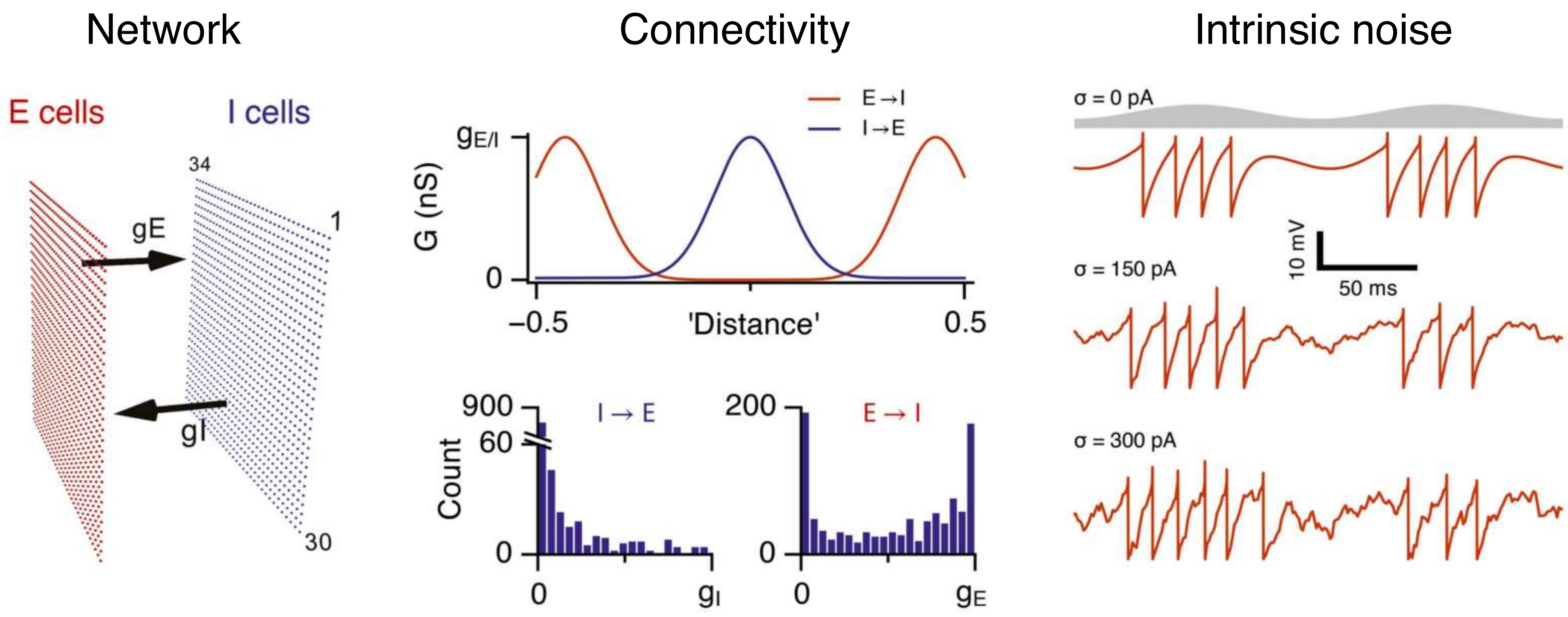
Systematic exploration of relationships between inhibitory and excitatory synaptic strength, grid firing and gamma oscillations

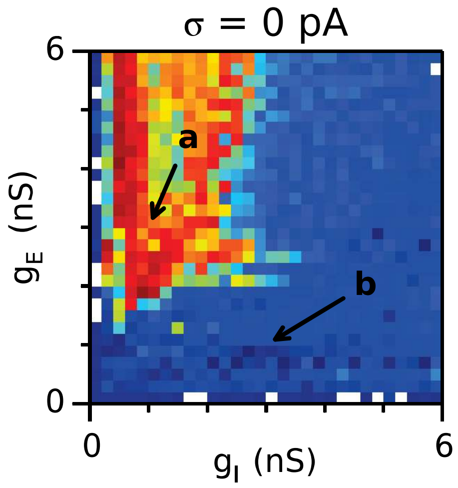


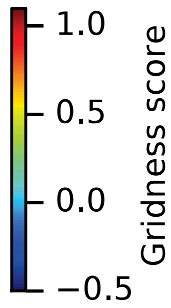
Simulated model: 1020 E cells, 1020 I cells, > 1 million synapses
Simulator: NEST
Simulations: 31 x 31 combinations of gE and gI (requires approximately 1 week using > 50 nodes on the supercomputer ECDF cluster)

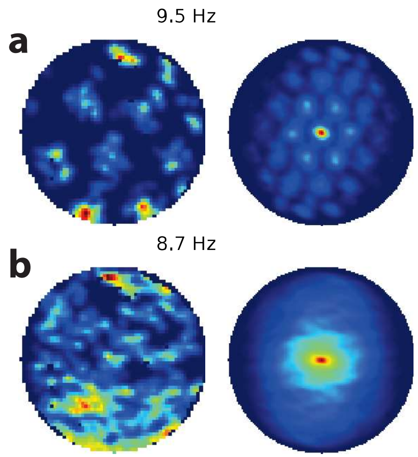
Solanka, van Rossum and Nolan, eLife (2015)
Shipston-Sharma, Solanka and Nolan, J. Physiol. (2016)

How do rate coded grid fields and network gamma oscillations vary with strength of excitatory and inhibitory connections?

In the absence of noise fine tuning of excitatory and inhibitory synapses is required for grid firing

