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A THEORY OF MEMORY STABILITY IN HIPPOCAMPAL AREA CA3

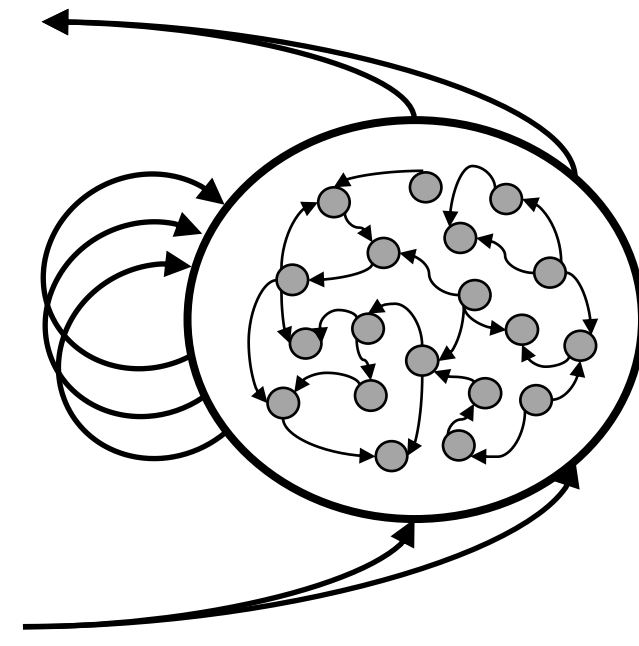
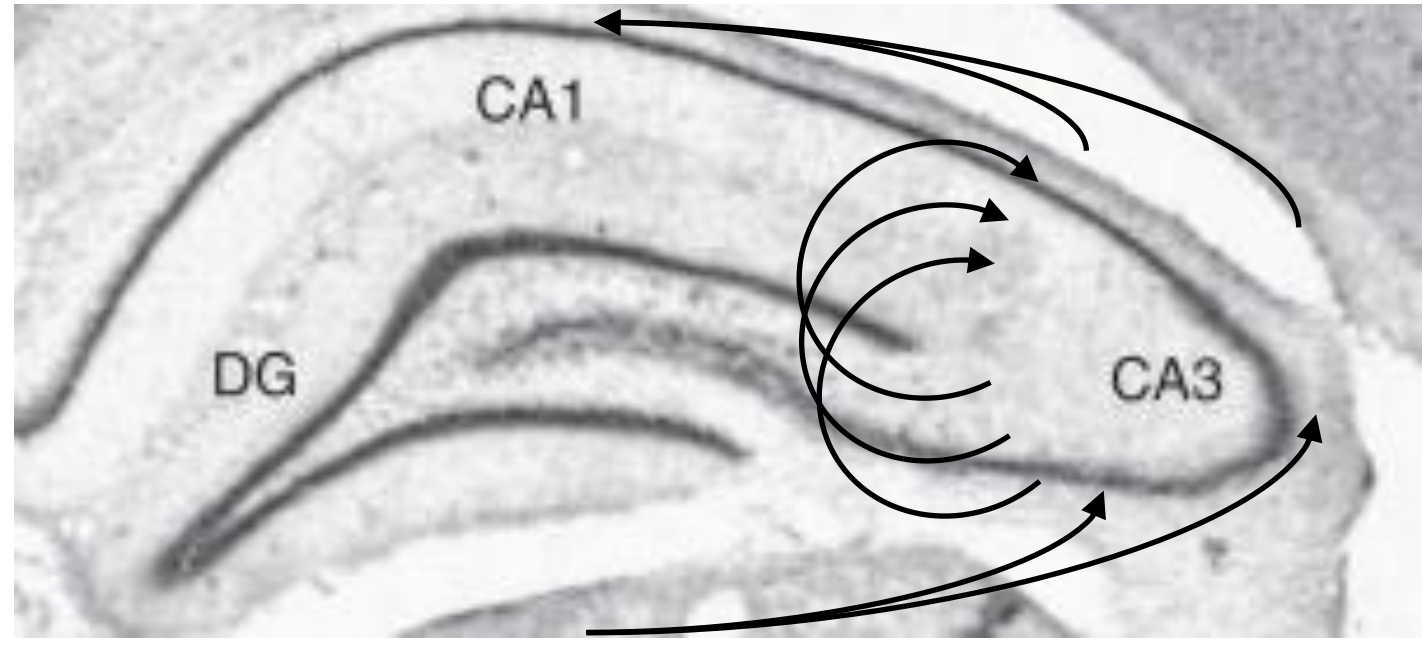
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Hippocampal area CA3 has been suggested to implement auto-associative memory [1-6].

