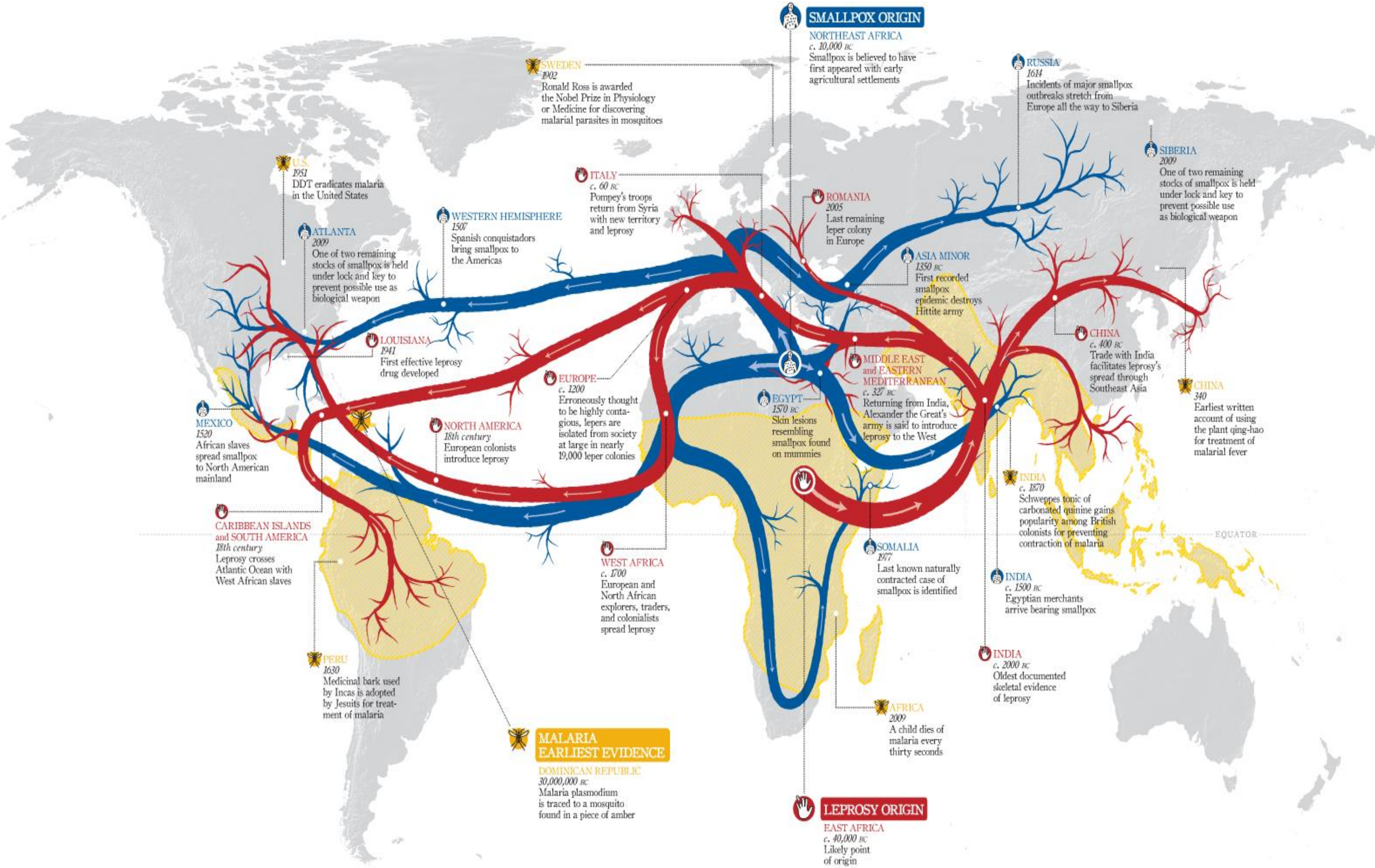
INTERACTING DYNAMICS ON NETWORKS

fakhteh.ghanbarnejad@gmail.com

Fakhteh Ghanbarnejad
Technische Universität Berlin

idonate project funded by DFG

2018
Tehran School


SMALLPOX ORIGIN
NORTHEAST AFRICA
c. 10,000 BC
Smallpox is believed to have first appeared with early agricultural settlements
SWEDEN
1902
Ronald Ross is awarded the Nobel Prize in Physiology or Medicine for discovering malarial parasites in mosquitoes
RUSSIA
1614
Incidents of major smallpox outbreaks stretch from Europe all the way to Siberia
SIBERIA
2009
One of two remaining stocks of smallpox is held under lock and key to prevent possible use as biological weapon
U.S.
1951
DDT eradicates malaria in the United States
ITALY
c. 60 BC
Pompey's troops return from Syria with new territory and leprosy
ROMANIA
2005
Last remaining leper colony in Europe
WESTERN HEMISPHERE
1507
Spanish conquistadors bring smallpox to the Americas
ATLANTA
2009
One of two remaining stocks of smallpox is held under lock and key to prevent possible use as biological weapon
ASIA MINOR
1350 BC
First recorded smallpox epidemic destroys Hittite army
LOUISIANA
1941
First effective leprosy drug developed
CHINA
c. 400 BC
Trade with India facilitates leprosy's spread through Southeast Asia
MIDDLE EAST and EASTERN MEDITERRANEAN
c. 327 BC
Returning from India, Alexander the Great's army is said to introduce leprosy to the West
EUROPE
c. 1200
Erroneously thought to be highly contagious, lepers are isolated from society at large in nearly 19,000 leper colonies
CHINA
340
Earliest written account of using the plant qing-hao for treatment of malarial fever
EGYPT
1570 BC
Skin lesions resembling smallpox found on mummies
MEXICO
1520
African slaves spread smallpox to North American mainland
NORTH AMERICA
18th century
European colonists introduce leprosy
INDIA
c. 1870
Schweppes tonic of carbonated quinine gains popularity among British colonists for preventing contraction of malaria
EQUATOR
CARIBBEAN ISLANDS and SOUTH AMERICA
18th century
Leprosy crosses Atlantic Ocean with West African slaves
WEST AFRICA
c. 1700
European and North African explorers, traders, and colonialists spread leprosy
SOMALIA
1977
Last known naturally contracted case of smallpox is identified
INDIA
c. 1500 BC
Egyptian merchants arrive bearing smallpox
INDIA
c. 2000 BC
Oldest documented skeletal evidence of leprosy
PERU
1630
Medicinal bark used by Incas is adopted by Jesuits for treatment of malaria
AFRICA
2009
A child dies of malaria every thirty seconds
MALARIA EARLIEST EVIDENCE
DOMINICAN REPUBLIC
30,000,000 BC
Malaria plasmodium is traced to a mosquito found in a piece of amber
LEPROSY ORIGIN
EAST AFRICA
c. 40,000 BC
Likely point of origin

OUTBREAK

Deadliest Pandemics in History

Because a virus doesn't care about state lines or national borders, it can wipe out millions and span multiple continents rapidly. Here is a look at the infectious diseases the world has battled throughout history.

What is a Pandemic?

Derived from the Greek word *pandemos* meaning "pertaining to all people," a pandemic is a widespread disease that affects humans over a wide geographic area.

Key:

PANDEMIC YEAR | DEATH TOLL

Fever, Chills, Headache, Weight Loss, Fatigue, Red Eyes, Bleeding, Diarrhea, Dehydration

Cough, Bubo, Vomiting, Sore Throat, Seizures

A bubo is an abnormal swelling of the lymph nodes.

Skin Discoloration, Rash, Lesions, Nausea

MEASLES
7th Century BC - 1963
200 million

HIV / AIDS
1981 - TODAY
25+ million

PLAGUE of JUSTINIAN
541 - 750
25 million

SMALLPOX
10,000 BC - 1979
300+ million

Bigpox?

In terms of an estimated death toll, smallpox is the deadliest pandemic in history. The highly contagious, rash-inducing infection has killed more than 500 million people. Some believe that 90 percent of the native population of the New World was wiped out by the disease.

SPANISH FLU
1918 - 1919
50-100 million

BLACK DEATH
1340 - 1771
75 million

THIRD PANDEMIC
1855
12 million

Ring Around the Rosie, a Pocket Full of Plague

Legend says the Black Death plague inspired the children's rhyme "Ring Around The Rosy," which alluded to the rash-like rings and ashes of the deceased victims.

TYPHUS
430 BC - TODAY
4 million

CHOLERA
1817 - TODAY
3 million

HONG KONG FLU
1968 - 1969
1 million

Honorable Mentions

Although the following viruses do not have a figure for total amount of lives claimed, they continue to terrorize various areas around the world.

MALARIA 1600 - Today

Common Symptoms

Chills, Headache, Fever, Jaundice, Muscle Pain, Nausea, Vomiting, Seizures

Death Toll

According to the World Health Organization's 2010 "World Malaria Report," an estimated 781,000 people are killed by the virus every year.

TUBERCULOSIS 700 BC - Today

Common Symptoms

Chest Pain, Cough, Fever, Chills, Fatigue

Death Toll

There are almost 2 million tuberculosis-related deaths worldwide every year.

YELLOW FEVER 16th Century - Today

Common Symptoms

Bleeding, Fever, Nausea, Vomiting, Delirium, Seizures, Jaundice

Death Toll

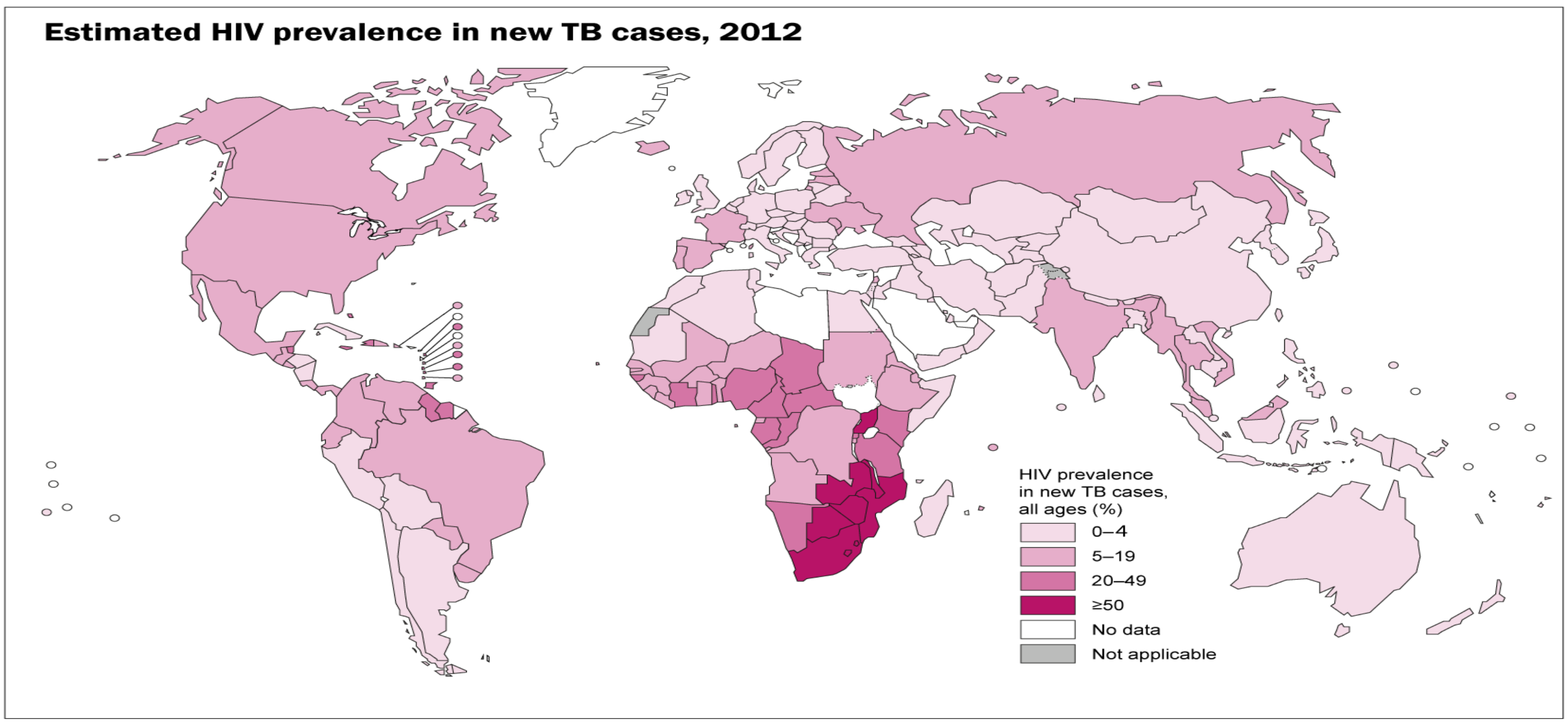
Worldwide, 30,000 deaths are caused by the infection every year.

Sources: Mayo Clinic // Centers for Disease Control and Prevention // World Health Organization // New York Times // National Center for Biotechnology Information

A COLLABORATION BETWEEN GOOD AND COLUMN FIVE

Coinfection

- Spanish flu & Pneumonia(1918–1919)
- HIV & hepatitis B and C , TB, malaria



The boundaries and names shown and the designations used on this map do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted and dashed lines on maps represent approximate border lines for which there may not yet be full agreement.

Data Source: *Global Tuberculosis Report 2013*. WHO, 2013.

