The Dynamic of Active Materials

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UCSB 2021 Physics REU

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What are active materials?

- Active materials consume energy, therefore they self-propell
- All of biology is active matter, studying dynamics of synthetic active particles and active nematics leads to models of complex concepts in biology

Source: https://www.youtube.com/watch?v=18ZY91xSe78

Project Overview

What are the types of dynamics of active materials?

- Characterizing active materials using the mean-squared displacement and the types of motion that are already well characterized, such as Brownian and Ballistic motion

Brownian Particles

Particles that are not self-propelled and therefore move by interacting with the water particles, because of this on average their position remains the same.

Synthetic beads (2 microns) in water

Mean-squared Displacement and Power Law

Mean-squared displacement (MSD) - characterizes the dynamics of particles

- Measure of particle deviation of position w.r.t, or diffusion

$$MSD =< [x(t) - x(0)]^2 >$$

x = position

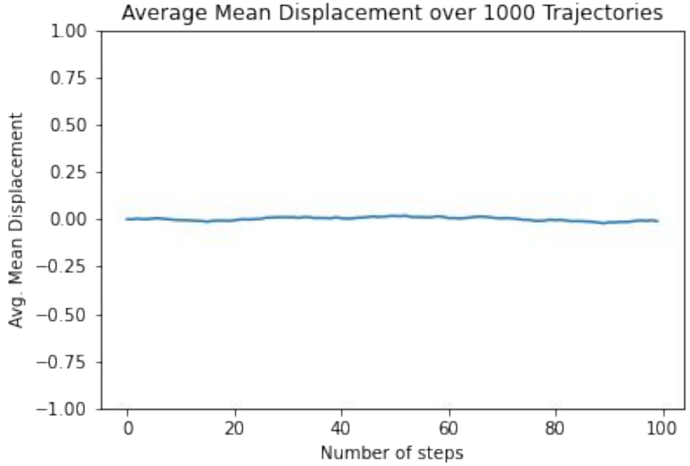
Power Law: $y = x^n$

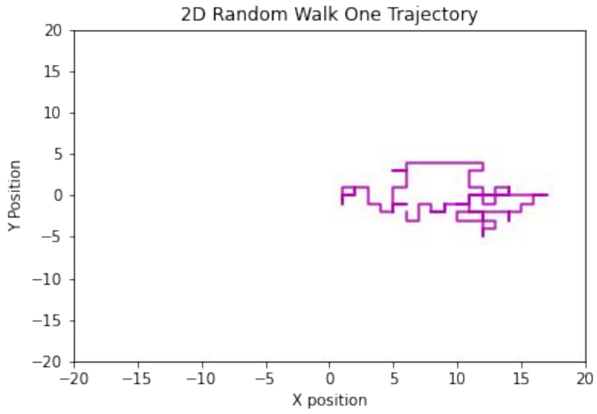
- **n** changes based on the type of motion being studied
- Mean - squared displacement as a function of the time is proportional to time to the **n** power $MSD(t) \sim t^n$
- Note:

