# CHRONUX functions for signal conditioning: removing slow fluctuations

## locdetrend

remove running line fit (using local linear regression)- continuous processes

usage: data=**locdetrend**(data,Fs,movingwin)

*Note that units of Fs, movingwin have to be consistent. If Fs in Hz, movingwin in secs.*

- data (data as a matrix times x channels or a single vector)
- Fs (sampling frequency) - optional. Default 1
- movingwin (length of moving window, and stepsize) [window winstep] - optional.

Default. window=full length of data (global detrend).

winstep=window -- global detrend

- output data: (locally detrended data)

# CHRONUX functions for signal conditioning: removing line elements (eg. 60 Hz)

## **rmlinesc**

removes significant sine waves from data (continuous data).

usage: data=**rmlinesc**(data,params,p,plt,f0)

- data (data as a matrix times x channels or a single vector)
- params structure containing parameters - has the following fields: tapers, Fs, fpass, pad.

*Note that units of Fs, fpass have to be consistent (eg. Hz)*

tapers: parameters for calculating Slepian tapers, NΔtW and K, the number of tapers.

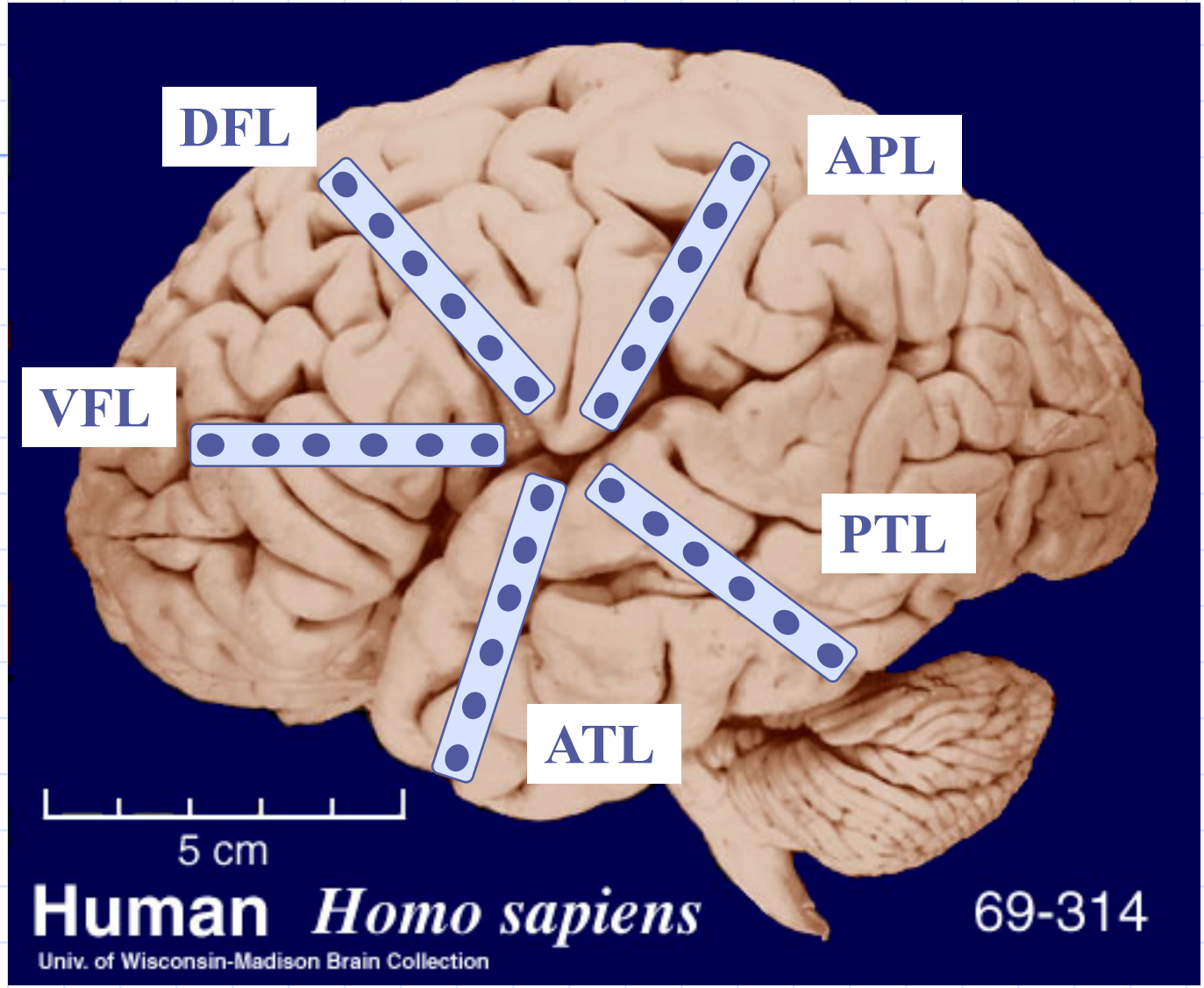
fpass: frequency band to be used

pad: padding factor for the FFT

p: p-value for F-test

f0: frequencies of lines to be removed if unspecified the F statistic is used to determine the appropriate lines for removal

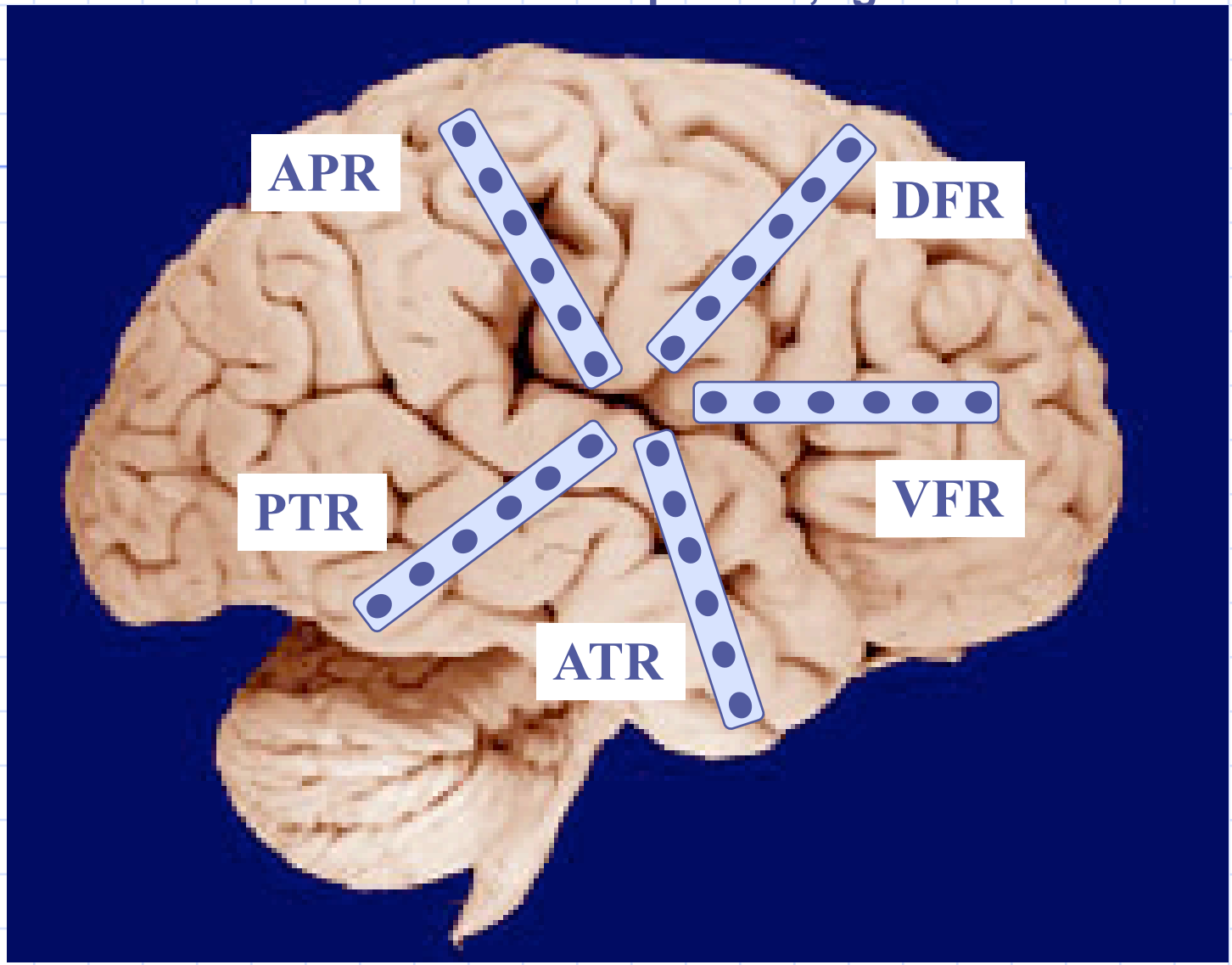
DFL=dorsal-frontal,left VFL=ventral-frontal,left
APL=anterior-parietal,left




ATL=anterior-temporal,left PTL=posterior-temporal,left

MTL=medial-temporal,left (not-shown, depth electrodes)

DFR=dorsal-frontal,right VFR=ventral-frontal,right
APR=anterior-parietal,right




ATR=anterior-temporal,right PTR=posterior-temporal,right

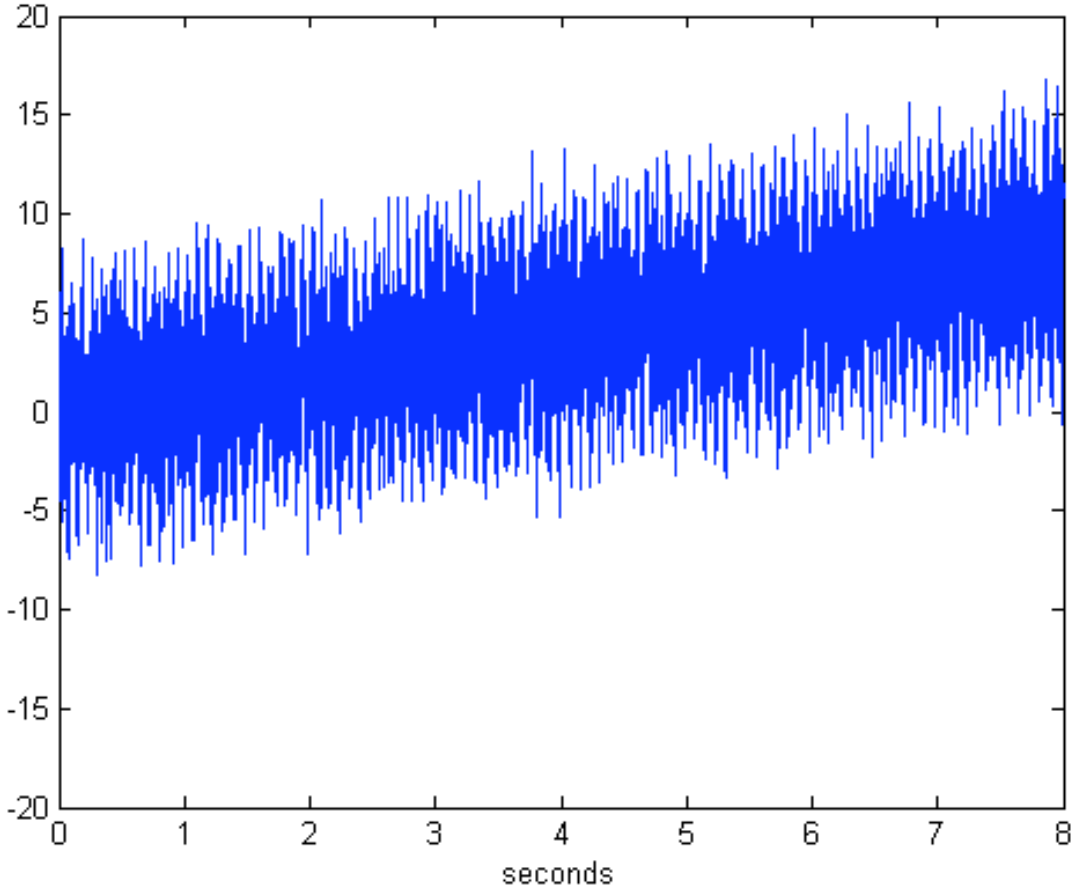
MTR=medial-temporal,right (not-shown, depth electrodes)

