Intermittent active dynamics at infinite persistence

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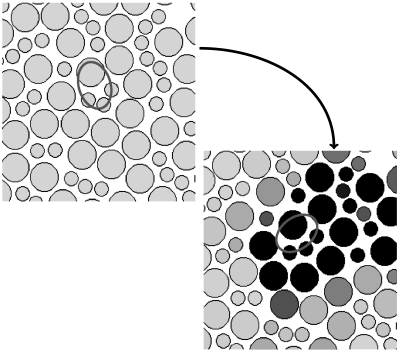
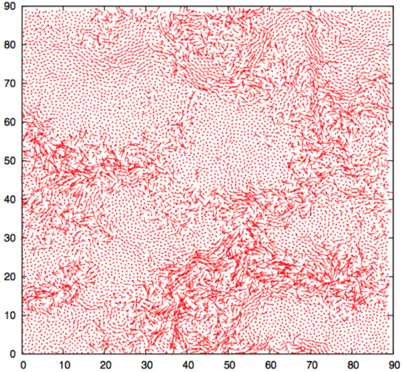
30/11/2022

Disordered collective motion in passive (dead) matter

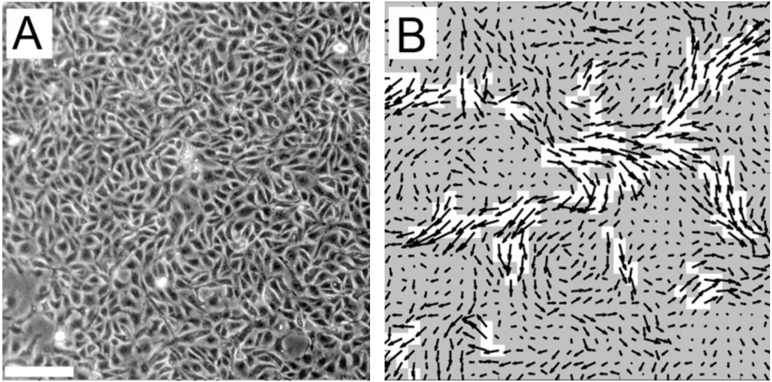


[Falk, Langer, 1998]



[Berthier, 2011]

- In dense disordered packings, particles must move in a correlated way. In passive systems close to arrest, where crowding competes with thermal excitation, these rearrangements are the result of rare activated events.
- Their accumulation leads to disordered collective motion in the form of dynamical heterogeneity.

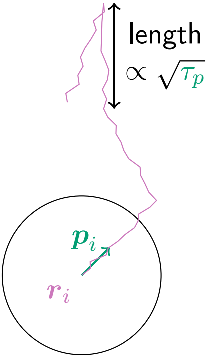


$100\,\mu m$

[Angelini *et al.*, 2011]

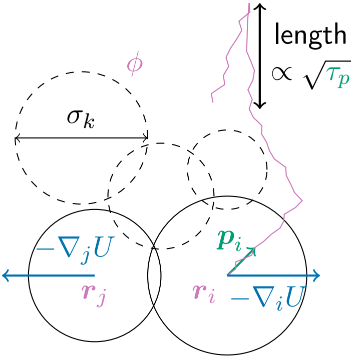
- Dense active systems (*e.g.*, cell tissues, bacterial colonies), in which crowding competes with nonthermal driving, also display disordered collective motion, reminiscent of passive systems.

- Overdamped self-propelled particles: propulsion force $\boldsymbol{p}_i$ with correlation time τ_p ($\equiv$ persistence time).



$$\xi \dot{\boldsymbol{r}}_i = \boldsymbol{p}_i \quad (1)$$
$$\tau_p \dot{\boldsymbol{p}}_i = -\boldsymbol{p}_i + \sqrt{2\xi^2 D_0} \boldsymbol{\eta}_i \quad (2)$$

- Overdamped self-propelled particles: propulsion force $\boldsymbol{p}_i$ with correlation time τ_p ($\equiv$ persistence time).
- Disordered mixture: pairwise interaction potential U for polydisperse particles with packing fraction ϕ in 2D.



$$\xi \dot{\boldsymbol{r}}_i = -\varepsilon \nabla_i U + \boldsymbol{p}_i \tag{1}$$
$$\tau_p \dot{\boldsymbol{p}}_i = -\boldsymbol{p}_i + \sqrt{2\xi^2 D_0} \boldsymbol{\eta}_i \tag{2}$$