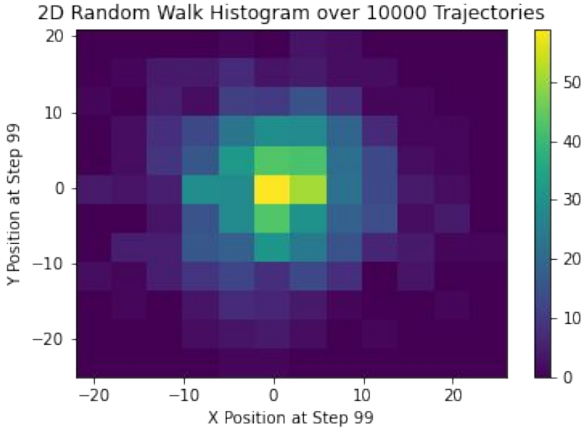
$$log(MSD) \sim nlog(t)$$

Random Walks

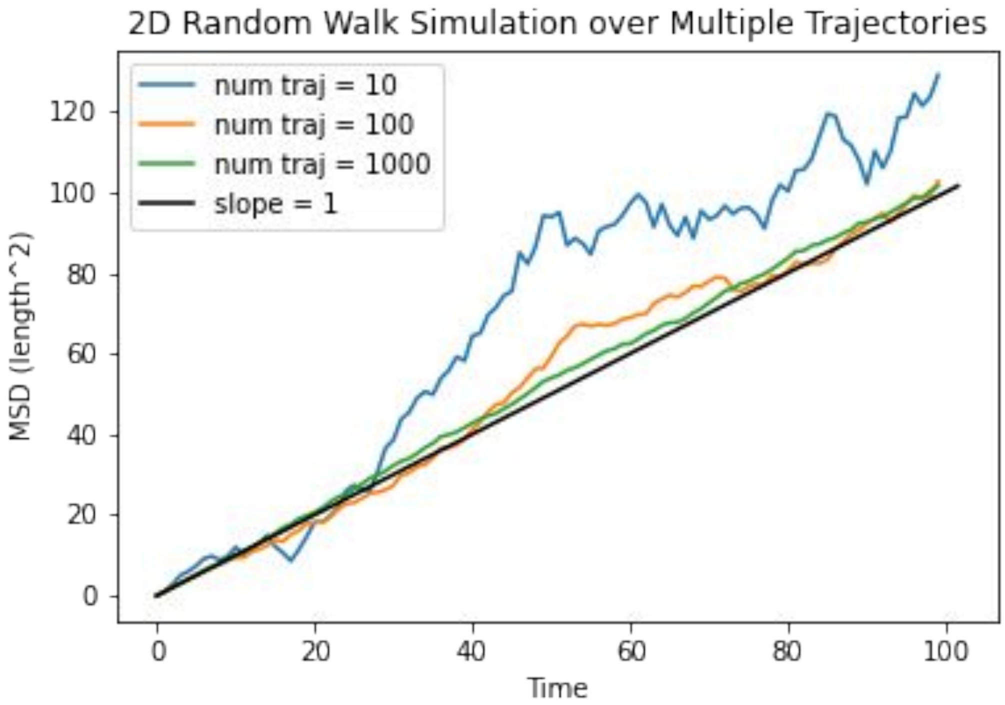
Random walk - random movement of a particle from an origin







