Multi-Echo fMRI

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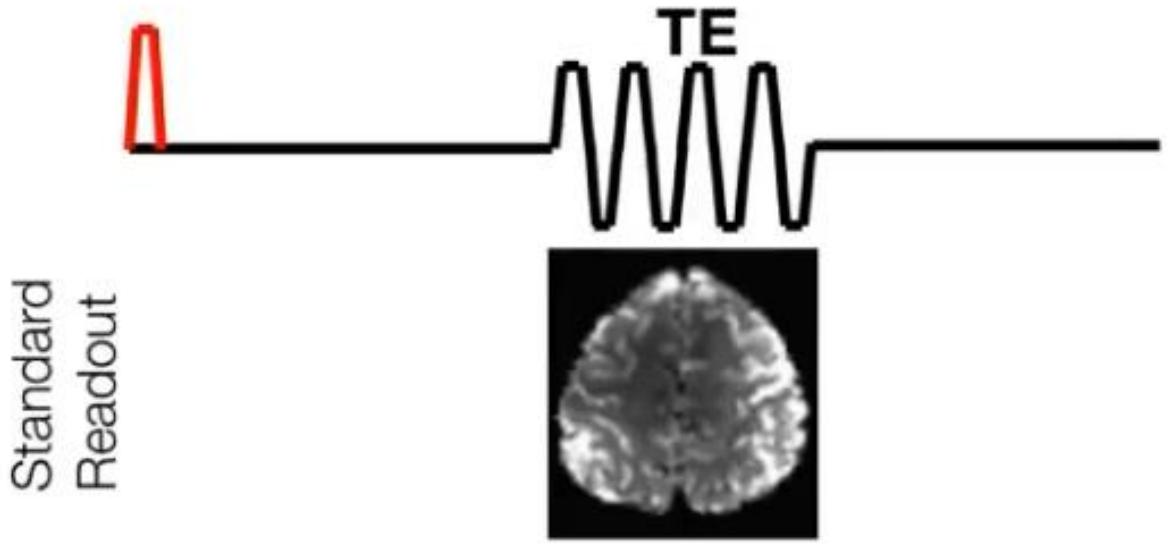
DBIC

Topics

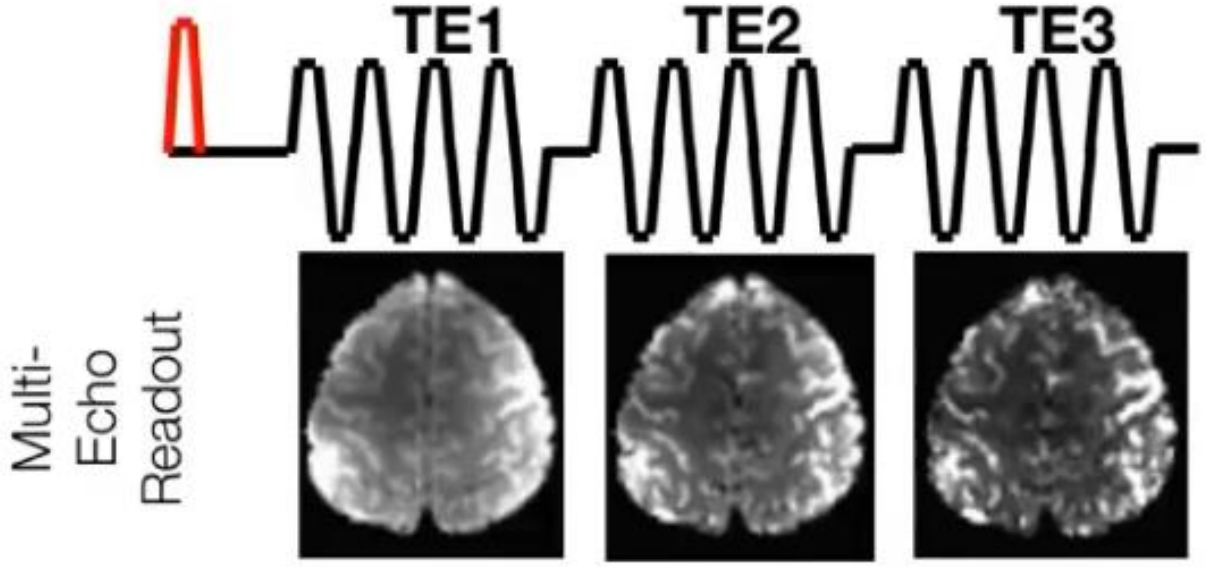
1. What and Why
2. How: Protocols and Data acquisitions
3. How: Data analysis

Section 1: **What and Why?**

Single Echo

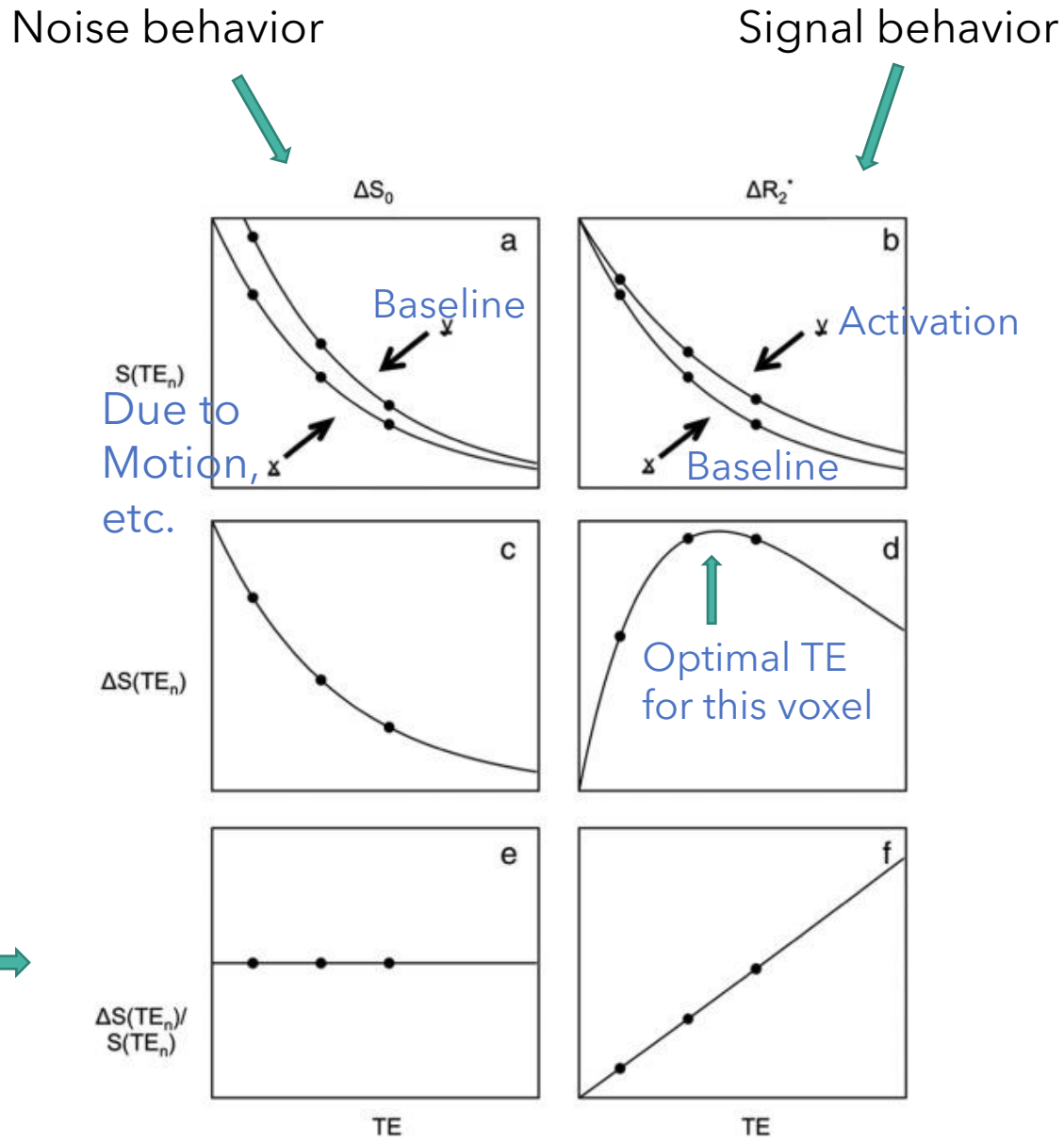


Multi Echo



Use already available information in T2* decay profile to enhance fMRI preprocessing and analysis

