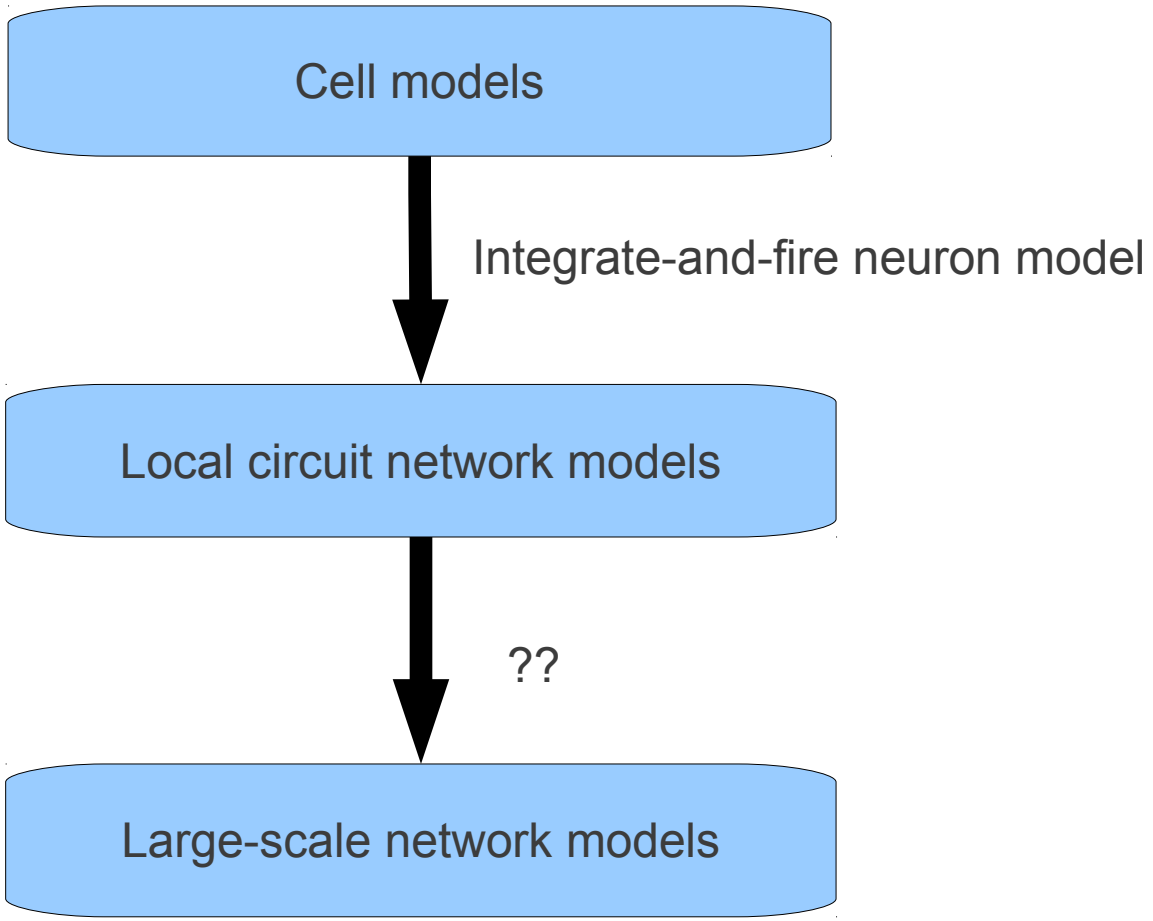
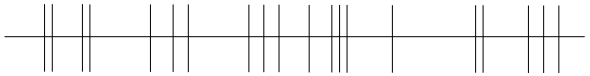
Brain networks to support memory ~~and attention~~

Albert Compte
Institute for Biomedical Research “August Pi i Sunyer”
IDIBAPS
Barcelona

Models for cognition: the problem of integrating multiple scales



Electrophysiology in behaving monkeys

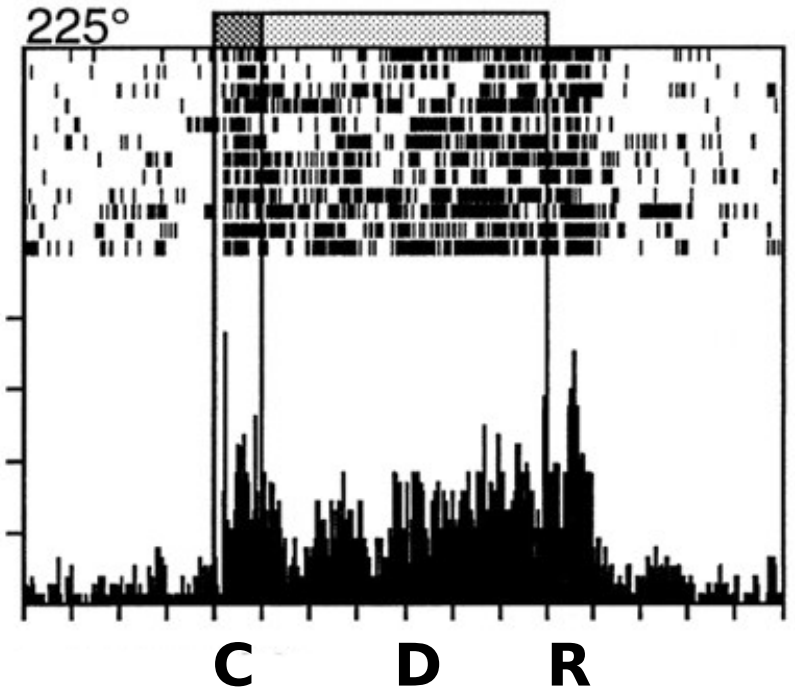


PFC: working memory

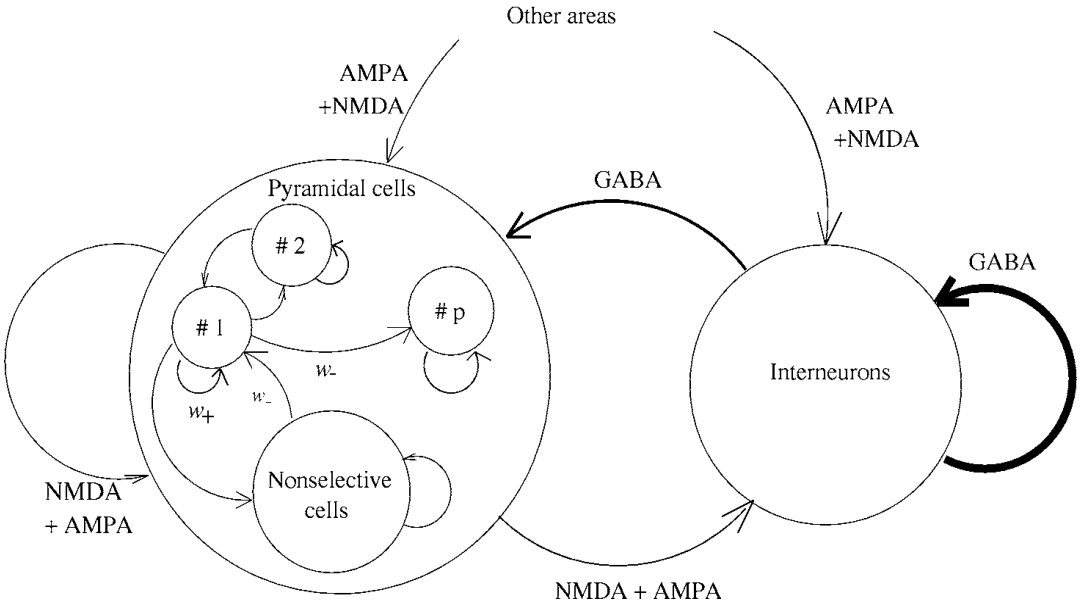
LIP: decision making

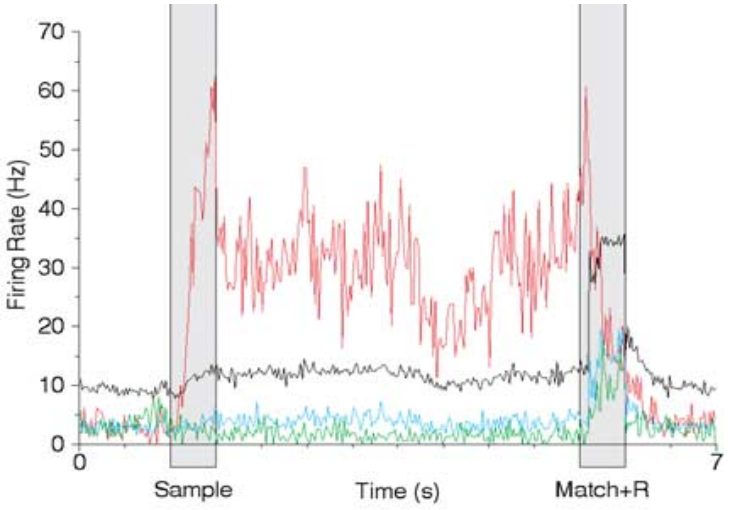
V4: selective attention

Working memory: persistent activity and reverberating circuit hypothesis



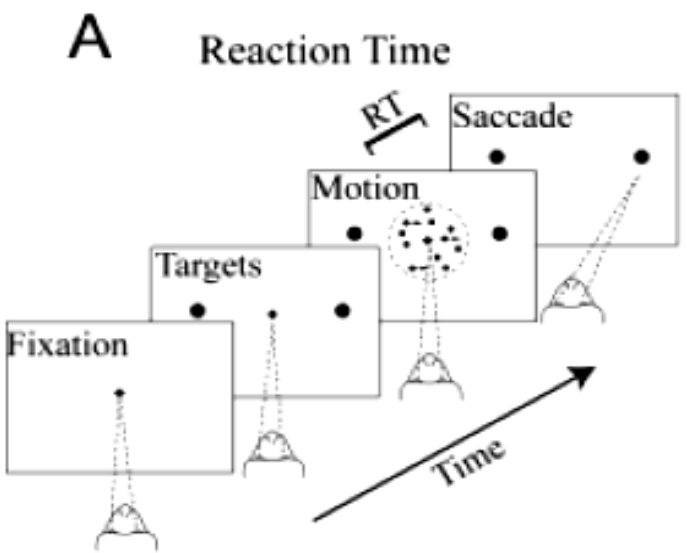
(Funahashi and Goldman-Rakic, J Neurophysiol 1989)

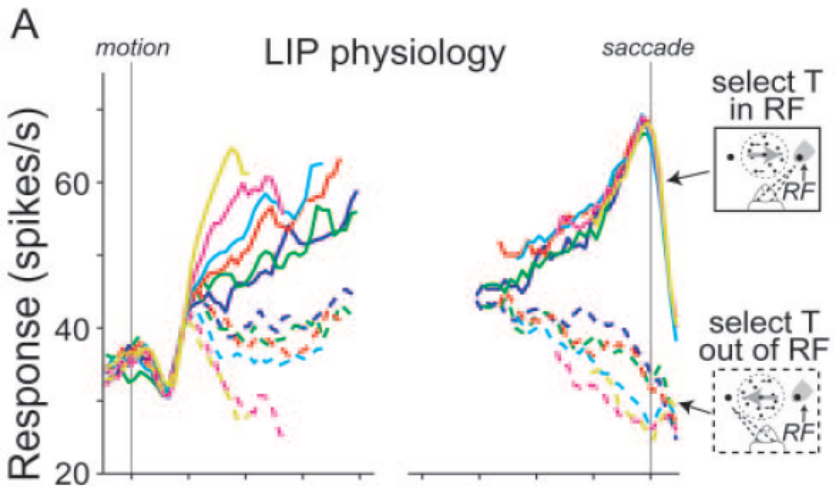




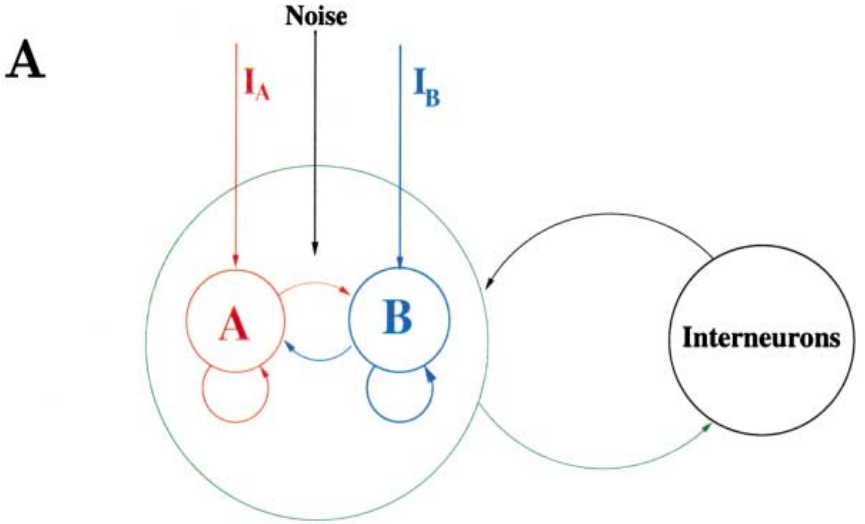
(Brunel and Wang, 2003)

