Lecture 11

Chimera patterns in networks: amplitude chimeras, chimera death and coherence-resonance chimeras

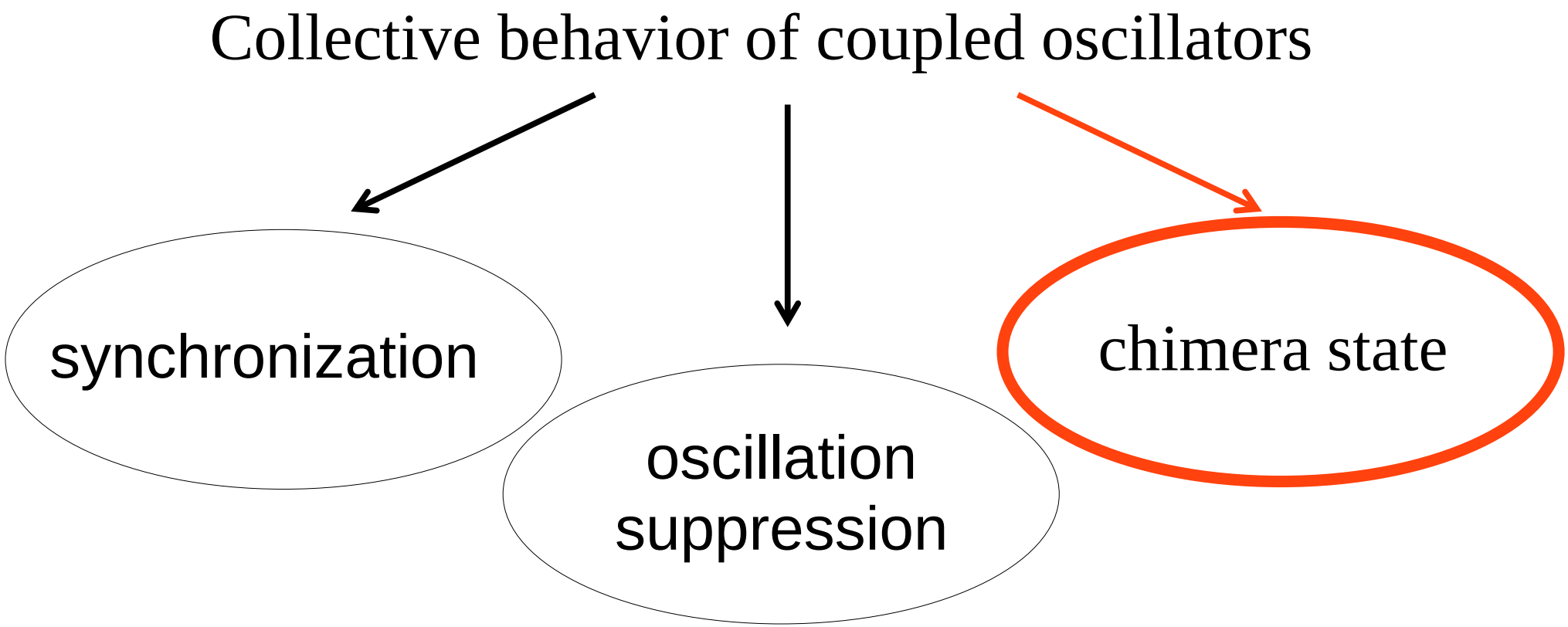
Anna Zakharova

SS 2019 “Nonlinear Dynamics in Complex networks”.

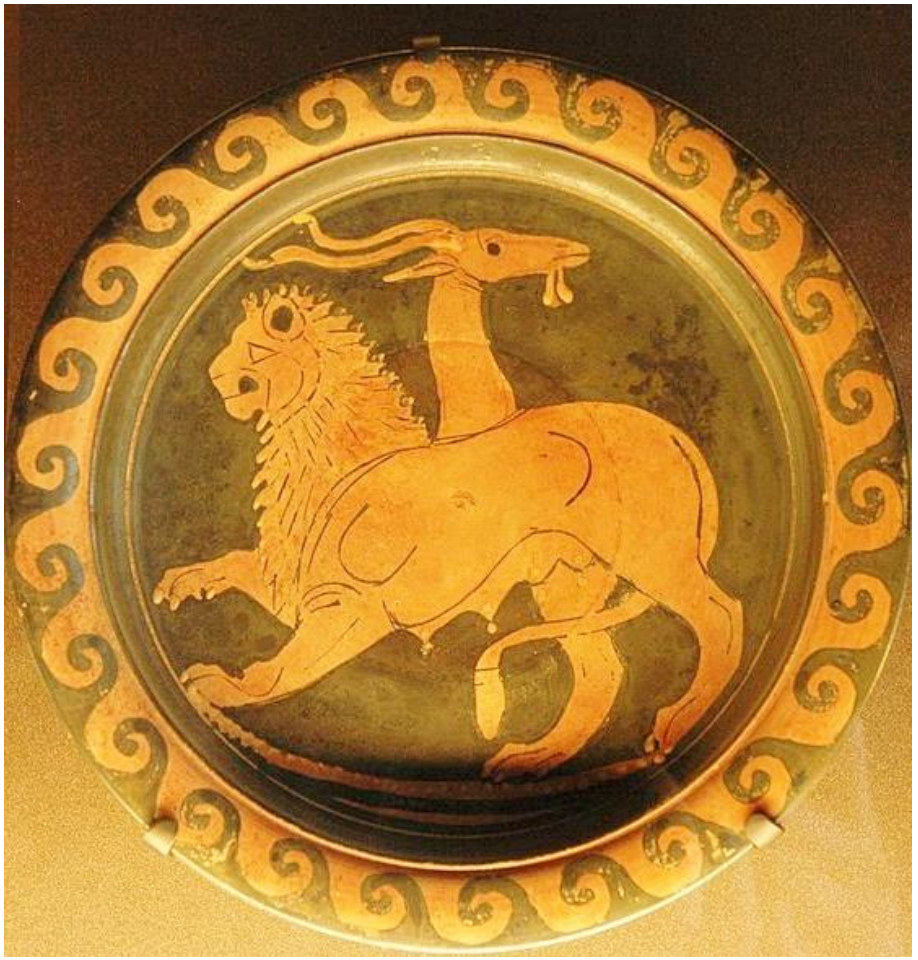
Outline

- Introduction: what is a chimera state?
- Amplitude chimeras and chimera death
- Coherence-resonance chimeras
- Conclusions and outlook

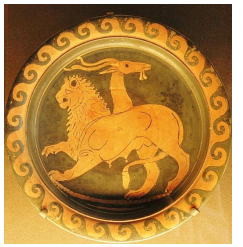
Introduction



What is a chimera state?

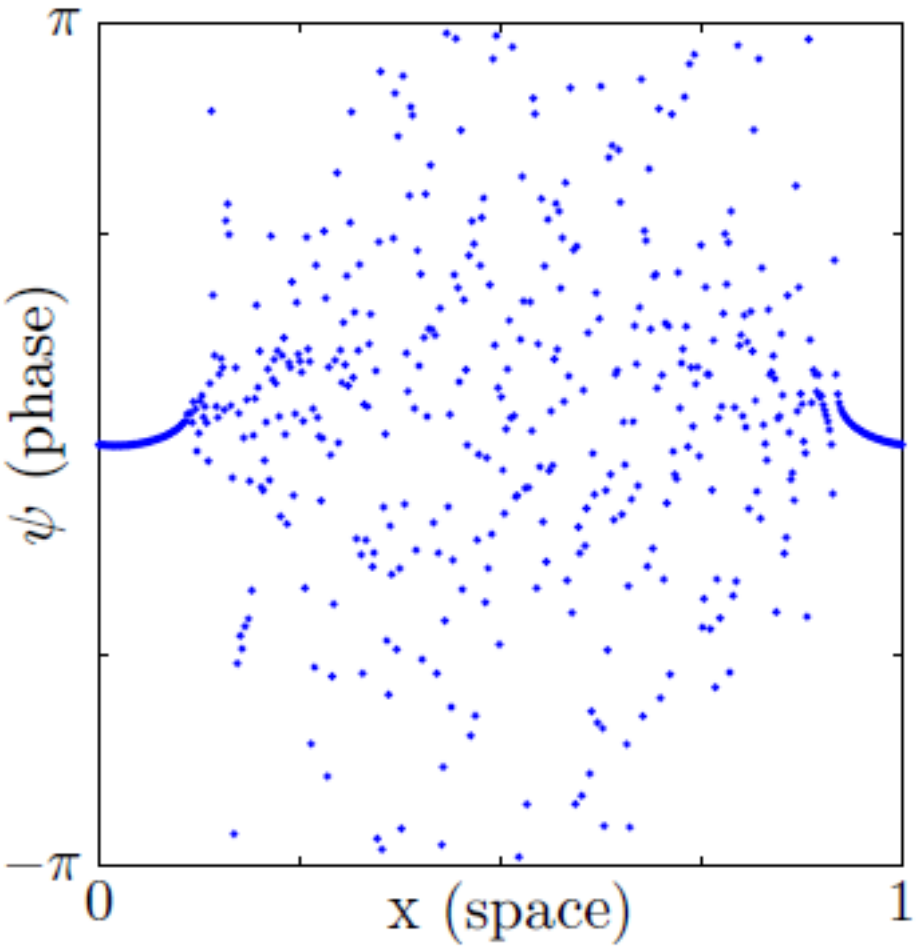


What is a chimera state?

