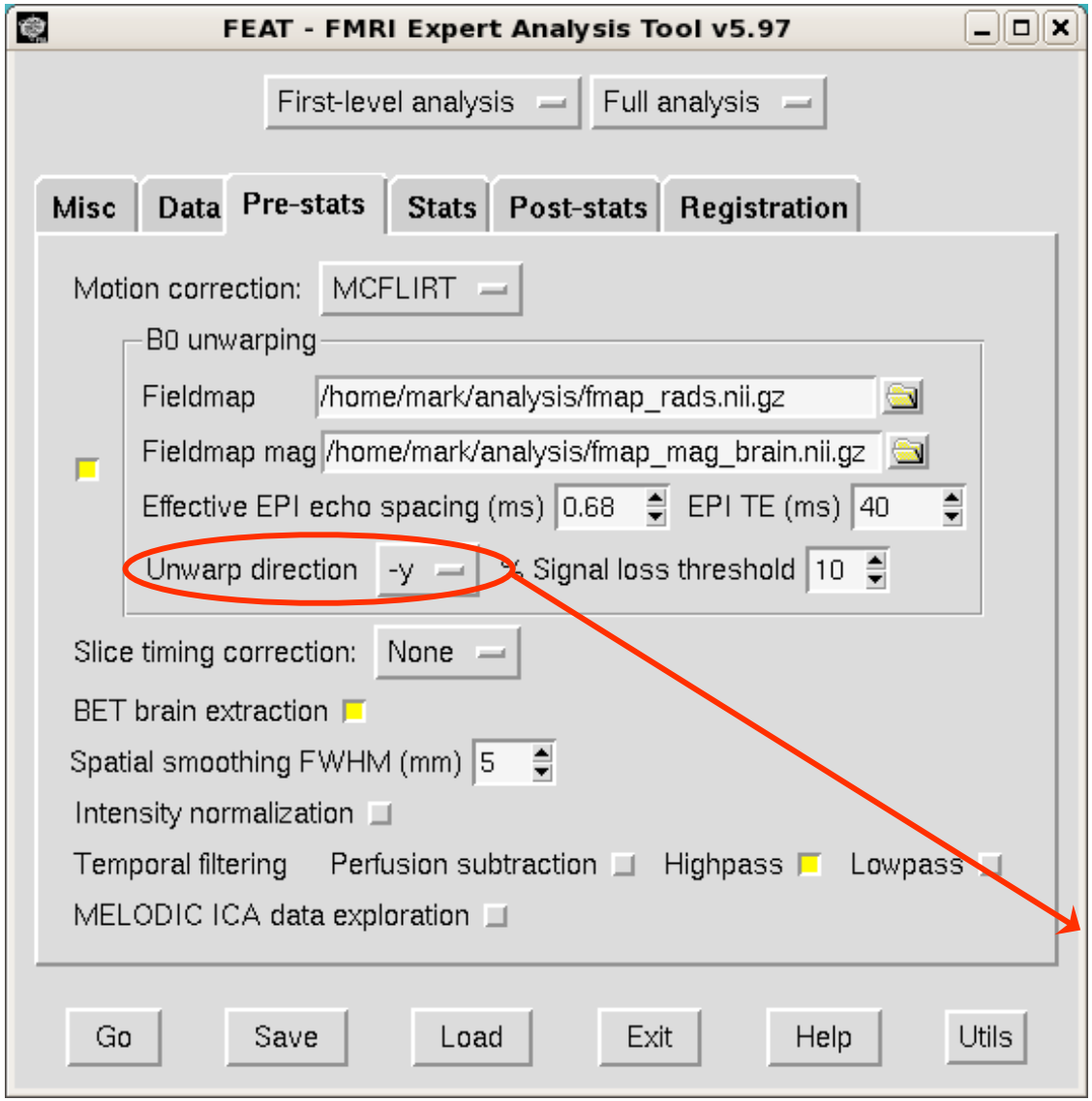
Fieldmap Magnitude

EPI echo spacing (ms)

EPI echo time (ms)

Normally about 30-40ms at 3T

Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

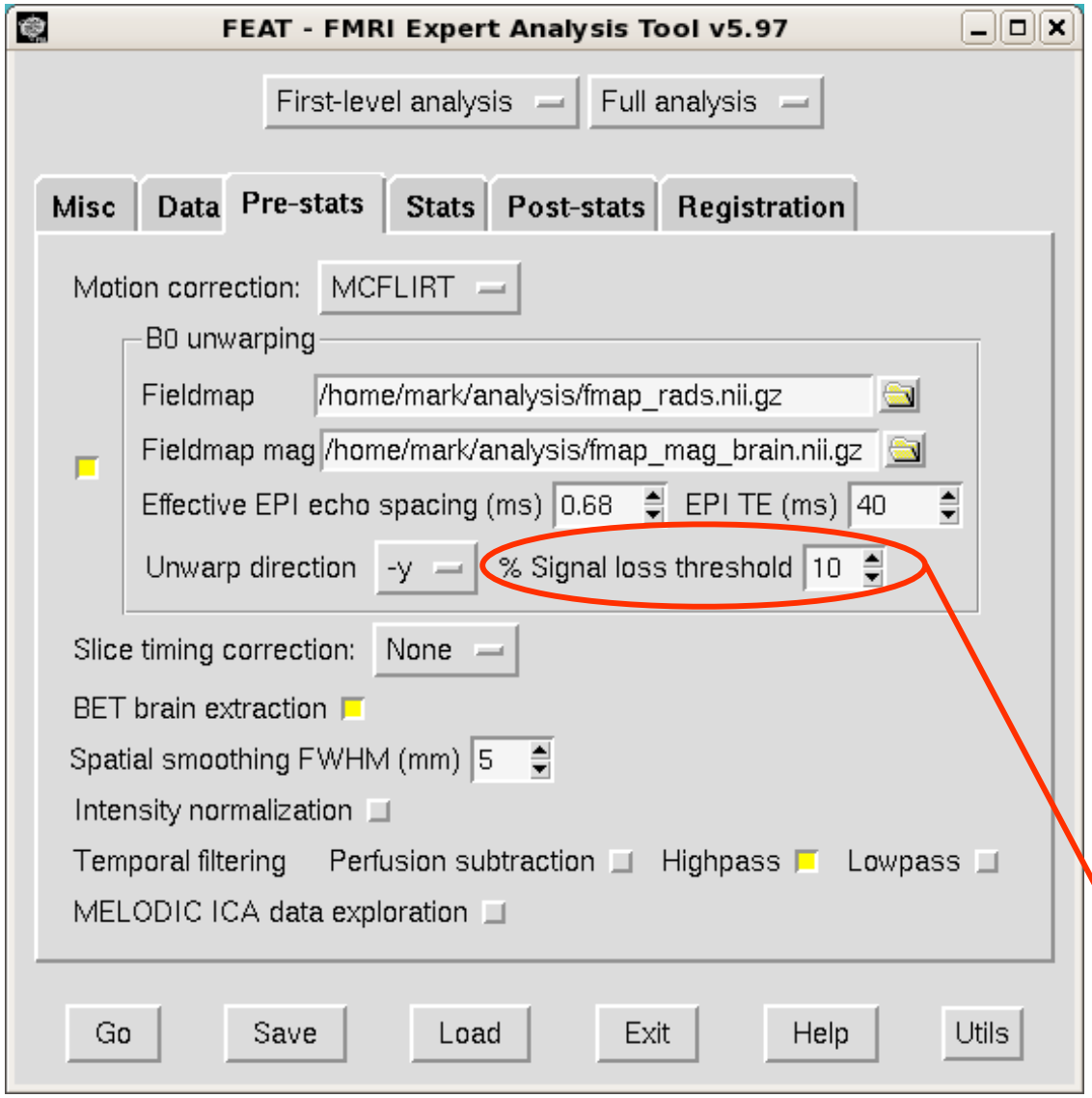
EPI echo spacing (ms)

EPI echo time (ms)