World Health Organization

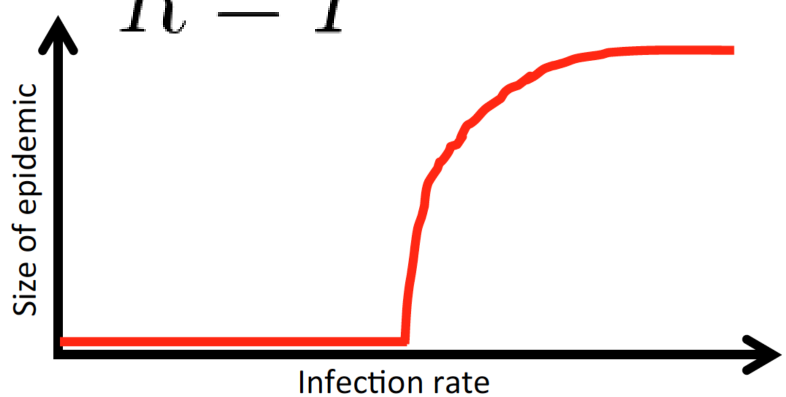
SINGLE DISEASE: SIR

$$S \xrightarrow{\alpha} I \longrightarrow R$$

$$\dot{S} = -\alpha S I$$

$$\dot{I} = +\alpha S I - I$$

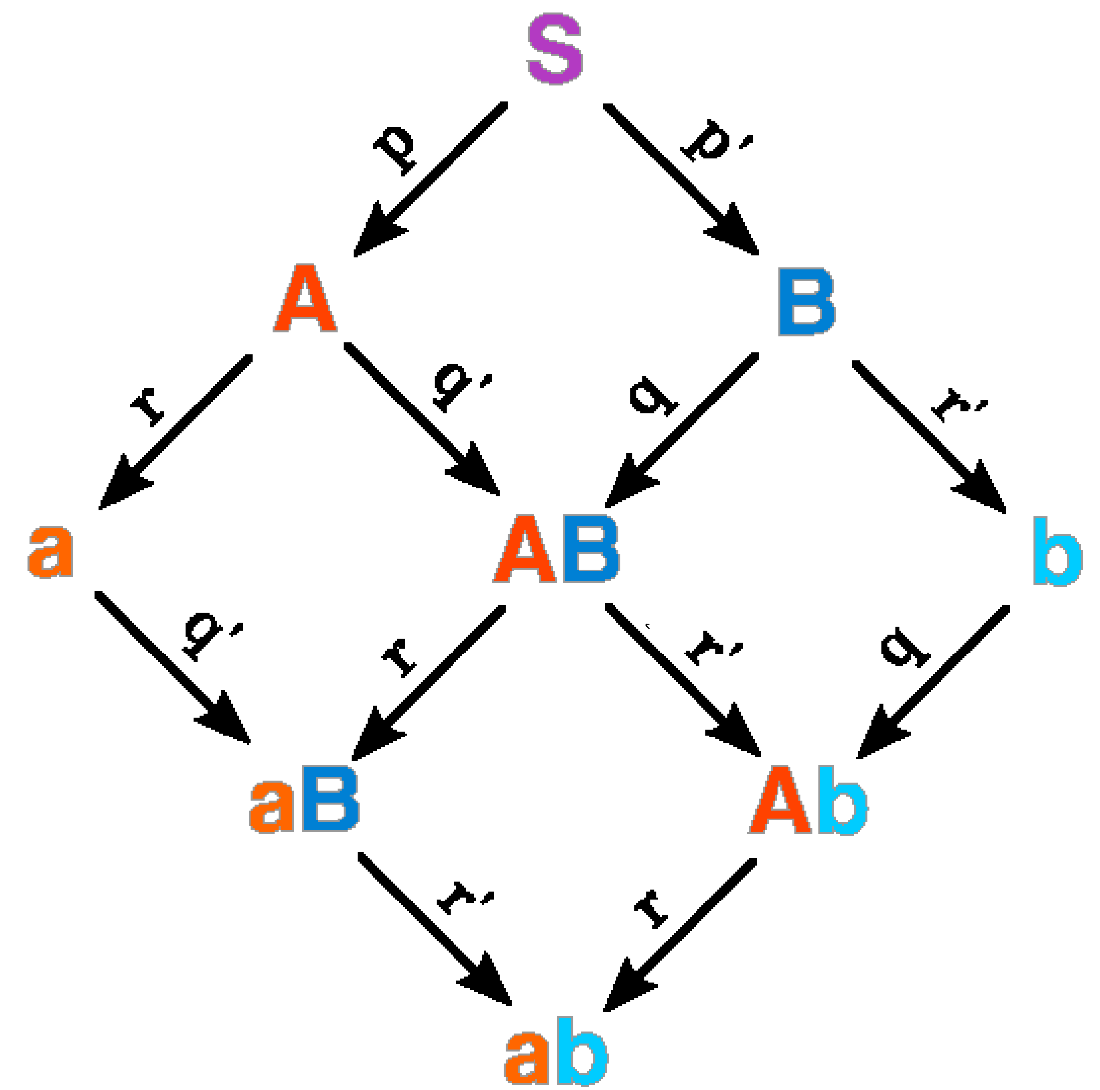
$$\dot{R} = I$$



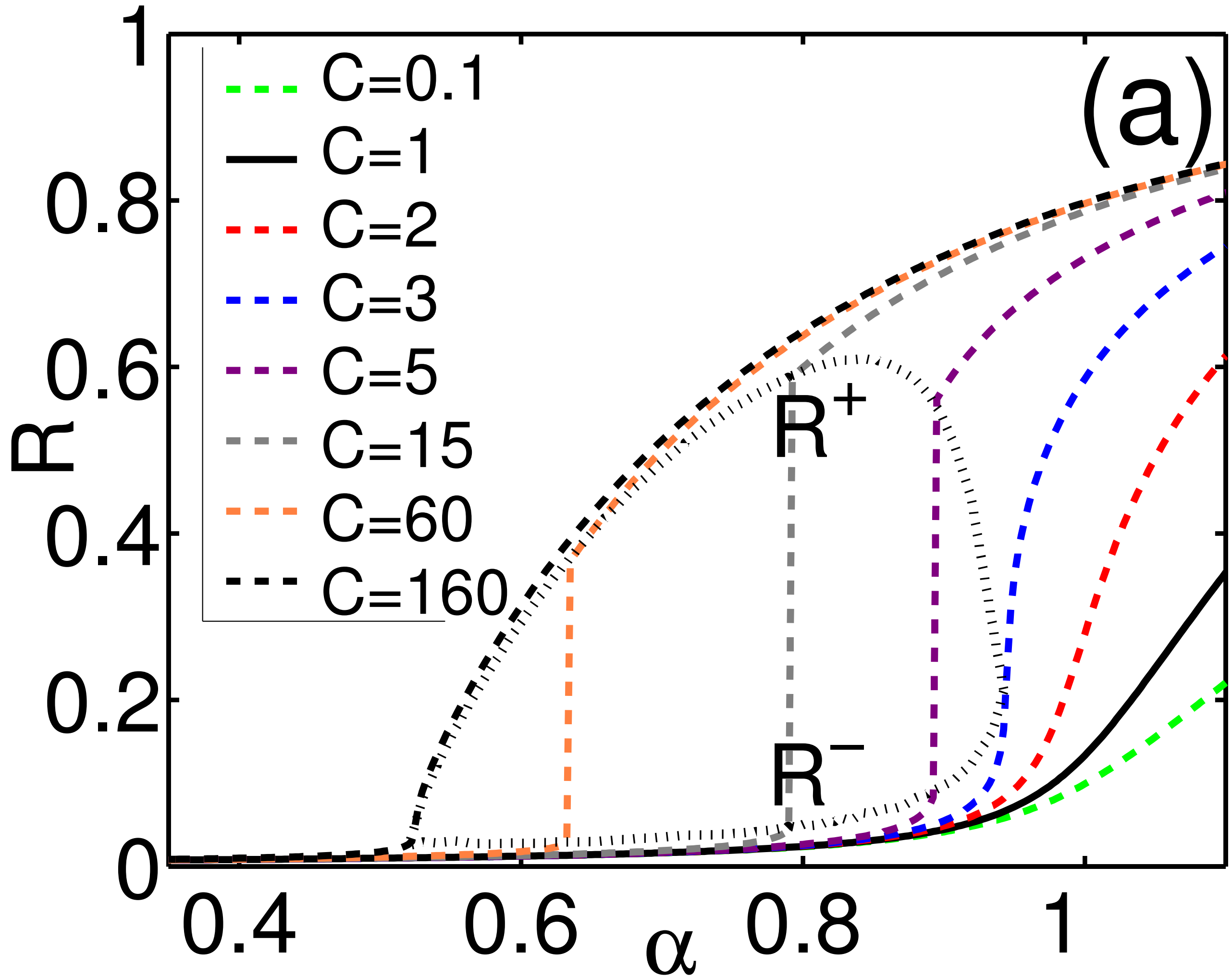
$$\text{No-epidemic} \xrightarrow{\alpha_c = 1} \text{Epidemic}$$

Continuous Transition

INTERACTING SPREADING DYNAMICS



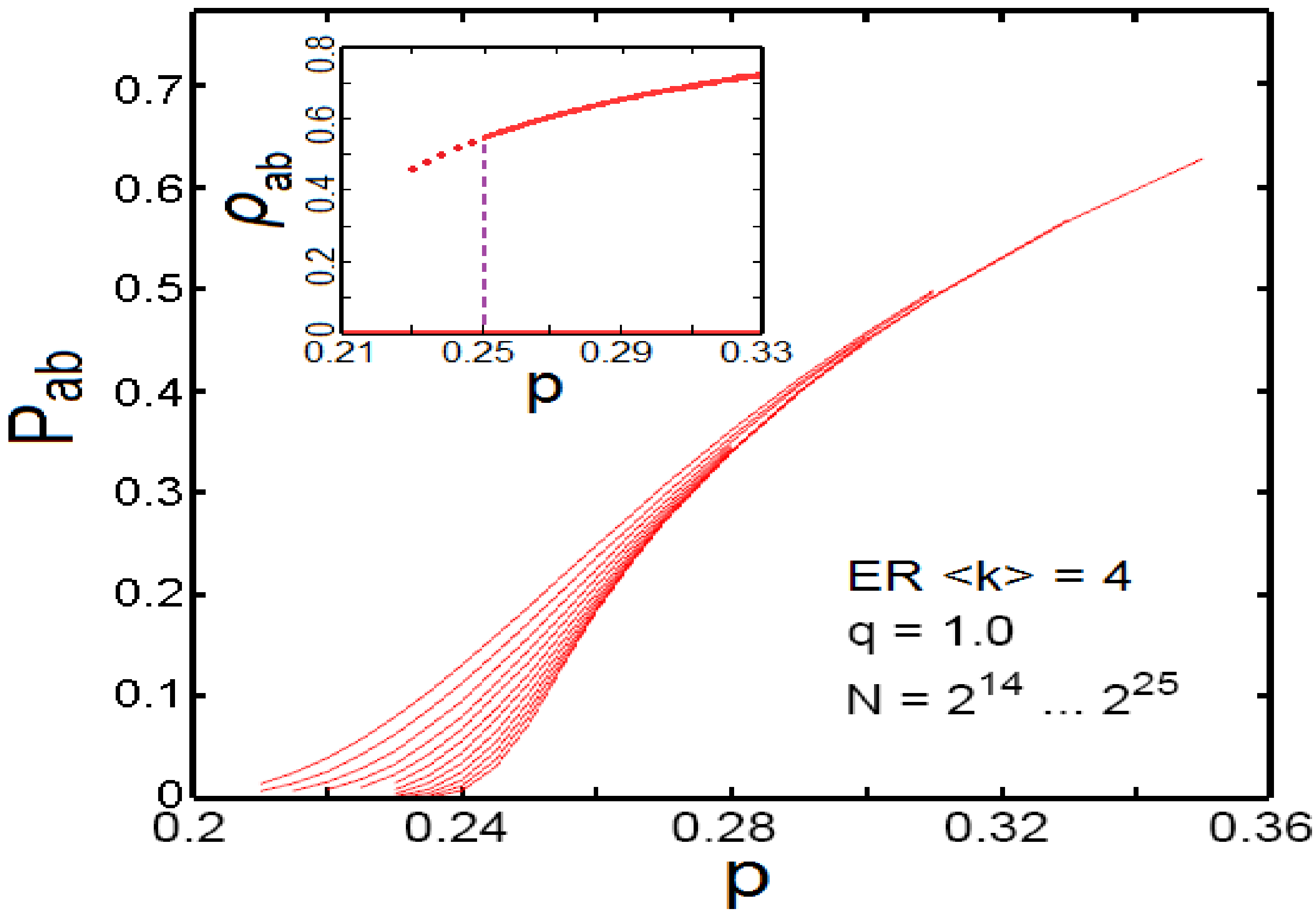
MF Numerical Results



EPL 104, 50001 (2013)

