The effects of multiple firing events on pattern stability in continuous attractor networks without lateral excitation

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Introduction

Background/Motivation:

- Continuous attractor networks have been used to model persistent neural activity in several contexts - e.g. working memory, head direction cells, and grid cells
- Networks form "bumps" in 1-D and "grids" in 2-D
- Synchrony induced by lateral excitation has been shown to adversely affect the stability of patterns in continuous attractor networks [1]
- Transient, local synchrony can emerge through brief, rapid firing cascades known as Multiple Firing Events (MFEs) [6]
- Experiments suggest that some systems (head direction cells, grid cells) can be modeled by continuous attractor networks without lateral excitation [7,8]

Are attractor networks with no lateral excitation more stable? What factors affect their stability?

Goals:

- Compare the stability properties of spiking continuous attractor networks with and without lateral excitation
- Determine the relationship between transient synchrony and pattern ("bump") stability in networks without lateral excitation
- Develop a mechanistic understanding of synchrony and pattern stability, in terms of MFEs

Model

Neuron model

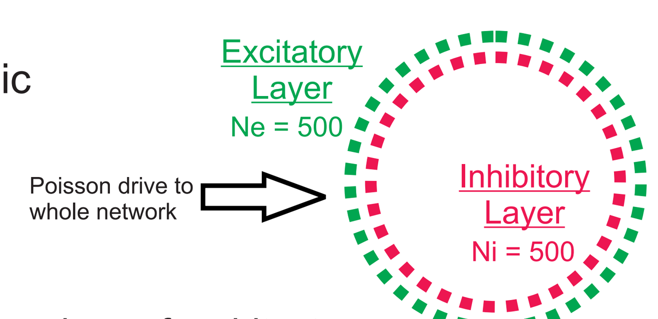
Leaky integrate-and-fire + conductance based synapses

