Spike-to-Field Mechanisms of Turbulence-Like Dynamics in Spatial Spiking Neural Networks

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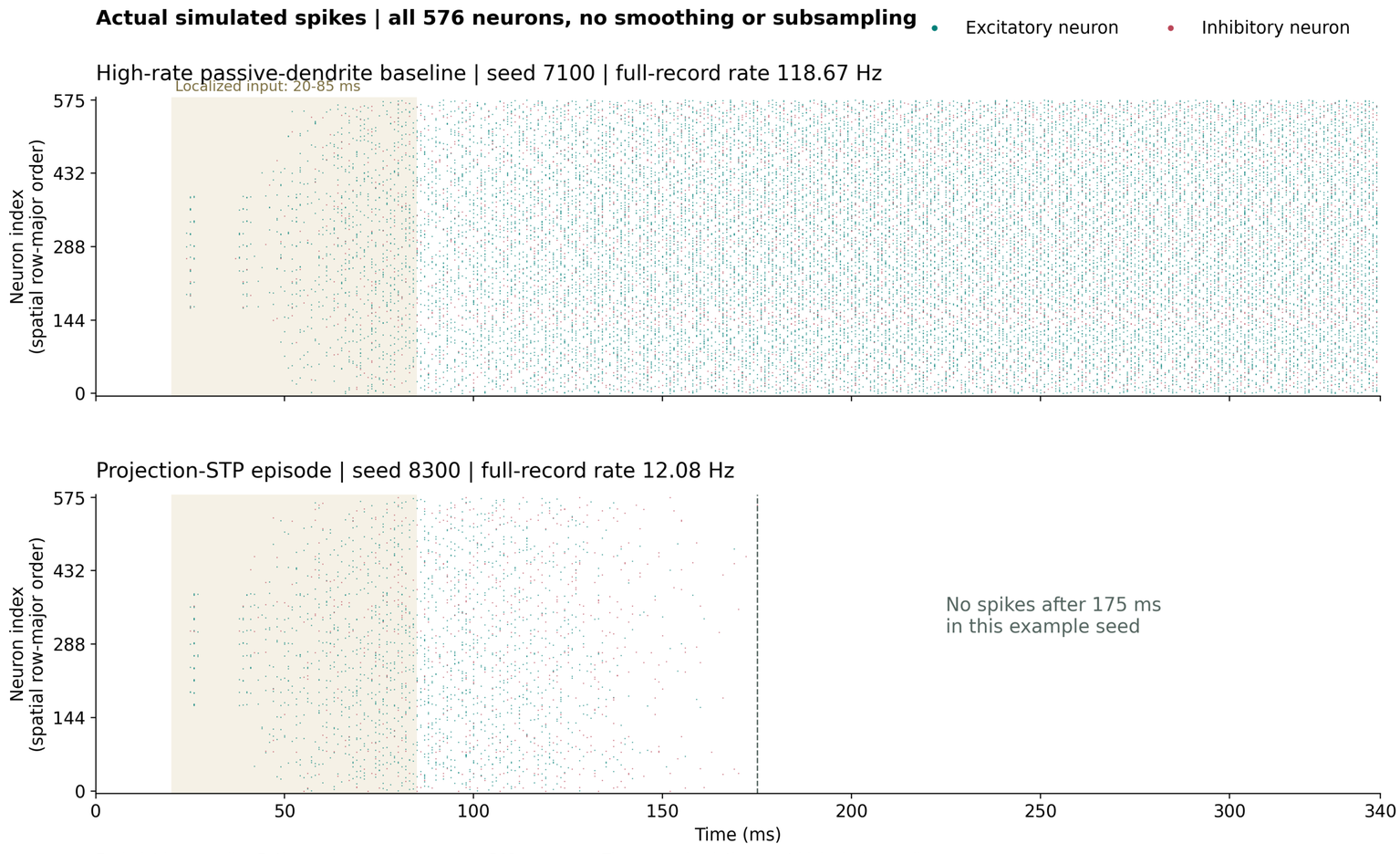
A spatial network of explicit spikes



Each dot is one spike. Both panels show the complete 340-ms record. These are simulations, not biological recordings.