# Human Electrocorticography (EcoG)

- Recordings obtained from a patient with intractable epilepsy undergoing evaluation for surgery (all procedures involving patients were approved by the IRB of the Weill Medical College of Cornell University, NYC).
- 60 electrodes are located on the surface of the cortex, under the dura: 6 electrodes/strip, 5 strips/ hemisphere. In addition, 16 depth electrodes (wires) are located in the middle-temporal lobe (8 wires/ hemisphere).
- Recordings made while the patient performed a simple maze navigation task.
- Sampling Rate: 500 Hz
- Sample Duration: 8 seconds

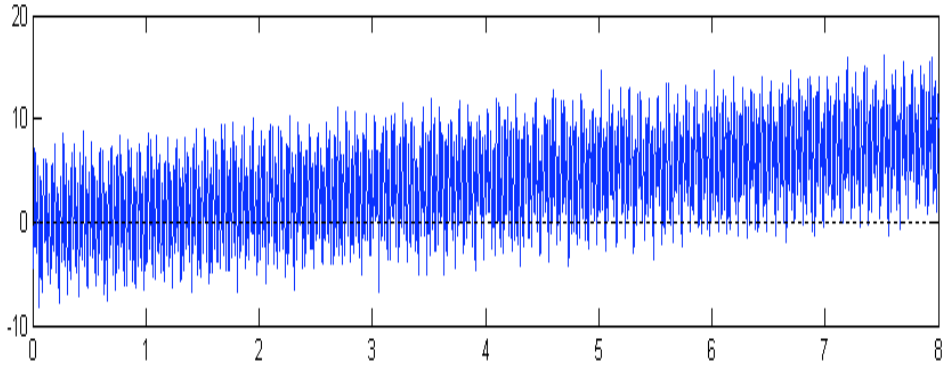
# Human Electrocorticography (EcoG): Problems when recording at bedside.

- 60 Hz line noise (50 Hz in Europe).
- Capacitative and inductive coupling to the alternating current used in the power distribution supplying the hospital room, OR, laboratory. Sources: room lighting, TVs, other medical equipment.
- Slow drifts in baseline voltage. Electrostatic charge distributions change as patient moves in the hospital bed.
- Transient voltage spikes generated by capacitative discharge of electrostatic charges built up around patient.
- Heart EKG, chest movements.

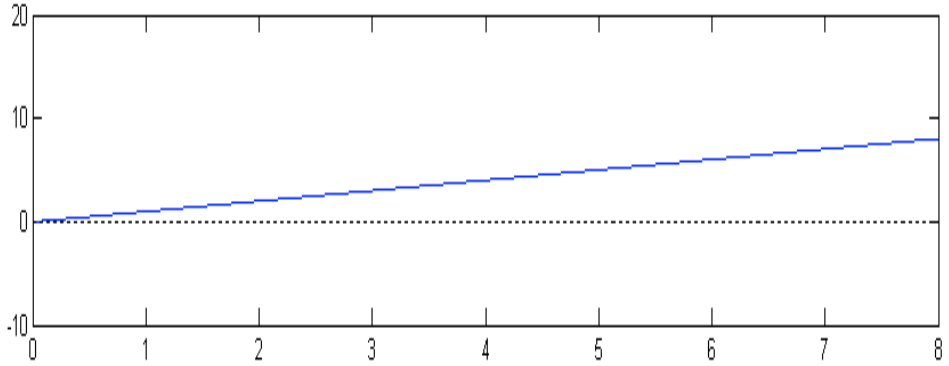



S=2*sin(2*pi*12*t)-5*sin(2*pi*40*t)+normrnd(0,1,[1 4000])+t

N=4000  Fs=500 Hz  t=(1:N)/Fs

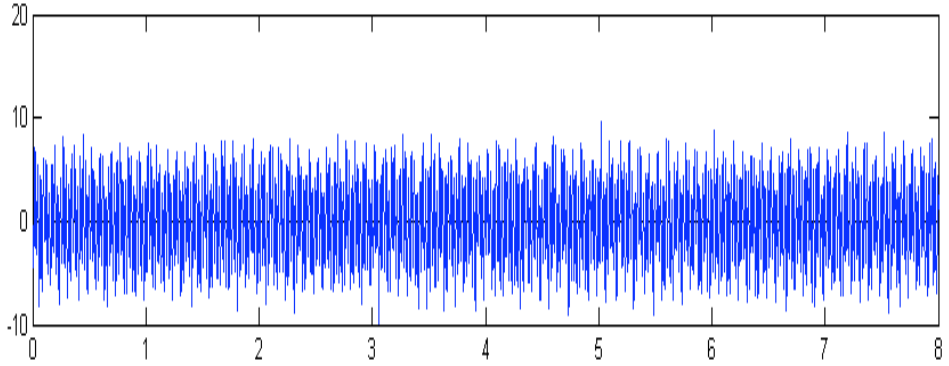



S(t)

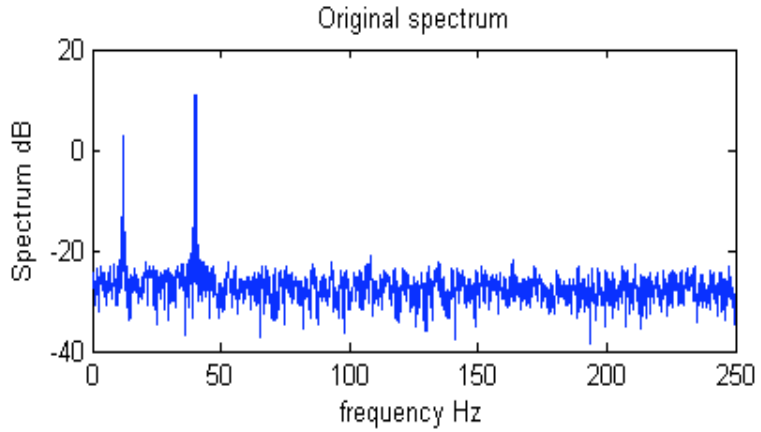


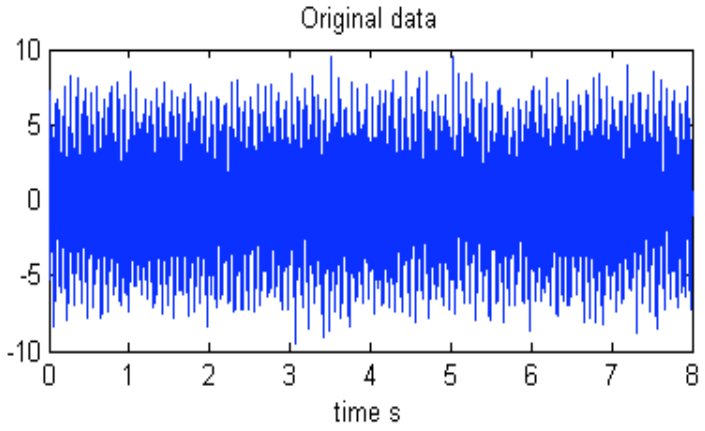

S(t)-LDs(t) where

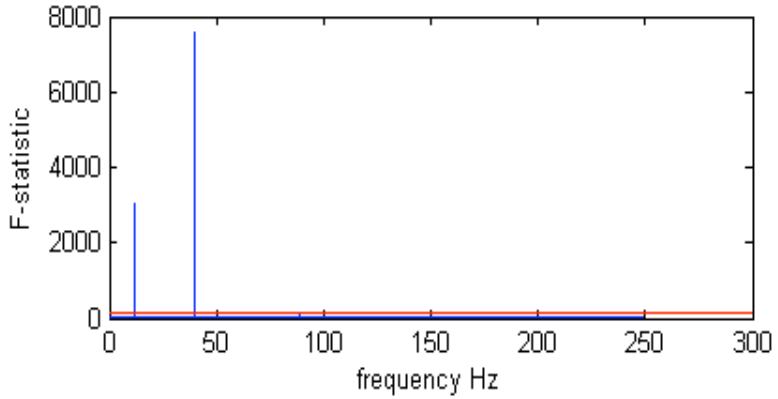
LDs(t)=locdetrend(S(t),Fs)

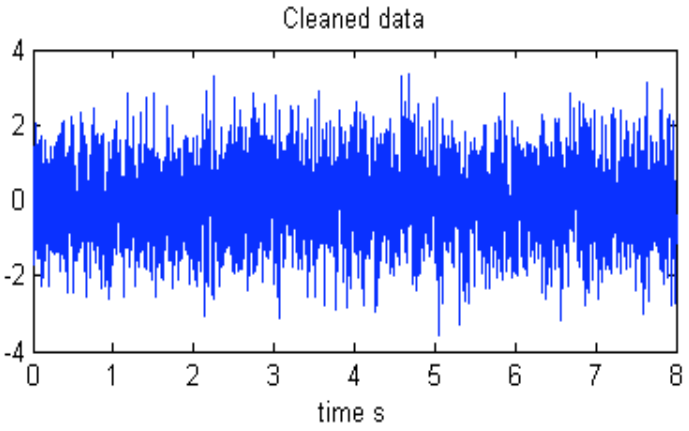


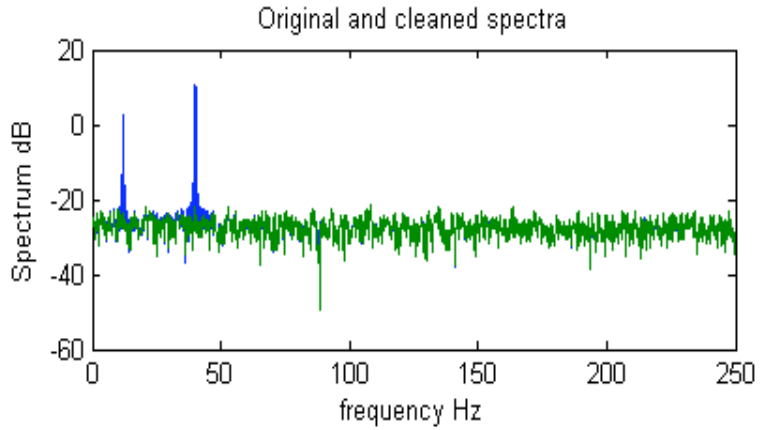

LDs(t)




```
rmlinesc(LDs,params,.05,'y');
Ktapers=4;  NW=(Ktapers+1)/2;
params.tapers = [NW Ktapers];
params.pad = 5;    params.Fs = 500;
params.fpass = [0 params.Fs/2];
```

