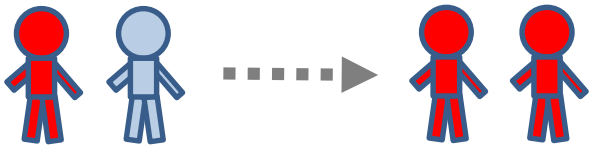
Experimental studies of percolation phenomena in driven-dissipative Rydberg gases

Oliver Morsch
INO-CNR and Dipartimento di Fisica, Pisa, Italy

Atomtronics 2019, Benasque, 09/05/2019



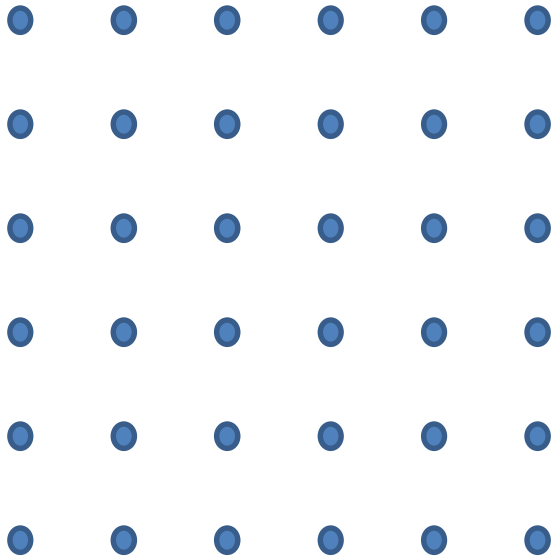
C. Simonelli, M. Archimi, E. Arimondo, D. Ciampini

Collaboration: R. Gutierrez, M. Marcuzzi, I. Lesanovsky

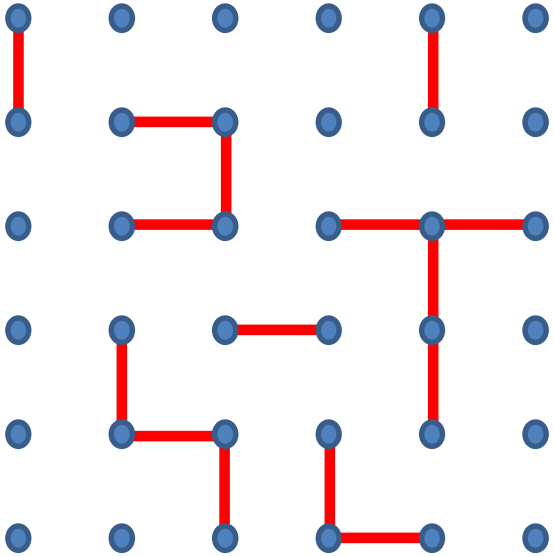
RySQ

IN SUPREMÆ DIGNITATIS
1343
UNIVERSITÀ DI PISA

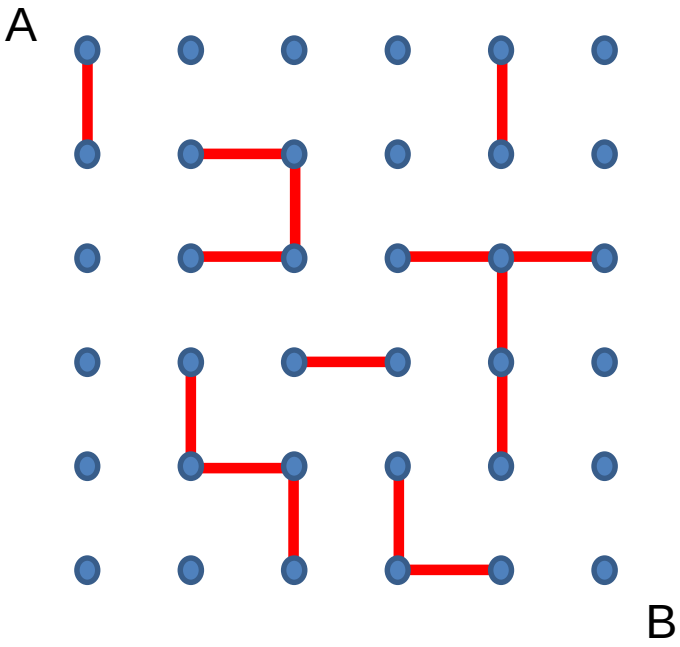
Percolation



Percolation

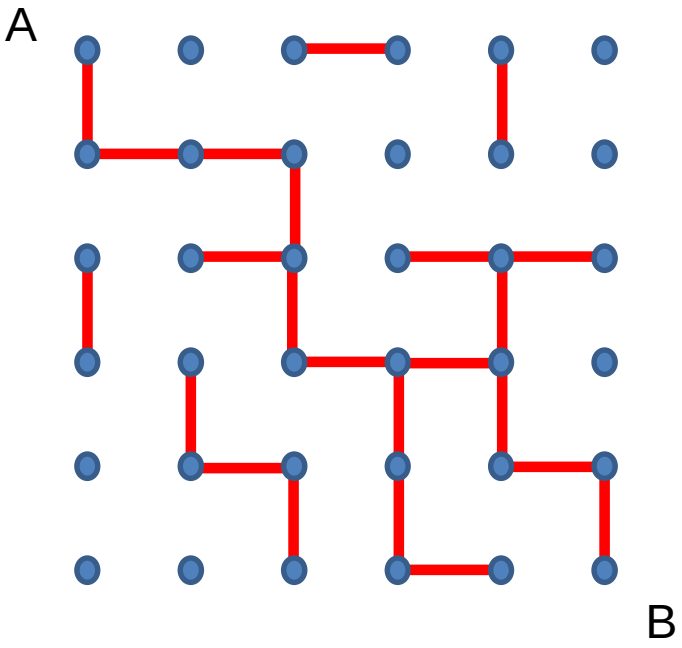


Percolation



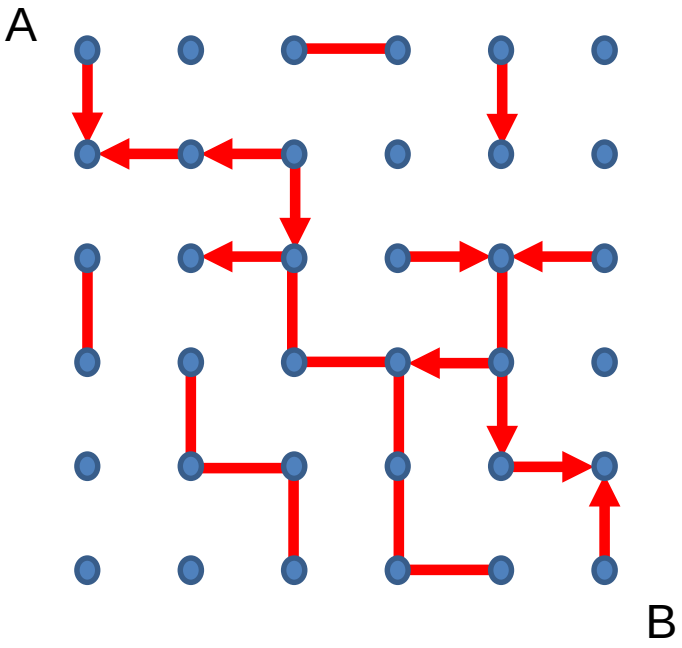
link probability $p < p_{crit}$

Percolation

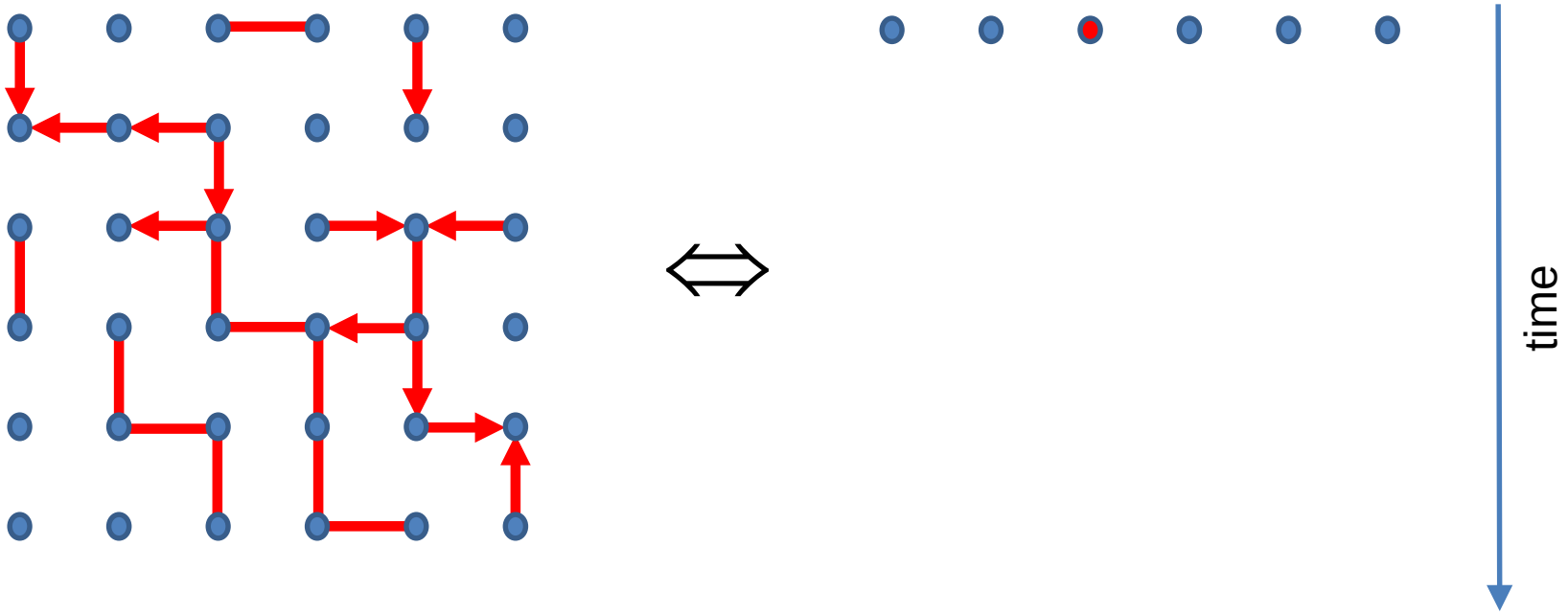


link probability $p > p_{crit} \Rightarrow$ system «percolates»