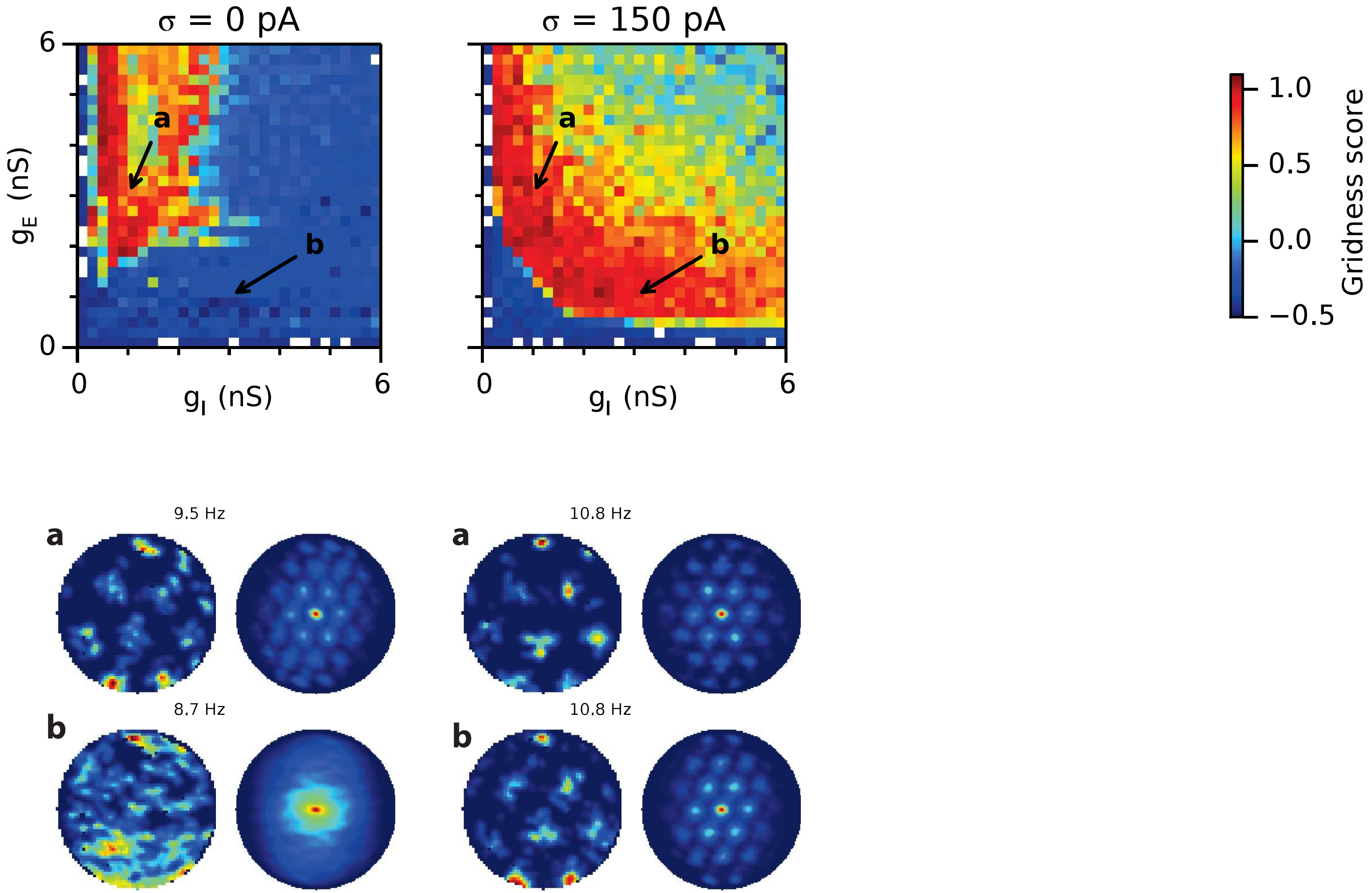






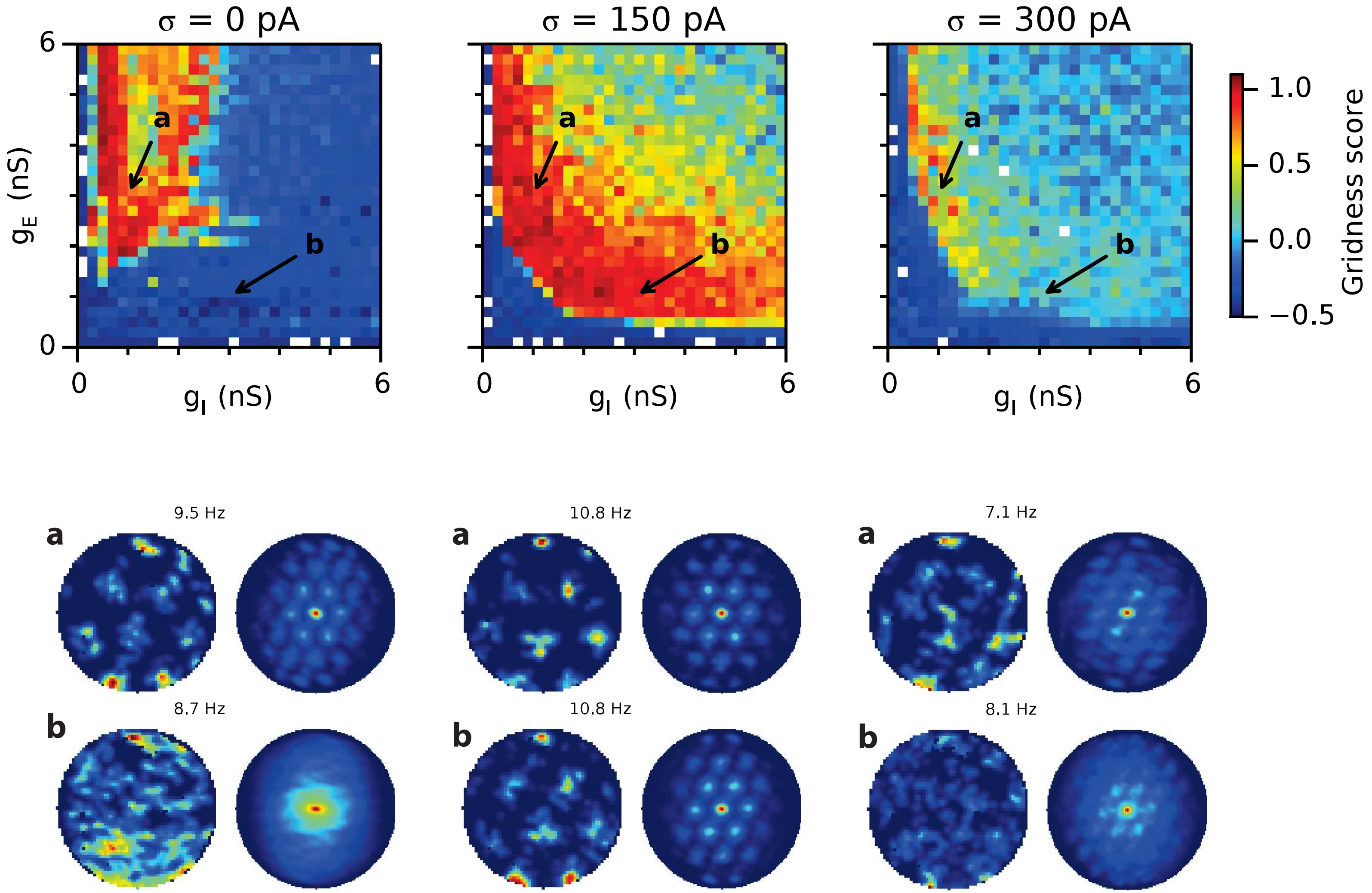
Solanka et al., eLife (2015)

Introducing intrinsic noise makes grid firing robust to changes in synaptic strength



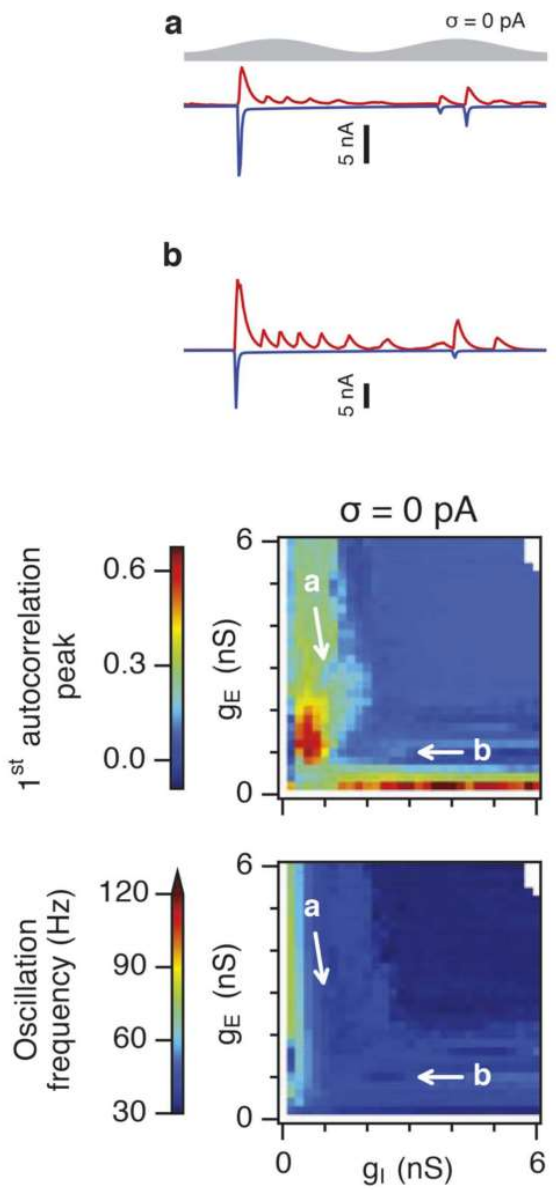
Solanka et al., eLife (2015)

