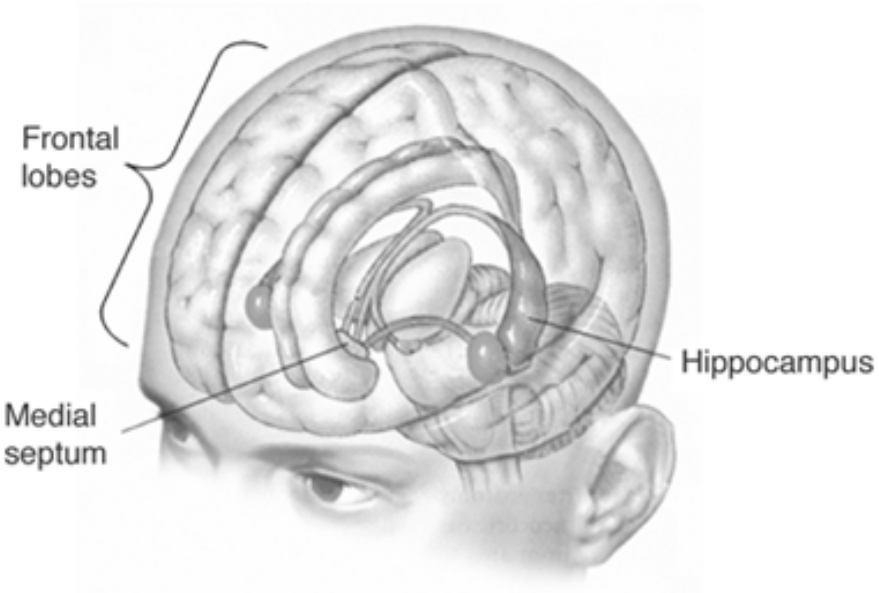
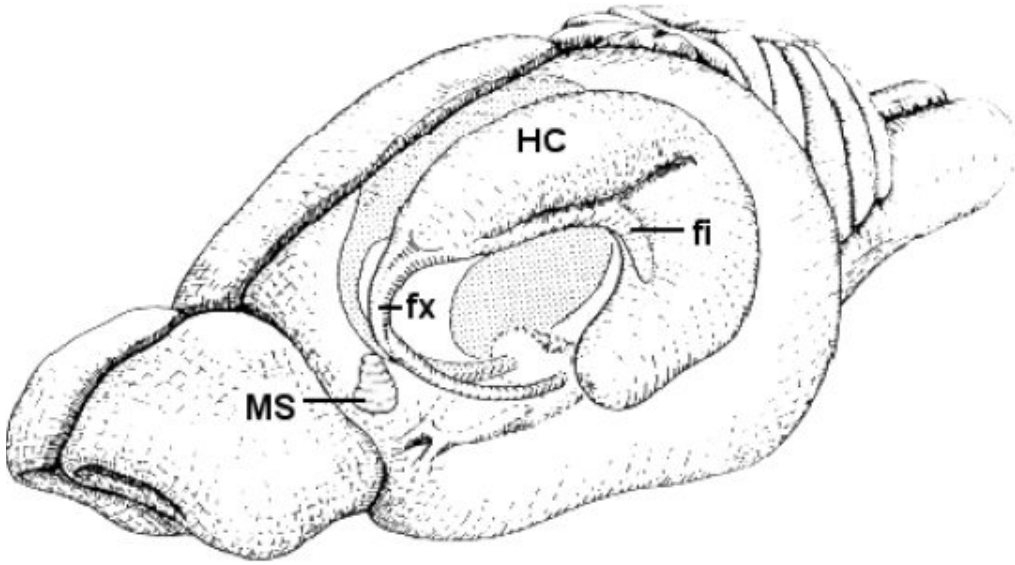
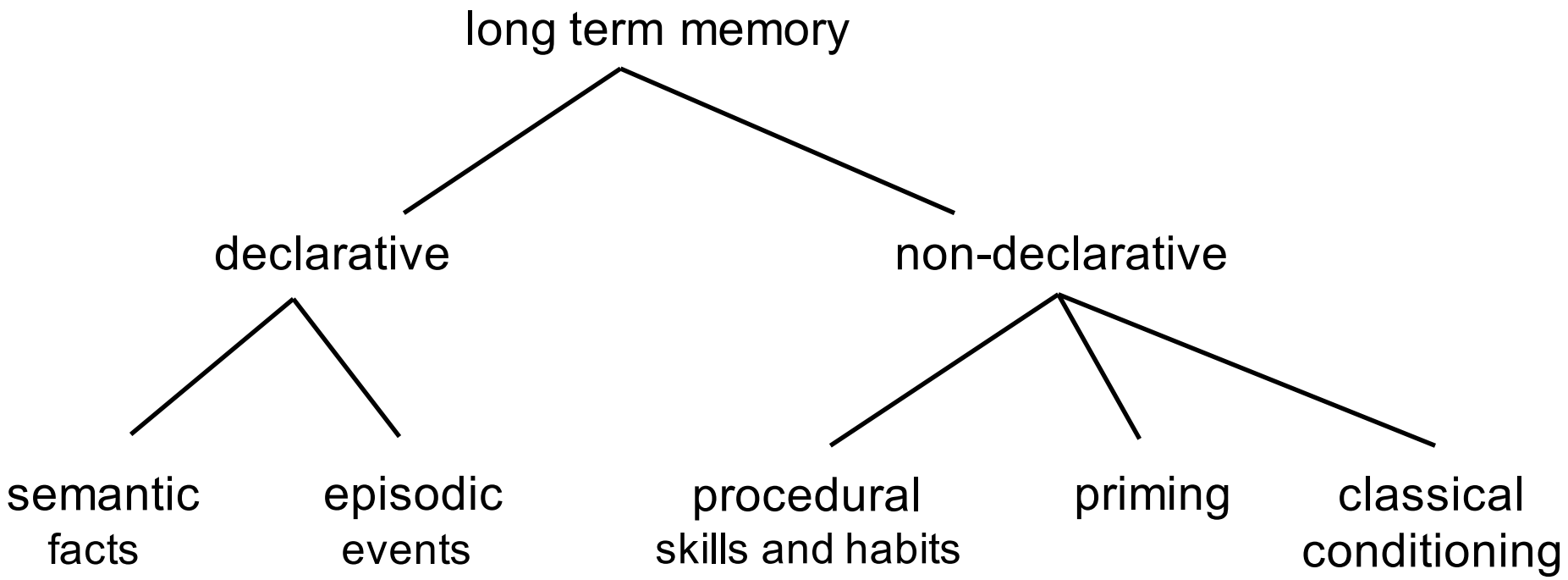
Hippocampus