Signal has a linear relationship with TE. Noise is independent of the TE.



Compare results

1. Compare the results across the individual echoes.

Noise removal

2. fMRI signal contains bold as well as non- BOLD signals. Non-BOLD - Noise :- participant motion and breathing, e.t.c

Because the BOLD signal decays at a set rate, multiple echoes allow us to assess the non-BOLD signal.

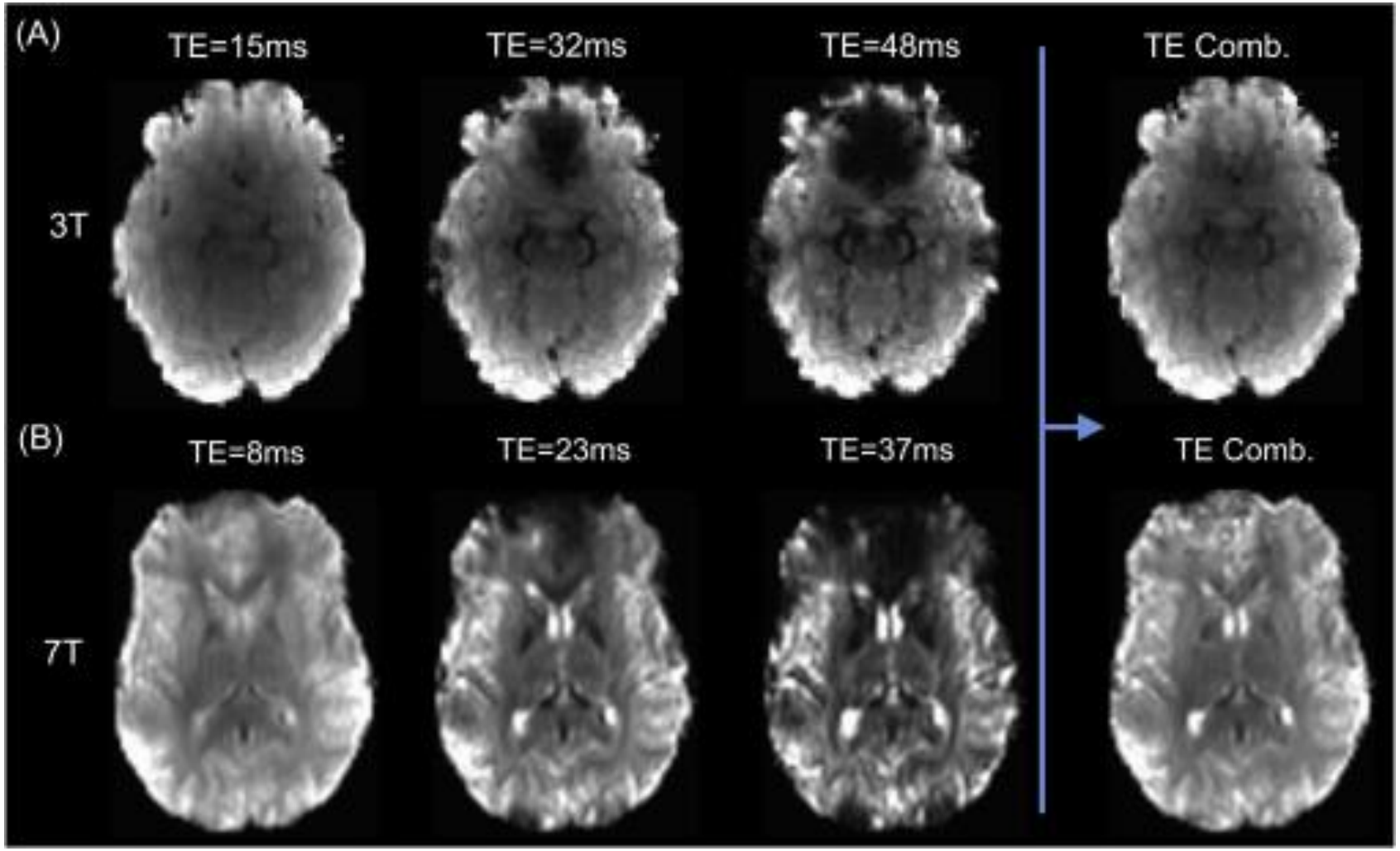
Optimal Combination

3. Combining the echoes to take advantage of the signal in the earlier echoes. Signal dropout due to T2* decay can be recovered in high susceptibility-gradients regions.

Optimal Combination

Not a difficult decision!

Vs.



Costs and benefits of multi-echo fMRI

1. Possible increase in TR - 10% longer TR for three echoes
2. Weighted averaging may lead to an increase in SNR

Software:
The optimal combination of echoes can currently be calculated in several software packages including **AFNI**, **fMRIPrep**, and **tedana**.