Unwarp (PE) direction

- Often A-P but can be anything
- Cannot tell if it is + or -
- *Try both* and see what works (see practical)

Distortion Correction within FEAT



Fieldmap in rad/s

Fieldmap Magnitude

EPI echo spacing (ms)

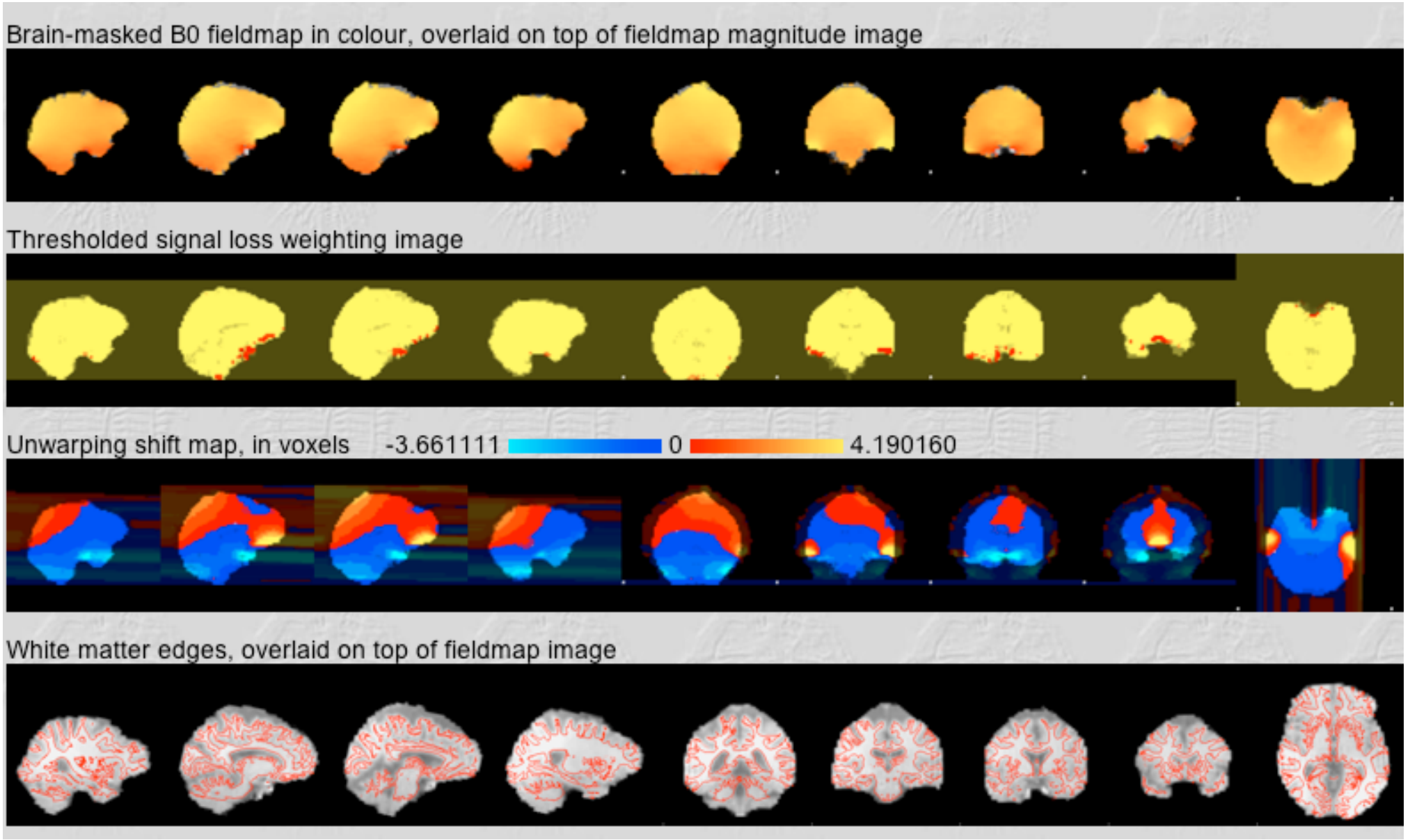
EPI echo time (ms)

