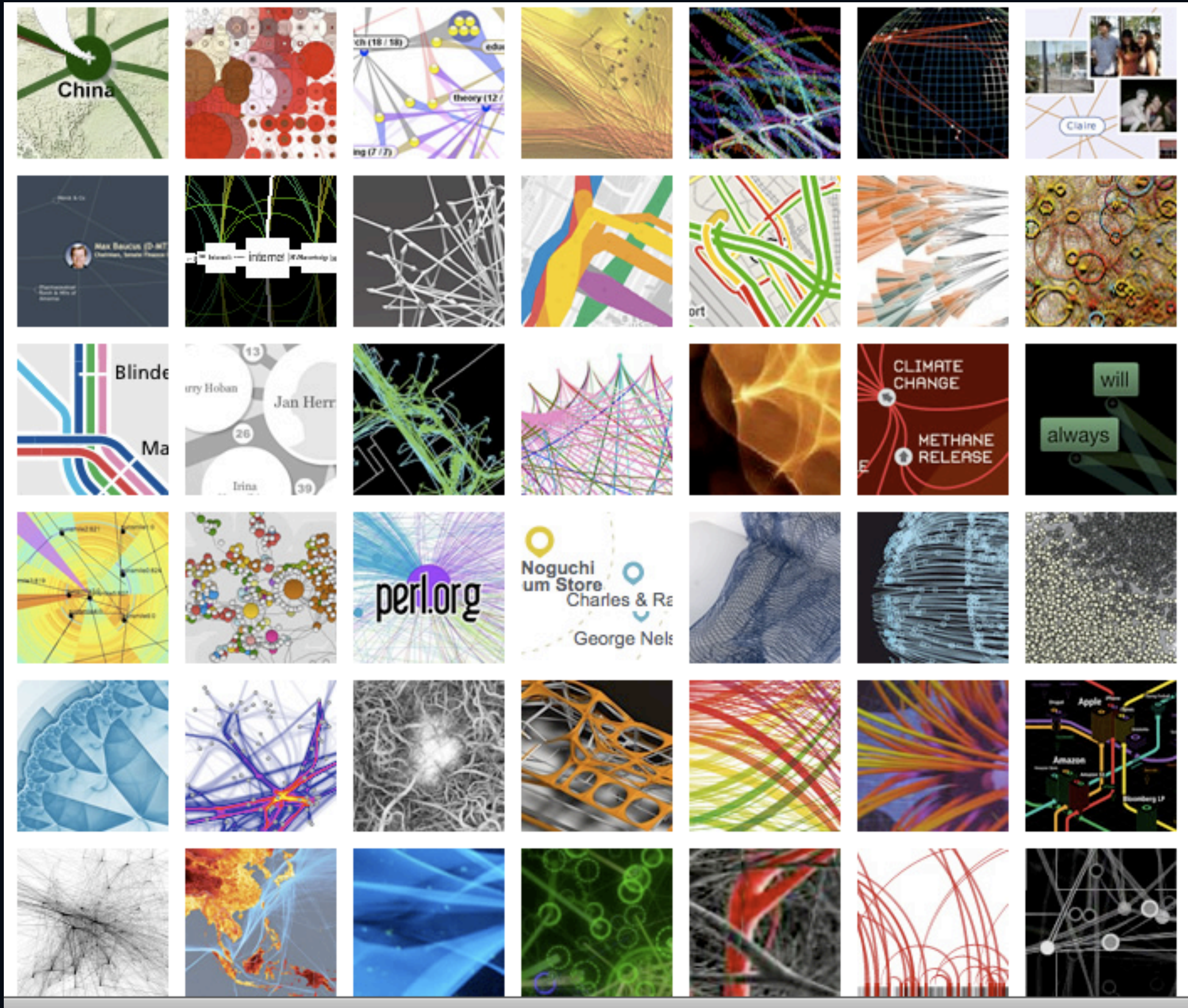
Brain & Spine Institute
CNRS-UMR 7225
Hôpital de la Pitié-Salpêtrière,
Paris, France.

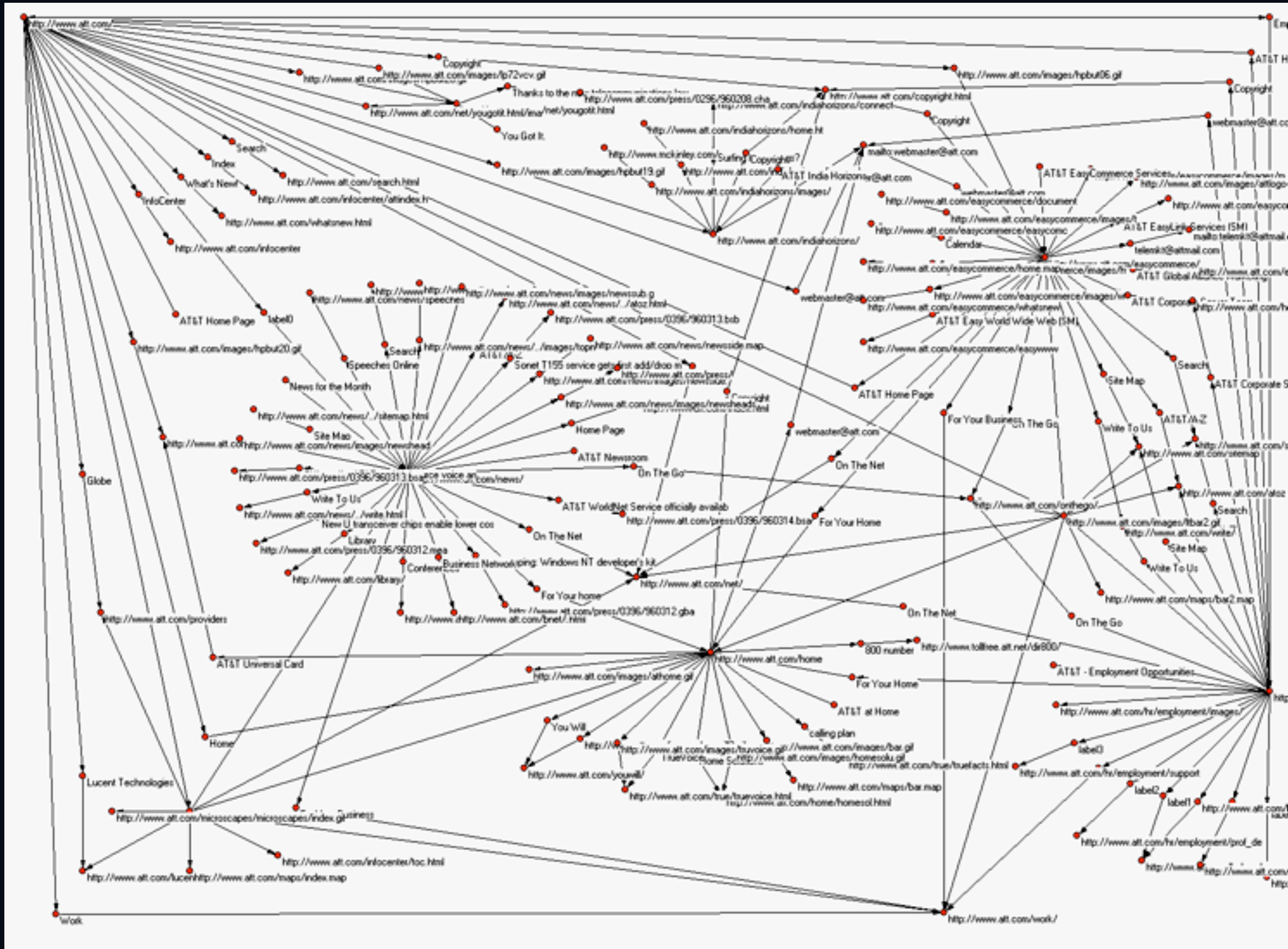
Brain networks: new trends for the analysis of brain dynamics

Mario Chavez

Jussieu, 2011

Different networks-common connectivity

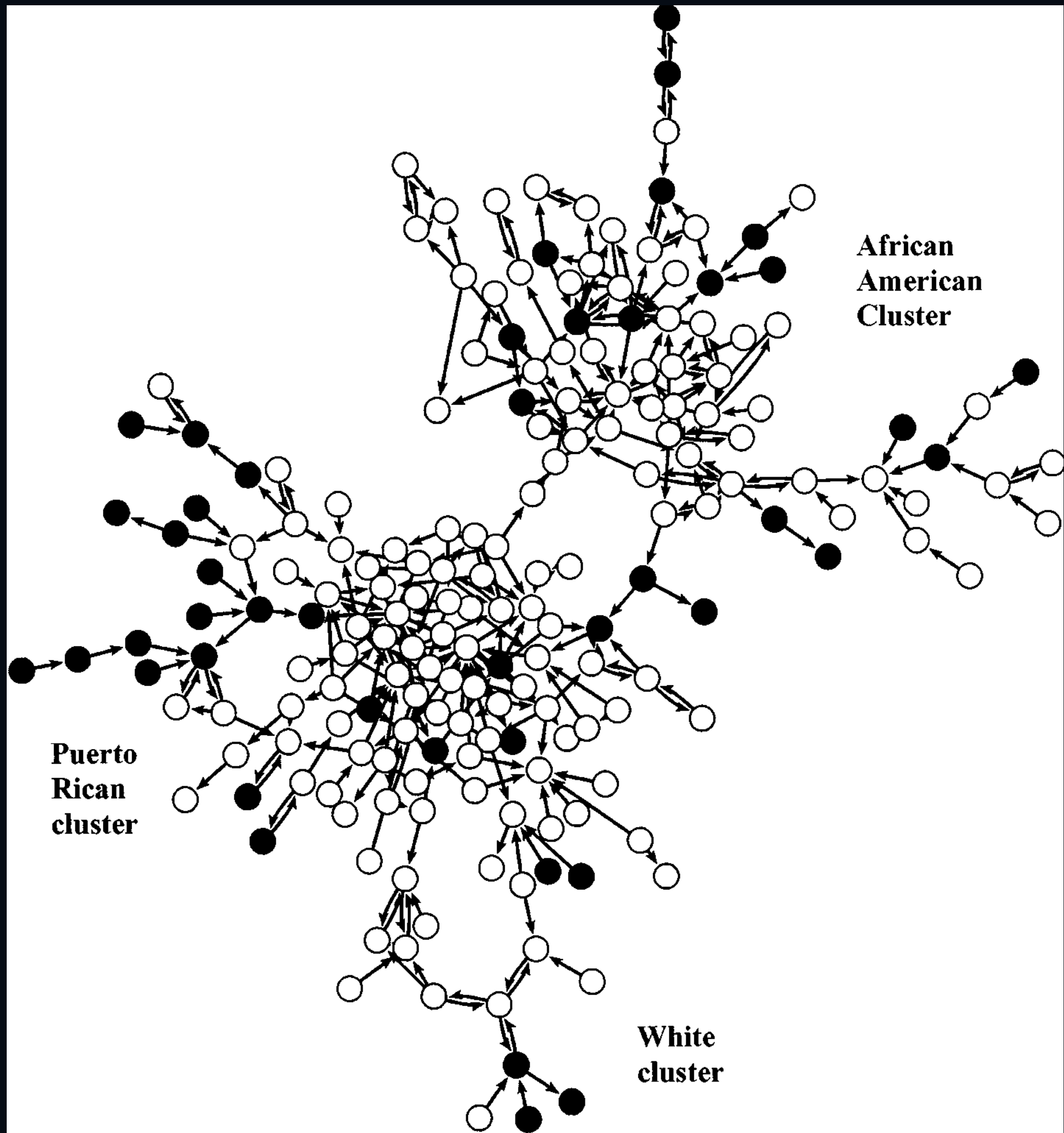




Transport networks (internet, subways, roads, aeroports, ...)

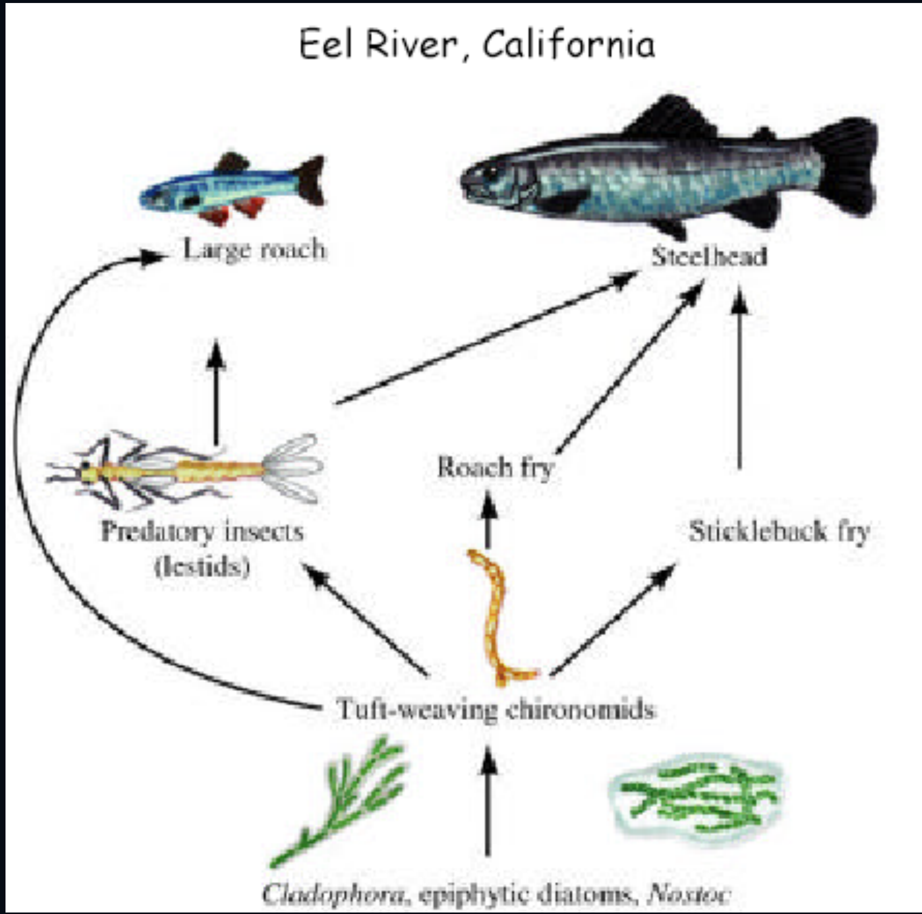
Social networks

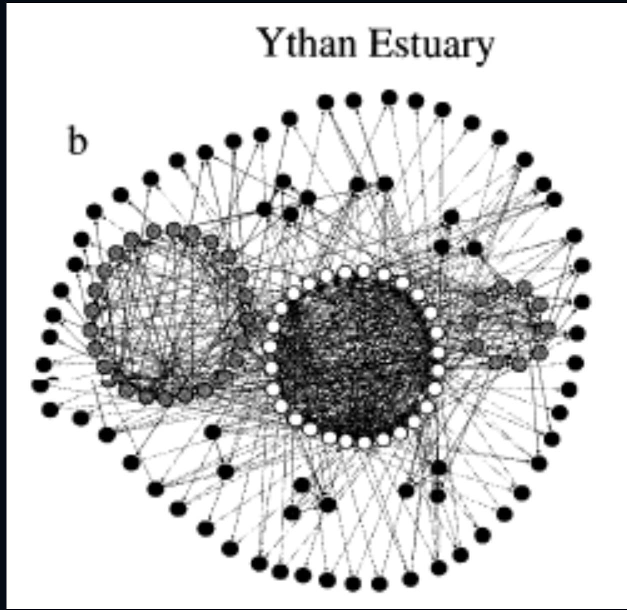
Social interactions between individuals (humans, political parties, foootball teams, dolphins, …)