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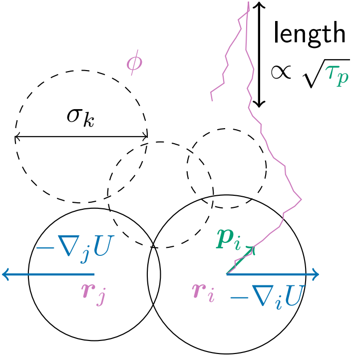
- Disordered mixture: pairwise interaction potential U for polydisperse particles with packing fraction ϕ in 2D.
- Solve overdamped Langevin dynamics to study the competition between crowding and forcing.



$$\dot{\boldsymbol{r}}_i = -\nabla_i U + \boldsymbol{p}_i \quad (1)$$

$$\tau_p \dot{\boldsymbol{p}}_i = -\boldsymbol{p}_i + \sqrt{2D_0}\boldsymbol{\eta}_i \quad (2)$$

$$\textit{units:}\ \text{length}\ \overline{\sigma} = 1,\ \text{time}\ \tau_0 = \xi\overline{\sigma}^2/\varepsilon = 1,\ \text{energy}\ \varepsilon = 1 \quad (3)$$

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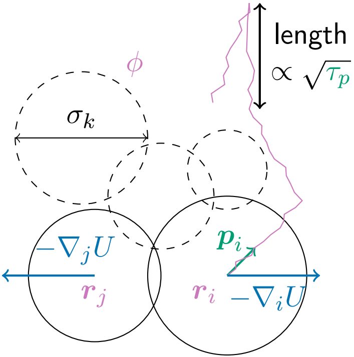

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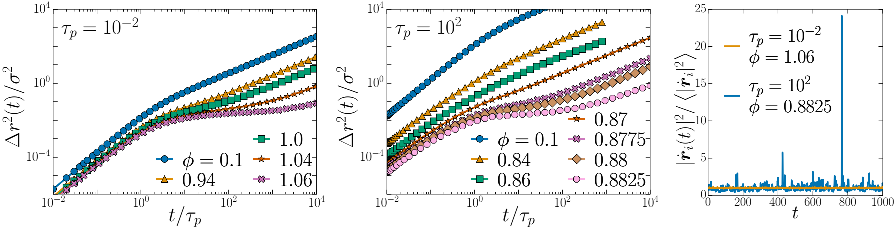
units: length $\overline{\sigma} = 1,$ time $\tau_0 = \xi\overline{\sigma}^2/\varepsilon = 1,$ energy $\varepsilon = 1$ (3)

control parameters: (D_0, τ_p, ϕ) (4)

$$\dot{\boldsymbol{r}}_i = -\nabla_i U + \boldsymbol{p}_i \tag{5}$$

$$\tau_p \dot{\boldsymbol{p}}_i = -\boldsymbol{p}_i + \sqrt{2D_0}\boldsymbol{\eta}_i \tag{6}$$

$$\Delta r^2(t) = \left\langle |\boldsymbol{r}_i(t) - \boldsymbol{r}_i(0)|^2 \right\rangle \tag{7}$$



[YEK, Jack, Berthier, 2022]

- Both small ($\tau_p \ll \tau_0$) and large ($\tau_p \gg \tau_0$) persistence systems exhibit two-step relaxation scenario as packing fraction ϕ increases.
- Velocity variance drops ($\langle|\dot{\boldsymbol{r}}_i|^2\rangle \ll \langle|\boldsymbol{p}_i|^2\rangle$) indicating the system is close to force balance.
- Instantaneous kinetic energy shows hints of intermittent behaviour.

$$t' = t/\tau_p \tag{8}$$

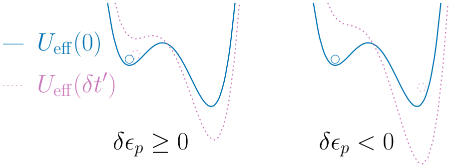
$$\frac{1}{\cancel{\tau_p}} \frac{\mathrm{d}\cancel{\boldsymbol{r}_i}}{\mathrm{d}t'} = -\nabla_i \left(U - \sum_j \boldsymbol{r}_j \cdot \boldsymbol{p}_j \right) \tag{9}$$

$$\frac{\mathrm{d}\boldsymbol{p}_i}{\mathrm{d}t'} = -\boldsymbol{p}_i + \sqrt{2D_0/\tau_p}\boldsymbol{\eta}'_i \tag{10}$$

$$t' = t/\tau_p \tag{8}$$

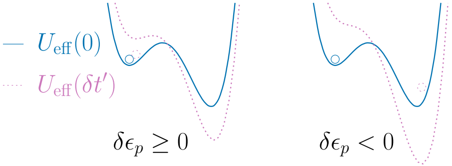
$$0 = -\nabla_i U_{\text{eff}}[\boldsymbol{r}_j, \boldsymbol{p}_j] \tag{9}$$

$$\frac{\mathrm{d}\boldsymbol{p}_i}{\mathrm{d}t'} = -\boldsymbol{p}_i + \sqrt{2f}\boldsymbol{\eta}'_i \tag{10}$$

