Tumbling and Spinning of Anisotropic Flat Particles

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BIRS Microplastic Workshop
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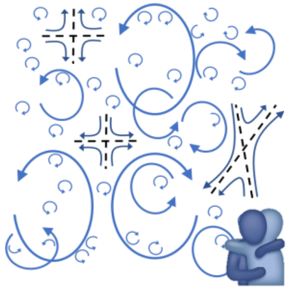
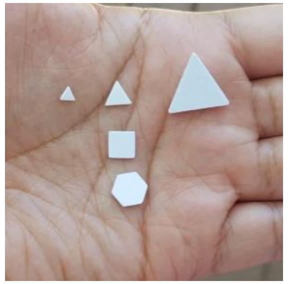
Berkeley Engineering

Outline



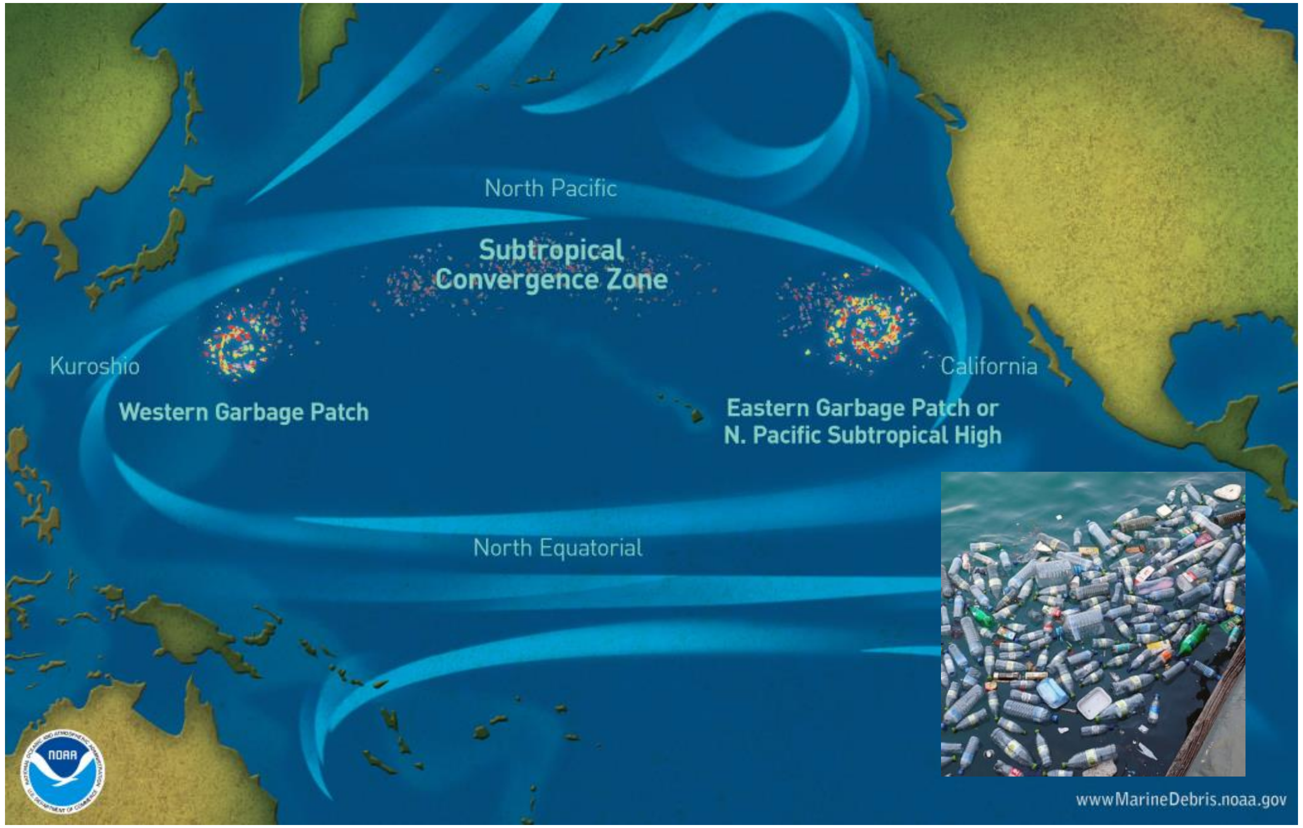


background and motivation

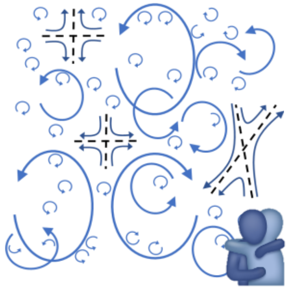
turbulence and movement

future questions

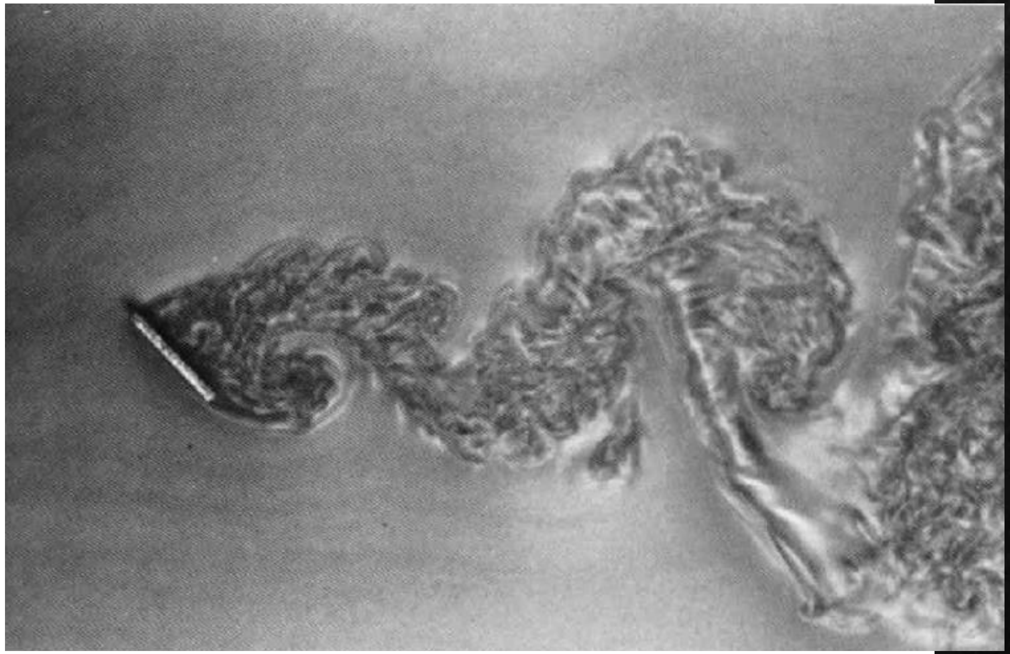
Particle transport in turbulence is an open question

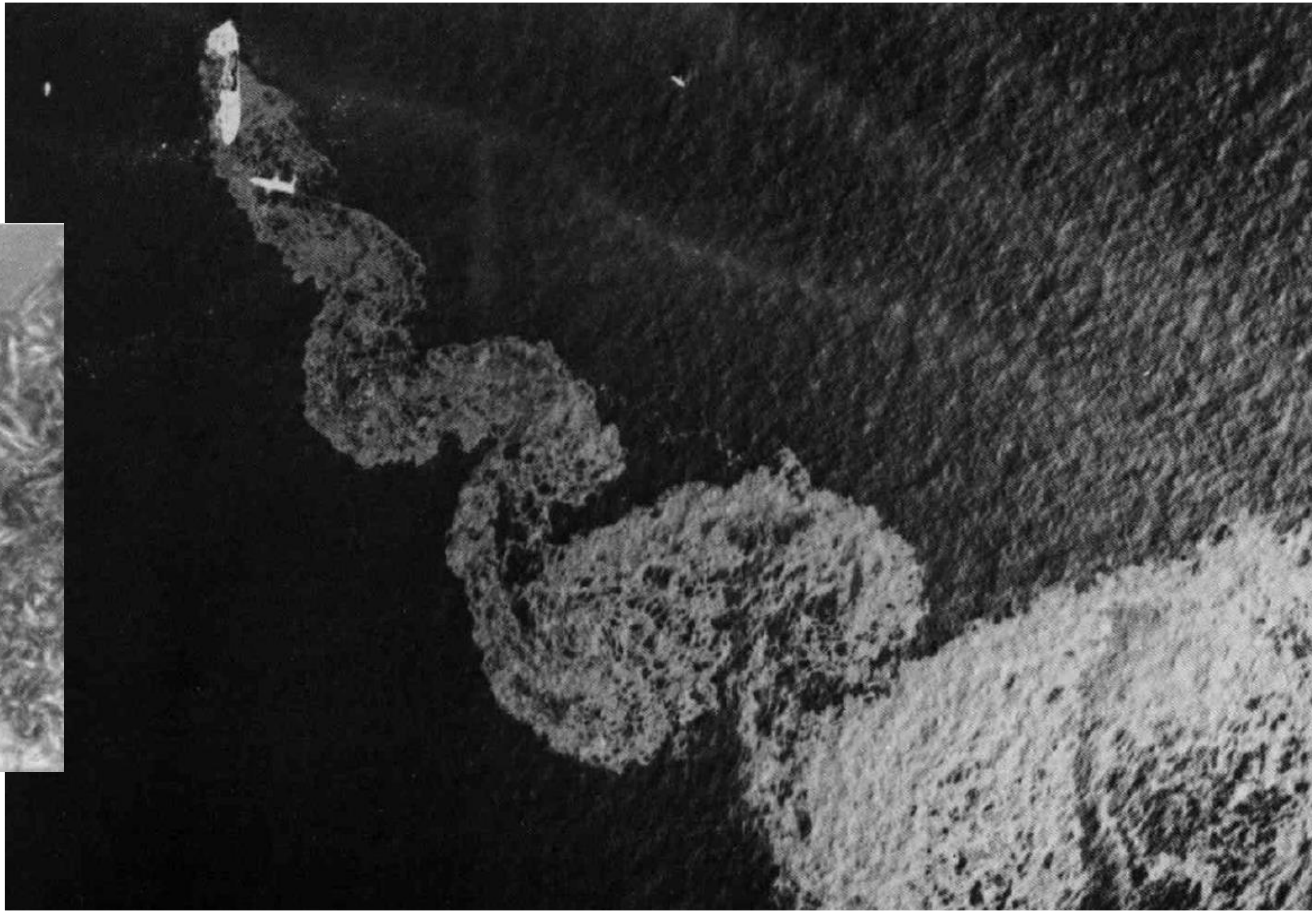


Background

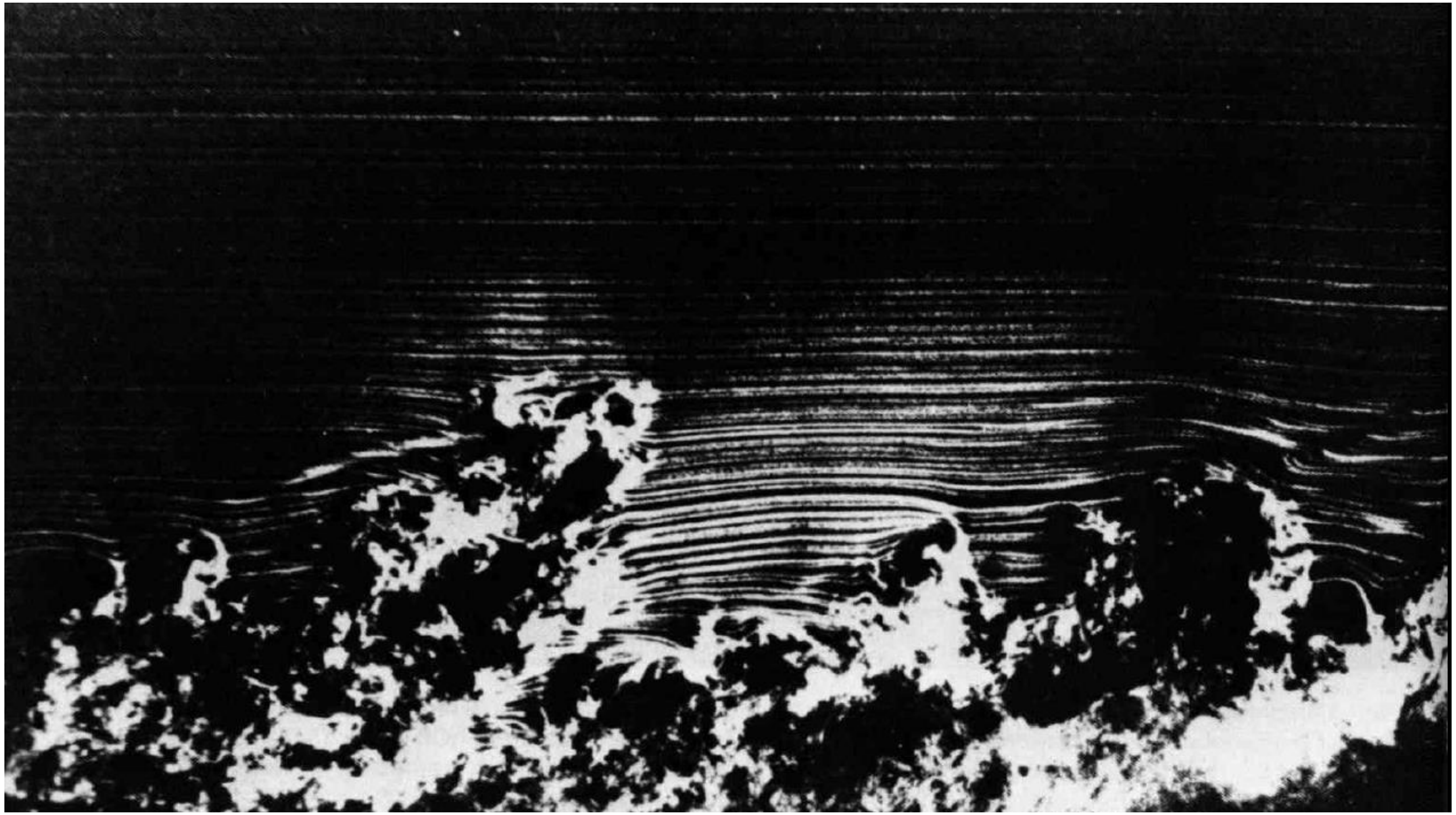


Turbulence is chaotic flow with universal properties

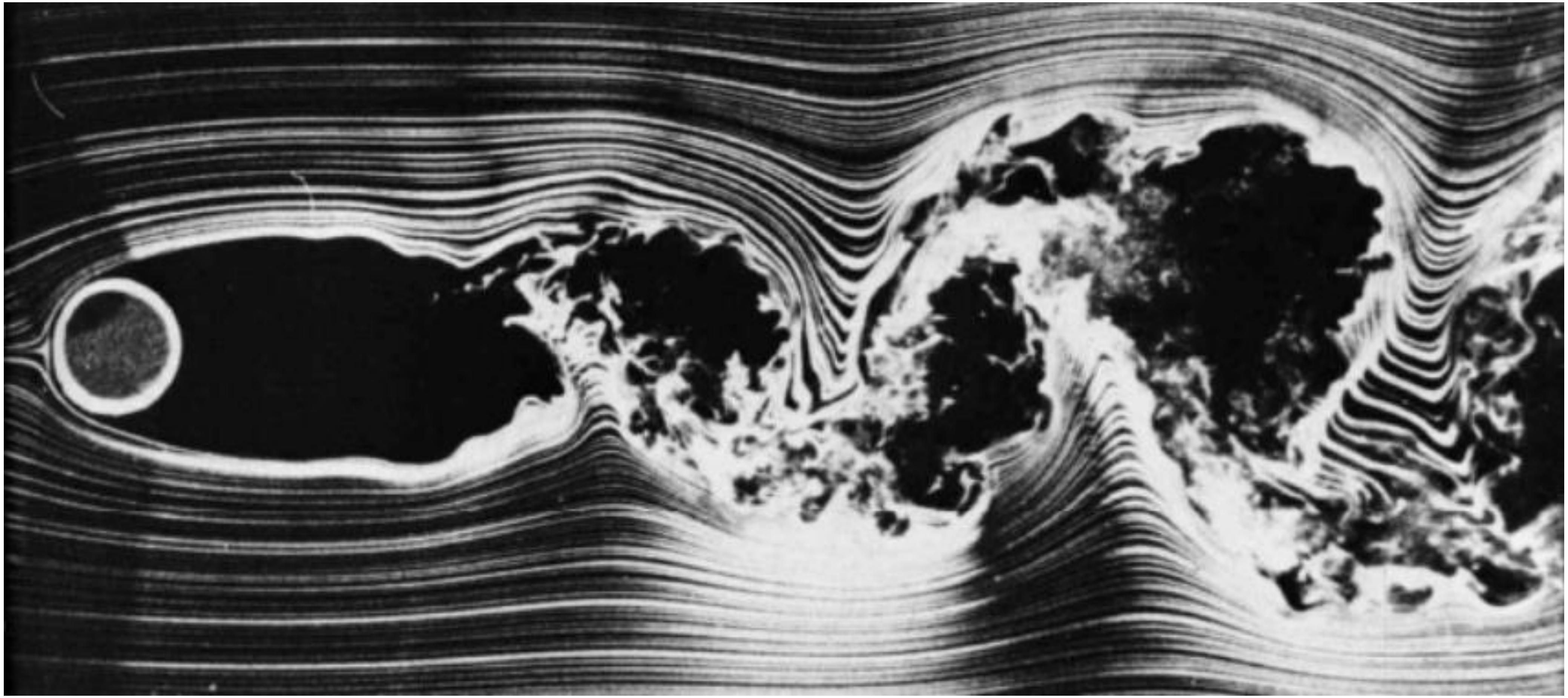




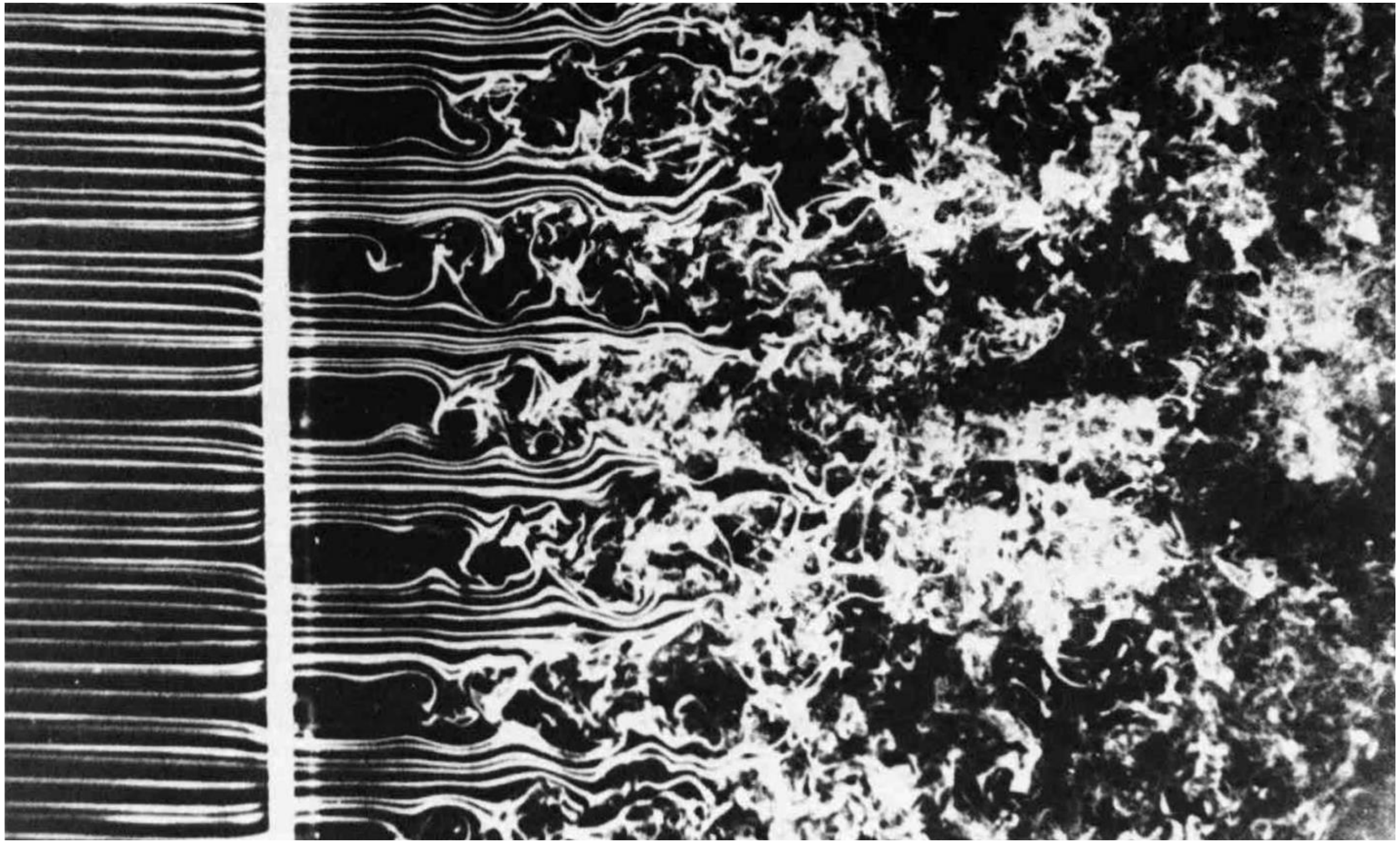
Turbulence is rarely homogeneous (translation invariant) or isotropic (rotation invariant)