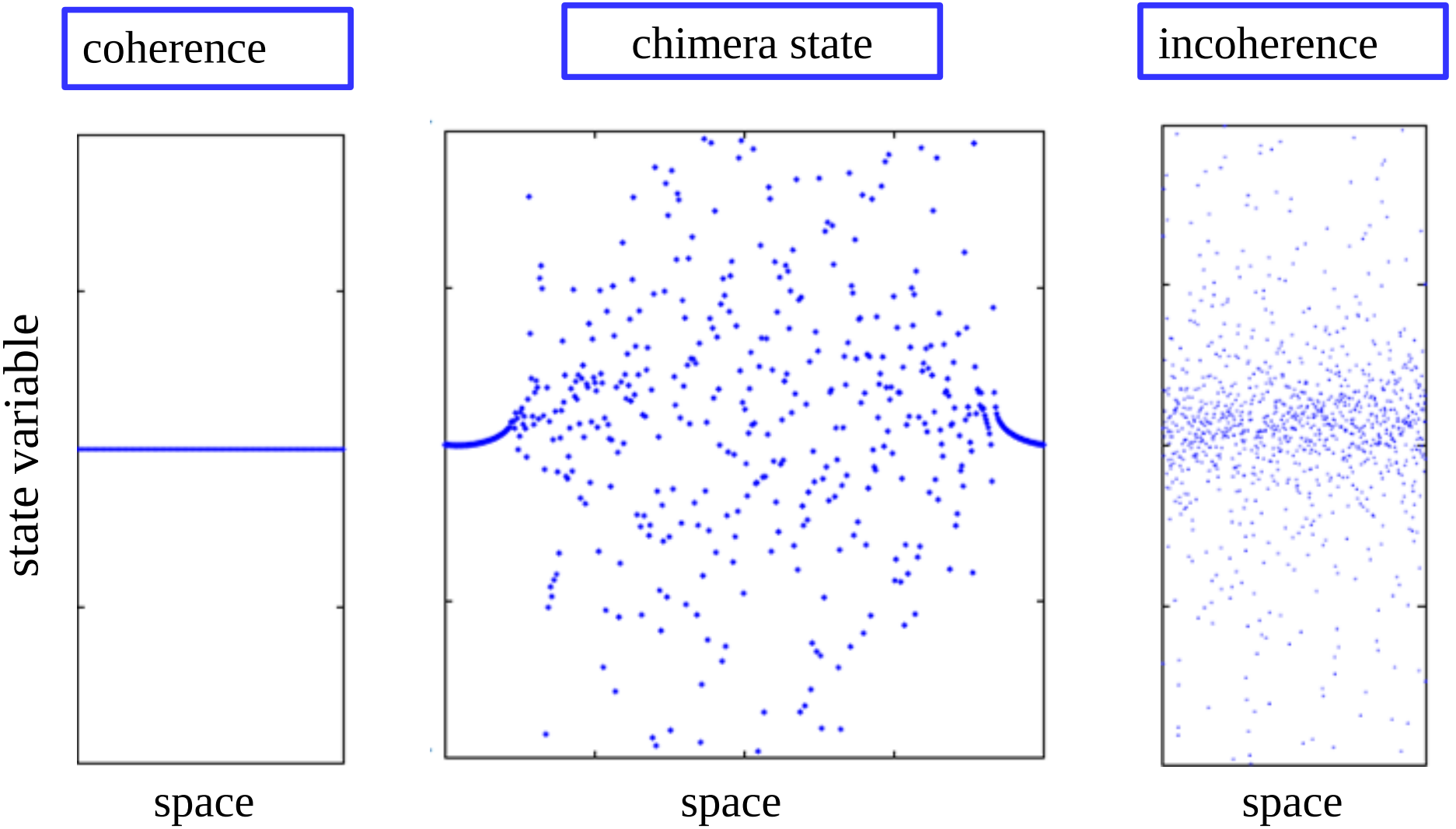


Spatial coexistence of coherent/synchronized and incoherent/desynchronized domains in a dynamical network

- discovered by Kuramoto and Battogtokh in 2002
- named ***chimera states*** by Abrams and Strogatz in 2004
- identical elements, symmetric topology



What is a chimera state?

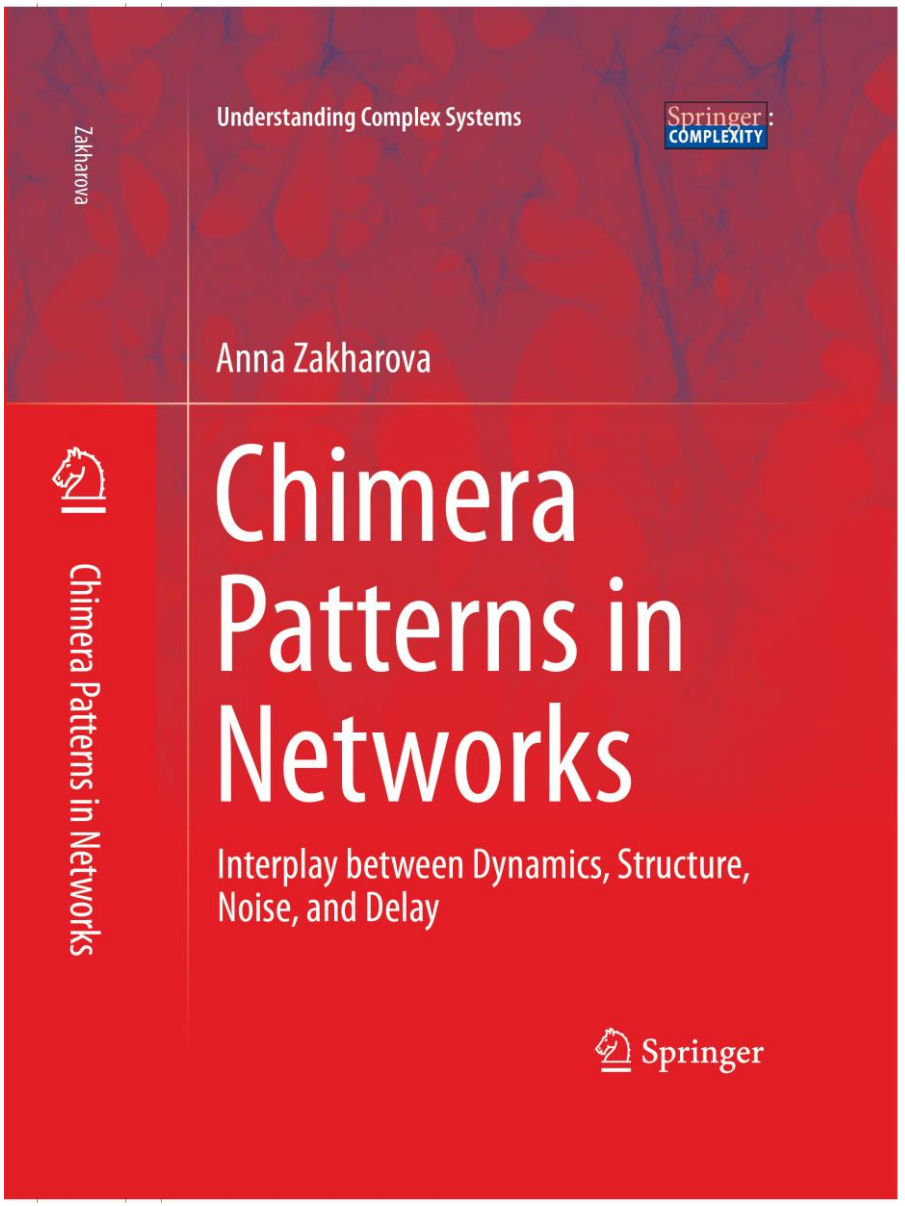


Reviews:

M. J. Panaggio and D. M. Abrams, Nonlinearity 28, R67 (2015)

E. Schöll, Eur. Phys. J. Spec. Top. 225, 891 (2016)

First book on chimera states



- Provides a timely overview and presents state-of-the-art research on chimera patterns
- Examines the complex interplay between stochasticity, time delay and network topology
- Discusses methods for controlling spatio-temporal patterns by means of the interplay of network structure, time delay and noise

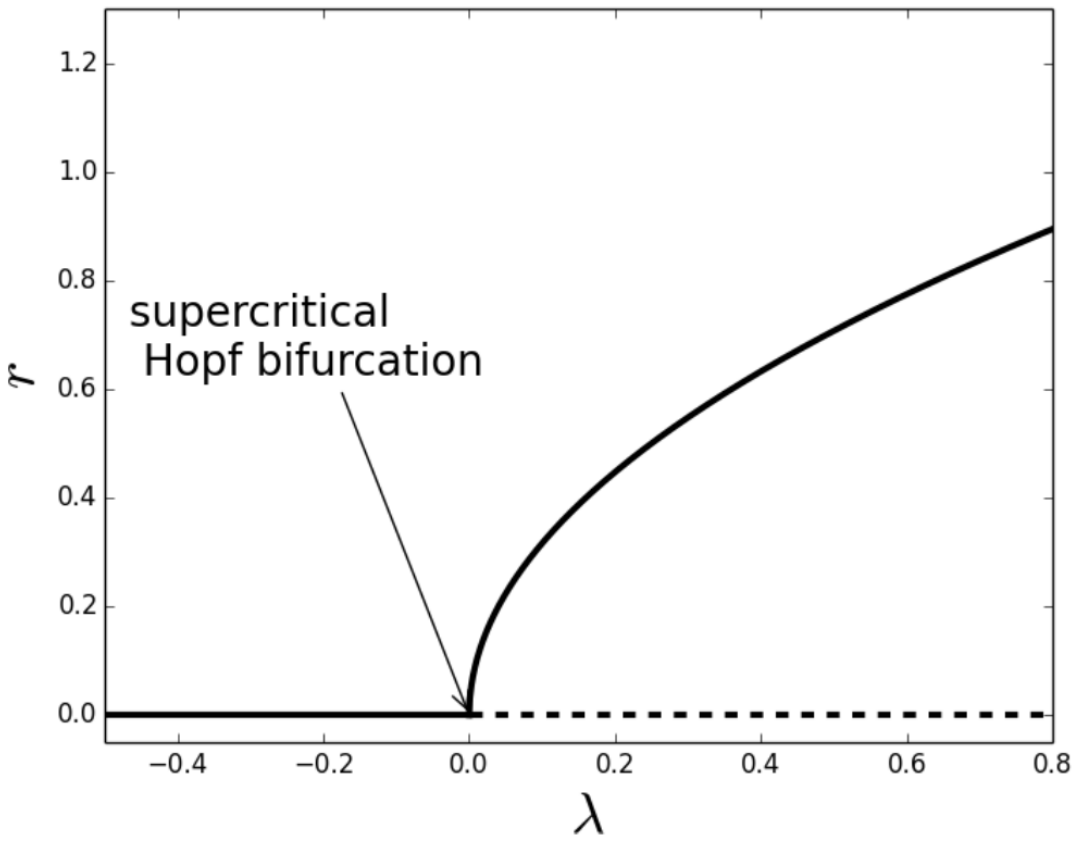
Amplitude chimeras and chimera death

Model: Stuart-Landau oscillator

Single node dynamics

$$\dot{z} = f(z) \equiv (\lambda + i\omega - |z|^2)z$$

$$z(t) = x(t) + iy(t)$$



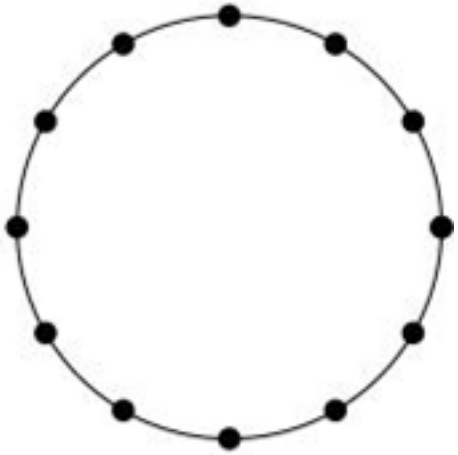
Model: Stuart-Landau oscillator

Single node dynamics

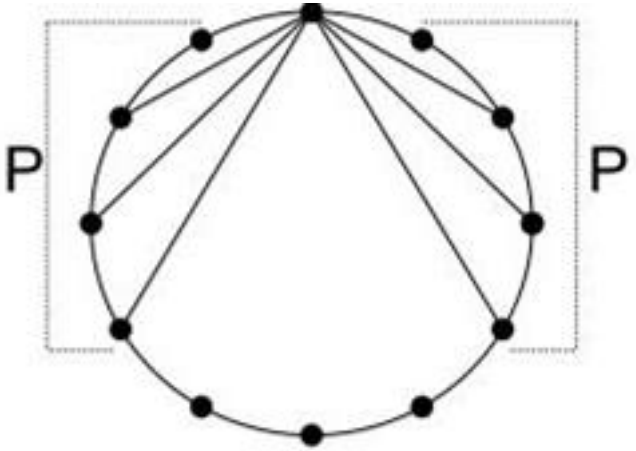
$$\dot{z} = f(z) \equiv (\lambda + i\omega - |z|^2)z$$

$$z(t) = x(t) + iy(t)$$

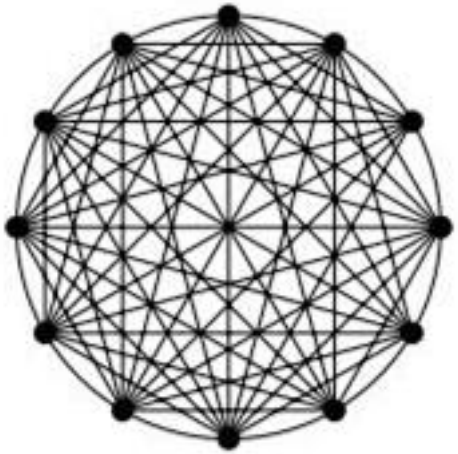
How to couple the oscillators?



local



nonlocal



global

Model: network of coupled Stuart-Landau oscillators

$$\dot{z}_j = f(z_j) + \frac{\sigma}{2P} \sum_{k=j-P}^{j+P} (\mathrm{Re}\, z_k - \mathrm{Re}\, z_j)$$

