Orientation dynamics of chiral particles in turbulence

Mees Flapper Sander Huisman Detlef Lohse

Physics of Fluids

UNIVERSITY OF TWENTE.

NWO

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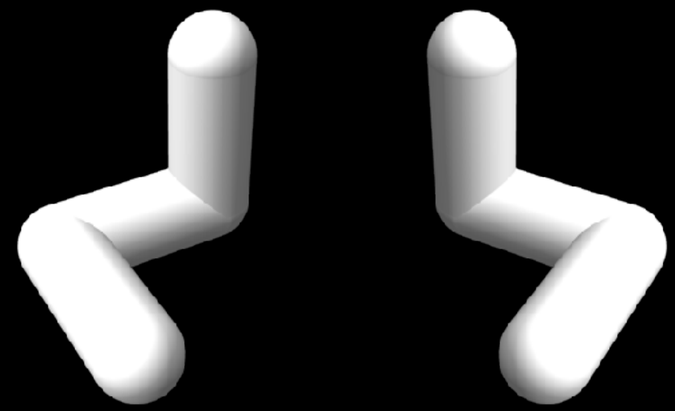
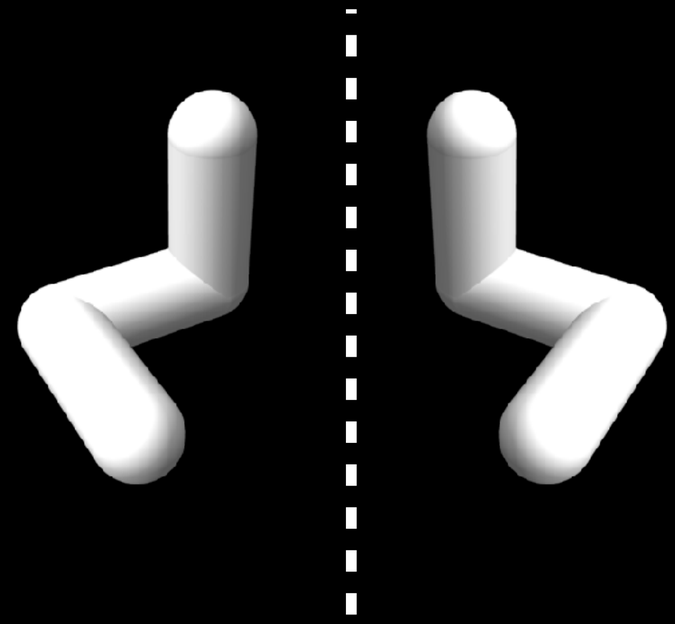
Chiral particles

- Break mirror symmetry



Chiral particles

- Break mirror symmetry



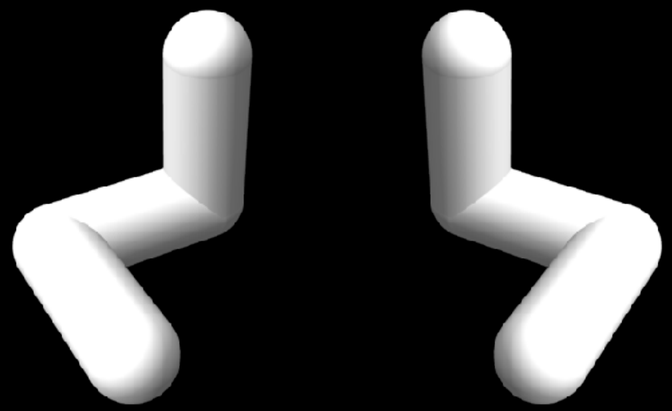
Chiral particles

- Chiral particles in nature
- Maple leaf
- Interesting rotational dynamics

Stephen Dalton

Chiral particles

- Break mirror symmetry
- What are orientation and rotation statistics in turbulence?
- Is there difference between two chiralities?



Chiral particles

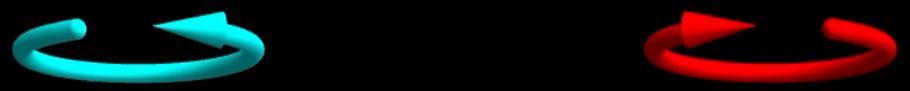
- Translation-rotation coupling
- Settling

Left Right

Chiral particles

- Translation-rotation coupling
- Settling

Chiral particles



- Translation-rotation coupling
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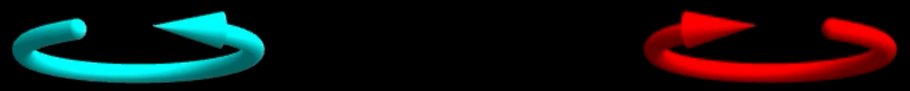
Chiral particles



- Translation-rotation coupling
- Settling

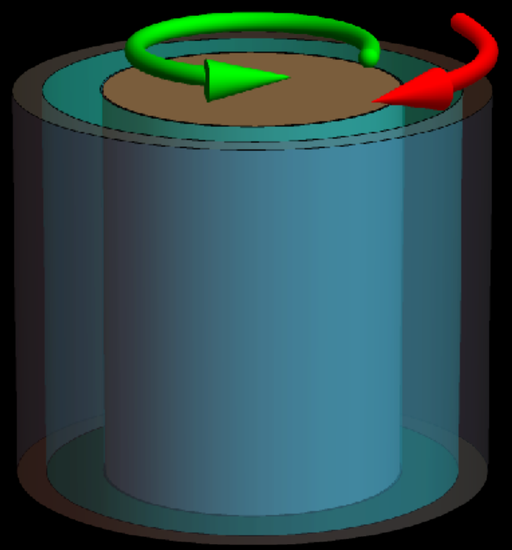
Chiral particles

- Translation-rotation coupling
- Turbulence?

Setup

Taylor–Couette turbulence

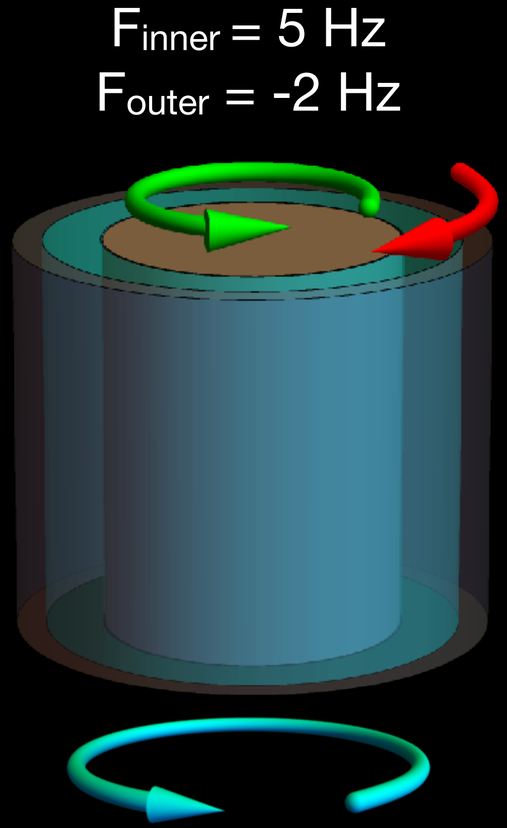
- Taylor–Couette
- Counter-rotation



Setup

Taylor–Couette turbulence

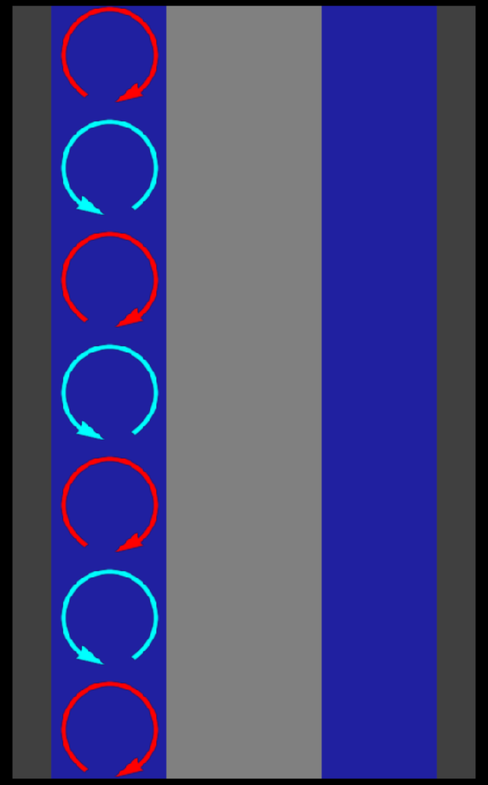
- Taylor–Couette
- Counter-rotation



Setup

Taylor–Couette turbulence

- Taylor–Couette
- Counter-rotation
- Taylor vortices



Setup

Taylor-Couette turbulence

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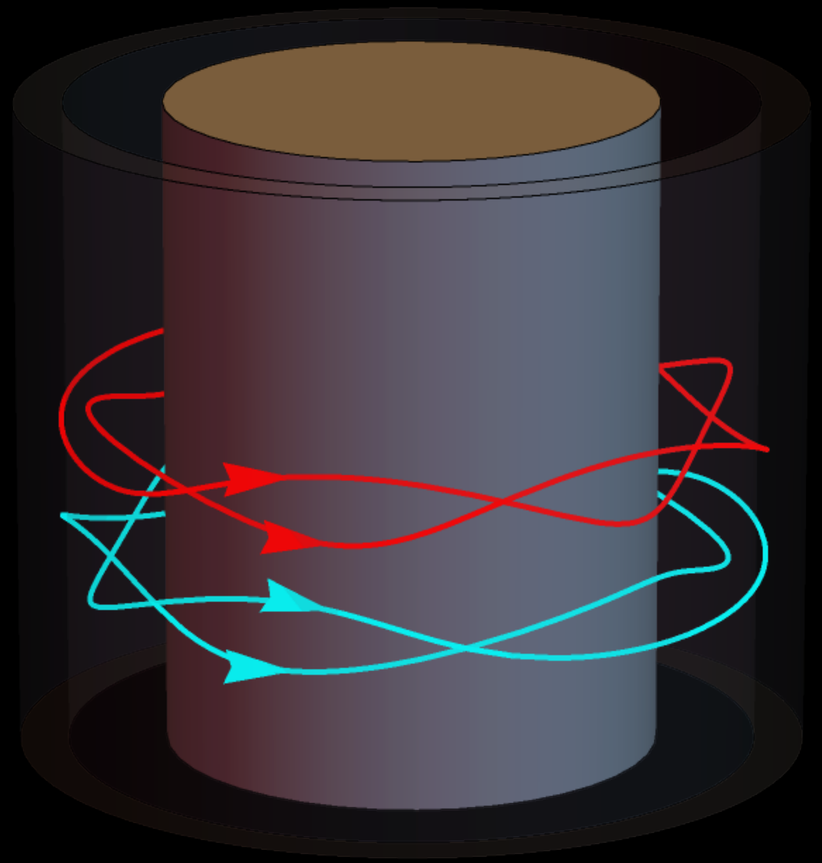
- Taylor Vortices