Human and Rodent

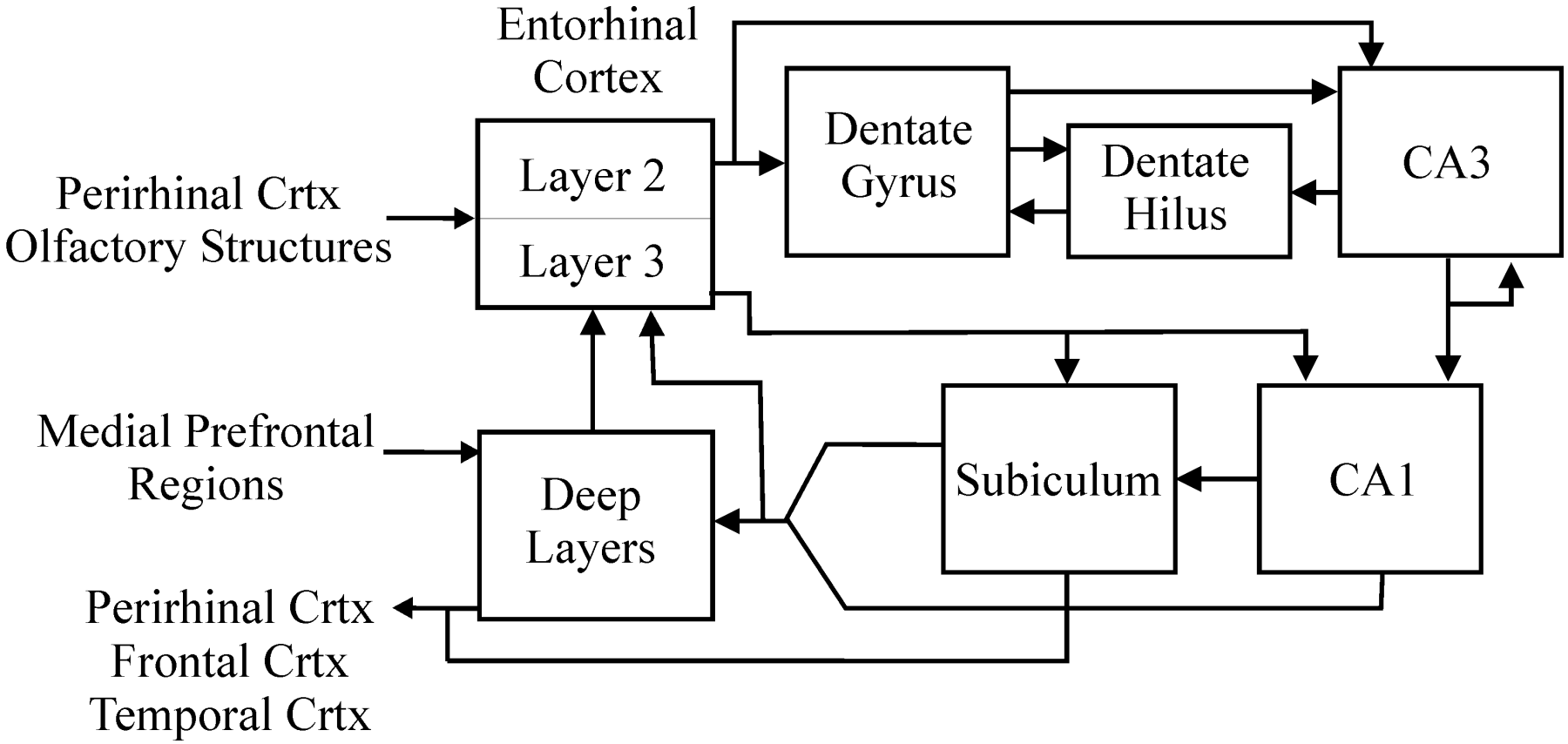




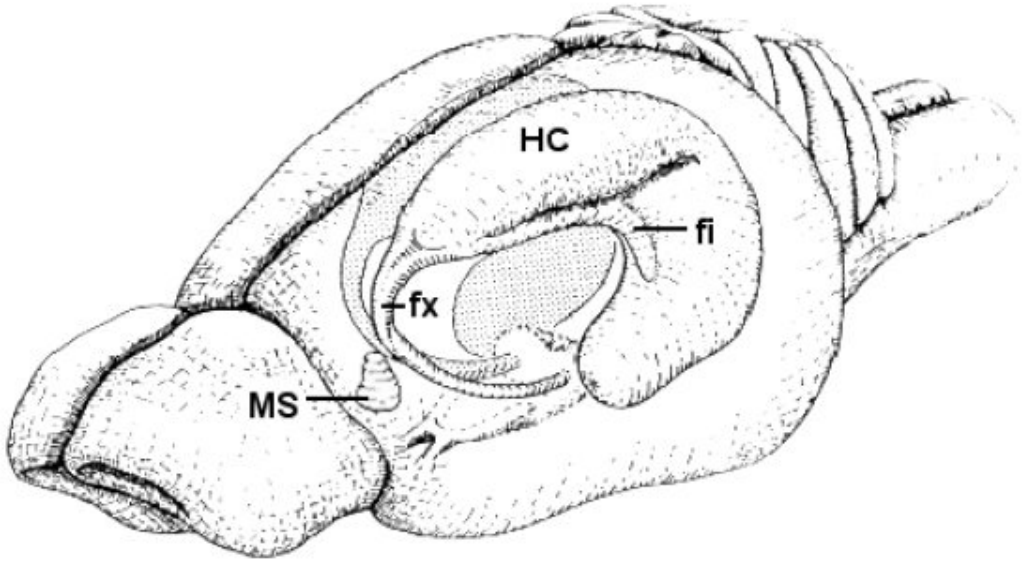
Taxonomy of Memory

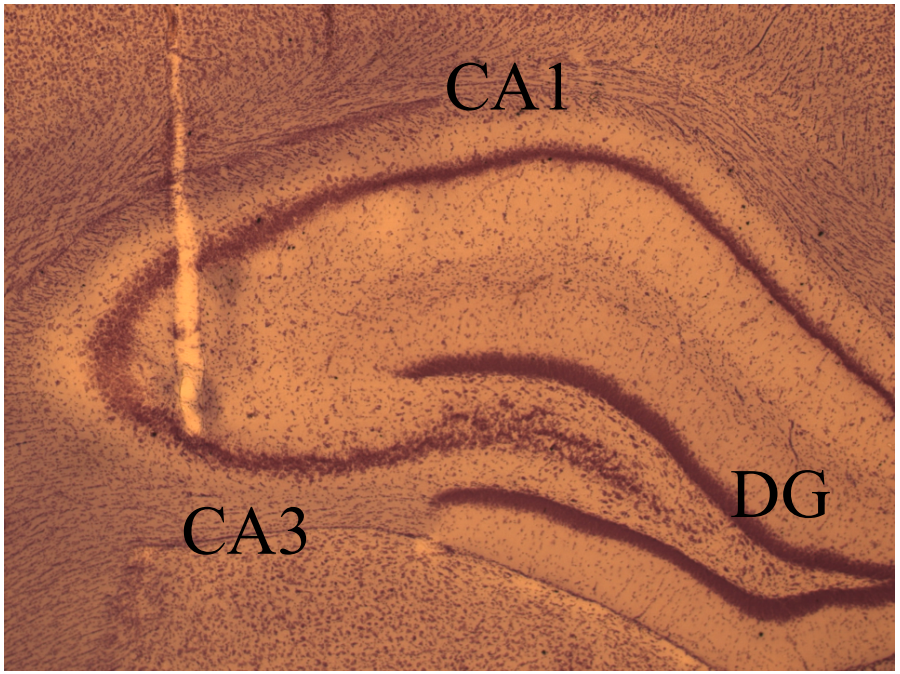


Anatomical Overview

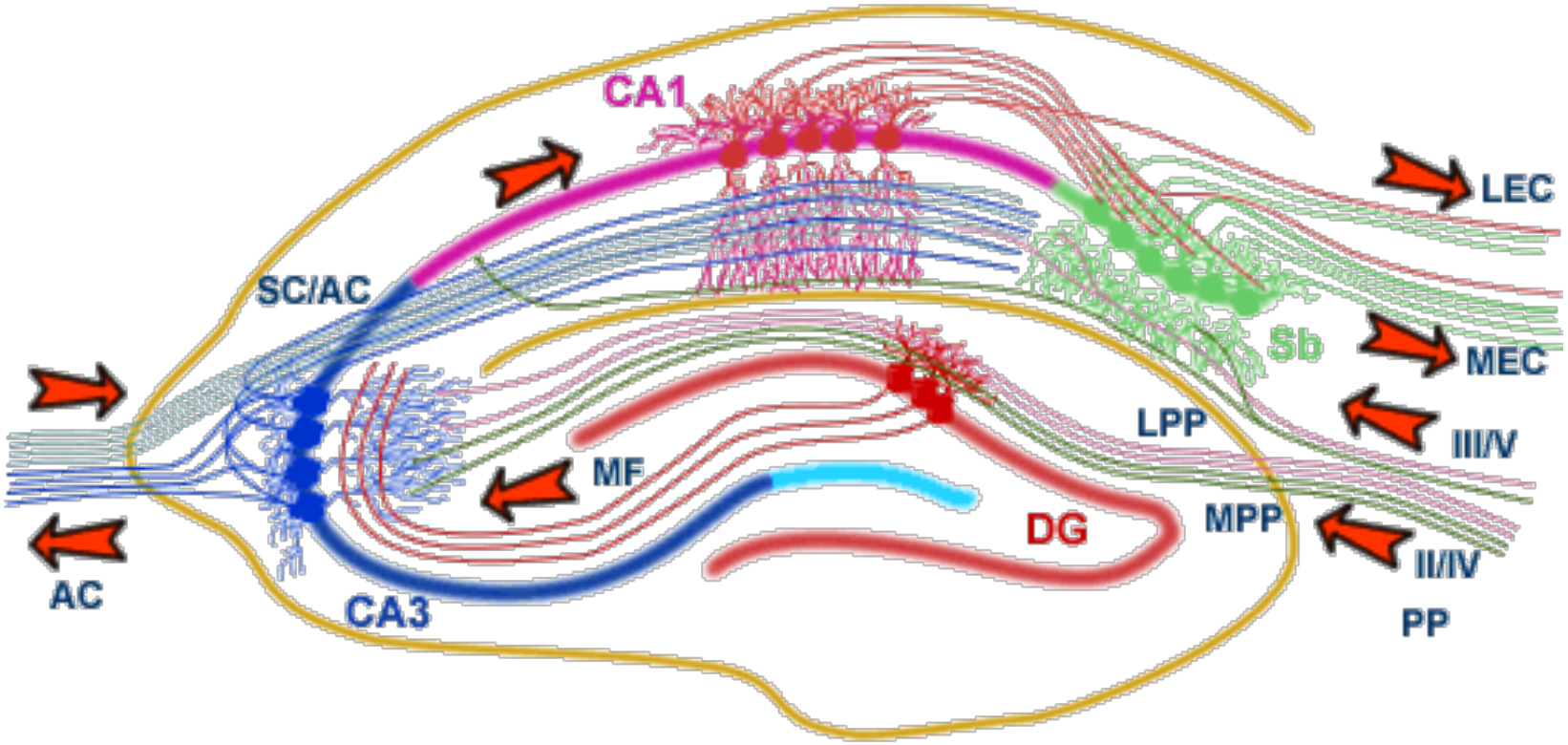


Hippocampal Pathways



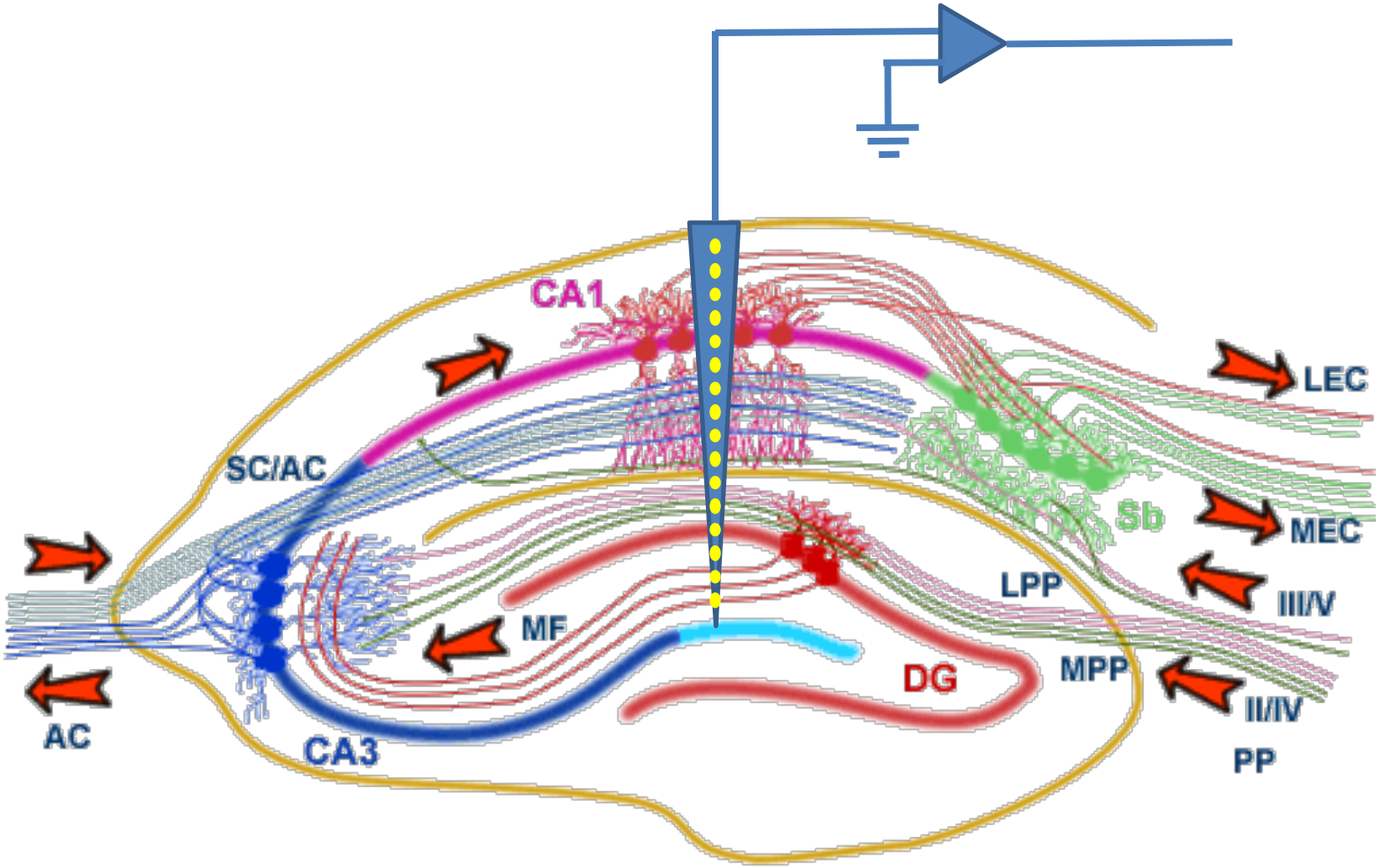


Hippocampal Pathways



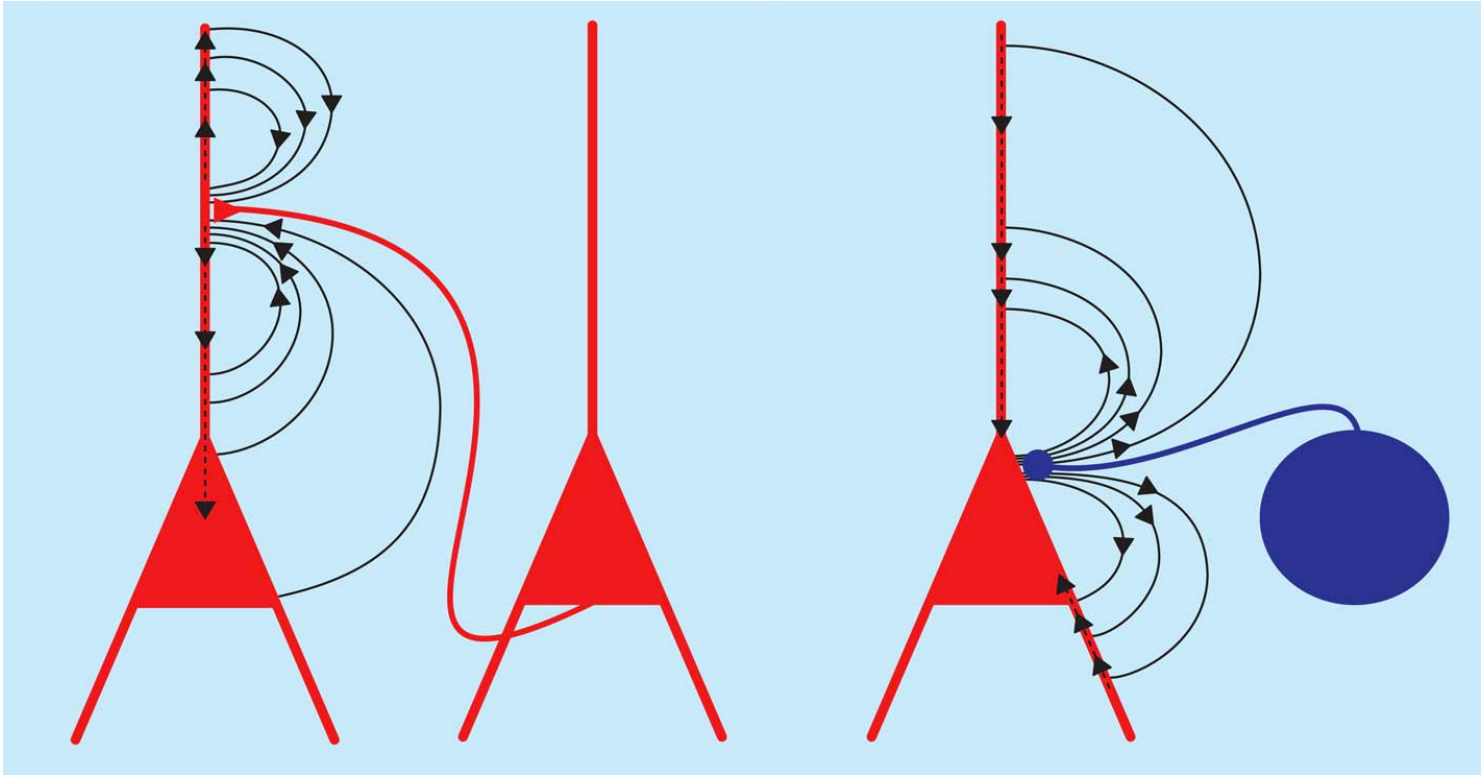
The Hippocampal Network: The hippocampus forms a principally uni-directional network, with input from the Entorhinal Cortex (EC) that forms connections with the Dentate Gyrus (DG) and CA3 pyramidal neurons via the Perforant Path (PP - split into lateral and medial). CA3 neurons also receive input from the DG via the mossy fibres (MF). They send axons to CA1 pyramidal cells via the Schaffer Collateral Pathway (SC), as well as to CA1 cells in the contralateral hippocampus via the Associational Commissural pathway (AC). CA1 neurons also receive input directly from the Perforant Path and send axons to the Subiculum (Sb). These neuron in turn send the main hippocampal output back to the EC, forming a loop.

