SAND2016-7534PE

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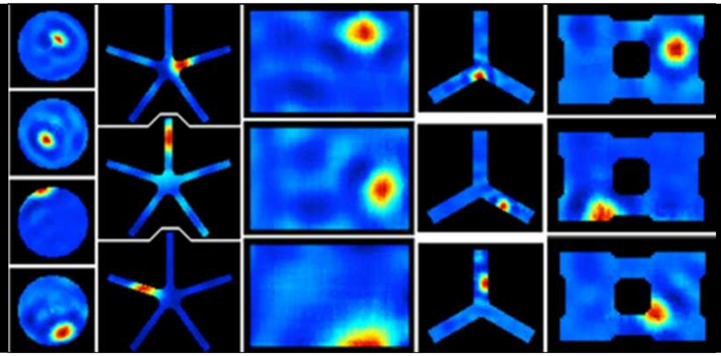

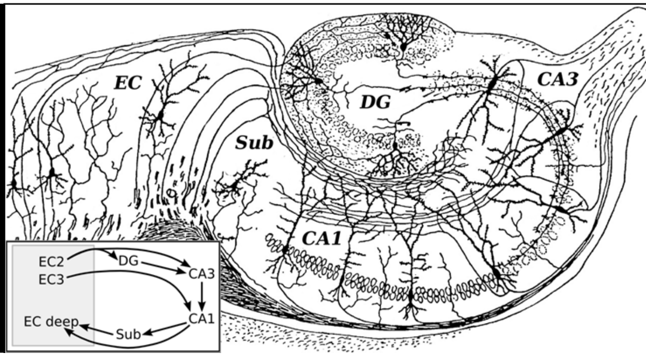

Computation in the Hippocampus

Frances Chance (1462)

August 3, 2016

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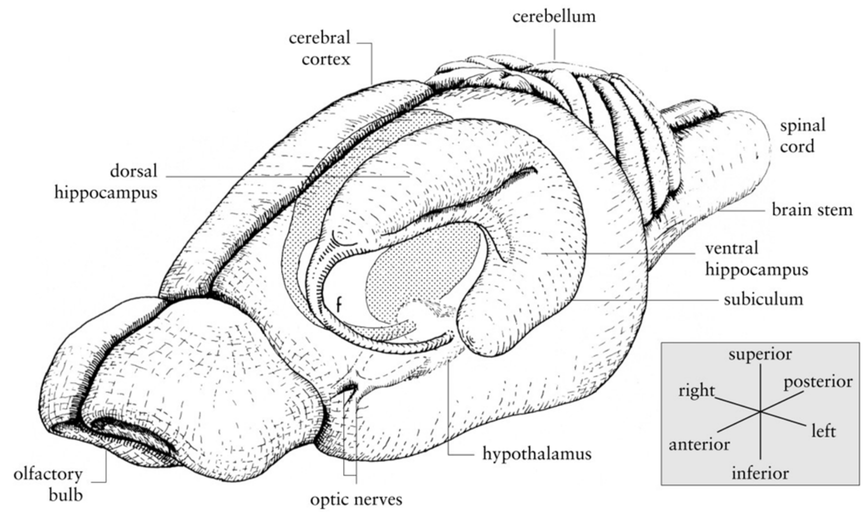
What is the hippocampus?



- Thought to be essential for memory formation
- In rodents - spatial coding

figures from https://en.wikipedia.org/wiki/Hippocampus and Amaral DG, Witter MP. (1995) Hippocampal formation. in: Paxinos G, editor. The Rat Nervous System.

What is the hippocampus?

- Patient H.M. (Henry Molaison)
  - Both hippocampi were surgically removed to treat epilepsy
  - After surgery could not form new memories

- 2014 Nobel Prize in Physiology or Medicine

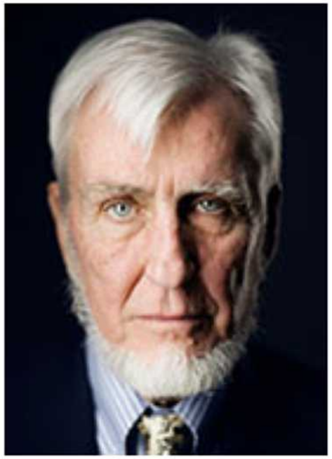
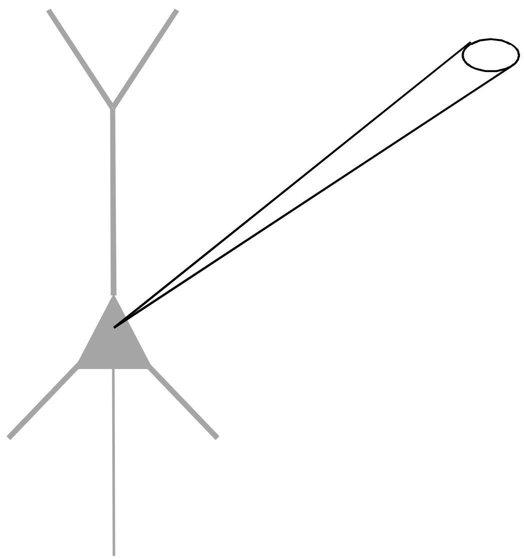


Photo: A. Mahmoud
John O'Keefe

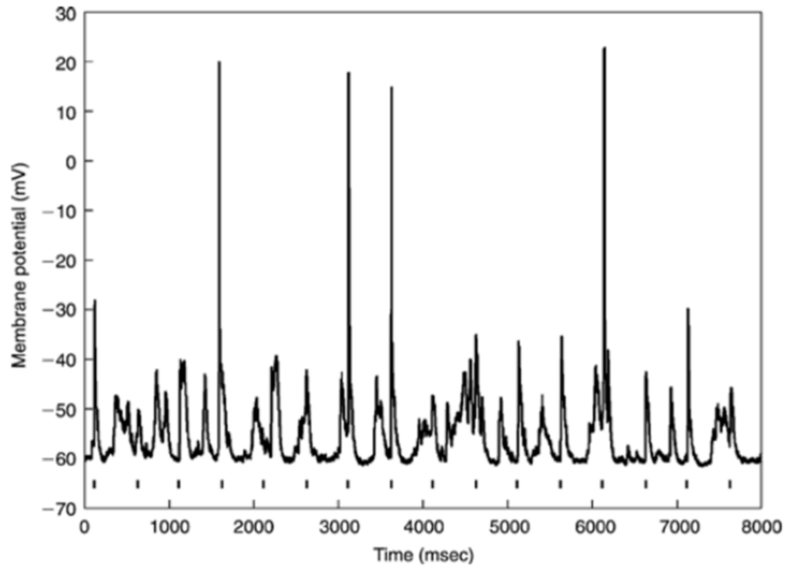
Photo: A. Mahmoud
May-Britt Moser

Photo: A. Mahmoud
Edvard I. Moser

Recording from neurons in the hippocampus



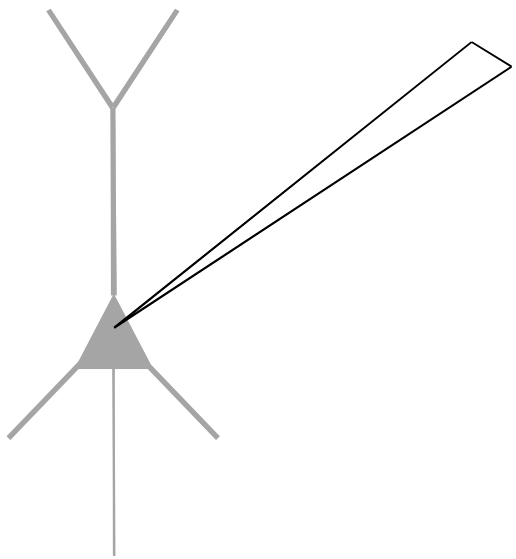
Intracellular (single unit)

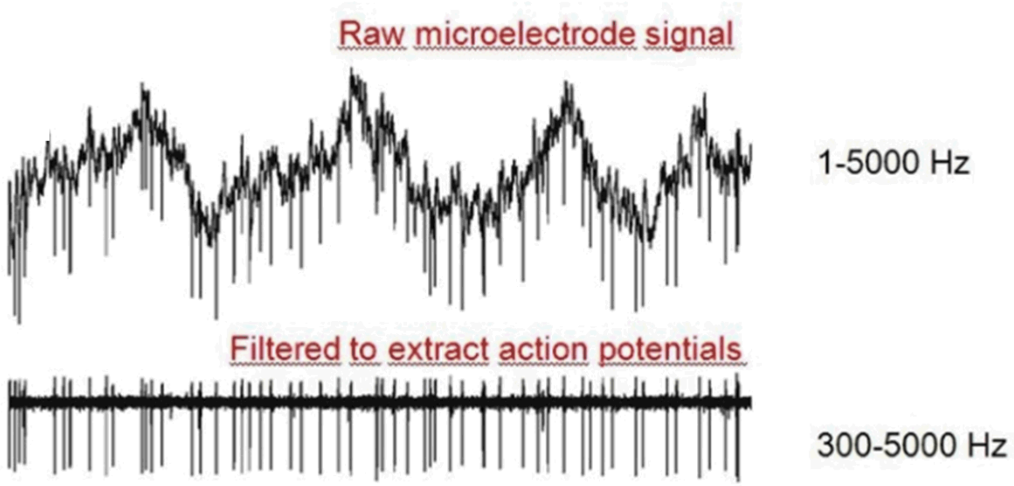


figures from http://dsp.rice.edu/sites/dsp.rice.edu/files/Lecture%208%20-%20recording%20techniques.pdf

Recording from neurons in the hippocampus

Extracellular (multi unit)





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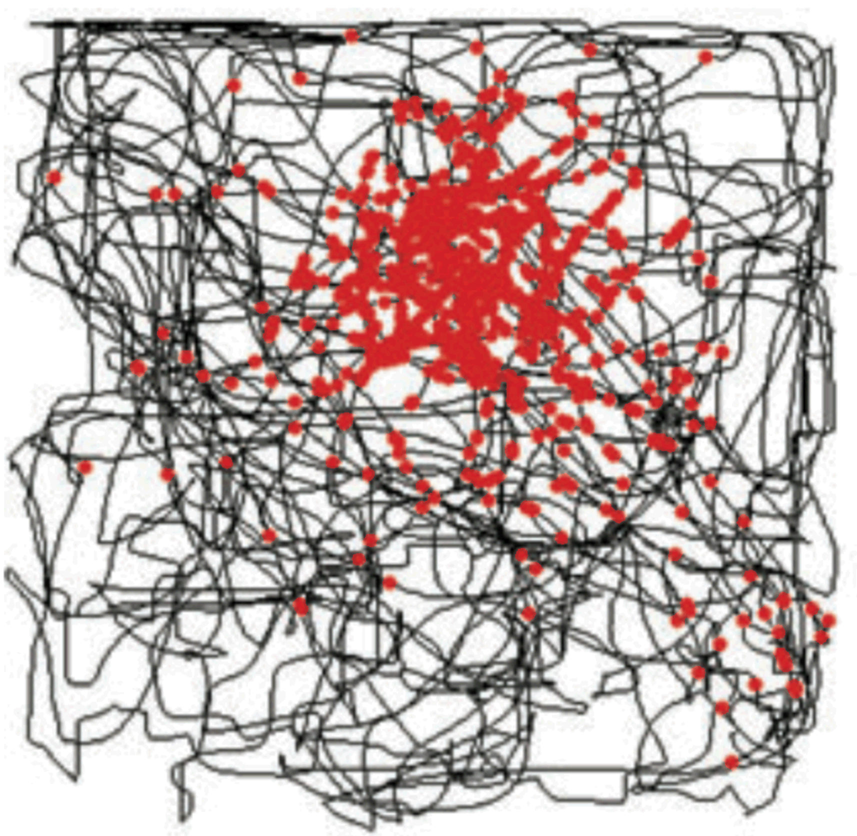
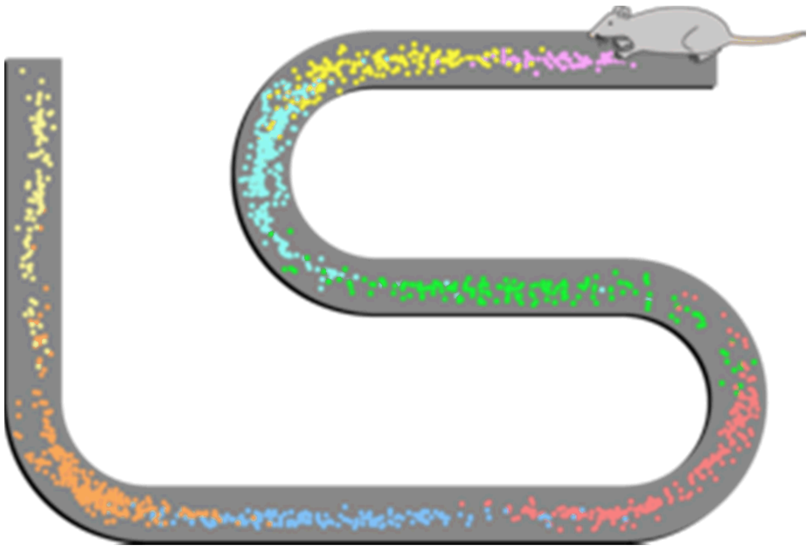
Spatial coding in the hippocampus





- form very fast
- “randomly” placed
- thought to tile space

figures from Moser et al (2008) Annu. Rev. Neurosci. 31: 69-89

Spatial coding in the hippocampus

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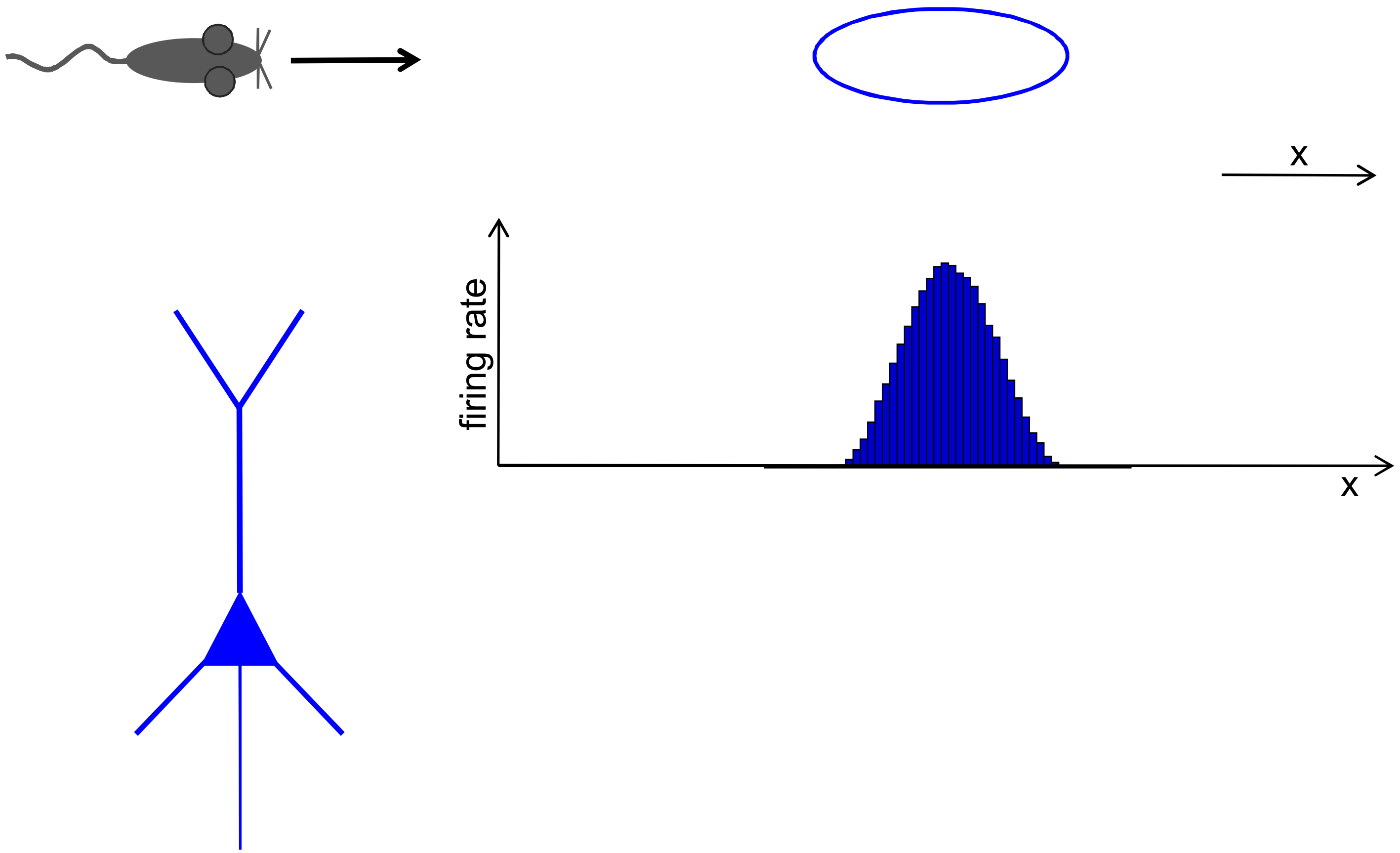
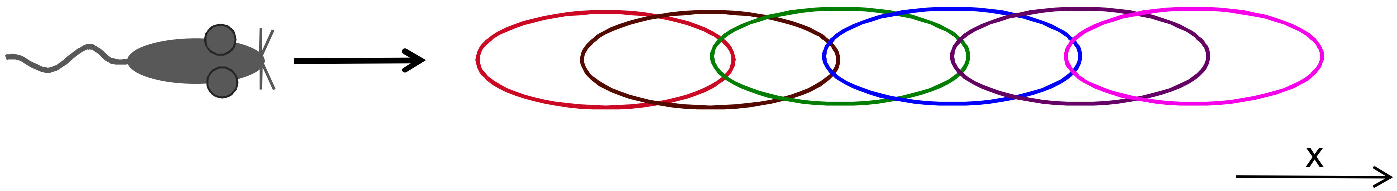
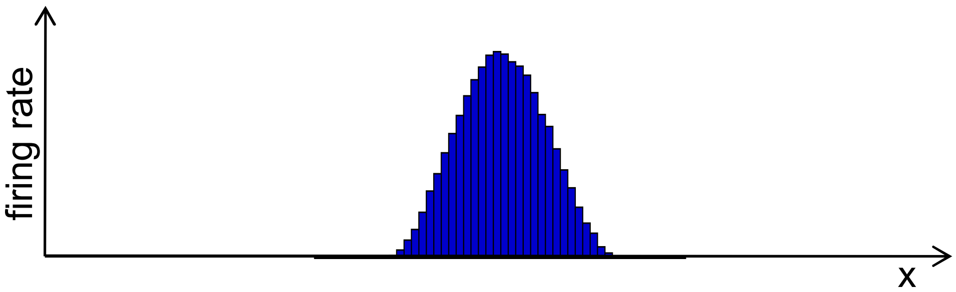
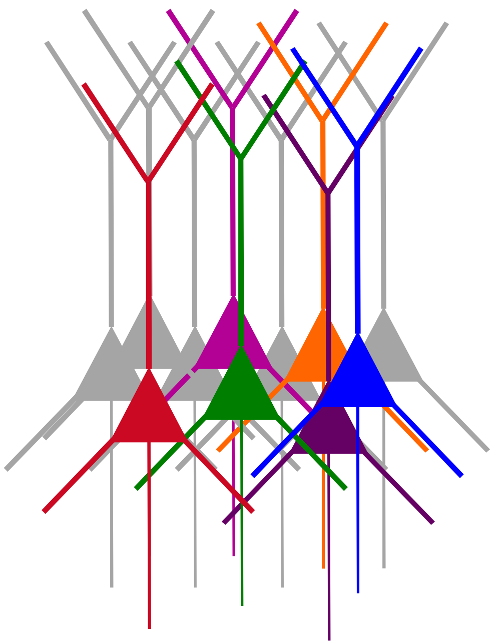


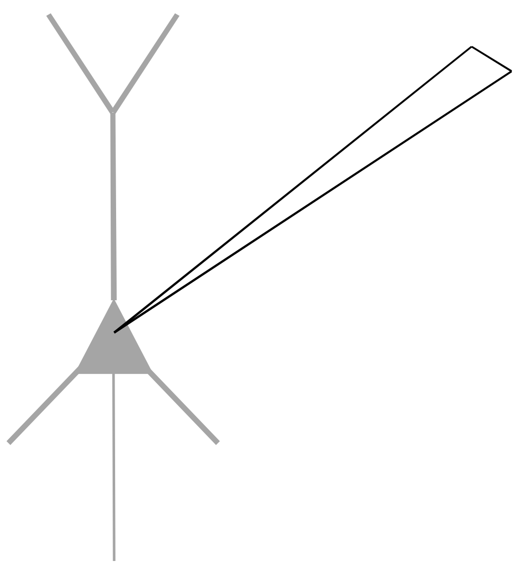
Spatial coding in the hippocampus



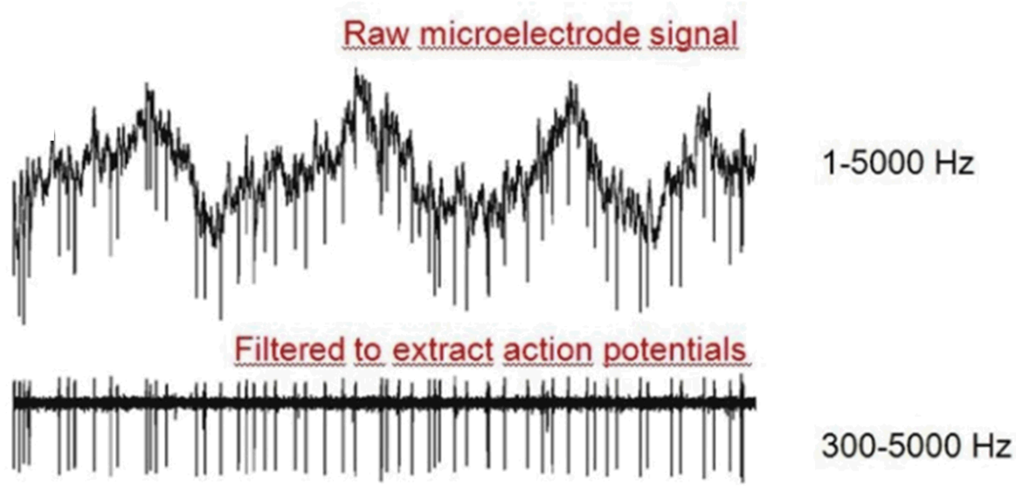




Temporal coding in the hippocampus



Extracellular (multi unit)