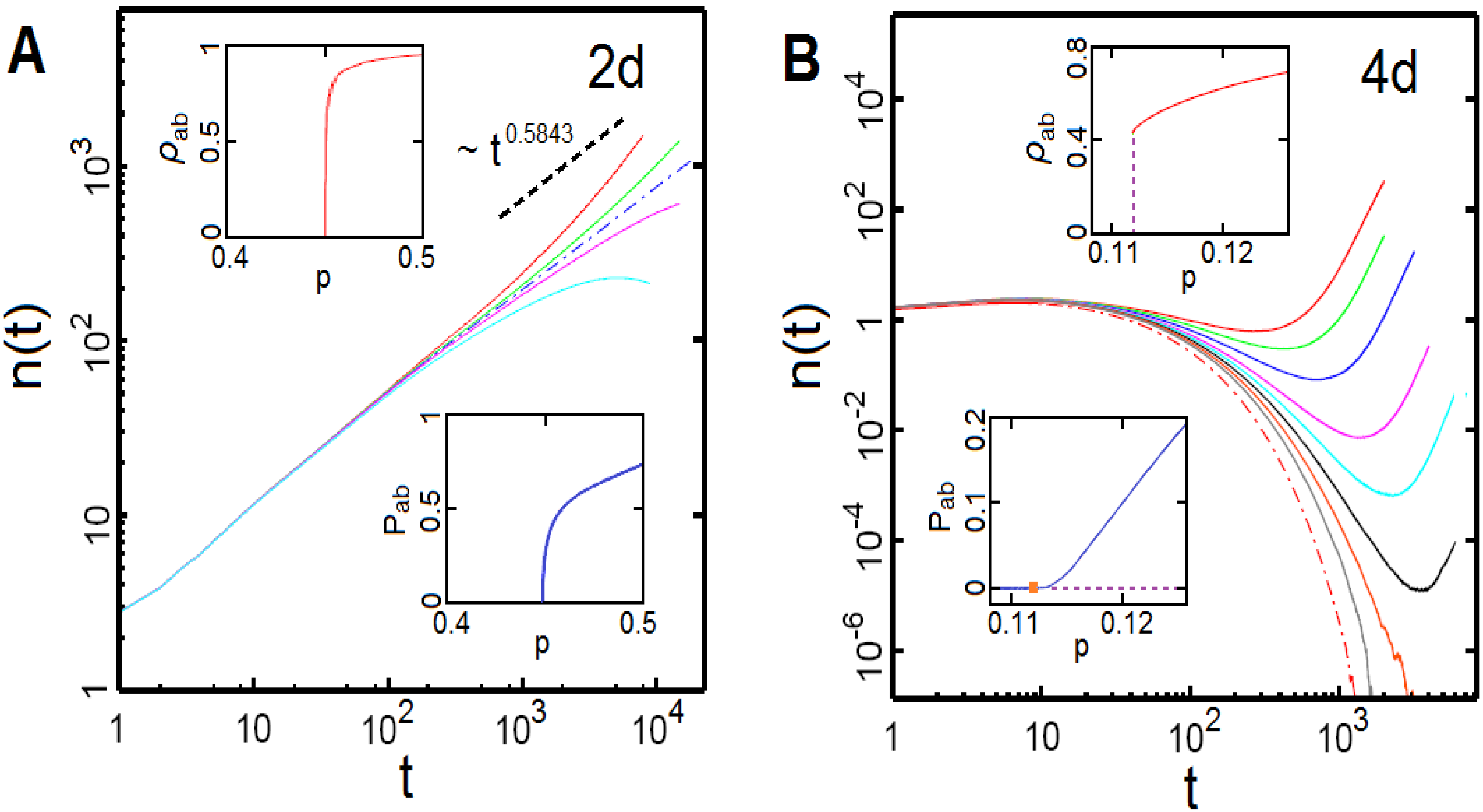
Cooperative SIRs on Networks

On Erdös-Renyi Networks



[Nature Physics 11, 936–940 (2015)]

On Lattices



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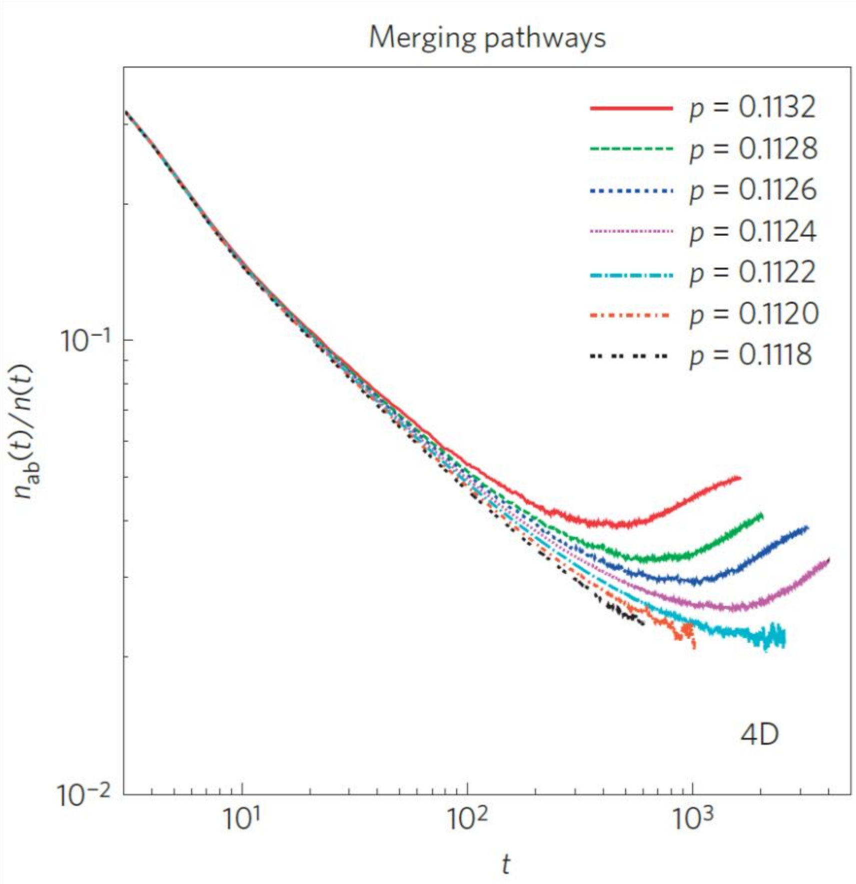
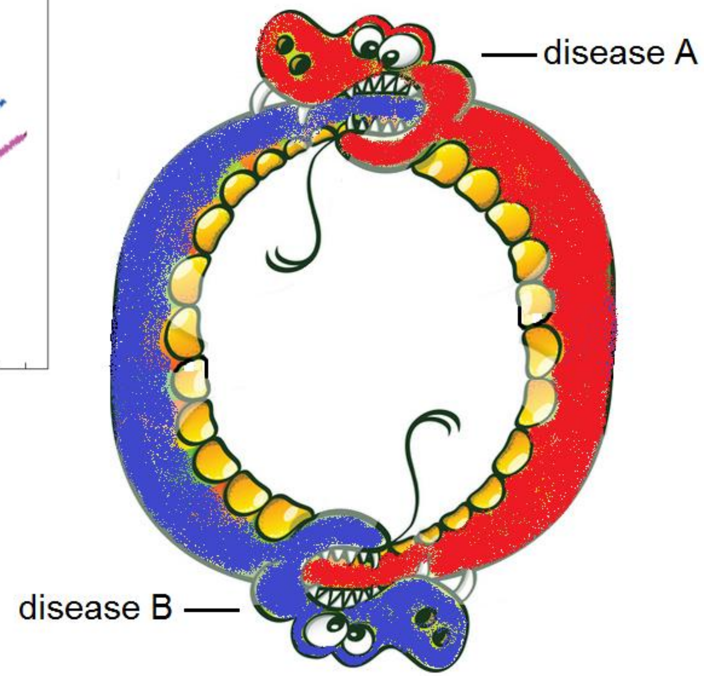
MICROSCOPIC MECHANISM





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December 2013
www.epljournal.org
epl A LETTERS JOURNAL EXPLORING THE FRONTIERS OF PHYSICS
EPL, **104** (2013) 50001
doi: 10.1209/0295-5075/104/50001

Outbreaks of coinfections: The critical role of cooperativity

Li Chen[1(a)], Fakhteh Ghanbarnejad[1(b)], Weiran Cai[2(c)] and Peter Grassberger[1,3(d)]

[1] Max Planck Institute for the Physics of Complex Systems - Dresden, Germany
[2] Faculty of Electrical and Computer Engineering, TU Dresden - Dresden, Germany

PHYSICAL REVIEW E 93, 042316 (2016)

Phase transitions in cooperative coinfections: Simulation results for networks and lattices

Peter Grassberger*
Max Planck Institute for the Physics of Complex Systems, Dresden, Germany and
JSC, FZ Jülich, D-52425 Jülich, Germany

Li Chen
Robert Koch Institute, 13353 Berlin, Germany and
Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Fakhteh Ghanbarnejad
Max Planck Institute for the Physics of Complex Systems, Dresden, Germany and
Robert Koch Institute, 13353 Berlin, Germany

Weiran Cai
Medical Faculty and Department of Electrical and Information En...
01307 Dresd...

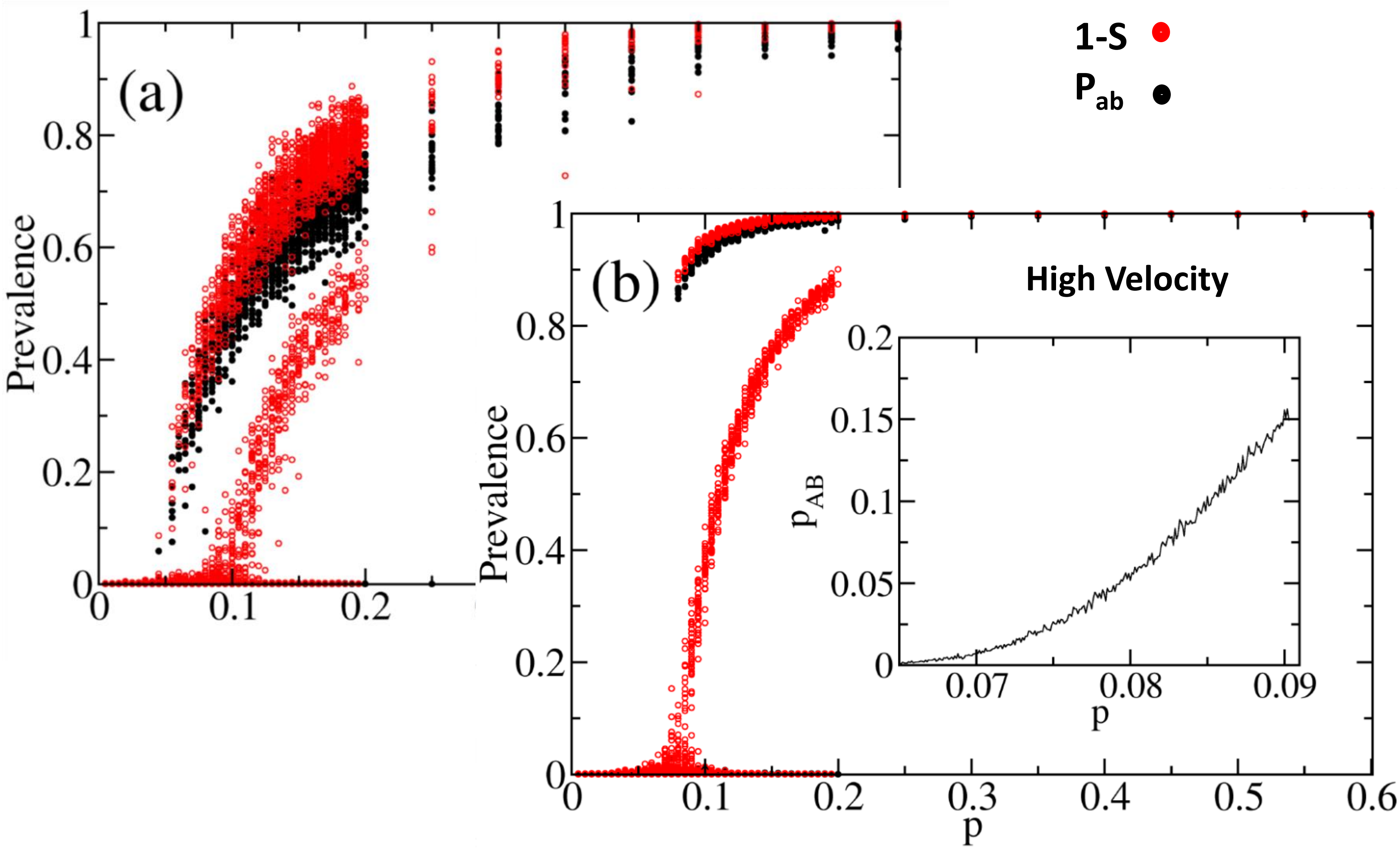
nature physics
LETTERS
PUBLISHED ONLINE: 7 SEPTEMBER 2015 | DOI: 10.1038/NPHYS3457

Avalanche outbreaks emerging in cooperative contagions

Weiran Cai[1,2*†], Li Chen[3,4†], Fakhteh Ghanbarnejad[3,4] and Peter Grassberger[4,5]