Unwarp (PE) direction

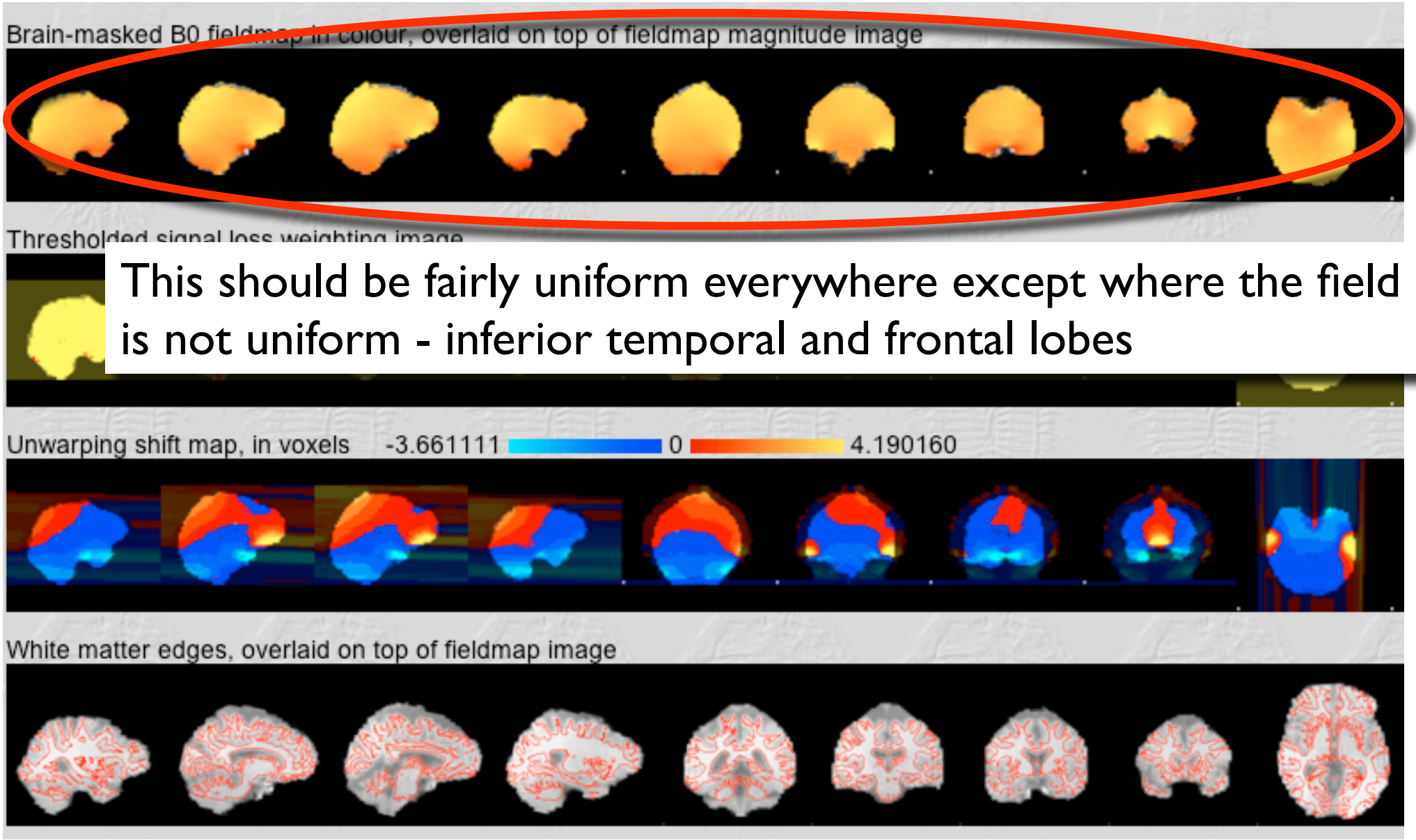
Signal loss thresh %

Ignore voxels with more than this signal loss in registration

Fieldmap use in FEAT

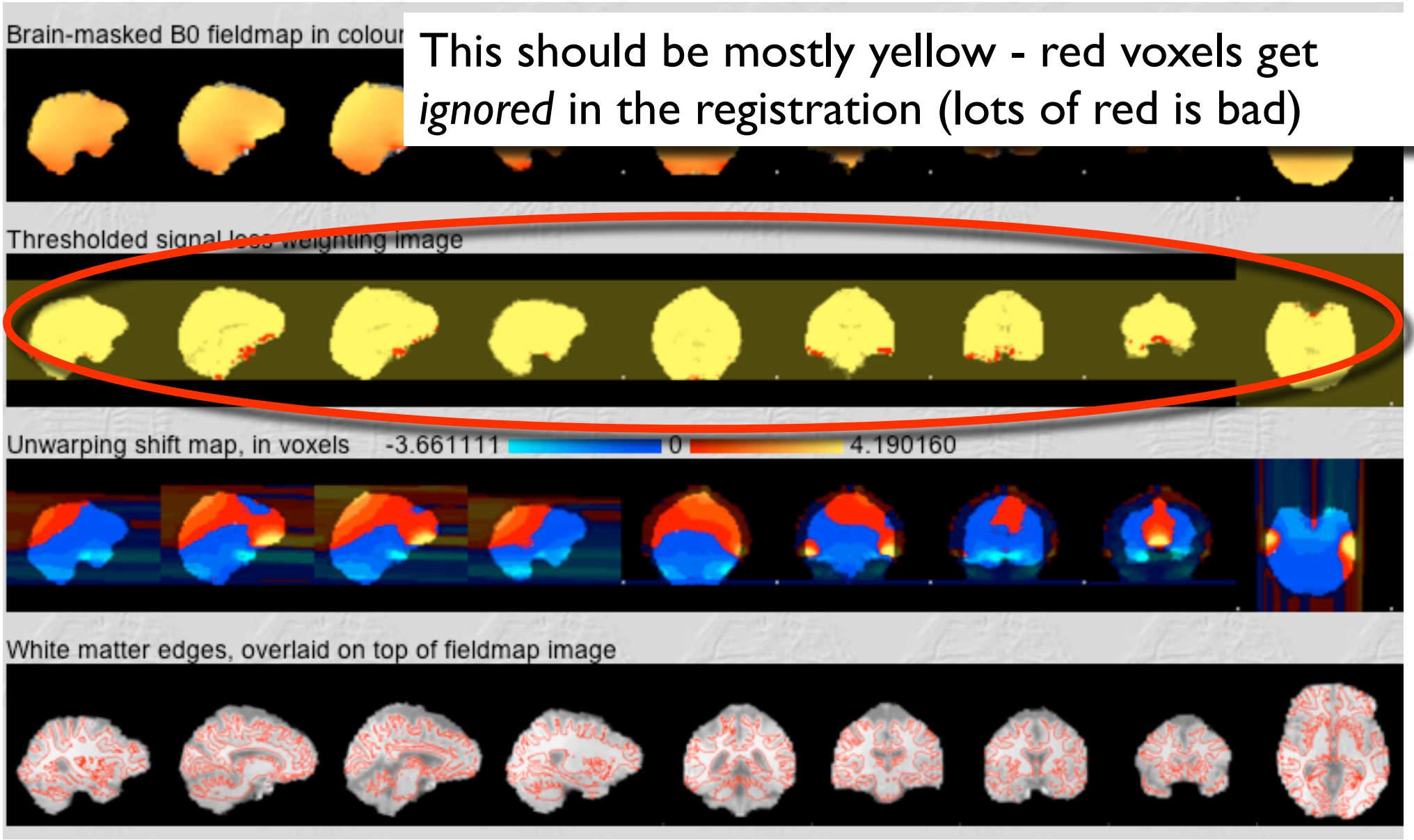


Fieldmap use in FEAT



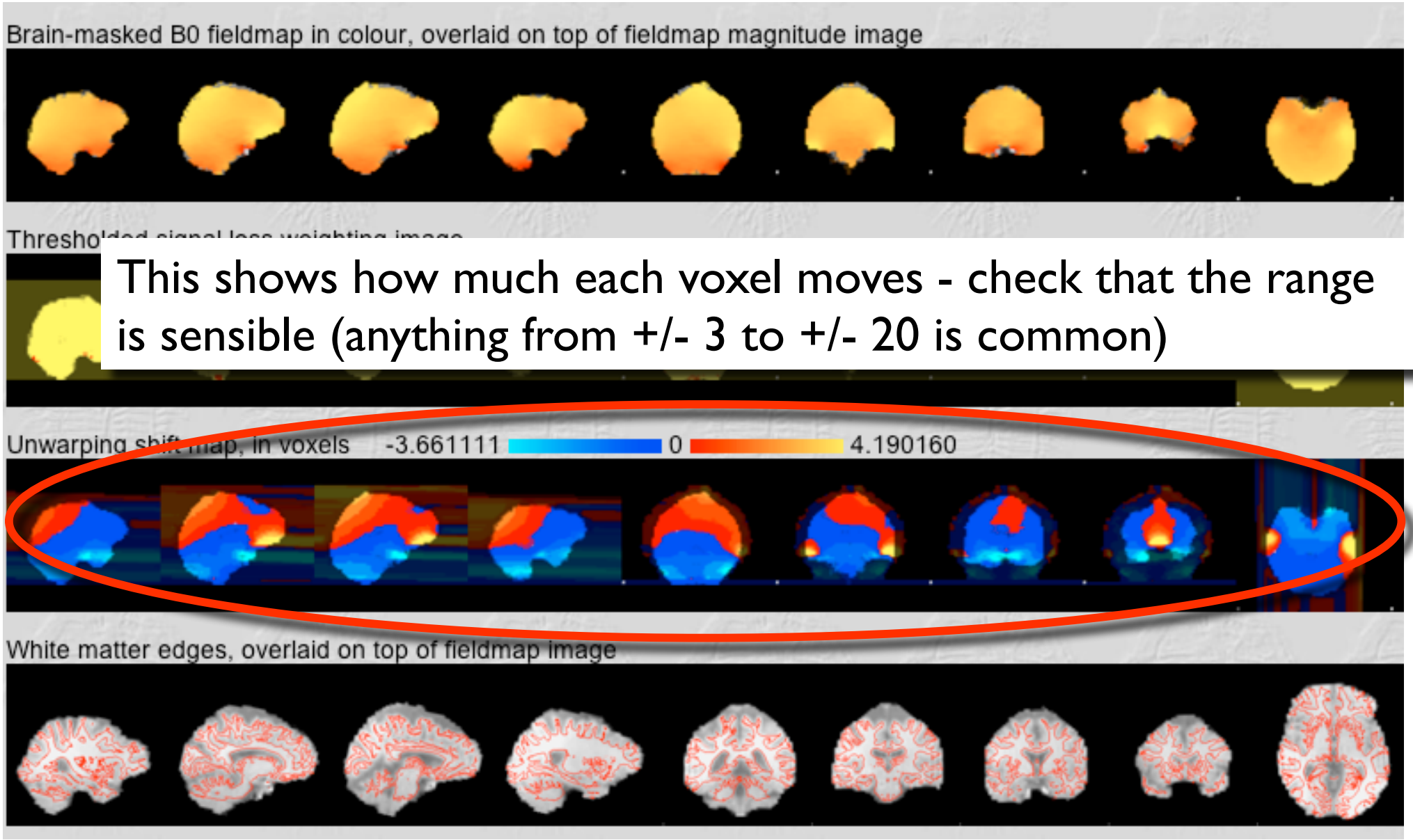
This should be fairly uniform everywhere except where the field is not uniform - inferior temporal and frontal lobes