Recording Neural Signals



Measure voltage fluctuations relative to ground (or reference electrode)

Origin of Extracellular Signals

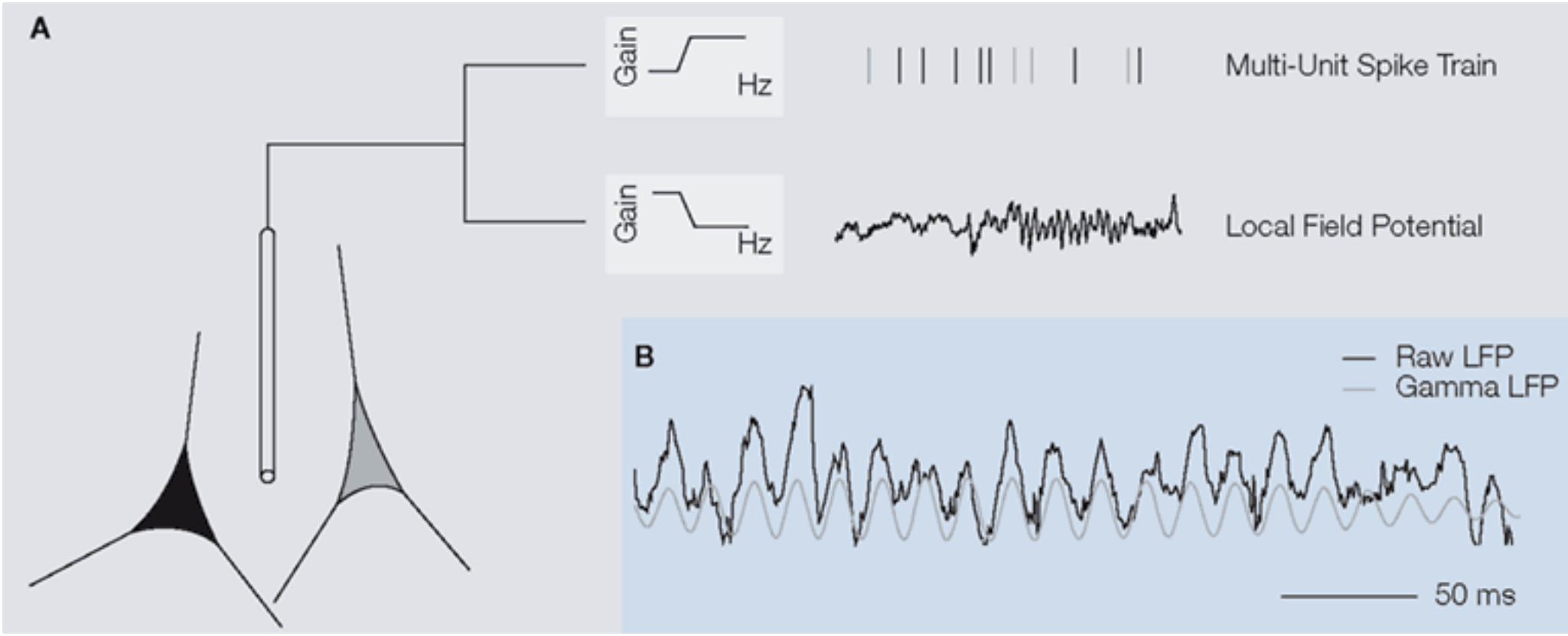


Extracellular voltages come from:

1) Synaptic currents
2) Dendritic currents
3) Somatic currents
4) Axonal currents

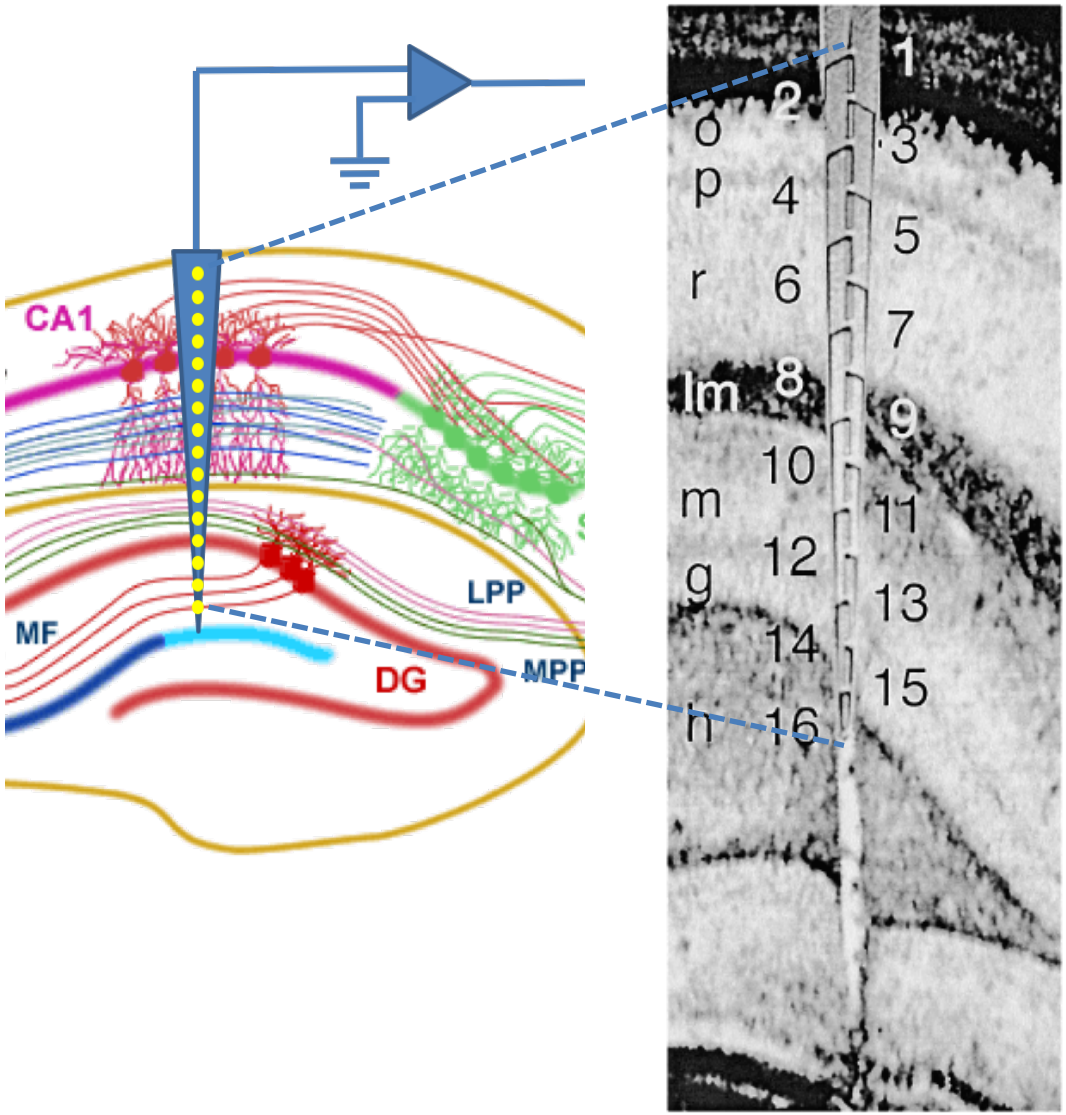
Ellender and Paulson, 2010

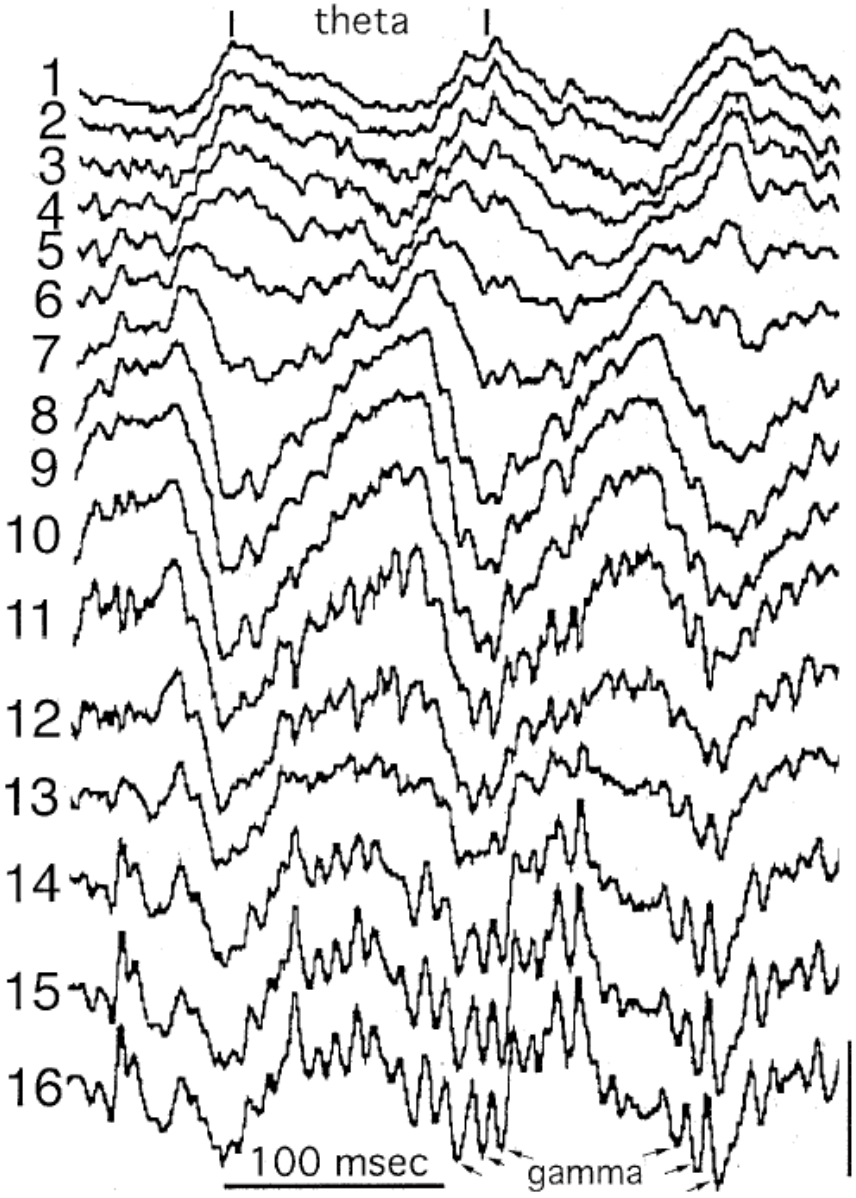
Components of Extracellular Signals



Berens, Keliris et. al. , 2008

Hippocampal LFP





Buzsaki, 2005

LFP Power and Frequencies

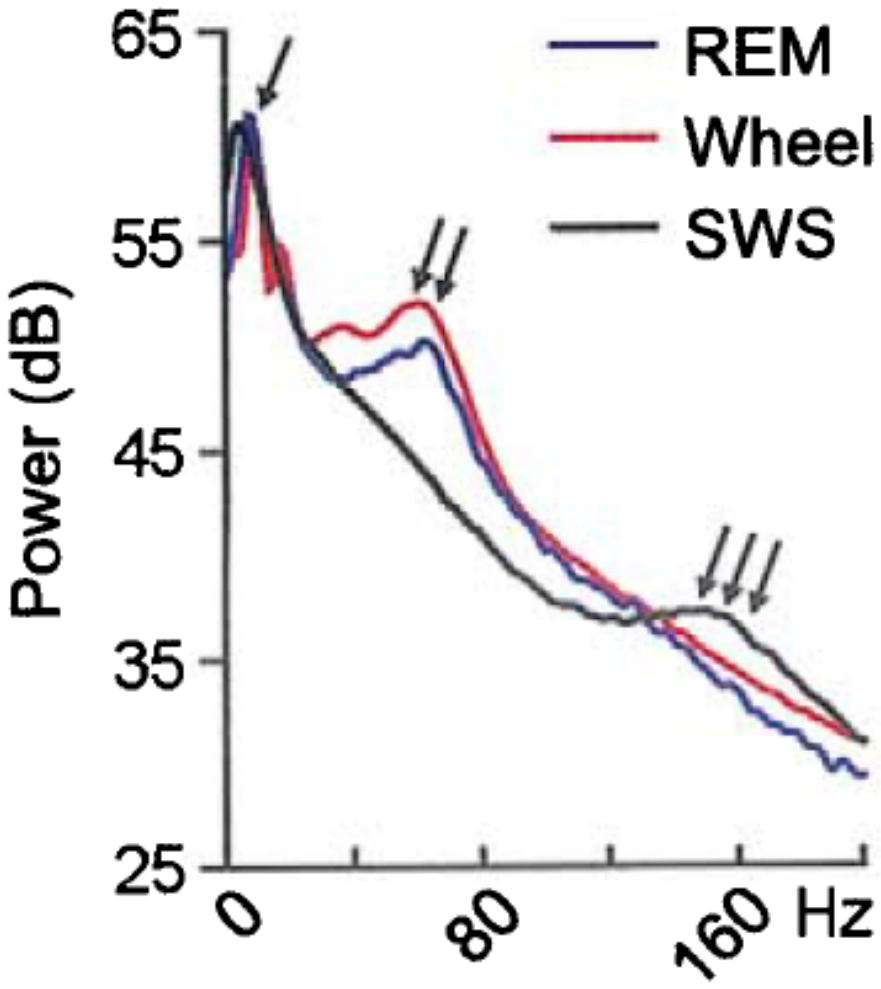
LFP typically has ~1/f power
(power is the square of amplitude)

Power is often measured in dB:
3 db ~= 2x
10 dB = 10x
20 dB = 100x

Common frequency bands:

Delta:	1-4 Hz
Theta:	6-12 Hz
Beta:	12-30 Hz
Gamma:	20 – 80 (or 140) Hz

There are distinct biophysical mechanisms
and putative functions associated with each band.