$\tau_{AMPA} = 2$ ms $\quad \tau_{GABA} = 5$ ms $\quad \tau_{NMDA} = 100$ ms

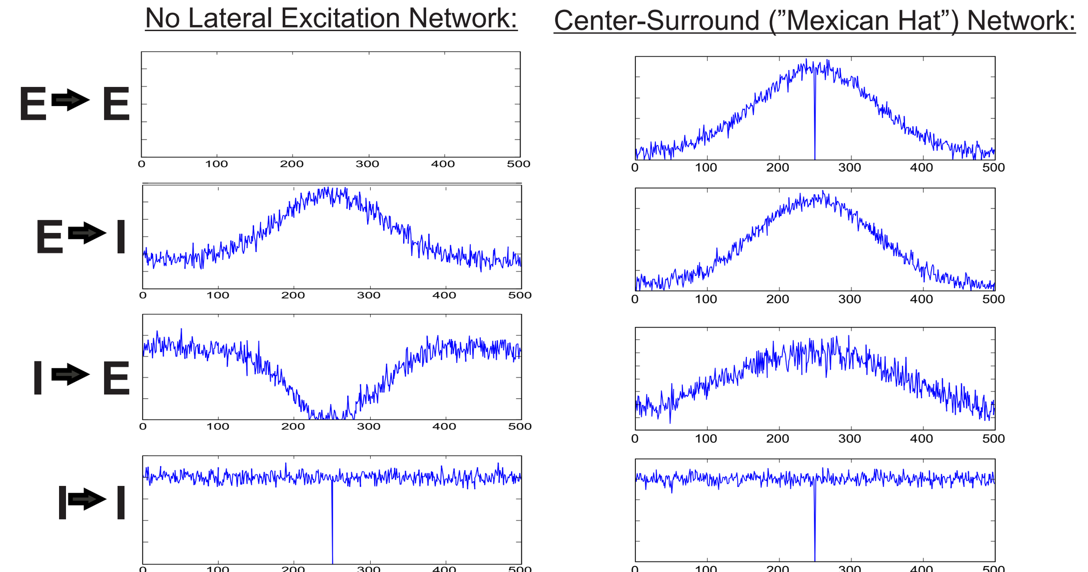
Network structure

1-D lattice with periodic boundary conditions

Spatially structured connectivity



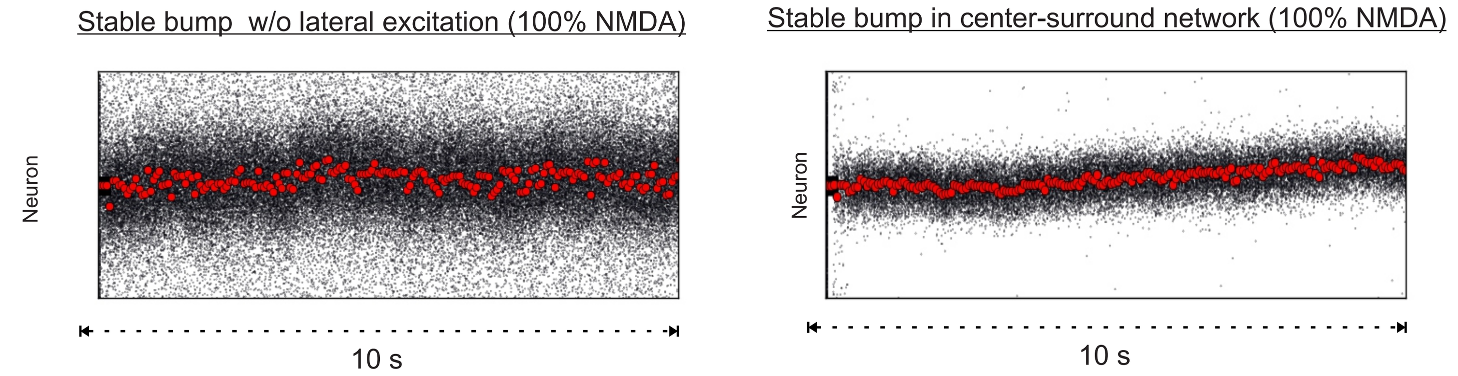
Comparison of architectures



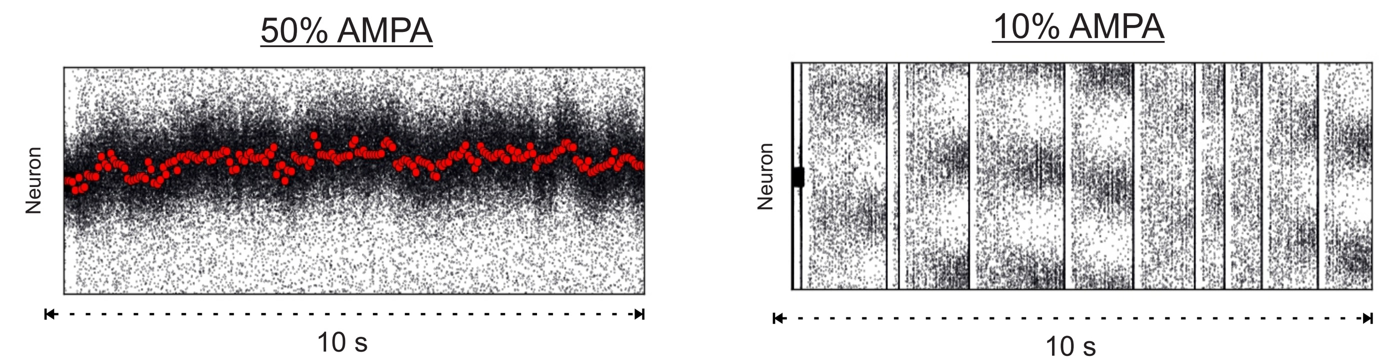
Results

Stability of activity patterns:

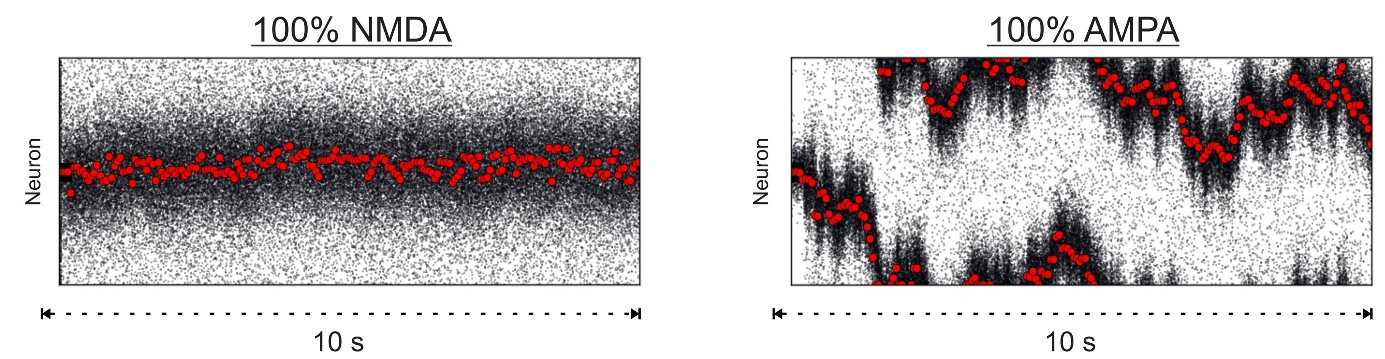
Stable bumps can form in both types of network architectures:



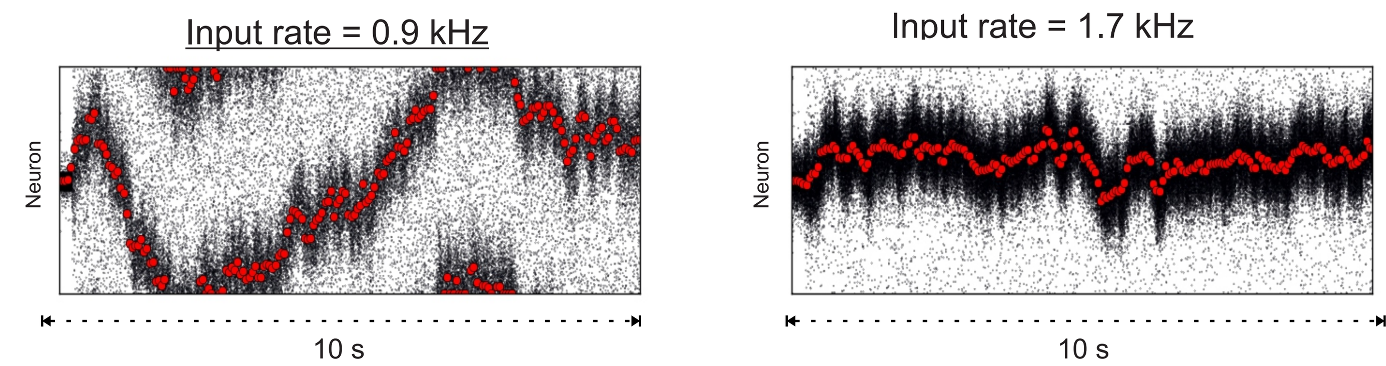
Bumps in networks without lateral excitation remain stable across a broader range of excitatory synaptic timescales:



Sufficent amount of fast E-I synapses can still destabilize pattern, leading to bump drift