Fieldmap use in FEAT



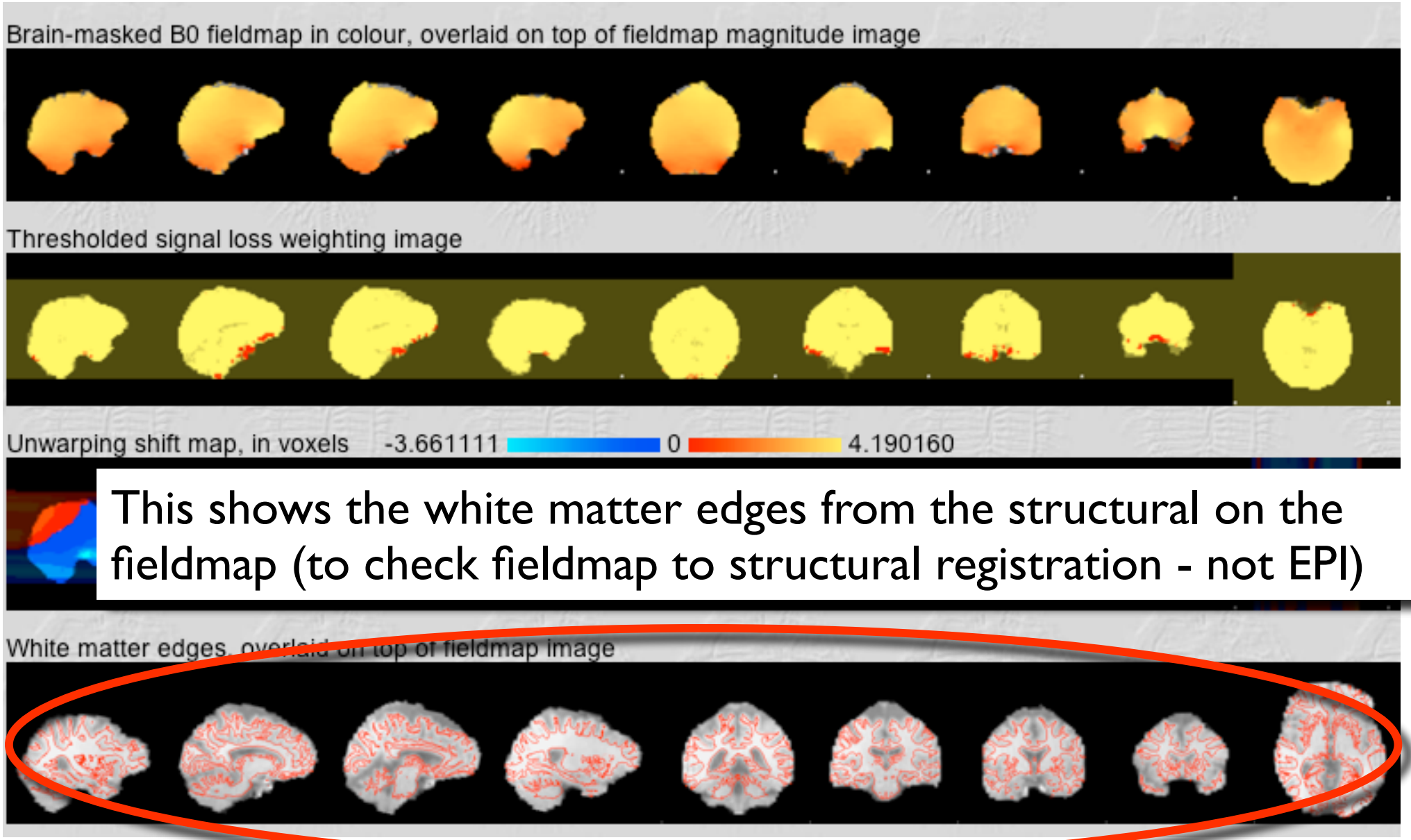
This should be mostly yellow - red voxels get *ignored* in the registration (lots of red is bad)

Fieldmap use in FEAT



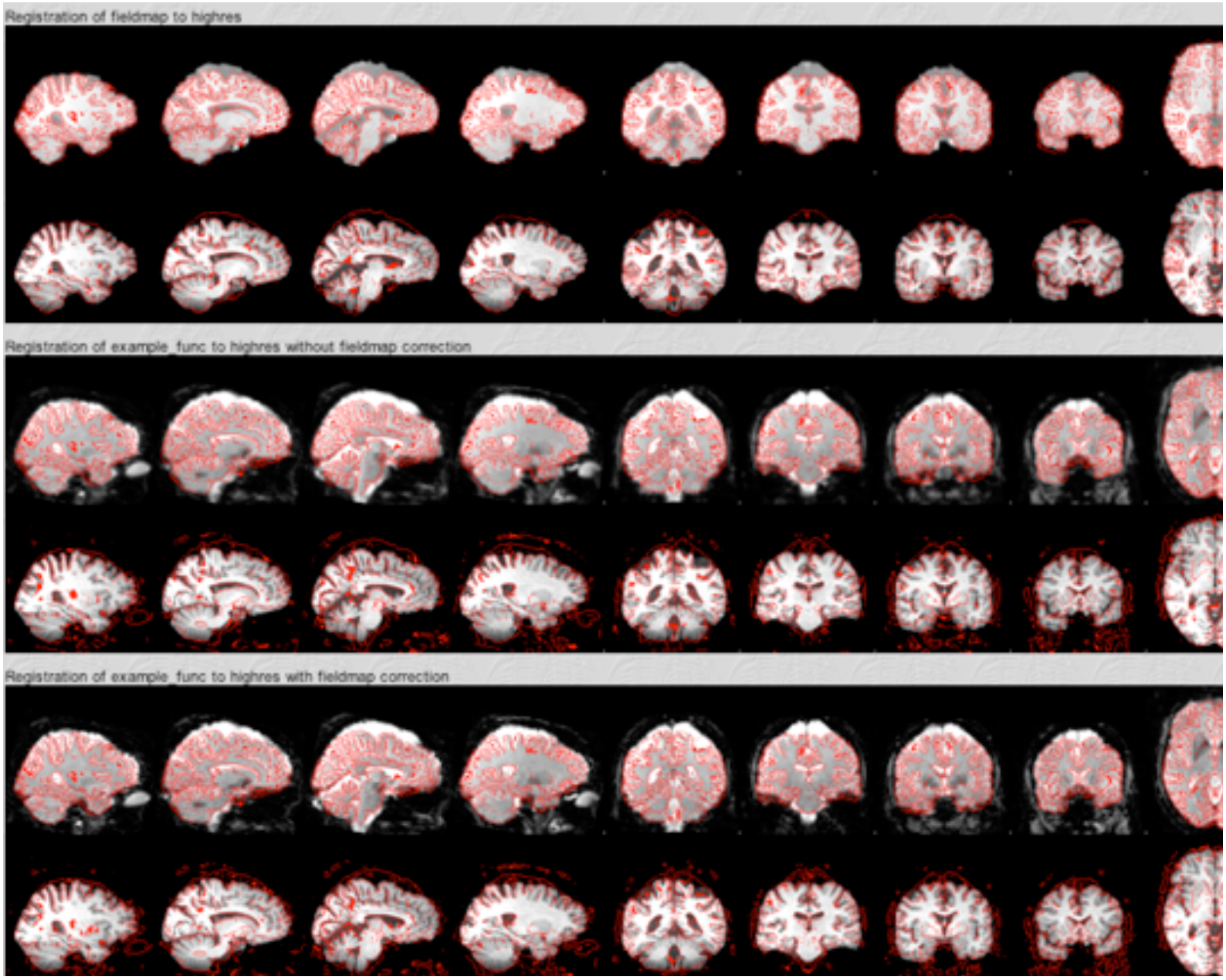
This shows how much each voxel moves - check that the range is sensible (anything from +/- 3 to +/- 20 is common)

Fieldmap use in FEAT



This shows the white matter edges from the structural on the fieldmap (to check fieldmap to structural registration - not EPI)

