CORTICAL RHYTHMS AND INTERNEURONS FOR READING WORKING MEMORY

(A COMPUTATIONAL STUDY OF PREFRONTAL CORTEX)

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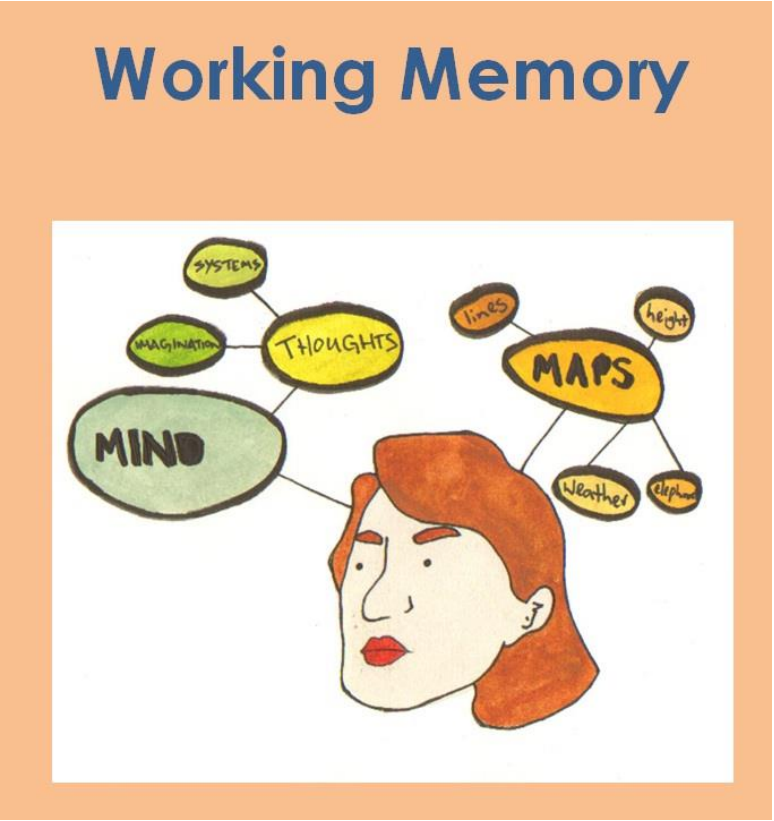
Overview

- What is working memory?
- Experimental data suggesting neural mechanisms.
- How can we understand them (i.e., models)?
- What are the ubiquitous interneurons and network oscillations doing (i.e., simulations)?
- An attempt at synthesis.

Working memory

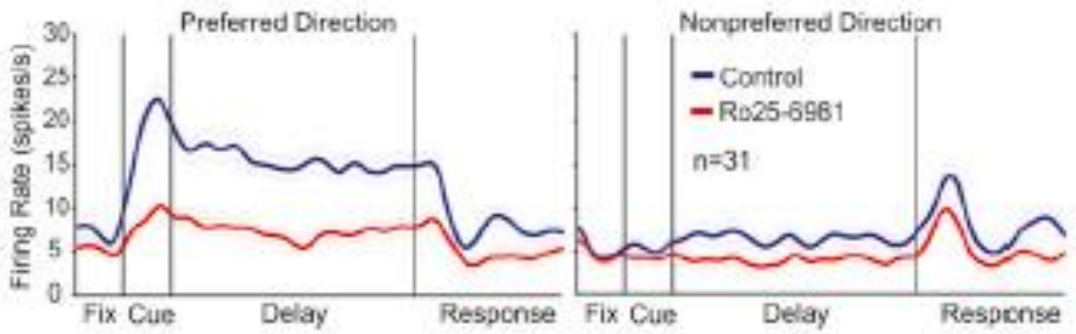
- Extends the temporal horizon of our ongoing thoughts.
- Provides an online basis for directing thought and action.
- Flexibly codes diverse content stored throughout the brain.
- Is used to govern most sensory and action systems.



