February 5, 2020 TU Berlin

Lecture 29

Coherence resonance in multiplex neural networks

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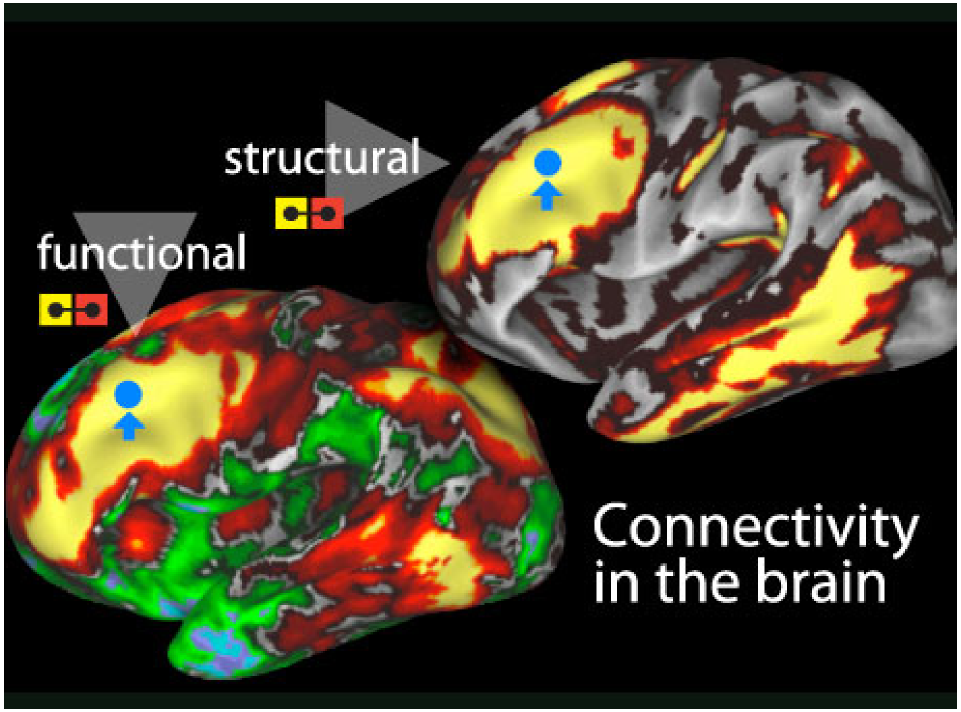
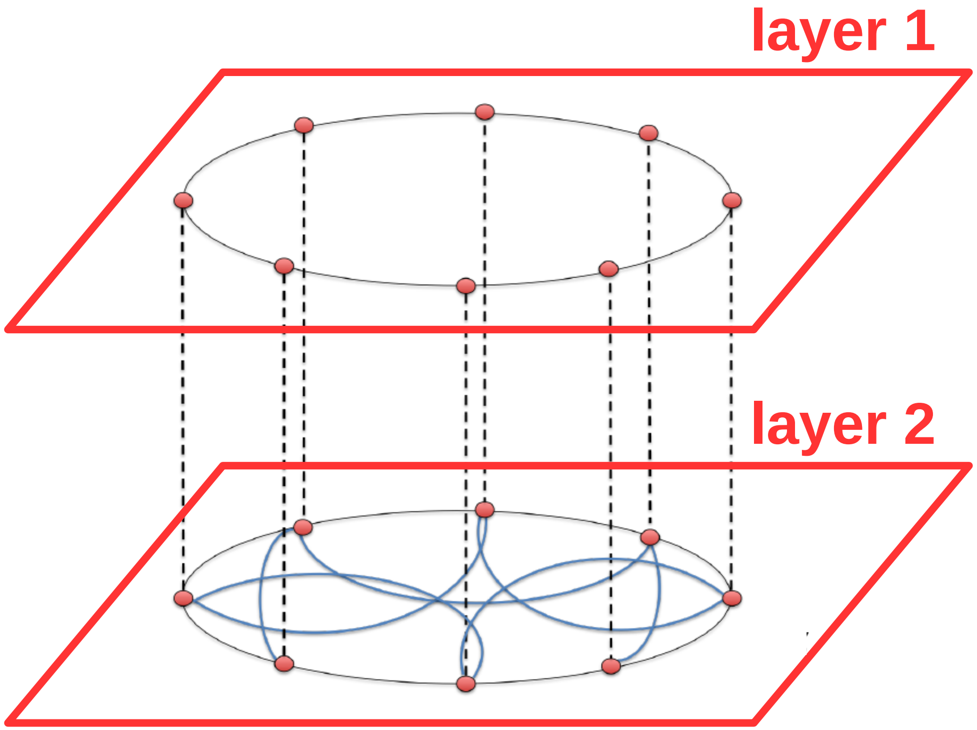
Winter Term 2019/20 Non-equilibrium Statistical Physics