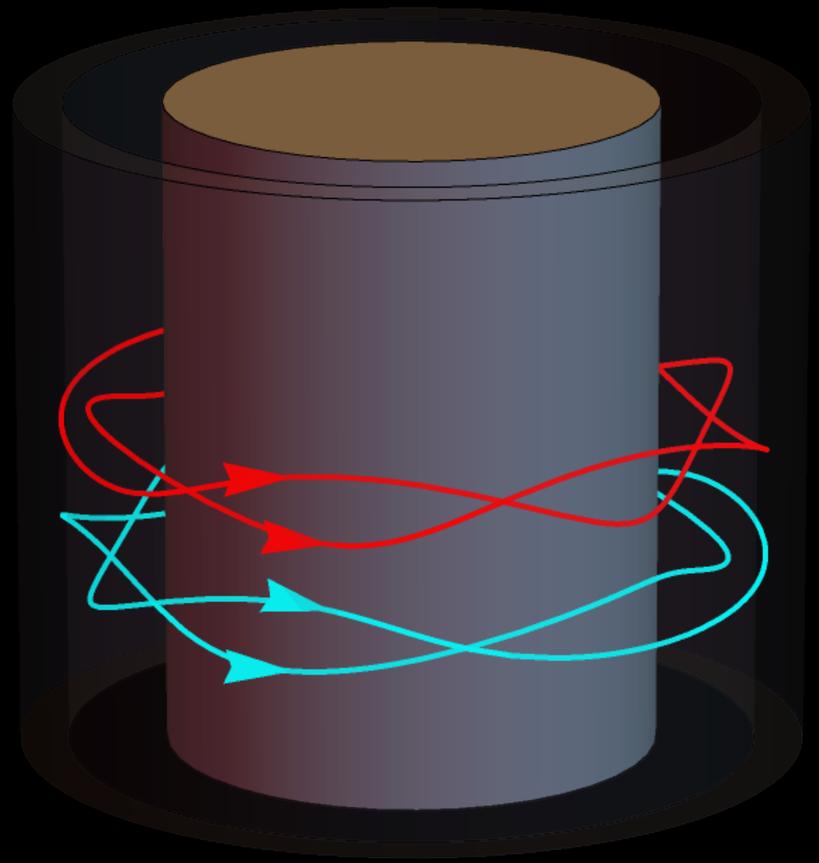


Setup

Taylor-Couette turbulence

Left

Right



Setup

Taylor-Couette turbulence

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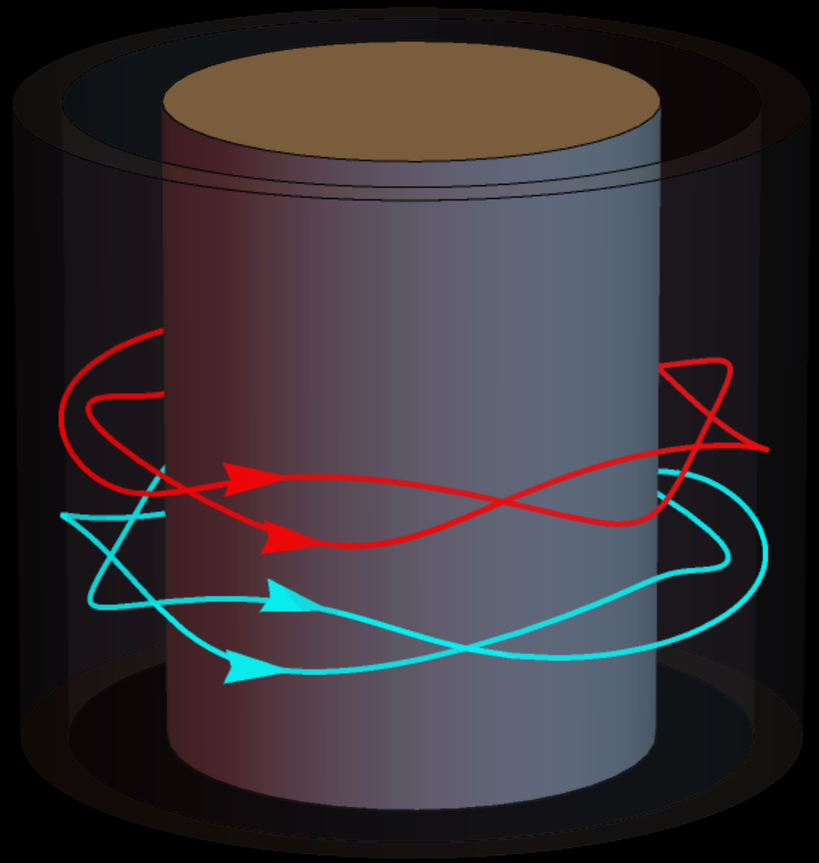

Setup

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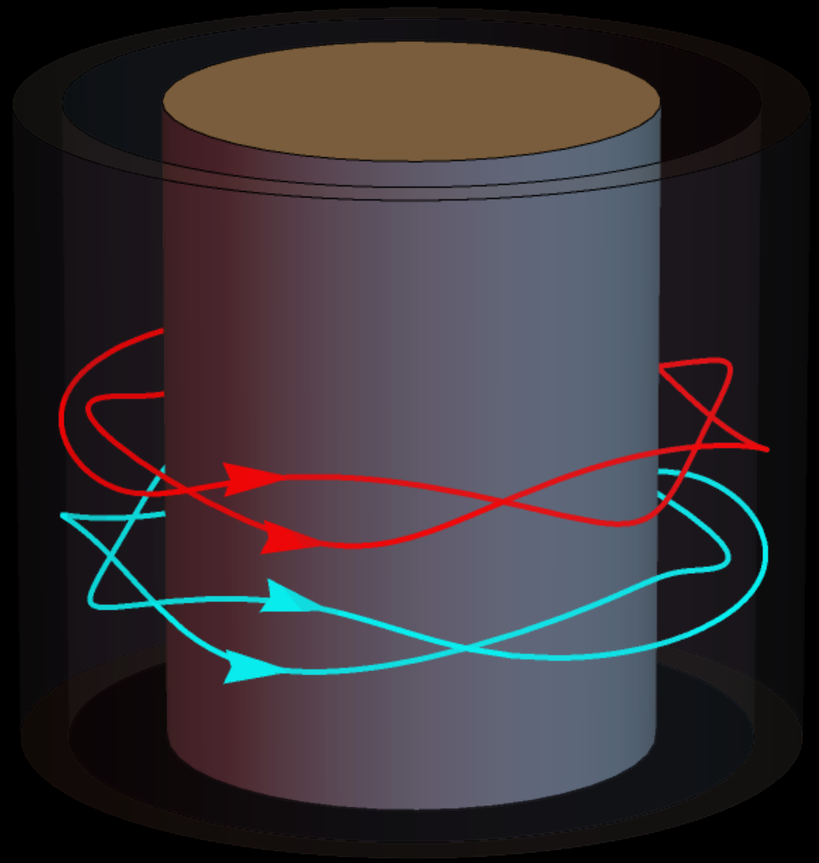

Setup

Taylor-Couette turbulence

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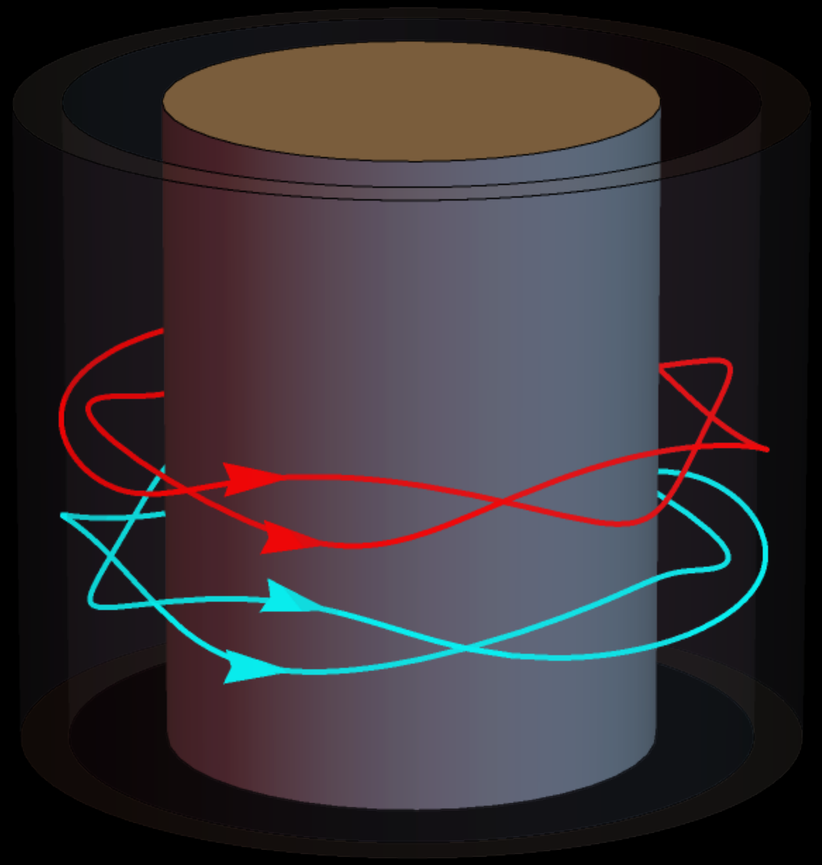

Setup

Taylor-Couette turbulence

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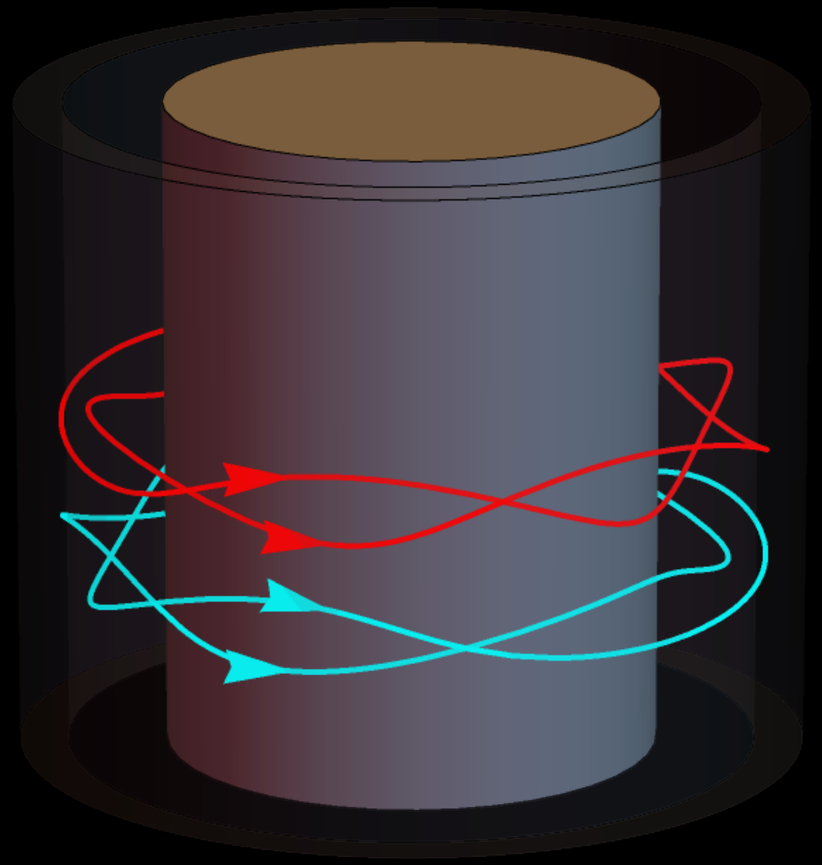