Experimental evidence

Working memory maintenance

- persistent spiking without stimulus

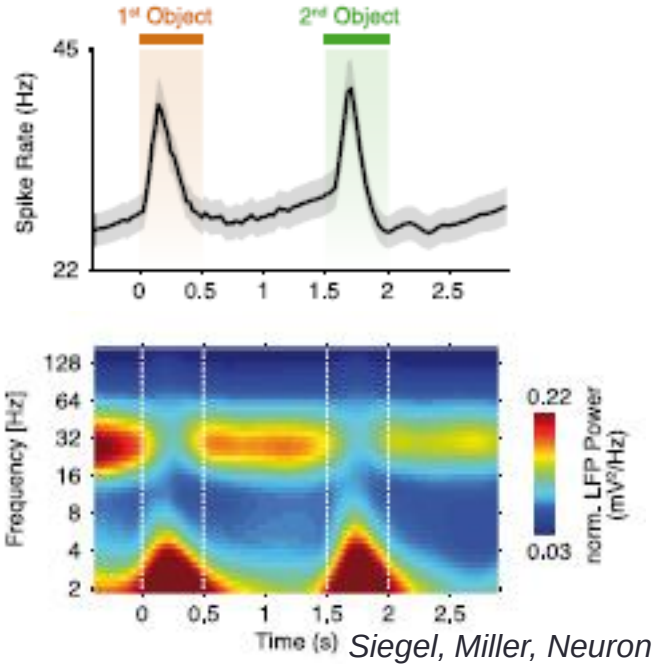


- oculomotor delayed response task (monkey dlPFC). control and w/ NMDAR antagonist.
- Primate DLPFC persistence requires NMDARs

Wang, Neuron 2013

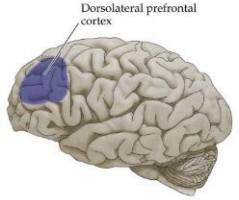
Prefrontal network rhythms

- cognitive correlates



Siegel, Miller, Neuron 2009

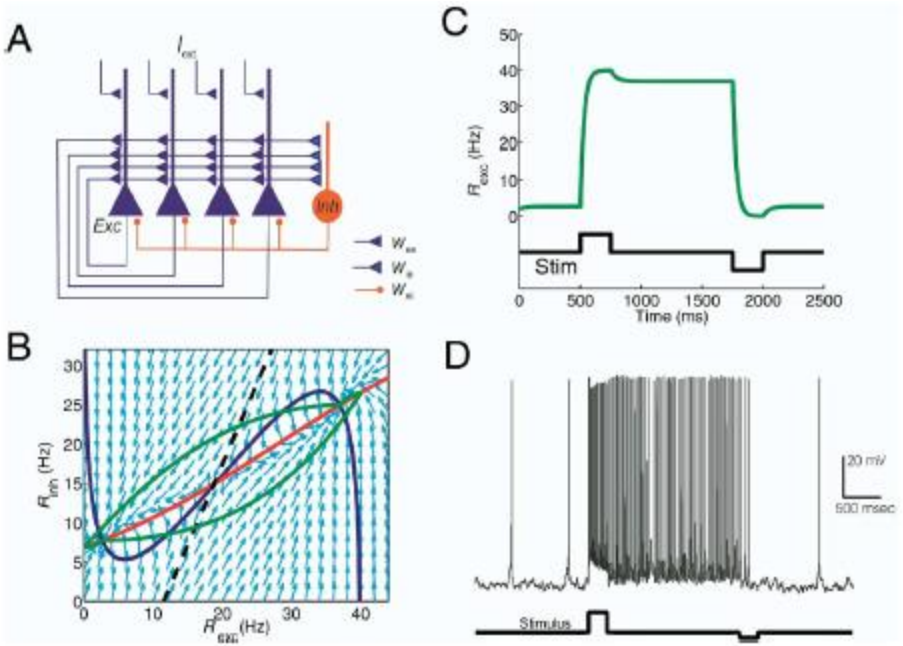
Persistent spiking and rhythms are present in dorsolateral prefrontal cortex (DLPFC) at the same time during tasks that require working memory.



Common biophysical models

Persistent cell spiking

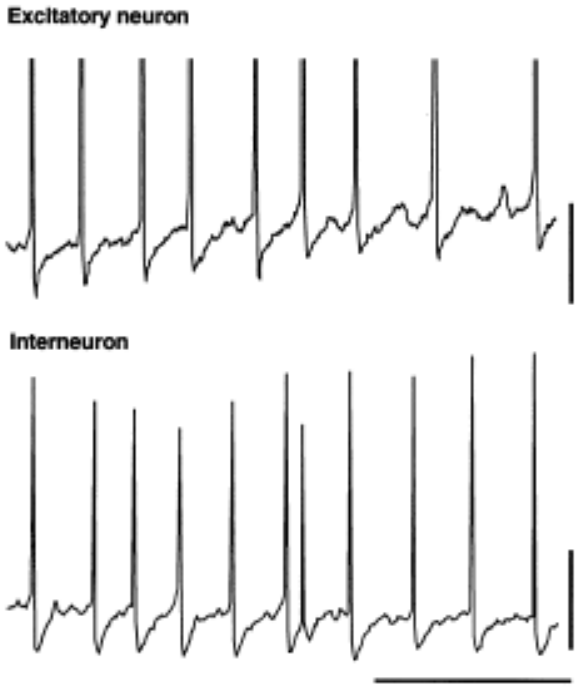
- recurrent network with slow current
- modular cortical architecture
  - (columnar separation supports stable persistent oscillations)