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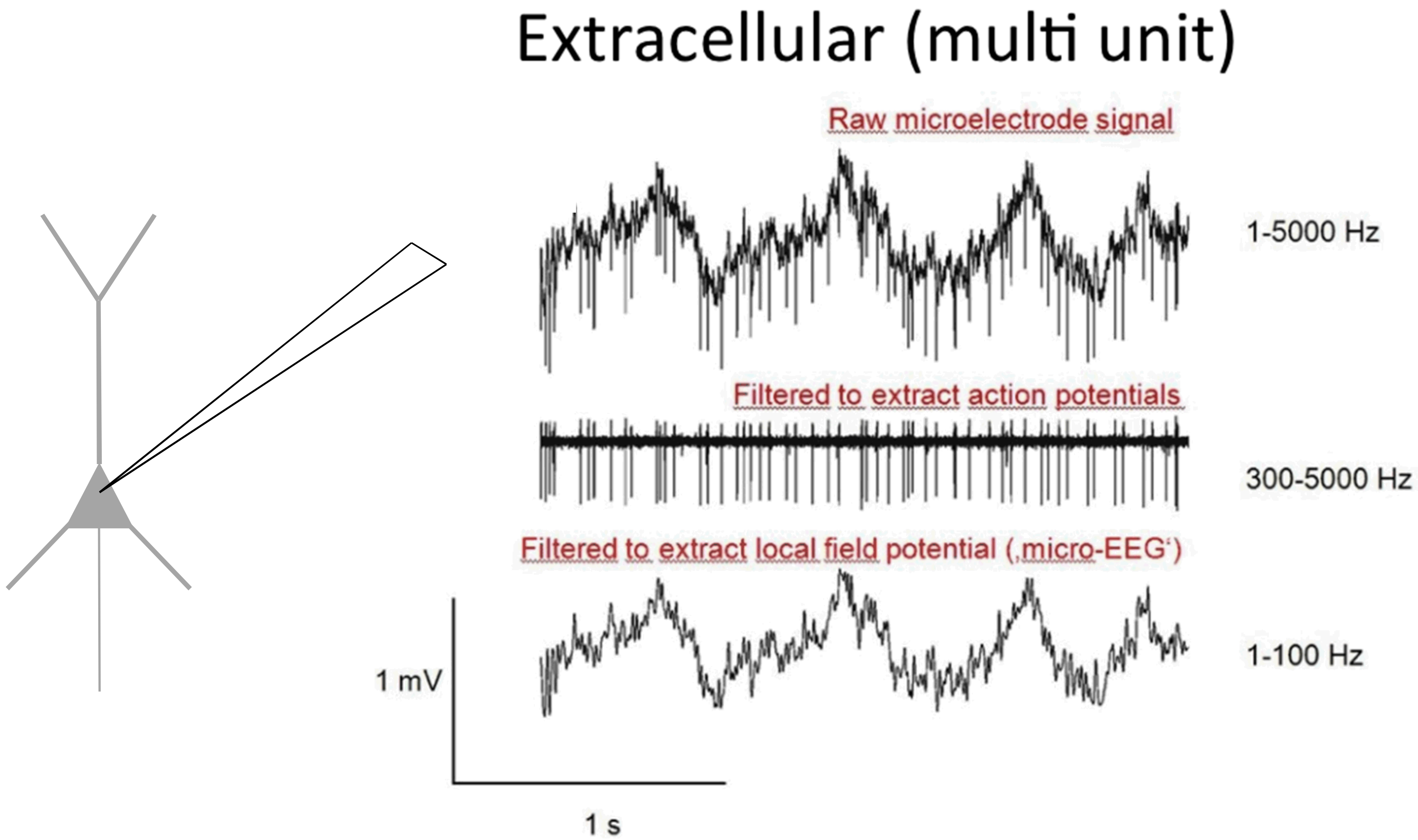
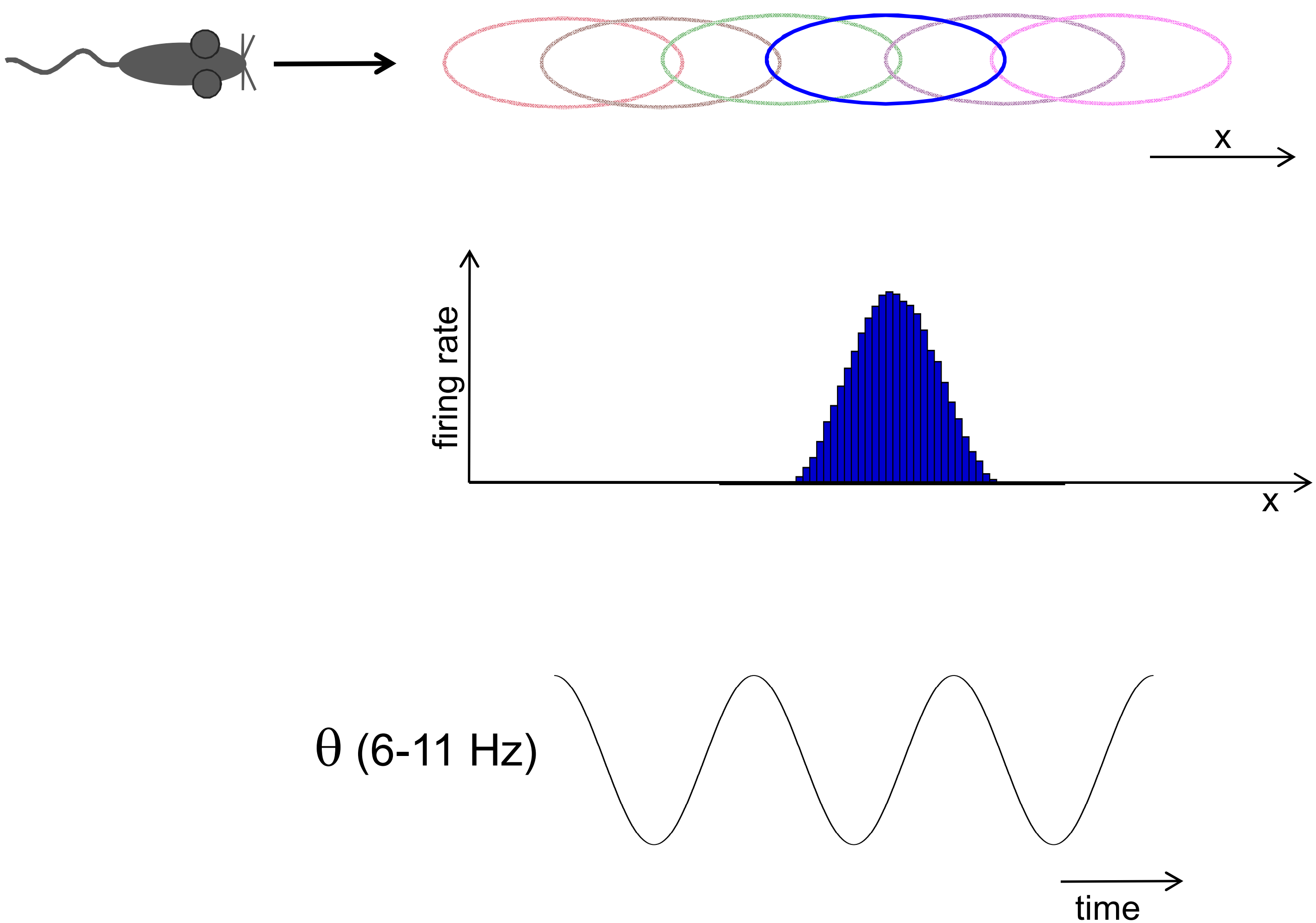
Temporal coding in the hippocampus

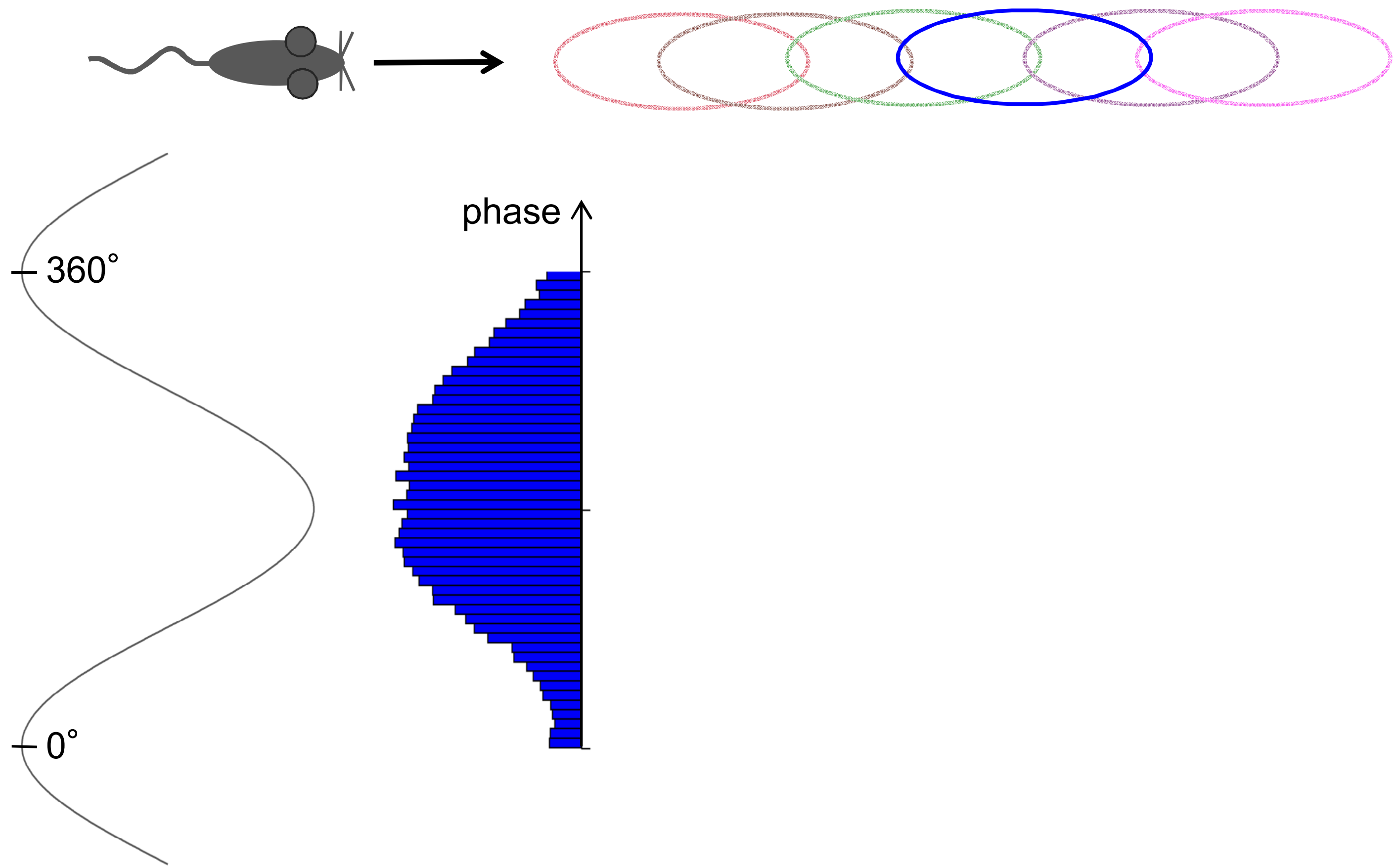


figures from http://dsp.rice.edu/sites/dsp.rice.edu/files/Lecture%208%20-%20recording%20techniques.pdf

Temporal coding in the hippocampus

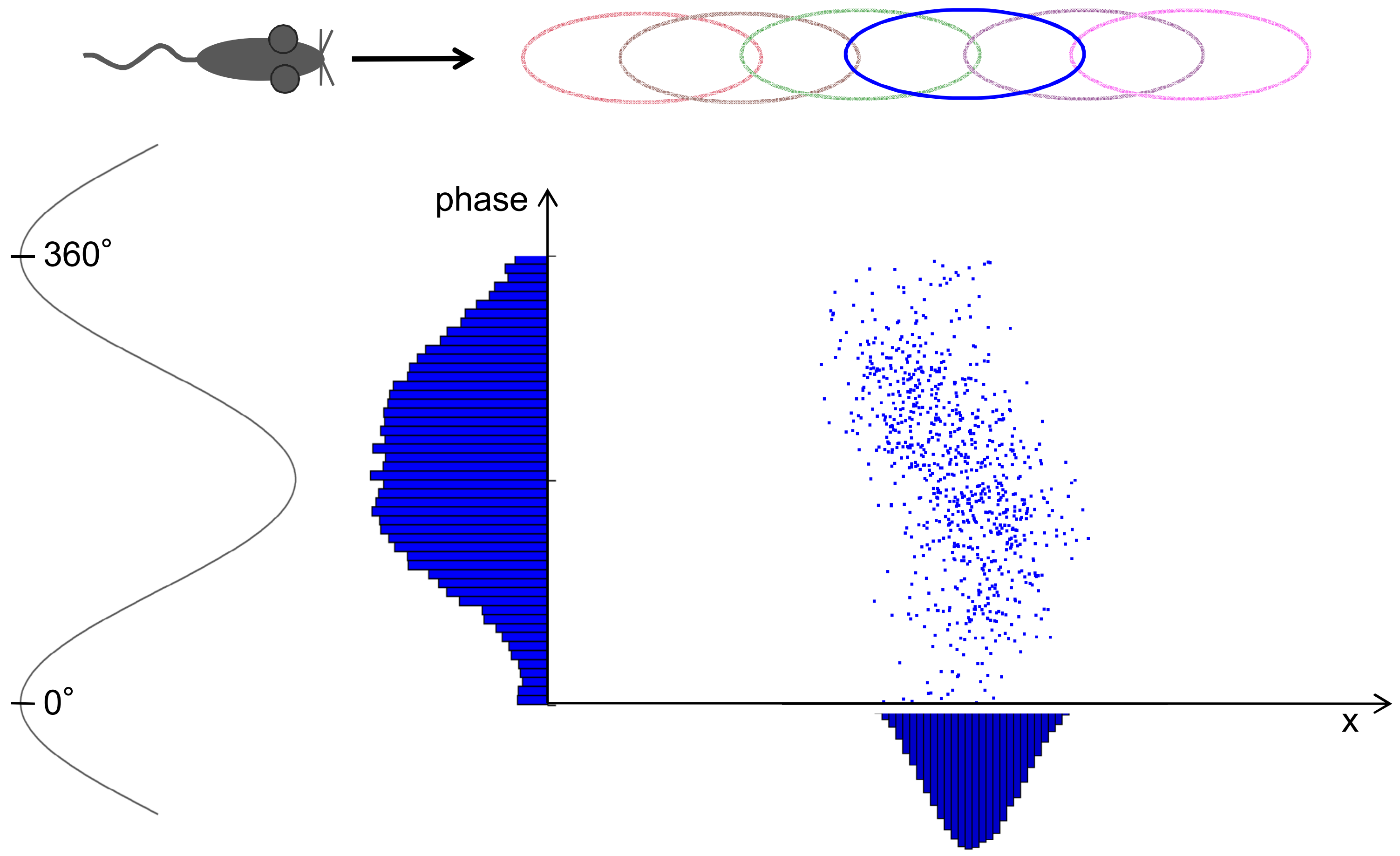


Phase precession



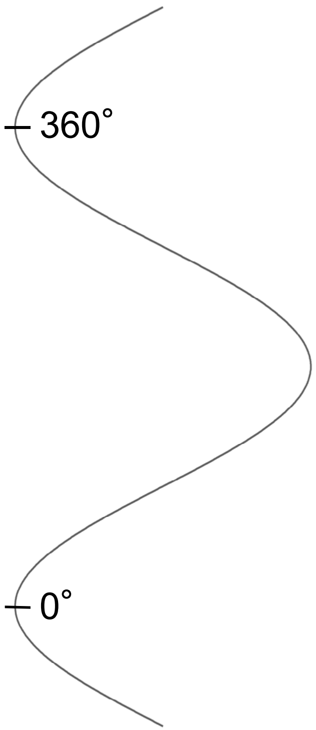
θ (6-11 Hz)

Phase precession

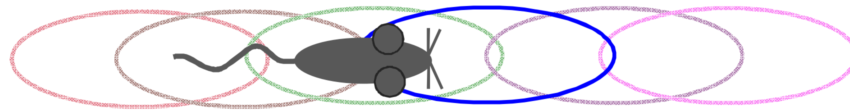


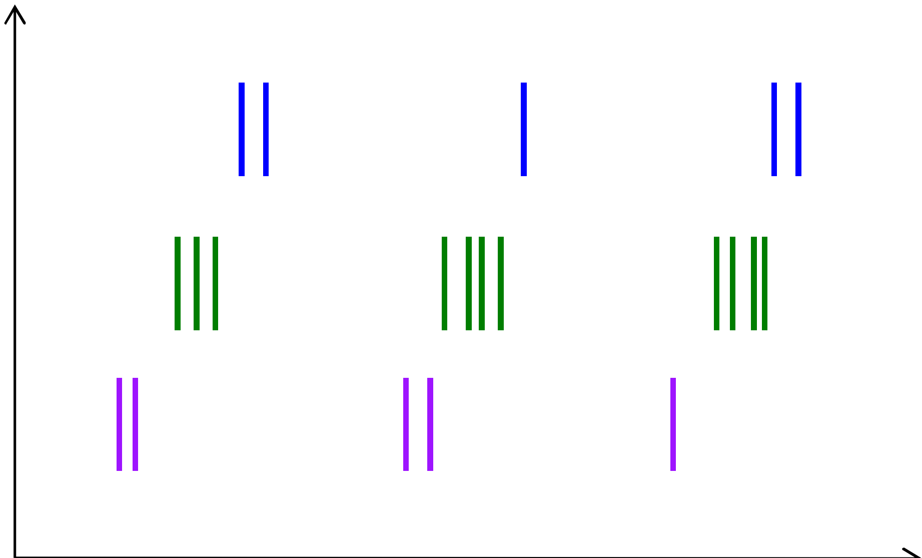
θ (6-11 Hz)

