Brain Dynamics: From Σ to $

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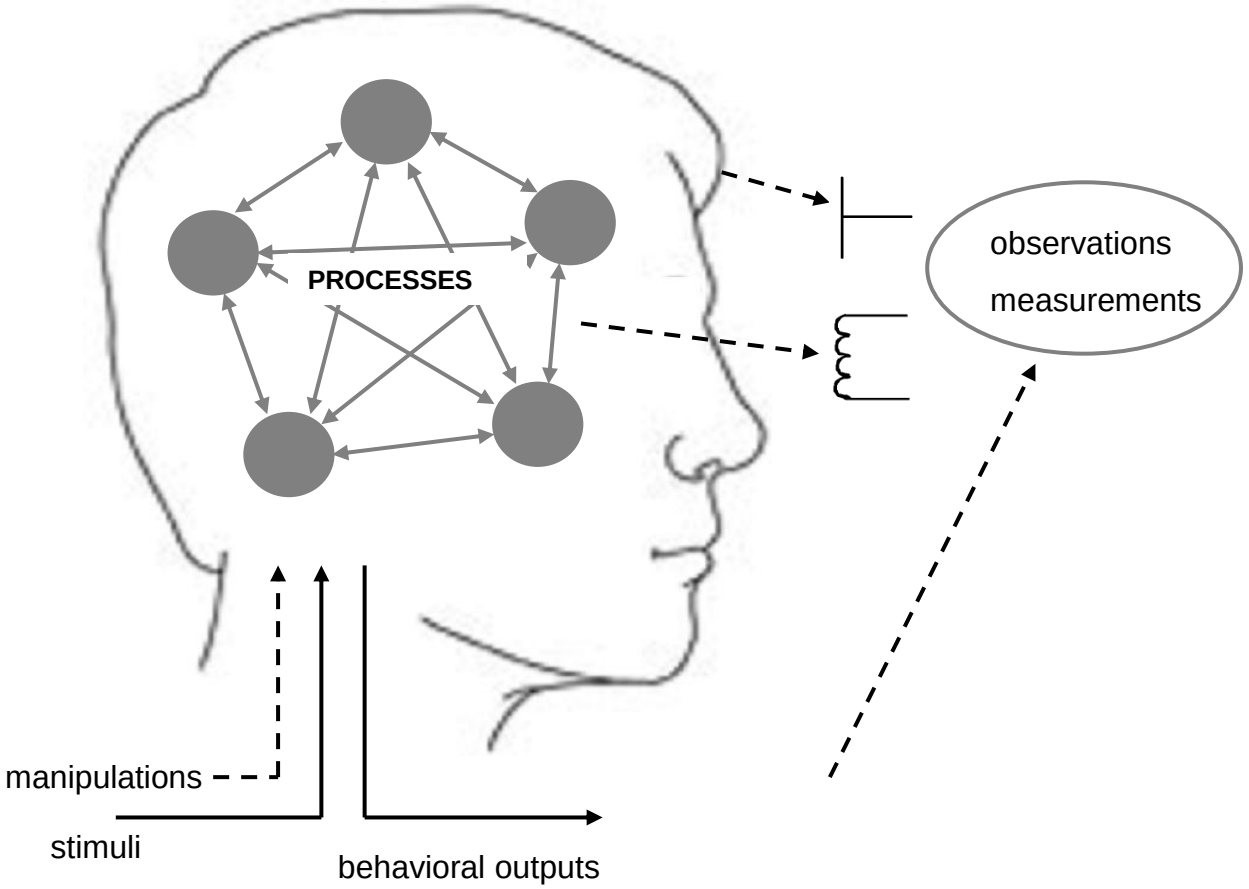
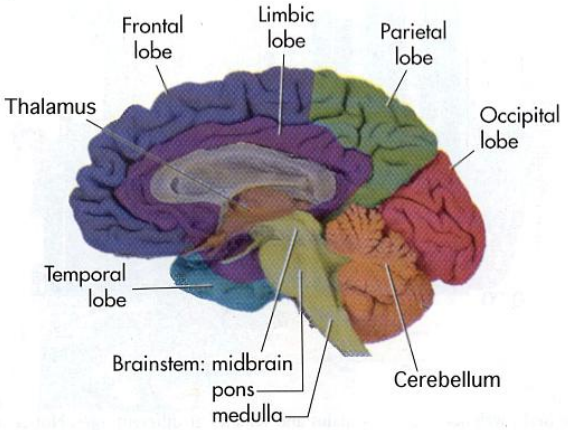
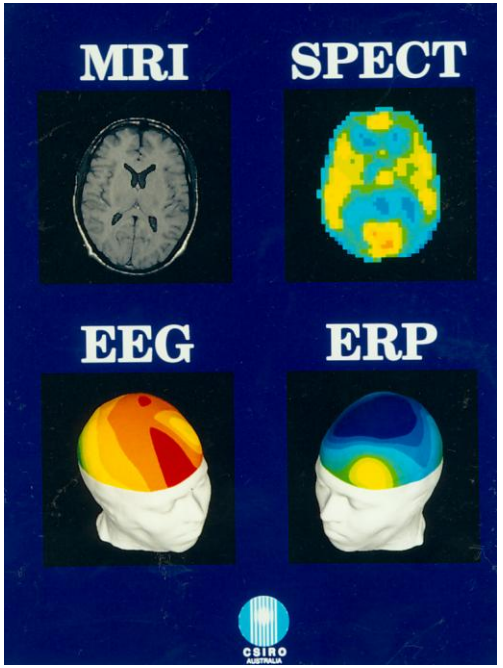
The Need for Integration







