Random organization with mediated interactions

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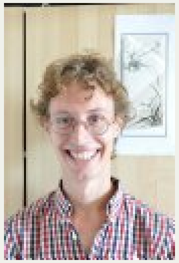
GDR IDE, Nov. 2022



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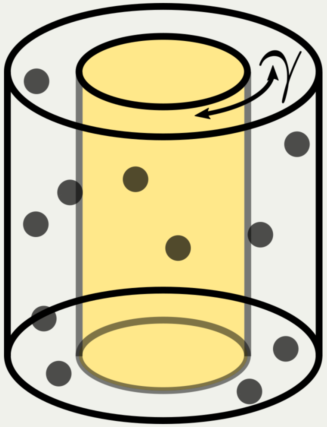
Reversible-irreversible transitions (RIT)

[Pine, Gollub, Brady, Leshansky, Nature 2005]
Non-Brownian suspensions of buoyant particles,
zero Reynolds



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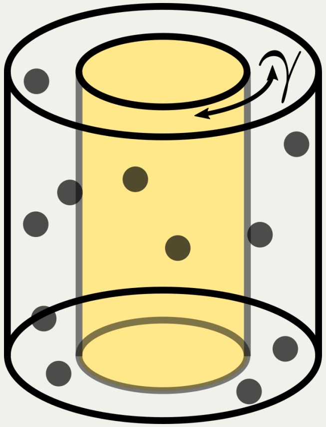
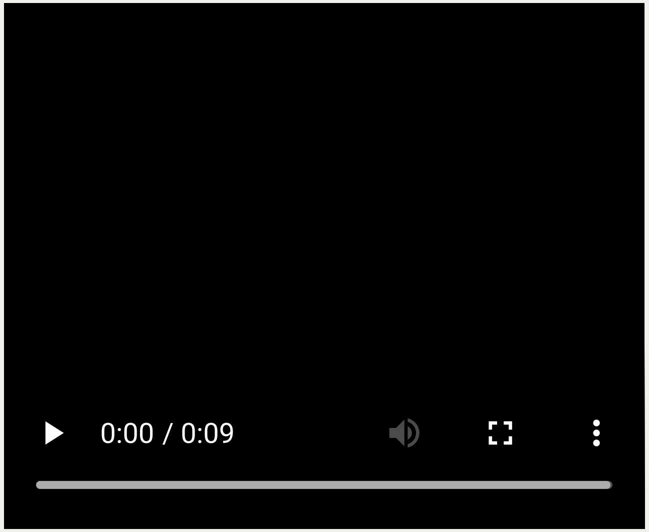
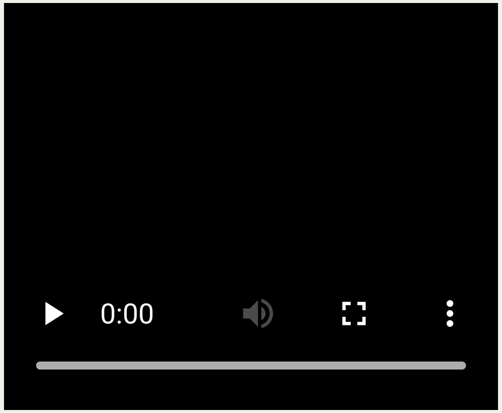




Stroboscopic time: continuous phase transition

$\gamma > \gamma_c$



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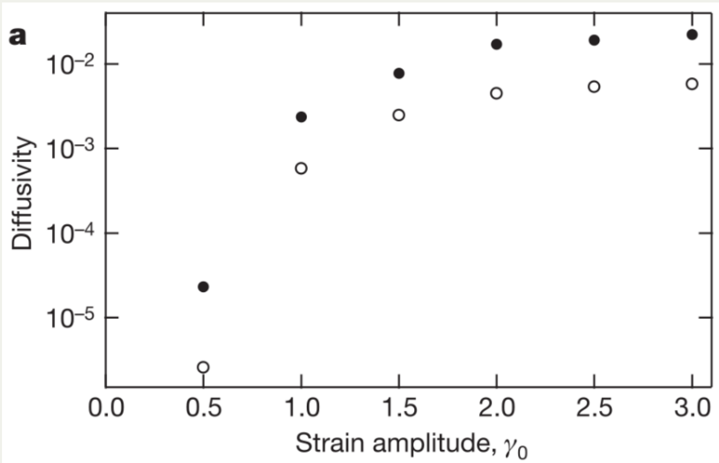