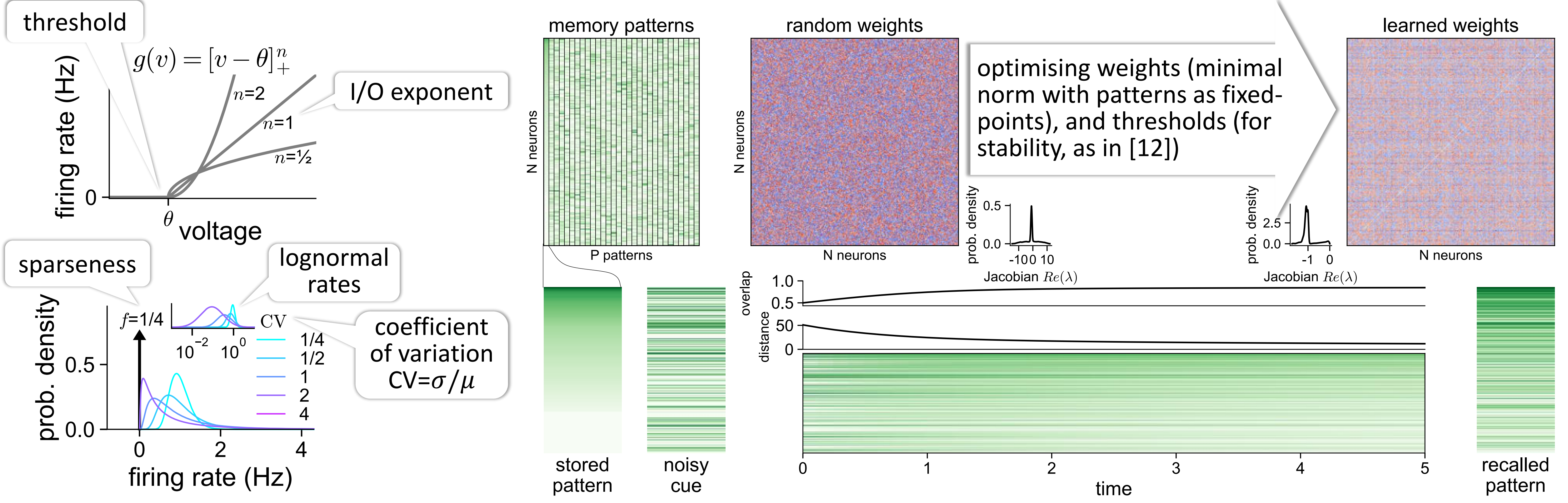
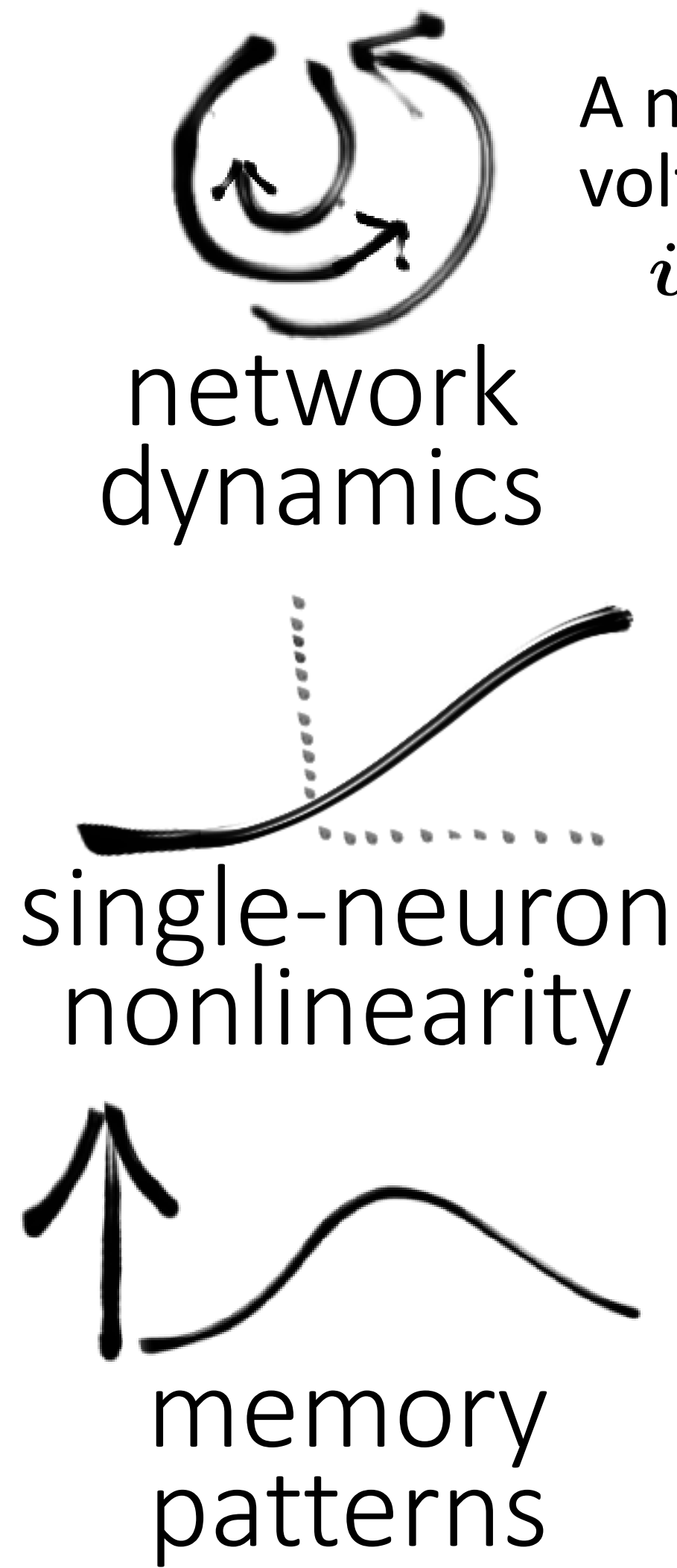


We provide a new analysis of the conditions for high-capacity storage of stable memories using biologically plausible recall dynamics.

How do single-neuron properties support stable recall of memories?