Durstewitz, Seamans, Nat Neuro 2006

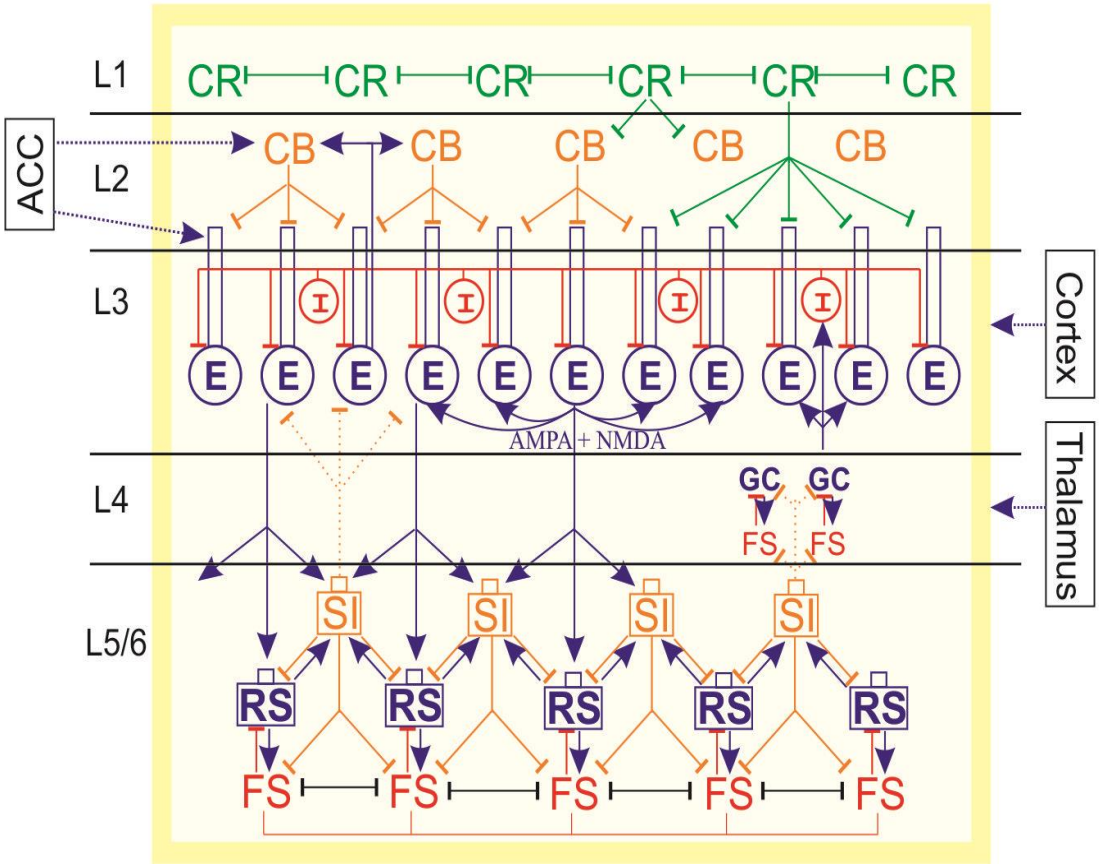
Cortical network rhythms

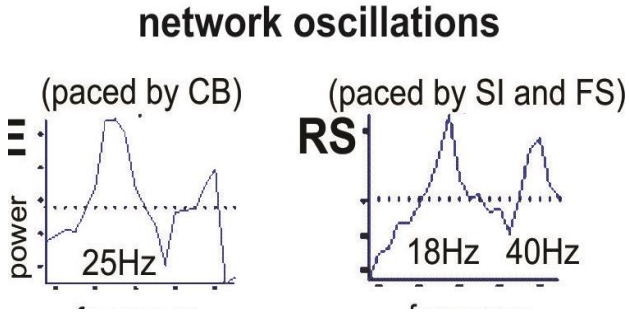
- PING (E/I ping-pong; paced by inhibition time constant)

