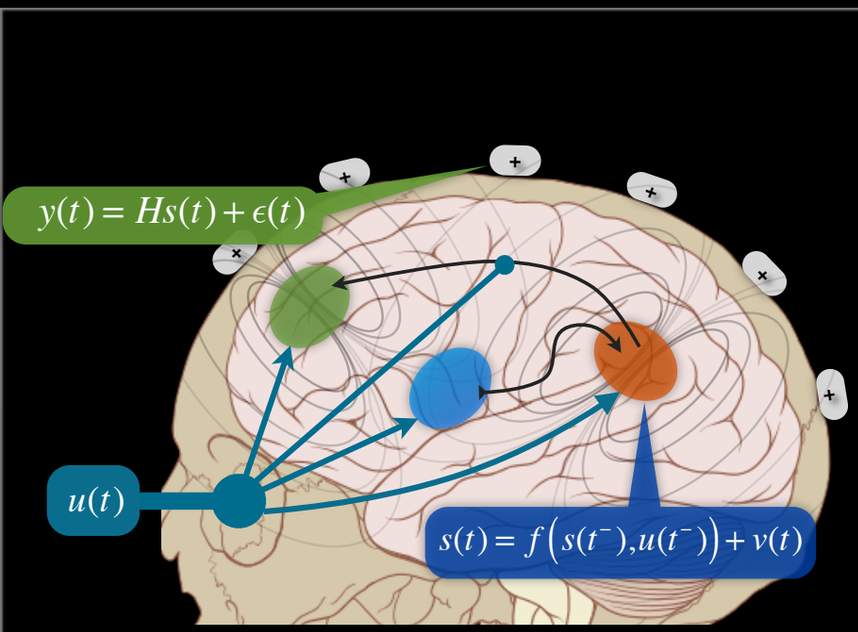
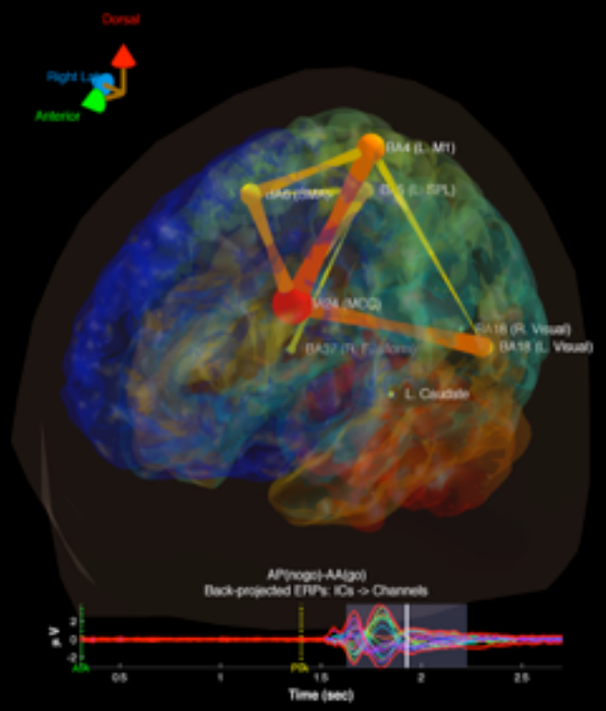
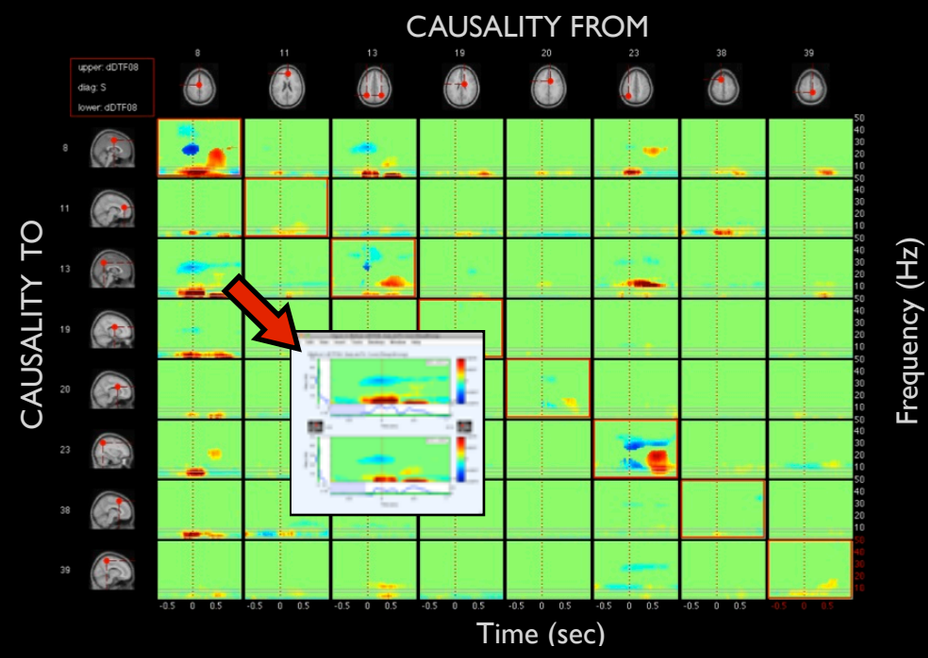
The Source Information Flow Toolbox



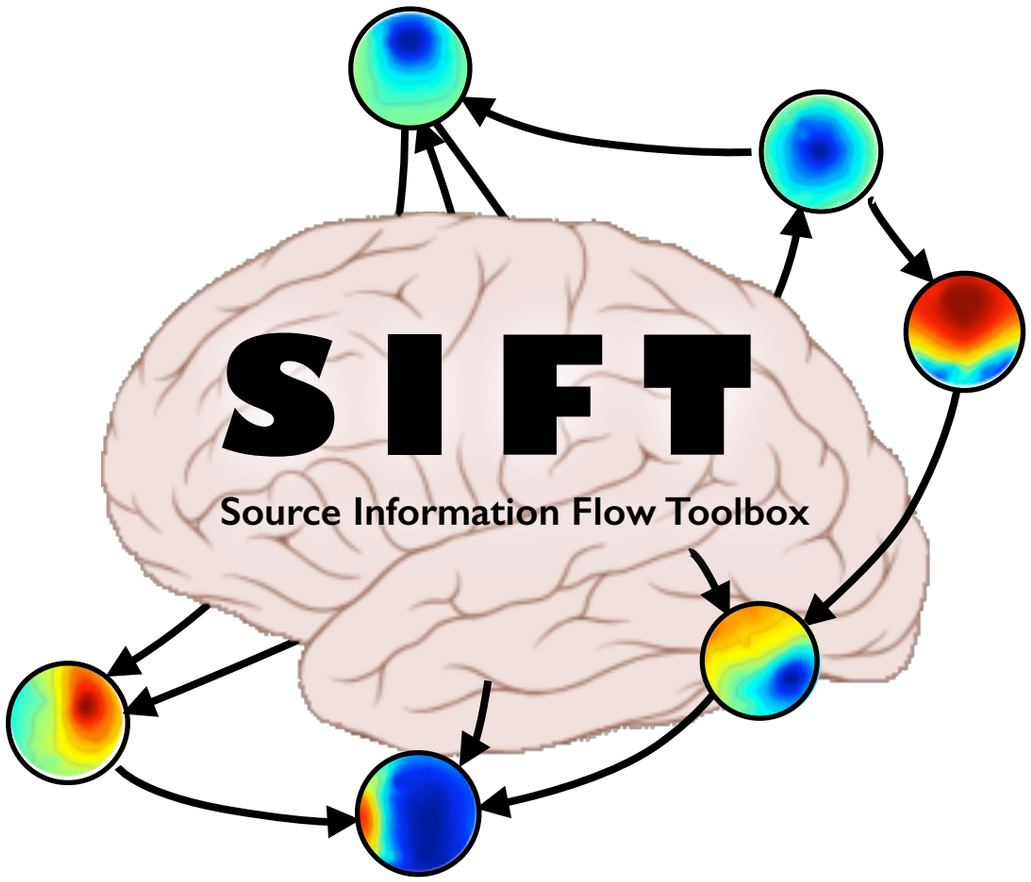




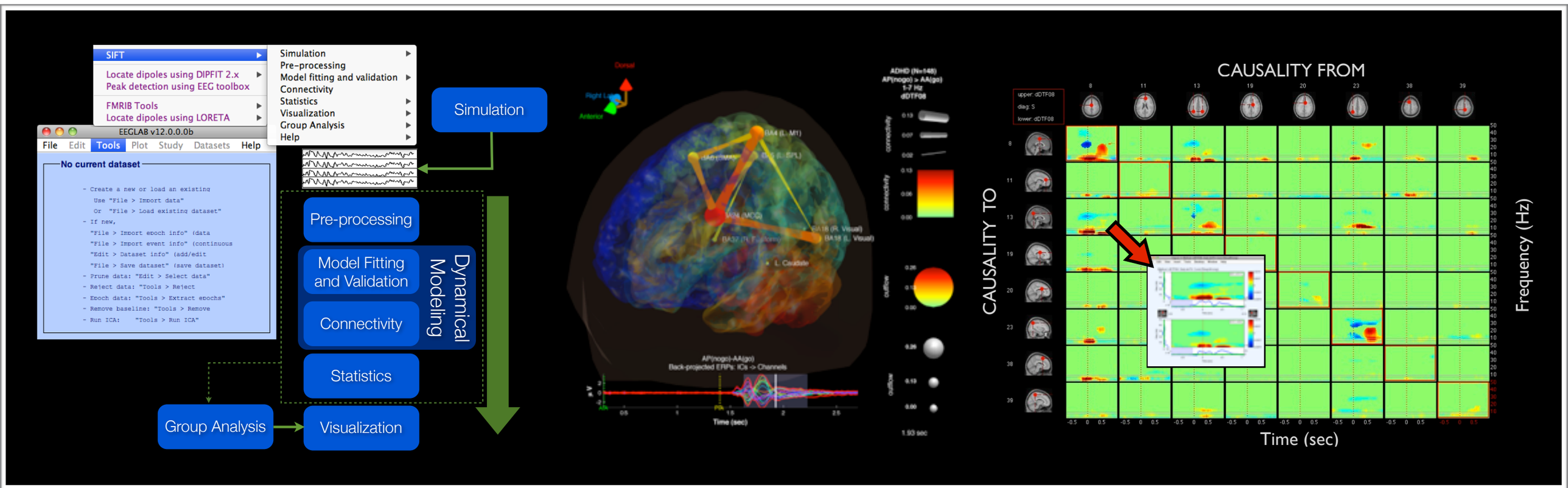
Tim Mullen, PhD

Swartz Center for Computational Neuroscience
Institute for Neural Computation
UC San Diego
and Intheon Labs

Mullen, T & Makeig, S., "The Source Information Flow Toolbox: An Electrophysiological Dynamical Modeling Toolbox for EEGLAB", *in prep*
Delorme, A., Mullen, T., et al, "EEGLAB, SIFT, NFT, BCILAB, and ERICA: New tools for advanced EEG/MEG processing." *Comp. Intel. and Neuro.*, vol 12, 2011



- A toolbox for (source-space) electrophysiological information flow and causality analysis (single- or multi-subject) integrated into the EEGLAB software environment.
- Modular architecture intended to support multiple modeling approaches
- Emphasis on vector autoregression and SSMs and time-frequency domain approaches
- Standard and novel interactive visualization methods for exploratory analysis of connectivity across time, frequency, and spatial location



Source Information Flow Toolbox (SIFT)

- **Requirements**: EEGLAB, MATLAB 2008a+
- Some functions leverage: Signal Processing Toolbox, Statistics Toolbox

The Source Information Flow Toolbox

SIFT
Locate dipoles using DIPFIT 2.x
Peak detection using EEG toolbox
FMRIB Tools
Locate dipoles using LORETA

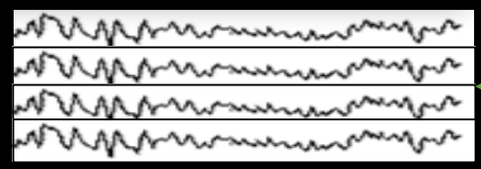
Simulation
Pre-processing
Model fitting and validation
Connectivity
Statistics
Visualization
Group Analysis
Help

EEGLAB v12.0.0.0b

File Edit Tools Plot Study Datasets Help

No current dataset

- Create a new or load an existing
  Use "File > Import data"
  Or "File > Load existing dataset"
- If new,
  "File > Import epoch info" (data
  "File > Import event info" (continuous
  "Edit > Dataset info" (add/edit
  "File > Save dataset" (save dataset)
- Prune data: "Edit > Select data"
- Reject data: "Tools > Reject
- Epoch data: "Tools > Extract epochs"
- Remove baseline: "Tools > Remove
- Run ICA: "Tools > Run ICA"