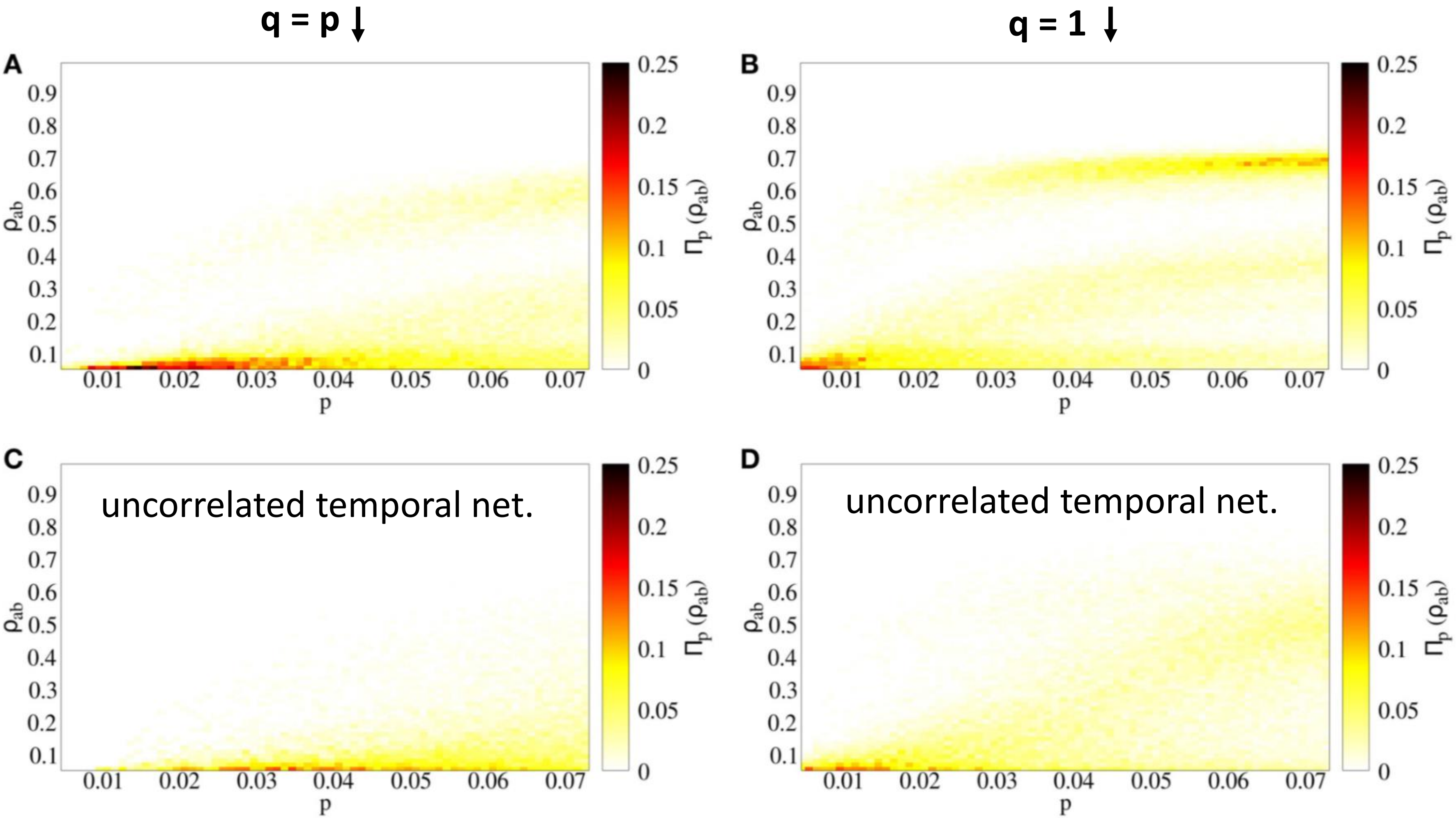
Cooperative SIRs on Temporal-Spatial Networks

Random Geometric Graphs



[Manuscript in preparation (2018)]

HOSPITAL NETWORKS



Frontiers in Physics, V5, P46 (2017)

ORIGINAL RESEARCH
published: 06 October 2017
doi: 10.3389/fphy.2017.00046

frontiers in Physics

Check for updates

Risk of Coinfection Outbreaks in Temporal Networks: A Case Study of a Hospital Contact Network

Jorge P. Rodríguez[1], *Fakhteh Ghanbarnejad*[2*] *and Víctor M. Eguíluz*[1*]

[1] Instituto de Física Interdisciplinar y Sistemas Complejos (IFISC), CSIC-UIB, Palma de Mallorca, Spain, [2] Institut für Theoretische Physik, Technische Universität Berlin, Berlin, Germany

Cooperation can lead to

- Abrupt outbreaks (first order phase transition)
- Decreasing of the epidemic threshold

- Topological features of the networks play role

BUT,

is cooperation a good evolutionary strategy?

Interacting Spreading Dynamics

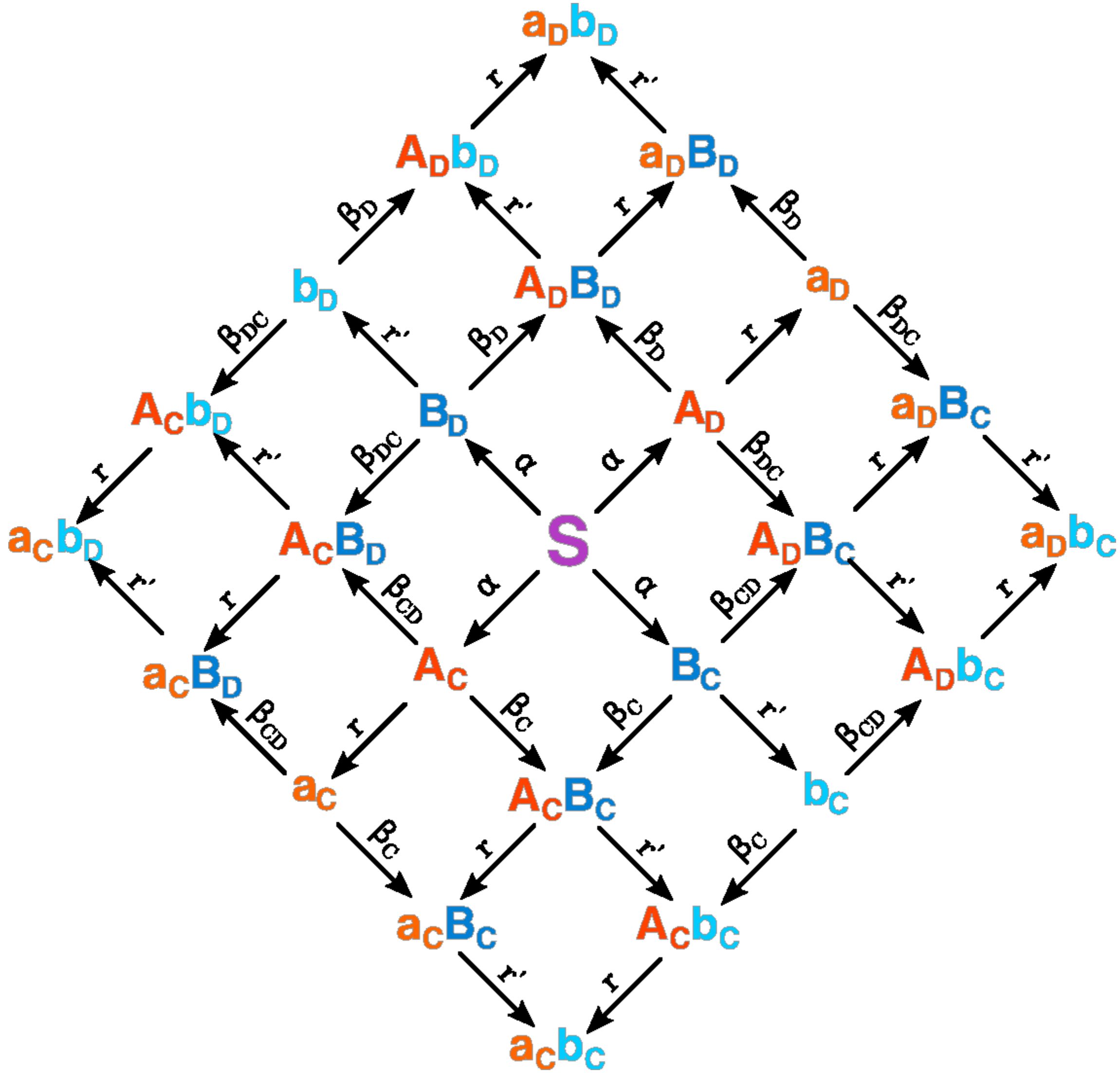
Two different pathogens

- A
- B

Two different strategies (strains):

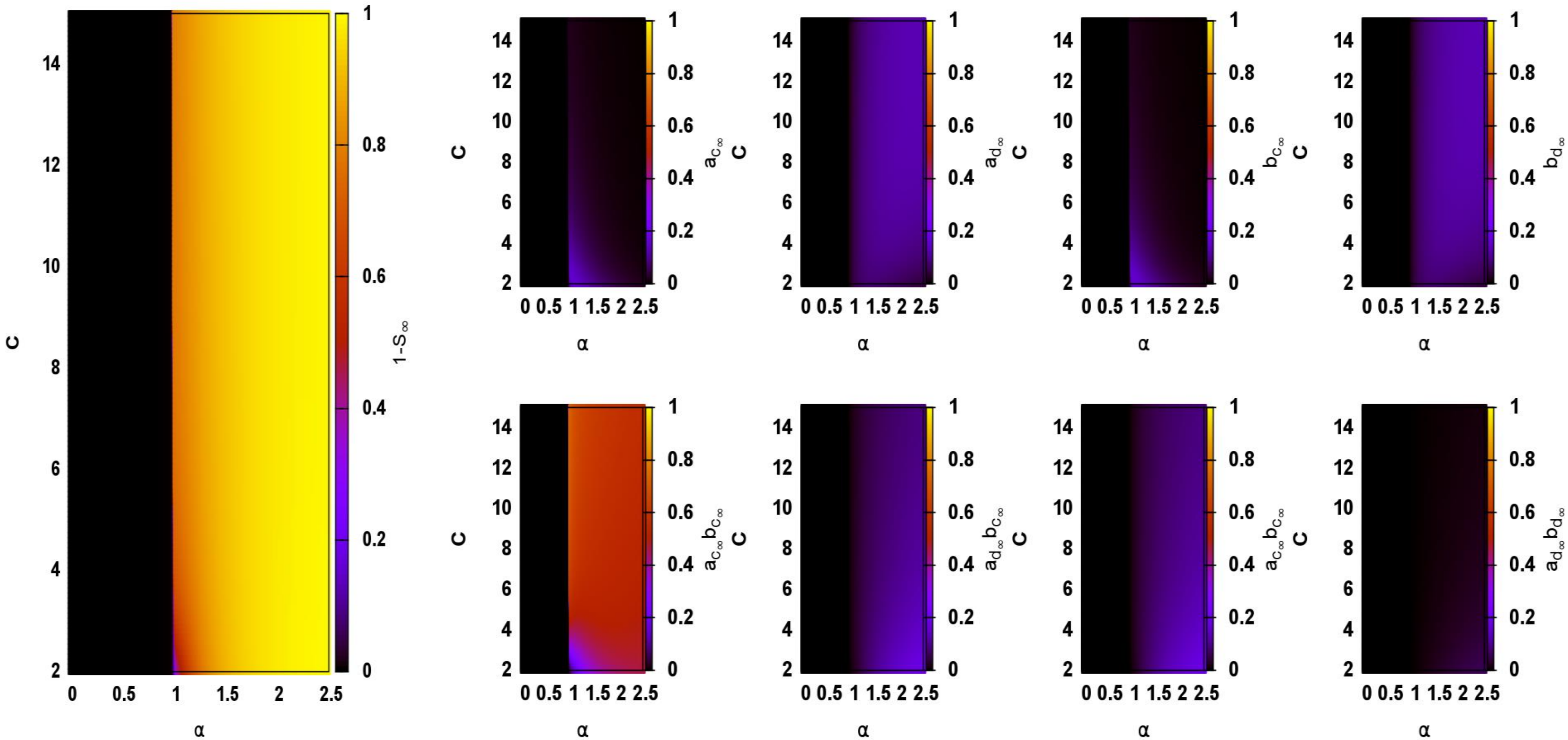
- Cooperation (C)
- Defection (D)