Phase precession

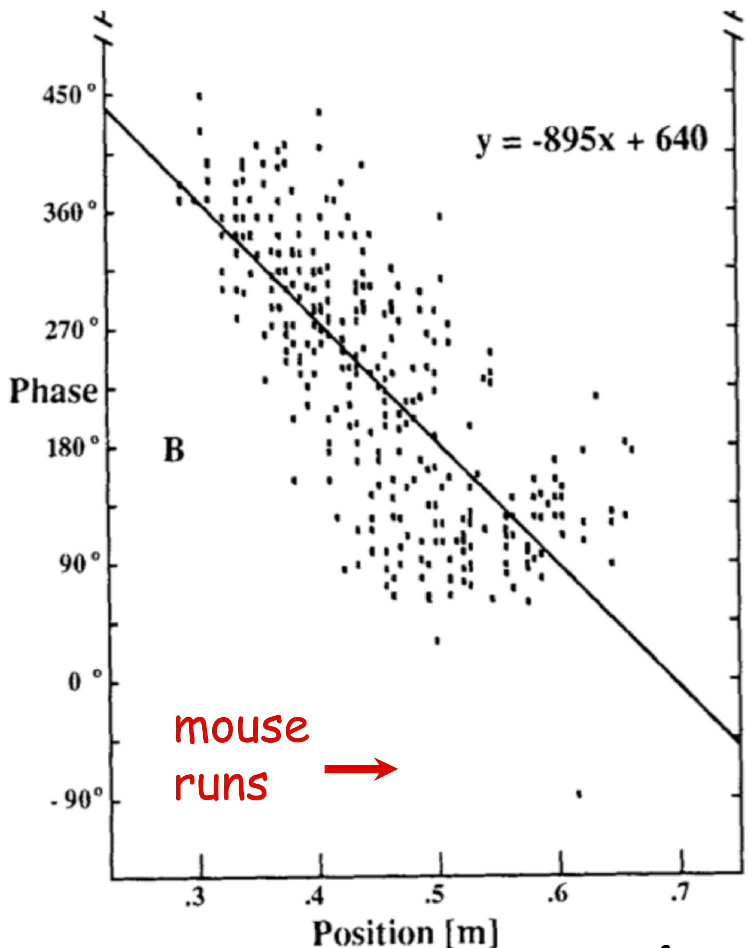


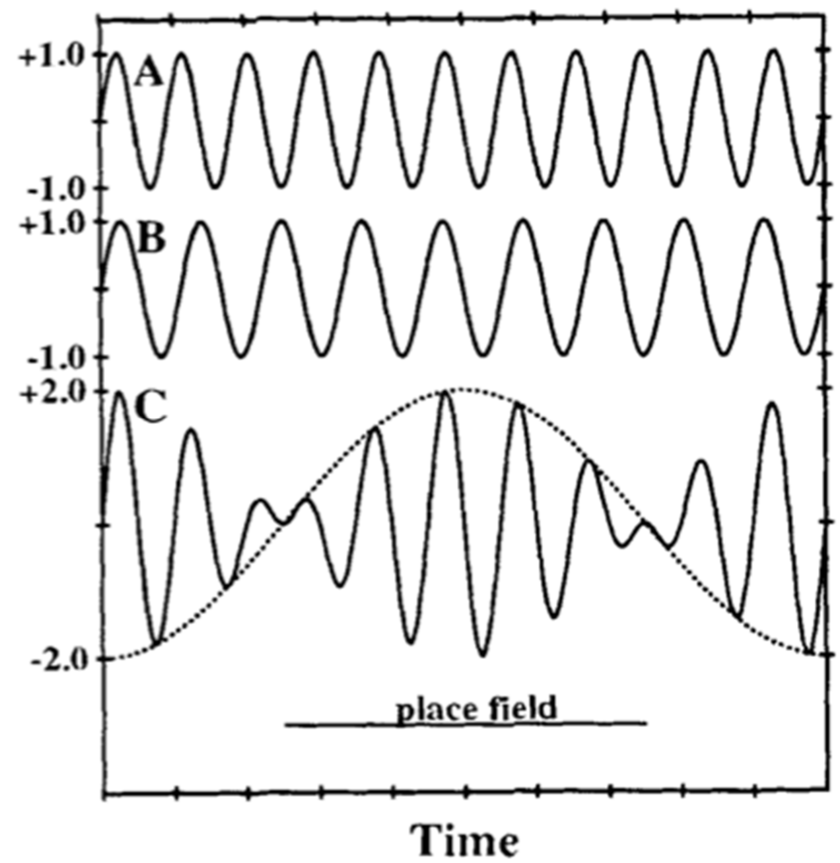
θ (6-11 Hz)





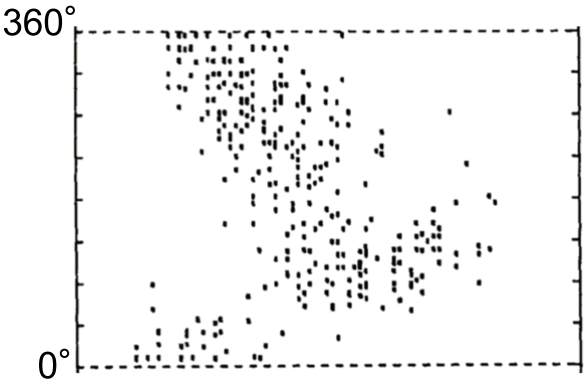
Models of phase precession in the hippocampus



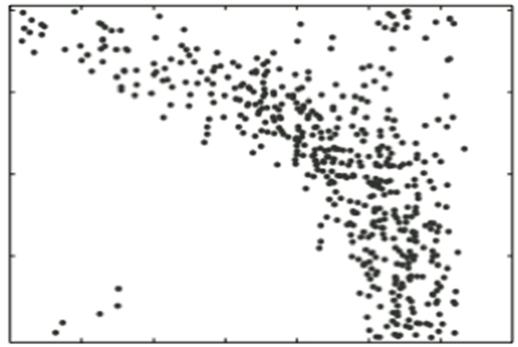


from O' Keefe & Recce (1993)

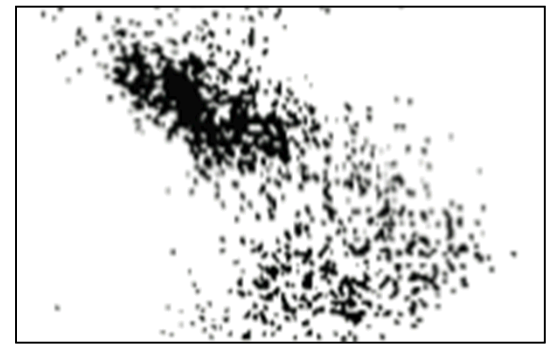
Phase precession



from O'Keefe & Recce (1993)

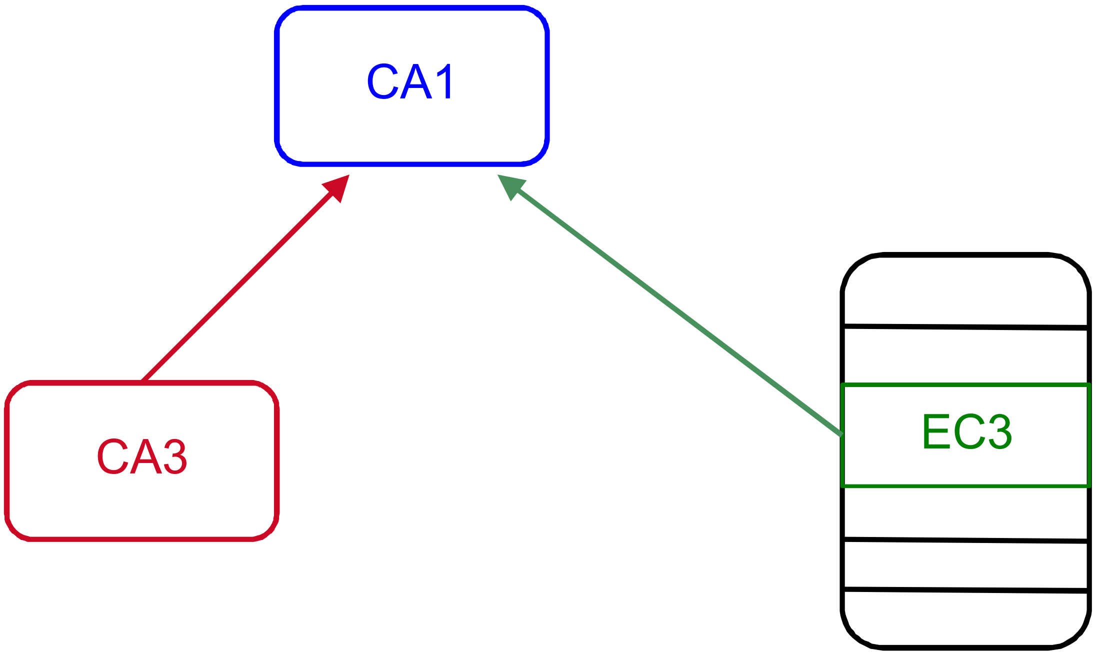


from Mehta et al (2002)



from Skaggs et al (1996)

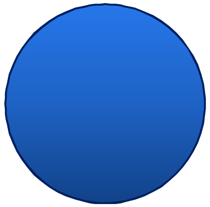
Phase Precession from Dual Components



CA1 pyramidal cells receive input from CA3 (via Schaffer collaterals) and from EC3 (via temporoammonic pathway)

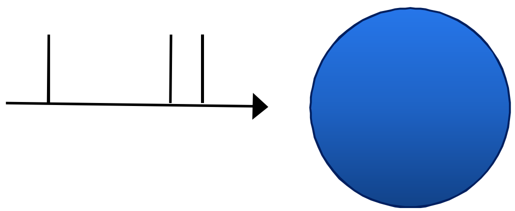
Chance FS (2012) J. Neurosci. 32: 16693

Integrate-and-Fire Model of a Neuron

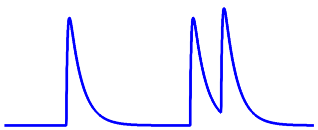


$$C\frac{dV}{dt} = g_L(E_L - V)$$

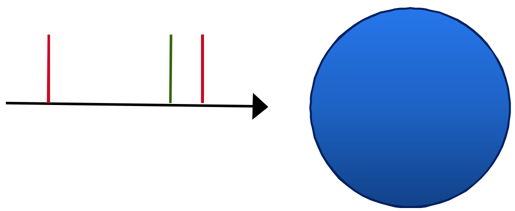
Integrate-and-Fire Model of a Neuron



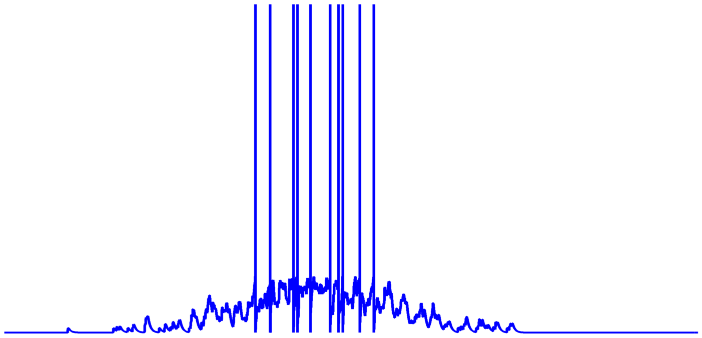
$$C\frac{dV}{dt} = g_L(E_L - V) + g_E(E_E - V)$$



Integrate-and-Fire Model of a Neuron

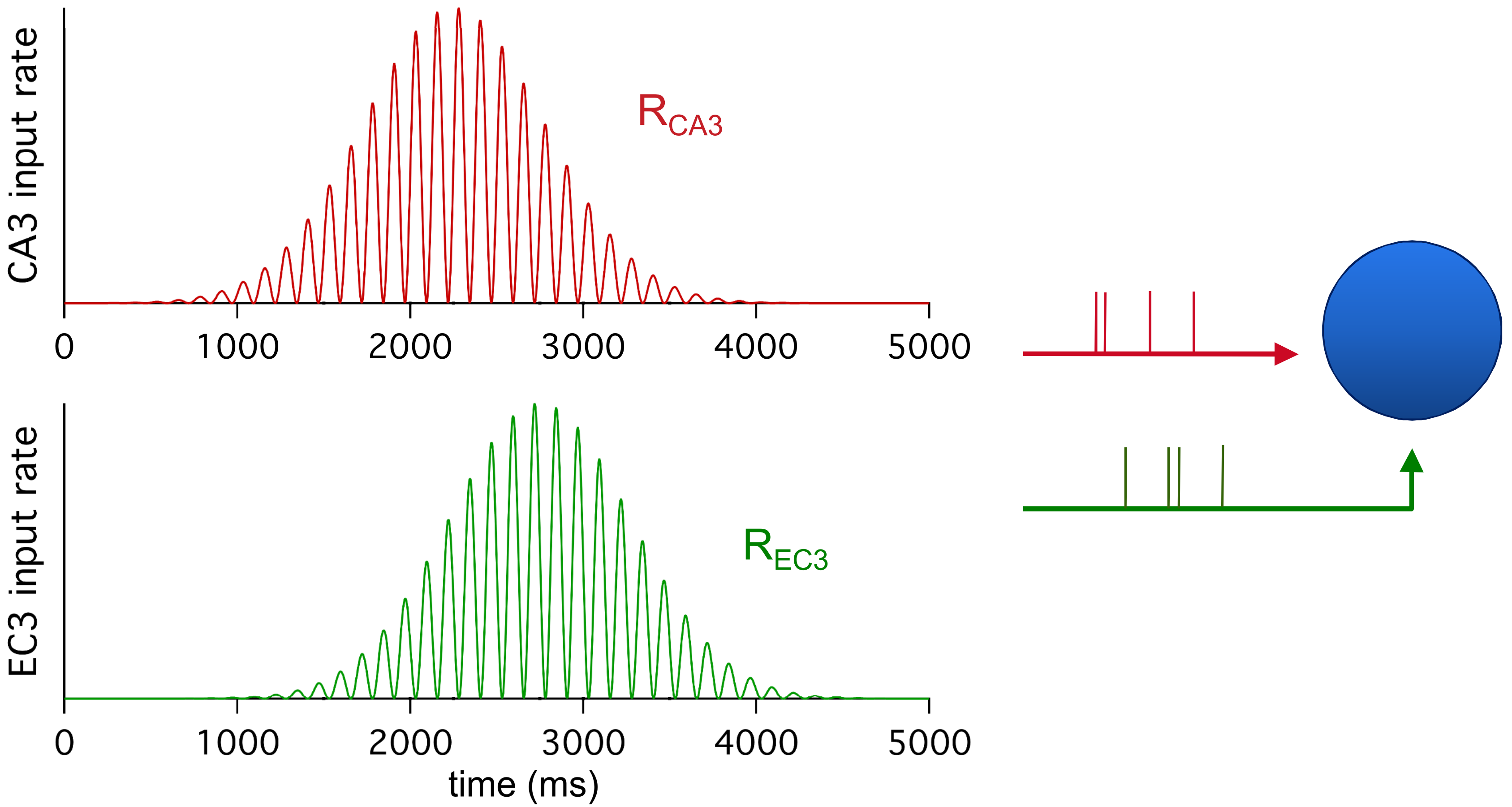


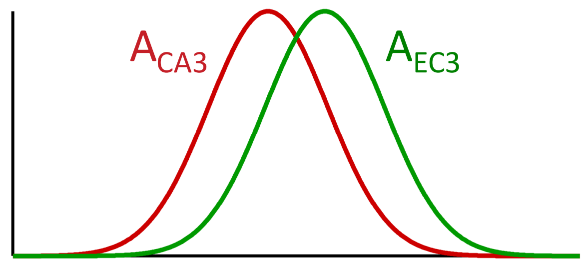
$$C\frac{dV}{dt} = g_L(E_L - V) + g_E(E_E - V)$$



Phase Precession from Dual Components

input rate = $R_{\mathrm{CA3,EC3}} = A(x)\lfloor\cos(2\pi f t + \phi_{\mathrm{CA3,EC3}}) + b\rfloor_{+}$





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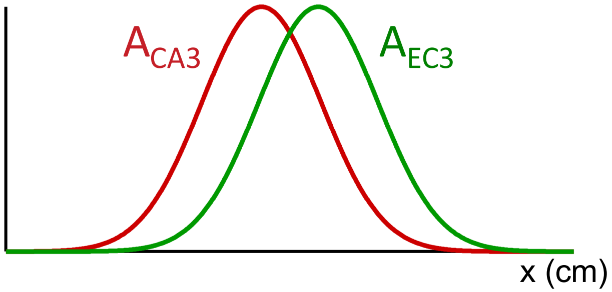
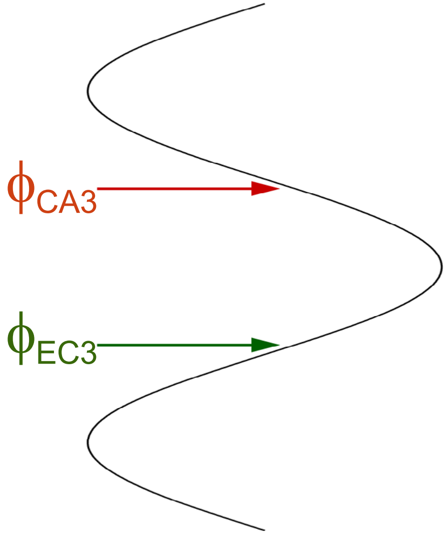
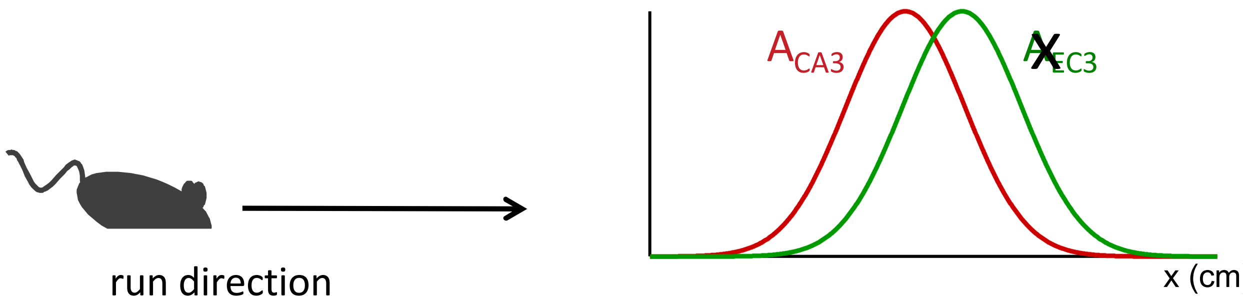
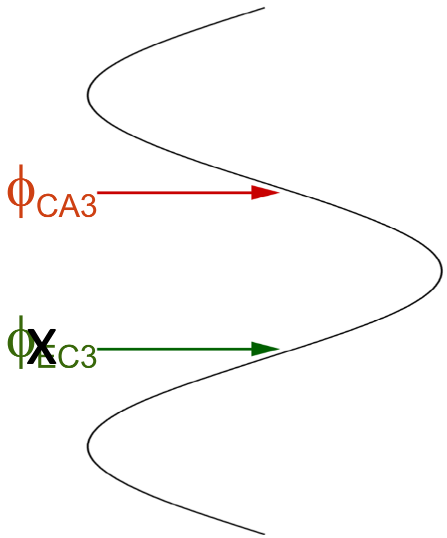


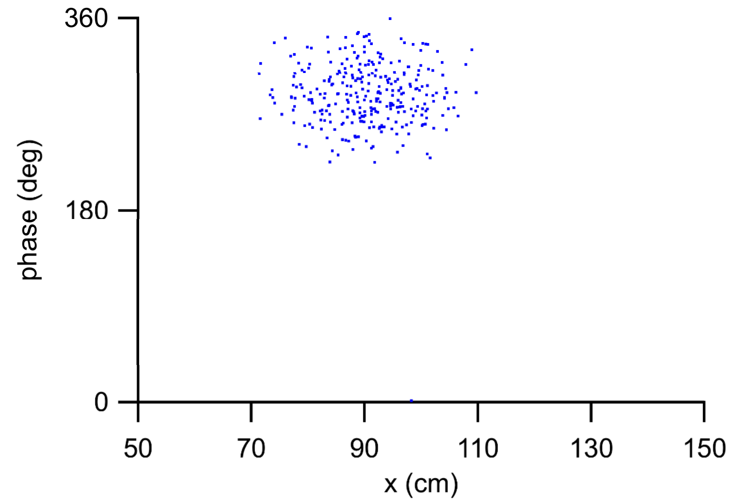


Mizuseki, Sirota, Pastalkova & Buzsáki (2009) Neuron 64: 267

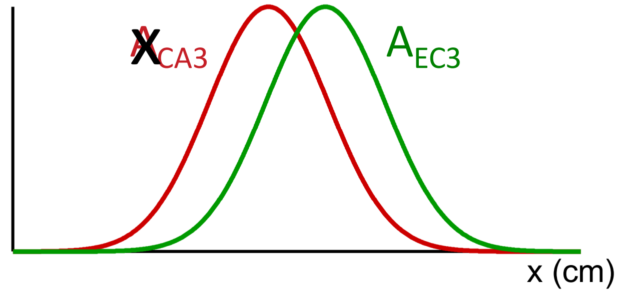


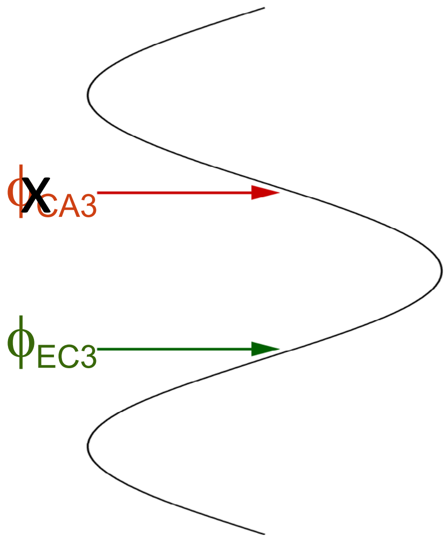
CA1 model spiking when driven only by CA3 input