Buzsaki et. al., 2003

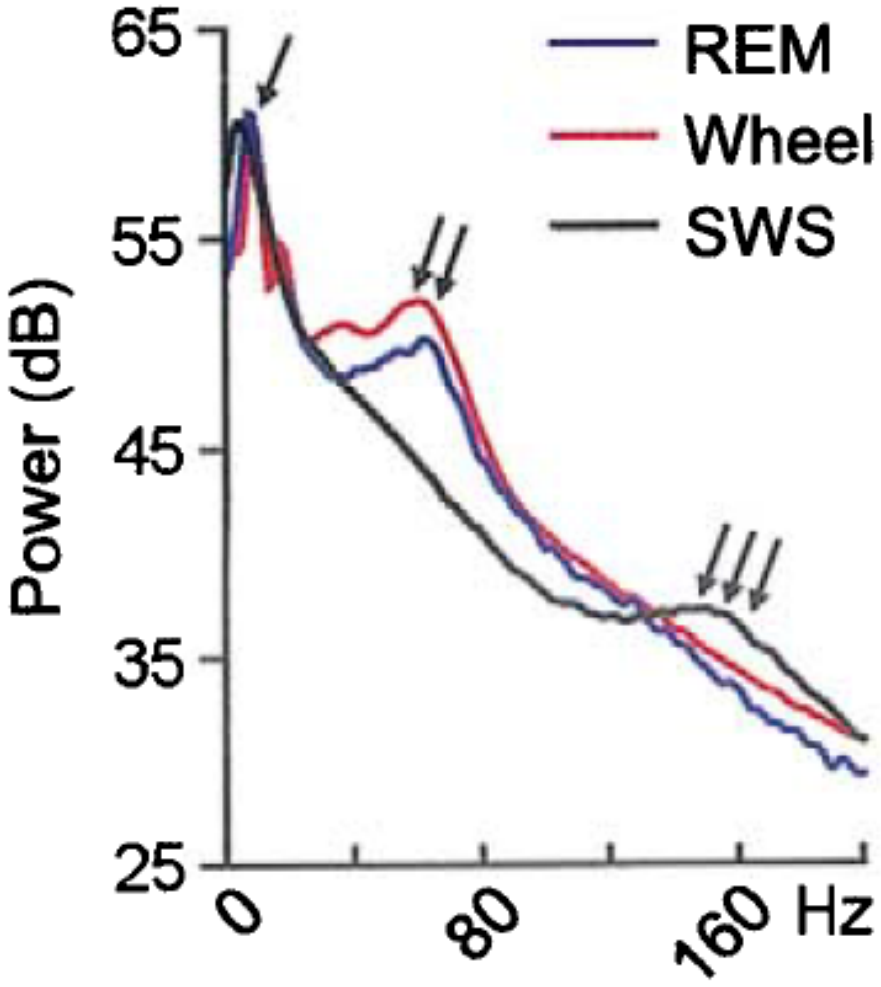
LFP Power and Frequencies

Important things to note:

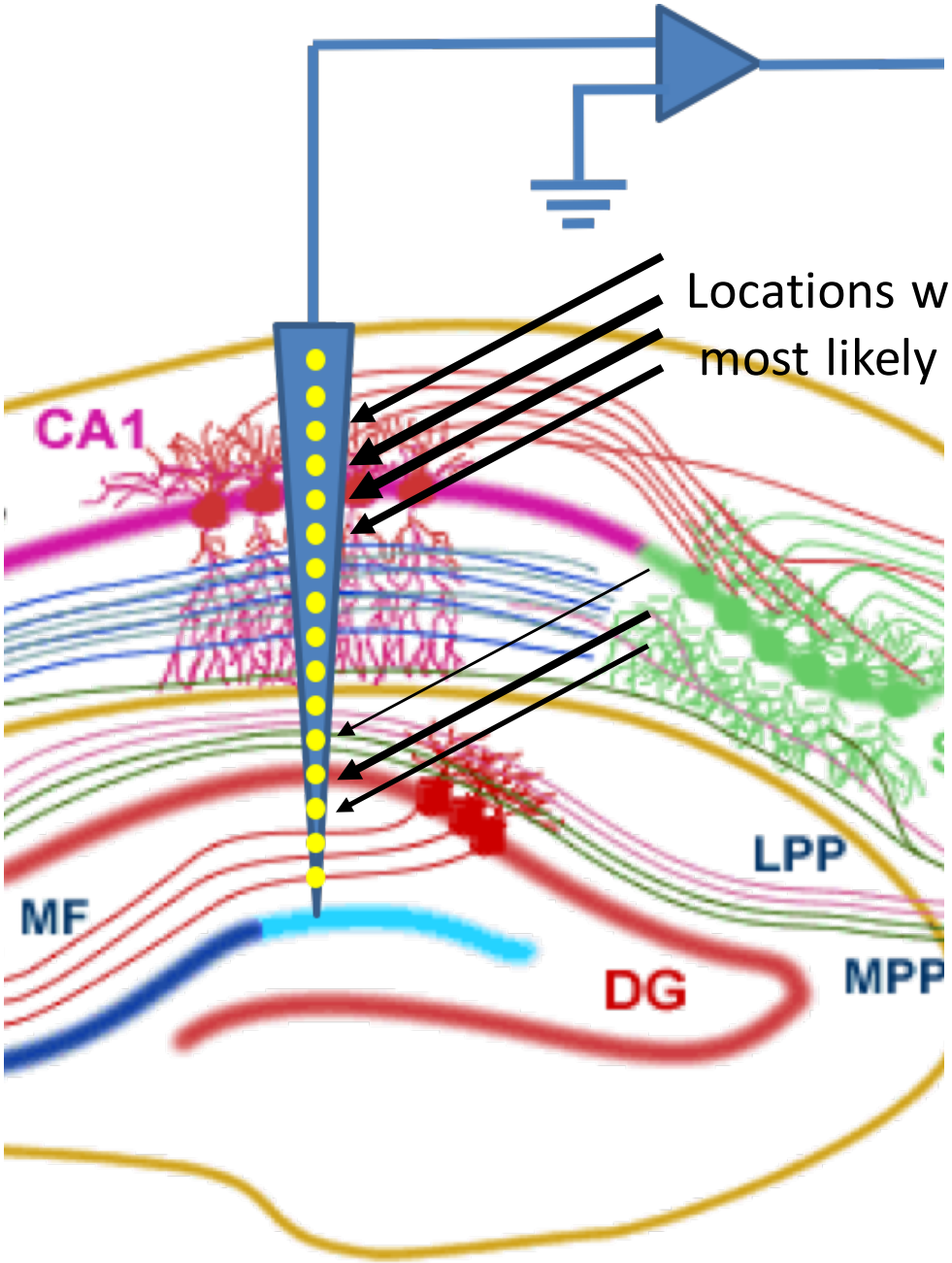
1) There is always power in all bands.

2) Power in a band does not mean there is a real oscillation.

3) My criterion: spiking of local or input neurons must be significantly phase locked to the band in question to consider it to be “real.”



Hippocampal Spiking Signals



Locations where spikes are most likely to be detected

Spiking is generally only detected near cell bodies (asynchronous)

LFP signals can be detected much farther away (volume conduction of more synchronous signal)

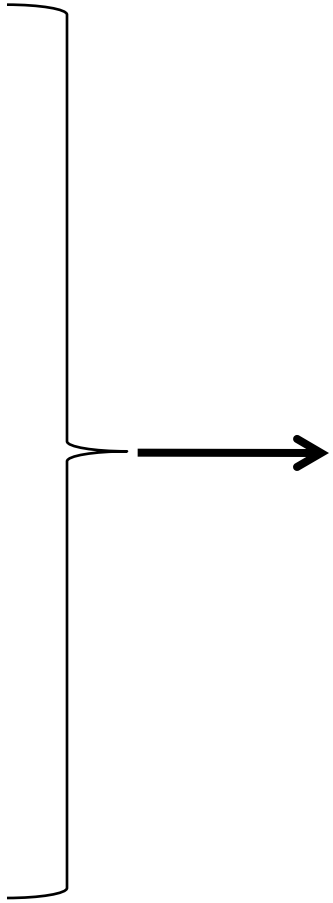
Memory Formation and Retrieval

Encoding

- Storage of new information within hippocampal circuits

Consolidation

- Slower process
- Interaction between hippocampus and neocortex



Retrieval

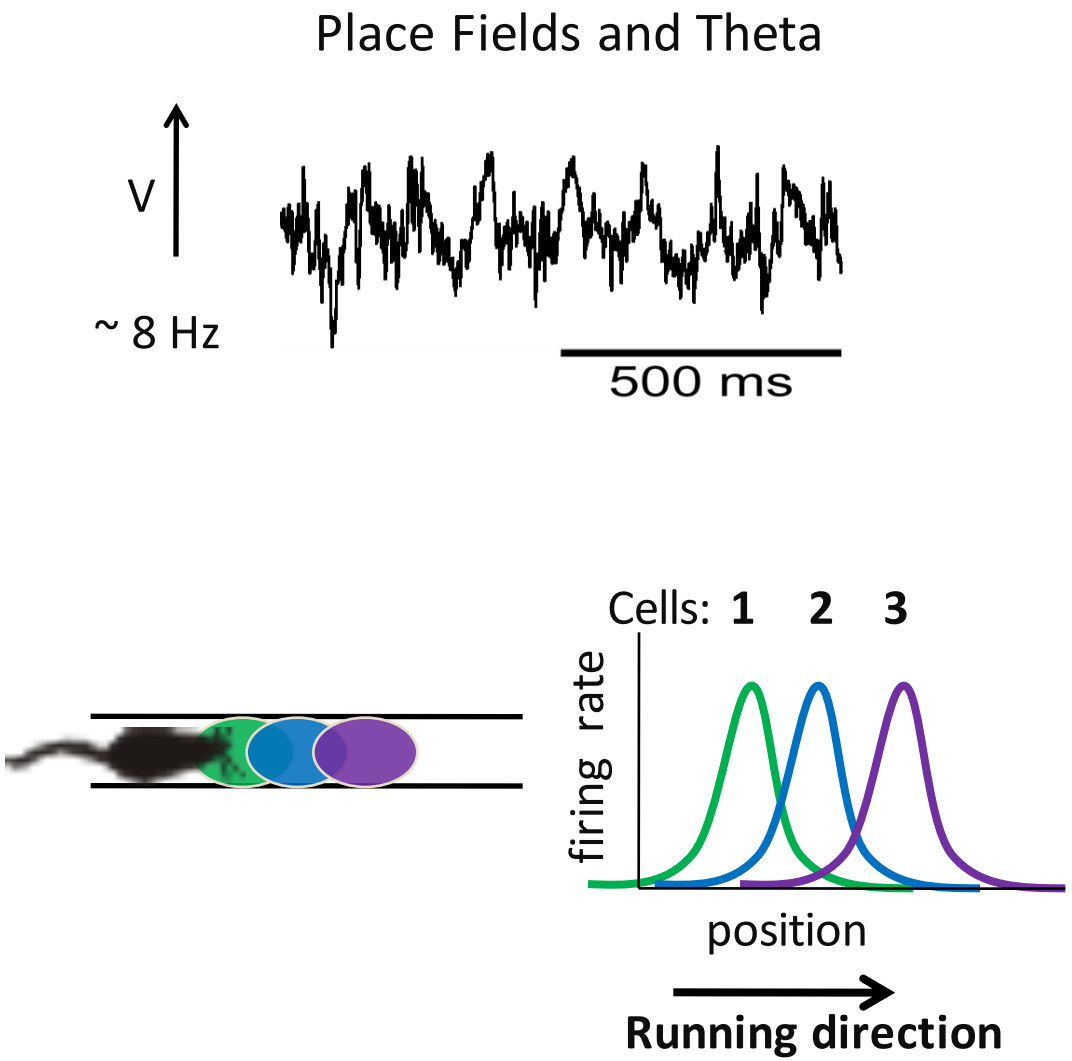
- Reinstate a memory
- Usually with partial cue

Encoding - Sequences

- Question: how does the brain bind together sequences of places or events into memories?