24 x 24 neurons
80% E / 20% I

Distance-dependent wiring and transmission delays

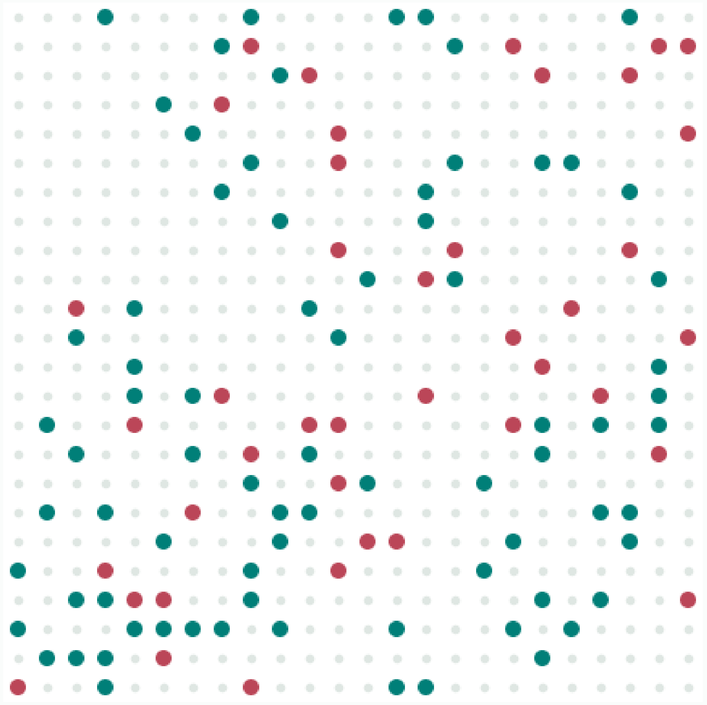
Reduced dendritic filtering
Localized stimulus