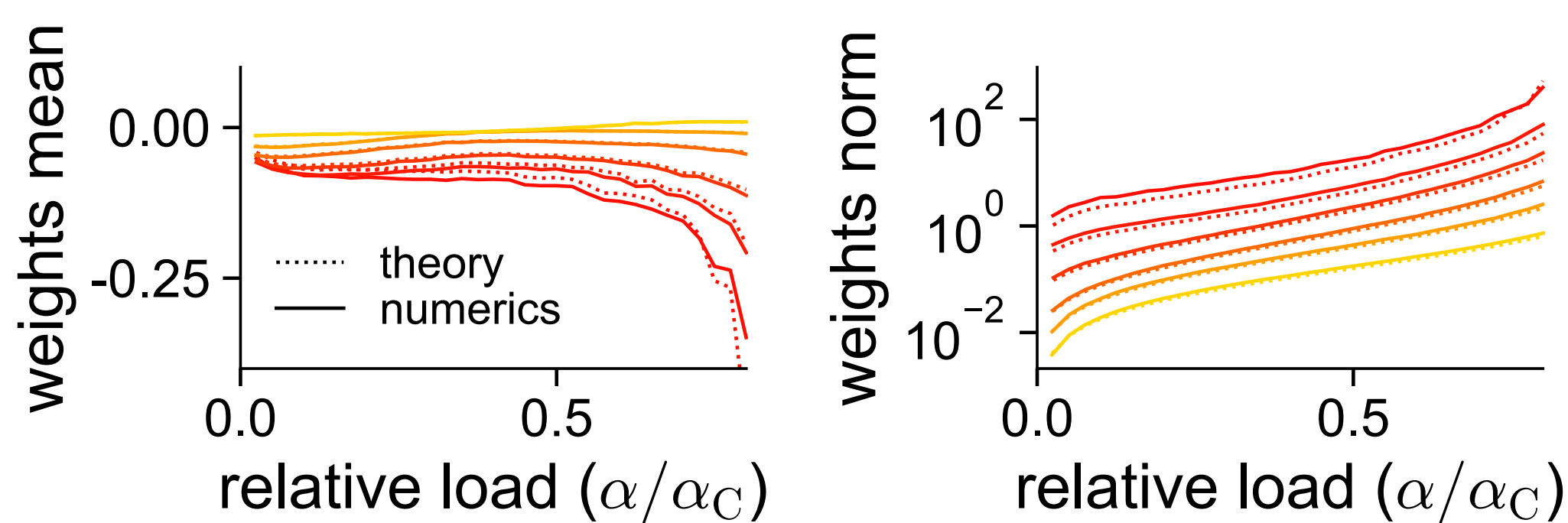
A network with nonlinear voltage dynamics:
 $\dot{v} = -v + Wg(v) - \theta$

Memories are stable fixed points of the dynamics:
 $r^\mu = g(Wr^\mu - \theta)$

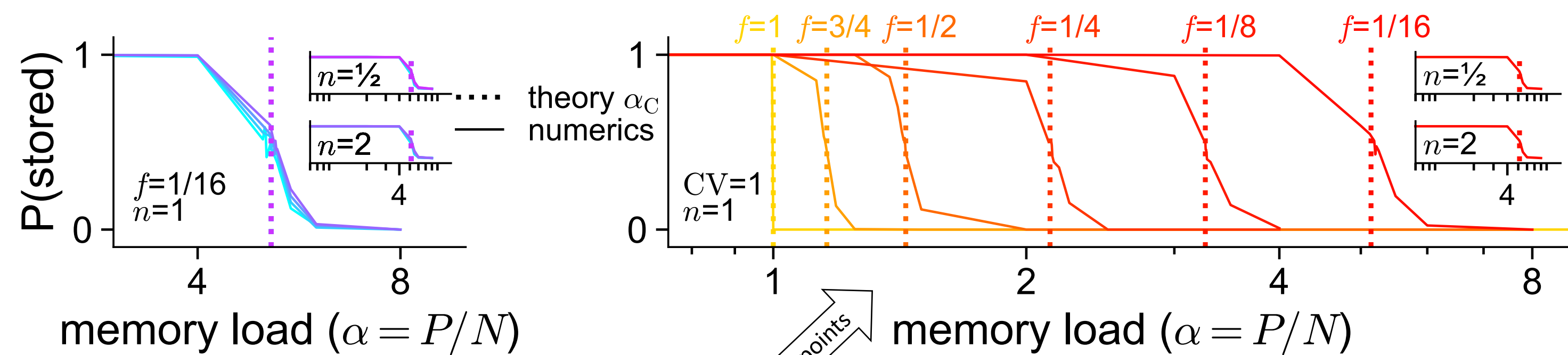


mean-field theory

Mean-field theory (à la [13-15]) fully describes the ability to store patterns as fixed-points.