SPREADING DYNAMICS

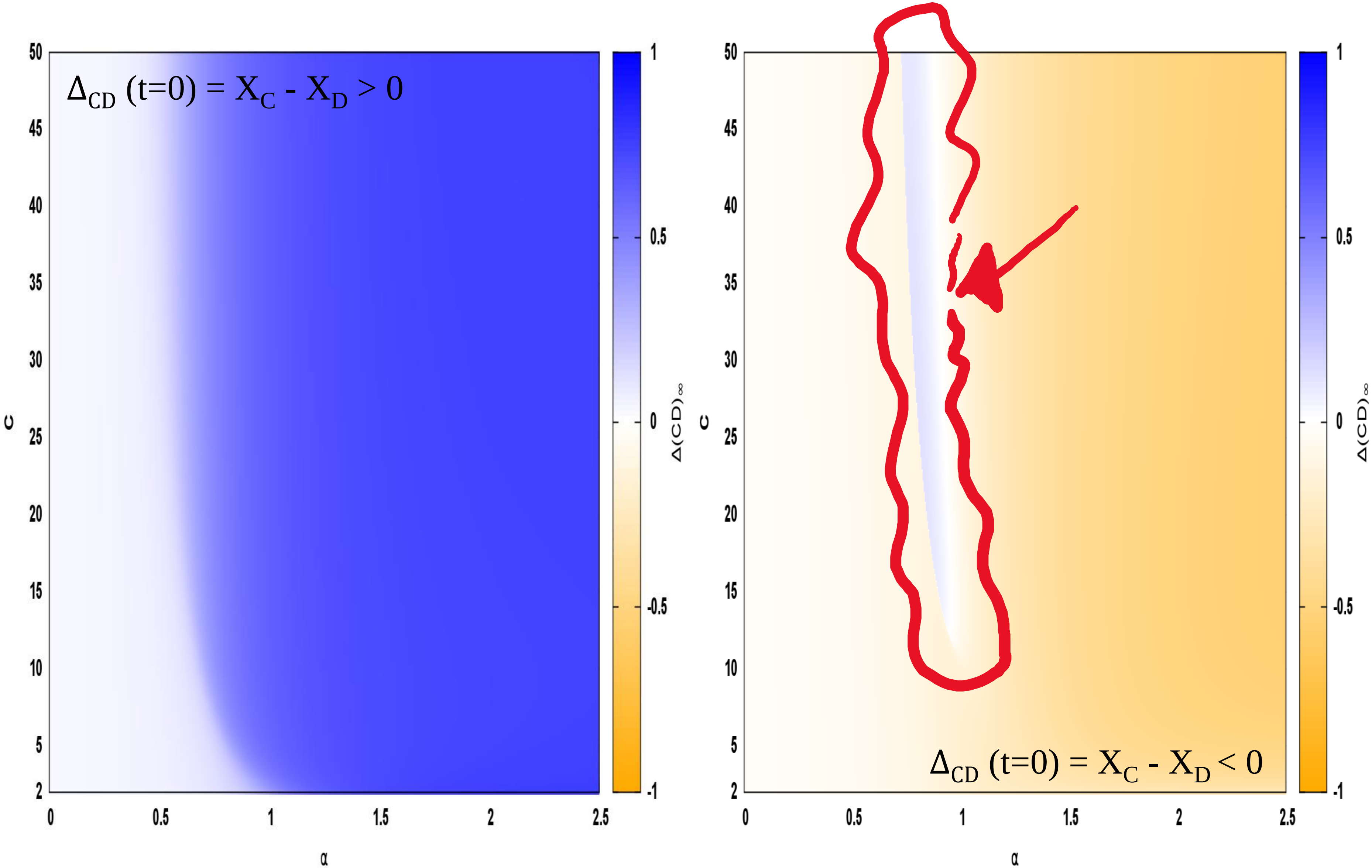


MF NUMERICAL RESULTS

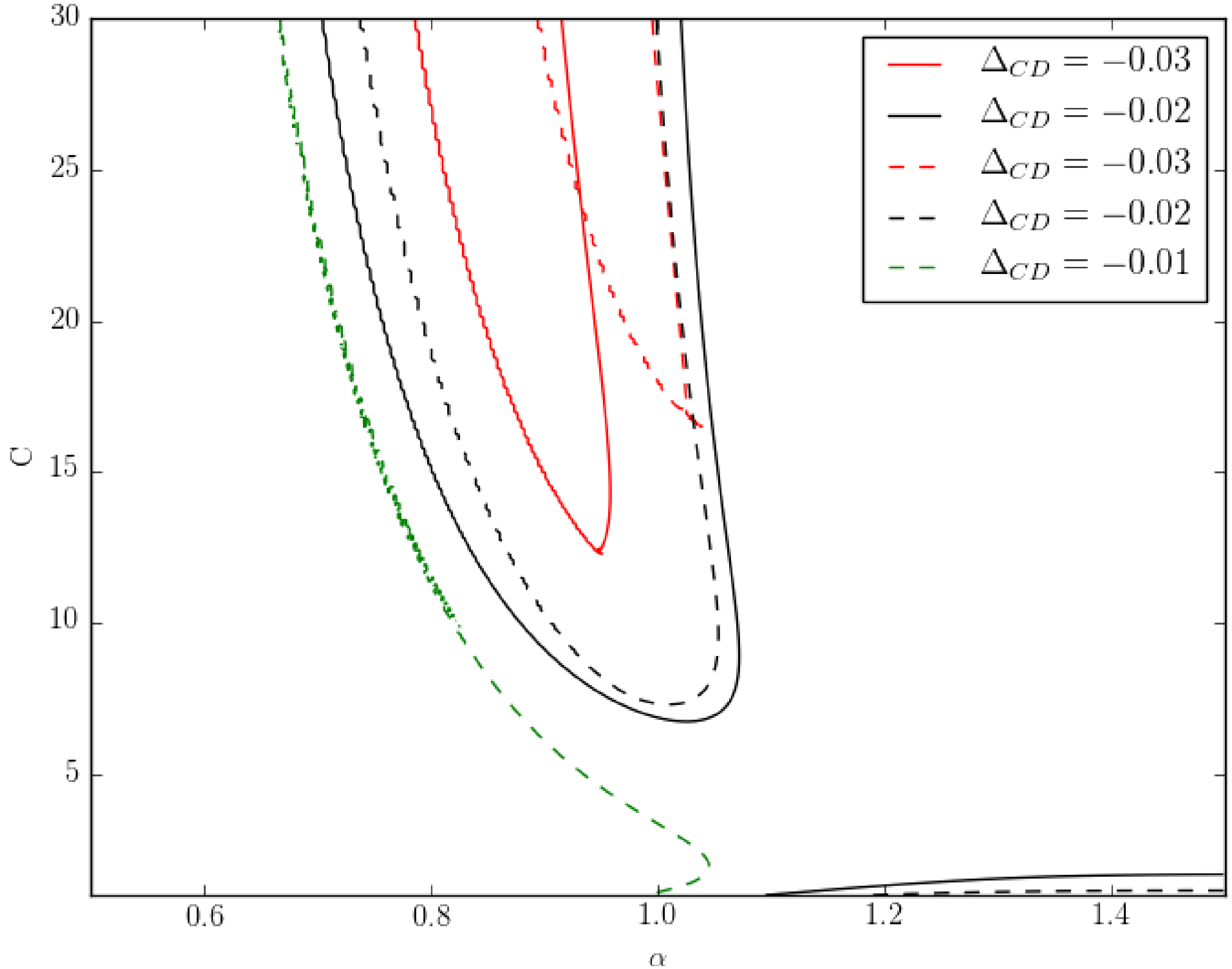
$$A \leftrightarrow B,\ C \leftrightarrow D,\ \beta_C = c\,\alpha,\ \beta_D = \frac{1}{\beta_C},\ \beta_{CD} = \frac{c}{2\alpha},\ \beta_{DC} = \frac{1}{\beta_{CD}}$$



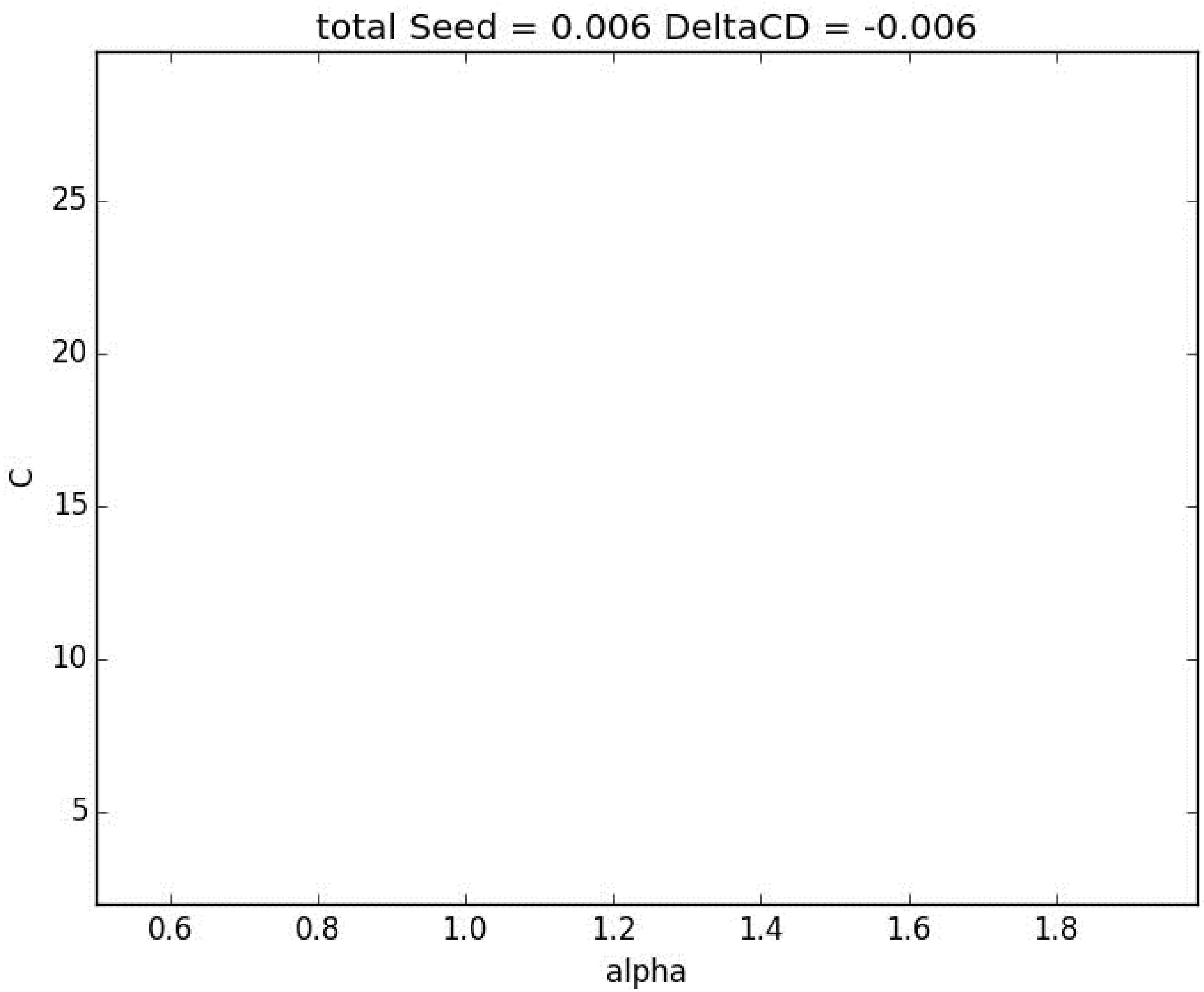
Breaking Symmetry



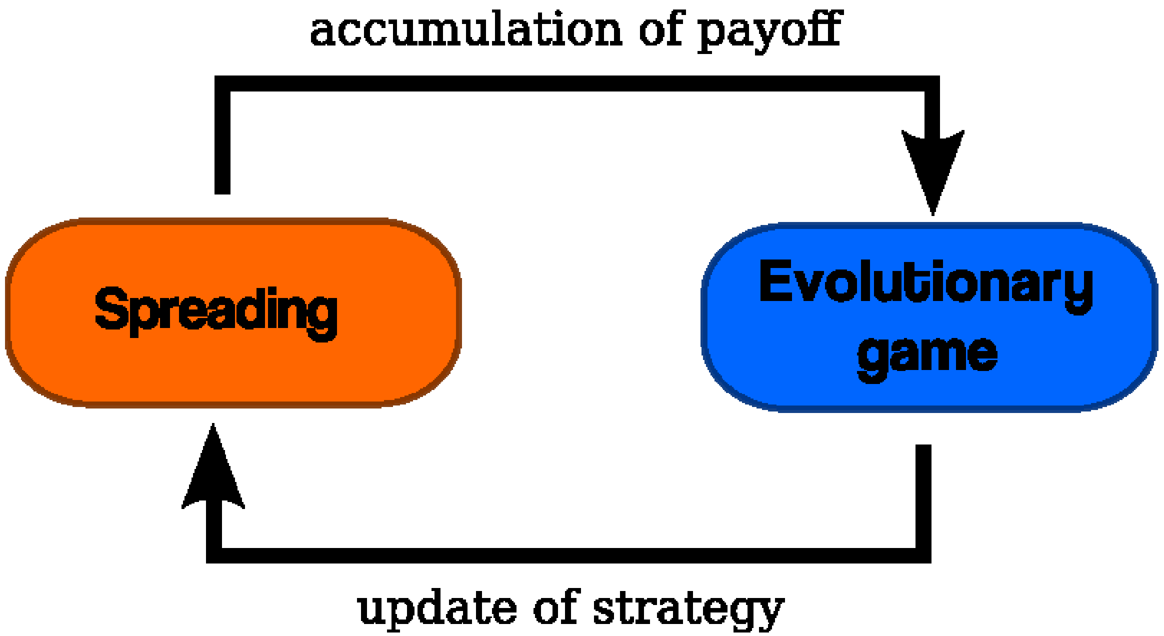
BREAKING SYMMETRY



BREAKING SYMMETRY



EVOLUTIONARY DYNAMICS



PAYOFFS

$$\pi_{X_y \to S} = C_0 = 1 \,,$$

$$\pi_{\substack{A_C \to B_C, b_C \\ B_C \to A_C, a_C}} = (C_1 \,, C_1) = \left(\frac{1}{2} \,, \frac{1}{2} \right) \,,$$

$$\pi_{\substack{A_D \to B_C, b_C \\ B_D \to A_C, a_C}} = (C_2 \,, C_3) = (\gamma \,, 1 - \gamma) \,,$$

$$\pi_{\substack{A_C \to B_D, b_D \\ B_C \to A_D, a_D}} = (C_3 \,, C_2) = (1 - \gamma \,, \gamma) \,,$$

$$\pi_{\substack{A_D \to B_D, b_D \\ B_D \to A_D, a_D}} = (C_4 \,, C_4) = \left(-\frac{1}{2}, -\frac{1}{2} \right)$$