Fieldmap use in FEAT

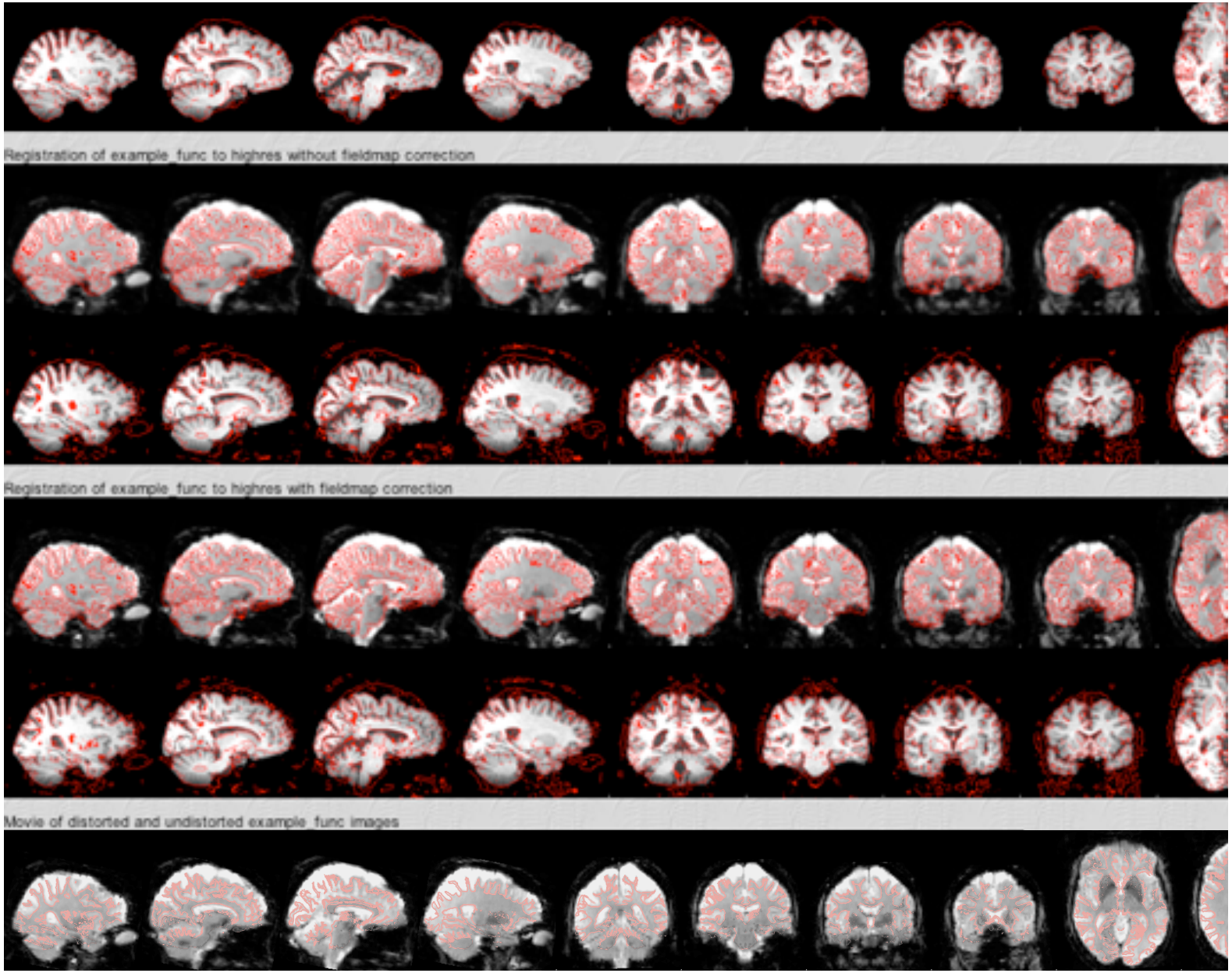


Fieldmap to highres (structural)

Functional (EPI) to highres (structural) - no correction

Functional (EPI) to highres (structural) - with fieldmap correction

Fieldmap use in FEAT



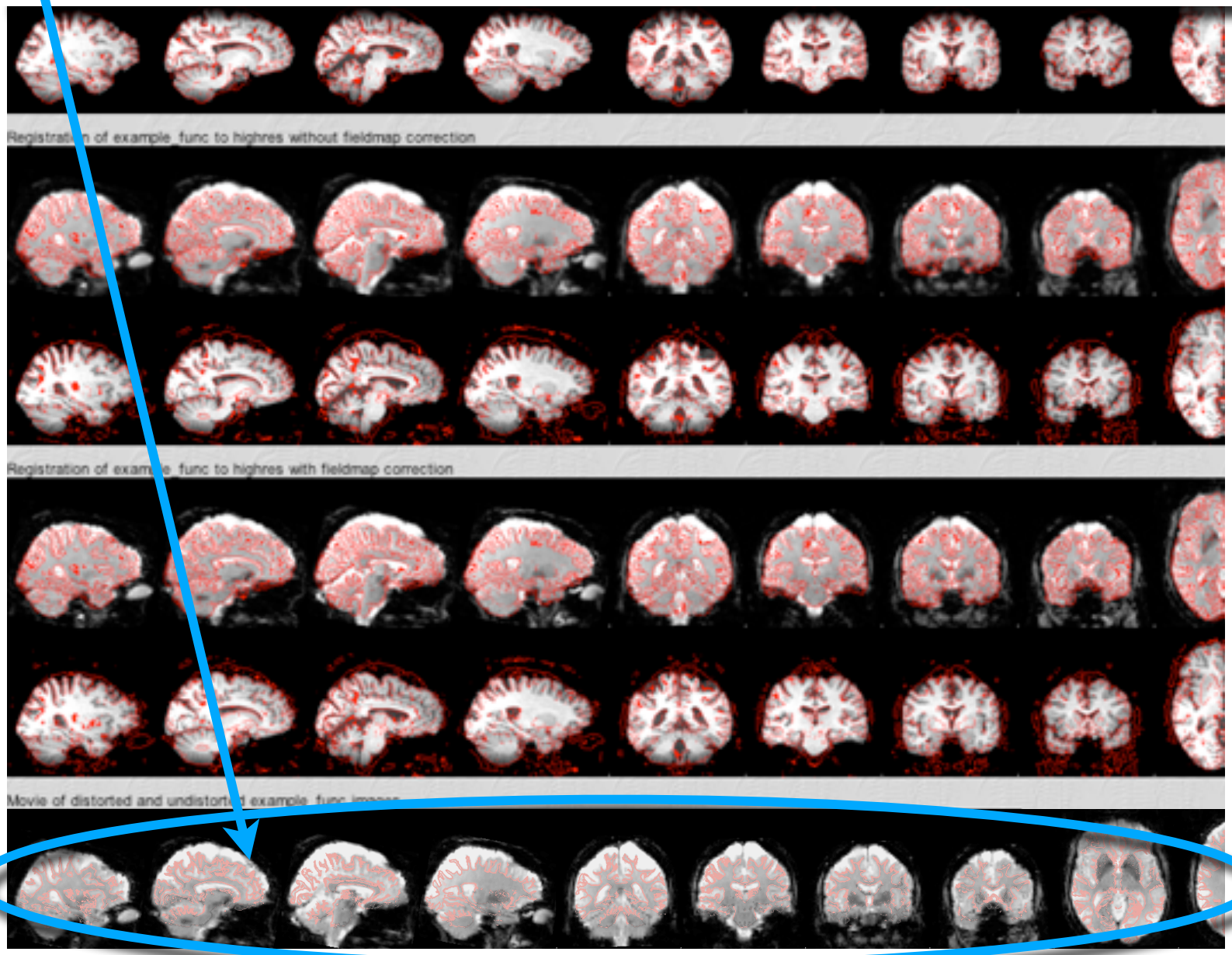
Functional (EPI) to highres (structural) - no correction