- **stimulus – activity – measurement** chain
- both directions: **observation** and **control**
- must combine multiple scales and modalities

The Integration Challenge

- Need to interrelate many kinds of observations
- Need to deal with many phenomena in a unified way
- Seek testable quantitative predictions
- Theories should be as simple as possible,
  but no simpler (Einstein)
- A balancing act between detail and tractability.

Neurons

- **Synapses**: Receive signals from other neurons via chemical neurotransmitters.
  - Approximate via rate constants.

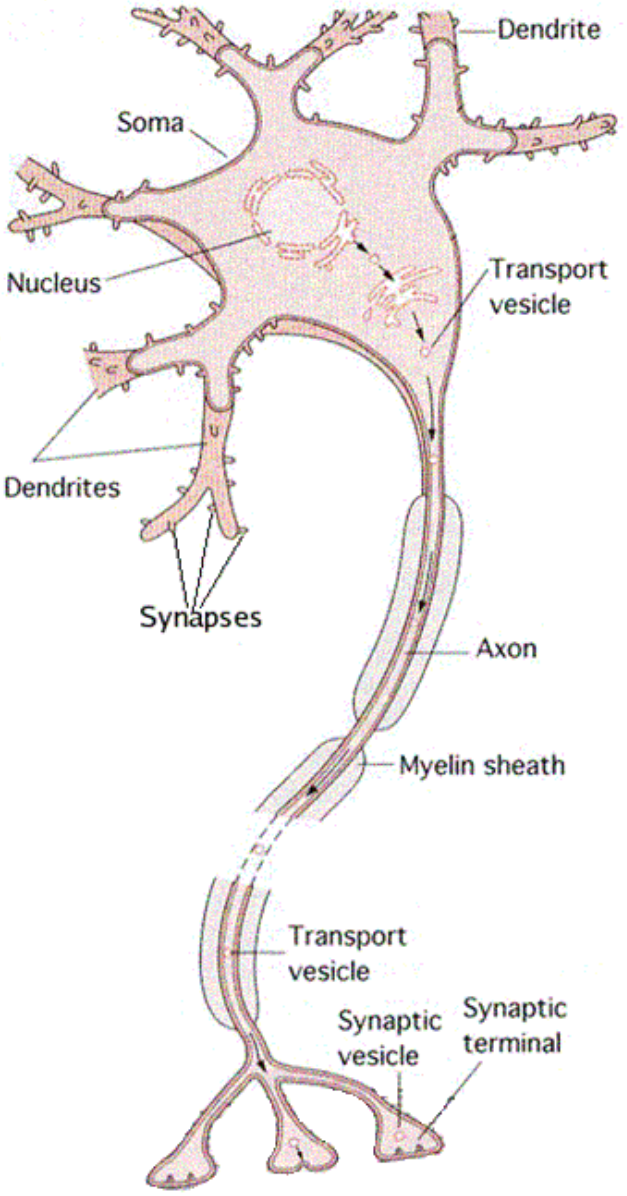
- **Dendrites**: Carry voltage changes to cell body.
  - Approximate spreading in dendritic cables.

- **Cell Body**: Voltage increments sum.
  - Weighted linear sum.

- **Axonal Hillock**: Voltage spikes above threshold.
  - Approximate population average as a sigmoid.

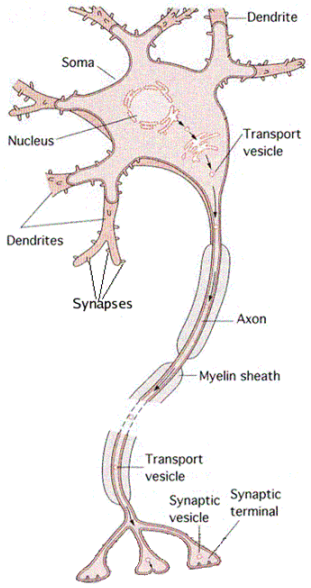
- **Axon**: Carries voltage spikes to axon terminals.
  - Damped wave propagation in population.