The multiscale chaos of turbulence is superimposed on the geometry of the original flow and instability



Special laboratory equipment can make homogeneous, isotropic turbulence



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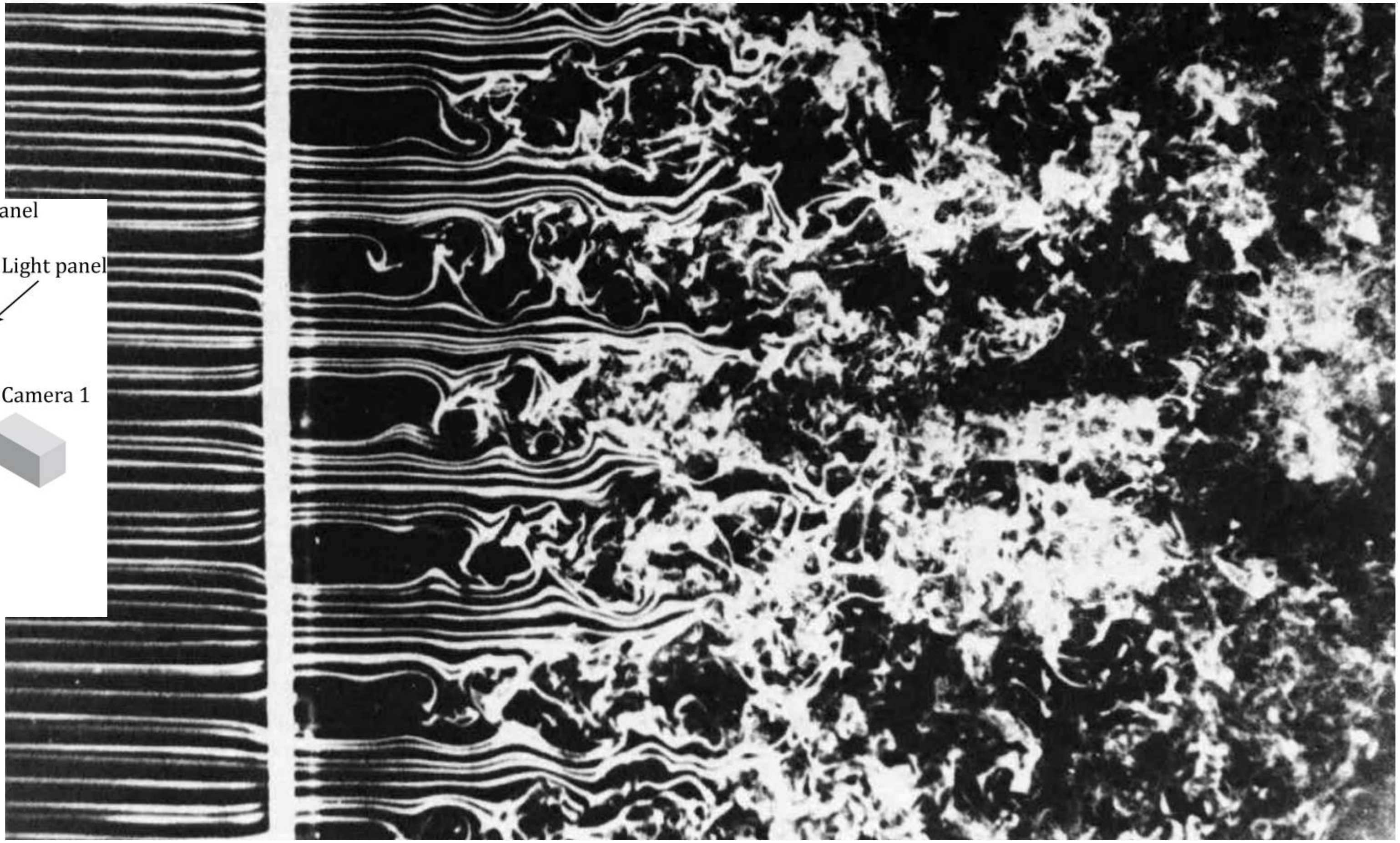
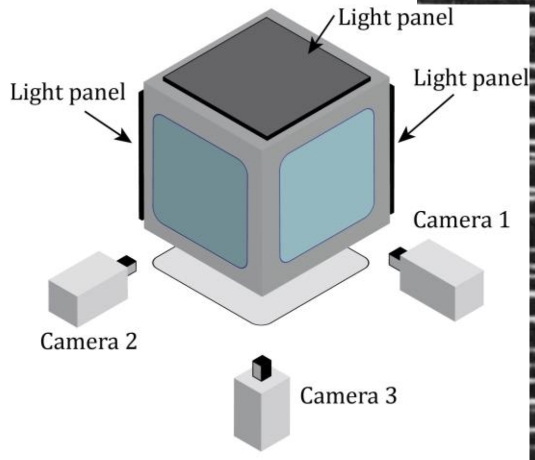
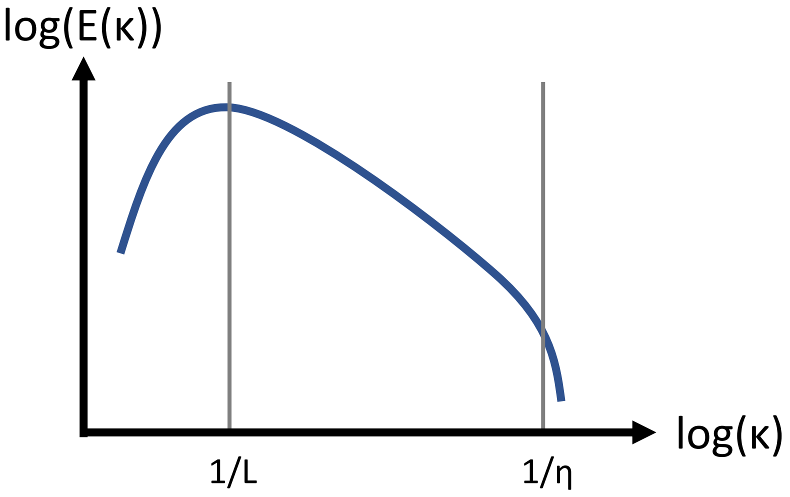




Turbulent Length Scales



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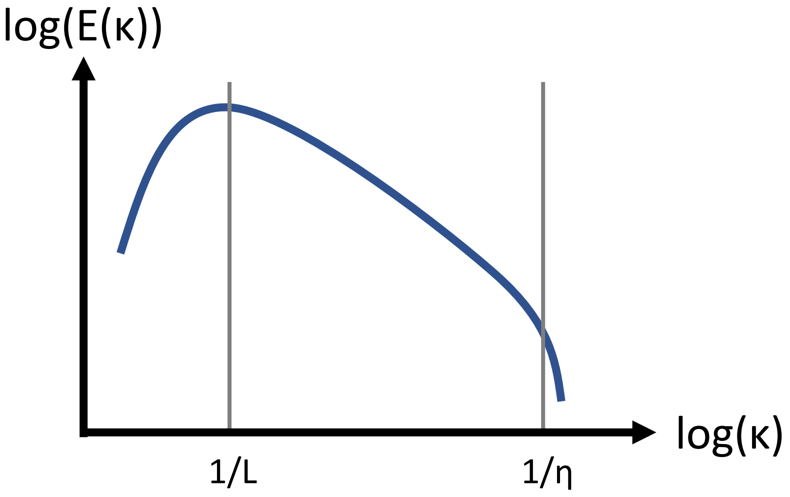
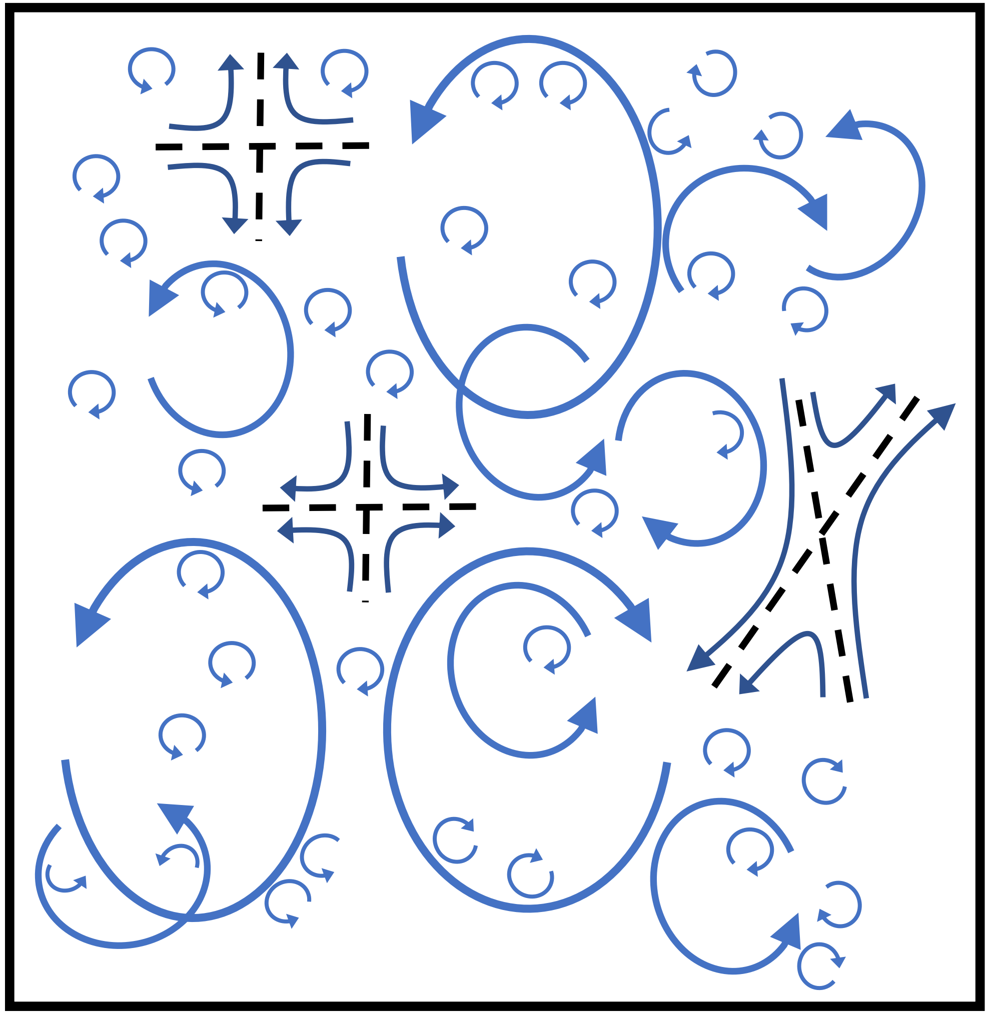
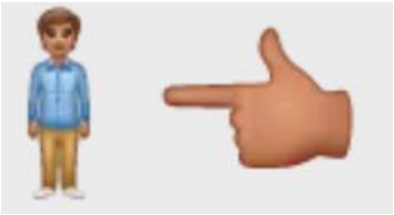
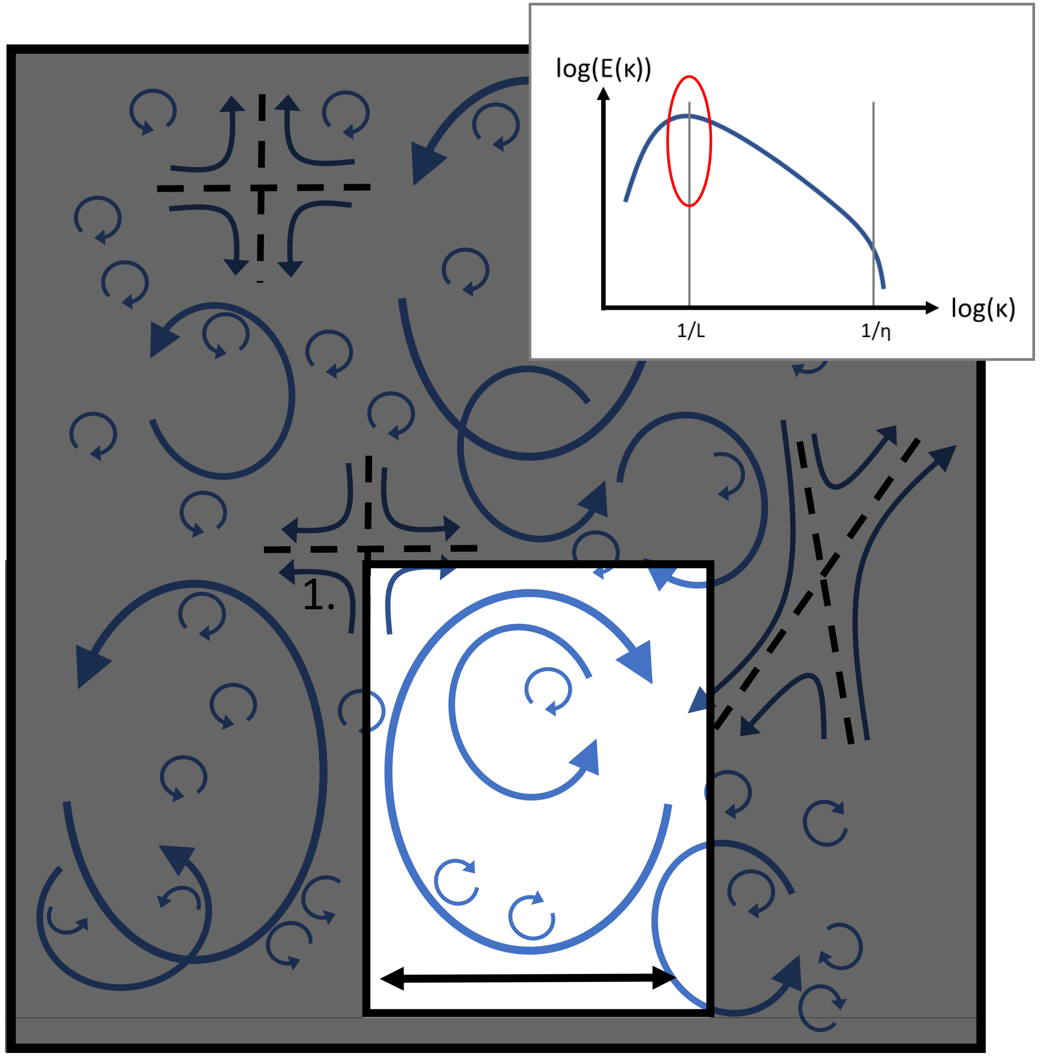




Turbulent Length Scales

1. Integral scale
   - Largest eddy





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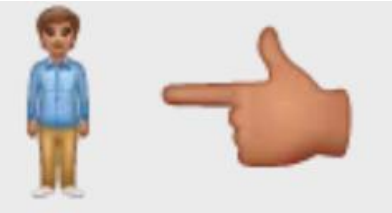
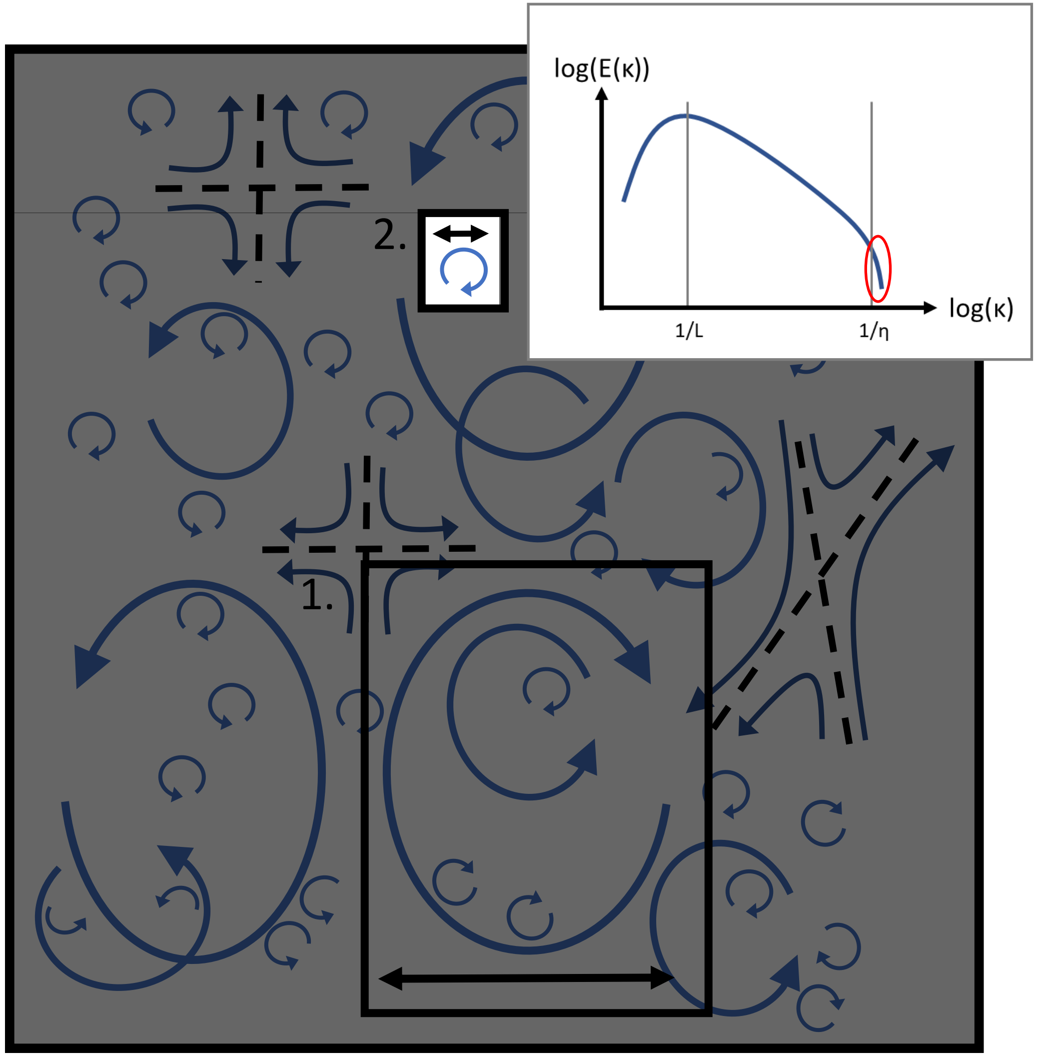