Hawk and Dove game

UPDATE OF STRATEGY

$$\rho_y^{j+1} = \rho_y^j \left(1 + \Pi_y^j \quad - \Phi^j \right)$$

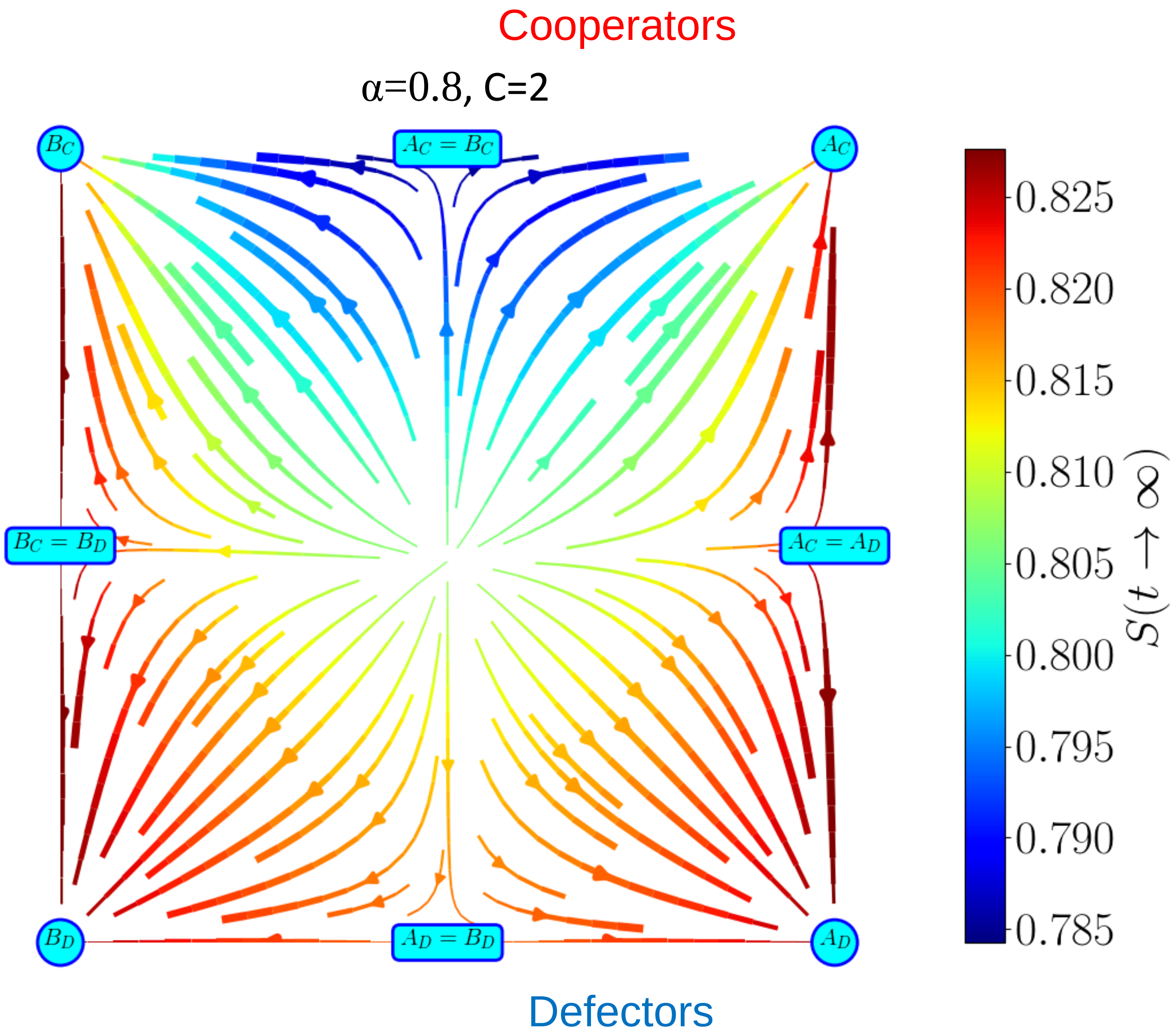
J: season

y: A_C, A_D, B_C, B_D

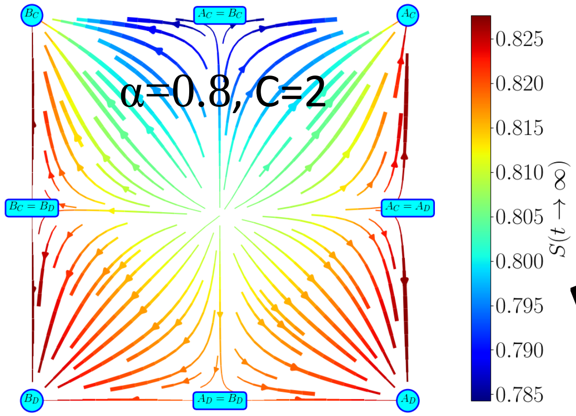
Π: payoff

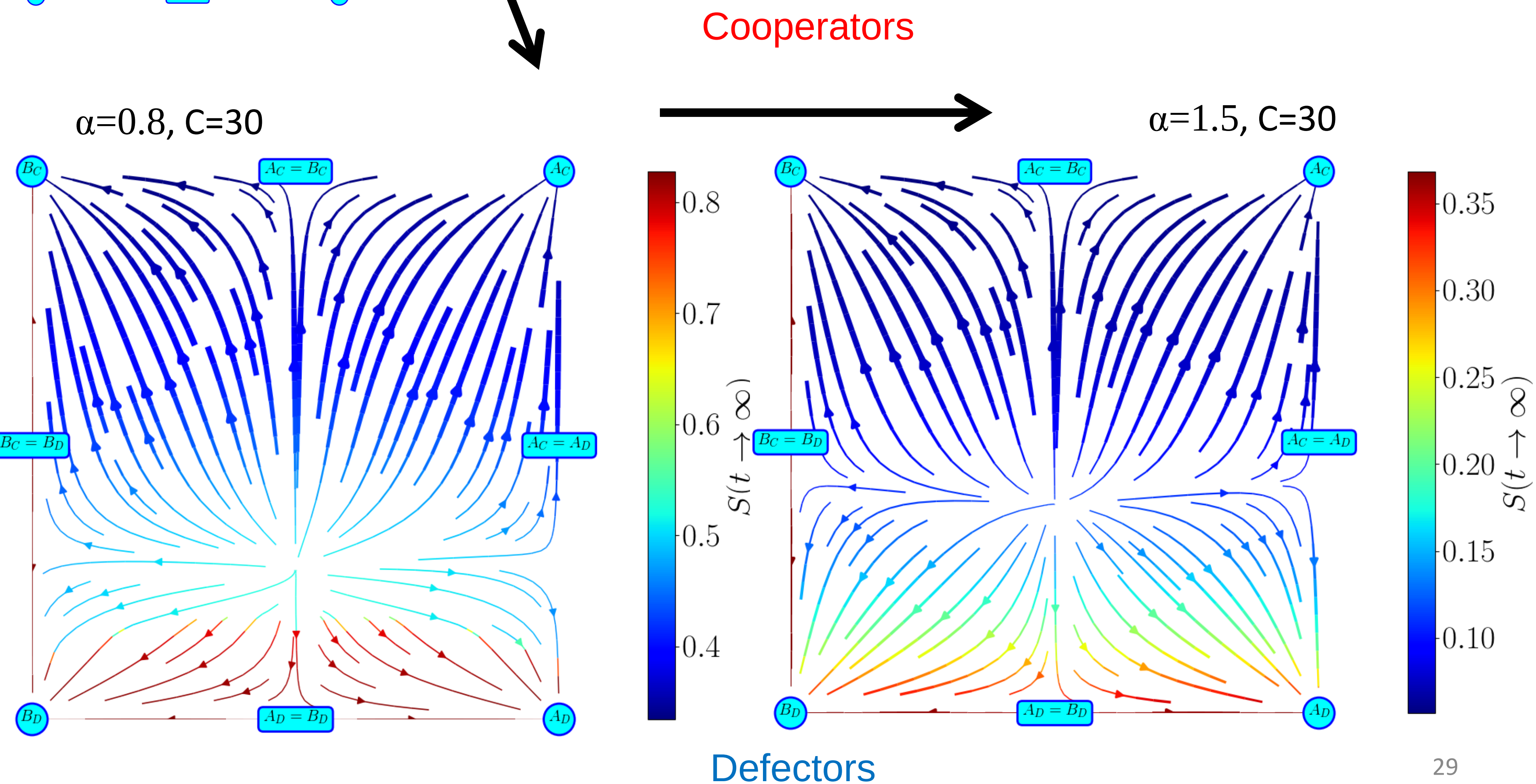
Φ: $< \Pi >$

Who wins?

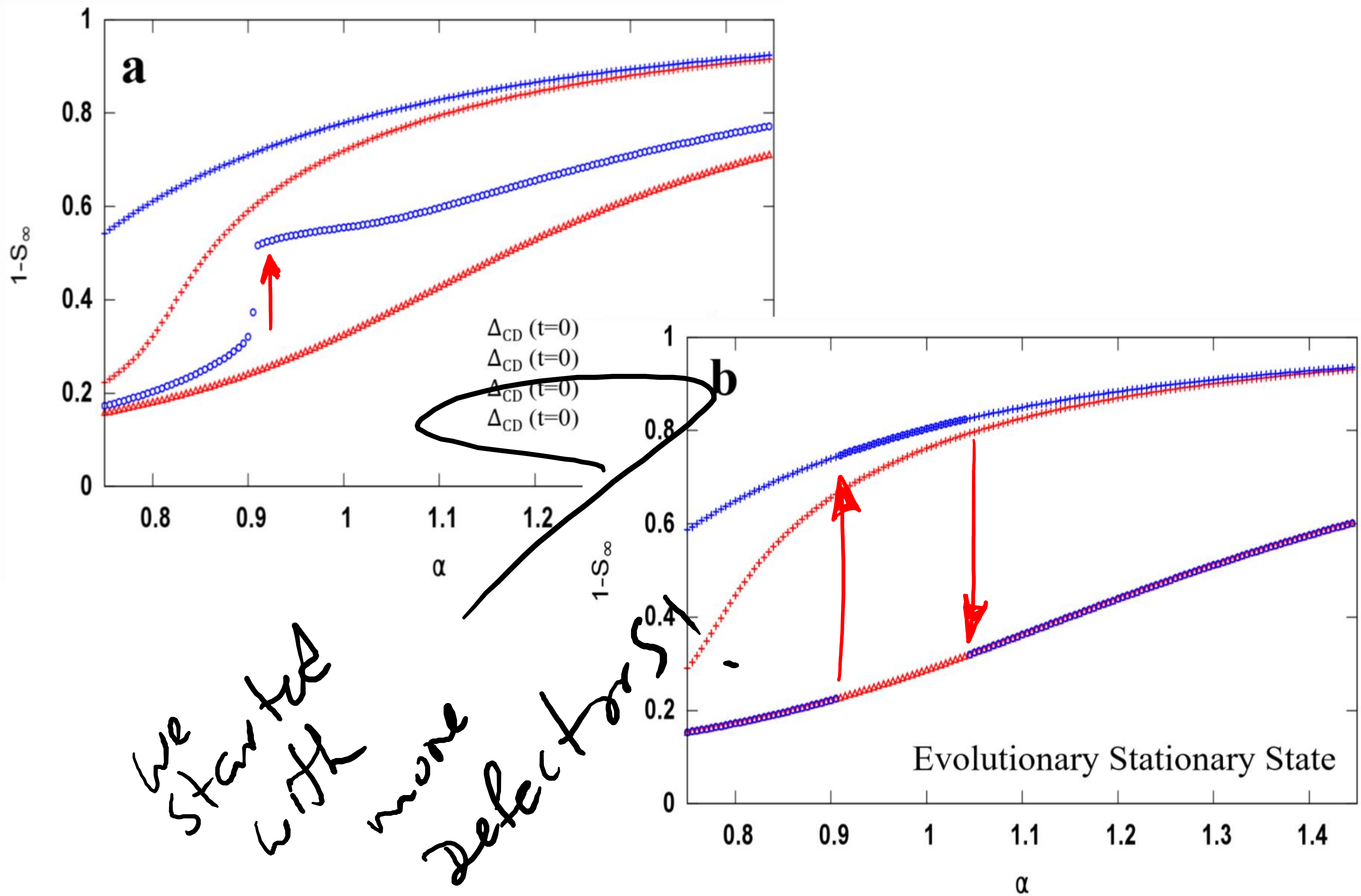

Cooperators
α=0.8, C=2
B_C
$A_C = B_C$
A_C
$B_C = B_D$
$A_C = A_D$
B_D
$A_D = B_D$
A_D
0.825
0.820
0.815
0.810
0.805
0.800
0.795
0.790
0.785
$S(t \to \infty)$
Defectors

WHO WINS?


α=0.8, C=2
$A_C = B_C$
B_C
A_C
$B_C = B_D$
$A_C = A_D$
B_D
$A_D = B_D$
A_D
0.825
0.820
0.815
0.810
0.805
0.800
0.795
0.790
0.785
$S(t \to \infty)$


Cooperators
α=0.8, C=30
α=1.5, C=30
B_C
$A_C = B_C$
A_C
$B_C = B_D$
$A_C = A_D$
B_D
$A_D = B_D$
A_D
0.8
0.7
0.6
0.5
0.4
$S(t \to \infty)$
0.35
0.30
0.25
0.20
0.15
0.10
Defectors

HOW MANY AFFECTED?



Evolutionary Cooperation

- Defectors are more at beginning of 1st season:
  - Cooperators can take over in a small regime α
  - & pathogens could affect more people by evolution.
  - But for larger α, evolutionary dynamics suppresses the dynamics abruptly
  - & cooperators can NOT take over any more

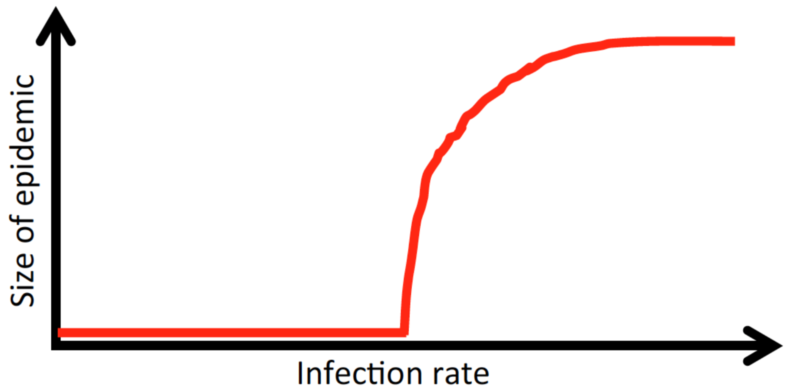
BUT,

What about SIS Dynamics?