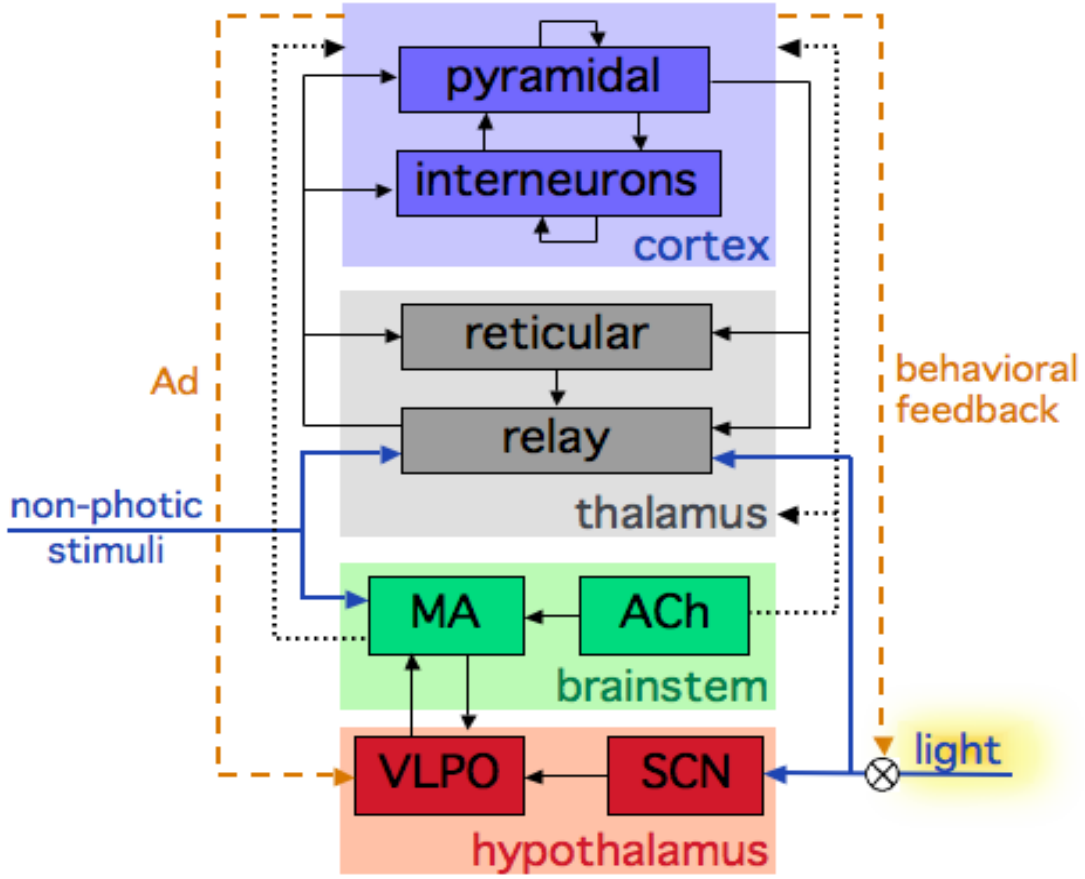
- **Axon terminals**: Synapses signal other neurons.



"Working Brain" Model via Neural Field Theory

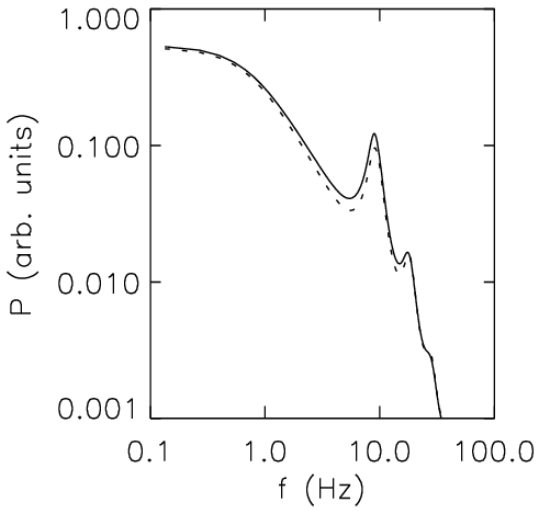
- **Neural Field Theory** at scales >0.1 mm.
- Can retain key anatomy/physiology at multiple scales: different neural types, biophysics, nuclei, brain.
- Doesn't track individual neurons.
- Anatomical connections between structures.
- Gives partial differential equations for fields.
- Measurable parameters and predictions.