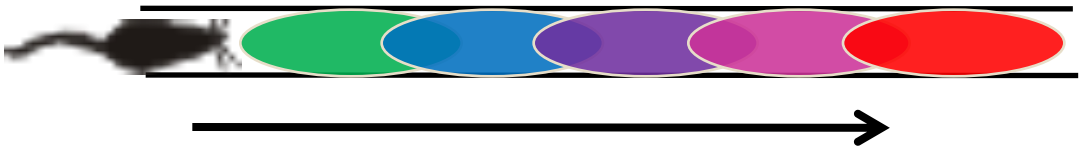
- Problem: Timescale
  - Cellular plasticity < 100 ms
  - Events > 1 second

Activity during awake exploration



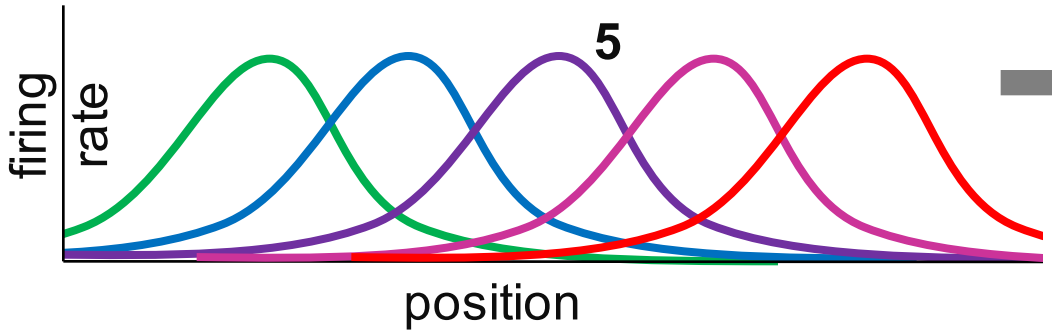
Place Fields: Spatial & Temporal Code

Spatial Code



Cells: 1 2 3 4 5

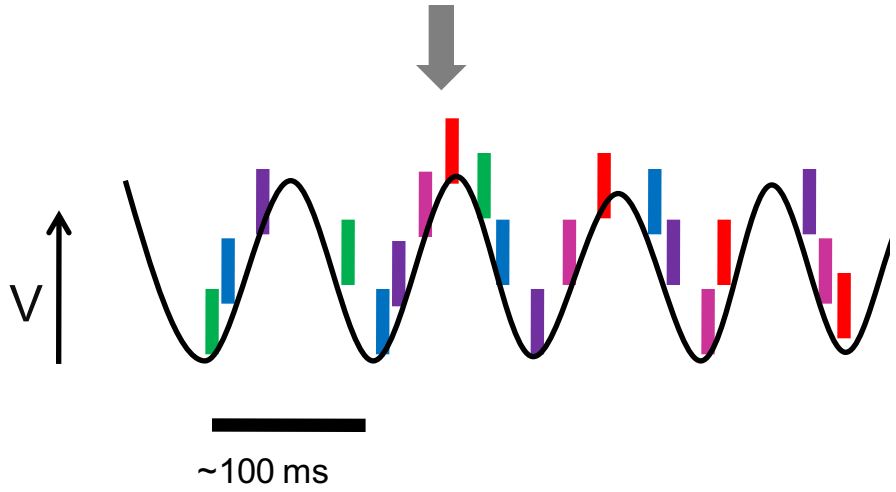
Place Fields



Individual Cells:
Place

Temporal Code

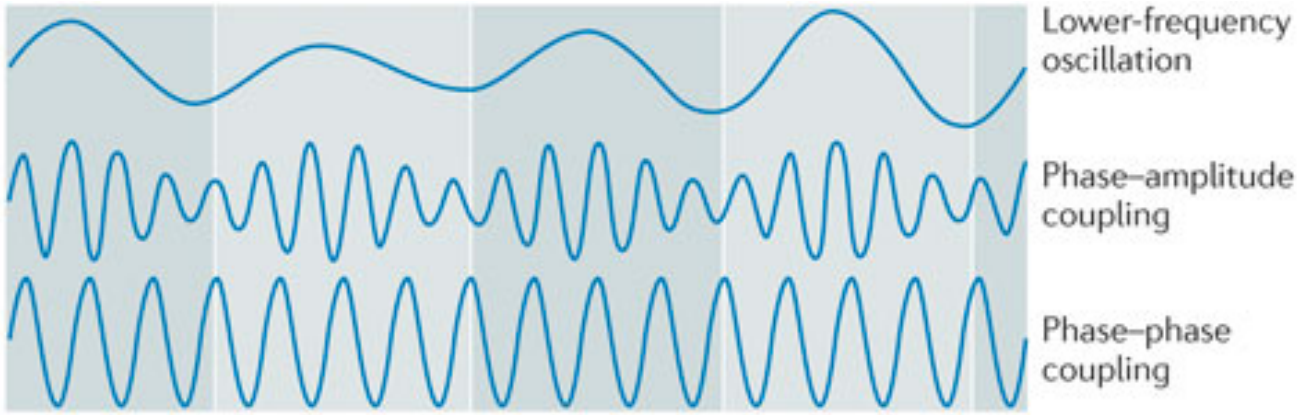
Theta Phase Precession

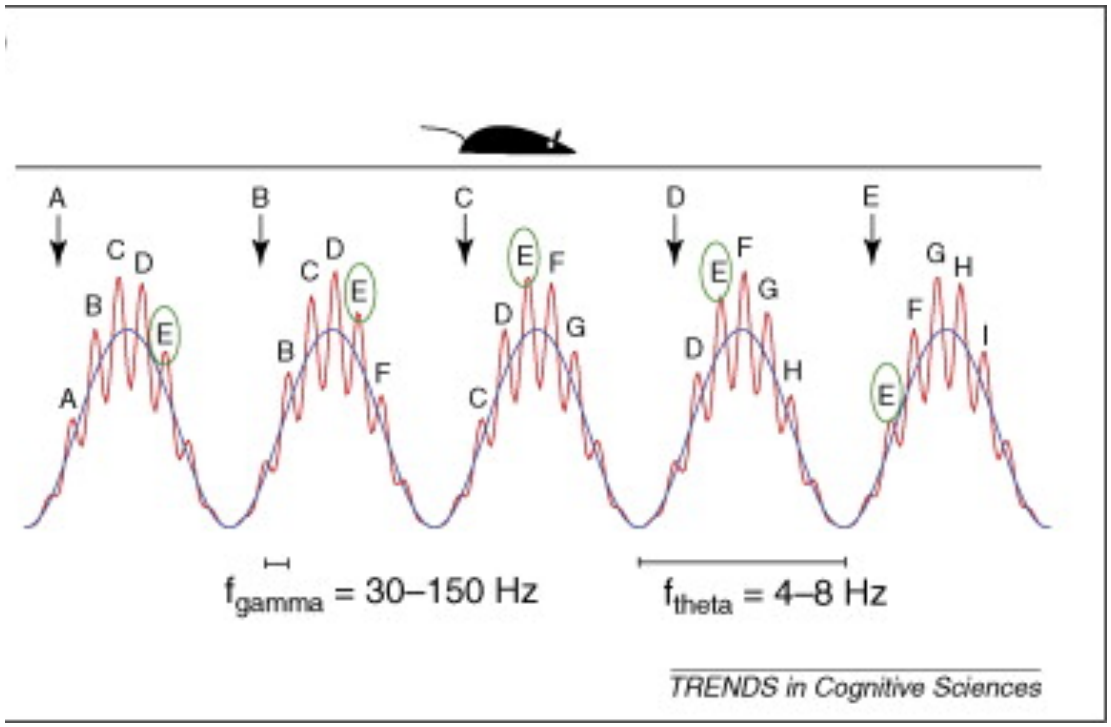


Relationships Between Cells:
Sequences
Episodic Memory?

O'Keefe and Recce 1993
Dragoi and Buzsaki, 2003

Phase precession:
An example of cross frequency coupling.





Fell and Axmacher, 2011
Jensen and Colgin, 2007

But …

- While theta is very prevalent in the rodent, it is not detectable in some species (e.g. bats).

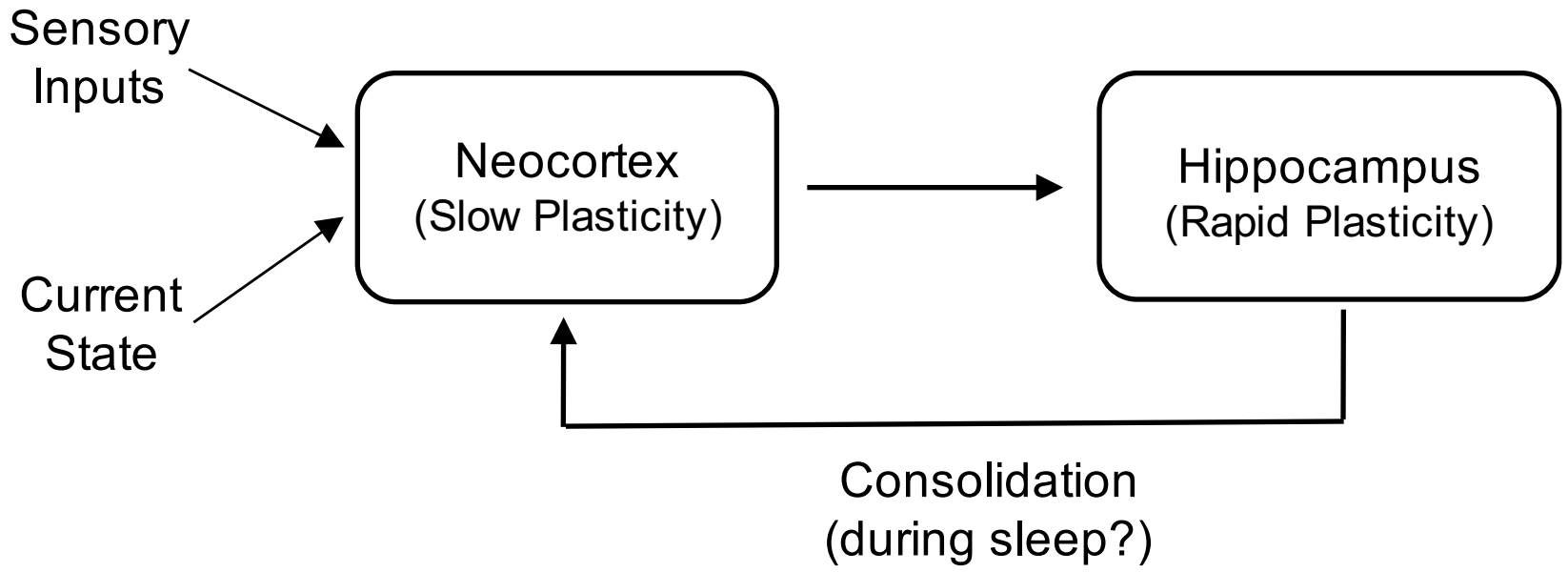
- A causal role for theta and phase precession has not been established.

Consolidation

- Question: how can information stored in the hippocampus be transferred to more broadly distributed circuits?

- Problem: neocortex generally cannot learn from single examples.