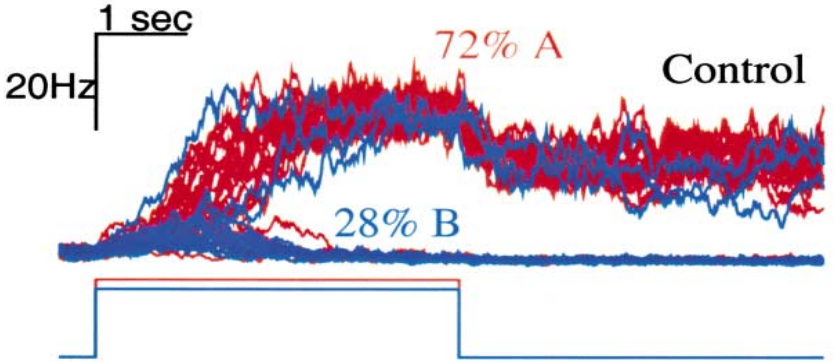
Decision making: integration of evidence





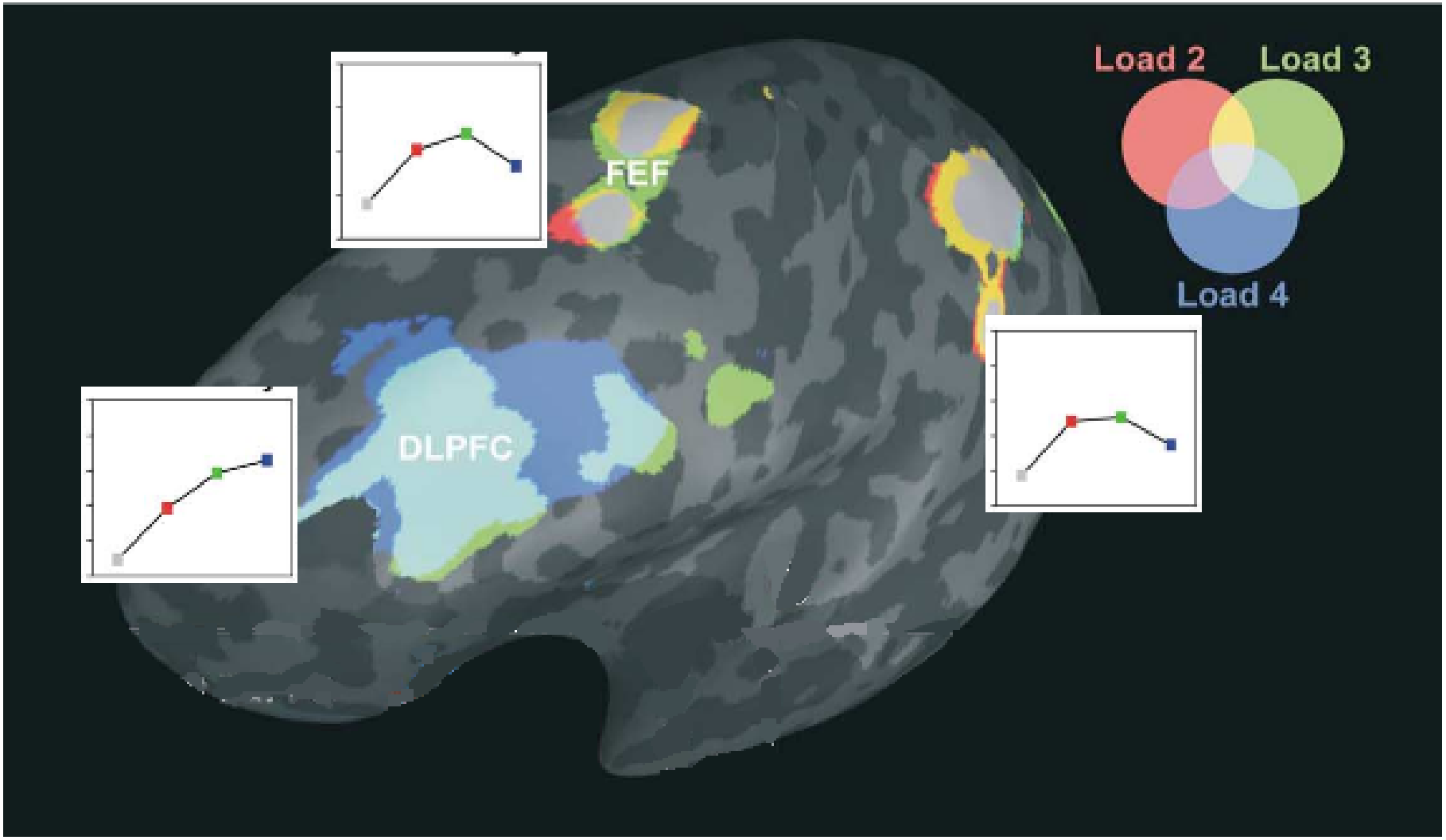
(Shadlen & Newsome; Roitman & Shadlen, 2002)





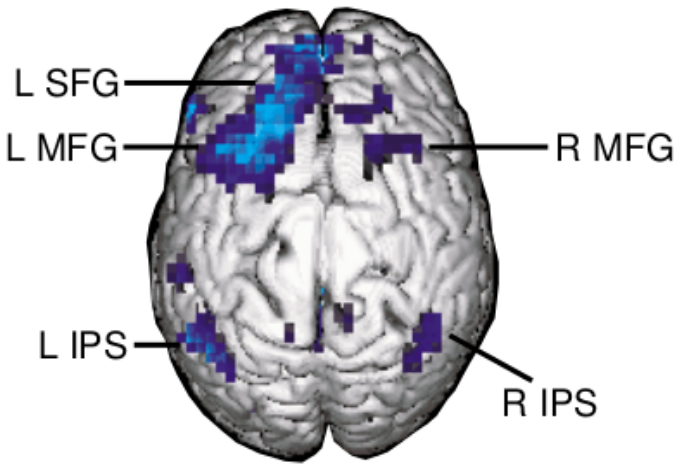
(Wang 2002)

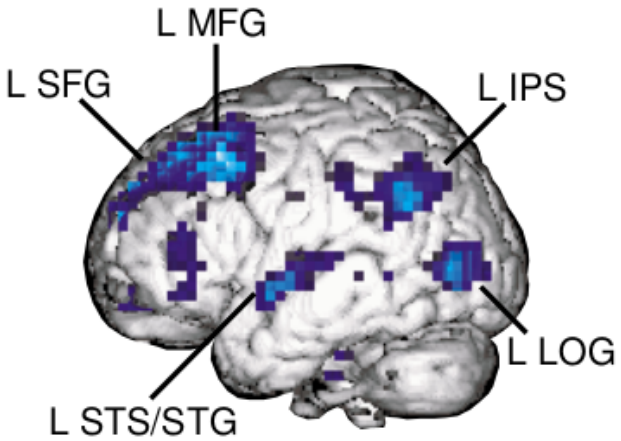
Working memory networks

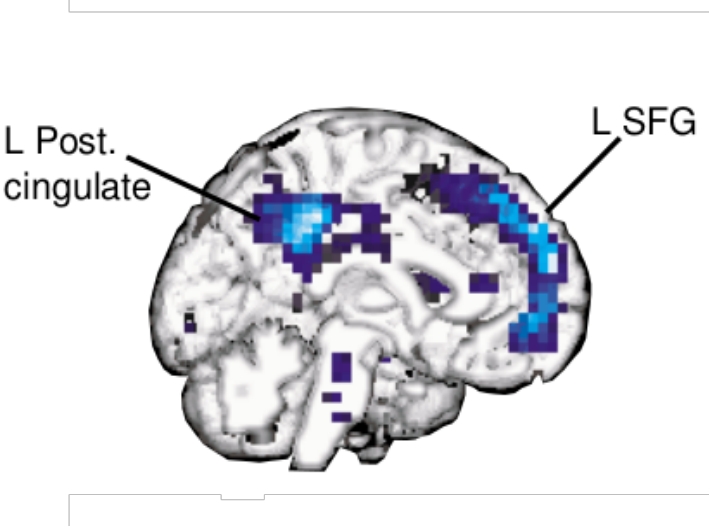


(Linden et al., *Neuroimage* 2003)

Attention networks







(Hopfinger, Buonocuore and Mangun *Nat Neurosci* 2000)

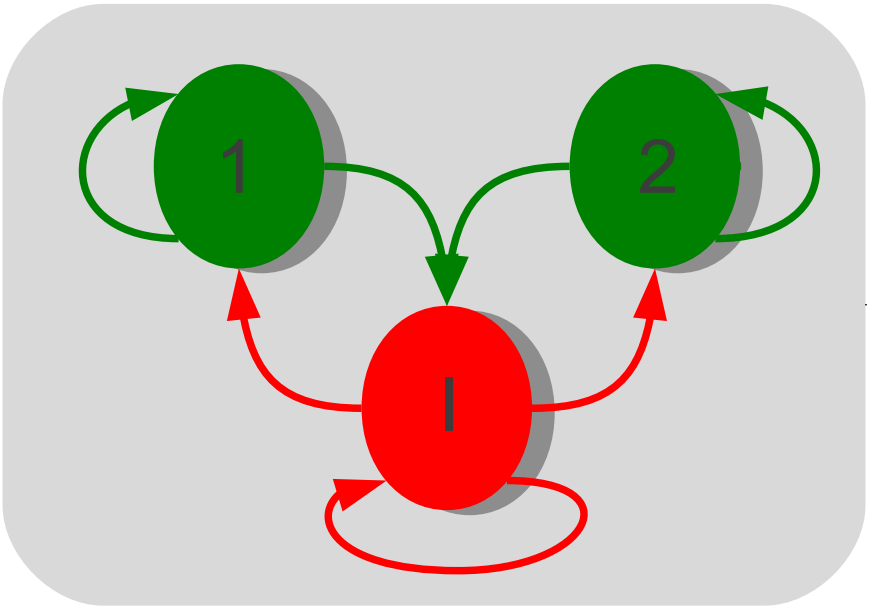
Dynamics at the local circuit level

- Attractor networks: fixed-point attractors
- Attractor networks: oscillations
- Transient dynamics
- ...

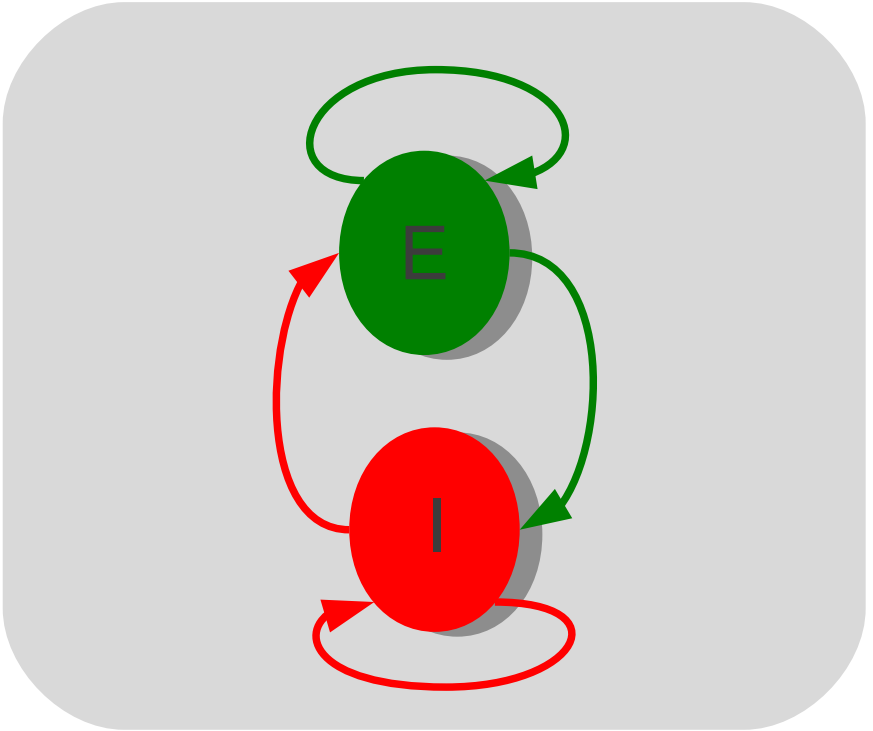
Dynamics at the brain network level

- Neural mass models
- Dynamic Causal Modeling (DCM)
- ...