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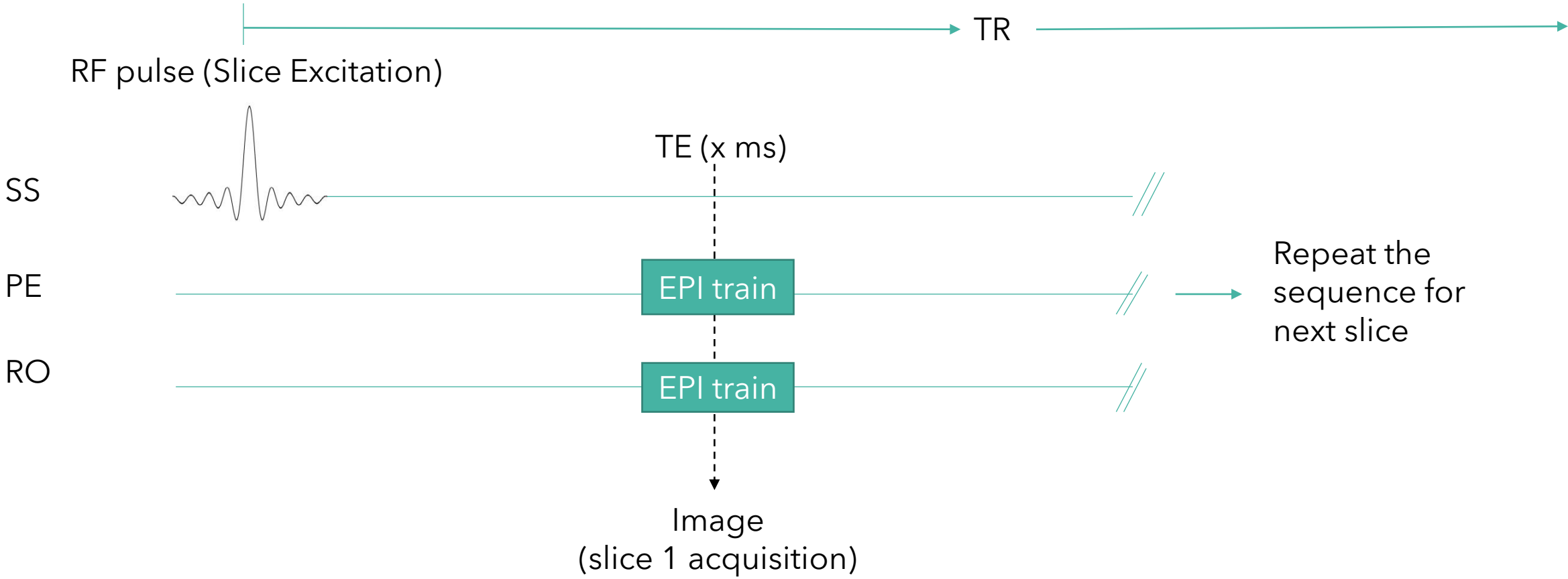
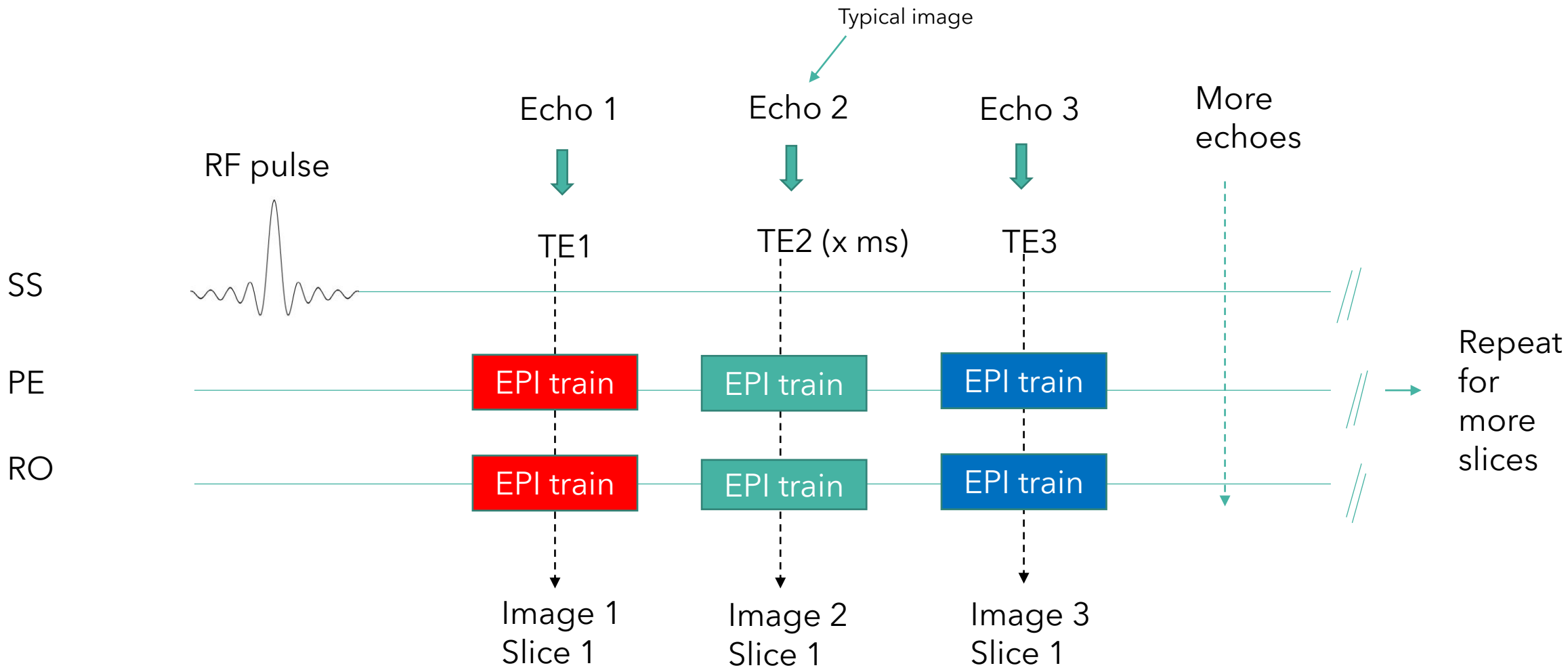
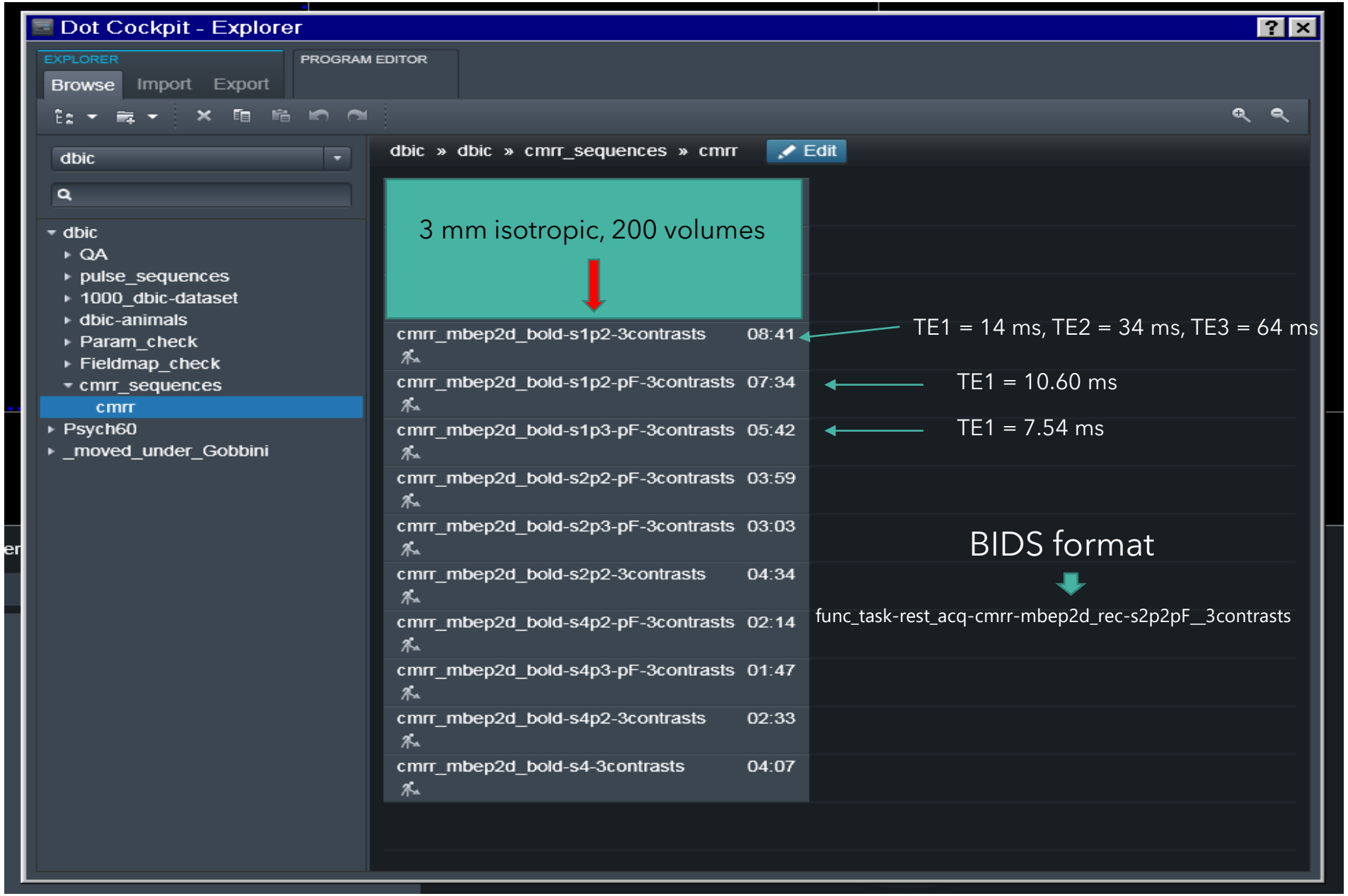
Section 2: **Single Echo vs Multi-Echoes and Acquisition**