Higher input rates re-stabilize the bump



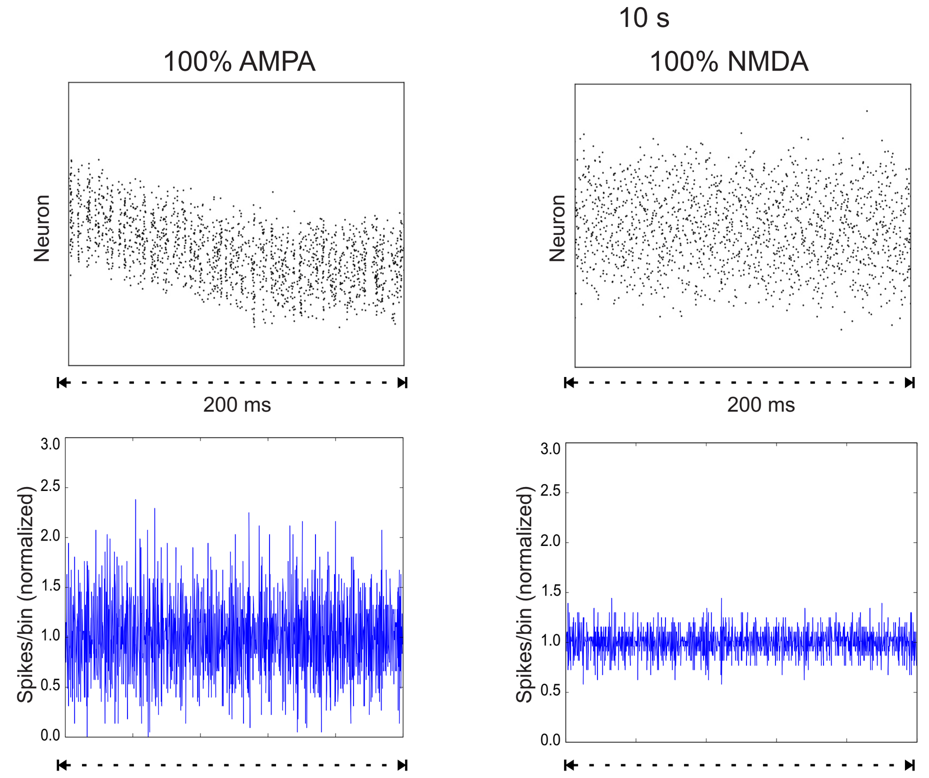
Bump drift is associated with synchrony

Measuring synchrony:

1. Bin all spikes in time (2.5 ms bins)

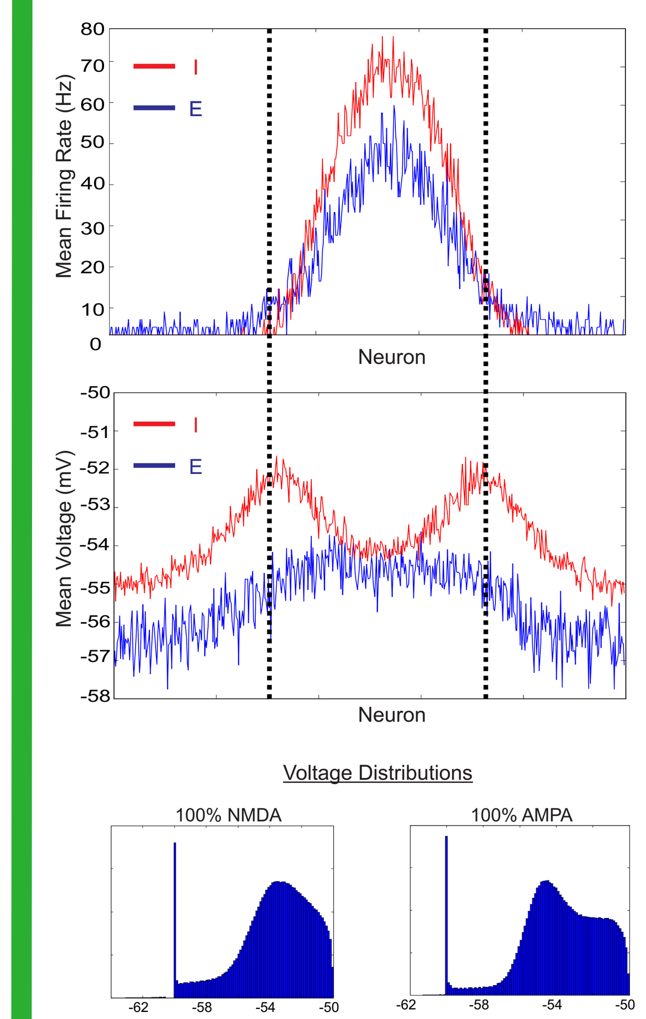
2. Compute variance of histogram

3. Divide by expected variance assuming ind. Poisson trains



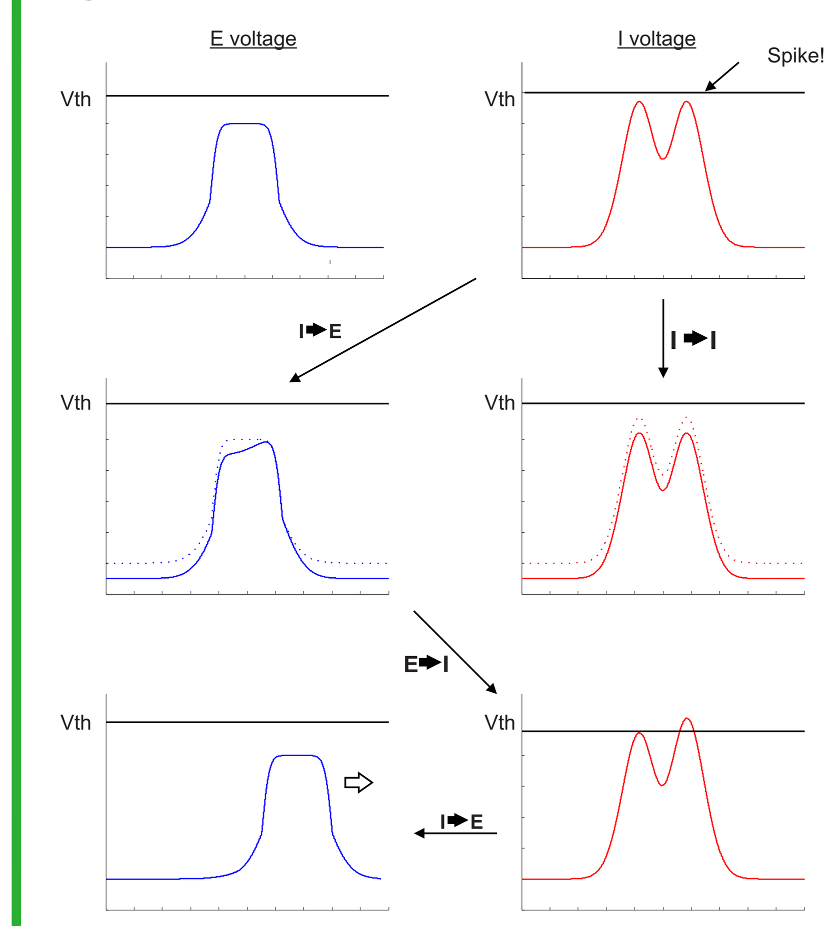
Dynamical mechanisms?

First, some observations:



Proposed mechanism:

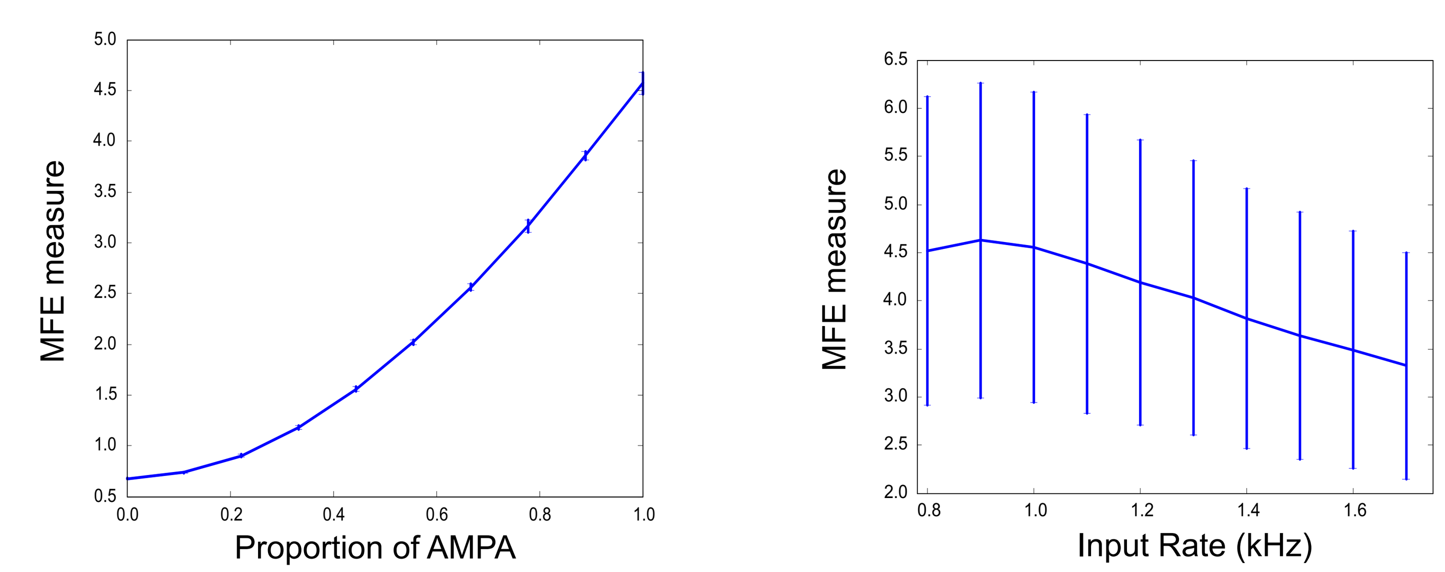
Ingredient 1: indirect I-I interaction



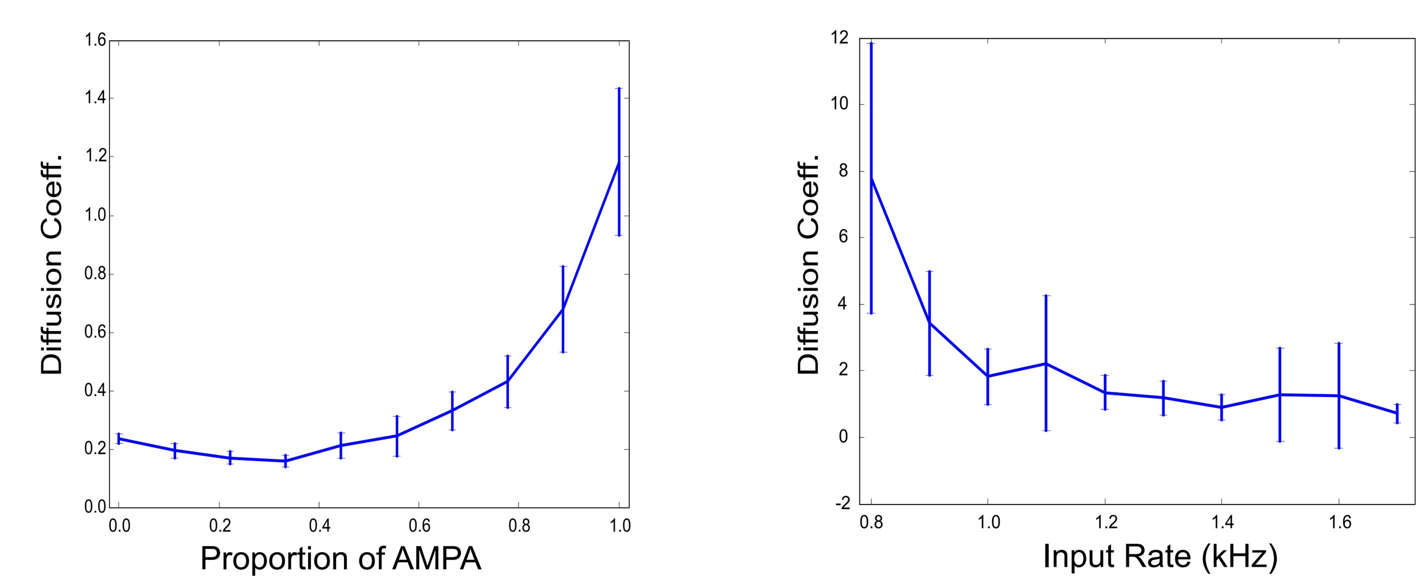
Ingredient 2: Multiple firing events (MFEs)