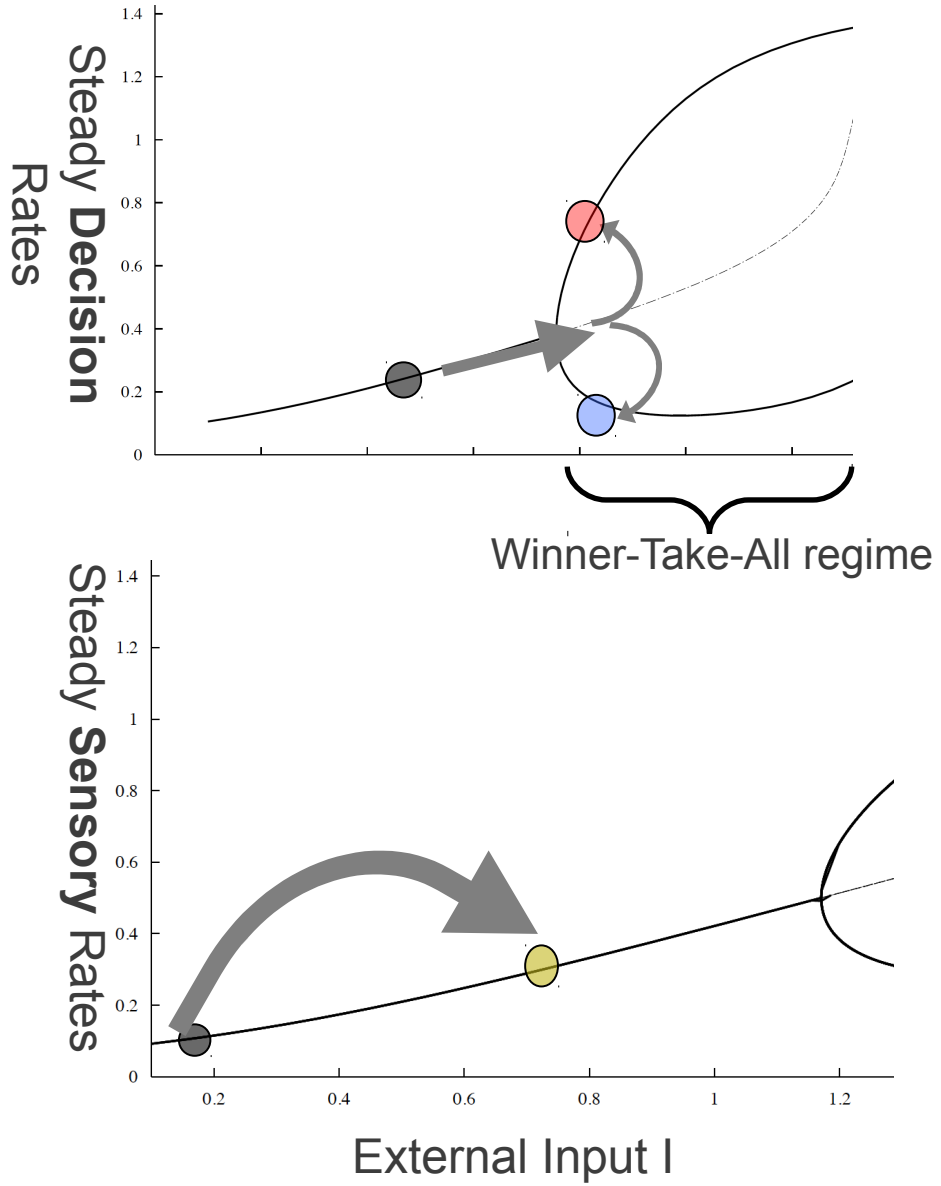
A simple cortical circuit

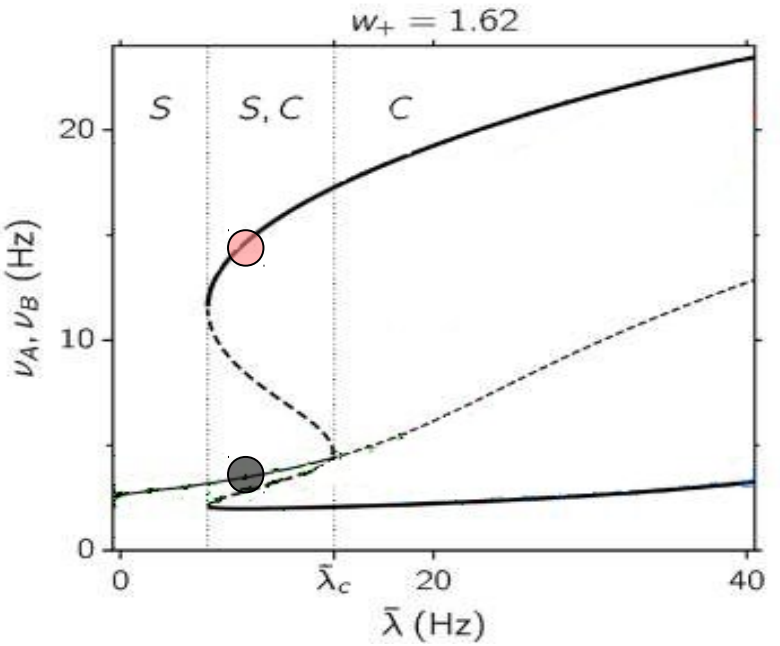


A *simpler* cortical circuit



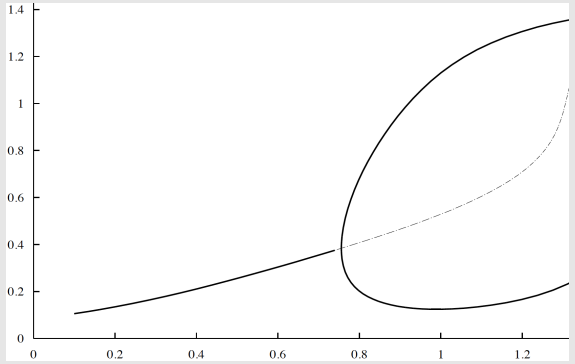
Different dynamical regimes

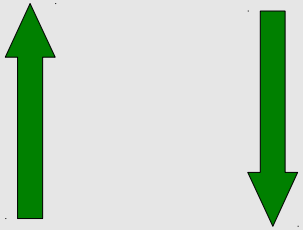


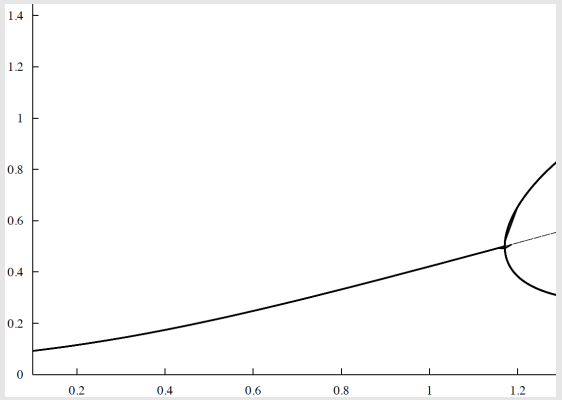


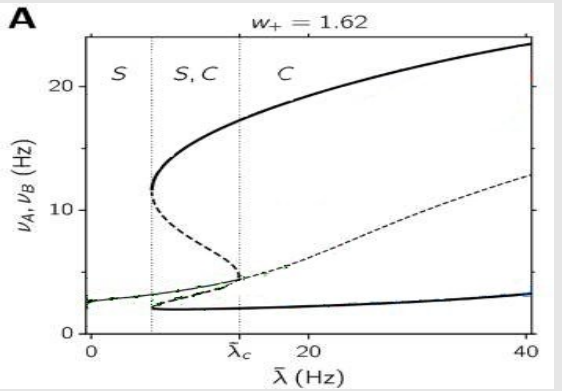
Wong & Wang '06; Wong et al '07; Roxin & Ledberg '08; Martí et al. '08

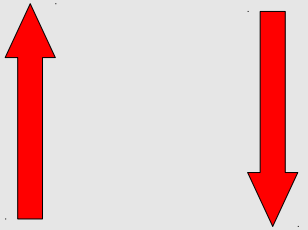
Elementary “large scale” networks

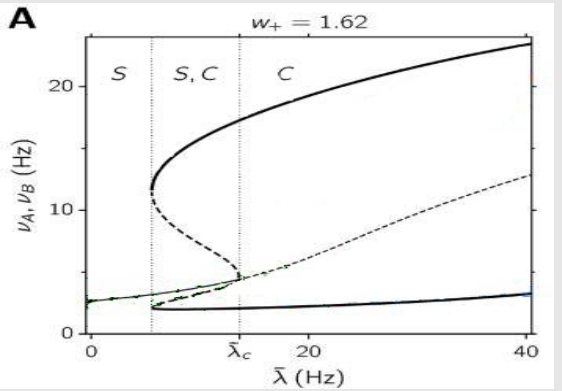






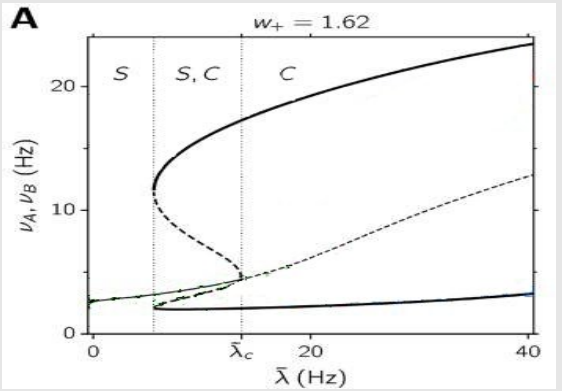


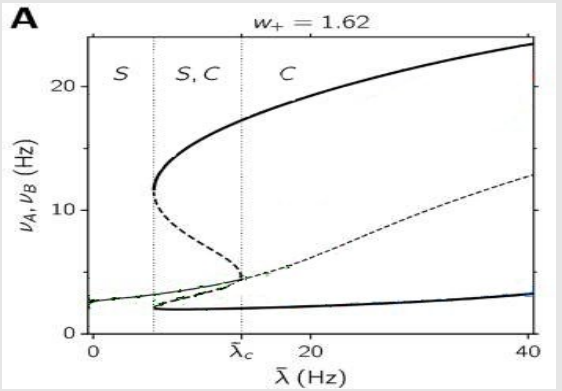




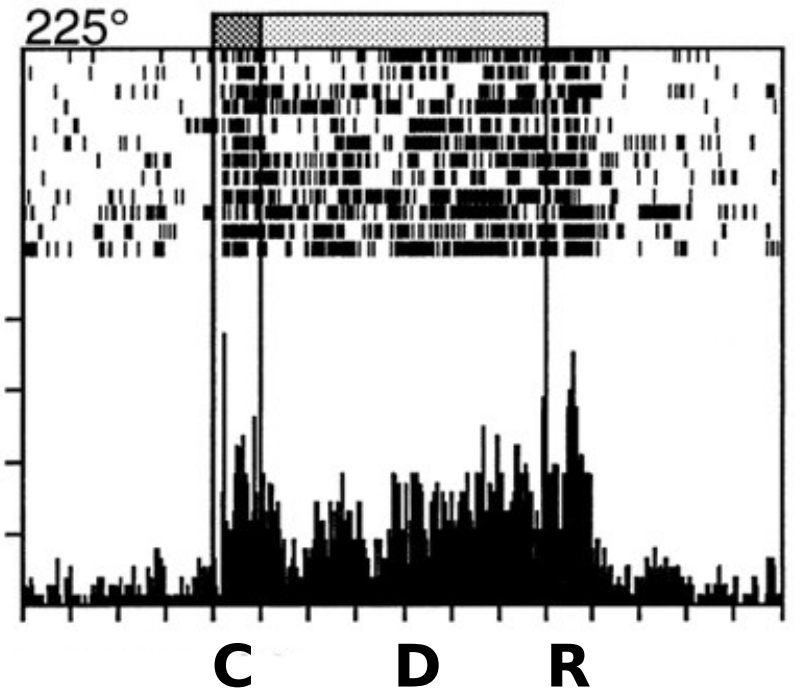
. . .