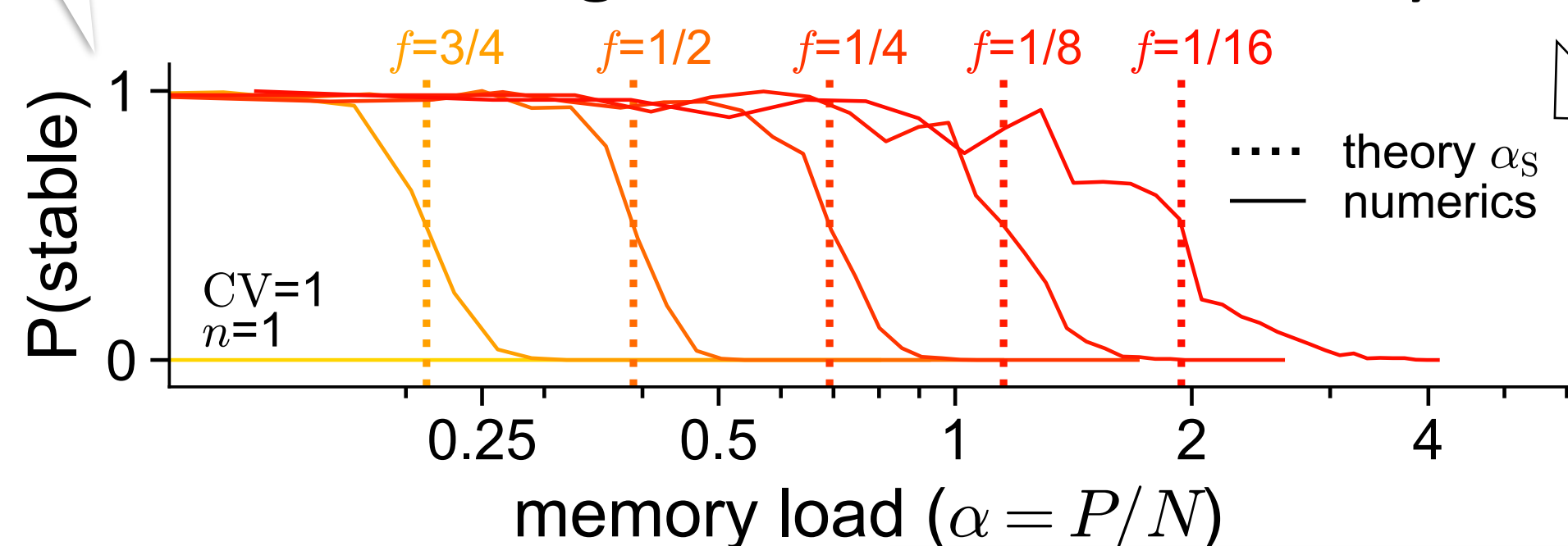
Number of fixed-points is invariant to CV and single-neuron non-linearity, depends only on sparseness (extending [15]).



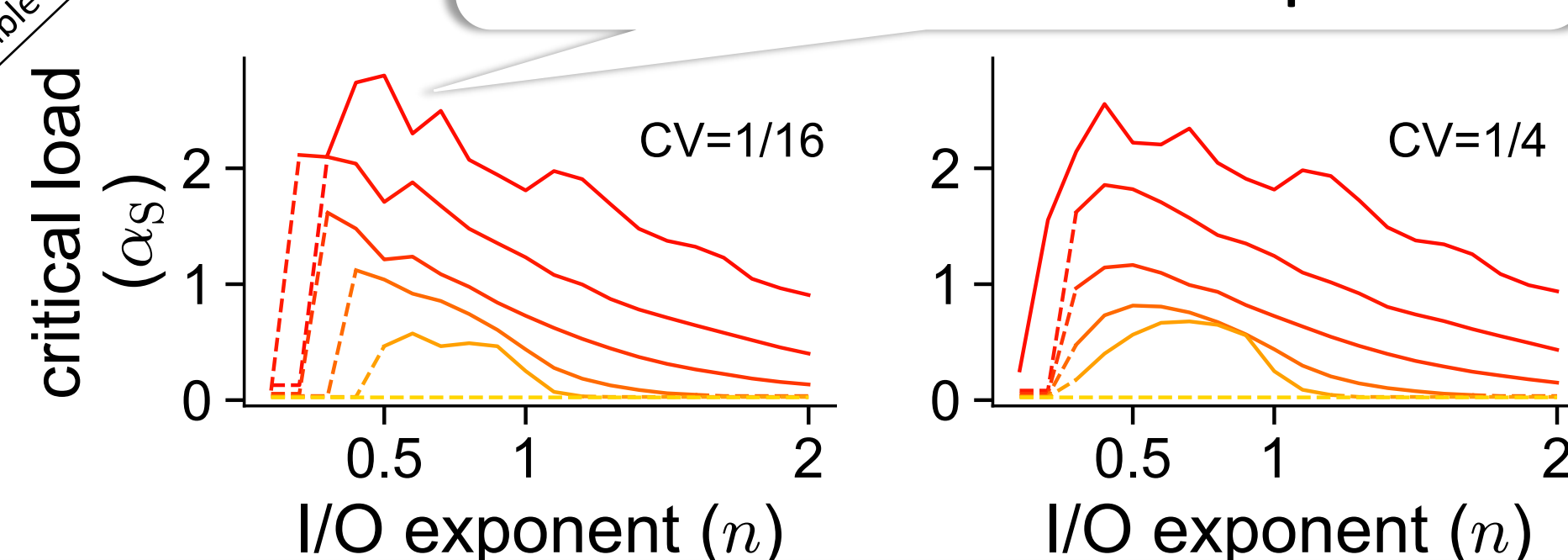
Non-trivial regime of stable memories; e.g., no stable fixed points for $n \geq 1$ and $\theta \geq 0$.