MSD of Random Walk over 10, 100, and 1000 trajectories

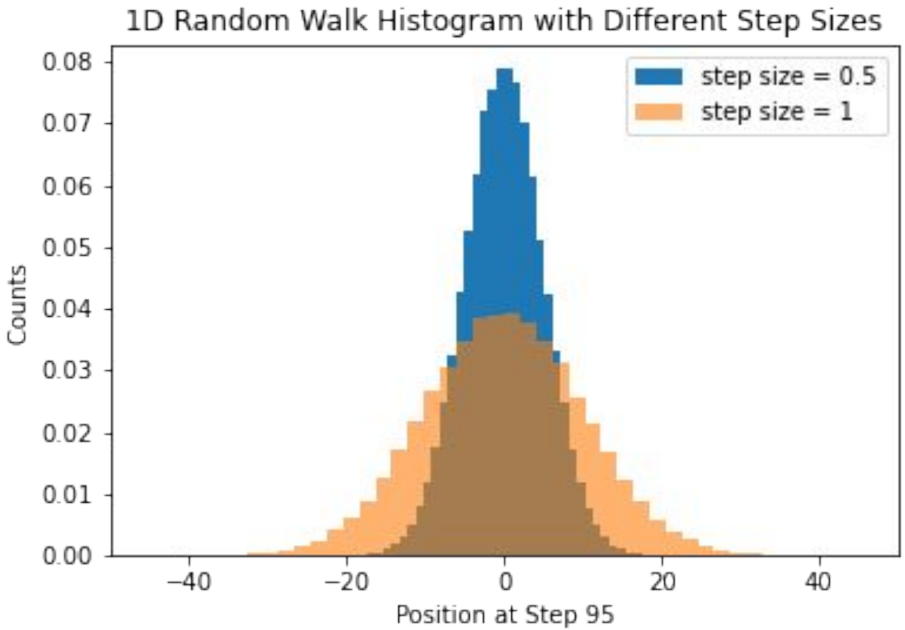


$$MSD(t) \sim t^n$$

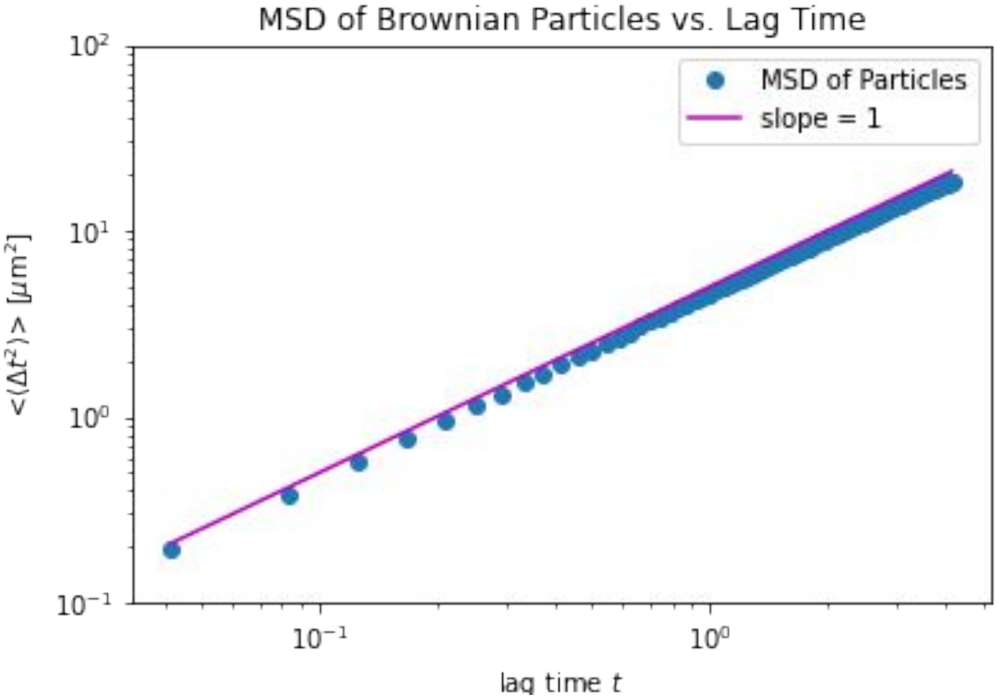
n= 1

Altering Step-size in the Random Walk

- The size of the step affects how dramatic the walkers fluctuations around zero are and the standard deviation
- **Standard deviation** is the width of the peak