All cells and spikes shown

Spike-to-field transformation

NEURAL INFORMATION PROCESSING SYSTEMS

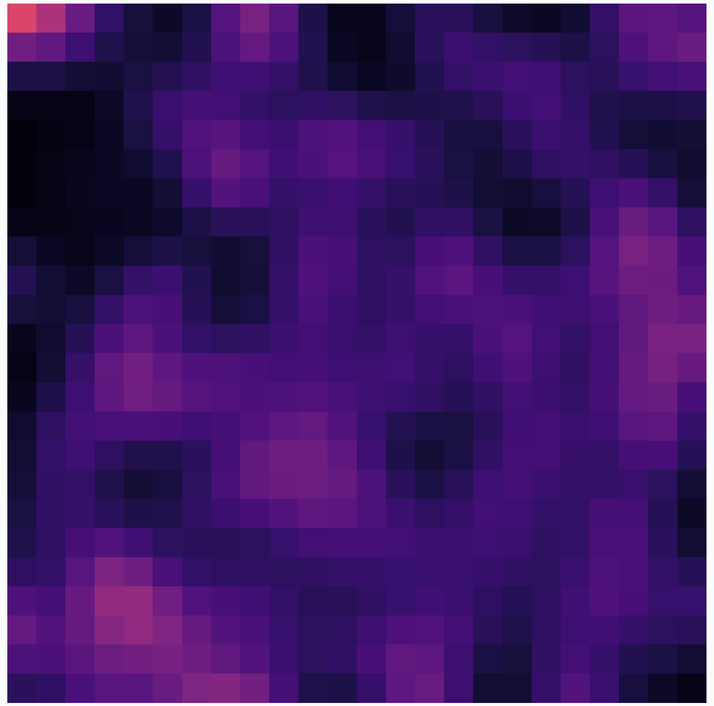
Spikes



Cells firing in the last 5 ms

Excitatory **Inhibitory**

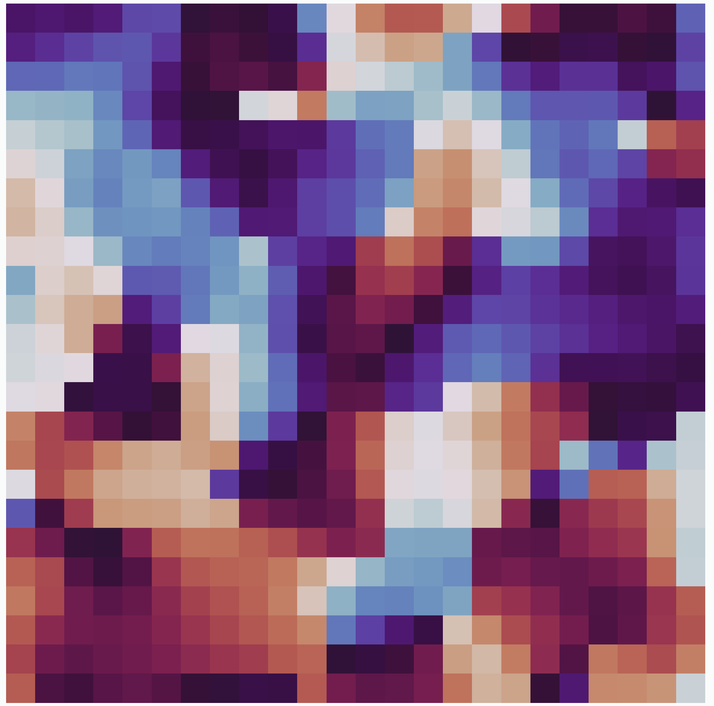
Activity density



Spatial + temporal smoothing

0 194 Hz / neuron

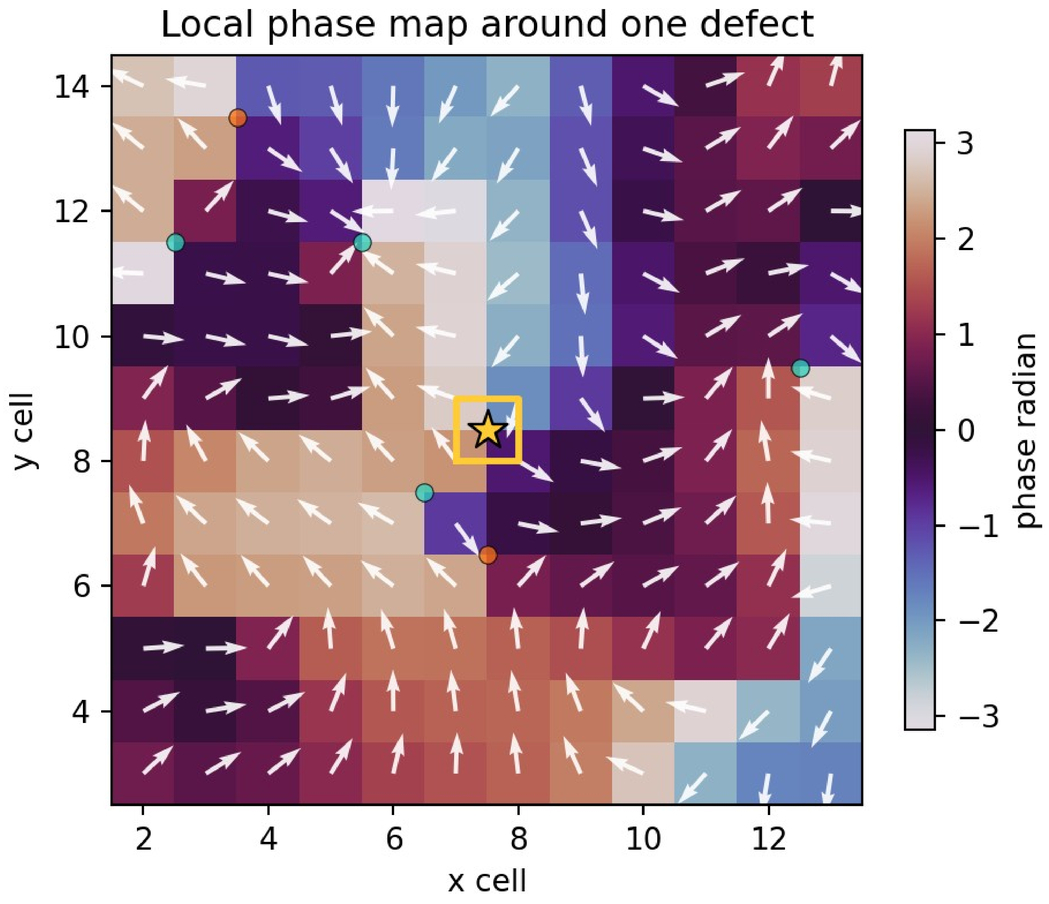
Derived phase



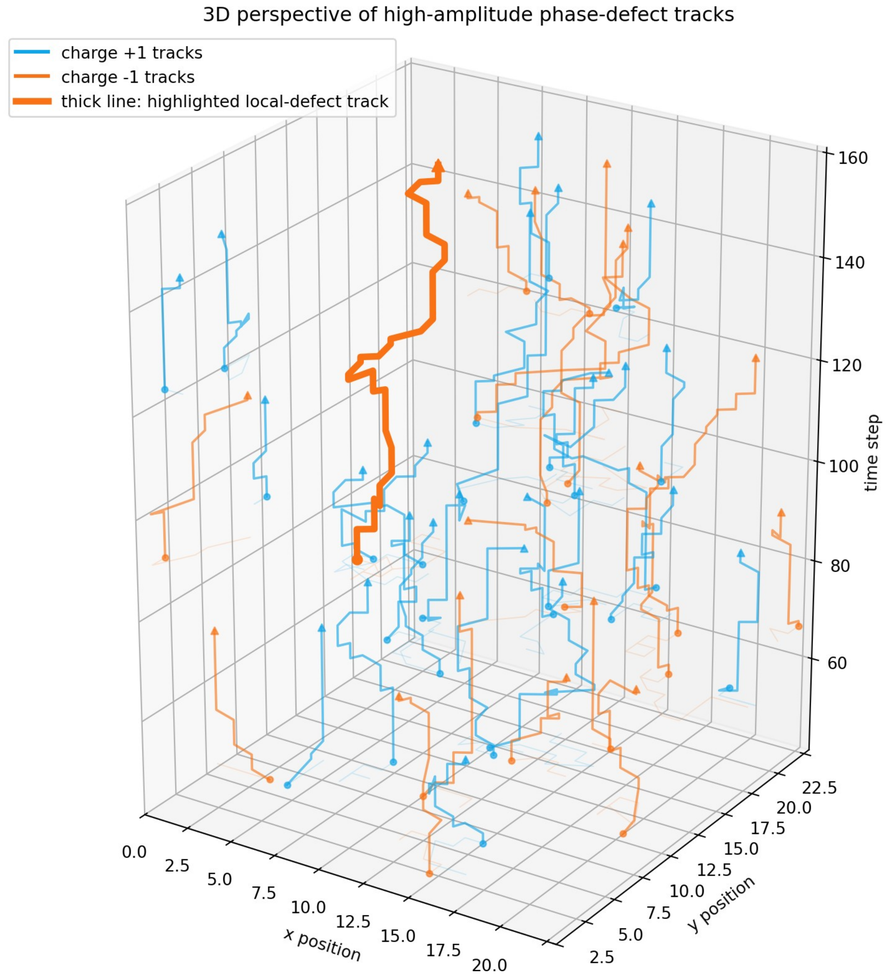
20-80 Hz band + Hilbert transform

-pi 0 +pi

Local phase winding and space-time tracks



Local winding identifies a phase defect



Highlighted track: 74 ms

Circuit interventions change field observables

Condition	Rate (Hz)	Defects / frame	Long tracks
Baseline	115.43	6.05	82.50
No distance delay	128.67	3.70	58.33
No passive dendrite	164.25	2.29	37.25
PV-only motif	14.12	0.35	4.08
SST-only motif	107.14	5.93	94.33

Means across 12 seeds. Original 340-ms assay. Long tracks: at least 8 frames.

PV/SST labels denote functional motifs. Counts depend on the observation pipeline.

Matched controls separate the observables

State	Rate shuffle	Spatial shuffle	Time shift
High-rate baseline	D, T, P	D, T	D, P
Low-rate episode	D, T	D, T, P	T, P

D Unfiltered-density S2 slope
T Delay-aligned transfer on raw spikes