2. Small scale
    - Passive tracers



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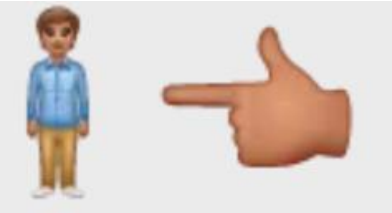
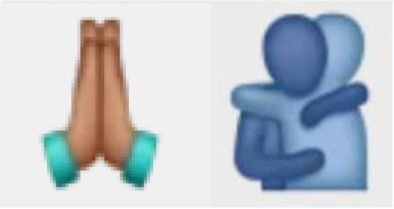
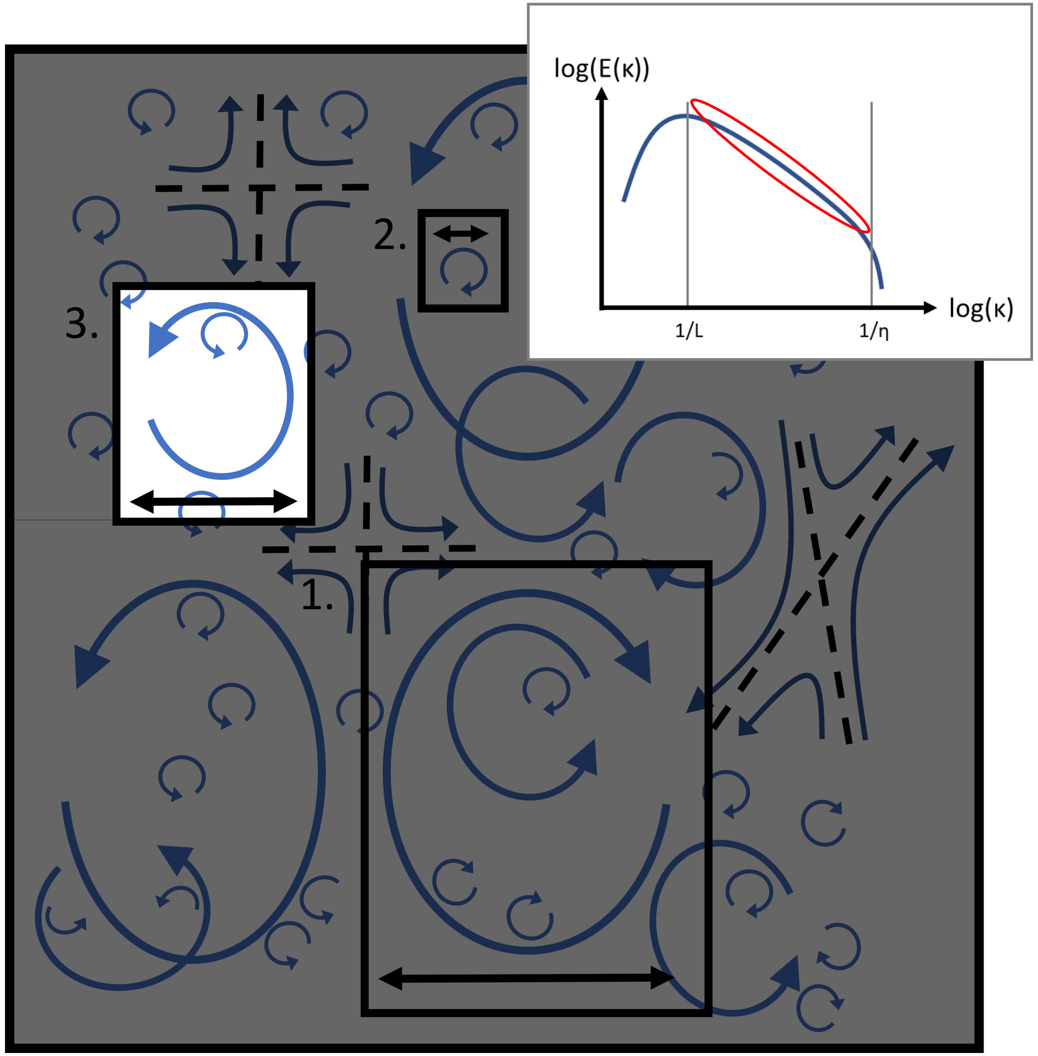


2. Small scale
   - Passive tracers

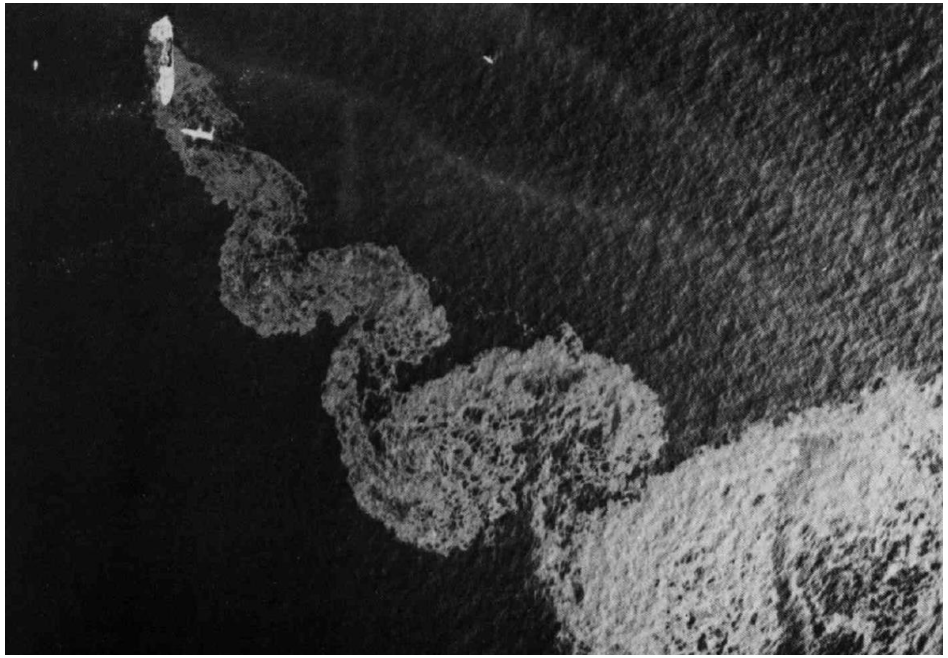
3. Taylor microscale
   - Difficult to model particles numerically





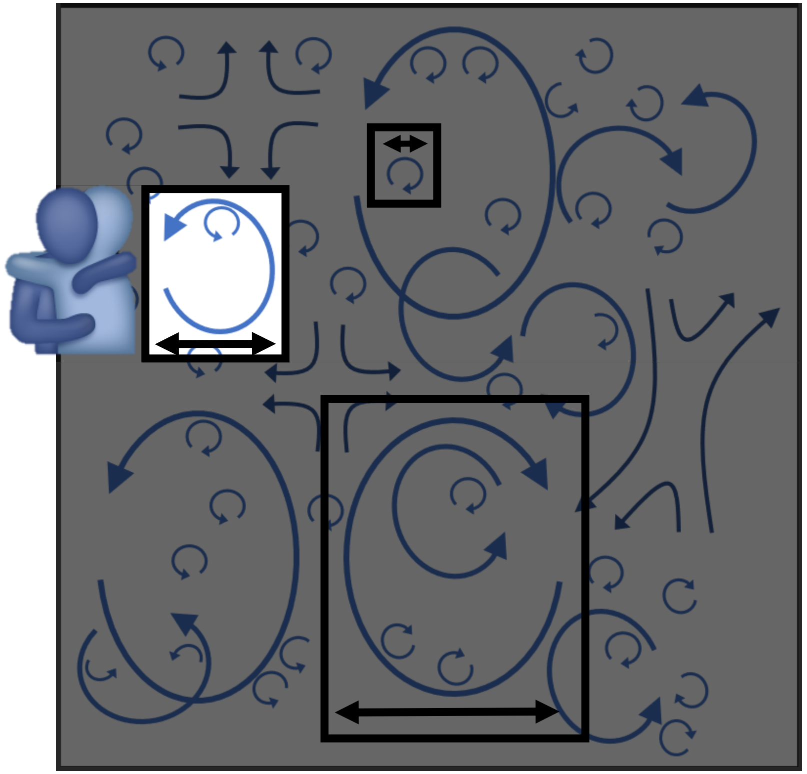
Turbulence makes these projects interesting and difficult

Turbulence

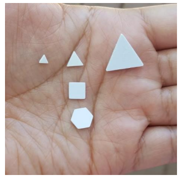


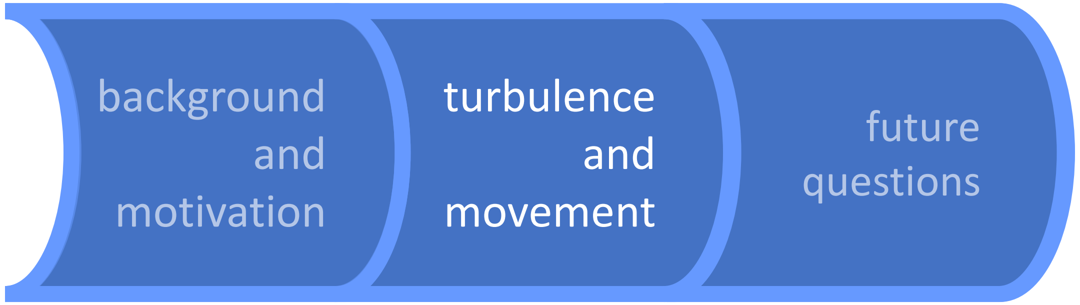
chaotic flow with universal properties

Scale



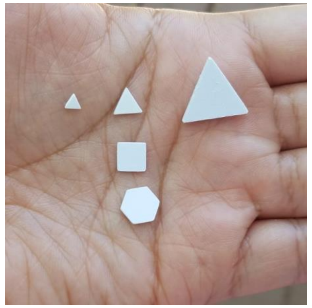
Particle Rotation





Neutrally buoyant flat particles in five different shapes and sizes were tested in the flow

Shape	Small d=5mm	Medium d=10mm	Large d=20mm
Triangle	✓	✓	✓
Square		✓	
Hexagon		✓	



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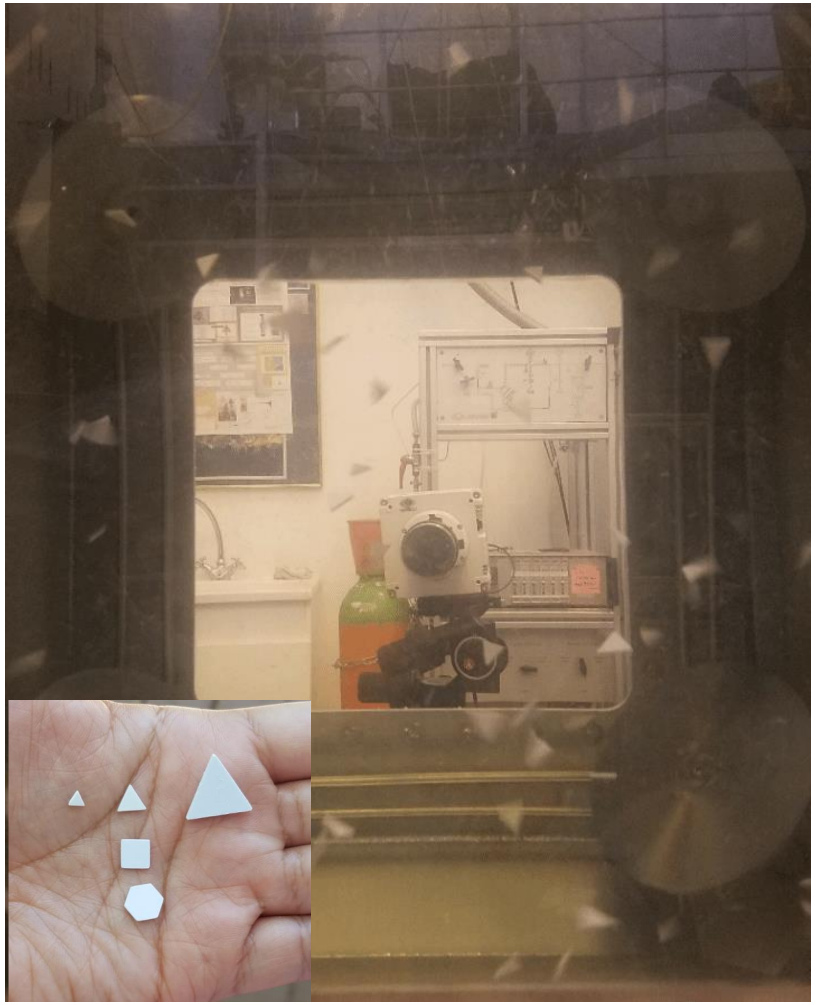
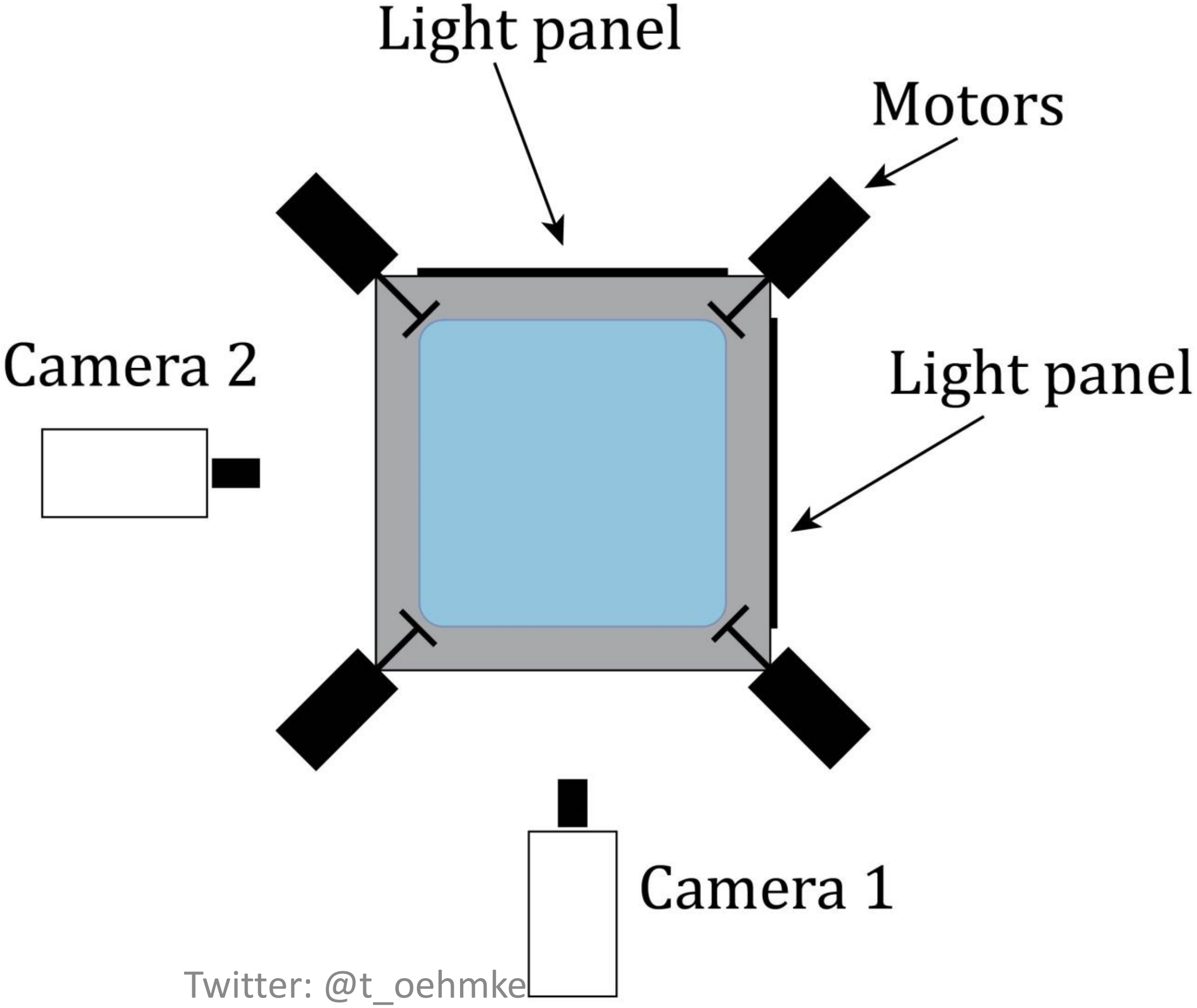


3 cameras were used to capture orthogonal images while motors were rotated in alternating directions



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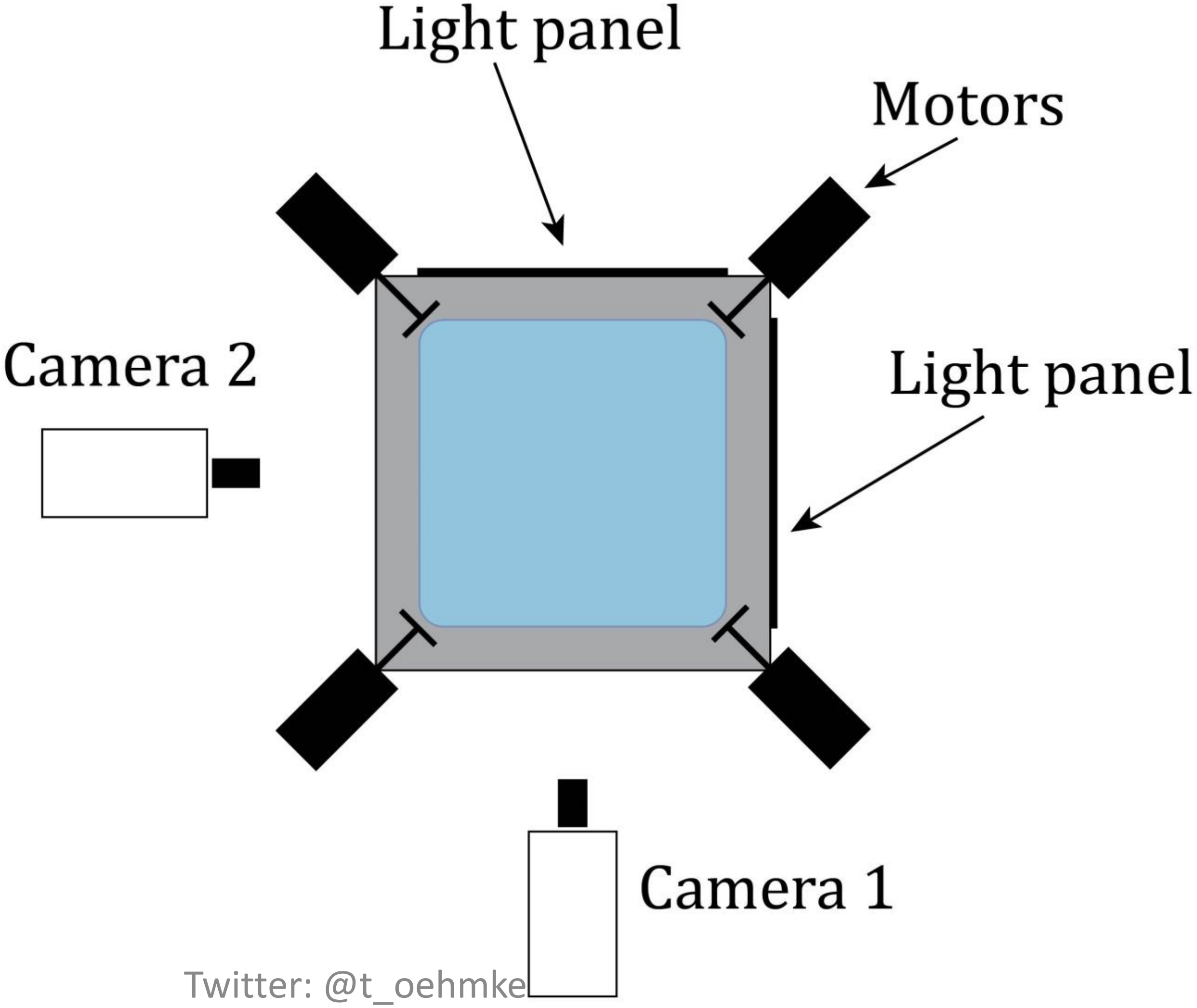