Network for working memory

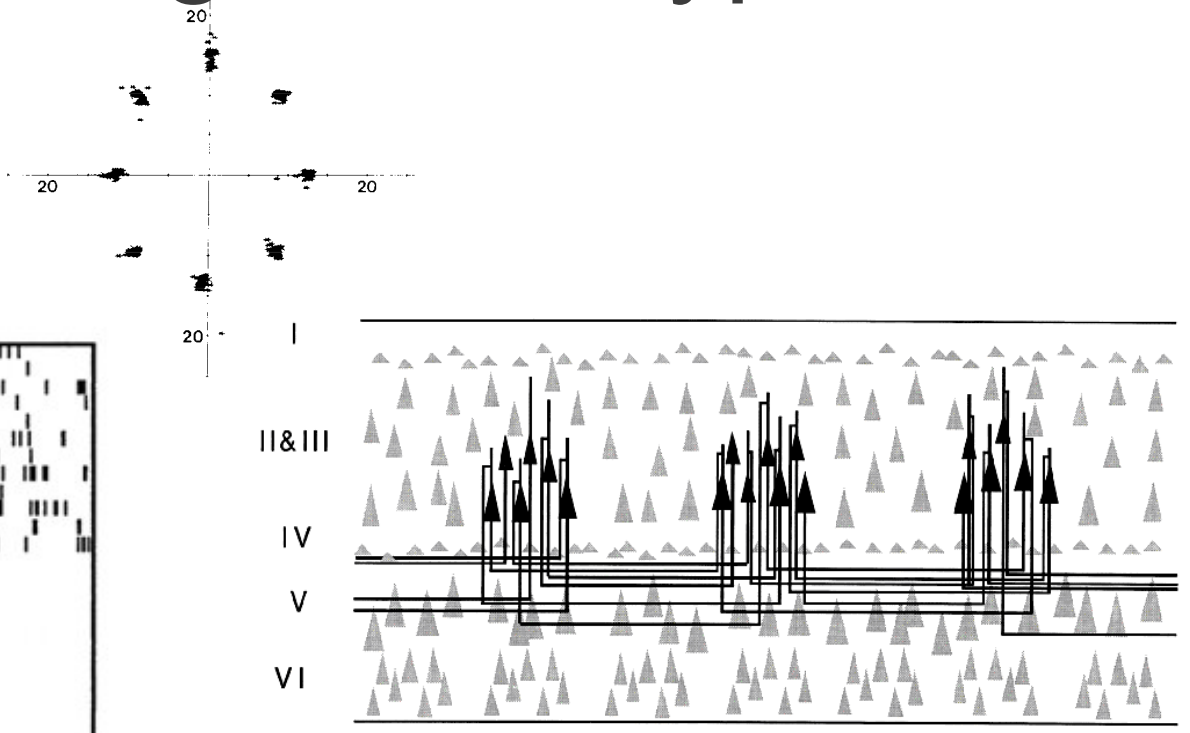




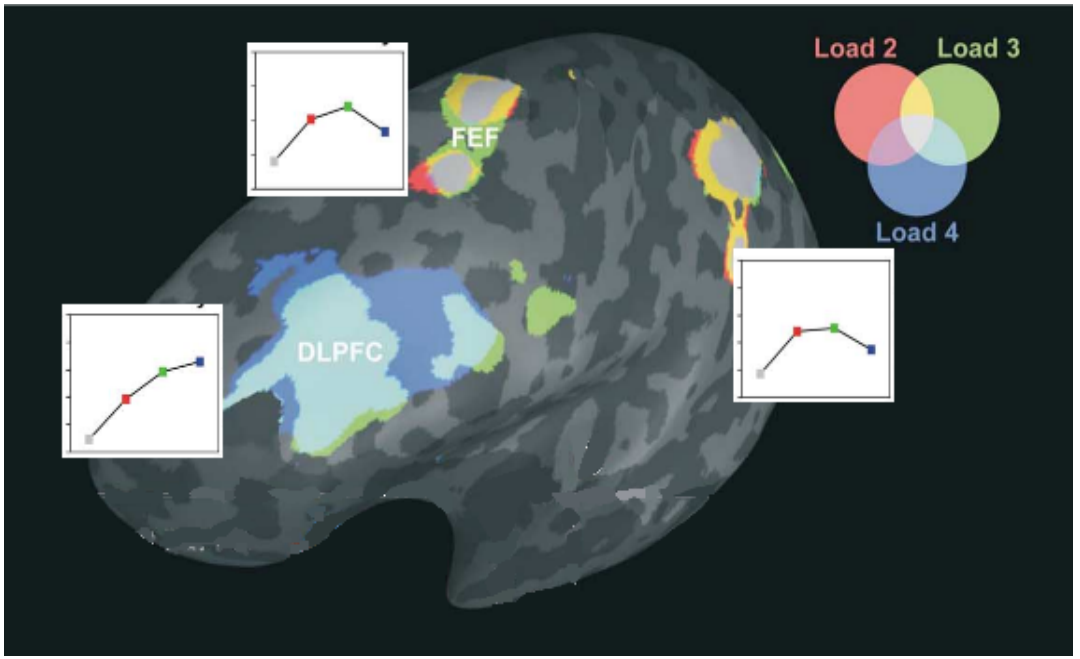
Working memory: persistent activity and reverberating circuit hypothesis



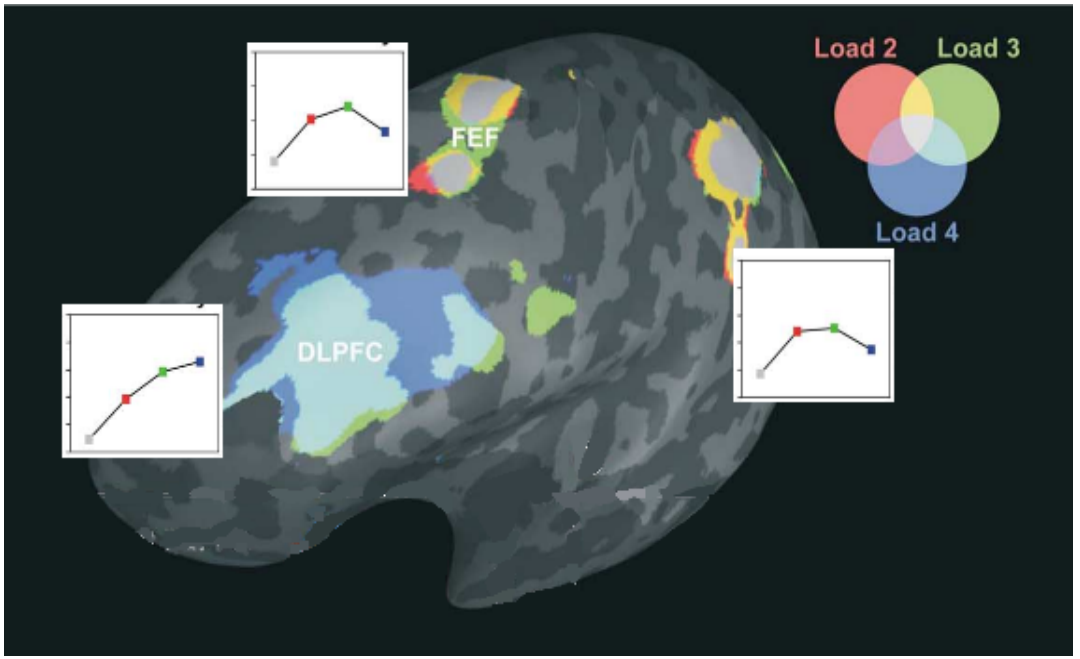
(Funahashi and Goldman-Rakic, J Neurophysiol 1989)



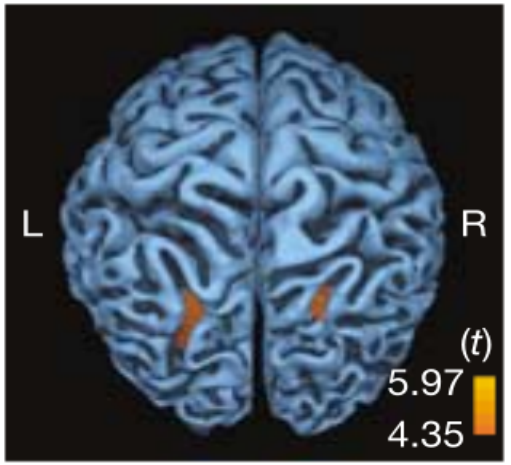
(Goldman-Rakic, Neuron 1995)

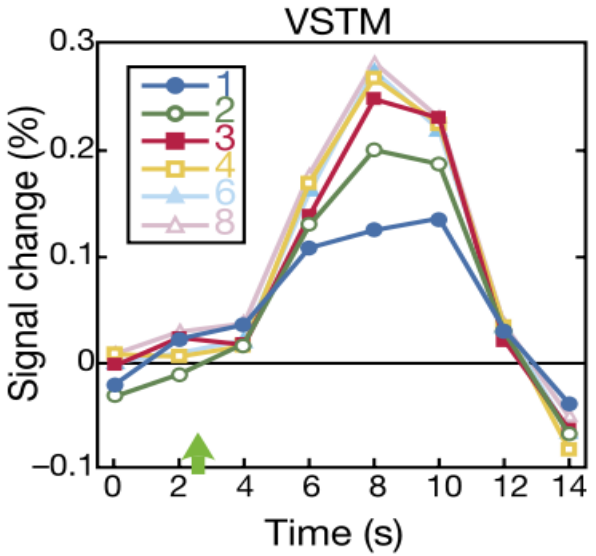


(Linden et al., *Neuroimage* 2003)

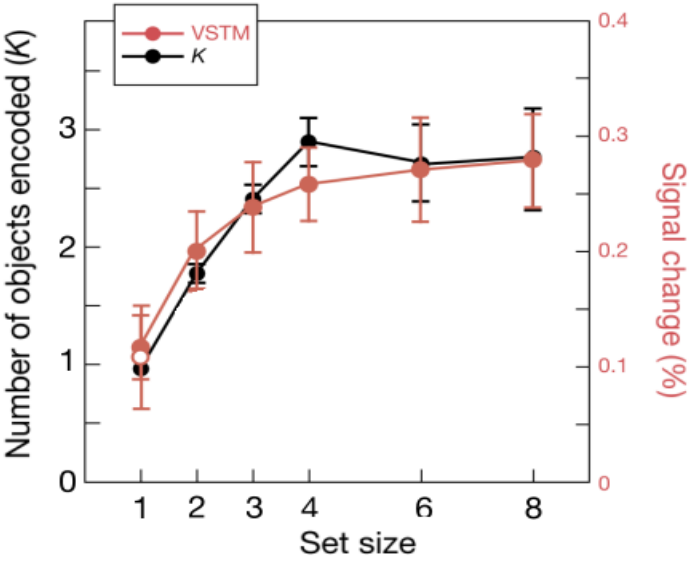


(Linden et al., *Neuroimage* 2003)