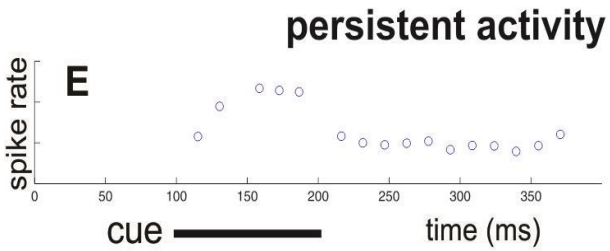


Whittington, Traub, Kopell, Ermentrout, Buhl 2000

Prefrontal cortical model



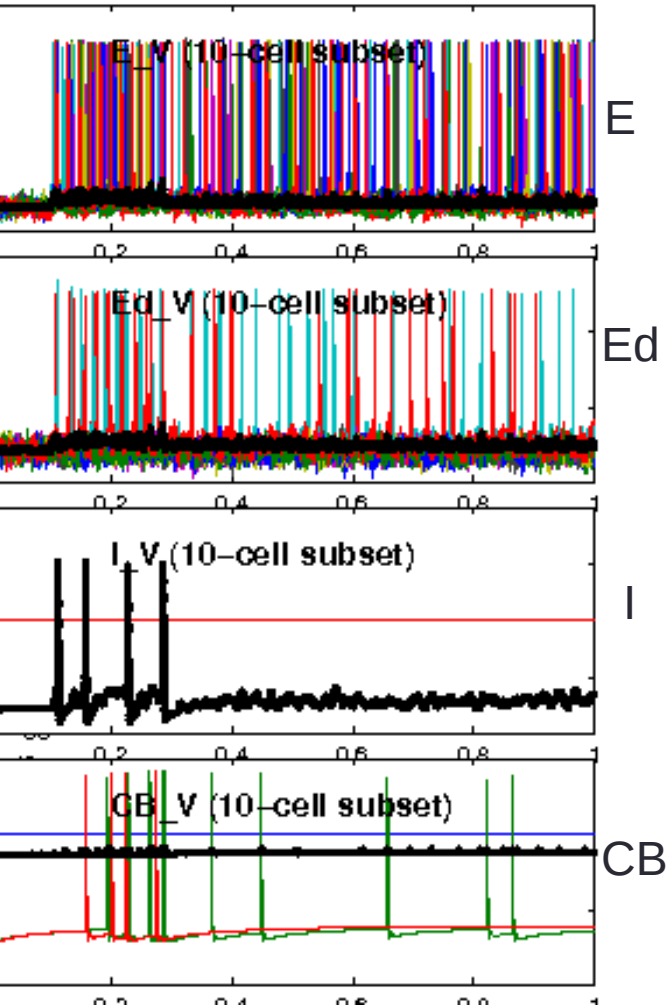


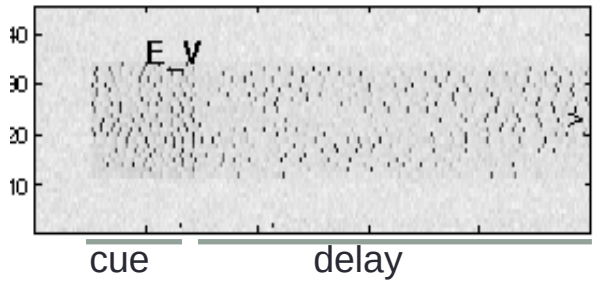


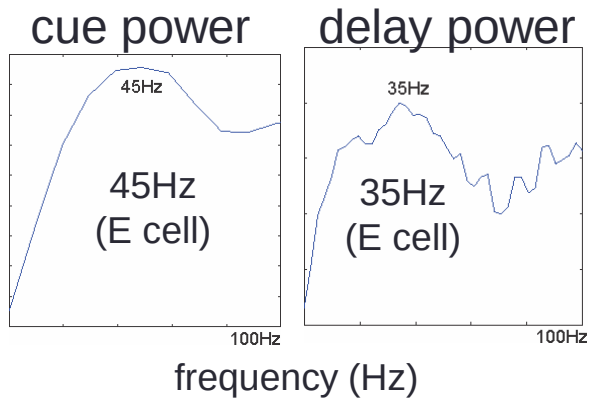
- Interneurons:
  - Calretinin-positive (CR)
  - Calbindin-positive (CB)
  - Parvalbumin-positive fast spiking (I)
- Excitatory: regular spiking pyramidal cells (E, RS)
- L2/3: inputs from ACC and sensory cortex.
- L5/6: outputs to subcortical and other cortical areas.