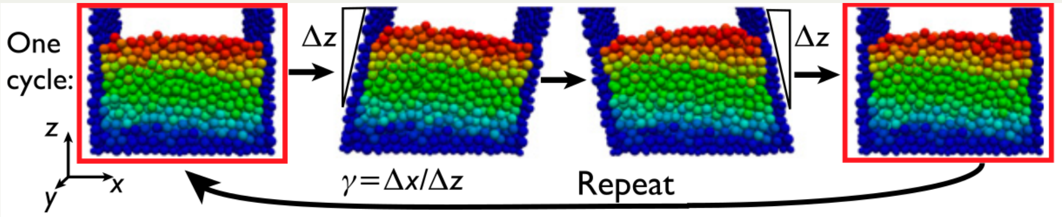
Reversible-irreversible transitions (RIT)

Dense suspensions [Pine et al, Corté et al, 2005-2009]

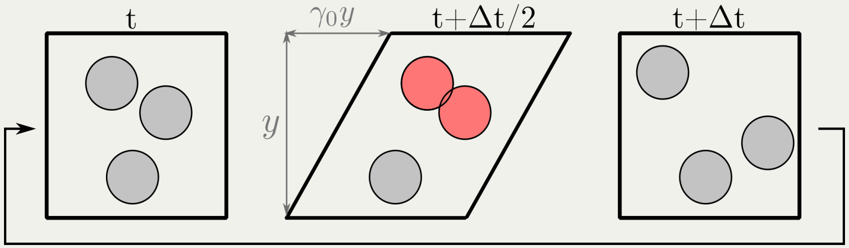
Emulsions, moderately concentrated [Jeanneret & Bartolo, 2014-2015], very concentrated [Knowlton, Pine & Cipelletti, 2014]

Soft glasses, experimental [Hima Nagamanasa et al, 2014], simulations [Fiocco, Foffi & Sastry, 2013]

Dry granular material [Royer & Chaikin, 2015]



RIT is an absorbing phase transition



Active state: irreversible event during shear (contact, plastic event)

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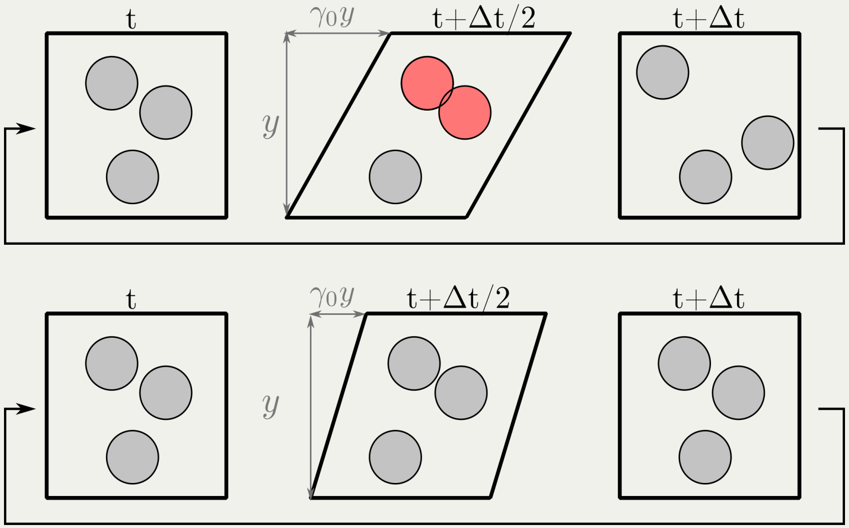

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Absorbing state: no irreversible event during shear

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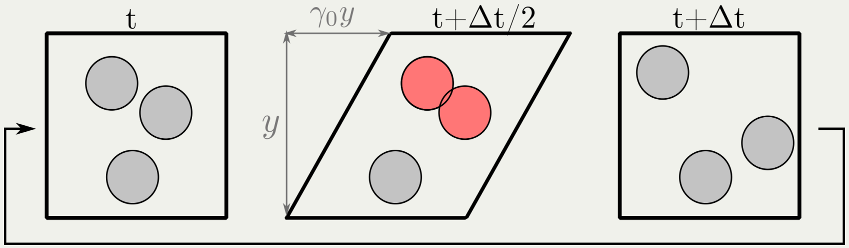

