DY 58: Chimera states: symmetry-breaking in dynamical networks (joint session DY/SOE)

Time: Thursday 10:00–13:00 Location: BH-N 128

DY 58.1 Thu 10:00 BH-N 128

Optimal design of the Tweezer control for chimera states — •Iryna Omelchenko[1], Oleh E. Omel'chenko[2], Anna Zakharova[1], and Eckehard Schöll[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Germany — [2]Weierstrass Institute, Berlin, Germany

Chimera states are complex spatio-temporal patterns which consist of coexisting domains of spatially coherent and incoherent dynamics in systems of coupled oscillators. In small networks, chimera states usually exhibit short lifetimes and erratic drifting of the spatial position of the incoherent domain. We introduce a tweezer feedback control scheme which can effectively stabilize and fix the position of chimera states in small systems [1]. We analyse the action of the tweezer control in small nonlocally coupled networks of Van der Pol and FitzHugh-Nagumo oscillators, and determine the ranges of optimal control parameters. We demonstrate that the tweezer control scheme allows for stabilization of chimera states with different shapes, and can be used as an instrument for controlling the coherent domains size, as well as the maximum average frequency difference of the oscillators.

[1] I. Omelchenko, O. E. Omel'chenko, A. Zakharova, M. Wolfrum, and E. Schöll, Phys. Rev. Lett. **116**, 114101 (2016).

DY 58.2 Thu 10:15 BH-N 128

Asymmetric frequencies in symmetric oscillator networks — •Diemut Regel[1,2] and Marc Timme[1,2] — [1]Network Dynamics, Max Planck Institute for Dynamics and Self-Organization, 37077 Goettingen — [2]Chair for Network Dynamics, Center for Advancing Electronics (cfaed) and Institute for Theoretical Physics, TU Dresden, 01062 Dresden

The emergence of collective order fundamentally underlies the function of dissipative dynamical systems. Certain symmetries such as a continuous translation symmetry or a discrete permutation symmetry constitute common conditions to enable dynamical ordering processes. Homogeneous changes to local system properties do not affect such symmetries. Here we report that homogeneously decreasing the entirely local self-interactions in symmetrically pulse-coupled oscillator networks may remove constraints common in all oscillator networks coupled continuously in time and thereby enable increased disorder during collective transient dynamics. Moreover, the persistent long-term dynamics may exhibit asymmetrically disordered average frequencies despite the system being entirely symmetric. We explain and systematically evaluate this anomalous phenomenon of collective network dynamics.

DY 58.3 Thu 10:30 BH-N 128

Chimeras in a minimal oscillator network and its thermodynamic counterpart — •Sindre W. Haugland[1,2], Felix Kemeth[1,2], and Katharina Krischer[1] — [1]Physik-Department, Nonequilibrium Chemical Physics, Technische Universität München, James-Franck-Str. 1, D-85748 Garching, Germany — [2]Institute for Advanced Study - Technische Universität München, Lichtenbergstr. 2a, D-85748 Garching, Germany

A network of nonlinear oscillators can exhibit chimera states, the coexistence of synchronized and desynchronized oscillation, for uniform parameters and symmetrical coupling. In the case of nonlinearly coupled Stuart-Landau oscillators, chimera states form spontaneously from generic initial conditions even when the coupling is purely global.

Here, we start by considering a minimal model of only four globally coupled Stuart-Landau oscillators, identifying a multitude of chimera and related states with a varying degree of symmetry, as well as the specific bifurcations in which these states are created and destroyed. Some of these states are also found to be co-stable. By systematically increasing the ensemble size, we subsequently trace how the minimal states develop and identify which of them give rise to the already known macroscopic chimera states.

DY 58.4 Thu 10:45 BH-N 128

Symmetry-Broken Amplitude- and Phase-Locking in Two Identical Symmetrically Coupled Stuart-Landau Oscillators — •André Röhm and Kathy Lüdge — Institut für Theoretische Physik, TU Berlin

In the model system of two instantaneously and symmetrically coupled identical Stuart-Landau oscillators we demonstrate that there exist stable solutions with symmetry-broken amplitude- and phase-locking. Similar to Chimera States, these states are a simple and approachable example of symmetry-breaking in oscillatory systems. They are characterized by a non-trivial fixed phase and amplitude relationship between both oscillators, while simultaneously maintaining perfectly harmonic oscillations of the same frequency. This is despite the fact, that we do not employ a symmetry-breaking coupling. These states have potential applications as bistable states for switches in a wide array of coupled oscillatory systems.