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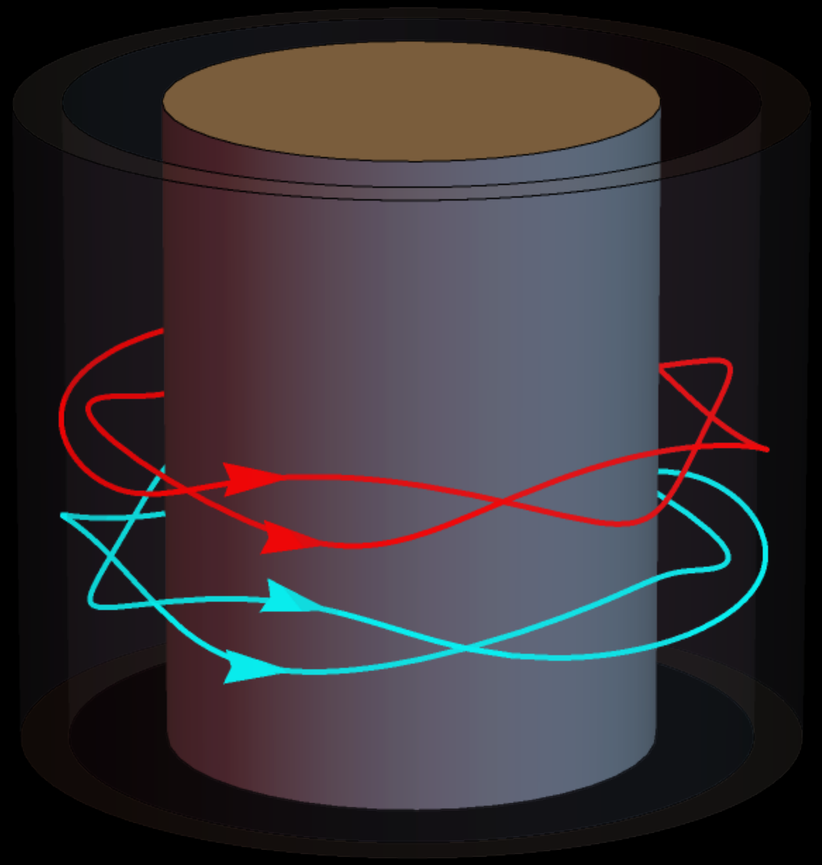
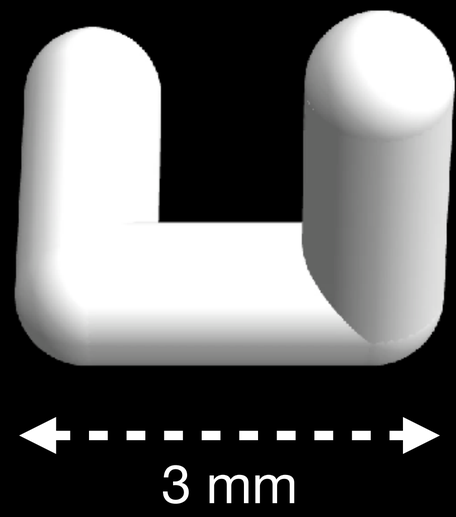
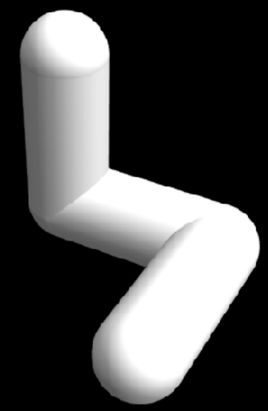
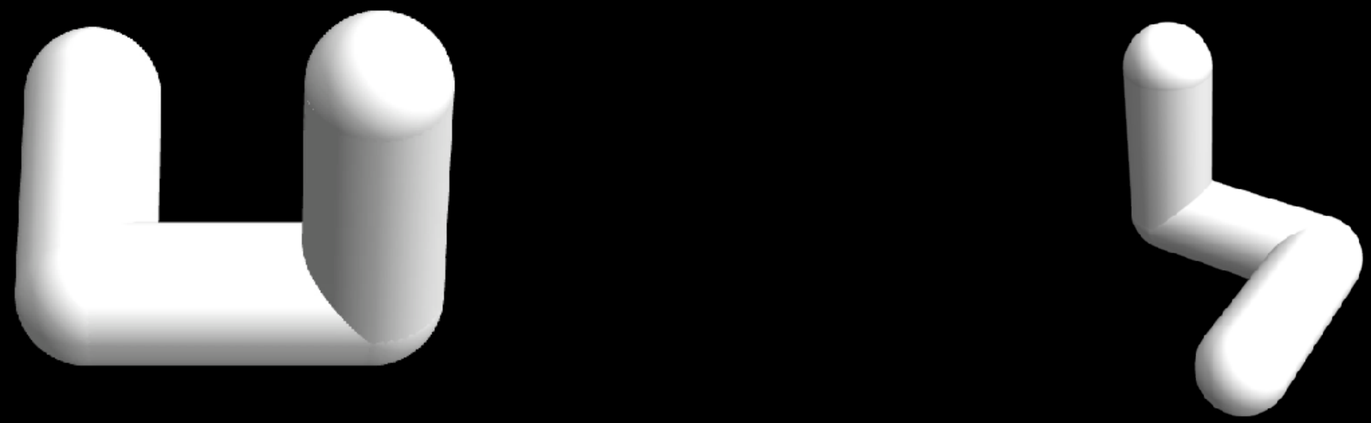