Acquaintances among drug-users with HIV

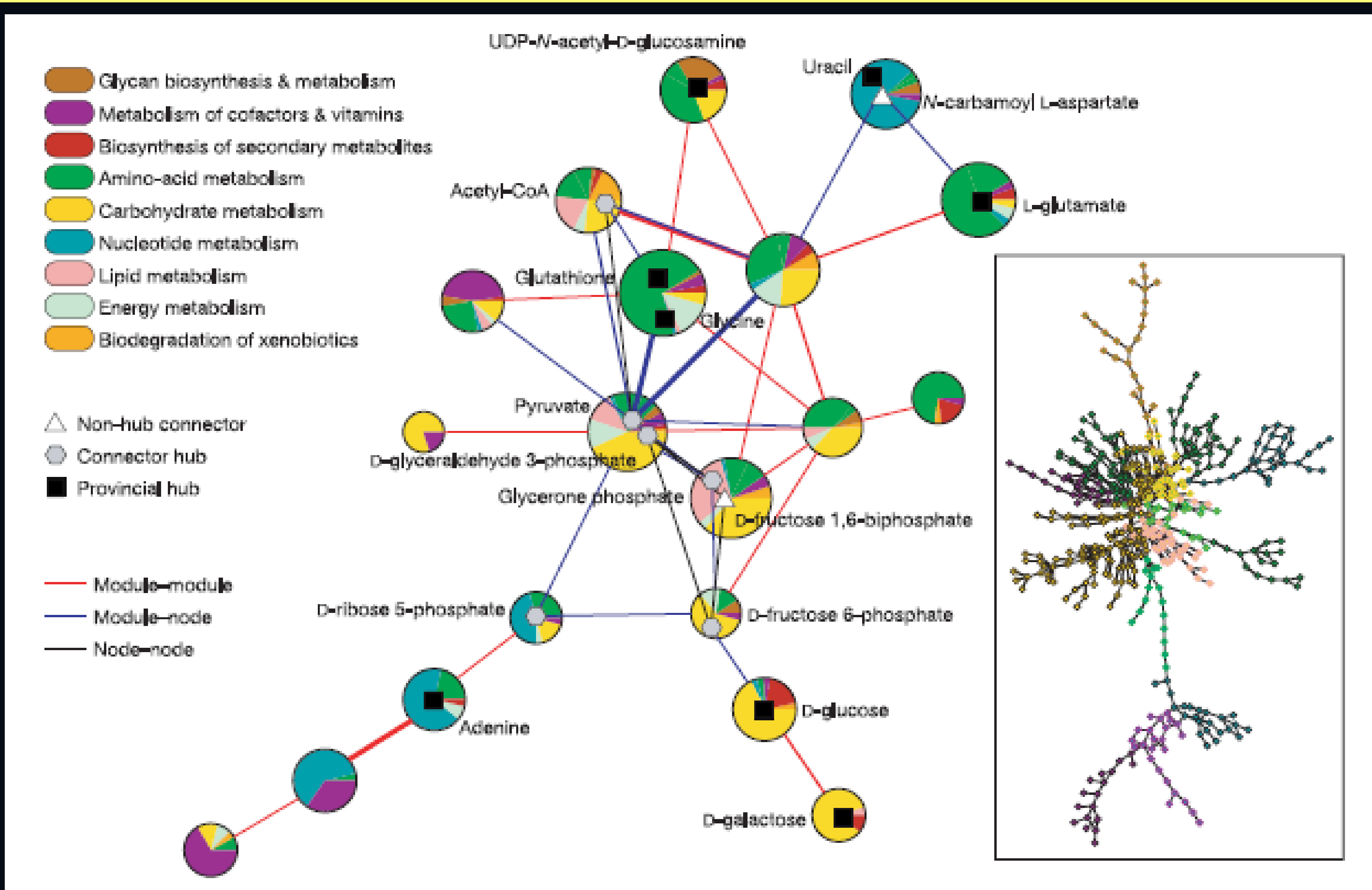
Biological complex networks





Metabolic networks (food webs, proteins, ...)

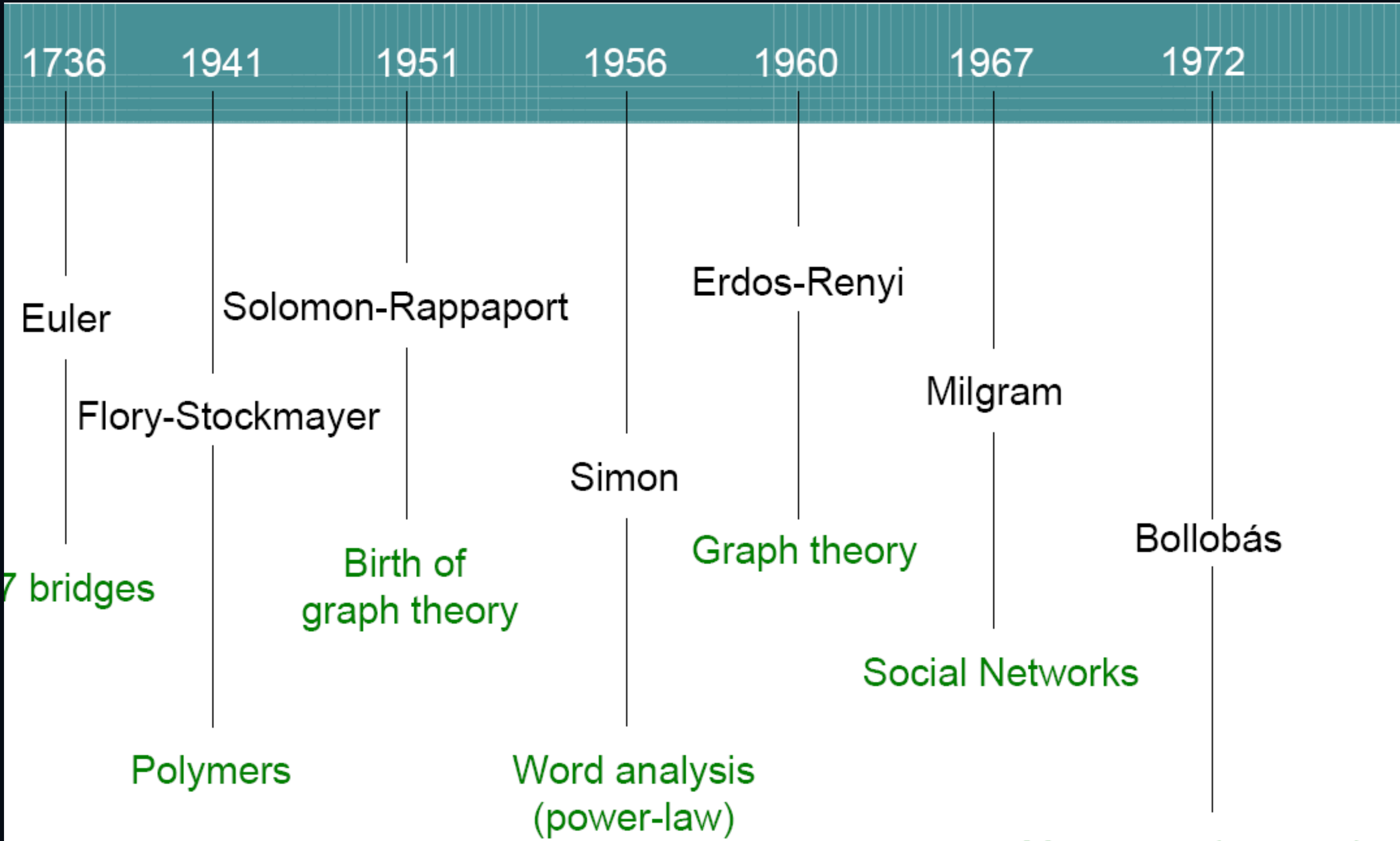
Can function be shaped by connectivity?



Metabolic network of *E. Coli*

Guimera, Nature 2005

Is the network's theory a new discipline?



Dorogovtsev, notes

Happiness is having happy friends

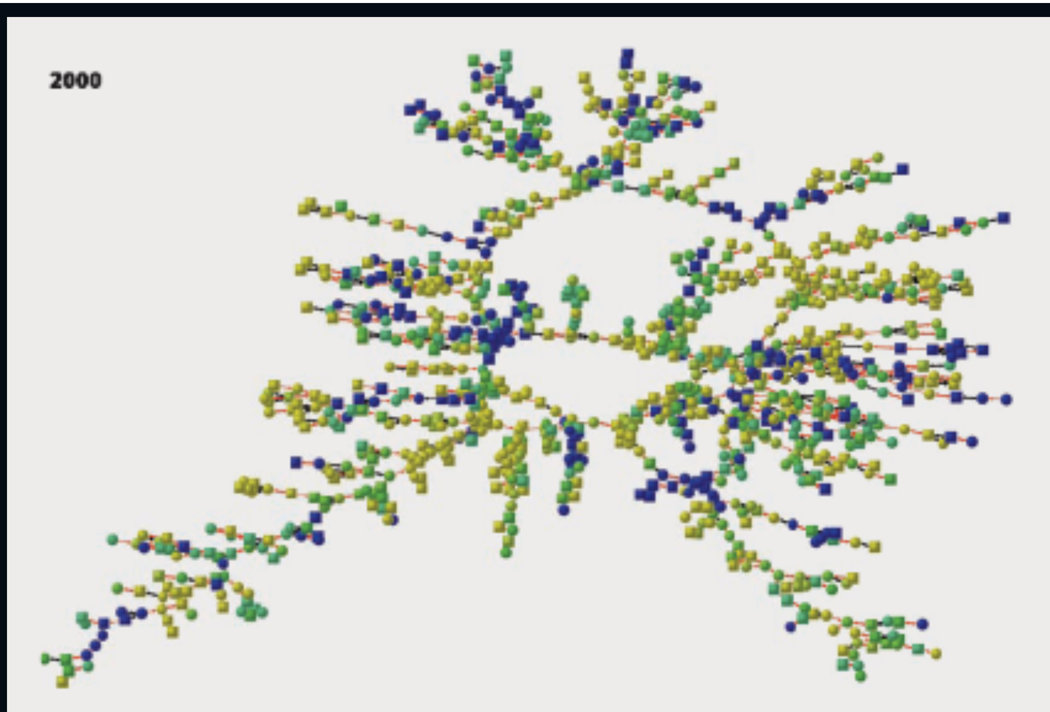
BMJ

RESEARCH

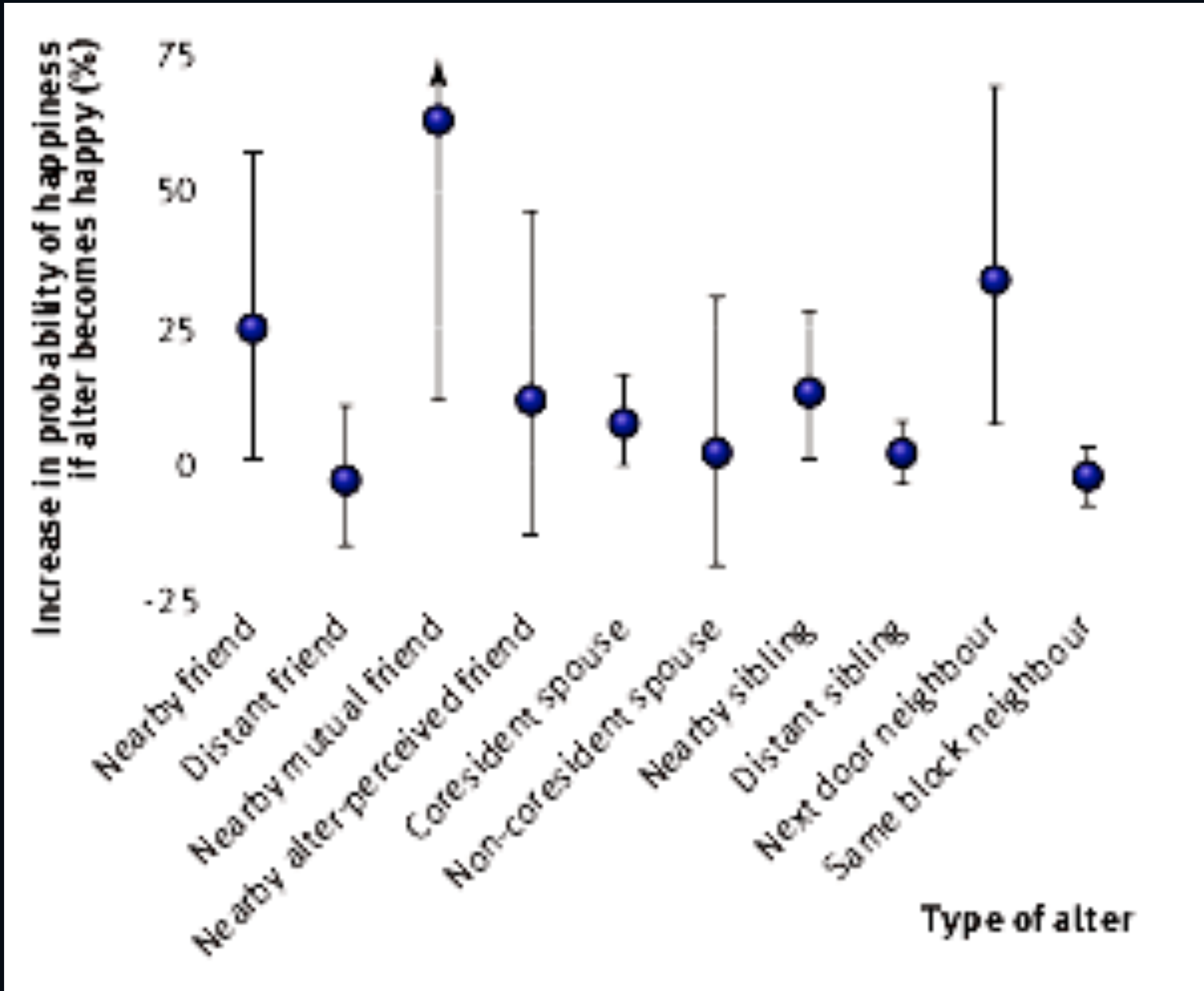
- journal's IF=14

Dynamic spread of happiness in a large social network: longitudinal analysis over 20 years in the Framingham Heart Study

James H Fowler, associate professor,[1] Nicholas A Christakis, professor[2]



Happiness is having happy friends



Can obesity be contagious ?