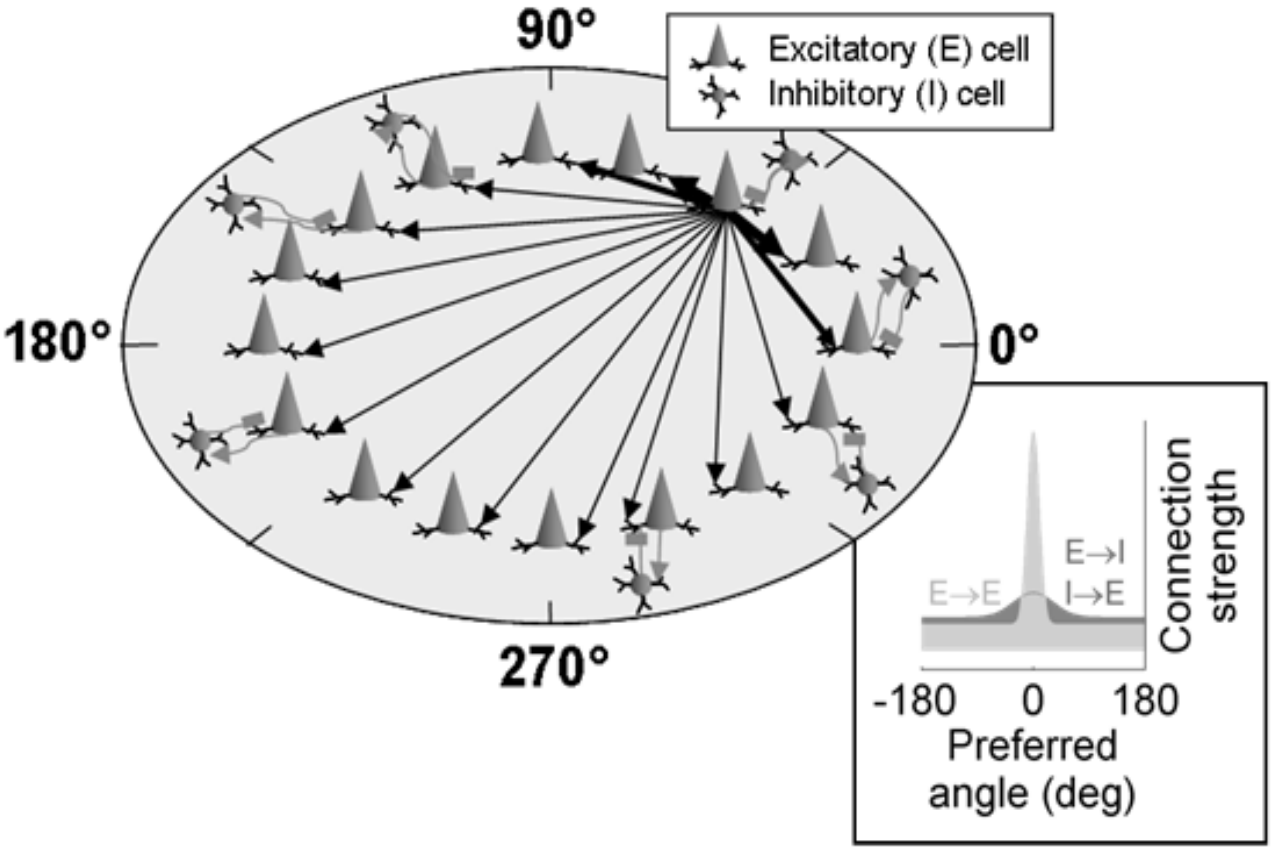




(Todd and Marois, *Nature* 2004)

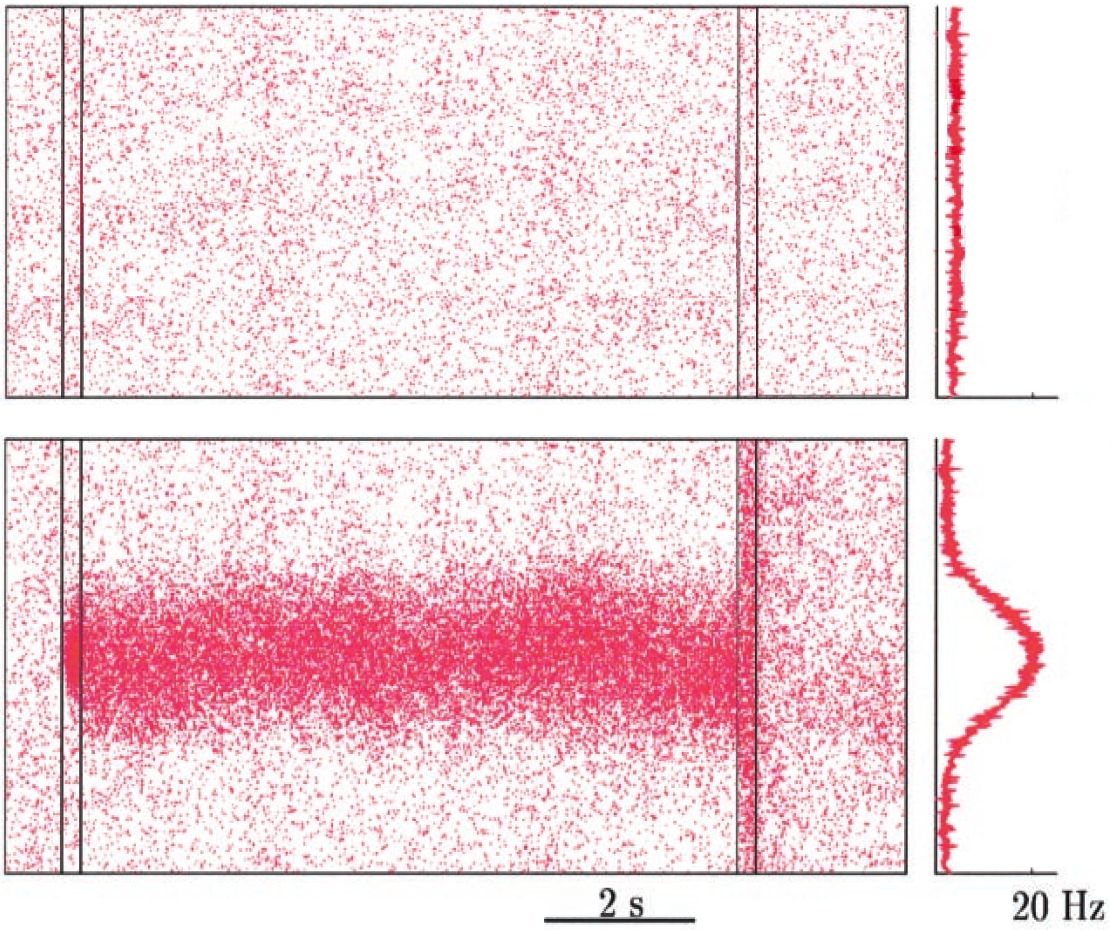


Ring model for *spatial* working memory storage



(Compte *et al.* Cereb Cortex 2000; Edin et al. PNAS 2009)

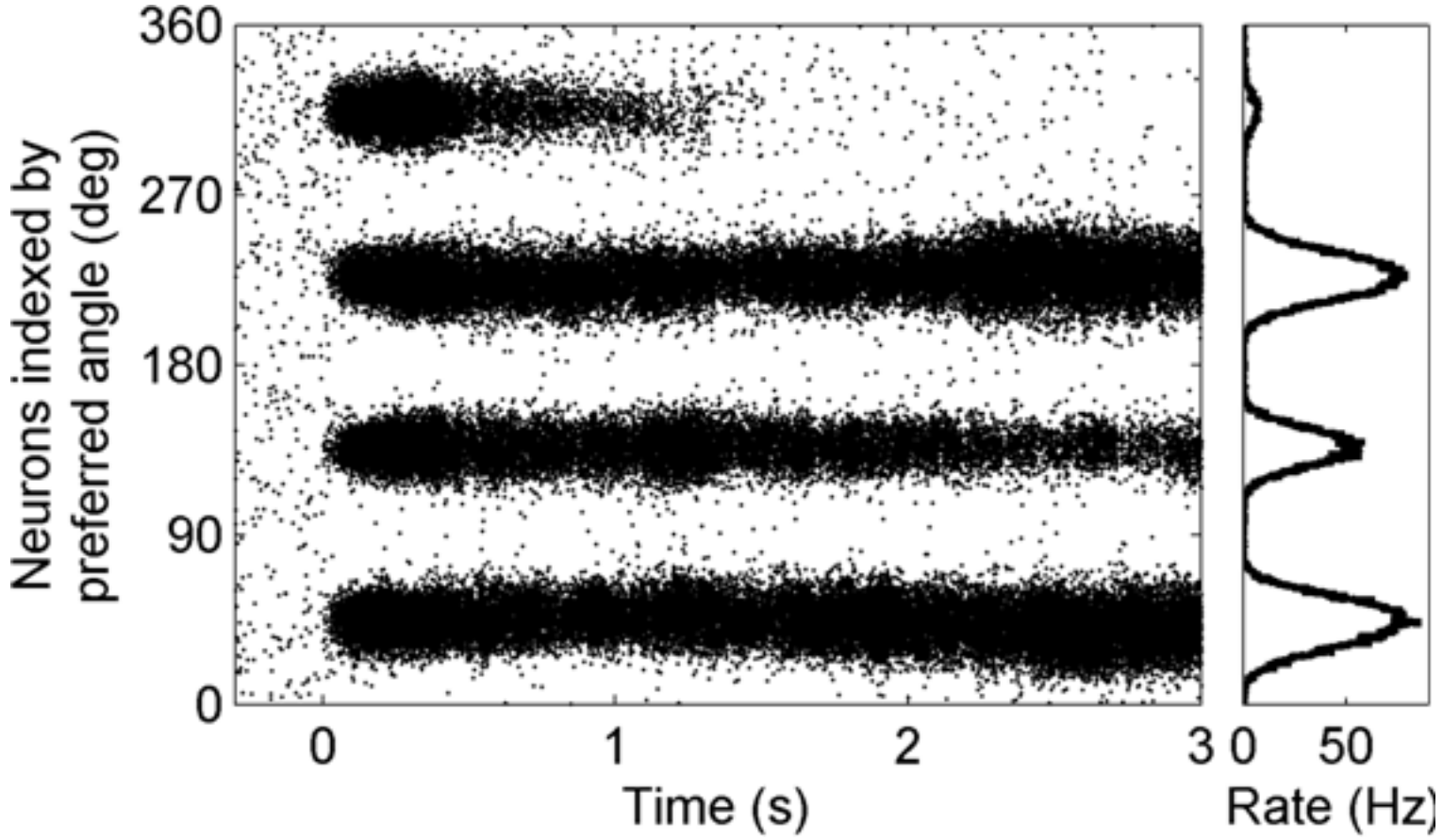
Local circuit mechanisms



- Strong focal excitation → persistence
- Strong non-selective inhibition → tuning

(Compte et al., Cereb Cortex 2000)

Limited capacity in the IPS storage area



Mean-field approach

- Follow (Amit and Brunel *Cereb. Cortex,* 1997; Brunel *Network*, 2000), but take the proportion of cells in a single active population, *w*, not negligible.
- Attractor solutions satisfy:

$$r = \Phi[G^{+} - G^{-}(p-1)]r + I_X)$$

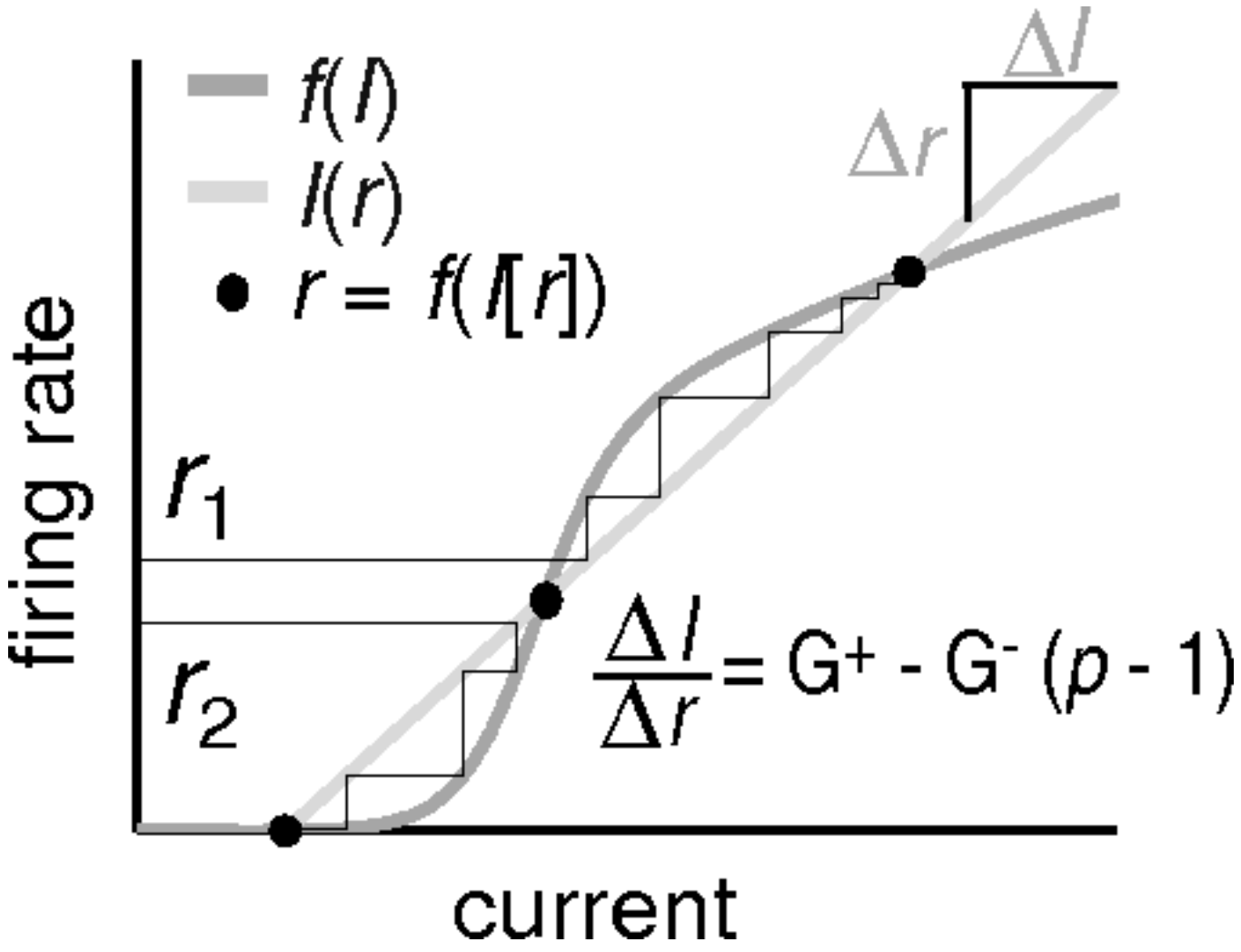
where p = number of items to store

$$G^{+} = w(G_{E\to E}g_{+} - G_{I\to E}G_{E\to I} / (1 / h + G_{I\to I}))$$

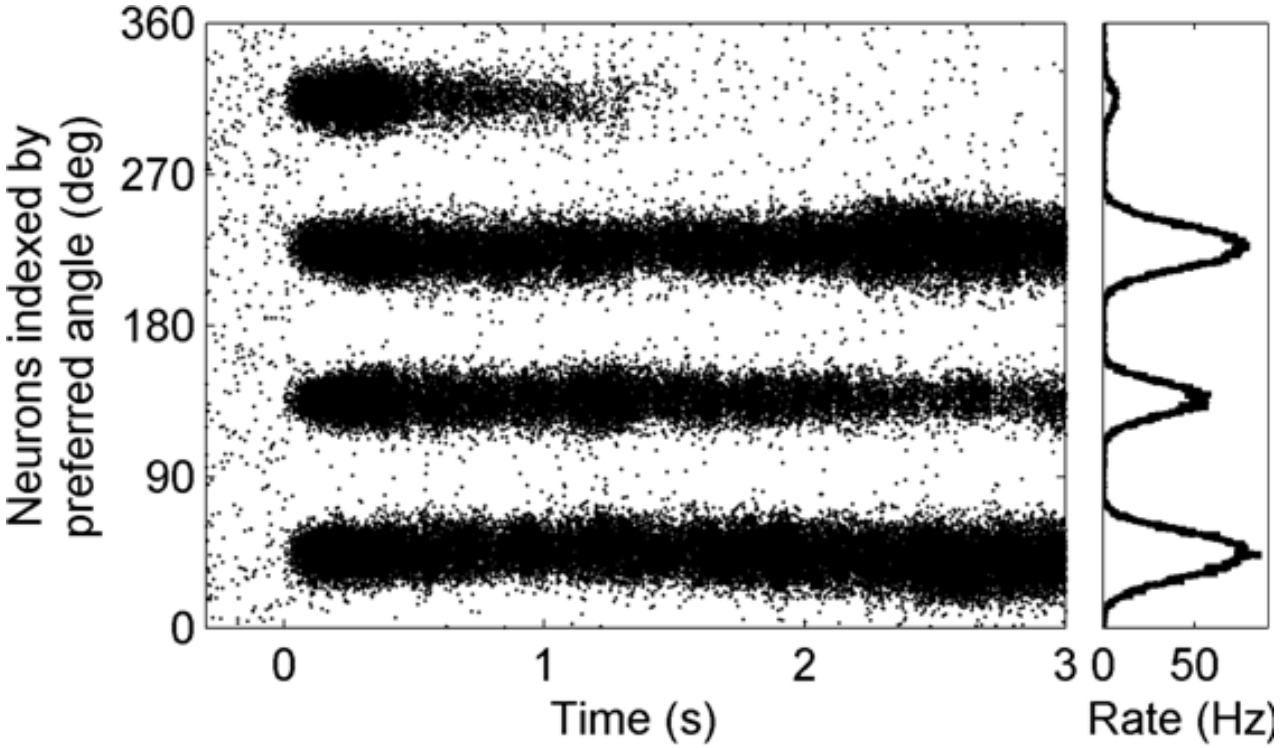
$$G^{-} = -w(G_{E\to E}g_{-} - G_{I\to E}G_{E\to I} / (1 / h + G_{I\to I}))$$

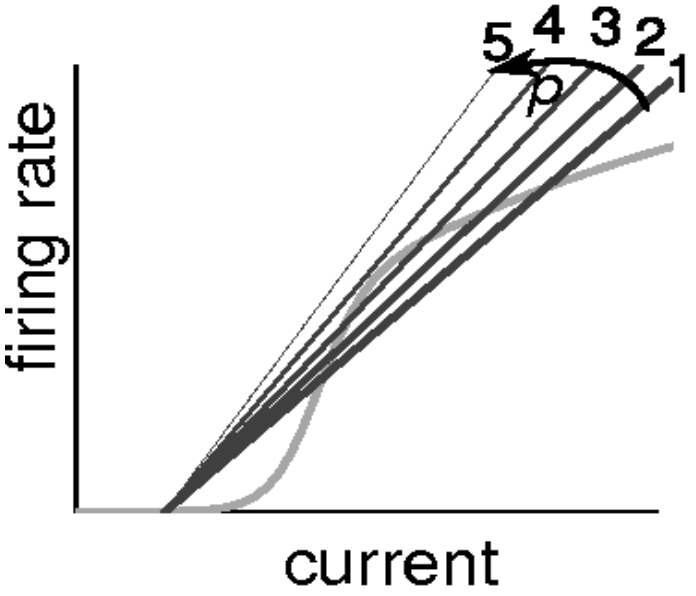
$$I_X \equiv g_L \mu_{xe} - \frac{G_{I\to E}}{1 / h + G_{I\to I}} g_L (\mu_{xi} - V_\theta)$$

$$r = \Phi([G^{+} - G^{-}(p-1)]r + I_X)$$



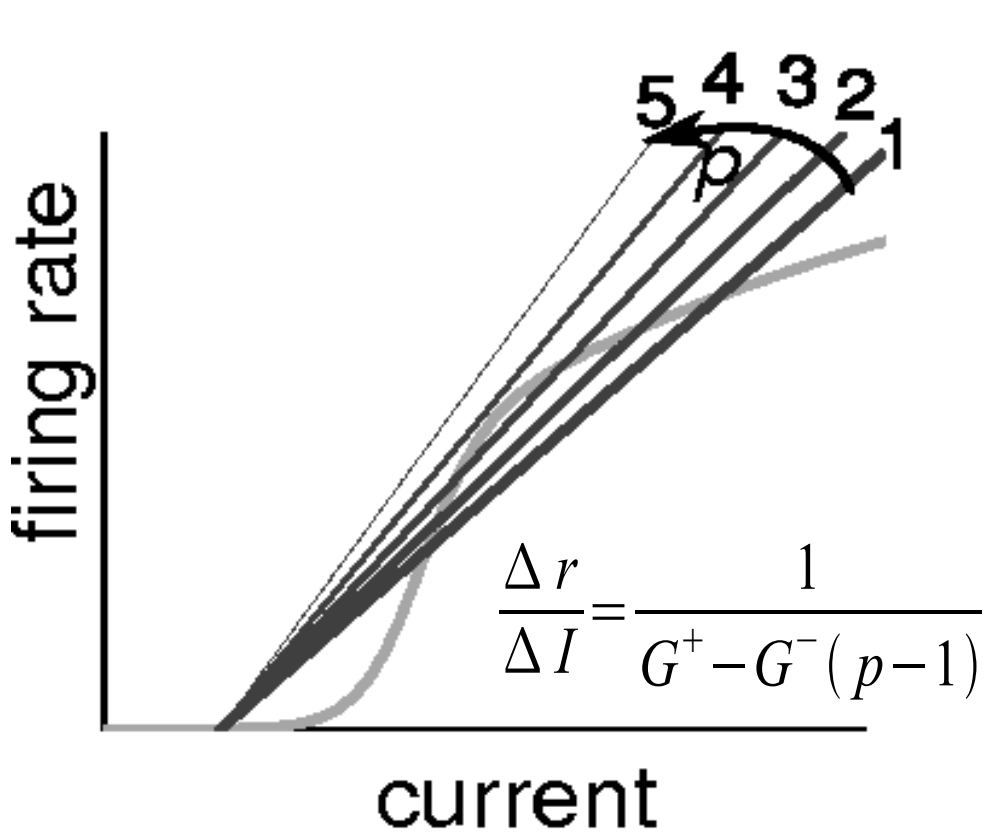
Inhibition limits the capacity of the spatial working memory model