Measurement



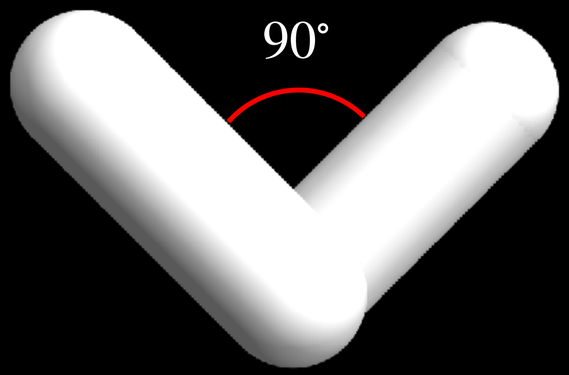


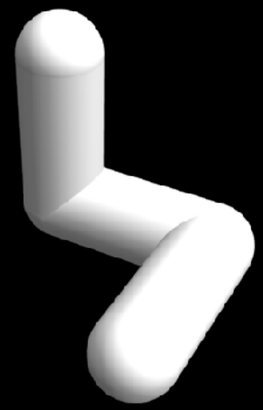
Measurement



Measurement

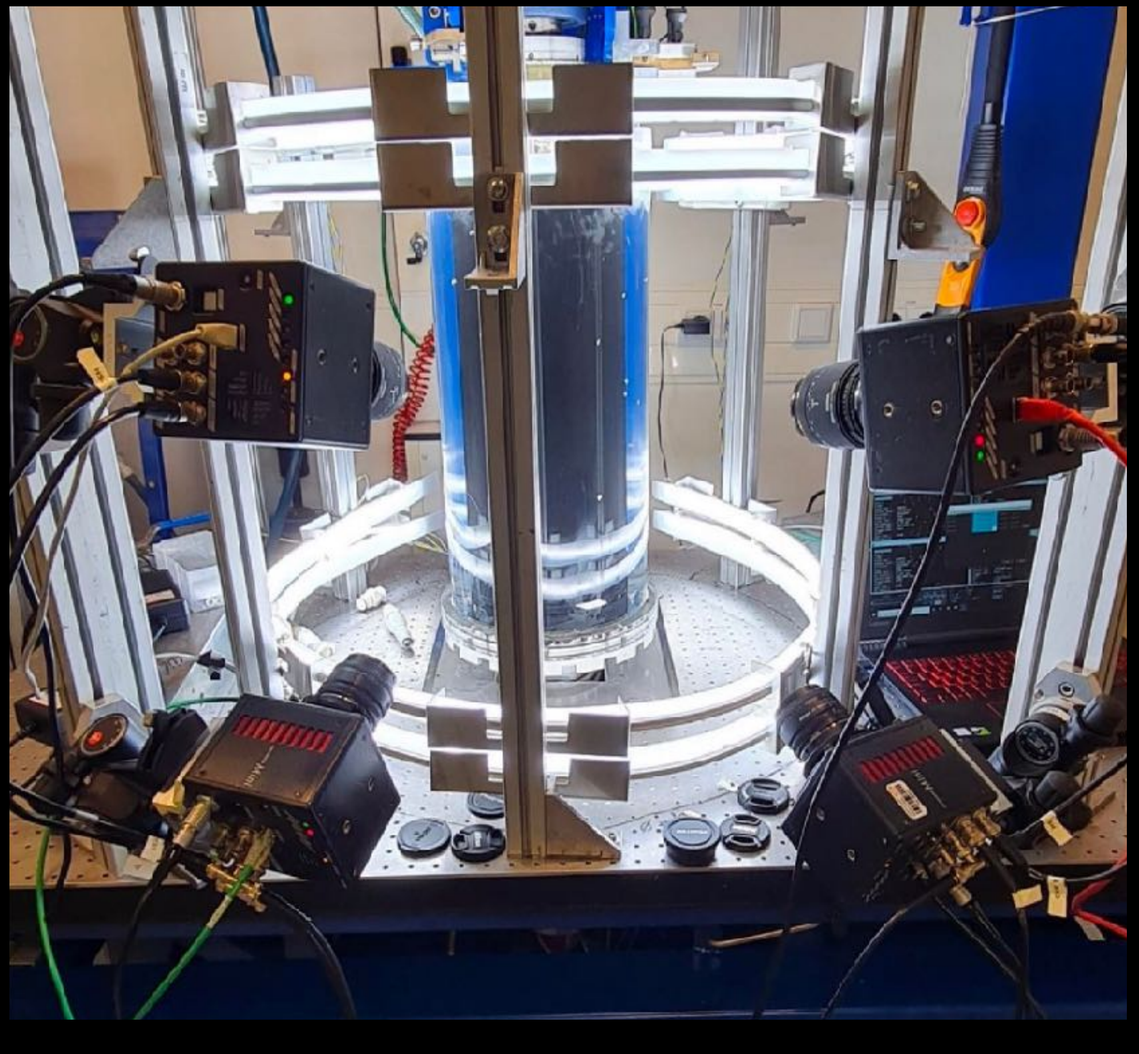
Measurement





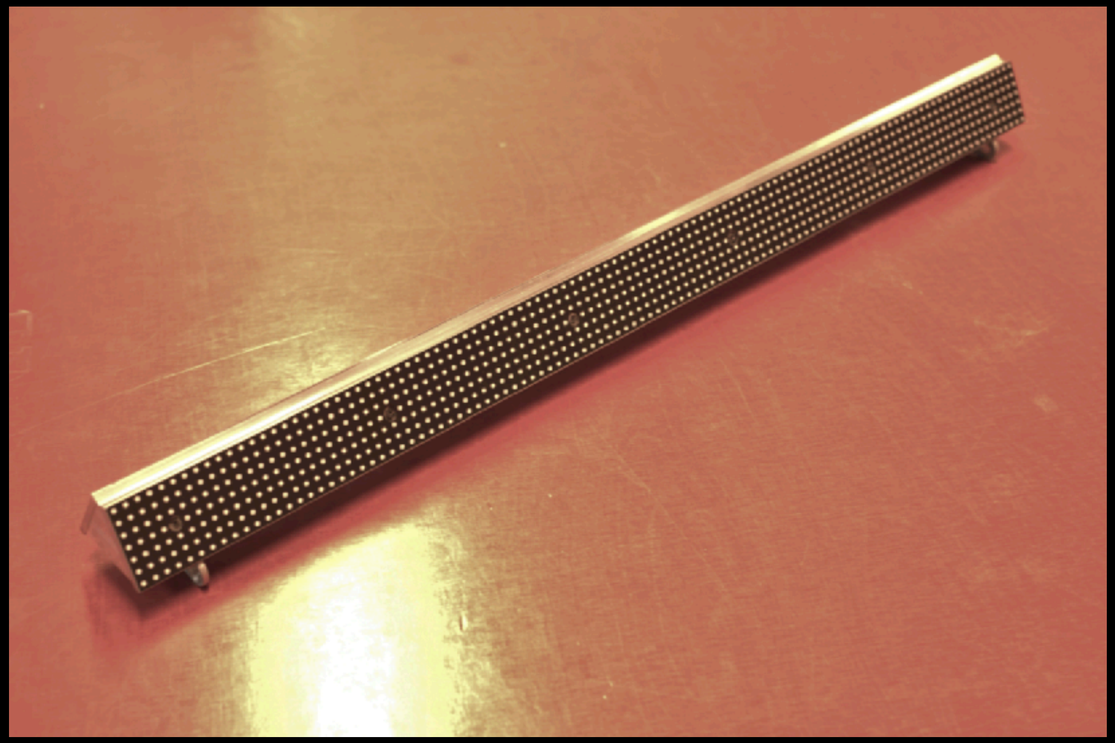
Measurement

- Image small part of setup
- 4 high-speed cameras
  Photron AX200 with
  50 mm objectives
  135 µm/px
  8 cm × 3 cm × 15 cm