persistent oscillations

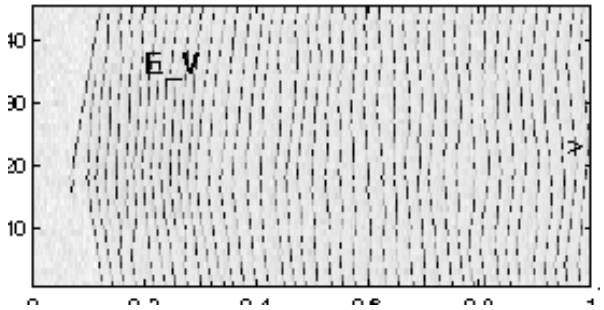
superficial cells (E-I-CB; gAMPA=0)



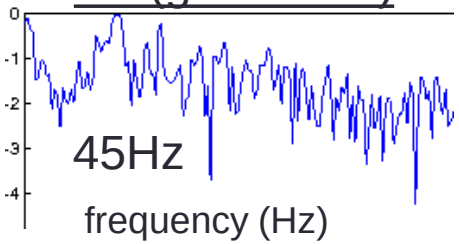




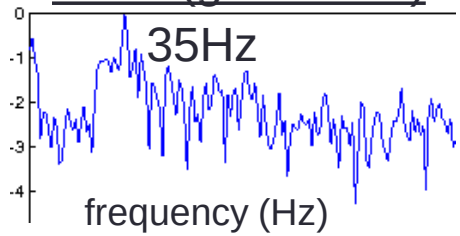
gAMPA=1



E-I (gAMPA=0)