# Alternative Approach for Signal Conditioning

- Combine SVD with spectral analysis
- Look for the subspace that does not contain noise and major artifacts
- Reconstruct a set of signals from the subspace for further analysis

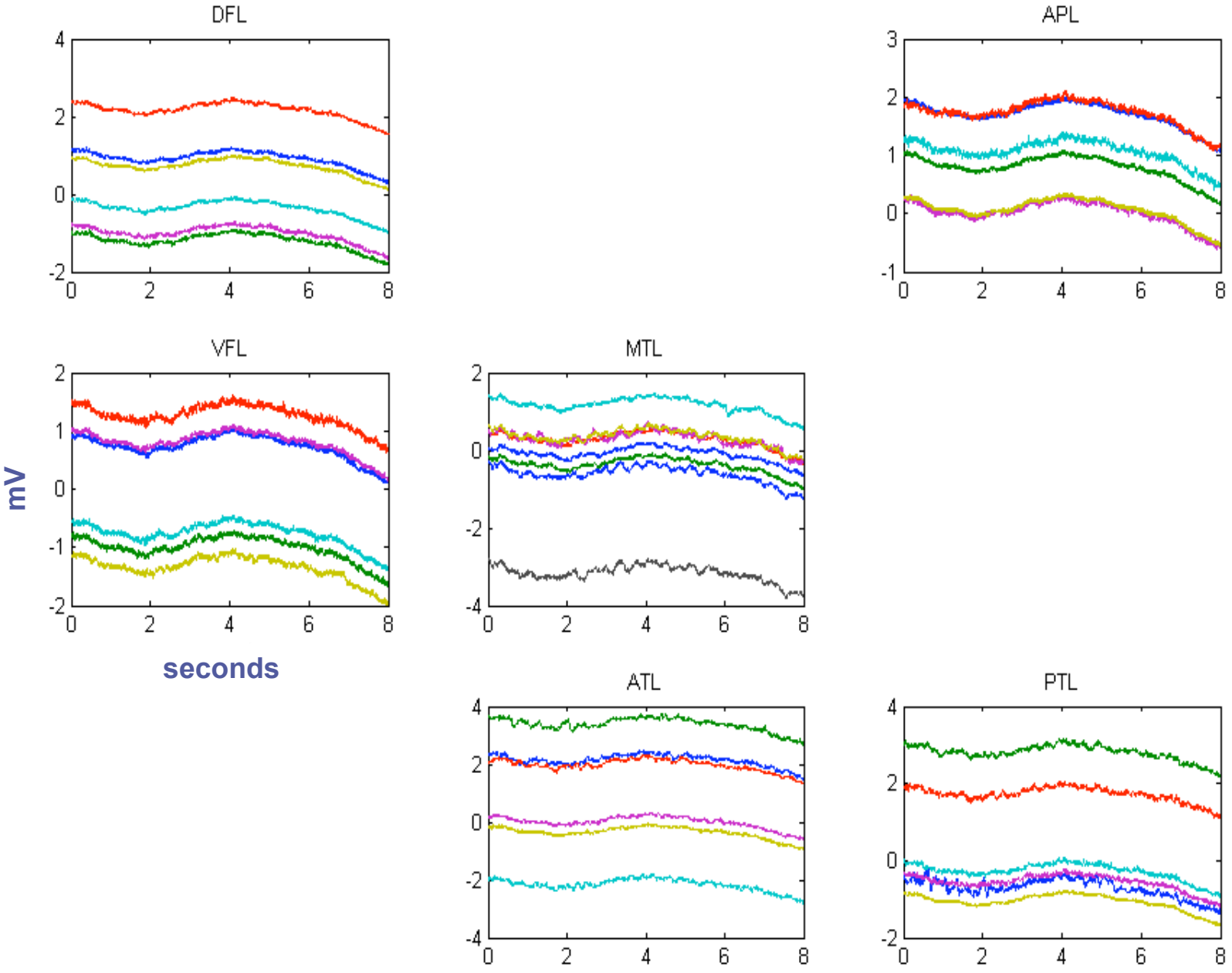
- >> **EcoG**

Loads EcoG_dataV6.mat
*should be compatible with all versions of MATLAB, 6 and above*

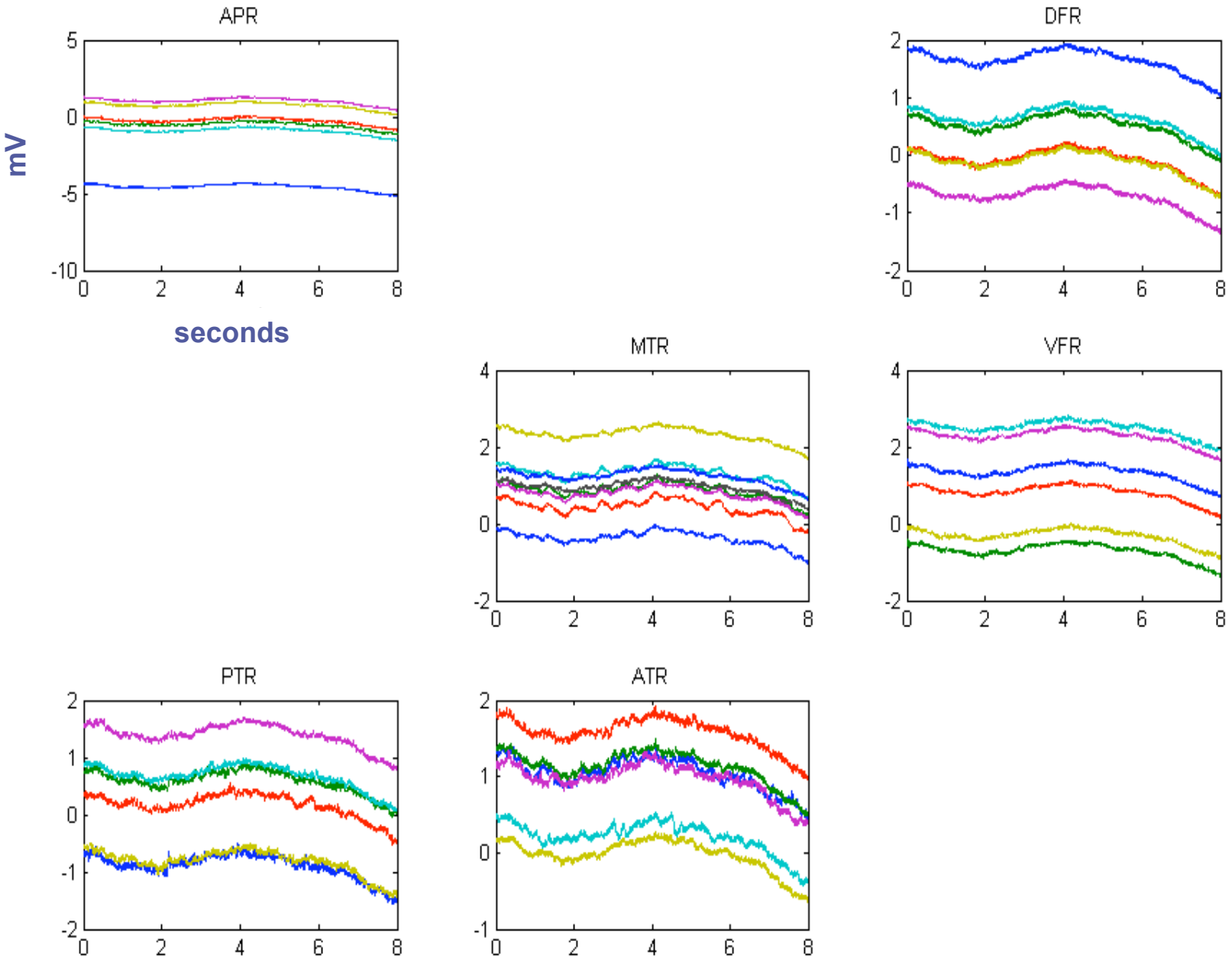
Defines variables: ATR, ATL, PTR, PRL, DFL, DFR, etc.

Generates two figures: 1) voltage traces for all channels from left hemisphere; 2) same for right hemisphere.