Learning and the Hippocampal Circuit

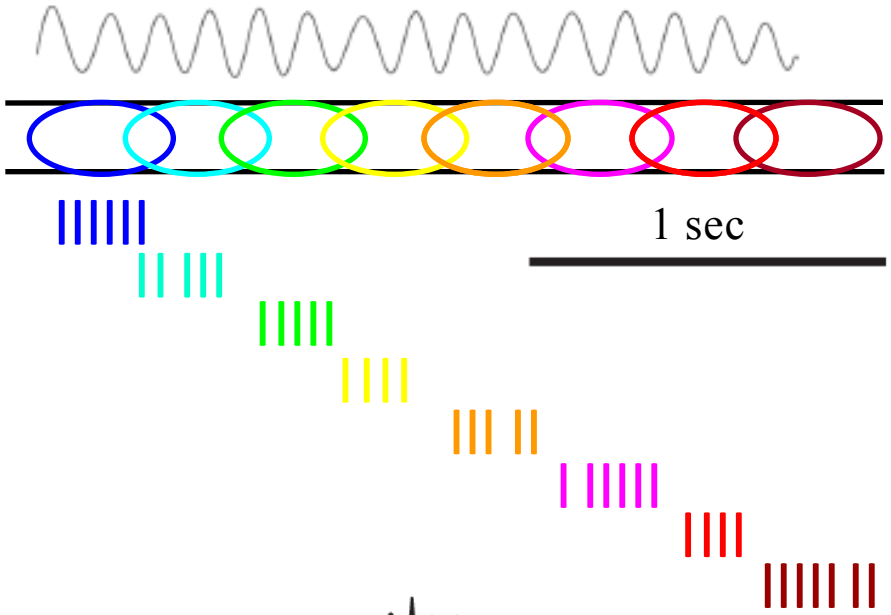


Activity Patterns in the Hippocampus

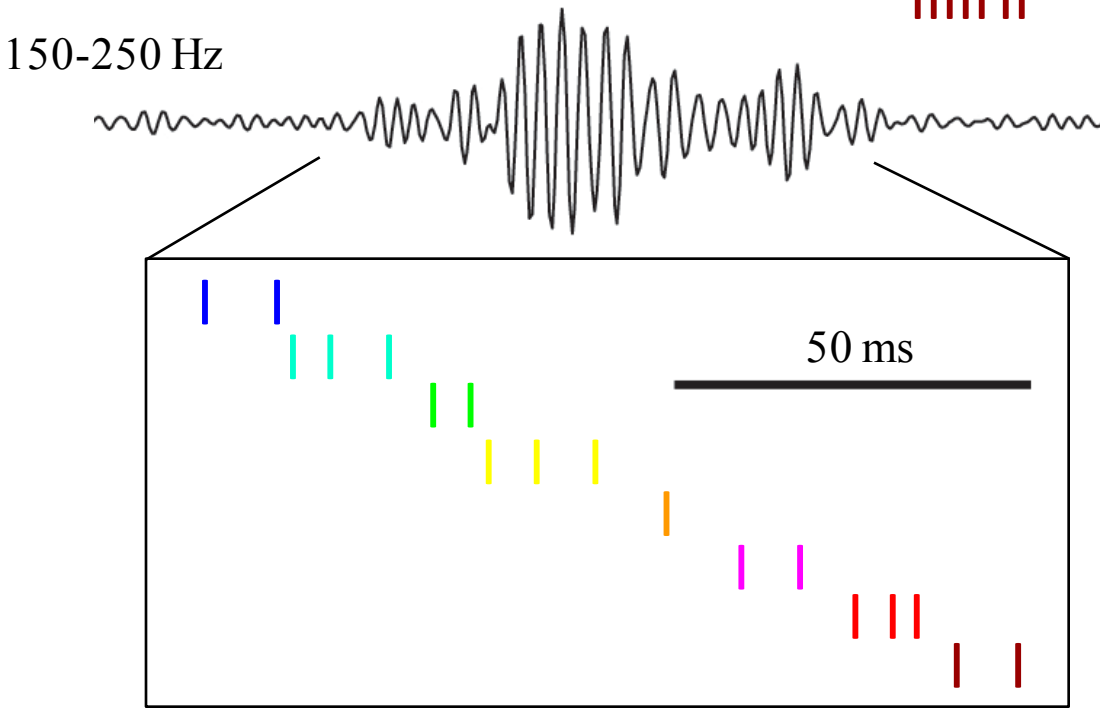
Theta Rhythm

Place Fields

Encoding?



Sharp-Wave Ripples

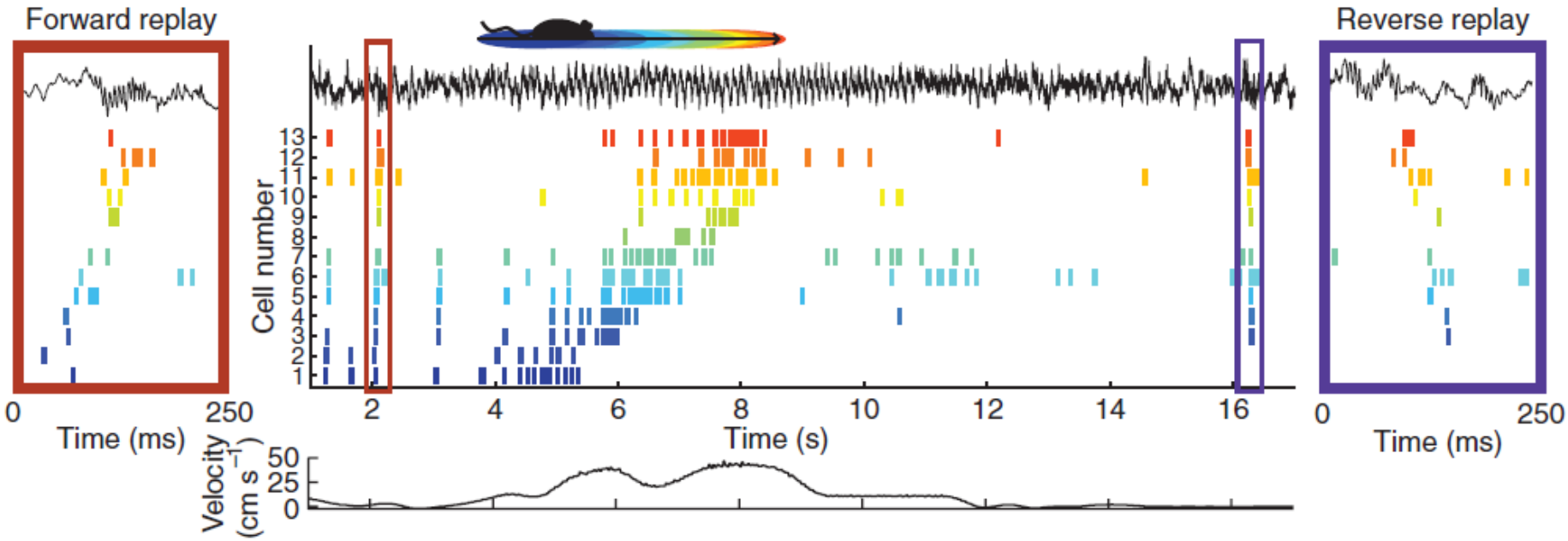


Replay / Reactivation of memory sequences during SWRs

Consolidation and Retrieval?

Awake Replay – Retrieval?

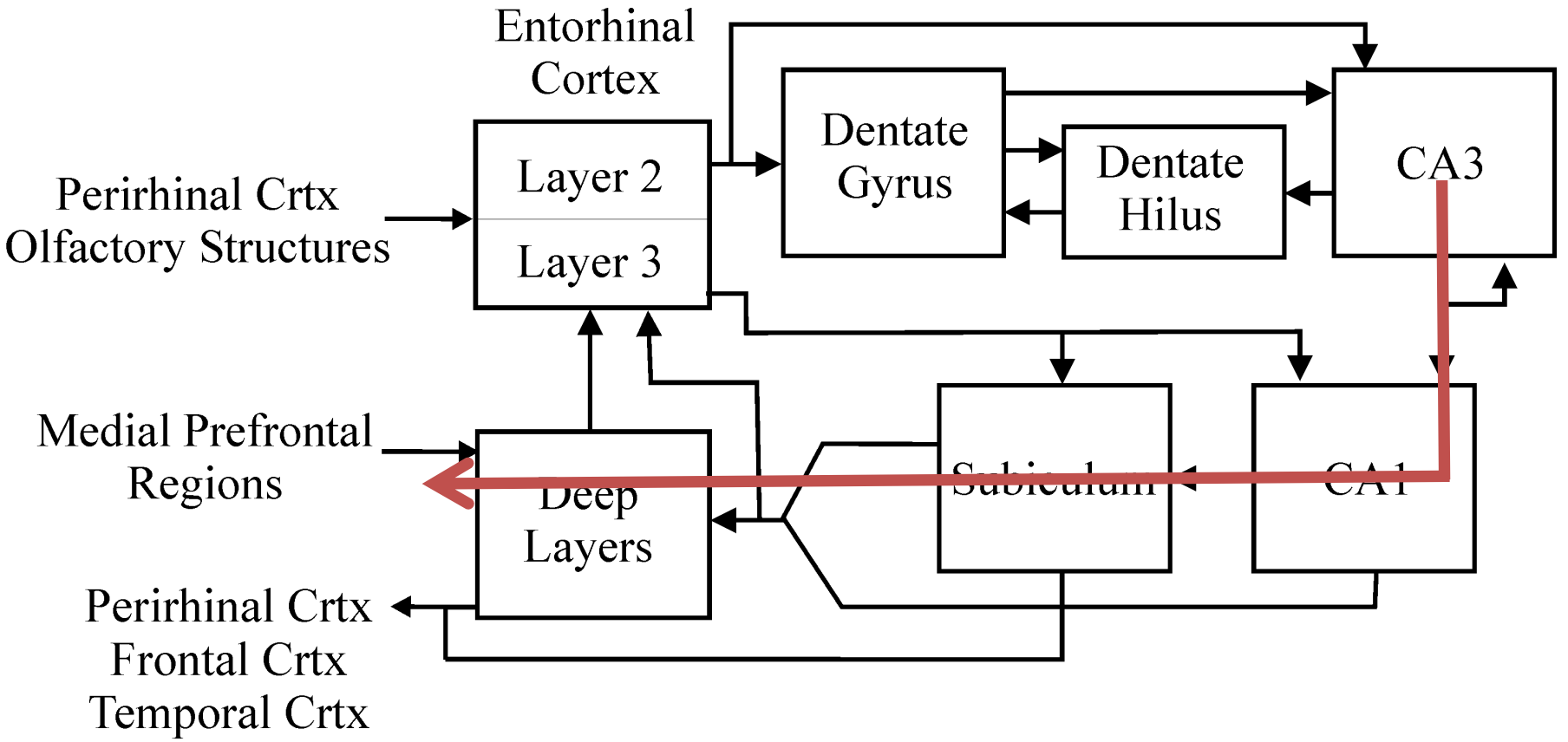
- Evidence for awake replay within an environment (Foster and Wilson, 2006; Diba and Buzsaki 2008)



- Evidence for awake replay after an experience (Karlsson and Frank, 2009)