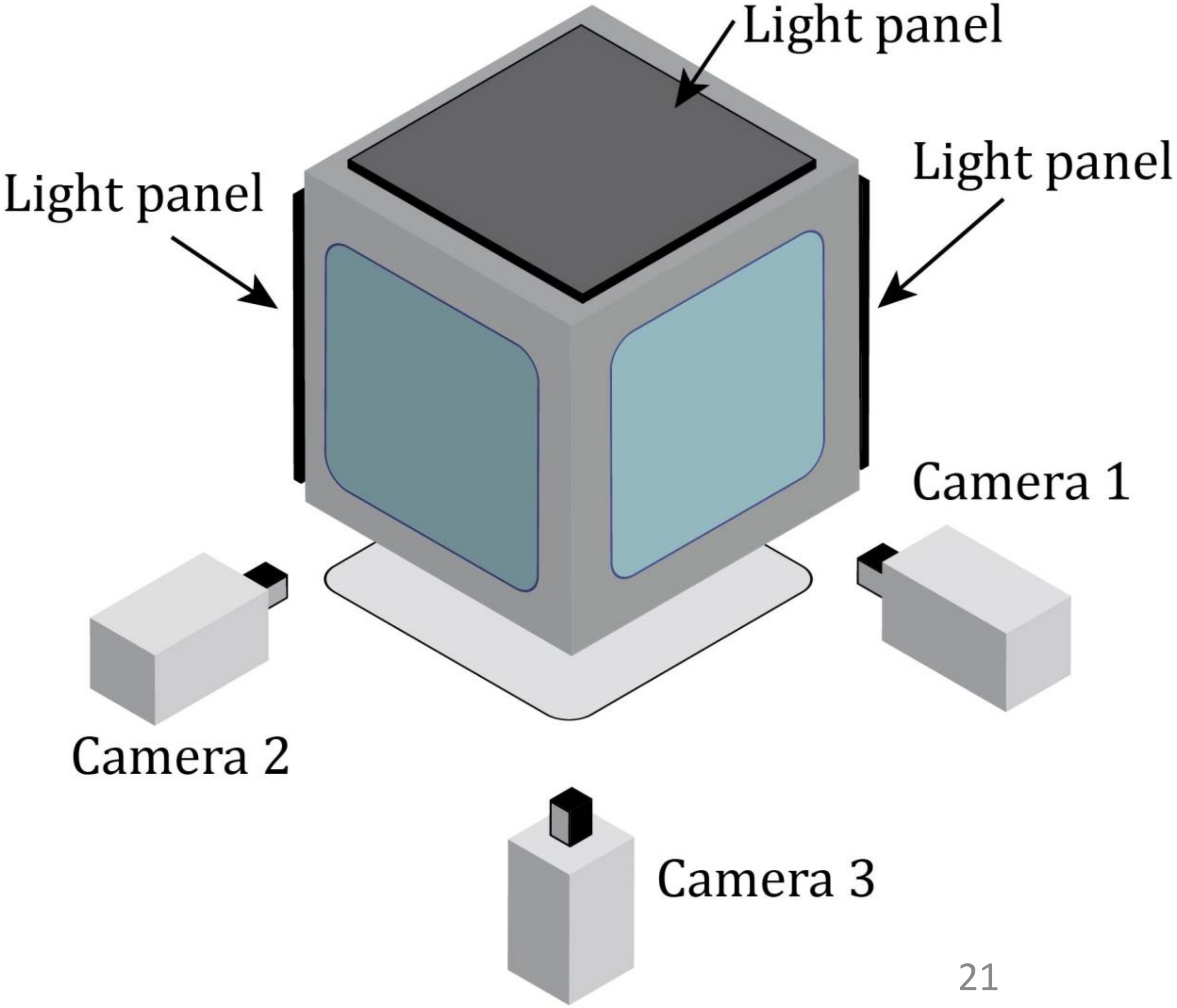

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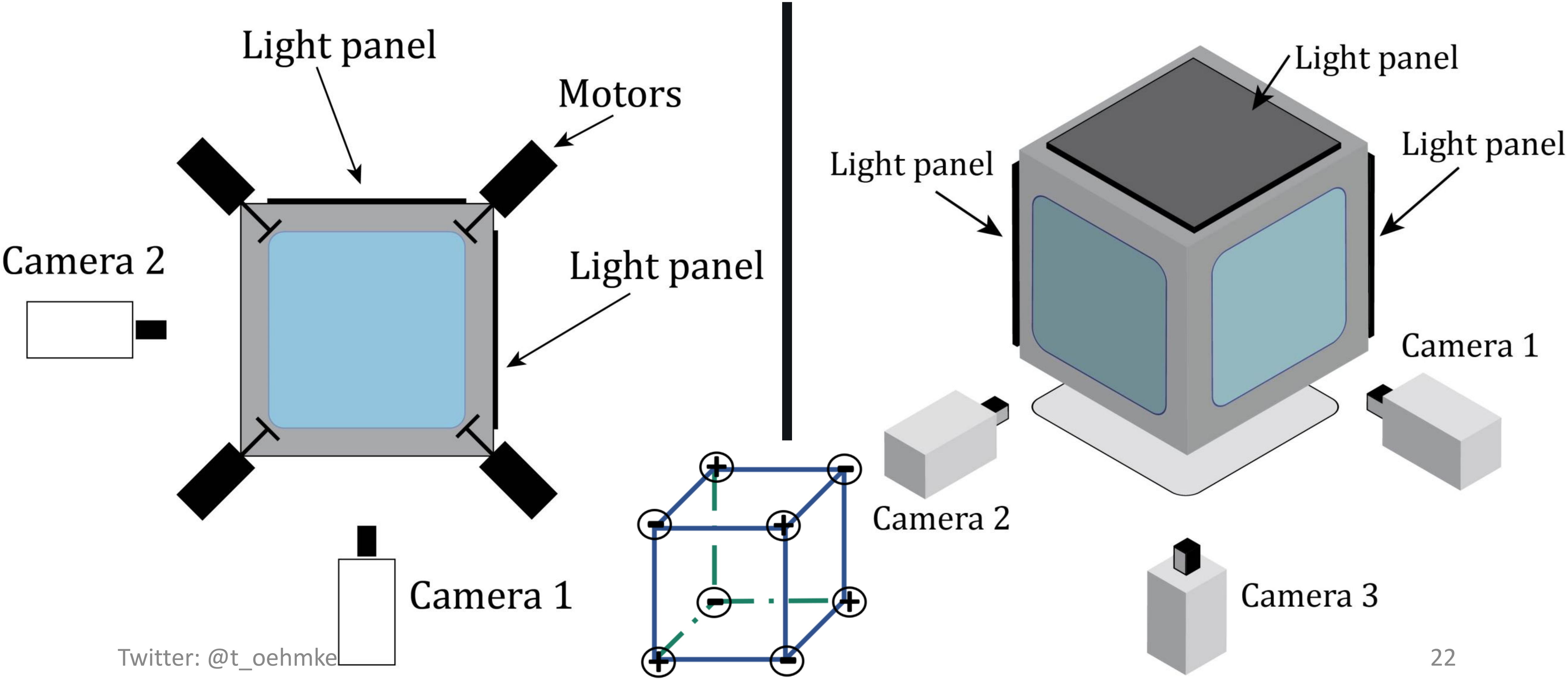
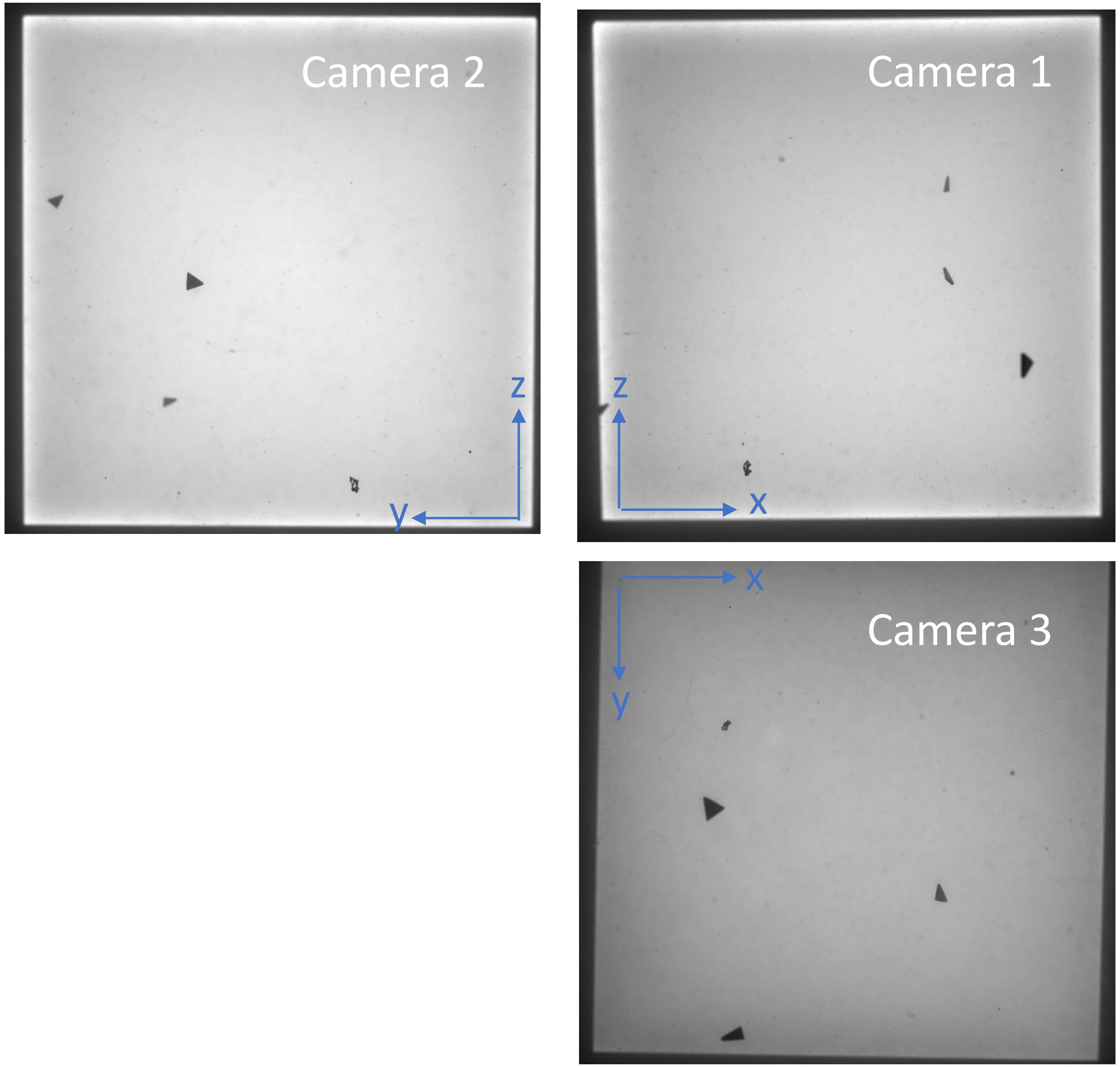
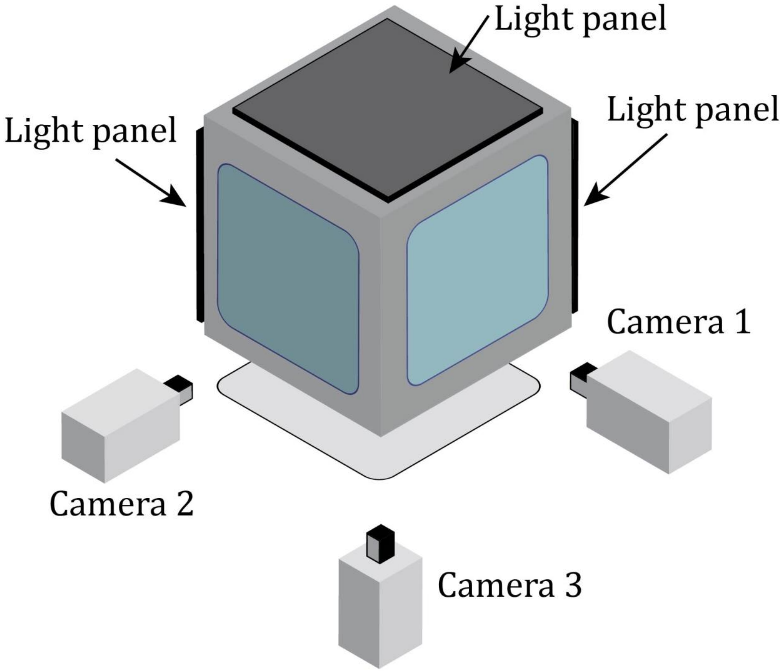
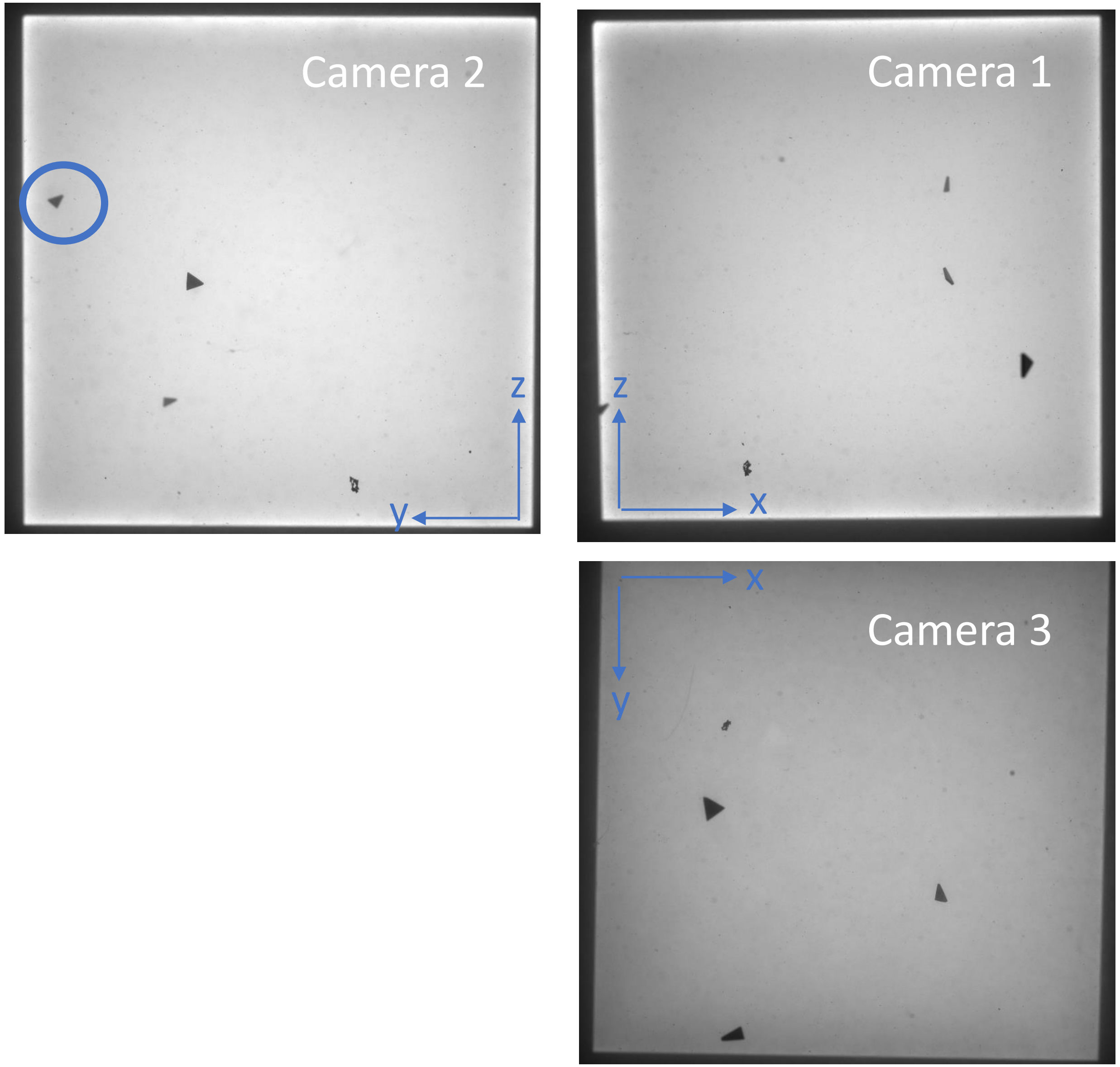




particles are identified in the images and linked to trajectories





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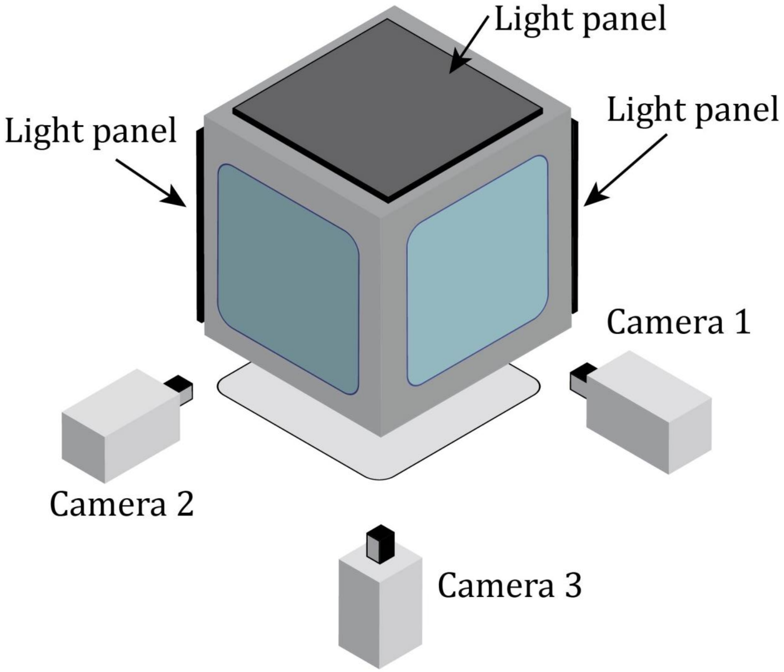