8 seconds of data shown



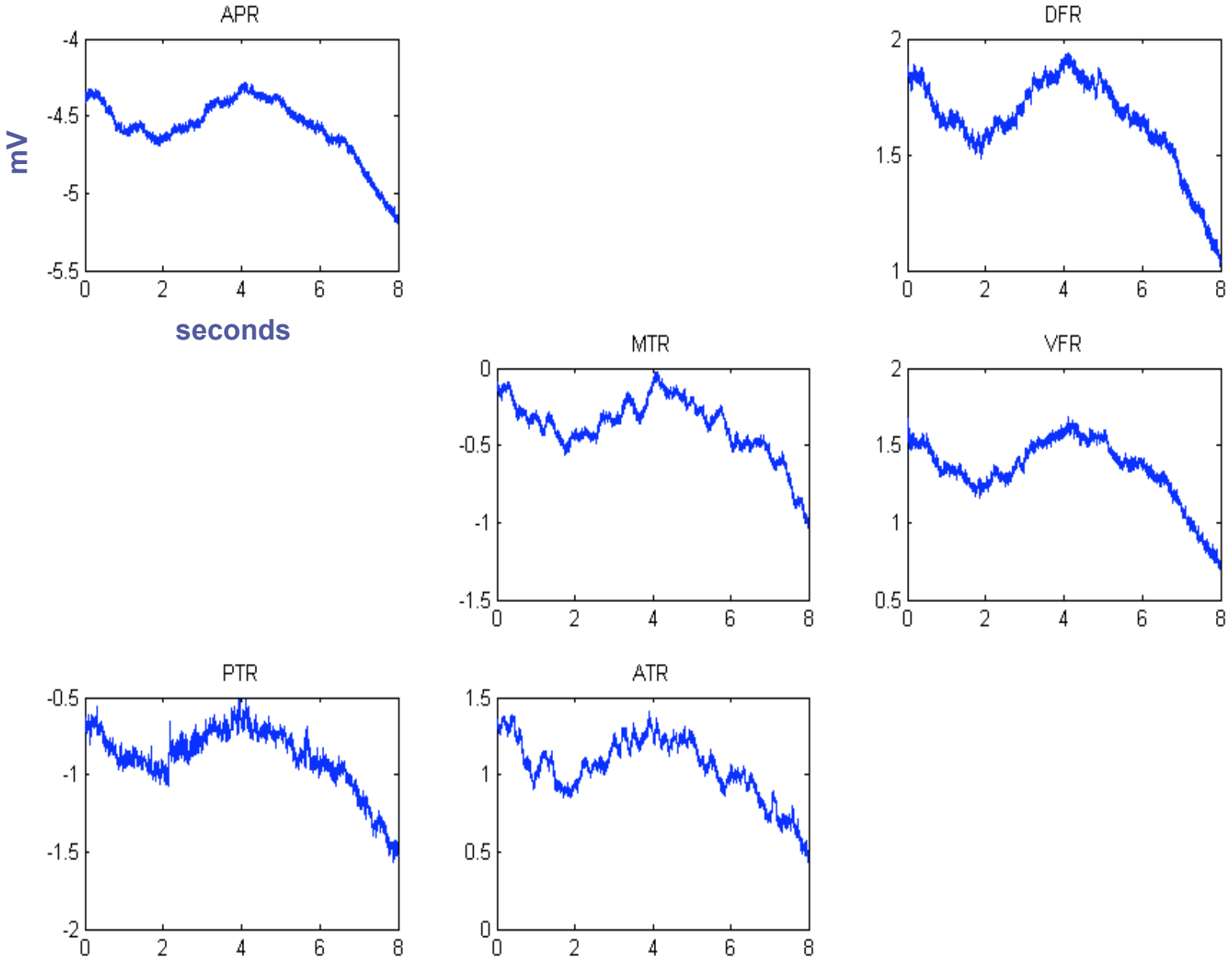

# Left Hemisphere (all channels)




# Right Hemisphere (all channels)

- `>> return`

Generates figure showing one channel of recording for each cortical region in right hemisphere




Right Hemisphere (one channel from each site)

- `>> return`

  *`(or uparrow)`*

**locdetrend** is run on each channel

Fs=500 Hz (sampling rate)

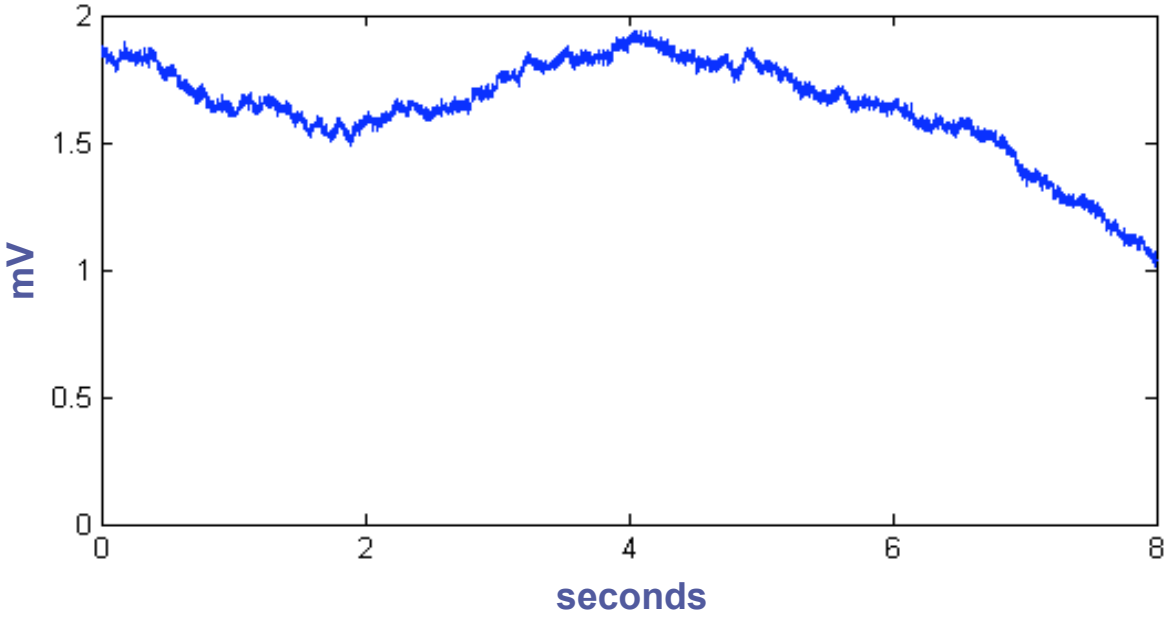
movingwin = [1. 0.5]

- window length = 1 second
- window step = 0.5 seconds

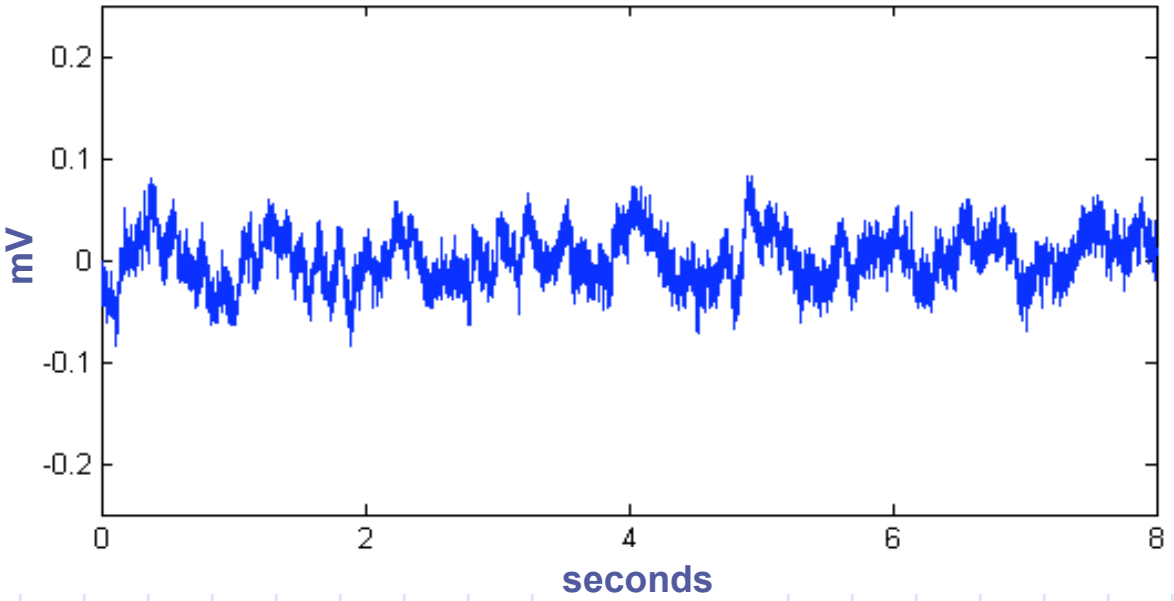
Ex. dfrontal(:,13) = **locdetrend**(frontal(:,13),Fs,movingwin);

generates figure showing a detrended channel, dfrontal(:,13) and the original time series, frontal(:,13)

frontal(:,13)




dfrontal(:,13) = **locdetrend**(frontal(:,13),Fs,movingwin);



>> `Locdetrend_Demo`

**locdetrend** is run on a channel selected from the frontal lobe EcoG leads.

movingwin: you will be prompted for

- window length
- window step

Generates a sequence of figures illustrating windowed samples of EcoG signal, the signal mean and the best fitting line to the sample.

Also shows how the results of the linear regression are locally weighted and combined into a estimate of the entire 8 second signal.

## How much detrending should be done? That is, how does one choose the window and winstep parameter values?

- The intermediate stage of detrending acts like a low-pass filter.
- The longer the window, the ‘smoother’ the signal will be that you subtract from your original, and hence, the more high-frequency content will be preserved in the residual.
- While its important to smooth the signal before subtracting from the original, remember not to smother it.
- Simple moving averages (low-pass filtering operations) produce significant distortions.

## >> Remove_Lines

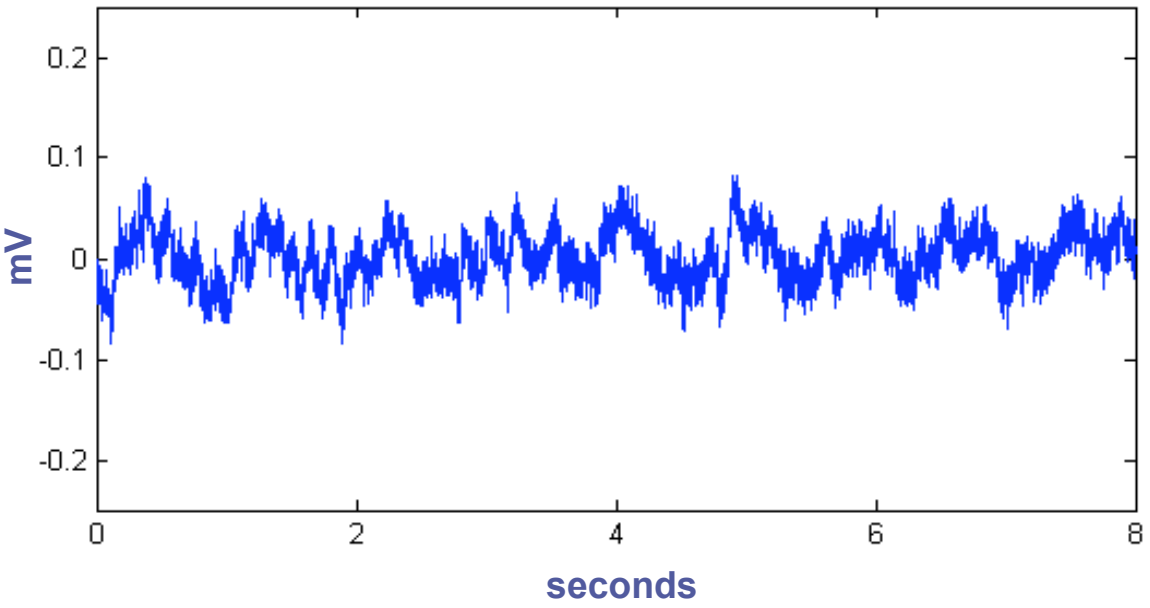
Multi-taper power spectra calculated for one, right hemisphere dorsal-frontal channel, DFR, after detrending.