Memories are all stable below a critical load

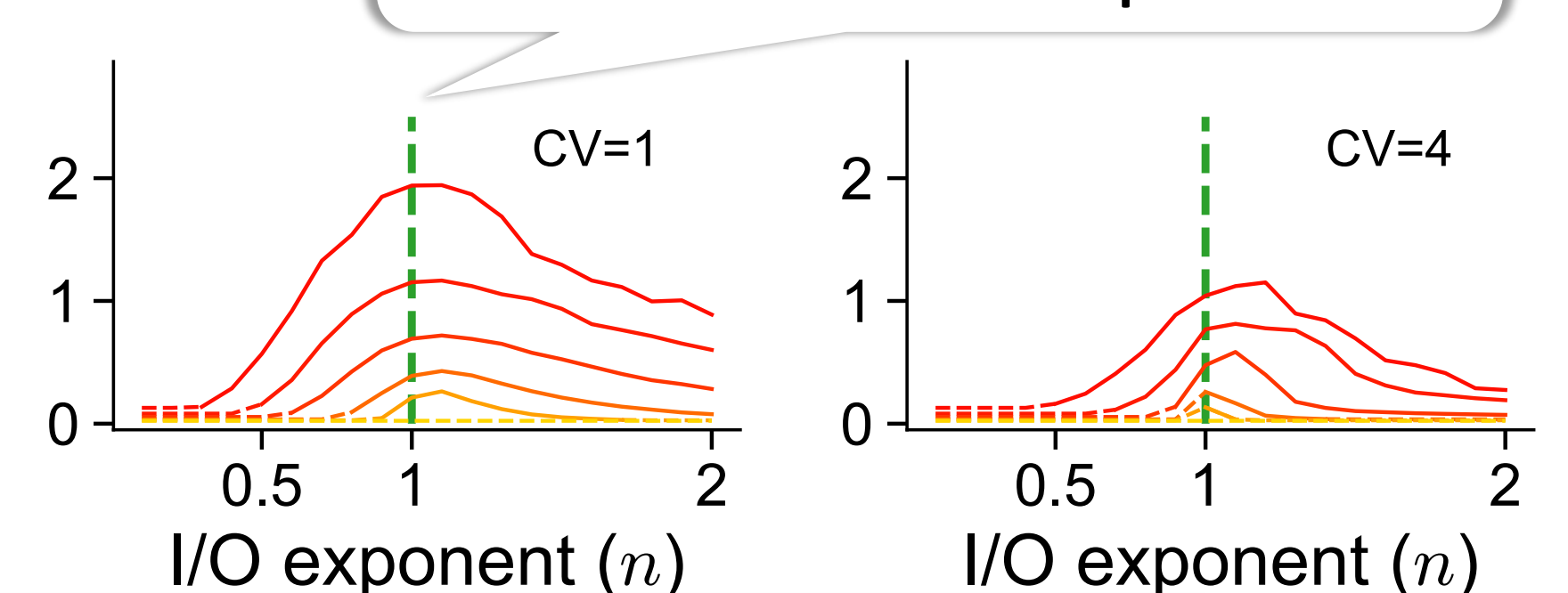
Number of **stable** fixed-points is **not** invariant to CV and single-neuron non-linearity!