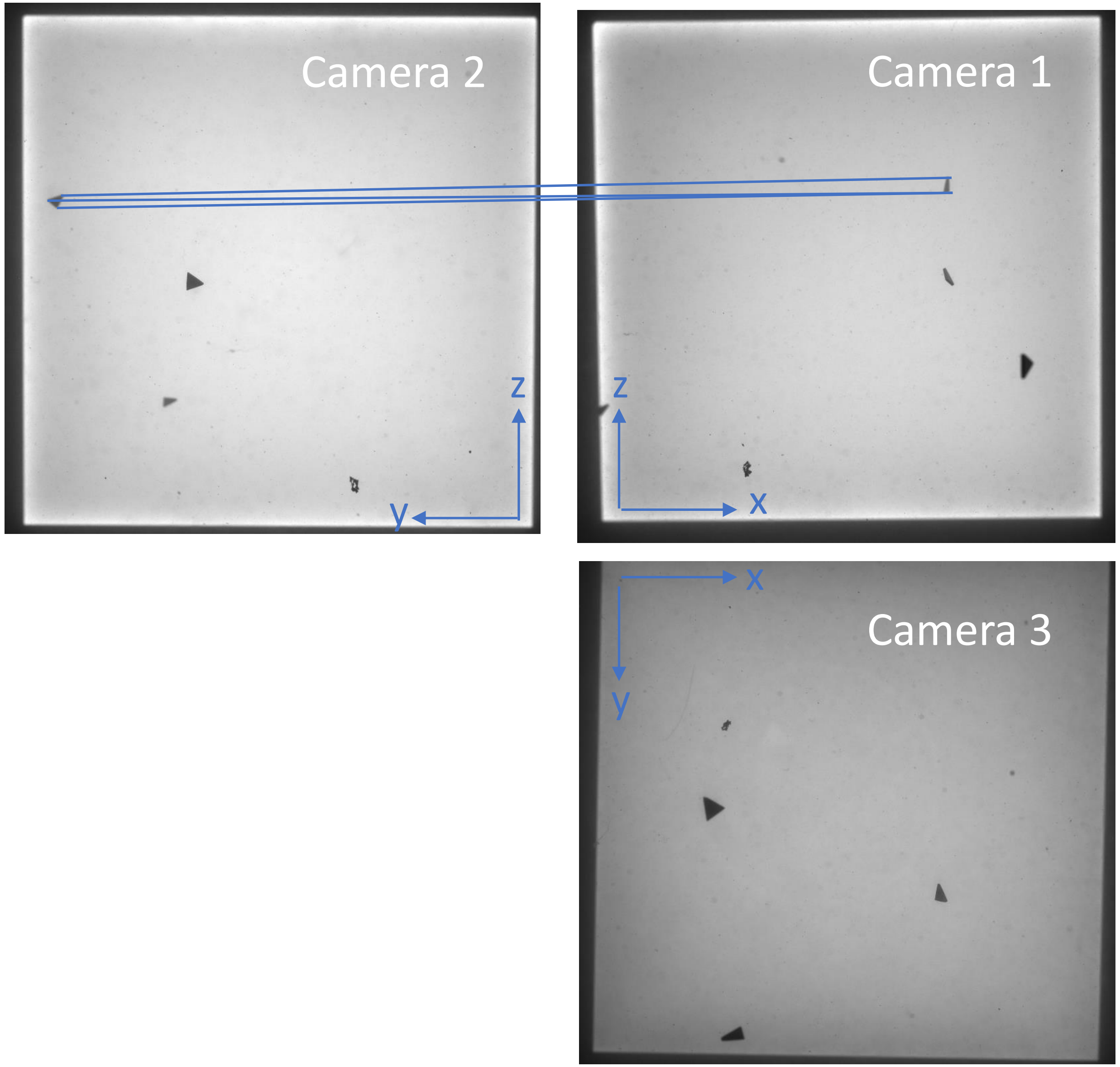

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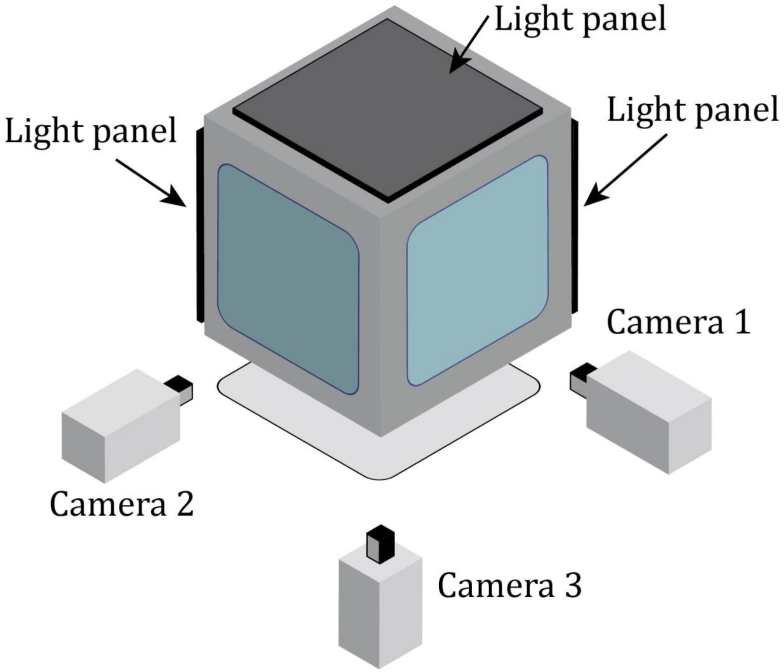

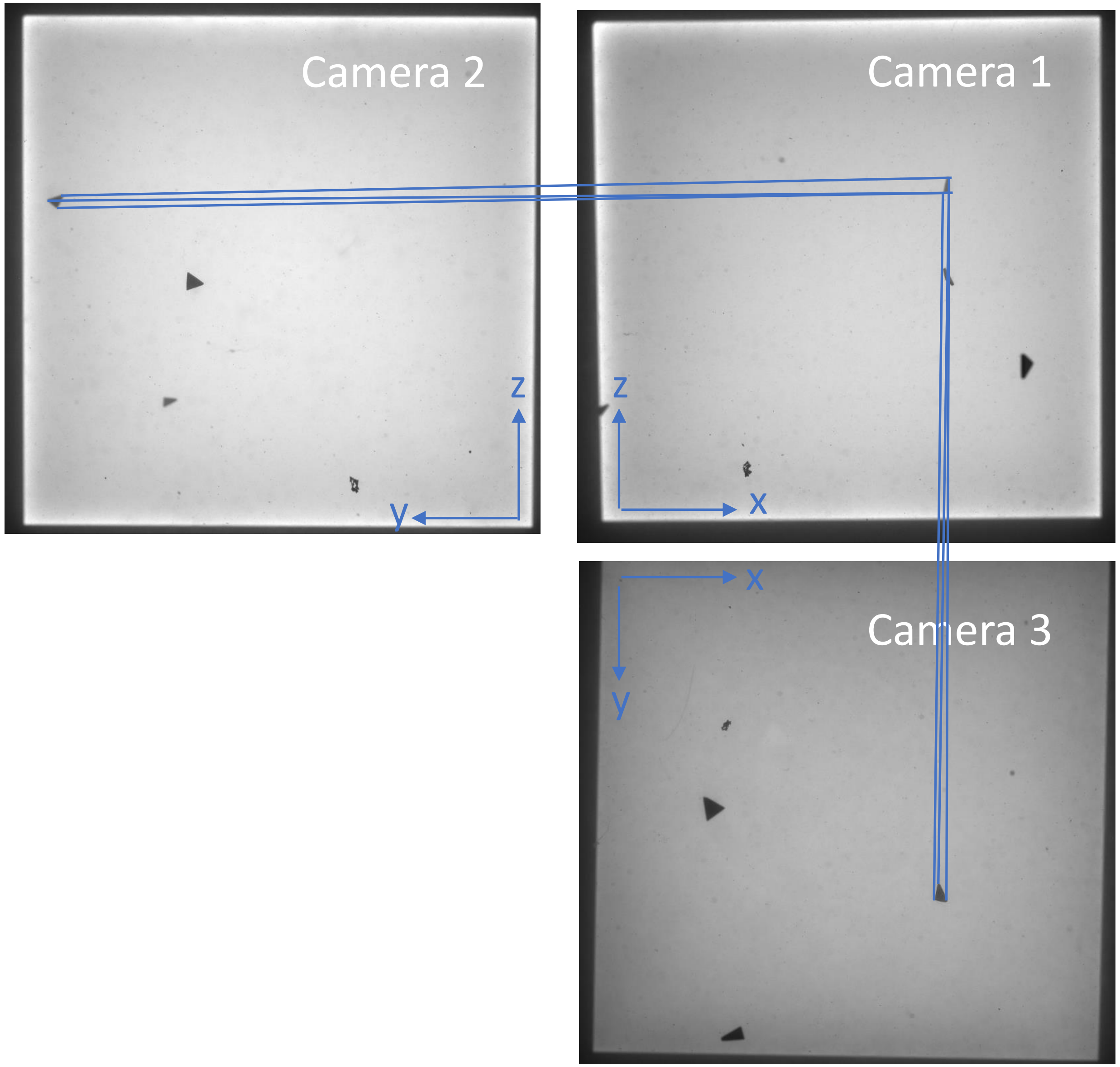

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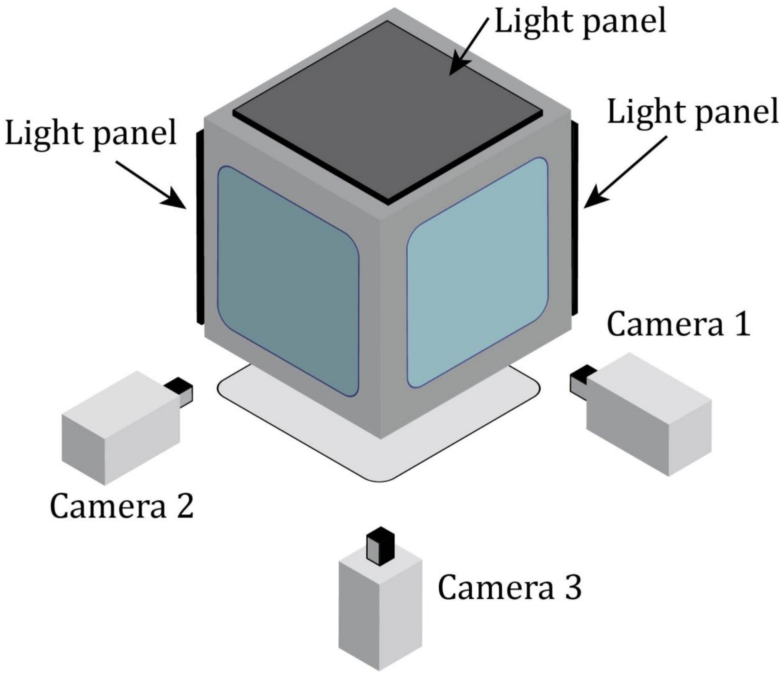

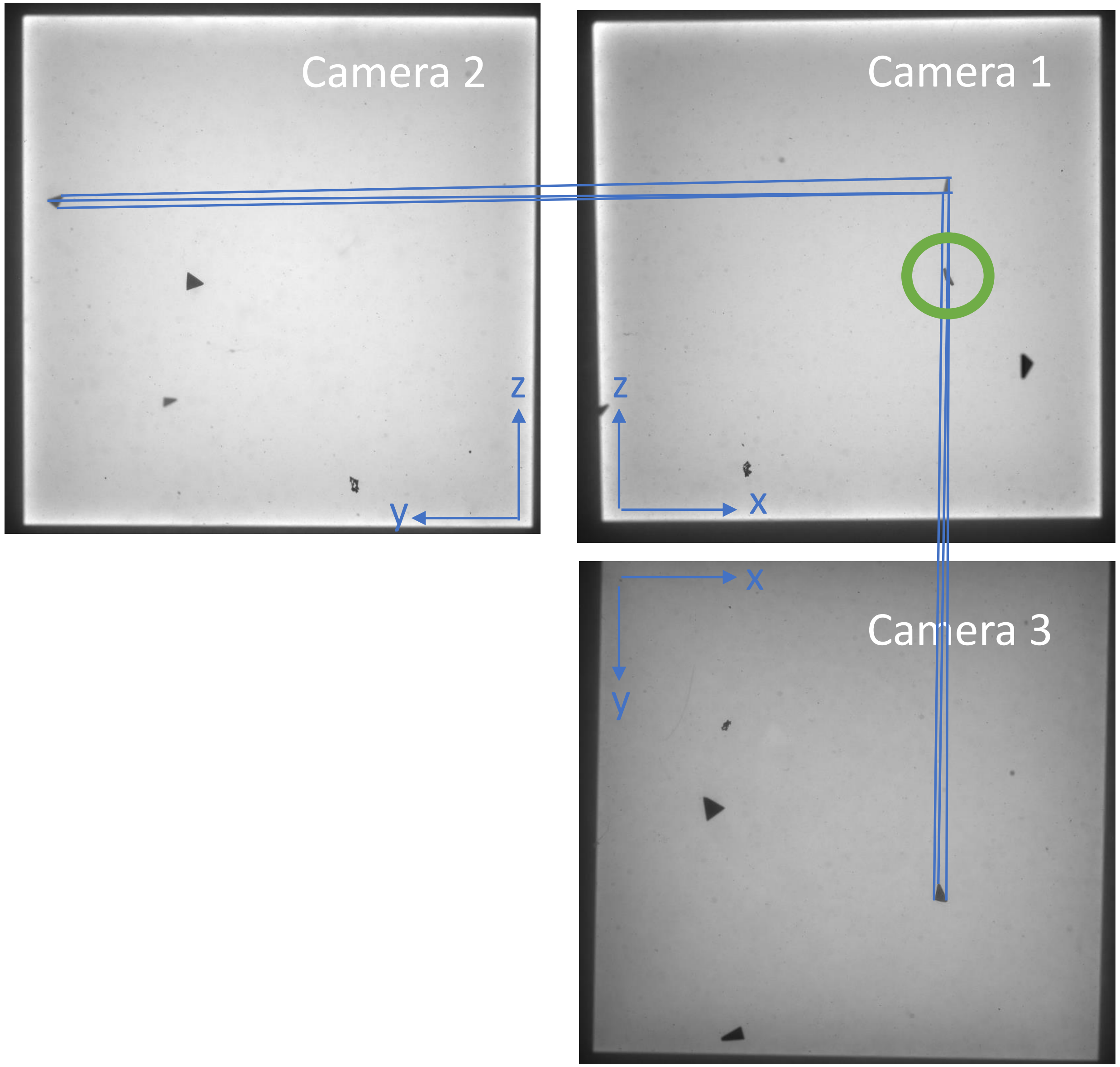

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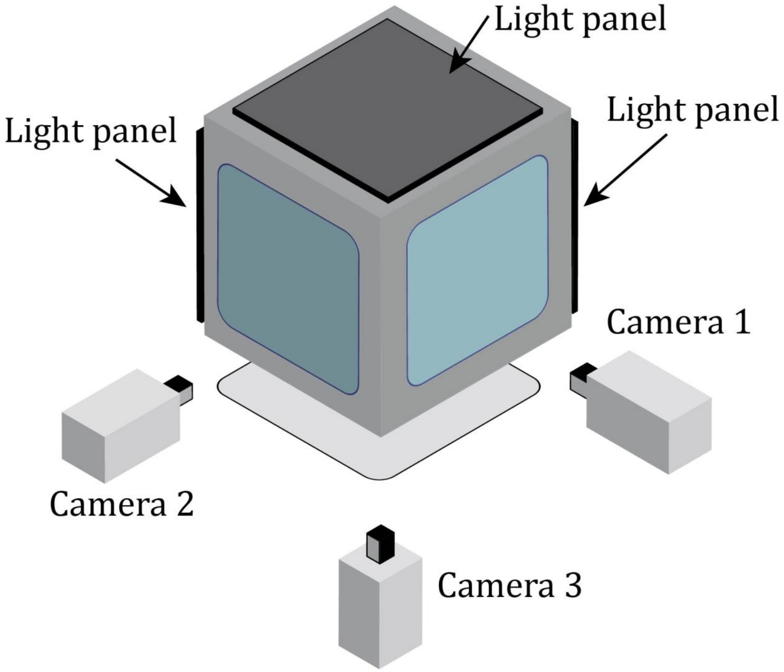
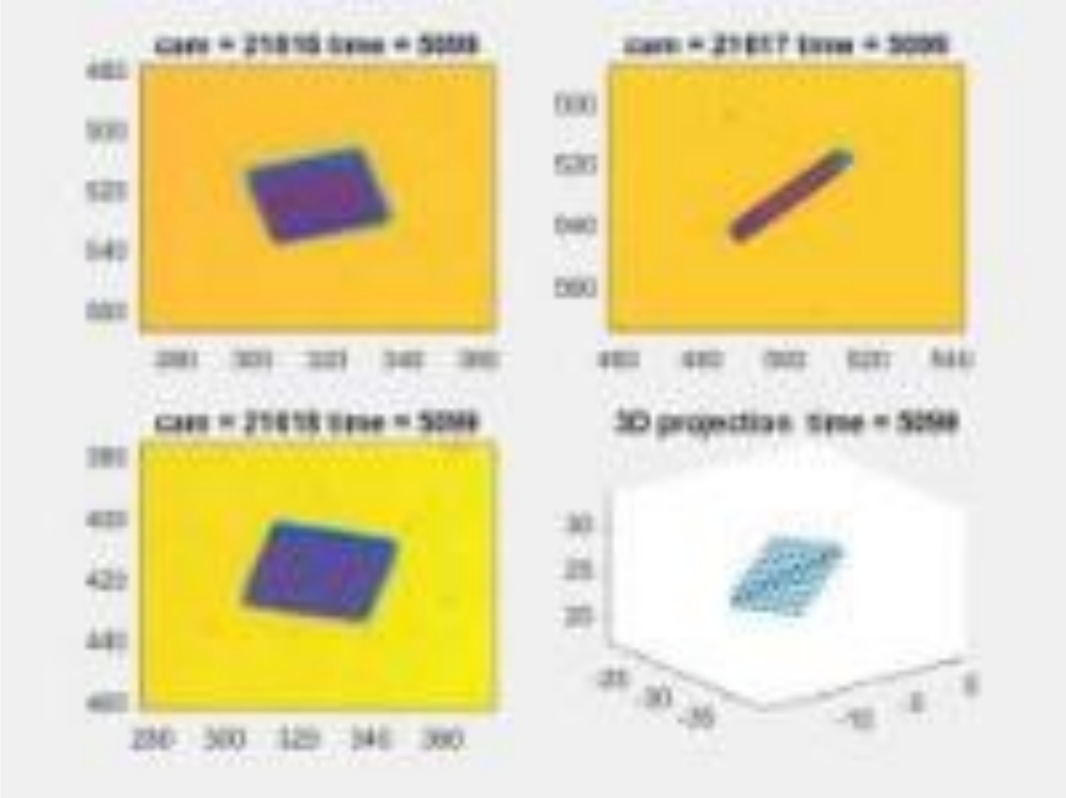
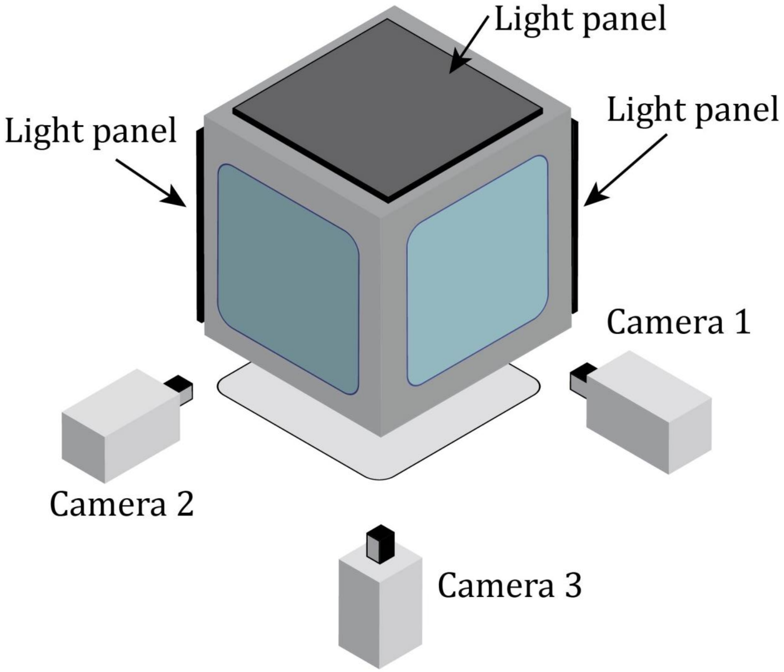
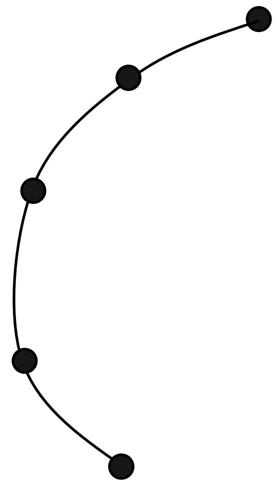


After 3D reconstruction, we can project the particles back onto a 2D plane to test our results





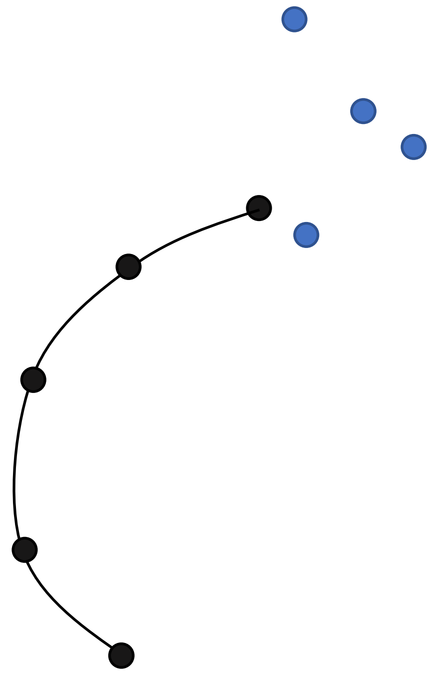
Individual particles were linked together in trajectories using the nearest neighbor method



Nearest neighbor figure adapted from A quantitative study of three-dimensional Lagrangian particle tracking algorithms by Ouellette, Xu, and Bodenschatz (2006)