[S,f] = **mtspectrumc** (dDFR,params)

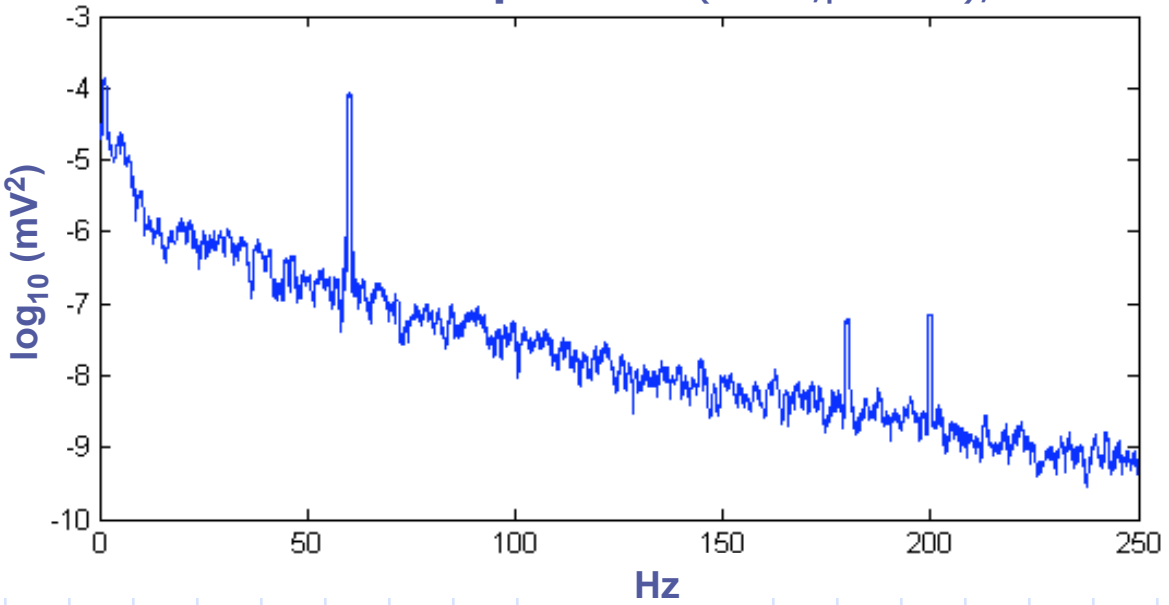
with

- Ktapers=8; NW=(Ktapers+1)/2
- params.tapers=[NW Ktapers]
- params.pad=5
- params.Fs=500
- params.fpass=[0 params.Fs/2]

dDFR




SDFR=**mtspectrumc**(dDFR,params);



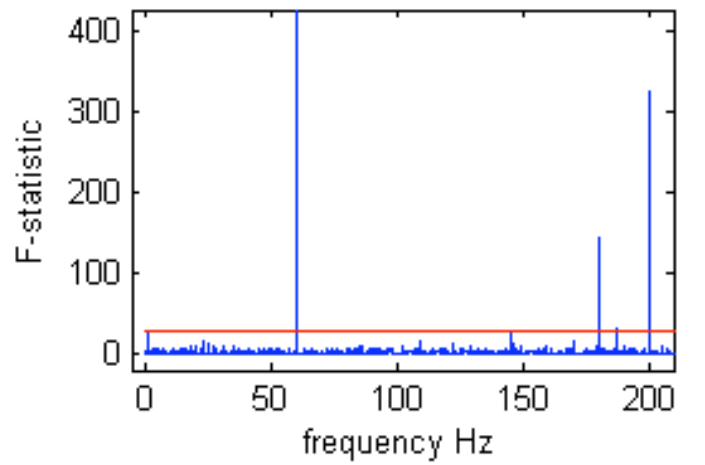
# Line-removal from one channel, dDFR.

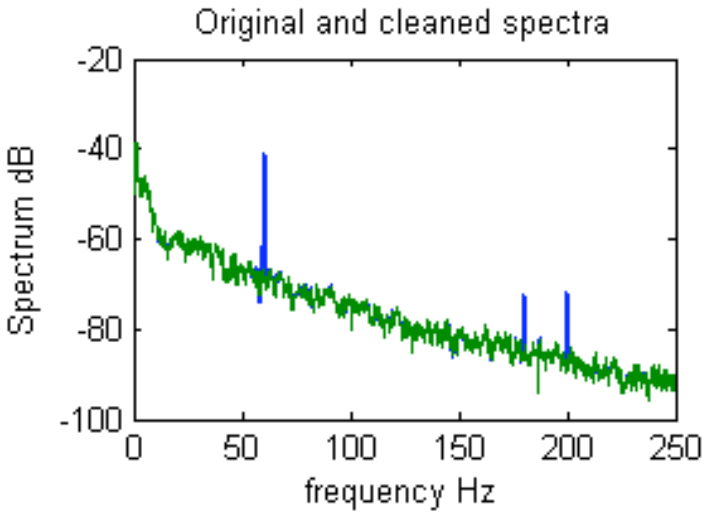
- `>> return` rmlinesc(dDFR,params,.05,'y')

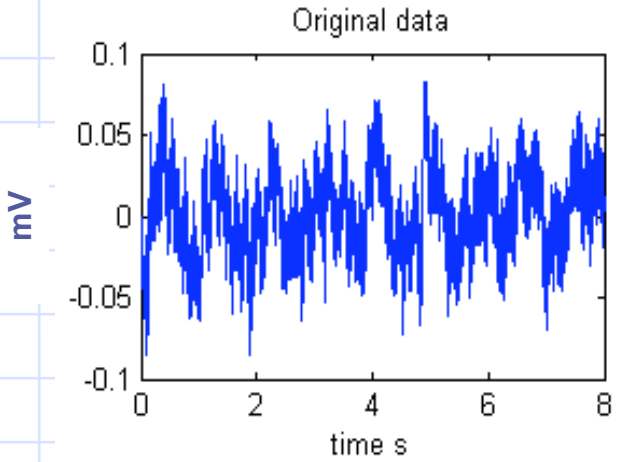
  with parameters
  - params.tapers = [ 4.5 8]
  - params.Fs = 500
  - params.fpass = [ 0 params.Fs/2]
  - params.pad = 5

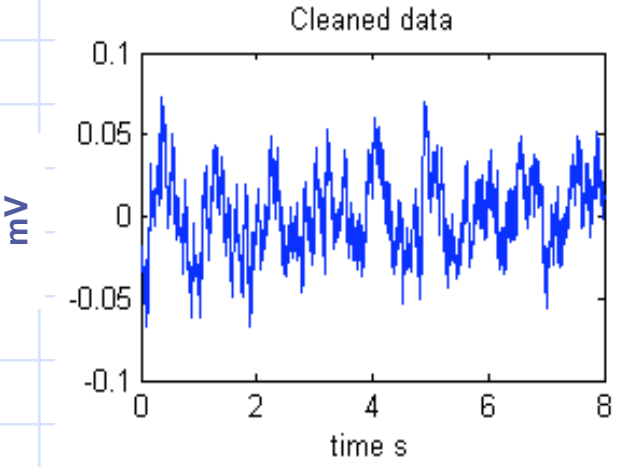
  Note that we will use the result of the F-test to determine which frequencies to remove (f0 is not explicitly specified), thus we must modify the p-value to compensate for multiple comparisons across many frequencies. This is done automatically in rmlinesc.

**Relying on the F-statistic to identify line-elements requires choosing a significance level that must then be corrected for multiple comparisons. It is possible to discard physiology and keep artifact.**



# Line-removal from one channel, dDFR.

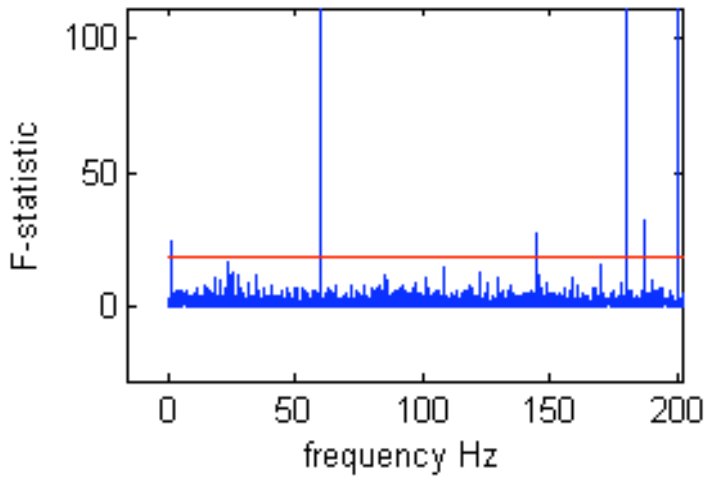
- `>> return` rmlinesc(dDFR,params,.5,'y')

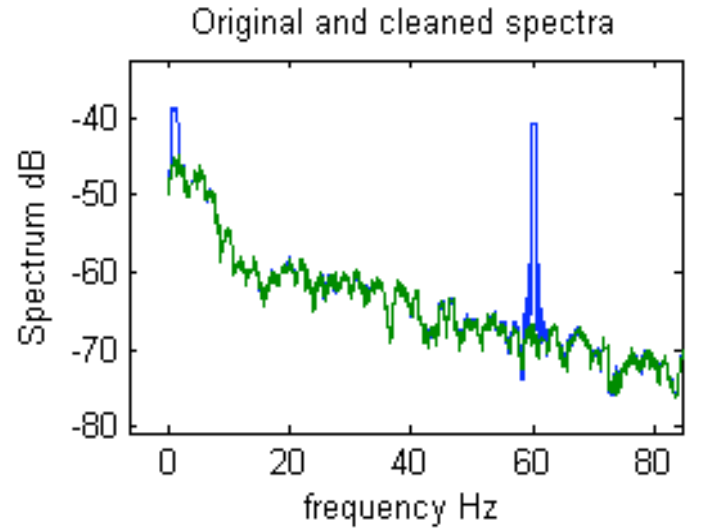
  with

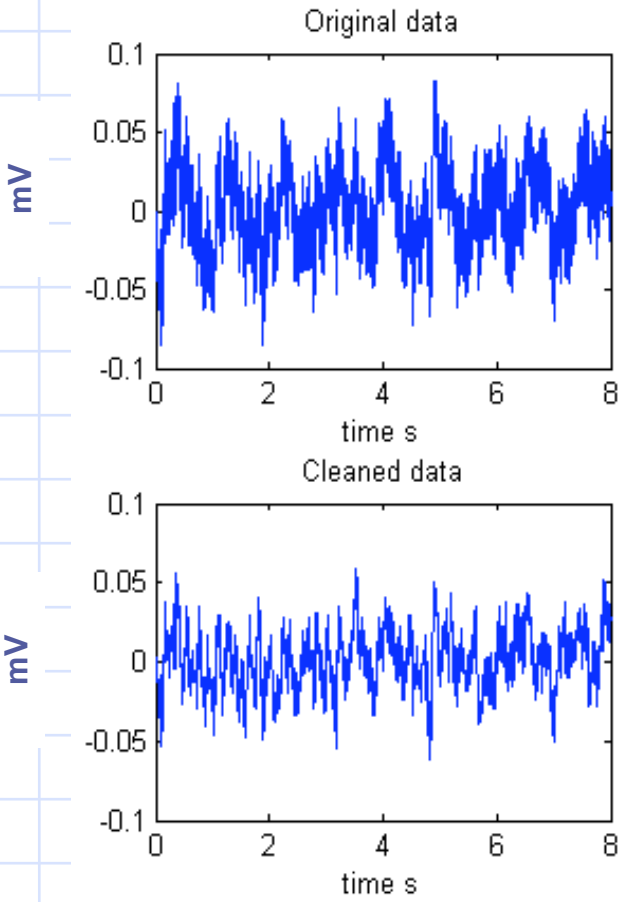
  - params.tapers = [ 4.5  8]
  - params.Fs = 500
  - params.fpass = [ 0 params.Fs/2]
  - params.pad = 5

  Here, an unusually low value is chosen for the F-statistic (by choosing p to be very large, 0.5).