Simulation

Pre-processing

Model Fitting and Validation

Connectivity

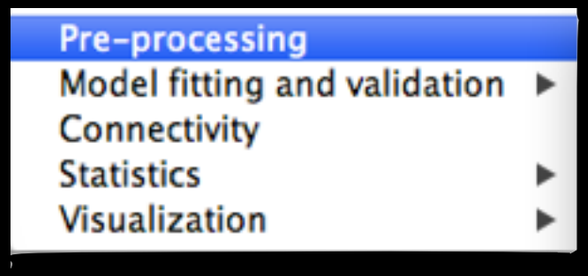
Dynamical Modeling

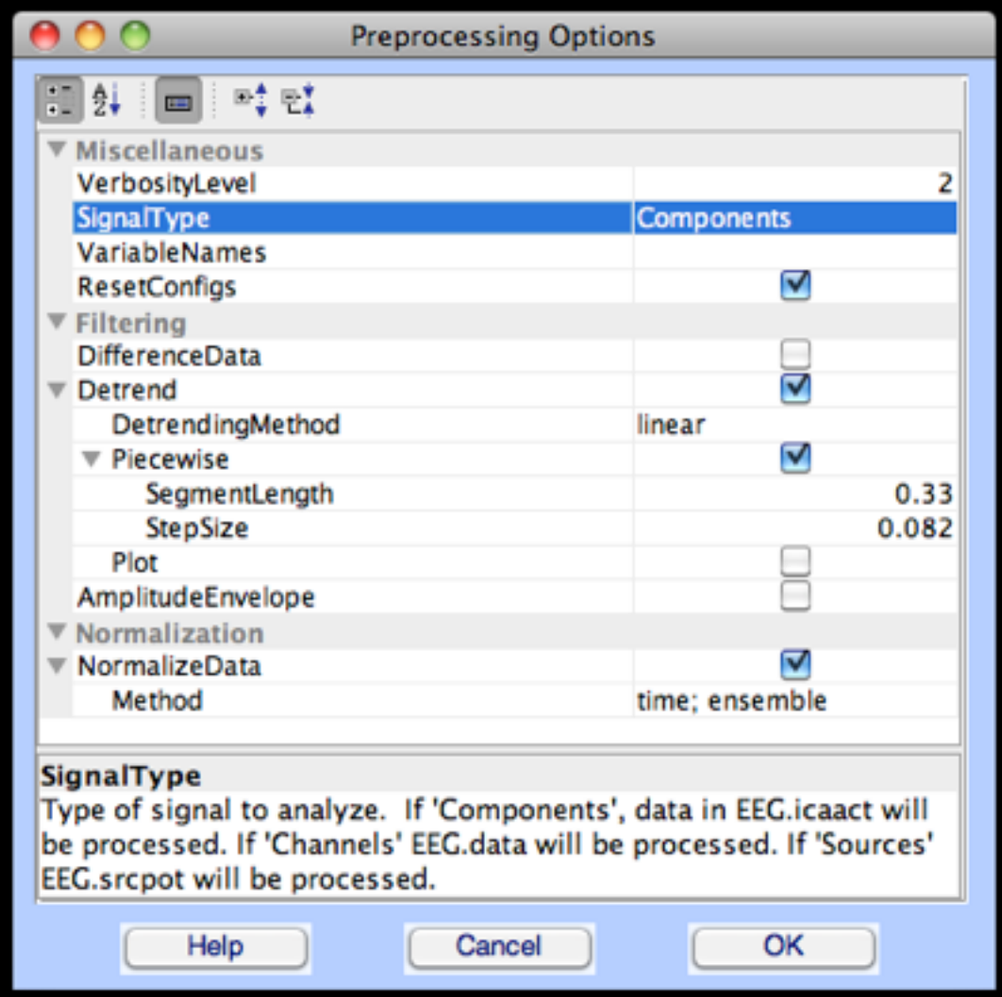
Statistics

Group Analysis

Visualization

Preprocessing | Modeling | Statistics | Visualization





Source reconstruction
(performed externally using EEGLAB or other toolboxes)

Local Detrending or Filtering

Downsampling (EEGLAB)

Differencing

Normalization (temporal or ensemble)

Preprocessing

Modeling

Model Fitting

Validation

Connectivity

Statistics

Visualization

Preprocessing | **Modeling** | Statistics | Visualization

Model Fitting | Validation | Connectivity

Modeling Algorithm (1)	Linear	Nonlinear
Segmentation VAR (Sliding Window)		
Unconstrained		
Vieira-Morf	☑	
ARfit	☑	
Regularized		
Ridge Regression (L_2)	☑	
Group Lasso ($L_{1,2}$) ADMM, DAL	☑	
Sparse Bayesian Learning (L_p) TMSBL, BSBL	☑	

Preprocessing | **Modeling** | Statistics | Visualization

Model Fitting | Validation | Connectivity

Modeling Algorithm (2)	Linear	Nonlinear
State-Space Modeling		
Linear Kalman Filtering	☑	
Dual Extended Kalman Filtering		☑
Cubature Kalman Filtering		☑
Sparsely Connected Components Analysis (SCSA)	☑	