Adding more noise impairs grid firing



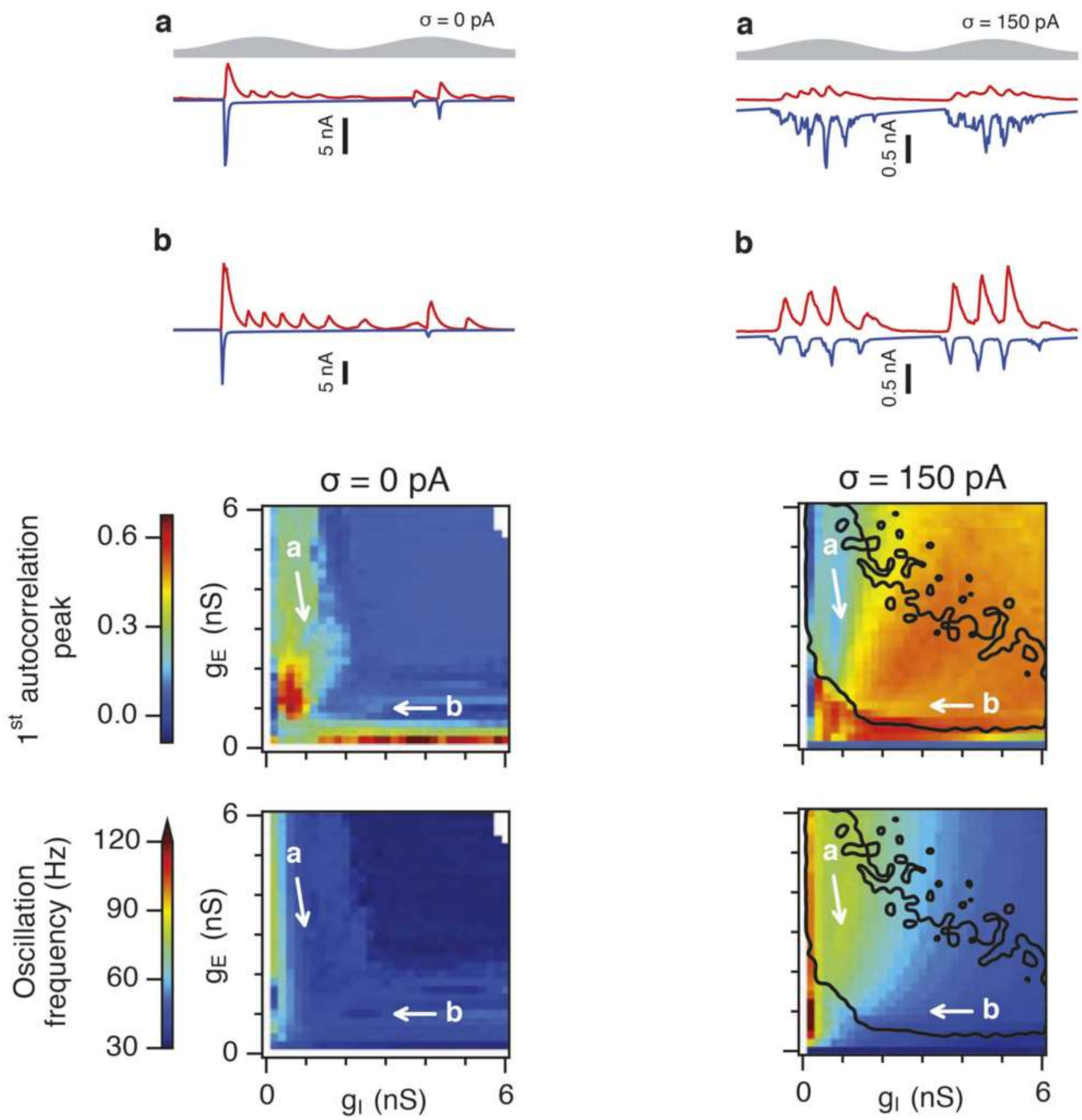
Solanka et al., eLife (2015)

Gamma oscillations are absent in noise free networks



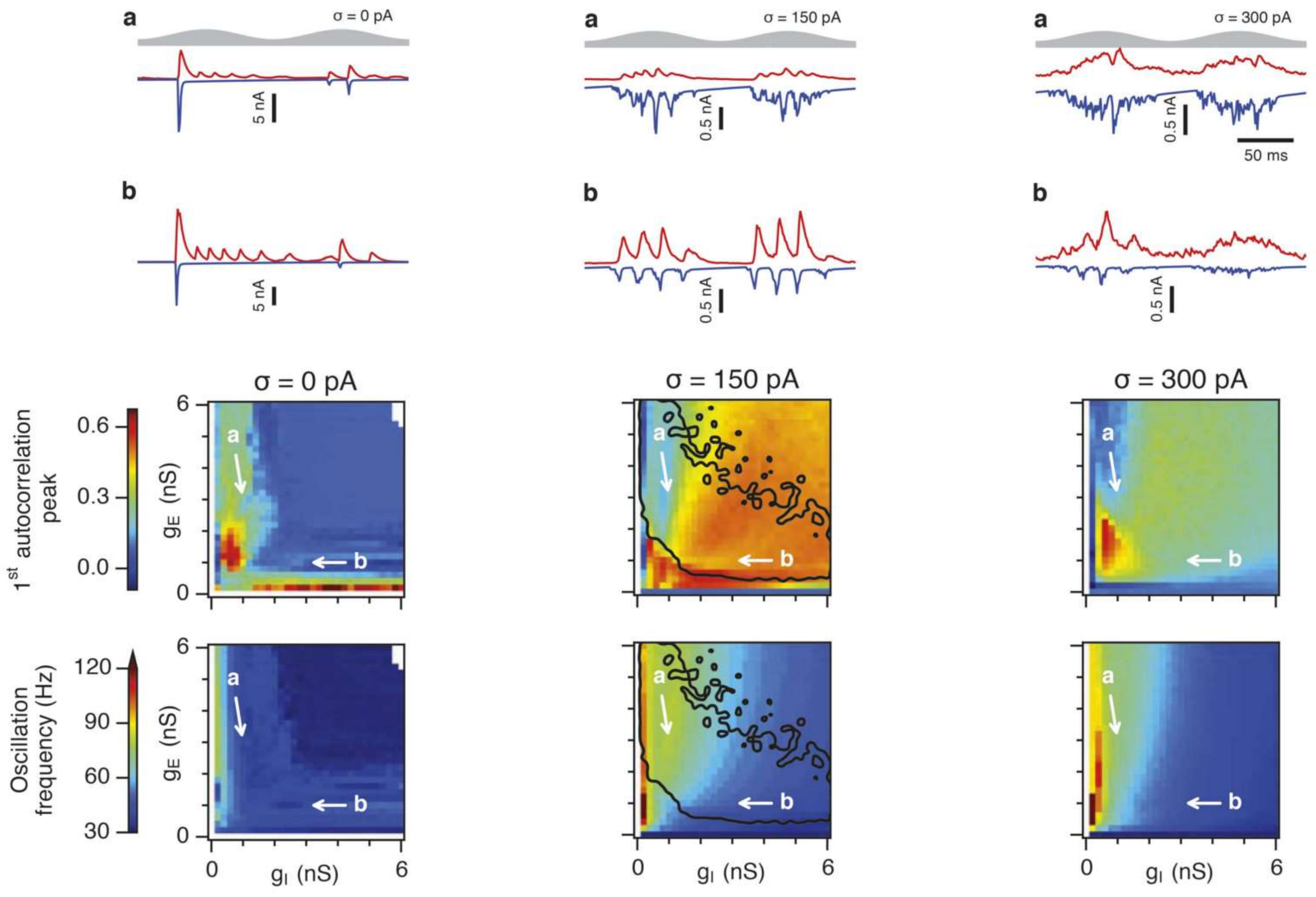
Solanka et al., eLife (2015)

Theta-nested gamma oscillations emerge with introduction of intrinsic noise



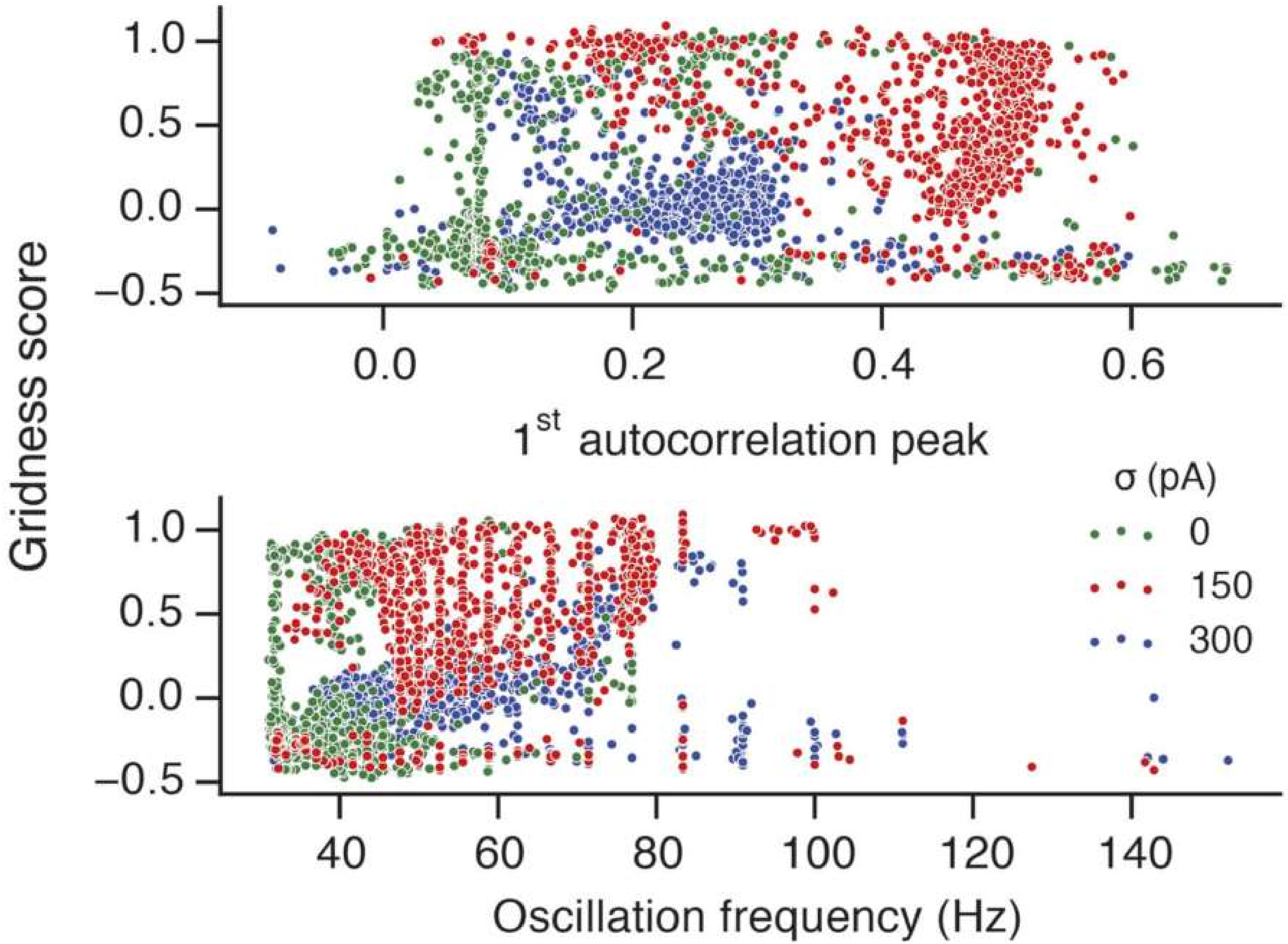
Solanka et al., eLife (2015)