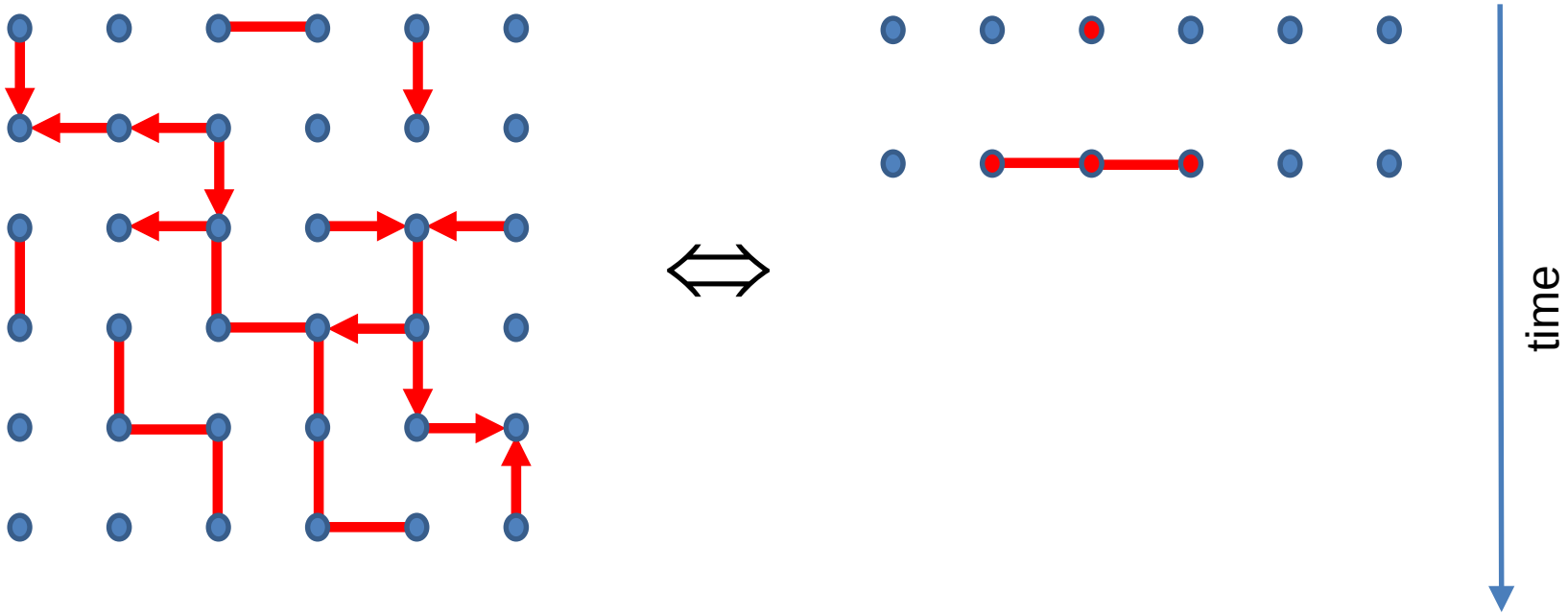
«Directed» percolation



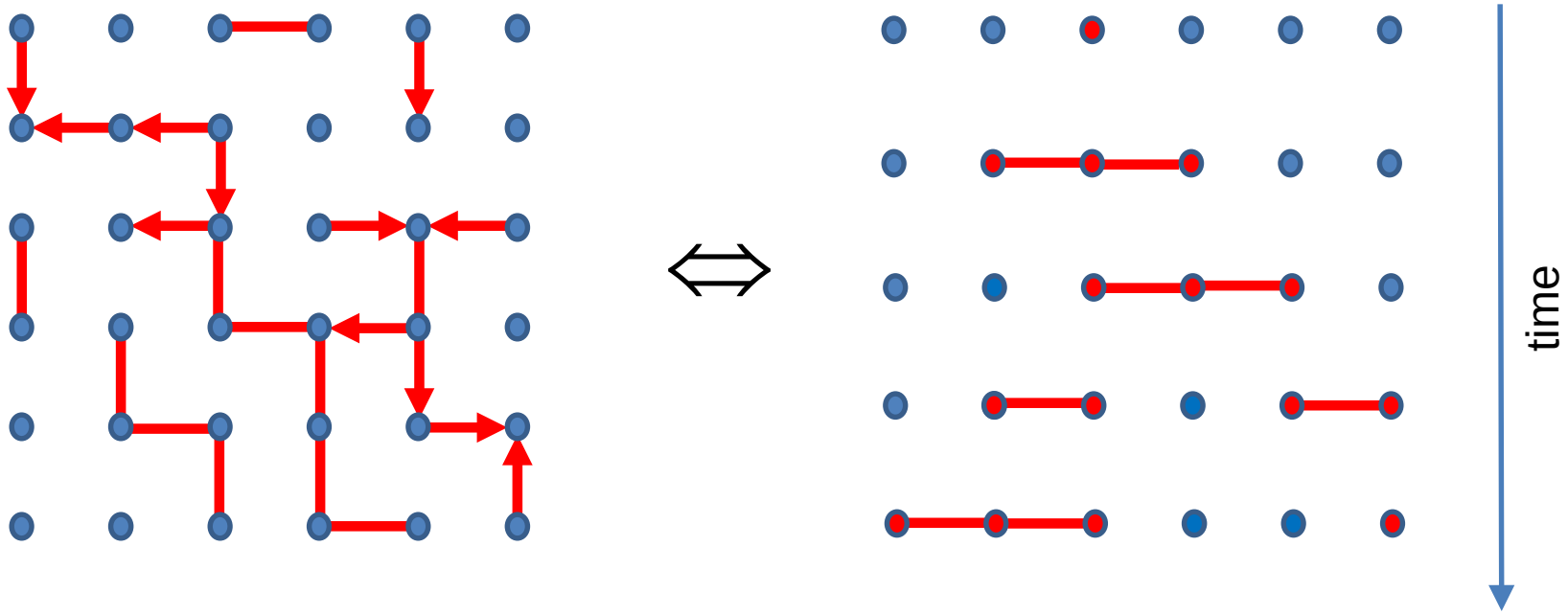
«Directed» percolation



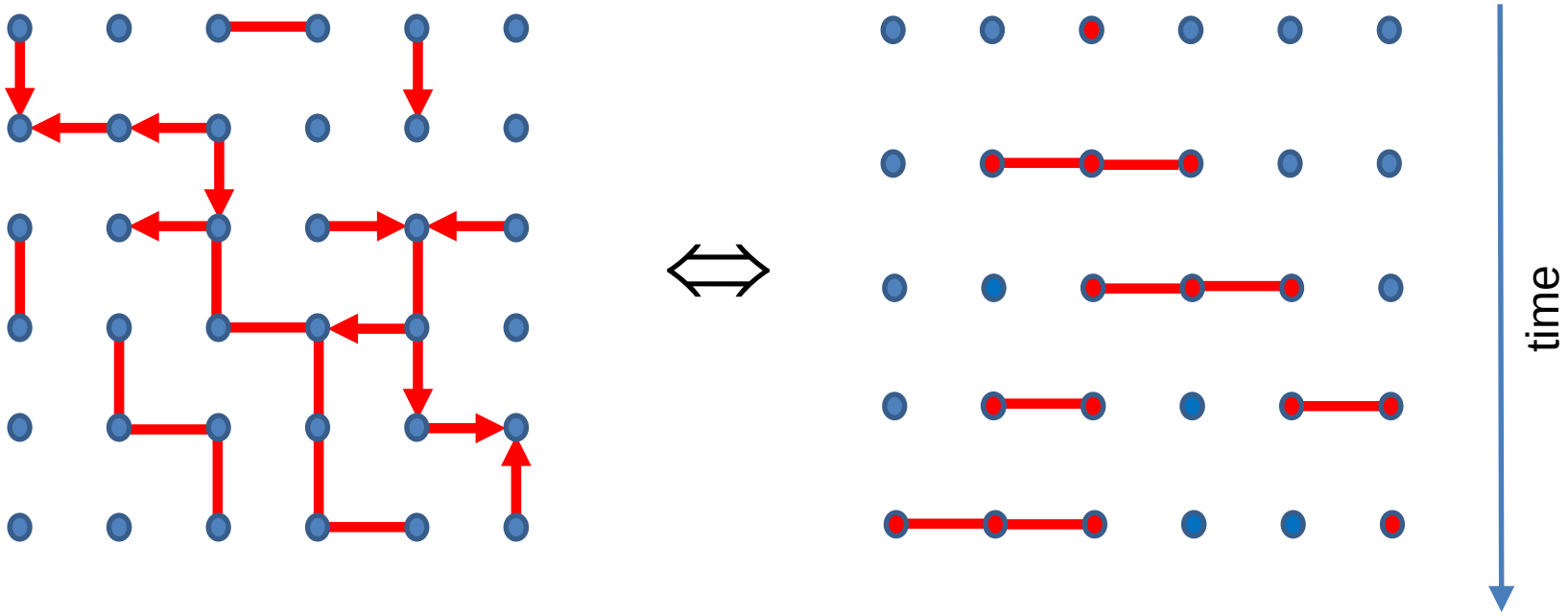
«Directed» percolation



«Directed» percolation

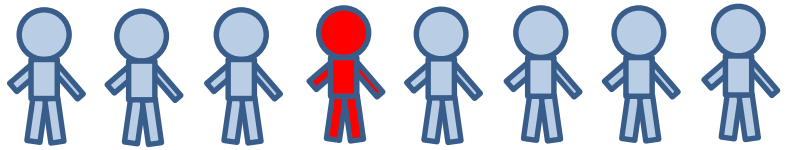


«Directed» percolation

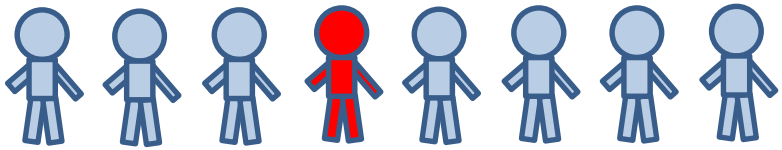


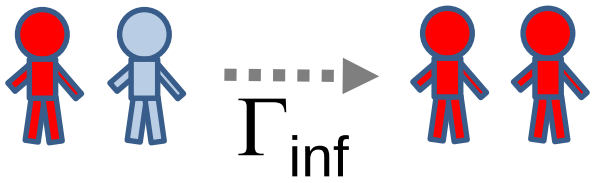
Non-equilibrium phase transition
Examples: wildfires, turbulence, spreading of infectious diseases

«Infection model» exhibits absorbing state phase transition

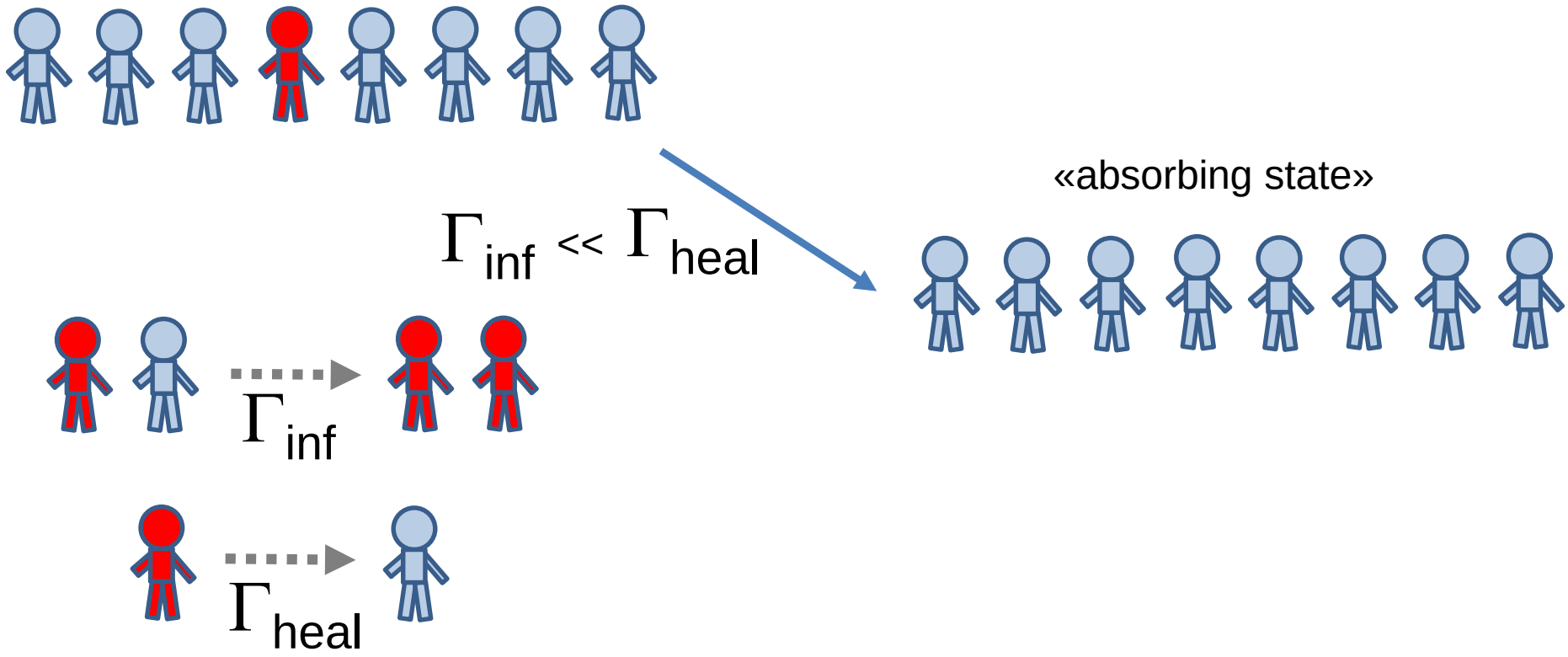


«Infection model» exhibits absorbing state phase transition

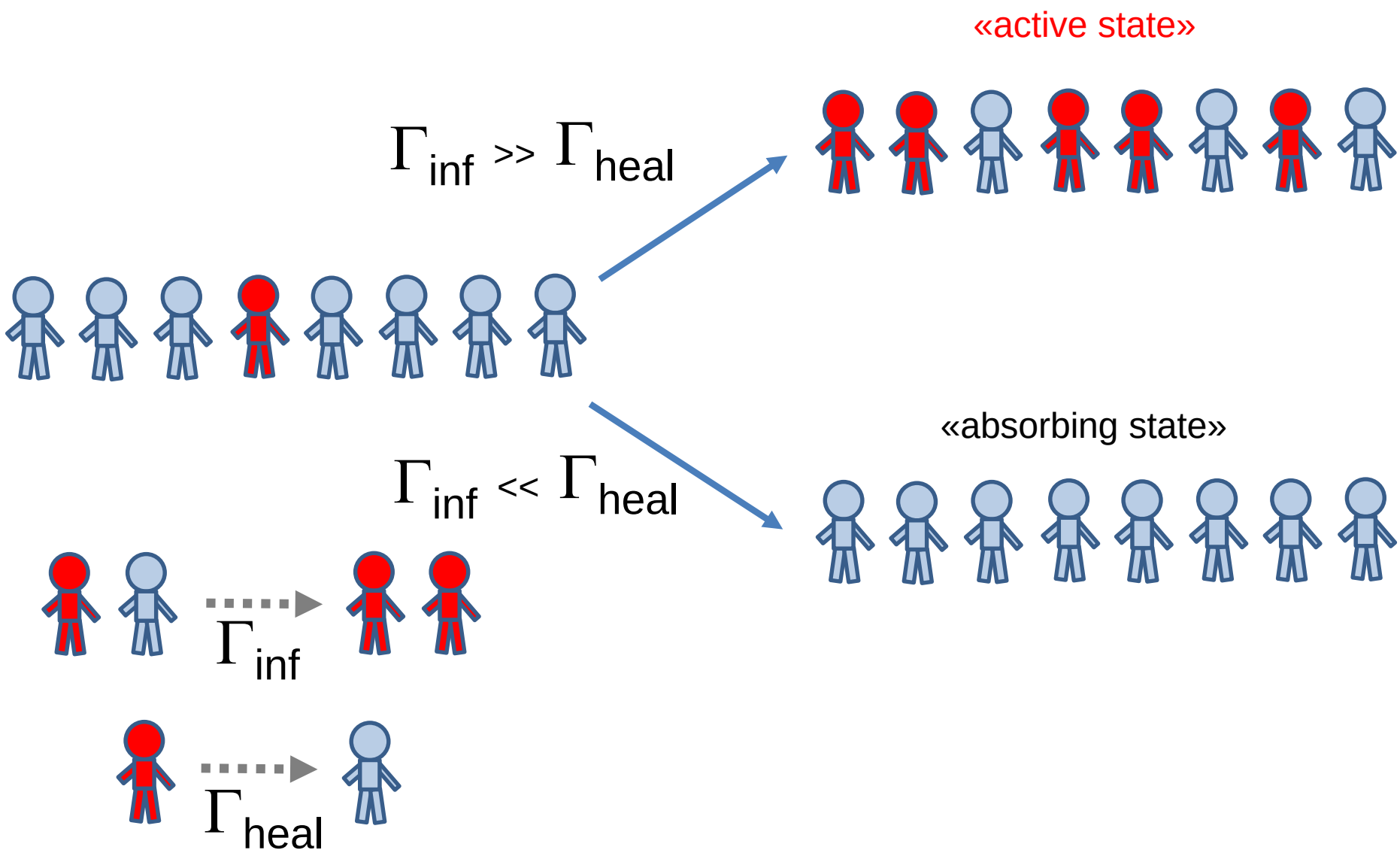




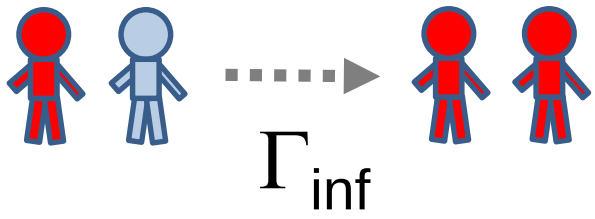
«Infection model» exhibits absorbing state phase transition



«Infection model» exhibits absorbing state phase transition

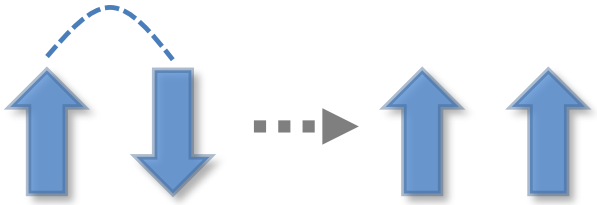


Basic processes leading to an absorbing state phase transition



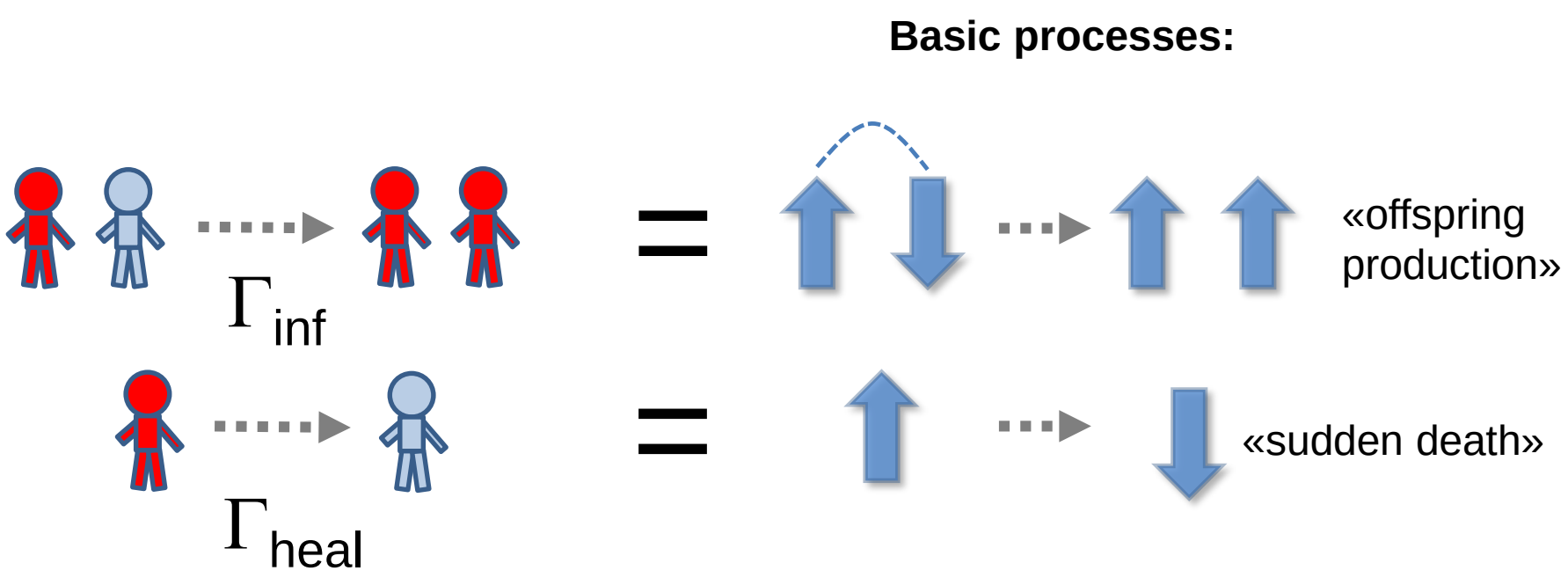
=

Basic processes:

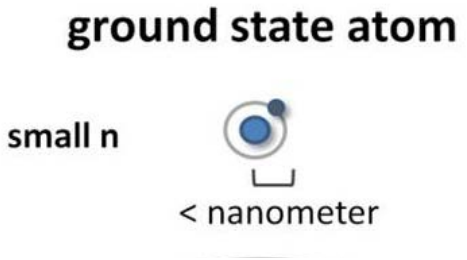


«offspring production»

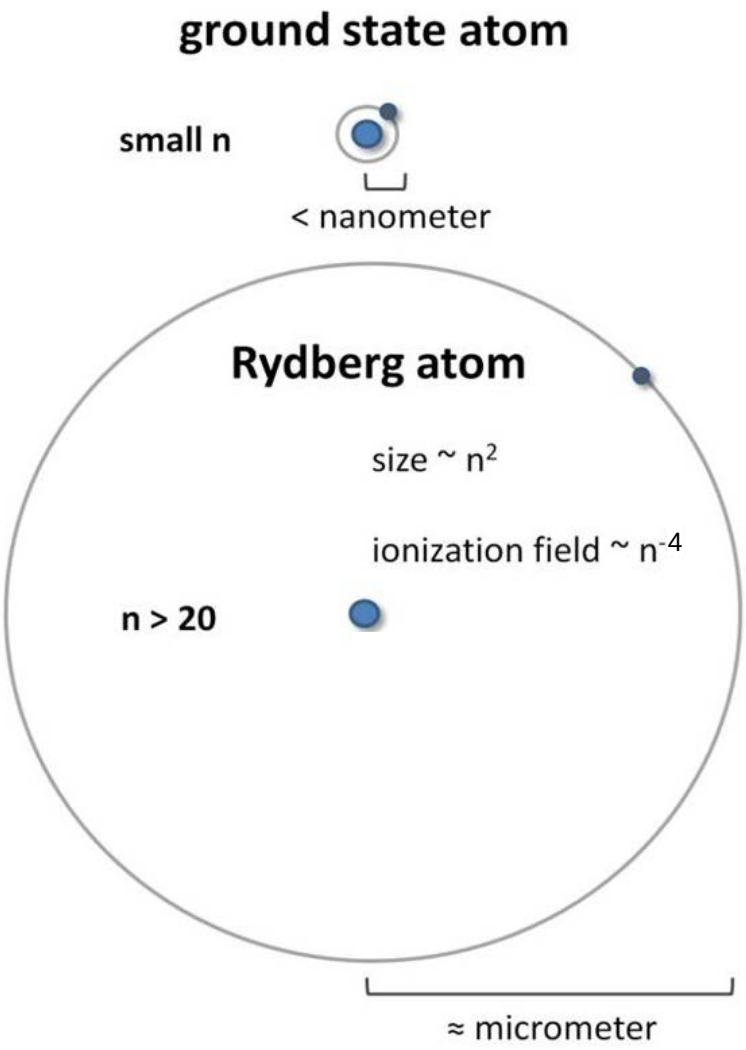
Basic processes leading to an absorbing state phase transition