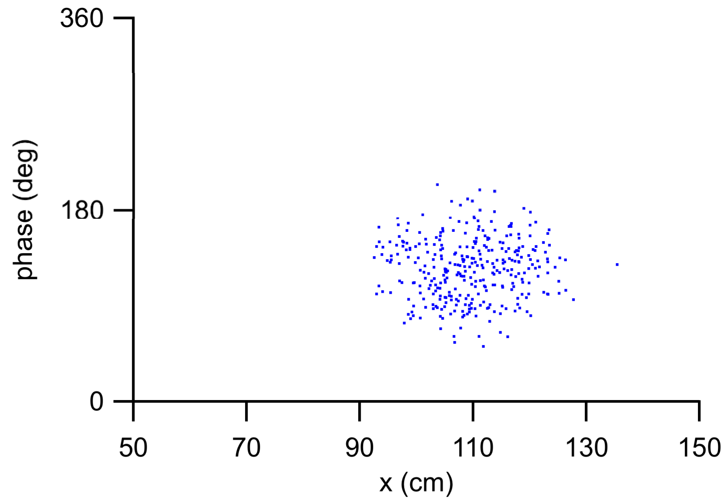




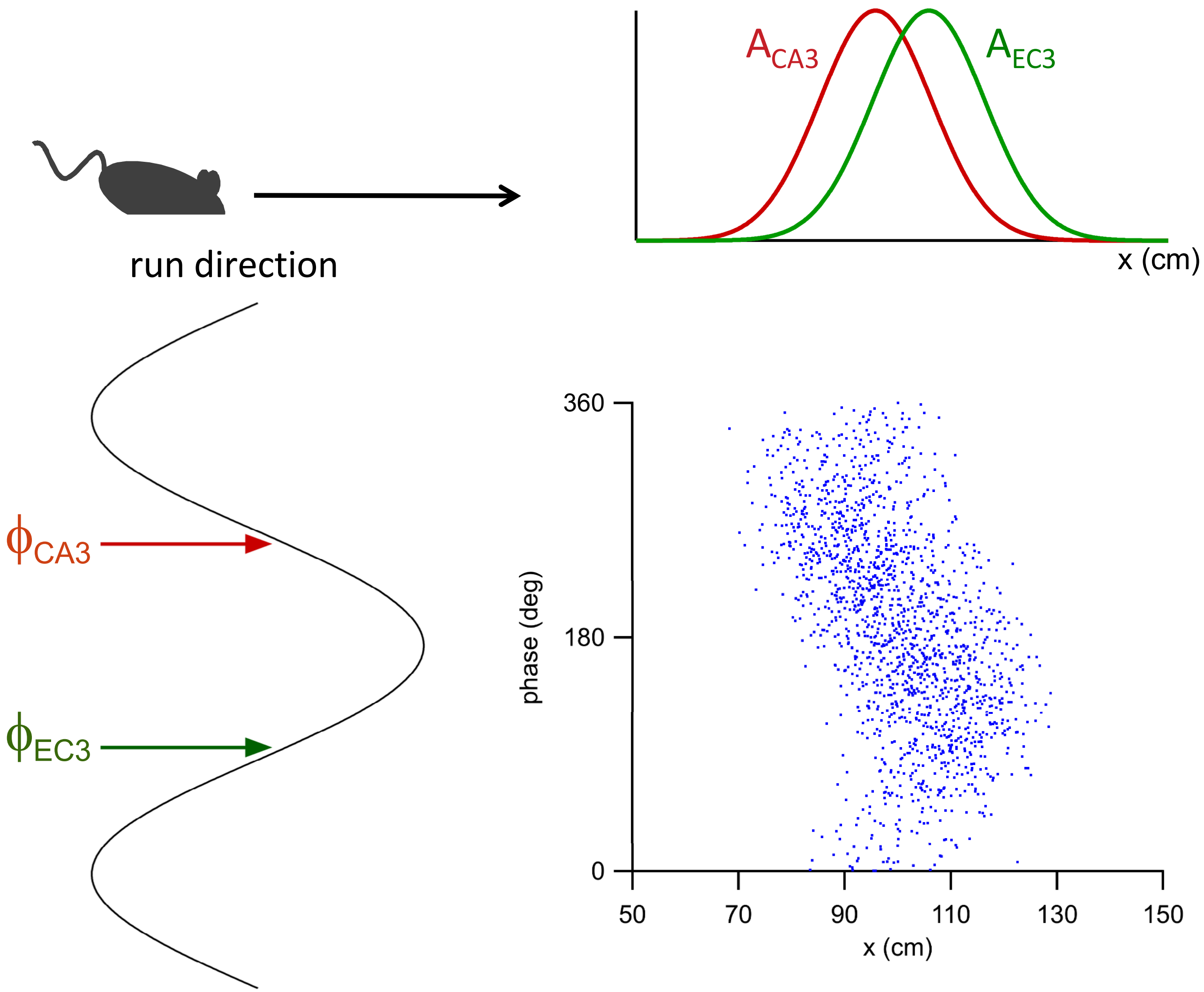
run direction





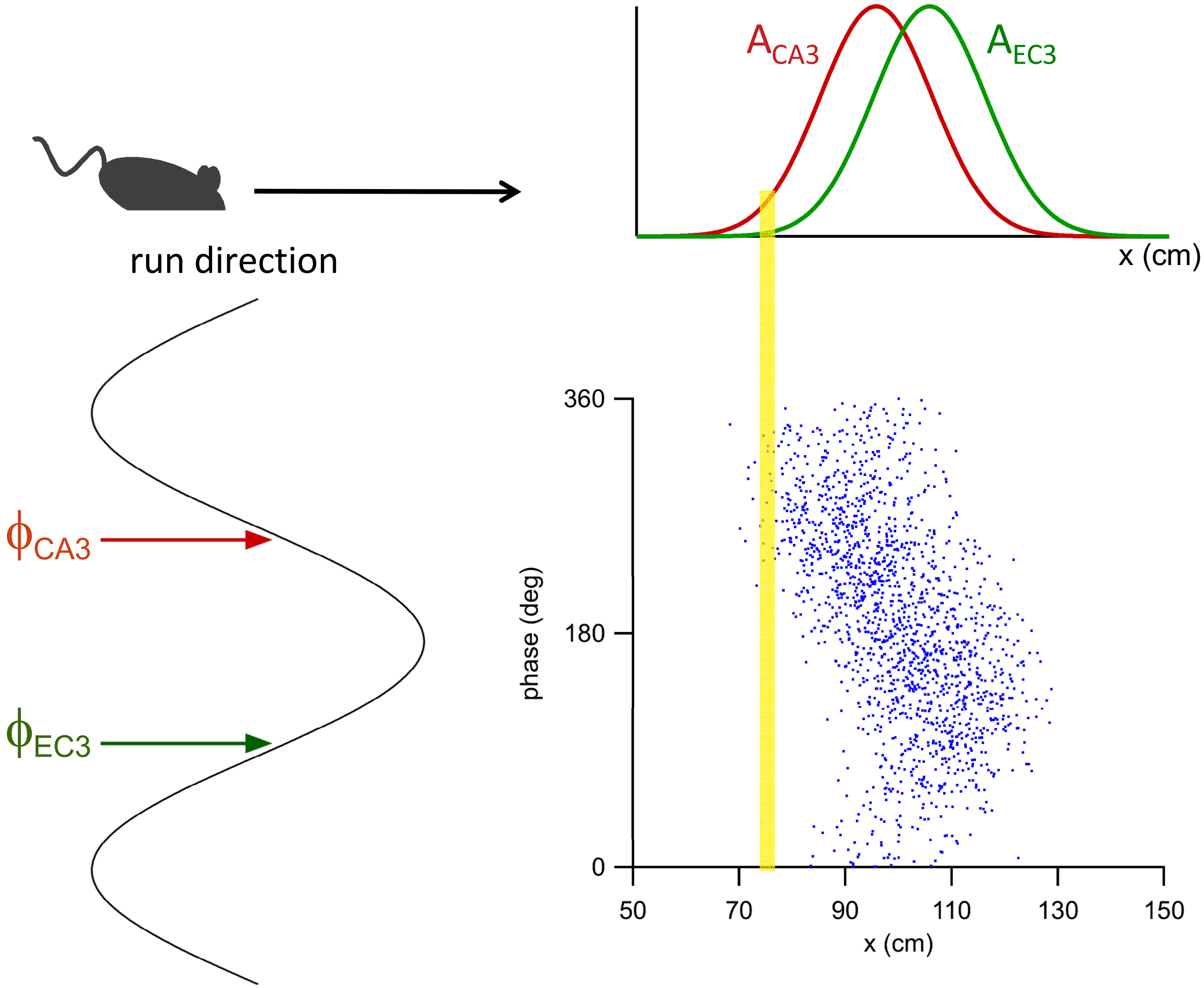


CA1 model spiking when driven only by EC3 input



PARAMETERS: ϕ_1 = 260 deg, ϕ_2 = 100 deg, x_1 = 90 cm, x_2 = 110 cm, $\sigma_1 = \sigma_2$ = 21.2 cm

Chance FS (2012) J. Neurosci. 32: 16693



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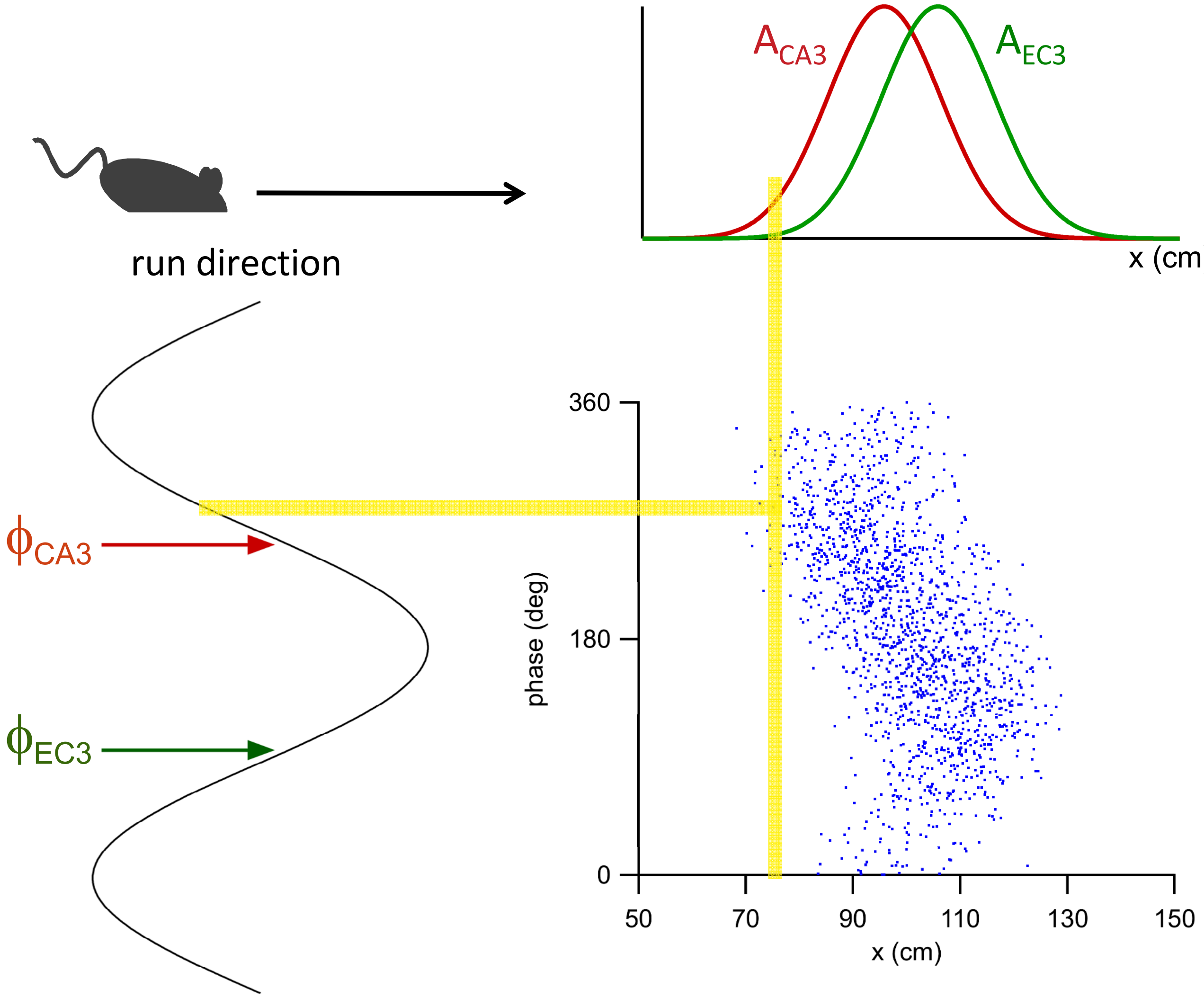

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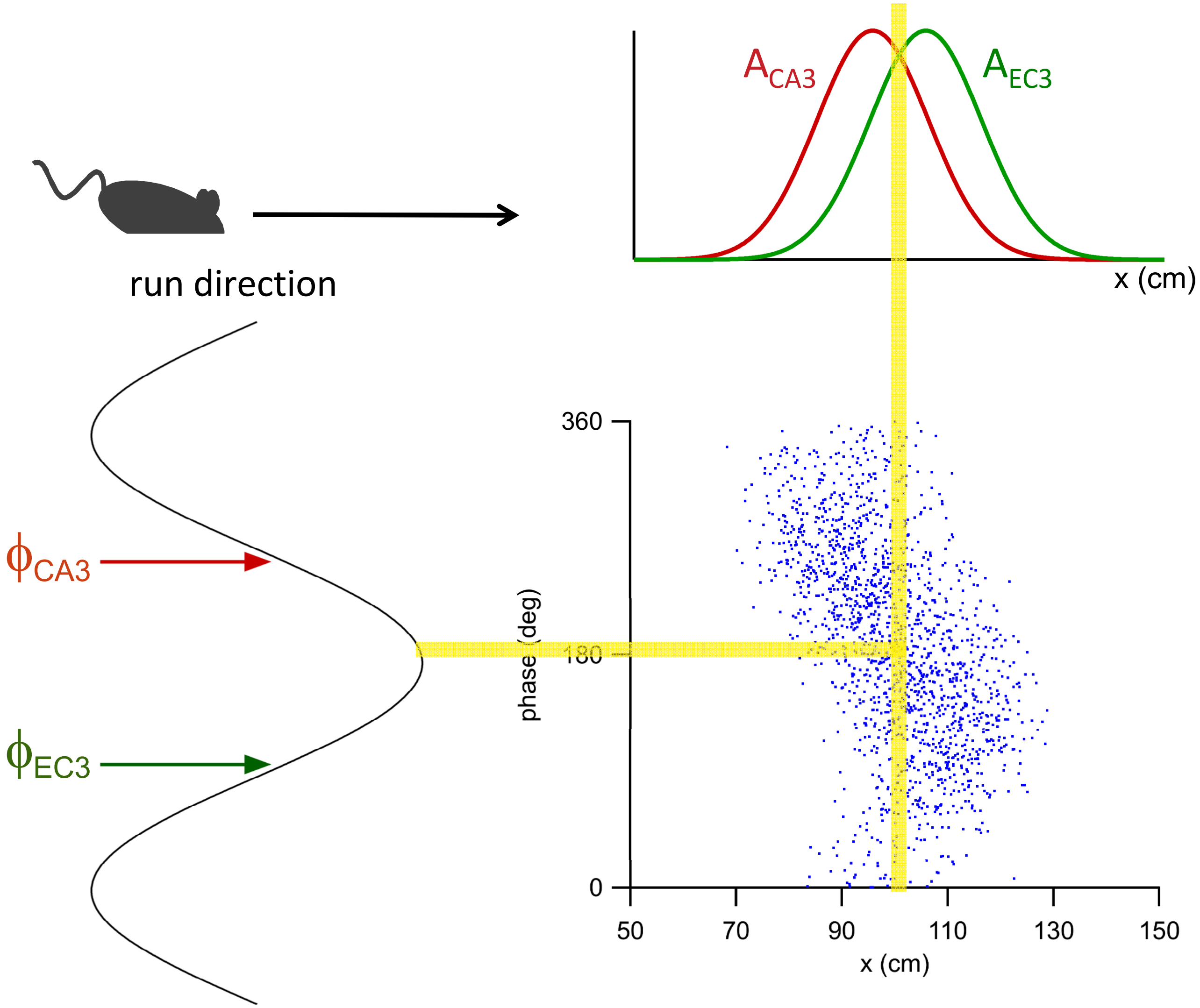

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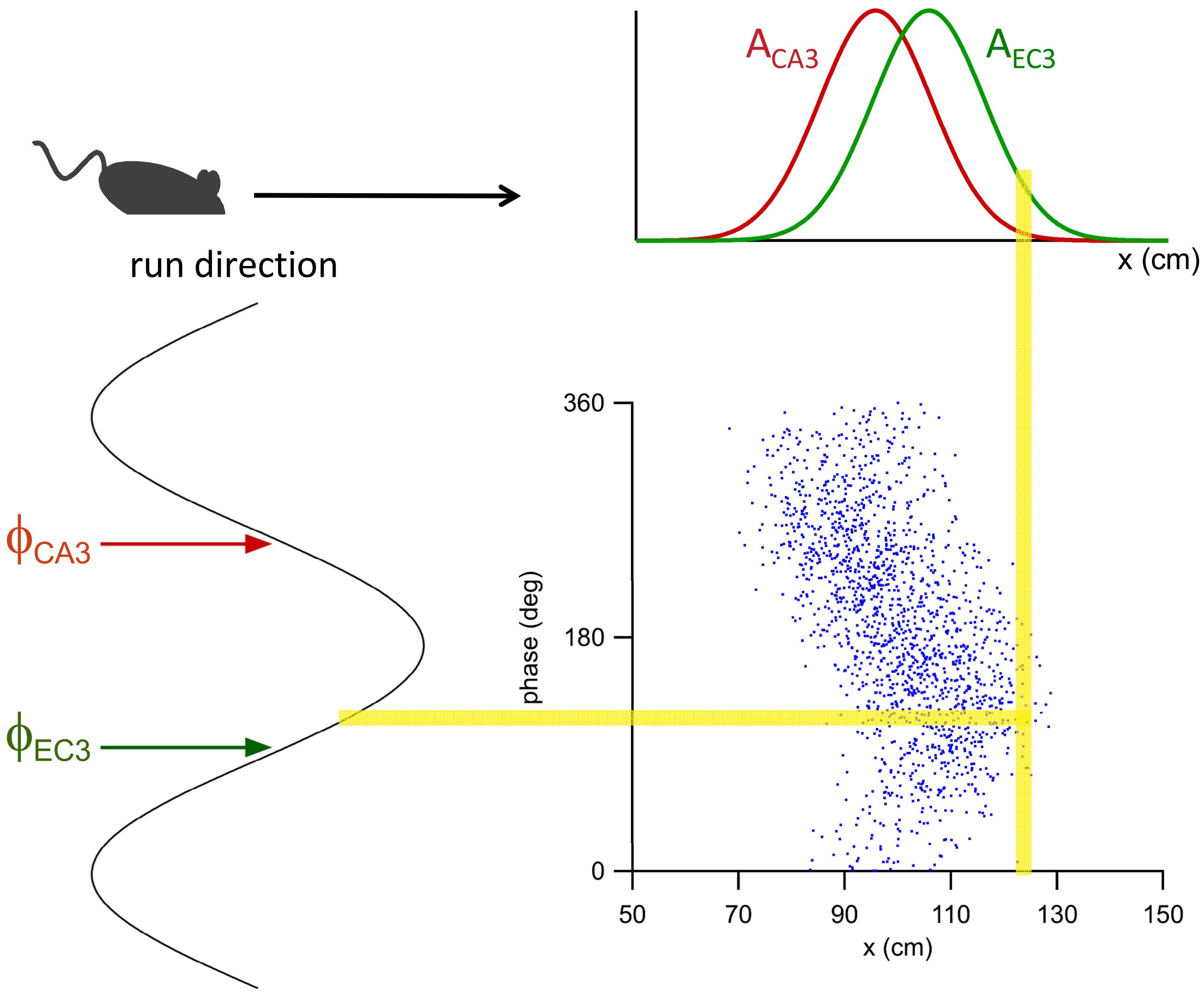

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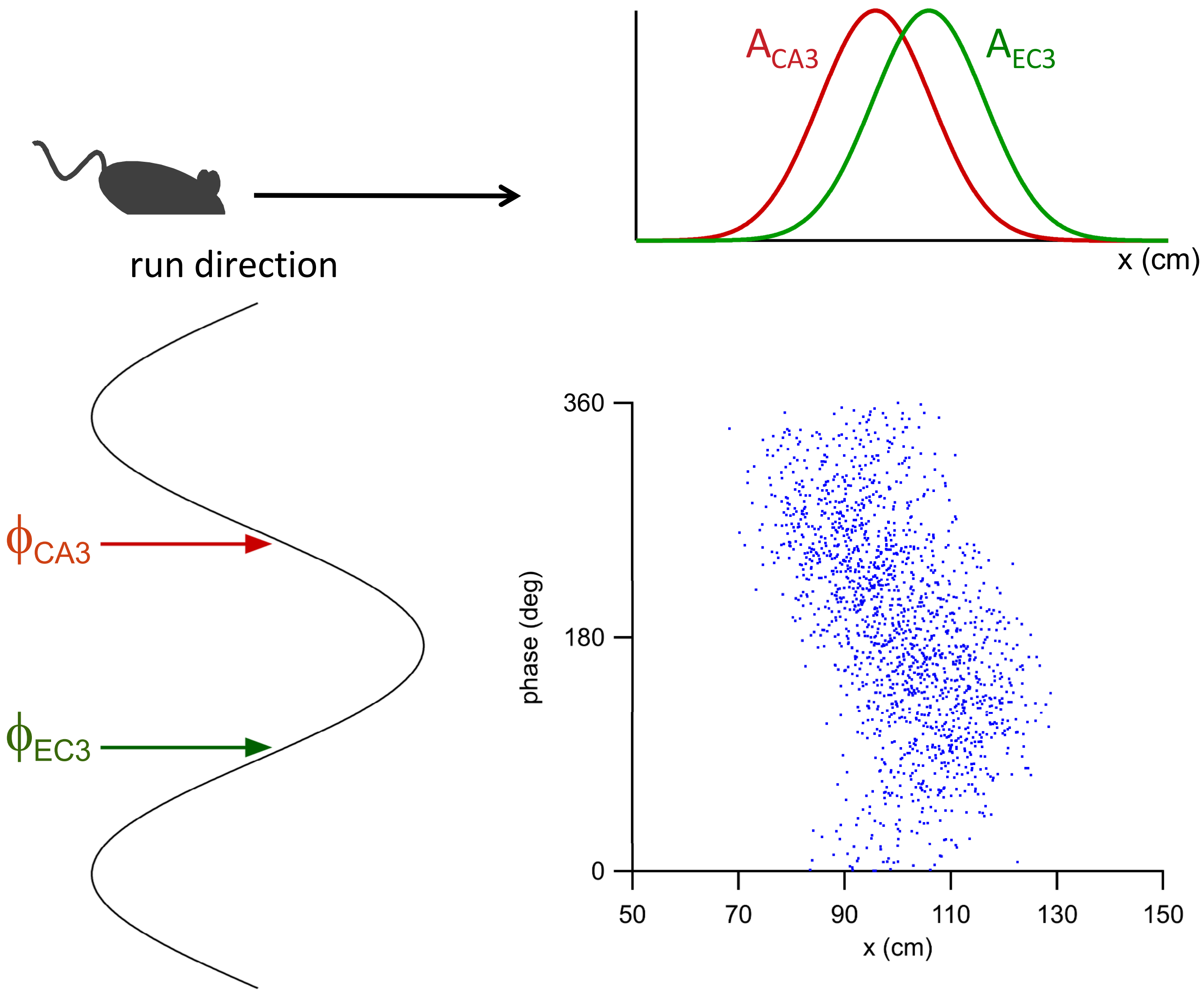