Preprocessing

Modeling

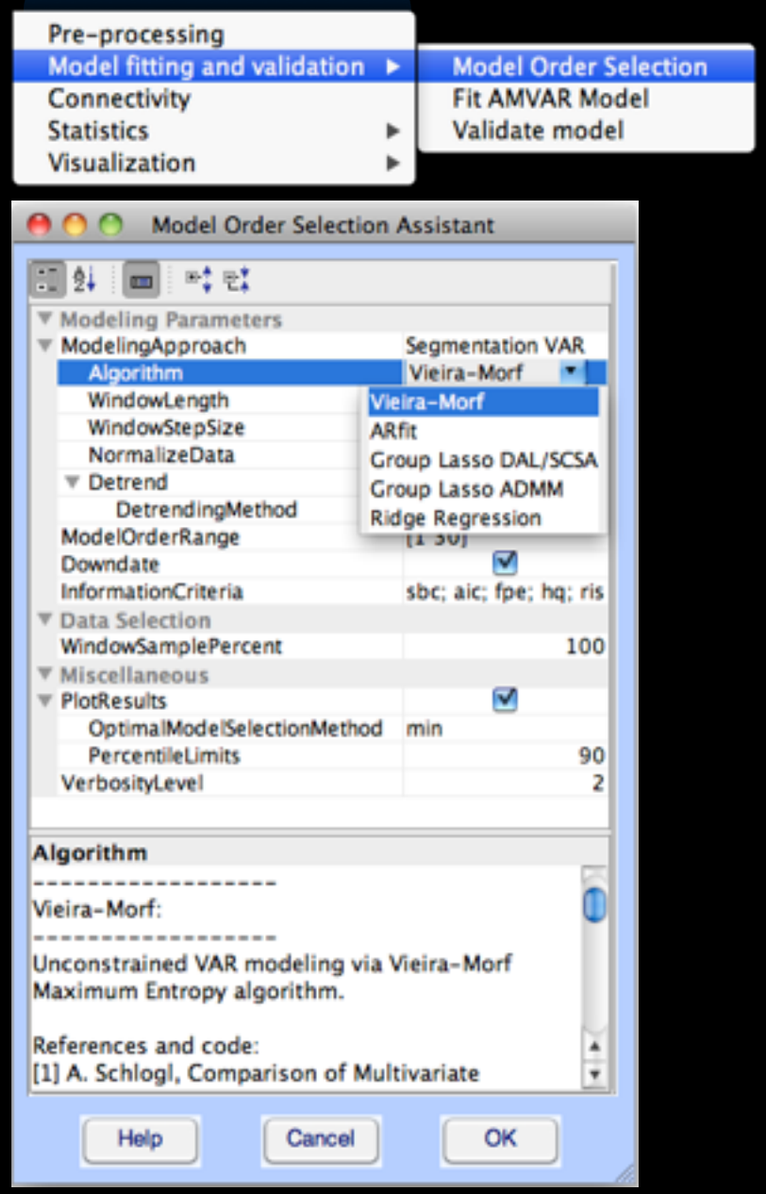
Statistics

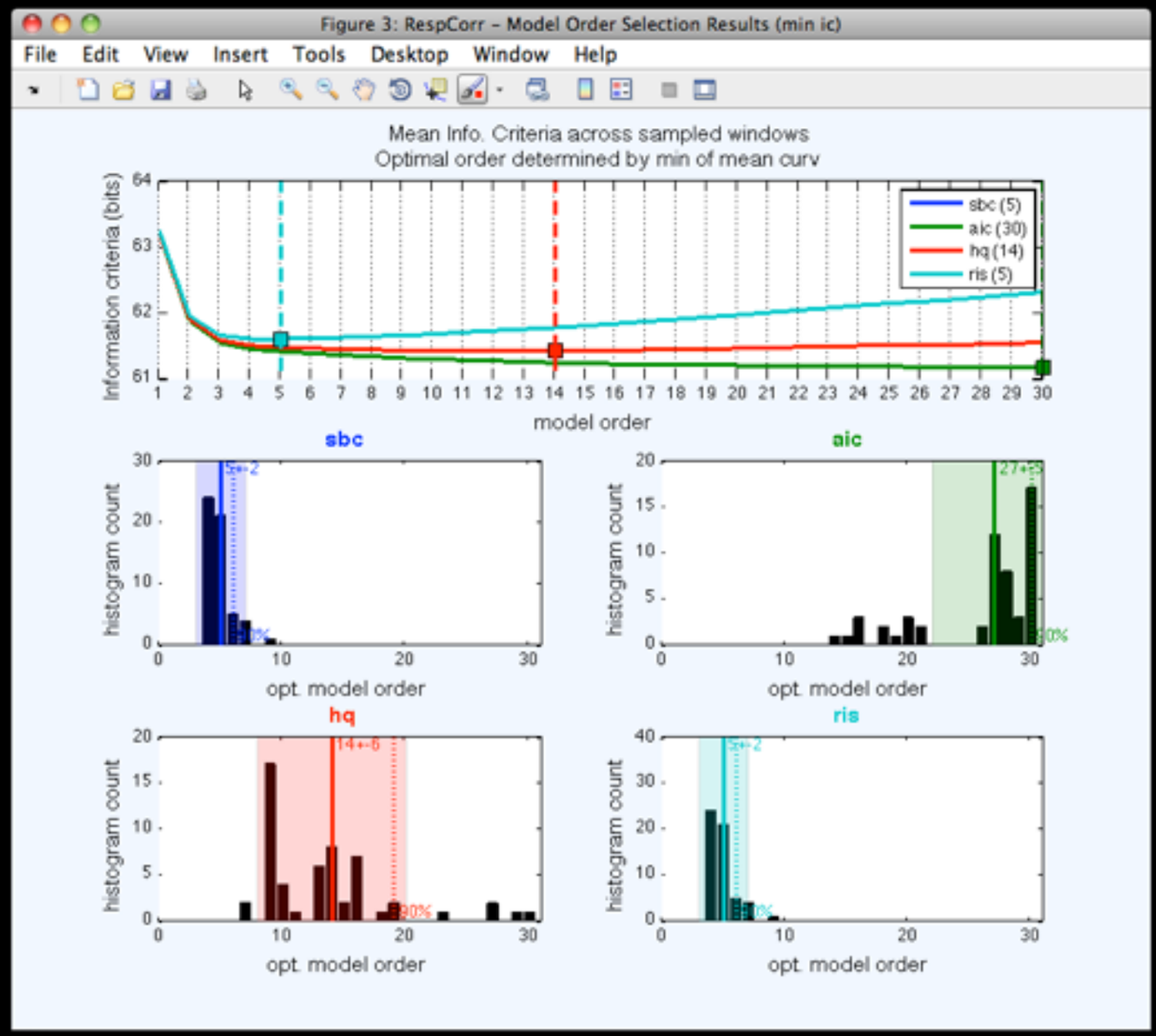
Visualization

Model Fitting

Validation

Connectivity





Preprocessing | **Modeling** | Statistics | Visualization

Model Fitting | **Validation** | Connectivity

VAR Model Validation

Residual ‘Whiteness’ Tests

- Multivariate portmanteau tests
- Residual autocorrelation probability test

Model Consistency

Model Stability

Preprocessing

Modeling

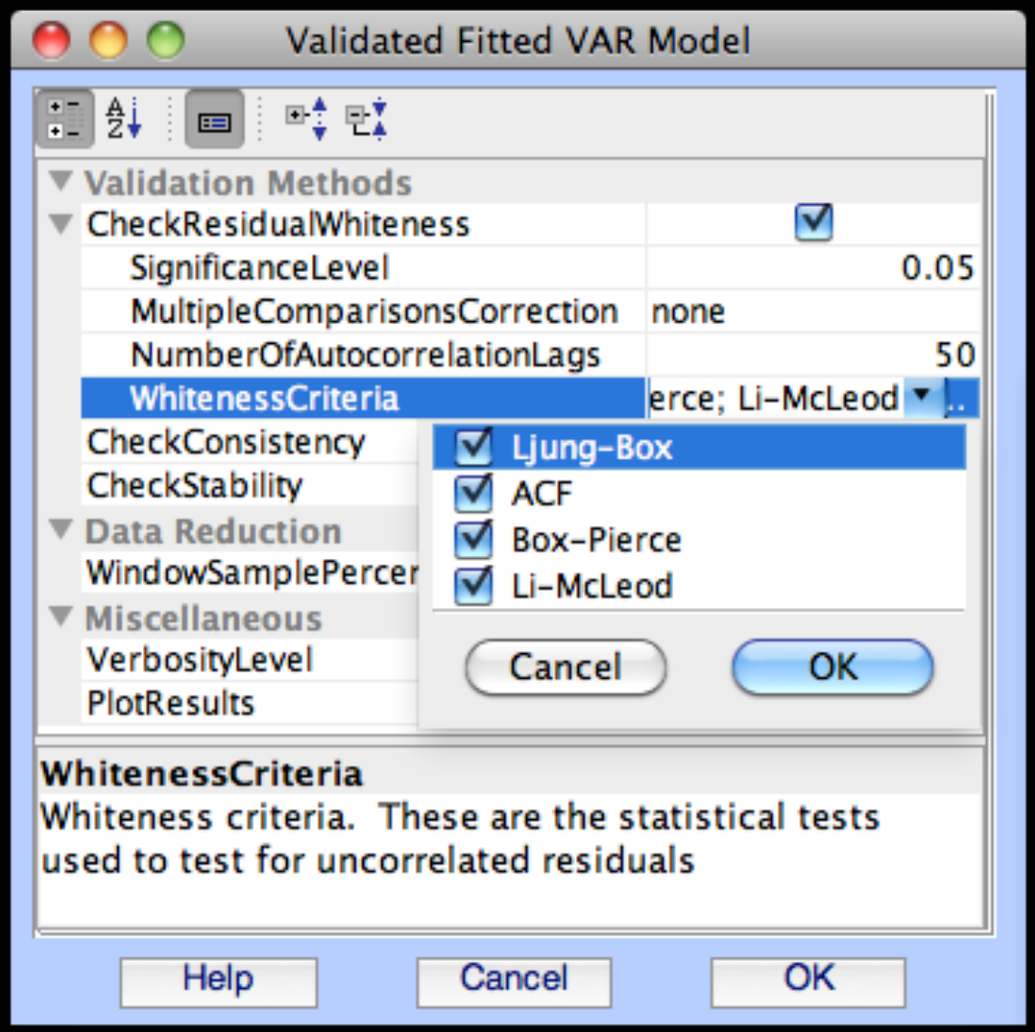
Statistics

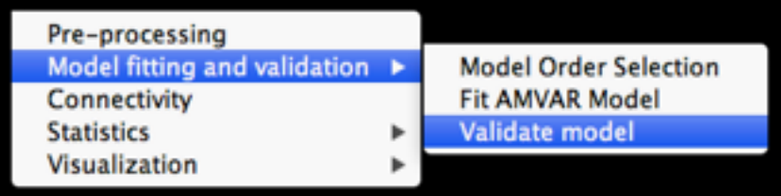
Visualization

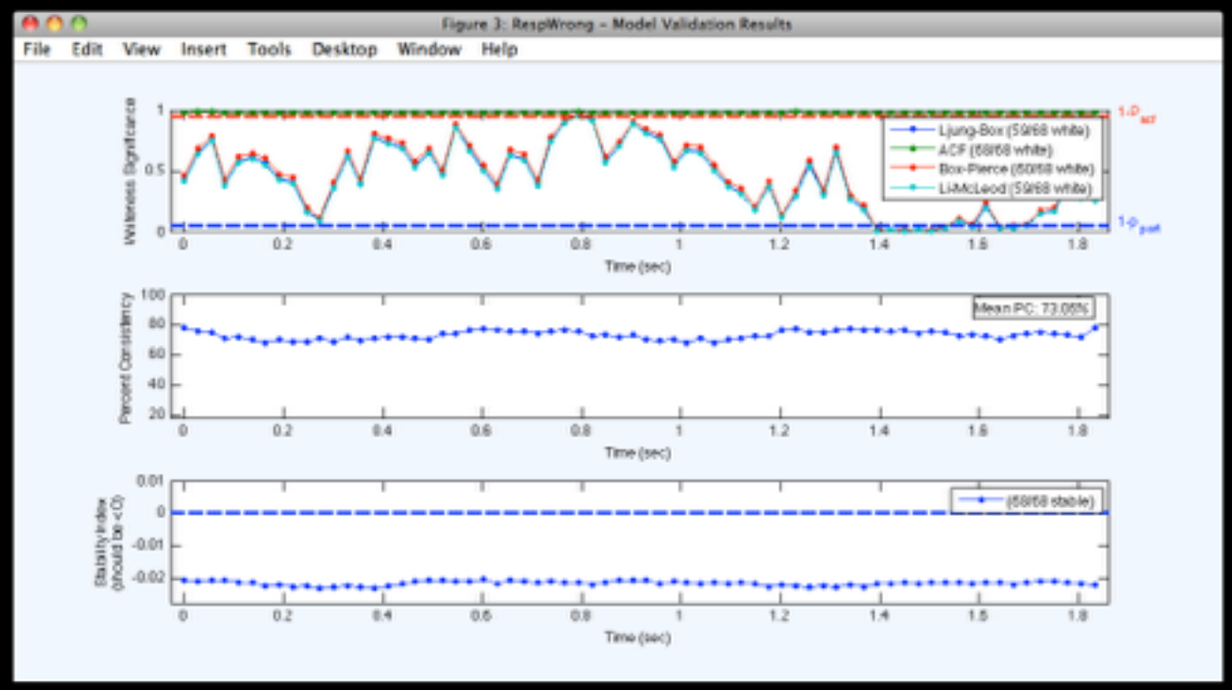
Model Fitting

Validation

Connectivity







Preprocessing

Modeling

Statistics

Visualization

Model Fitting

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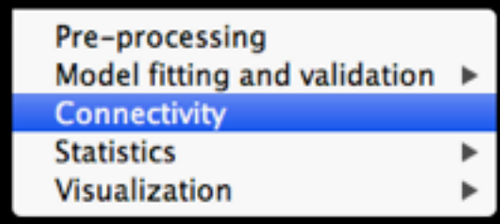
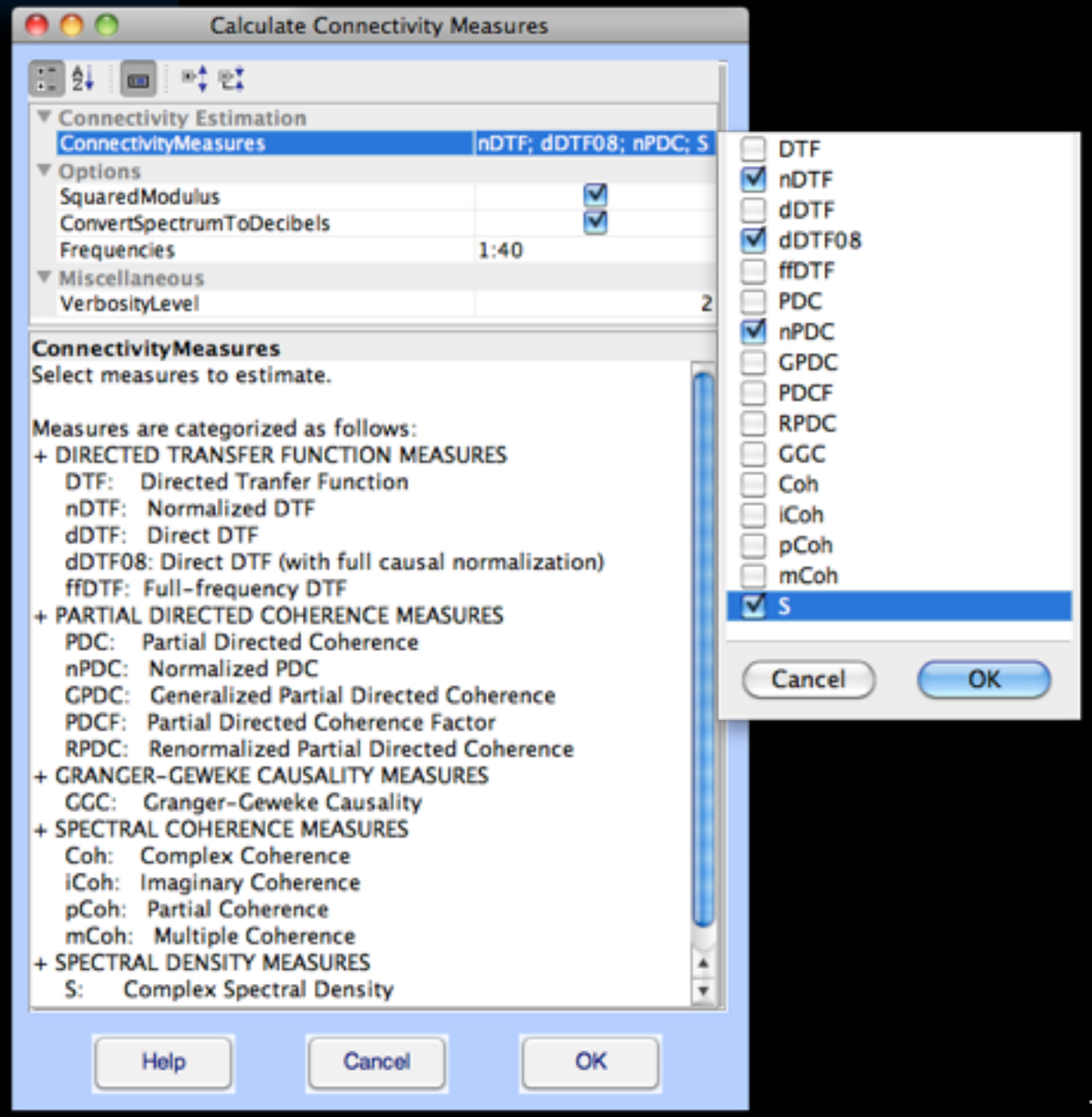
Connectivity



VAR-based Measures

- Power spectrum (ERSP)
- Coherence (Coh), Partial Coherence (pCoh), Multiple Coherence (mCoh)
- Partial Directed Coherence (PDC)
- Generalized PDC (GPDC)
- Partial Directed Coherence Factor (PDCF)
- Renormalized PDC (rPDC)
- Directed Transfer Function (DTF)
- Direct Directed Transfer Function (dDTF)
- Bivariate Granger-Geweke Causality (GGC)
- Principal Oscillation Pattern Analysis (POP)



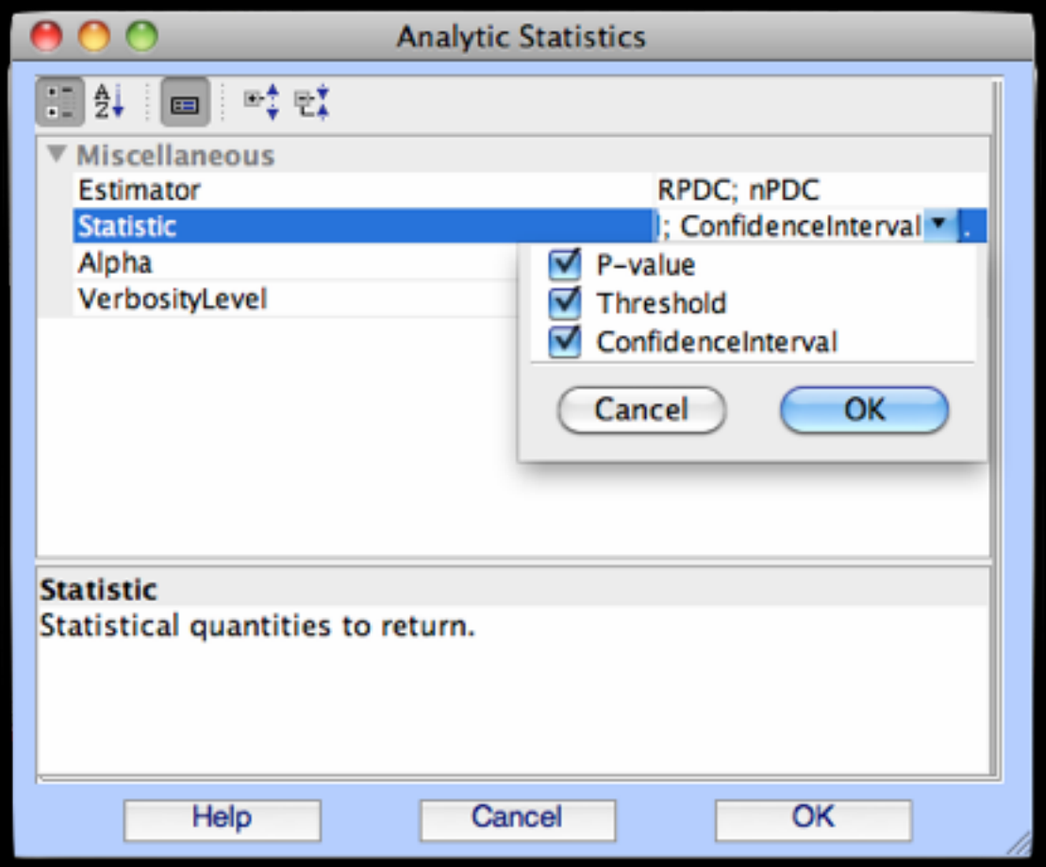
Preprocessing | Modeling | **Statistics** | Visualization

Statistical Approach	Test	Parametric	Nonparam.
Asymptotic analytic estimates of confidence intervals. Applies to: PDC, nPDC, DTF, nDTF, rPDC	H_{null}, H_{base}, H_{AB}	☑	
Theiler phase randomization Applies to: all	H_{null}		☑
Bootstrap, Jacknife, Cross-Validation Applies to: all	H_{AB}, H_{base}		☑
Confidence intervals using Bayesian B-spline smoothing Applies to: all	H_{base}, H_{AB}	☑	☑

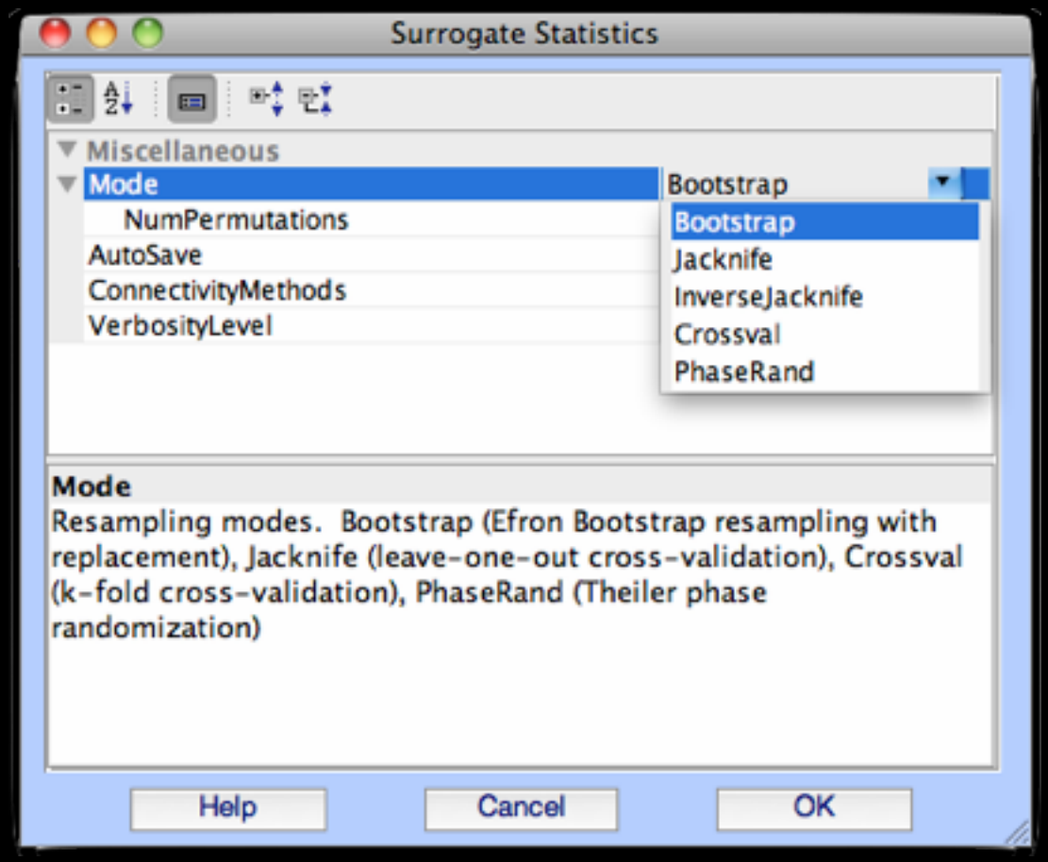
$H_{null}: \mathbf{C}_{ij} = 0$ $H_{base}: \mathbf{C}_{ij} = \mathbf{C}_{baseline}$ $H_{AB}: \mathbf{C}^{A}_{ij} = \mathbf{C}^{B}_{ij}$