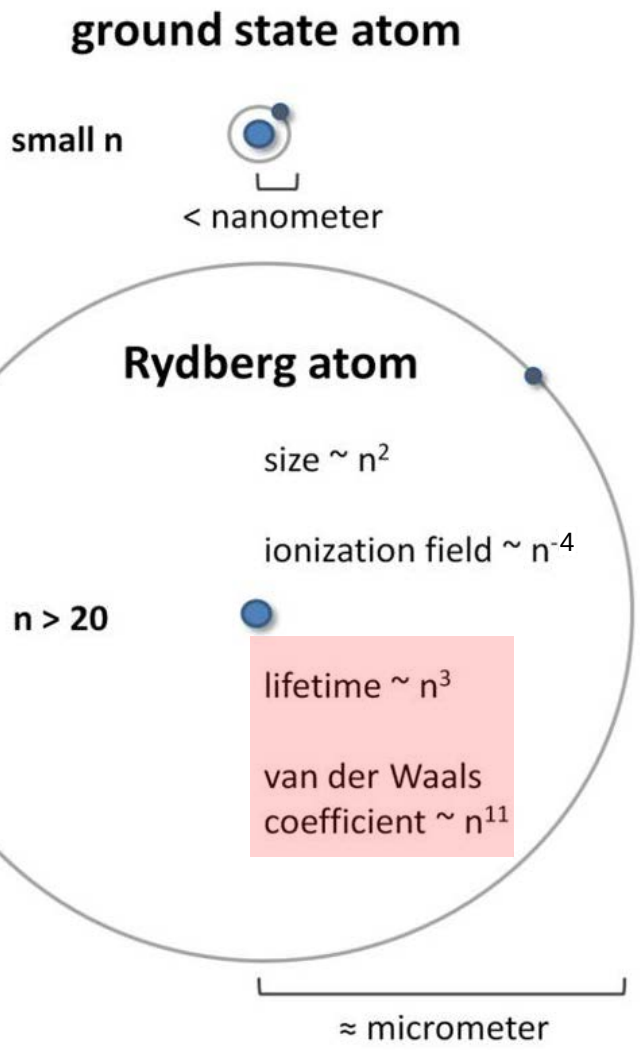
Rydberg atoms are long-lived and interact strongly



Rydberg atoms are long-lived and interact strongly

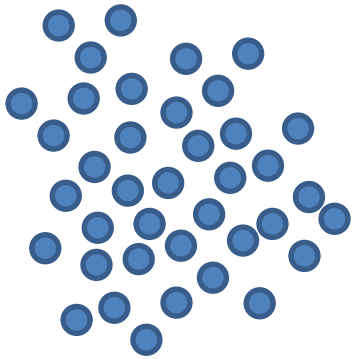


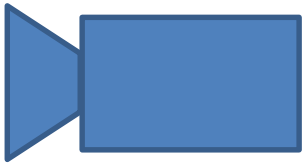
Rydberg atoms are long-lived and interact strongly



Ex.: Rb n=70, ~ MHz at 10 μm
lifetime around 150 μs

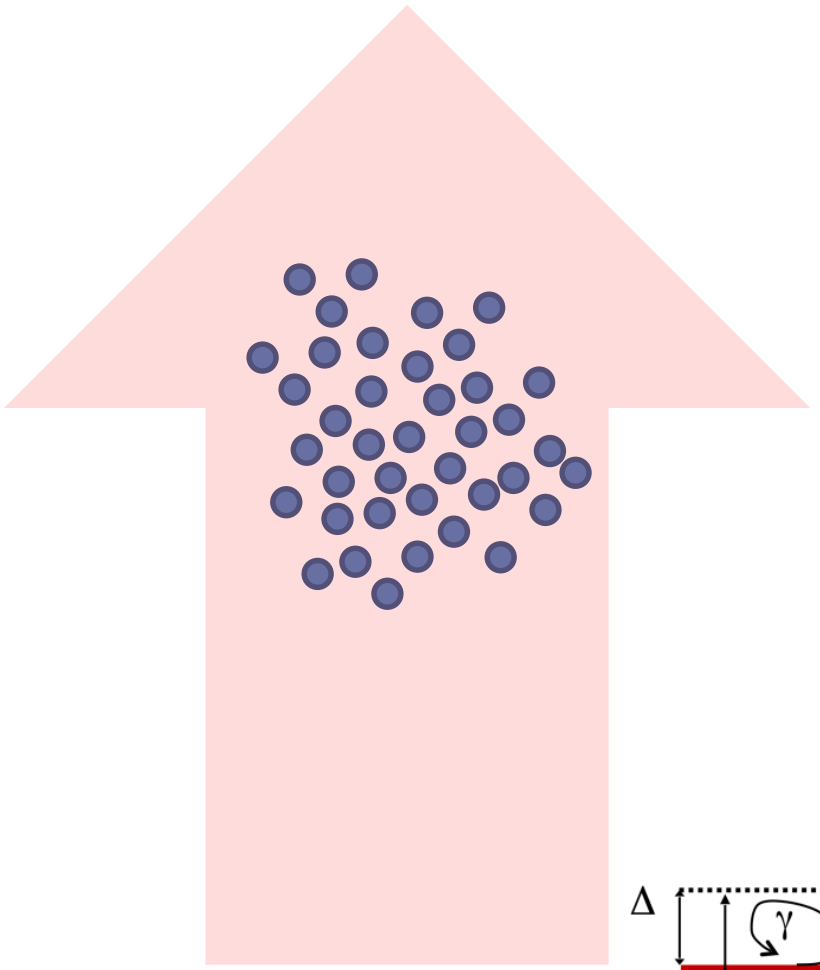
Rydberg atoms are excited in a MOT…

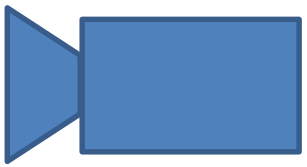


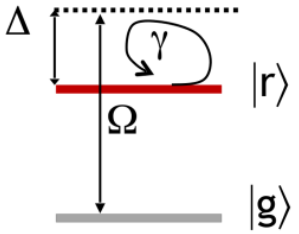


^{87}Rb atoms in a MOT
T ~ 150 micro Kelvin («frozen gas»)
N ~ few 10^5
size around 150 microns

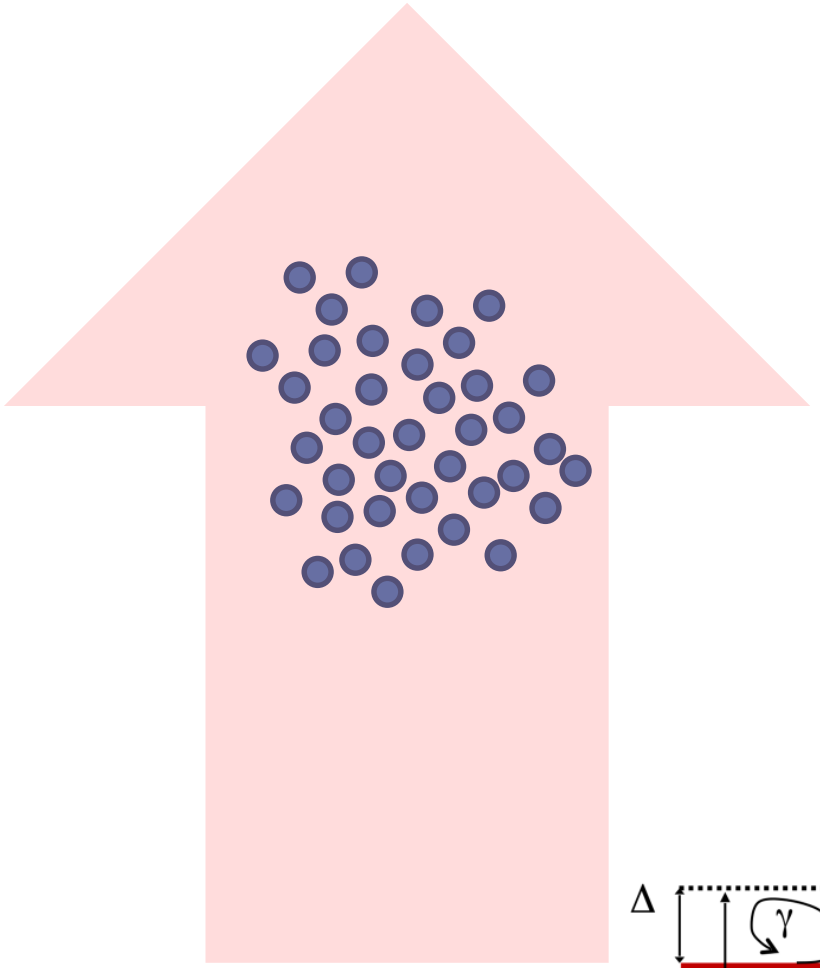
Rydberg atoms are excited in a MOT…

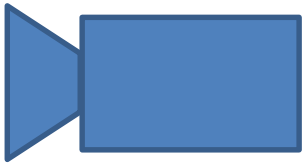


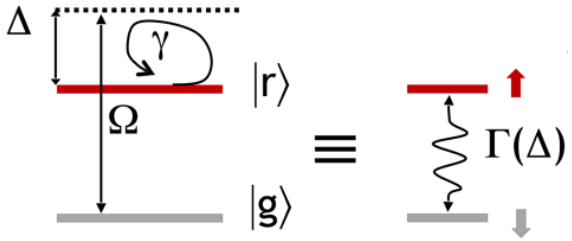




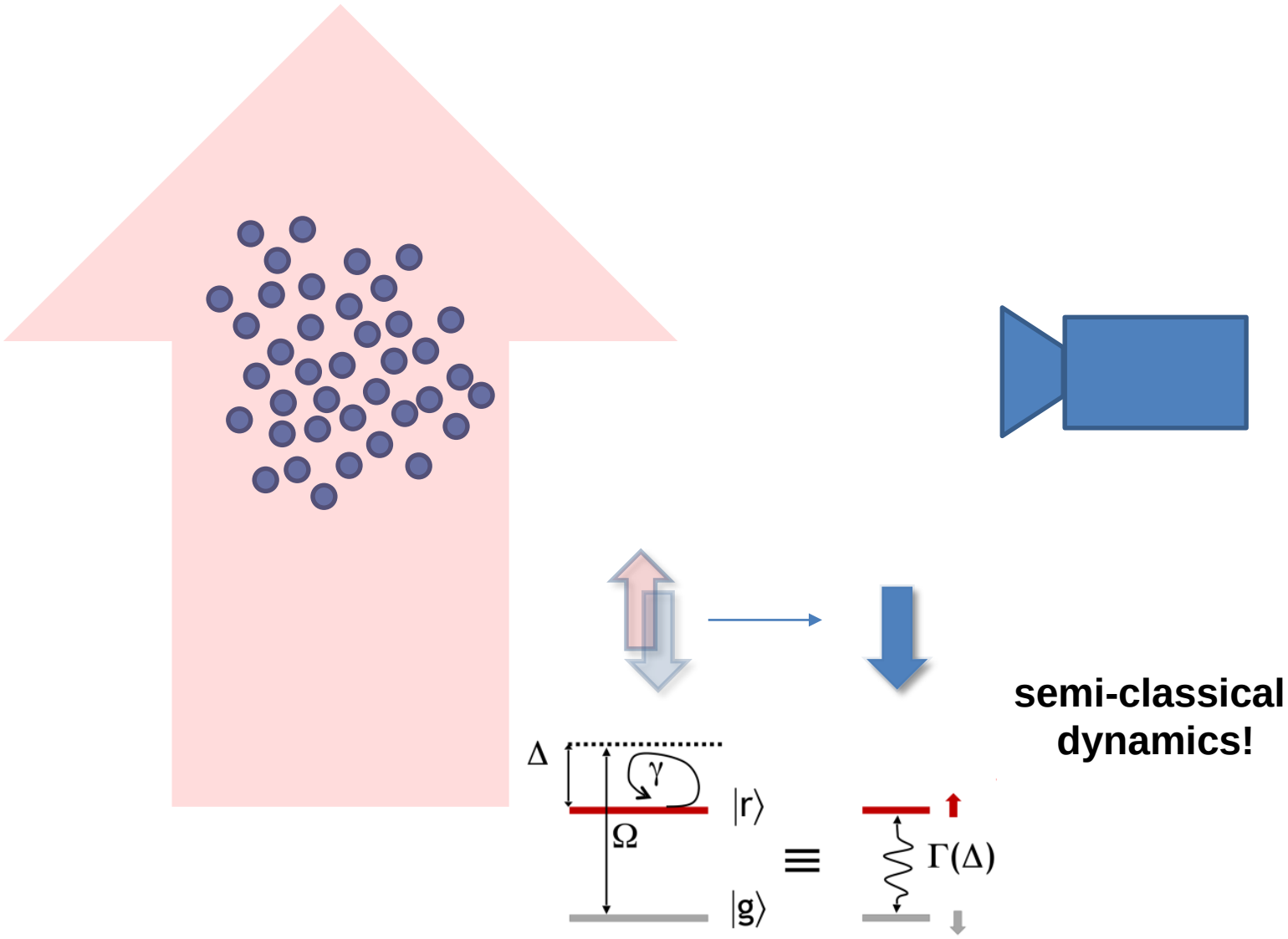
Rydberg atoms are excited in a MOT…





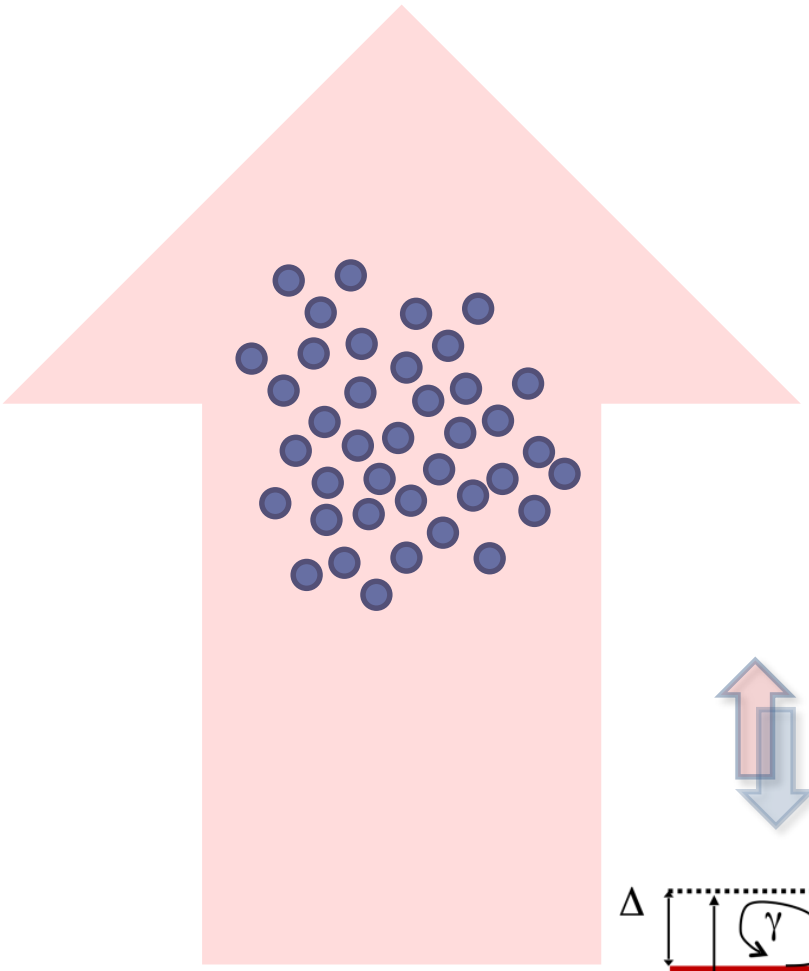


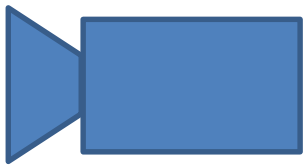
Rydberg atoms are excited in a MOT…

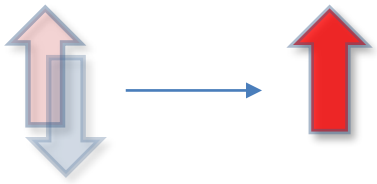


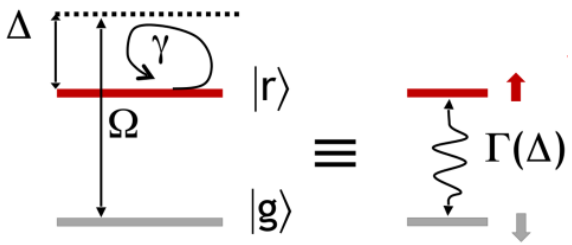
semi-classical dynamics!