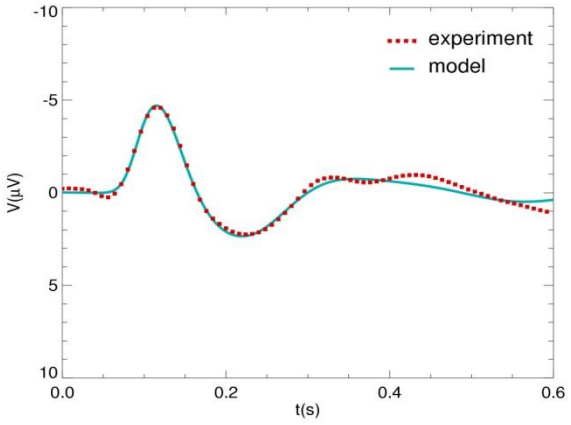


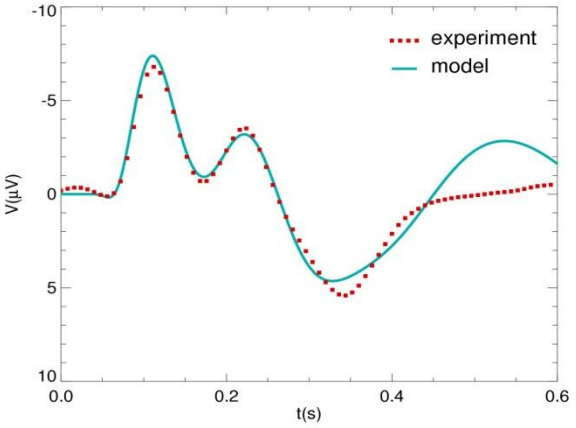


Predictions vs. Experiment

- Small perturbations from steady states are linearly proportional to stimuli.
- Linear perturbations yield EEG spectra and ERPs as responses to white-noise and impulse inputs, respectively.

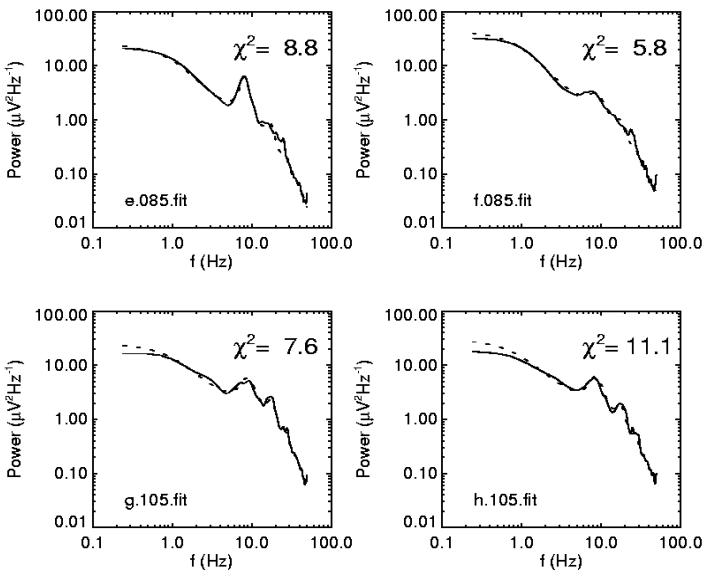


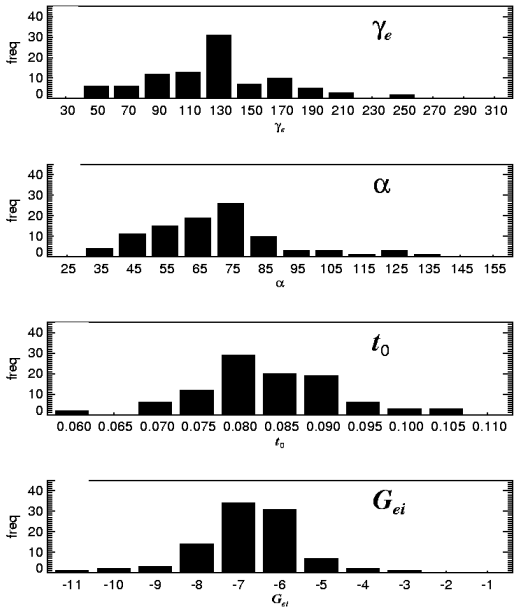




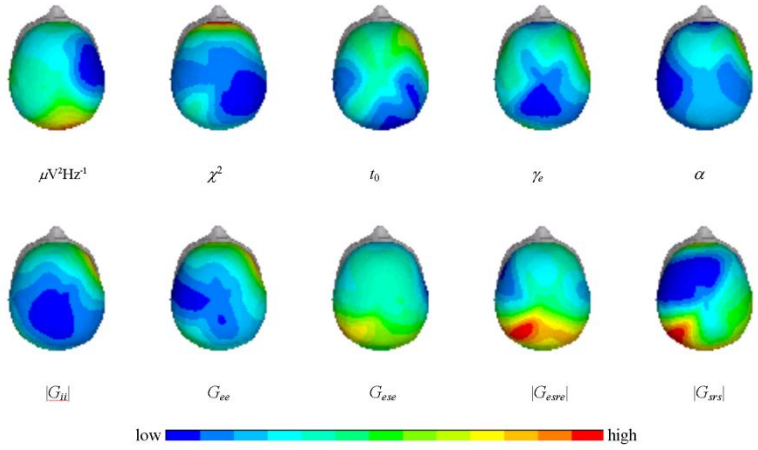
Inversion

- Fitting predictions to data yields best estimates of parameters for **individuals**



