Bursting emerges from synaptic adaptation in networks of coupled spiking neurons

Richard Gast[1,*], Helmut Schmidt[1] & Thomas R. Knösche[1,2]

[1] Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

[2] Technische Universität Ilmenau, Ilmenau, Germany

* rgast@cbs.mpg.de

Introduction

- Next to intrinsically bursting cells (e.g. [1]), bursting cells have also been found in coupled cell populations without known intrinsic bursting mechanisms [2,3], suggesting that bursting can also emerge from network interactions.
- So far, among proposed mechanisms for emergent bursting are excitatory-inhibitory feedback loops [2], neuromodulatory effects [3] and feedforward inhibition.
- In this study, we investigate bursting as a phenomenon emerging from short-term, synaptic adaptation mechanisms in a globally coupled network of quadratic integrate-and-fire neurons (QIF). To this end, we employ both a microscopic and a macroscopic description of the network dynamics

Methods

Microscopic description: The membrane potential V_i of each QIF neuron is given by

$$\tau \dot{V}_i = V_i^2 + \eta_i + I(t) + J s \tau \qquad s = \frac{1}{N}\sum_{j=1}^{N}\sum_{k \backslash t_j^k < t} \delta(t - t_j^k)$$

η_i	excitability of neuron	τ	membrane time constant
J	global coupling strength	$I(t)$	extrinsic input

Macroscopic description: Employs the mean-field derivation of Montbrió *et al.* [4] that describes the macroscopic dynamics in terms of the average firing rate *r* and average membrane potential *v*:

$$\tau \dot{r} = \frac{\Delta}{\pi \tau} + 2rv \qquad \tau \dot{v} = v^2 + \eta + I(t) + J s \tau - (\pi r \tau)^2$$

η	mean excitability in population
Δ	FWHM of excitability in population

Short-term adaptation: Adding a neuron-specific adaptation variable A_i coupled to the mean-field *s*, the adaptation variable reduces to a mean-field as well. Thus, the evolution equation of the average membrane potential changes to $\tau \dot{v} = v^2 + \eta + I(t) + J(1-A) r \tau - (\pi r \tau)^2$ with adaptation dynamics *A* modeled as convolution of *r* with an alpha kernel:

$$\tau_A \ddot{A} = \alpha r - 2\dot{A} - \frac{A}{\tau_A}$$

α	adaptation rate	τ_A	adaptation time constant

Results

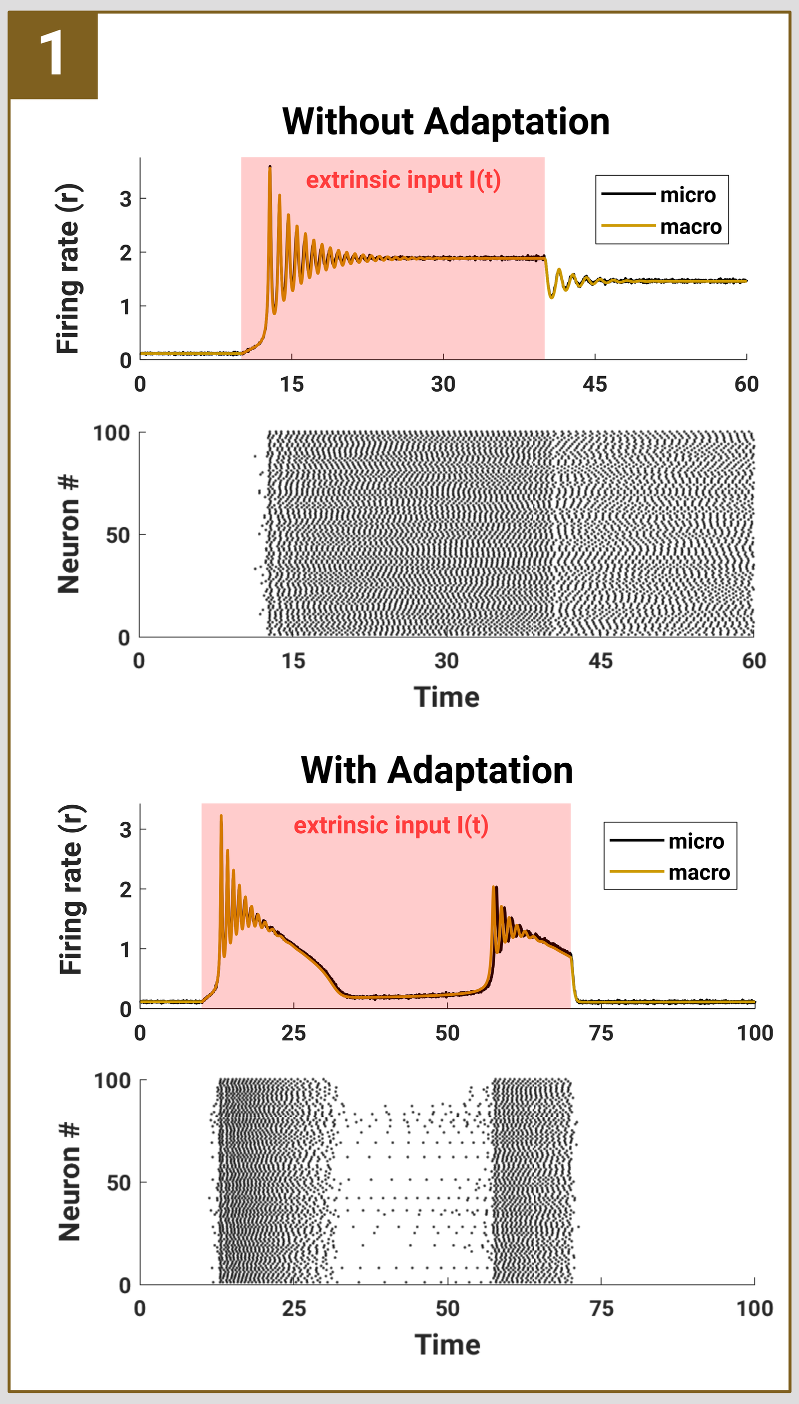


Figure 1: Numerical simulation of QIF population dynamics with and without synaptic adaptation