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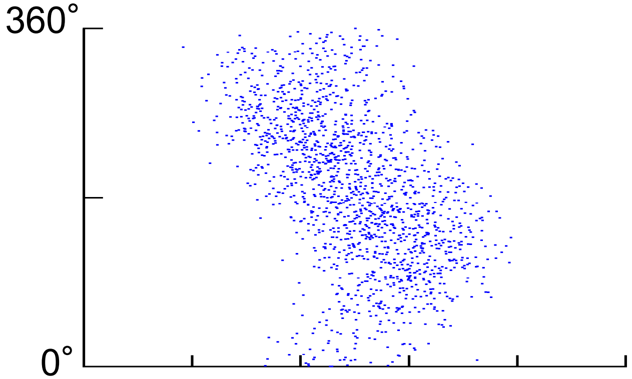
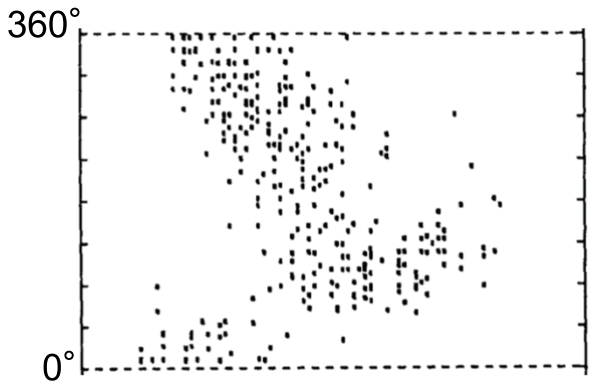
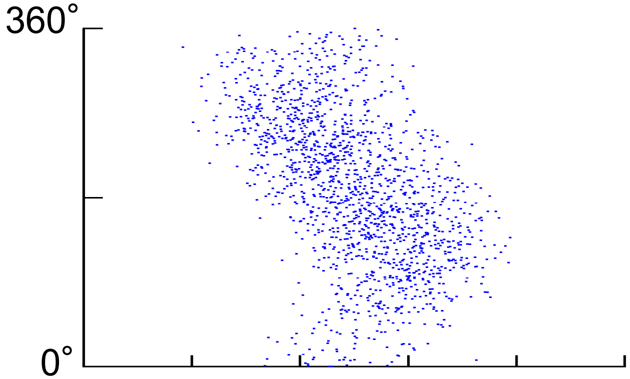
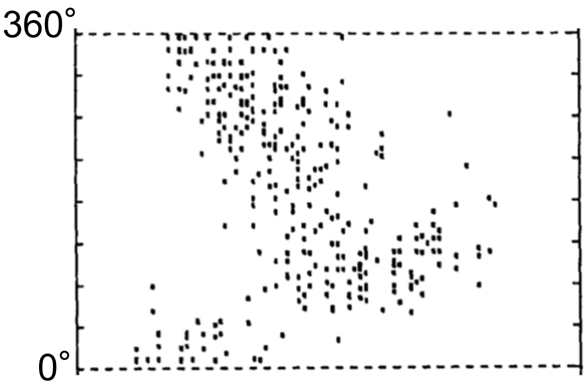
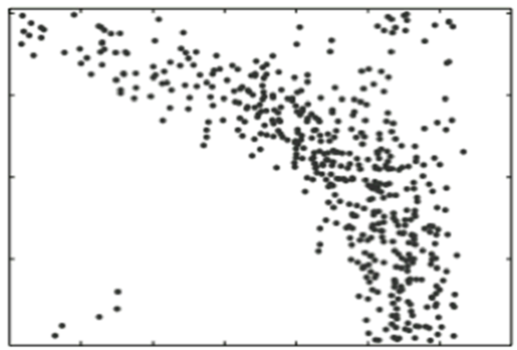


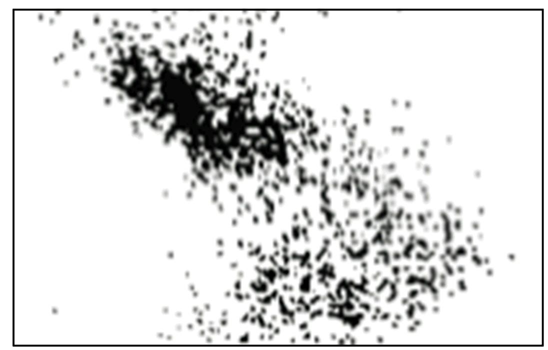


from O'Keefe & Recce (1993)







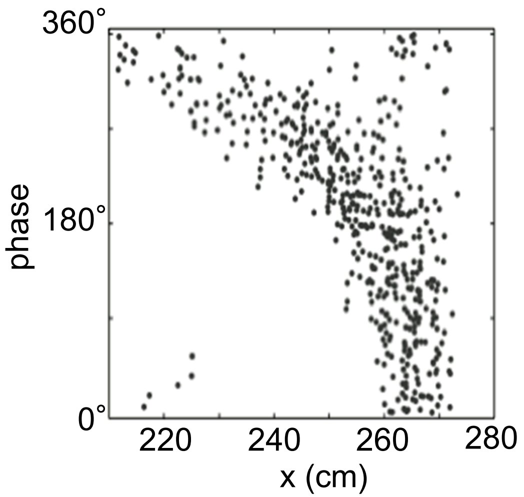


from O'Keefe & Recce (1993)

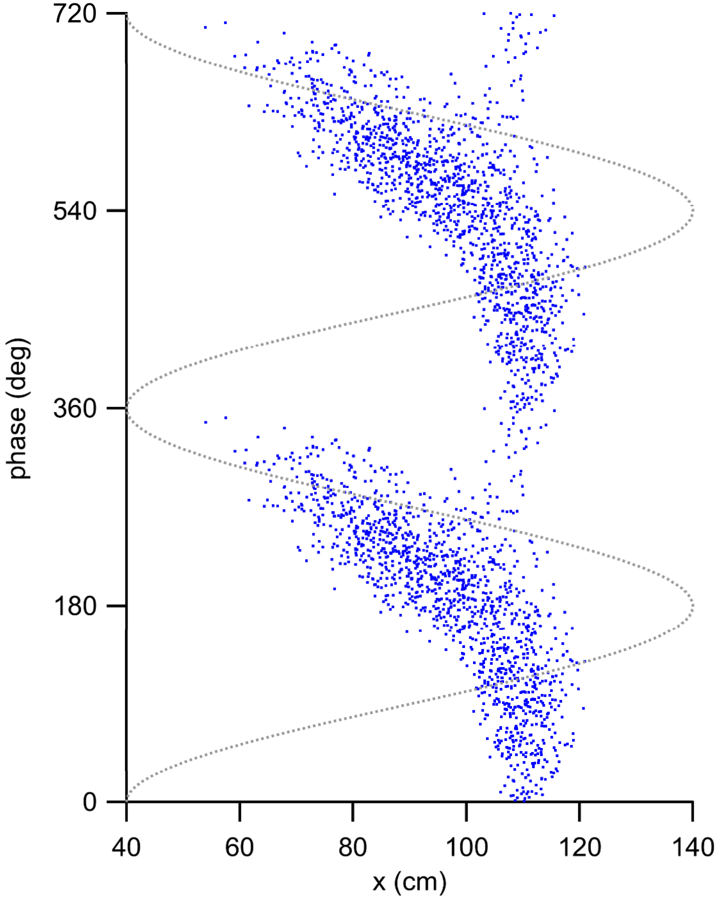
from Mehta et al (2002)

from Skaggs et al (1996)

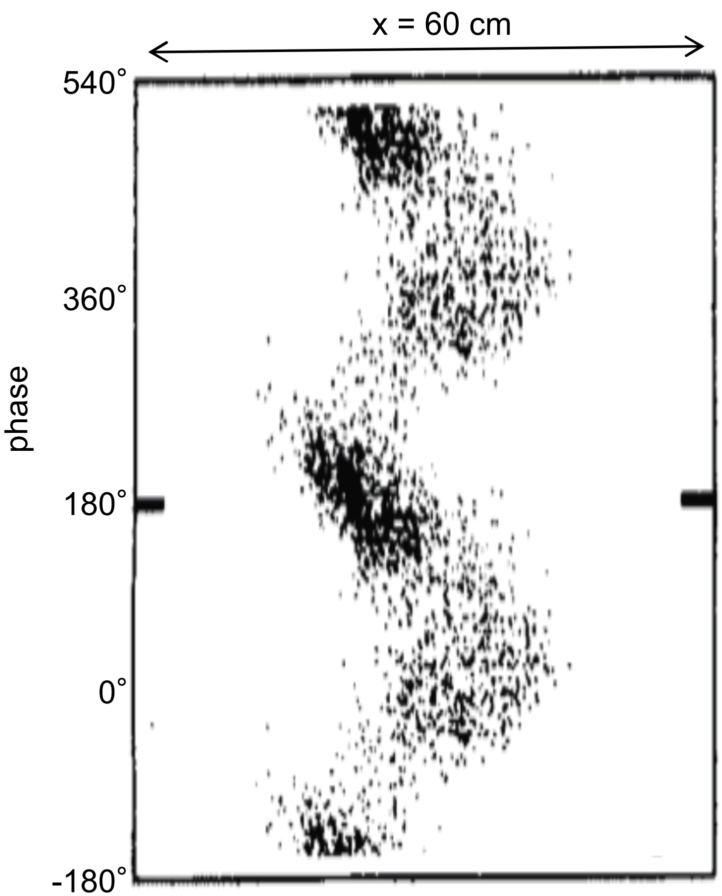
weak EC3 input / strong CA3 input



from Mehta et al (2002)

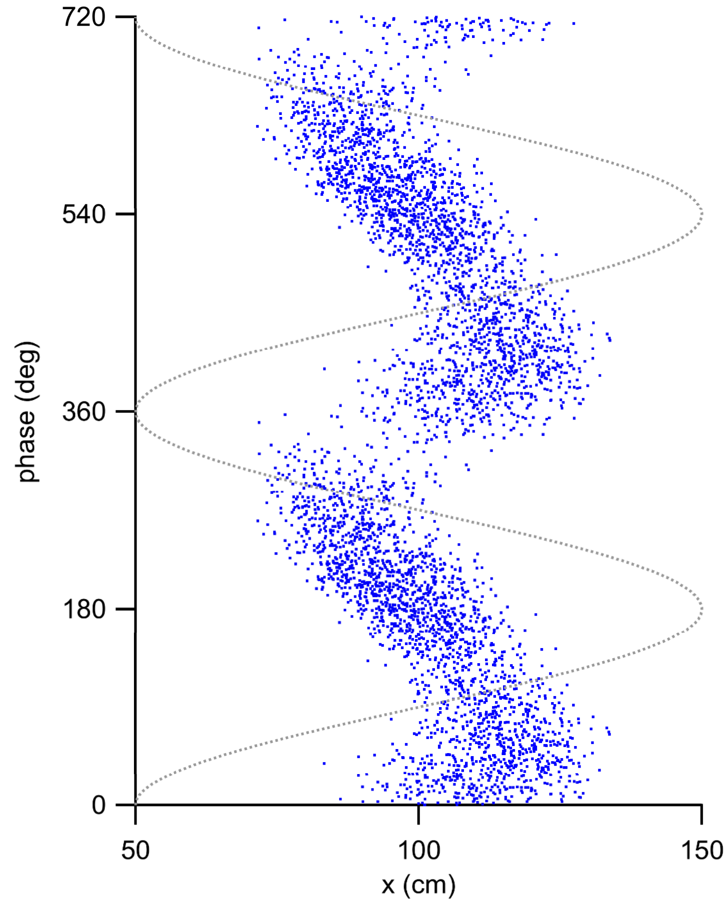


PARAMETERS: ϕ_1 = 230 deg, ϕ_2 = 0 deg, x_1 = 95 cm, x_2 = 110 cm, σ_1 = 35.36 (left), 21.2 (right), σ_2 = 7.2 cm, k = 2.7 deg/cm, $b_1 = b_2 = 1$, x_0 = 80 cm, EC3/CA3 amplitude ratio = 0.75



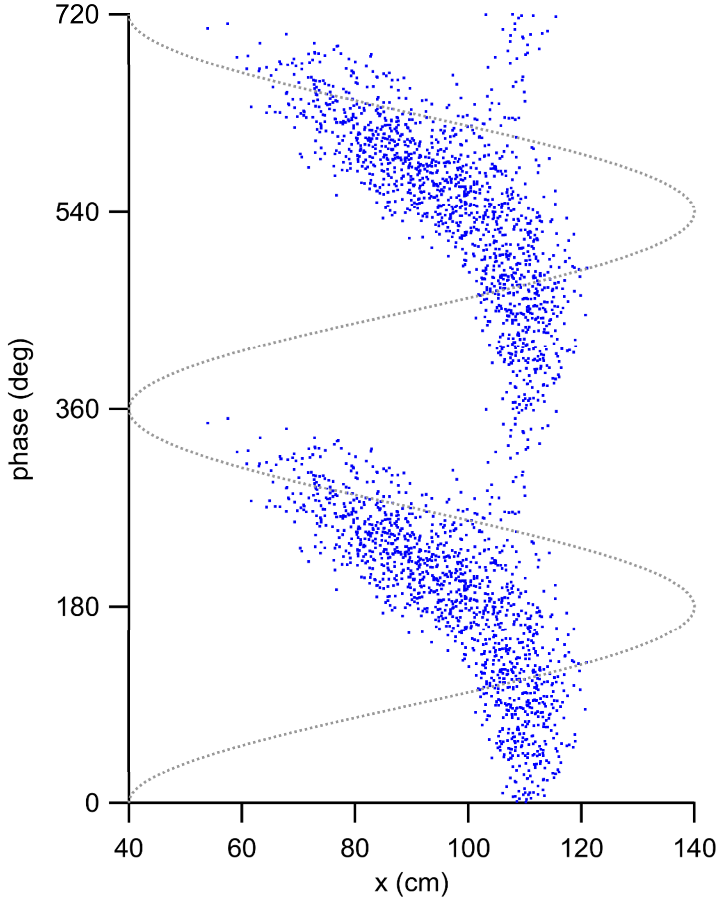
from Skaggs et al (1996)

stronger EC3 input / weaker CA3 input

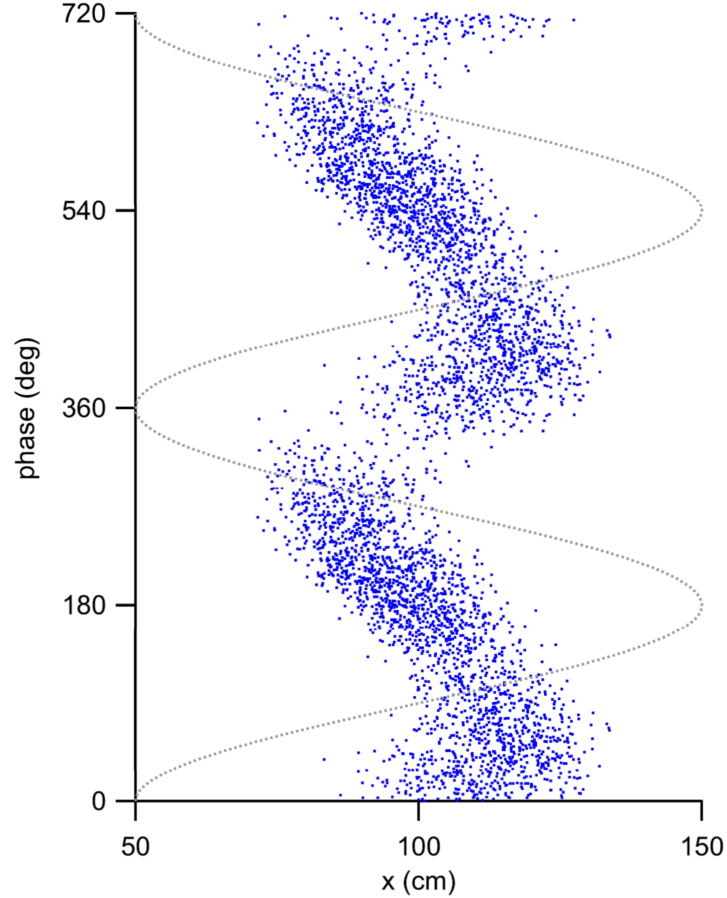


PARAMETERS: ϕ_1 = 230 deg, ϕ_2 = 0 deg, x_1 = 95 cm, x_2 = 110 cm,
$\sigma_1 = \sigma_2$ = 21.2 cm, k = 2.7 deg/cm, $b_1 = b_2$ = 0.5, x_0 = 80 cm.
EC3/CA3 amplitude ratio = 0.8

weak EC3 input / strong CA3 input



stronger EC3 input / weaker CA3 input



Chance FS (2012) J. Neurosci. 32: 16693

Model of CA1 pyramidal cell activity

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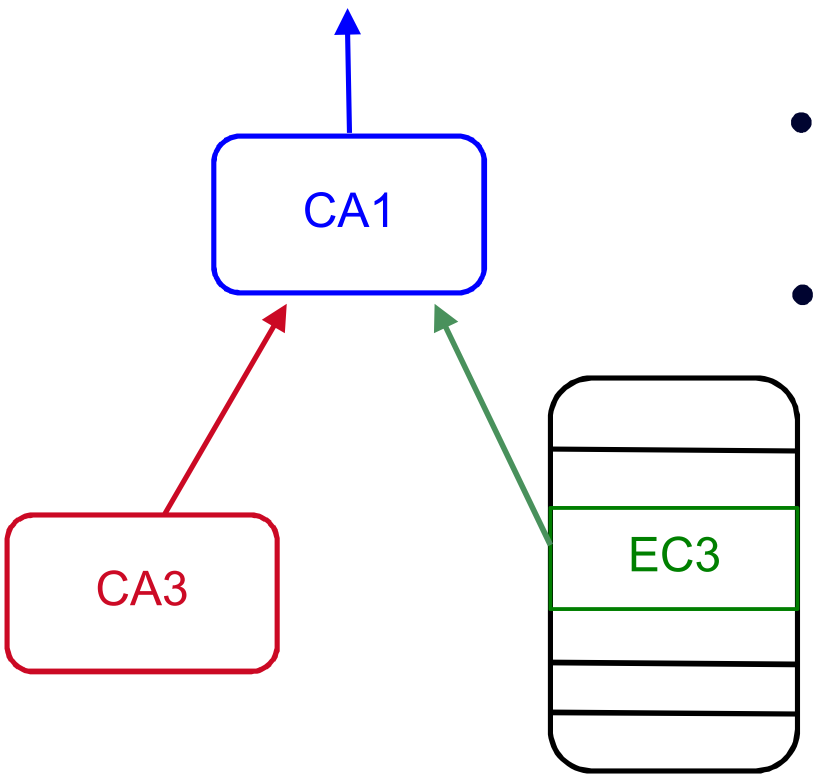
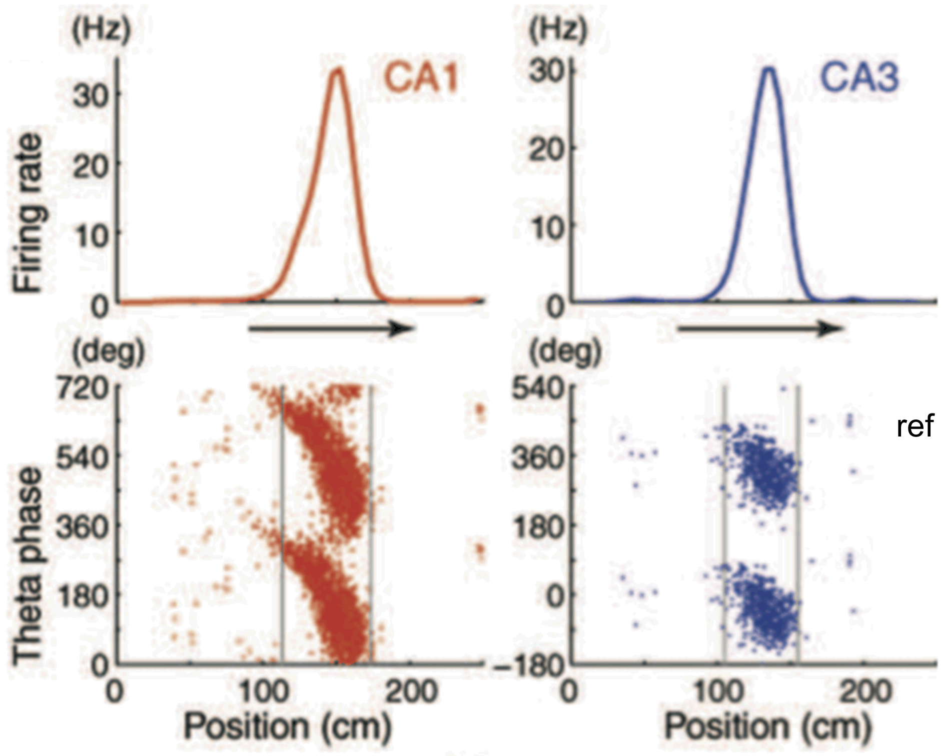