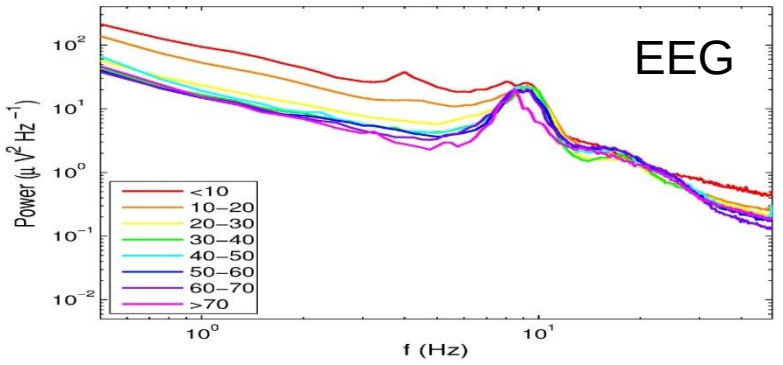


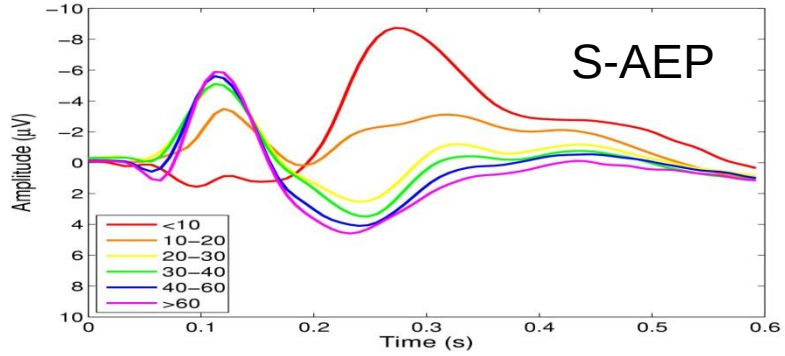
- Can map parameters: a new diagnostic window.

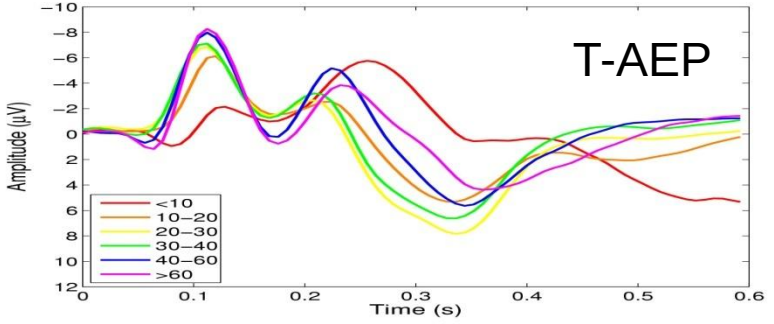


Brain Resource International Database (BRID)

- Database of circa 100 000 subjects, aged 6-86+
- Approx. 50 functional measures per subject + MRI.
- Excellent statistics.
- Labs in circa 10 countries.
- First fully standardized international brain function database.
- Access via **www.brainnet.org.au**.
- 300 affiliated researchers
- BR floated on ASX: Market Cap = $33M, 40 employees, profit making: www.brainresource.com.