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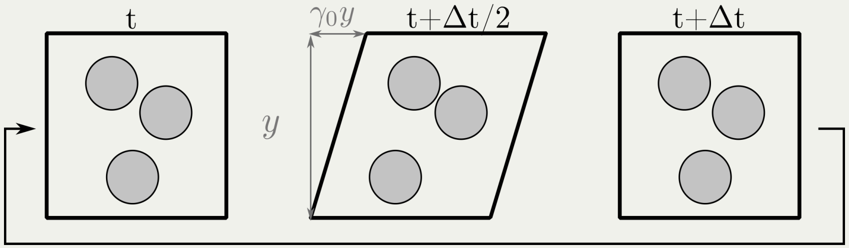

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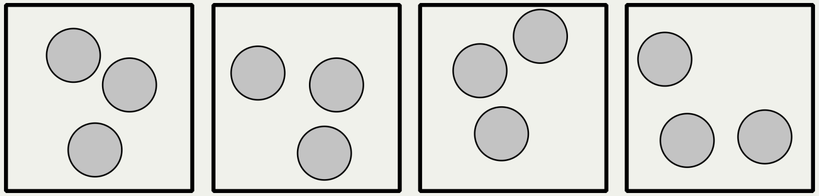

Infinitely many absorbing states, all those which do not create irreversible events under a cycle

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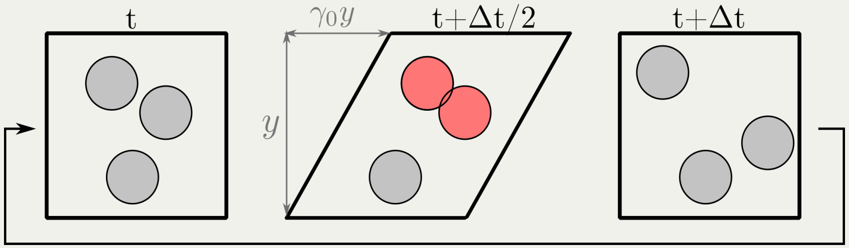

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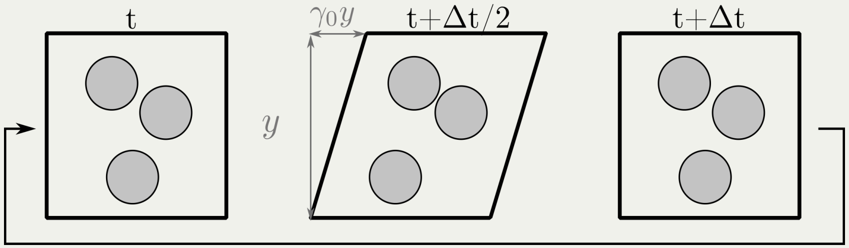

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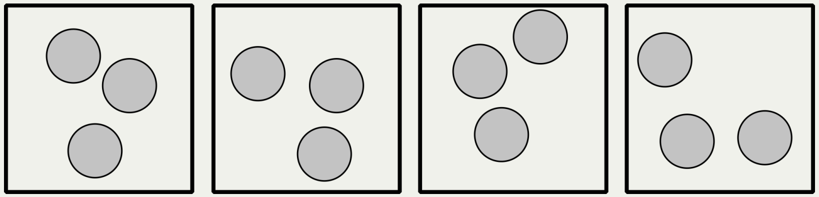


Infinitely many absorbing states, all those which do not create irreversible events under a cycle

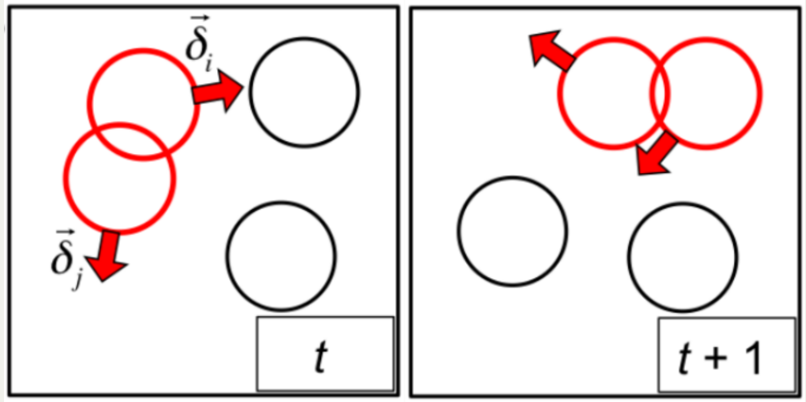
Stroboscopic sampling:
absorbing phase transition with infinitely many absorbing states and a conserved quantity

Expectation: continuous transition in the **Conserved Directed Percolation (CDP) class** [Pastor-Satorras & Vespignani, 2000]

