Defect interactions enhance colloidal motility in active turbulence

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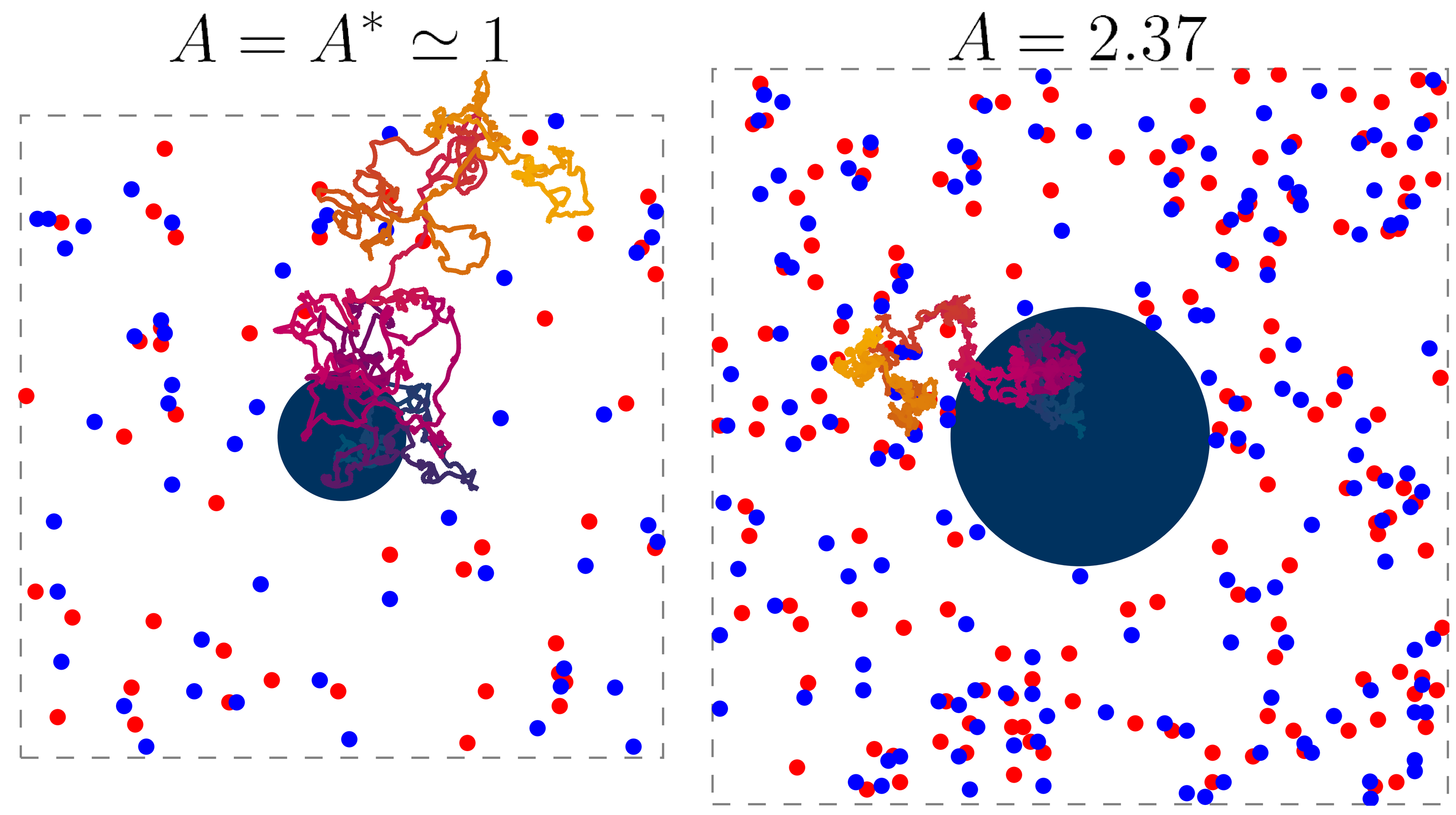


Motivation

- There has been much recent interest on the behaviour of solutes in active-nematic turbulence [1, 2], which spontaneously produce pairs of advected $-1/2$ and self-motile $+1/2$ defects.
- In passive systems ($A = 0$), strong nematic surface anchoring induces companion topological defects [3].
- The interplay between strongly anchored colloidal particles and active nematic turbulence has yet to be explored.