SINGLE DISEASE: SIS

$$S \underset{}{\overset{\alpha}{\rightleftarrows}} I$$

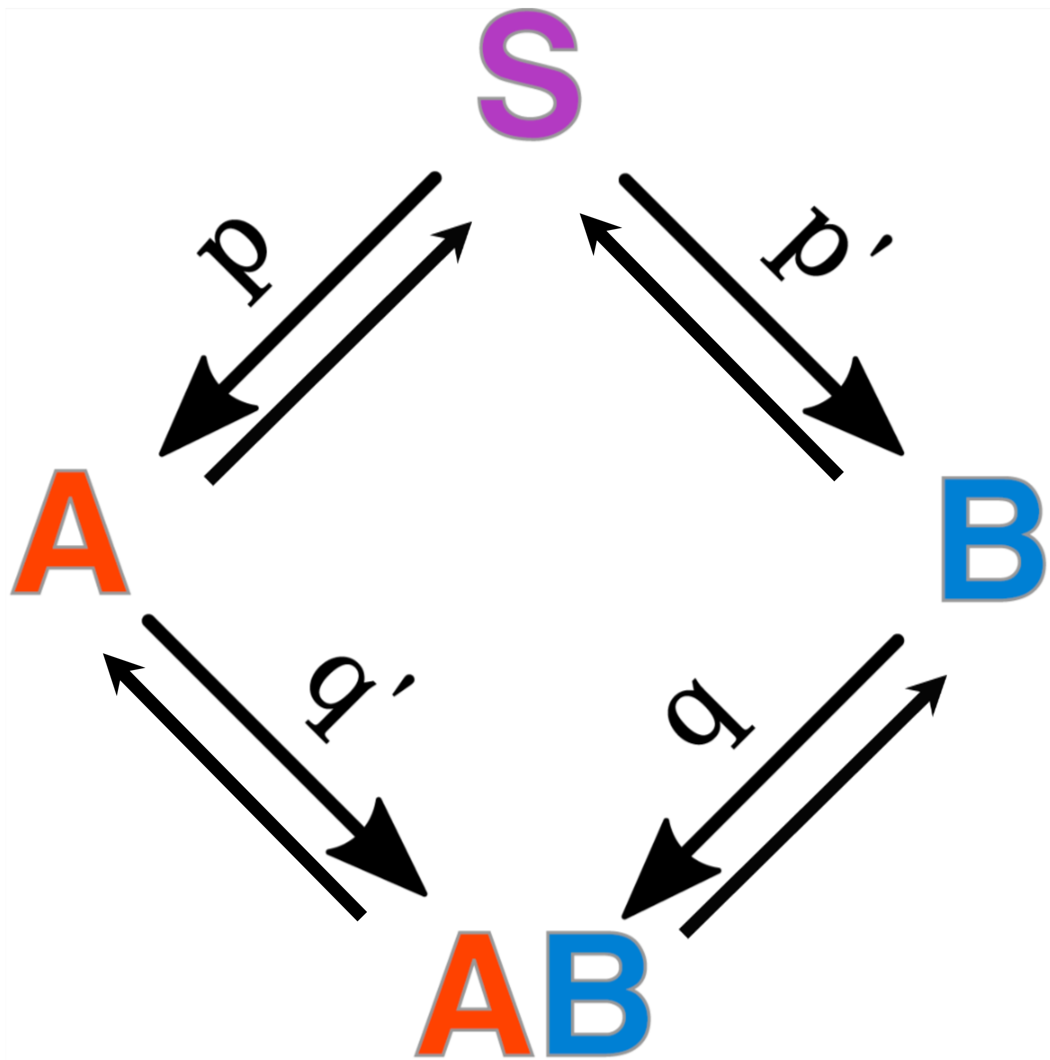
$$\dot{S} = -\alpha S I + I$$
$$\dot{I} = +\alpha S I - I$$



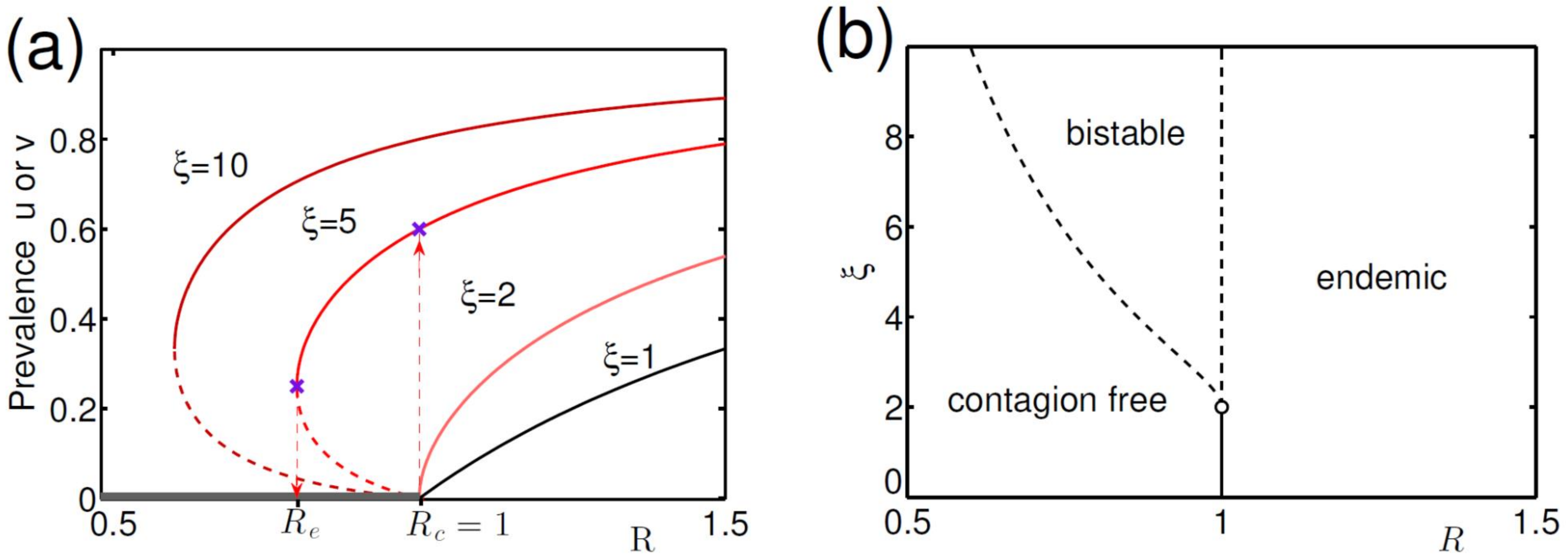
$$\text{No-epidemic} \xrightarrow{\alpha_c=1} \text{Epidemic}$$

Continuous Transition

INTERACTING SPREADING DYNAMICS



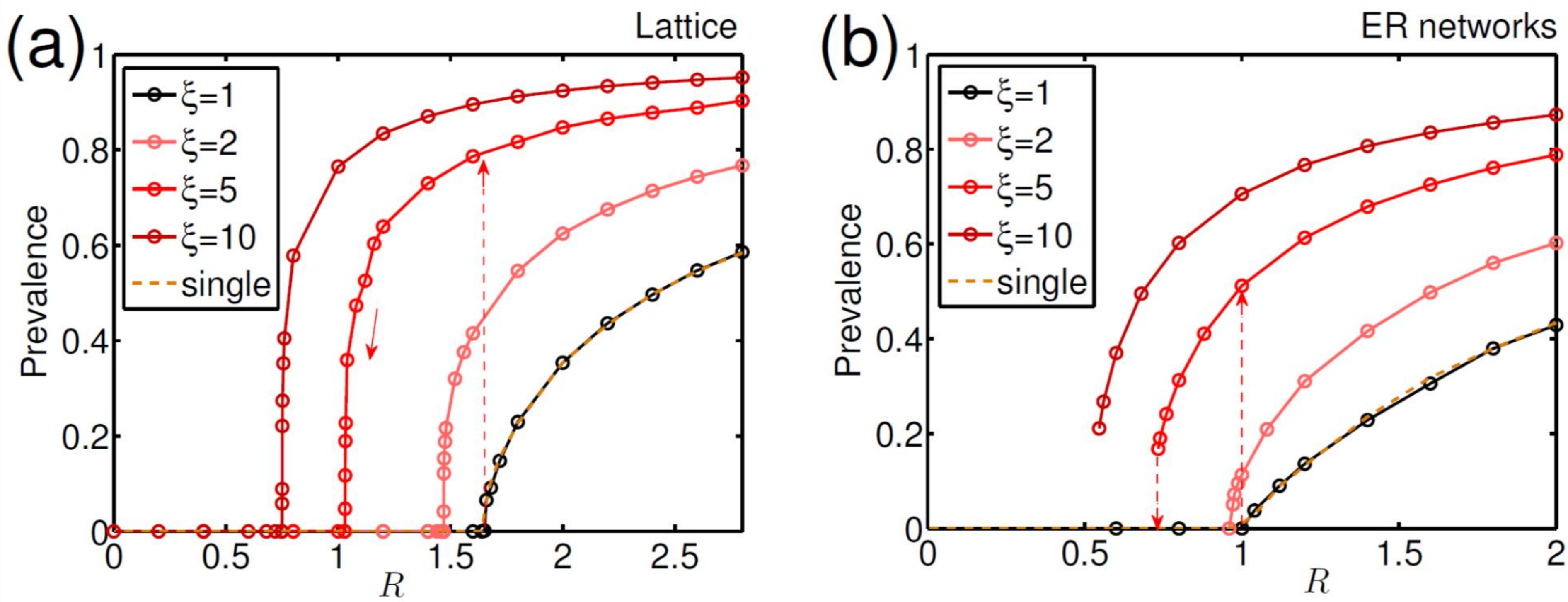
COOPERATIVE SISs (MF)



New J. Phys. **19** 103041 (2017)