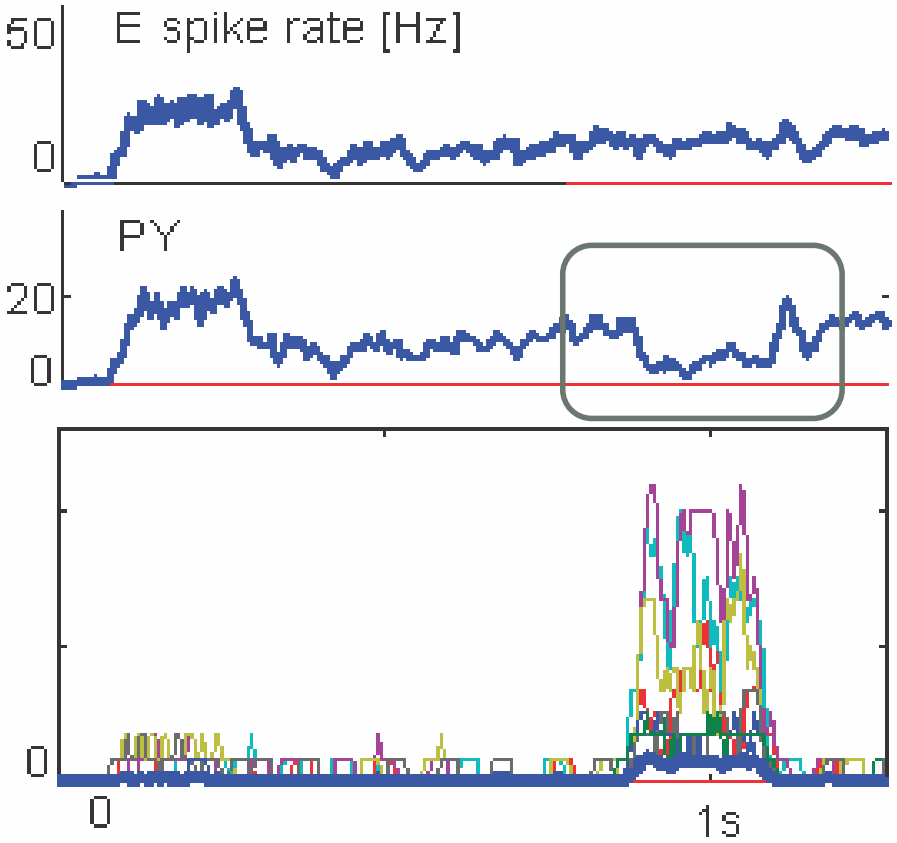


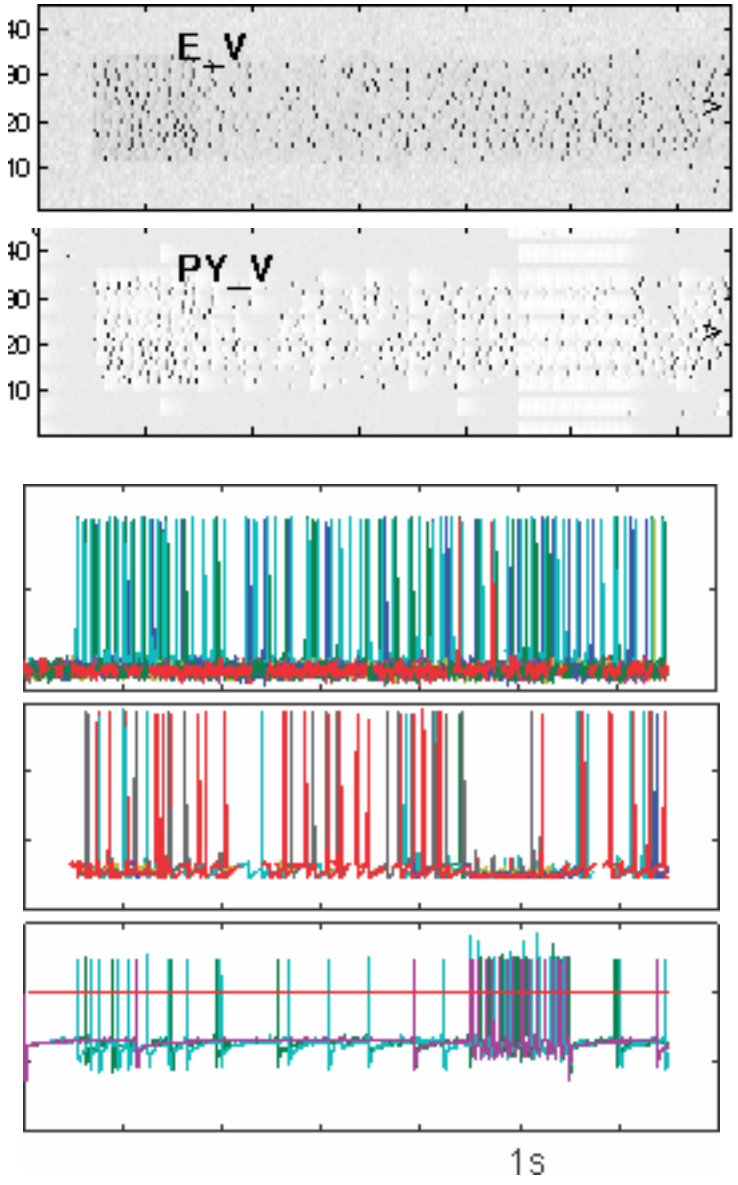
E-CB (gAMPA=0)