Solvent and solute model

- A two-dimensional extensile active-nematic solvent is simulated using AN-MPCD [4], a technique which replicates fluctuating active nematic turbulence.
- Colloidal disks are modelled as rigid boundary conditions with strong nematic surface anchoring that are free to move within the solvent [5].
- The effect of varying the colloidal radius R_C and the active length scale ℓ_α is quantified through a dimensionless activity number A, defined as

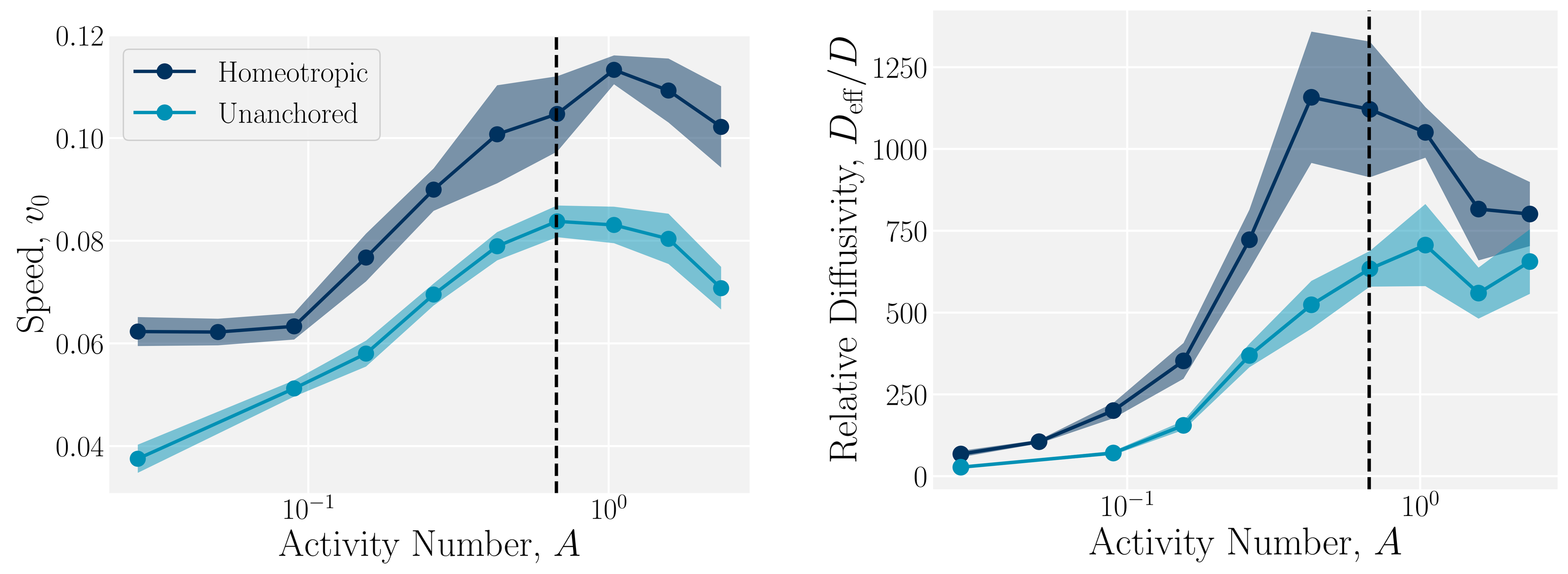
$$A = \frac{\pi R_C^2}{\pi\left({\ell_\alpha}^2 + 2R_C\ell_\alpha\right)} \sim \frac{R_C^2}{{\ell_\alpha}^2}.$$

Activity enhanced diffusion

- Differences in colloidal motility can be quantified through the mean squared displacement (MSD) $\langle \Delta r^2 \rangle$ of colloidal trajectories $\boldsymbol{r}(t)$. They can be compared through a common MSD model of self-propelled particles