Preprocessing | Modeling | **Statistics** | Visualization

Parametric



Non-parametric

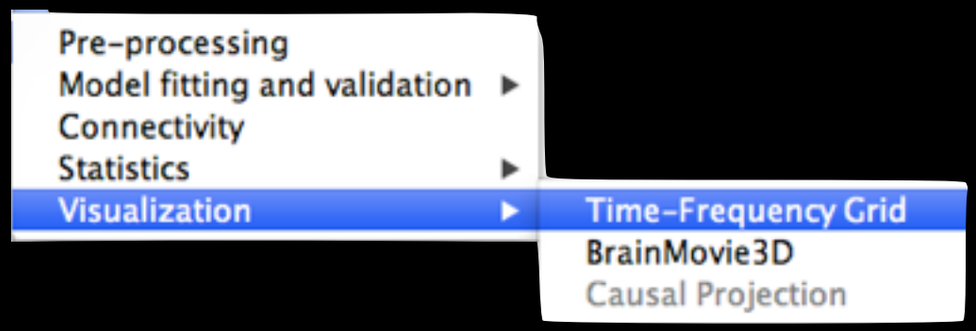


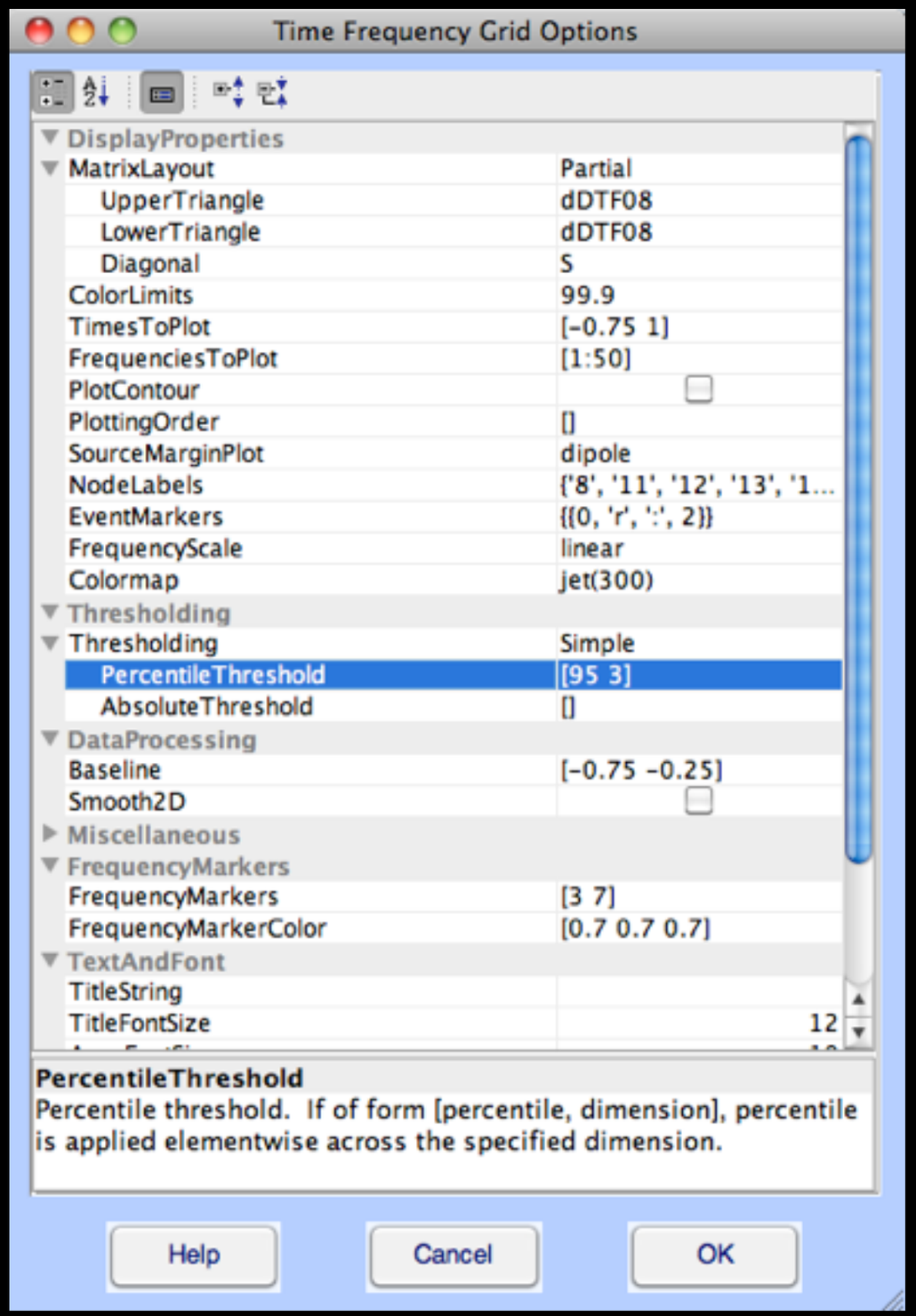
Preprocessing | Modeling | Statistics | Visualization

Interactive Visualizers

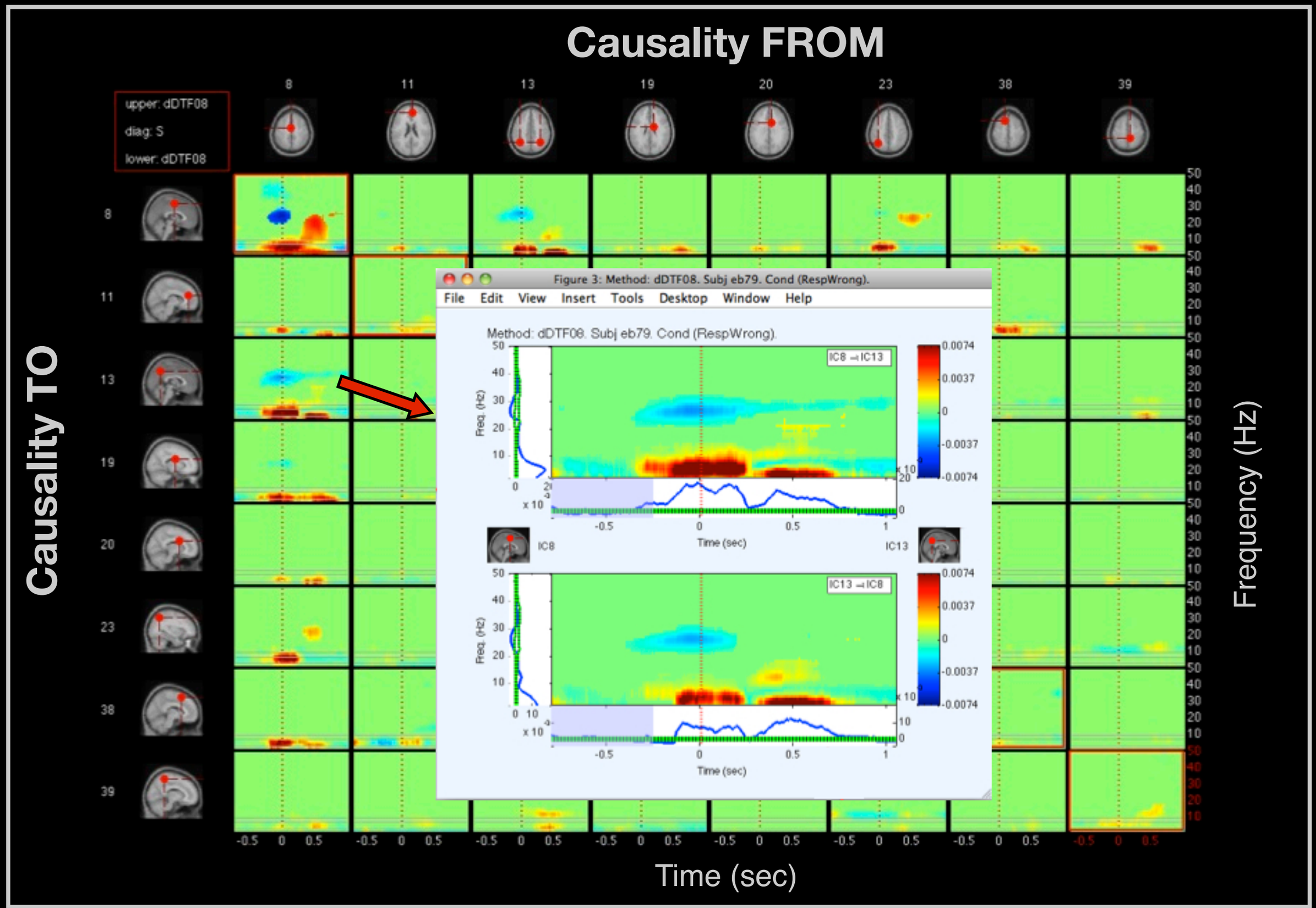
- Interactive Time-Frequency Grid
- Interactive 3D Causal Brainmovie
- Causal Projection Movie
- Directed Graphs and Graph Theoretic Analysis (Bioinformatics Toolbox Interface)
- and more ...