Individual particles were linked together in trajectories using the nearest neighbor method

points in frame n+1



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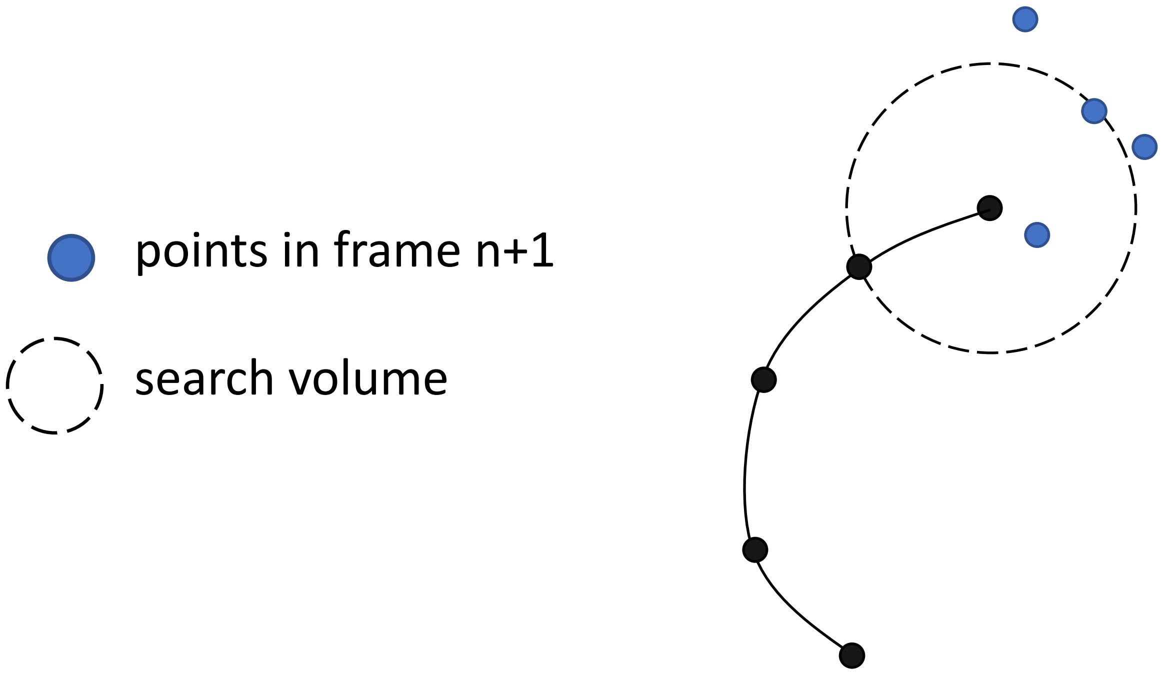

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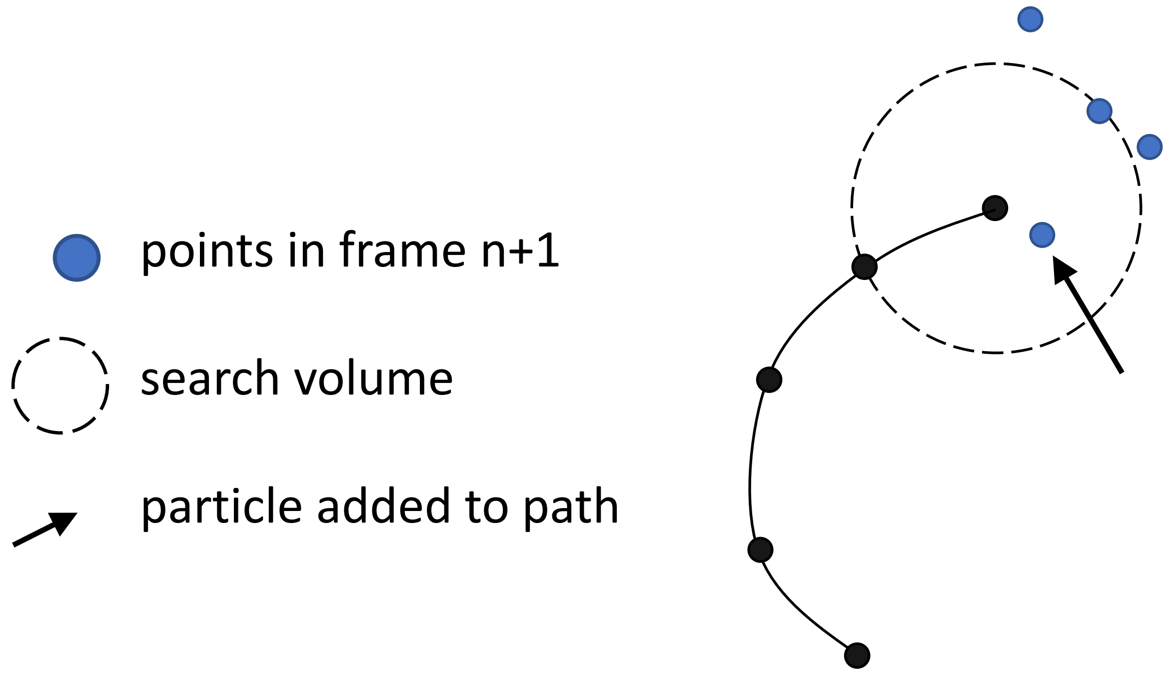

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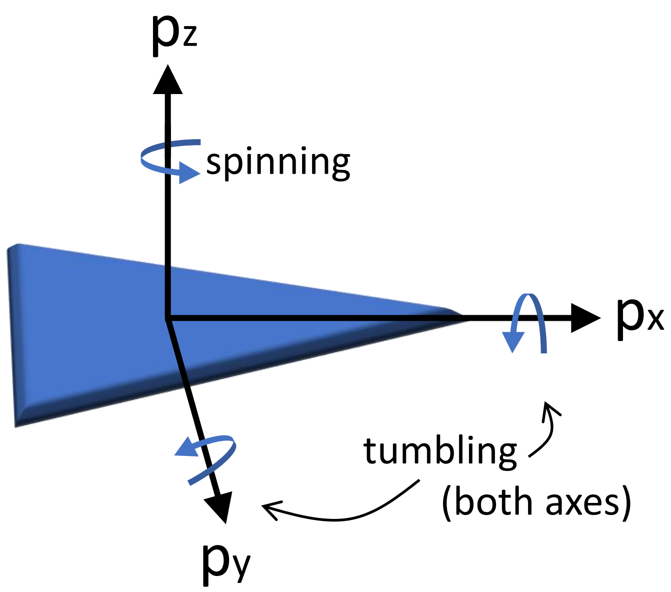
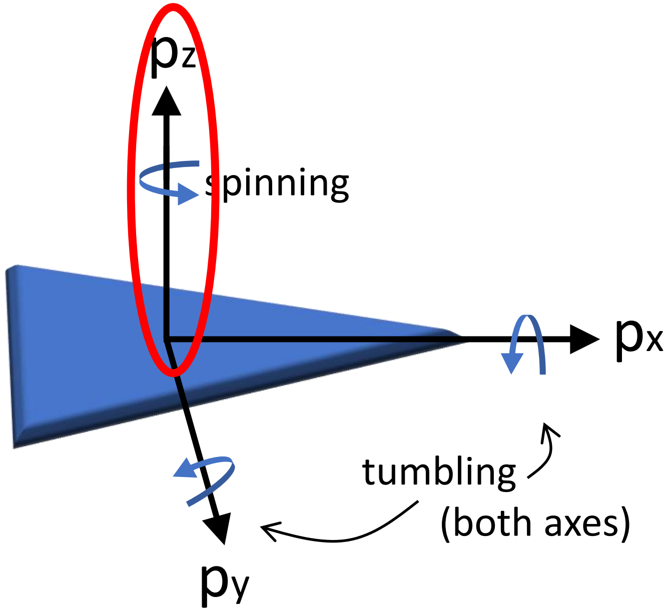
Particle rotation can be decomposed into tumbling and spinning



reference particle, known location and orientation

Particle rotation can be decomposed into tumbling and spinning



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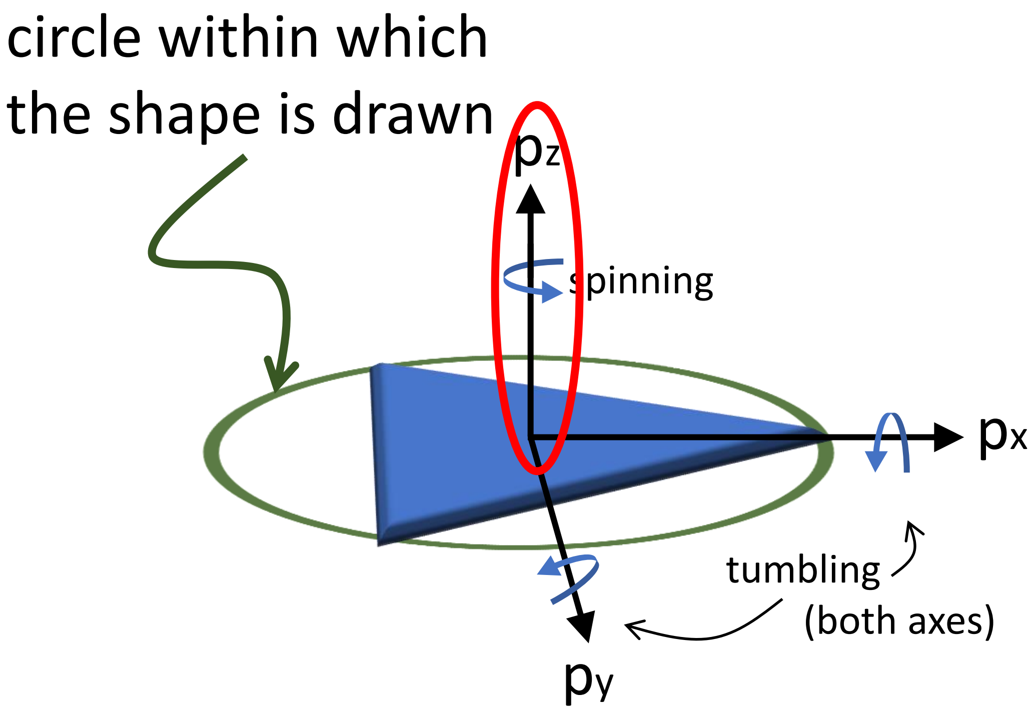

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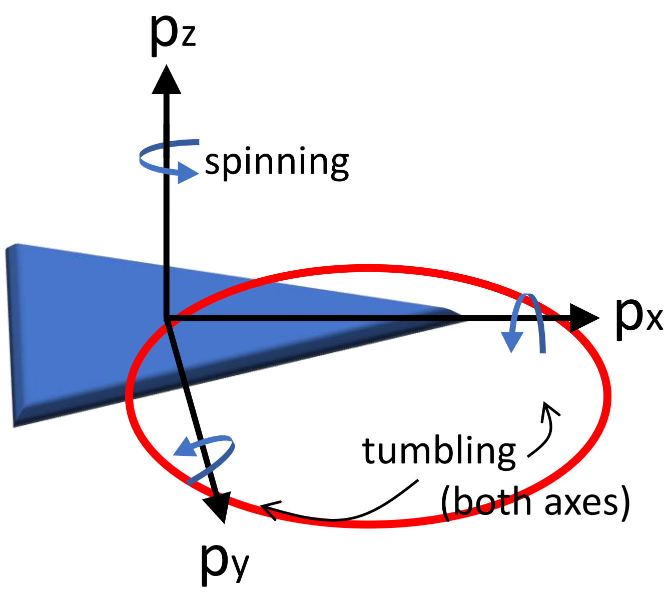

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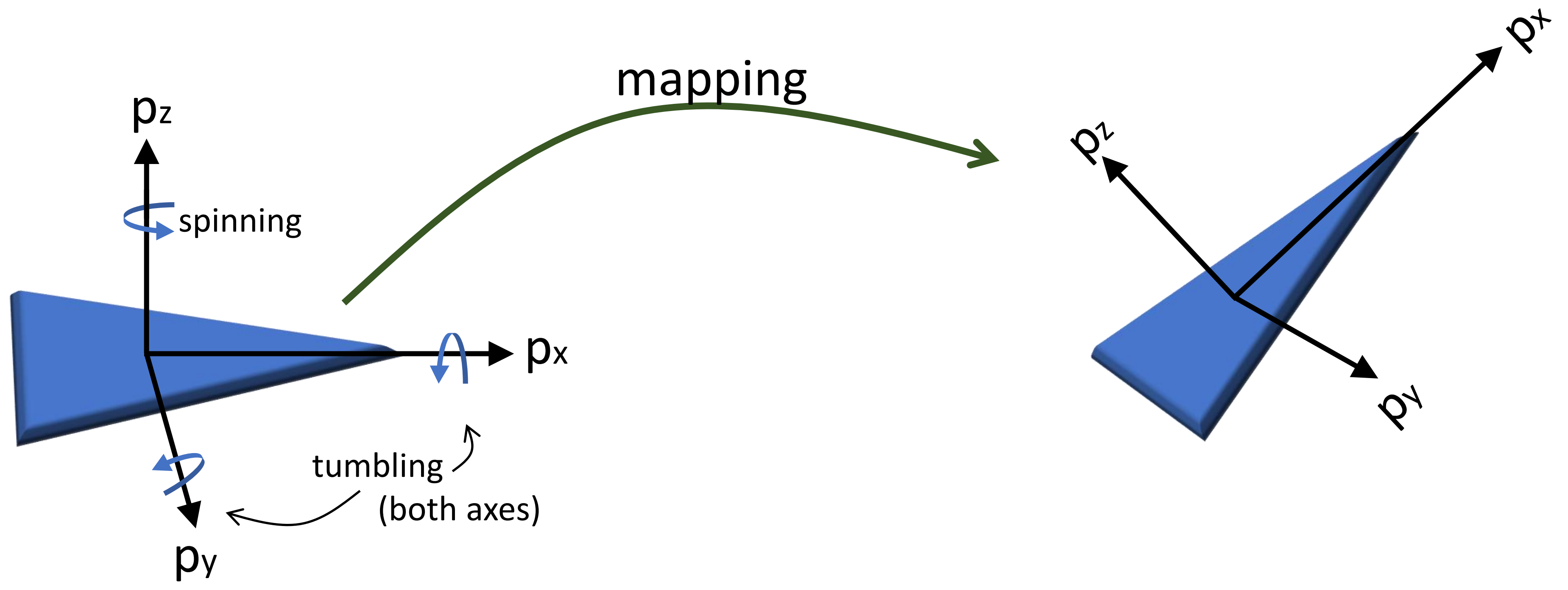


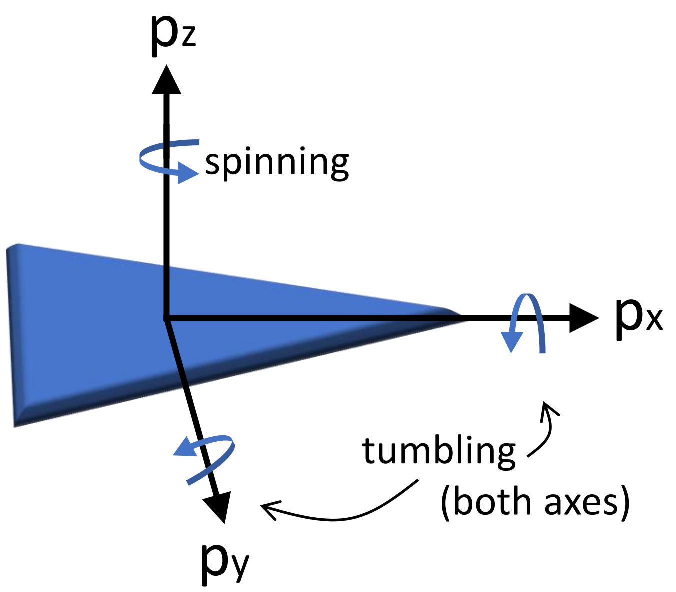
reference particle, known location and orientation

particle of interest

Particle rotation can be decomposed into tumbling and spinning

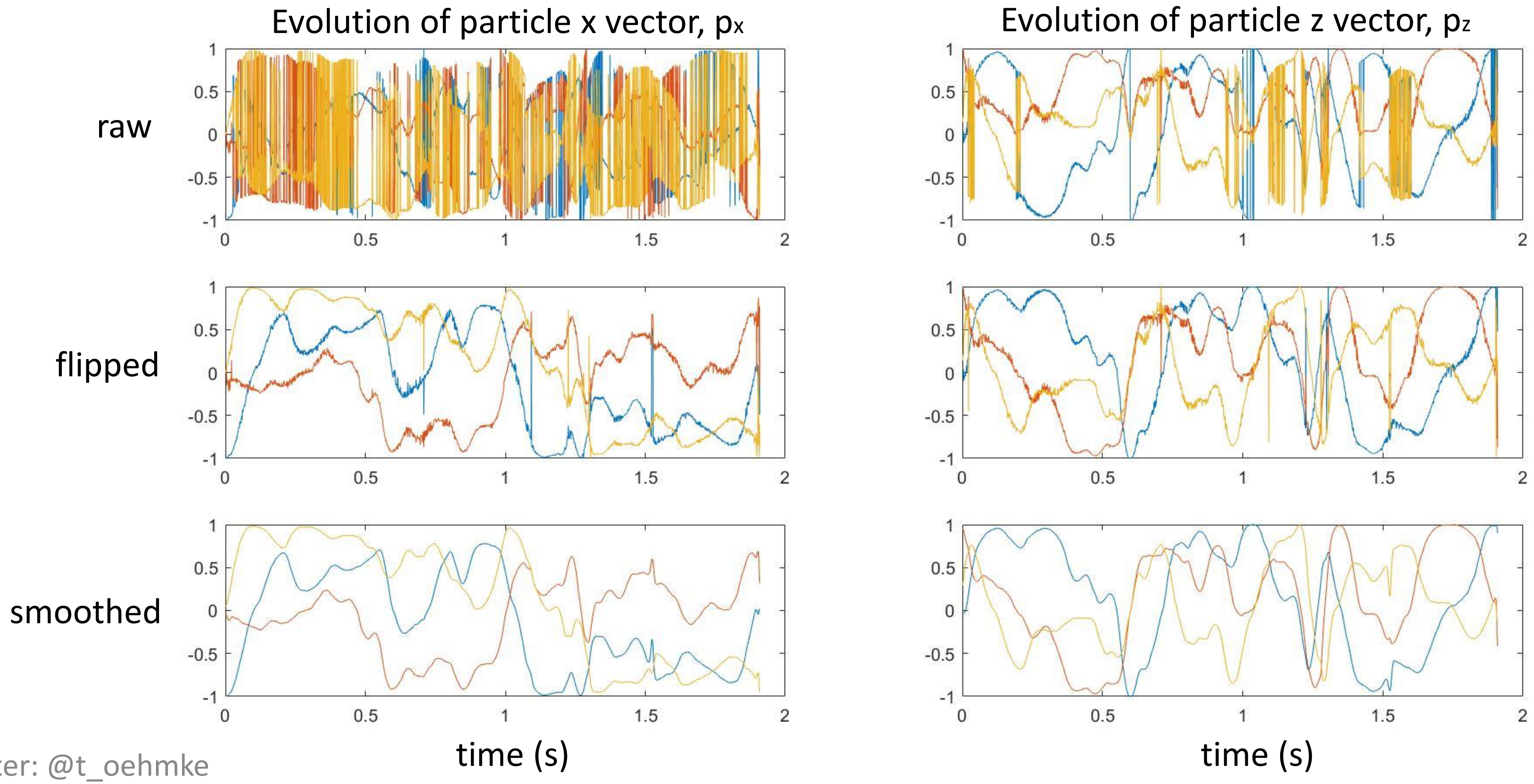
$$R = \begin{bmatrix} cos\theta & -sin\theta & 0 \\ sin\theta & cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R = R_T R_S$$



Where R is the rotation matrix
And R_T is the tumbling matrix
And R_S is the spinning matrix