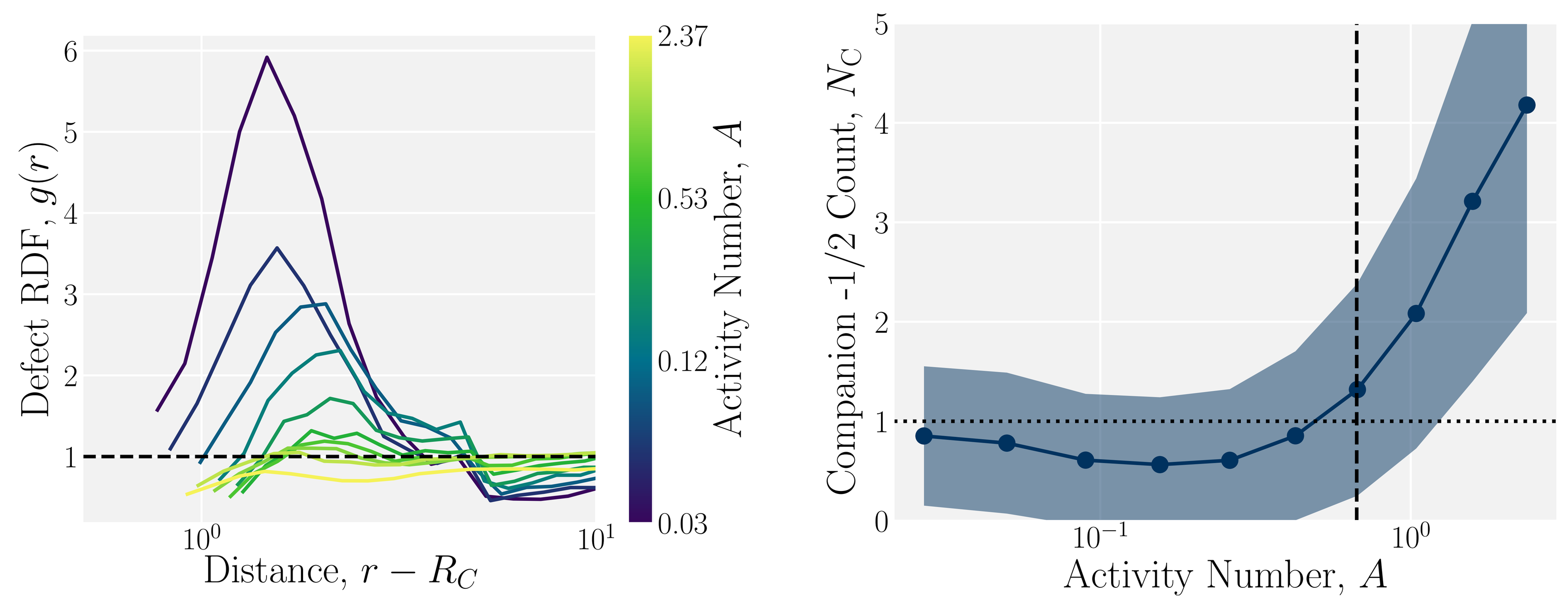
$$\langle \Delta r^2 \rangle (\delta t) = 2dD_{\text{eff}}\delta t - 2v_0^2\tau_r^2(1 - e^{-\delta t/\tau_r})\,;\; D_{\text{eff}} = D + v_0^2\tau_r/d,$$

where d is the dimensionality, D_{eff} is an effective diffusion coefficient that includes passive Brownian diffusion D, the instantaneous self-propulsion speed v_0, and the reorientation time τ_r.
- The instantaneous speed of the colloid v_0 increases with activity A, plataung for $A = A^* \simeq 0.67$. Likewise, the relative diffusion $D_{\text{eff}}/D = 1 + D_\alpha/D$ observes a similar trend, but with a local maxima at $A = A^*$.
- However, unanchored colloids exhibit smaller speeds, and do not exhibit local maxima in the effective diffusion, which is instead monotonic.