Interactive Time-Frequency Grid

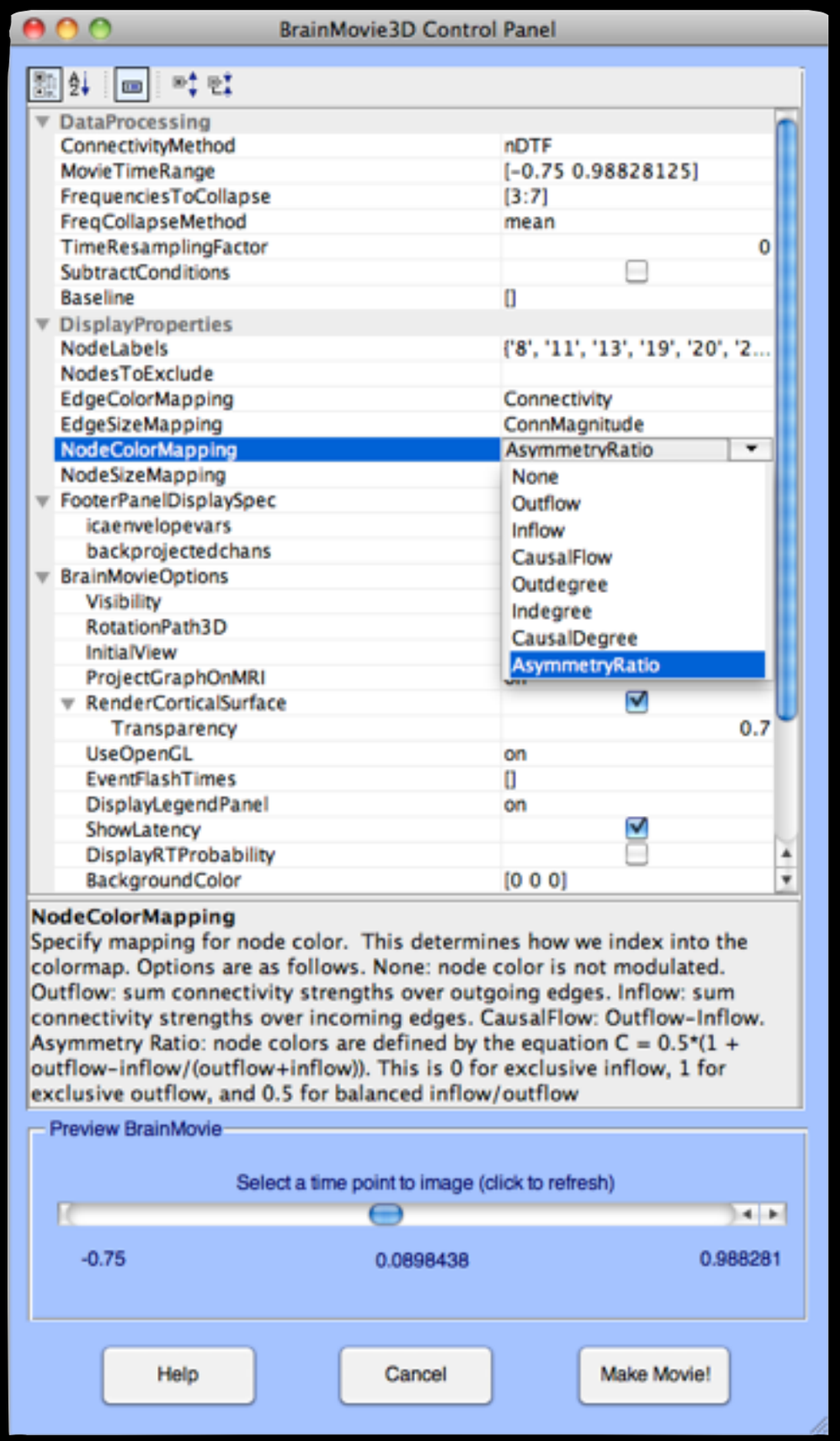


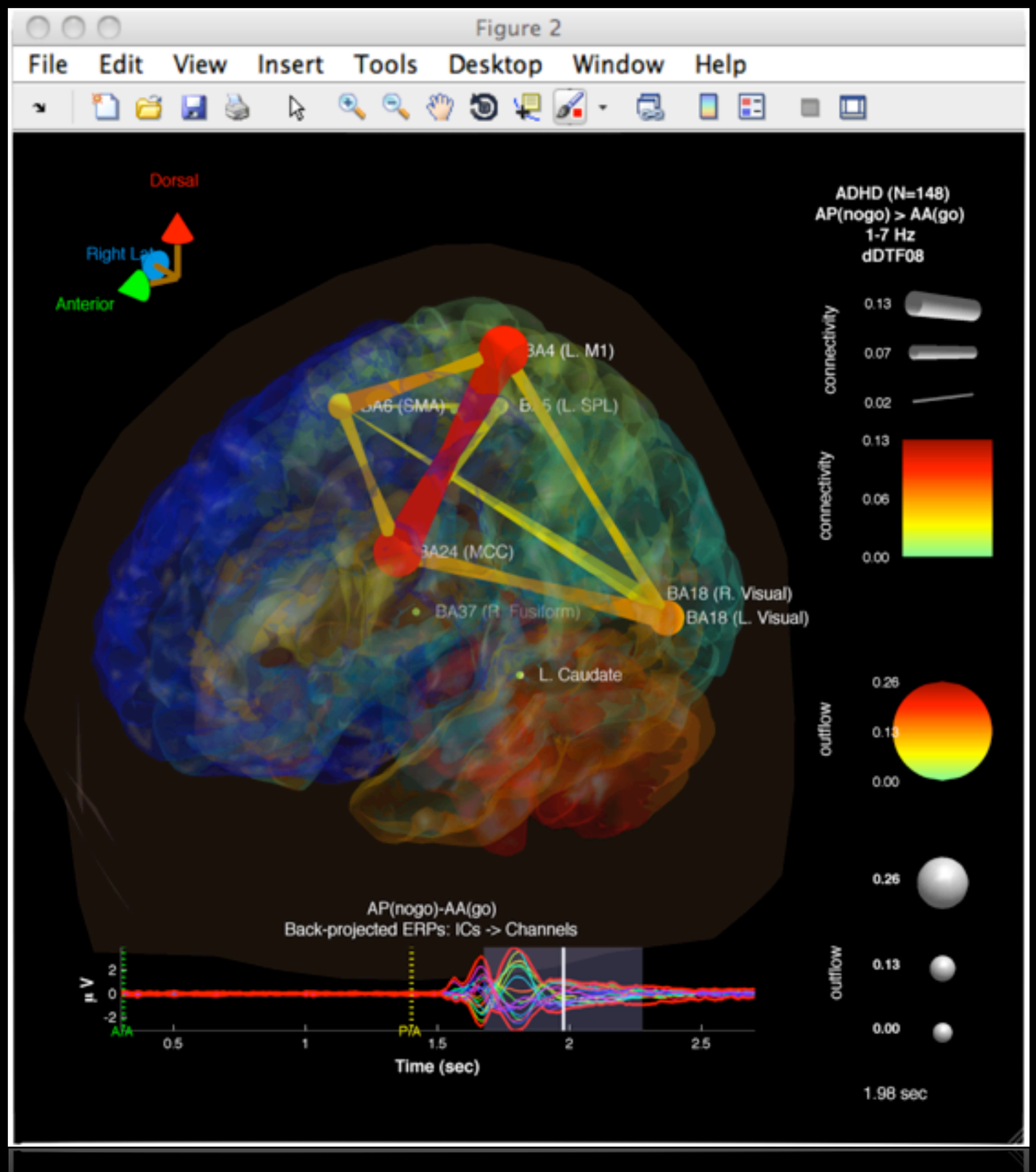


Interactive Time-Frequency Grid



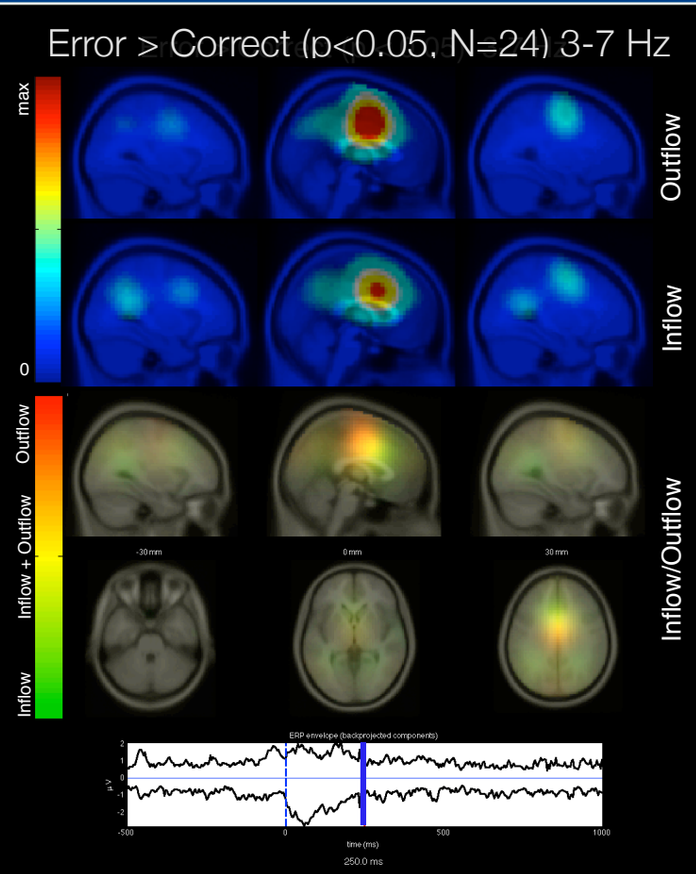
Interactive Causal BrainMovie3D





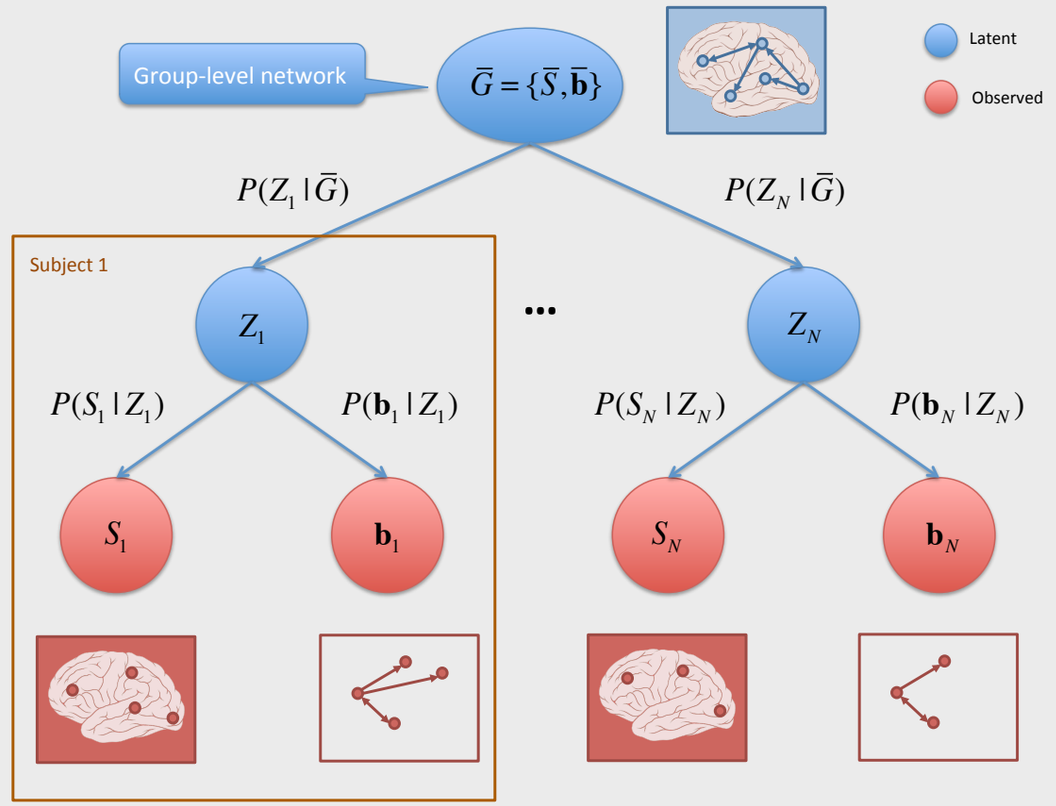
Group Analysis (beta)

Causal/Measure Projection



Mullen, et al, 2010, HBM, Barcelona
Bigdely-Shamlo, et al, 2013, *NeuroImage*

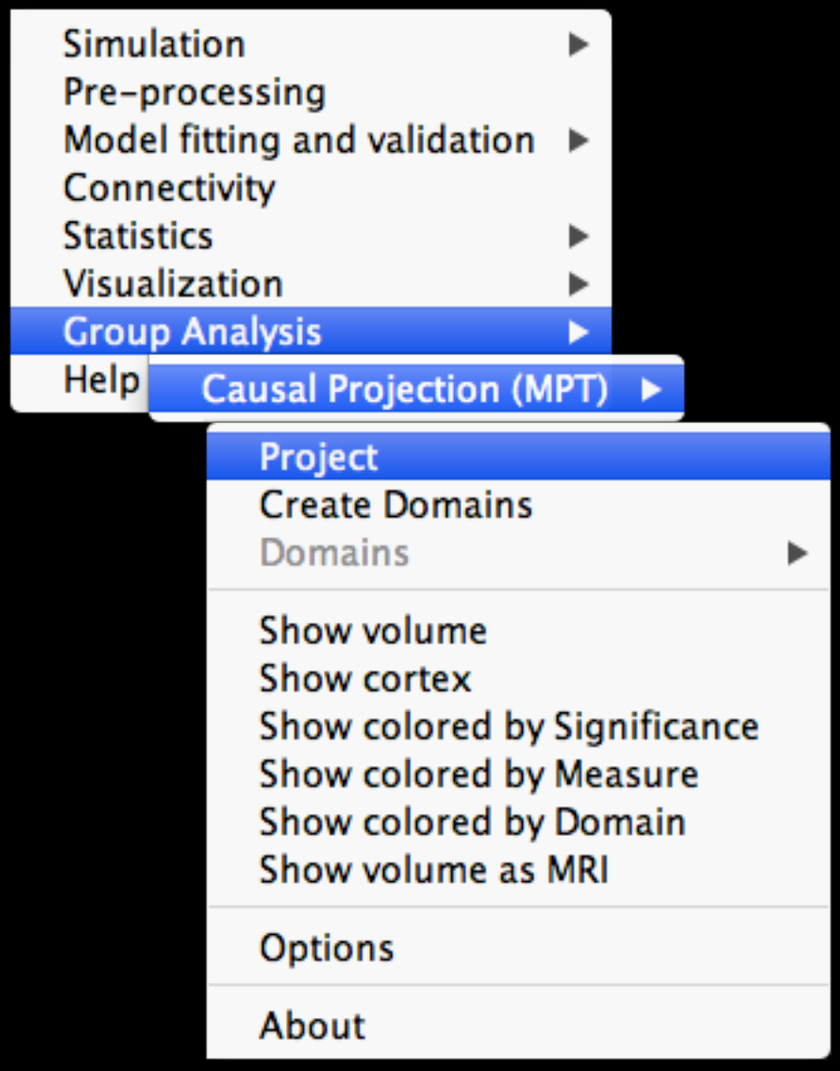
Bayesian Hierarchical Model

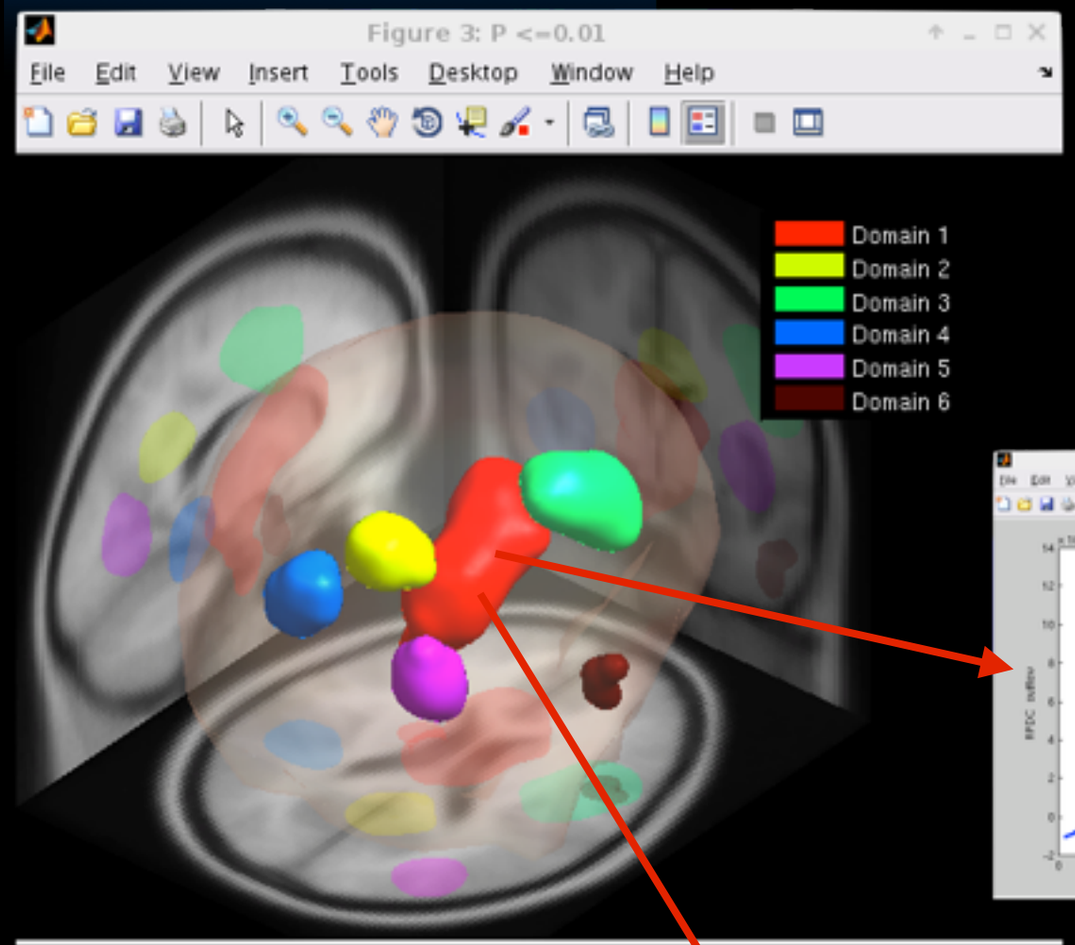


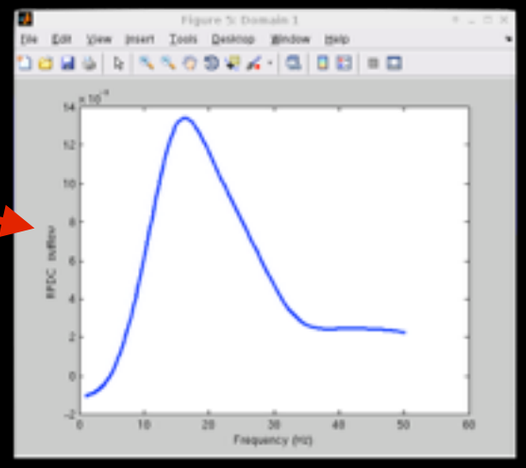
Thompson, Mullen, Makeig, 2011, ICONXI
Thompson, Mullen, Makeig, 2012, *in prep*