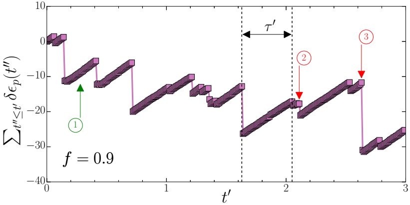


[YEK, Mandal, *et al.*, 2022]

$$t' = t/\tau_p \quad (8)$$
$$0 = -\nabla_i U_{\text{eff}}[\boldsymbol{r}_j, \boldsymbol{p}_j] \quad (9)$$
$$\frac{\mathrm{d}\boldsymbol{p}_i}{\mathrm{d}t'} = -\boldsymbol{p}_i + \sqrt{2f}\boldsymbol{\eta}'_i \quad (10)$$



[YEK, Mandal, *et al.*, 2022]

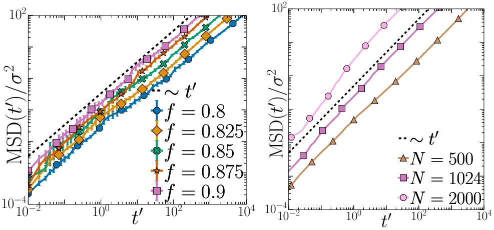


- Intermittent dynamics similar to AQS [Maloney, Lemaître, 2006] and AQRD [Morse *et al.*, 2021] without deformation of the system.
- Propulsions forces are updated quasistatically similary to AQRF [Morse *et al.*, 2021], however this update is stochastic and the system supports an isotropic dynamical steady state.

$$0 = -\nabla_i U_{\text{eff}}[\boldsymbol{r}_j, \boldsymbol{p}_i] \tag{11}$$

$$\frac{\mathrm{d}\boldsymbol{p}_i}{\mathrm{d}t'} = -\boldsymbol{p}_i + \sqrt{2f}\boldsymbol{\eta}'_i \tag{12}$$

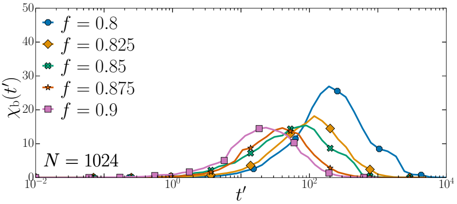
$$\Delta r^2(t) = \left\langle |\boldsymbol{r}_i(t) - \boldsymbol{r}_i(0)|^2 \right\rangle \tag{13}$$



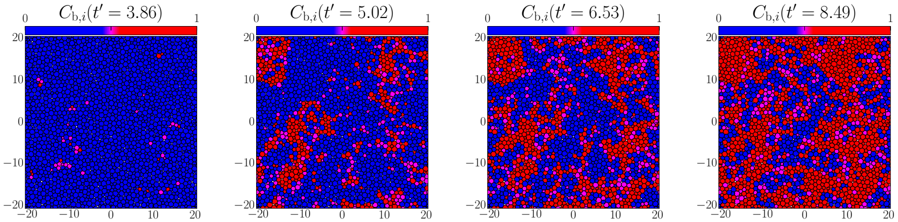
- Dynamics is diffusive at small and large times.
- Dynamics speeds up with increasing N: there are more frequent and larger plastic events.

$$0 = -\nabla_i U_{\mathrm{eff}}[\boldsymbol{r}_j, \boldsymbol{p}_i] \quad (14)$$

$$\chi_b(t') = \mathrm{Var}(\text{fraction of } \textit{initially close} \text{ particles } \textit{still close} \text{ at } t') \quad (15)$$

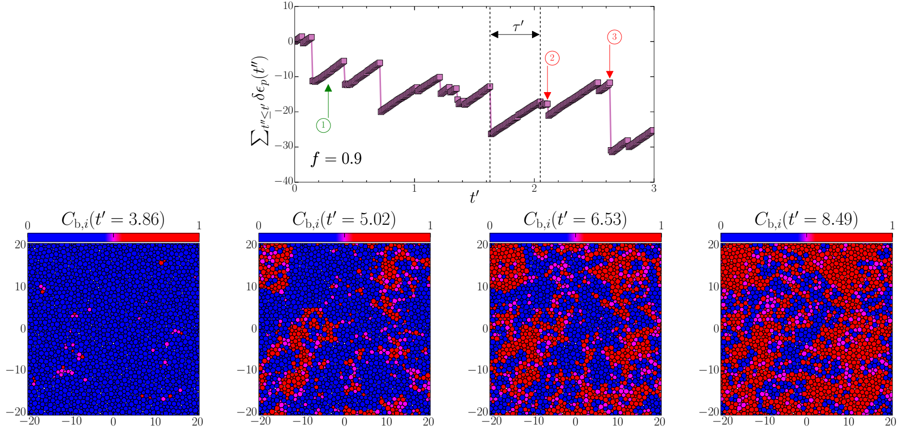


- Relaxation is slower and more heterogeneous as f is decreased.