Minimal model: random organization

[Corté, Chaikin, Gollub, Pine, Nature 2008]
[Hexner & Levine, PRL 2015]
[Tjhung & Berthier, PRL 2015]

Discrete-time model for stroboscopic dynamics



Random jumps with size δ
Particle volume fraction $\phi \leftrightarrow$ strain amplitude γ_0

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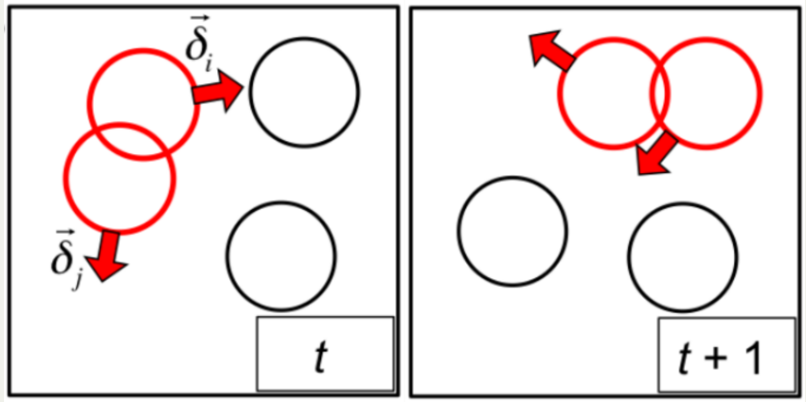
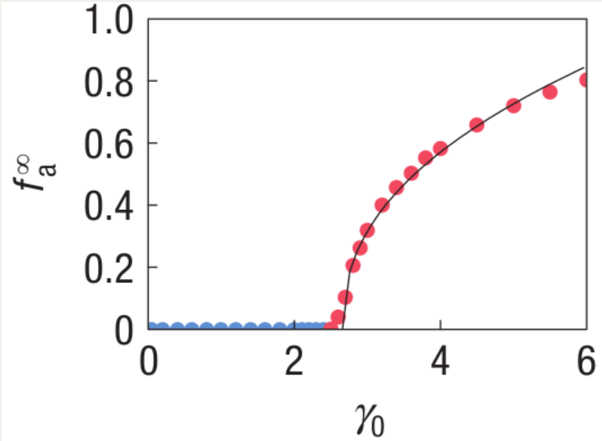


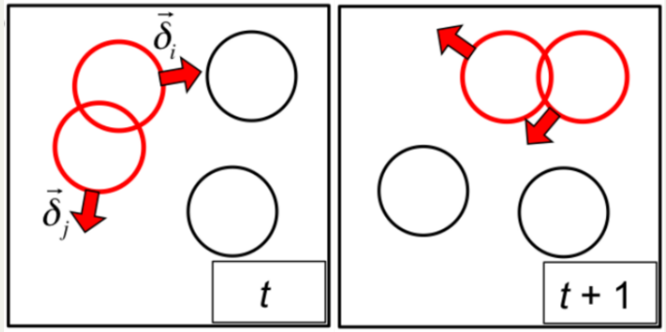
Random jumps with size δ
Particle volume fraction $\phi \leftrightarrow$ strain amplitude γ_0

Absorbing phase transition $A \sim (\phi - \phi_c)^\beta$

$\beta < 1$, values compatible with CDP (although debated)



Conserved directed percolation



[Menon & Ramaswamy, 2009]

Two fields:

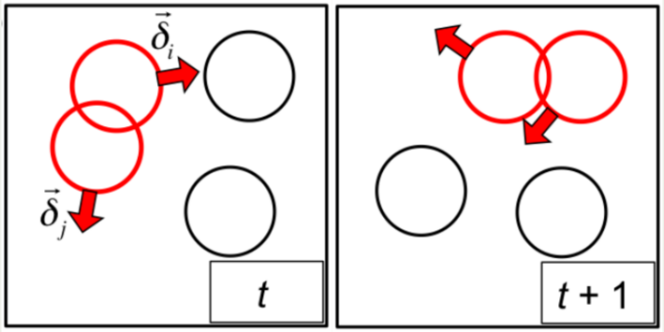
- Local volume fraction ϕ (conserved)
- Local active particle density A (not conserved)

$$\partial_t \phi = D_\rho \nabla^2 A$$
$$\partial_t A = (-\alpha + k\phi)A - \lambda A^2 + D_A \nabla^2 A + \sigma\sqrt{A}\eta$$