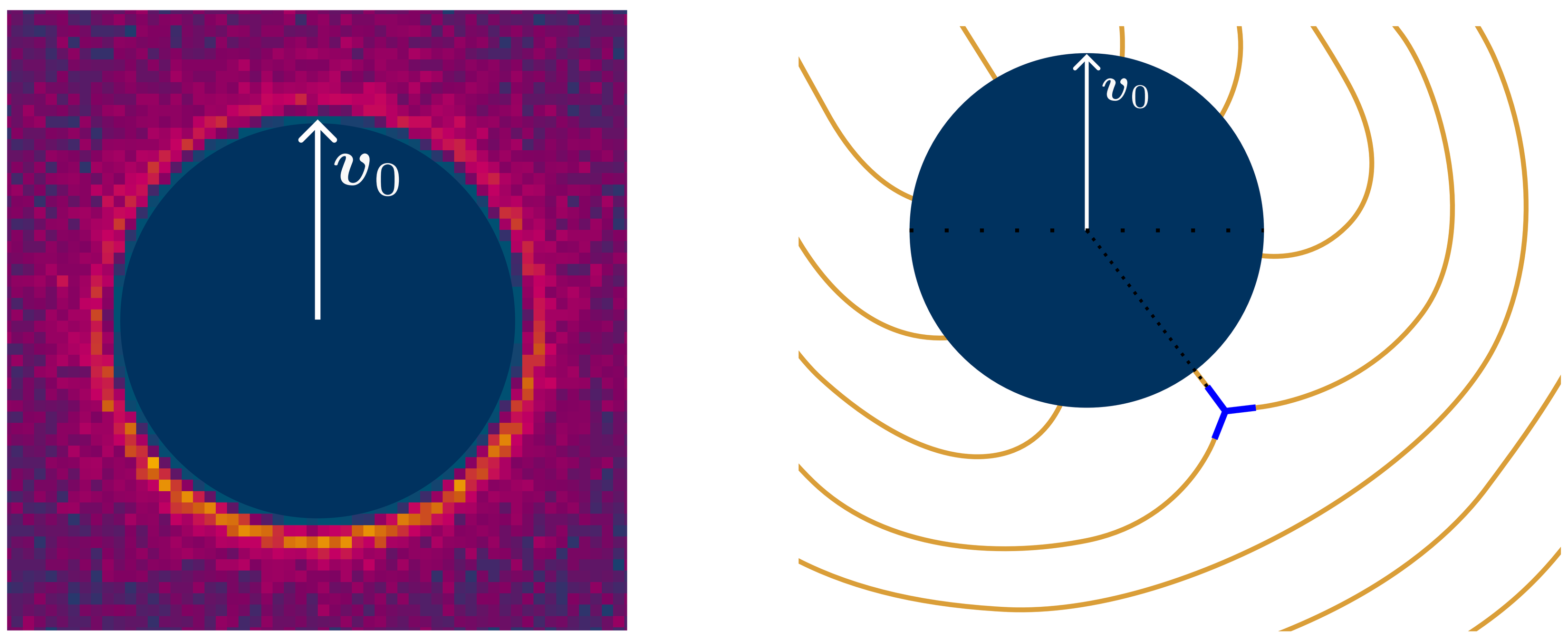
Changes in topological surroundings

- The radial distribution function (RDF) of $-1/2$ defects describes the distribution of defects around the colloid.
- At low activities, the RDF exhibits a peak at short distances, indicative of companion defects. As activity rises towards A^*, companion defects become indistinguishable, becoming more homogeneously distributed akin to a gas.
- Unlike the passive case, where there are 2 companion defects, low activities exhibit 1 companion on average. For $A \gtrsim A^*$, the number of companions rises.