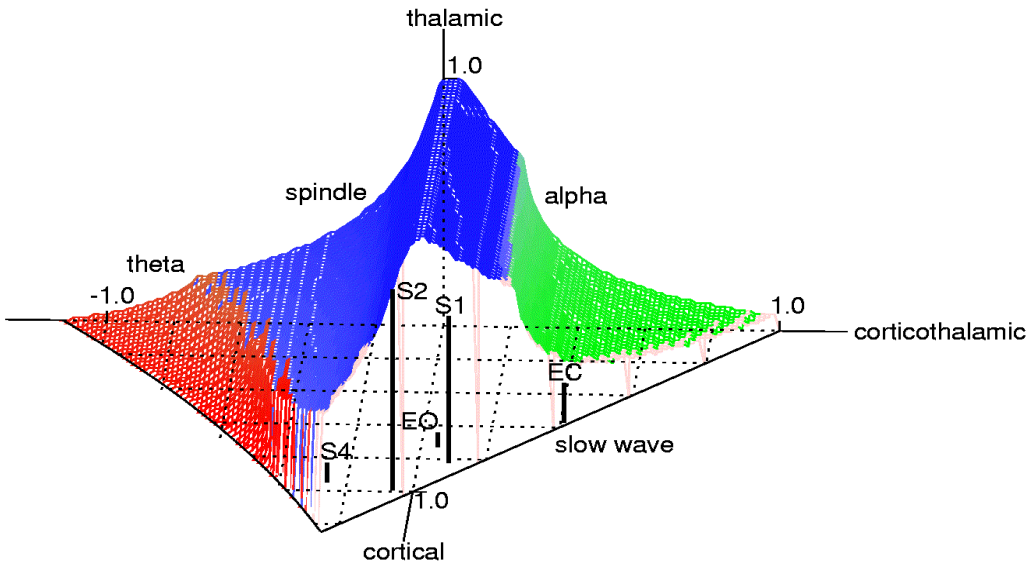


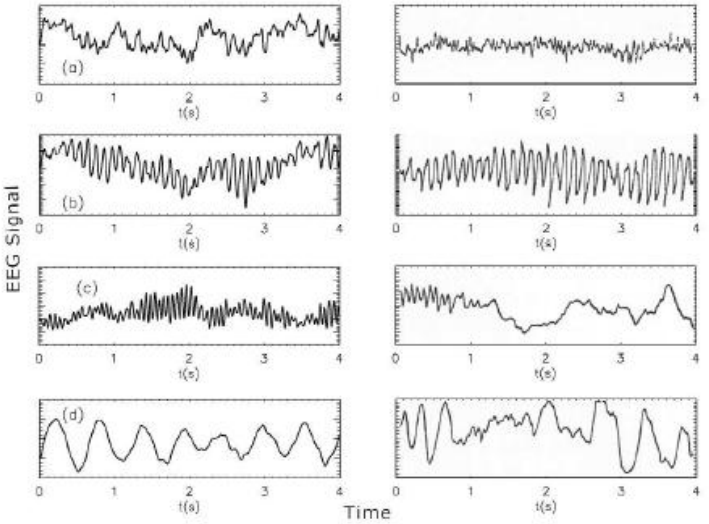


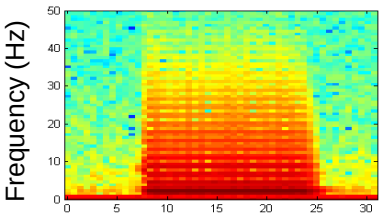


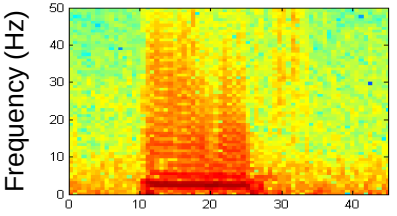
States, Stability, Seizures

- Patent on inversion methods
- Real-time state tracking device pending
- Applications to alertness, seizures
- Nonlinear dynamics via NFT