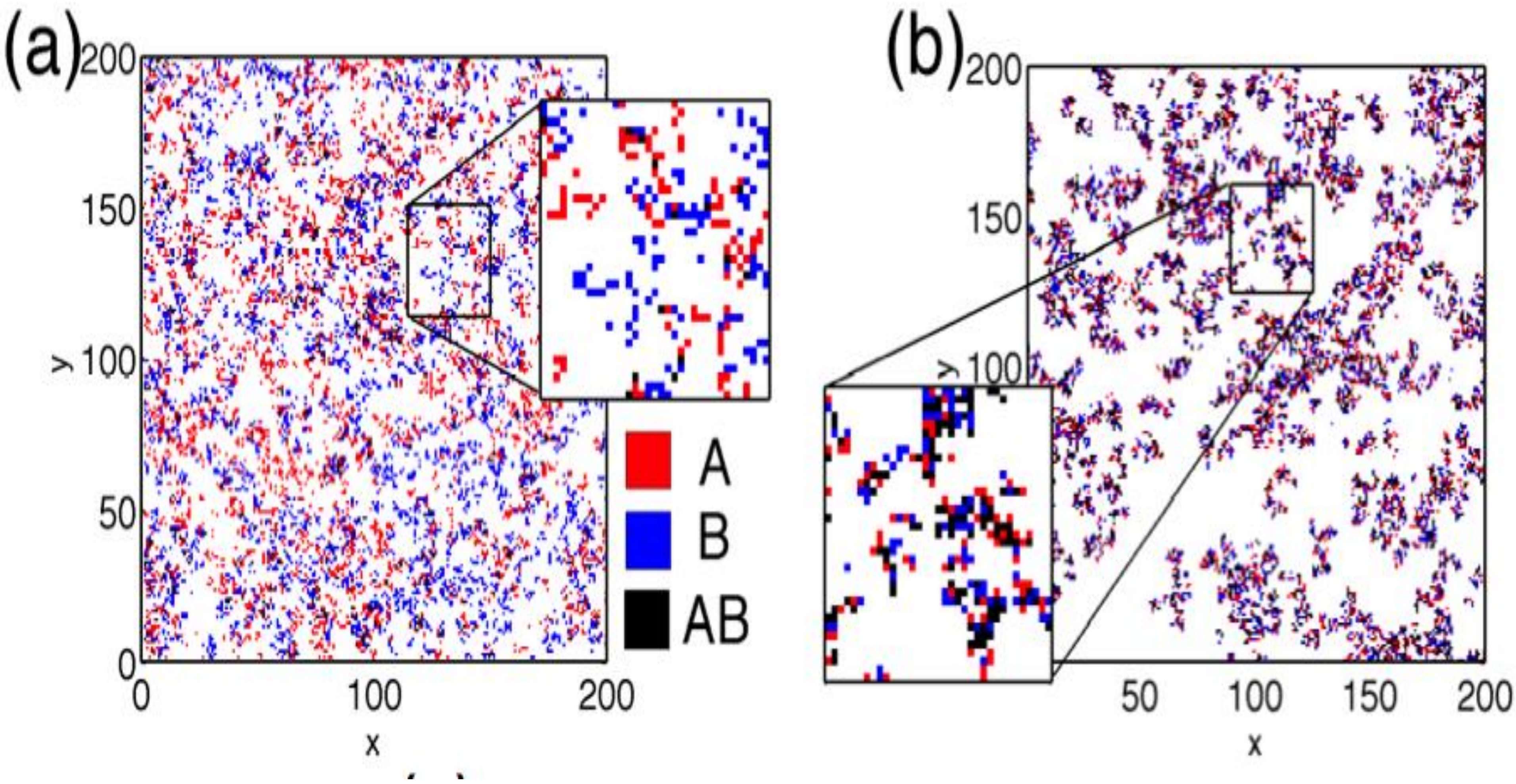
Cooperative SISs on Networks

SIS-SIS: HYSTERESIS



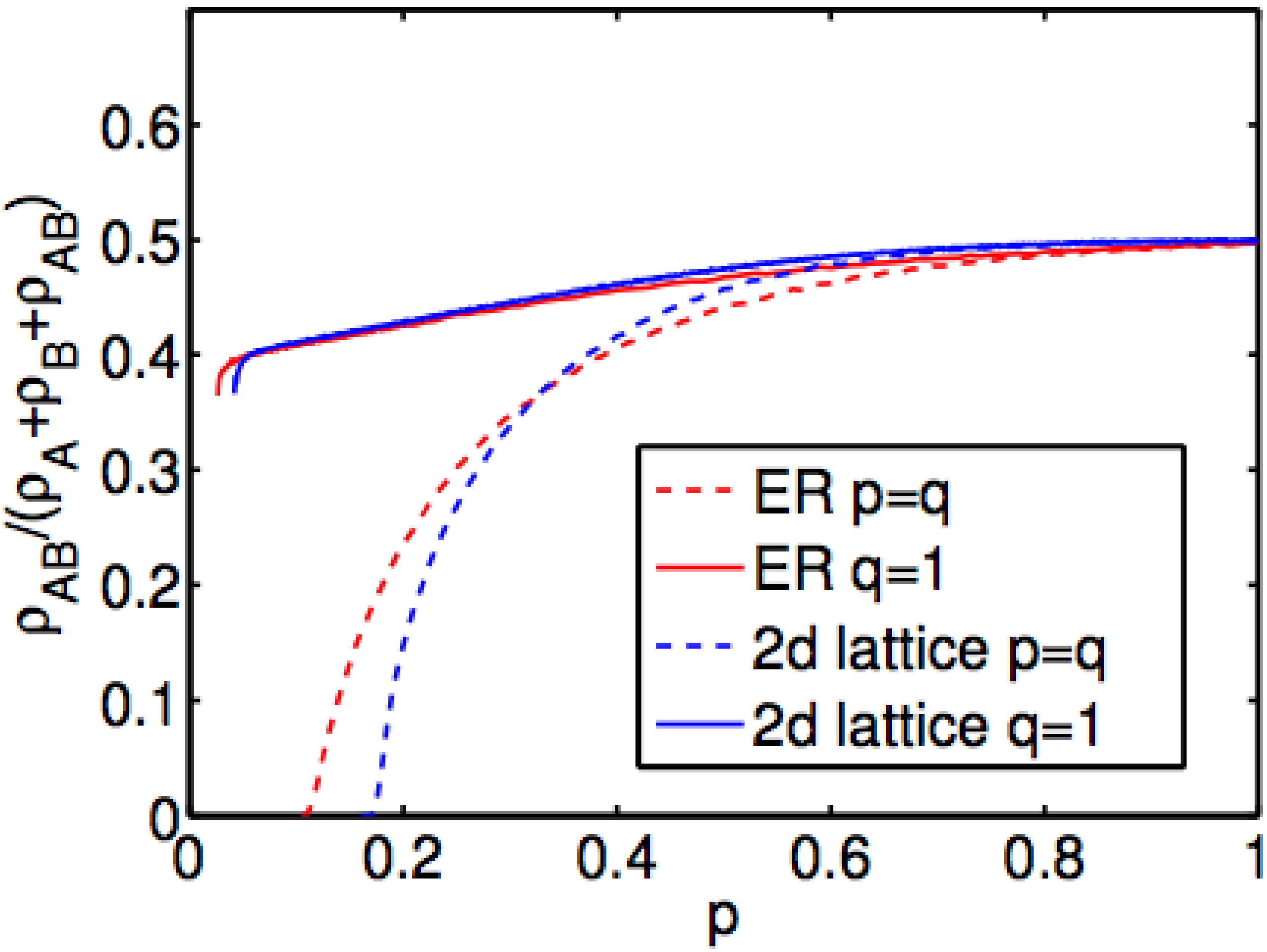
arxiv1603.09082v1(2016)

Microscopic Mechanism



arxiv1603.09082v1(2016)

MICROSCOPIC MECHANISM



arxiv1603.09082v1(2016)

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PAPER

Fundamental properties of cooperative contagion processes

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RECEIVED
20 June 2017

REVISED
4 September 2017

ACCEPTED FOR PUBLICATION
12 September 2017

PUBLISHED
1 November 2017

Li Chen[1,2,3,5], **Fakhteh Ghanbarnejad**[2,3,5] **and Dirk Brockmann**[2,4,5]

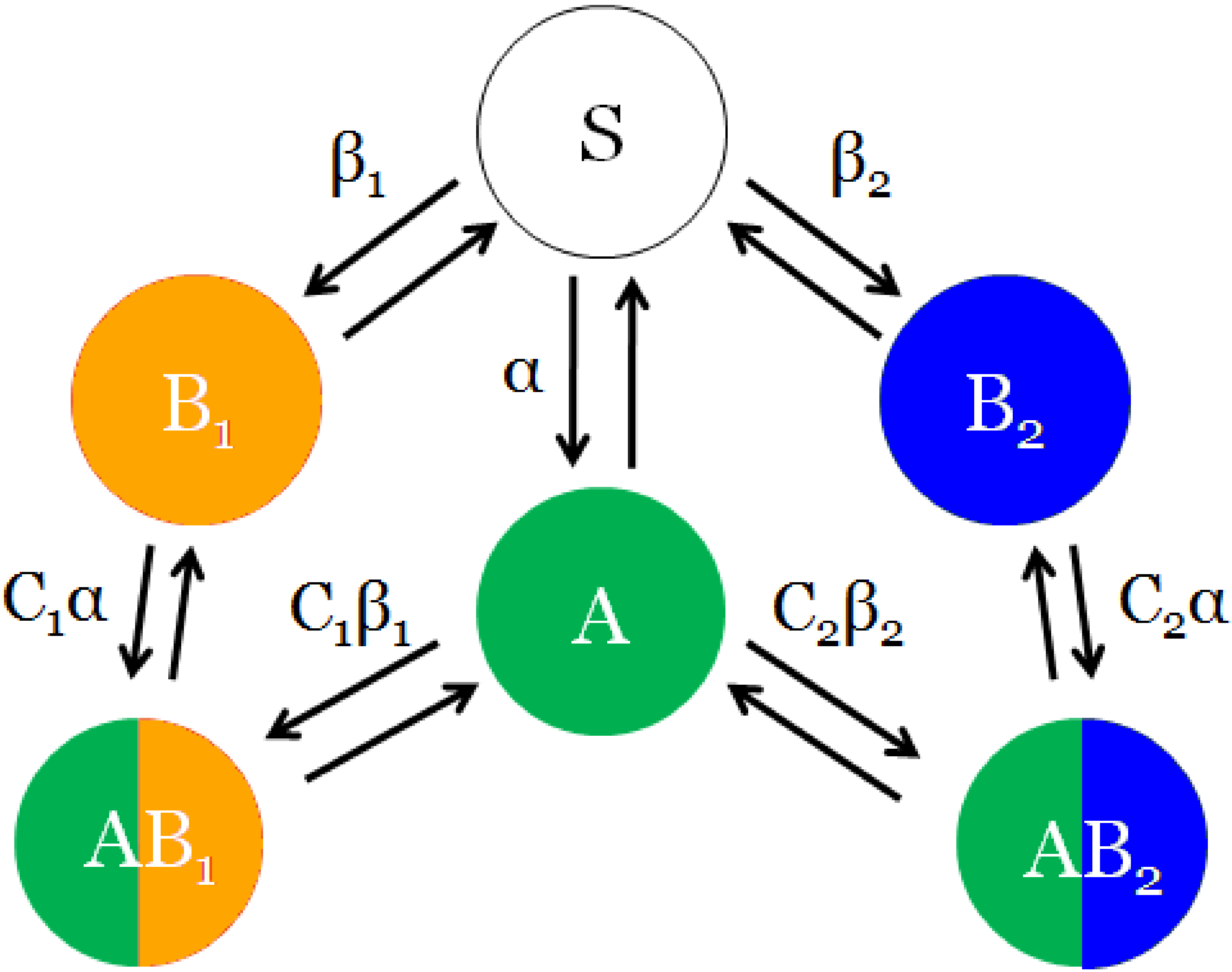
1 School of Physics and Information Technology, Shaanxi Normal University, Xi'an 710062, People's Republic of China
2 Robert Koch-Institute, Nordufer 20, D-13353 Berlin, Germany
3 Max Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germay
4 Institute for Theoretical Biology & Integrative Research Institute for the Life Sciences, Humboldt Universität zu Berlin, Philippstr. 13, Haus 4, D-10115 Berlin, Germany
5 Authors to whom any correspondence should be addressed.

E-mail: chenl@snnu.edu.cn, fakhteh@pks.mpg.de and dirk.brockmann@hu-berlin.de

Cooperation can lead to

- Hysteresis outbreaks (first order phase transition)
- Topological features of the networks play role

Cooperative vs Competitive SISs



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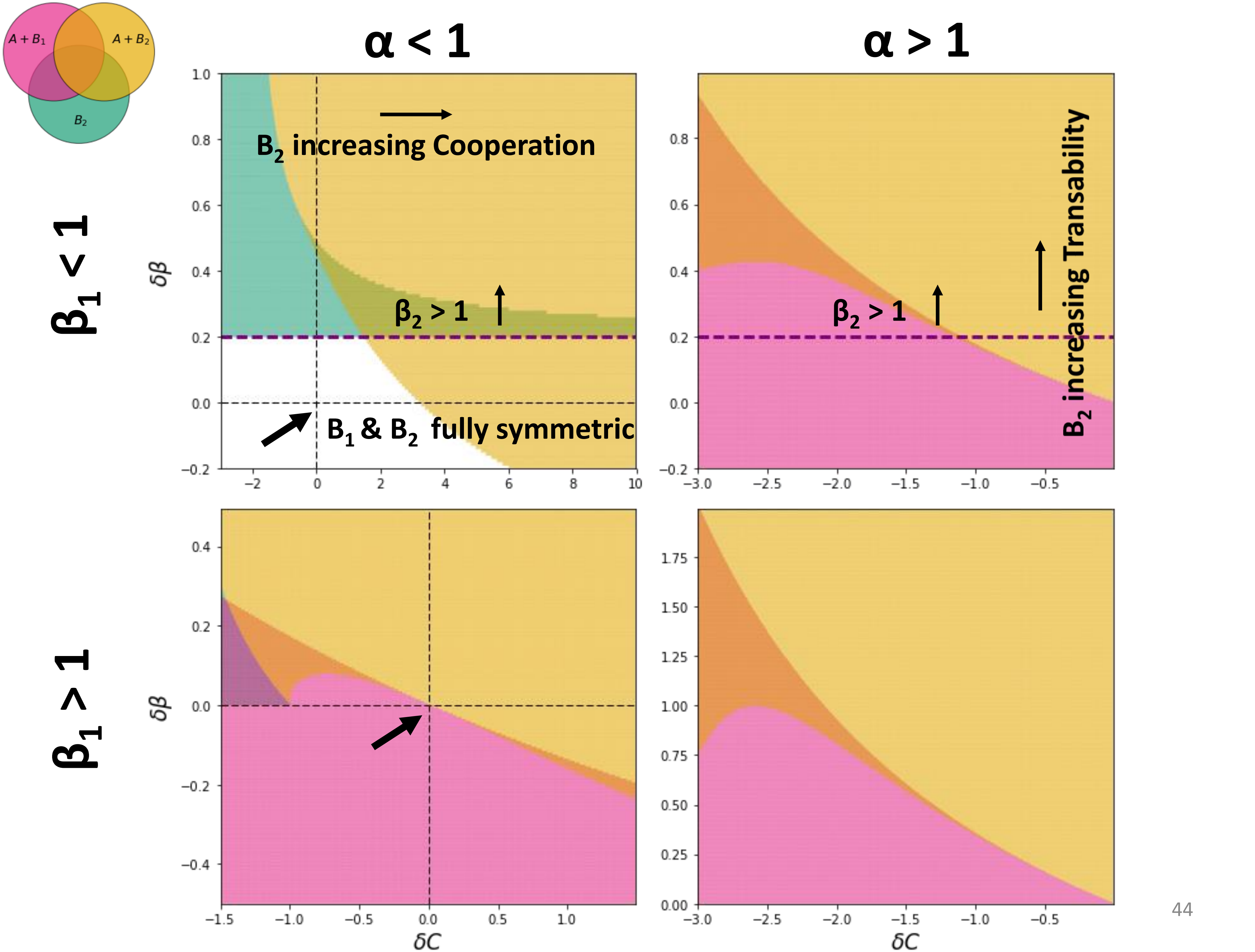

$A+B_1$
$A+B_2$
B_2
α < 1
α > 1
β1 < 1
β1 > 1
B2 increasing Cooperation
β2 > 1
β2 > 1
B1 & B2 fully symmetric
B2 increasing Transability
δβ
δβ
δC
δC

Cooperation vs. Competition

- Best strategy? difficult in bistable regions
- Several strategies for strain B_2 to dominate over B_1:
  - Where $\beta_1 > 1$ (small initial densities): increasing cooperativity is NOT always wise while increasing infectivity is always good
  - If only $\beta_1 > 1$, then B_2 may win while not being cooperative at all, provided transmissibility is large enough.

Thanks

idonate project
funded by
DFG

- (ITP, TU Berlin,Germany): Philipp Hövel, Kai Seegers, Felix Köster
- (EPFL, Lausanne, Switzerland) : Alessio Cardillo
- (EPICX-Lab, Paris, France): Chiara Poletto, Francesco Pinotti
- (Shaanxi Normal University, Xi'an, China): Chen Li
- (TU Dresden, Germany): W. Cai
- (NIC, Research Center Juelich, , Germany): Peter Grassberger
- (GESIS, Köln, Germany): Fariba Karimi
- (Sharif University of Technology, Tehran, Iran):
  Reza Ejtehadi, Ebrahim Sajjadi, Fatemeh Zarei, Saman M. Araghi
- (IFISC (CSIC-UIB), Palma de Mallorca, Spain):
  Víctor M. Eguíluz, Jorge P. Rodríguez
- (BIFI, University of Zaragoza, Spain):
  Jesus Gomez Gardenes, Sandro Meloni, Yamir Marono

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August 25-29, 2018

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Thank you!