- fast spiking I-cells pace cue activity
- slower CB-cells pace delay activity

working memory gate

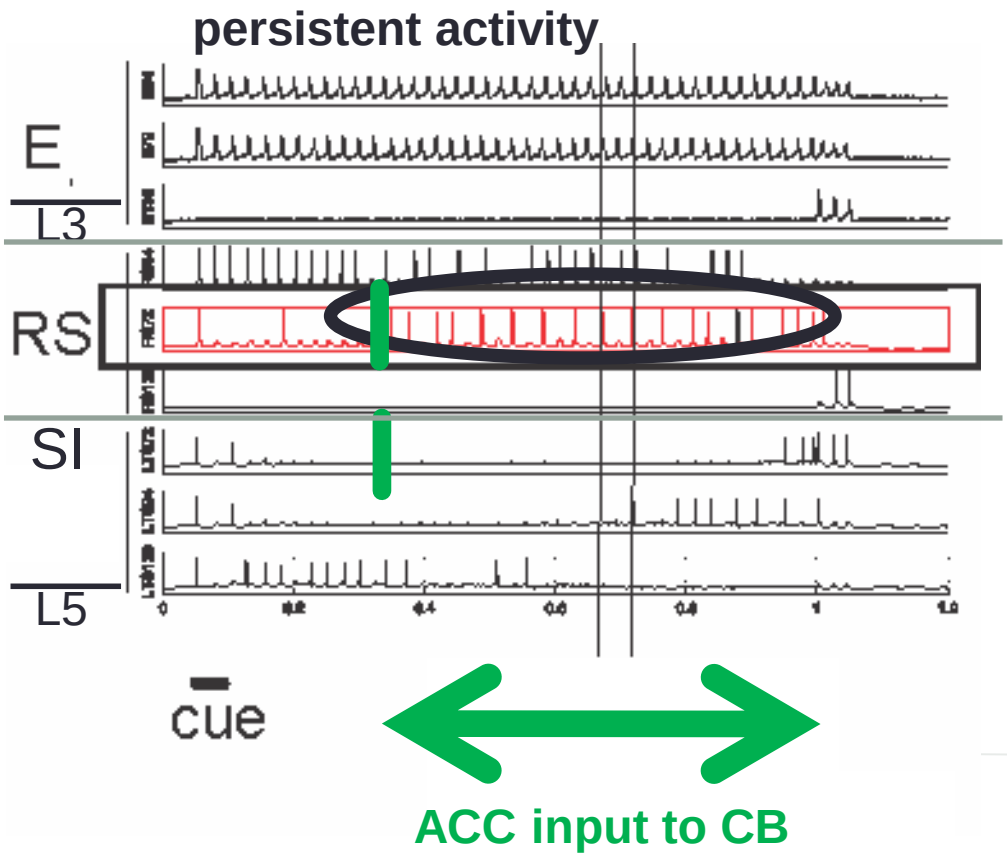




Persistent spiking gated during maintenance by bitufted INs.

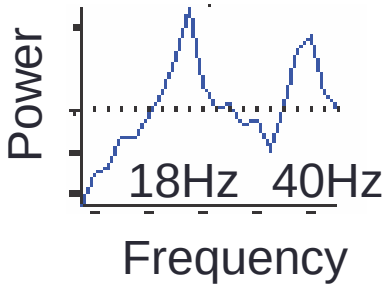
reading working memory

Combined effects of network oscillations and gated output:



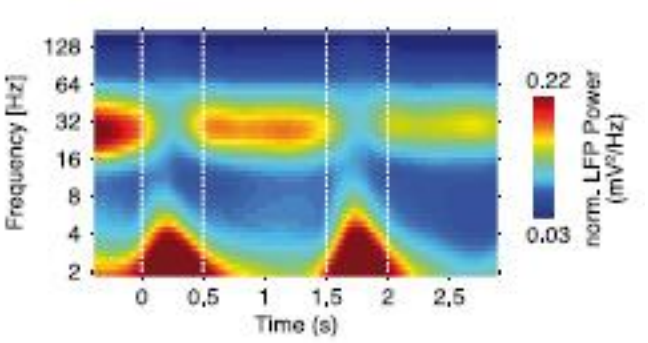
rhythmic readout

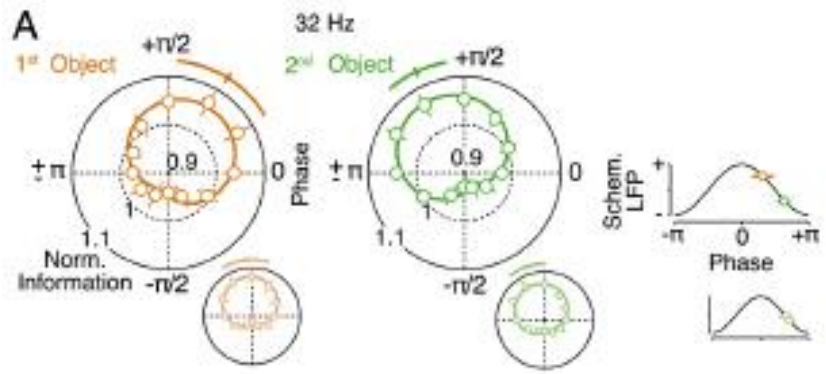
RS (paced by SI & FS)