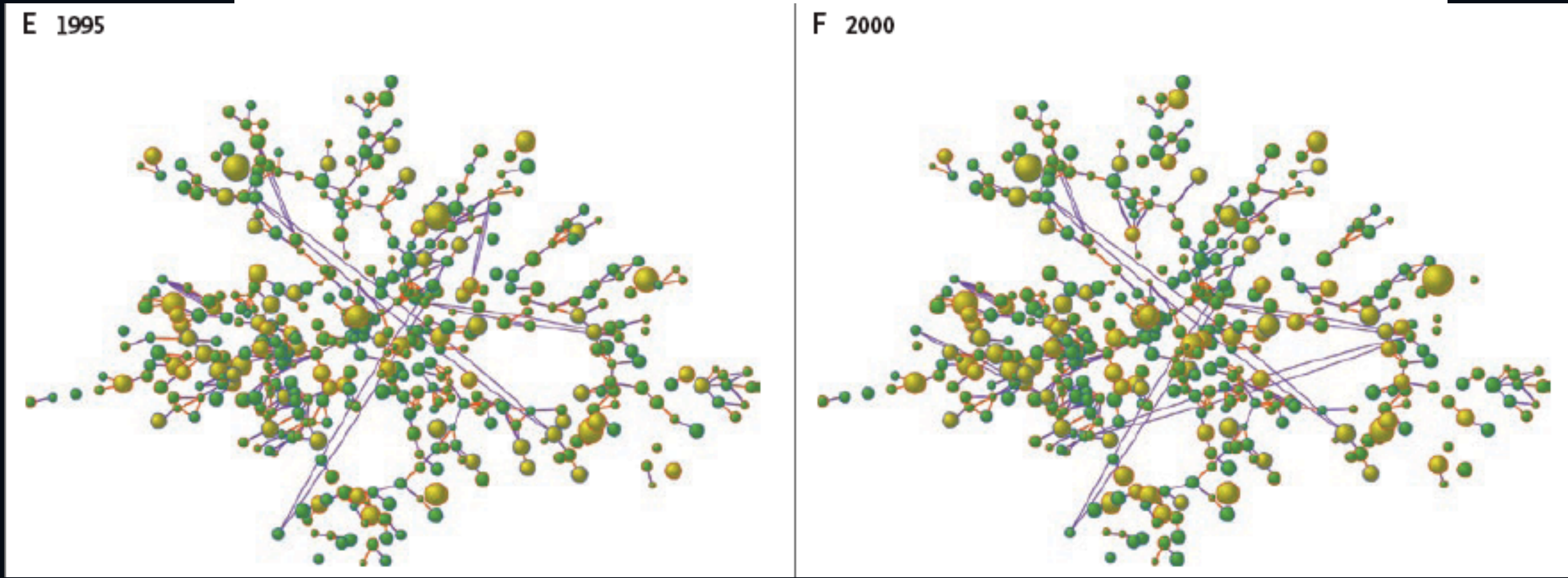
- journal's IF= 47

The NEW ENGLAND JOURNAL of MEDICINE

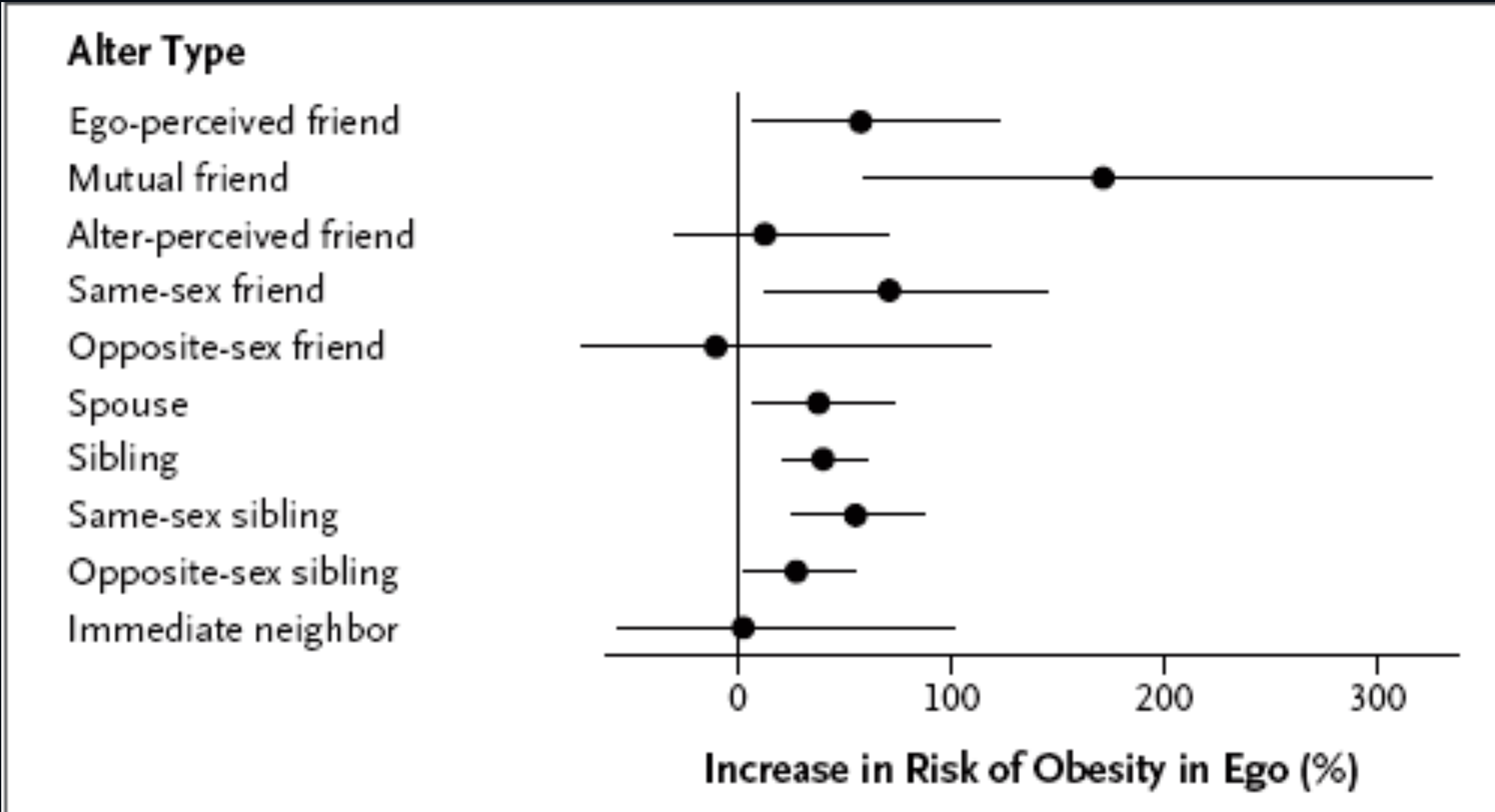
SPECIAL ARTICLE

The Spread of Obesity in a Large Social Network over 32 Years

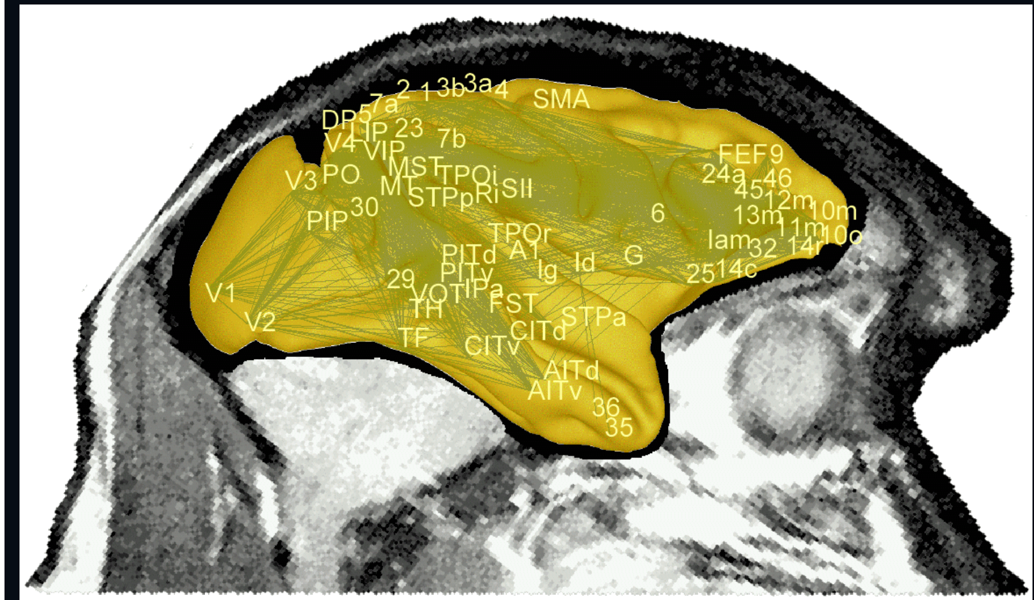
Nicholas A. Christakis, M.D., Ph.D., M.P.H., and James H. Fowler, Ph.D.

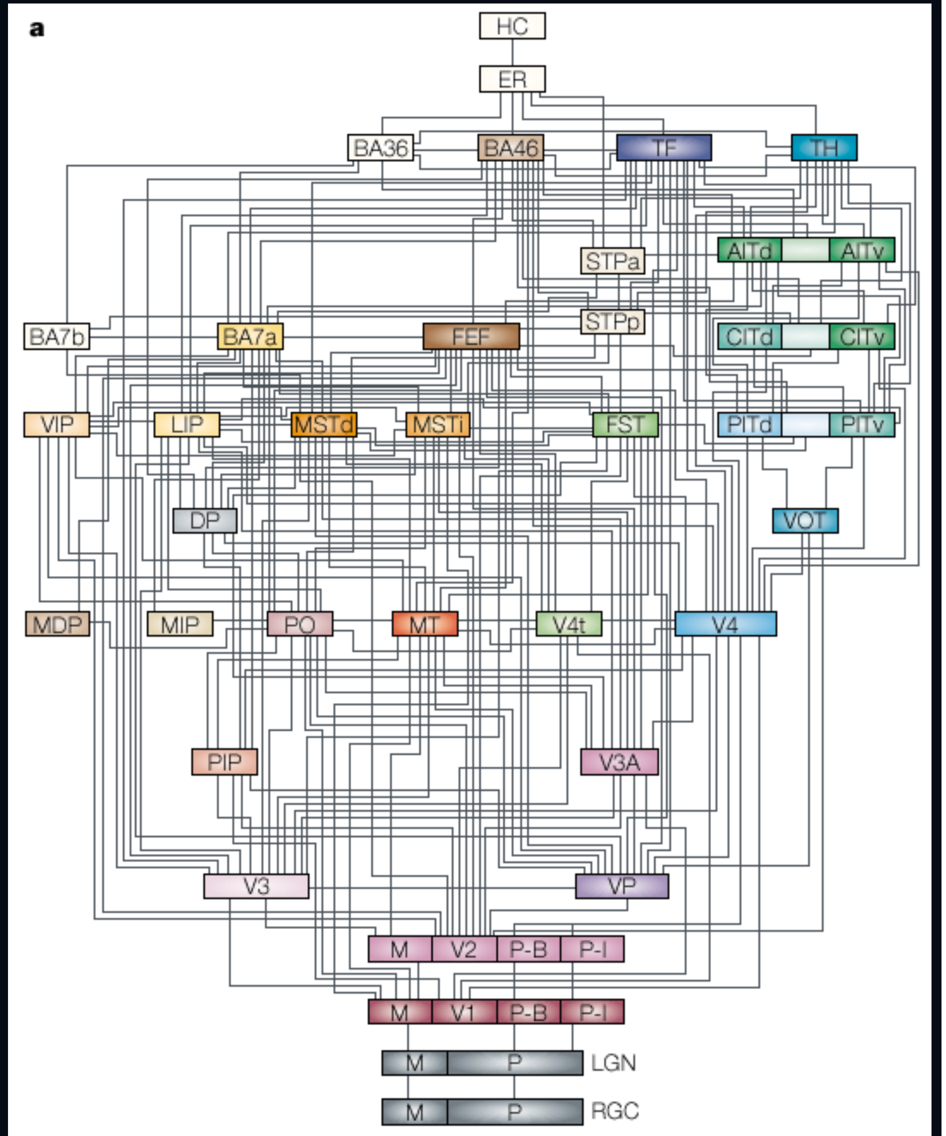


Can obesity be contagious ?

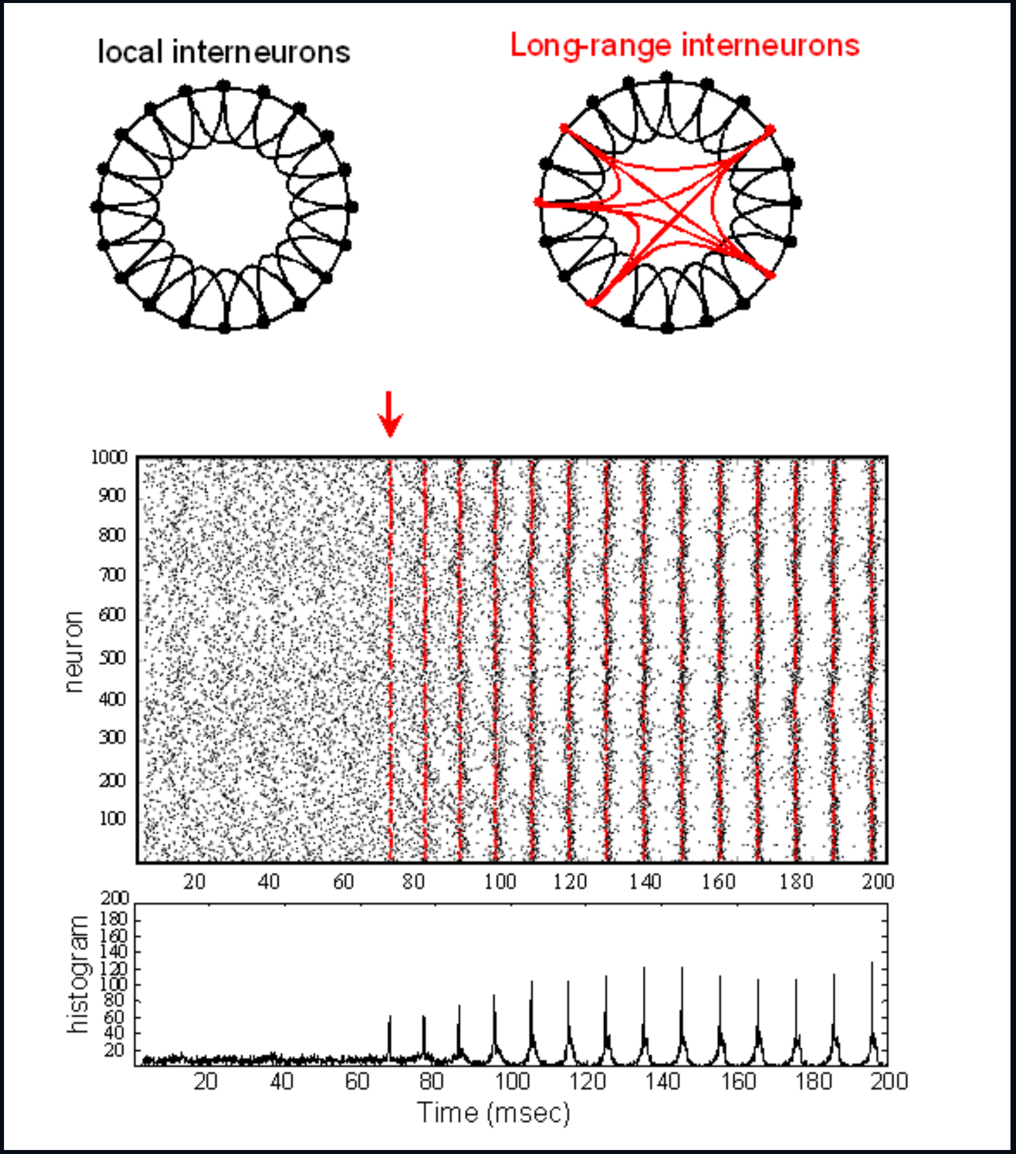


Brain connectivity - Networks





Relevance for neural dynamics

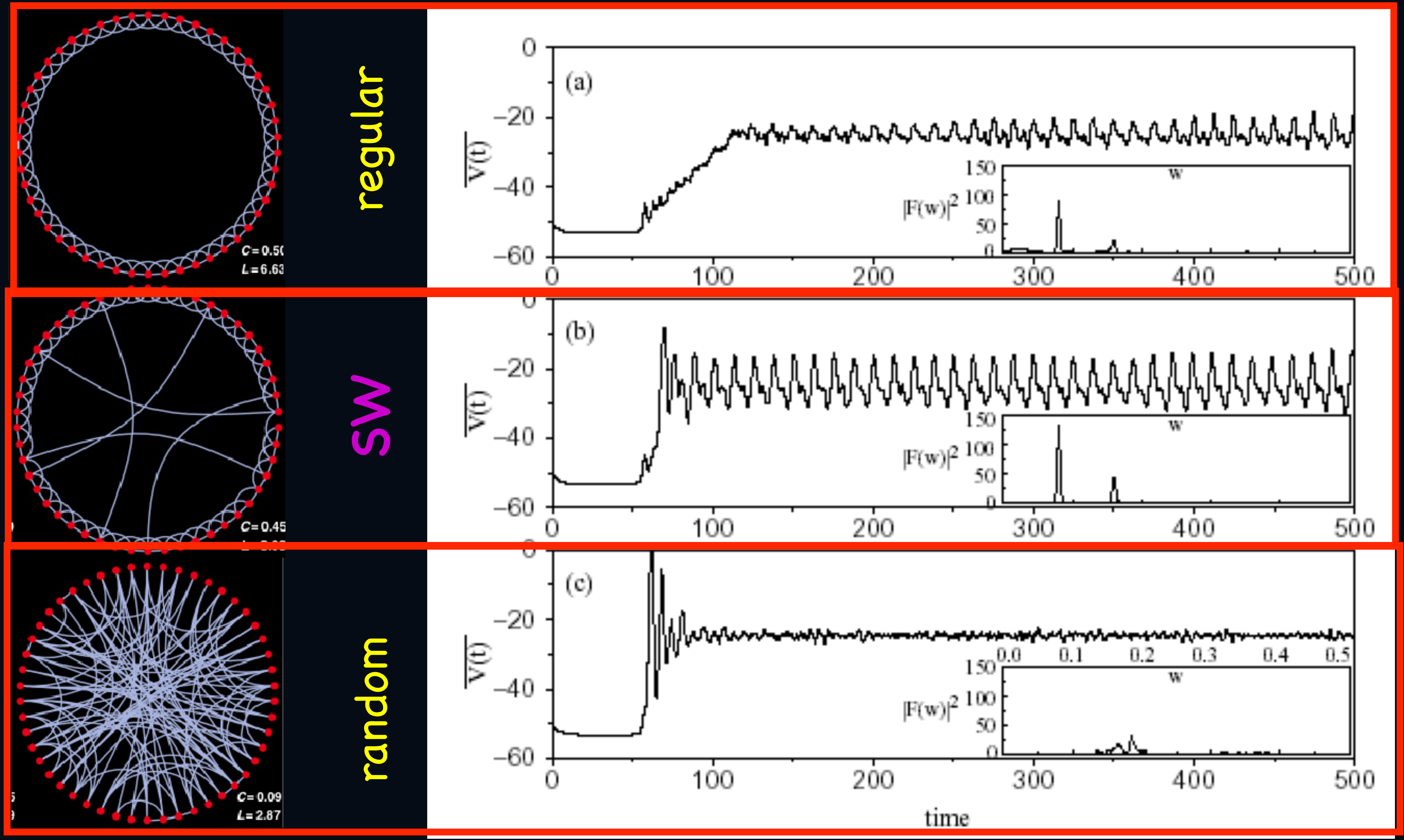


Synchrony may be enhanced by adding random shortcuts

Le van Quyen et al.