Rydberg atoms are excited in a MOT…



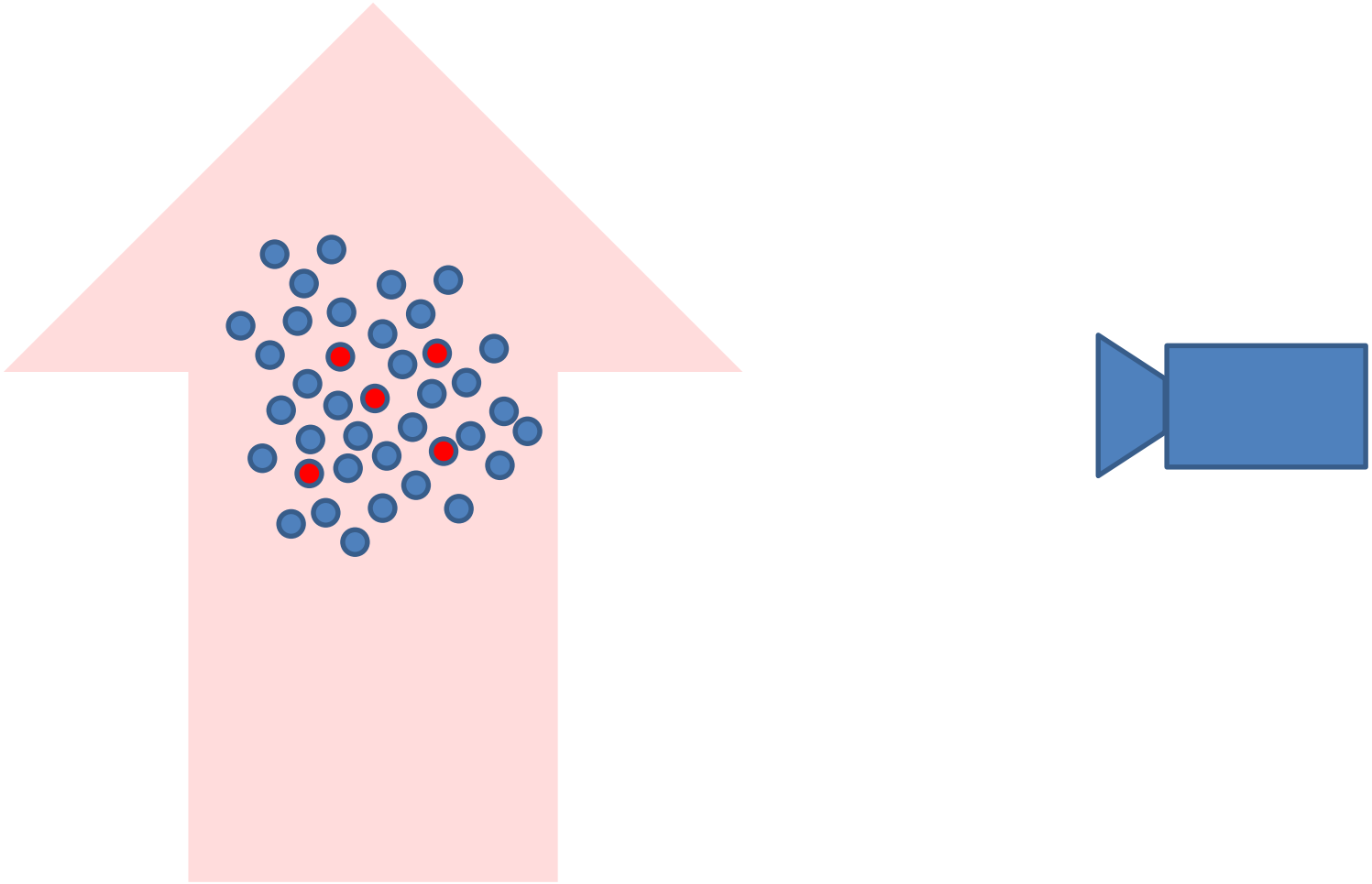




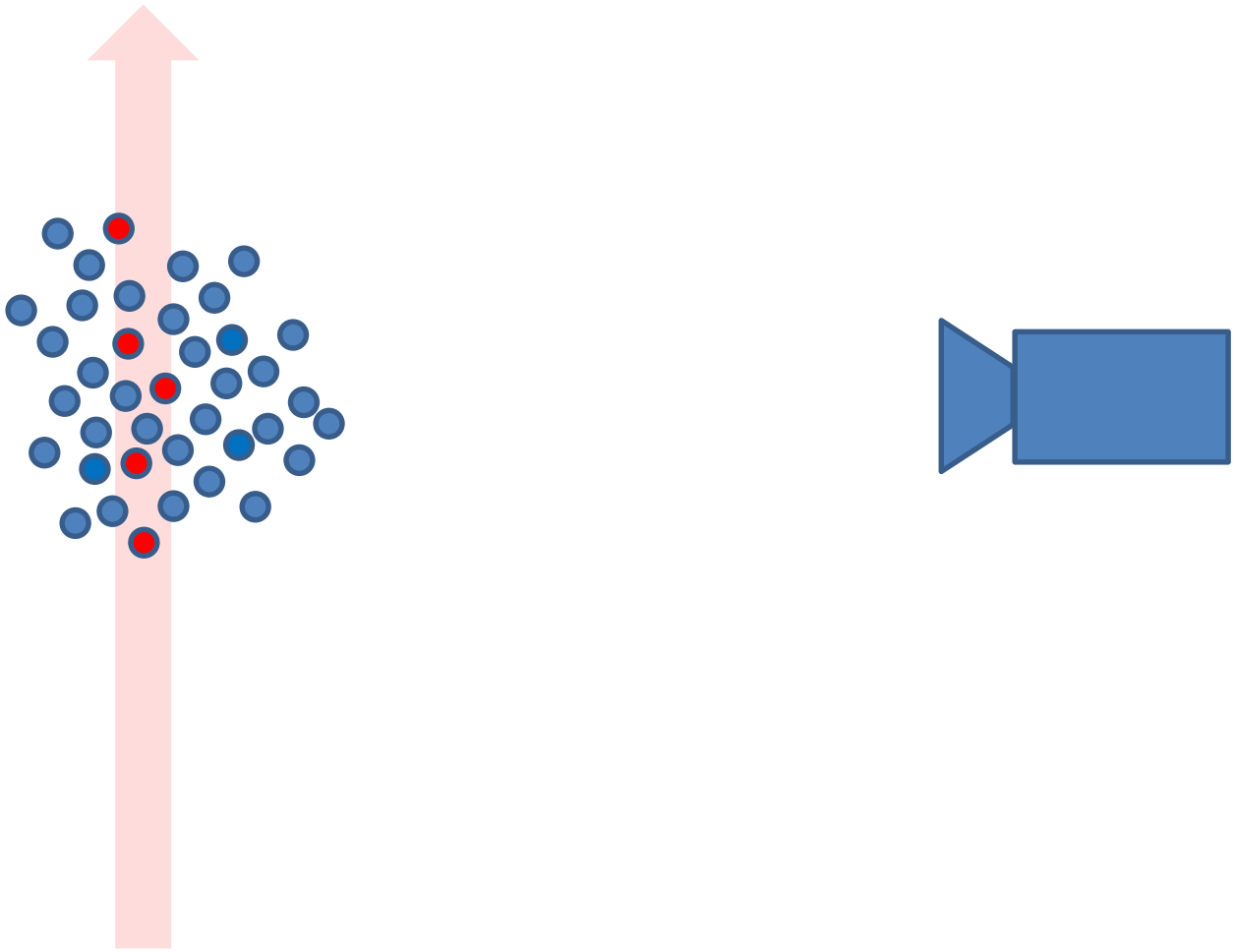


semi-classical dynamics!

… many-body dynamics takes place…

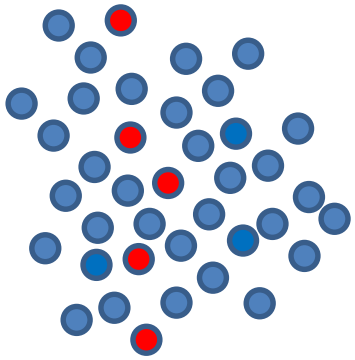


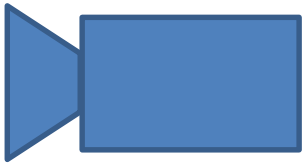
… many-body dynamics takes place…



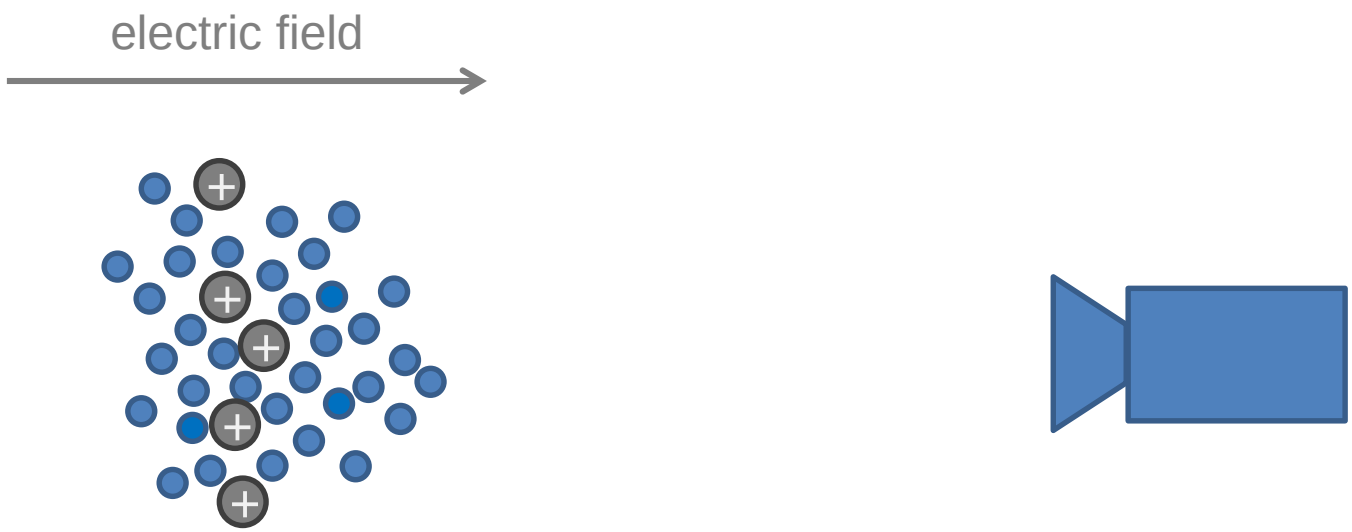
effective 1D dynamics

… then the system is probed using field ionization

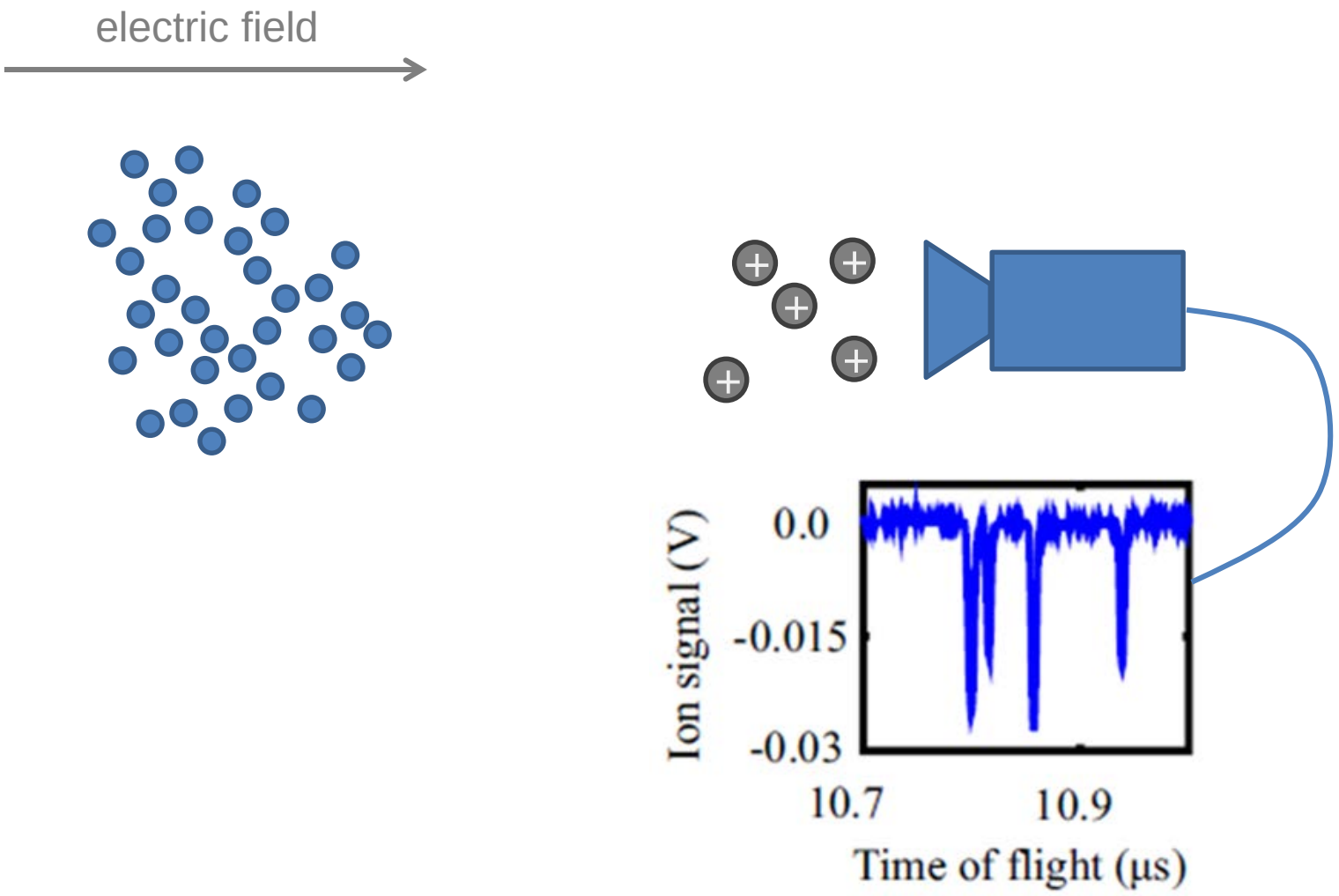




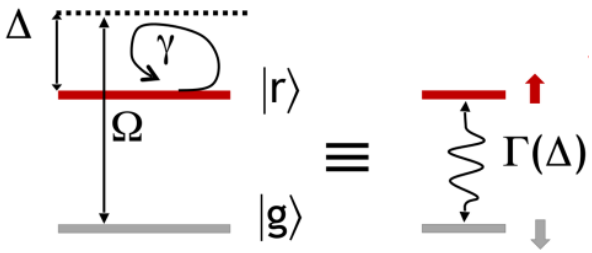
… then the system is probed using field ionization



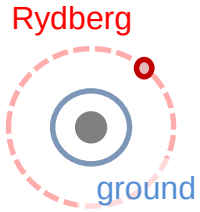
… then the system is probed using field ionization



Off-resonant driving leads to facilitated excitation

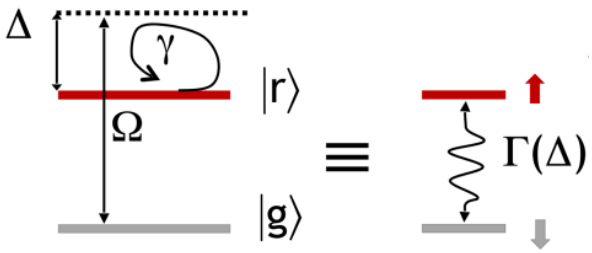


$$\Gamma_i(\Delta) = \frac{\Omega^2}{2\gamma}\left[1 + \left(\frac{\Delta}{\gamma}\right)^2\right]^{-1}$$

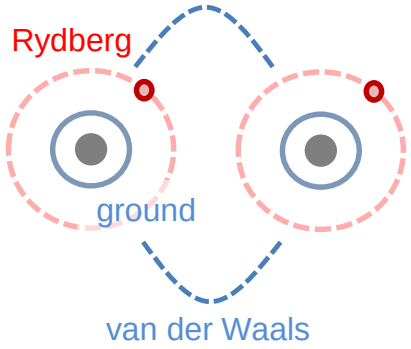


PHYSICAL REVIEW A **93**, 040701(R) (2016)

Off-resonant driving leads to facilitated excitation

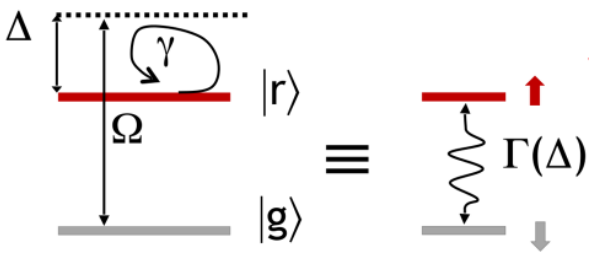


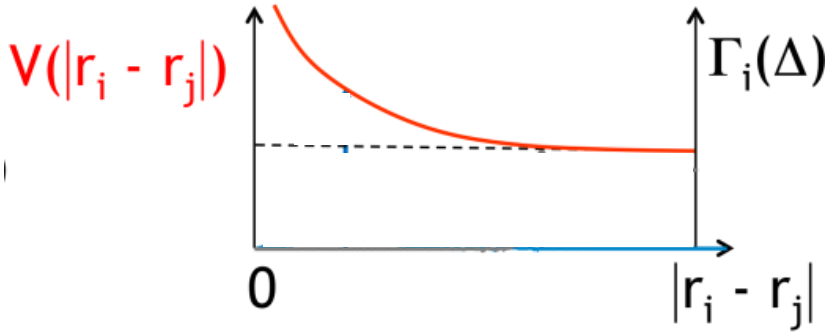
$$\Gamma_i(\Delta) = \frac{\Omega^2}{2\gamma}\left[1 + \left(\frac{\Delta - \frac{1}{\hbar}\sum_{i\neq j} V_{ij} n_j}{\gamma}\right)^2\right]^{-1}$$