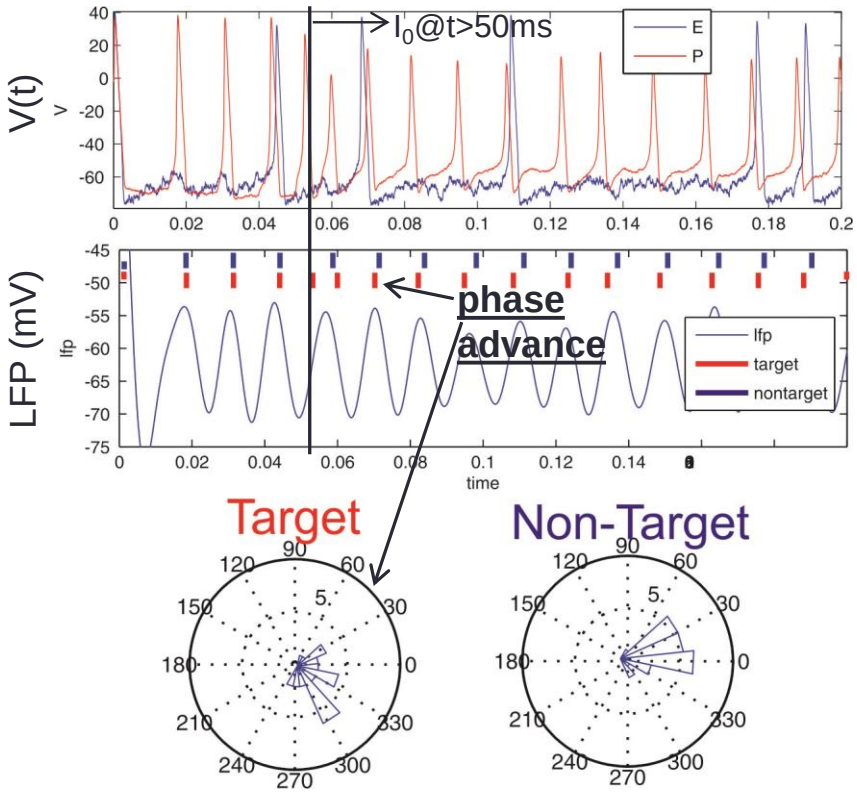


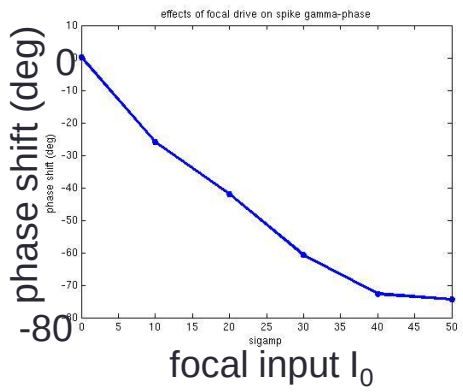
ACC-targeted CB disinhibit RS by silencing SI

phase coding







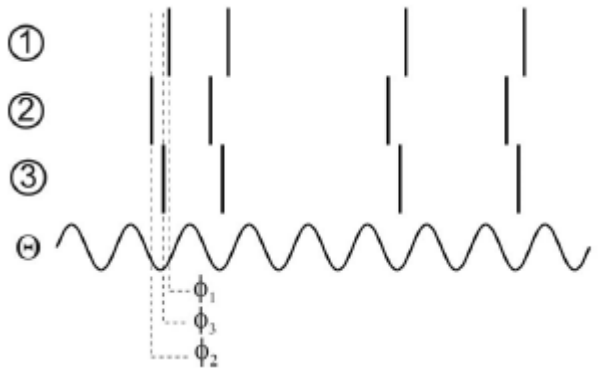


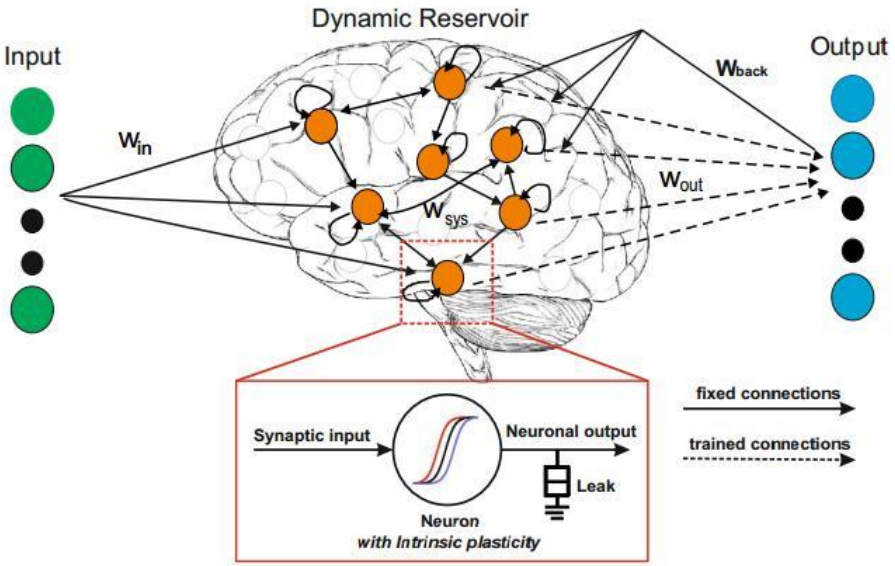
- may provide amplitude-to-phase transformation for multiplexed readout.
- can be read-out by coincidence detector.
- can code sequential order.

Siegel, Miller, Neuron 2009

Further issues

- cell responses actually much more complex
- heterogeneity
- nonstationarity (e.g., dynamic network connectivity)
- high dimensionality, mixed selectivity
- ACC/DLPFC reservoir computing





Durstewitz, Seamans, Nat Neuro 2006

Acknowledgments

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