Activity drives the dynamics

Activity creates and destroys activity,
and acts like a local temperature

Conserved directed percolation



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Concave transtion

$$\langle A \rangle \sim (\phi - \phi_c)^\beta$$

with $\beta \approx 0.64$ for $d = 2$ (1 in MF)

Fluctuations diverge

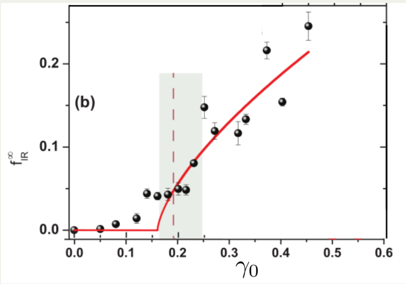
$$N\langle (A - \langle A \rangle)^2 \rangle \sim (\phi - \phi_c)^{-\gamma'}$$

with $\gamma' \approx 0.37$ for $d = 2$ (0 in MF)

RIT is conserved directed percolation?

CDP class: density of active particles $A \sim (\gamma_0 - \gamma_c)^\beta$,
with $\beta \approx 0.84$ for $d = 3$

Early experiments argued compatible with CDP [Corté et al, Nat. Phys. 2009; Hima Nagamanasa et al., PRE 2014]



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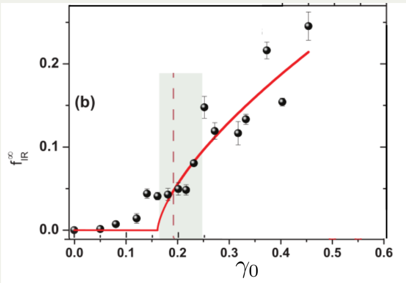
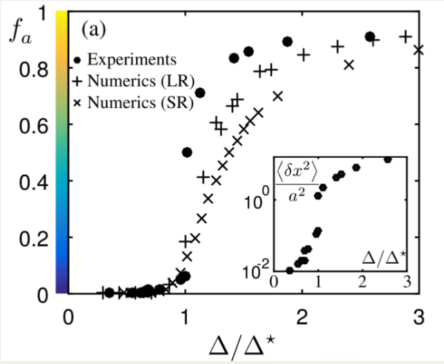
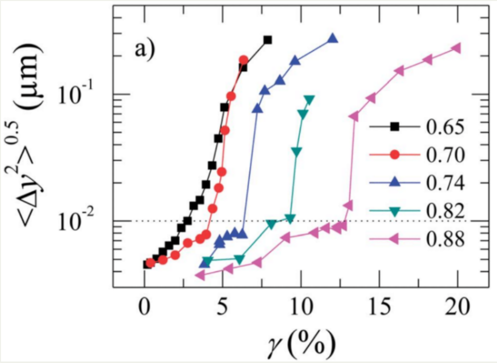


However many **non-CDP behaviors** observed in other experiments, e.g. emulsions with $\beta > 1$ (convex transition)

Semi-dilute [Weijs, Jeanneret, Dreyfus, Bartolo, PRL 2015]



Concentrated [Knowlton, Pine, Cipelletti, Soft Matter 2014]



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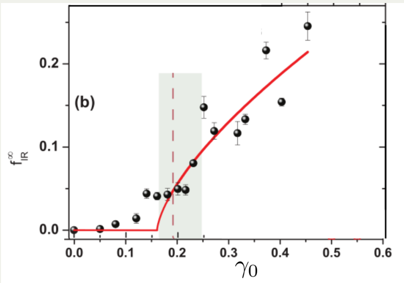

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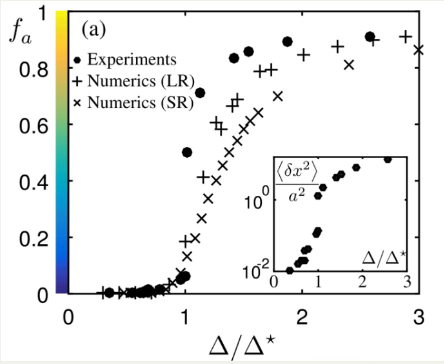

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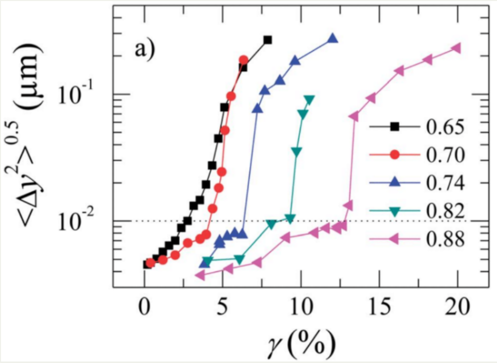