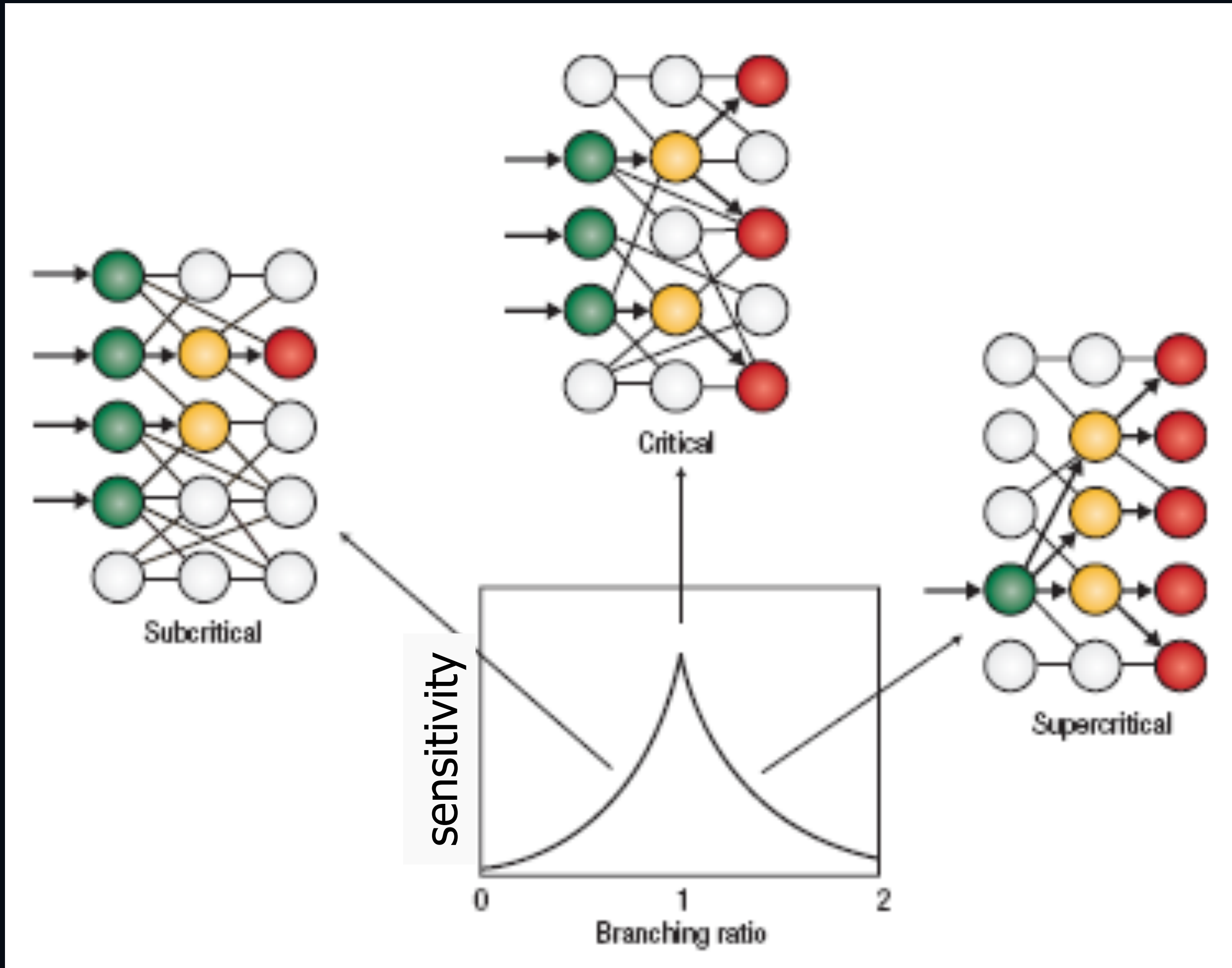
Relevance for neural dynamics

Small world property facilitates the transfer of information.



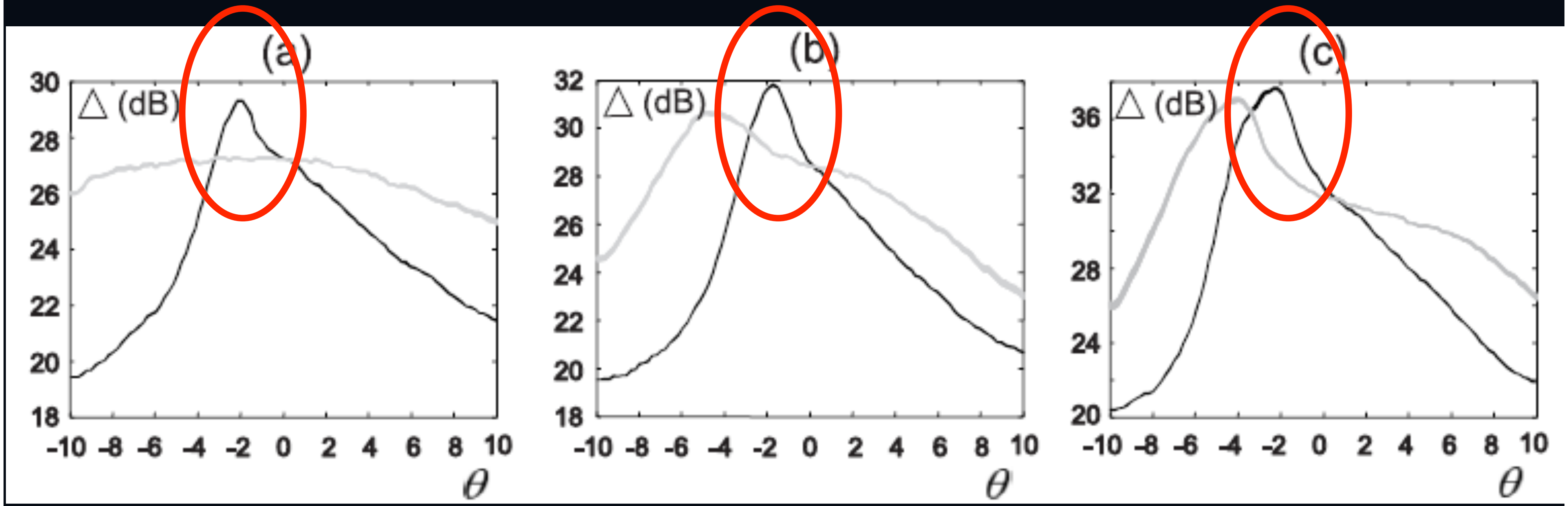
Huerta, PRL 2000

Sensitivity of excitable systems



Sensitivity is optimal at a critical propagation

Sensitivity of real brain networks



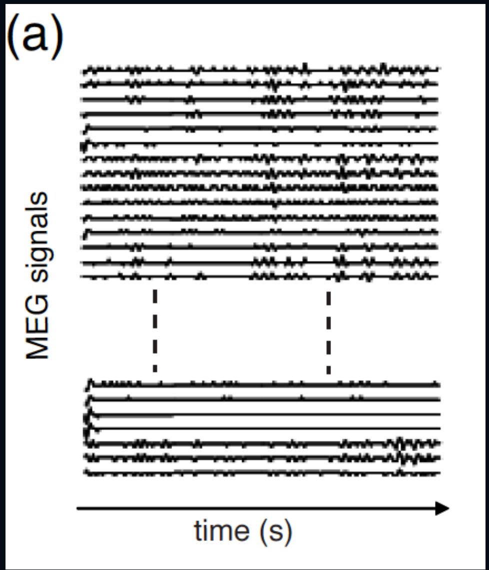
Cat cortex

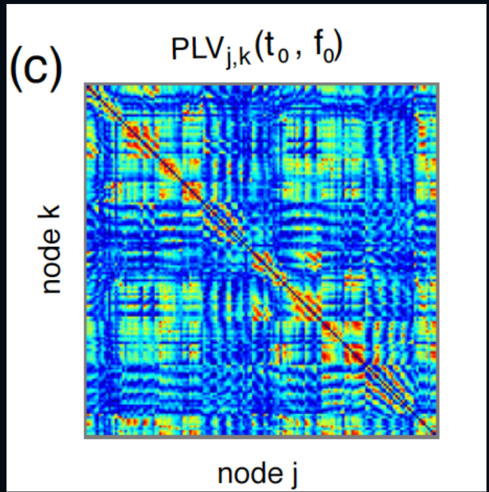
Macaque cortex

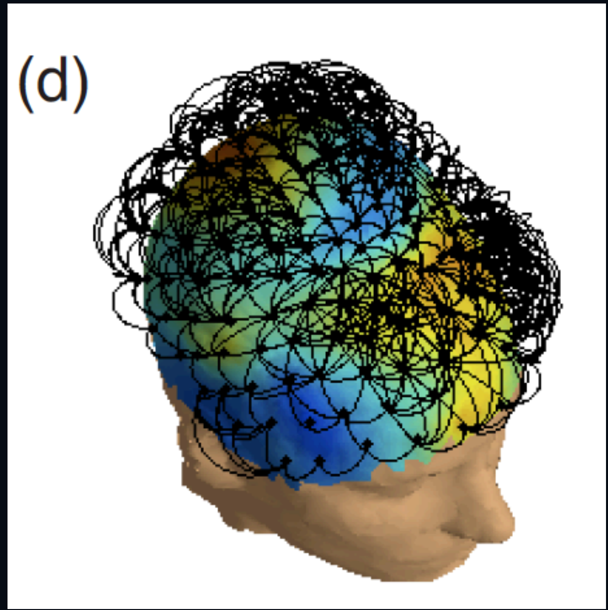
C.elegans

Chavez et al.,
Prog. Biol. Phys.

Basic principles for the construction





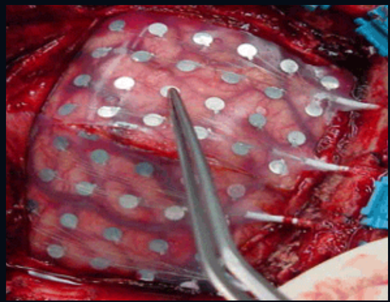


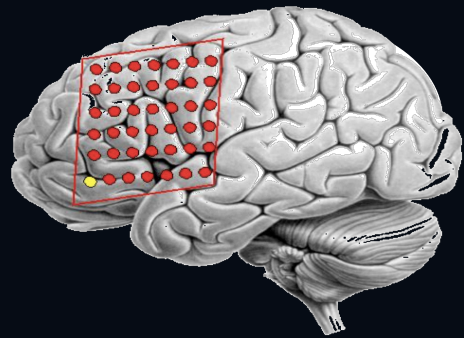
EEG/MEF/fMRI signals

Functional connectivity matrix (coherence, synchrony, ...)

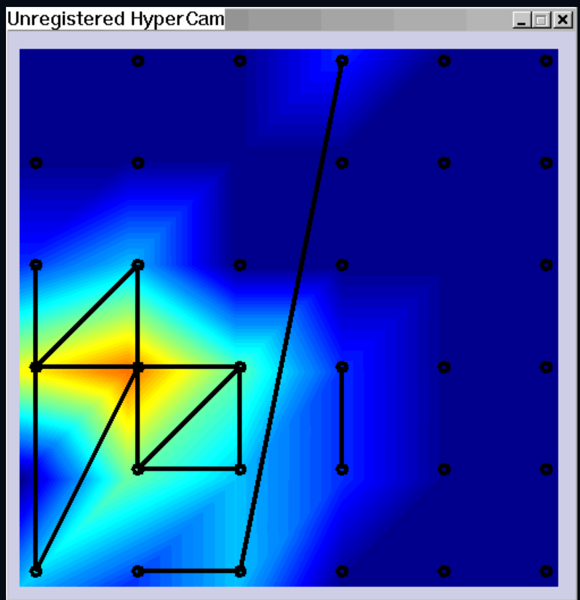
Connectivity network

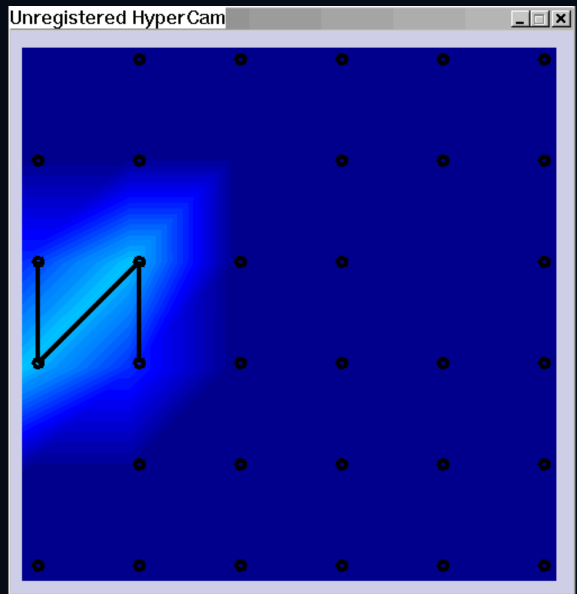
Brain networks underlying seizures

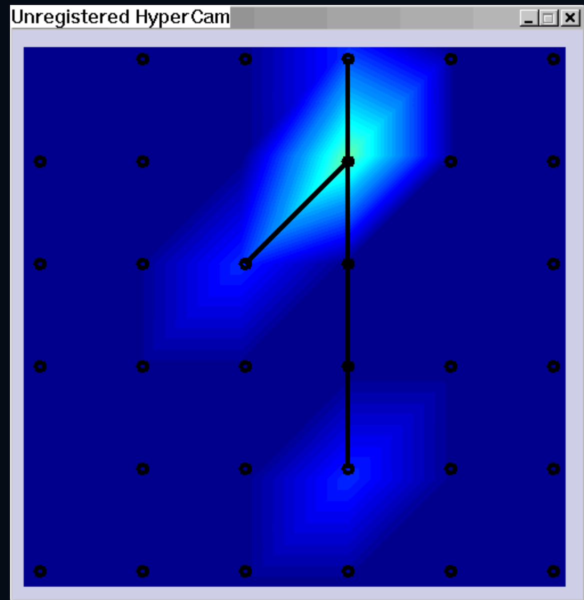




Interictal dynamics — Pre-ictal evolution — Seizure dynamics



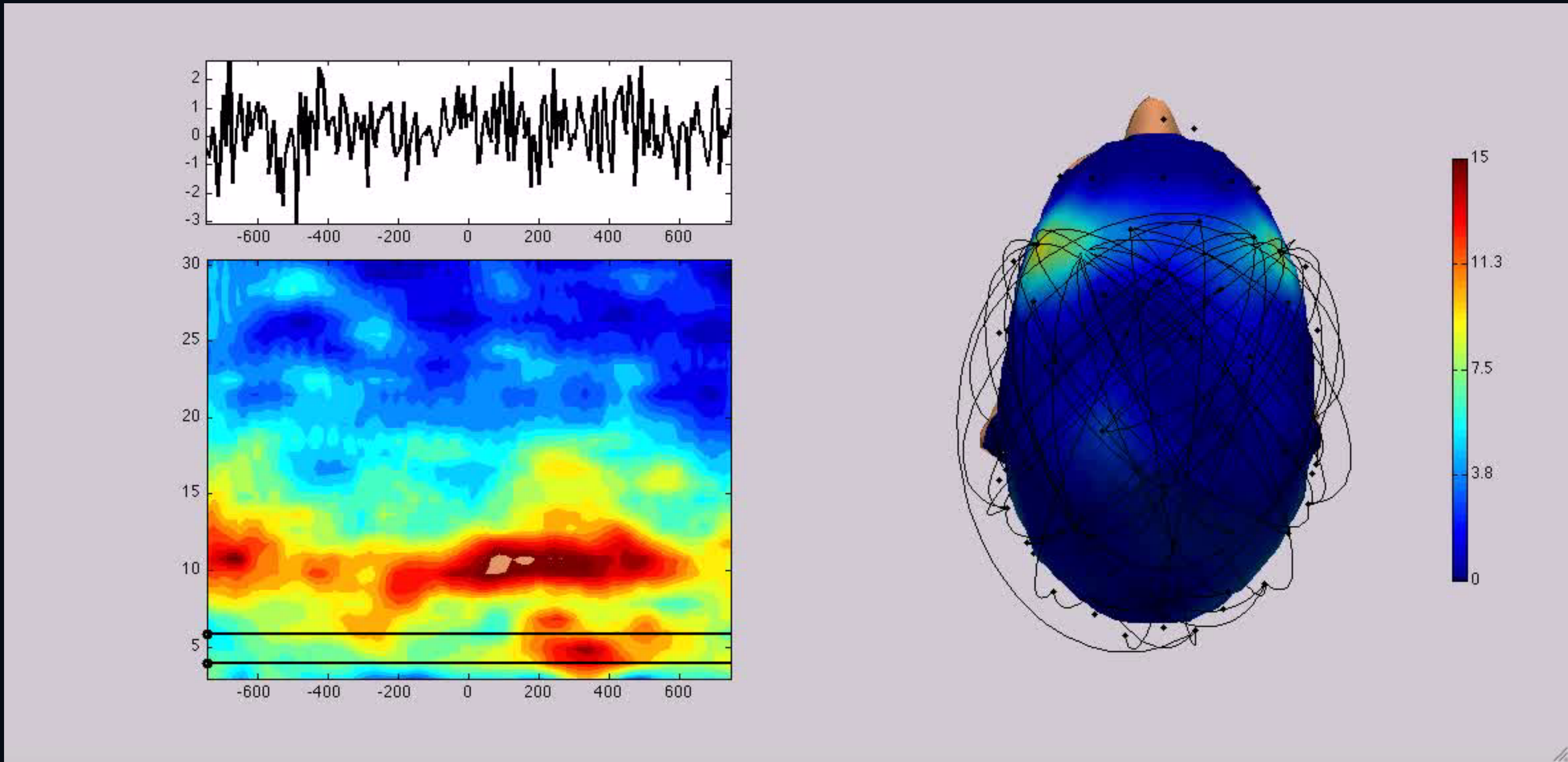




A correlation decrease in the band 10-20 Hz
>>30 min before seizure

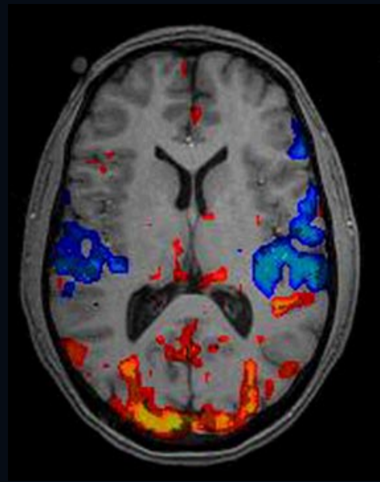
Le van Quyen et al.