MSD of Brownian Motion

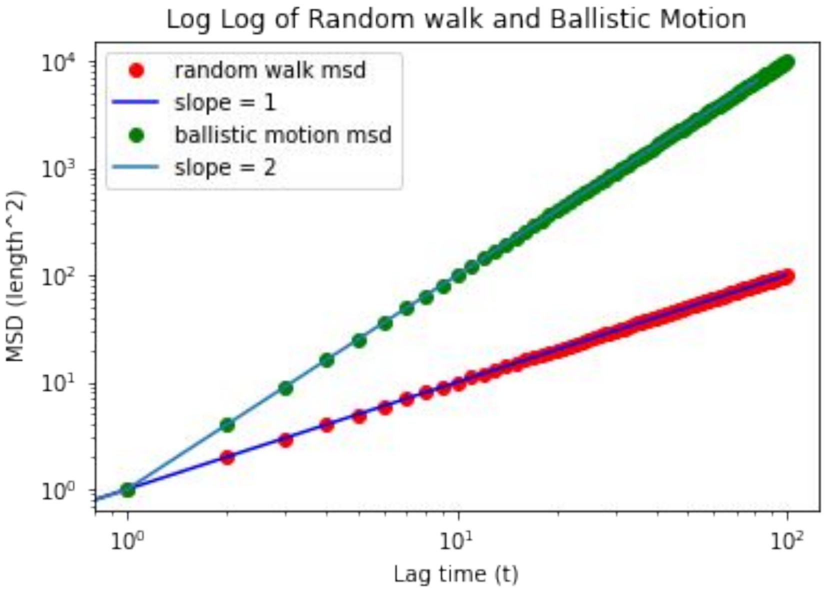


$$MSD(t) \sim t^n$$

n= 1

Ballistic Motion

- The ability to only move in a forward direction



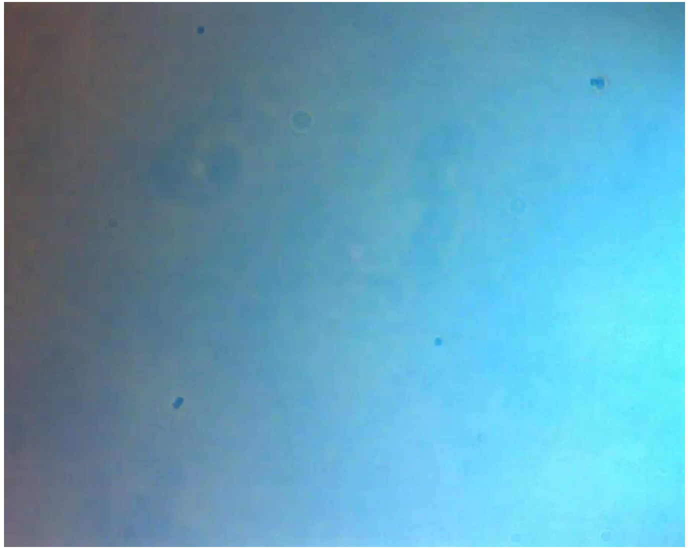
$$MSD(t) \sim t^n$$

$$log(MSD) \sim nlog(t)$$

n= 2

Active Particles

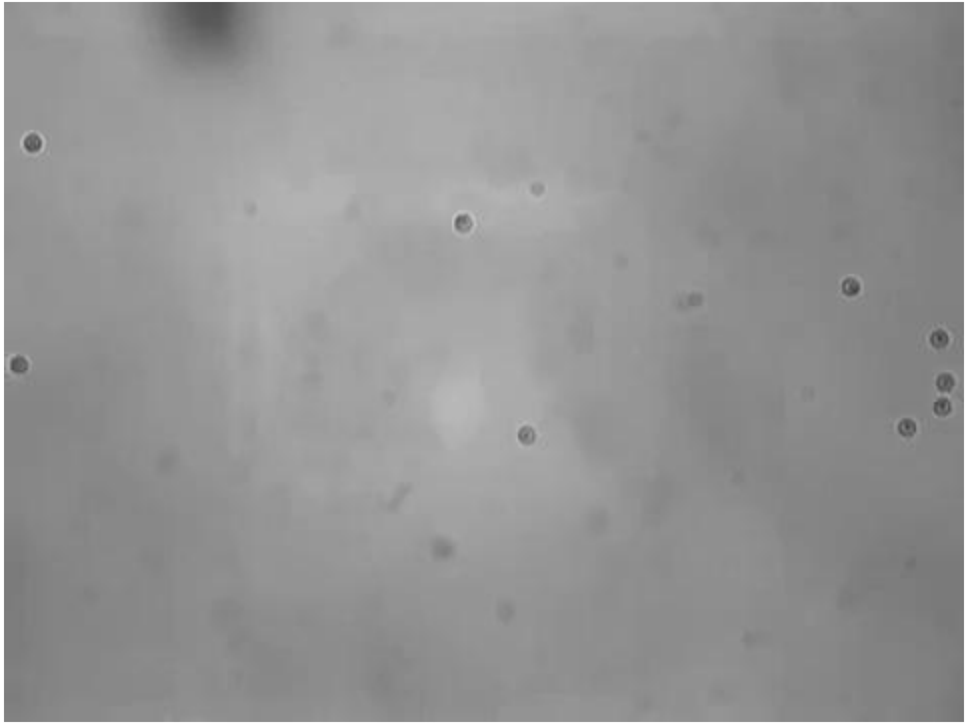
- Particles that consume energy and are able to self-propel.