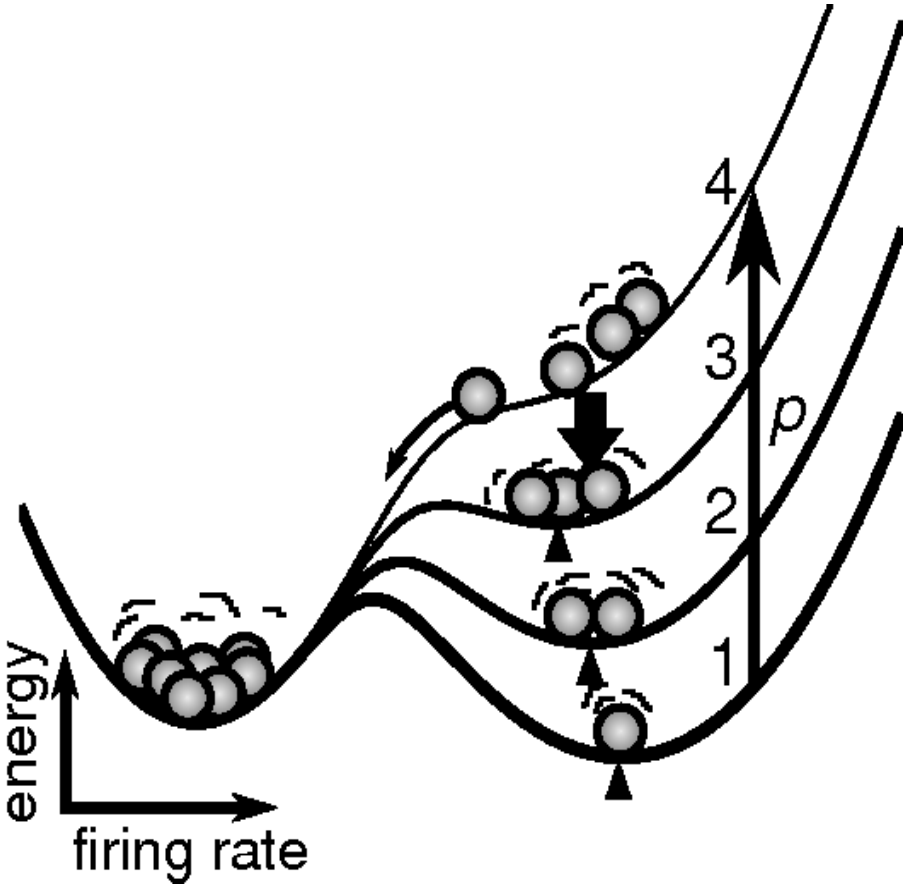




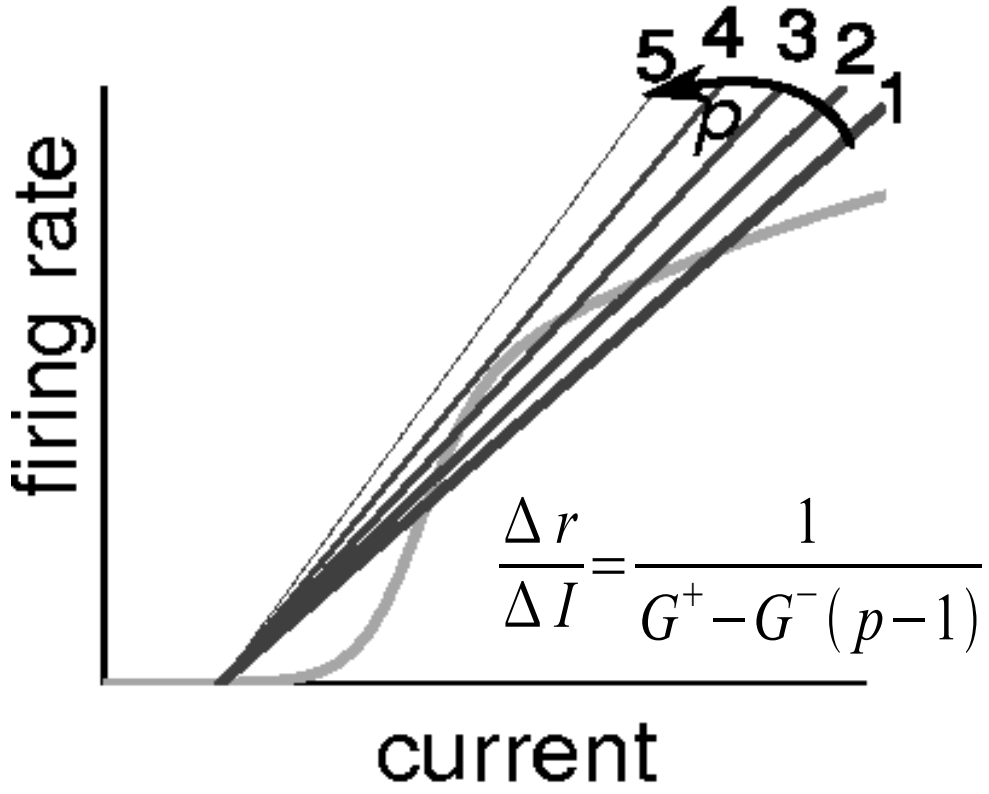
Edin et al. PNAS 2009

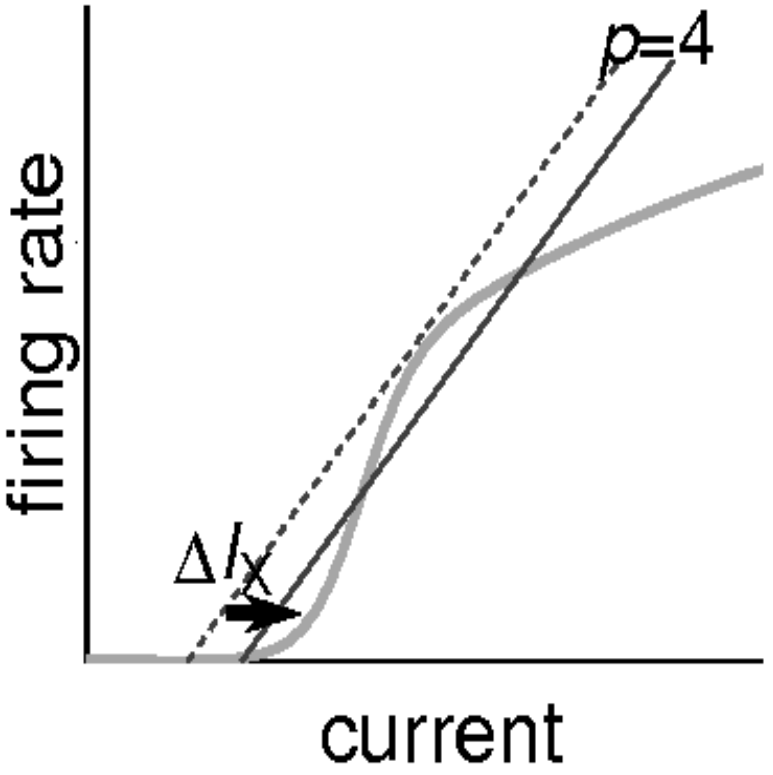
The mechanism of capacity limits



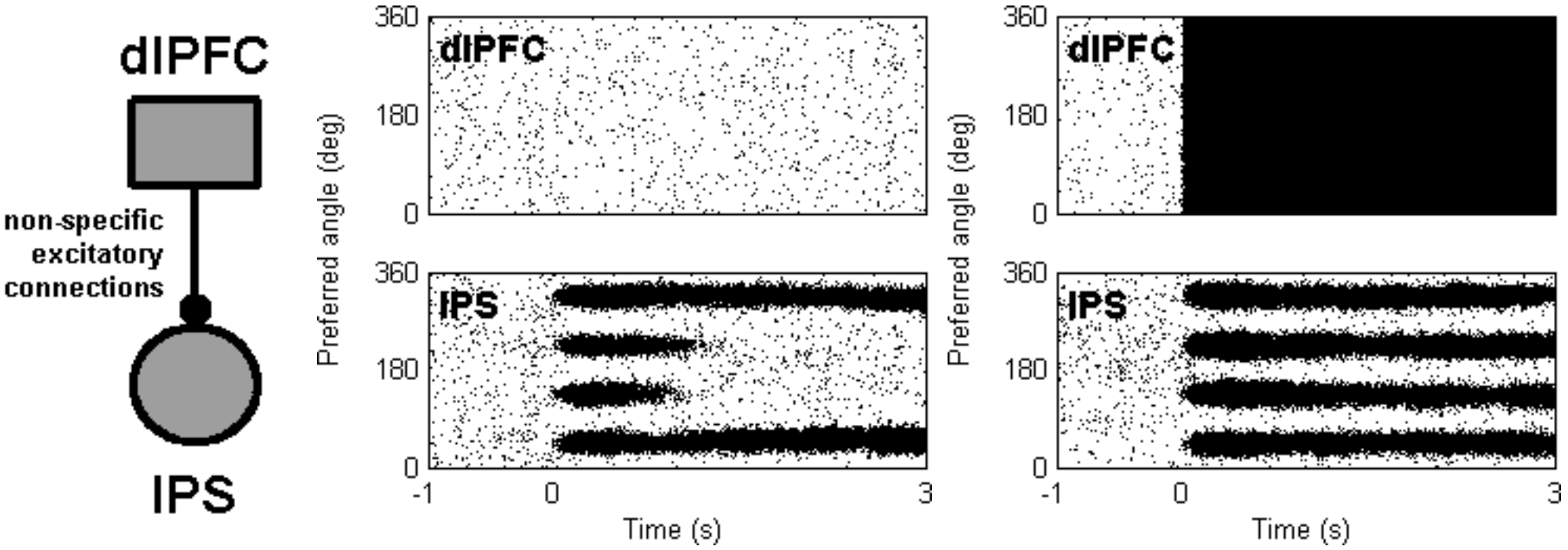


Capacity can be “boosted” by external inputs



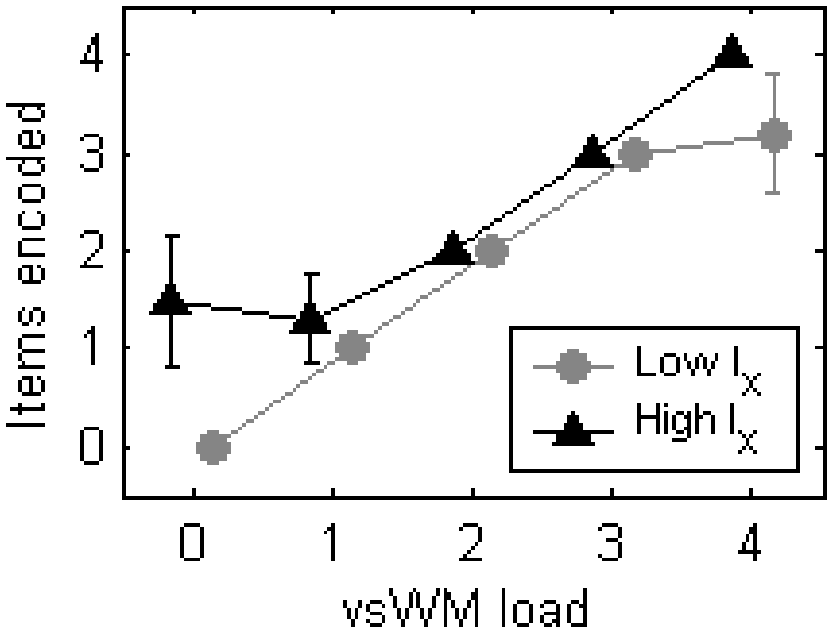


Nonselective excitatory top-down *boosts* working memory capacity



Edin et al. PNAS 2009

Permanent boosting is not optimal: it generates false positives at load 0



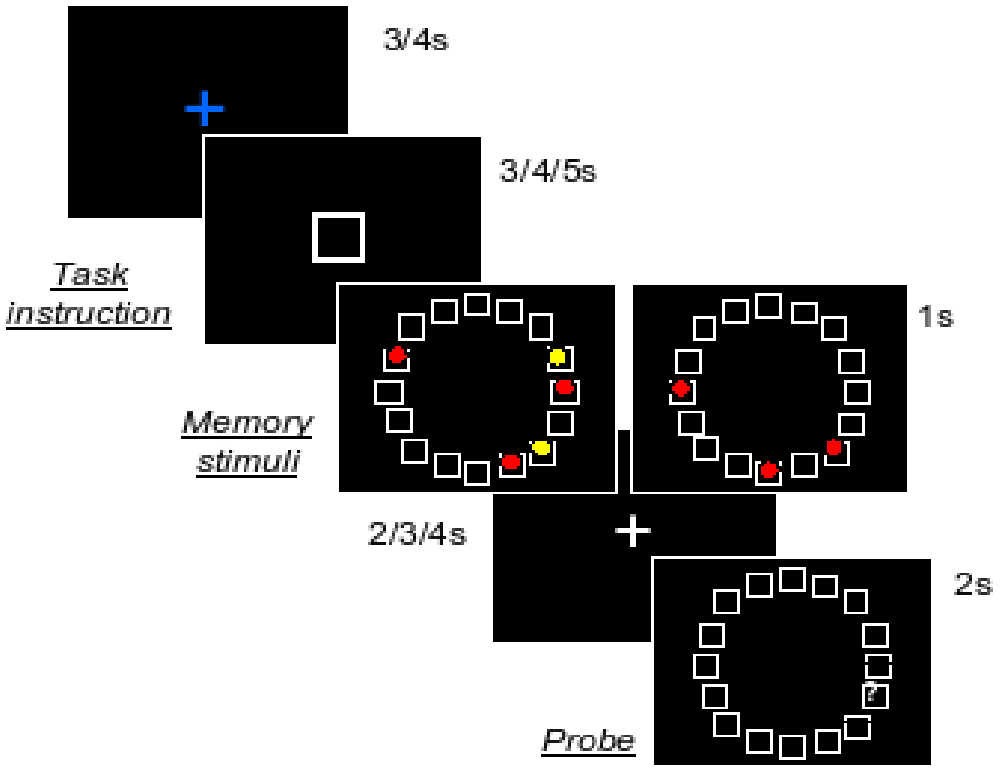
Hypotheses

- top-down control of WM is exerted by excitatory inputs on attractor networks
- Such inputs increase capacity of a WM attractor network

Predictions

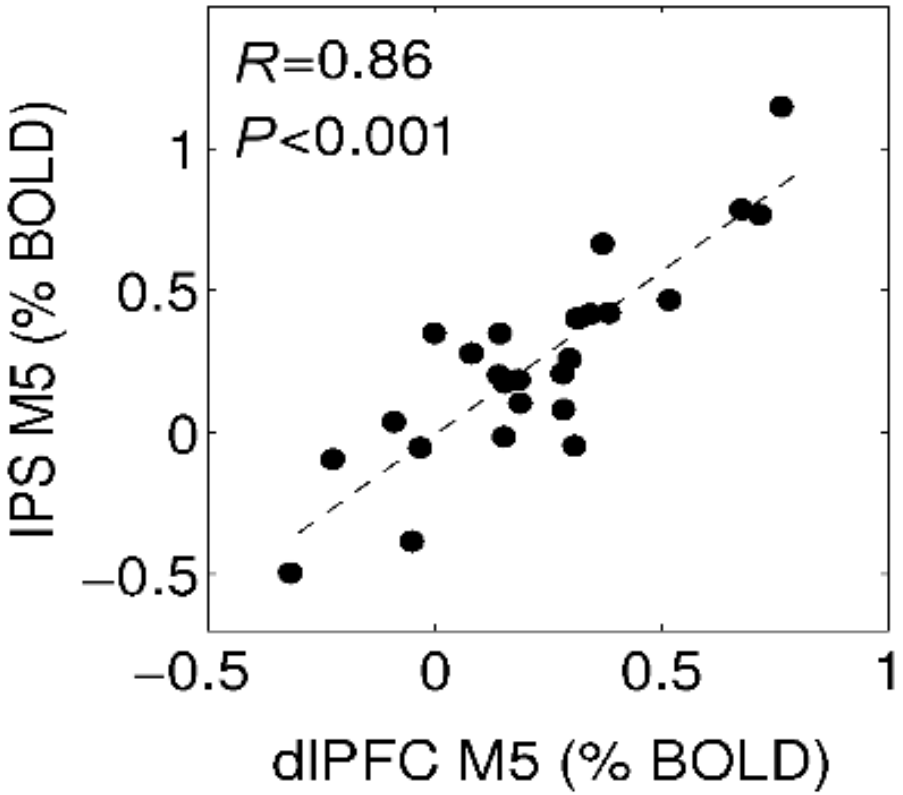
- For **high-load trials** individuals with strong dlPFC have also strong IPS activations, and they perform better
- For **low-load trials** there is no correlation between dlPFC and IPS activations, and only IPS activation correlates with behavior