Brain connectivity and dynamics



Time evolution of brain connectivity during a cognitive task

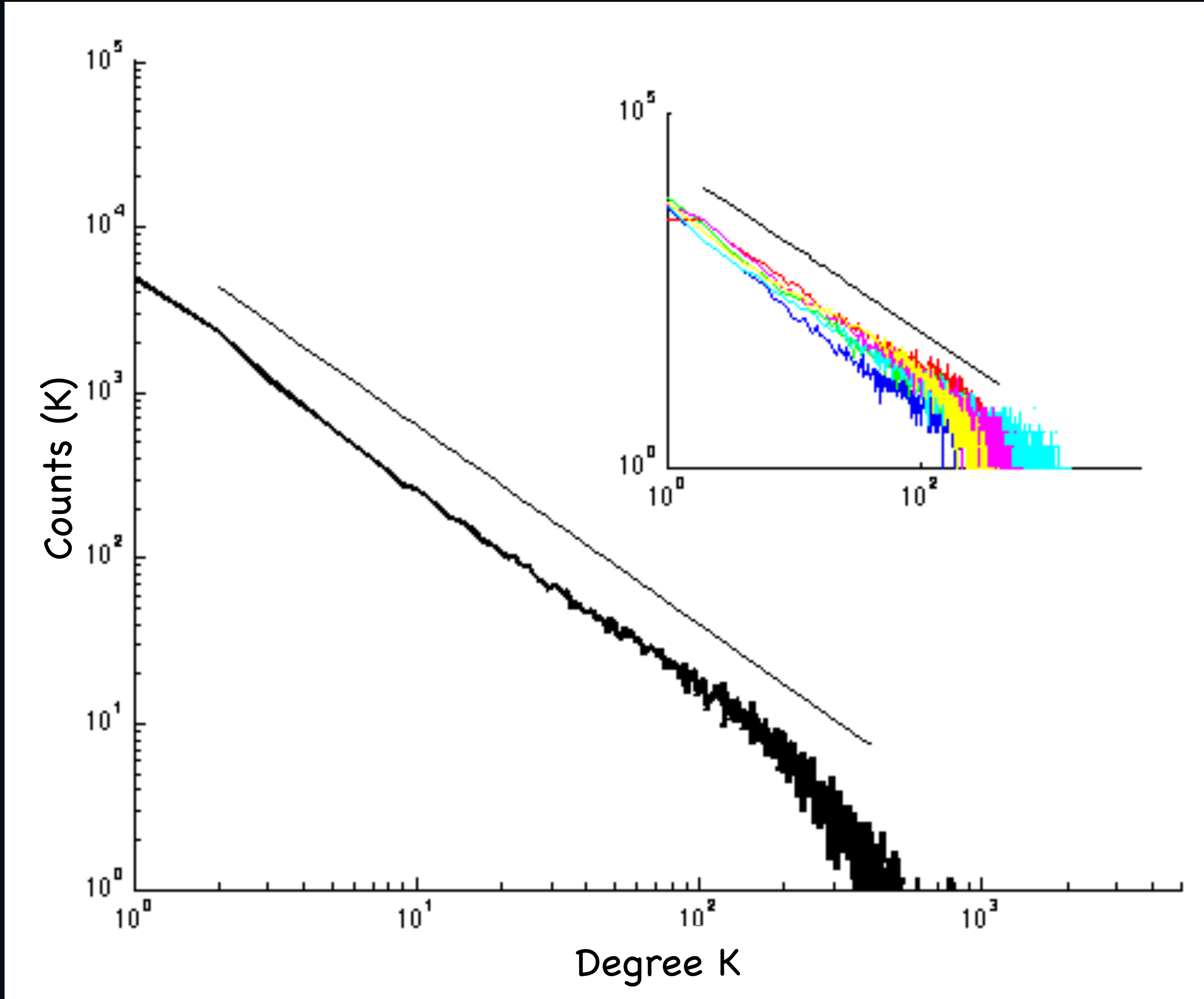
At a finer spatial scale



- fMRI: hemo-dynamic activity

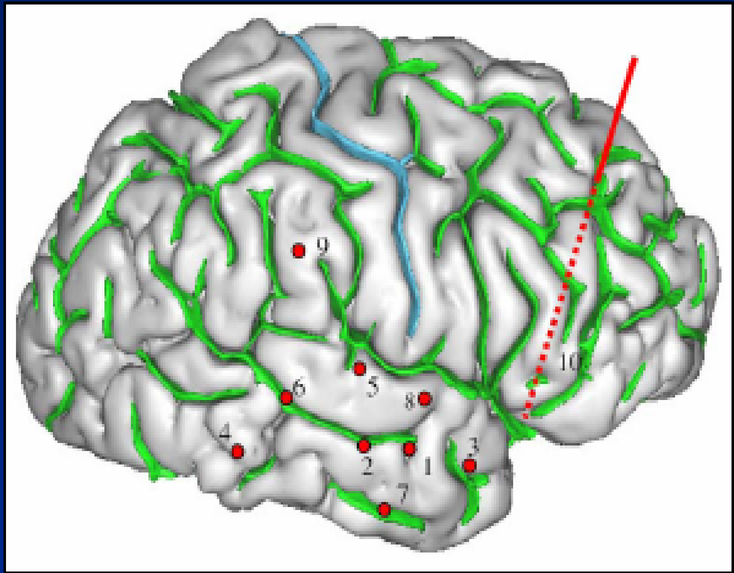
- Stationary signals over long periods of time (10 min) from 6 subjects
- Resting state activity, "stimulus-independent"
- Networks with N>20 000 nodes (voxels)

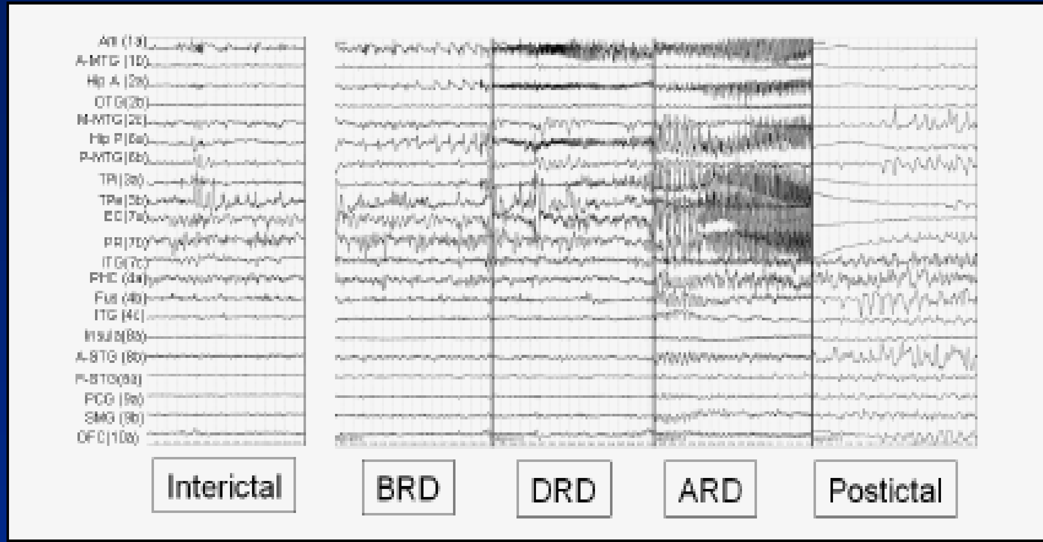
Scale free distribution of connections



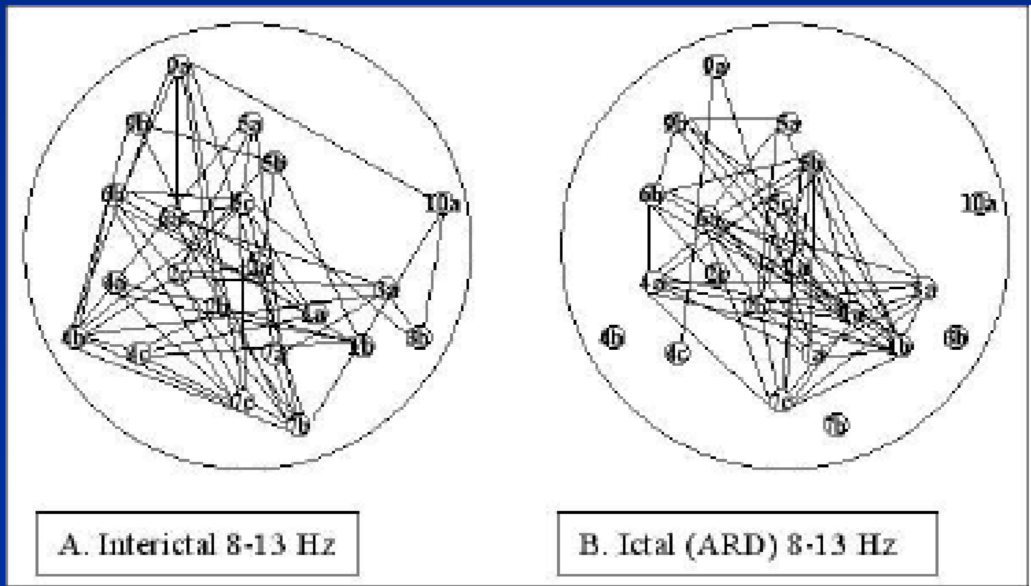
Similar to results of Chialvo et al. PRL 2004

Functional brain networks



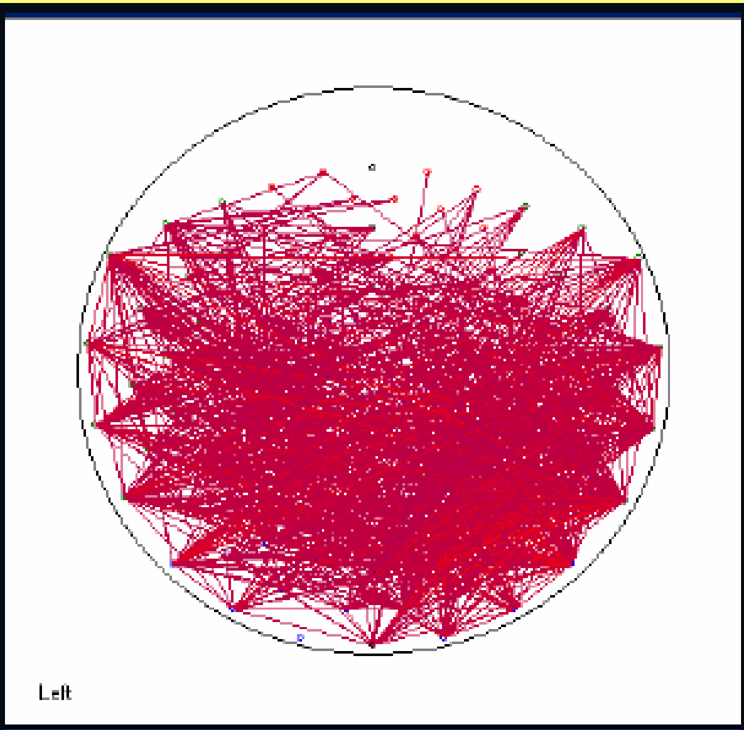


Example: EEG signals of epileptic patients

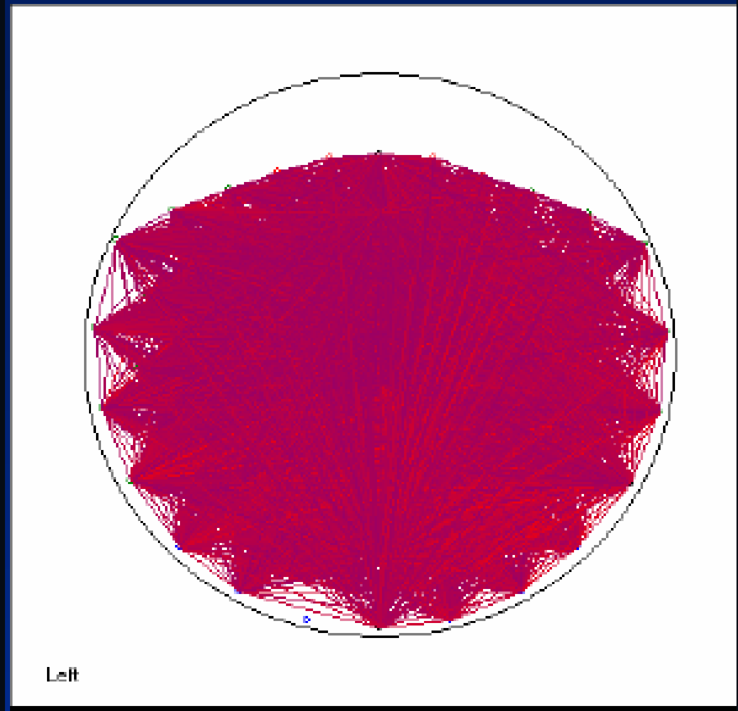


Ponten et al. (2007)
Clin Neurophysiol **118**:918.