- CA1 place cells are driven by two input components
- input components are distinguished by spatial and theta-phase preferences
- phase precession arises through interaction between two input components
- model phase precession matches experimentally-observed phase precession in CA1

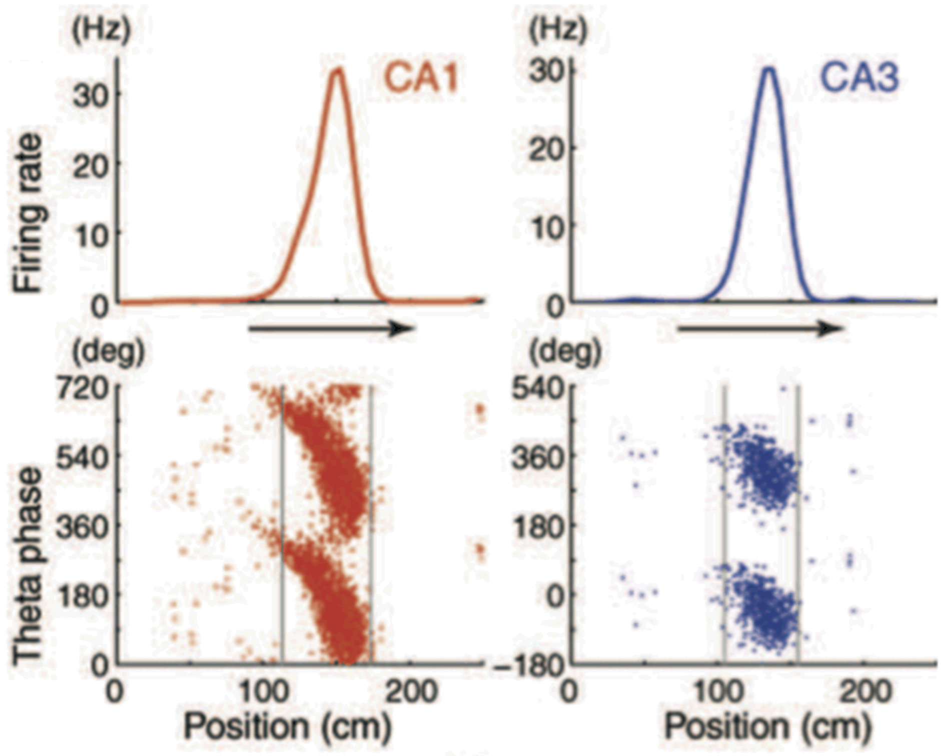
Range of phase precession is less in CA3 compared to CA1

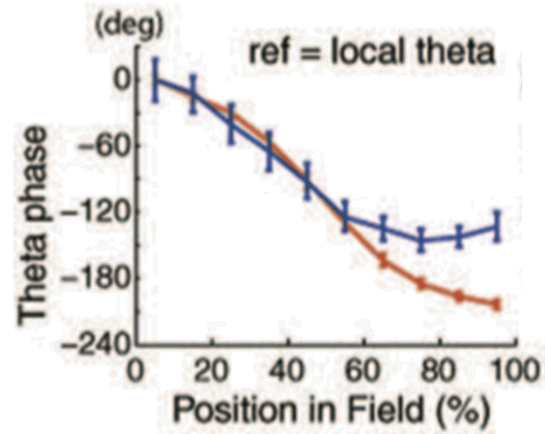


ref = local theta

from Mizuseki et al (2012) Hippocampus 22: 1659

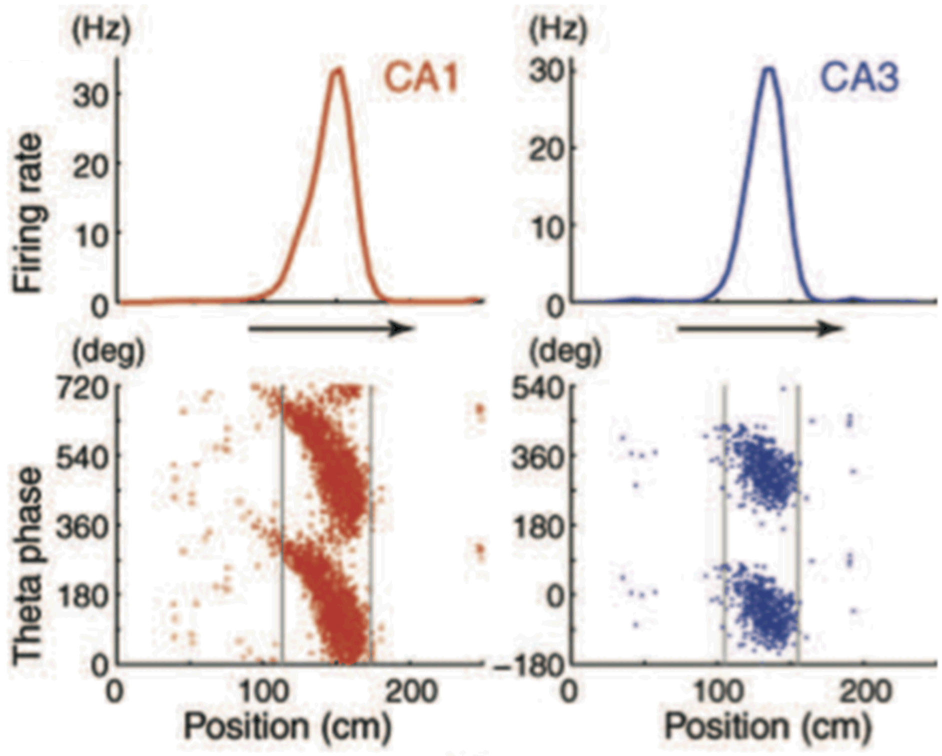
Range of phase precession is less in CA3 compared to CA1

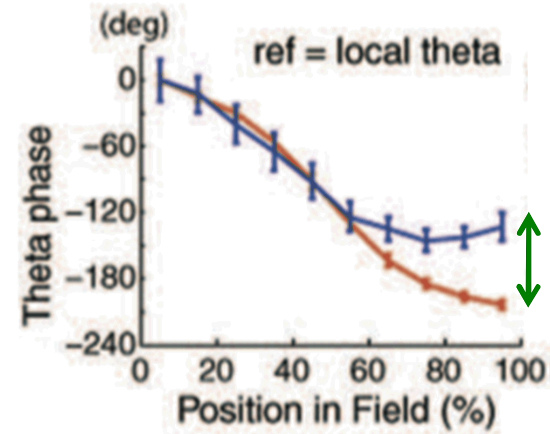




from Mizuseki et al (2012) Hippocampus 22: 1659

Range of phase precession is less in CA3 compared to CA1

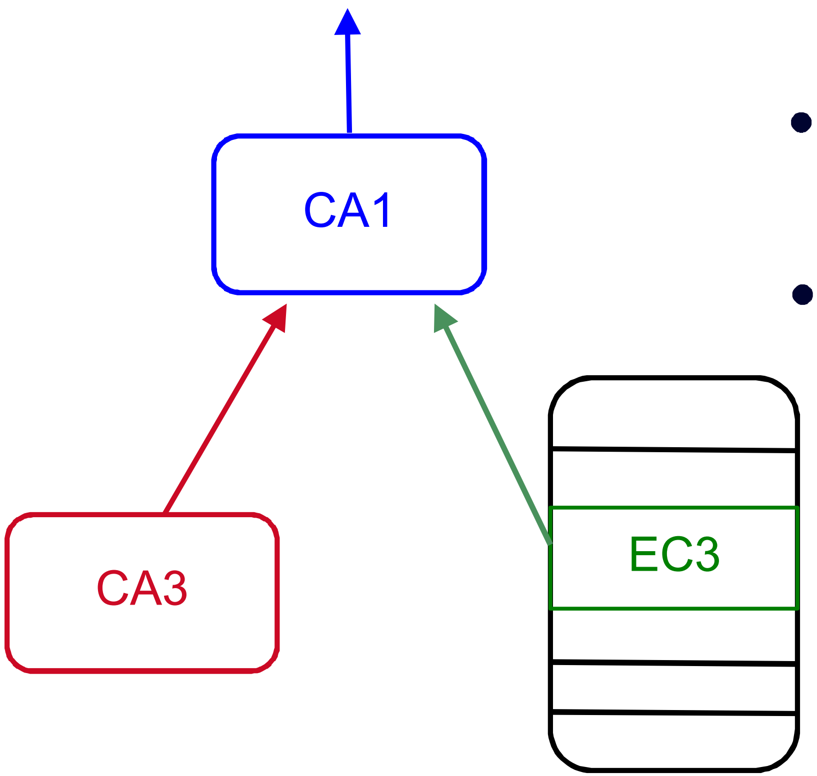




extra component of phase precession from EC3

from Mizuseki et al (2012) Hippocampus 22: 1659

Model of CA1 pyramidal cell activity



- CA1 place cells are driven by two input components
- input components are distinguished by spatial and theta-phase preferences
- phase precession arises through interaction between two input components
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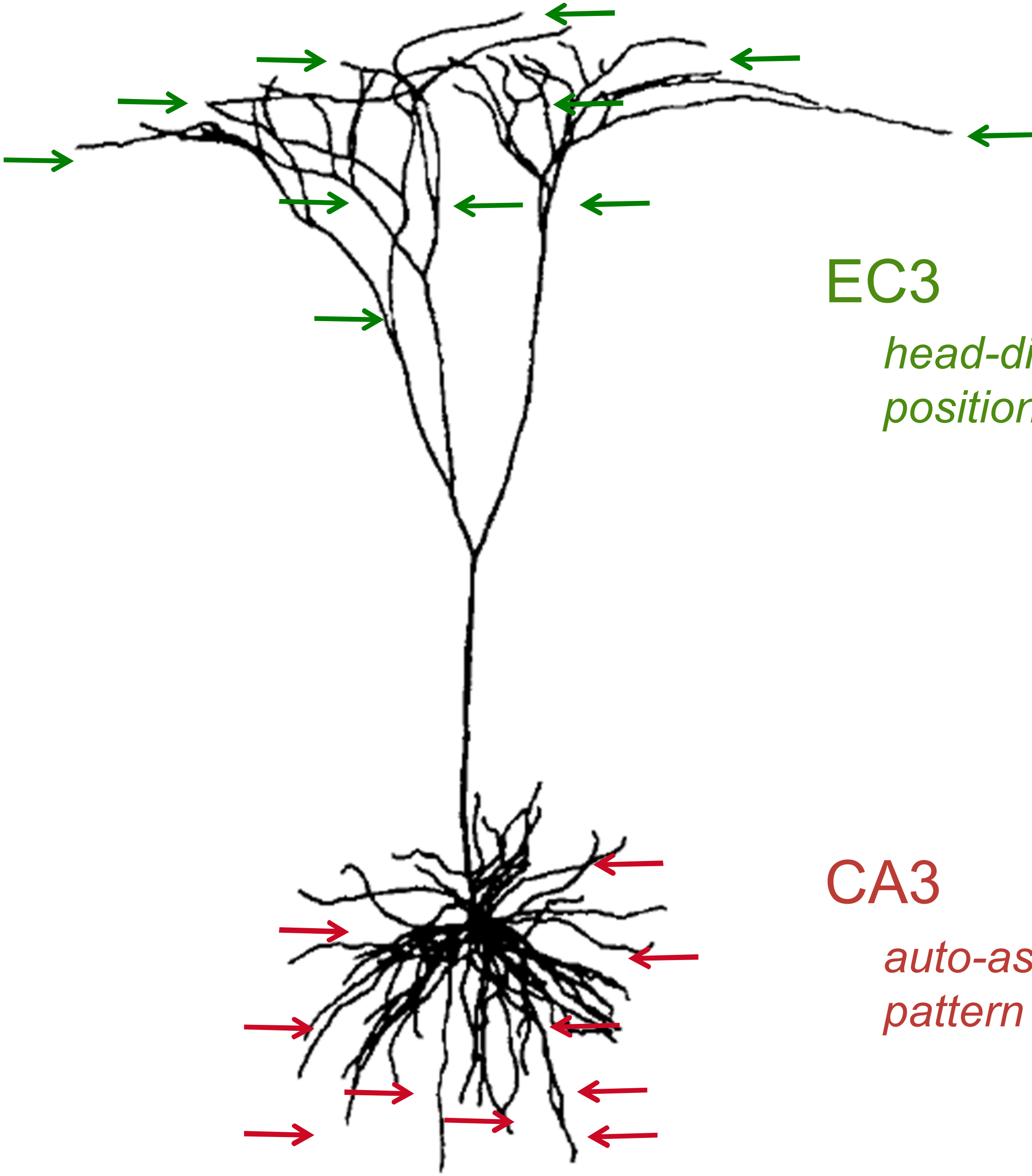
What does this mean about how CA1 neurons represent information?



EC3

head-direction information
position information

CA3

auto-associative function
pattern completion

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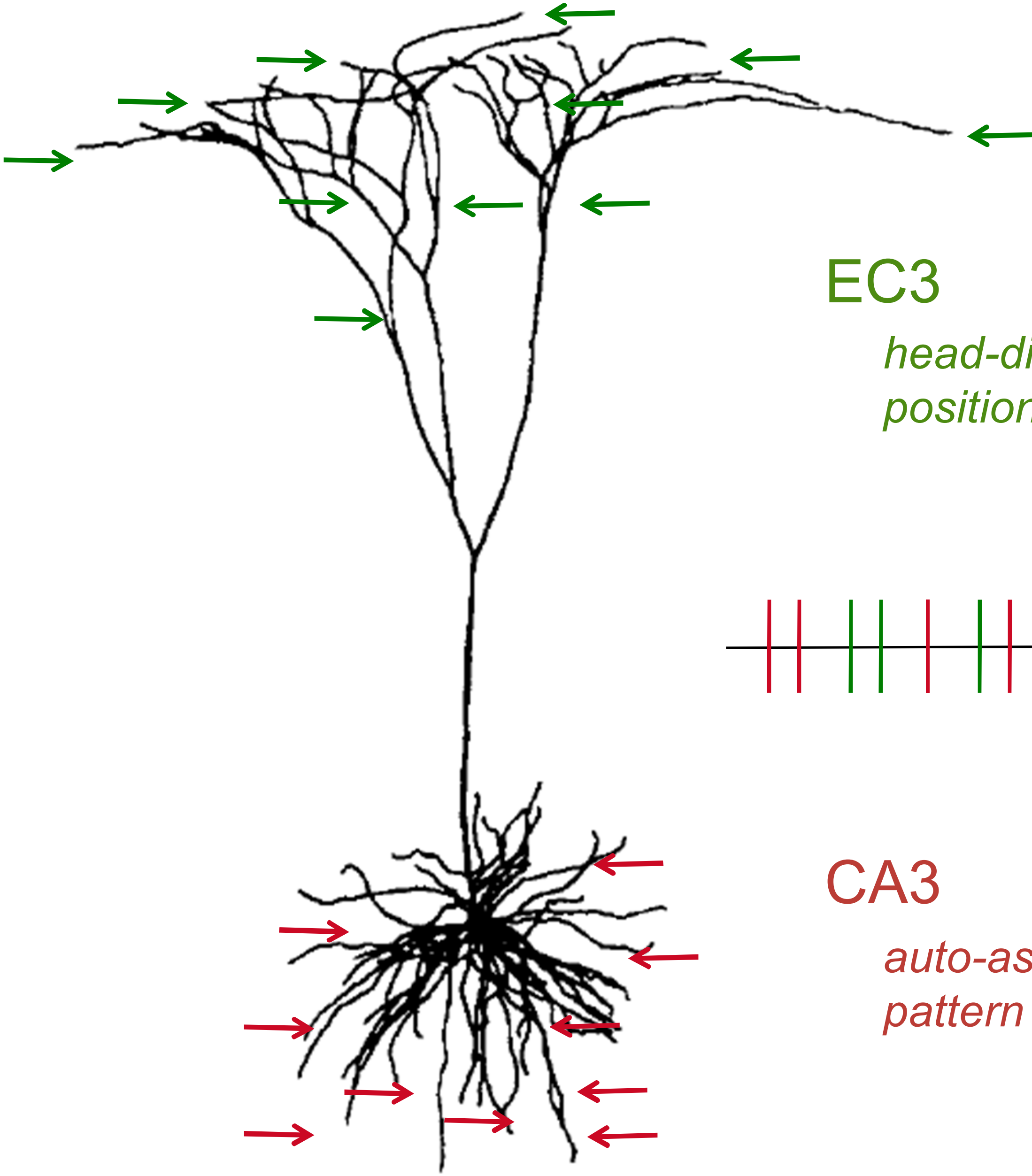
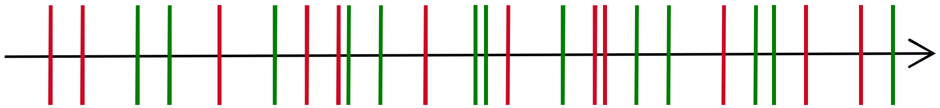


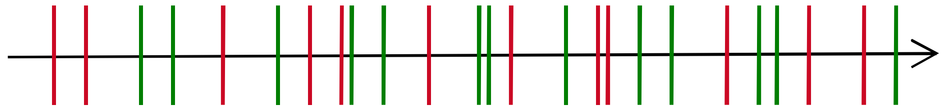
EC3

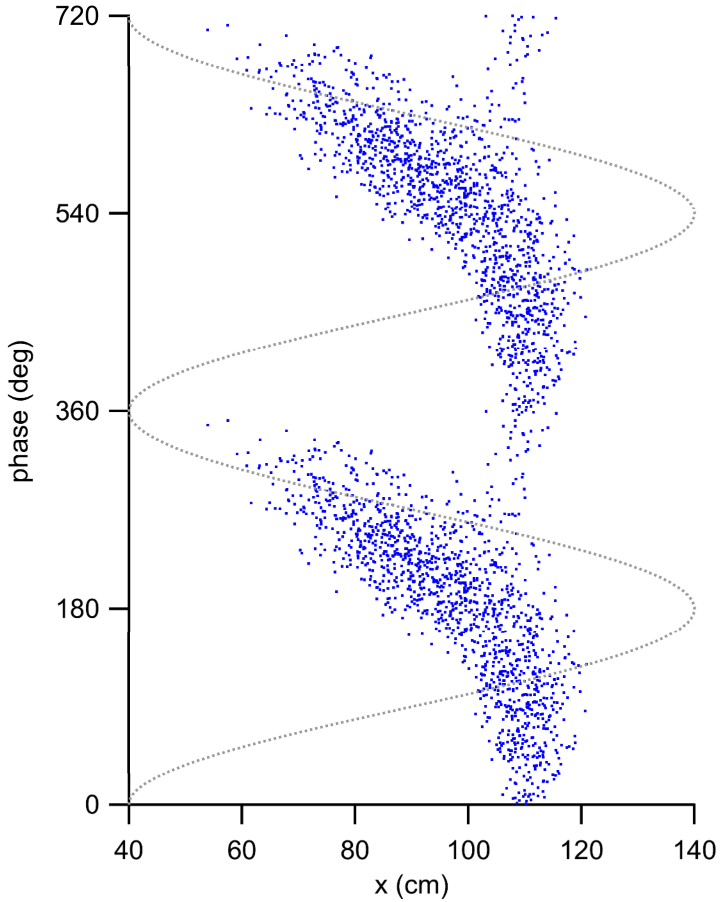
head-direction information
position information