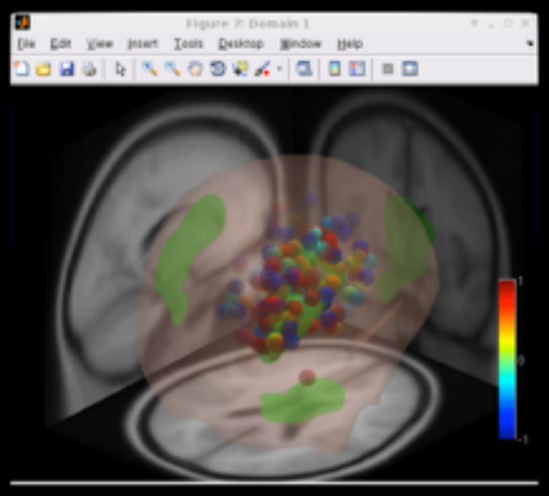
Group Analysis (beta)

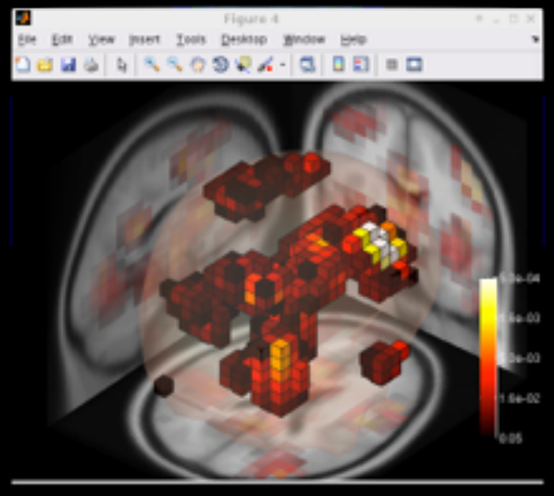
Measure Projection Toolbox

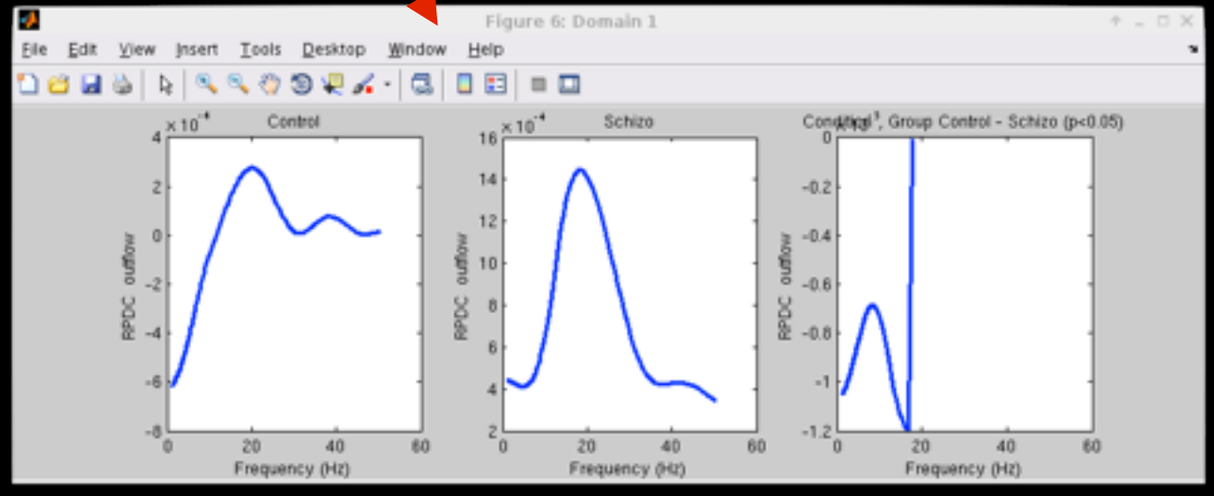








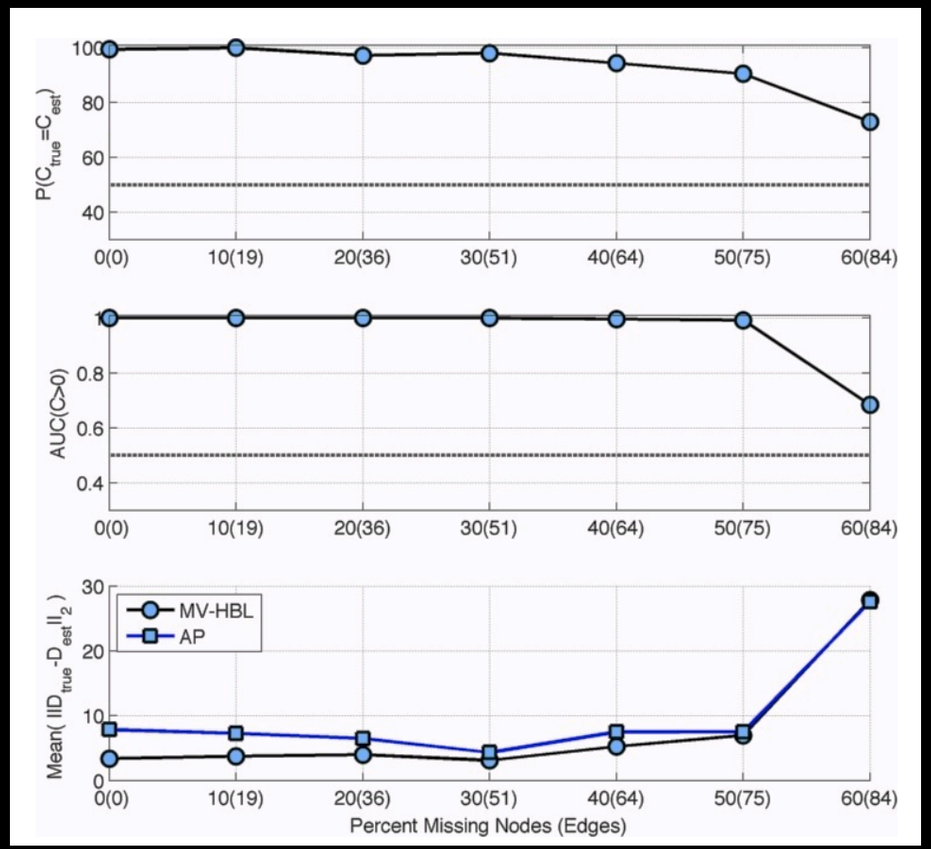


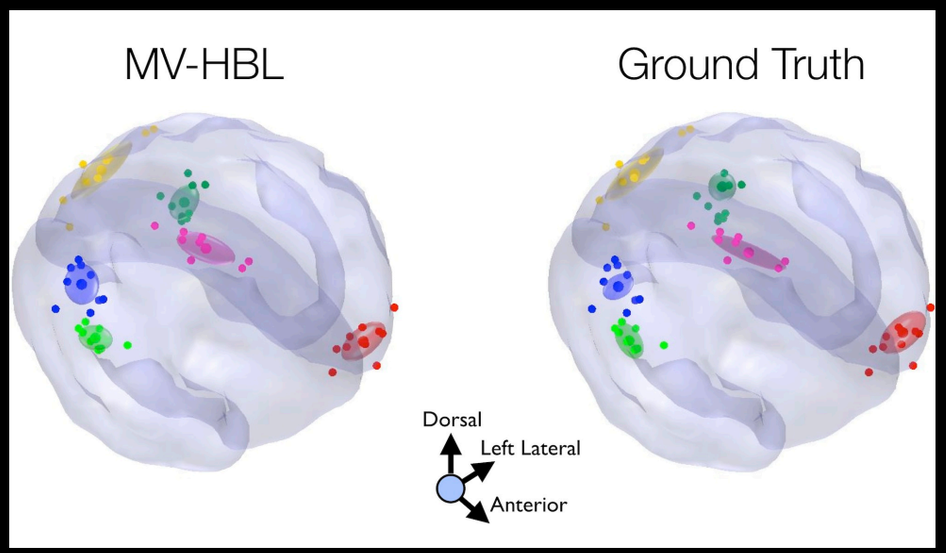


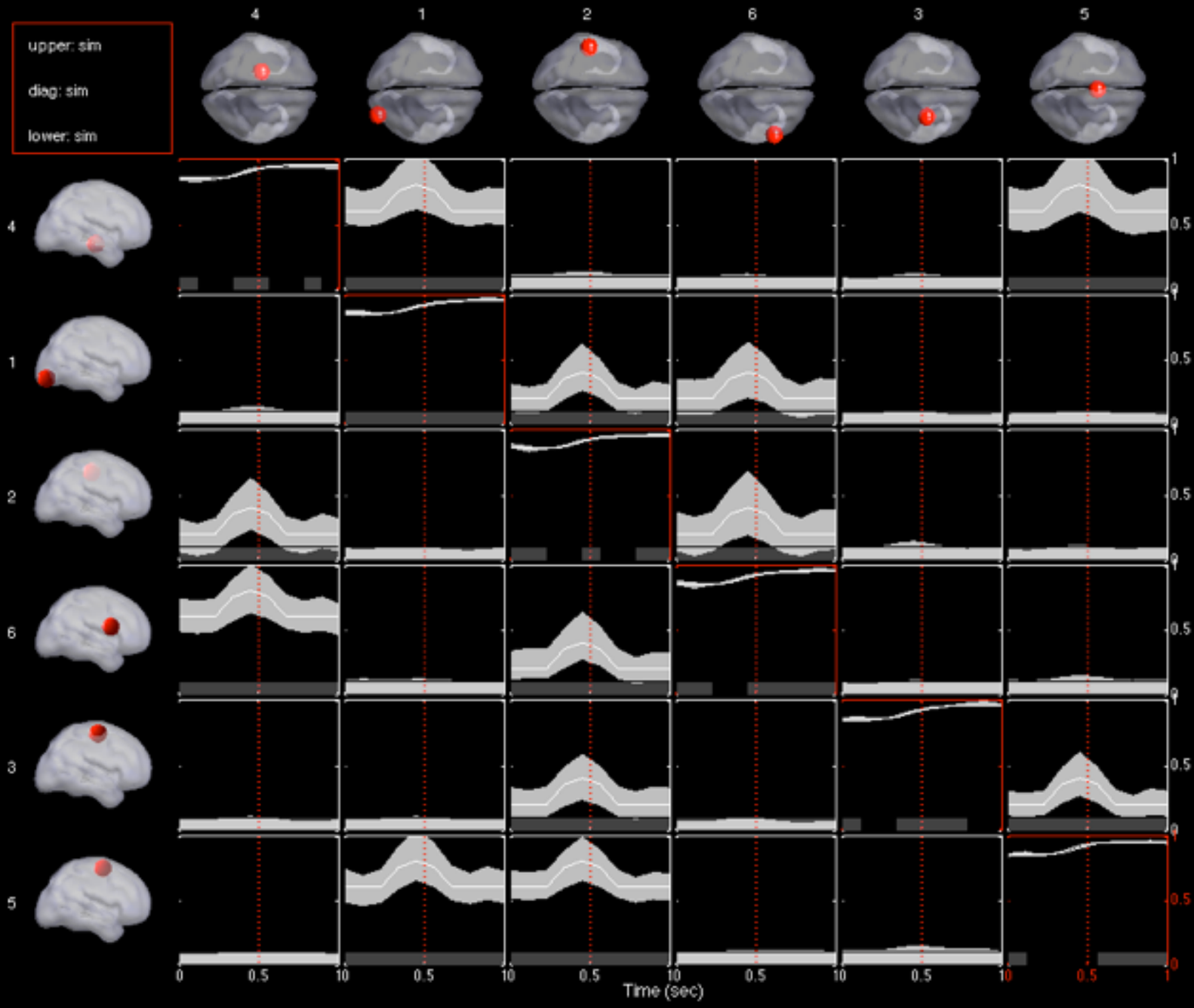
MV-HBL

Sim: 10 Subjects, 30% missing dipoles

Estimated 95% CI (gray) with Ground Truth Superimposed (white)







Est = True ($p < 0.05$)