Expected consequences:
1. Larger MFEs -> more drift
2. Lots of (smaller) MFEs, e.g., at high input rates, average out -> less drift

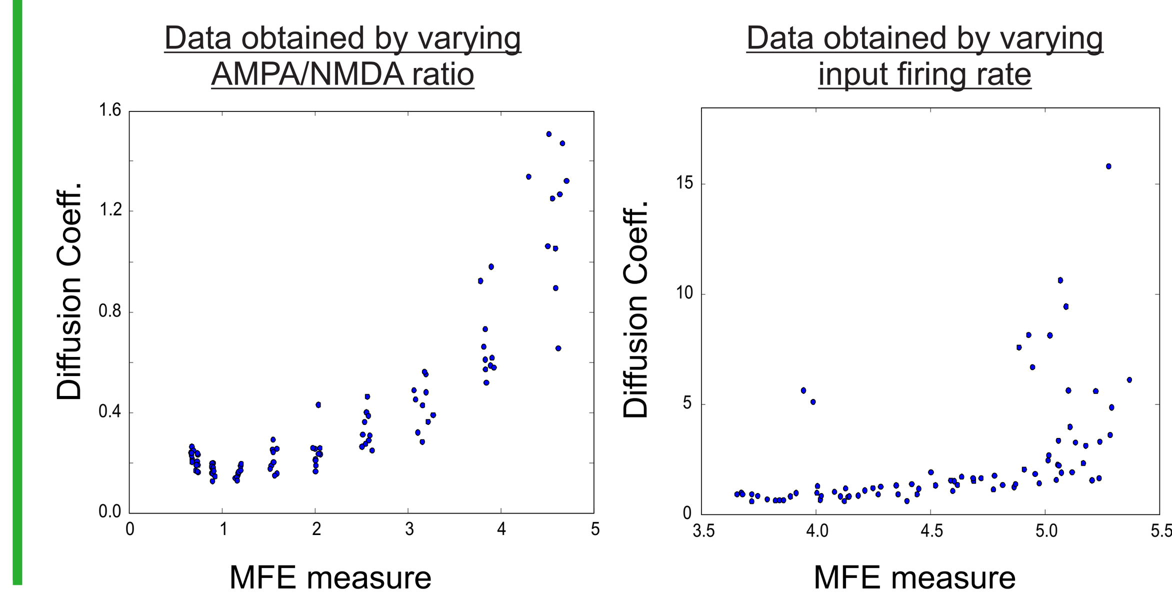
MFEs become more prominent with fast synapses, also affected by input rates:



Bumps drift more with faster synapses, less at higher input rates:



MFEs are correlated with bump drift:



Conclusions

- Attractor networks without lateral excitation are stable across a broader range of excitatory timescales
- With sufficiently fast excitatory synapses, bumps can still become unstable and wander
- We propose a dynamical mechanism based on indirect I->I interactions and MFEs

On-going/future work:

- Other relevant dynamical features, e.g., spatial voltage distibution
- Quantitative analysis?

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