P Phase-defect or track counts

D and T cover all six comparisons

Positive pointwise 95% intervals. 20,000 paired resamples, 12 seeds per state.

Projection-specific STP supports a finite episode

195.2 +/- 11.9 ms

Time of last spike

21.31 +/- 2.51 Hz

Active-support mean firing rate

12.25 Hz over the full 340-ms record

Corrected field estimates

Defects/frame: 3.42 +/- 0.92
Long tracks: 21.08 +/- 9.07
S2 slope: 0.768 +/- 0.029

Mean +/- SD, 12 held-out seeds

Finite episode and ongoing activity are distinct tests.

Measurement and criticality boundaries

Phase topology	No consistent high-rate 20-80 Hz peak above background. Filter choice changes defect counts: 6.51 vs 4.39 per frame.
Network size	Common-lag slopes: 0.757-0.779 across 16 x 16 to 40 x 40. This is a size robustness check, not finite-size scaling.
Avalanche tails	Weak-drive spike-bin assay: log-normal wins at 5 of 6 drives. The remaining drive favors a truncated power law.

A mechanistic testbed with explicit controls

Circuit mechanisms shape collective activity.

Matched controls determine what field observables establish.

Next: empirical observation models and perturbation experiments.

Paper: arxiv.org/abs/2611.12627
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