Est. 95% CI

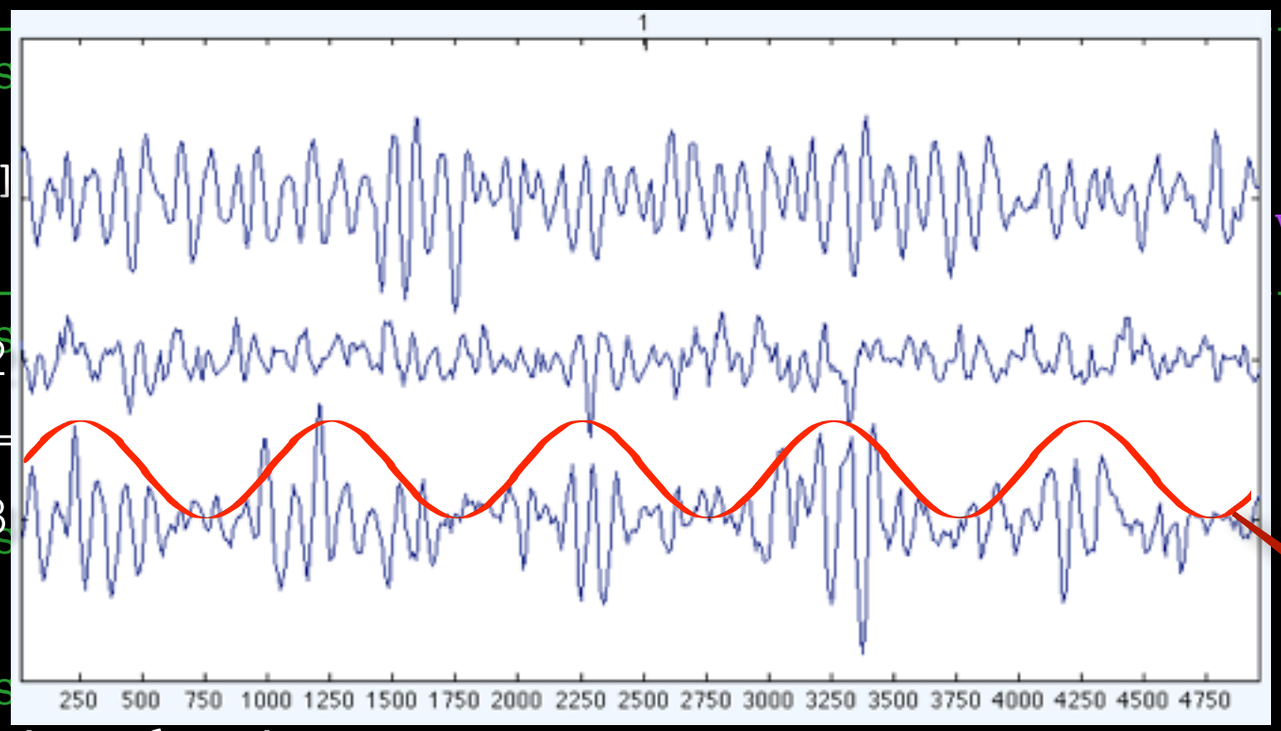
Simulation

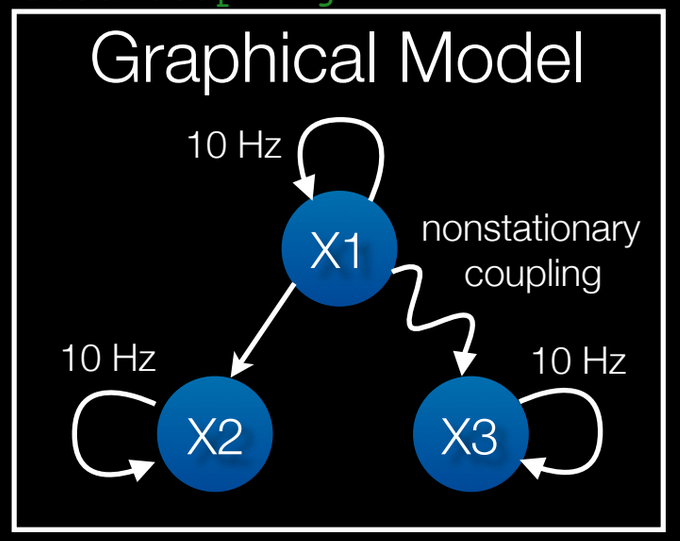
Dynamical System Simulation Workbench

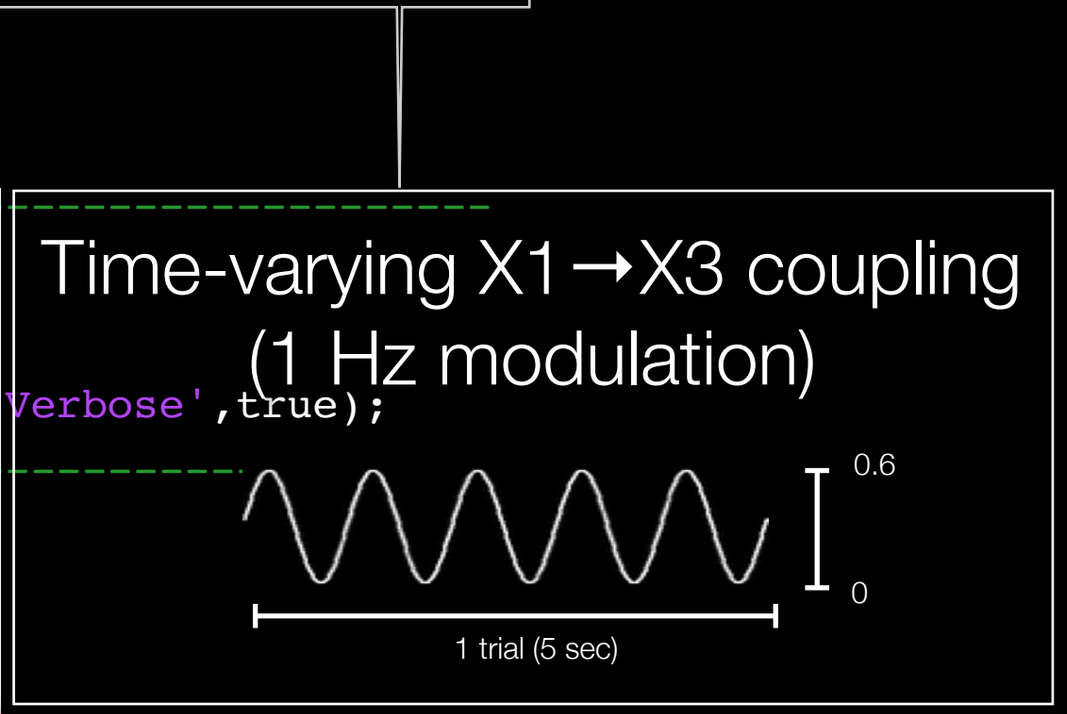
- Realistic source dynamics
  - Systems of linear stochastically-forced damped coupled oscillators
    - Support for arbitrary time-varying (non-stationary) coupling dynamics
    - Intuitive equation-based model definition
    - Support for generalized gaussian or hyperbolic secant innovations
  - Nonlinear Dynamical Systems
    - Rössler and Lorenz Systems
- Realistic scalp EEG generation through forward head model
  - Convenient source definitions via cortical atlas (Mobilab Object)

```
% Example: Trivariate damped coupled oscillators with sinusoidally-modulated coupling
% ------------------------------------------------------------------------
% STEP 1: create prototype VAR structure

Fs = 100;                   % Sampling Rate (Hz)
Nl = 500;                   % length of each epoch (samples)
Nr = 100;                   % number of trials (realizations)
ndisc = 1000;               % number of startup samples to discard
ModelOrder = 2;             % model order
f0 = 10;                    % central oscillation frequency (Hz)

expr = {...
    ['x1(t) = ' sim_dampedOscillator(f0,9,Fs,1) '                                  + e1(t)'] ...
    ['x2(t) = ' sim_dampedOscillator(f0,2,Fs,2) ' + -0.1*x1(t-2)                   + e2(t)'] ...
    ['x3(t) = ' sim_dampedOscillator(f0,2,Fs,3) ' + {0.3*sin(2*pi*t/100)+0.3}*x1(t-2) + e3(t)'] ...
};

Aproto = sim_genVARModelFromEq(expr,ModelOrder);

% ------------------------------------------------------------------------
% S
[A]
X1
% ------------------------------------------------------------------------
% S
X2
M =
X3
% S
Mu
% S
sigma = 1;
E = sigma*eye(M);

% generate simulated data with laplacian (supergaussian) innovations
data = sim_tvarsim(Mu,A,E,[Nl Nr],ndisc,1,1,'gengauss');
```

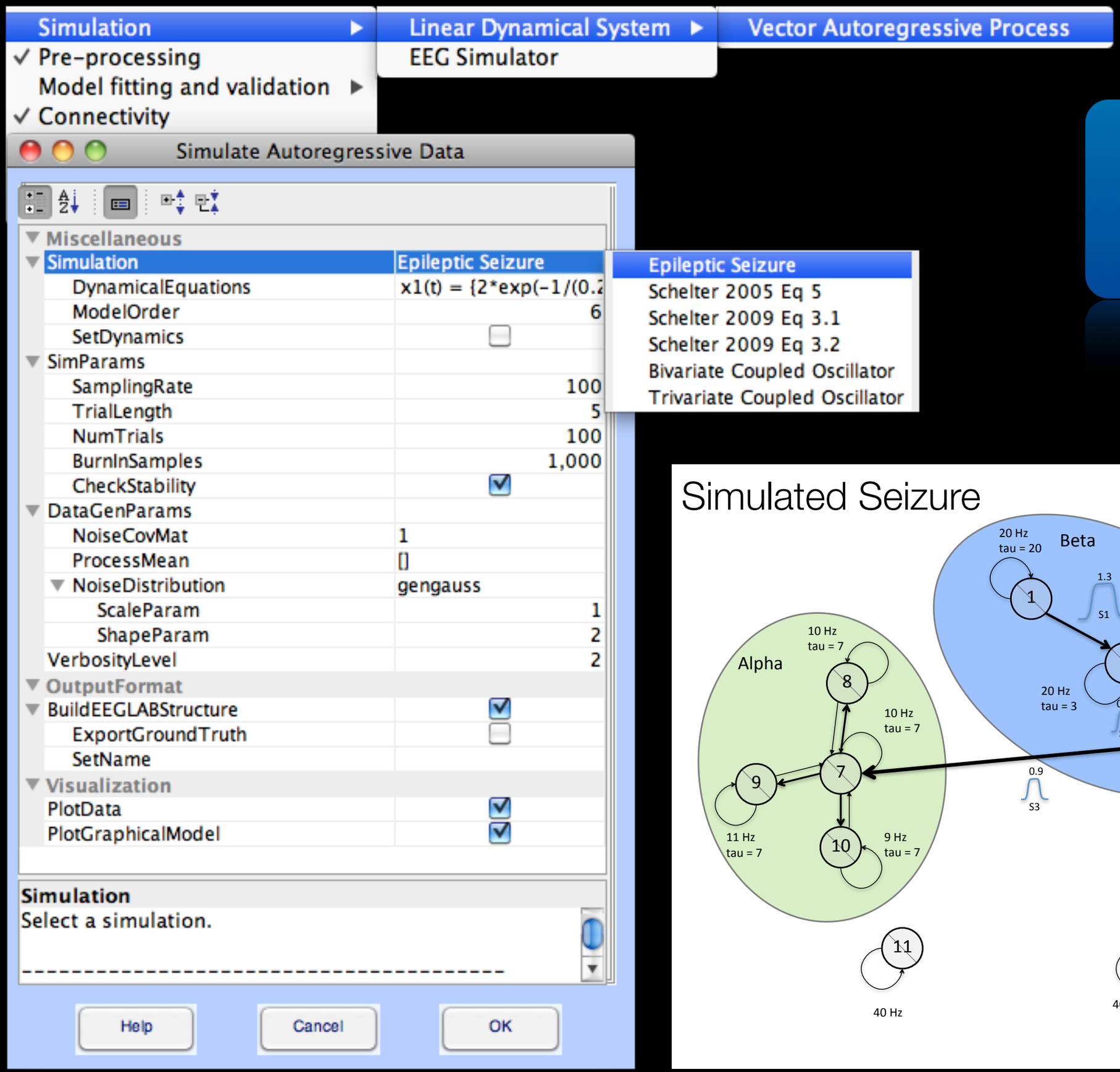
Verbose',true);







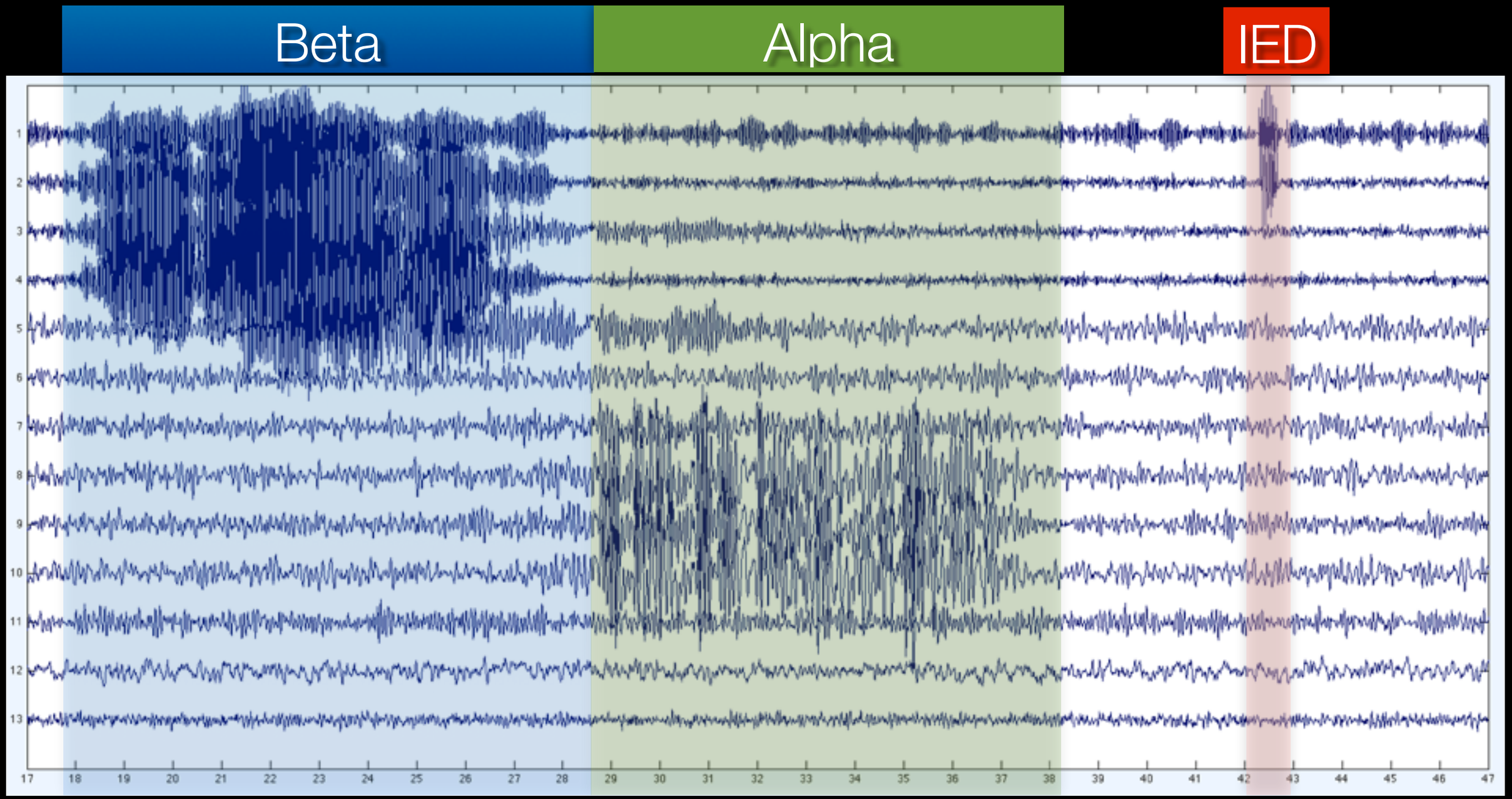
Amplitude Modulation (PAC)