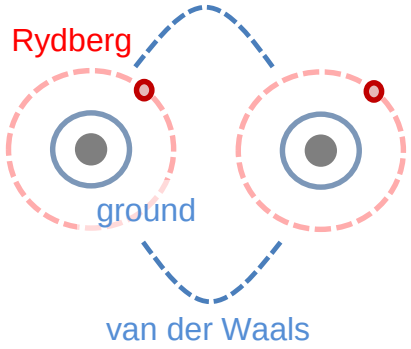


PHYSICAL REVIEW A **93**, 040701(R) (2016)

Off-resonant driving leads to facilitated excitation

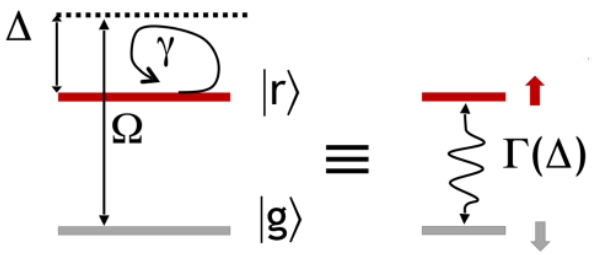


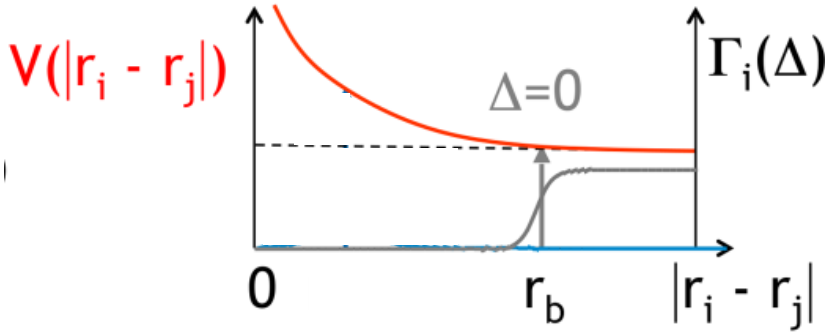


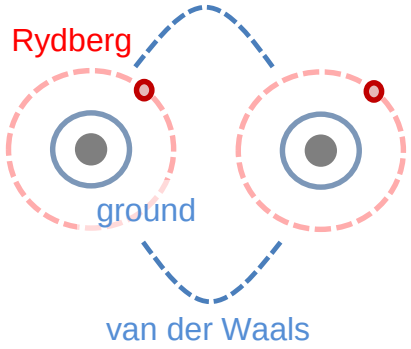


PHYSICAL REVIEW A **93**, 040701(R) (2016)

Off-resonant driving leads to facilitated excitation

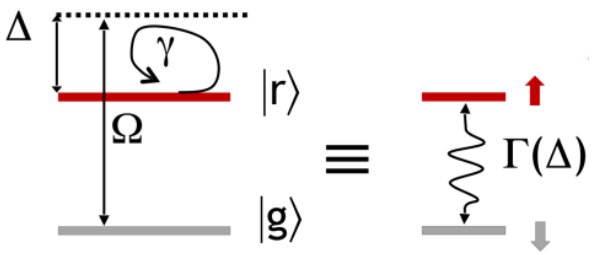


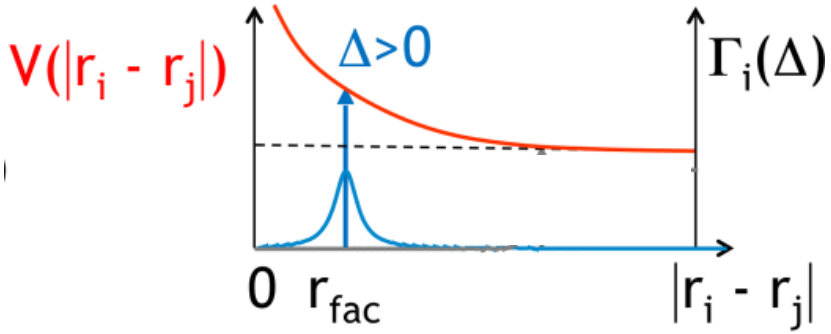


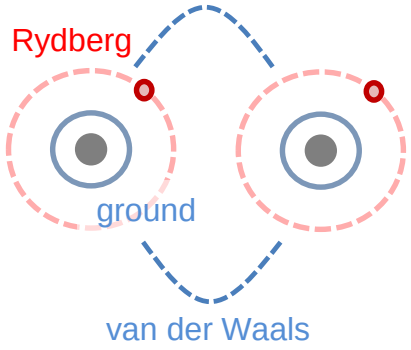


PHYSICAL REVIEW A 93, 040701(R) (2016)

Off-resonant driving leads to facilitated excitation

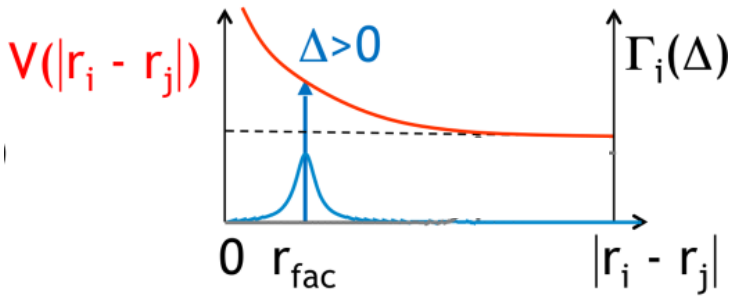




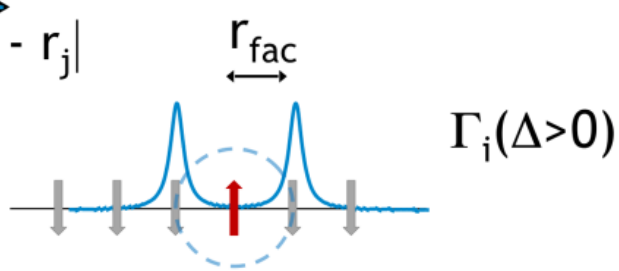


PHYSICAL REVIEW A **93**, 040701(R) (2016)

Facilitation dynamics = «offspring production»

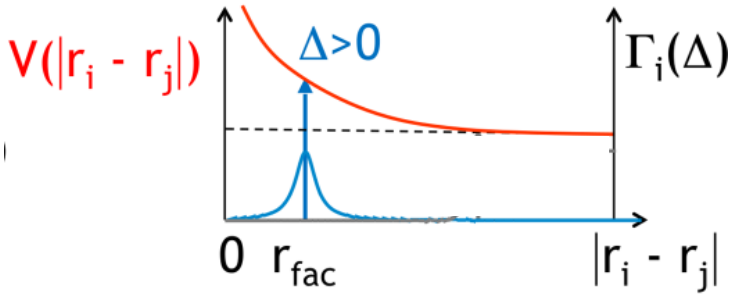


$r_{fac} \sim 7\ \mu m$

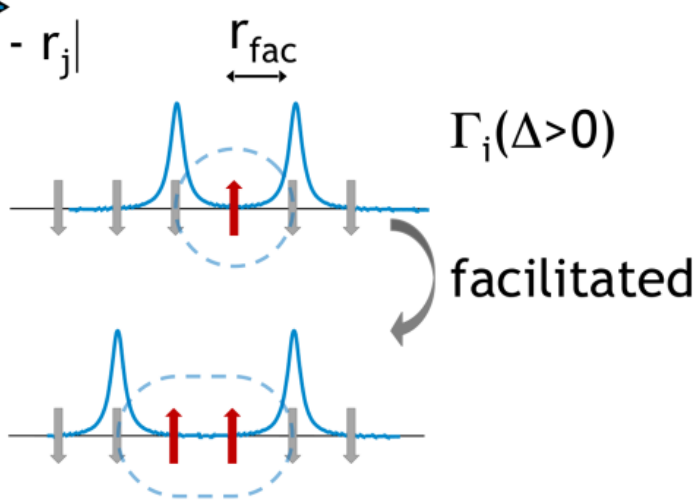


PHYSICAL REVIEW A **93**, 040701(R) (2016)

Facilitation dynamics = «offspring production»

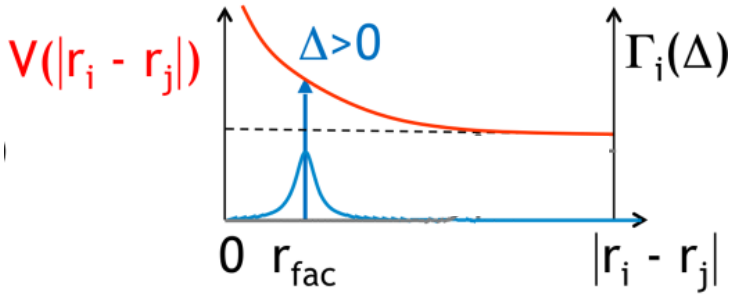


$r_{fac} \sim 7\ \mu m$

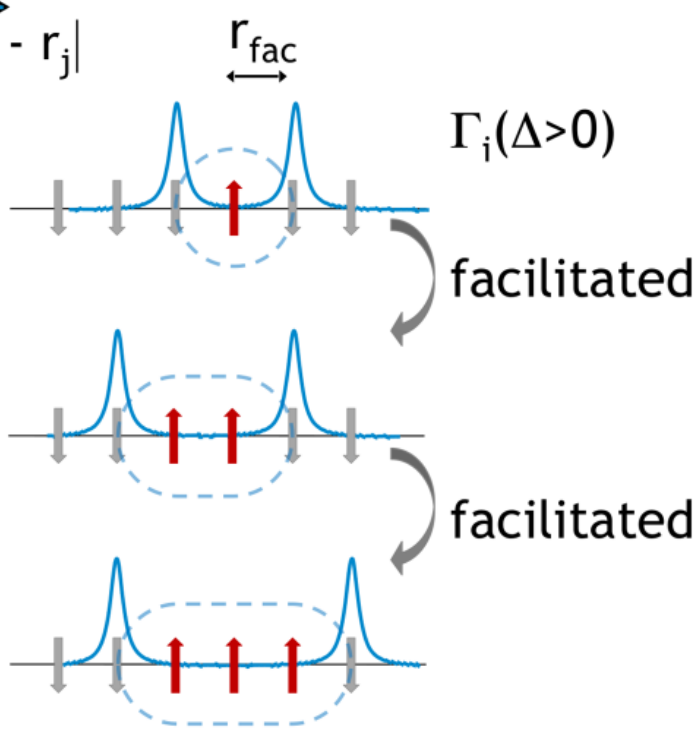


PHYSICAL REVIEW A **93**, 040701(R) (2016)

Facilitation dynamics = «offspring production»

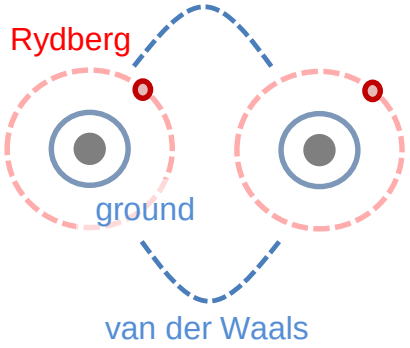


$r_{fac} \sim 7\ \mu m$



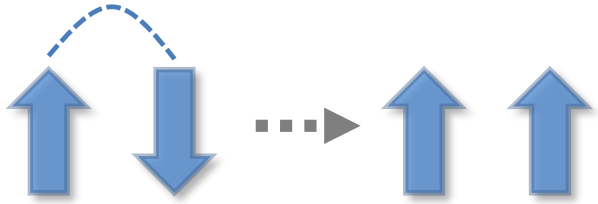
PHYSICAL REVIEW A **93**, 040701(R) (2016)

Facilitation dynamics = «offspring production»

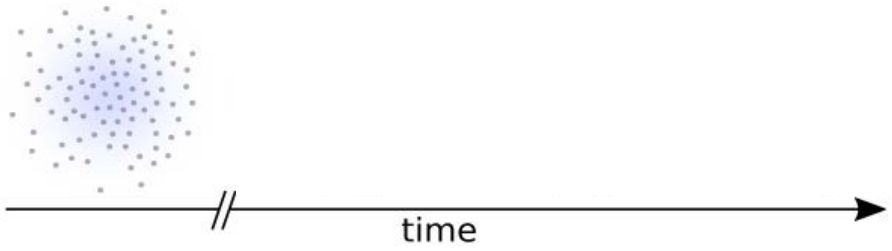


facilitated
excitation

=

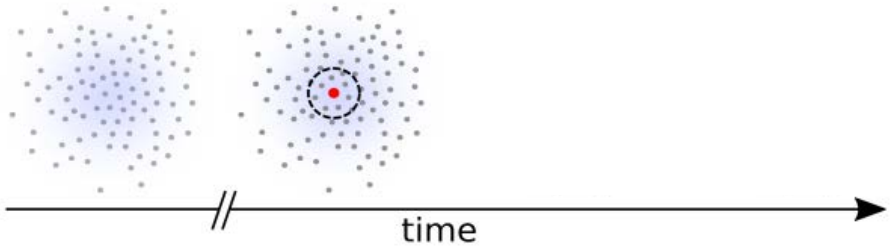


Facilitation dynamics needs to be seeded



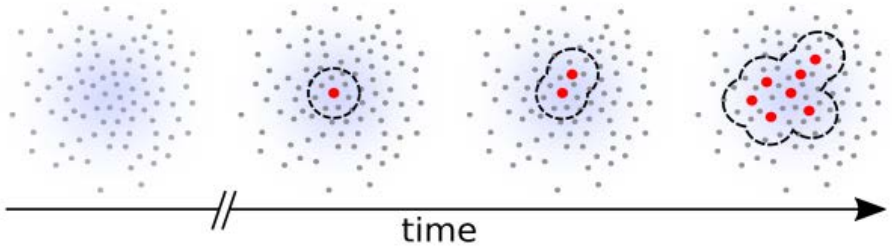
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

Facilitation dynamics needs to be seeded



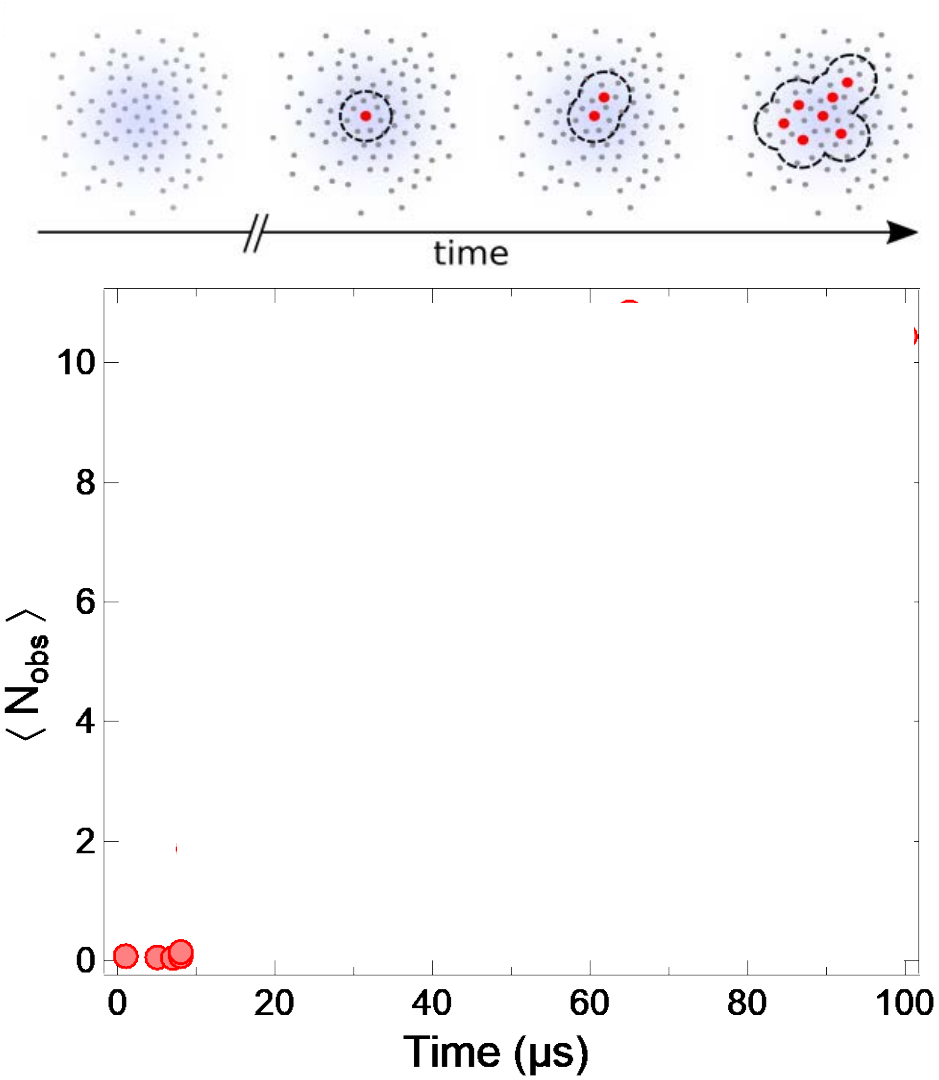
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