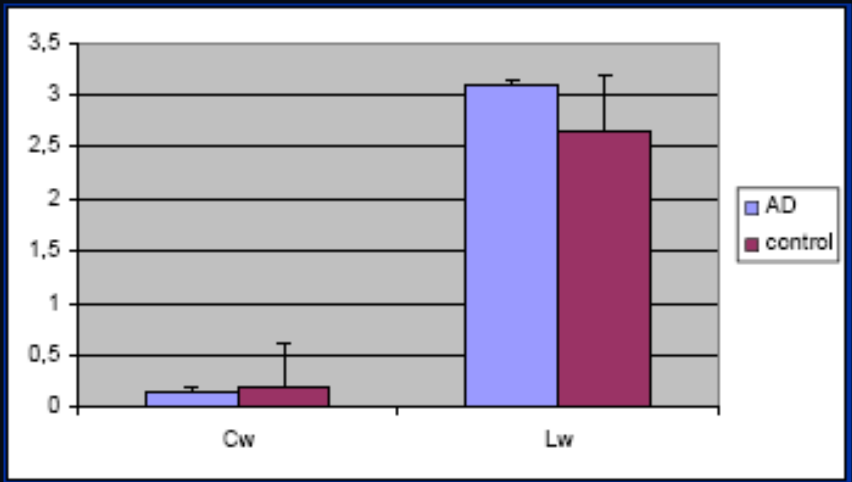
Brain connectivity in Alzheimer



Alzheimer patients



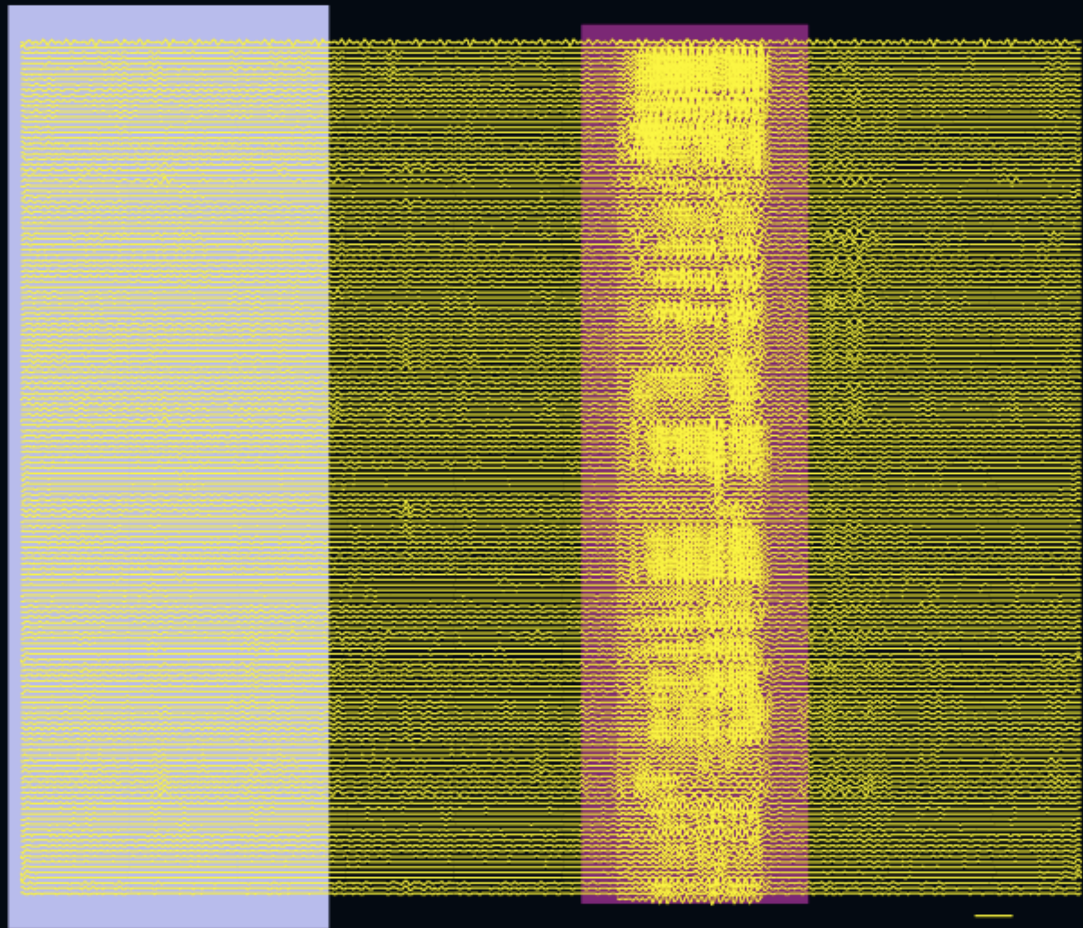
Normal subjects



Stam et al., HBM

Connectivity from MEG signals

- Magnetoencephalographic (MEG) activities of epileptic patients (5) and healthy subjects (5)

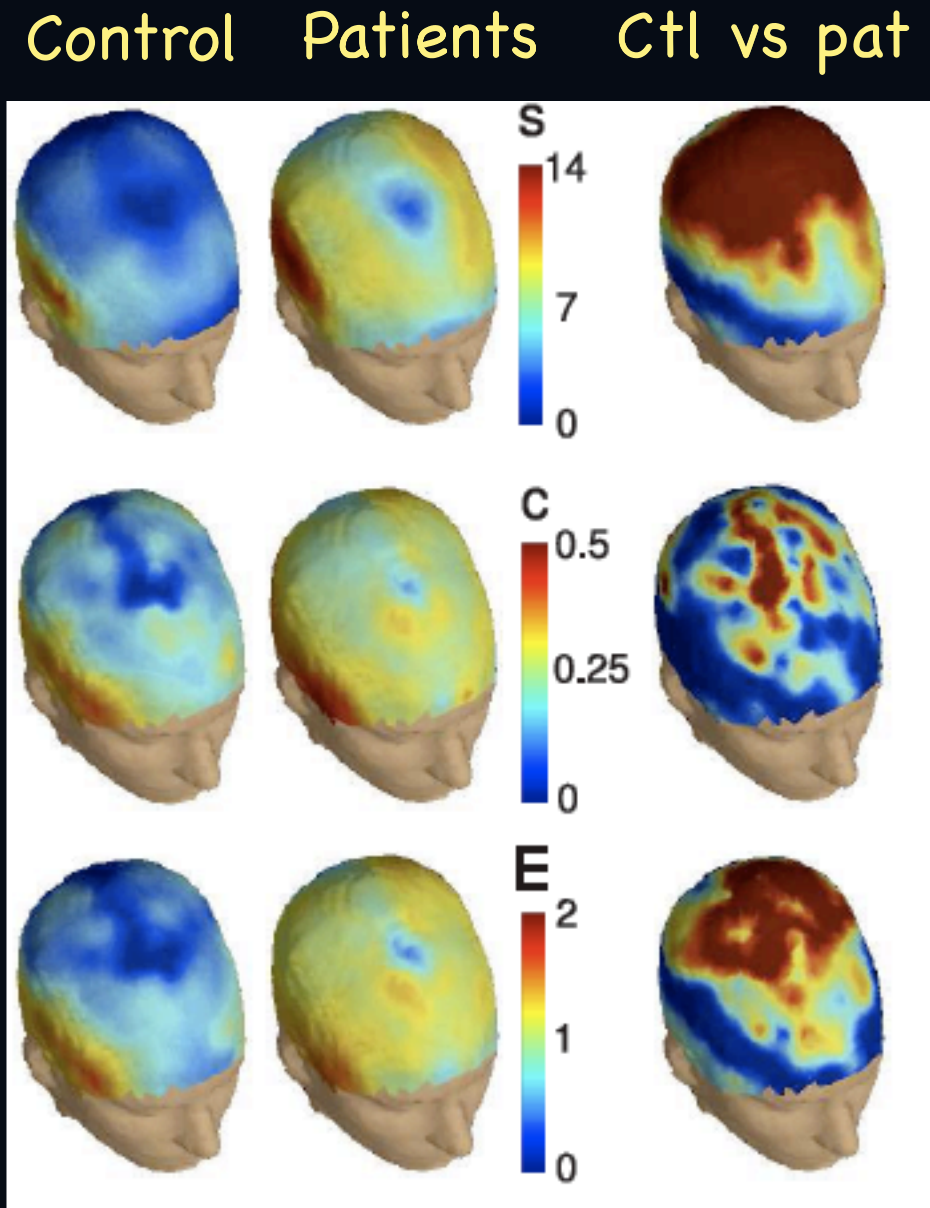


resting state

absence seizure

Topological features of brain webs

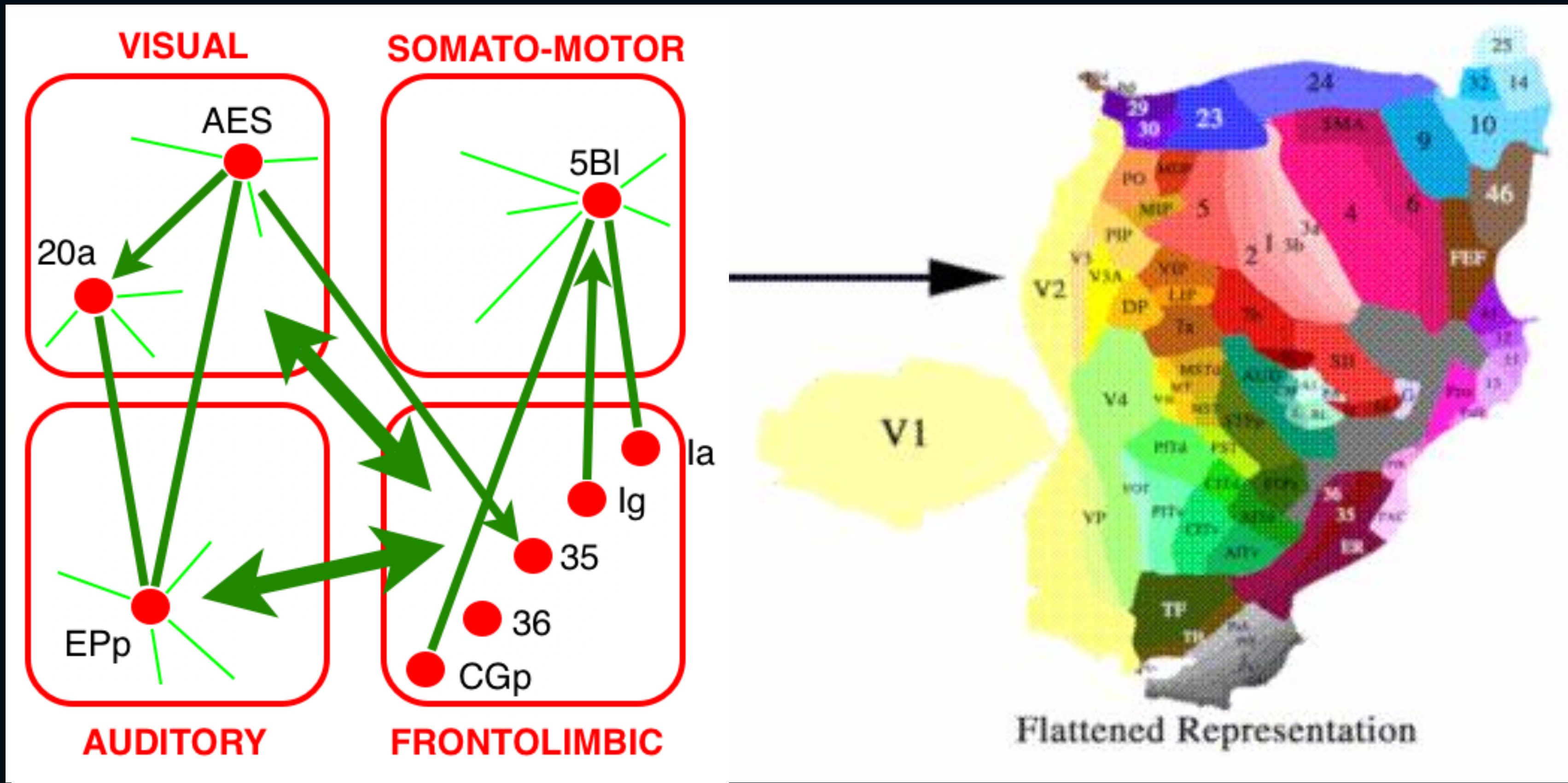
- Degree: number of connections
- Clustering index: cliqueness of local neighborhood
- Efficiency: topological measure of information flow



Brain connectivity: specialization & integration

- Specialization: brain regions with specific structure and function
- Integration: interactions between specialized processors

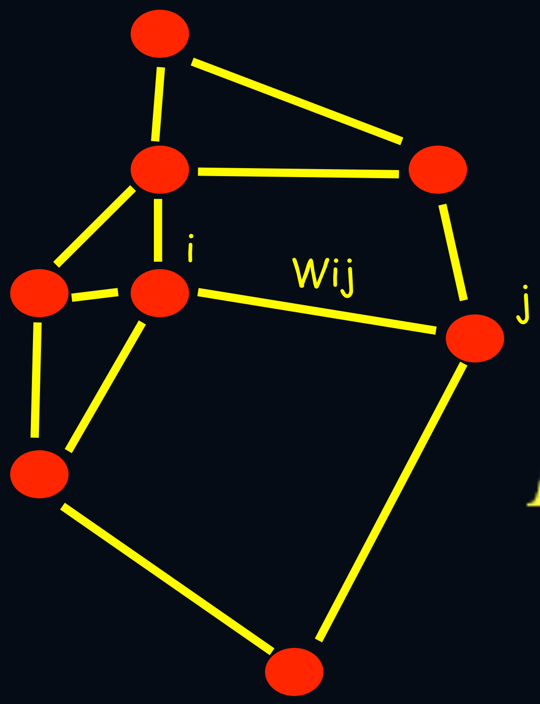
Anatomical brain modularity



Macaque's cortex structure

Adapted from van Essen

Detection of modules: random walks on graphs



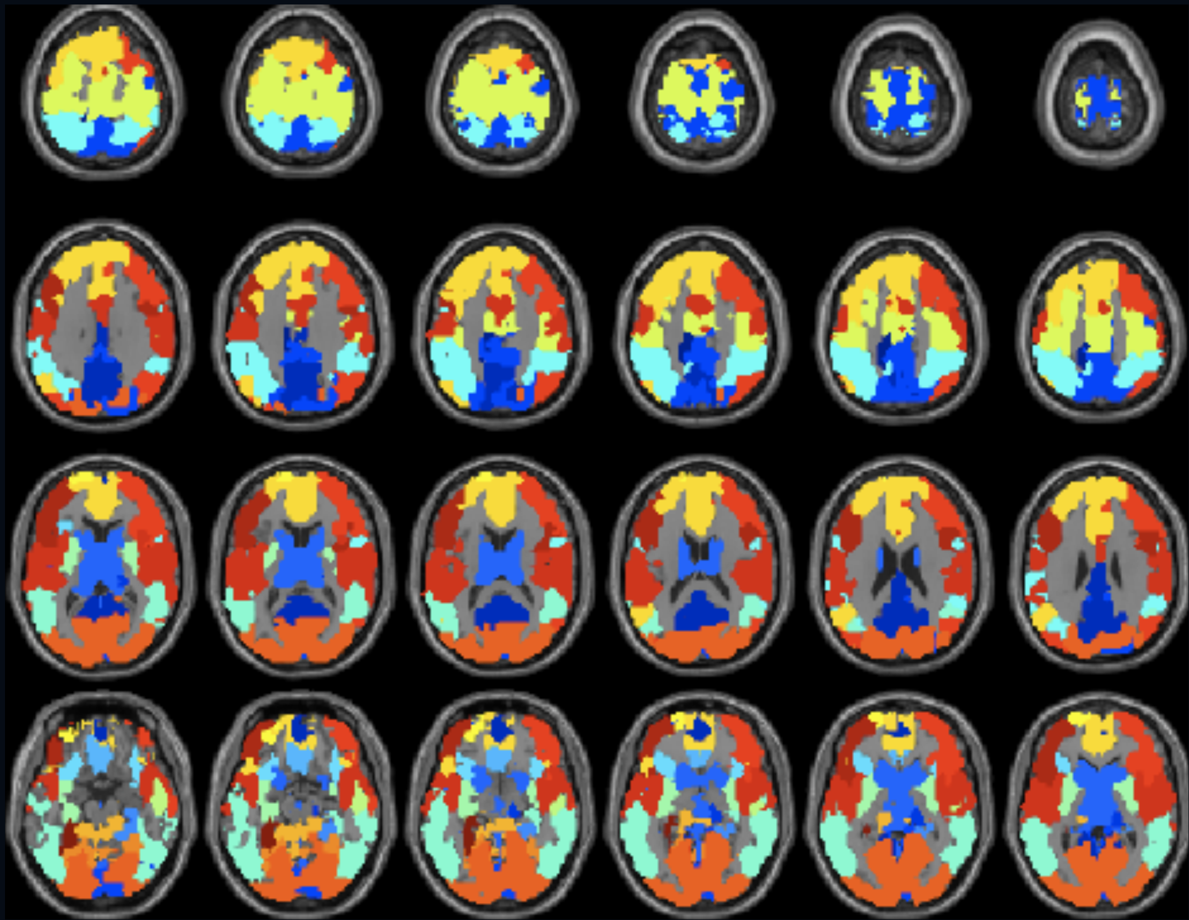
Probability of transition from node i to node j

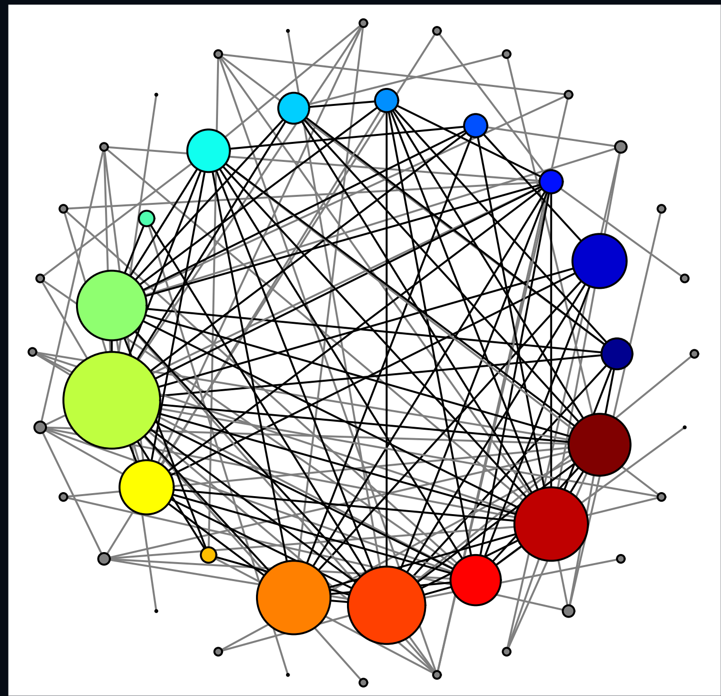
$$p^{w}_{i\to j} = \frac{w_{ij}}{s_i} \qquad s_i = \sum_{j \in v(i)} w_{ij}$$