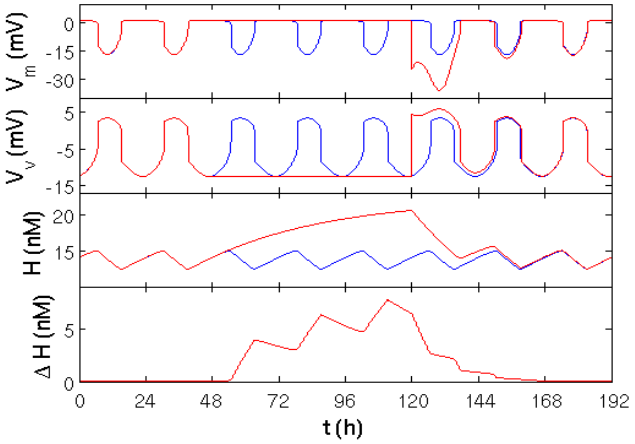


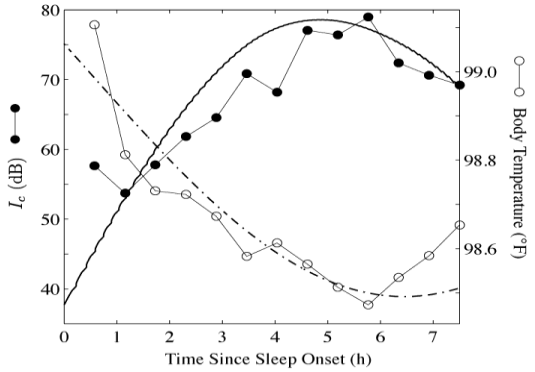


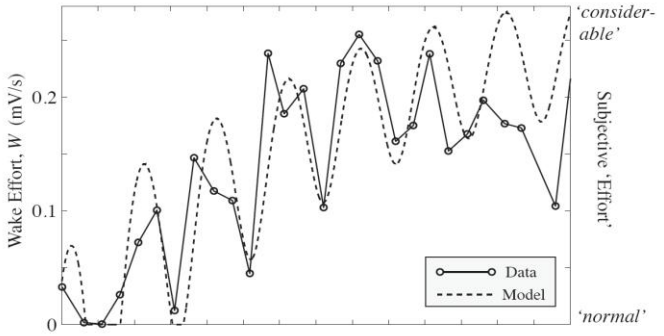


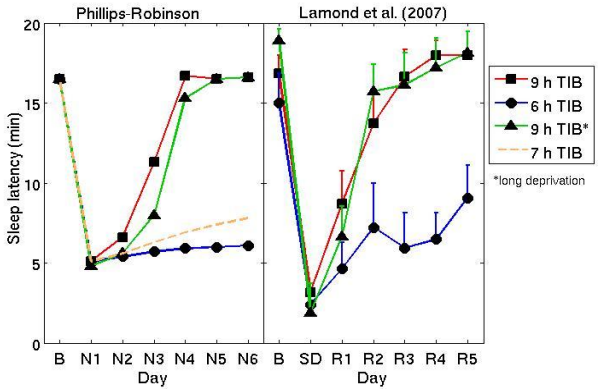


Sleep Dynamics

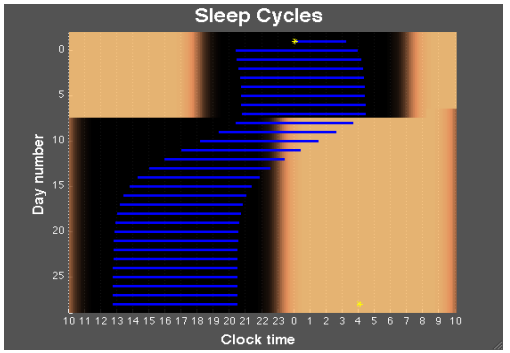


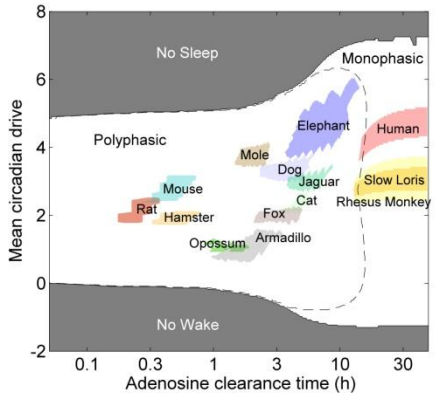


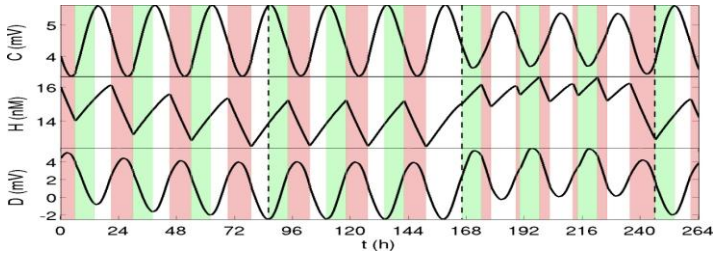


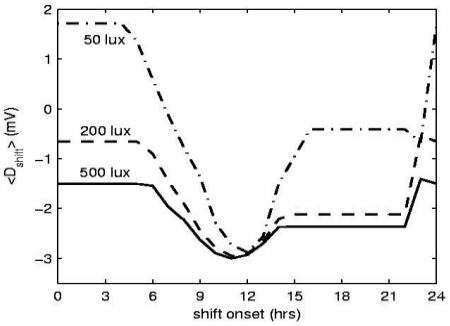


- Arousal thresholds.
- Wake effort/fatigue.
- Performance.
- Sleep latencies.
- Drug effects.
- Circadian, pathologies.
- Jetlag/shiftwork + light.
- Chronotype.
- Other species.
- Alertness monitoring