Single Echo EPI Acquisition



Multi-Echo EPI





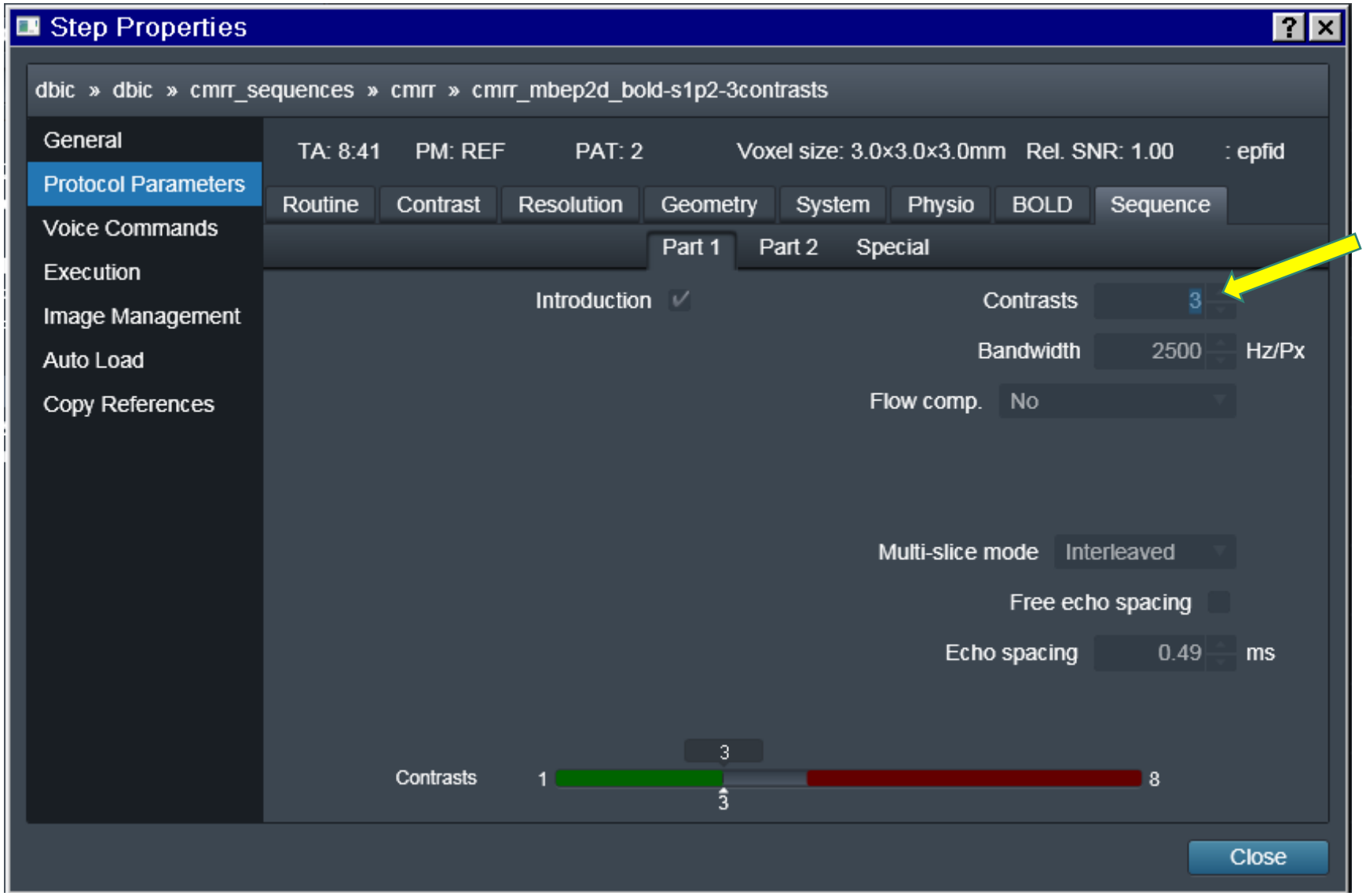
Home Built Protocols

S = MB (sms) factor
P = GRAPPA factor
pF = Partial Fourier

Start building your protocol from one these!

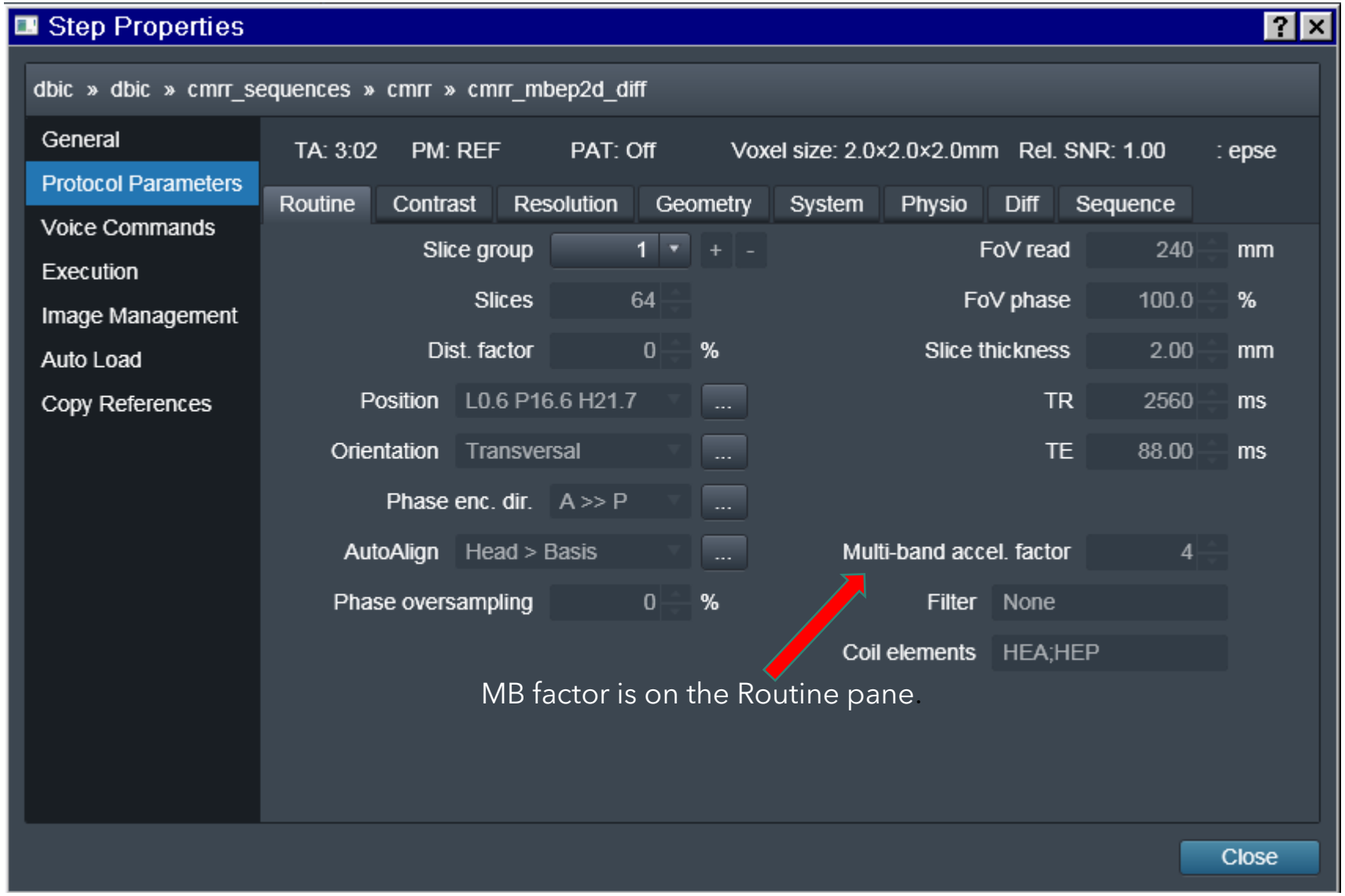
Rename according to BIDS convention. If you don't, you will have a tough time running fMRIprep.