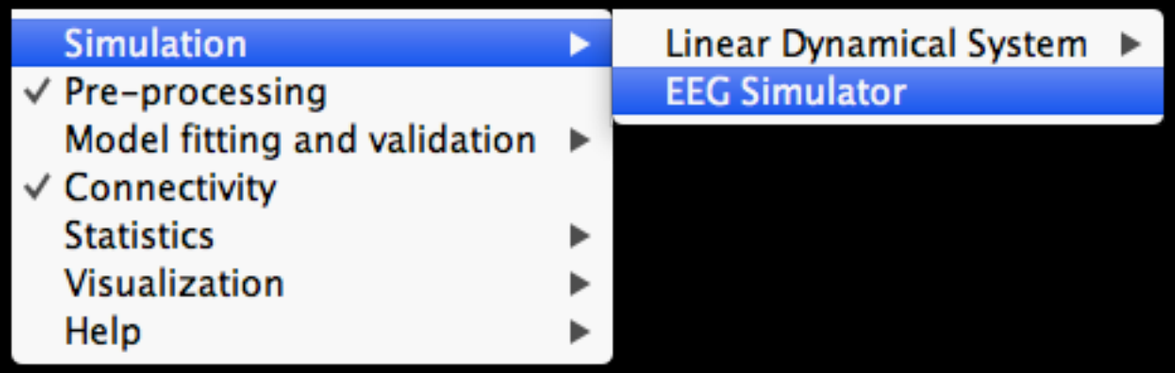


Simulation

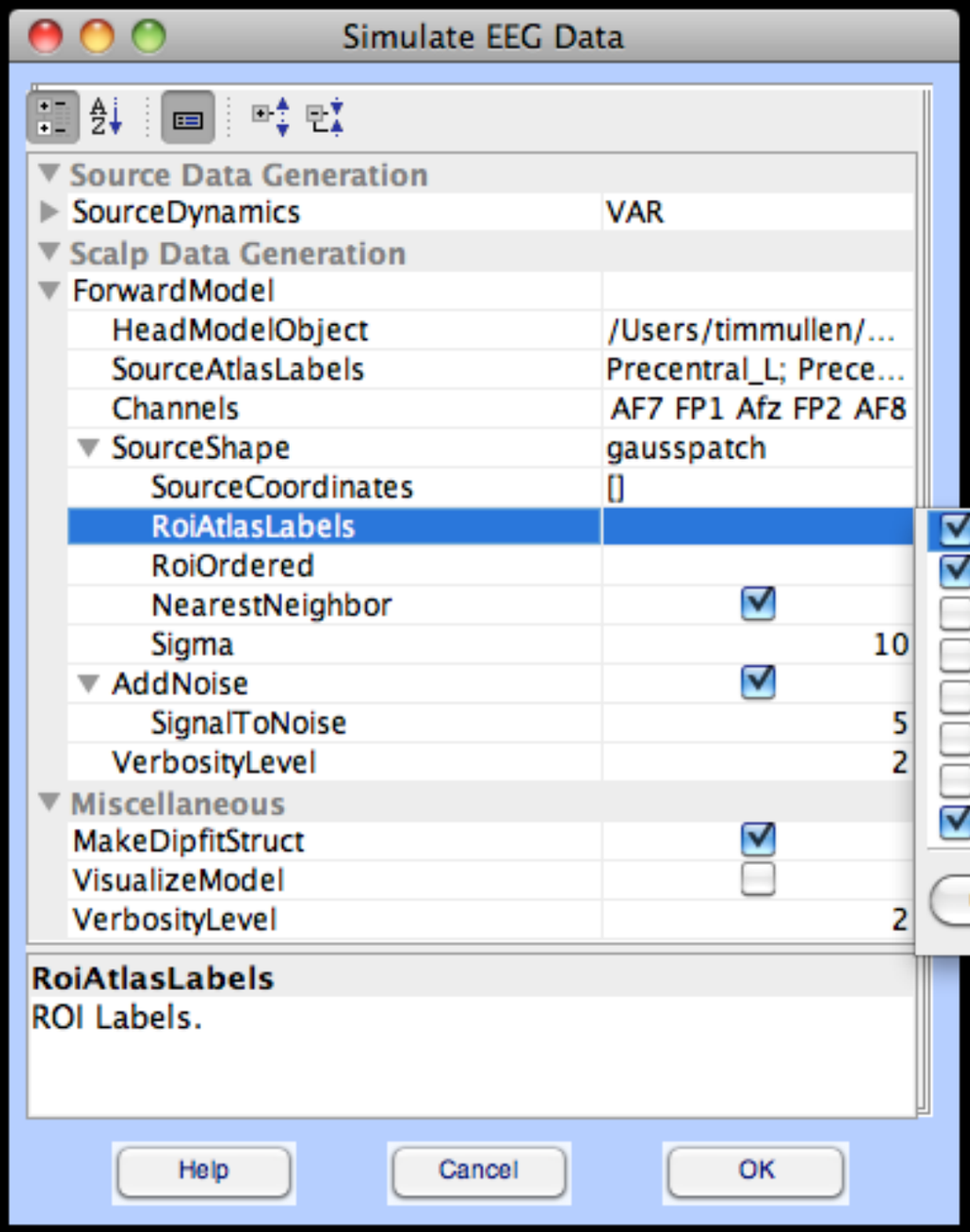
Simulated Seizure

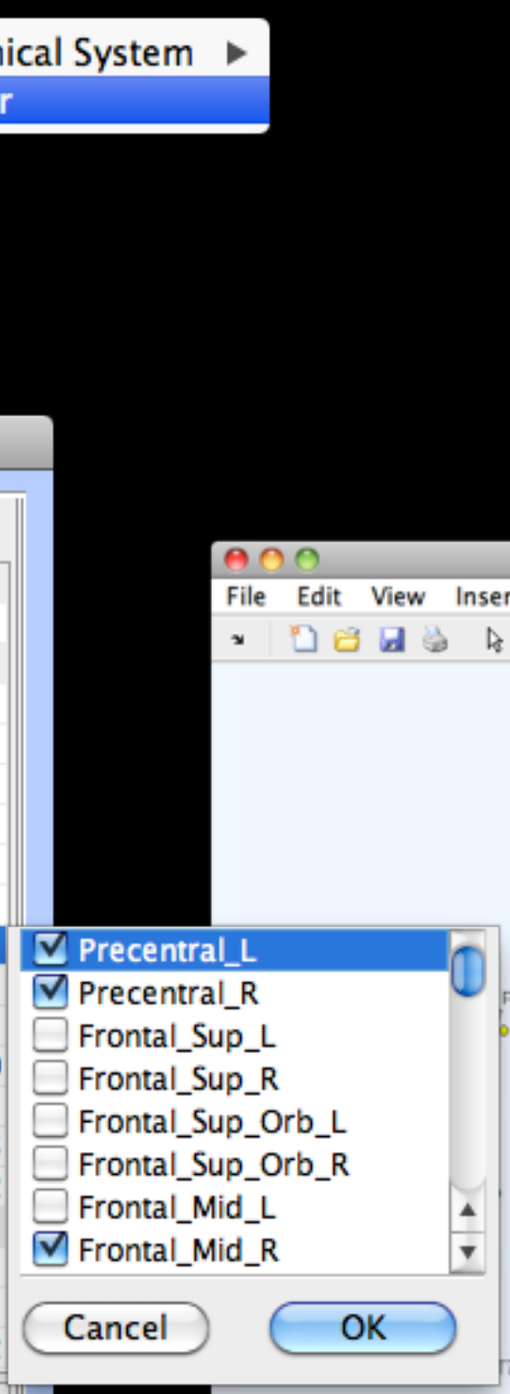
Simulated Seizure Sources




Simulation
Pre-processing
Model fitting and validation
Connectivity
Statistics
Visualization
Help
Linear Dynamical System
EEG Simulator

Simulation


Simulate EEG Data
Source Data Generation
SourceDynamics VAR
Scalp Data Generation
ForwardModel
HeadModelObject /Users/timmullen/...
SourceAtlasLabels Precentral_L; Prece...
Channels AF7 FP1 Afz FP2 AF8
SourceShape gausspatch
SourceCoordinates []
RoiAtlasLabels
RoiOrdered
NearestNeighbor
Sigma 10
AddNoise
SignalToNoise 5
VerbosityLevel 2
Miscellaneous
MakeDipfitStruct
VisualizeModel
VerbosityLevel 2
RoiAtlasLabels
ROI Labels.
Help
Cancel
OK


Precentral_L
Precentral_R
Frontal_Sup_L
Frontal_Sup_R
Frontal_Sup_Orb_L
Frontal_Sup_Orb_R
Frontal_Mid_L
Frontal_Mid_R
Cancel
OK

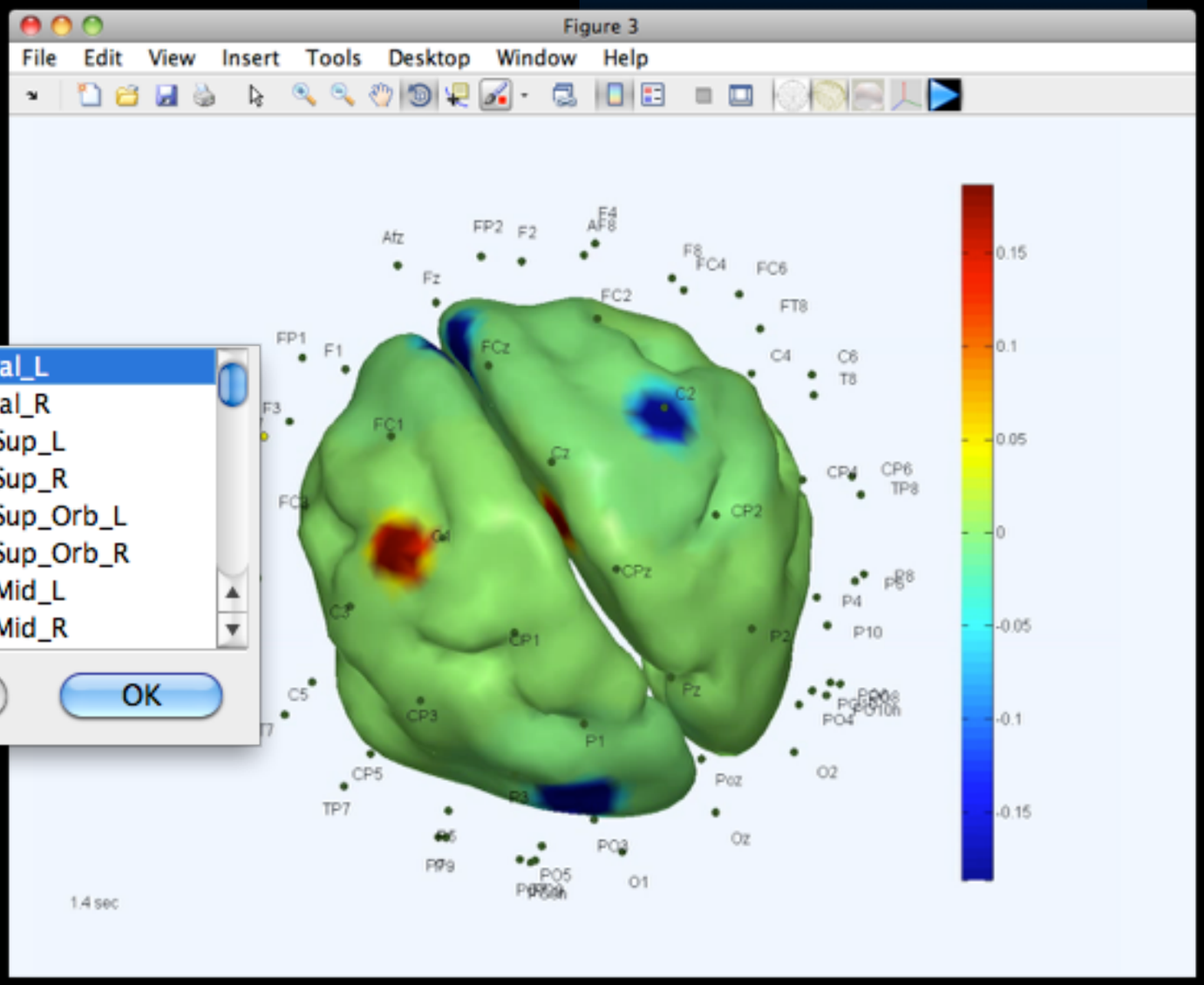


Figure 3
File Edit View Insert Tools Desktop Window Help
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
1.4 sec

Distribution and Educational Resources

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- Online EEGLAB Workshop
- Download EEGLAB
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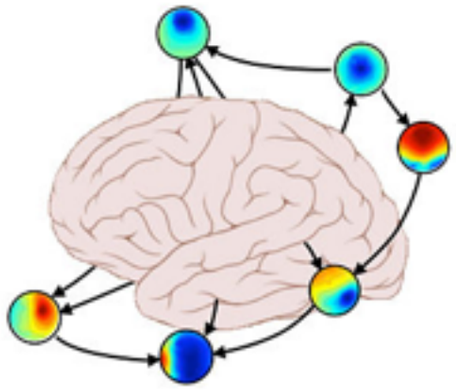
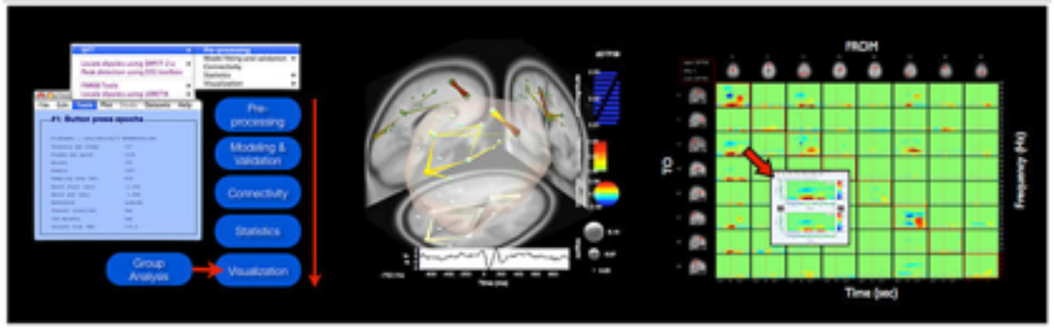
SIFT





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Welcome to the repository for the Source Information Flow Toolbox (SIFT)

Developed and Maintained by: Tim Mullen (SCCN, INC, UCSD)
Web: http://www.antillipsi.net
Email: <Tim's first name> (at) sccn (dot) ucsd (dot) edu

SIFT is an EEGLAB-compatible toolbox for analysis and visualization of multivariate causality and information flow between sources of electrophysiological (EEG/ECoG/MEG) activity. It consists of a suite of command-line functions with an integrated Graphical User Interface for easy access to multiple features. There are currently four modules: data preprocessing, model fitting and connectivity estimation, statistical analysis, and visualization

SIFT Online Handbook and User Manual

A video-lecture on the (very) basic theory of application of SIFT to modeling distributed brain dynamics in EEG is available he

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Can also get from EEGLAB Plugin Manager or NITRC.org