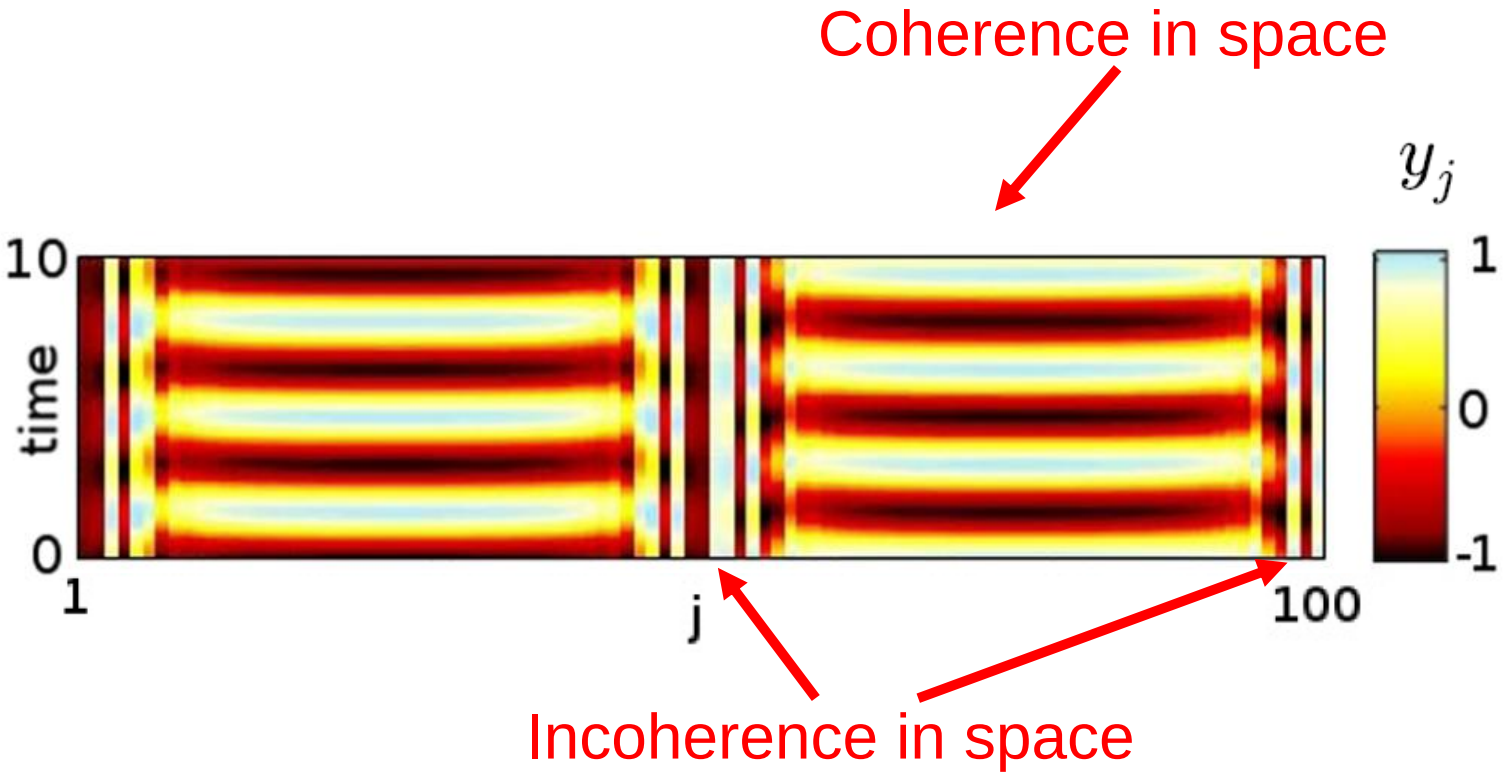
Symmetry-breaking coupling

amplitude chimeras

chimera death

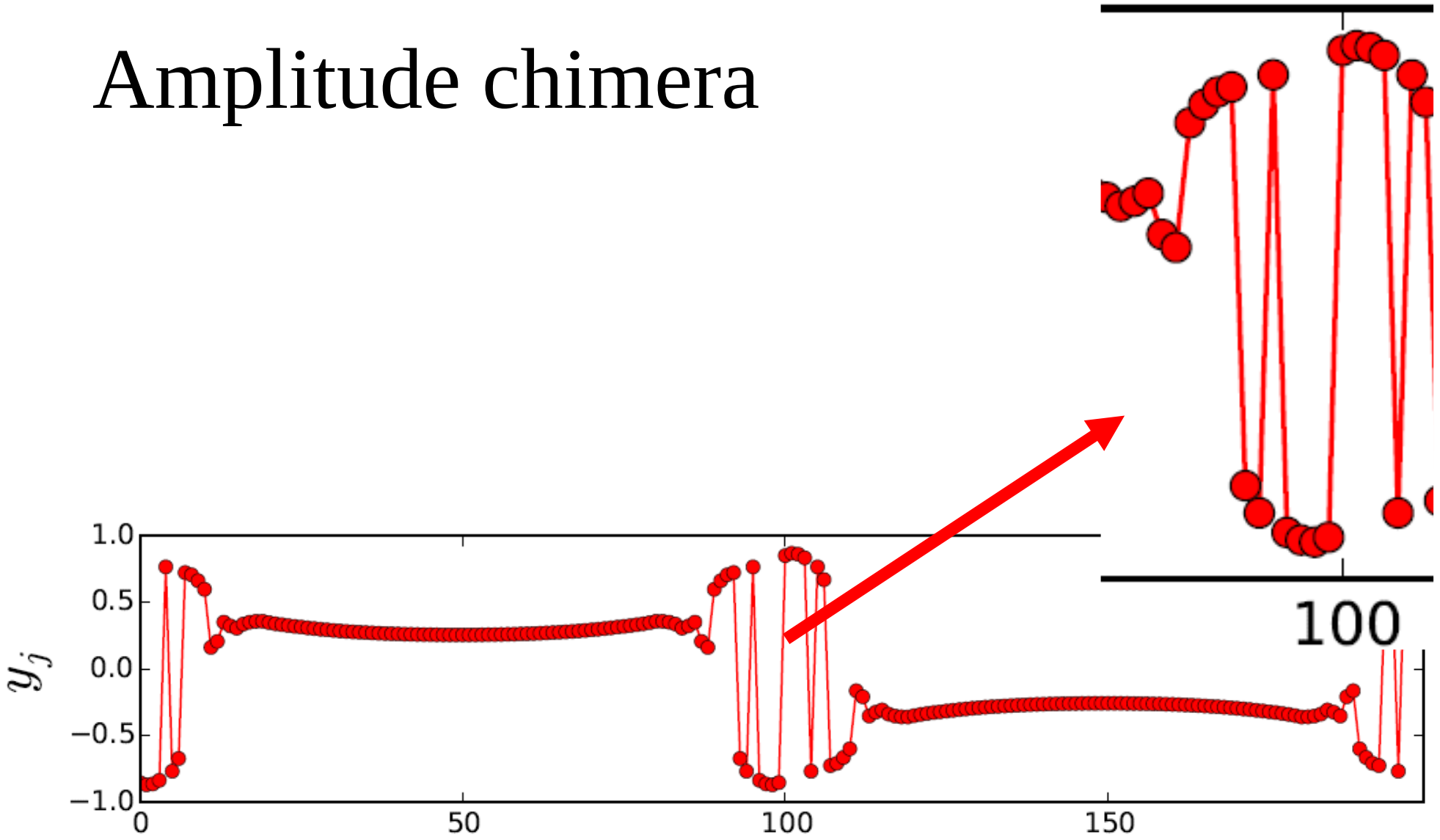
A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Amplitude chimera



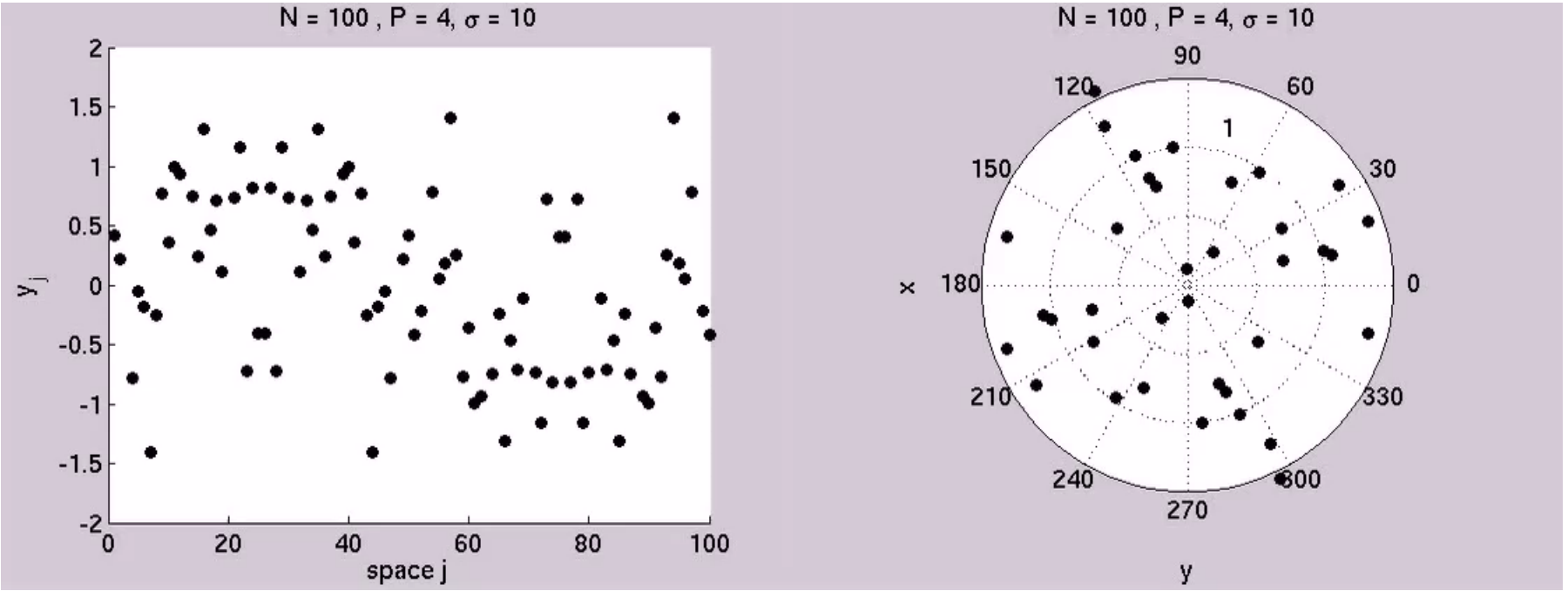
A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Amplitude chimera