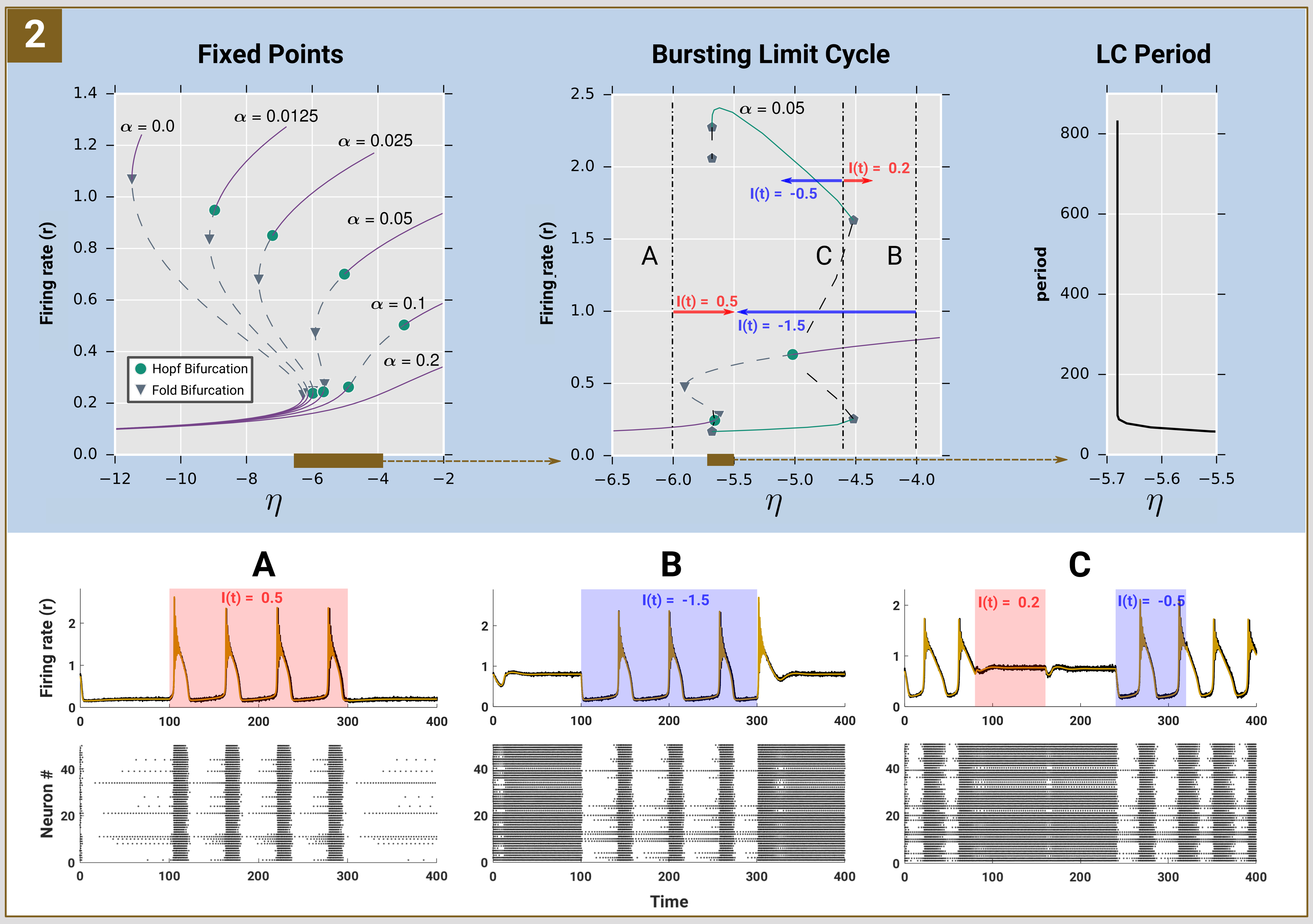


Figure 2: One parameter continuation of macroscopic QIF population dynamics with microscopic validations of the major bifurcations

Figure 3: Investigation of the stability and period of the busting limit cycle in two parameters