Facilitation dynamics needs to be seeded



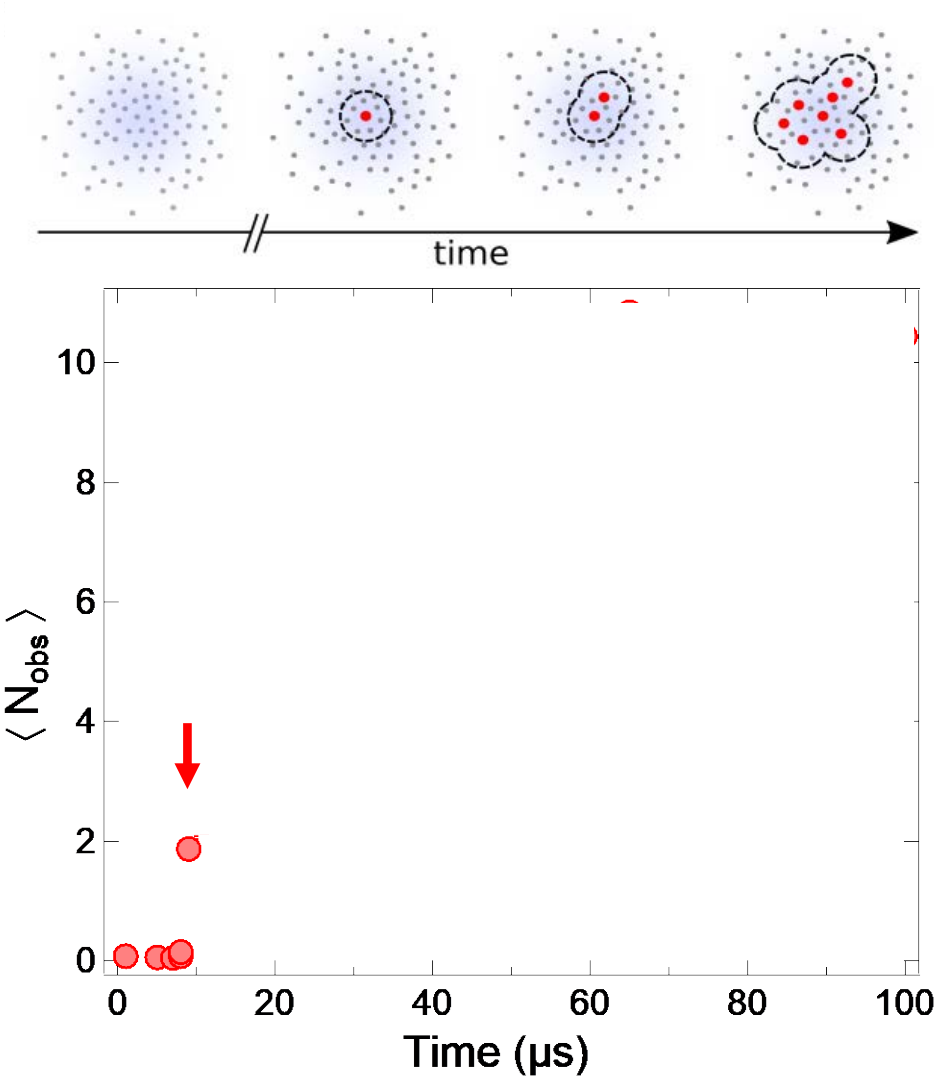
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

Facilitation dynamics needs to be seeded



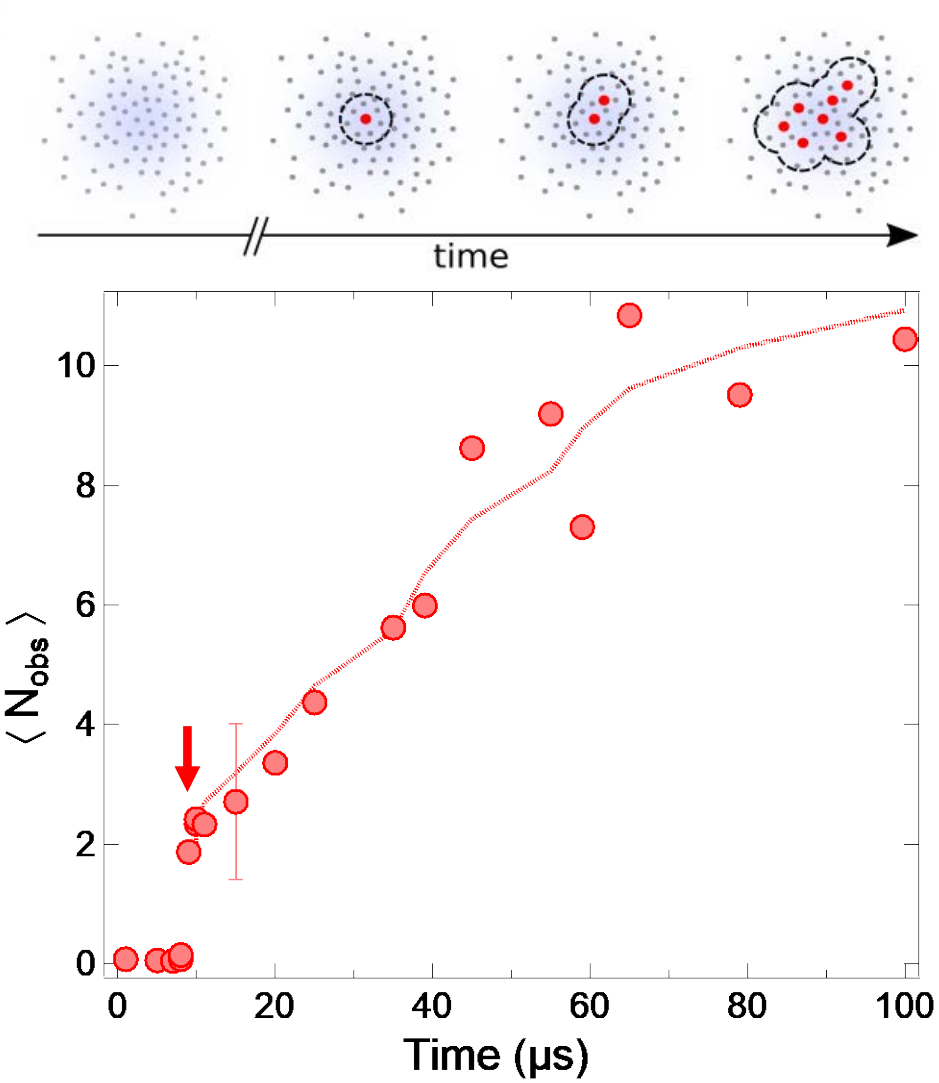
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

Facilitation dynamics needs to be seeded



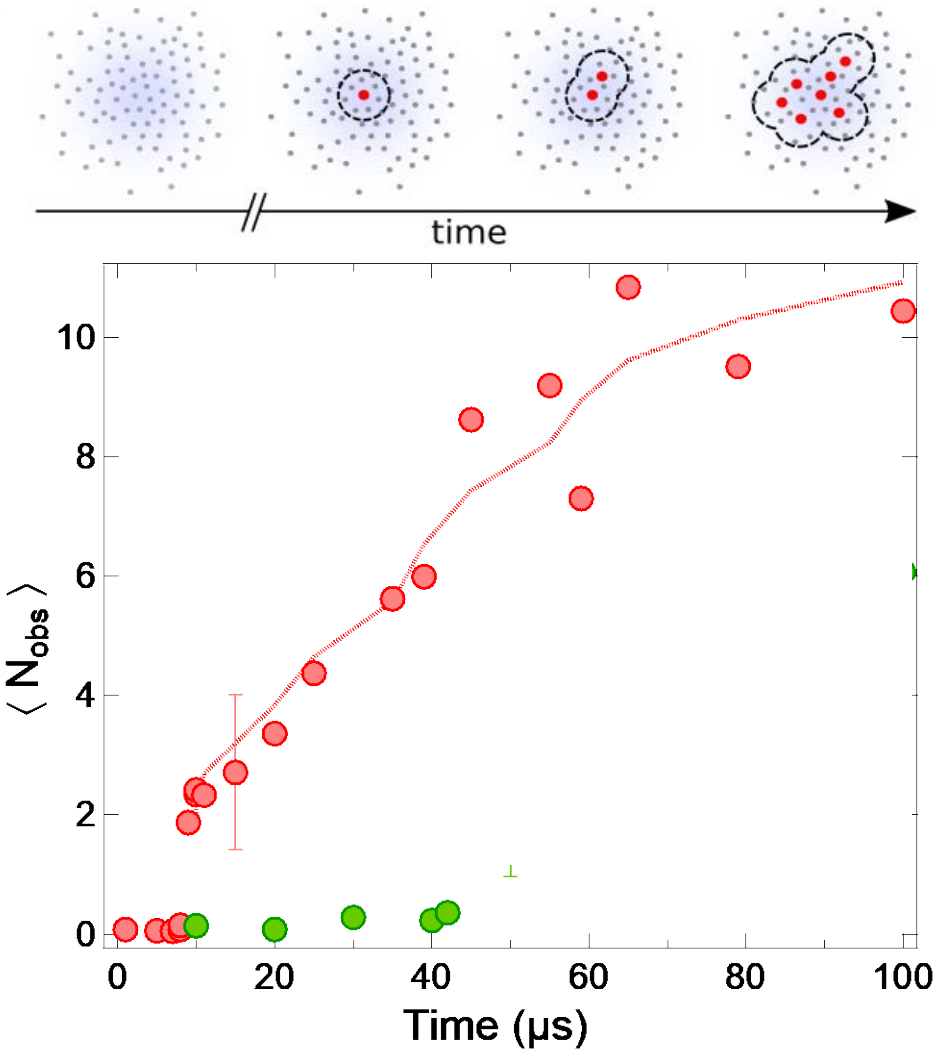
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

Facilitation dynamics needs to be seeded



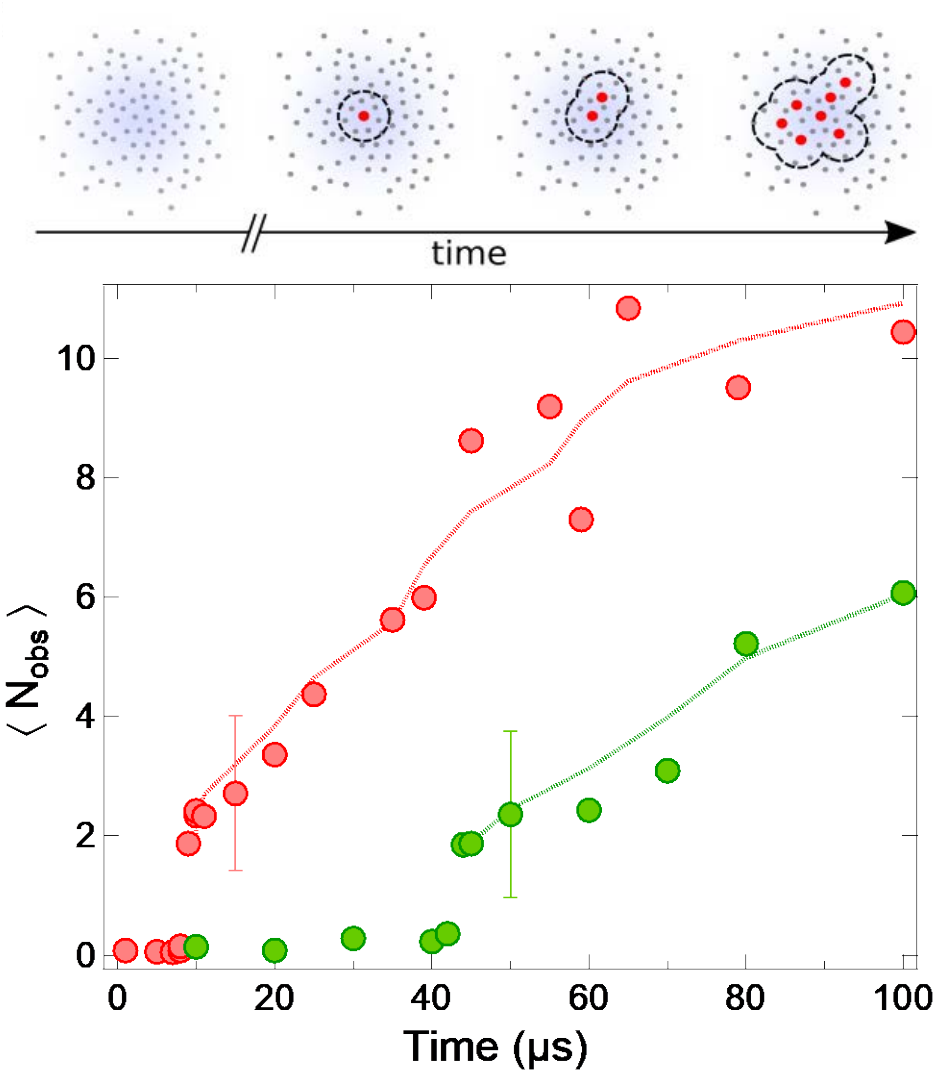
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

Facilitation dynamics needs to be seeded



C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

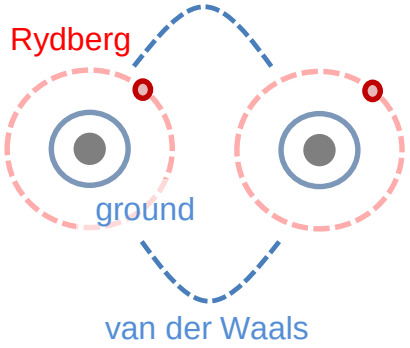
Facilitation dynamics needs to be seeded



(see also work by R. Löw (Stuttgart))

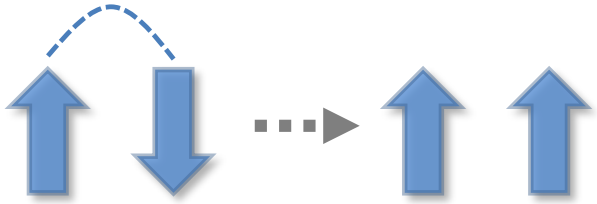
C. Simonelli *et al.* , J. Phys. B 49, 154002 (2016)

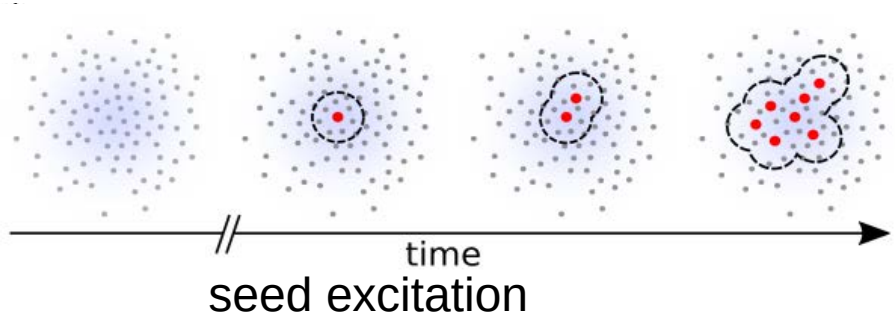
Facilitation and decay realize the basic processes for absorbing state phase transition



facilitated excitation

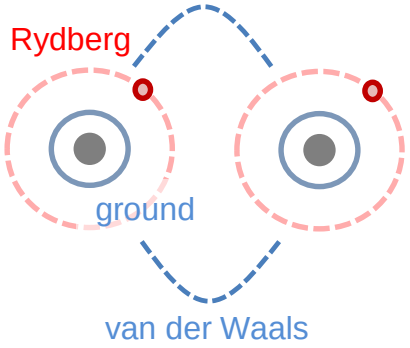
=





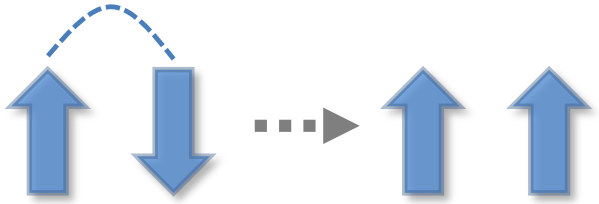
needed to prepare the system away from the absorbing state