While some of the surrounding bifurcations have been previously described, we present the first detailed analytical and numerical description of these states and present analytically and numerically how they are embedded in the bifurcation structure of the system, arising both from the in-phase as well as the anti-phase solutions. The dependence of both the amplitude and the phase on parameters can be expressed explicitly with analytic formulas. As opposed to previous reports, we find that these symmetry-broken states are stable, which can we can show analytically.

DY 58.5 Thu 11:00 BH-N 128

Experimental observation of spiral wave chimeras in coupled chemical oscillators — •Jan Frederik Totz[1], Julian Rode[1], Mark Tinsley[2], Kenneth Showalter[2], and Harald Engel[1] — [1]Technische Universität Berlin, Berlin, Germany — [2]West Virginia University, Morgantown, USA

In 2002, studying synchronization of nonlocally coupled oscillators, Kuramoto and coworkers made a remarkable observation: Although both the natural frequency of the individual oscillators as well as their coupling among each other were identical, for certain initial conditions some oscillators became phase-synchronized while others do not [1]. The discovery of this counterintuitive state, named chimera state, triggered an increasing number of studies on partial synchronization. I will present a versatile setup based on optically coupled catalytic micro-particles [2], that allows for the experimental study of synchronization patterns in very large networks of relaxation oscillators under well-controlled laboratory conditions. In particular I will show our experimental observation of the spiral wave chimera, predicted by Kuramoto [2]. This pattern features a wave rotating around a spatially extended core that consists of phase-randomized oscillators [3].

[1] Kuramoto in Nonlinear Dynamics and Chaos, CRC Press (2002)

[2] Taylor et al. PCCP (2015)

[3] Totz et al. Nature Physics (2017)

15 min. break

DY 58.6 Thu 11:30 BH-N 128

Chimera states in multi-strain epidemic models with temporary immunity — •Philipp Hövel[1,2], Larissa Bauer[1], Jason Bassett[1], Yuliya Kyrychko[3], and Konstantin Blyuss[3] — [1]TU Berlin — [2]BCCN Berlin — [3]University of Sussex

We investigate a time-delayed epidemic model for multi-strain diseases with temporary immunity [1]. In the absence of cross-immunity between strains, dynamics of each individual strain exhibits emergence and annihilation of limit cycles due to a Hopf bifurcation of the endemic equilibrium, and a saddle-node bifurcation of limit cycles depending on the time delay associated with duration of temporary immunity. Effects of all-to-all and non-local coupling topologies are systematically investigated by means of numerical simulations, and they suggest that cross-immunity is able to induce a diverse range of complex dynamical behaviors and synchronization patterns, including discrete traveling waves, solitary states, and amplitude chimeras. Interestingly, chimera states are observed for narrower cross-immunity kernels, which can have profound implications for understanding the dynamics of multi-strain diseases.

Reference: [1] L. Bauer, J. Bassett, P. Hövel, Y. N. Kyrychko, and K. B. Blyuss, CHAOS **27**, 114317 (2017).

DY 58.7 Thu 11:45 BH-N 128

Chimera states in brain networks: empirical neural vs. modular fractal connectivity — •Teresa Chouzouris[1], Iryna

Omelchenko[1], Anna Zakharova[1], Jaroslav Hlinka[2,3], Premysl Jiruska[4], and Eckehard Schöll[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Institute of Computer Science, Czech Academy of Sciences, Pod Vodarenskou vezi 2, 18207 Prague, Czech Republic — [3]National Institute of Mental Health, Topolova 748, 250 67 Klecany, Czech Republic — [4]Institute of Physiology, Czech Academy of Sciences, Videnska 1083, 14220 Prague, Czech Republic

The interplay of synchrony and asynchrony in complex brain networks is an important aspect in studies of both brain function and disease. Motivated by its potential application to epileptology, we analyse and compare the collective dynamics of FitzHugh-Nagumo neurons in complex networks with two topologies: an empirical structural neural connectivity derived from diffusion-weighted magnetic resonance imaging and a mathematically constructed network with modular fractal connectivity [1]. We qualitatively simulate the dynamics of epileptic seizures and study the influence of the removal of nodes on the network synchronizability, which can be useful for applications to epileptic surgery.

[1] T.Chouzouris, I. Omelchenko, A. Zakharova, J. Hlinka, P. Jiruska, and E. Schöll, Chimera states in brain networks: empirical neural vs. modular fractal connectivity. arXiv:1710.08219 (2017).