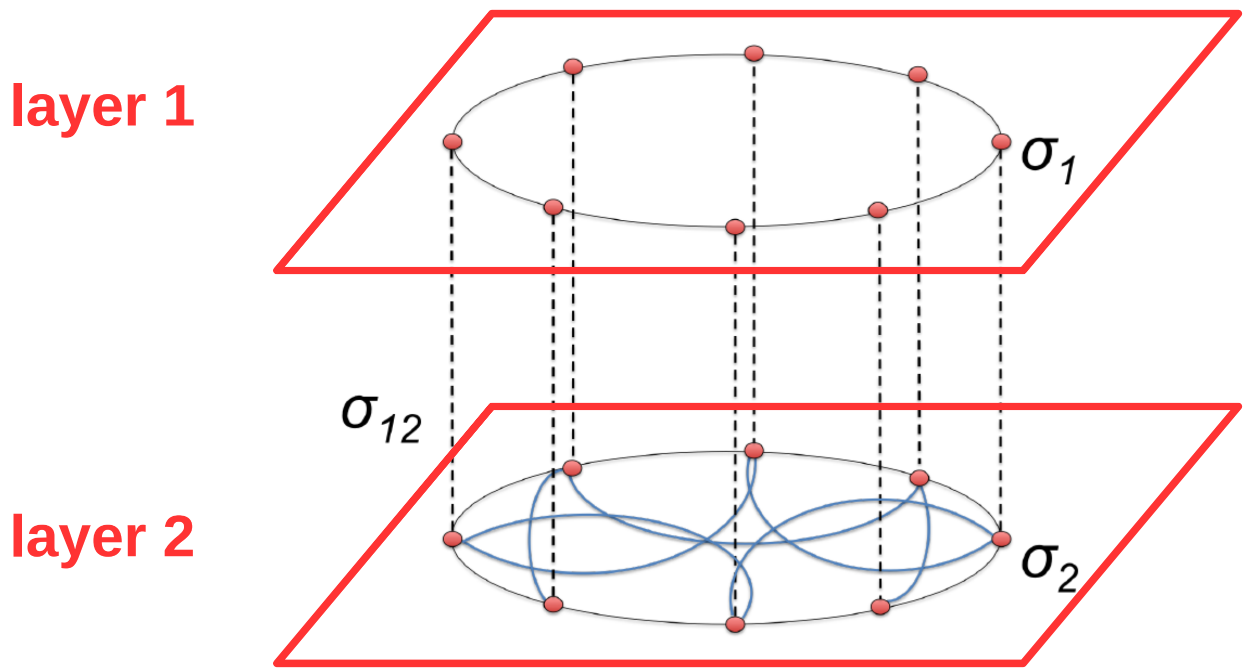
Multilayer modeling of brain networks

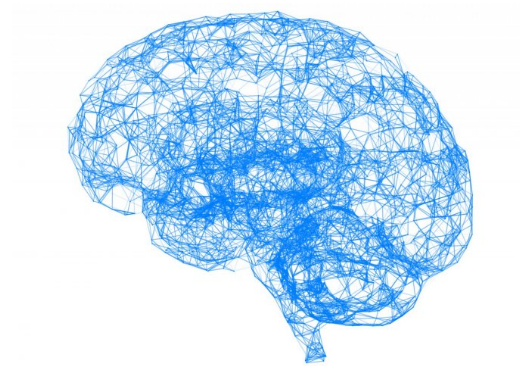




M. De Domenico, Multilayer modeling and analysis of human brain networks, Gigascience 6, 1 (2017)

Control by multiplexing

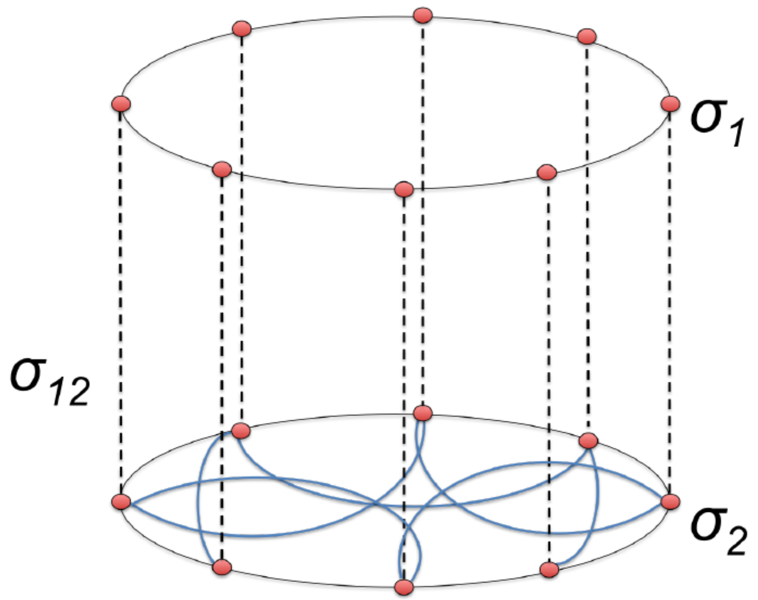




Controling one layer by manipulating the parameters of the other layer

Strong and weak multiplexing

Multiplex network



weak multiplexing
$\sigma_{12} < \sigma_1, \sigma_{12} < \sigma_2$

strong multiplexing
$\sigma_{12} \geq \sigma_1, \sigma_{12} \geq \sigma_2$

Can weak multiplexing have a strong impact on the dynamics?

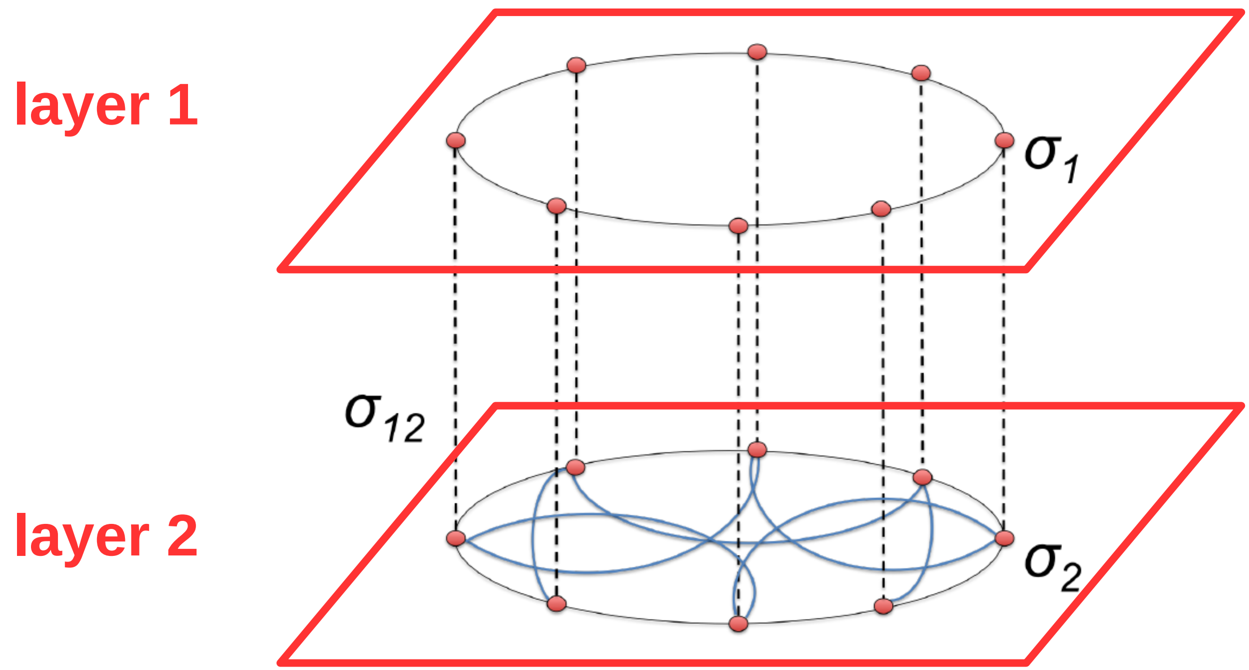
Strong multiplexing:

S. Ghosh, A. Kumar, A. Zakharova, S. Jalan, Birth and death of chimera: interplay of delay and multiplexing, EPL 115, 60005 (2016)

S. Ghosh, A. Zakharova, S. Jalan, Non-identical multiplexing promotes chimera states, Chaos, Solitons and Fractals 106, 56-60 (2018)

Weak multiplexing

Can we control the dynamics in the presence of weak multiplexing?



Can we control one layer by manipulating the parameters of the other layer?

Coherence resonance

Model: FitzHugh-Nagumo system in excitable regime

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

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

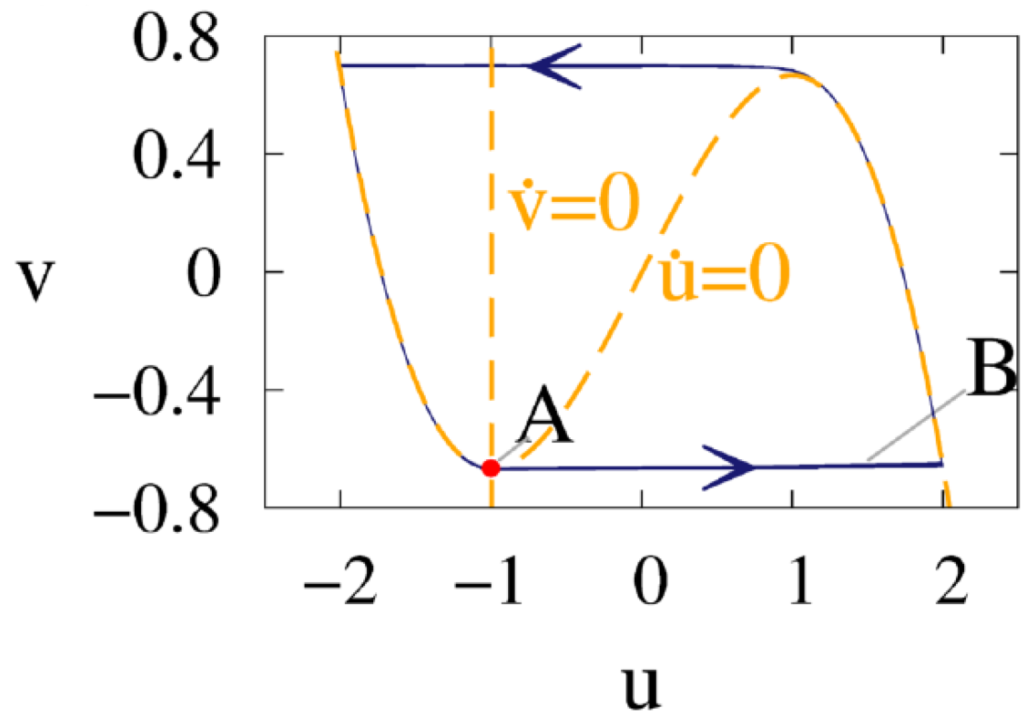
single node dynamics

u – activator

v – inhibitor

$|a_i| < 1$
oscillatory

$|a_i| > 1$
excitable



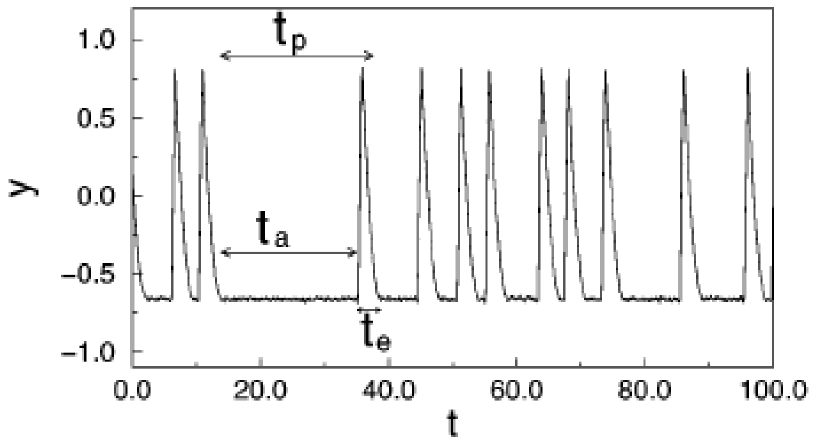
System parameters: $\varepsilon = 0.01$, a=1.001, D=0.0001