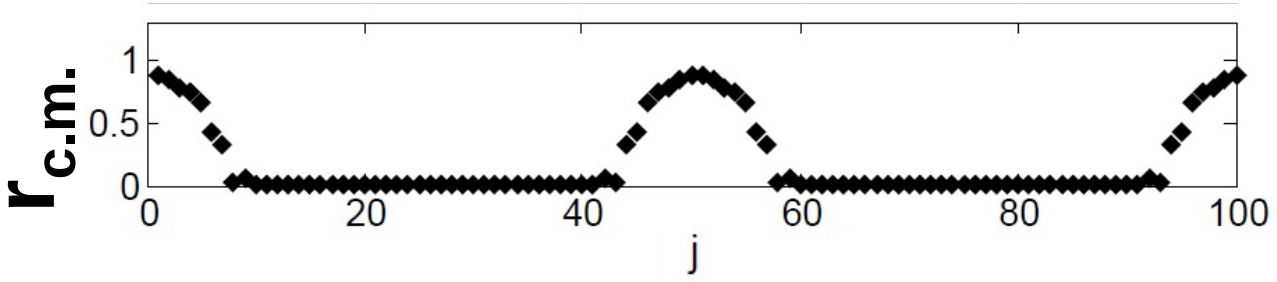
A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Amplitude chimera

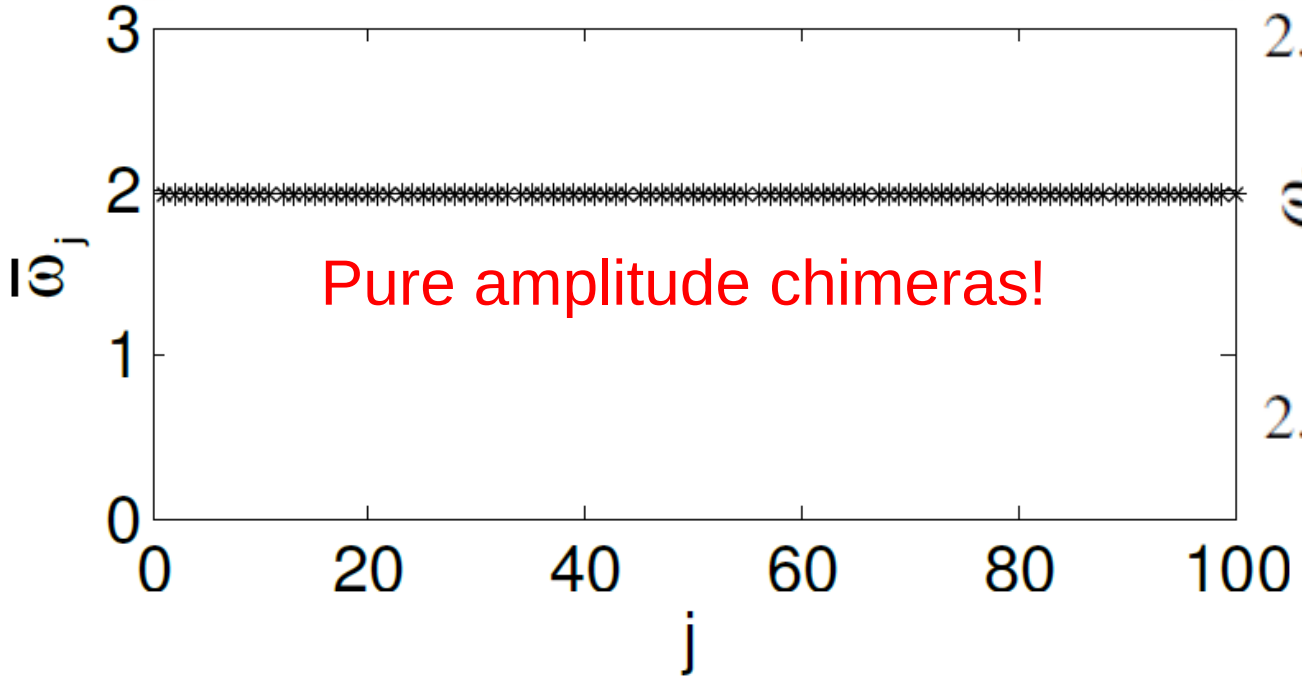


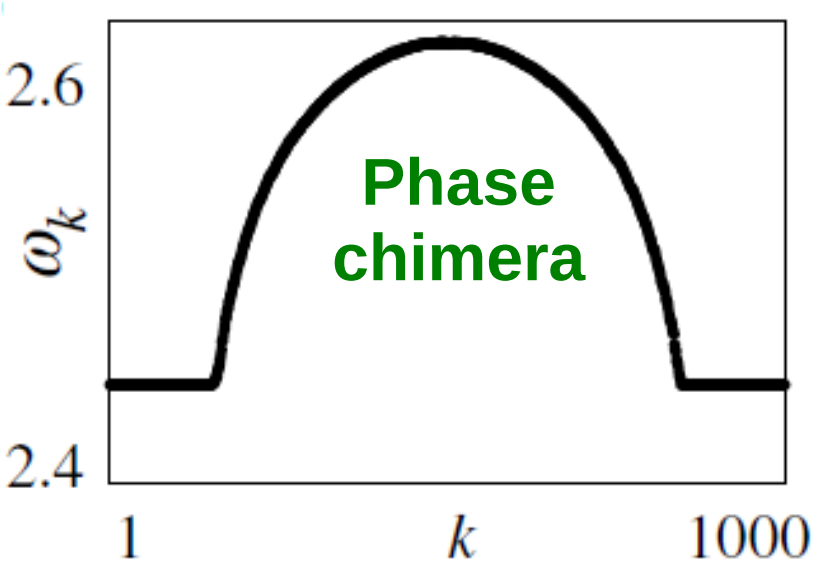
A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Amplitude chimera