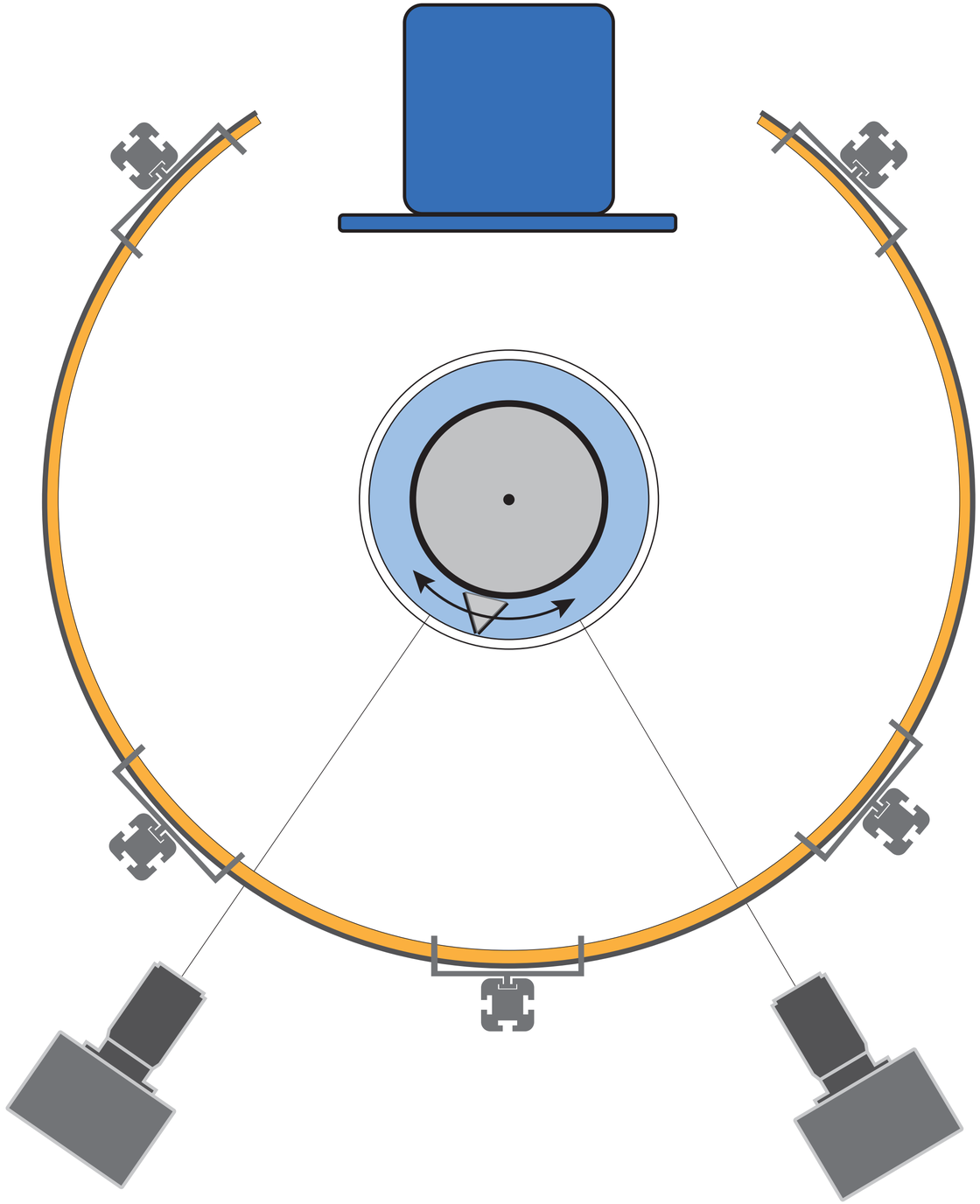


Calibration

- Triangular target mounted to inner cylinder



Calibration



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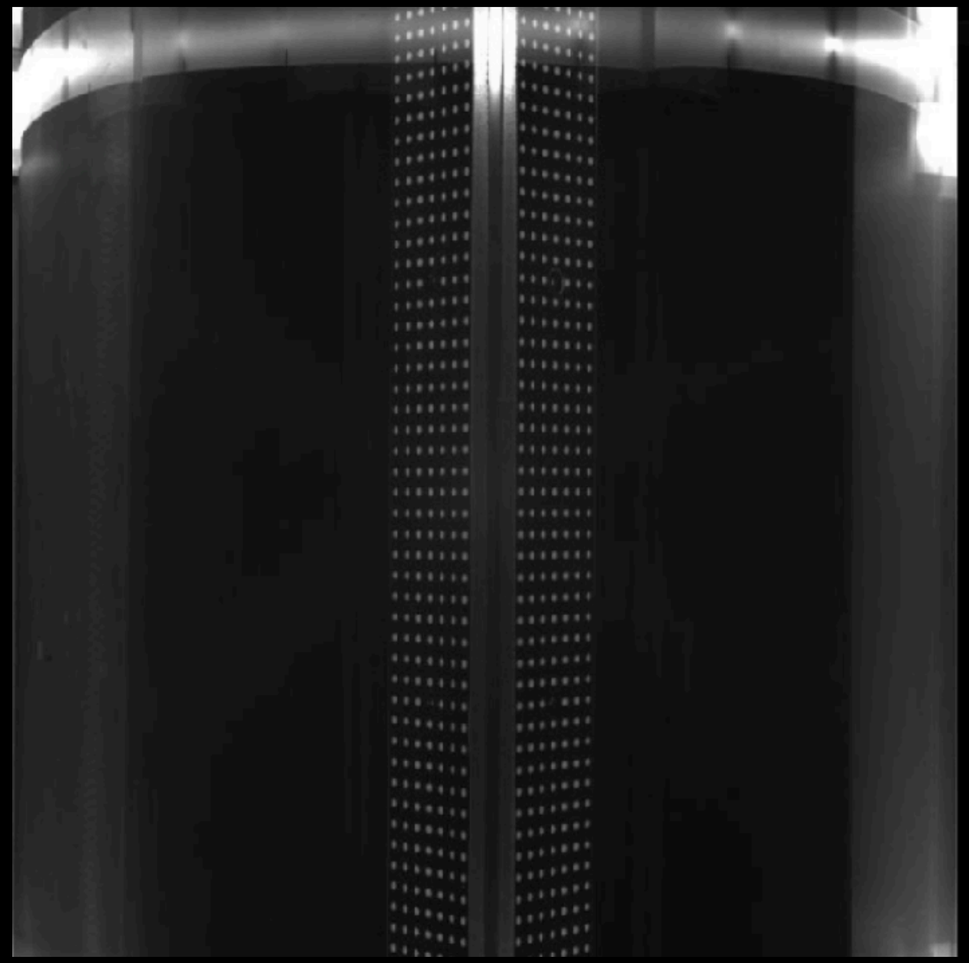
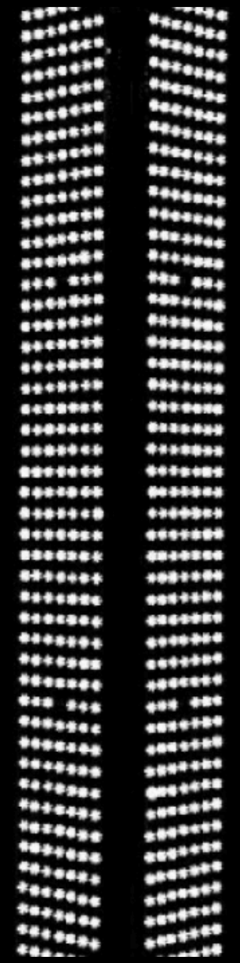
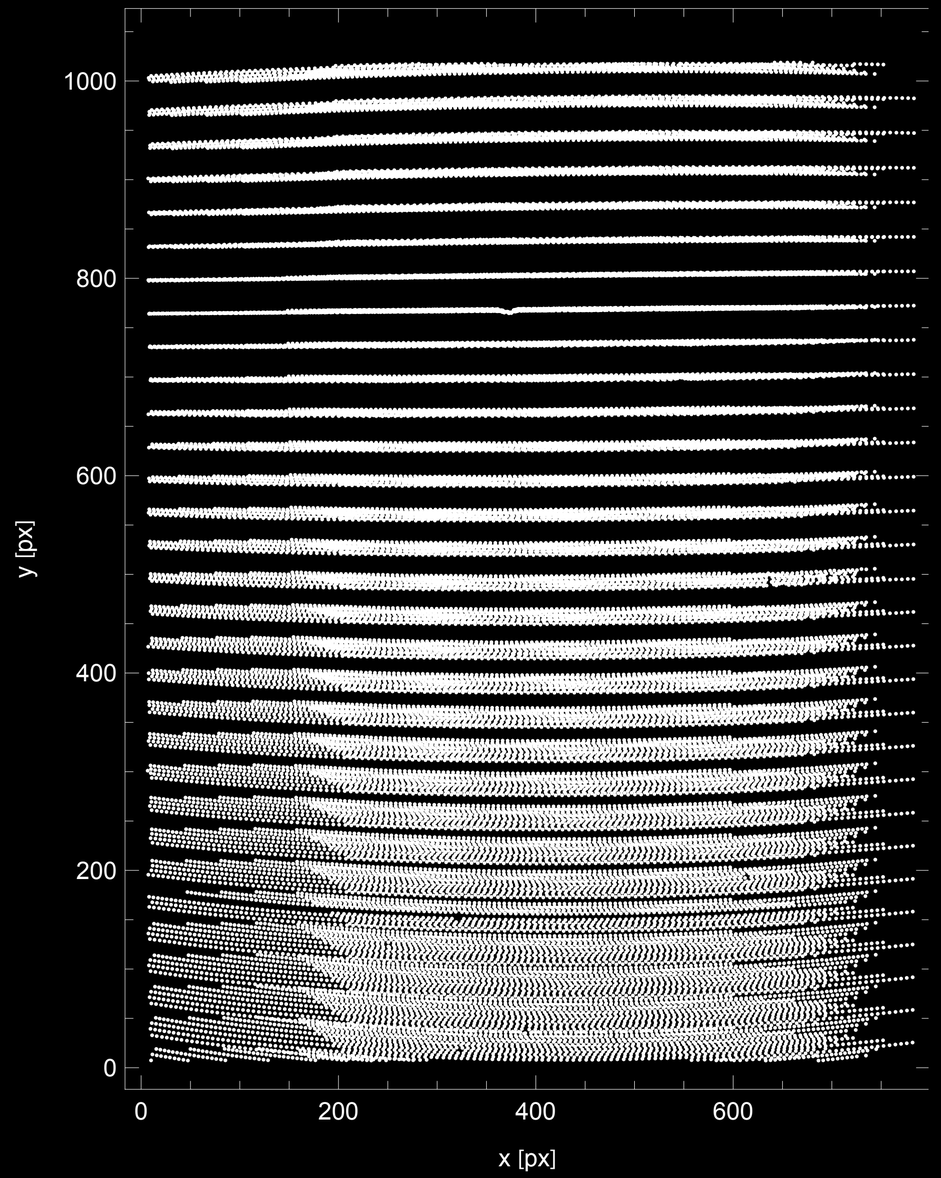
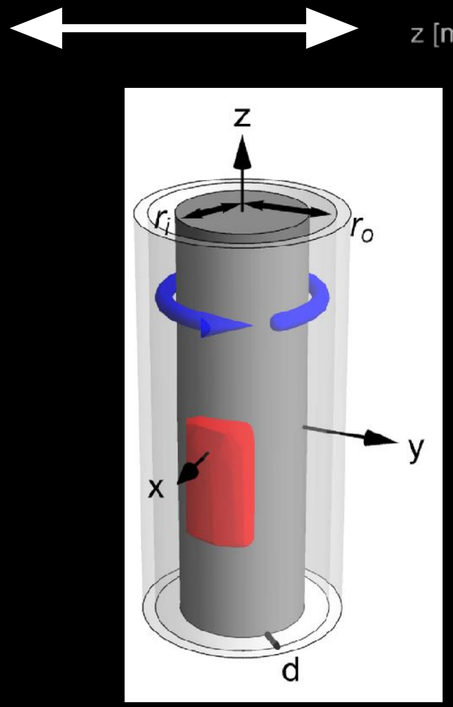
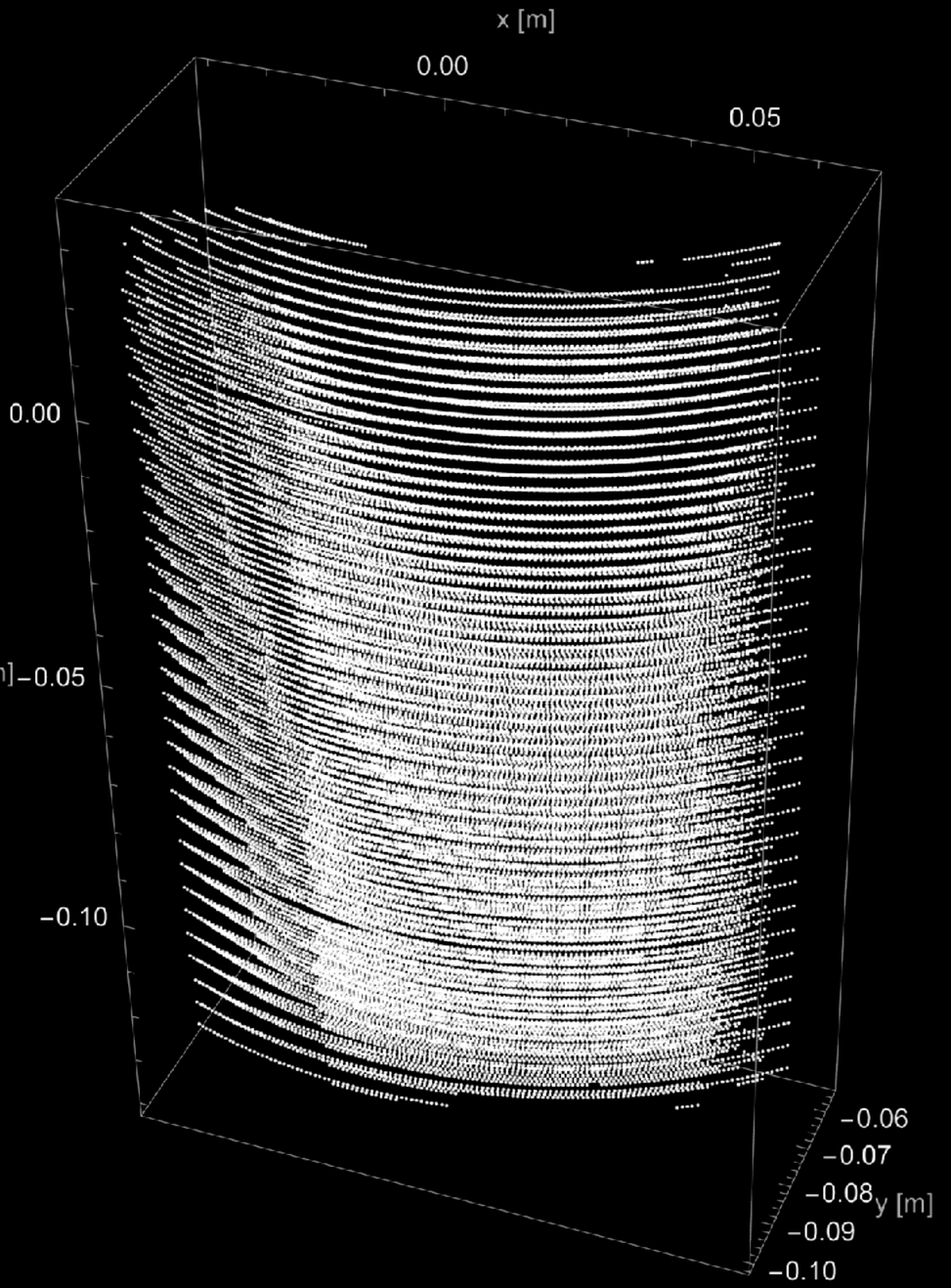




Calibration 2D and 3D points







Measurement

- $Re_w = \frac{u'(r_{out} - r_{in})}{\nu} = 4.6 \cdot 10^3$
- $Re_p = \frac{u' L_{particle}}{\nu} = 4.6 \cdot 10^2$
- $Stk = \frac{t_0 u'}{L_{particle}} = 25$

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Particle tracking

Particle tracking

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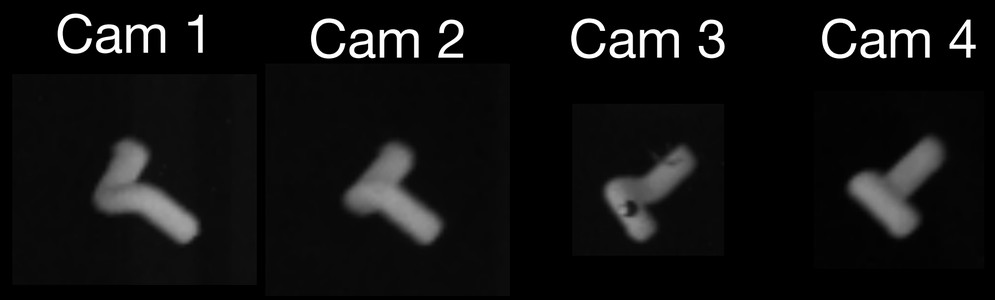
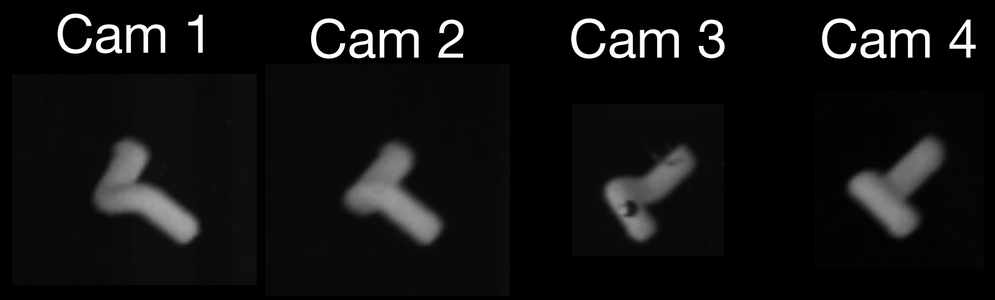
Particle tracking

Experimental images



Particle tracking

Experimental images

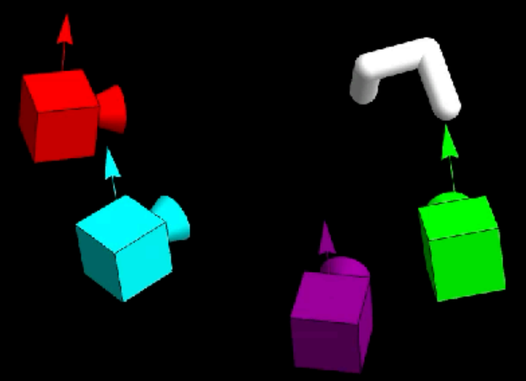


Particle tracking

Cam 1 Cam 2 Cam 3 Cam 4

Experimental images

Synthetic projections



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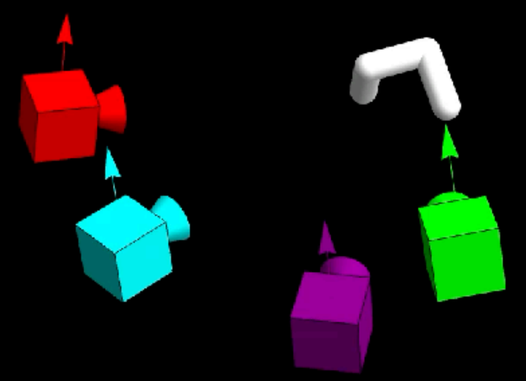