Coherence resonance: measures

Normalized standard deviation of the interspike interval

single node

$$R_T = \frac{\sqrt{\langle t_{ISI}^2 \rangle - \langle t_{ISI} \rangle^2}}{\langle t_{ISI} \rangle}$$



network

$$R_T = \frac{\sqrt{\langle \overline{t_{ISI}^2} \rangle - \langle \overline{t_{ISI}} \rangle^2}}{\langle \overline{t_{ISI}} \rangle}$$

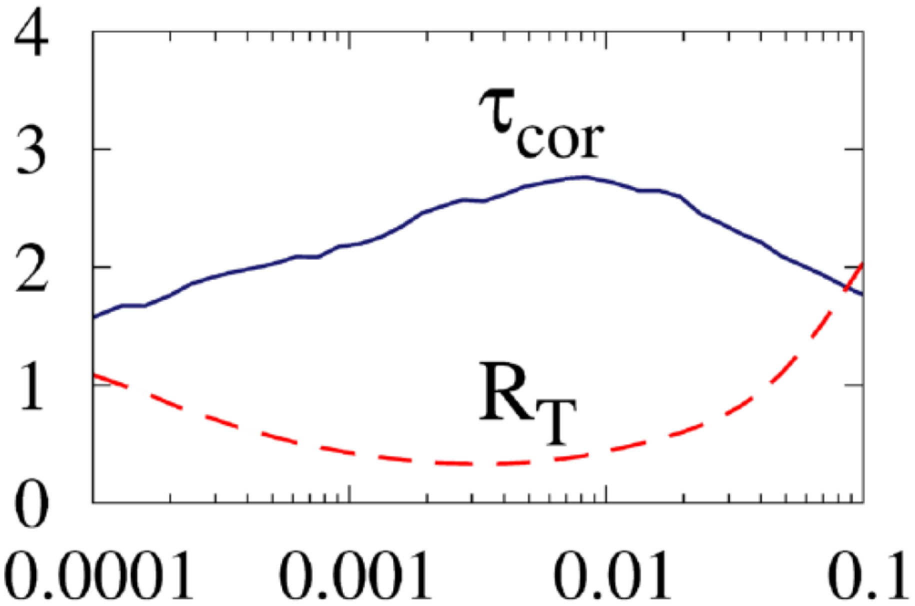
N. Semenova and A. Zakharova, Weak multiplexing induces coherence resonance, Chaos 28, 5, 051104 (2018)

Model: FitzHugh-Nagumo system in excitable regime

$$\varepsilon \dot{u} = u - \frac{u^3}{3} - v,$$
$$\dot{v} = u + a + \sqrt{2D}\xi(t)$$

$|a_i| > 1$
excitable

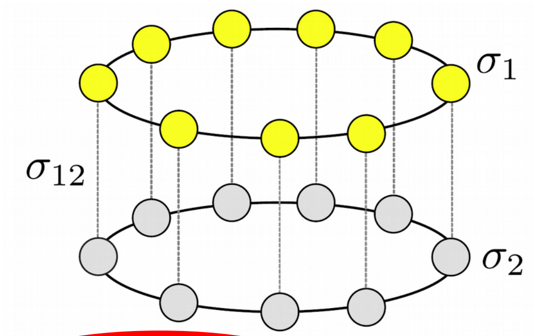
Coherence resonance



System parameters: $\varepsilon = 0.01$, a=1.001, D=0.0001

Can we control coherence resonance by weak multiplexing?

Multiplex network of excitable FHN neurons



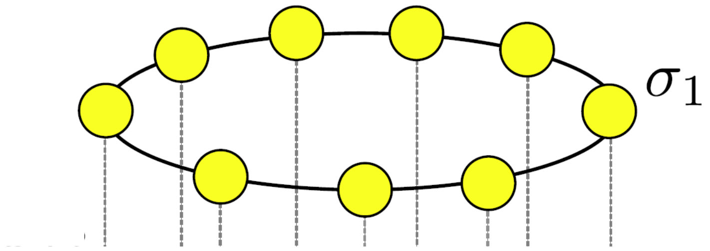
$$\varepsilon \frac{du_{1i}}{dt} = u_{1i} - \frac{u_{1i}^3}{3} - v_{1i} + \frac{\sigma_1}{2} \sum_{j=i-1}^{i+1} (u_{1j} - u_{1i}) + \sigma_{12}(u_{2i} - u_{1i}),$$

$$\frac{dv_{1i}}{dt} = u_{1i} + a + \sqrt{2D_1}\xi_i(t),$$

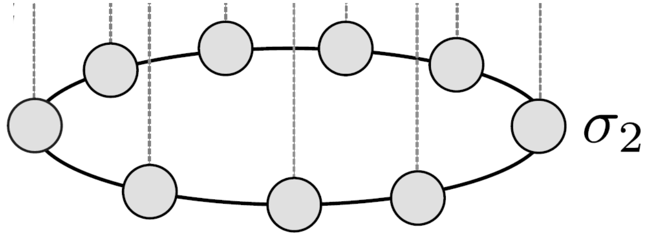
$$\varepsilon \frac{du_{2i}}{dt} = u_{2i} - \frac{u_{2i}^3}{3} - v_{2i} + \frac{\sigma_2}{2} \sum_{j=i-1}^{i+1} (u_{2j} - u_{2i}) + \sigma_{12}(u_{1i} - u_{2i}),$$

$$\frac{dv_{2i}}{dt} = u_{2i} + a + \sqrt{2D_2}\eta_i(t),$$

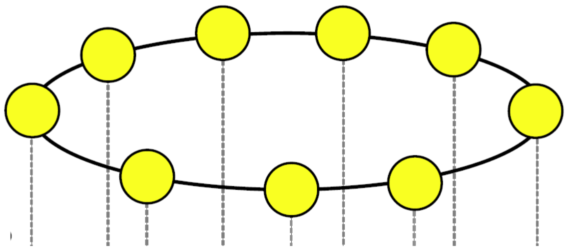
N. Semenova and A. Zakharova, Weak multiplexing induces coherence resonance, Chaos 28, 5, 051104 (2018)