$r_{c.m.}$ is the shift of the center of mass from the origin



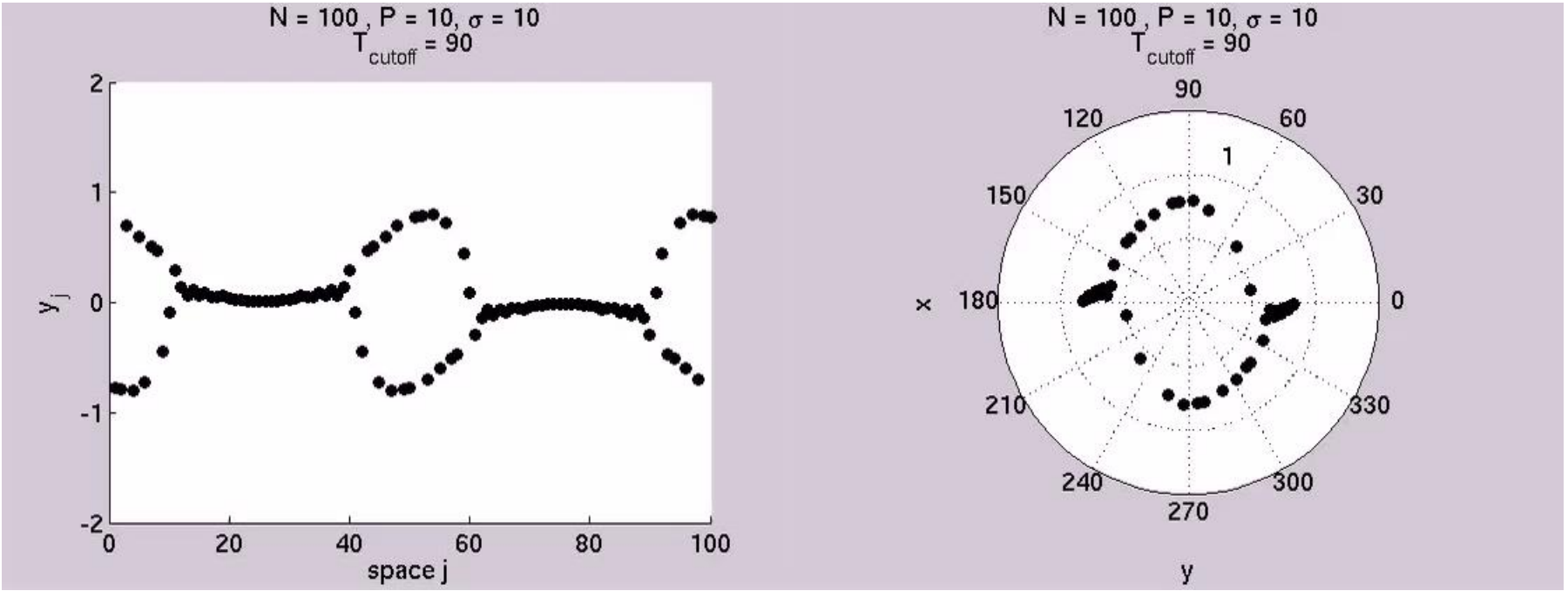


A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Amplitude chimera

	Amplitude	Phase
◦**Classical chimeras** Kuramoto and Battogtokh (2002), Abrams and Strogatz (2004)	no amplitude dynamics	
◦**Amplitude-mediated chimeras** Sethia and Sen (2014)		
◦**Amplitude chimeras** Zakharova, Kapeller, Schöll (2014)		

Amplitude chimera



A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Classical chimeras:

the dynamics is chaotic in time

M. Wolfrum and O. Omel'chenko, Chimera states are chaotic transients, *Phys Rev E 84*, 015201 (2011)

Amplitude chimeras:

the dynamics is periodic in time!

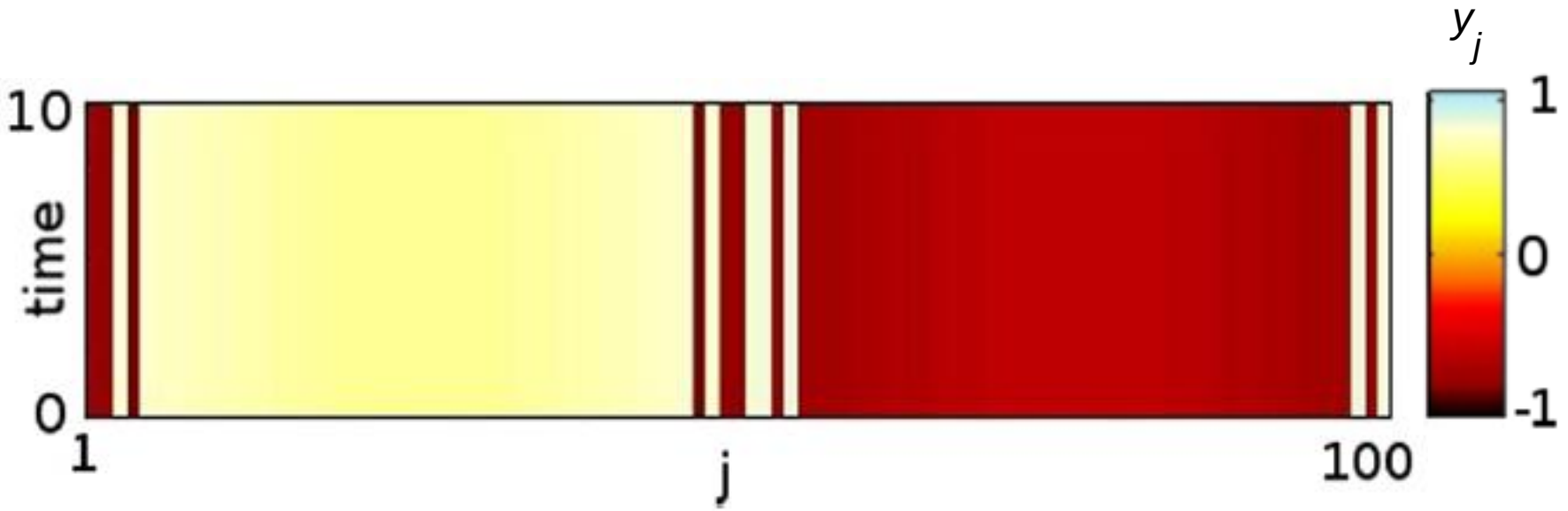
Amplitude chimeras are long-living transients!

A. Zakharova, M. Kapeller, E. Schöll, *J. Phys. Conf. Series* 727, 012018 (2016)

Chimera death

Chimera death

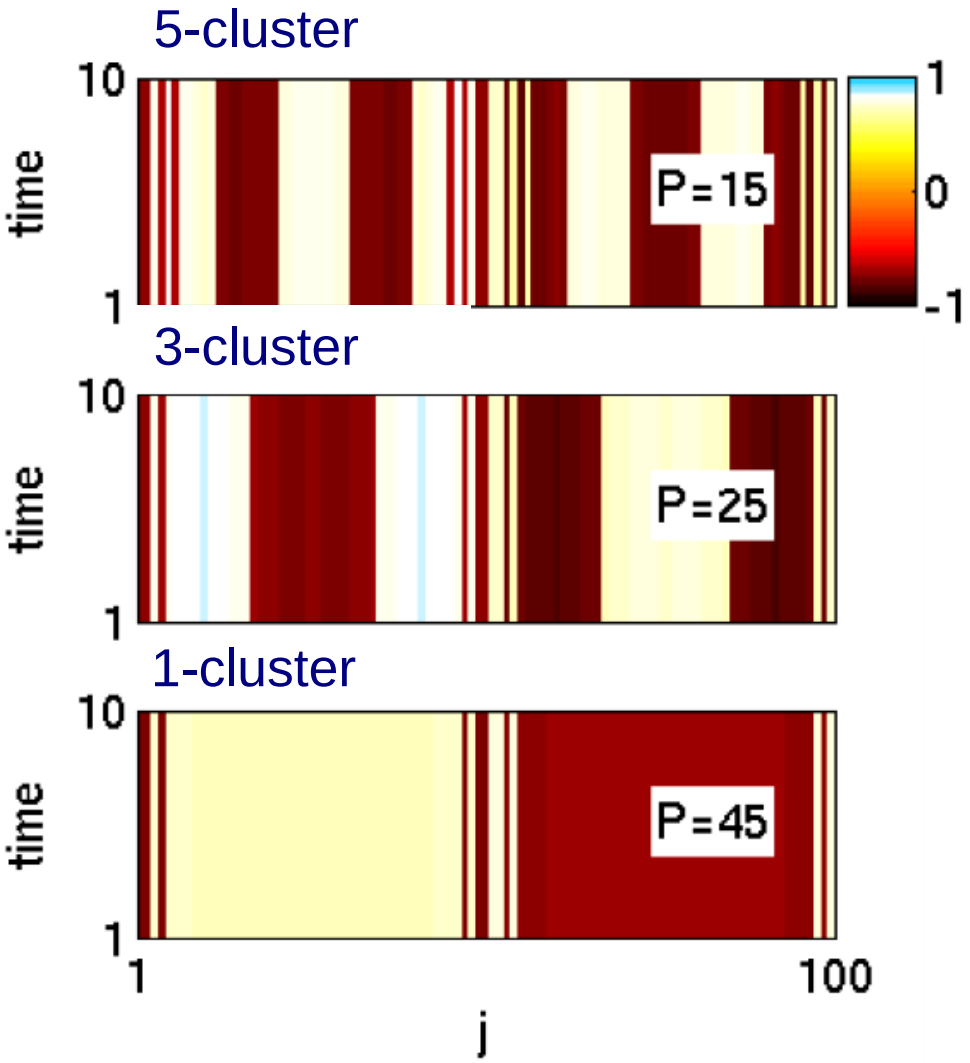
coexisting domains of spatially coherent and spatially incoherent oscillation death

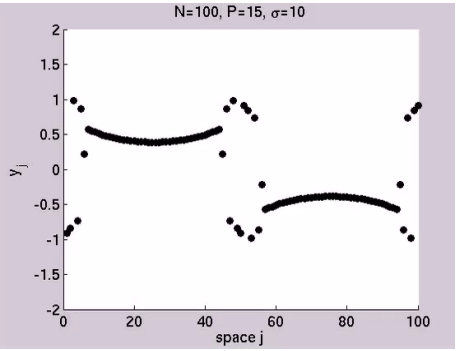


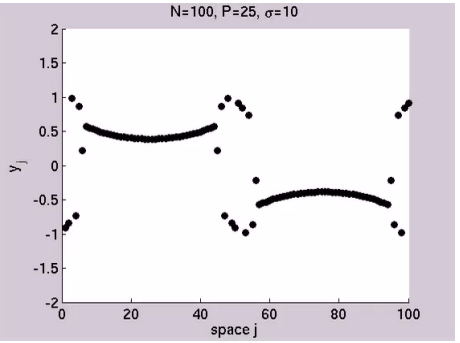
Chimera of steady states!