Additional noise suppresses gamma oscillations



Solanka et al., eLife (2015)

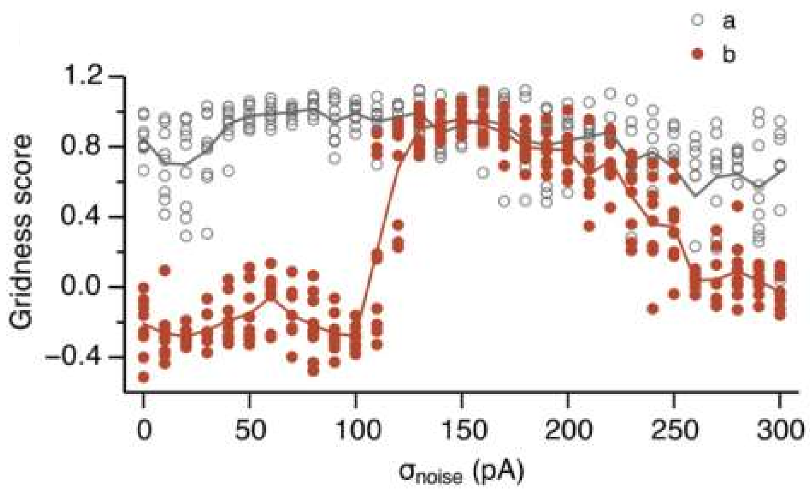
Properties of gamma oscillations vary with synaptic strength, but do not predict rate coded grid computations



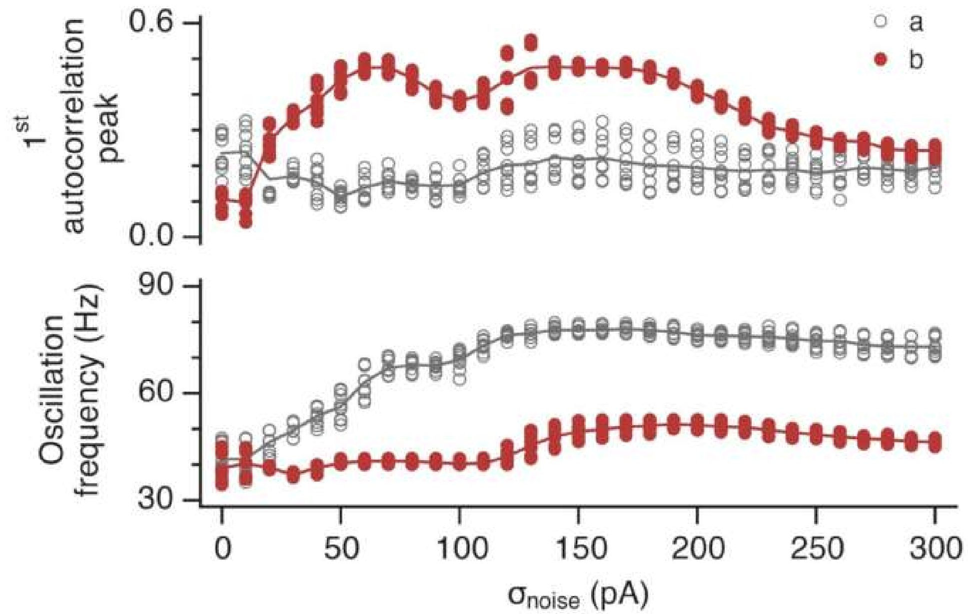
Solanka et al., eLife (2015)

Noise-dependence of grid firing and gamma oscillations

Grid firing

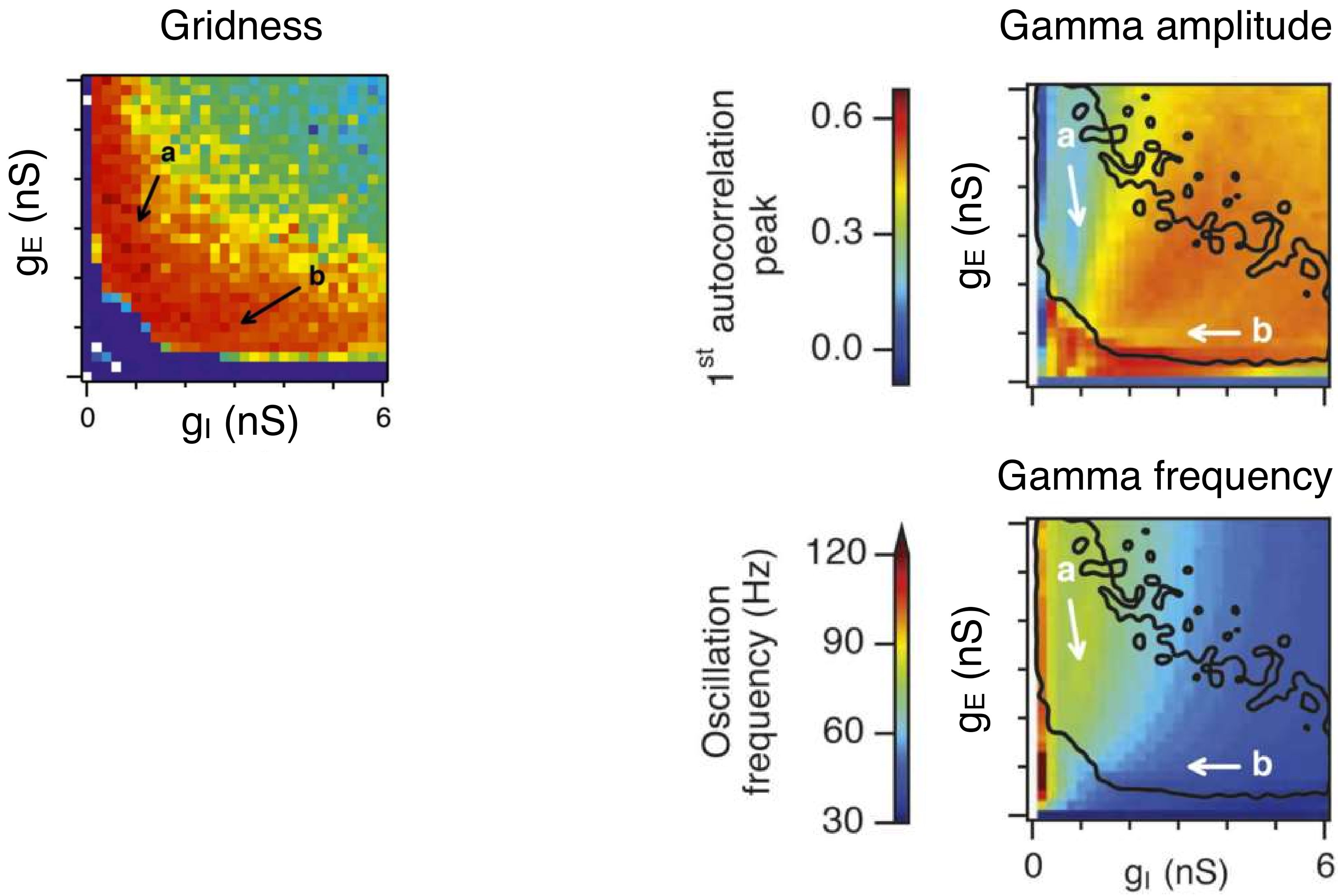


Gamma oscillations



Solanka et al., eLife (2015)