At low firing rate CV, a sublinear f-I curve is optimal



At high firing rate CV, a linear f-I curve is optimal

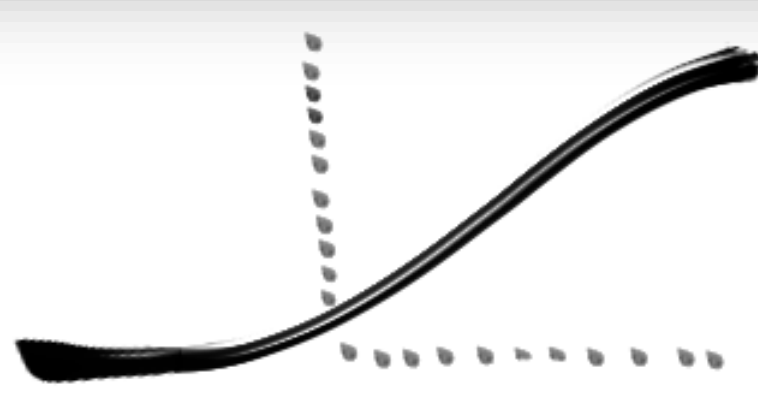


experimental data analysis

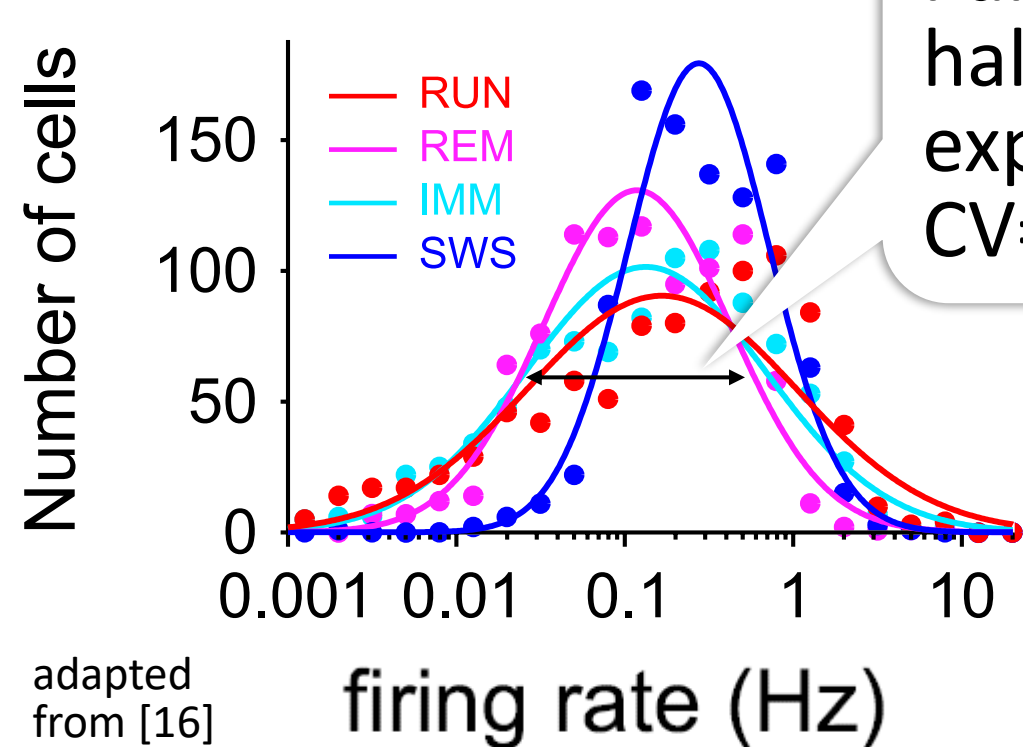
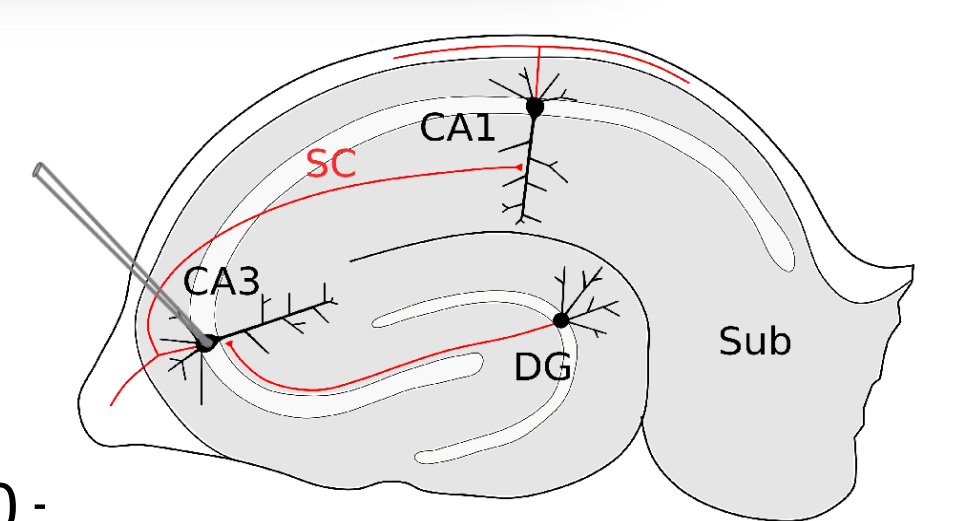
Due to its high-CV memory patterns, CA3 pyramidal neurons should have near-linear f-I curves, and negative threshold (i.e., should spontaneously fire if recurrent connections are suppressed)