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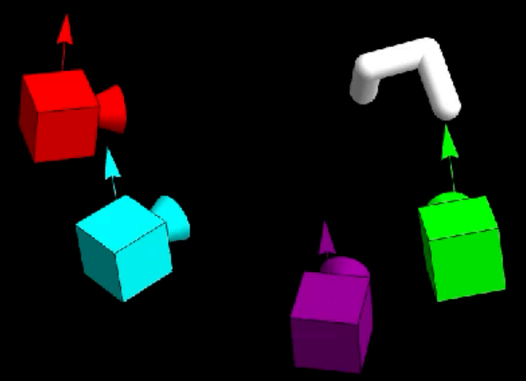
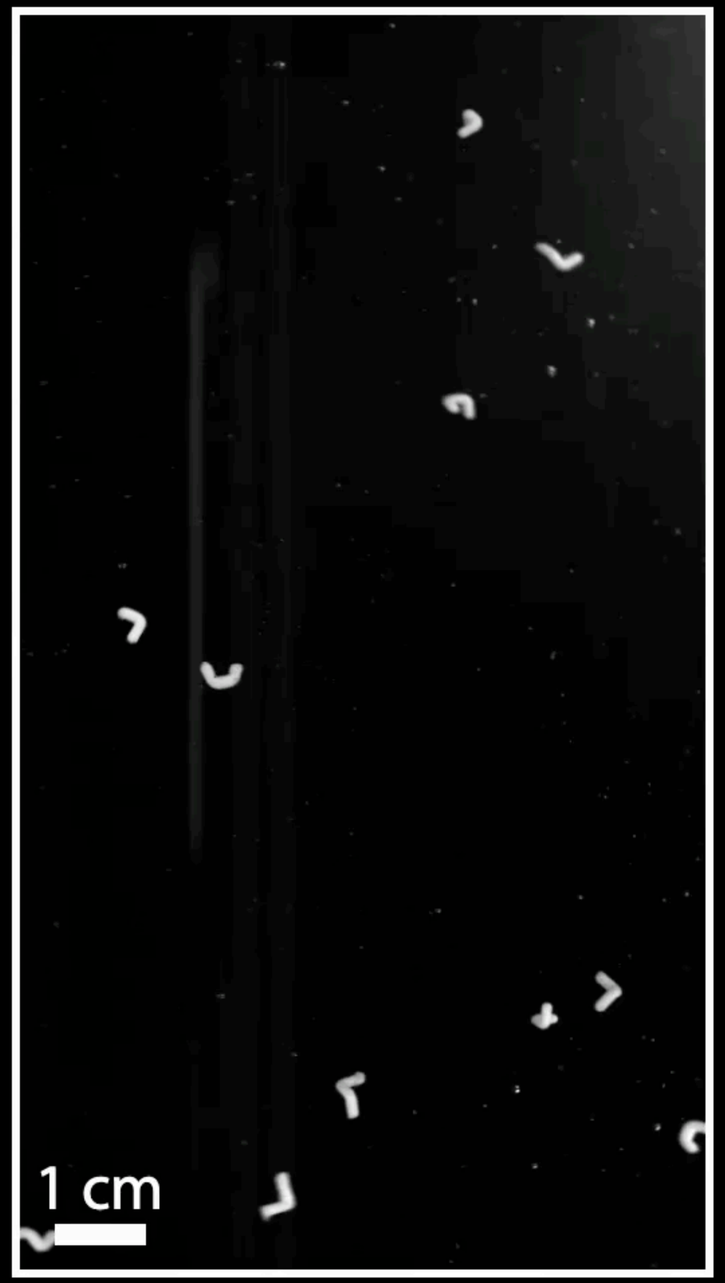
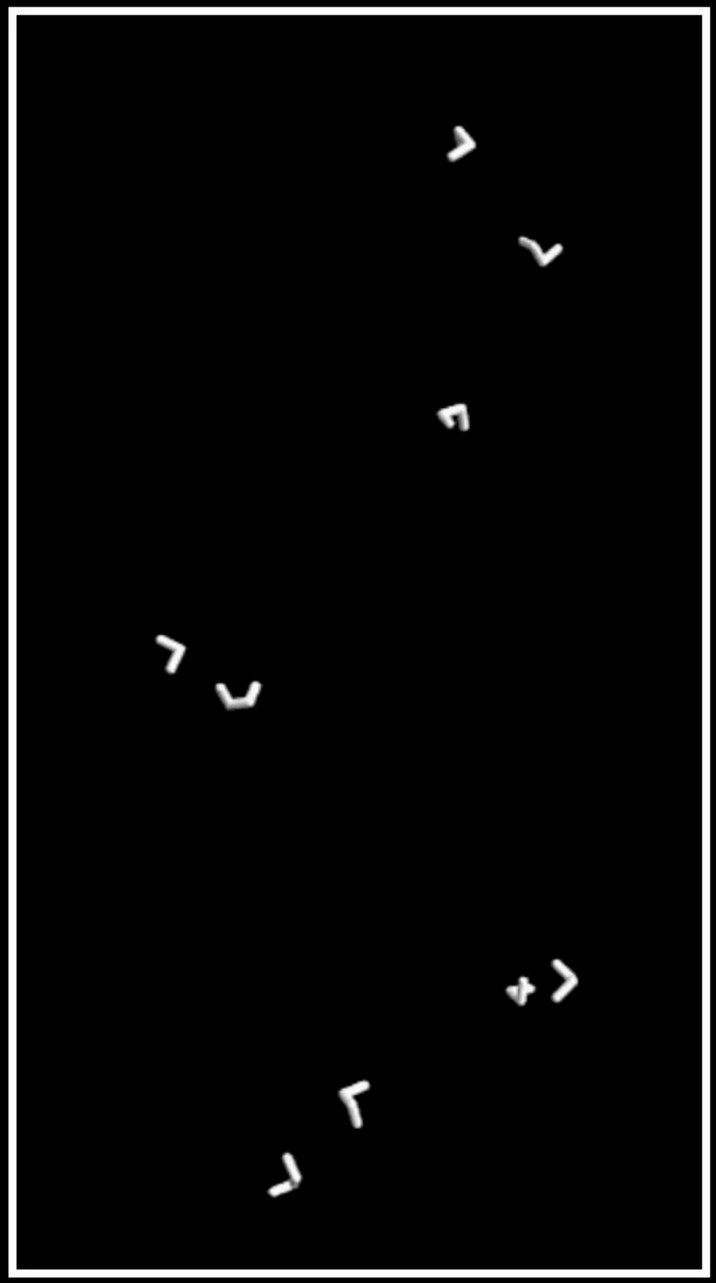