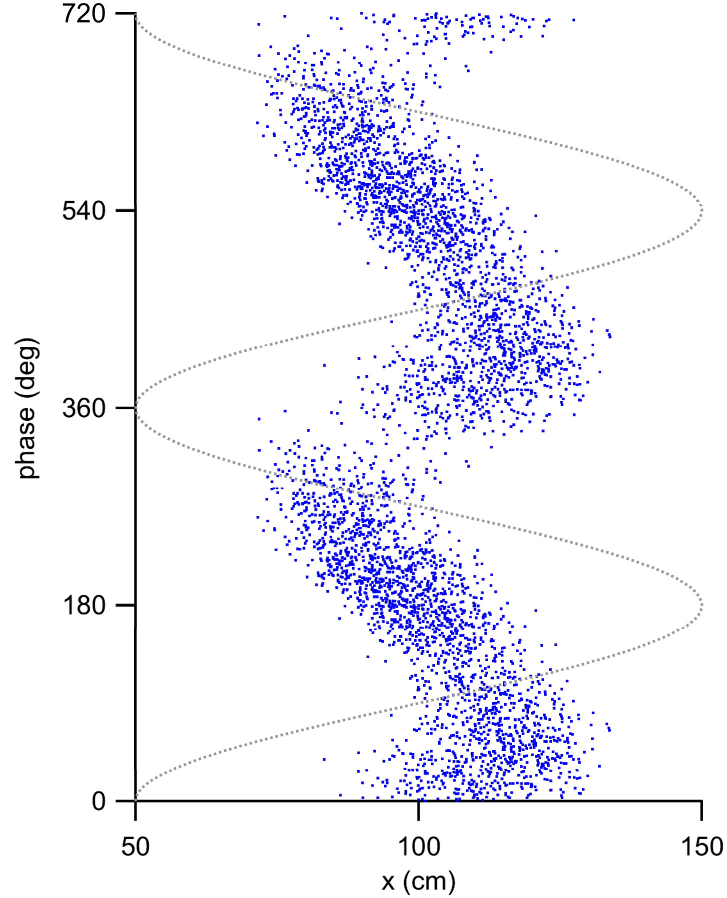


CA3

auto-associative function
pattern completion







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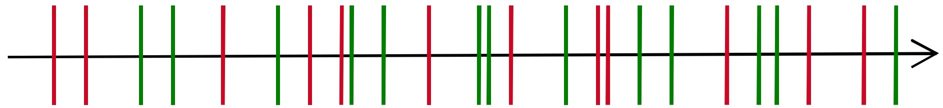

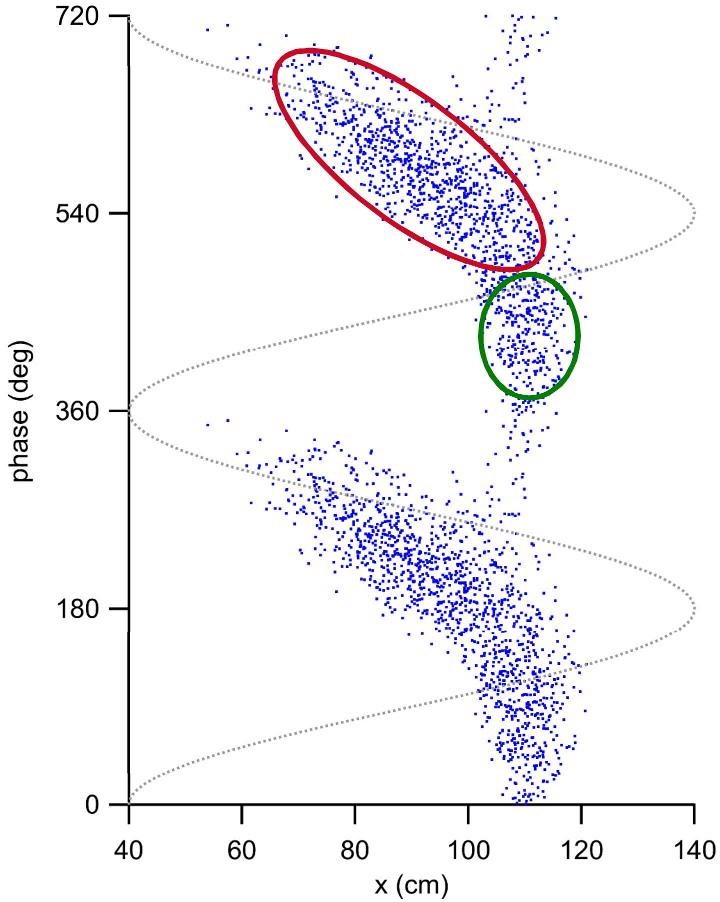

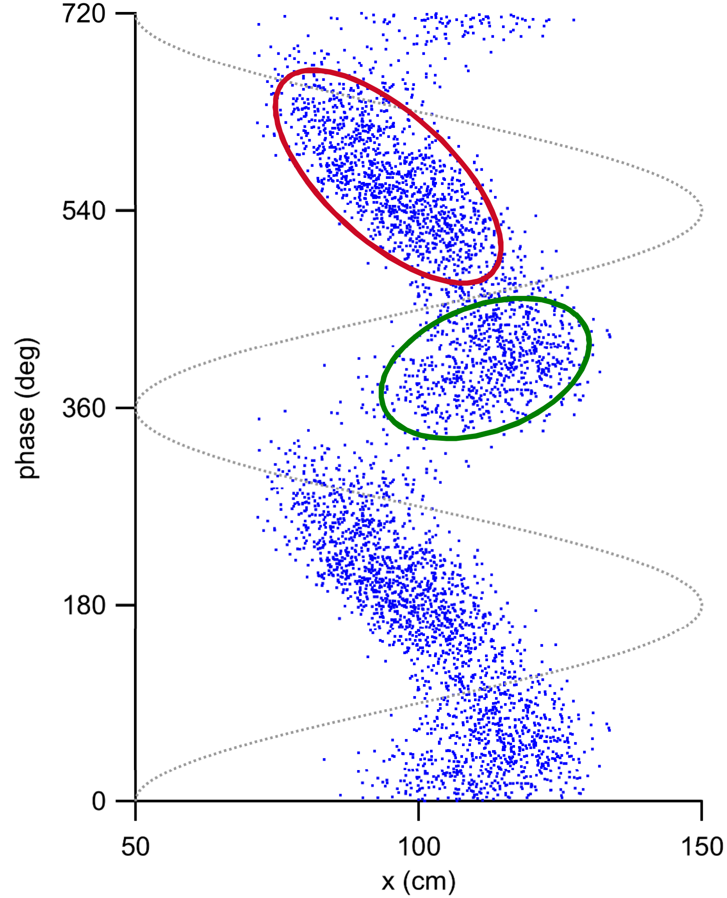

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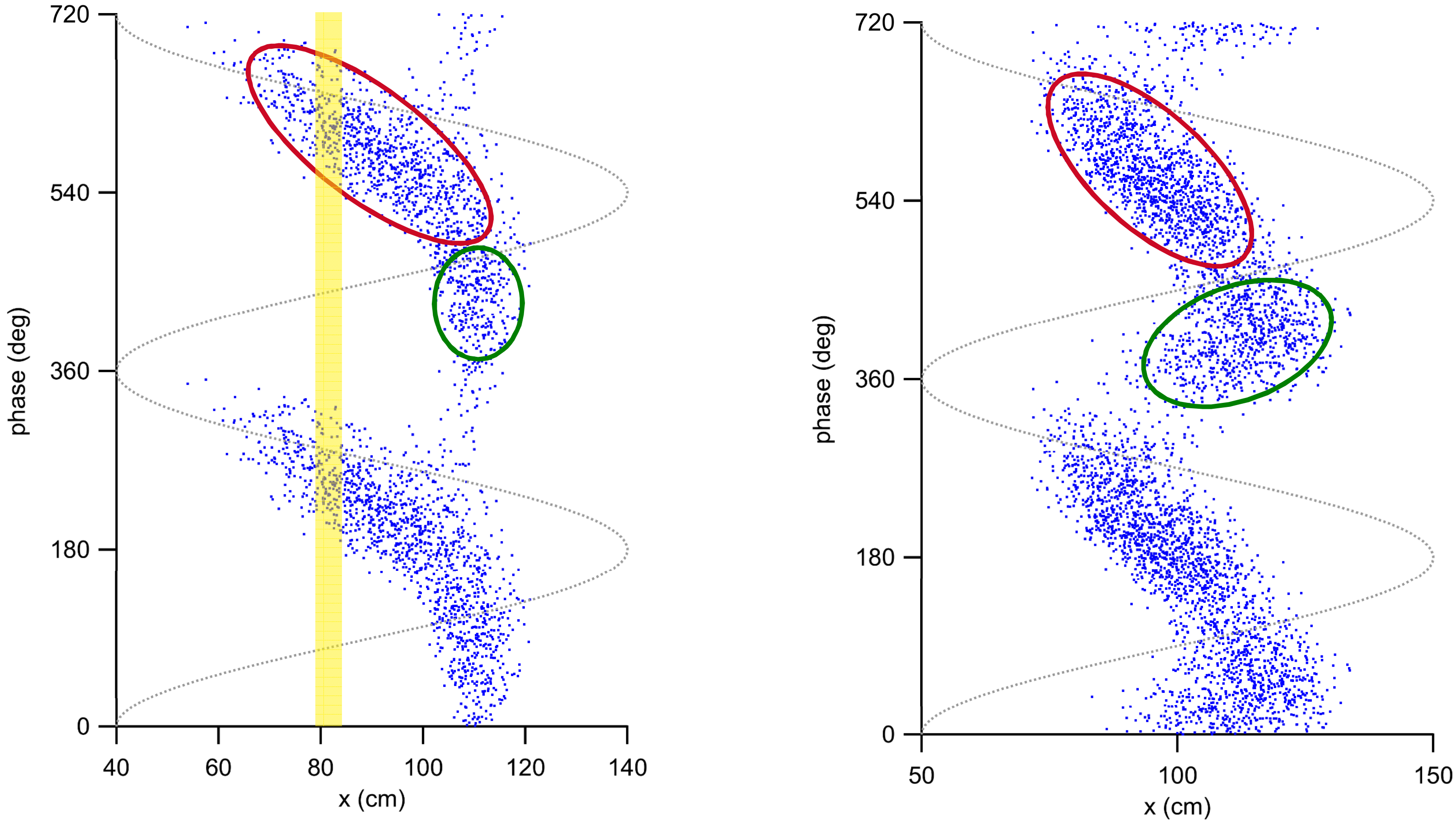

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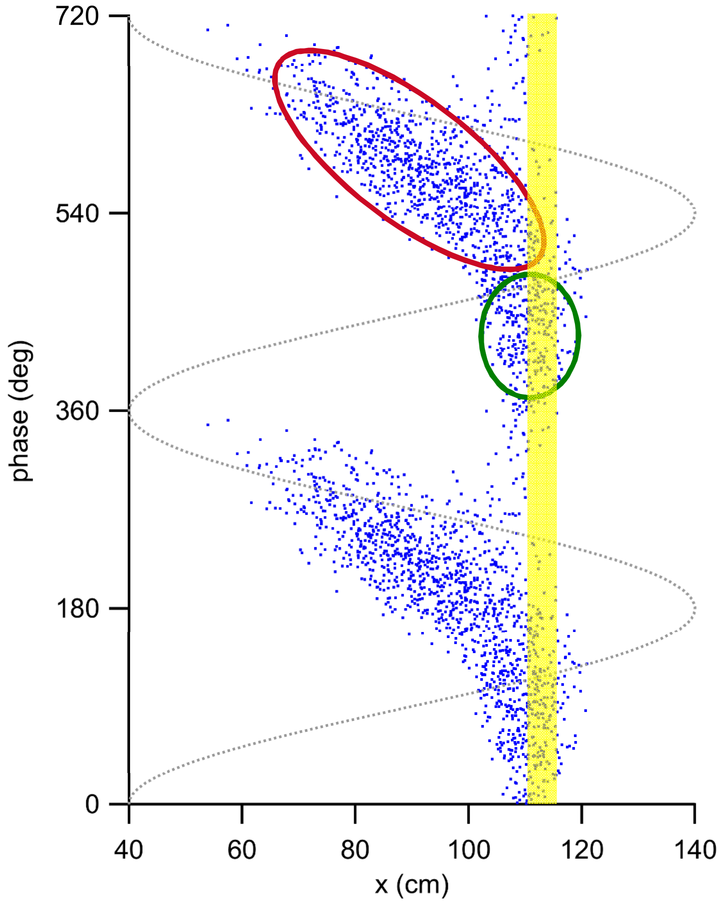

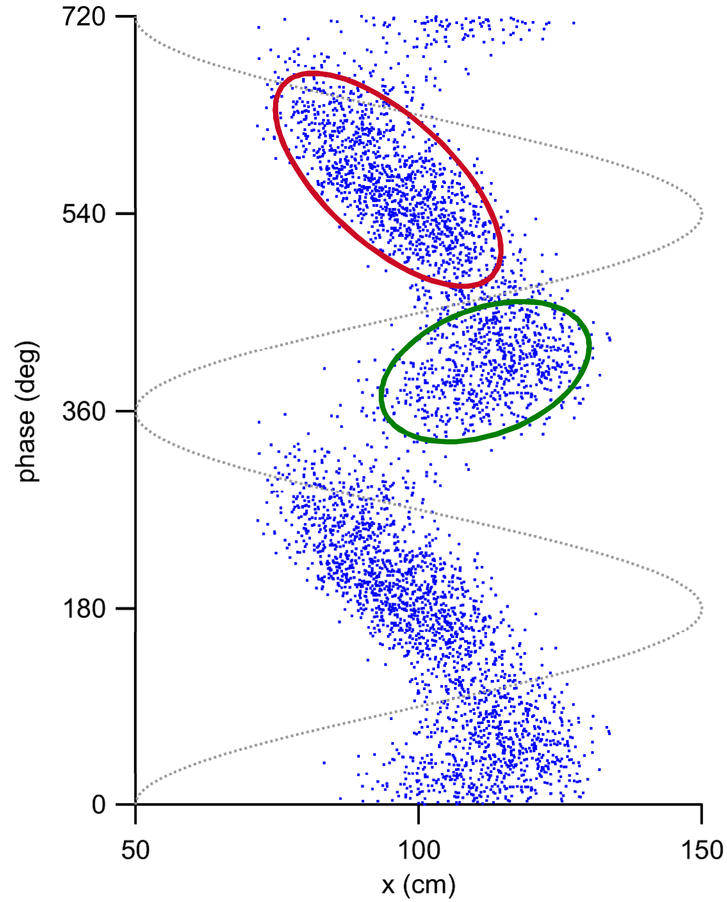

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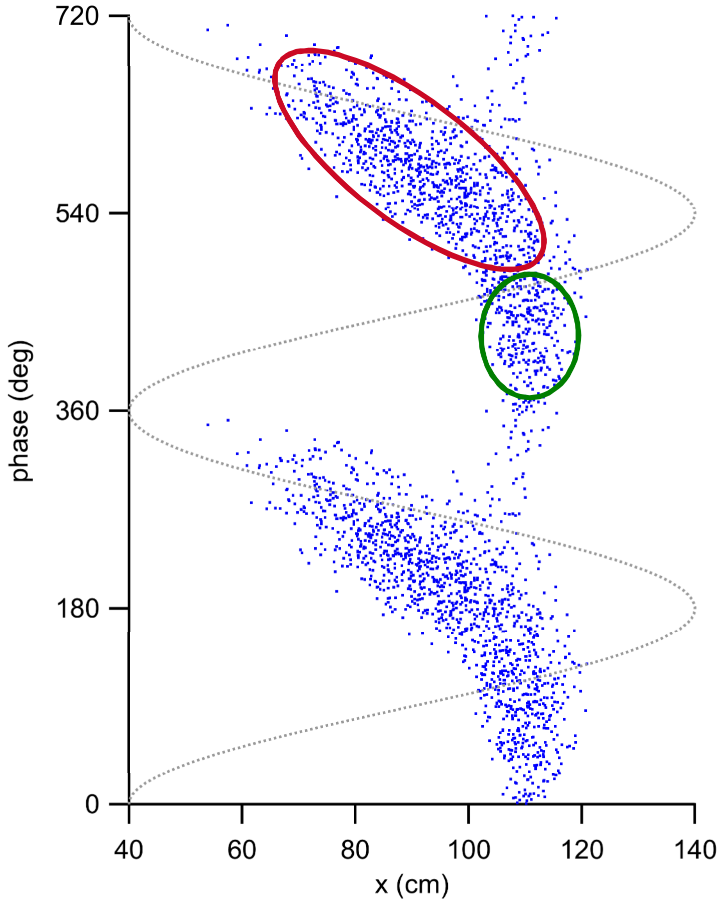

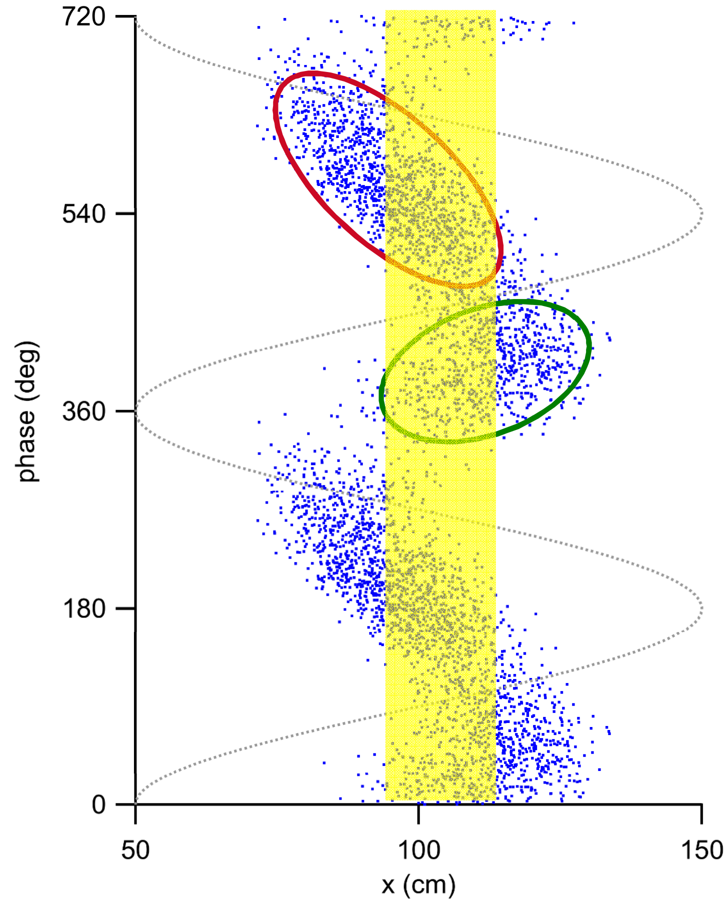

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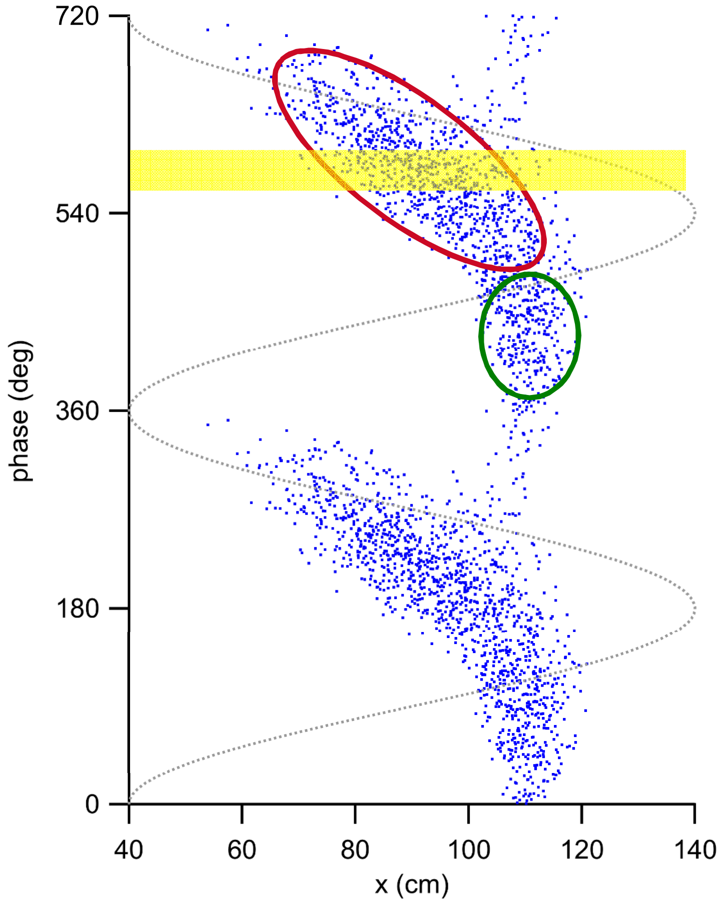