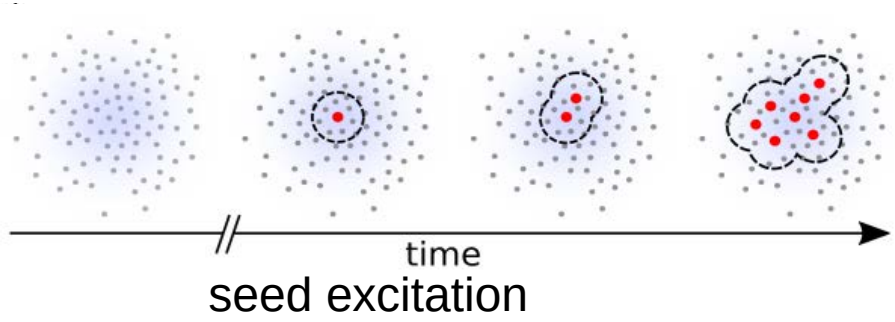
Facilitation and decay realize the basic processes for absorbing state phase transition



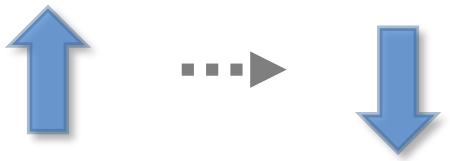
facilitated excitation

=

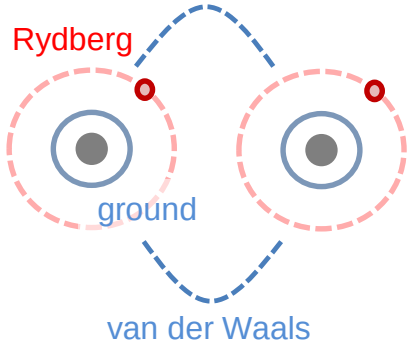




needed to prepare the system away from the absorbing state

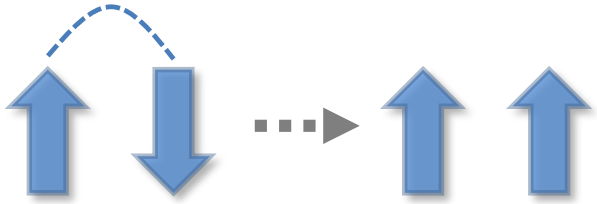


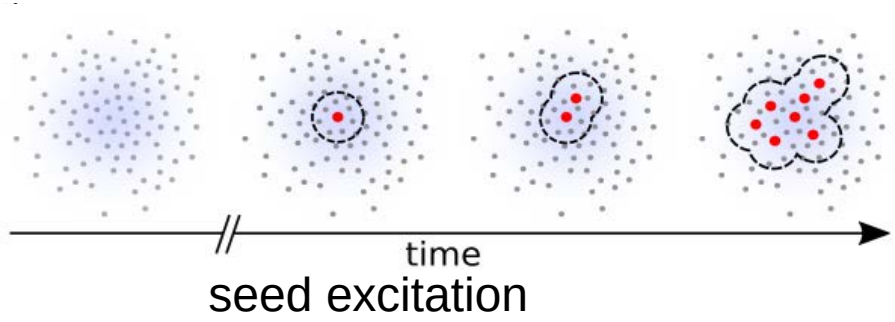
Facilitation and decay realize the basic processes for absorbing state phase transition



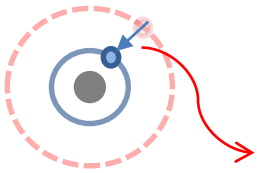
facilitated excitation

=





needed to prepare the system away from the absorbing state

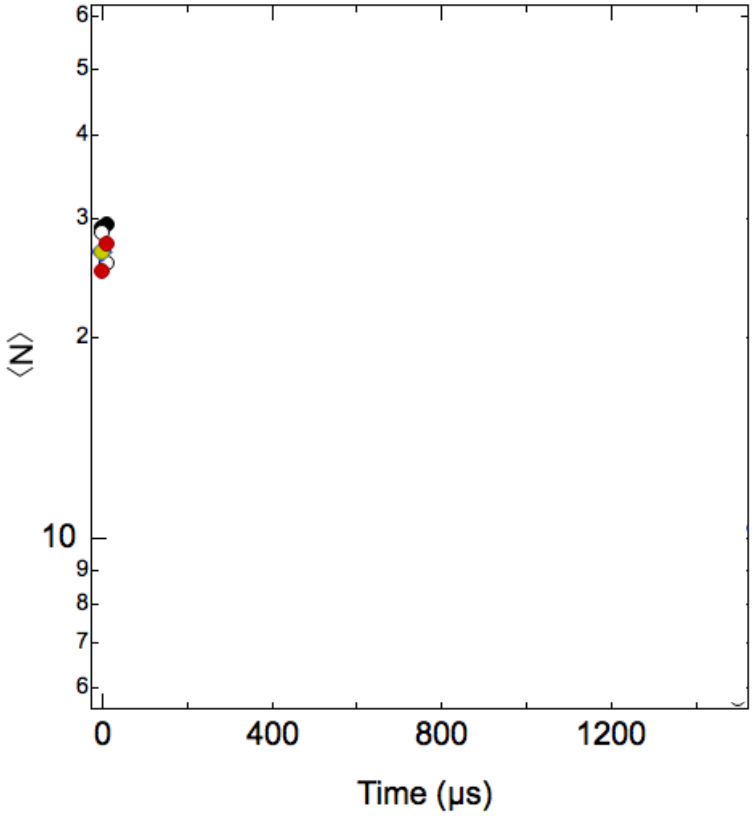


spontaneous decay

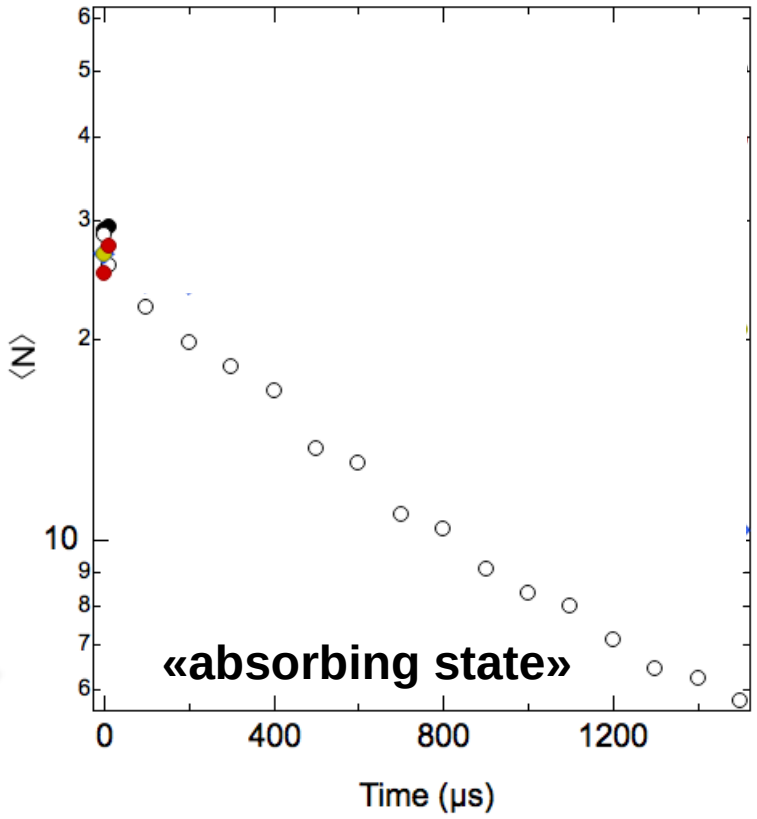
=

Absorbing state phase transition probed by varying the driving (facilitation) strength

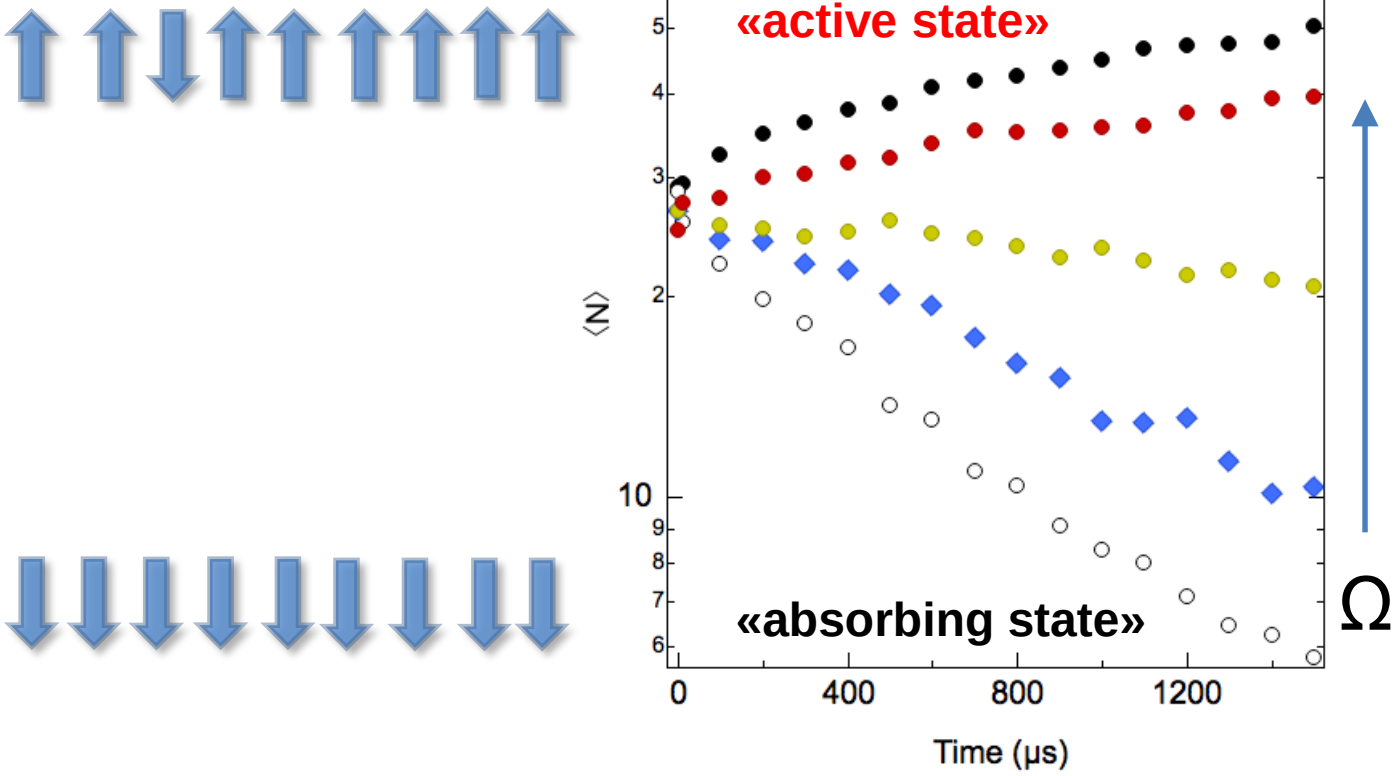
system is initially seeded



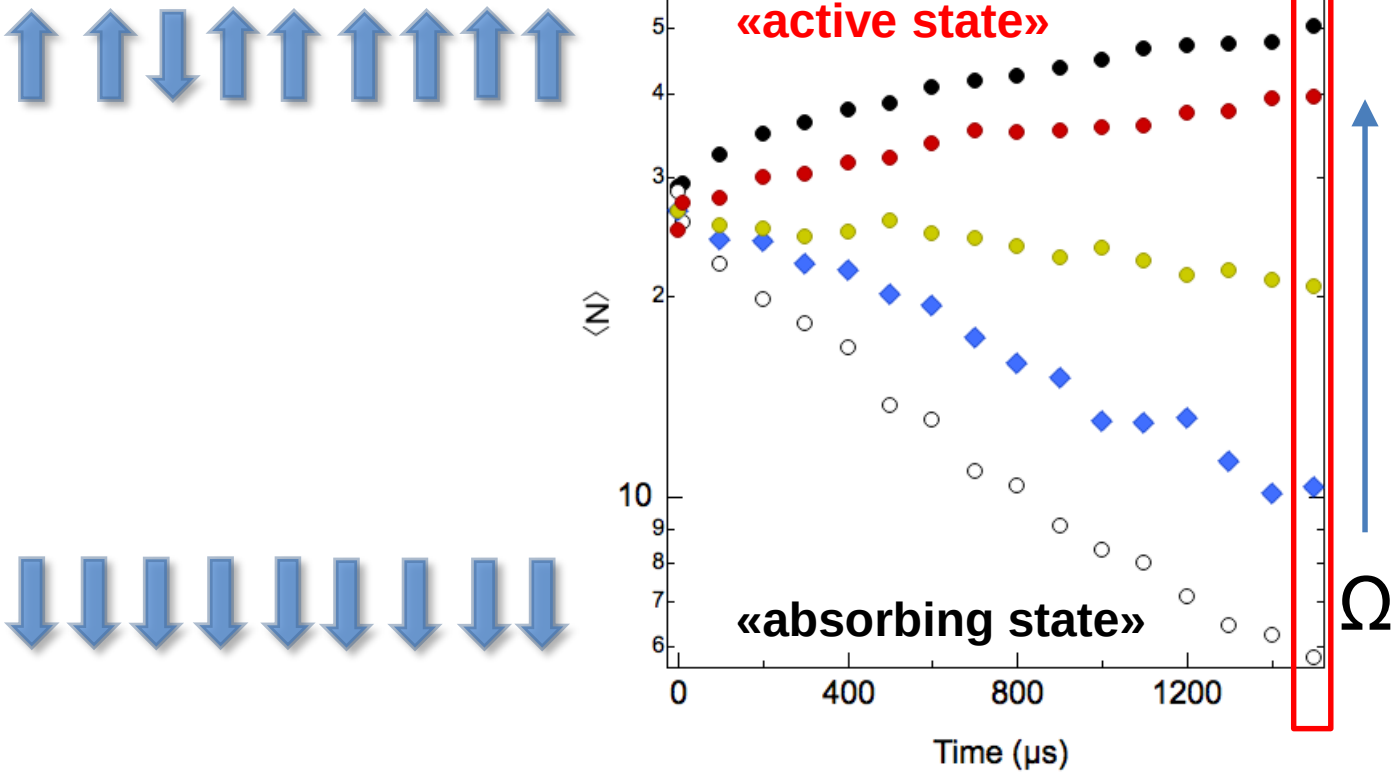
Absorbing state phase transition probed by varying the driving (facilitation) strength



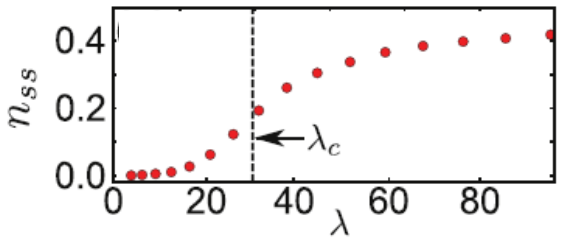
Absorbing state phase transition probed by varying the driving (facilitation) strength



Absorbing state phase transition probed by varying the driving (facilitation) strength

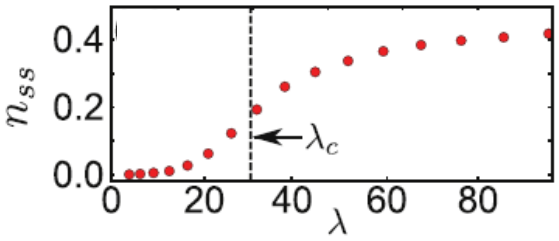


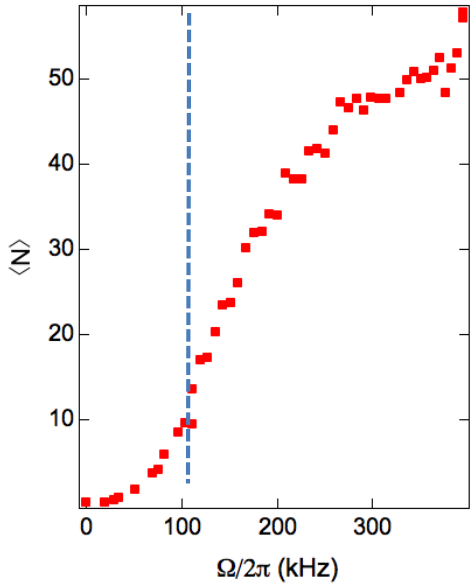
A crossover between absorbing and active states is observed



New J. Phys. **17**, 072003 (2015)

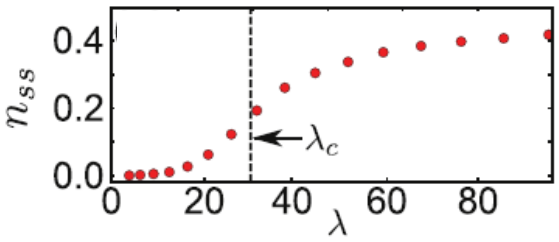
A crossover between absorbing and active states is observed