Raw video

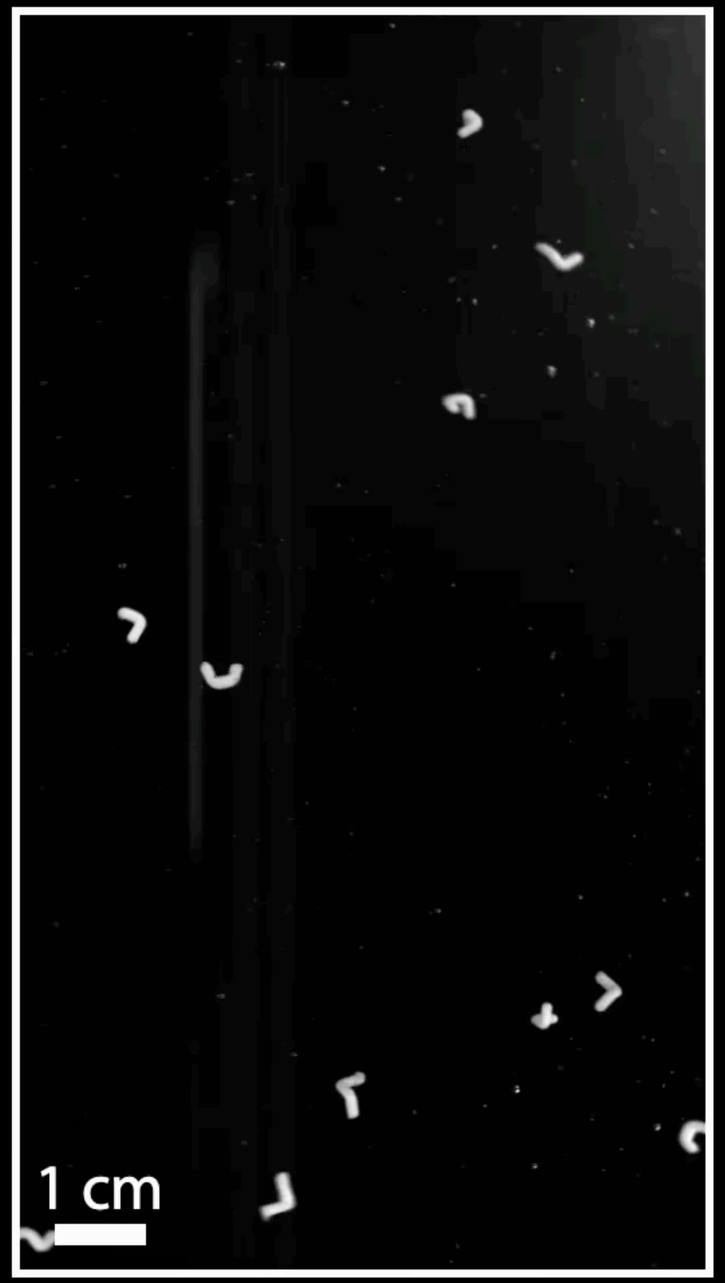


Reconstruction



Slowed 33x

Raw video



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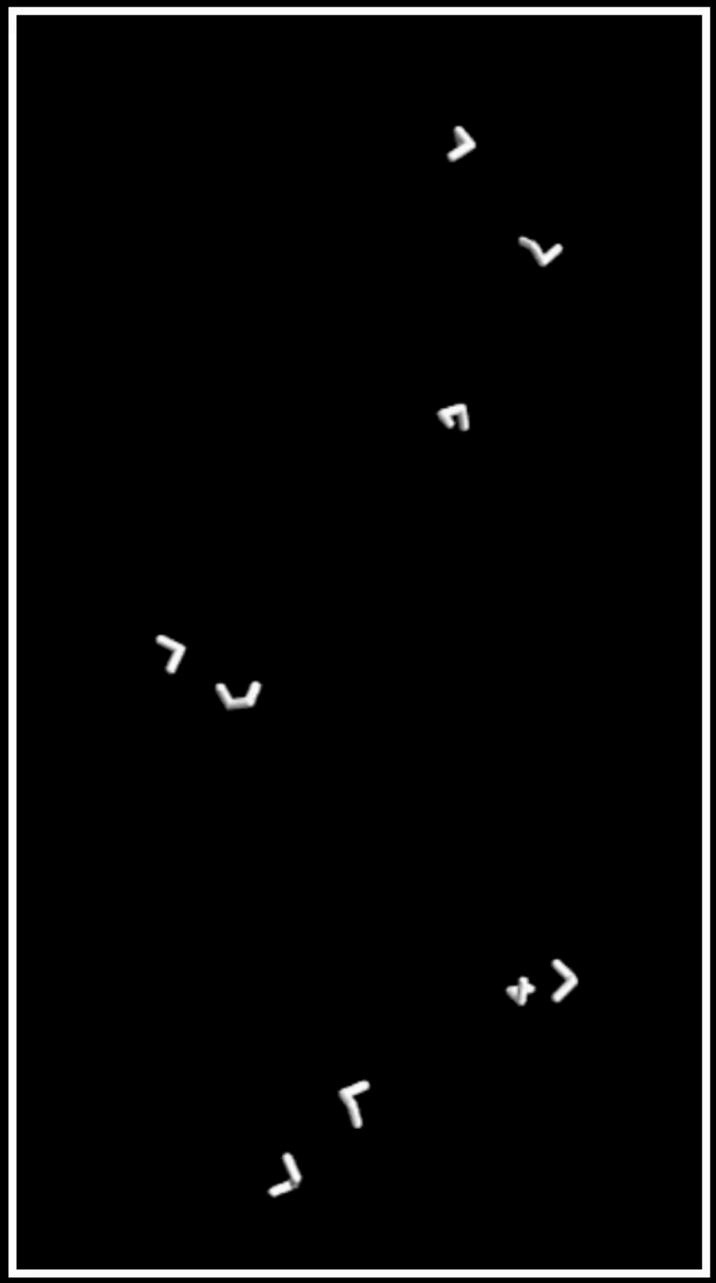
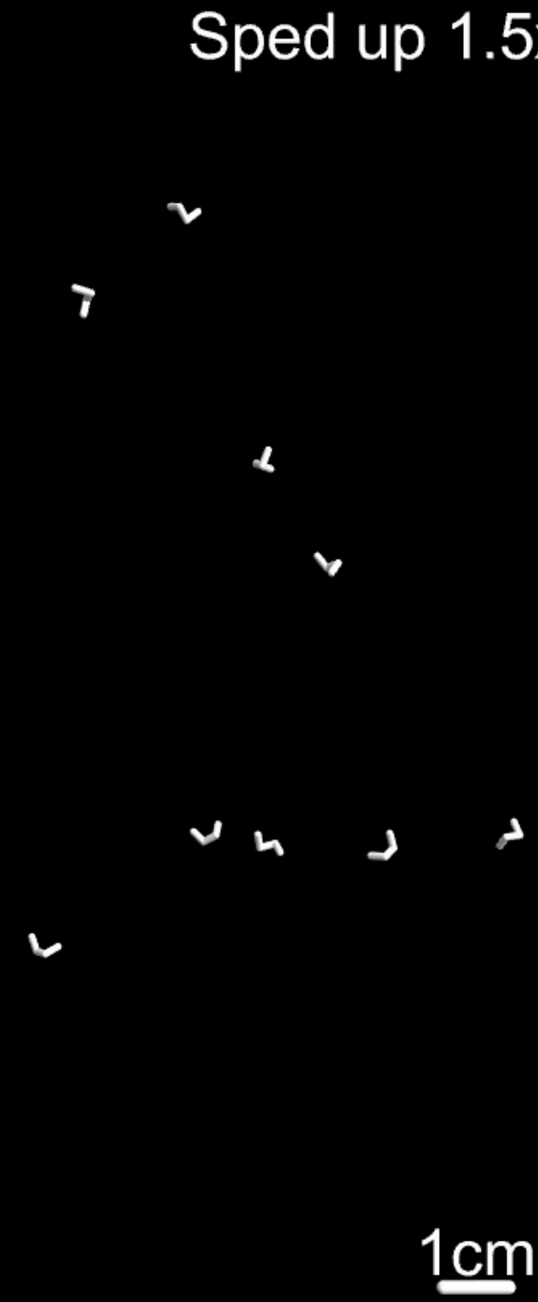


Slowed 33x

Particle tracks

Taylor vortices



Particle tracks

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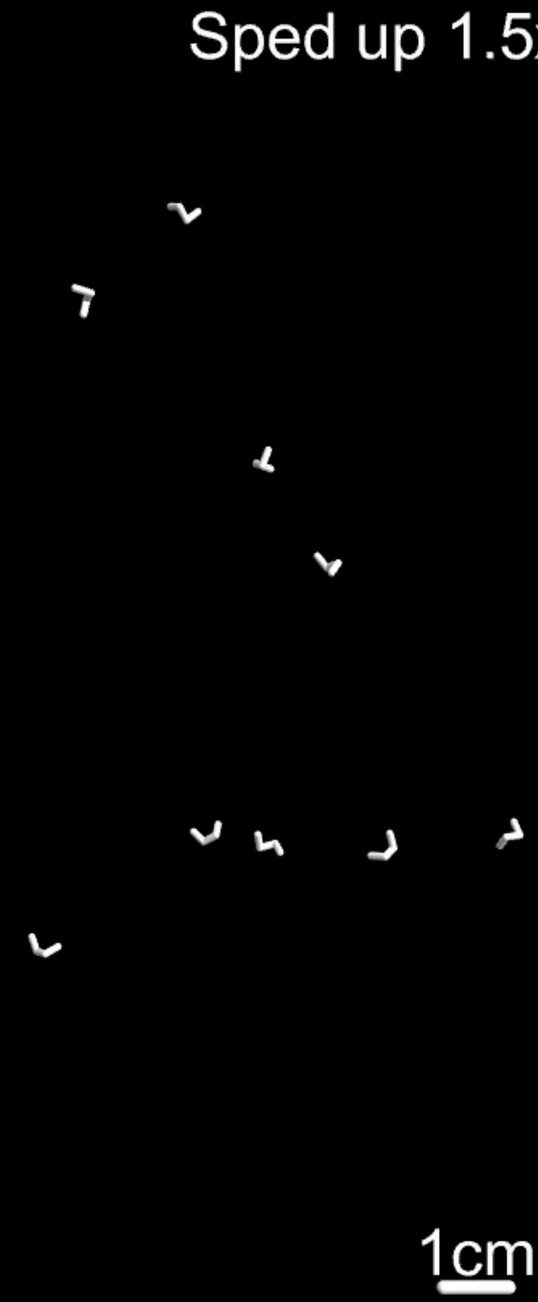
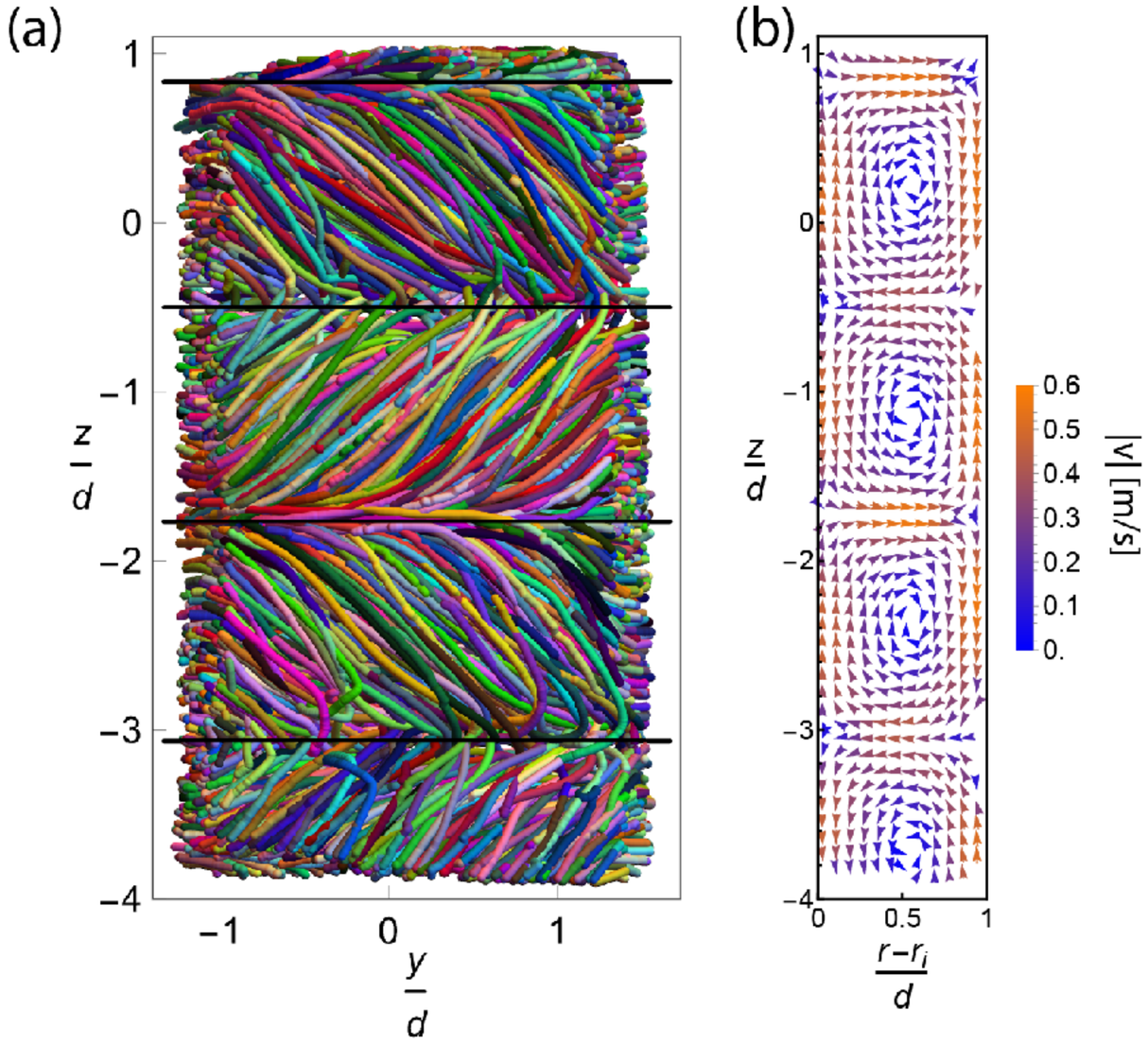