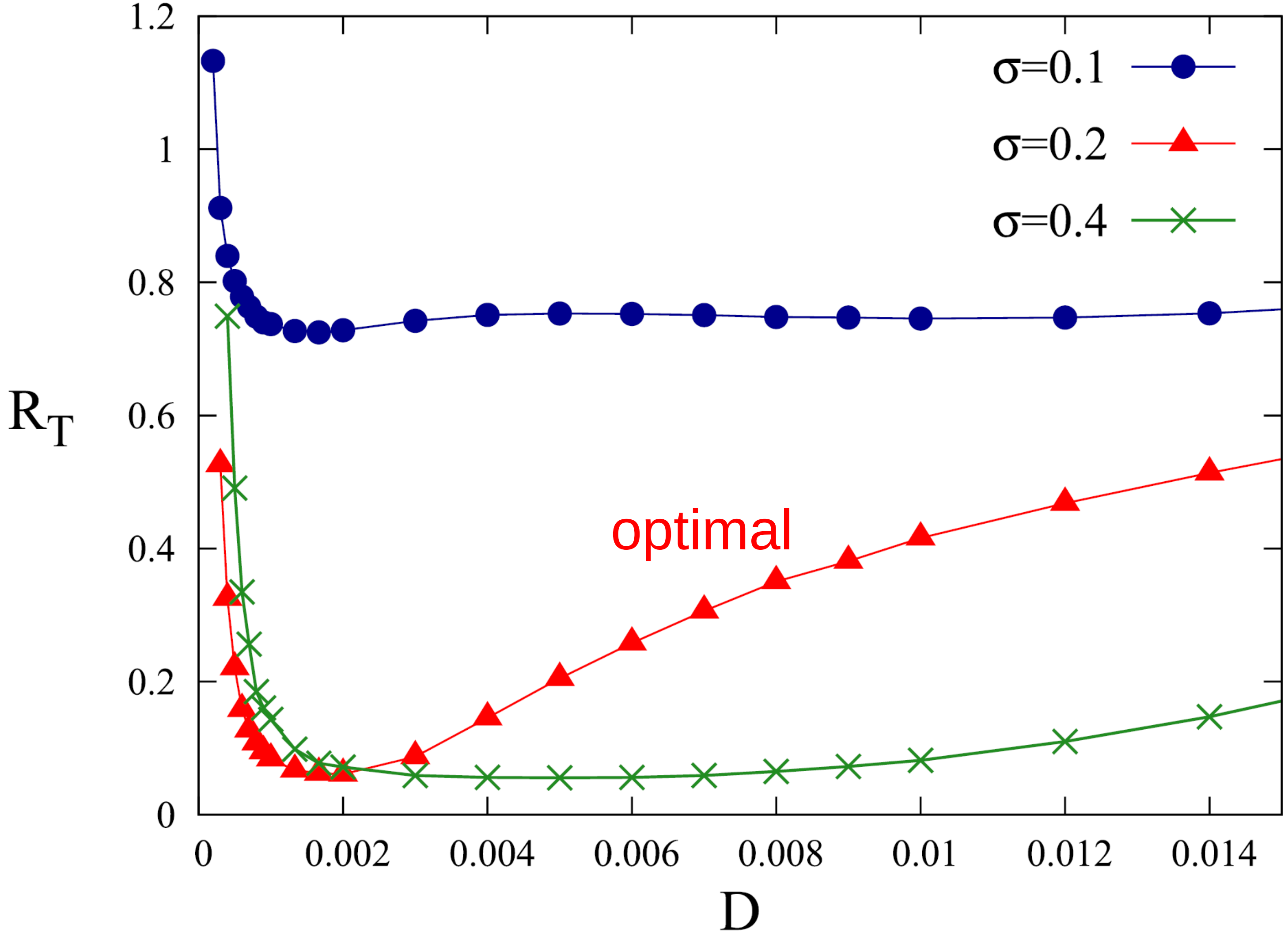


Dynamics of isolated layers

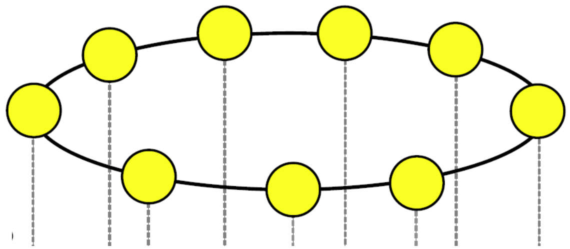


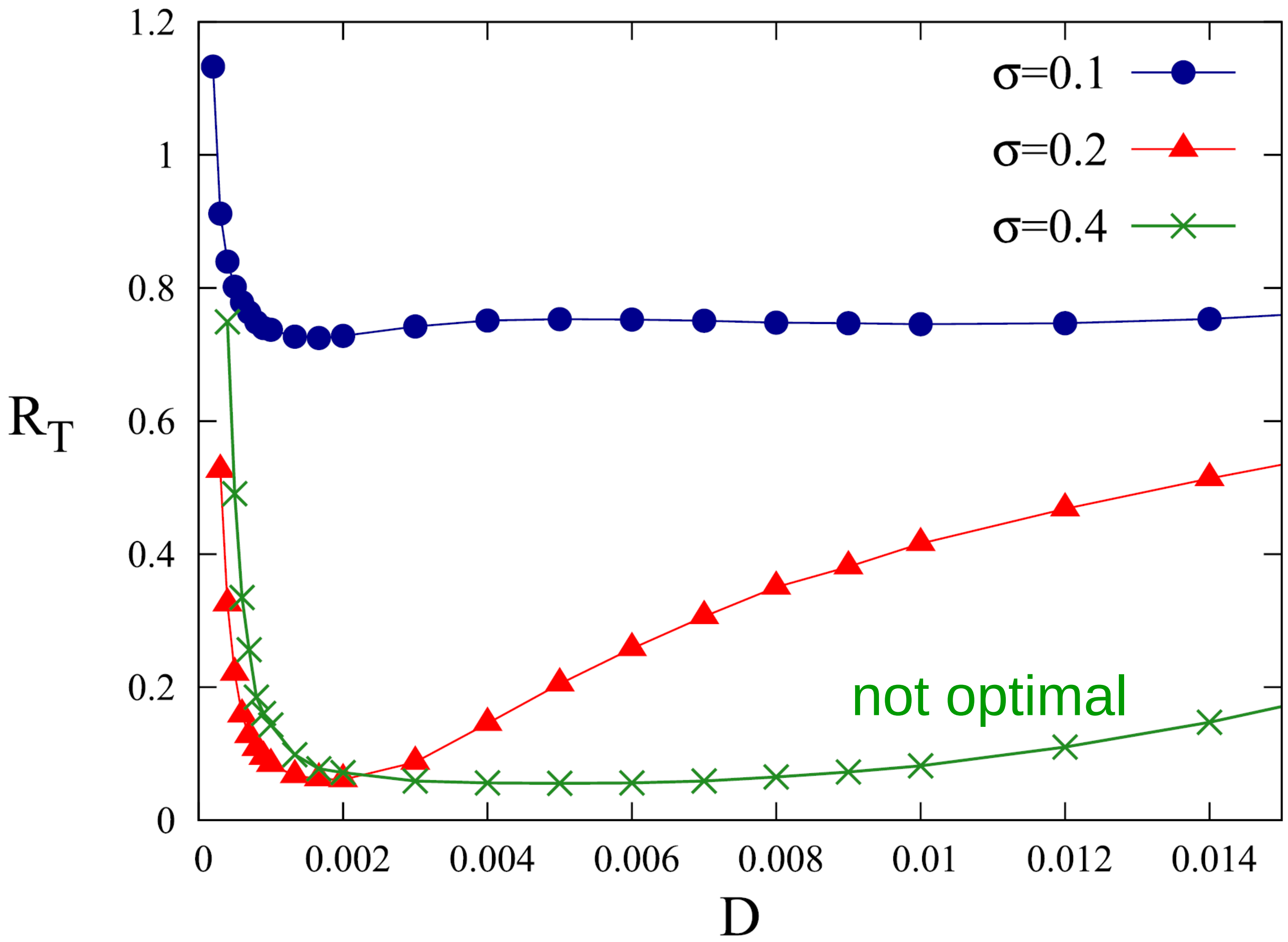
Isolated ring network



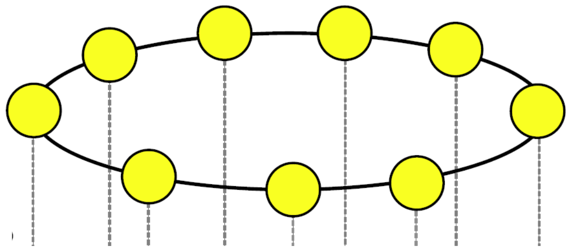