Trajectories were filtered to remove measurement and experimental noise



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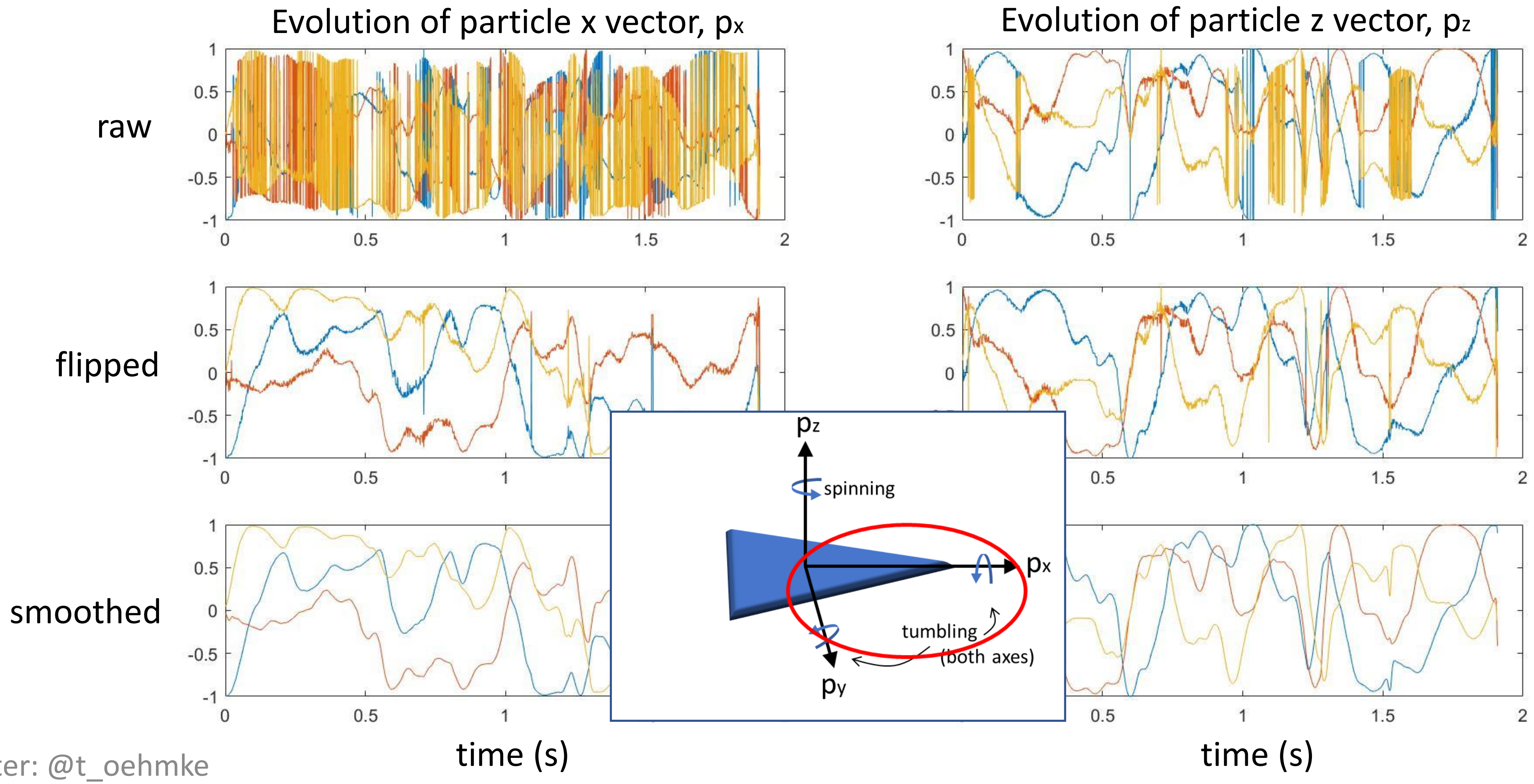

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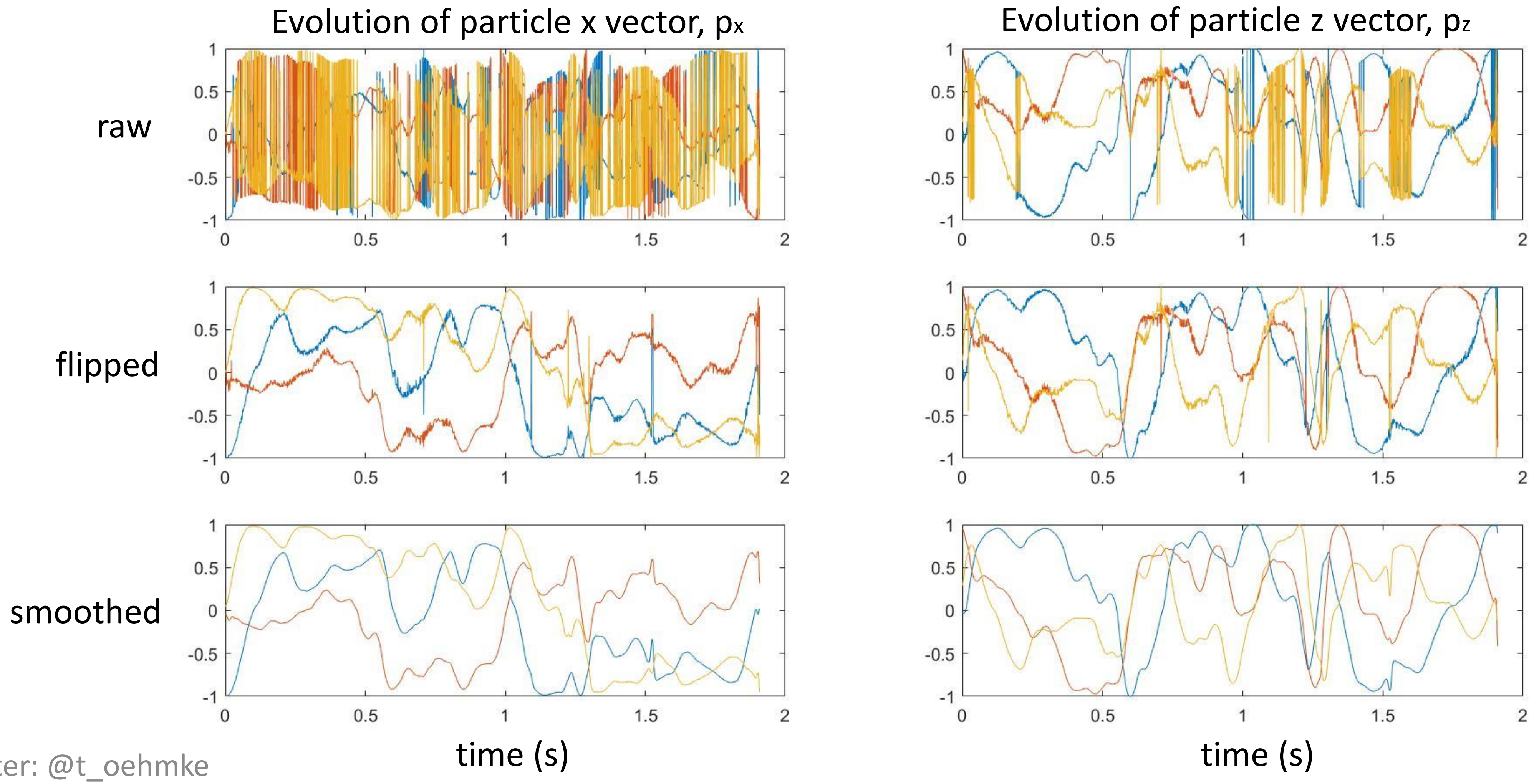
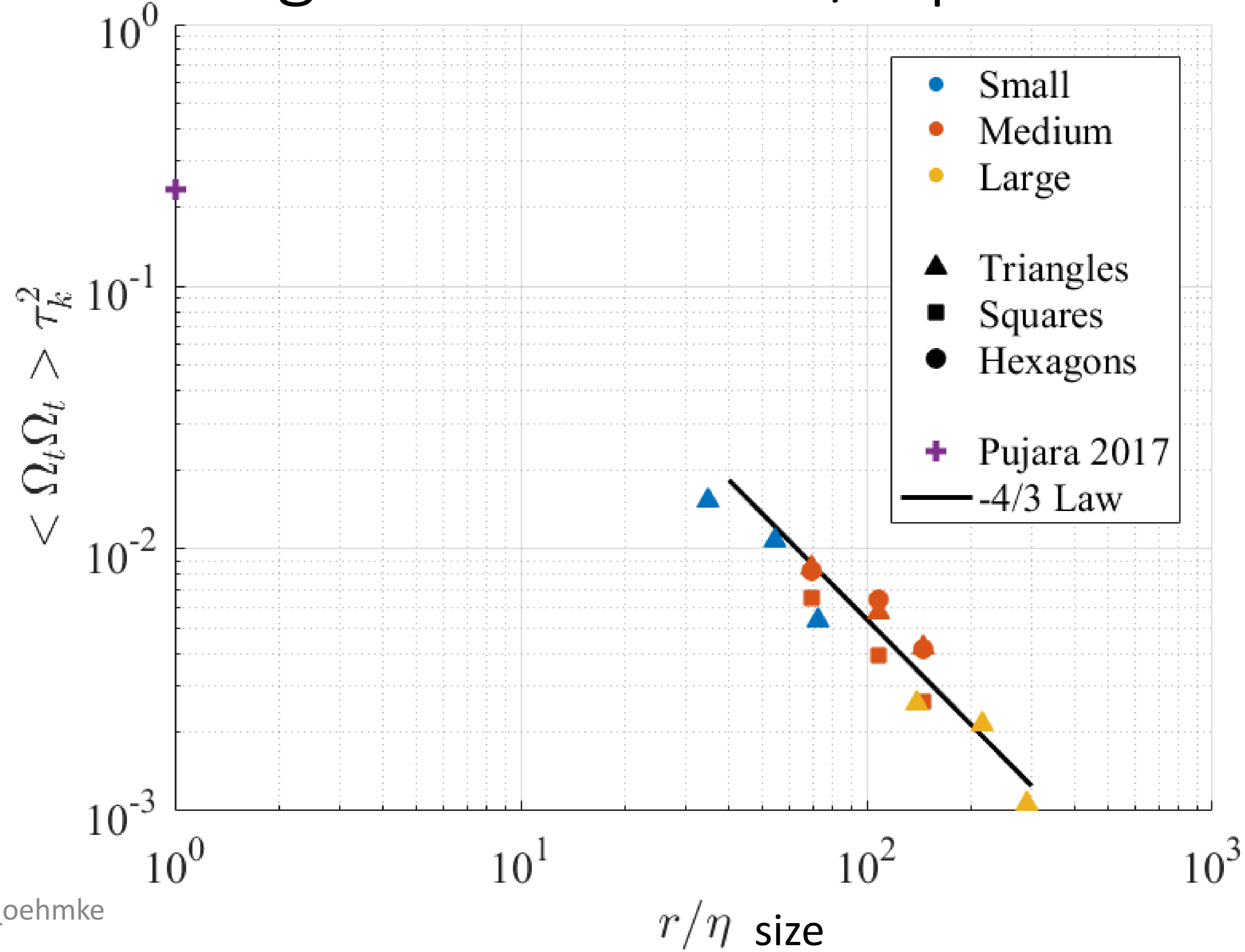
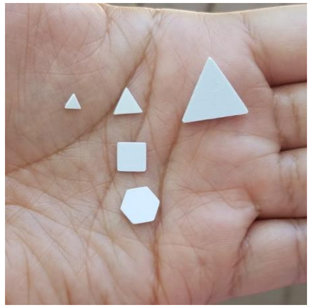


Tumbling rates follow -4/3 power law

tumbling rate



size



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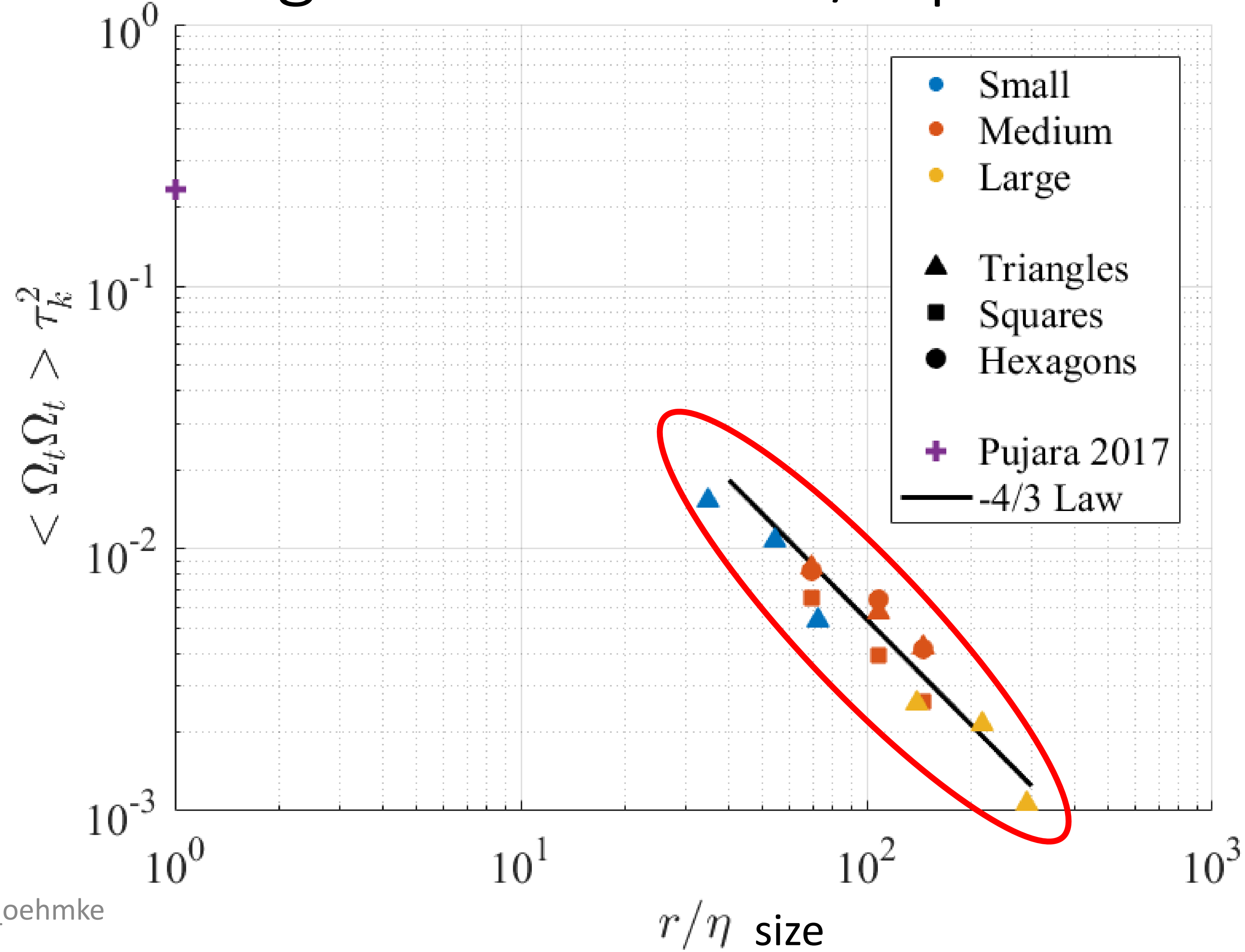

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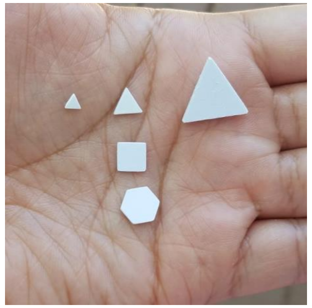

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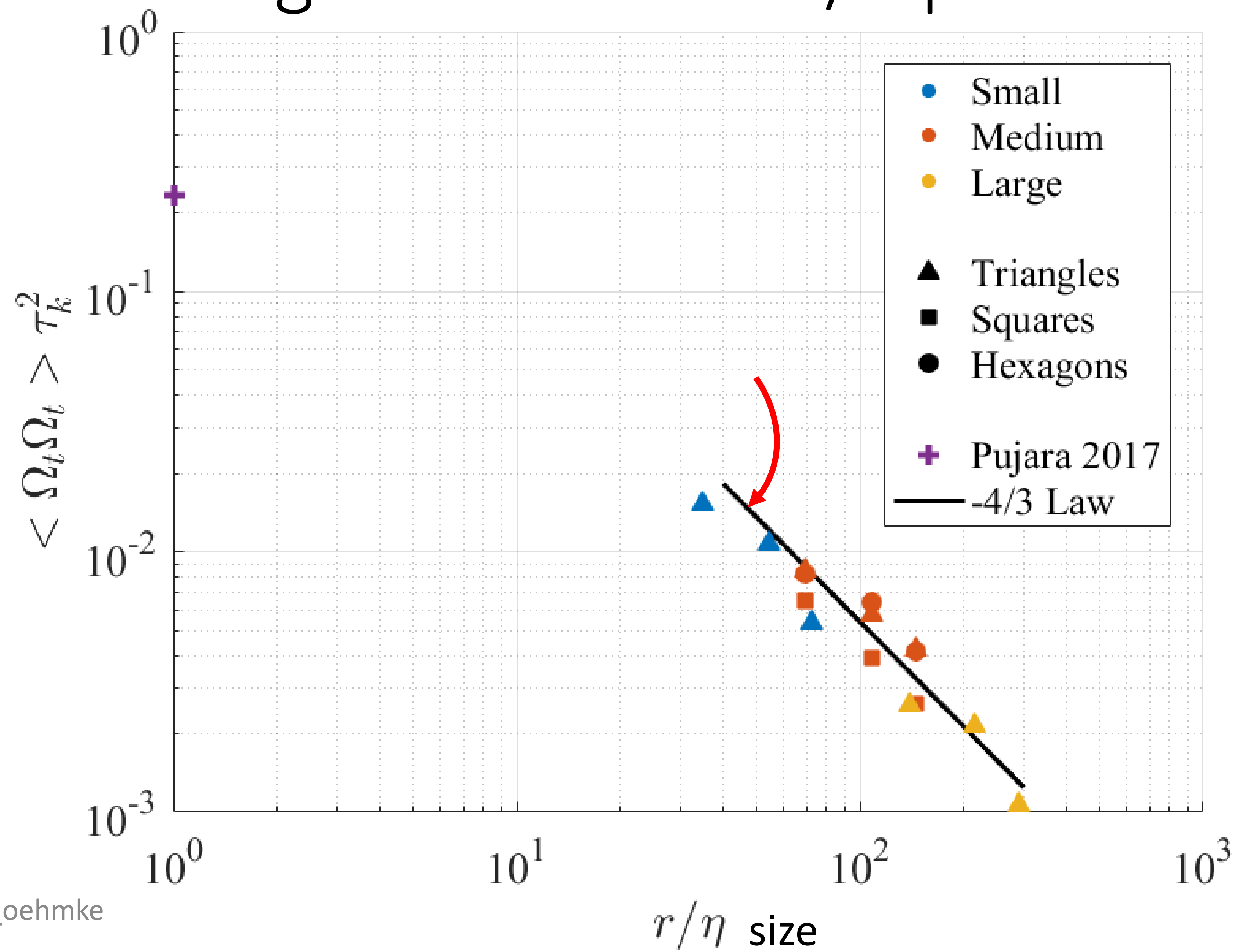

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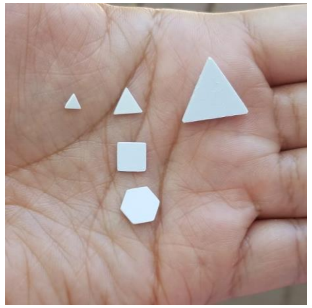