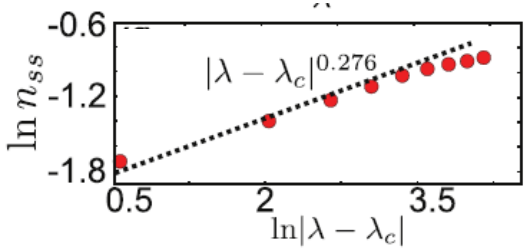


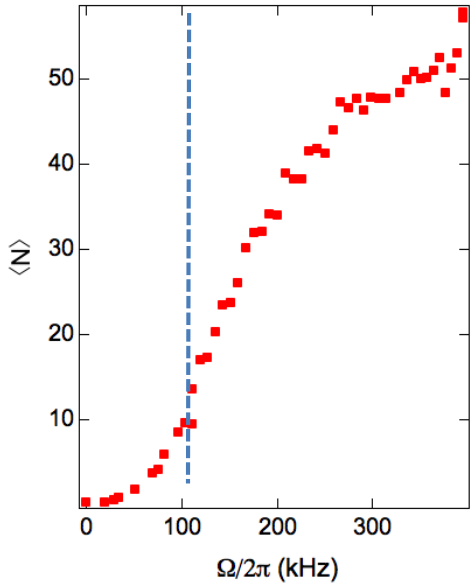


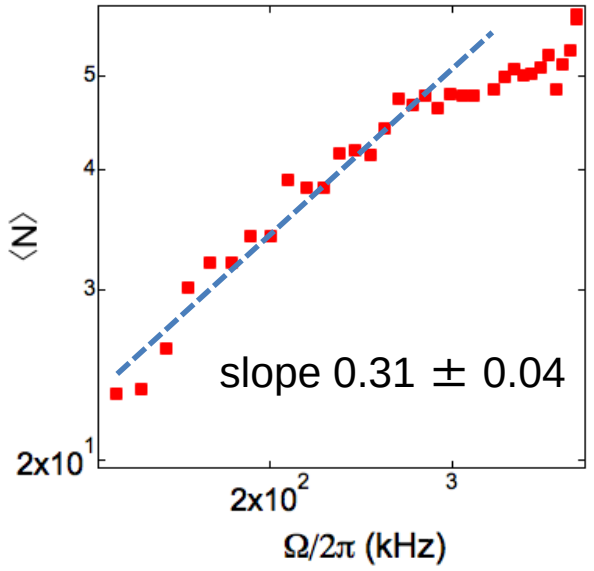
New J. Phys. **17**, 072003 (2015)

A crossover between absorbing and active states is observed







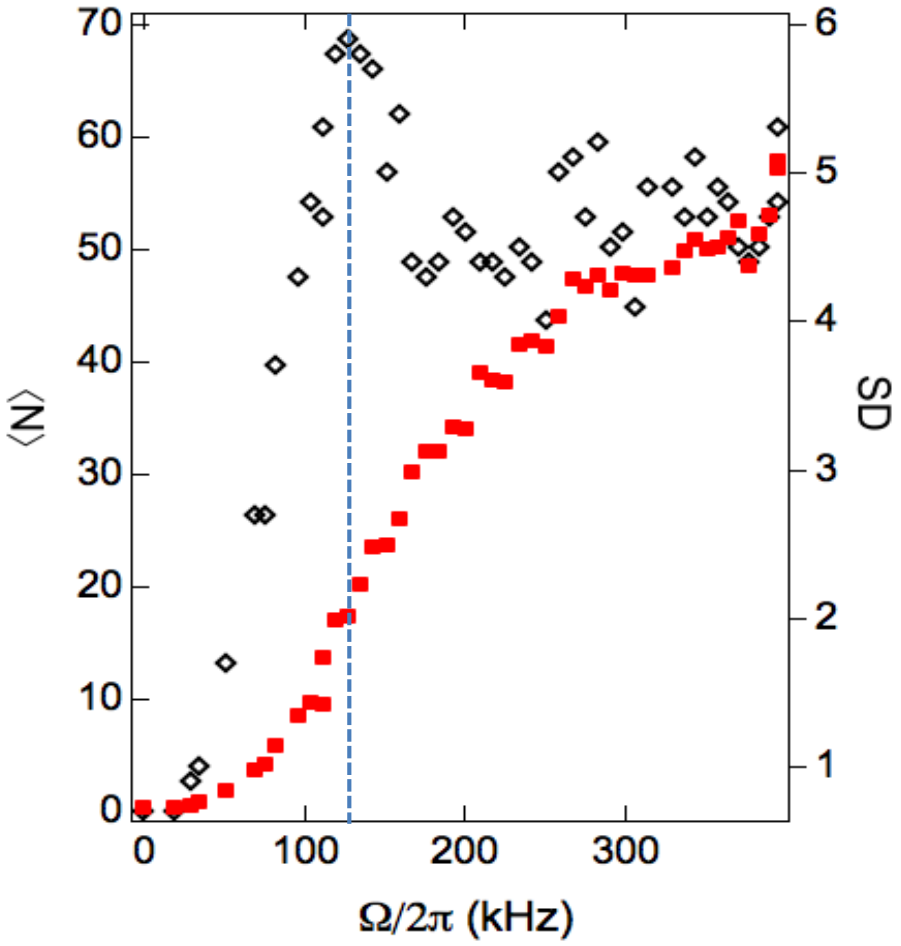


Compatible with 1D directed percolation ($\beta \backsim 0.276$)

New J. Phys. **17**, 072003 (2015)

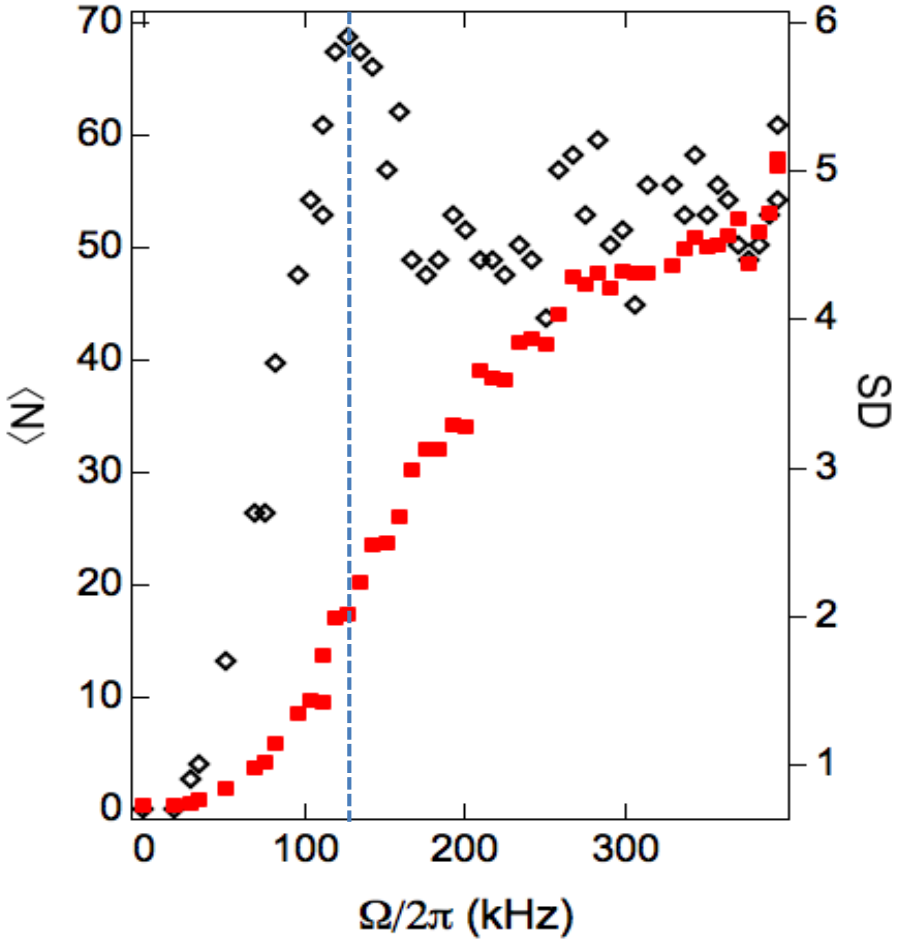
Phys. Rev. A **96**, 043411

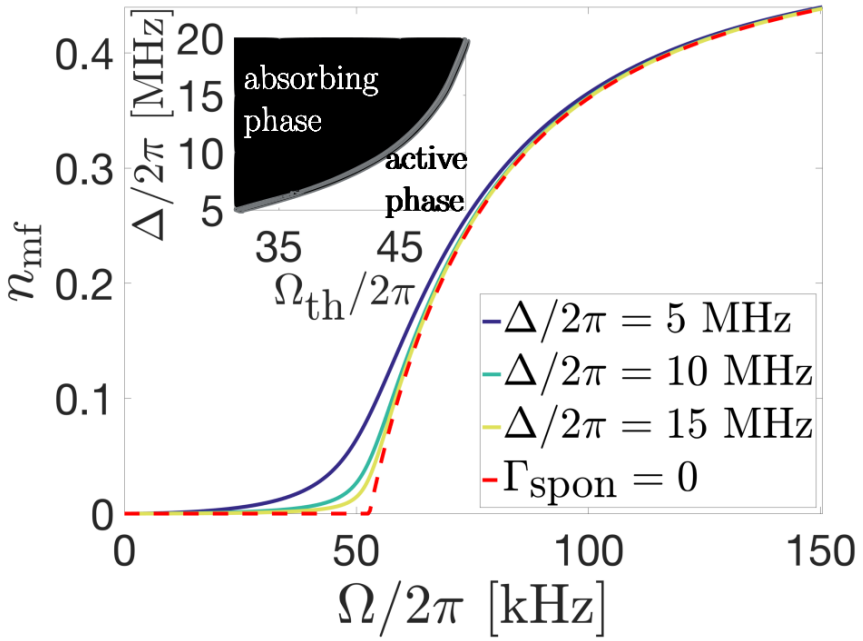
The phase transition is signalled by a peak in the fluctuations



Phys. Rev. A **96**, 043411

The phase transition is signalled by a peak in the fluctuations



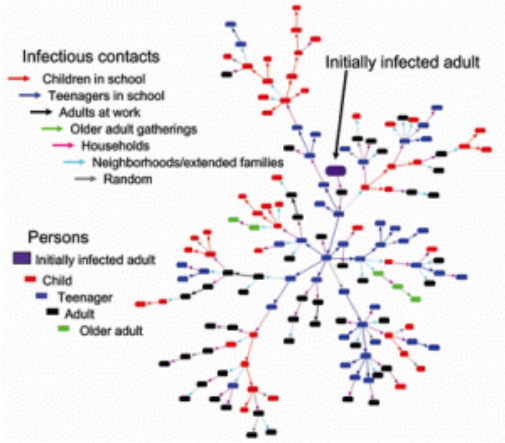


Refinements:
- spontaneous excitations
- atomic motion

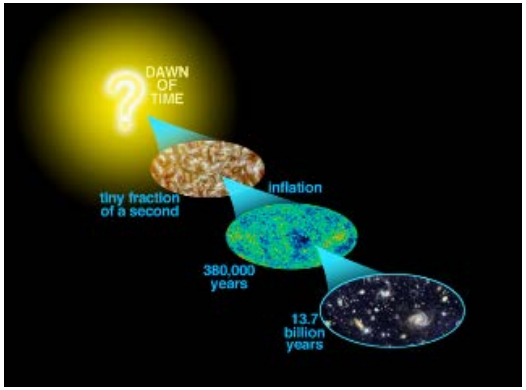
Phys. Rev. A **96**, 043411

(see also work by S. Whitlock)

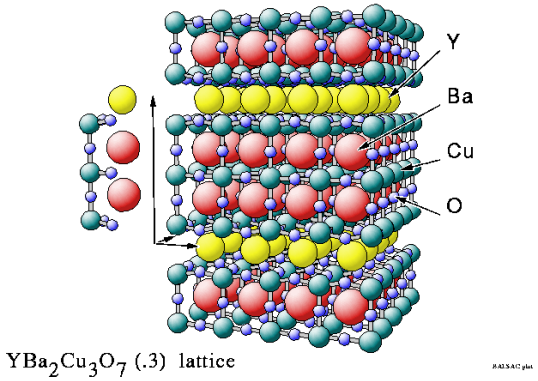
Outlook: towards quantum percolation

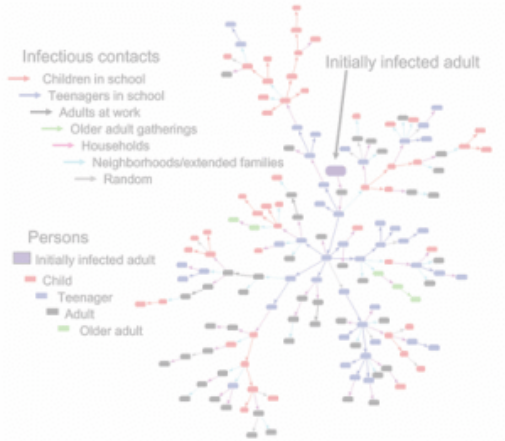


Percolation ***classical***

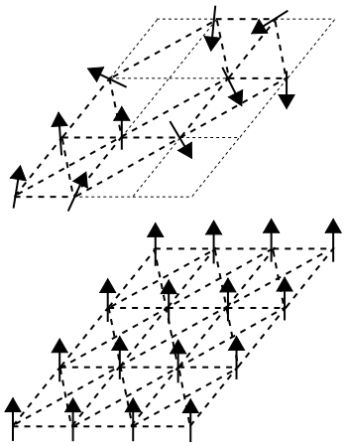


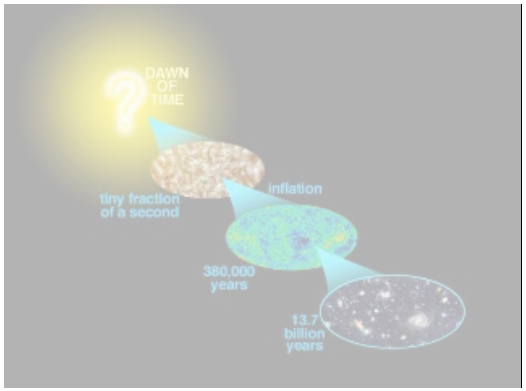
Outlook: towards quantum percolation



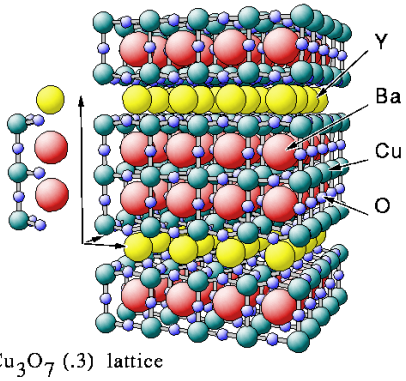


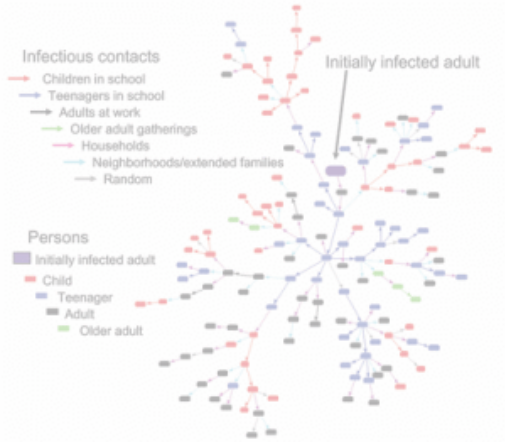
quantum **Percolation** ***classical***



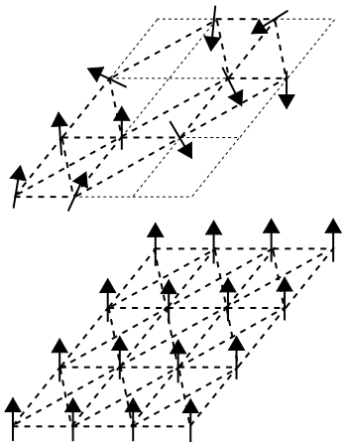


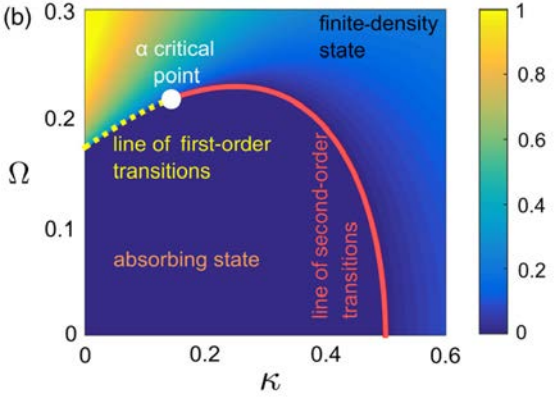
Outlook: towards quantum percolation

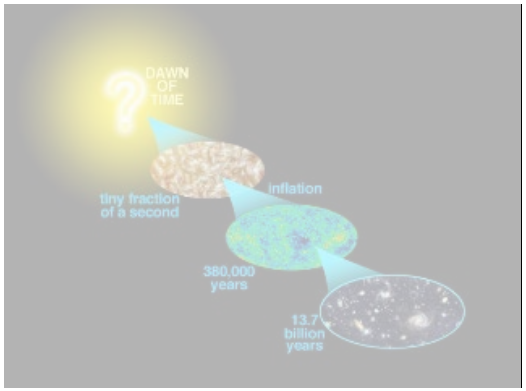




quantum **Percolation** ***classical***







Marcuzzi et al., Phys. Rev. Lett **116**, 245701 (2016)