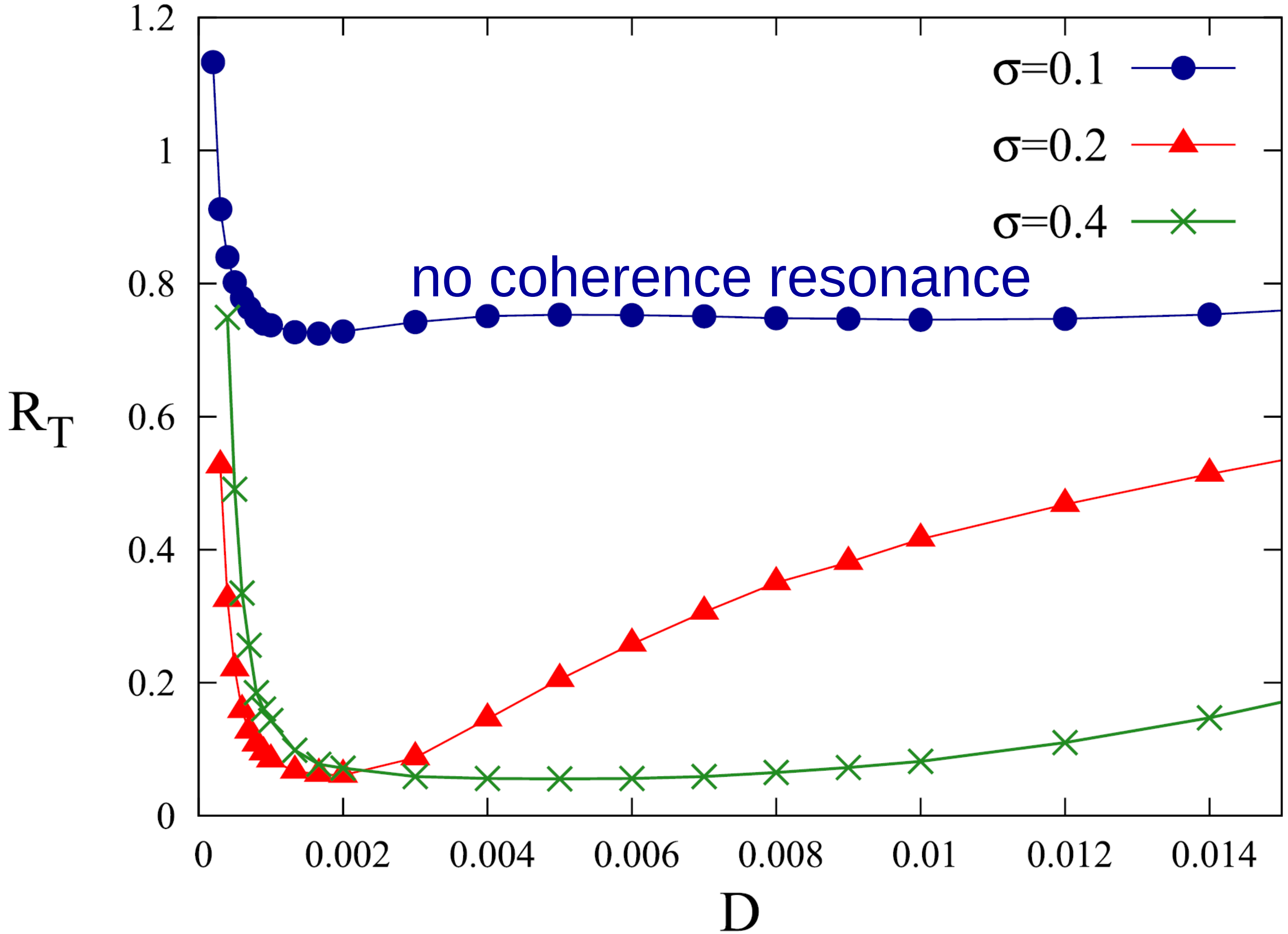
Isolated ring network



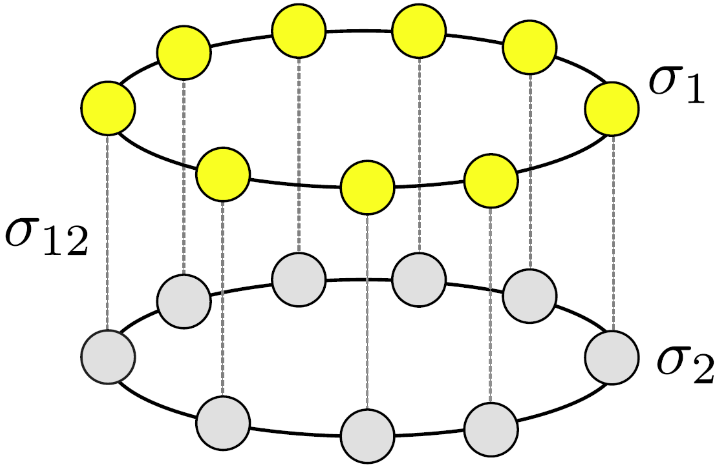


Isolated ring network

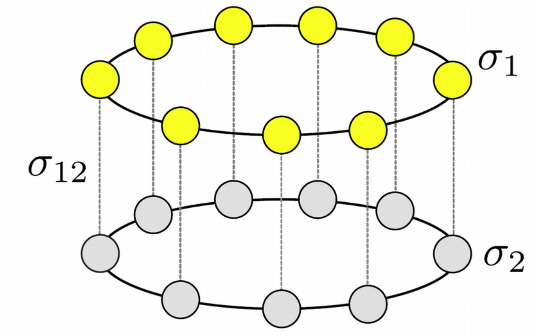


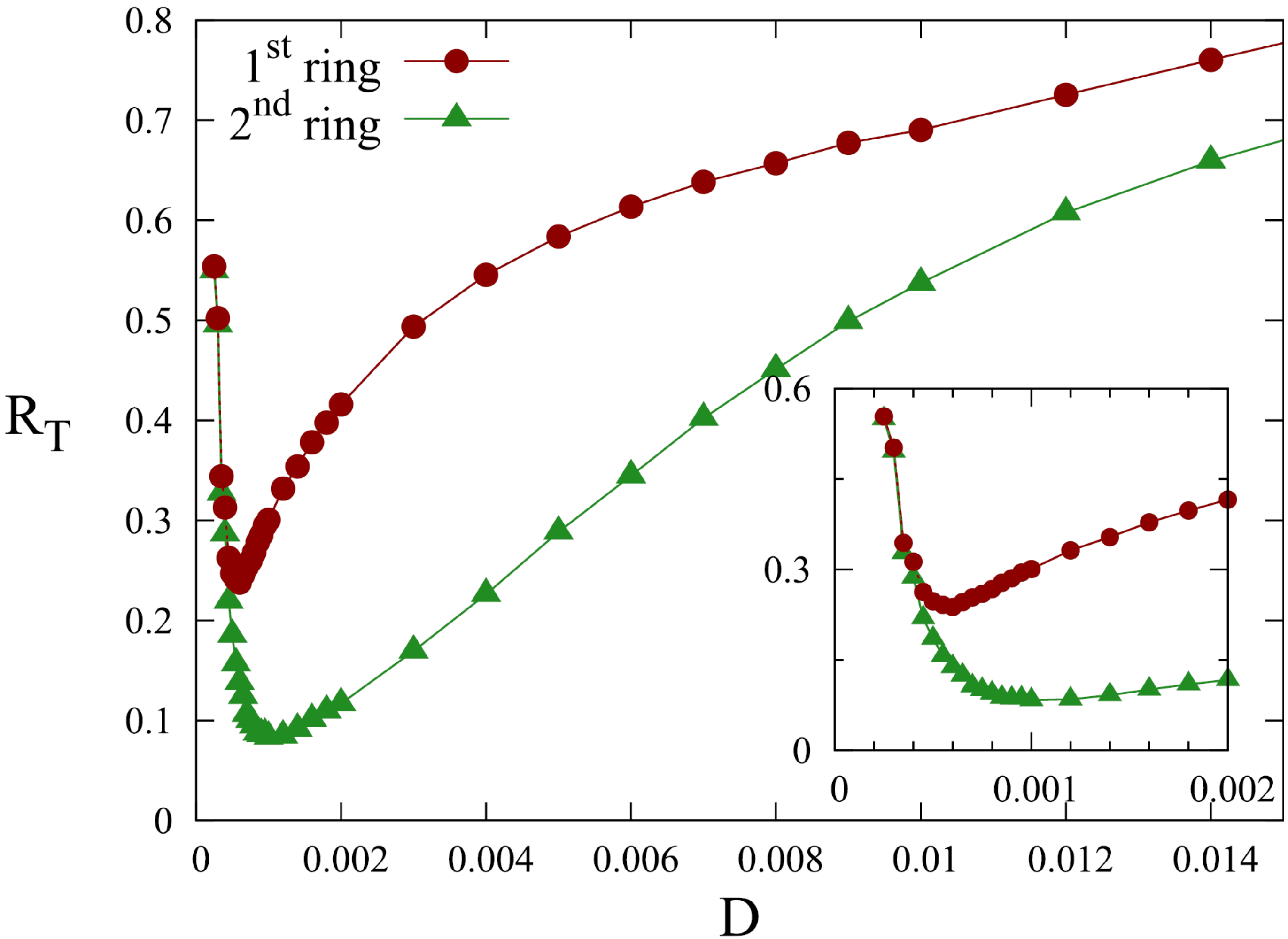


Multiplex network: coupling strength mismatch