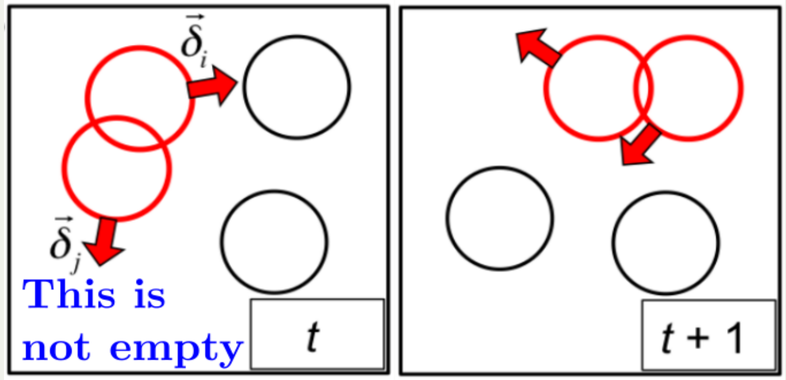
Not clarified by simulations of realistic models either (observed CDP, continuous but not CDP, first order)

Need for refined minimal models

Refining random organization

In random organization, irreversibility has local effect only.

Experiments (and realistic simulations) have **mediated interactions**, elasticity or hydrodynamics.



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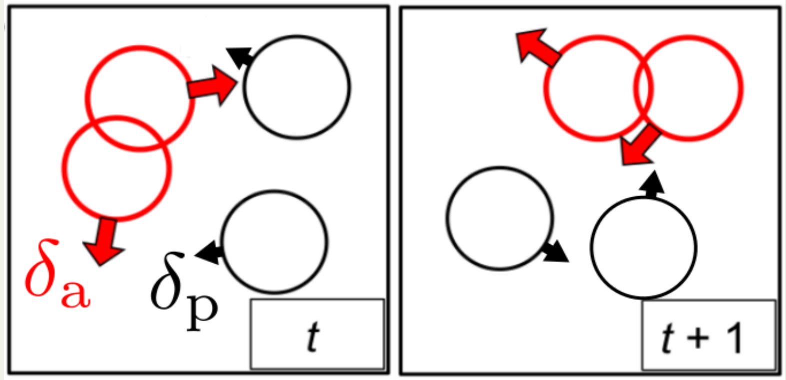

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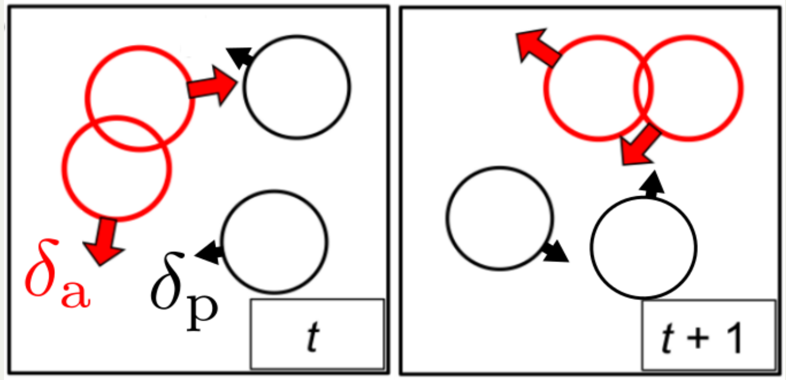

Overlapping: jumps with size δ_a

Not overlapping ("passive"): jumps with size δ_p

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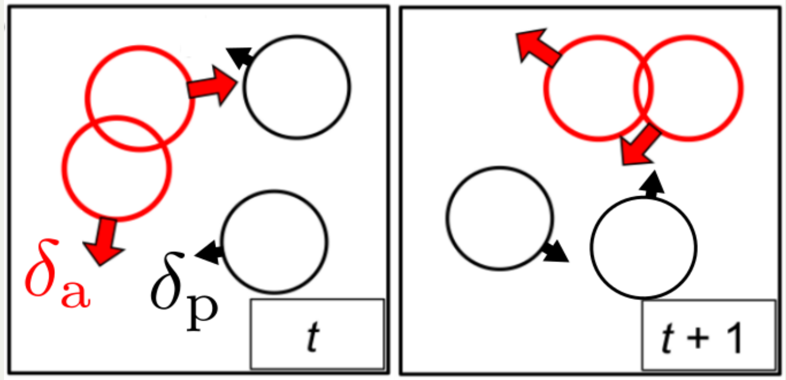