Synthetic janus particle in water

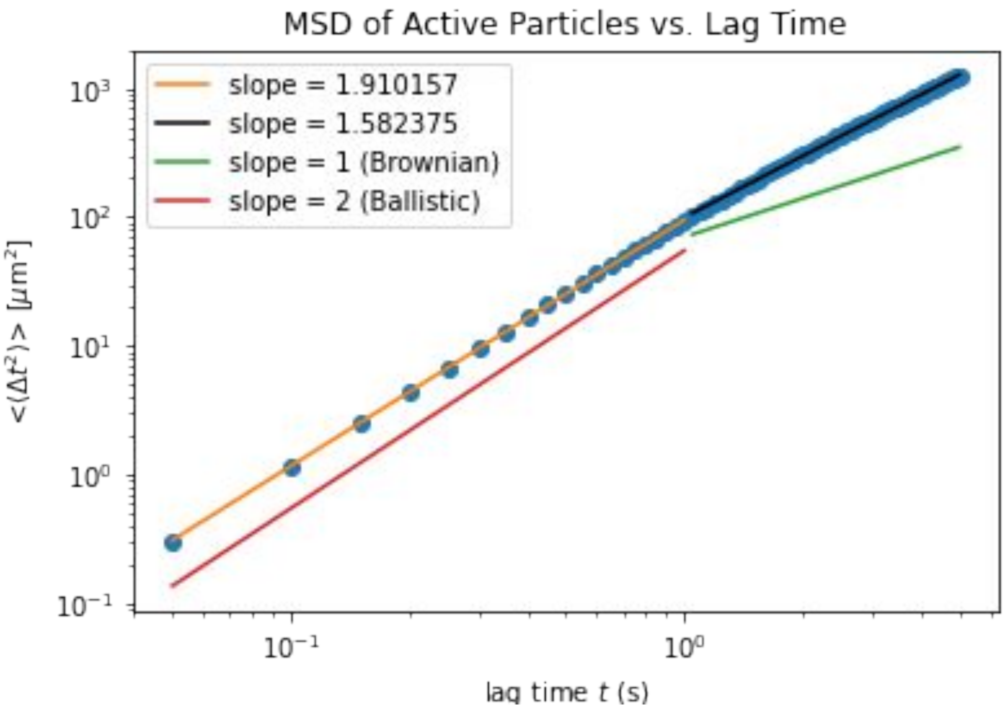
E.coli bacteria

Brownian vs. Active particles



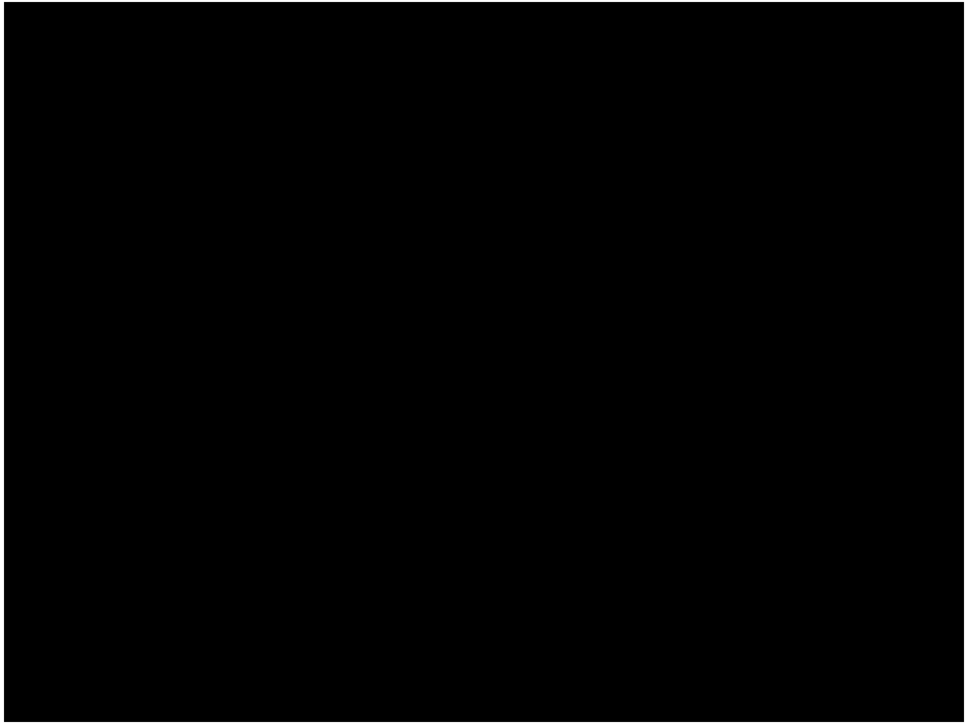
Palacci, J.et al, 2013, Science

MSD of Active Particles



$$MSD(t) \sim t^n$$
$$log(MSD) \sim nlog(t)$$

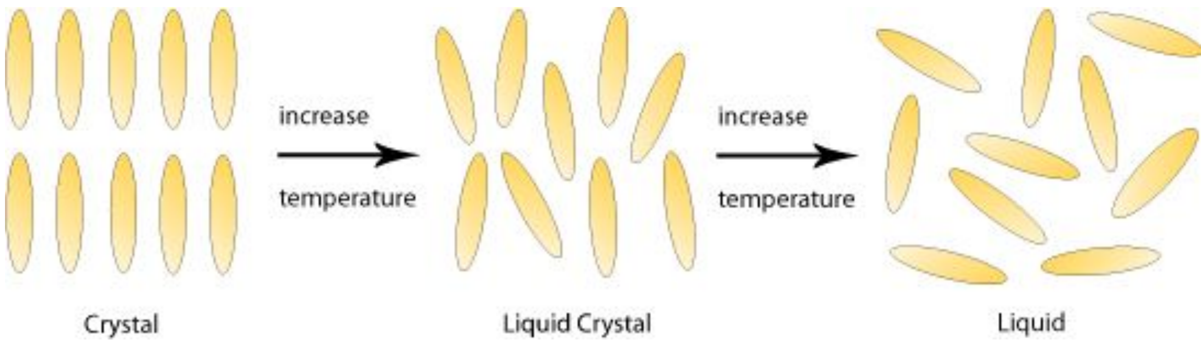
Active Nematics



2D microtubule bundles

What is a liquid crystal?

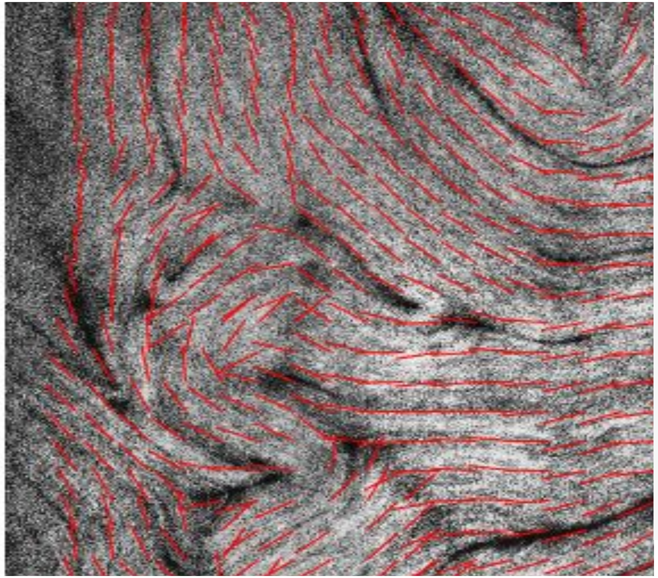
Different state of matter (phase) where molecules aren't fixed, like in a liquid, but a small portion of orientational order remains.



Source:https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.doitpoms.ac.uk%2Ftlplib%2Fliquid_crystals%2Fintro.php&psig=AOvVaw3FRCzj_f4o2srvo2ywscQo&ust=1628625985333000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCIDmmN3epPICFQAAAAAdAAAAABAD

Nematics, Director Fields, and Defects

- The term ***nematic*** liquid crystals denotes that there is an nematic order in microtubules.
- Director fields the collective alignments of the rods
- Defects are points of discontinuity in nematics where, the direction of the microtubules changes abruptly