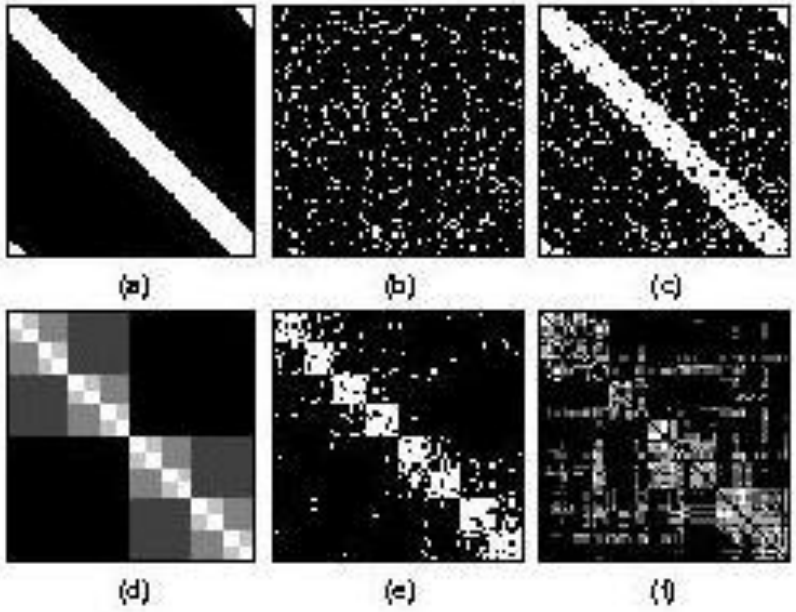


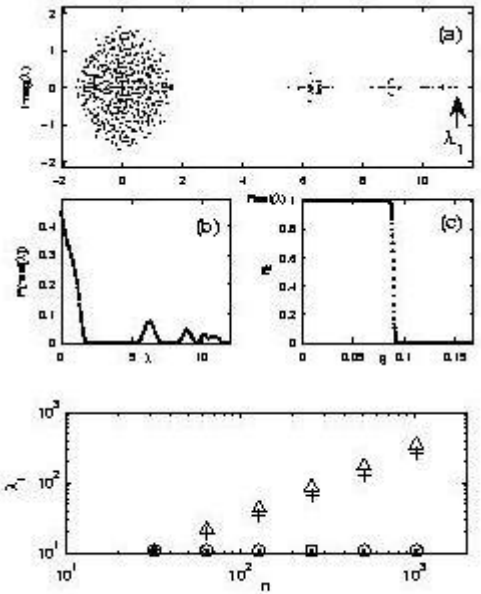




Brain Networks: Dynamical Stability

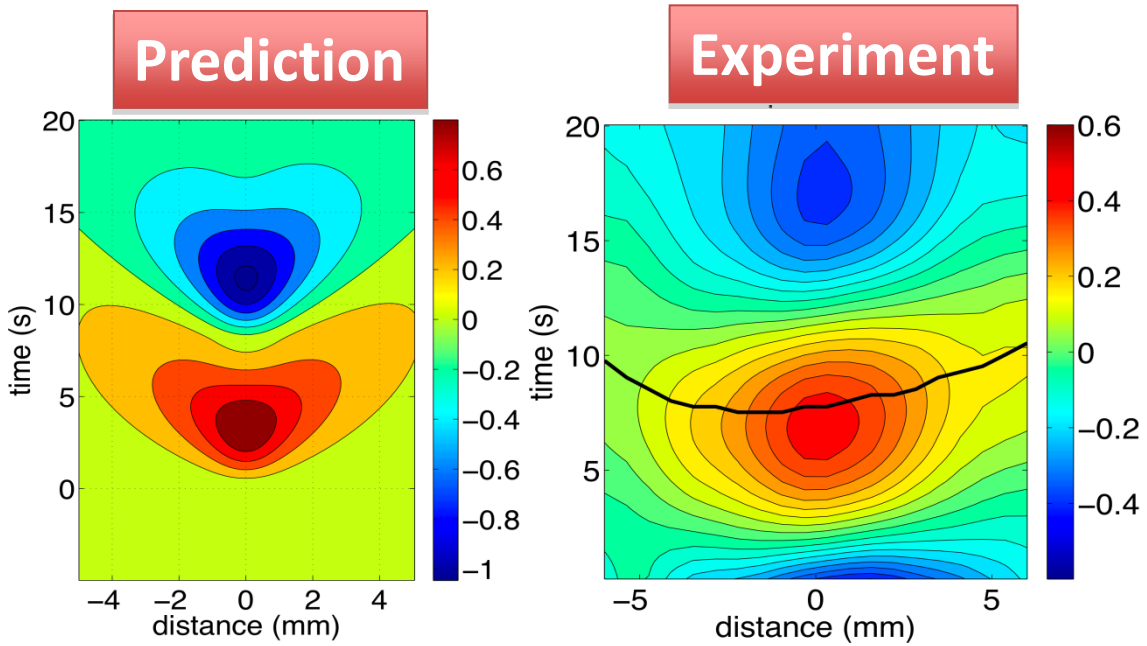
- Brain structures connect and disconnect constantly to carry out tasks.
- **New criteria:** Must occur without changing stability, requiring major numbers of reconnections, or changing the architecture.
- Hierarchical networks satisfy these requirements.
- Could the brain have evolved a different architecture?
- We are investigating network structure and evolution.





fMRI and Hemodynamic Waves

- Theoretical prediction from new poroelastic theory.
- Predict and verify hemodynamic waves.
- **Next:** New ways to improve images; new wave phenomena.



Brain Dynamics

- Ranges over **theory, computation, experimental data, software development, and commercialization.**
- Tackles real-world applications.
- Neural field theory unifies phenomena across scales
- Many successful predictions including:
  - **Steady states, stability, spectra, impulse responses.**
  - **Multimodal imaging: EEG, ERP, fMRI, etc.,**
  - **Nonlinear dynamics: seizures, Parkinson's, driven brain**
  - **State tracking and parameter mapping.**
  - **Alertness dynamics: normal, abnormal, drugs, jetlag, shiftwork, etc.**
  - **Vision, neural plasticity, bursting neurons**
  - **Network dynamics**
- **Current Directions**: Working Brain, State Tracking, NFT fundamentals, Dynamical Networks