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Motion of passive particles sum of incoherent contributions from active particles

$\delta_\mathrm{p} = \lambda\sqrt{\bar{A}}$, with $\bar{A} = N_A/N$

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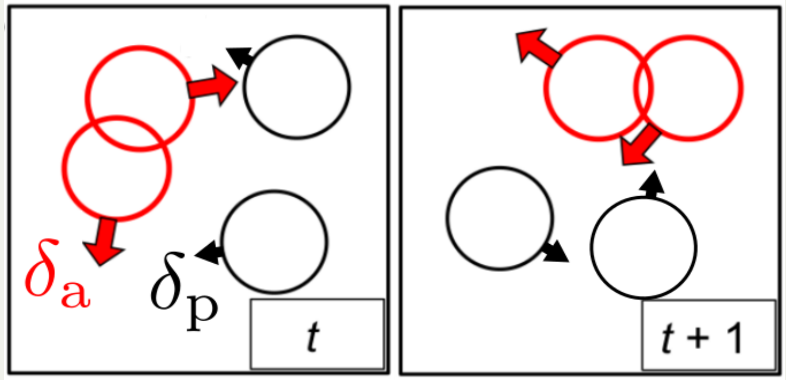

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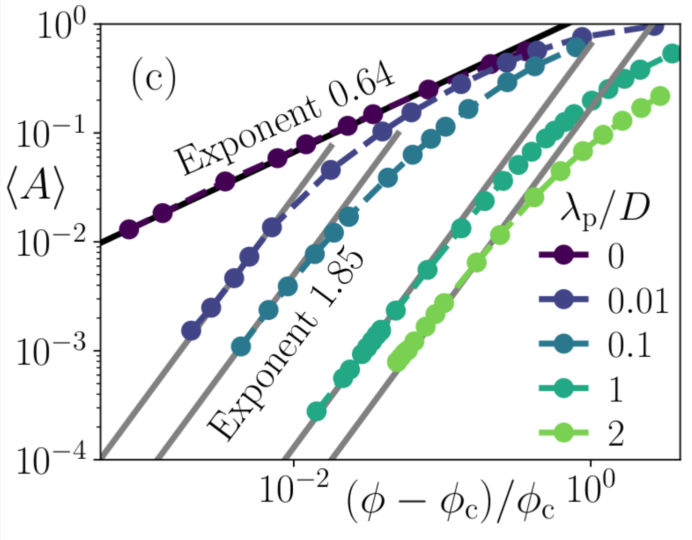
$\delta_p = \lambda\sqrt{\bar{A}}$, with $\bar{A} = N_A/N$

Passive particles can spontaneously create activity (even far from other active zones)

$$\partial_t A = (-\alpha + k\phi)A - \lambda A^2 + ??? + D_A\nabla^2 A + \sigma\sqrt{A}\eta$$

Numerical simulations



Convex transition, $\beta > 1$

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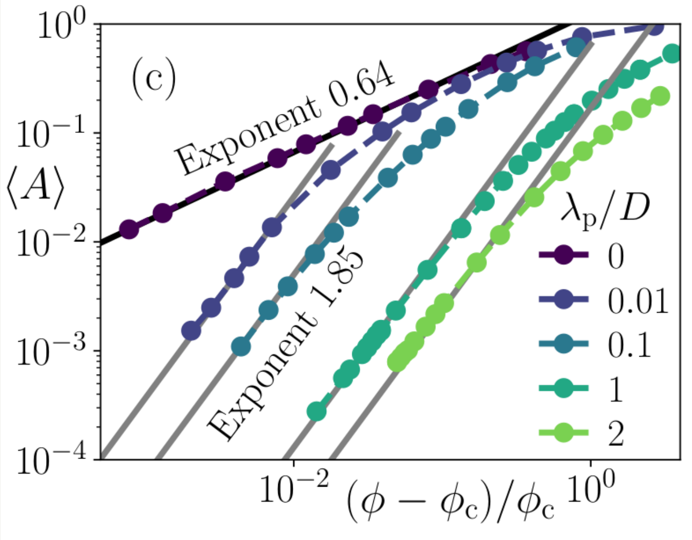