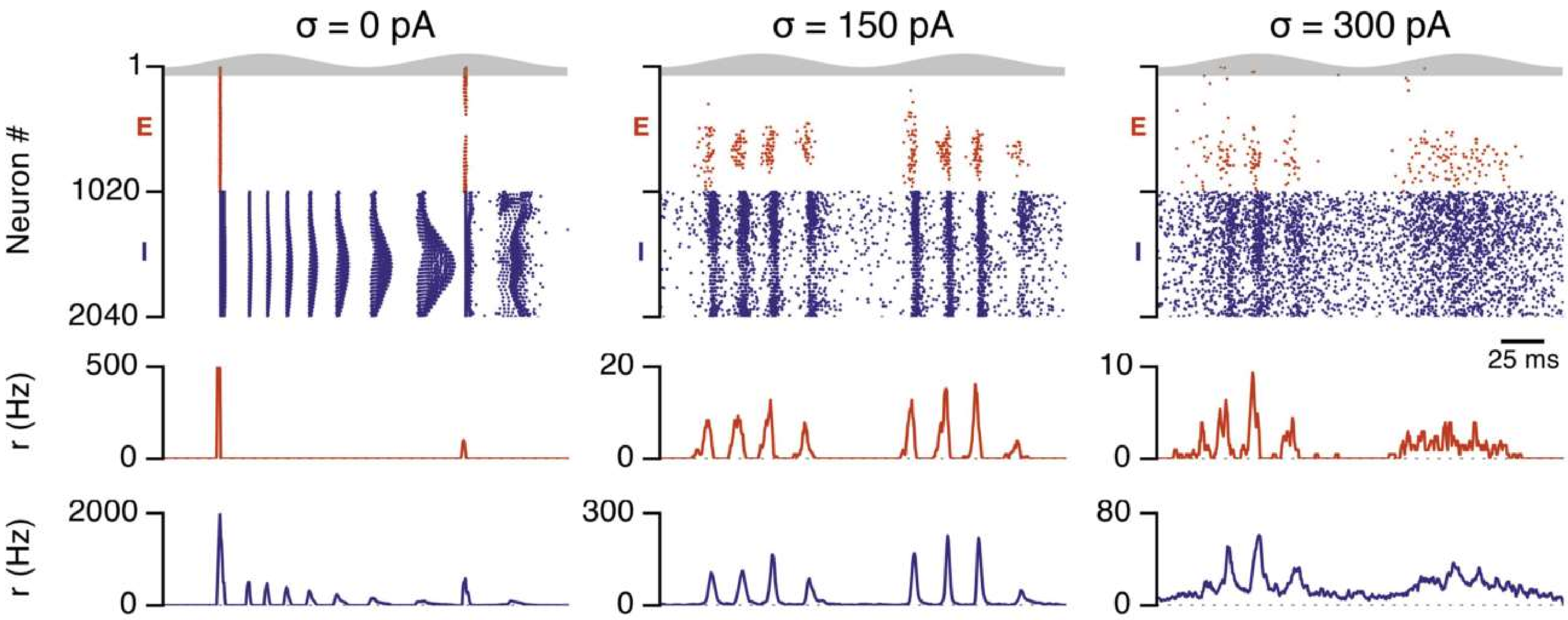
Gamma oscillations can be tuned while maintaining grid firing



Solanka et al., eLife (2015)

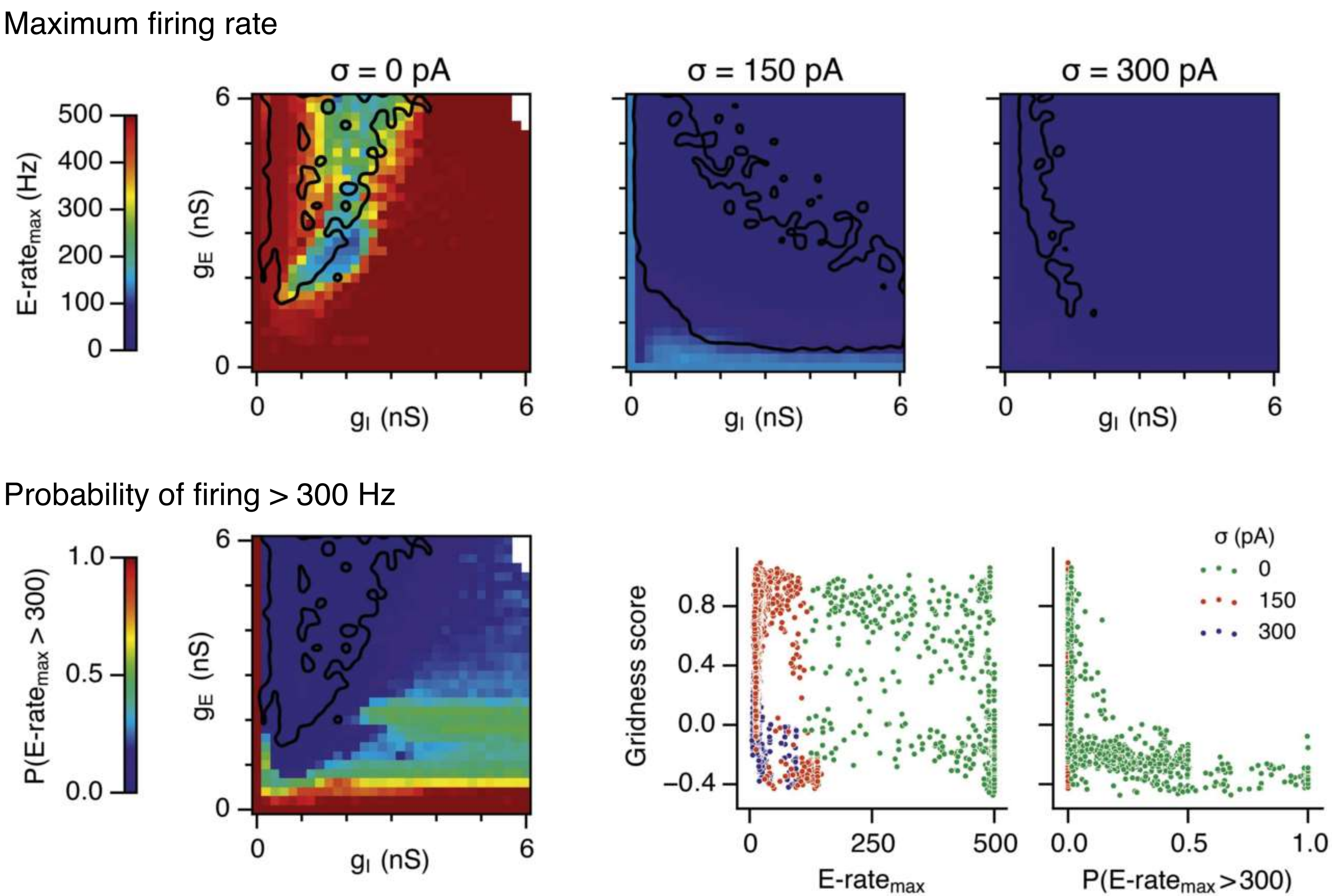
How does intrinsic noise promote grid firing and gamma oscillations?

Seizure-like states emerge in the absence of intrinsic noise



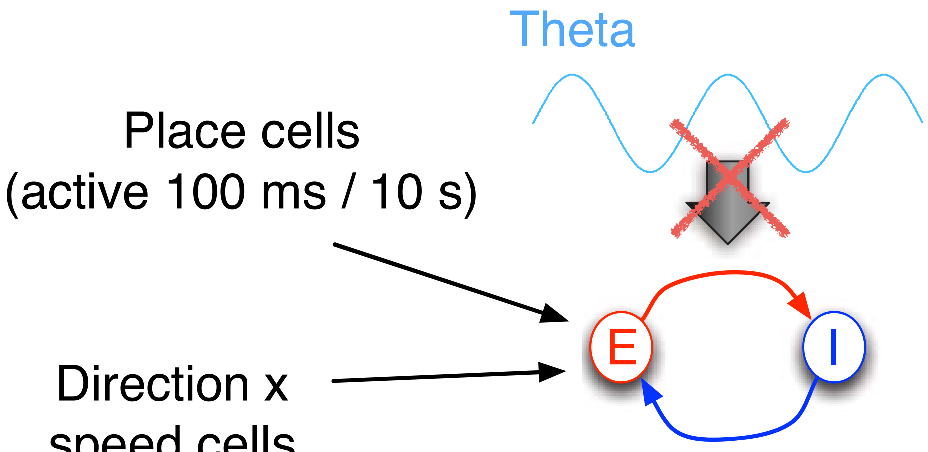
Solanka et al.,
eLife (2015)