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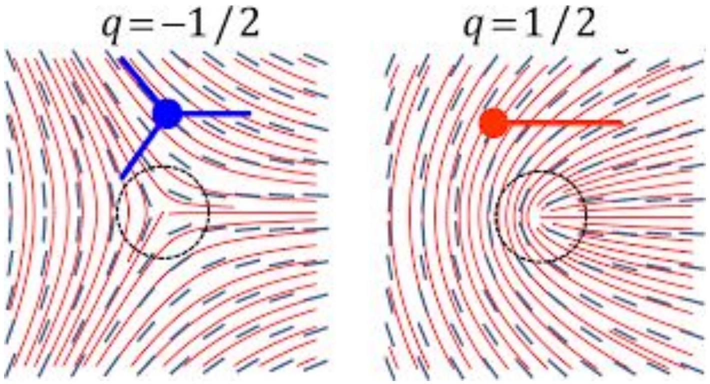
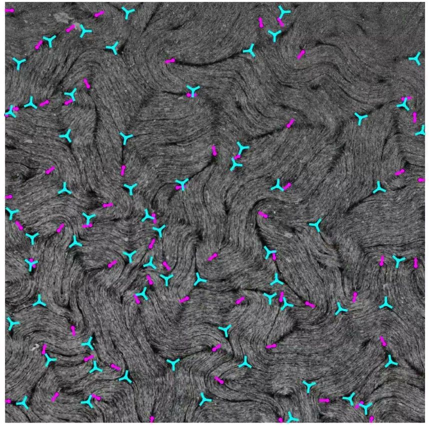
Active Nematics

- Active sliding between microtubules in the nematics
- ½ represents ordering along the director field





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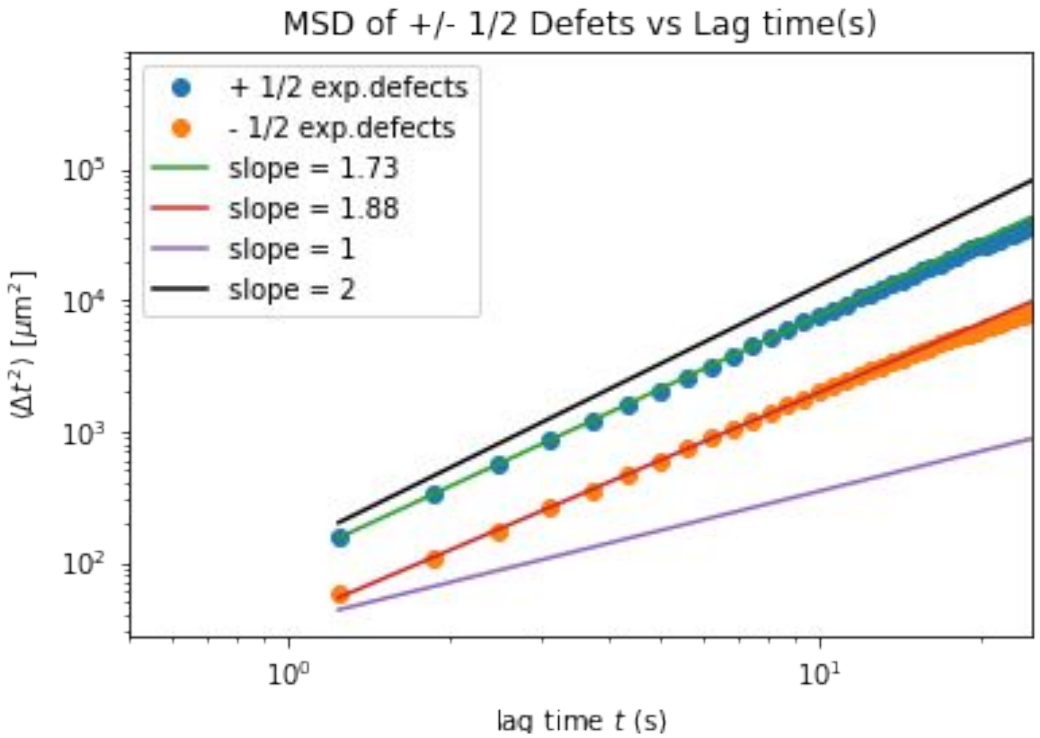
MSD +/- ½ Defects



$$MSD(t) \sim t^n$$
$$log(MSD) \sim nlog(t)$$

Conclusions

- The slope of the MSD for Brownian motion is 1, while for ballistic motion it is 2
- Active particles are moving in a more ballistic motion at short timescales, and as time increases their motion is more similar to Brownian motion
- Unable to track nematic defects over long timescales, so we have to observe the positive and negative ½ defects at short timescales

Future Work

- Creating a simple model for motion of defects
- Tracking defects over longer timescales

Acknowledgements

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