Coupling strength mismatch





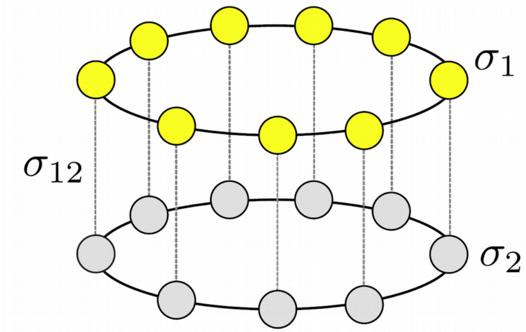
weak multiplexing
$\sigma_{12} = 0.04$

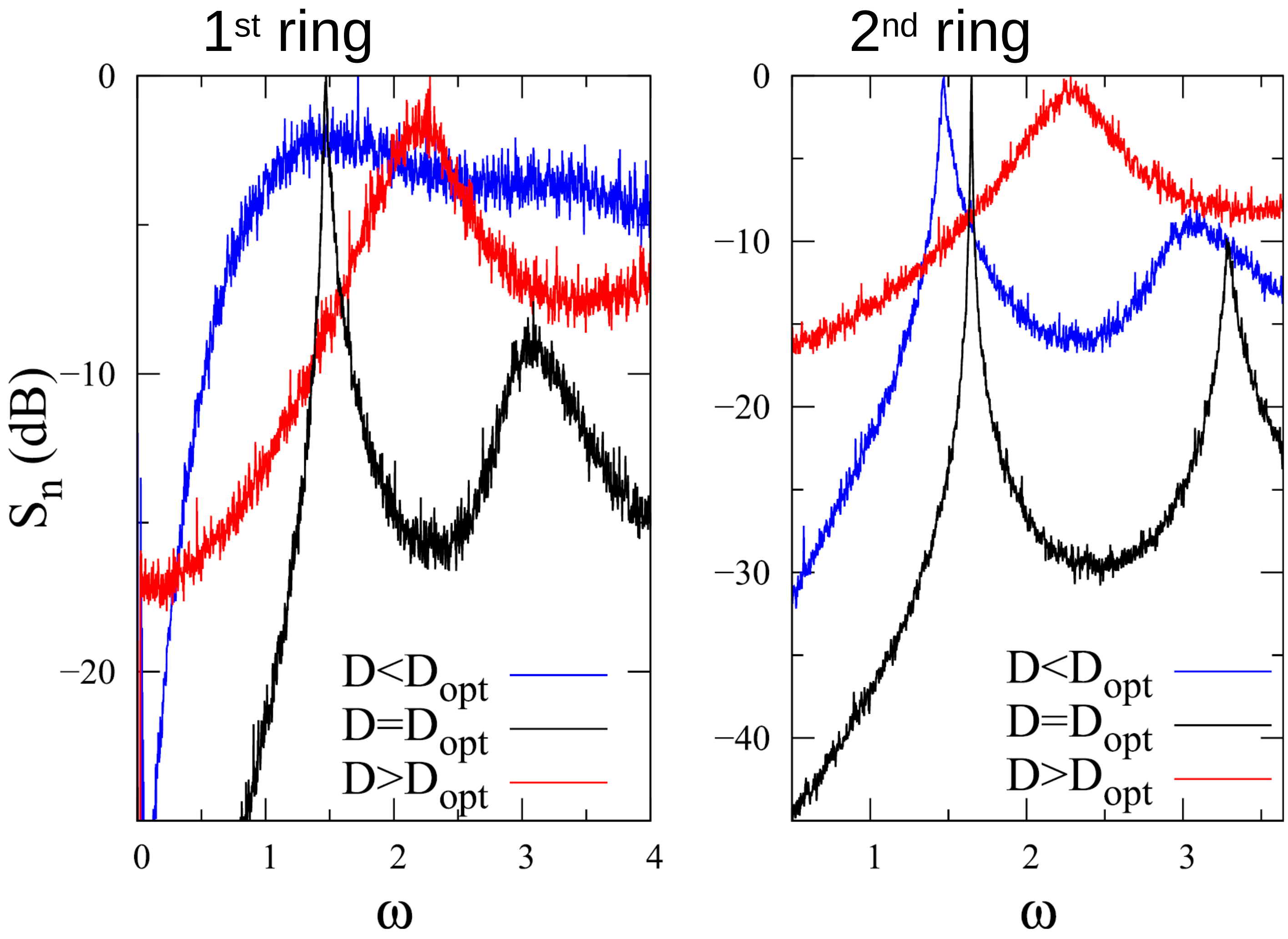
$\sigma_1 = 0.1$ (no CR in isolation)

$\sigma_2 = 0.2$ (optimal)