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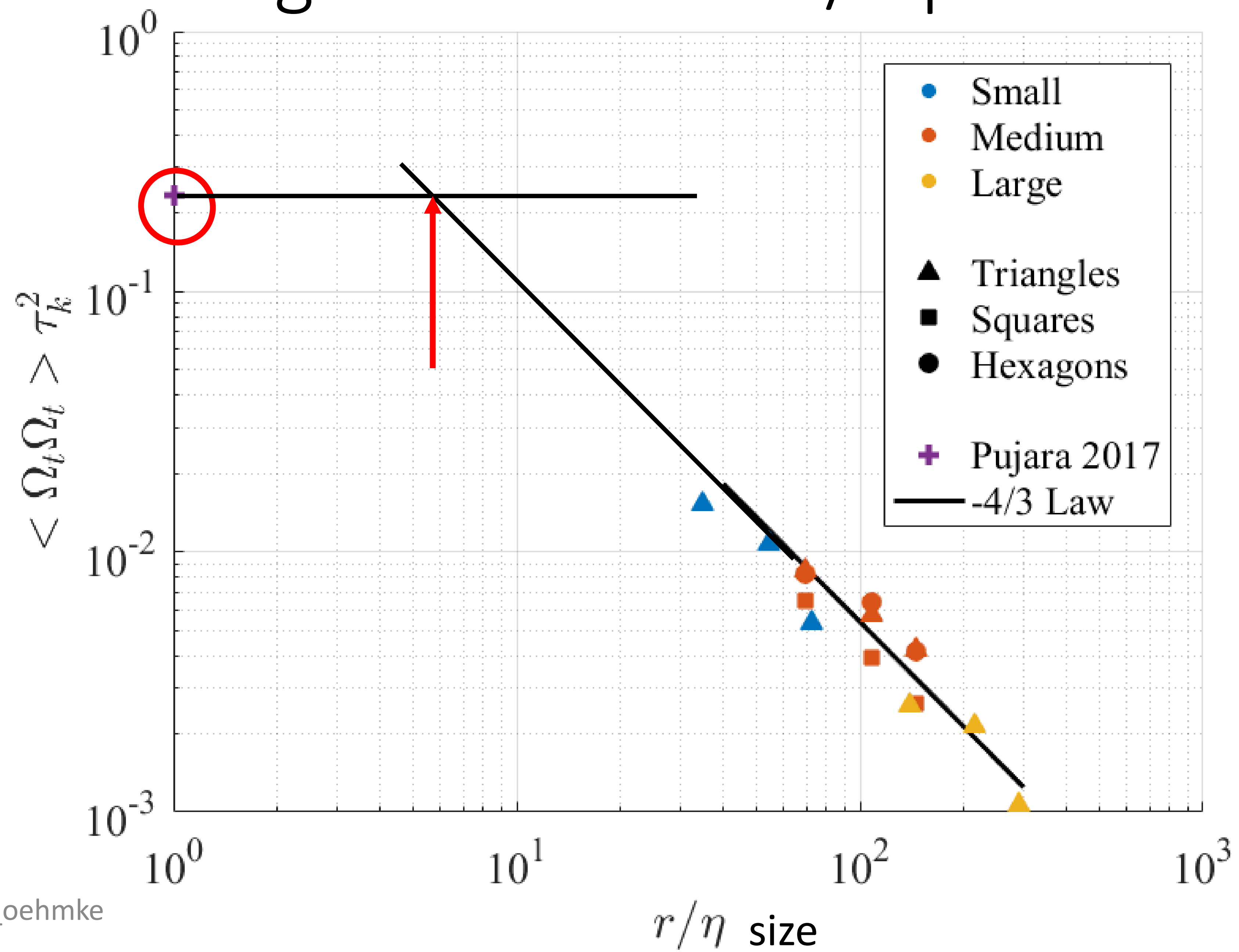

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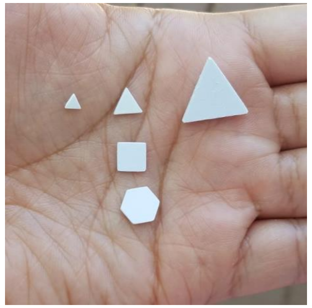
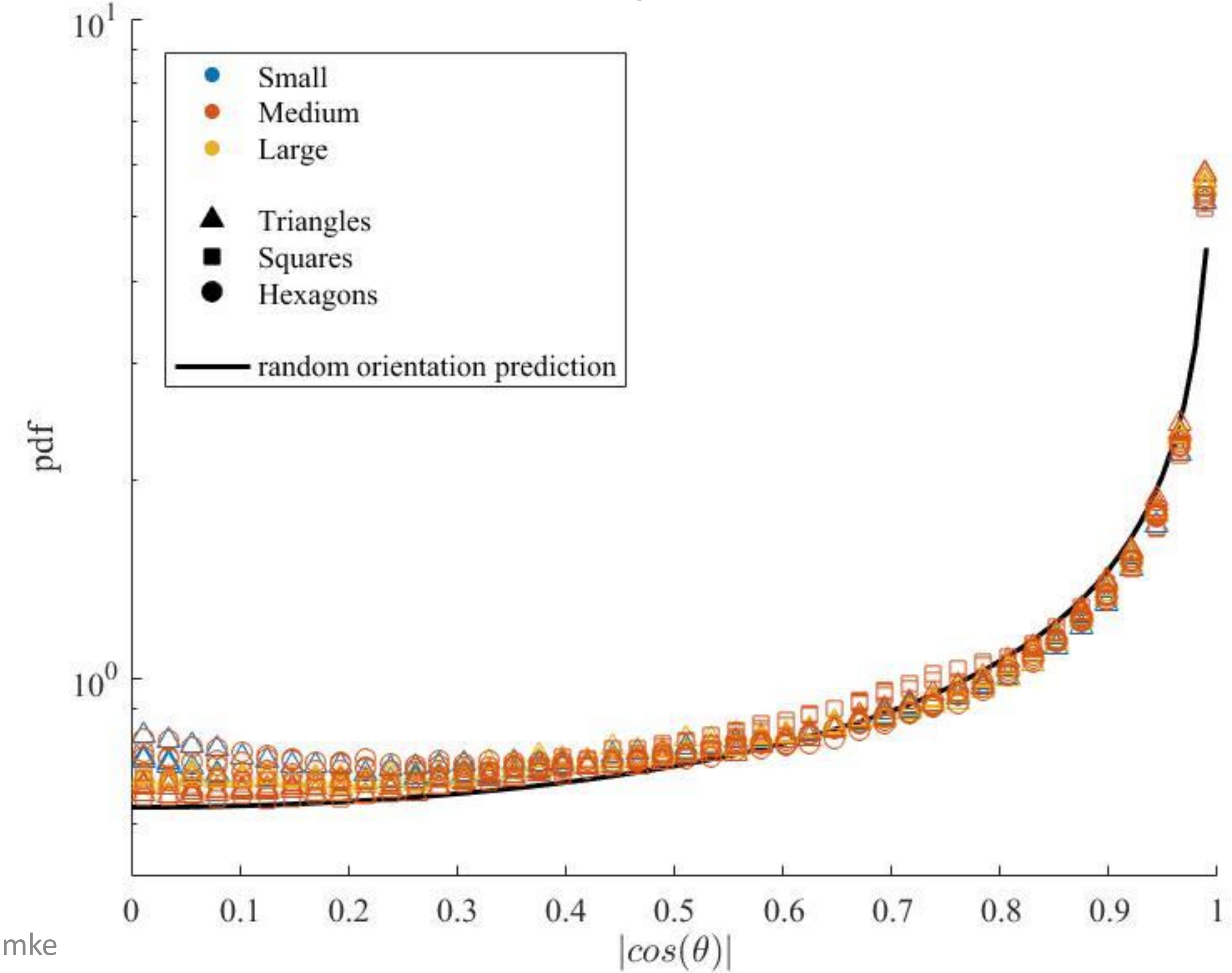


Particles do not show a preferential orientation



Twitter: @t_oehmke

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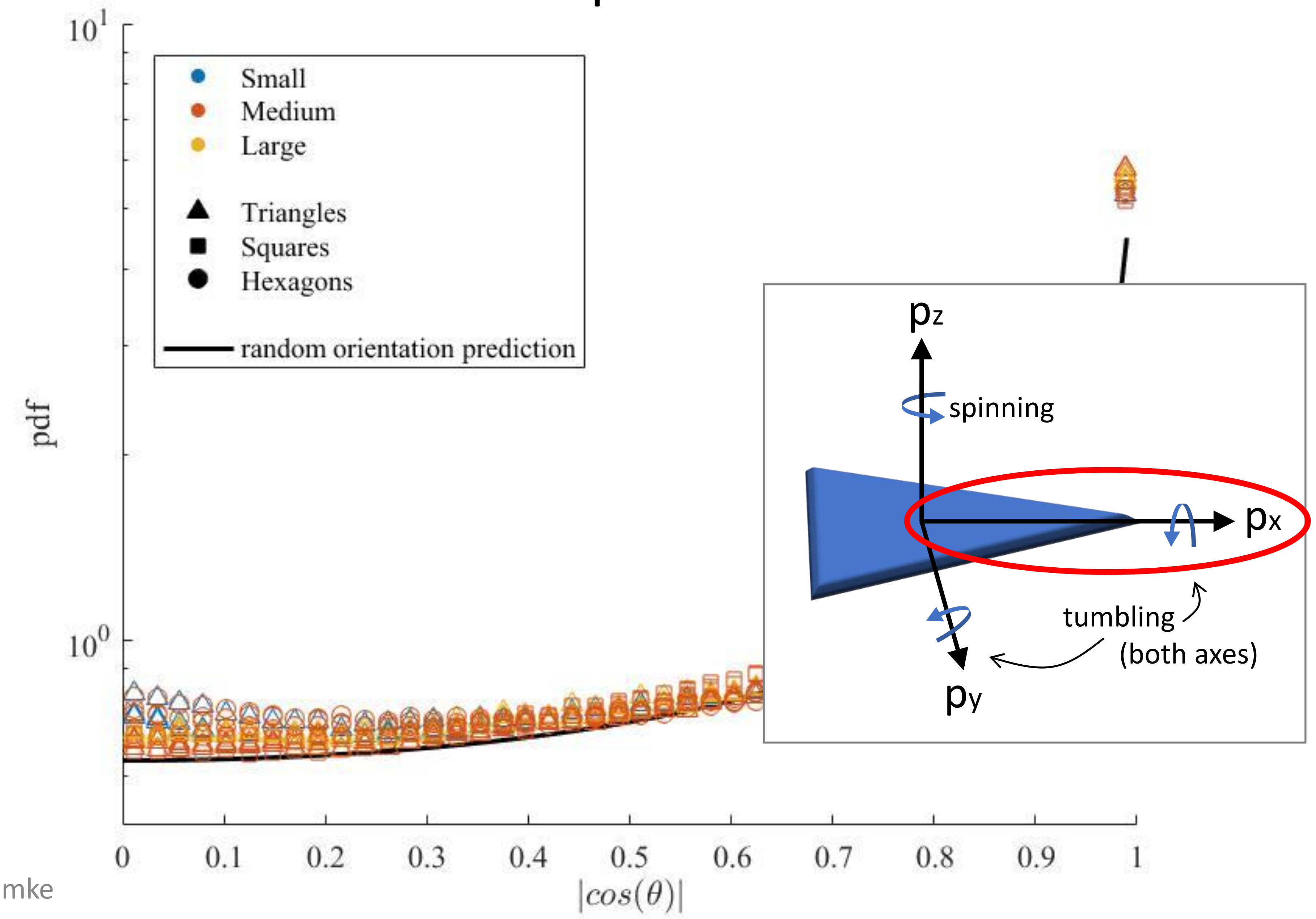

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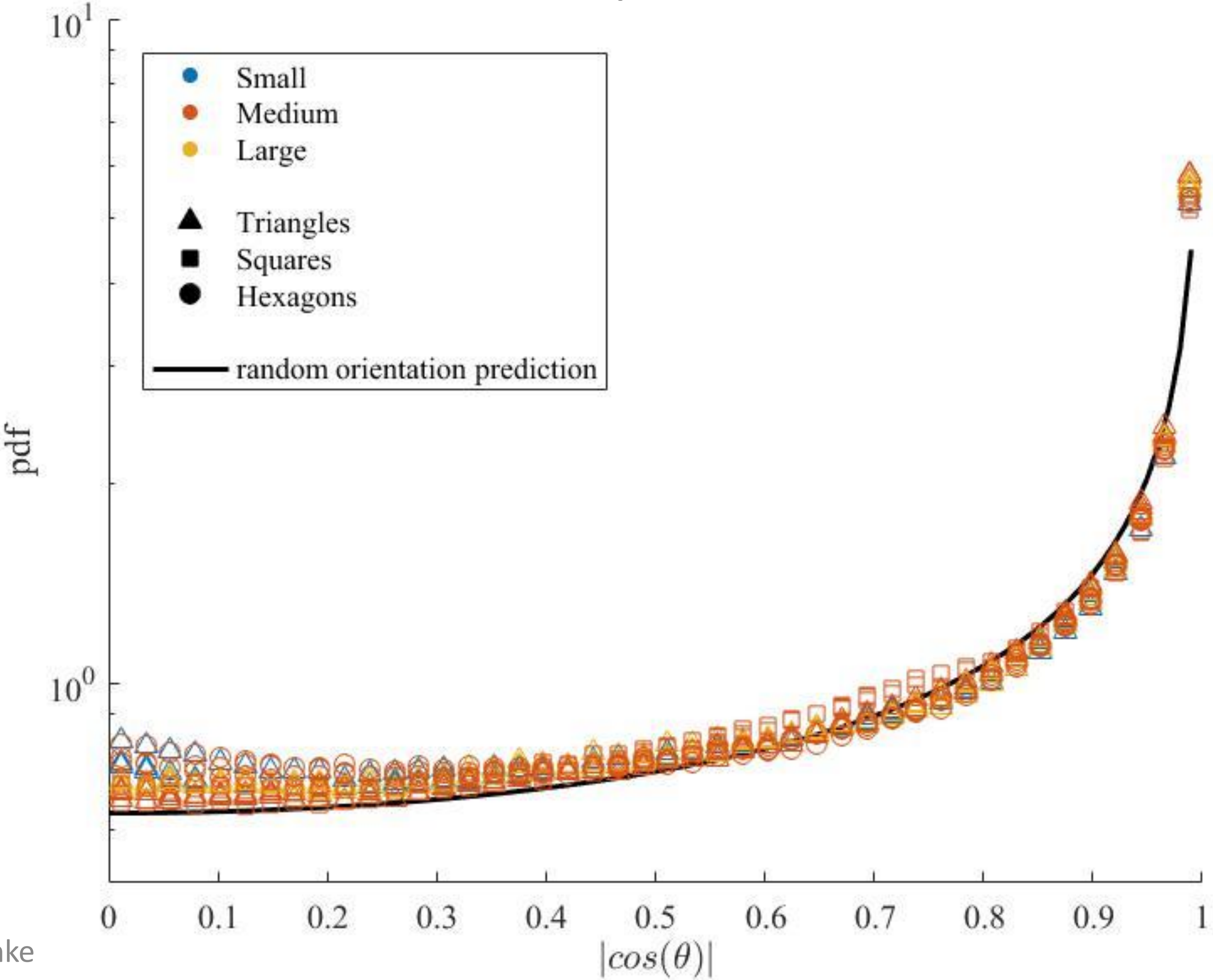

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Perspectives: size matters more than shape

- The particles do not show a preferential orientation

- Particles follow a -4/3 power law scaling, meaning these particles are rotated and aligned by eddies of their size
  - This means that size matters more than shape

- These findings agree with results for solid, 3D particles as well

Questions to answer

background and motivation

turbulence and movement

future questions

Particle transport in turbulence impacts many aspects of science

- Particle transport prediction
  - Where and how do transported particles eventually settle out of the flow?

Particle transport in turbulence impacts many aspects of science

- Particle transport prediction
  - Where and how do transported particles eventually settle out of the flow?
- Intermittency
  - What is the role of turbulence intermittency on particle kinematics?

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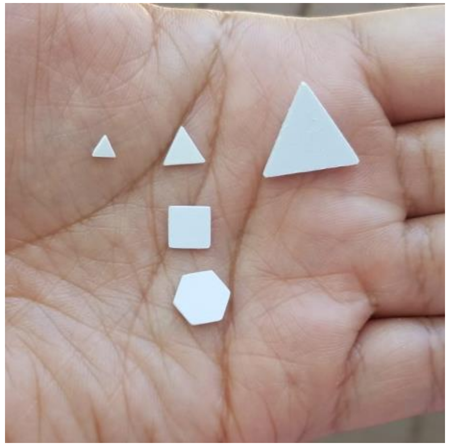
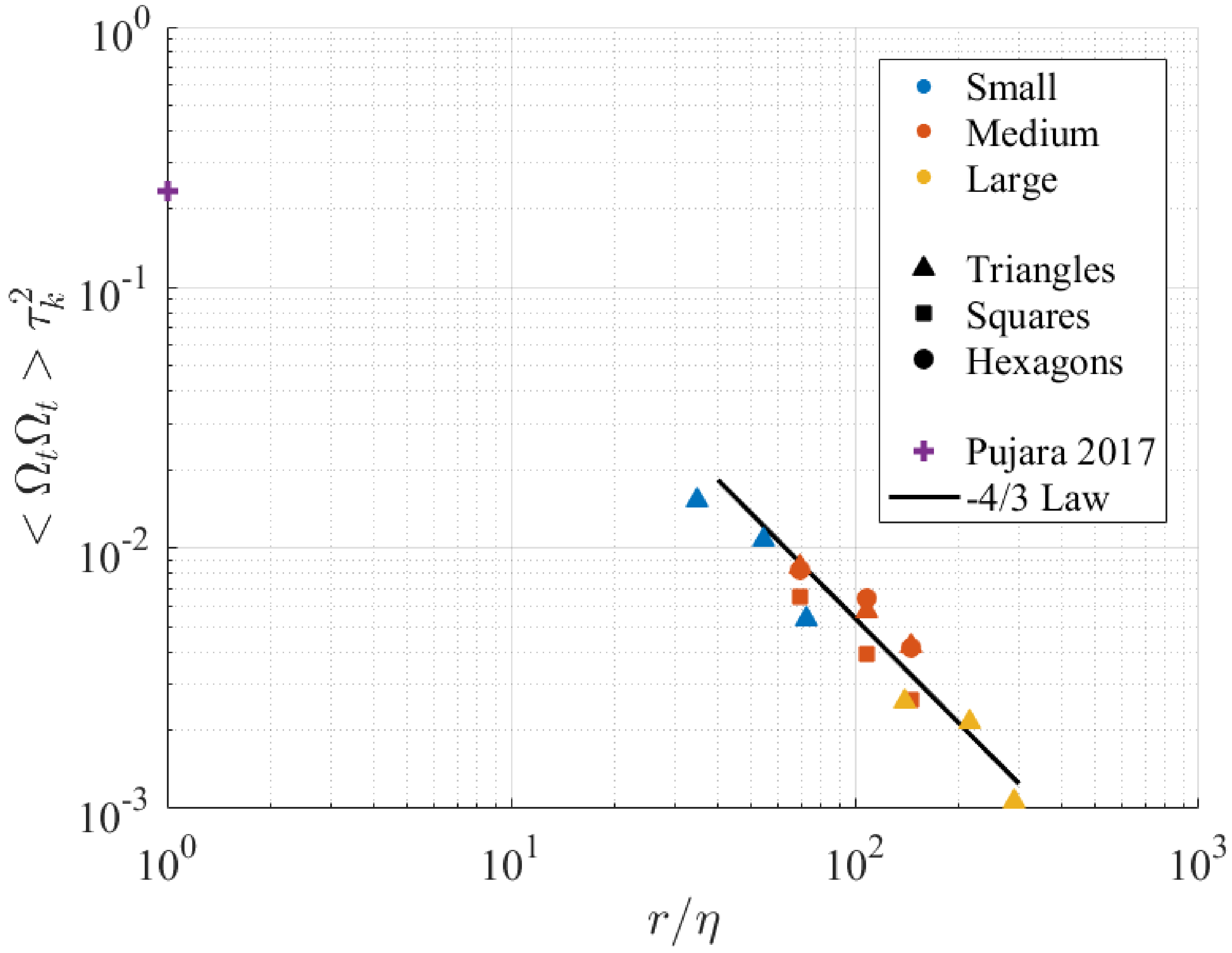
Questions?





10^0
10^{-1}
10^{-2}
10^{-3}
$< \Omega_t \Omega_t > \tau_k^2$
10^0
10^1
10^2
10^3
r/η
Small
Medium
Large
Triangles
Squares
Hexagons
Pujara 2017
-4/3 Law

Parsa and Voth 2014

rotation rate for tracers : $\langle \dot{p}_i \dot{p}_i \rangle \sim {\tau_k}^{-2}$

rotation rate for scale l : $\langle \dot{p}_i \dot{p}_i \rangle \sim {\tau_l}^{-2}$

define τ_l in the inertial range : $\tau_l = l/u_l = l/(l\langle \epsilon \rangle)^{1/3}$

rotation rate for scale l : $\langle \dot{p}_i \dot{p}_i \rangle \sim l^{-4/3}$