Functional (EPI) to highres (structural) - with fieldmap correction

Movie of EPI with and without correction

Fieldmap use in FEAT

Look for areas where unwarping (correction) changes brain shape



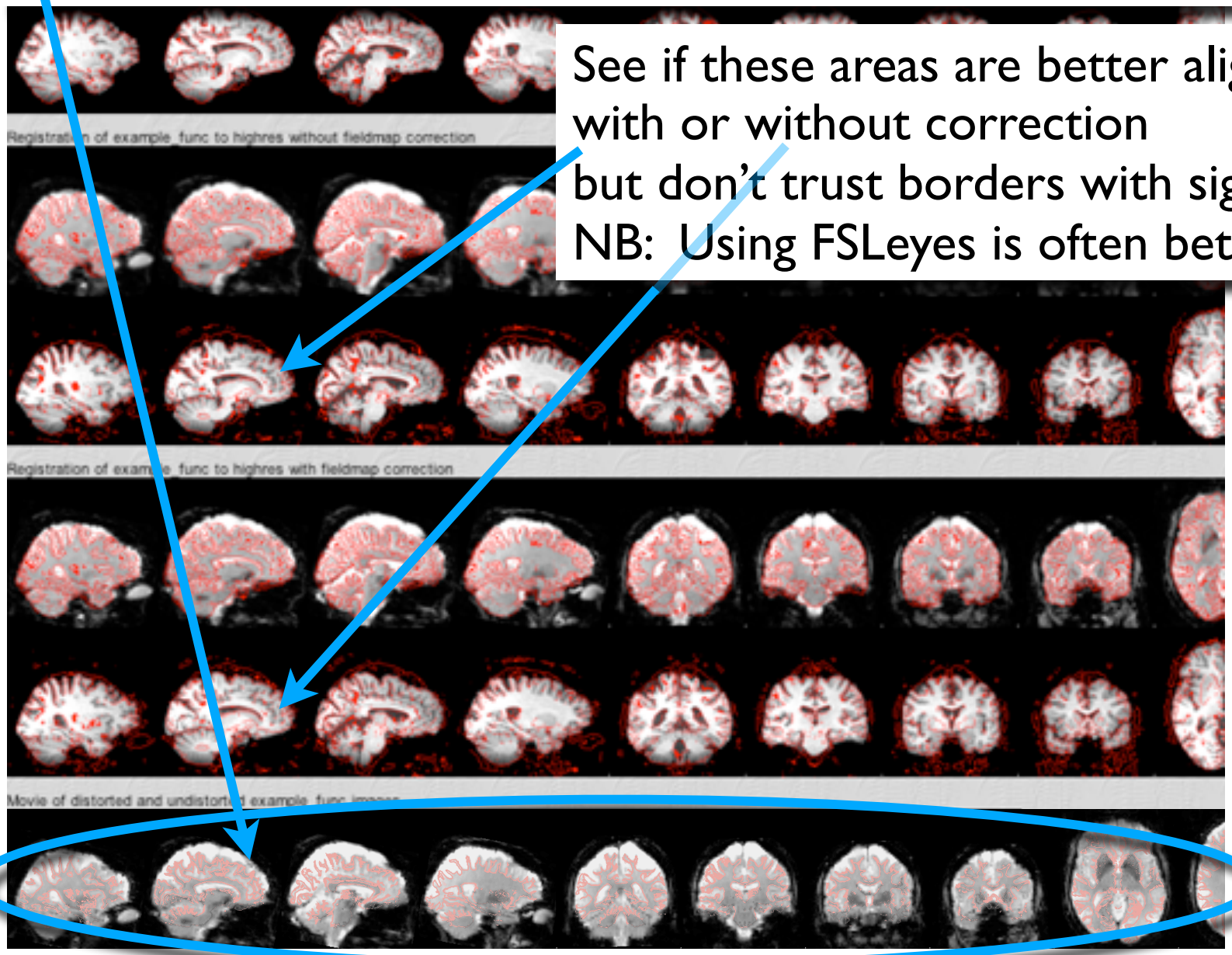
Functional (EPI) to highres (structural) - no correction

Functional (EPI) to highres (structural) - with fieldmap correction

Movie of EPI with and without correction

Fieldmap use in FEAT

Look for areas where unwarping (correction) changes brain shape



See if these areas are better aligned
with or without correction
but don't trust borders with signal loss areas
NB: Using FSLeyes is often better

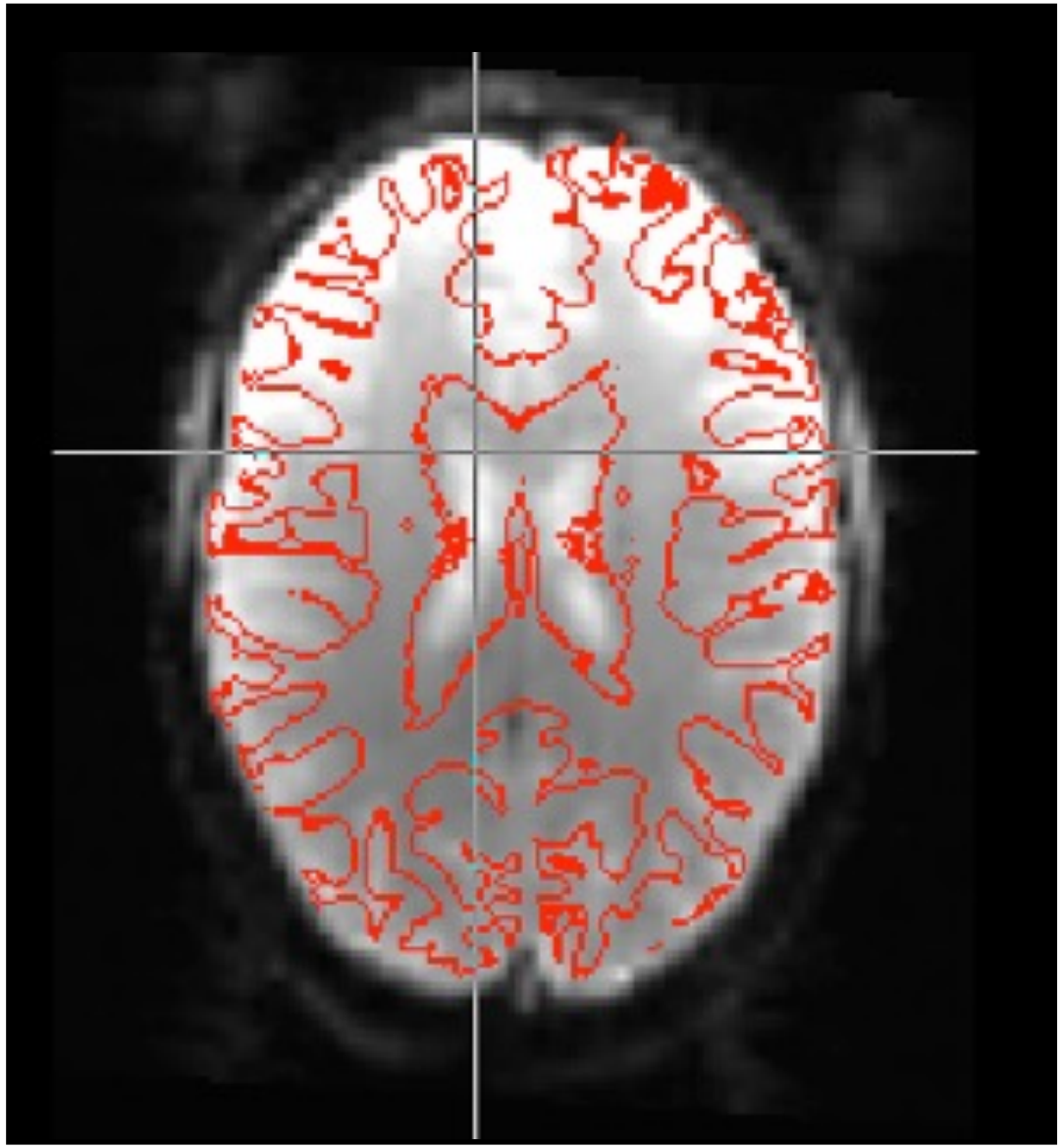
highres (structural)
- with fieldmap correction