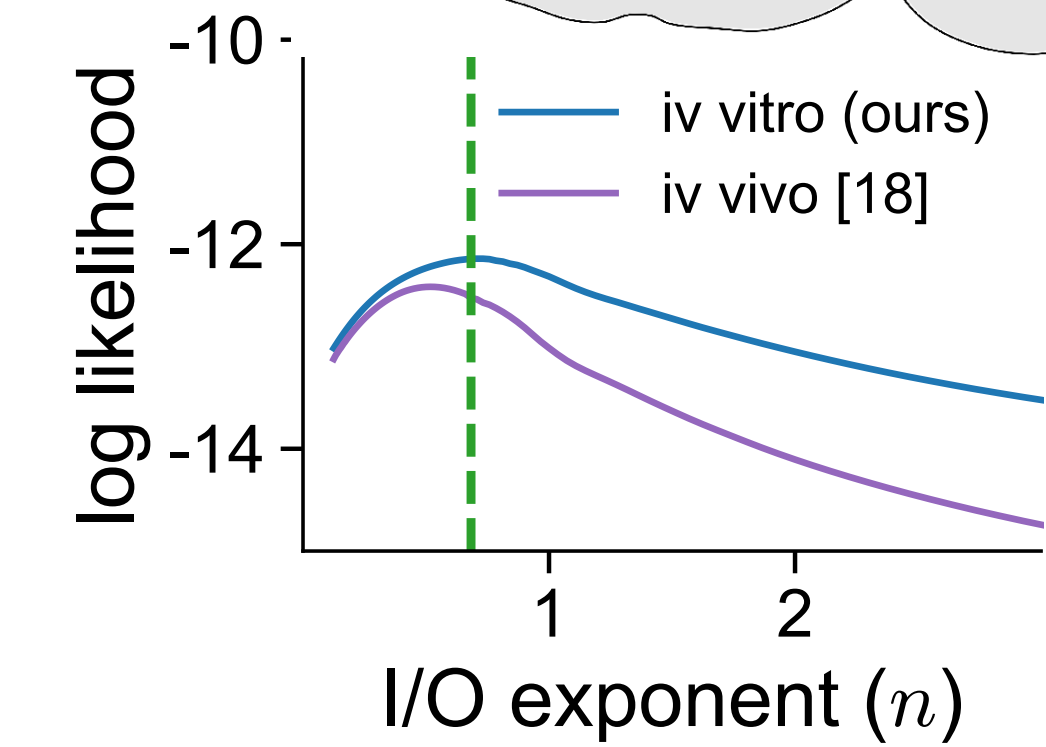
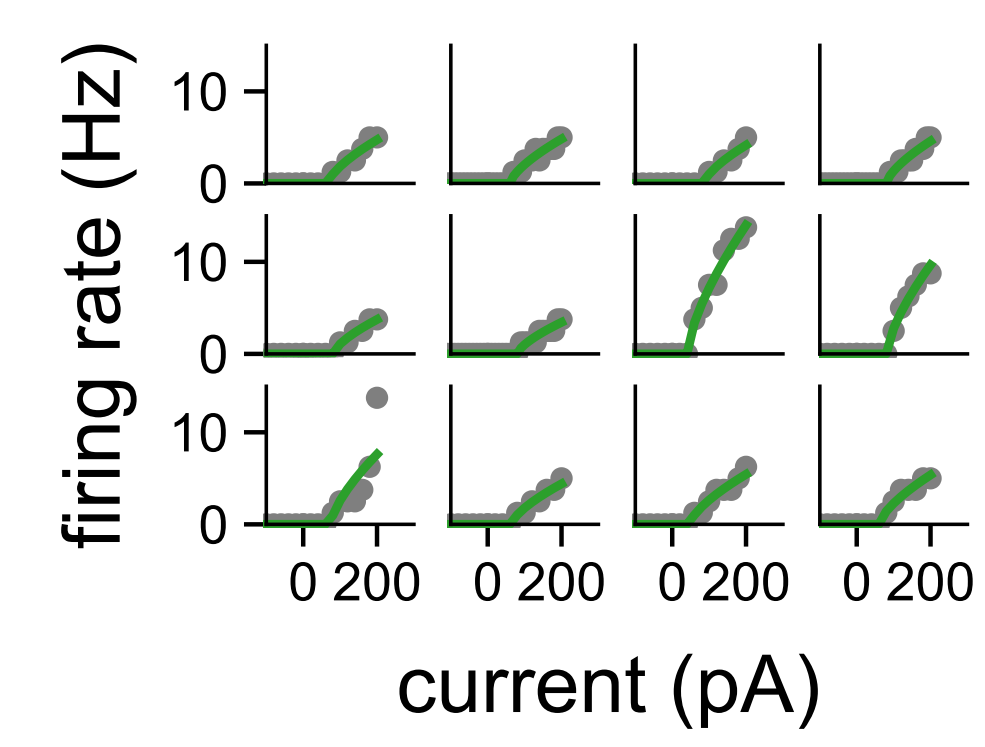
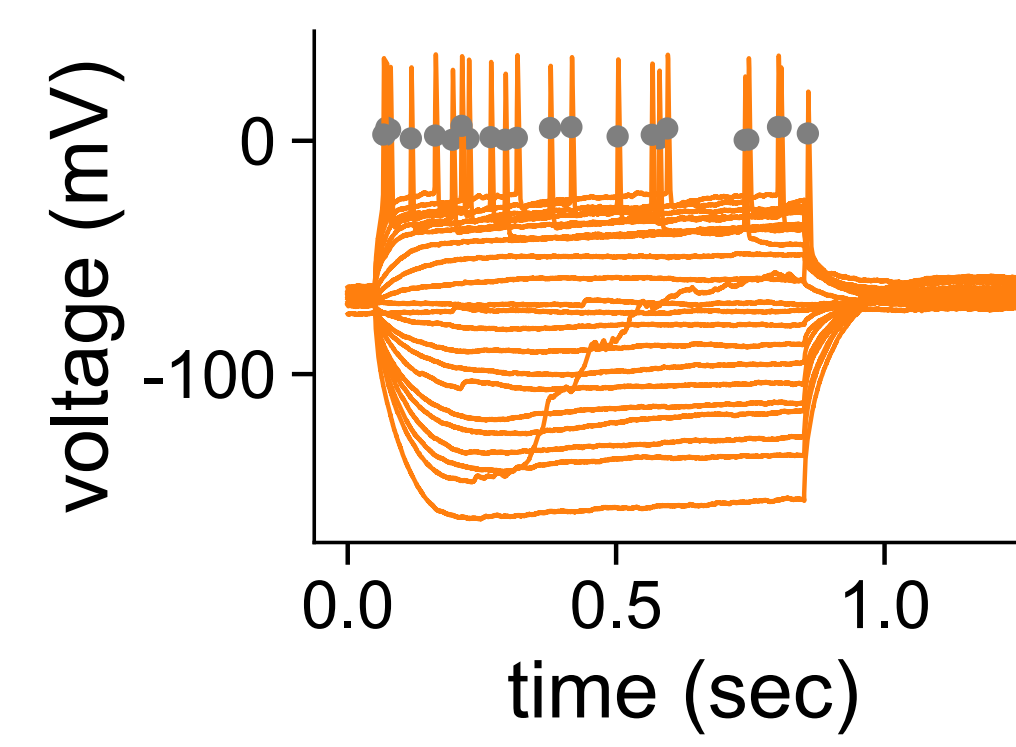
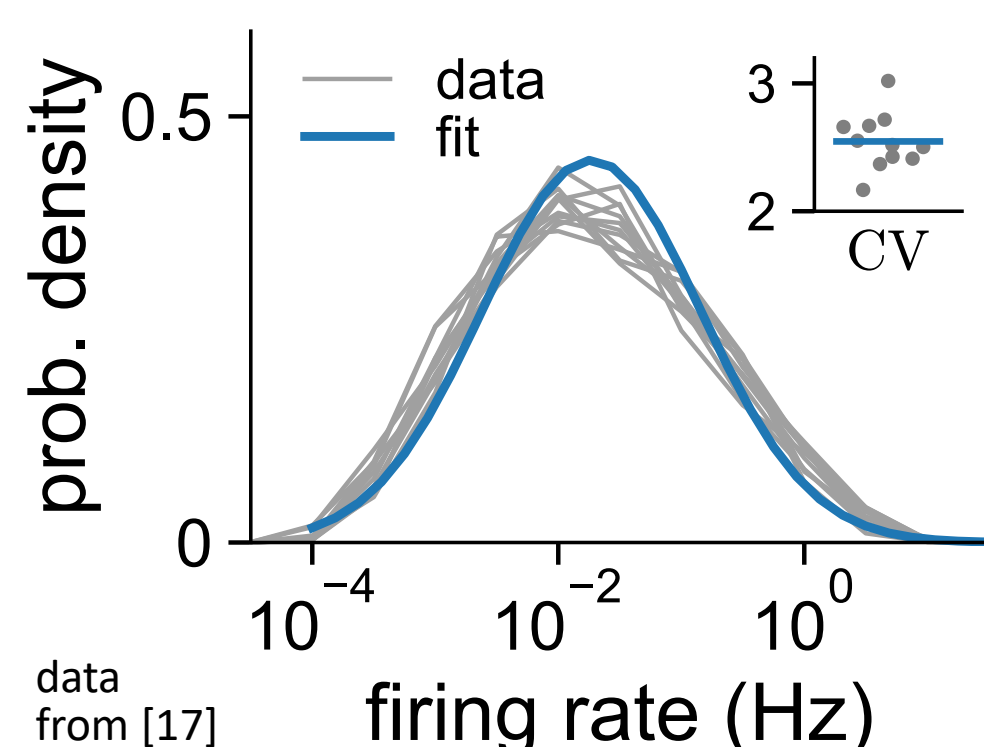
analysis of place cell activity in CA3 of freely moving rats [16-17]