CMRR multi-band EPI pulse sequence:

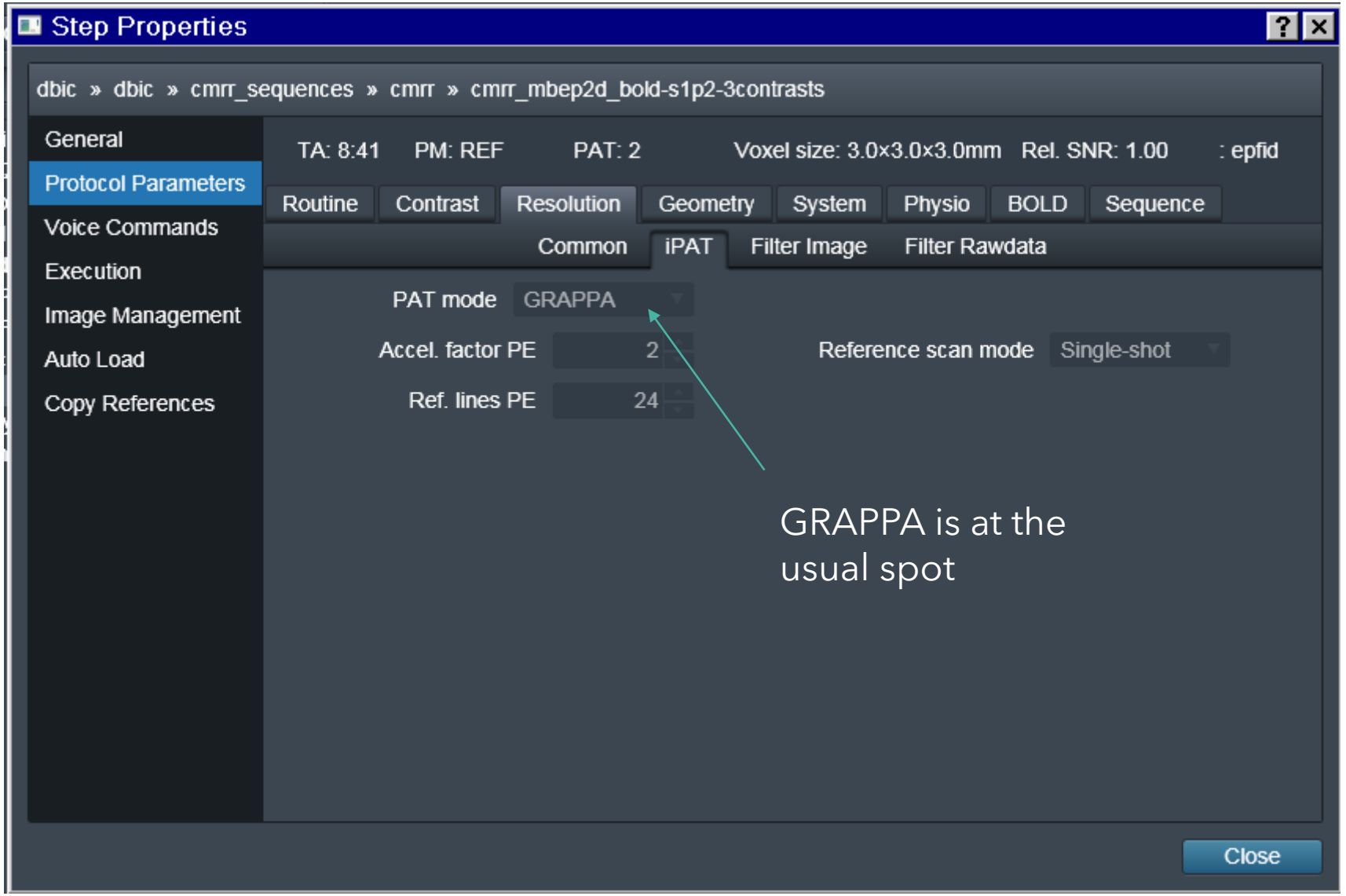


Multi-echo factor

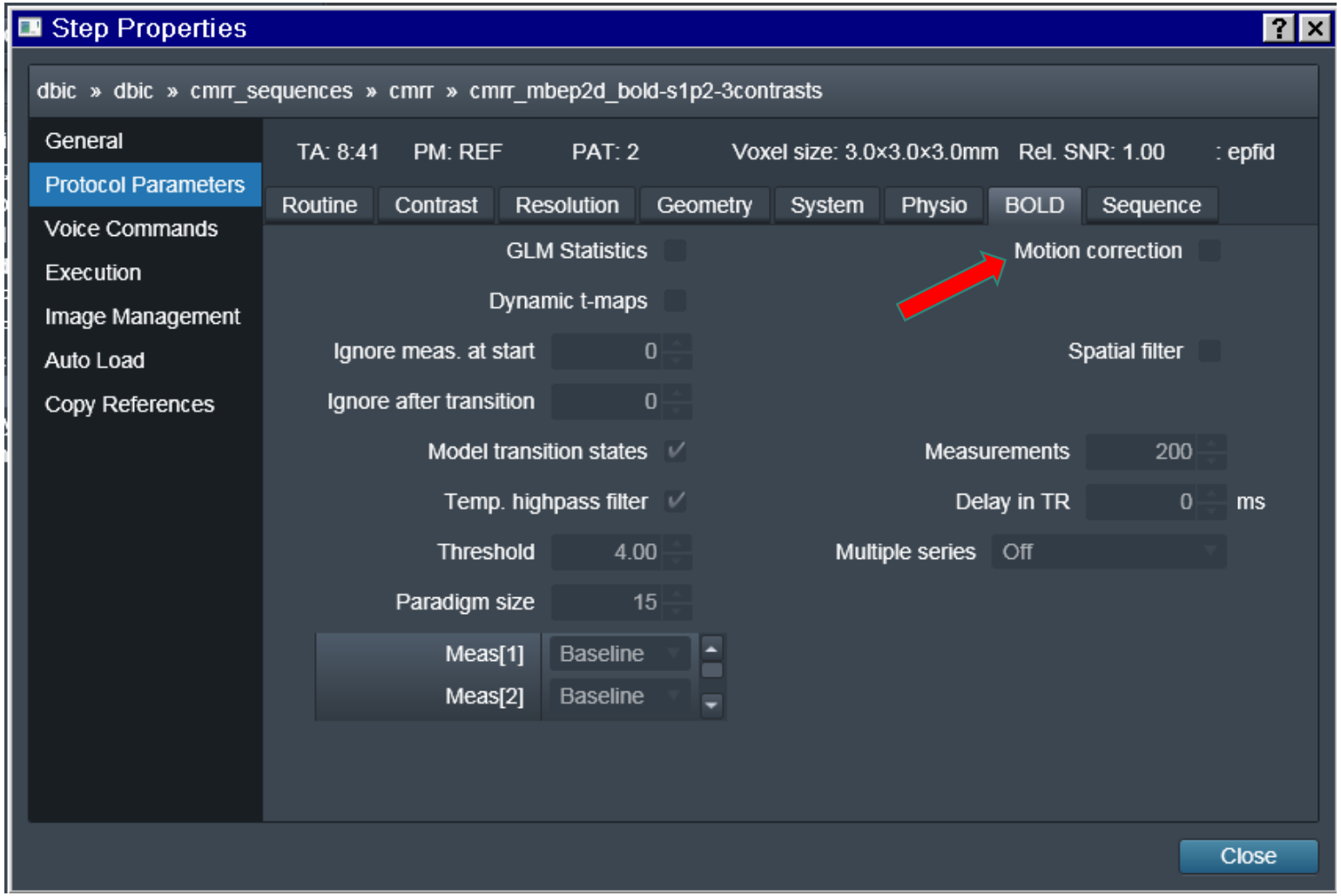
CMRR multi-band EPI pulse sequences:



Choosing GRAPPA



No motion correction with multi-echo data !



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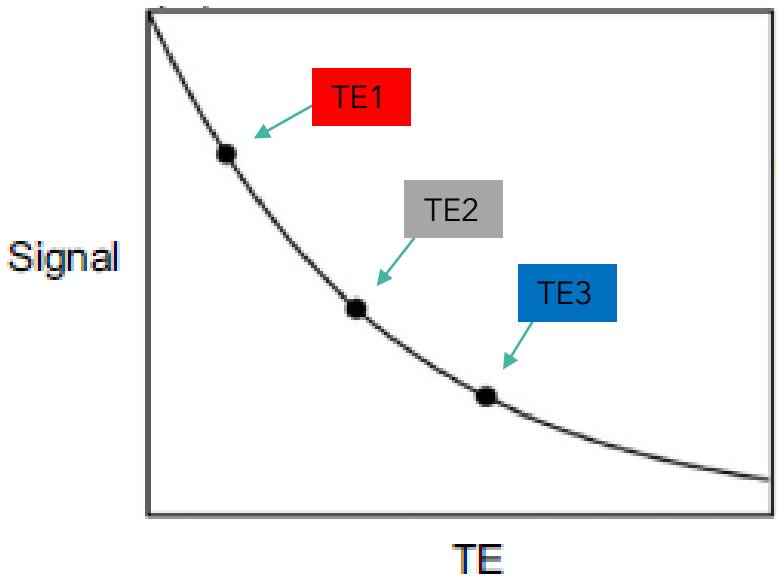
Section 3: **ANALYSIS**

1. Optimal Combination
2. Deniosing

Optimal Combination

Experimental data

T_2* Decay



Voxel wise Fitting

Theoretical relationship

$$S(TE) = S_0 \exp(-TE/T_2^*)$$

Acquired Signal (per voxel)

Baseline Signal

Spin-spin (transverse) relaxation time

**T_2* **

T_2* map

Weighted/optimal combination

$$w(T_2^*)_n = \frac{TE_n \cdot \exp(-TE/T_{2(\text{est})}^*)}{\sum_n TE_n \cdot \exp(-TE/T_{2(\text{est})}^*)}$$

- BOLD effects modulate T_2*
  - -Activation increases T_2*
- Artifactual fluctuations modulate S_0
  - -Artifacts affect base signal, and not much effect on T_2*

Optimal Combination: fMRIPrep

BIDS layout of the dataset

```
me_bids/
├── CHANGES
├── dataset_description.json
├── README
└── sub-01
    ├── anat
    │   ├── sub-01_acq-MPRAGE_T1w.json
    │   └── sub-01_acq-MPRAGE_T1w.nii
    ├── func
    │   ├── sub-01_task-rest_run-1_echo-1_bold.json
    │   ├── sub-01_task-rest_run-1_echo-1_bold.nii