Testing the model in fMRI



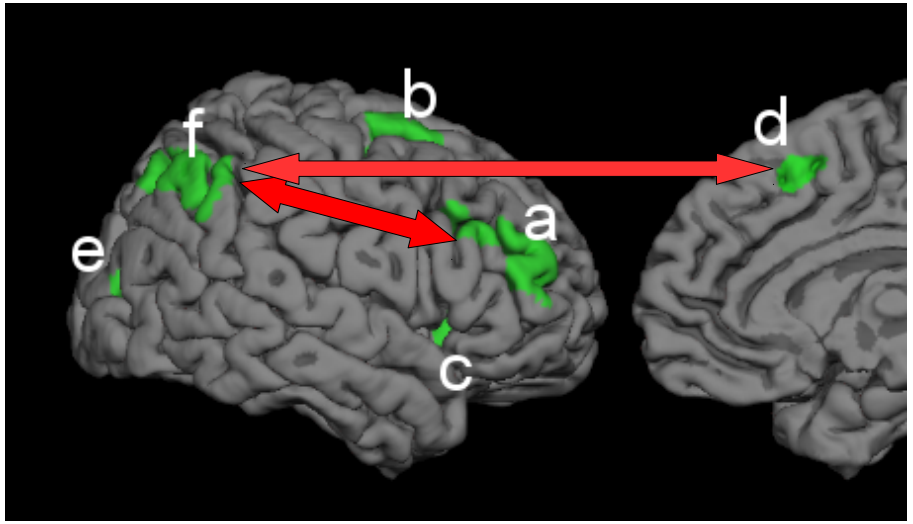
(McNab and Klingberg, Nat Neurosci 2007)

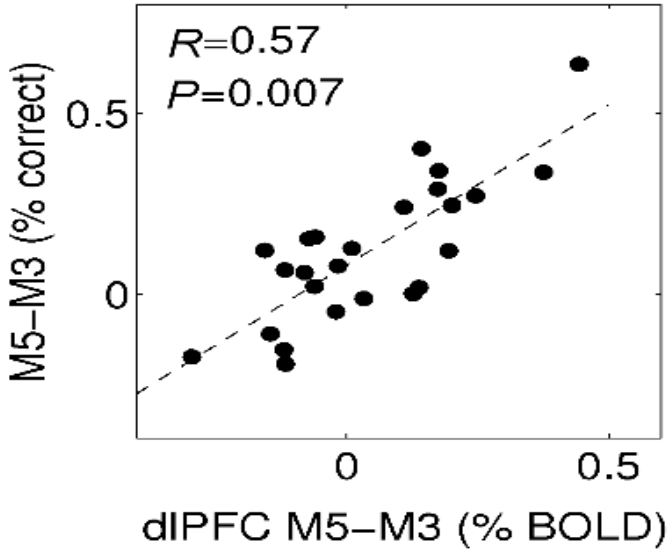
PFC-IPS activations correlate according to the model predictions



dlPFC-IPS correlations were stronger in M5 than M3 trials (P=0.034)

PFC and IPS correlate with behavioral responses as expected





- Participants with dlPFC boost (M5-M3) above average performed better in M5 (P=0.015), but not in M3 (P=0.7)

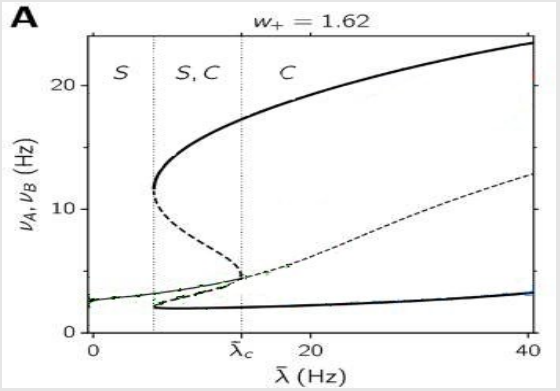
- Participants performing above average had stronger dlPFC boost (P=0.02)

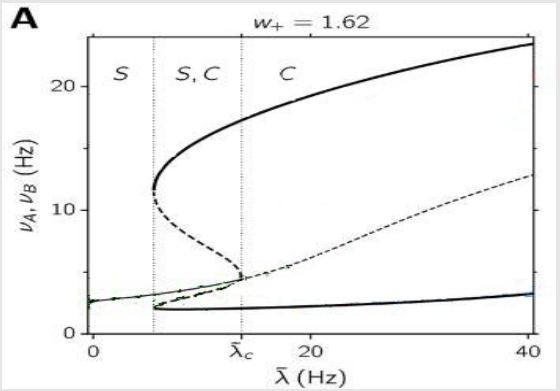
activation / behavior	IPS	dlPFC
M5-M3	R=0.47	R=0.57
M3	R=0.44	

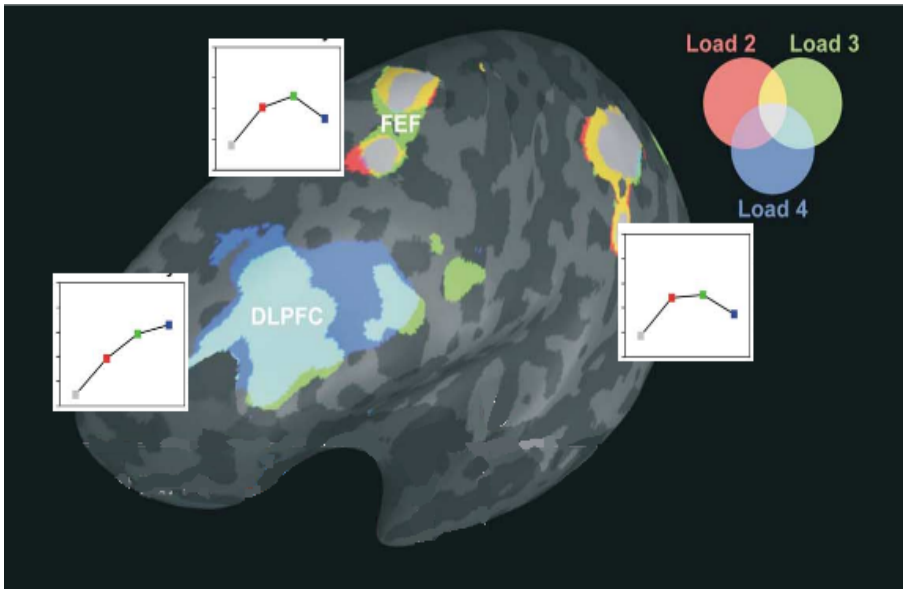
Prefrontal top-down control in working memory

- top-down excitation boosts capacity in IPS, and explains individual variability in WM capacity
- WM capacity may have two components: storage capacity in IPS and boosting capacity in dlPFC.

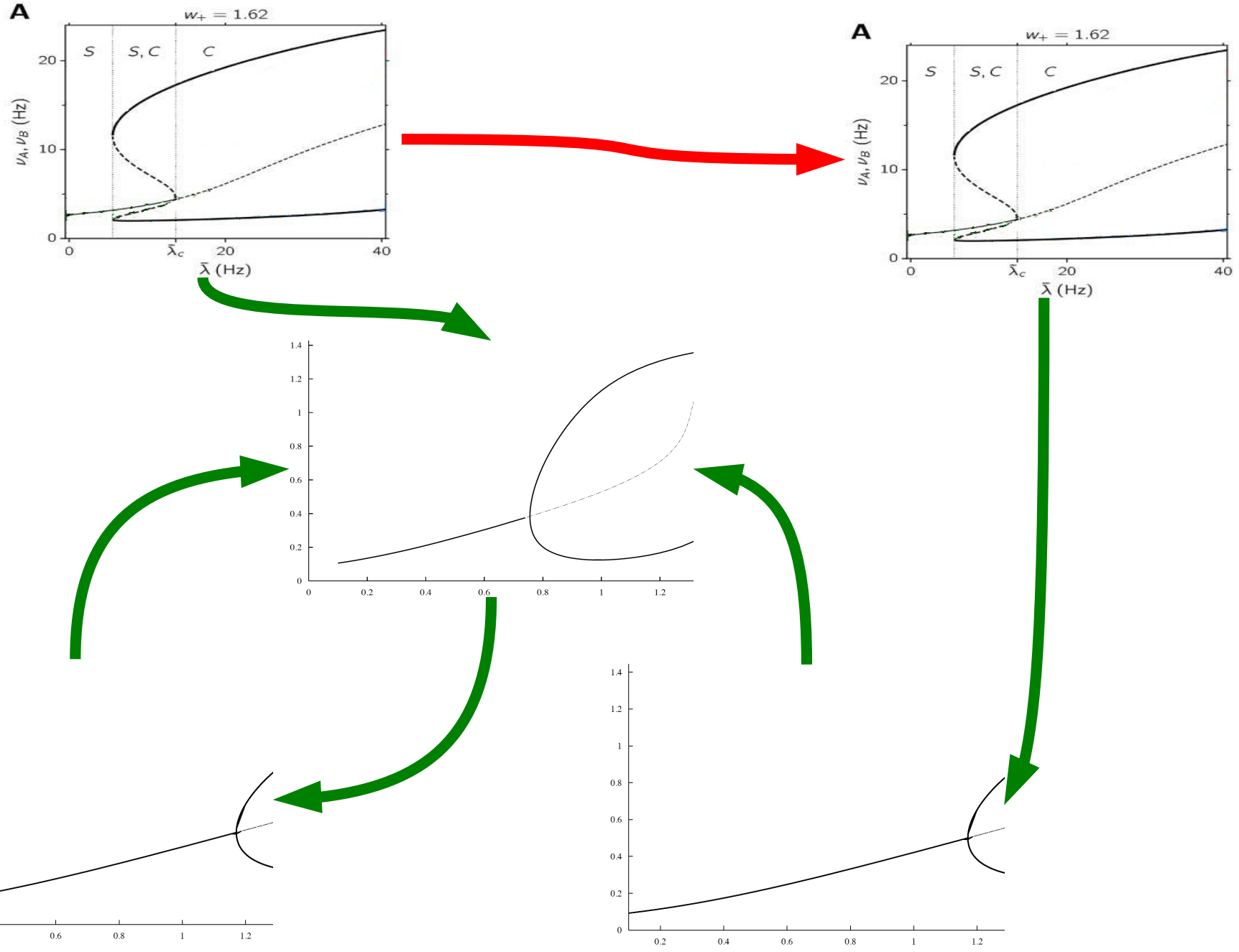
New function derived from network model



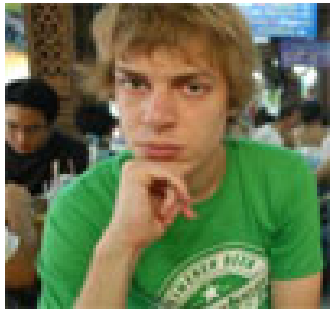




(Linden et al., *Neuroimage* 2003)


A
$w_+ = 1.62$
S
S, C
C
ν_A, ν_B (Hz)
$\bar{\lambda}_c$
$\bar{\lambda}$ (Hz)
A
$w_+ = 1.62$
S
S, C
C
ν_A, ν_B (Hz)
$\bar{\lambda}_c$
$\bar{\lambda}$ (Hz)

Thanks to...



Fredrik Edin

Pär Johansson

Fiona McNab

Jesper Tegnér

Torkel Klingberg

Karolinska Institutet

IDIBAPS Institut d'Investigacions Biomèdiques August Pi i Sunyer

Jaime de la Rocha

Klaus Wimmer

Juan Pablo Ramírez