Recording activity from mice CA3 pyramidal neurons in *in vitro* whole-cell experiments, we find near-linear f-I curves, and see similar results in existing *in vivo* data [18].



Full-width half-maximum expected at CV=2



References: [1] Marr D (1971) Simple memory: a theory for archicortex. Philos. Trans. R. Soc. Lond. B Biol. Sci. 262:23-81. [2] McNaughton BL, Morris RG (1987) Hippocampal synaptic enhancement and information storage within a distributed memory system. Trends Neurosci. 10:408-15. [3] Treves A, Rolls ET (1994) Computational analysis of the role of the hippocampus in memory. Hippocampus 4:374-91. [4] Nakazawa K, Quirk MC, Chitwood RA, Watanabe M, Yeckel MF, Sun LD, ... Tonegawa S (2002) Requirement for hippocampal CA3 NMDA receptors in associative memory recall. Science, 297:211-8. [5] Wills TJ, Lever C, Cacucci F, Burgess N, O'Keefe J (2005) Attractor dynamics in the hippocampal representation of the local environment. Science 308:873-6. [6] Khona M, Fiete IR (2022) Attractor and integrator networks in the brain. Nat. Rev. Neurosci. 23:744-66. [7] Hopfield JJ (1982) Neural networks and physical systems with emergent collective computational abilities. Proc. Natl. Acad. Sci. USA 79:2554-8. [8] Tsodyks MV, Feigl'man MV (1988) The enhanced storage capacity in neural networks with low activity level. EPL 6:101. [9] Treves A (1990) Graded-response neurons and information encodings in autoassociative memories. Phys. Rev. A 42:2418. [10] Krotov D, Hopfield JJ (2016) Dense associative memory for pattern recognition. Adv. Neural Inf. Process. 29. [11] Lengyel M, Kwag J, Paulsen O, Dayan P (2005) Matching storage and recall: hippocampal spike timing-dependent plasticity and phase response curves. Nat. Neurosci., 8:1677-83. [12] Festa D, Hennequin G, Lengyel M (2014) Analog memories in a balanced rate-based network of EI neurons. Adv. Neural Inf. Process. 27. [13] Gardner E (1988) The space of interactions in neural network models. J. Phys. A Math. Theor. 21:257. [14] Amit DJ, Gutfreund H, Sompolinsky H (1985) Storing infinite numbers of patterns in a spin-glass model of neural networks. Phys. Rev. Lett. 55:1530. [15] Schönsberg F, Roudi Y, Treves A (2021) Efficiency of local learning rules in threshold-linear associative networks. Phys. Rev. Lett. 126:018301. [16] Mizuseki K, Buzsáki G (2013). Preconfigured, skewed distribution of firing rates in the hippocampus and entorhinal cortex. Cell reports, 4:1010-21. [17] Alme CB, Miao C, Jezek K, Treves A, Moser EI, Moser MB (2014). Place cells in the hippocampus: eleven maps for eleven rooms. Proc. Natl. Acad. Sci. USA, 111:18428-35. [18] Malezieux M, Kees AL, Mulle C (2020). Theta oscillations coincide with sustained hyperpolarization in CA3 pyramidal cells, underlying decreased firing. Cell Reports 32.