    │   ├── sub-01_task-rest_run-1_echo-2_bold.json
    │   ├── sub-01_task-rest_run-1_echo-2_bold.nii
    │   ├── sub-01_task-rest_run-1_echo-3_bold.json
    │   └── sub-01_task-rest_run-1_echo-3_bold.nii
    └── sub-01_scans.tsv
```

fmriprep_run.sh

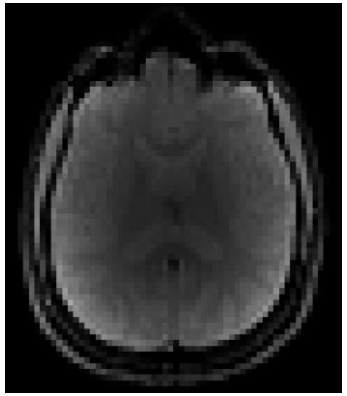
```
#!/bin/bash

singularity run --cleanenv
/home/kodiweera/my_images/fmriprep-20.2.3.sif \
--participant_label sub-01 \
--bold2t1w-dof 9 \
--dummy-scans 3 \
--use-aroma \
--dummy-scans 3 \
--fs-license-file
/home/kodiweera/data/freesurfer_license.txt \
/home/kodiweera/data/multi_echo/me_bids
/home/kodiweera/data/multi_echo/out participant -w
/home/kodiweera/data/multi_echo/work
```

Extraction from fMRIPrep-method report

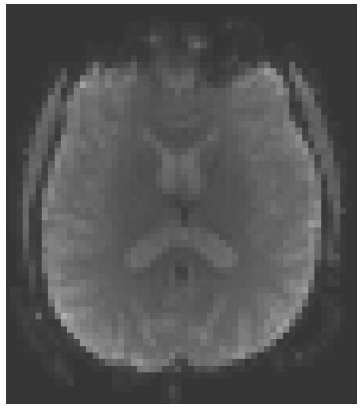
A T2* map was estimated from the preprocessed BOLD by fitting to a monoexponential signal decay model with nonlinear regression, using T2*/S0 estimates from a log-linear regression fit as initial values. For each voxel, the maximal number of echoes with reliable signal in that voxel were used to fit the model. The calculated T2* map was then used to optimally combine preprocessed BOLD across echoes following the method described in (Posse et al. 1999). **The optimally combined time series was carried forward as the preprocessed BOLD**.