- Weak multiplexing induces coherence resonance

Coupling strength mismatch





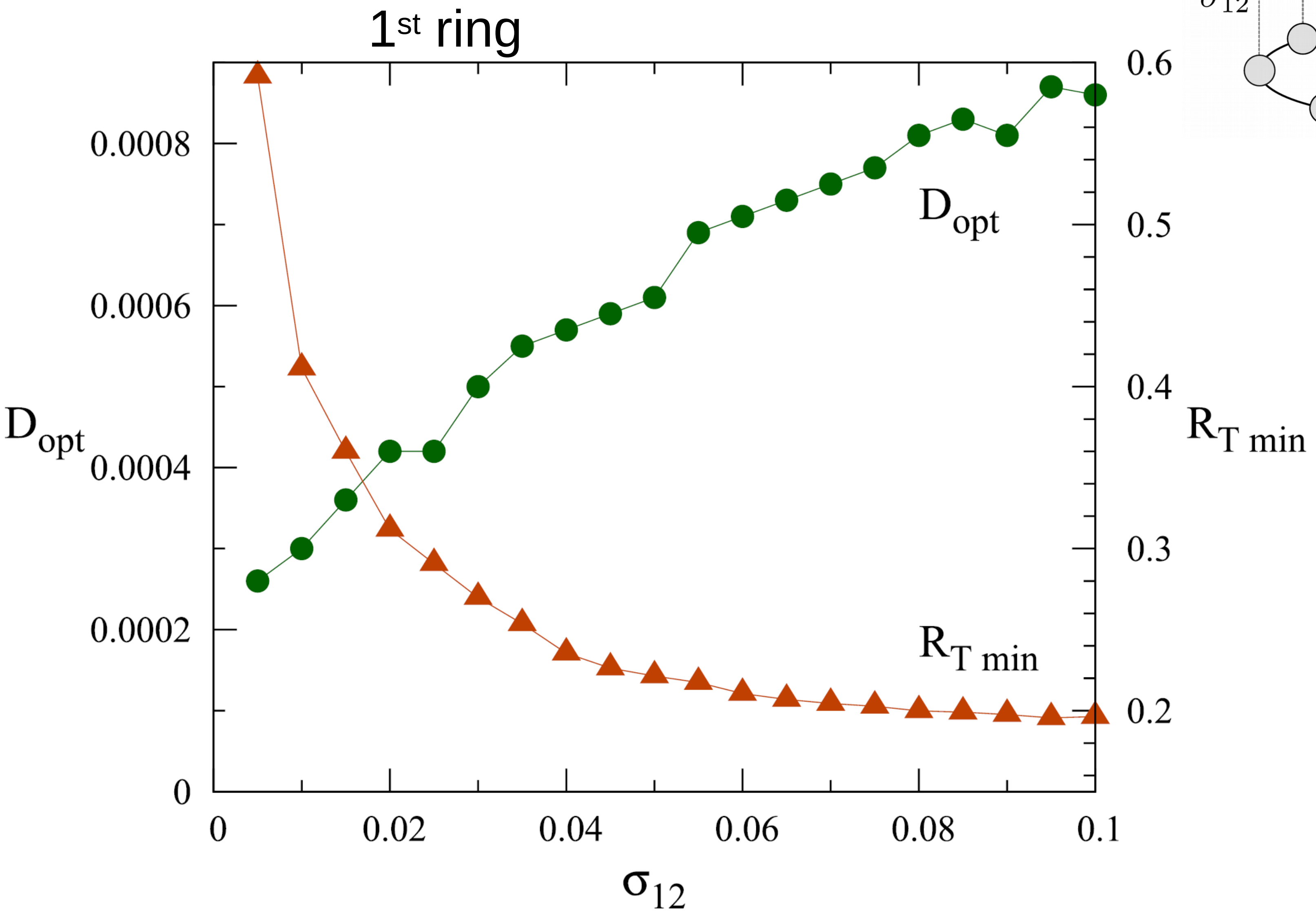
weak multiplexing
$\sigma_{12} = 0.04$

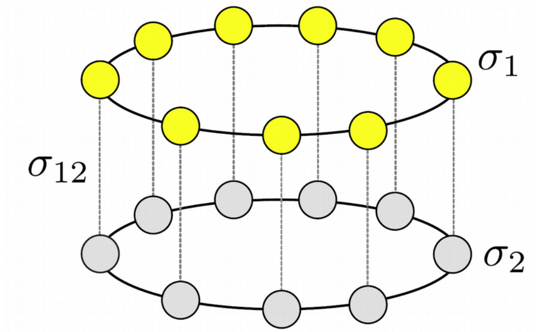
$\sigma_1 = 0.1$ (no CR in isolation)

$\sigma_2 = 0.2$ (optimal)

- Coherence resonance is better pronounced in the 2nd ring

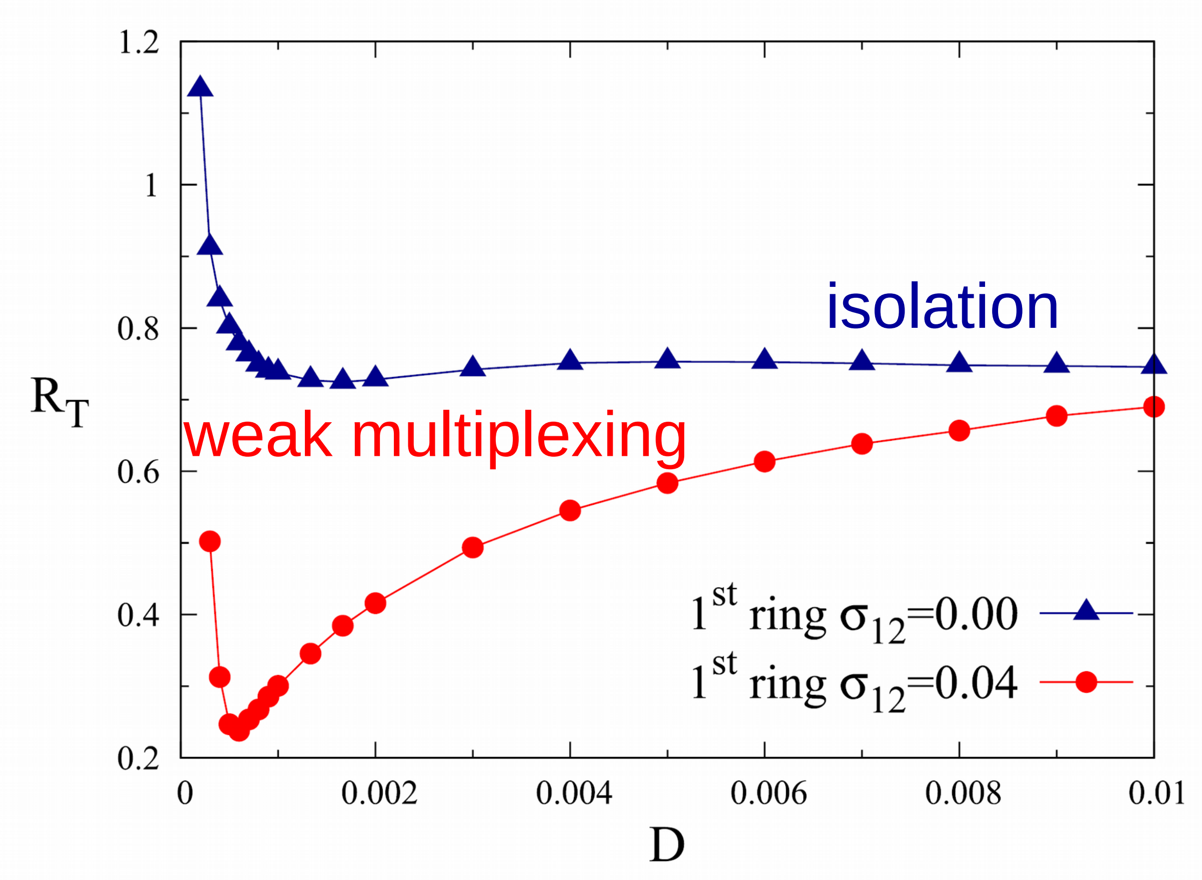
Coupling strength mismatch

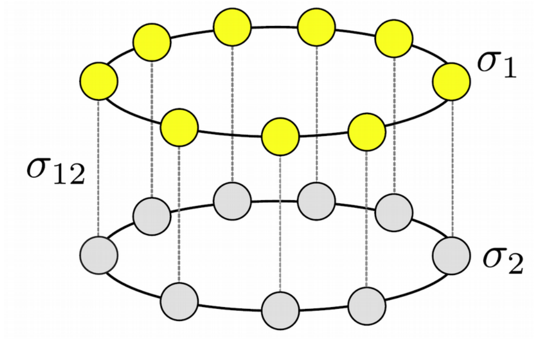




- Stronger multiplexing increases the coherence of oscillations in the 1st ring

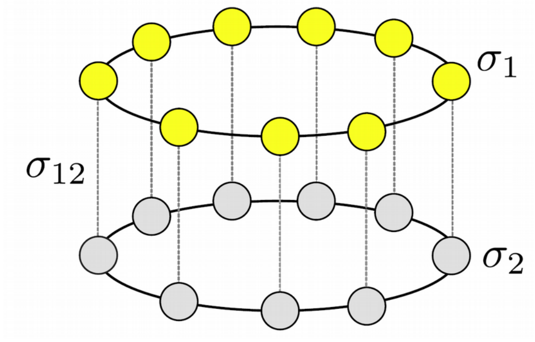
Coupling strength mismatch





- Weak multiplexing induces coherence resonance

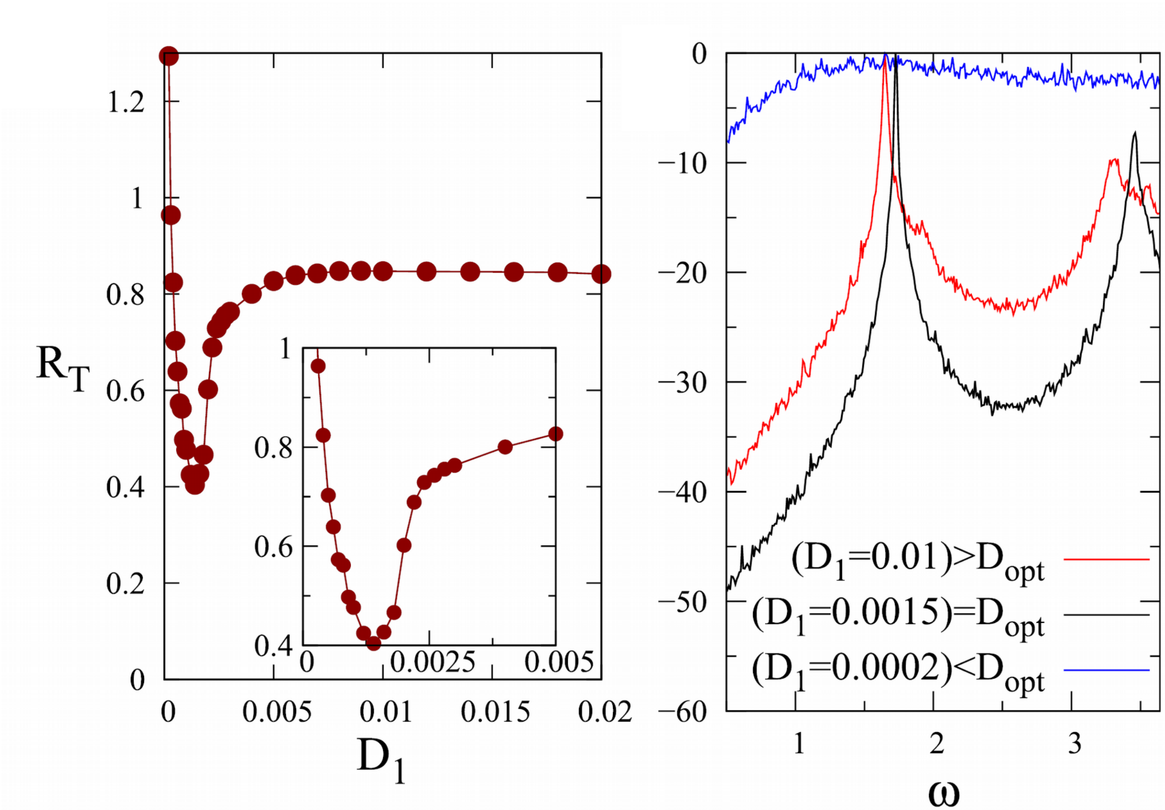
N. Semenova and A. Zakharova, Weak multiplexing induces coherence resonance, Chaos 28, 5, 051104 (2018)