Ripples

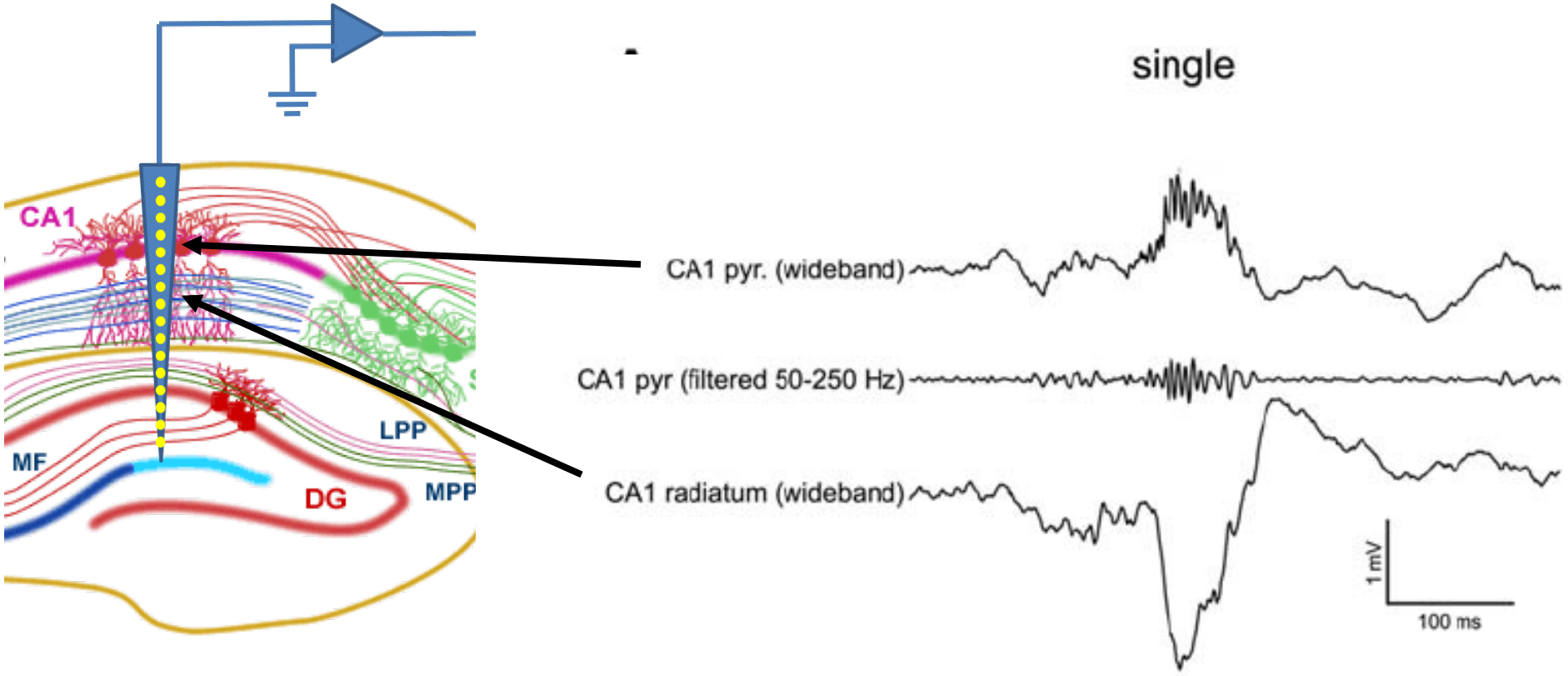
- High frequency bursts of activity



Buzsaki and colleagues, 1994, 1999 …

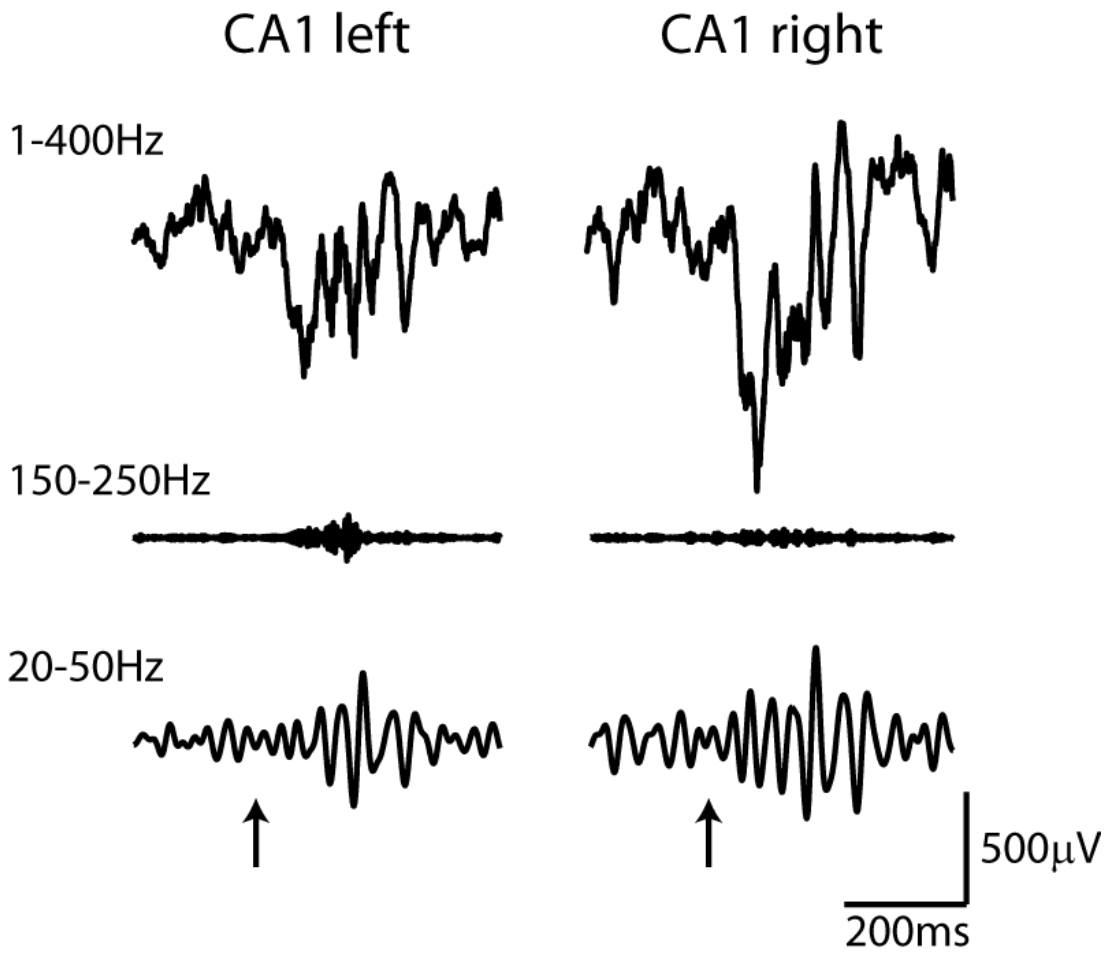
Sharp-wave Ripples (SWRs)