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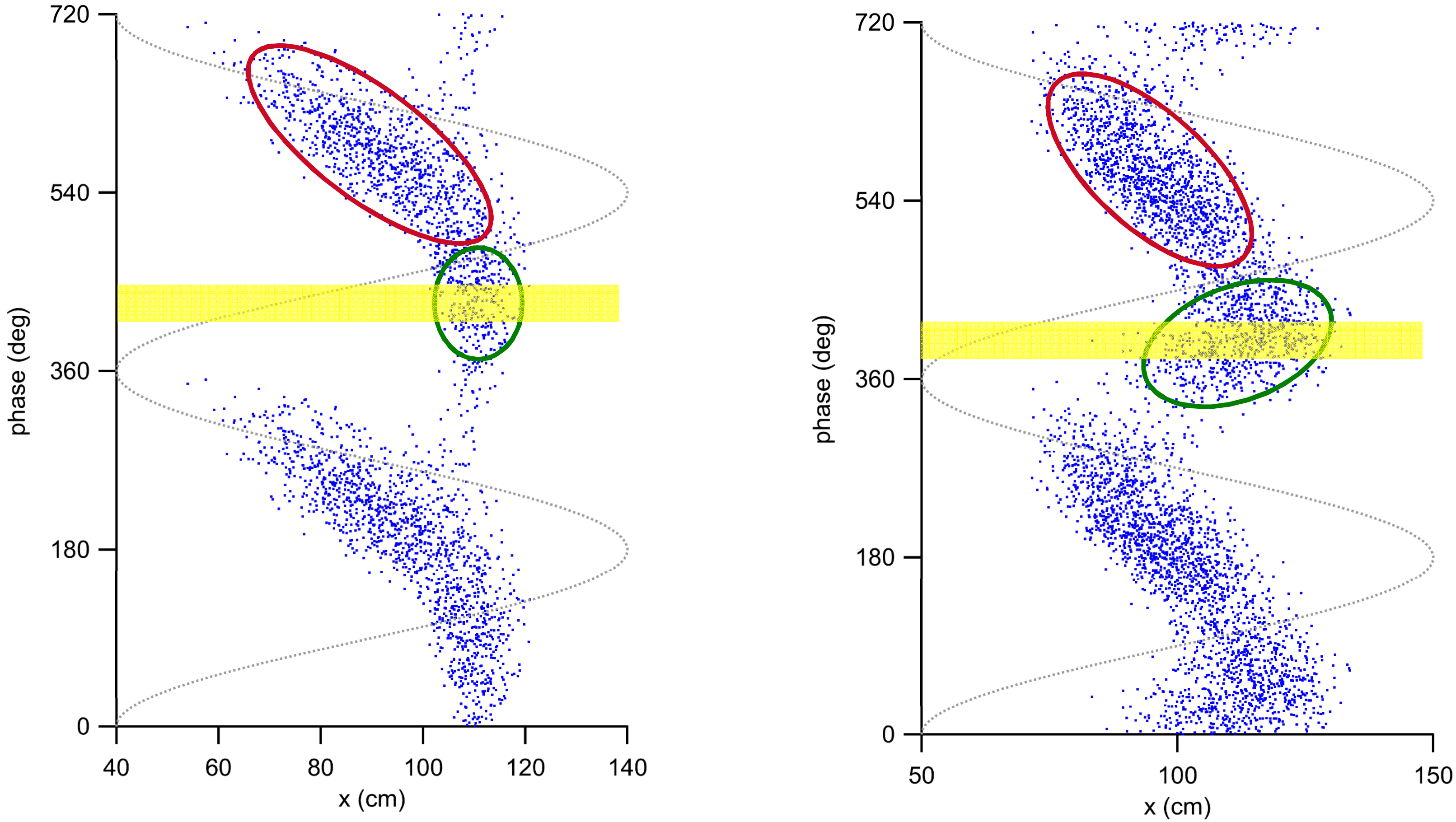

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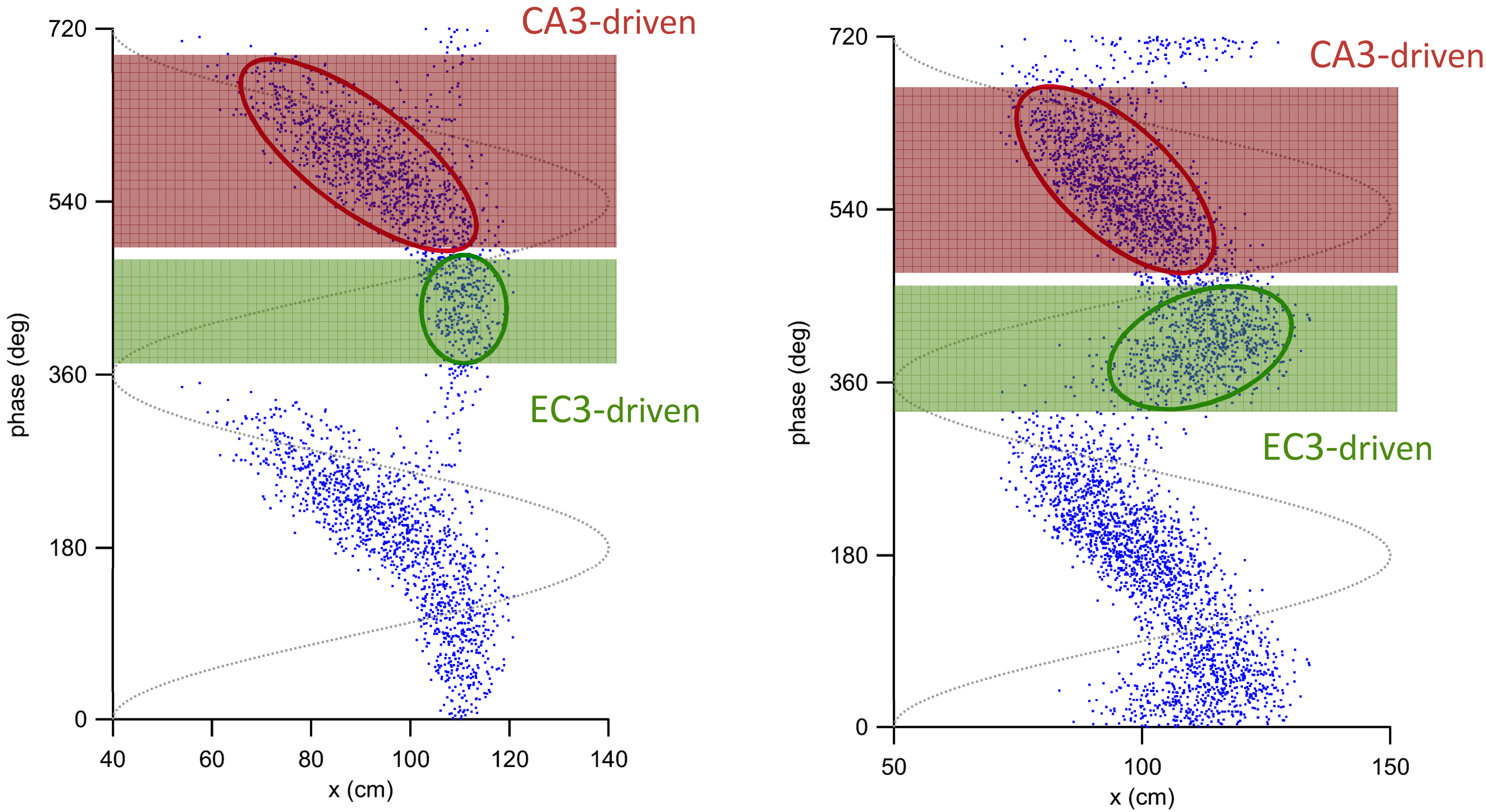
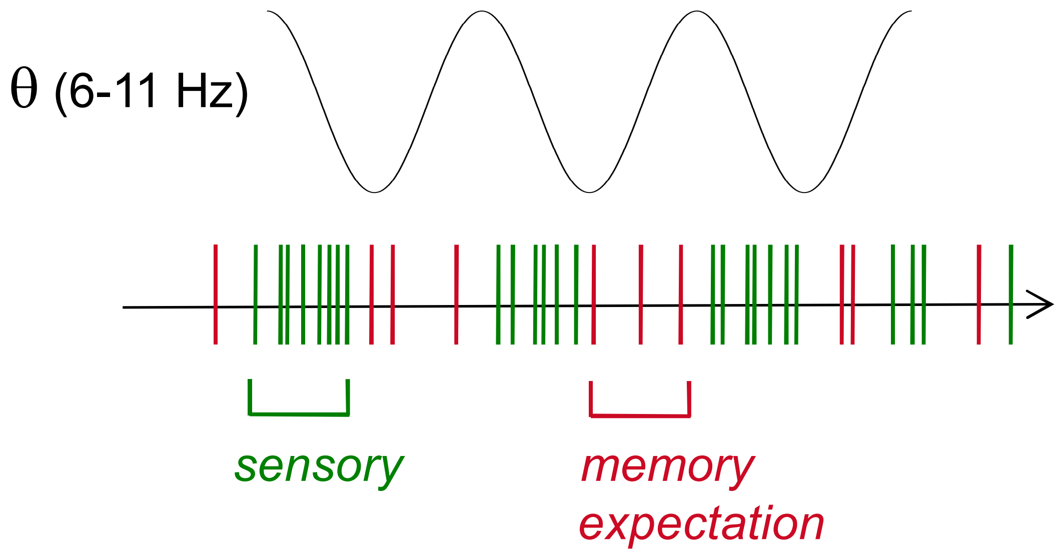
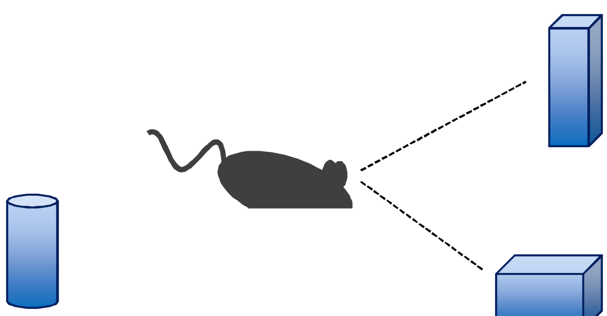


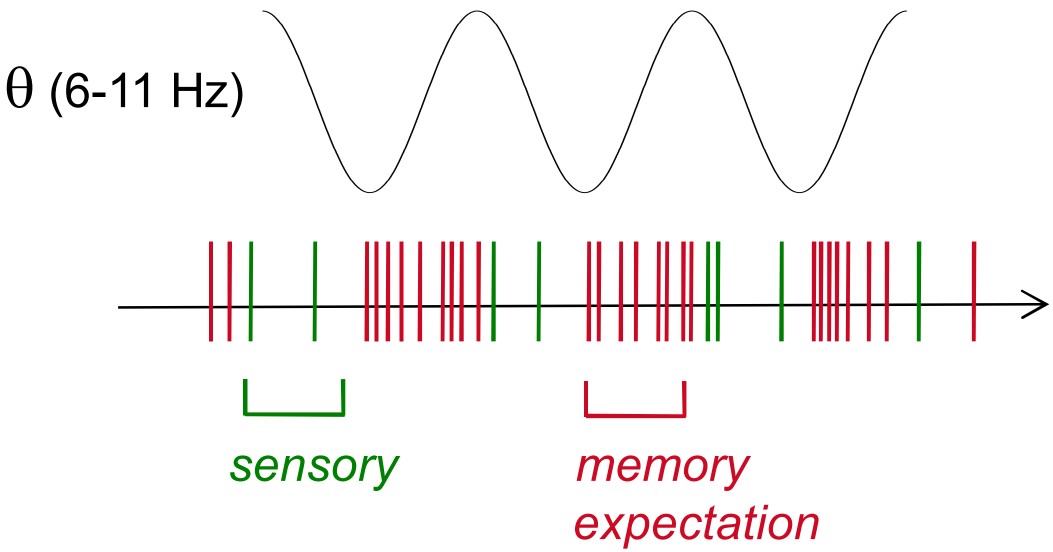
Chance FS (2012) J. Neurosci. 32: 16693

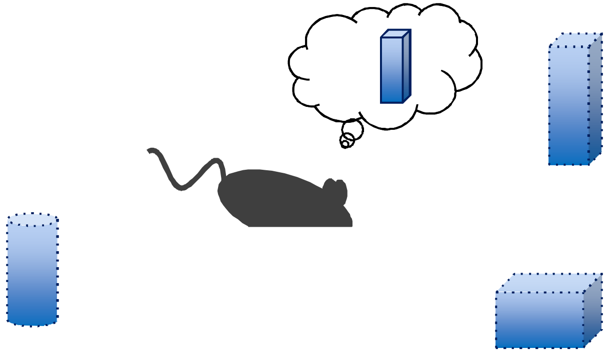
Prediction for neurophysiological data





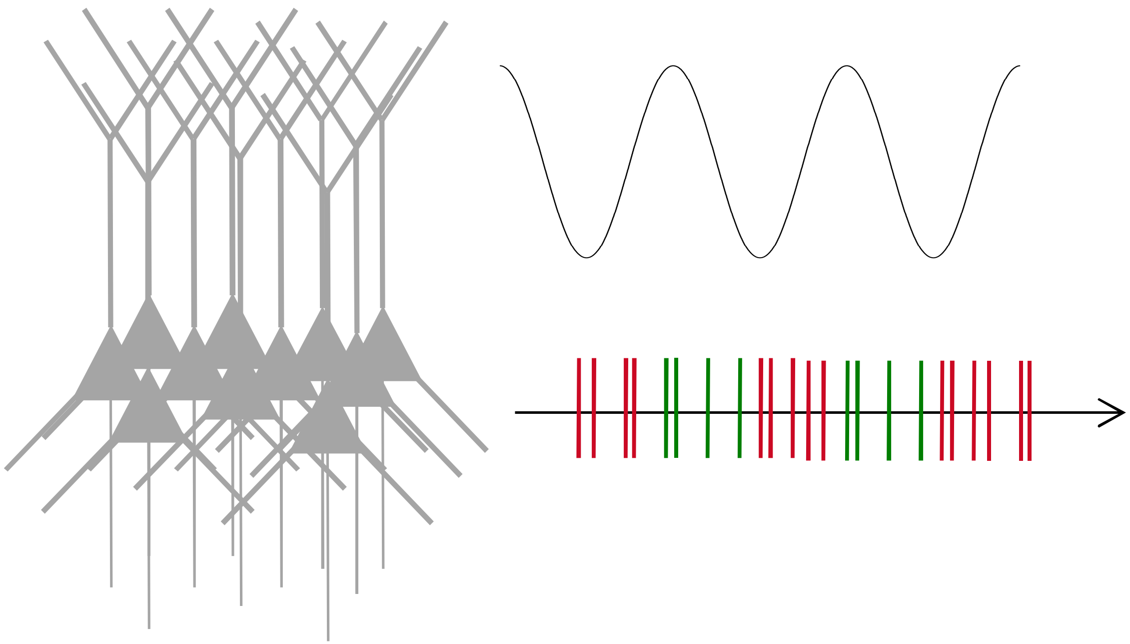
Prediction for neurophysiological data





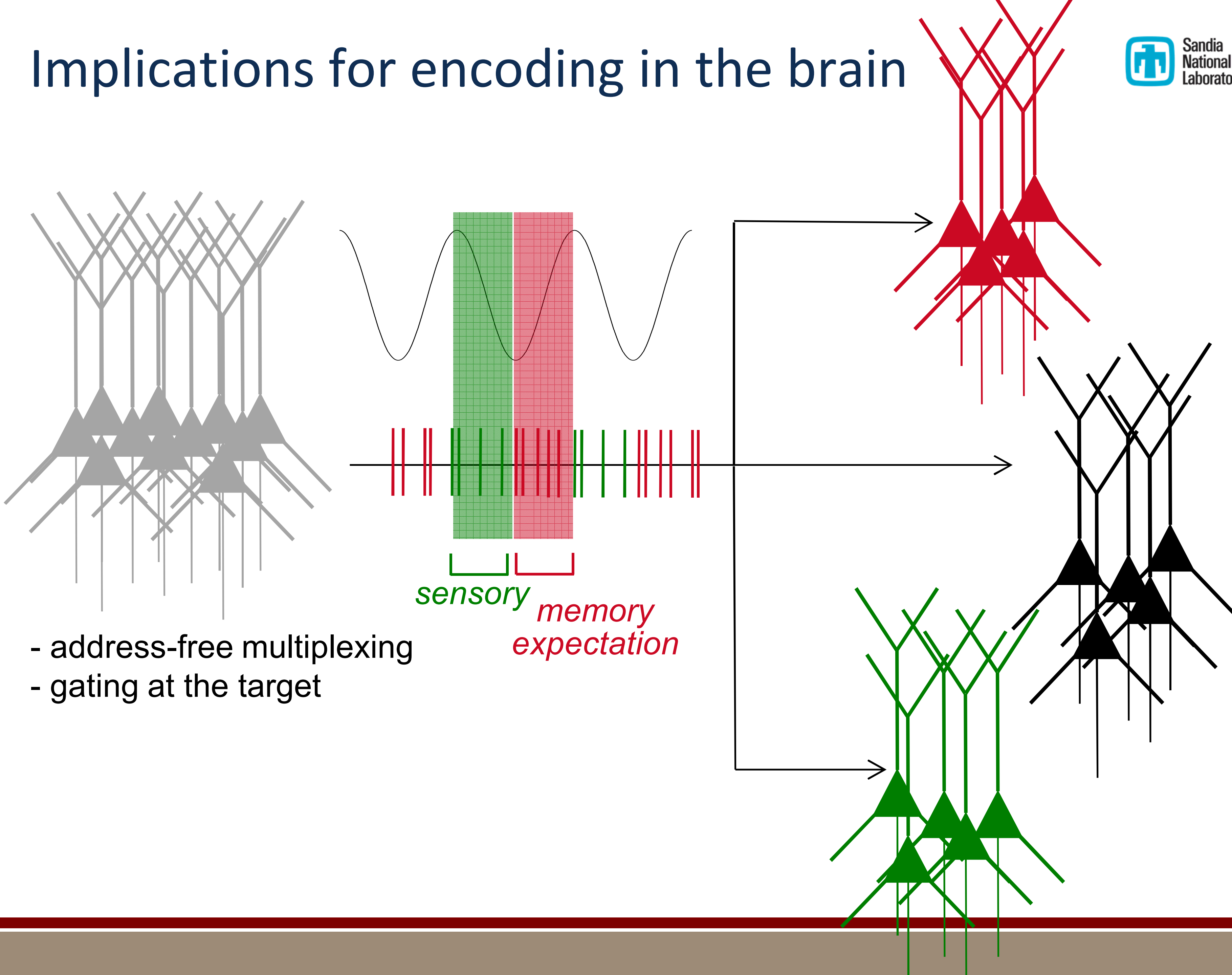
Cabral et al (2014) Neuron 81: 402-415.

Implications for encoding in the brain



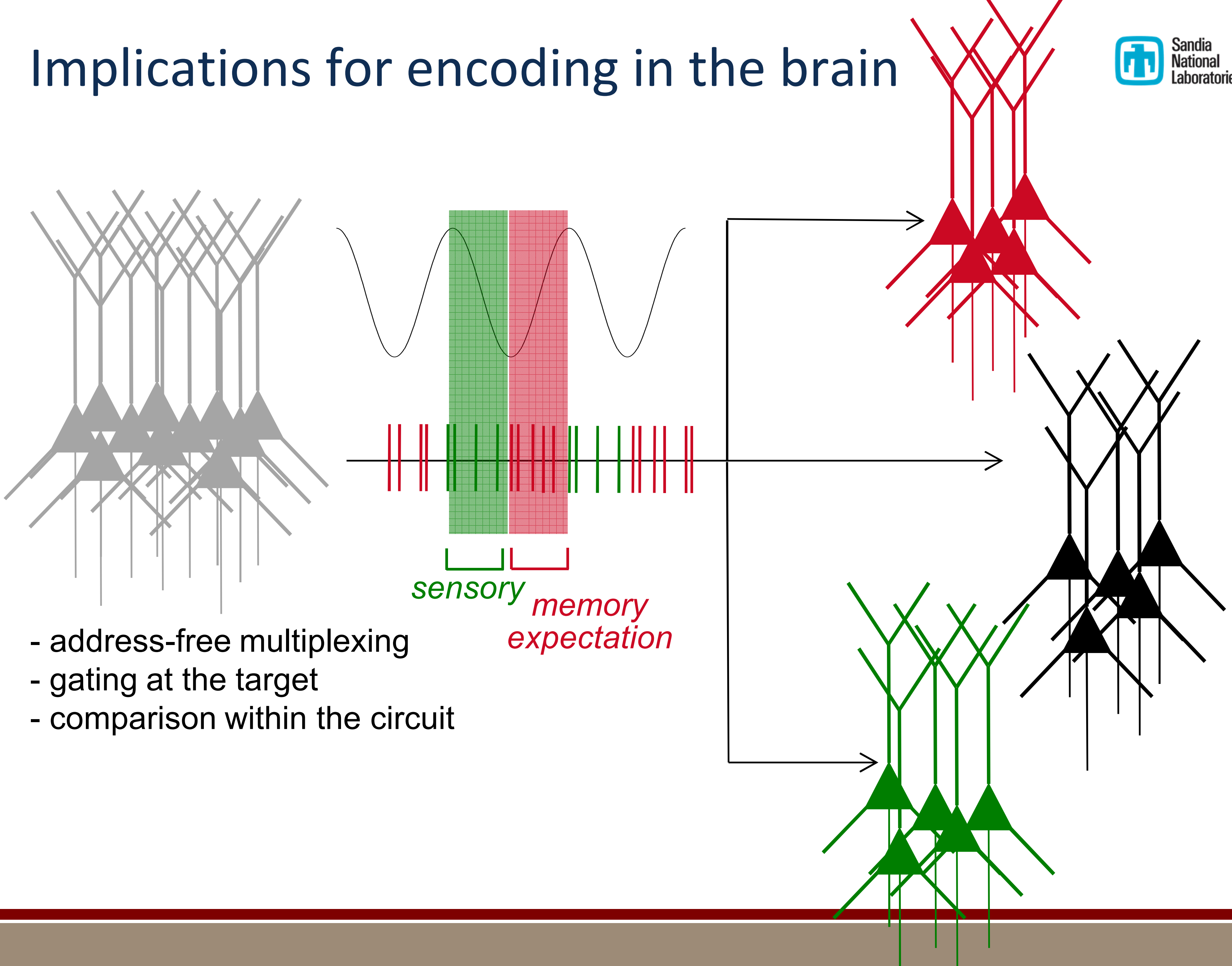
- address-free multiplexing

Implications for encoding in the brain



- address-free multiplexing
- gating at the target

Implications for encoding in the brain



- address-free multiplexing
- gating at the target
- comparison within the circuit

<the end>

- CA1 pyramidal cells receive input from CA3 (via Schaffer collaterals) and from EC3 (via temporoammonic pathway)