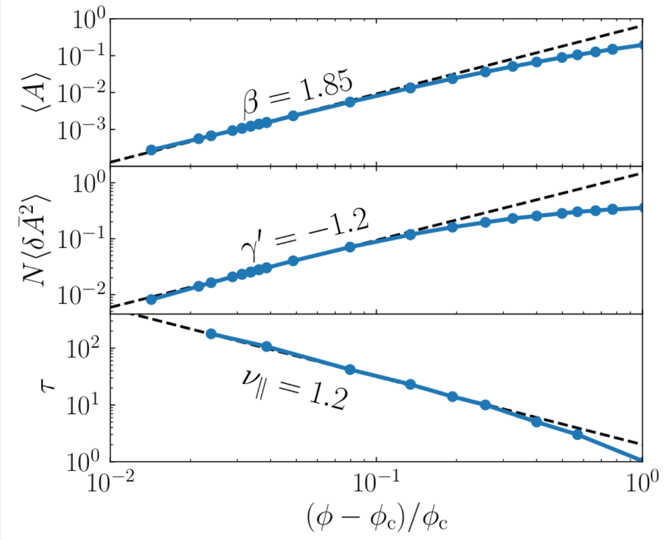

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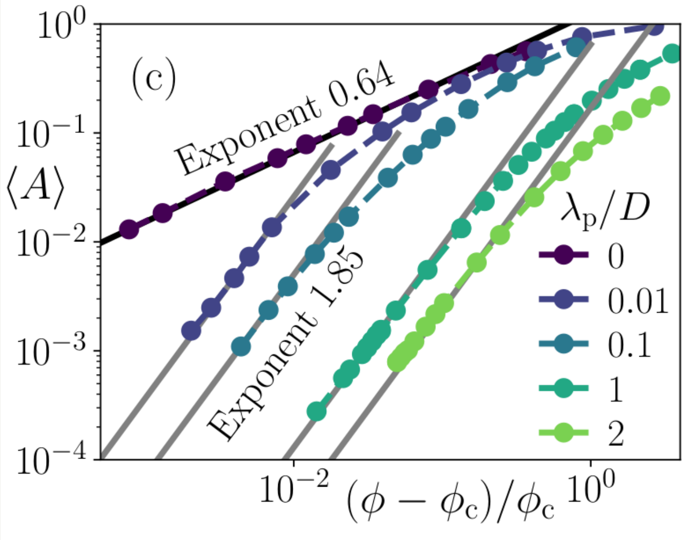

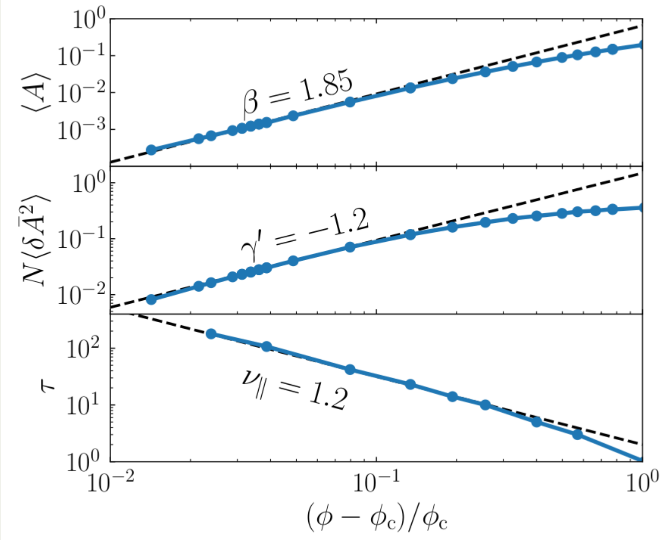

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Activity created from passive particles motion

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Mean-field is convex, with $\beta = 2$!

New universality class for RIT with mediated interactions?

Vanishing fluctuations?

Vanishing but large enough to get non-mean field behavior,
Ginzburg criterion violated: $N\langle \delta A^2 \rangle \gg \langle A \rangle$ close to ϕ_c

Large β linked to small fluctuations via hyperscaling $\gamma' = d\nu_\perp - 2\beta$ [Lübeck 2004]

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Yielding of yield-stress fluids!

Hershel-Bulkley law: $\sigma = \sigma_c + K\dot{\gamma}^{1/\beta}$

Control parameter σ, order parameter $\dot{\gamma}$:

$\dot{\gamma} \sim (\sigma - \sigma_c)^\beta$, with $\beta \in [1.5, 2]$

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Work with Tristan Jocteur, Kirsten Martens,
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For Picard model

[Picard, Ajdari, Lequeux & Bocquet, 2004]