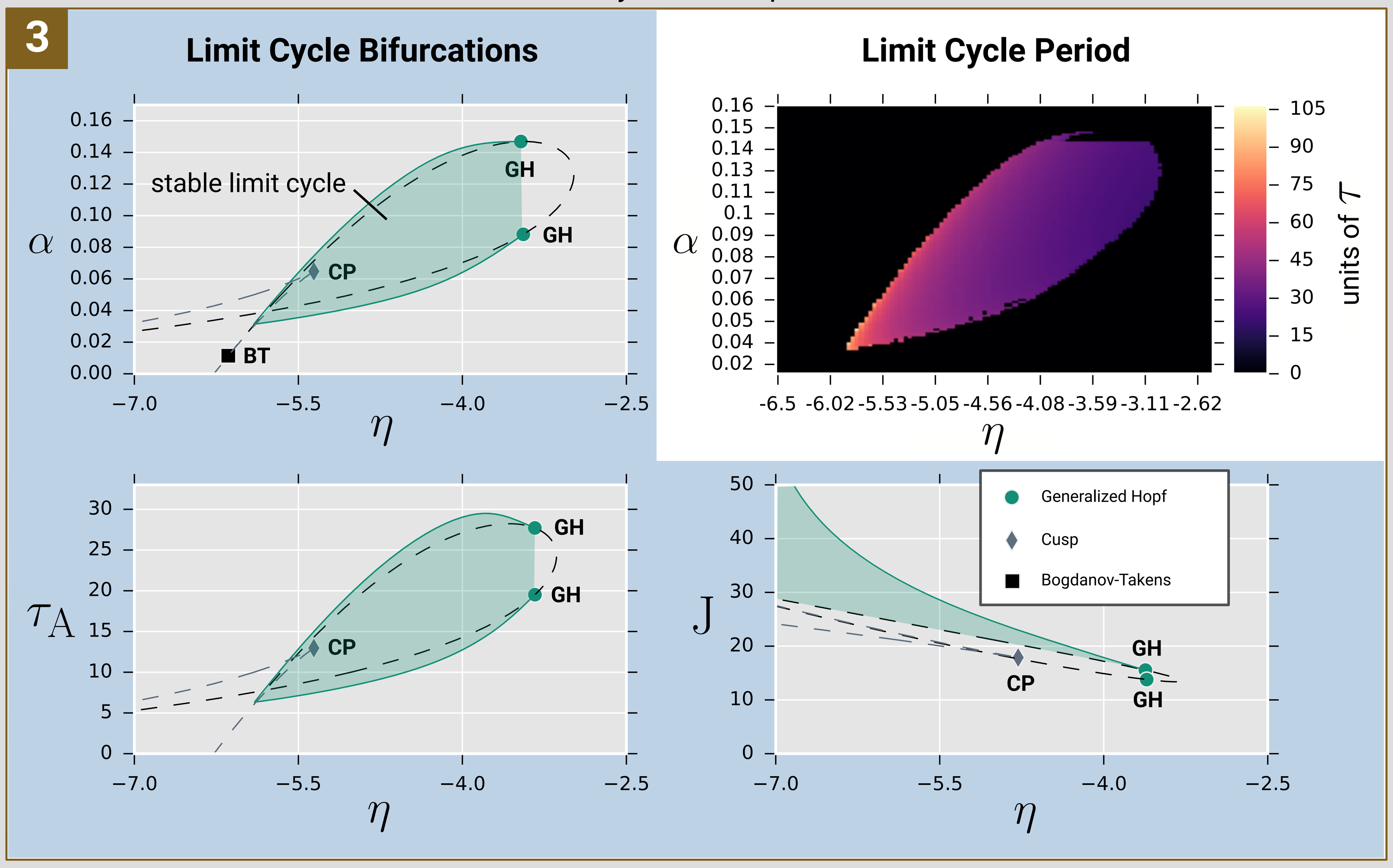
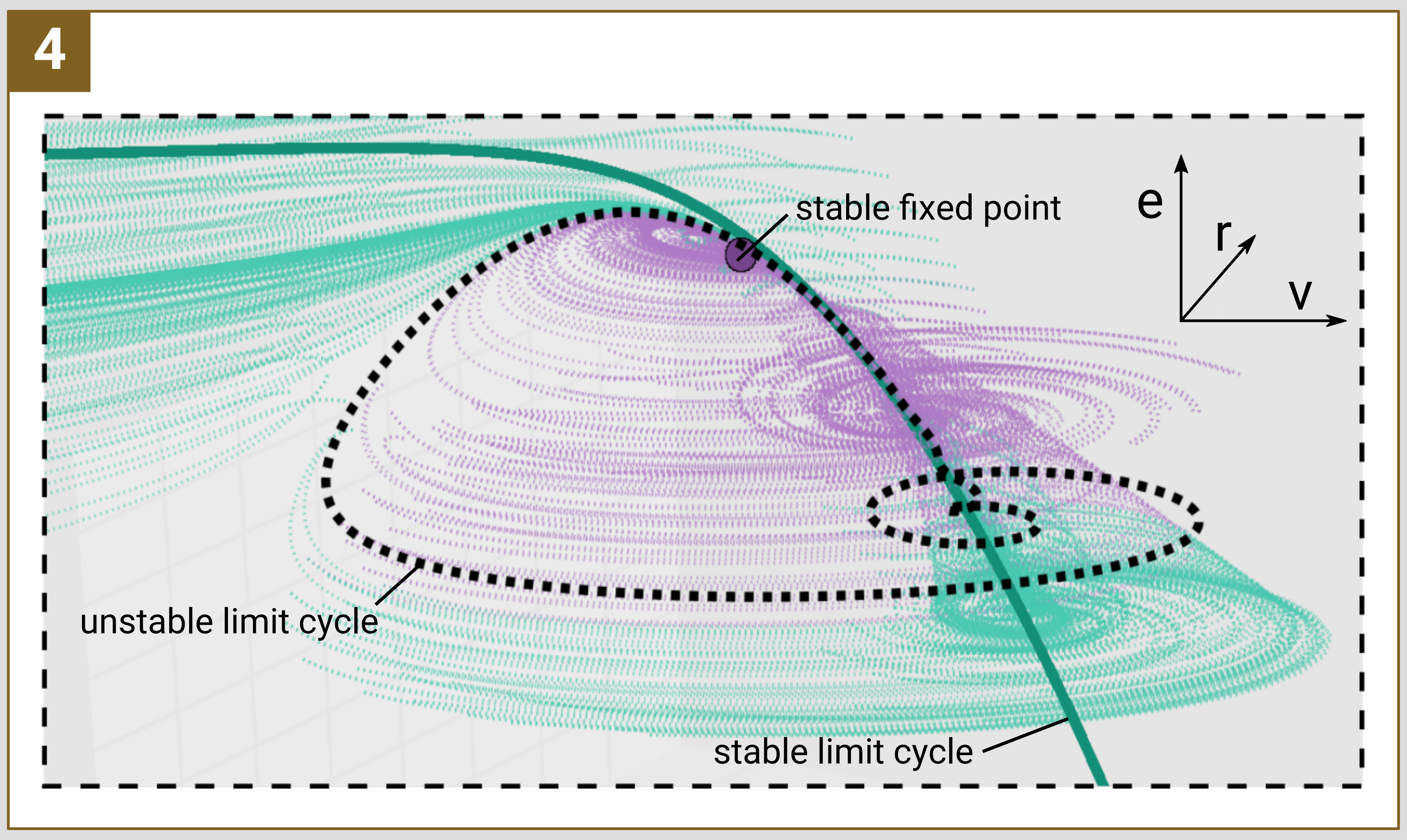


Figure 4: Depiction of the attractor landscape within the bi-stable dynamic regime



Conclusion

- Dynamic, short-term adaptation of post-synaptic efficacies can lead to the emergence of bursting in a globally coupled, excitatory population of spiking neurons.
- Necessary conditions for this are (**a**) a slow adaptation time-scale compared to the membrane time constant, (**b**) sufficiently strong coupling and (**c**) sufficiently strong adaptation.
- Hysteresis can be observed for systematic changes of the excitability of the QIF population.
- These results have been found in both the macroscopic and microscopic description of the population dynamics. Their generalization to other populations and adaptation mechanisms are currently investigated.

References

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