Functional (EPI) to highres (structural)
- no correction

Movie of EPI with and without correction

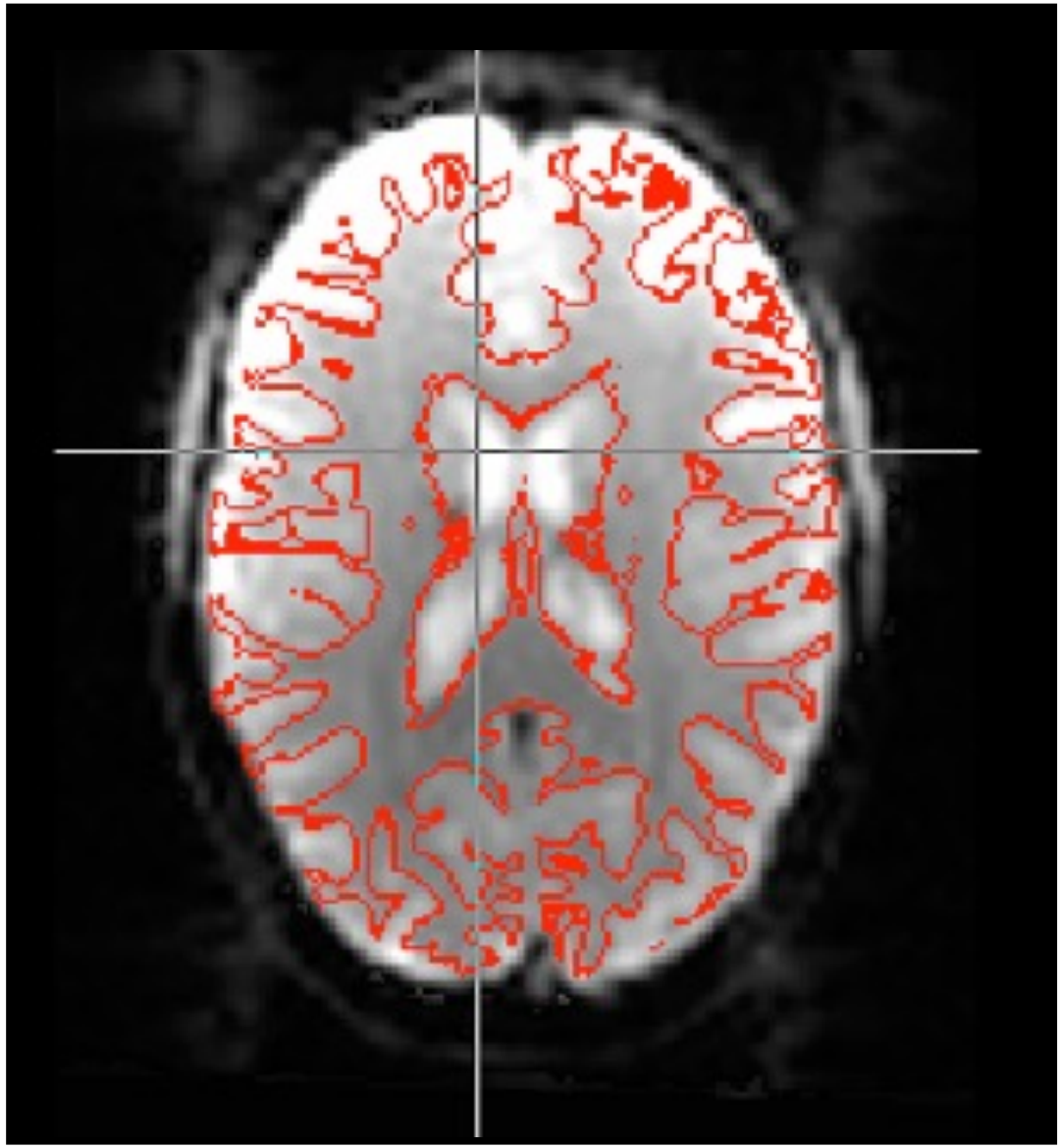
BBR and Fieldmaps

Standard FLIRT



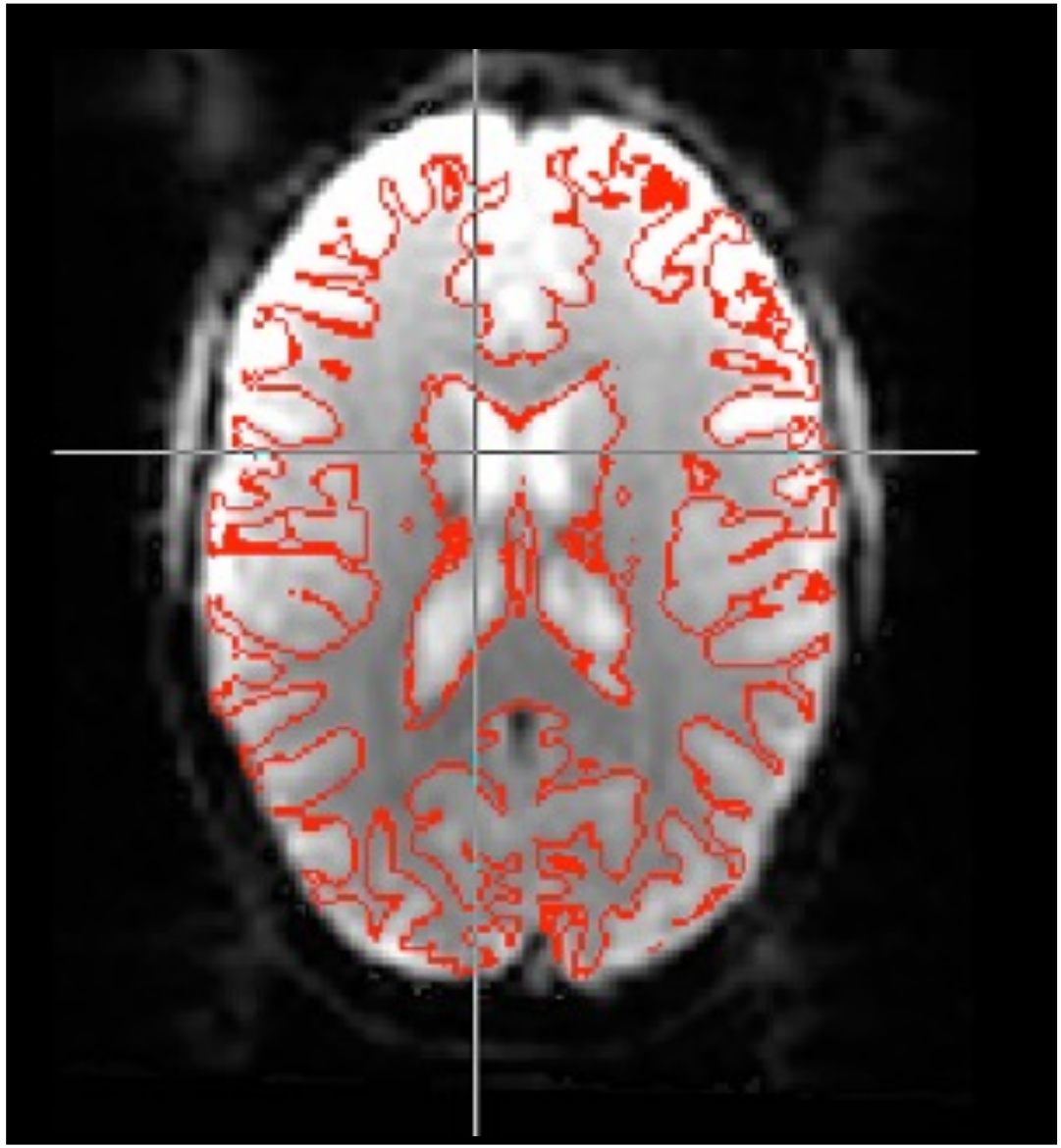
BBR and Fieldmaps

BBR FLIRT



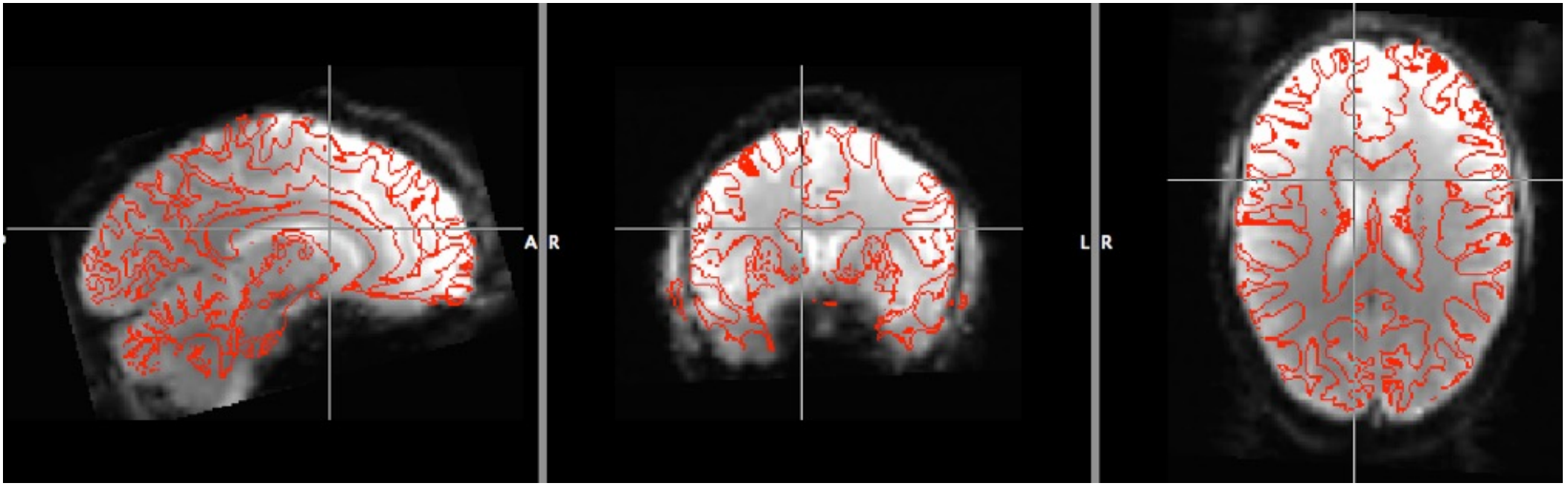
BBR and Fieldmaps

BBR FLIRT with Fieldmap



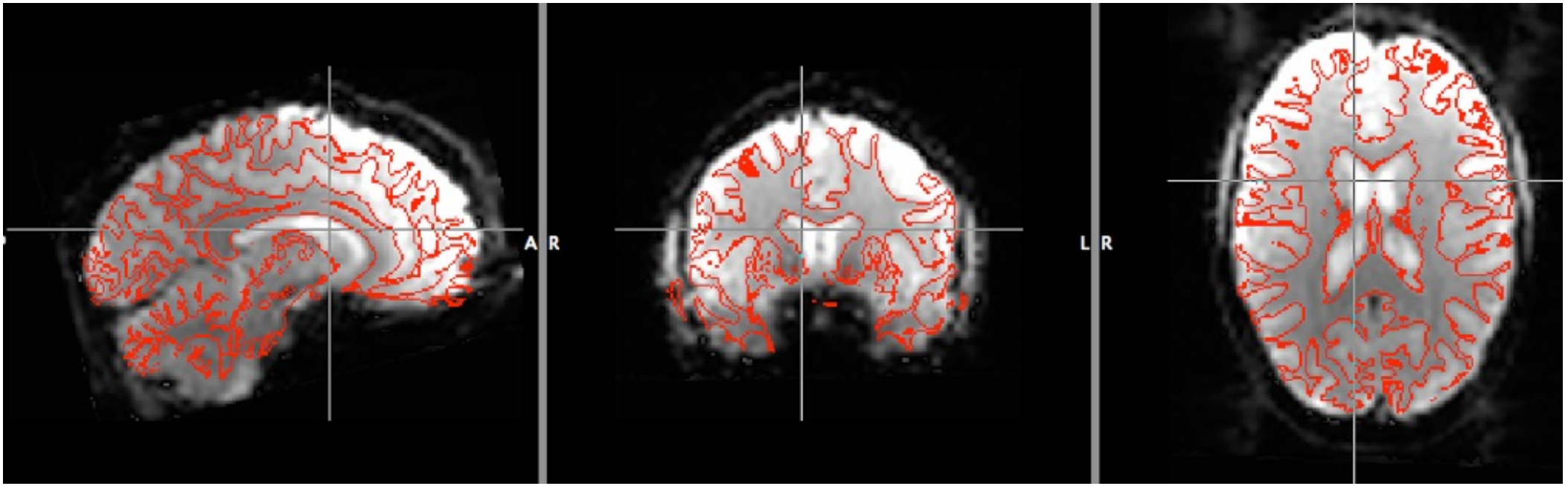
BBR and Fieldmaps

Standard FLIRT



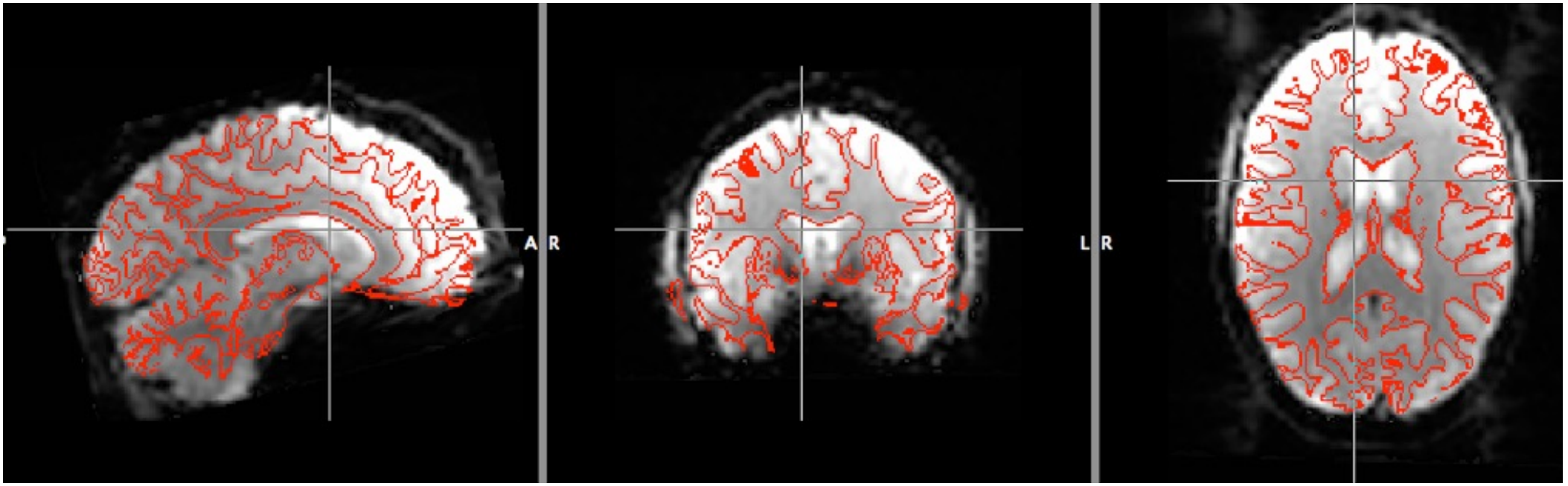
BBR and Fieldmaps

BBR FLIRT



BBR and Fieldmaps

BBR FLIRT with Fieldmap



Registration: EPI Distortion Correction and Registration

Summary:

- Geometric distortions and signal dropouts affect fMRI acquisitions (using EPI)
- We can correct for geometric distortions and take account of signal loss using fieldmaps
- BBR is the cost function used for EPI-structural registration with fieldmaps
- Look at results in typical areas of distortion (inferior frontal and temporal lobes)