- Structural relaxation events tend to happen in the vicinity of previous ones: dynamical facilitation?

Thank you for listening!



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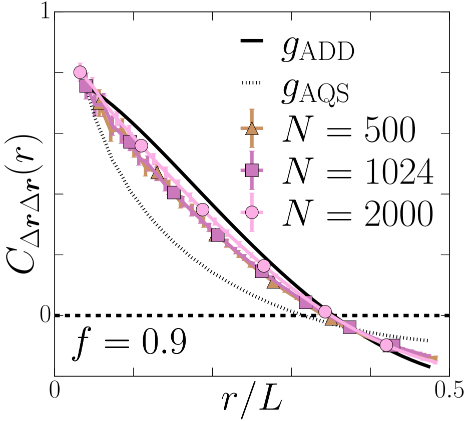
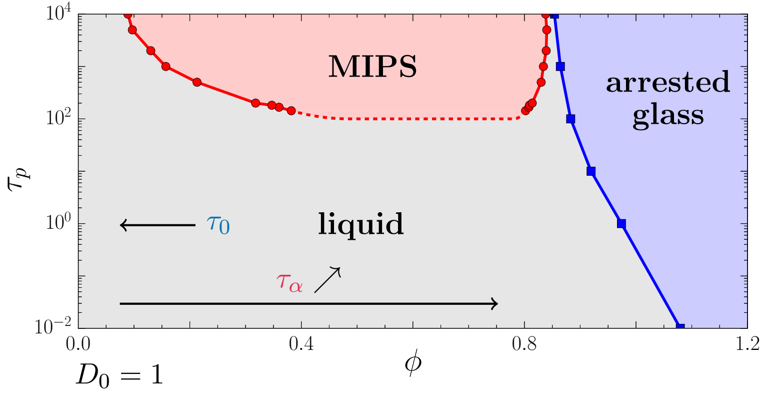
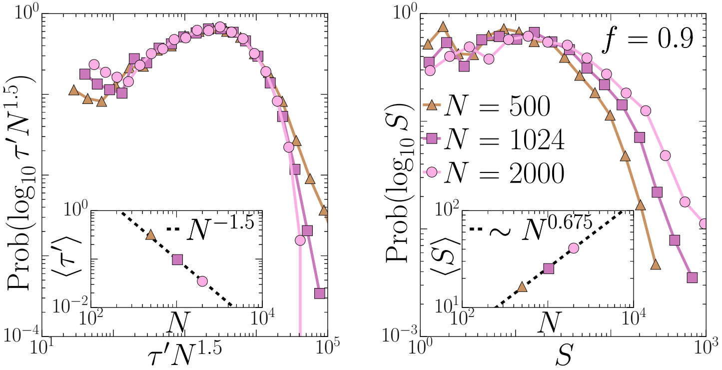
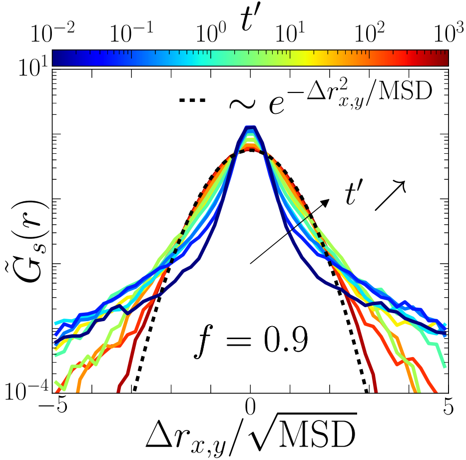
Elastic displacement correlations




10^4
10^2
10^0
10^-2
τ_p
MIPS
arrested
glass
liquid
τ_0
τ_α ↗
0.0
0.4
0.8
1.2
φ
D_0 = 1


10^0
10^{-4}
10^1
10^5
$\mathrm{Prob}(\log_{10} \tau' N^{1.5})$
$\tau' N^{1.5}$
$\langle \tau' \rangle$
$N^{-1.5}$
10^0
10^{-2}
10^2
10^4
N
10^0
10^{-3}
10^0
10^3
$\mathrm{Prob}(\log_{10} S)$
S
$f = 0.9$
$N = 500$
$N = 1024$
$N = 2000$
$\langle S \rangle$
$\sim N^{0.675}$
10^2
10^1
10^2
10^4
N

Displacement distribution



Proportion of *un*broken bonds