Protocol: s1p2; 200 volumes; 3 mm isotropic

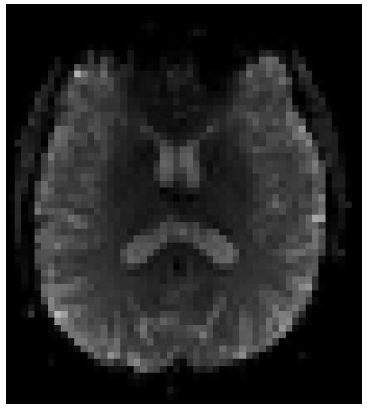
TE1 (TE = 14 ms)

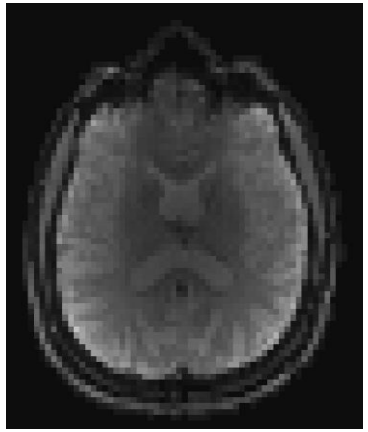


TE2 (TE = 34 ms)



TE3 (TE = 64 ms)





← Enhanced SNR

Denoising

Installation: **pip install tedana**

https://tedana.readthedocs.io/en/stable/installation.html

Running a dataset:

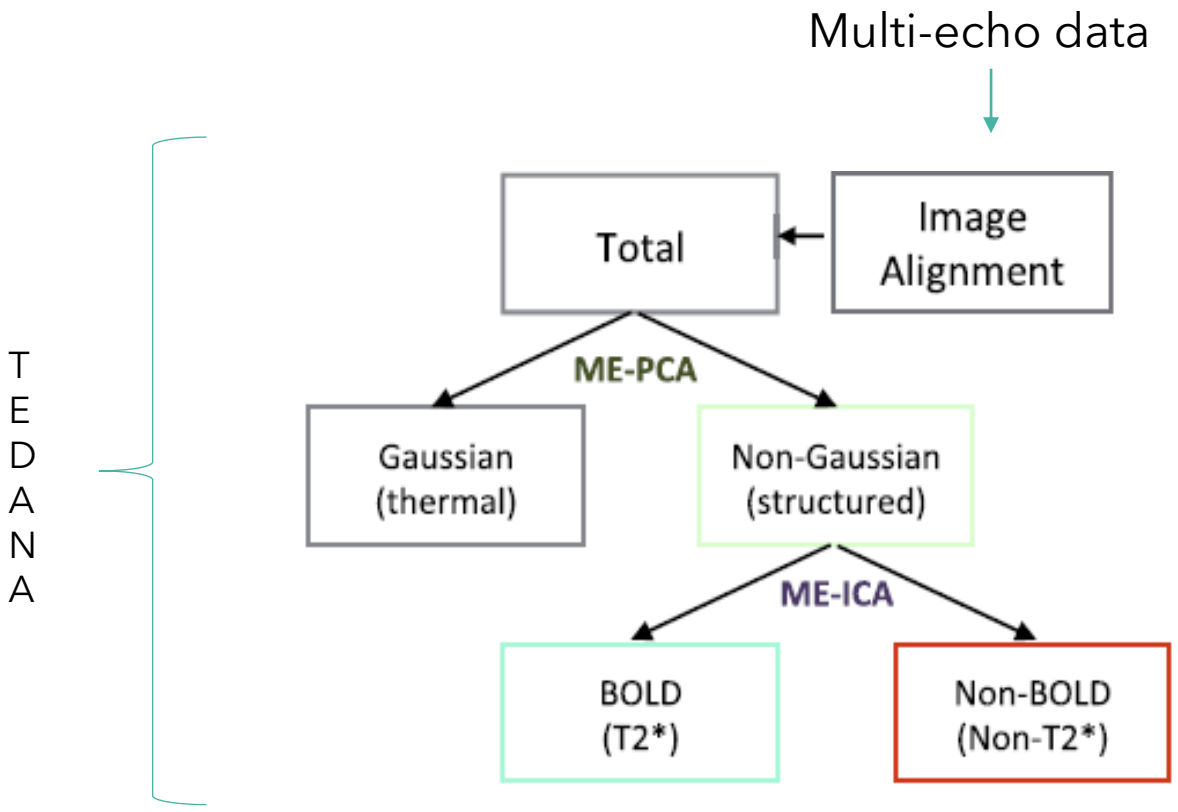
This is my command →

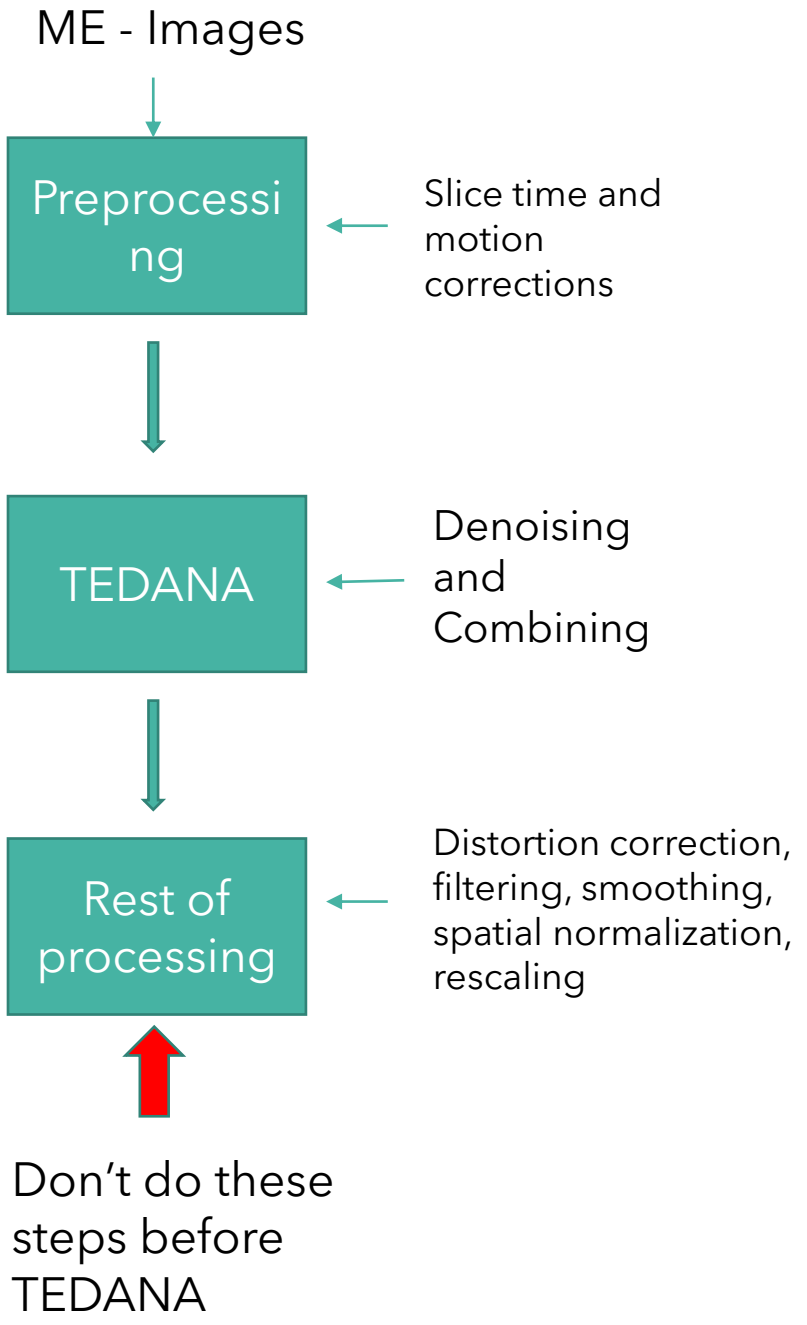
tedana **-d** *sub-01_task-rest_run-1_echo-1_bold.nii sub-01_task-rest_run-1_echo-2_bold.nii sub-01_task-rest_run-1_echo-3_bold.nii* **-e** *14 34 64* **--out-dir** */home/kodiweera/data/multi-echo/tedana_out*