- Distance between nodes

$$r_{ij} = \sqrt{\sum_k \frac{\left(p_{ik} - p_{jk}\right)^2}{s_k}}$$

Functional brain modularity



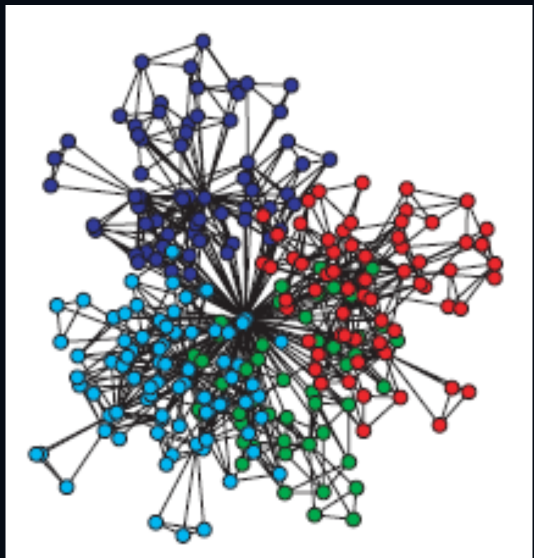


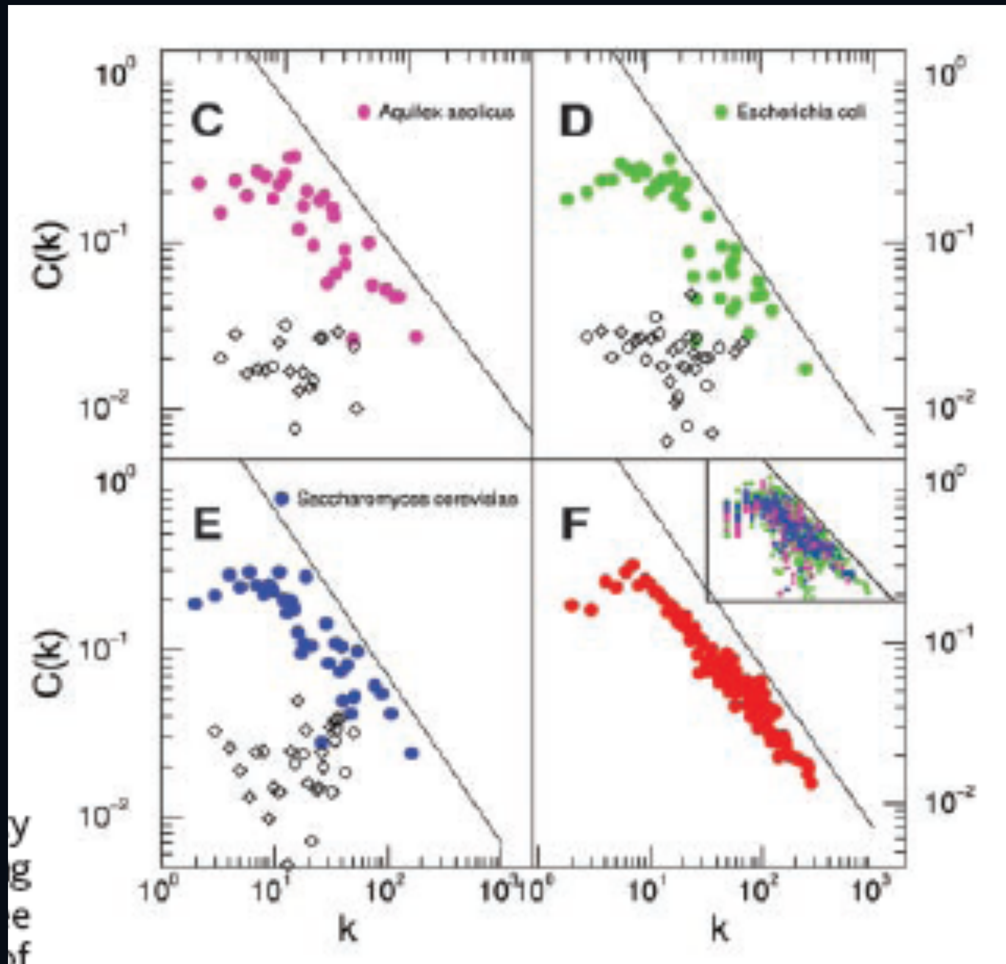
Valencia et al., 2009

- Good correspondence (>75%) with current "a priori" atlas

Hierarchical Organization of Modularity in Metabolic Networks

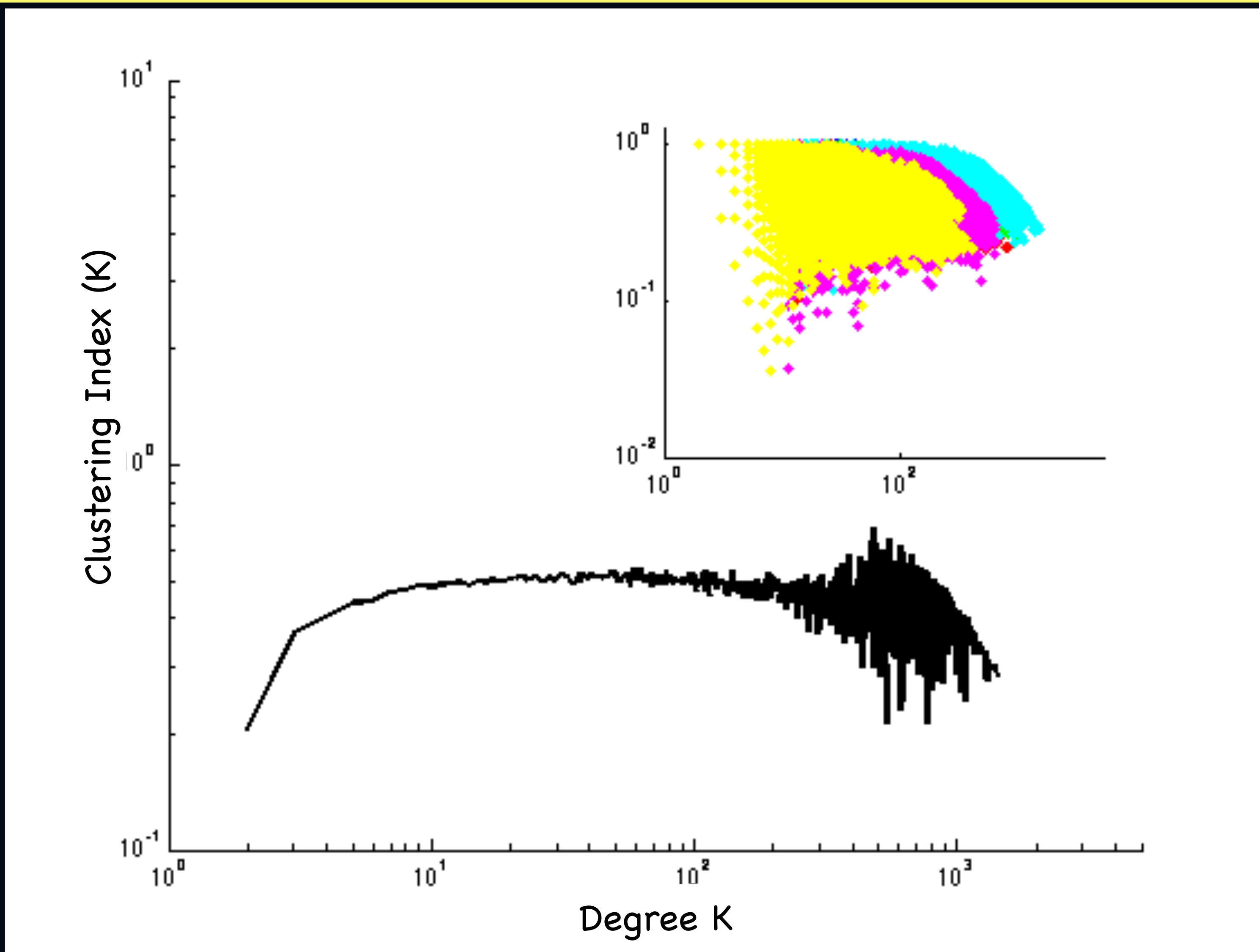
E. Ravasz,[1] A. L. Somera,[2] D. A. Mongru,[2] Z. N. Oltvai,[2]*
A.-L. Barabási[1]*





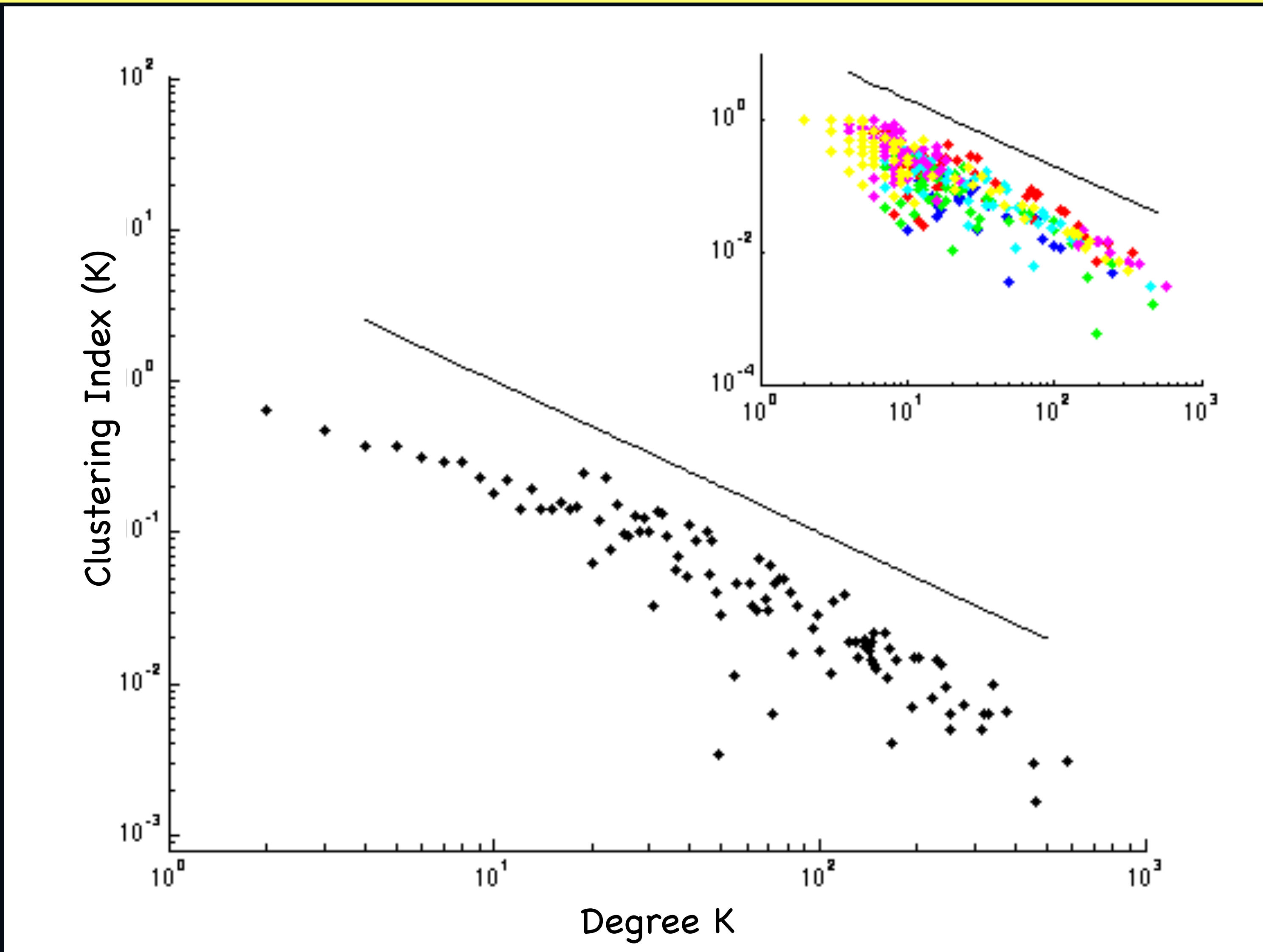
Hierarchy implies a power law of the clustering index vs degree