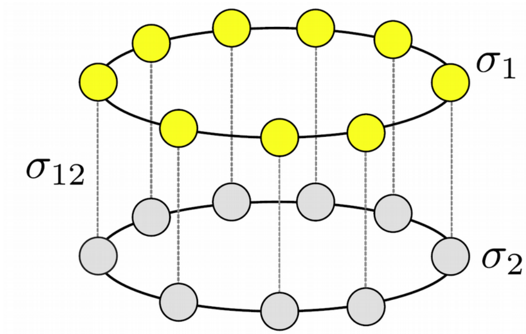


Deterministic layer multiplexed with a noisy layer

Deterministic layer multiplexed with a noisy layer

2^{nd} ring





weak multiplexing
$\sigma_{12} = 0.01$

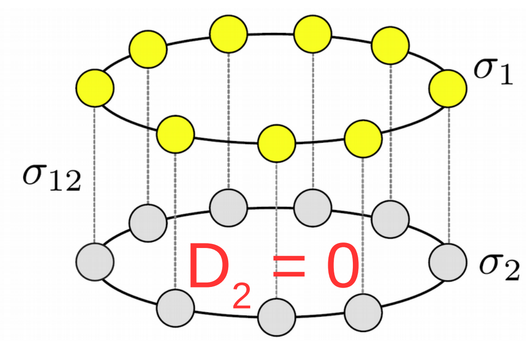
$\sigma_1 = \sigma_2 = 0.1$

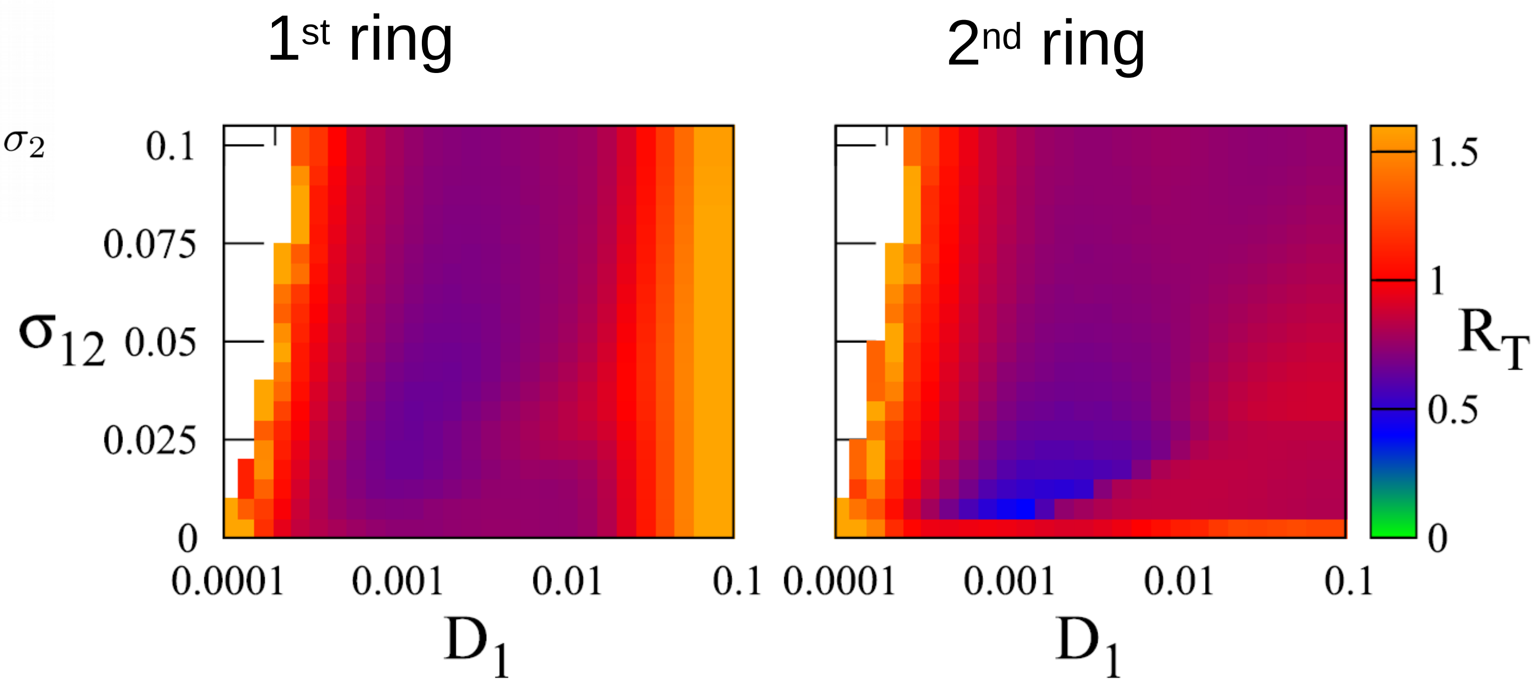
$D_2 = 0$

- Weak multiplexing induces coherence resonance in the deterministic layer

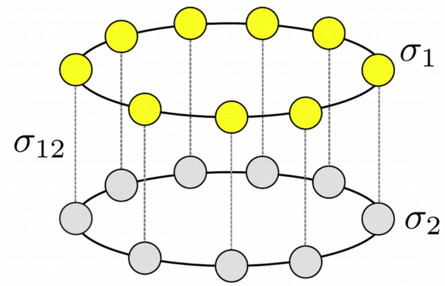
N. Semenova and A. Zakharova, Weak multiplexing induces coherence resonance, Chaos 28, 5, 051104 (2018)

Deterministic layer multiplexed with a noisy layer

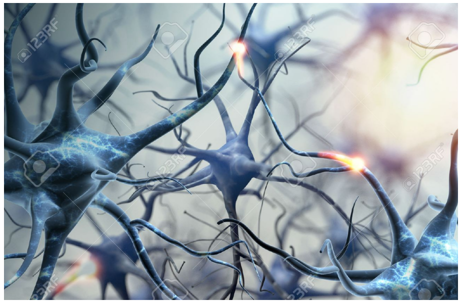




- Coherence resonance is more pronounced in the 2nd layer
- Stronger multiplexing shifts the minimum of R_T to larger values of noise
- Multiplexing induces coherence resonance for rather small values of σ_{12}



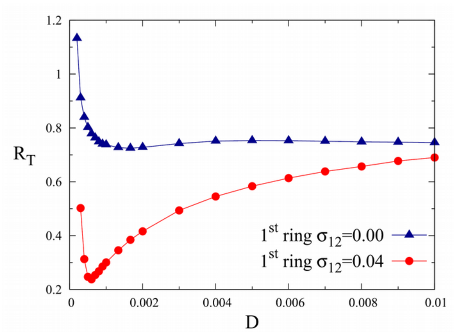
Conclusions



Weak multiplexing is a powerful method to control neural networks

Induces **coherence resonance** in the parameter regimes where it is absent for isolated networks

the coupling strength is not optimal



there is **no noise** noise exciting the elements