-d *sub-01_task-rest_run-1_echo-1_bold.nii*
sub-01_task-rest_run-1_echo-2_bold.nii
sub-01_task-rest_run-1_echo-3_bold.nii

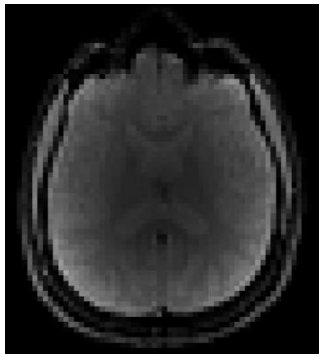
-e *14 34 64*

--out-dir */home/kodiweera/data/multi-echo/tedana_out*


Multi-echo data
TEDANA
Total
Image Alignment
ME-PCA
Gaussian (thermal)
Non-Gaussian (structured)
ME-ICA
BOLD (T2*)
Non-BOLD (Non-T2*)

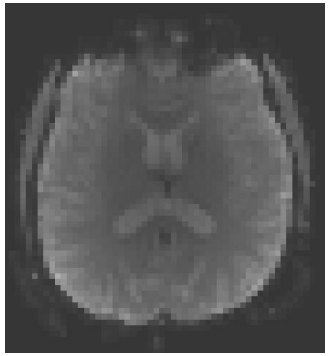

ME - Images
Preprocessing
Slice time and motion corrections
TEDANA
Denoising and Combining
Rest of processing
Distortion correction, filtering, smoothing, spatial normalization, rescaling
Don't do these steps before TEDANA

TE1



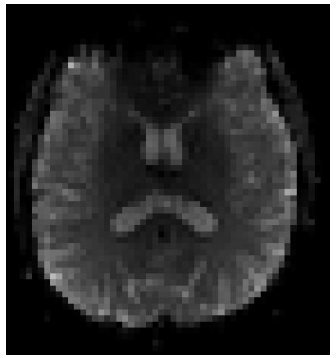
ME-ICA components (199)

TE2



ME-ICA components (199)

TE3



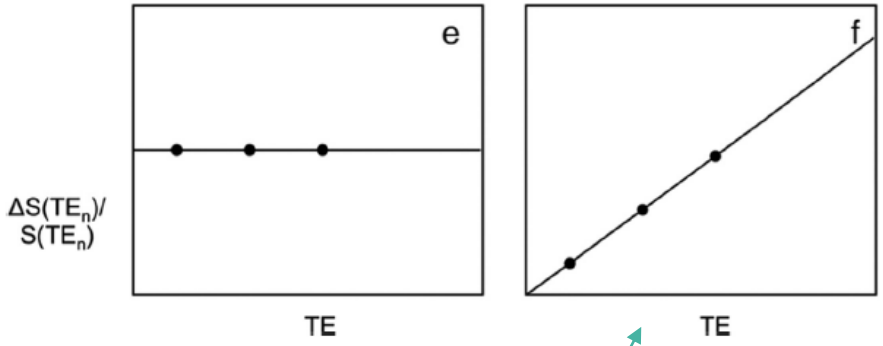
ME-ICA components (199)

Classify the ICA components as signal and noise

Classify these components as noise

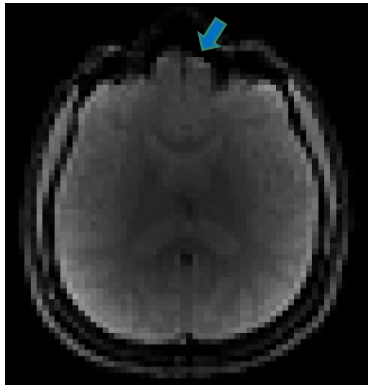
noise

signal

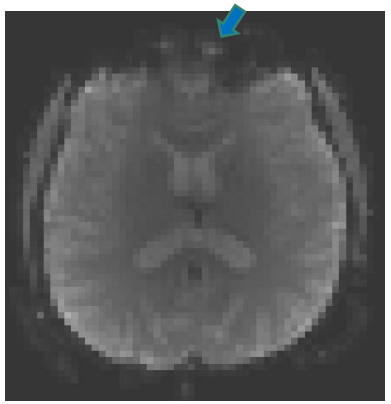


Classify as signal and combine these components to produce de-noised image.

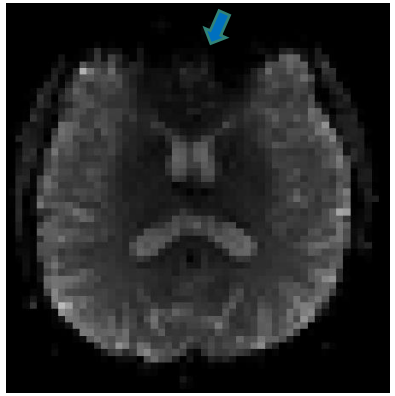
TE1



TE2

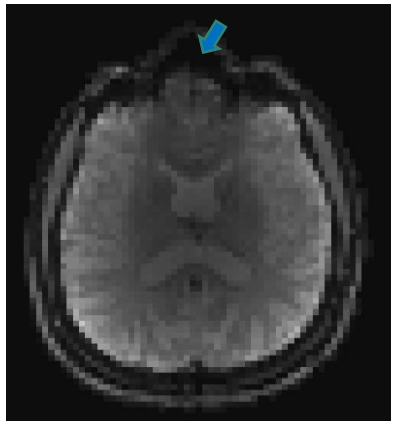


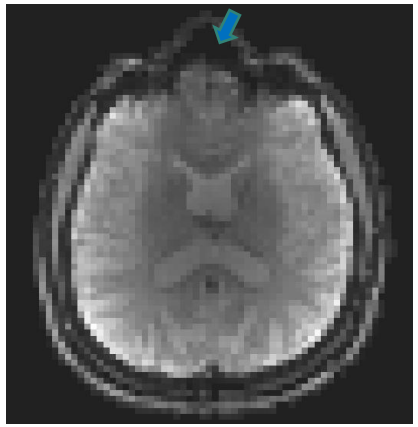
TE3



Optimally Combined

fMRIprep

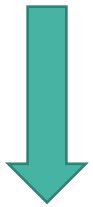




Denoised and optimally combined

TEDANA

Your Resource



https://tedana.readthedocs.io/en/stable/index.html

TEDANA output files ⟶ **https://tedana.readthedocs.io/en/stable/outputs.html**

From TEDANA website:

> *"If a data set is expected to be used for future analyses in later years, it is likely that more powerful approaches to multi-echo denoising will sufficiently mature and add even more value to a data set."*

That's enough of multi-echo fMRI !