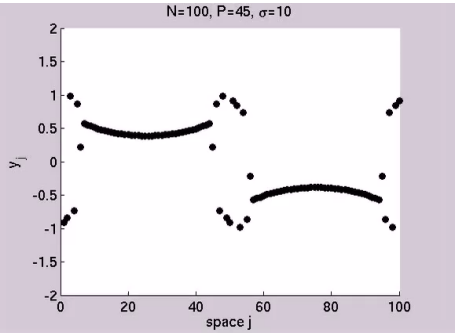
A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Chimera death: formation of clusters









A. Zakharova, M. Kapeller, E. Schöll, *Phys. Rev. Lett.* 112, 154101 (2014)

Coherence-resonance chimeras

Model: FitzHugh-Nagumo system in excitable regime

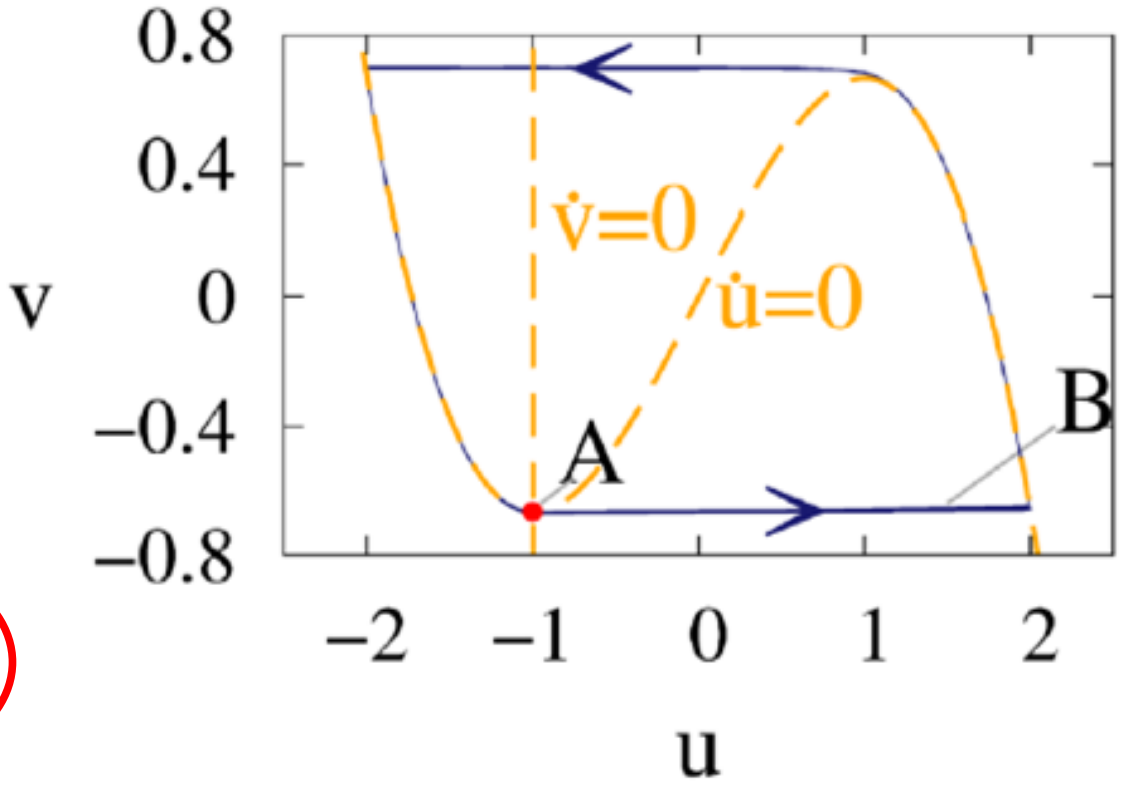
Single node dynamics

$$\varepsilon \dot{u} = u - \frac{u^3}{3} - v,$$

$$\dot{v} = u + a + \sqrt{2D}\xi(t)$$

$|a_i| < 1$ oscillatory

$|a_i| > 1$ excitable



Model: network of coupled FitzHugh-Nagumo systems

Nonlocally coupled ring

$$\varepsilon \dot{u}_i = u_i - \frac{u_i^3}{3} - v_i + \frac{\sigma}{2I} \sum_{j=i-I}^{i+I} (v_j - v_i),$$

$$\dot{v}_i = u_i + a_i + \frac{\sigma}{2P} \sum_{j=i-P}^{i+P} [\quad i)] + \sqrt{2D}\xi_i(t)$$