**Relying on the F-statistic to identify line-elements requires choosing a significance level that must then be corrected for multiple comparisons. It is possible to discard physiology and keep artifact.**



# Line-removal from one channel, dDFR.

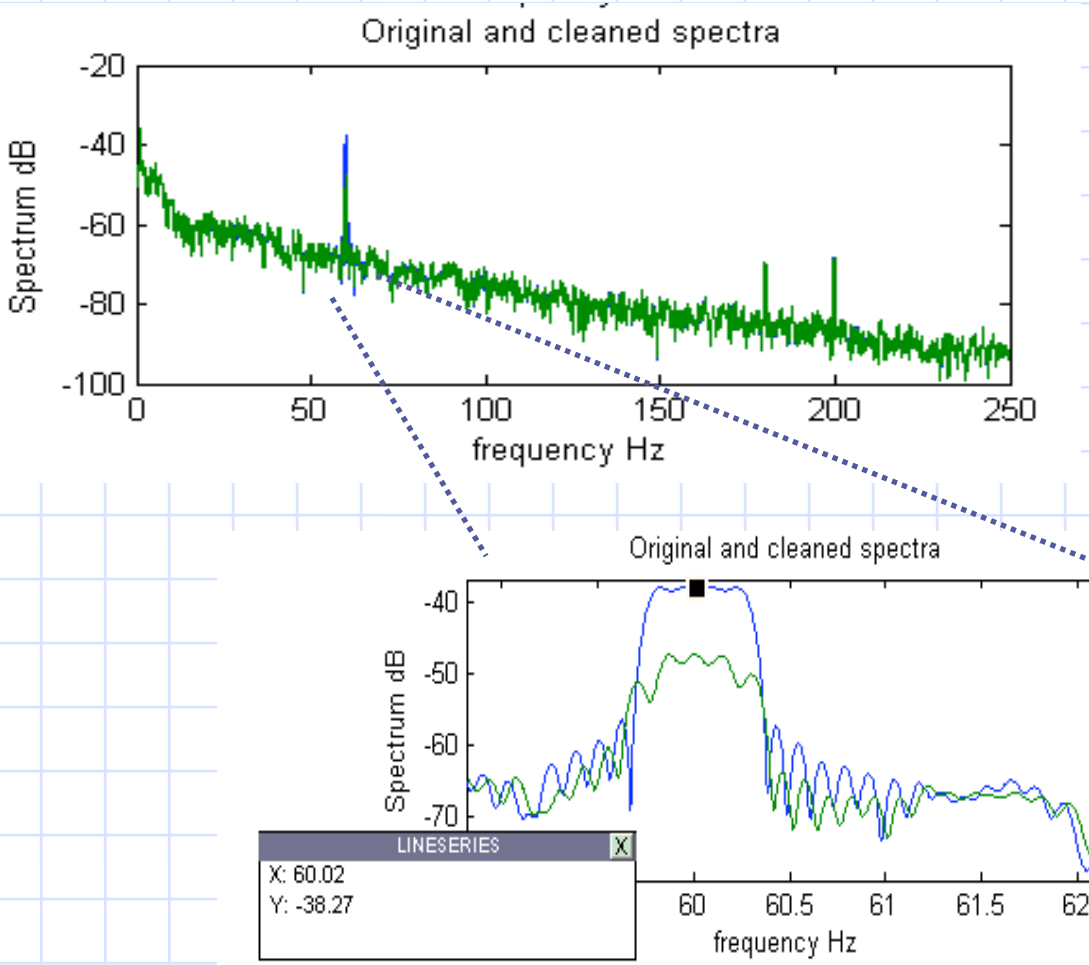
- `>> return`

rmlinesc(dDFR,params,.05,'y',f0)

with

- f0 = 60 Hz
- params.tapers = [ 2.5  4]
- params.Fs = 500
- params.fpass = [ 0 params.Fs/2]
- params.pad = 5

Here a single frequency is examined, so p-value = 0.05. No correction is made for multiple comparisons.




**The “60 Hz” line noise is actually at 60.025 Hz. Set f0 = 60.025, and to catch the third harmonic, set f0 to 60.025 * 3 = 180.075.**

# Line-removal from one channel, dDFR.

- `>> return`

cleanDFR1= rmlinesc(dDFR,params,.05,'y',f0)

with

- **f0 = 60.025**

Then, cleanDFR2= rmlinesc (cleanDFR1,params,.05,'y',f0)

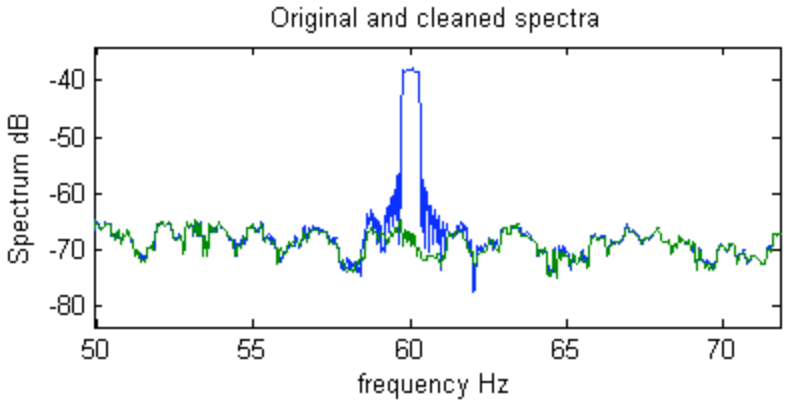
with

- **f0 = 180.075**

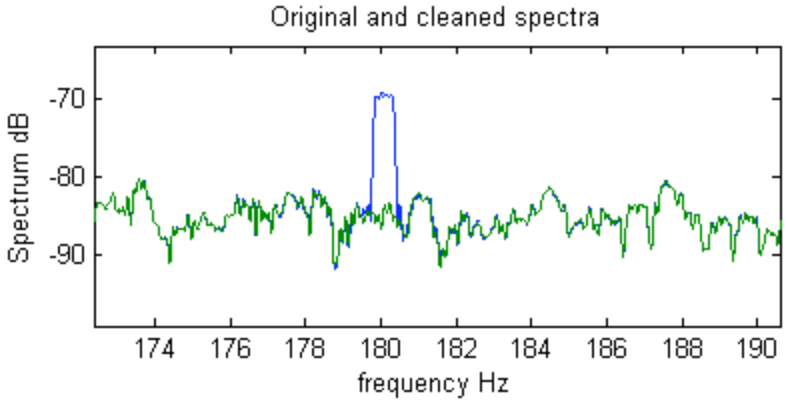
Then, cleanDFR3= rmlinesc (cleanDFR2,params,.05,'y',f0)