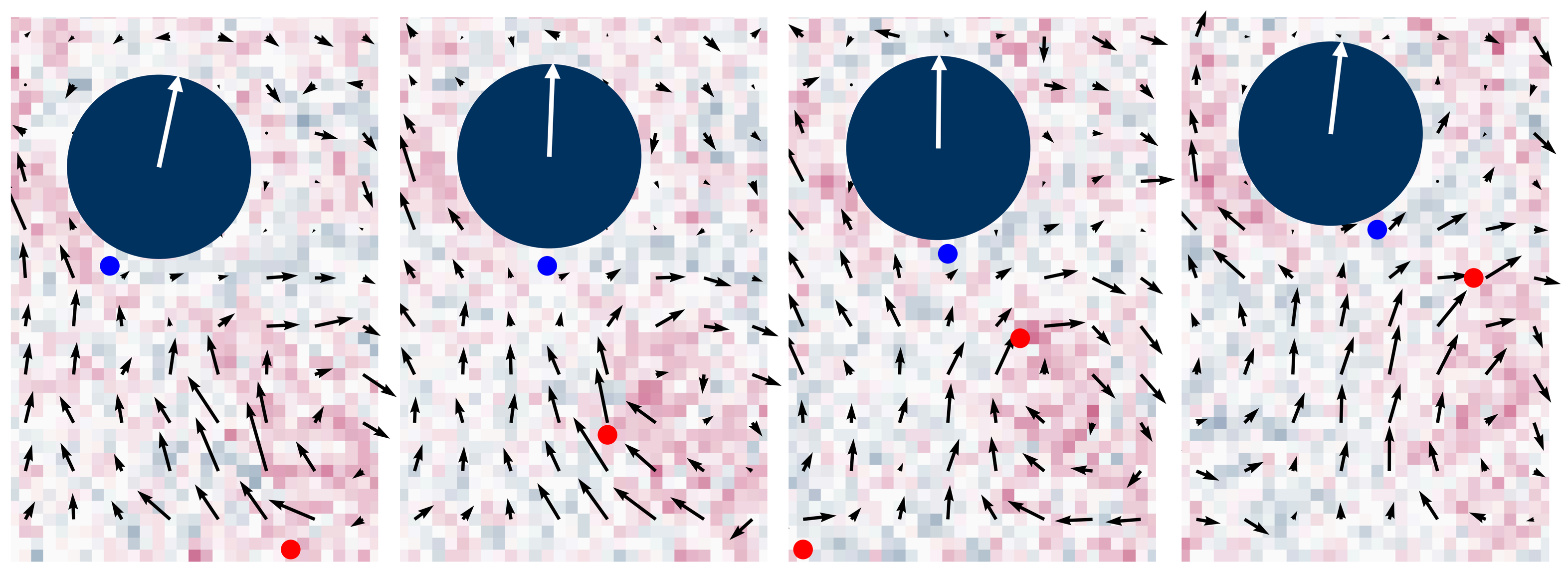
Radial symmetry breaking

- This single remaining companion defect is found to lie behind the colloid, relative to the direction of motion.
- This leaves a colloid-companion complex with an effective $+1/2$ charge, which suggests it should be self-motile.
- However, the director pattern of this complex is in the opposite direction to the colloid's motion, inconsistent with $+1/2$ defects.



Mechanism for enhanced diffusion

- Rather than the net charge of the colloid-companion complex, the enhanced motility of the colloid is attributed to the interplay between the complex and surrounding $+1/2$ defects.
- $+1/2$ defects are attracted to the remaining companion defect, but are deflected due to the elastic forces from colloidal anchoring. The resulting flow fields push the colloid-companion complex away, resulting in enhanced motility.



Conclusions and outlook

- We have revealed a novel mechanism for the enhanced motility of strongly anchored colloids in active turbulence, dependent on a dimensionless activity number that compares the colloidal radius to the active length scale.
- For low activities $A \lesssim A^*$, colloids exhibit enhanced motility and non-monotonic diffusion due to $+1/2$ defects deflected by elastic forces.
- At higher activities $A \gtrsim A^*$, the homogeneous topological surroundings of the colloid balances any net flow from incoming $+1/2$ defects, saturating ballistic speed and decreasing effective diffusion.
- This work begins to extend the rich dynamics of anchored colloidal suspensions in passive nematics to active turbulence, opening the door to using colloids as a means of manipulating and controlling defect behaviour in active systems.

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