coherence-resonance chimeras

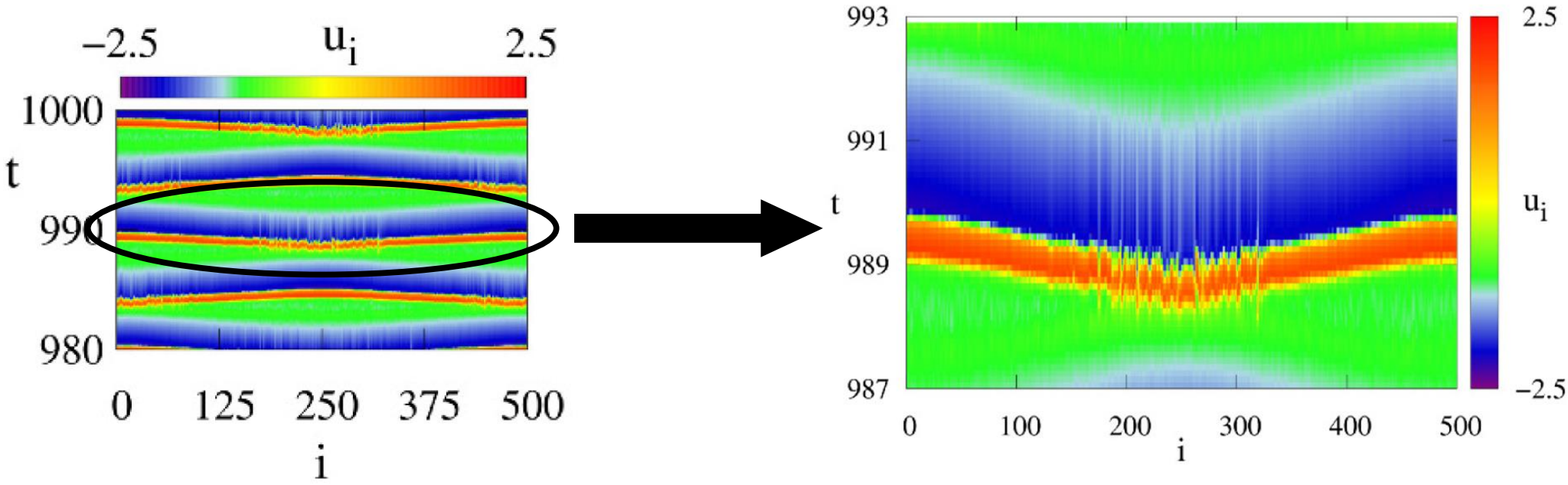
$|a_i| > 1$ excitable

noise

N. Semenova, A. Zakharova, V. Anishchenko, E. Schöll, *Phys. Rev. Lett.* 117, 014102 (2016)

Coherence-resonance chimeras

domains of coherent and incoherent spiking

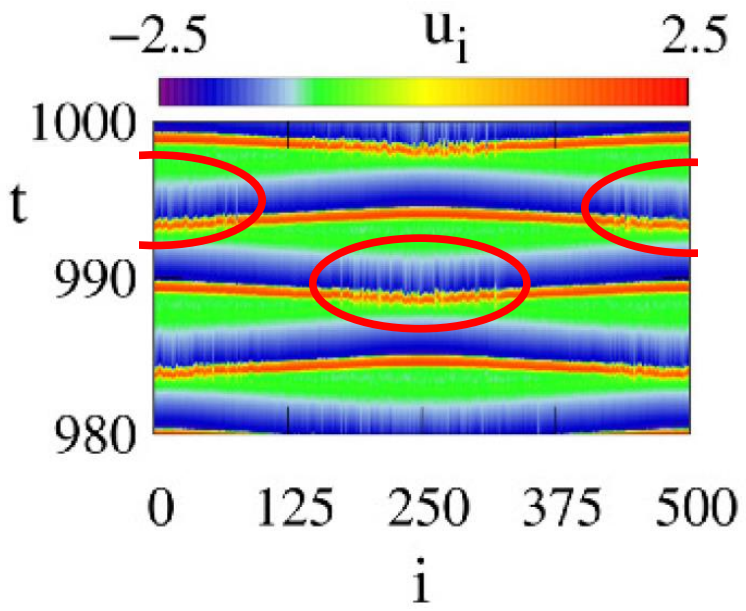


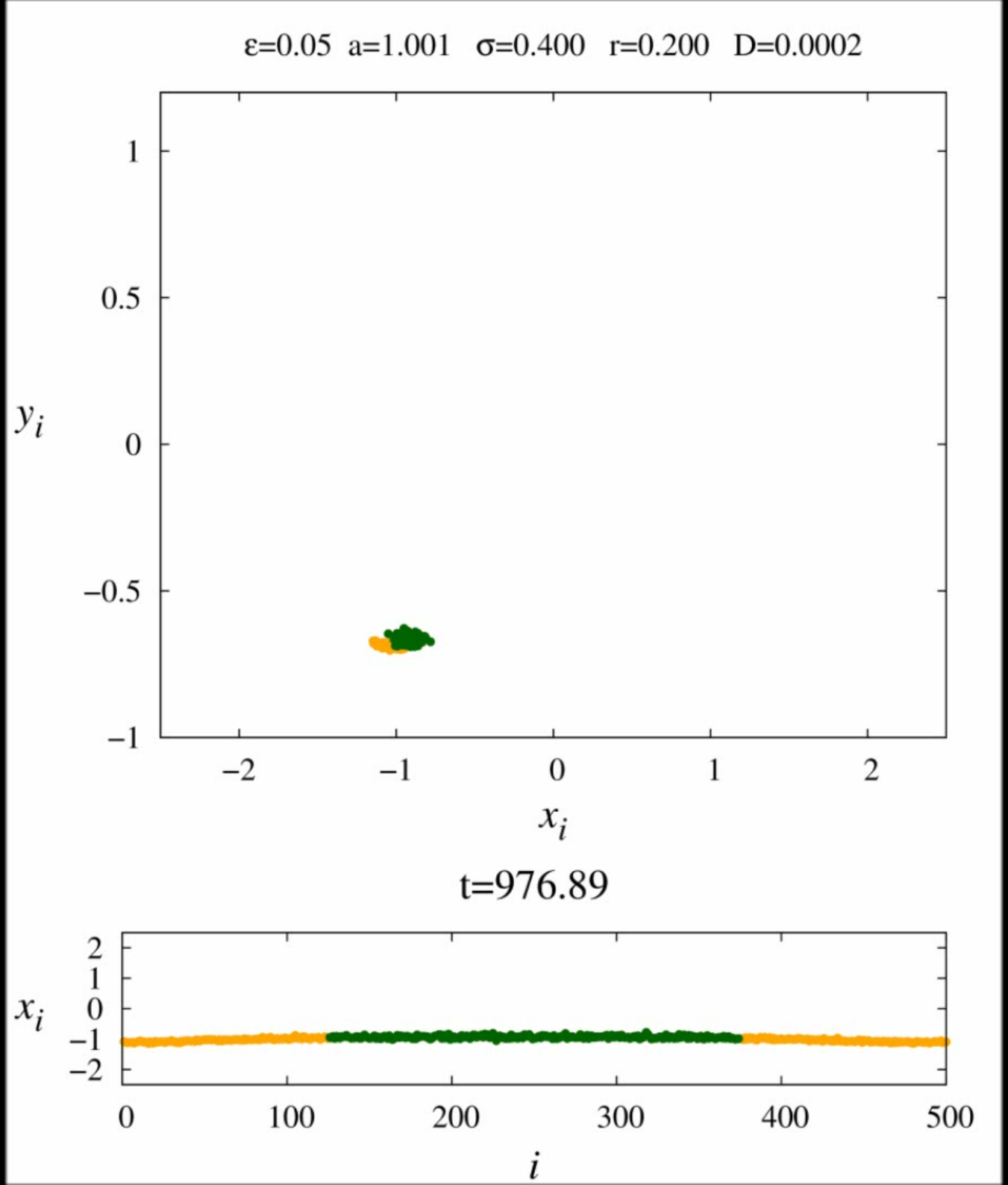
Intermediate noise intensities 0.000062≤D≤0.000325!

N. Semenova, A. Zakharova, V. Anishchenko, E. Schöll, *Phys. Rev. Lett.* 117, 014102 (2016)

Coherence-resonance chimeras

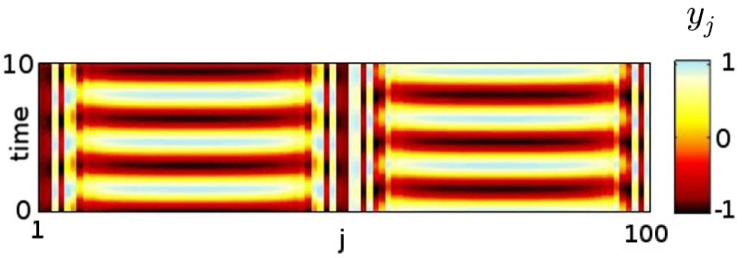
- noise-induced
- coherence resonance + chimera state
- alternating behavior



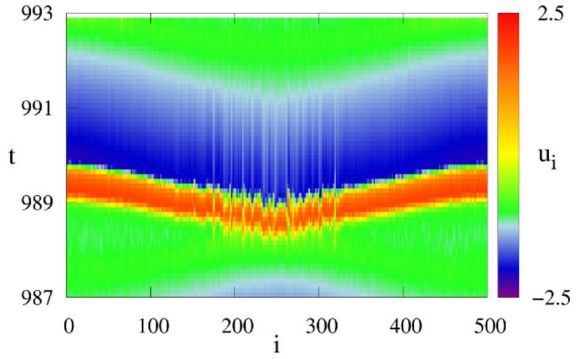

ε=0.05 a=1.001 σ=0.400 r=0.200 D=0.0002
1
0.5
0
−0.5
−1
y_i
−2
−1
0
1
2
x_i
t=976.89
2
1
0
−1
−2
x_i
0
100
200
300
400
500
i

Conclusions

1. Amplitude chimeras and chimera death in ring networks (Stuart-Landau oscillator)



2. Noise-induced chimera states – coherence-resonance chimeras (FitzHugh-Nagumo system)



Conclusions

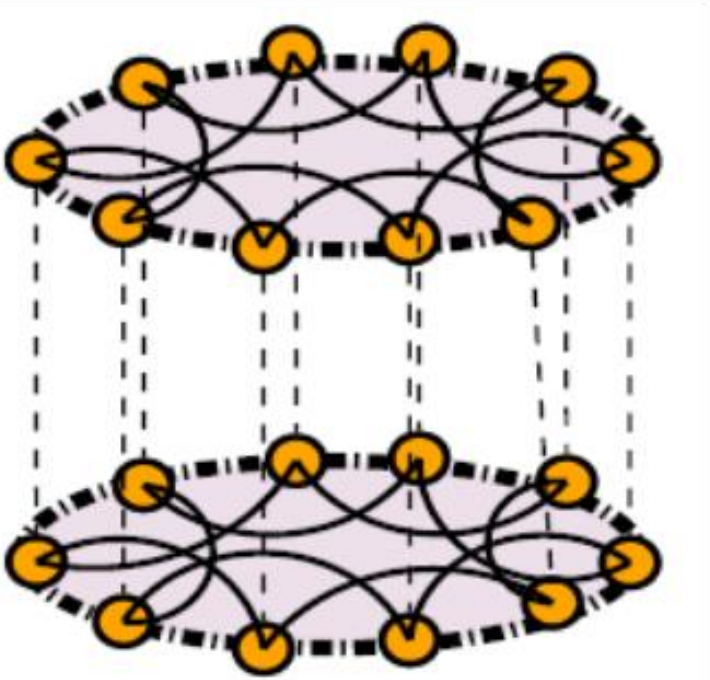
Outlook

Multilayer networks: dynamics and control

- **Social networks:** friendships in Facebook

- **Transportation networks:** air transport

- **Neural networks:** chemical link or ionic channel



S. Ghosh, A. Kumar, A. Zakharova, S. Jalan:
Birth and Death of Chimera: Interplay of Delay and Multiplexing, EPL **115**, 60005 (2016)