No hierarchy at this scale



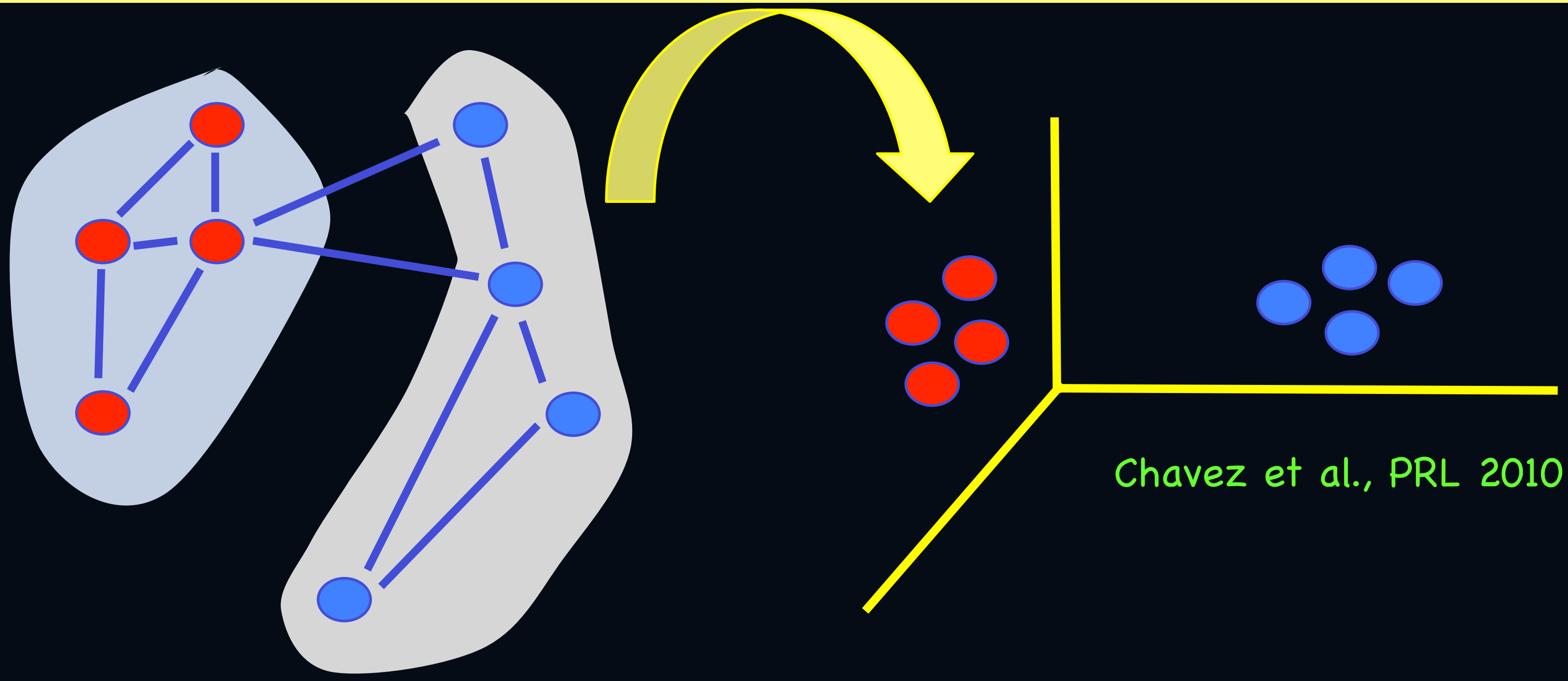
- Robust against failures of nodes

Hierarchical organization of modules



- Very sensitive to small perturbations

Spectral embedding of graphs



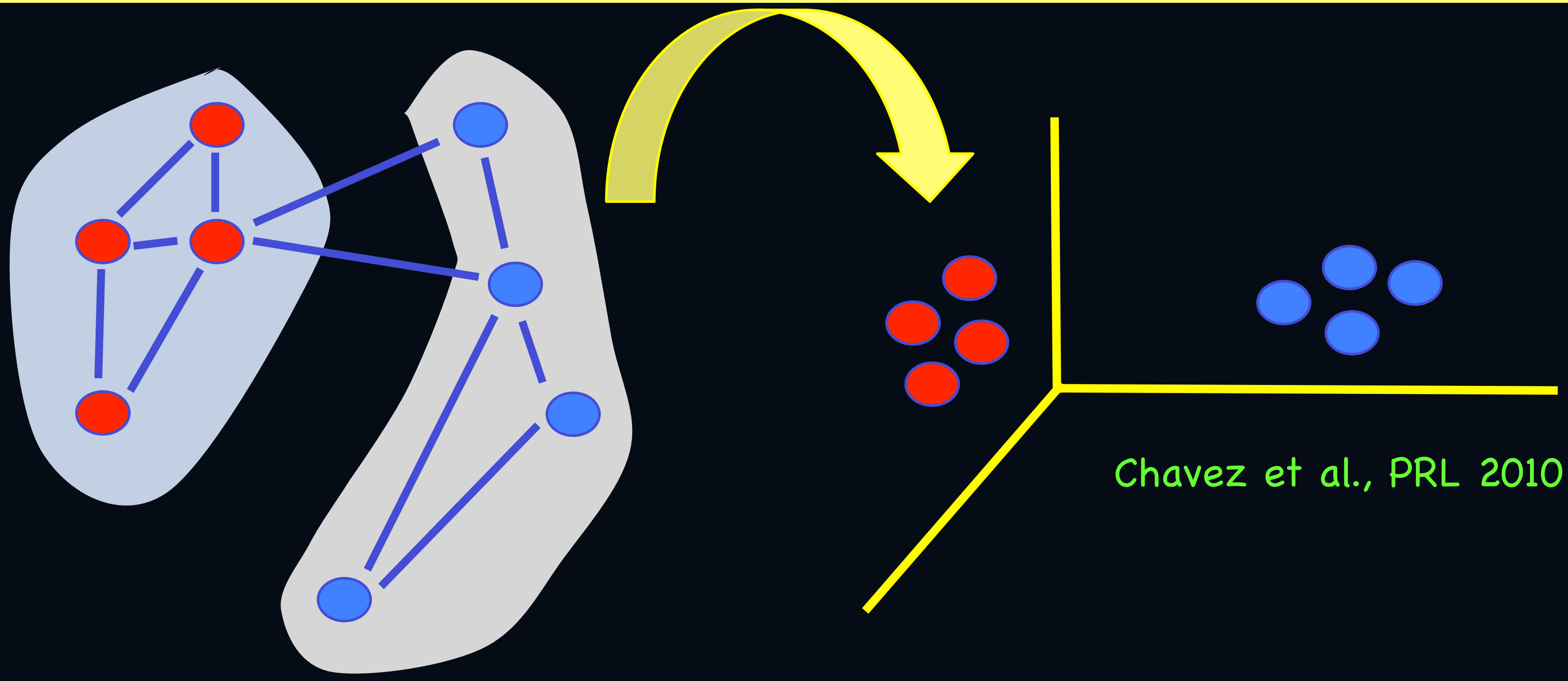
- Topological space

- Euclidean space

- Difficult to define distances between nodes

- Classical distances/ divergences can be used between nodes

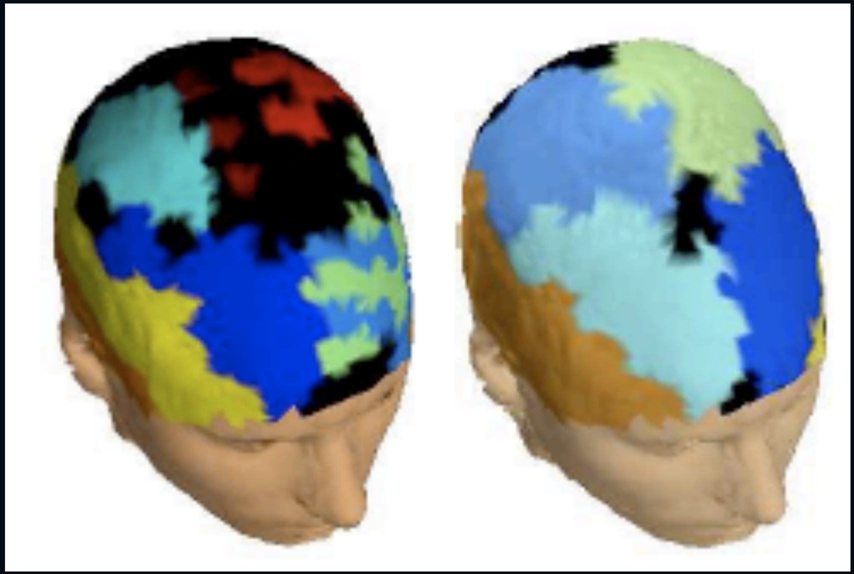
Spectral embedding of graphs



$$X_p \mapsto \Phi_m^t(X_p) \equiv \{\lambda_1^t \varphi(X_p), \lambda_2^t \varphi(X_p), \ldots, \lambda_m^t \varphi(X_p)\}$$

$$d_{ij}^2(t) = \sum_{k \geq 1}^{m} \lambda_k^{2t} (\psi_k(i) - \psi_k(j))^2$$

Functional organization of MEG signals



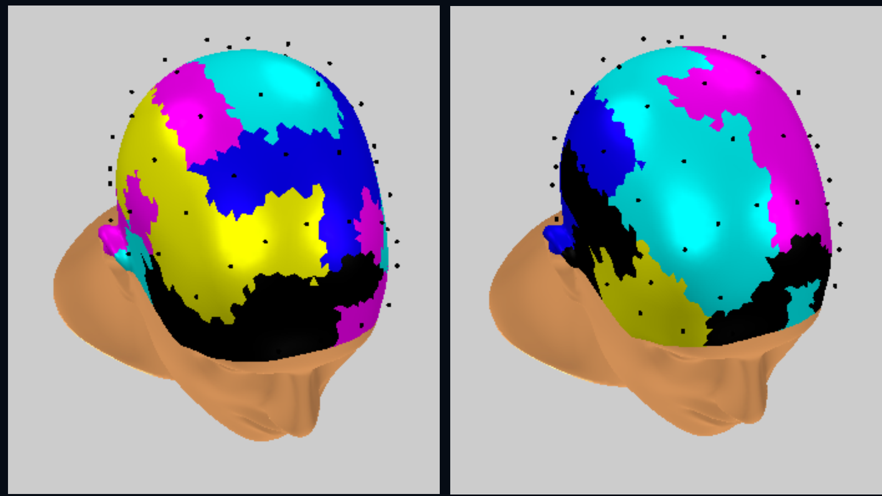
CTL PAT

Chavez et al., PRL 2010

- Stationary signals over long periods of time (>10 min) from 5 control subjects and 5 patients
- Resting state activity.

What about other data

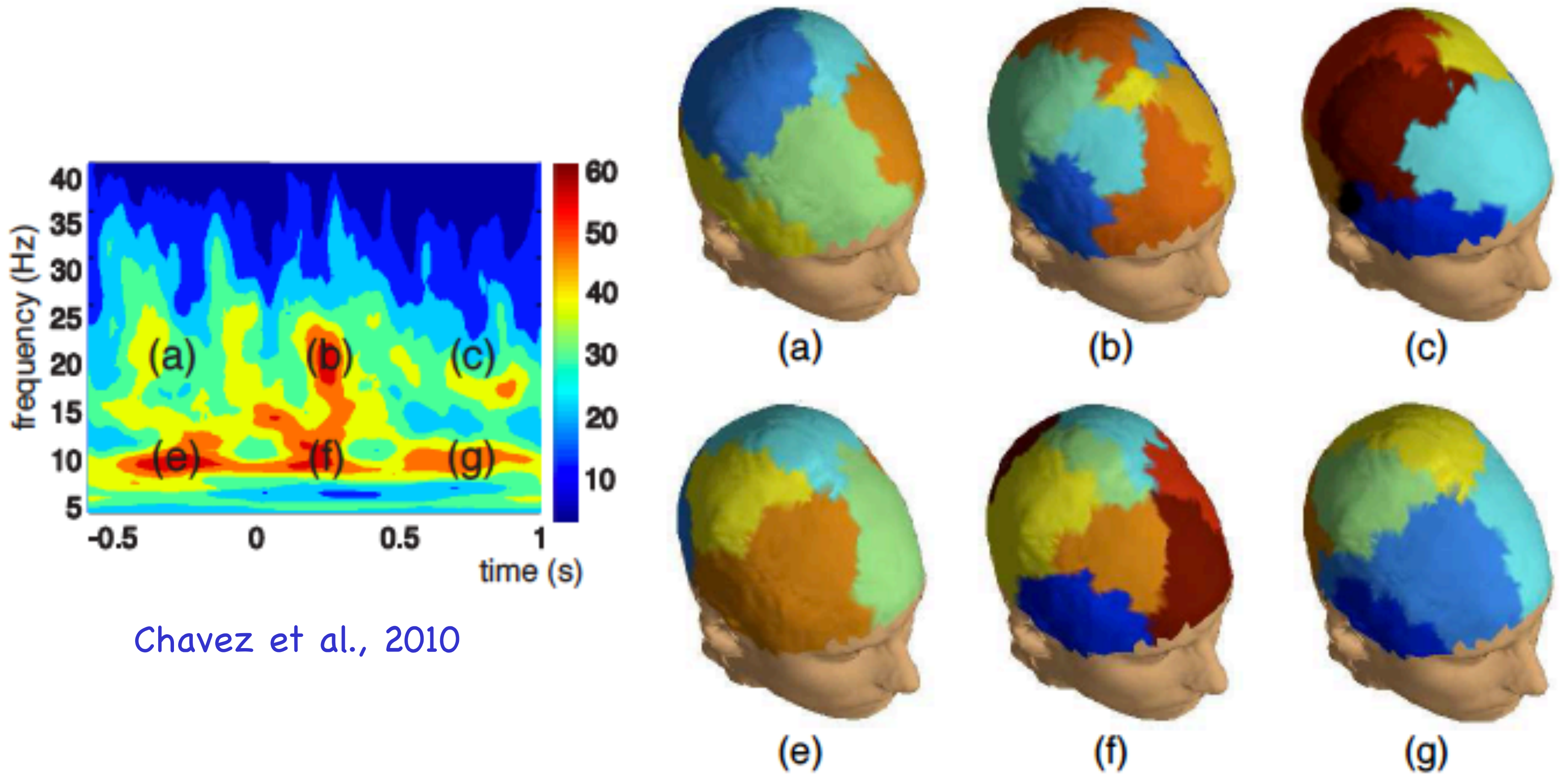
EEG: multiple sclerosis



Chavez et al., in preparation

- Stationary signals over long periods of time (5 min) from 5 control subjects and 5 patients
- Resting state activity.

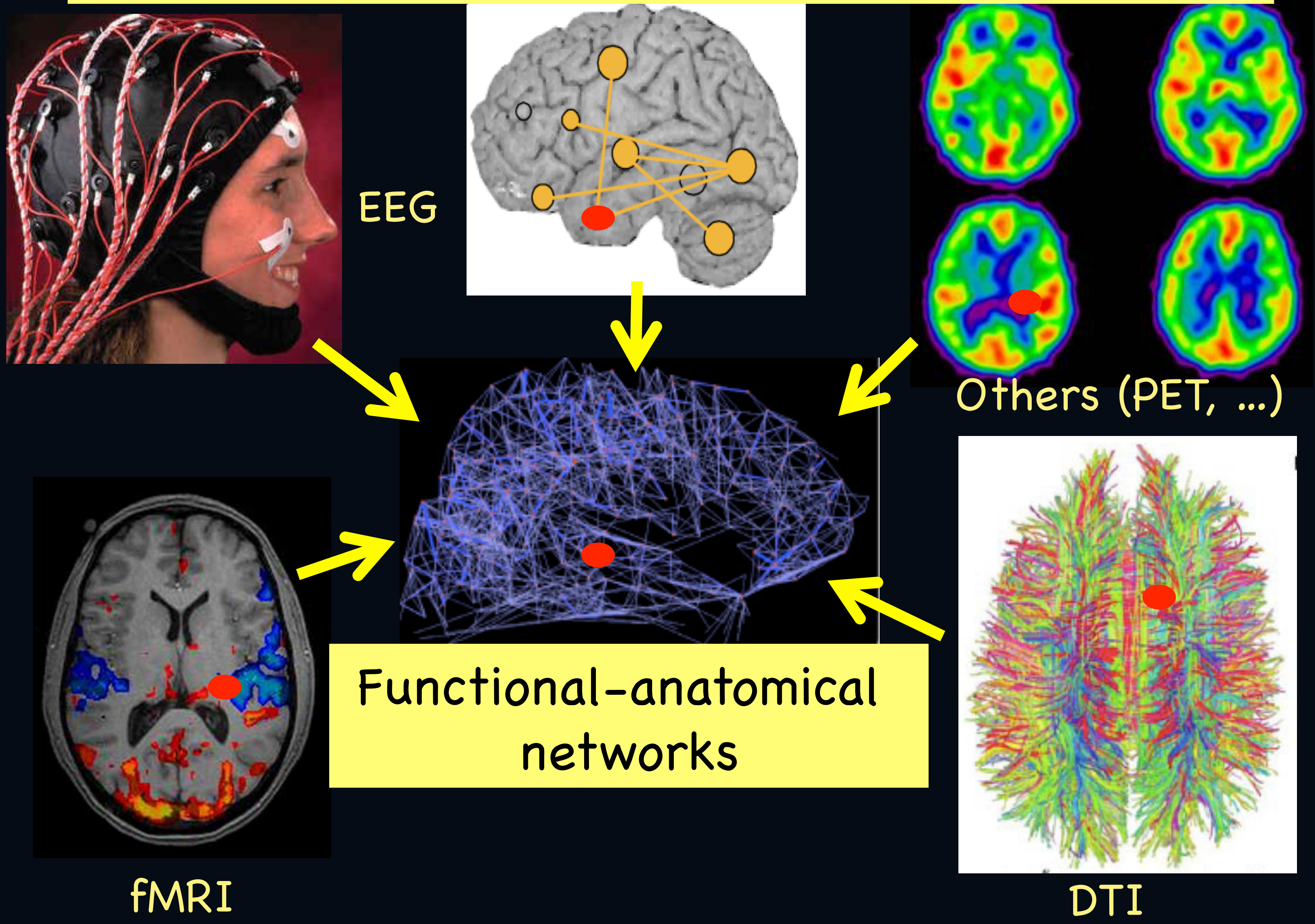
Time varying modules



Chavez et al., 2010

- MEG signals during a cognitive (memory) task

Challenge I: Fusion of networks



Thank you !!

- Main collaborators

- Jacques Martinerie (head of the group),
- Claude Adam (MD),
- Jean Louis Nandrino (MD),

- Vito Latora, Catania, Italy
- Miguel Valencia, Pamplona, Spain
- Fabrizio DeVico Fallani, Roma, Italy
- Are you interested?

- Financial support:

European contracts GABA-NEST-FP6

& EPILEPSIAE-FP7

Time for marketing ☺

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Physics Reports 424 (2006) 175–308

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www.elsevier.com/locate/physrep

Complex networks: Structure and dynamics

S. Boccaletti[a,*], V. Latora[b,c], Y. Moreno[d,e], M. Chavez[f], D.-U. Hwang[a]

PRL 94, 218701 (2005) PHYSICAL REVIEW LETTERS week ending 3 JUNE 2005

Synchronization is Enhanced in Weighted Complex Networks

M. Chavez,[1,2] D.-U. Hwang,[1] A. Amann,[1,3] H. G. E. Hentschel,[4] and S. Boccaletti[1]

PRL 94, 138701 (2005) PHYSICAL REVIEW LETTERS week ending 8 APRIL 2005

Synchronization in Complex Networks with Age Ordering

D.-U. Hwang,[1] M. Chavez,[1,2] A. Amann,[1,3] and S. Boccaletti[1]

PRL **104**, 118701 (2010) PHYSICAL REVIEW LETTERS week ending 19 MARCH 2010

Functional Modularity of Background Activities in Normal and Epileptic Brain Networks

M. Chavez,[1] M. Valencia,[1] V. Navarro,[2] V. Latora,[3,4] and J. Martinerie[1]

International Journal of Bifurcation and Chaos, Vol. 20, No. 6 (2010) 1–10

DOI: 10.1142/S0218127410026757

COMPLEX NETWORKS: NEW TRENDS
FOR THE ANALYSIS OF BRAIN CONNECTIVITY

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CHAOS **19**, 023119 (2009)

Complex modular structure of large-scale brain networks

M. Valencia,[1] M. A. Pastor,[2] M. A. Fernández-Seara,[2] J. Artieda,[2] J. Martinerie,[1] and M. Chavez[1]