- CA3 drive of CA1 spiking

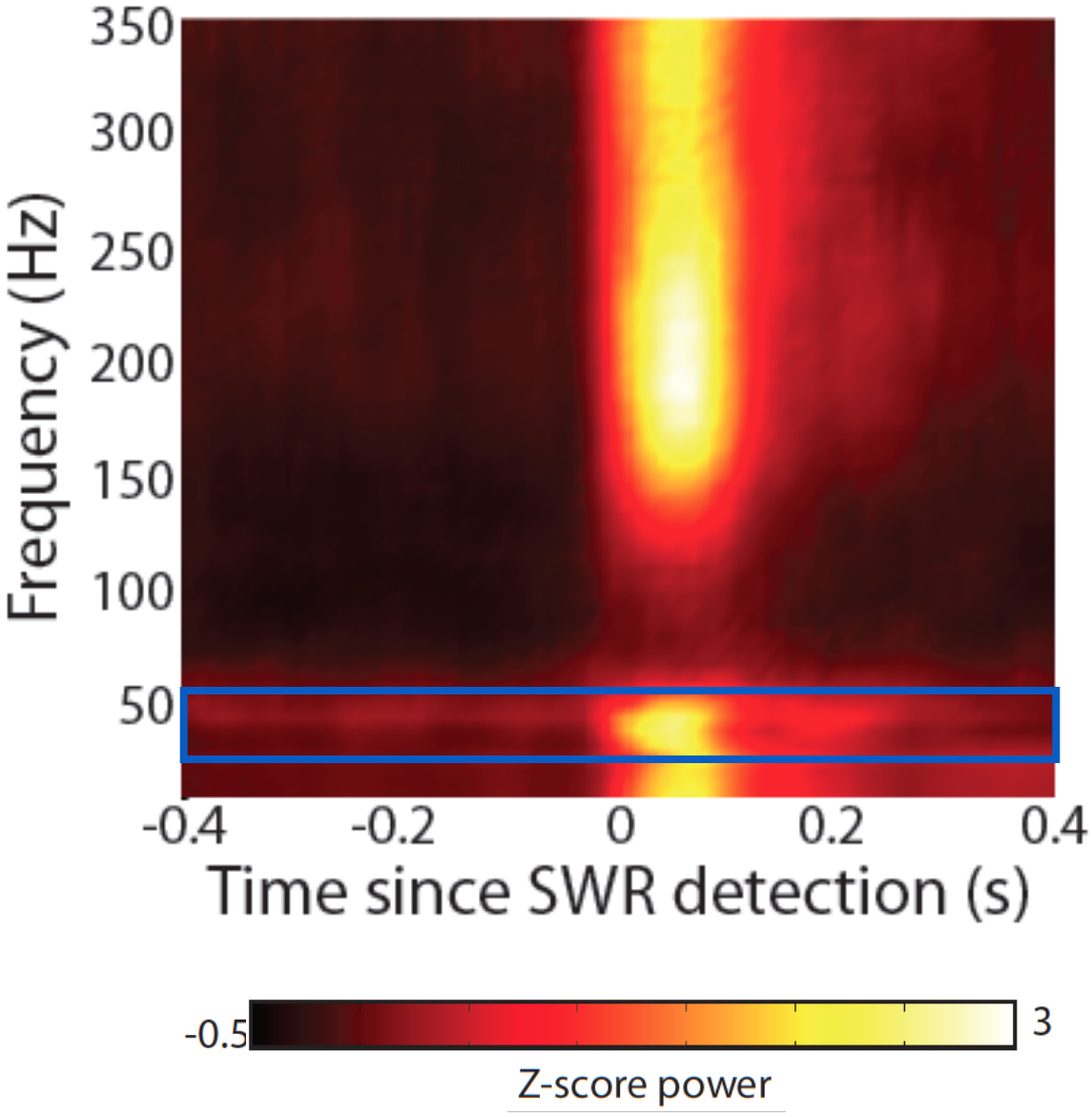


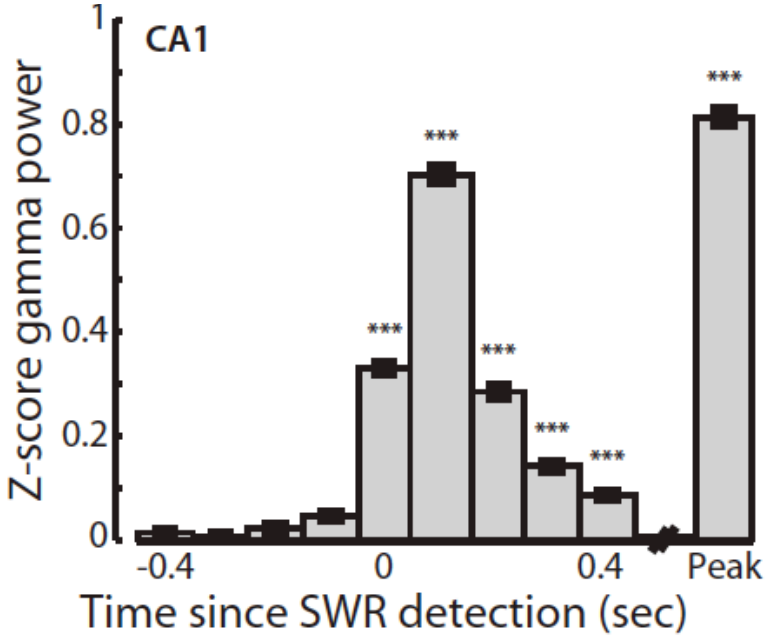
Buzsaki, 2015

SWRs: Different Frequency Bands



Gamma Oscillations During SWRs



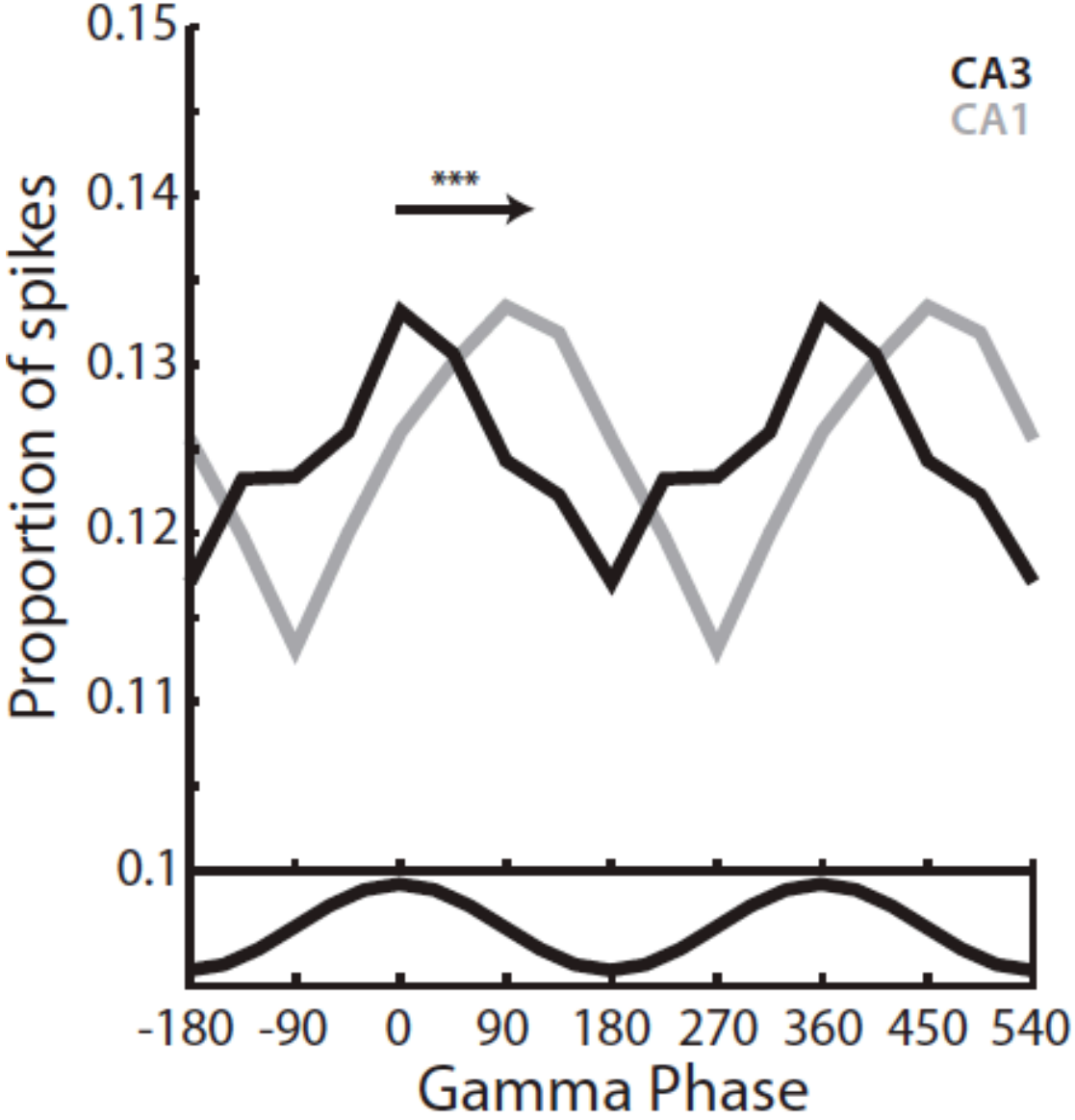


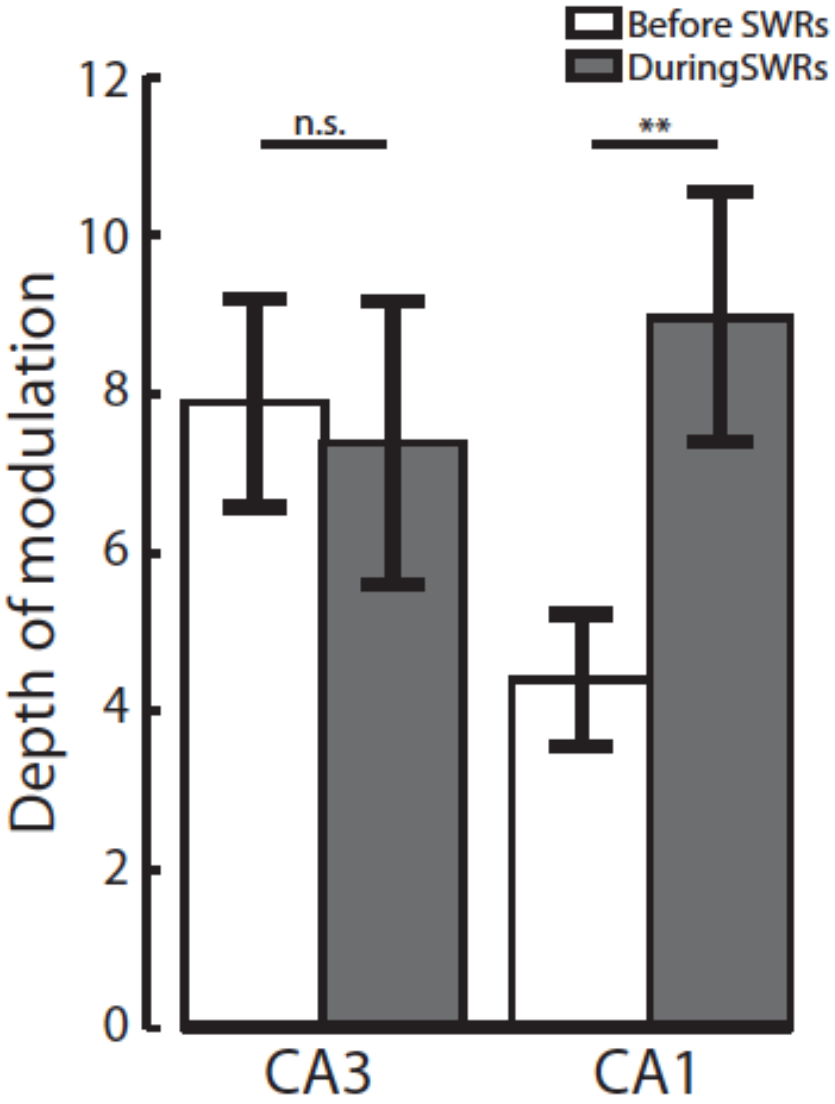
20-50 Hz "slow gamma" band reflects CA3 input to CA1

Gamma entrains CA3 and CA1 spiking

Carr et. al, 2012

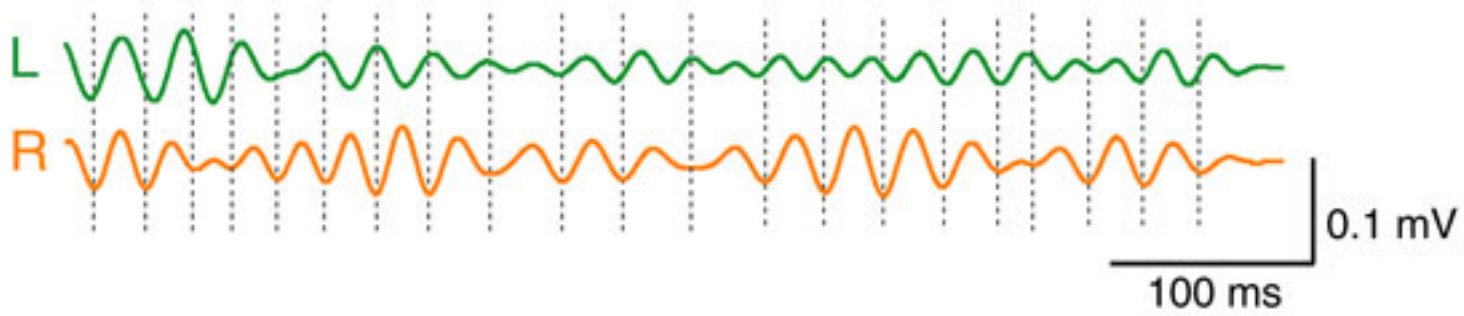
Spiking during SWRs is modulated by gamma



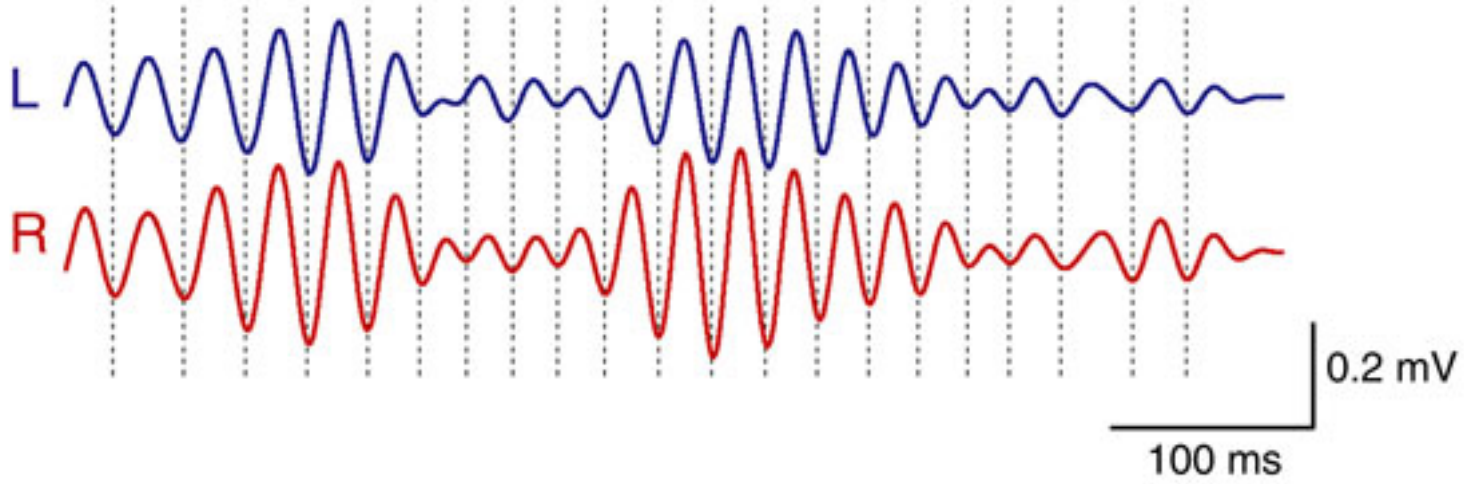


Gamma coherence

Reared in Isolation (lower coherence)

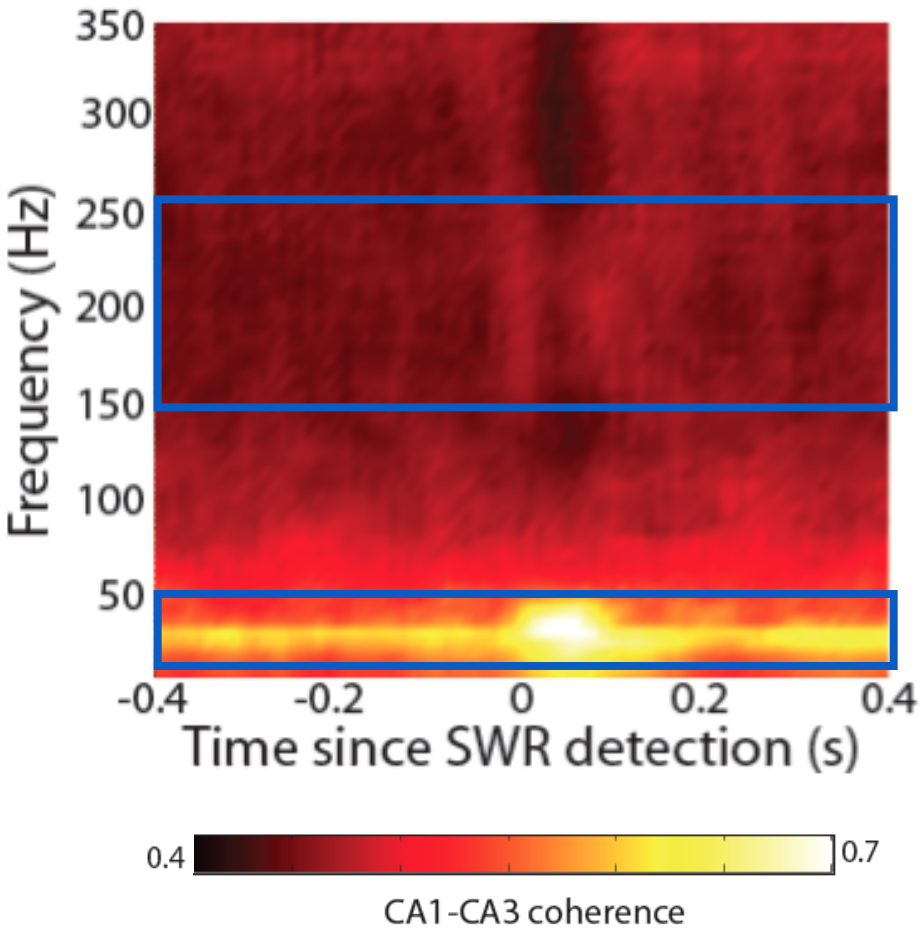


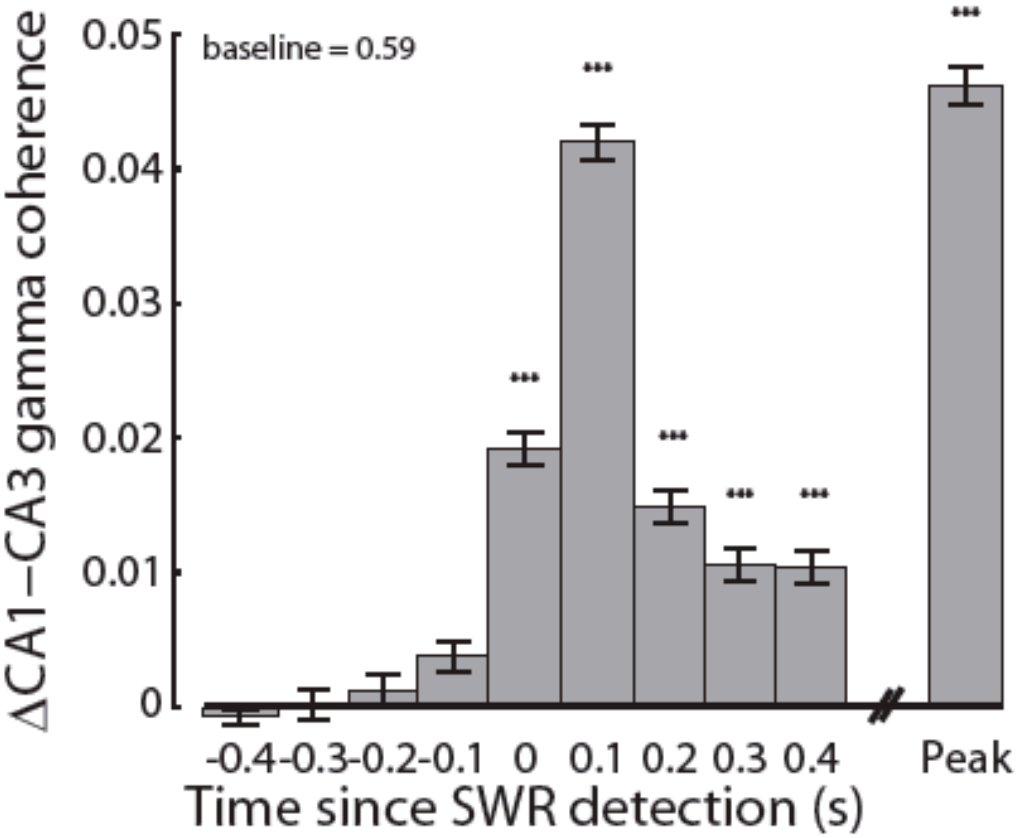
Reared in Enriched Environment (higher coherence)



Shinohara et. al, 2013

CA3 – CA1 Gamma coherence transiently increases during SWRs





Gamma coherence also predicts the quality of replay

Carr et. al, 2012

Summary

Different patterns of hippocampal activity may support different types of memory

Place field activity and replay are associated with different hippocampal rhythms.