Frequent seizure-like states disrupt grid firing

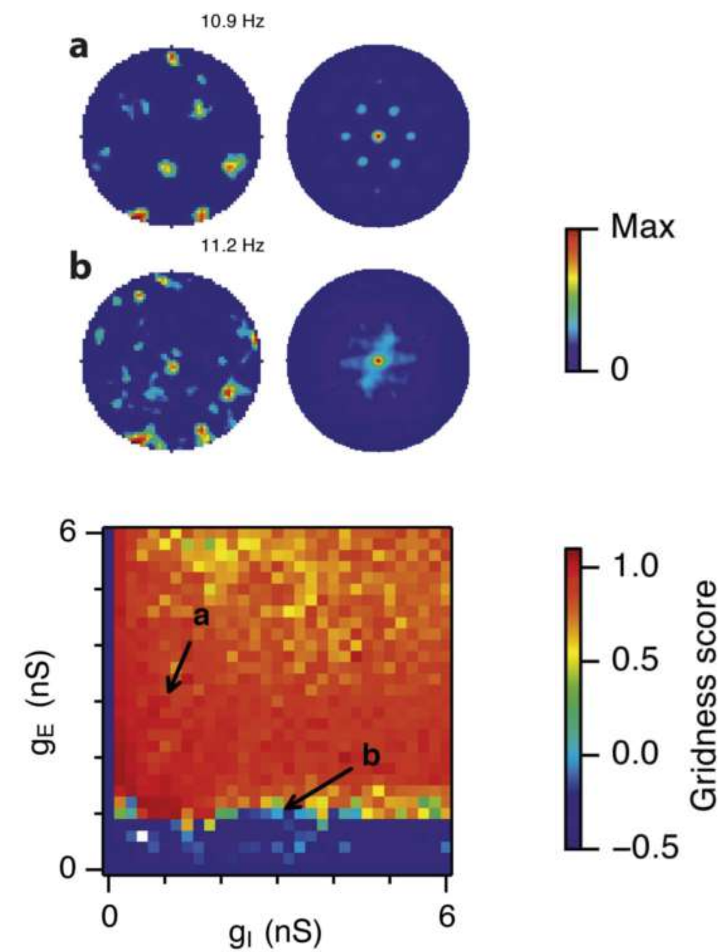


Solanka et al., eLife (2015)

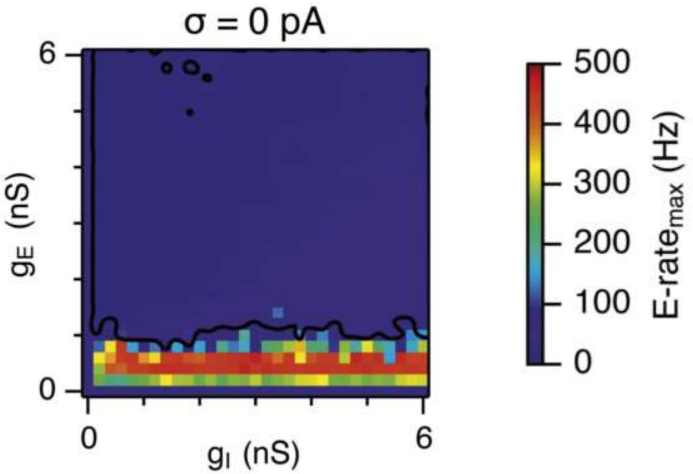
Seizures are reduced when theta input is removed



Grid firing

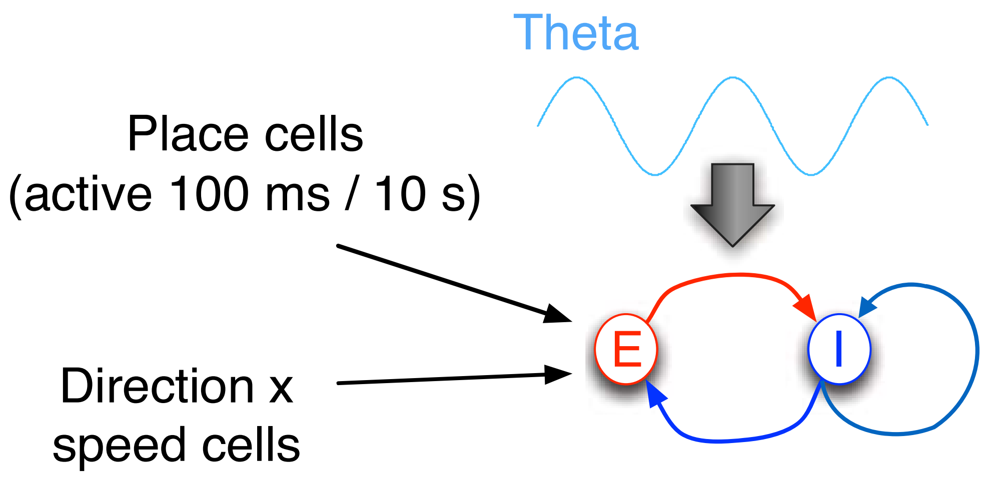


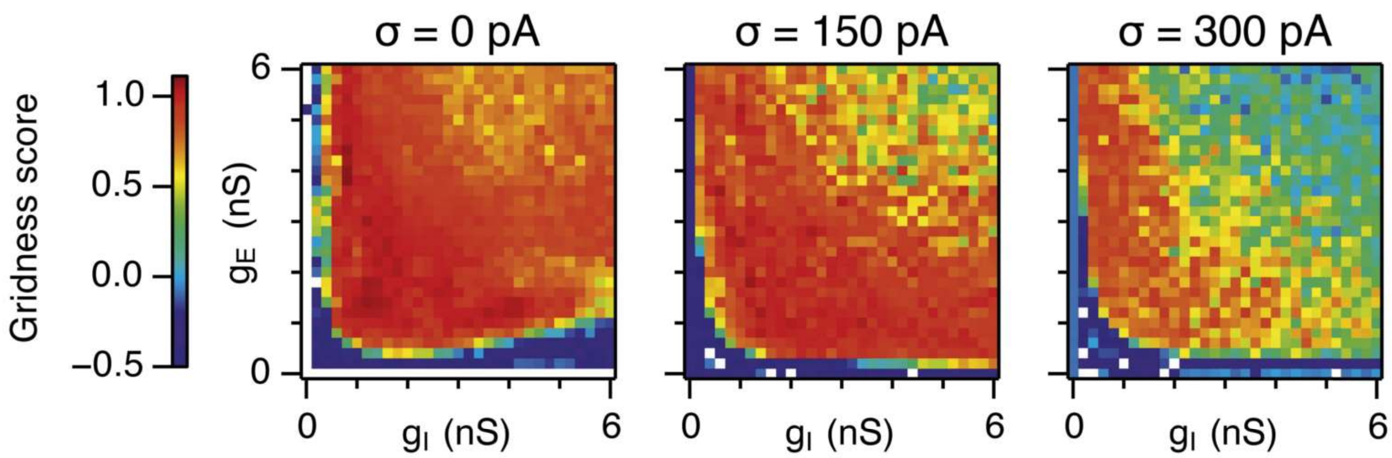
Maximum firing rate



Solanka et al., eLife (2015)