with

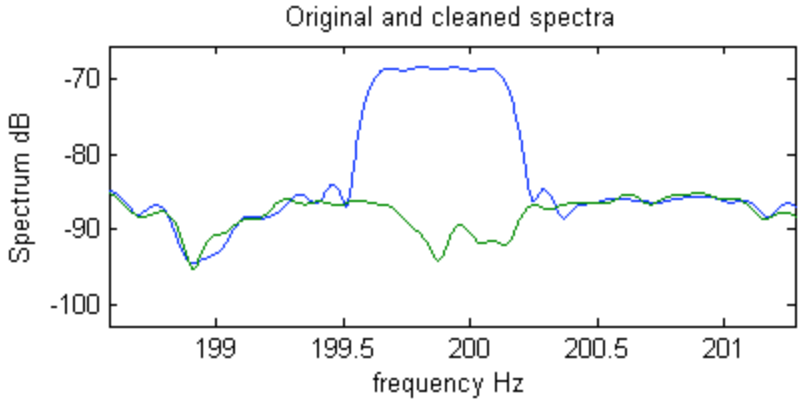
- **f0 = 199.88**




f0 = 60.025




f0 = 180.075

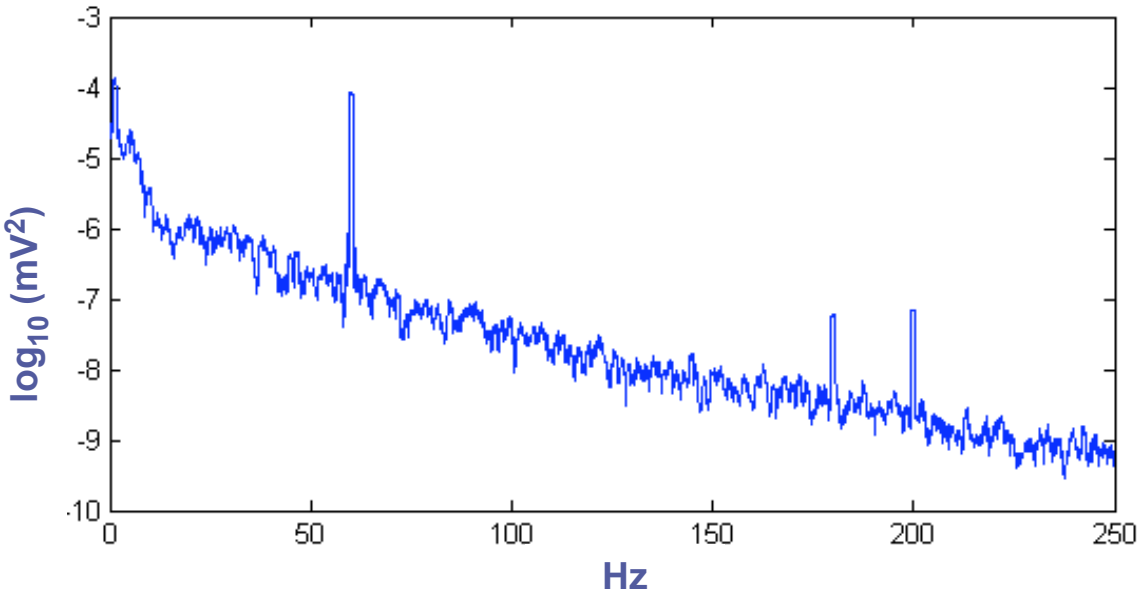



f0 = 199.88

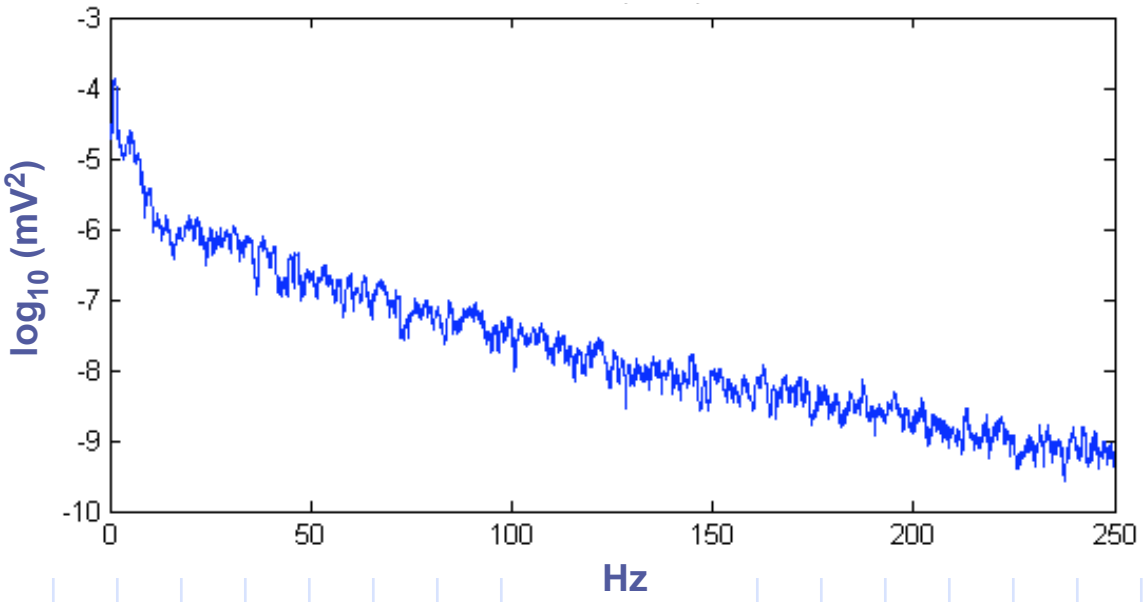
Blue = original spectra

Green = cleaned spectra

SDFR




rmlinesc(dDFR)



# Line-removal from one channel, dDFR.

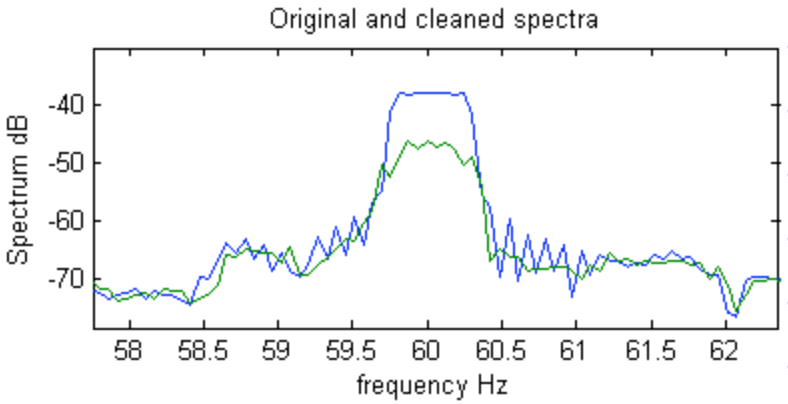
- `>> return`

cleanDFR= rmlinesc(dDFR,params,.05,'y',f0)

with

- f0 = 60.025

But now with params.pad = 1, instead of params.pad = 5.

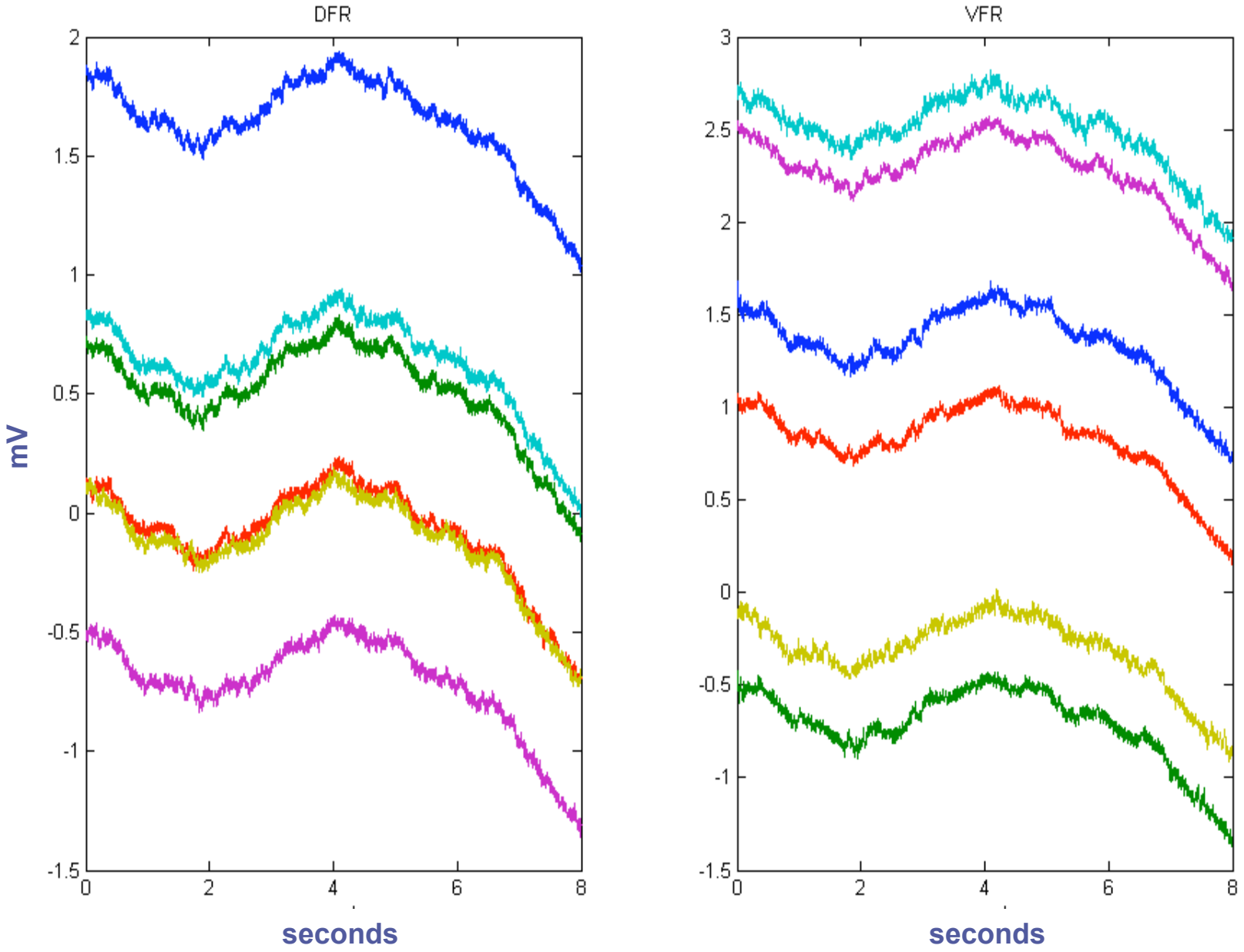



Pad factor controls the amount of zero-padding that is done when calculating the FFT. A higher pad value computes the FFT on a finer frequency grid. If the grid is not of sufficient resolution it is difficult to isolate line elements in the spectra.

# Alternative Approach for Signal Conditioning

- Combine SVD with spectral analysis
- Look for the subspace that does not contain noise and major artifacts
- Reconstruct a set of signals from the subspace for further analysis

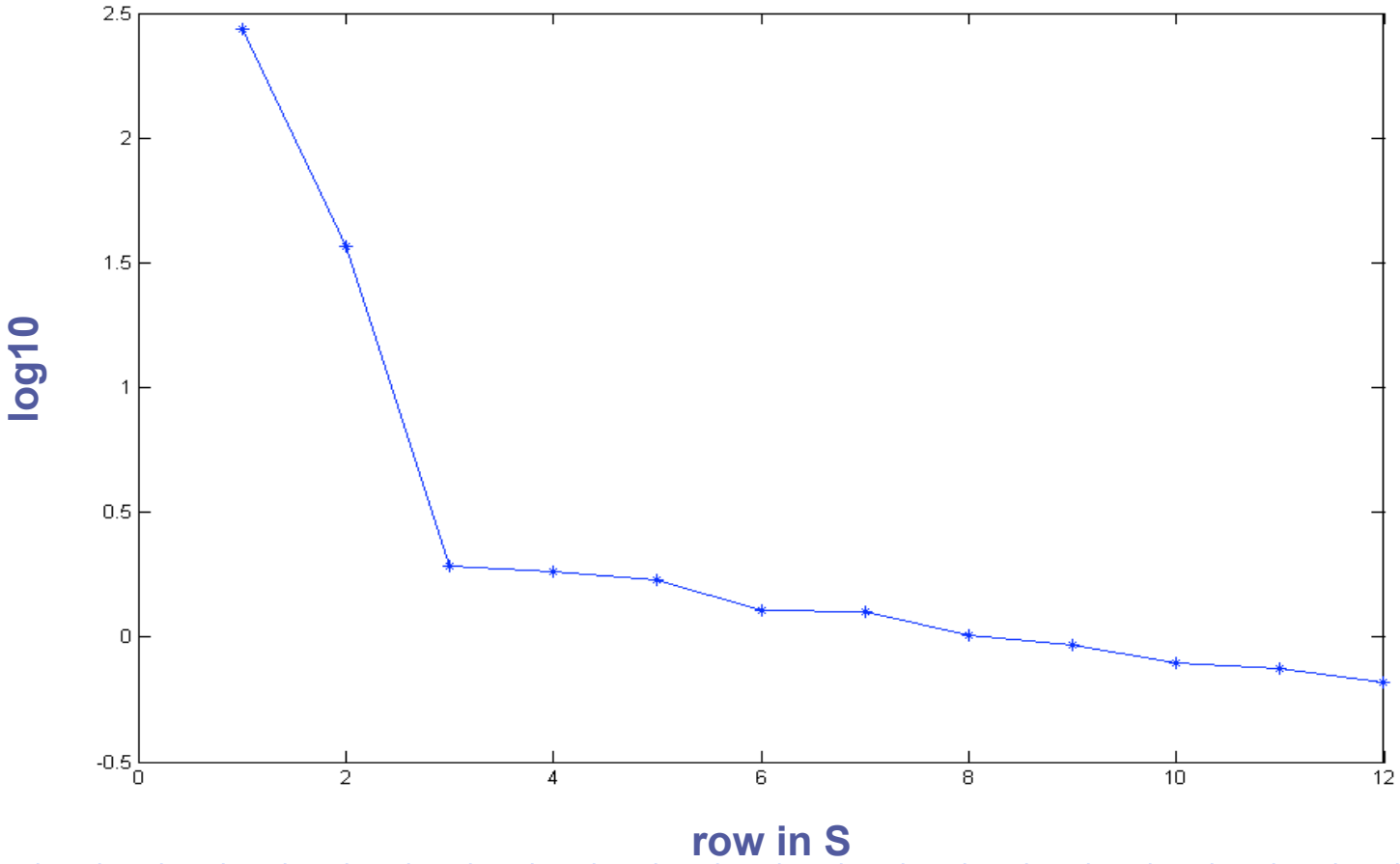
- >>DeNoise_SVD




FrontalR = [ DFR(:,1:6)  VFR(:,1:6) ]

# Multivariate analysis

- FrontalR is a rectangular matrix, 4000 rows (times samples) x 12 columns (recording channels)
- in MATLAB, we can produce a factorization of this matrix by singular value decomposition with:
  - [U,S,V] = svd(FrontalR,0);
    - Columns in U are the temporal modes of FrontalR
    - Columns in V are the “spatial” modes of FrontalR
    - diag(S) gives the singular values of FrontalR
    - “economy size” decomposition
- **`>> return`**




First two singular values account for ~96% of the total variance in the data. We will compare the spectra of the first two temporal modes with that of the other modes. Guess is that line noise and slow fluctuation artifacts reside in the first two temporal modes.