DY 58.8 Thu 12:00 BH-N 128

Chimera State in Neuron Populations with Dynamical Synapses — Ali Calim[1], Philipp Hövel[2], Mahmut Özer[3], and •Muhammet Uzuntarla[1] — [1]Department of Biomedical Engineering, Bulent Ecevit University, 67100 Zonguldak, TURKEY — [2]Institut für Theoretische Physik, Technische Universitat Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [3]Department of Electrical-Electronics Engineering, Bulent Ecevit University, 67100 Zonguldak, TURKEY

Current literature on Chimera state in neuronal populations mostly discusses the topic with dynamical system arguments which does not provide information about potential concrete biological reasons giving rise to emergence of Chimera in neural medium. With this motivation, our aim is to investigate the influence of short-term synaptic plasticity (STP) on Chimera state in a non-locally coupled network of spiking Morris-Lecar neurons. We first show that Chimera state can appear in population with static synapses (non-plastic) in case of either weak synaptic strength or sparse connectivity between neurons. When there exists strong synaptic strength and dense connectivity, the whole population exhibits synchronized behavior. But, we found that optimal levels of synaptic depression and facilitation at chemical synapses can induce Chimera and Multi Chimera states in such strongly and densely coupled neural populations. Notably, to the best our knowledge, we here show for the first time the existence of Chimera state with Morris-Lecar model neurons.

DY 58.9 Thu 12:15 BH-N 128

Synchronization of chimera states in two-layer networks of nonlocally coupled chaotic maps — •Galina Strelkova[1], Andrei Bukh[1], Eckehard Schöll[2], and Vadim Anishchenko[1] — [1]Saratov State University, Saratov, Russia — [2]Technical University of Berlin, Berlin, Germany

We explore numerically synchronization effects and their dynamical and statistical properties in two different two-layer networks of nonlocally coupled chaotic maps. The first network is represented by two coupled one-layer networks of nonlocally coupled identical logistic maps with a control parameter detuning. The second two-layer network we study is made of two coupled one-layer networks of nonlocally coupled chaotic Henon and Lozi maps. We show that both two-layer networks under consideration can demonstrate the phenomena of external and mutual synchronization of various complex spatiotemporal structures, including different chimera states. We quantify the identity of synchronous structures by calculating the cross-correlation coefficient. In the synchronization regime this characteristic is very close to 1. We also show that the synchronization phenomena in the considered two-layer networks are observed within a finite region in the parameter space. To illustrate this we construct the synchronization regions for synchronized chimera structures in the plane of two control parameters of the considered networks.

DY 58.10 Thu 12:30 BH-N 128

Impact of noise on the lifetime of chimera states and spatio-temporal intermittency in ensembles of nonlocally coupled chaotic oscillators — •Nadezhda Semenova[1], Galina Strelkova[1], Vadim Anishchenko[1], and Anna Zakharova[2] — [1]Department of Physics, Saratov State University, 83 Astrakhanskaya Street, Saratov 410012, Russia — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

We describe numerical results for the dynamics of networks of nonlocally coupled chaotic oscillators. It has been demonstrated that elements in amplitude chimera clusters are characterized by a nonstationary dynamics. This process looks like nonperiodic switchings between amplitude and phase chimeras. It has been shown that in autonomous ensembles, the nonstationary regime of switchings has a finite lifetime and represents a transient process towards a stationary regime of phase chimera. Our numerical studies have shown that a single noise perturbation of the ensemble elements in the nonstationary regime can increase the lifetime (duration) of this mode and even revive the amplitude chimera. If single noise perturbations are introduced into the network elements constantly in certain time intervals, then the transient process can be observed for an infinite time. However, has been established that the noise source, which is constantly acting on the ensemble with the phase chimera, does not induce new regimes and structures and leads only to noisy snapshots. The stationary phase chimera regime turns out to be stable towards noise perturbations.

DY 58.11 Thu 12:45 BH-N 128

Chimera states in networks of logistic maps with hierarchical connectivities — •Alexander zur Bonsen, Iryna Omelchenko, Anna Zakharova, and Eckehard Schöll — Institut für Theoretische Physik, Technische Universität Berlin, Germany

Chimera states are complex spatiotemporal patterns consisting of coexisting domains of coherence and incoherence. We study networks of nonlocally coupled logistic maps and analyze systematically how the dilution of the network links influences the appearance of chimera patterns. The network connectivities are constructed using an iterative Cantor algorithm to generate fractal (hierarchical) connectivities. Increasing the hierarchical level of iteration, we compare the resulting spatiotemporal patterns. We demonstrate that a high clustering coefficient and symmetry of the base pattern promotes chimera states, and asymmetric connectivities result in complex nested chimera patterns.

A. zur Bonsen, I. Omelchenko, A. Zakharova, and E. Schöll, *Chimera states in networks of logistic maps with hierarchical connectivities.* arXiv:1711.03287 (2017)