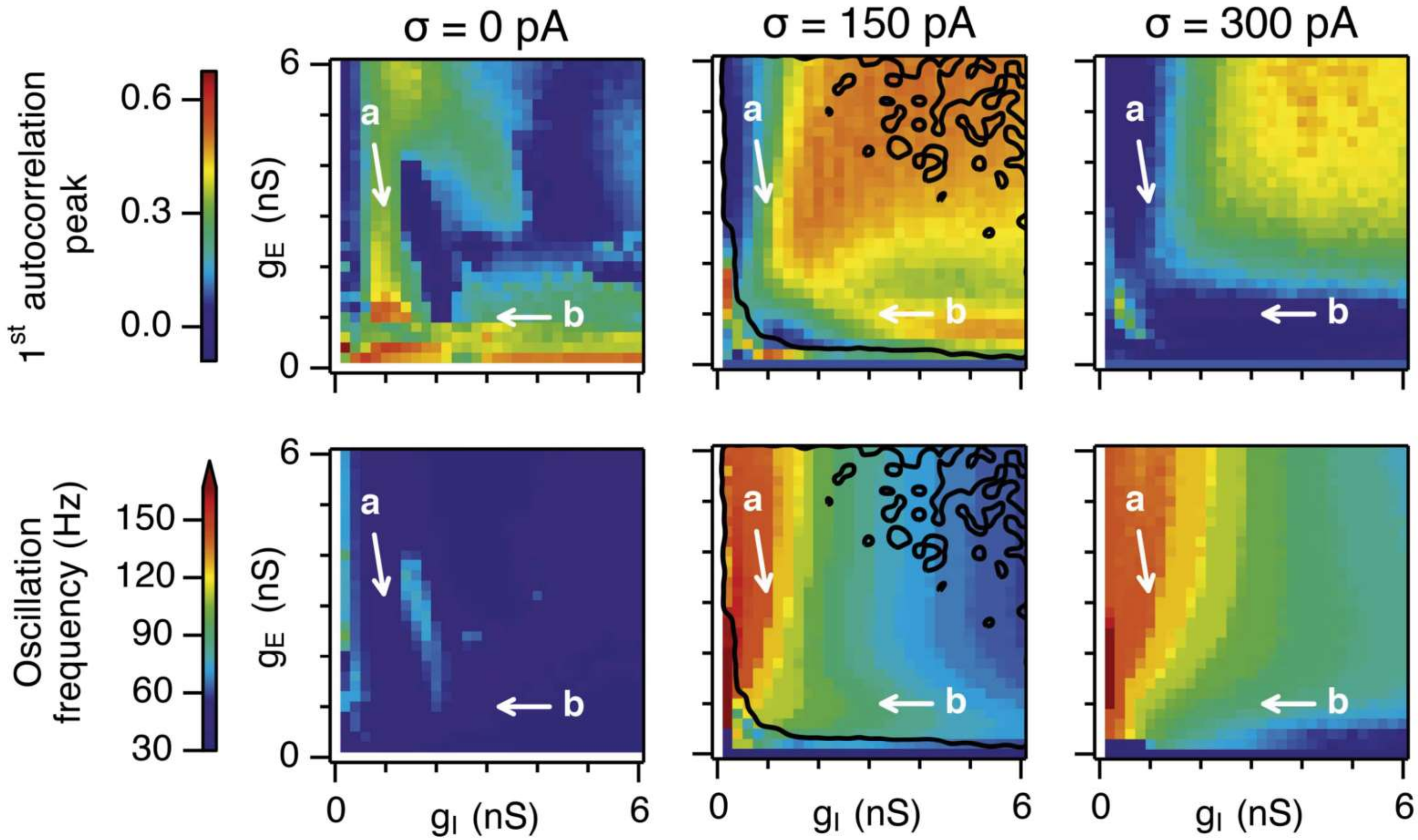
Recurrent inhibition abolishes seizures and promotes grid firing





Solanka et al., eLife (2015)

Gamma oscillations and grid firing can be independently tuned in networks with recurrent inhibition



Solanka et al., eLife (2015)

Summary

1. Experimentally constrained E-I models account for rate coded grid firing and gamma oscillations through a shared circuit mechanism.

2. Rate coded grid firing and gamma oscillations can be independently controlled by adjusting gE or gI.

3. Gamma oscillations vary with network state, but are a poor predictor of rate coded computations.

4. Noise suppresses disruptive seizure-like dynamics.

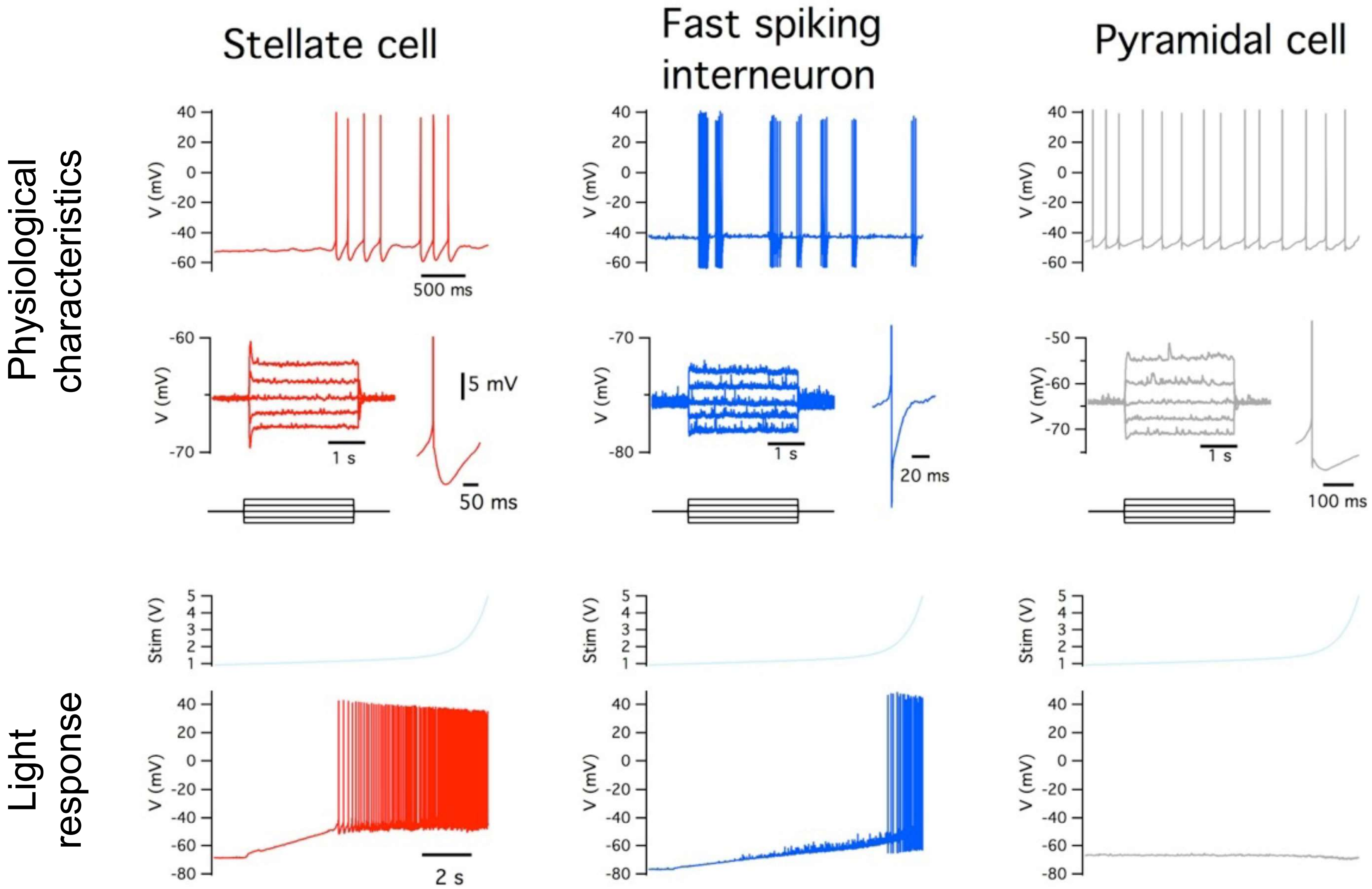
Acknowledgements

Hugh Pastoll
Helen Ramsden
Lukas Solanka

Mark van Rossum

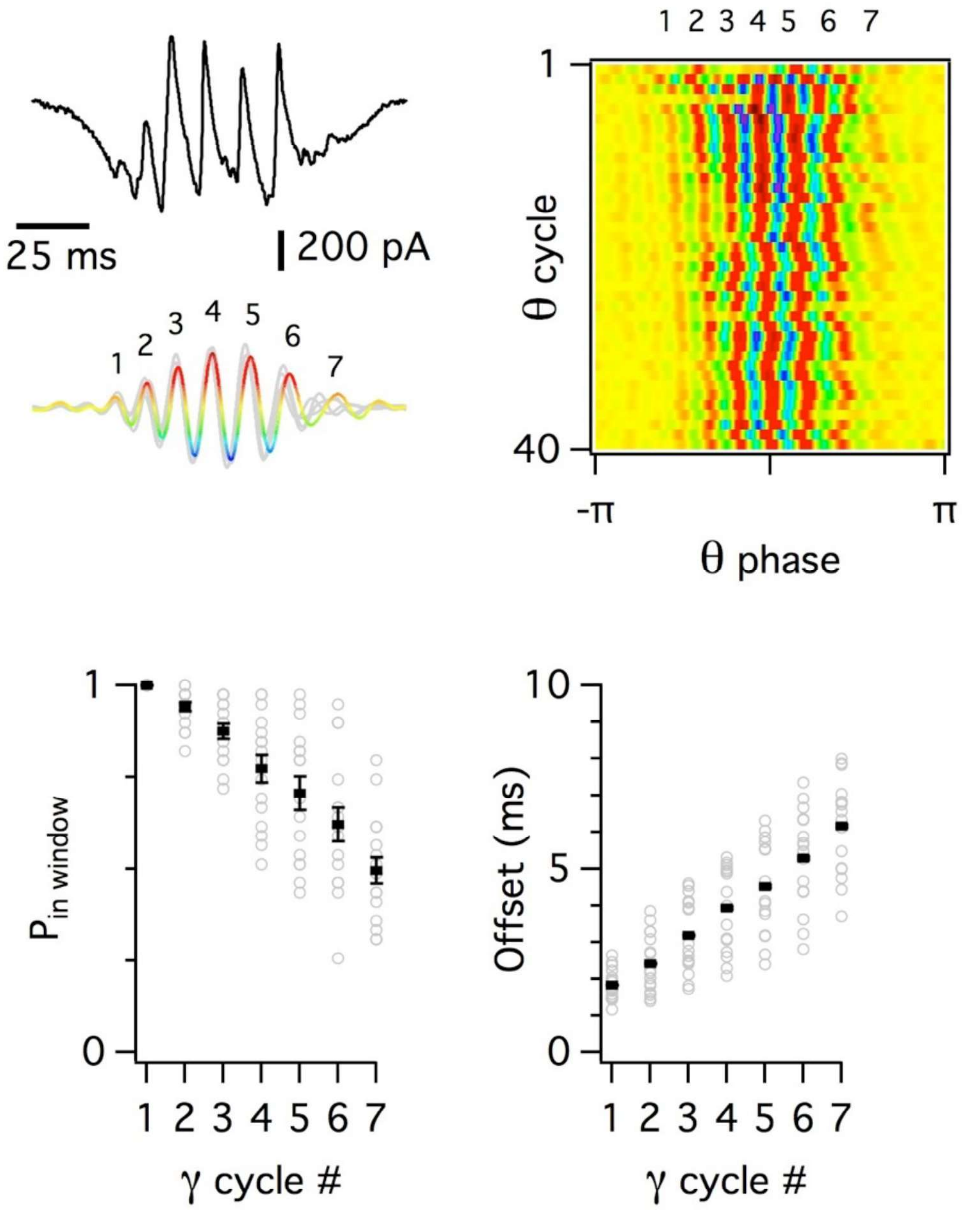
Code: https://github.com/MattNolanLab/ei-attractor