## >> return

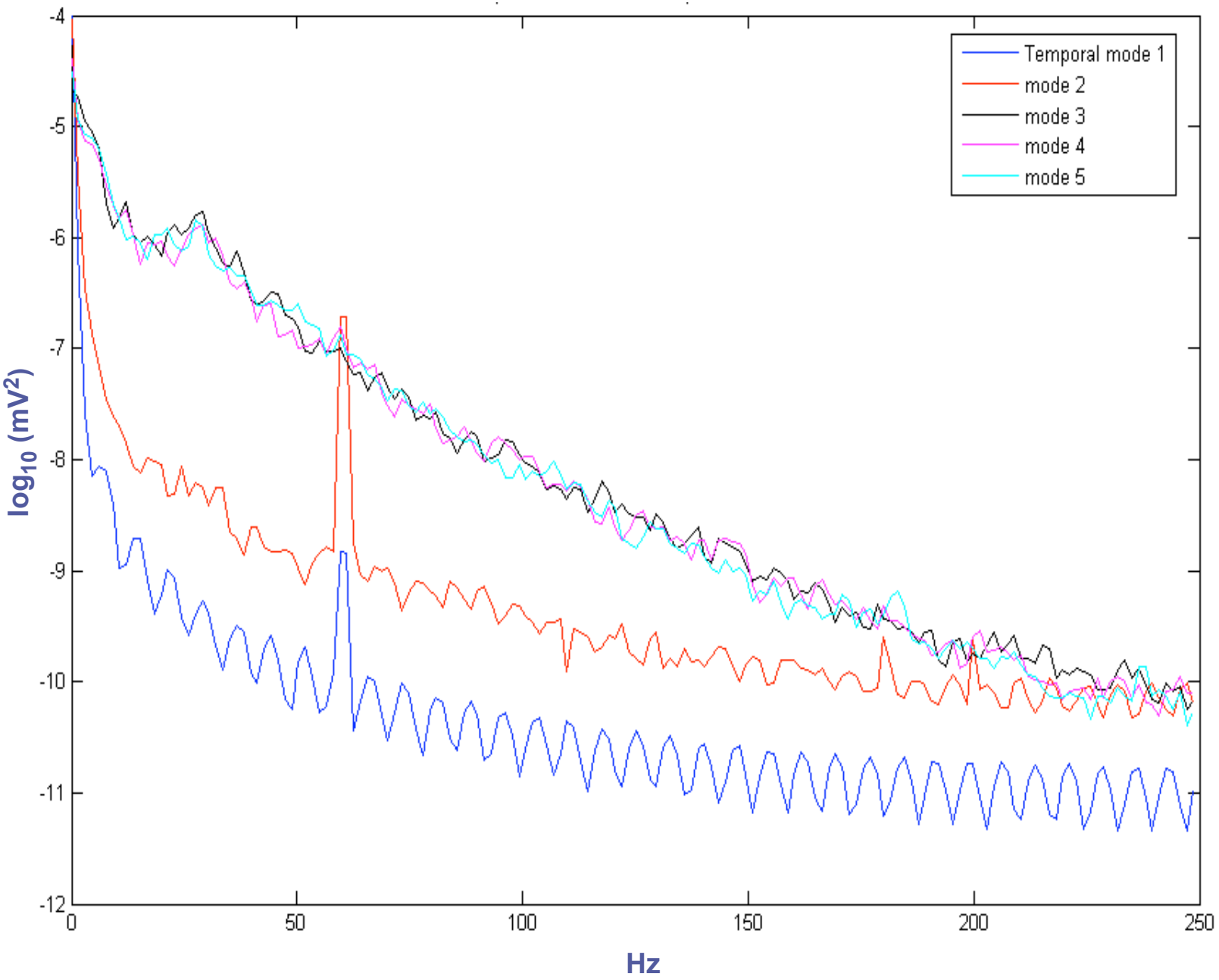
Multi-taper power spectra calculated for each of the temporal modes in U

[US(:,1),f] = **mtspectrumc**(U(:,1),params)

with

- Ktapers=20; NW=(Ktapers+1)/2
- params.tapers=[NW Ktapers]
- params.pad=5
- params.Fs=500
- params.fpass=[0 params.Fs/2]

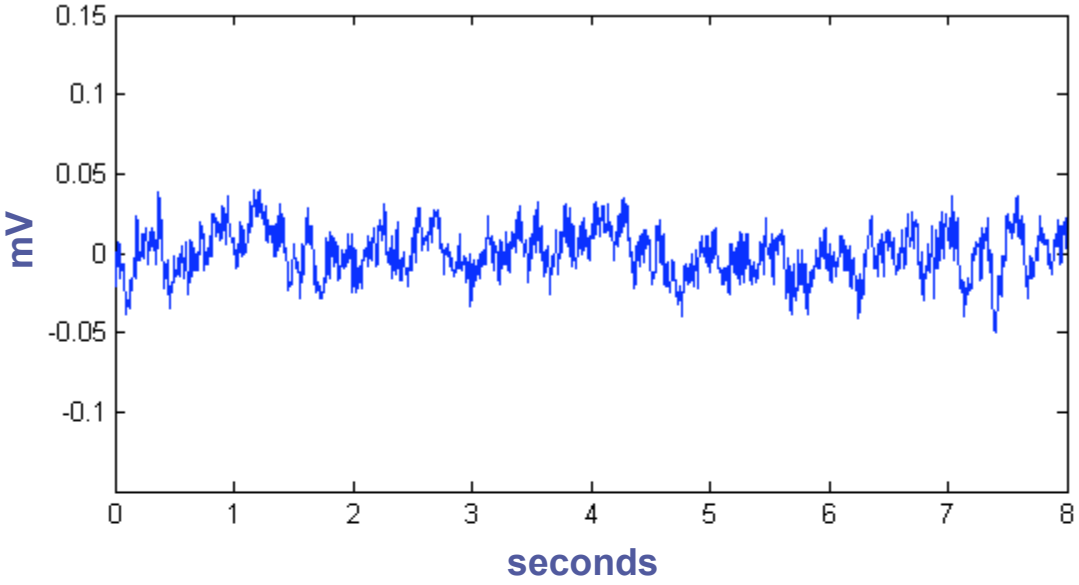
# Spectra of the first 5 temporal modes



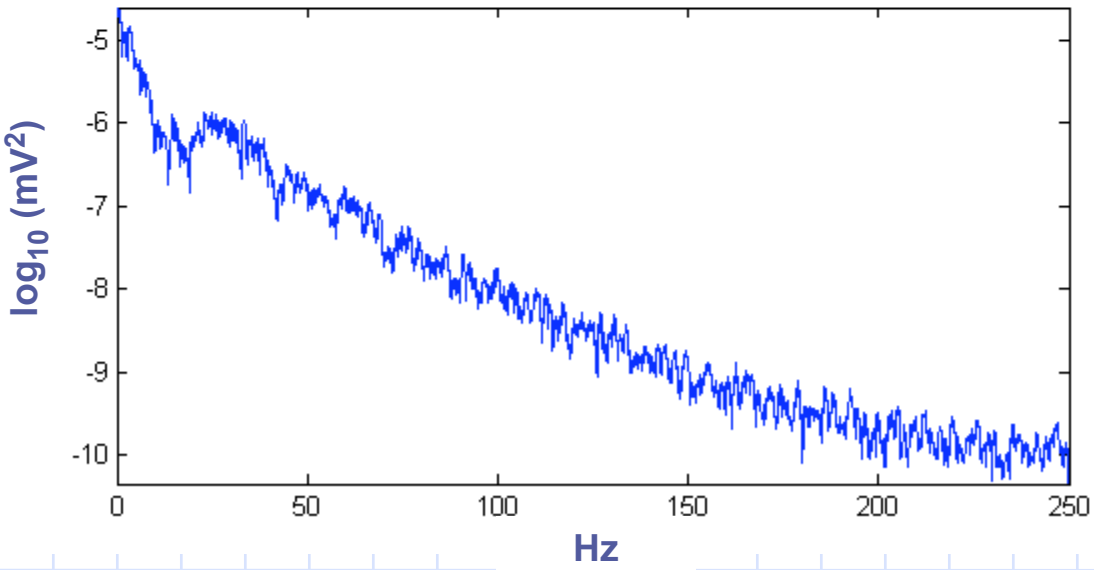
- We drop the first two temporal modes and construct a set of signals from the remaining modes.
- U(3:end,3:end)*S(3:end,3:end)*V(3:end,3:end)′
- = FrontalRsvd

- `>> Hit UPARROW or type return`

reconstructed signal (FrontalRsvd)




Spectrum of reconstructed signal



- Note that neither **locdetrend** nor **rmlinesc** were used in this approach to signal conditioning.
- Yet the slow, large fluctuations in voltage were removed as well as all the line elements at 60.025, 180.075 and 199.88 Hz.
- Approach is more useful as a demonstration of SVD than as a method for removing the electrical artifacts common in EcoG recordings.

- `>> DeNoise_Demo`

  evaluate how noise and denoising alters the time-frequency

**You will be prompted to choose a region of the cortex to examine.**

- **1 – frontal (24 channels)**
- **2 – parietal (12 channels)**
- **3 – temporal (24 channels)**
- **4 – medial-temporal (16 channels)**

**You will be prompted to either detrend or not detrend (Y/N).**

- **If 'Y', locdetrend will be run; you will be prompted for:**
  - **Window length**
  - **Window step**

**You will be prompted to either remove line noise or not (Y/N).**

- **If 'Y', rmlinesc will be run; you will be prompted for:**
  - **Number of tapers to be used for spectral analysis; careful, a large number of tapers could tax limited computer memory**
  - **Padding factor; good value to choose … >2.**
  - **p-value for significance testing of harmonics; Bonferroni correction is done automatically.**

**Singular value decomposition is done on the brain region's channel set. The data are either denoised or not, based on your choices.**

**A plot is generated of the spectra of the first 5 temporal modes.**