Selective optical activation of stellate cells and fast spiking interneurons



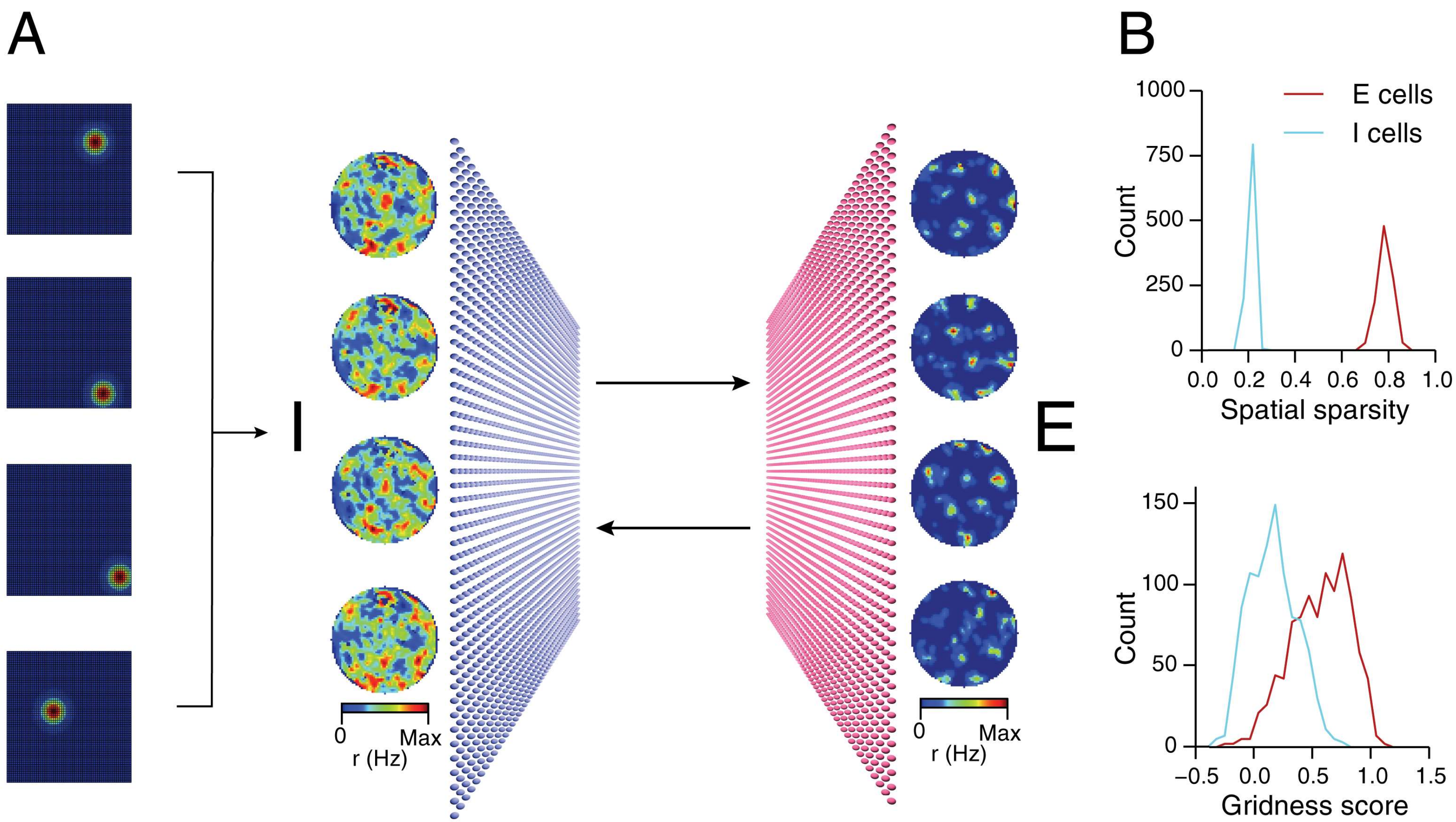
Hugh Pastoll

Timing of gamma oscillations relative to theta is consistent



Pastoll, Solanka, van Rossum and Nolan, Neuron (2013)

Grid firing is maintained when interneurons receive "noisy" spatial inputs



Grid patterns of interneuron firing become undetectable

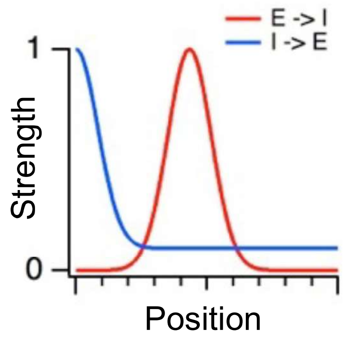
A subset of excitatory cells have grid firing fields

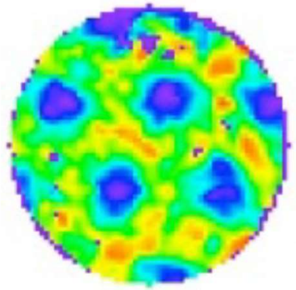
Solanka, van Rossum and Nolan, eLife (2015)
Shipston-Sharma, Solanka and Nolan, J. Physiol. (2016)

E-I models predict that interneurons have spatial firing fields

Model with surround excitation

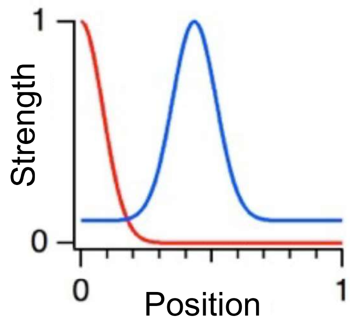
Interneuron firing field

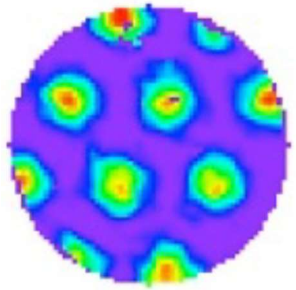




Model with surround inhibition

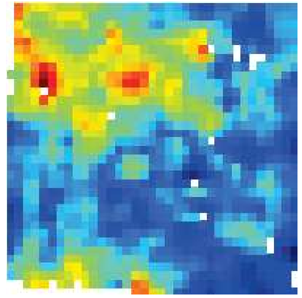
Interneuron firing field





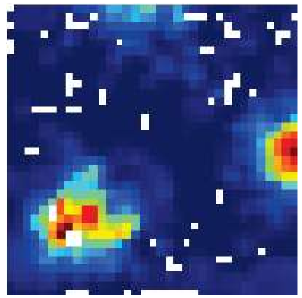
Experimentally observed interneuron firing fields (Buetferring, Allen & Monyer, Nature Neuroscience (2014)

62.2 Hz



High spatial information, low grid score

25.6 Hz



High spatial information, high grid score (n = 12 / 140)

Spatial representation by interneurons depends on network organization

Pastoll, Solanka, van Rossum and Nolan, Neuron (2013)