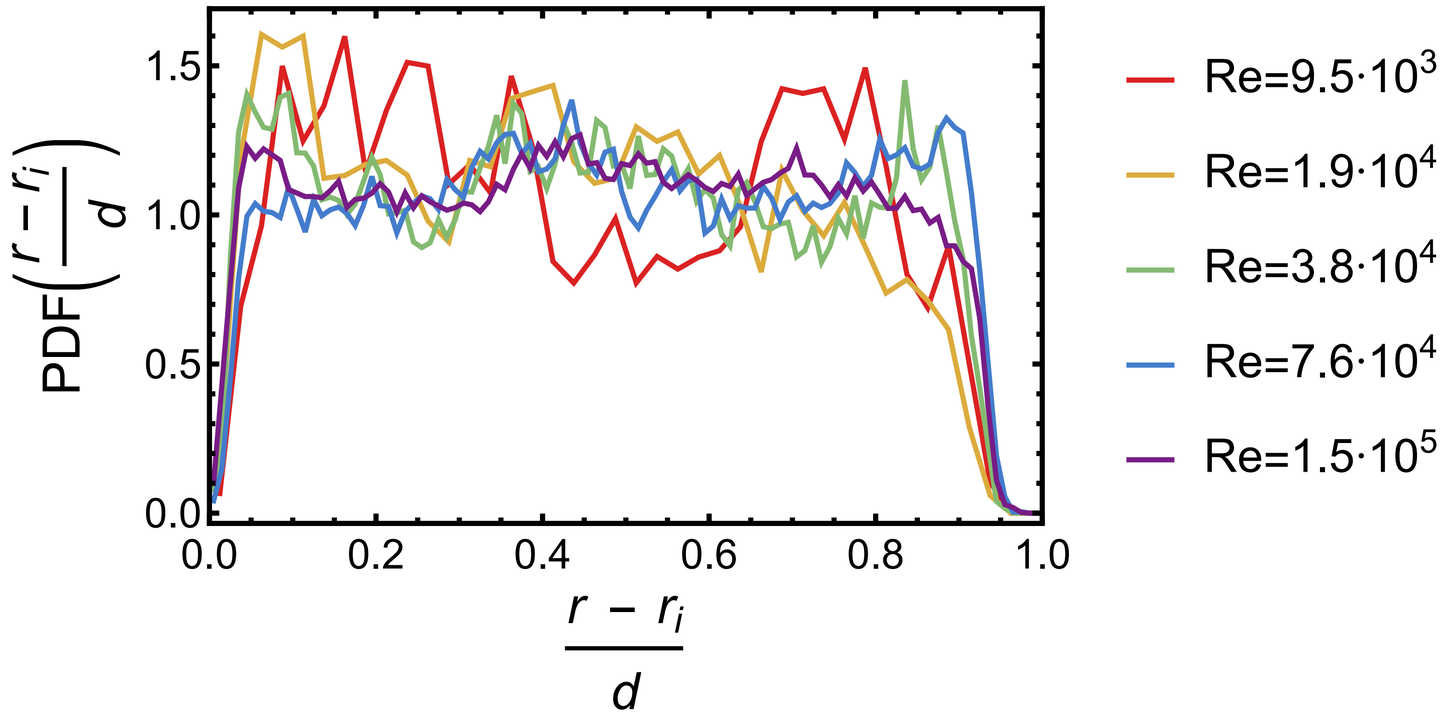
Particle tracks



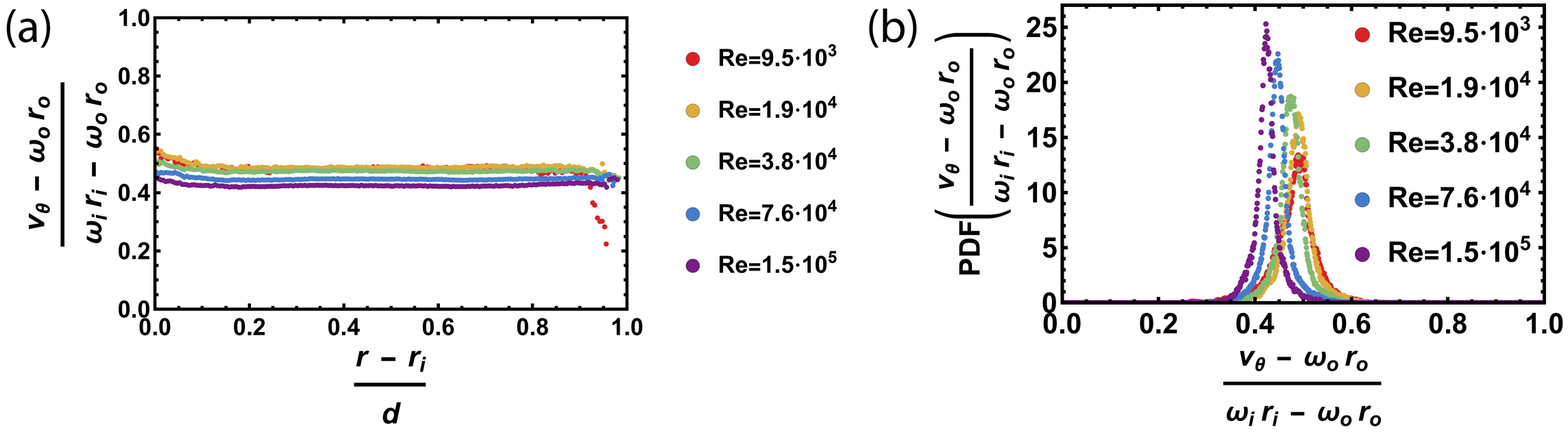
Experiments

$\omega_i/(2\pi)$ (1/s)	$\omega_o/(2\pi)$ (1/s)	Re	Ta	ϵ (m^2/s^3)	τ_η (s)	η_k (m)	Stk
0.625	−0.25	$9.5 \cdot 10^3$	$1.4 \cdot 10^8$	$4.0 \cdot 10^{-3}$	$1.8 \cdot 10^{-2}$	$1.5 \cdot 10^{-4}$	59
1.25	−0.5	$1.9 \cdot 10^4$	$5.5 \cdot 10^8$	$2.6 \cdot 10^{-2}$	$7.0 \cdot 10^{-3}$	$9.6 \cdot 10^{-5}$	$1.5 \cdot 10^2$
2.5	−1	$3.8 \cdot 10^4$	$2.2 \cdot 10^9$	$1.7 \cdot 10^{-1}$	$2.7 \cdot 10^{-3}$	$6.0 \cdot 10^{-5}$	$3.9 \cdot 10^2$
5	−2	$7.6 \cdot 10^4$	$8.8 \cdot 10^9$	1.1	$1.0 \cdot 10^{-3}$	$3.7 \cdot 10^{-5}$	$1.0 \cdot 10^3$
10	−4	$1.5 \cdot 10^5$	$3.5 \cdot 10^{10}$	7.6	$4.1 \cdot 10^{-4}$	$2.3 \cdot 10^{-5}$	$2.5 \cdot 10^3$

Particle distribution

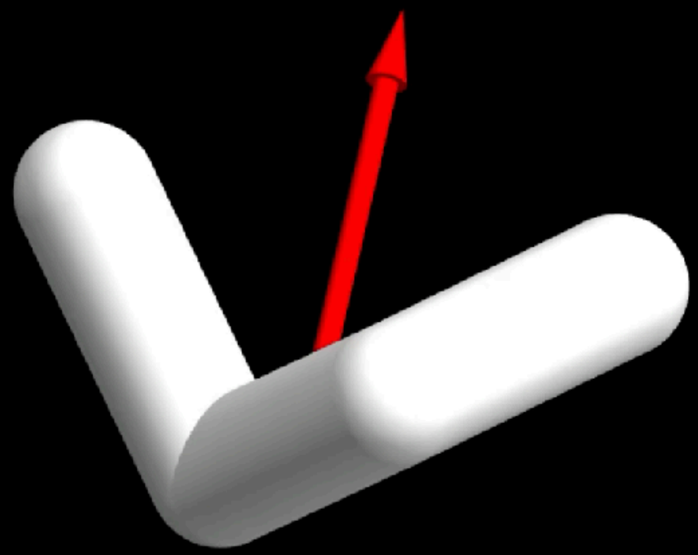


Particle velocities



Orientation statistics

- Follow particle in Lagrangian frame
- Find orientation statistics



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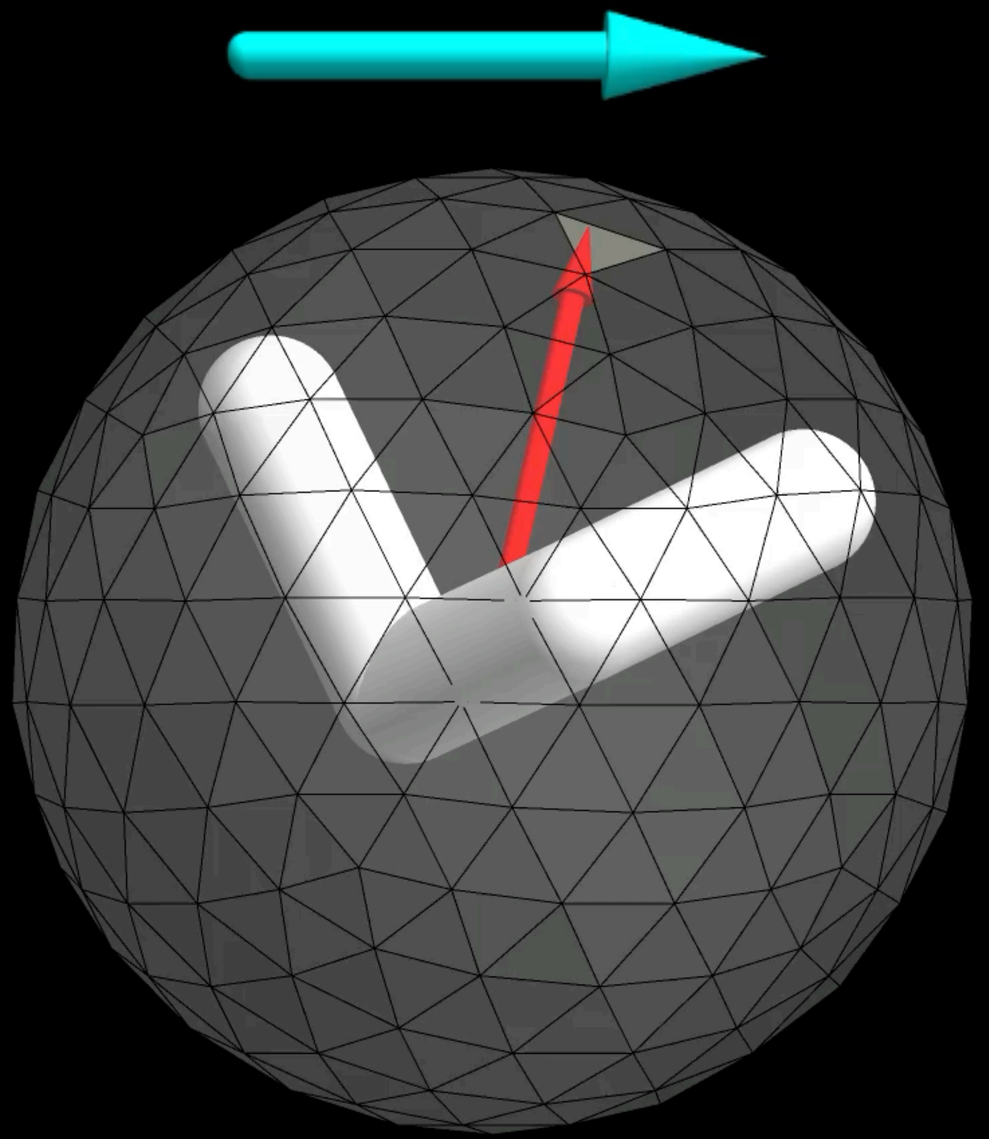
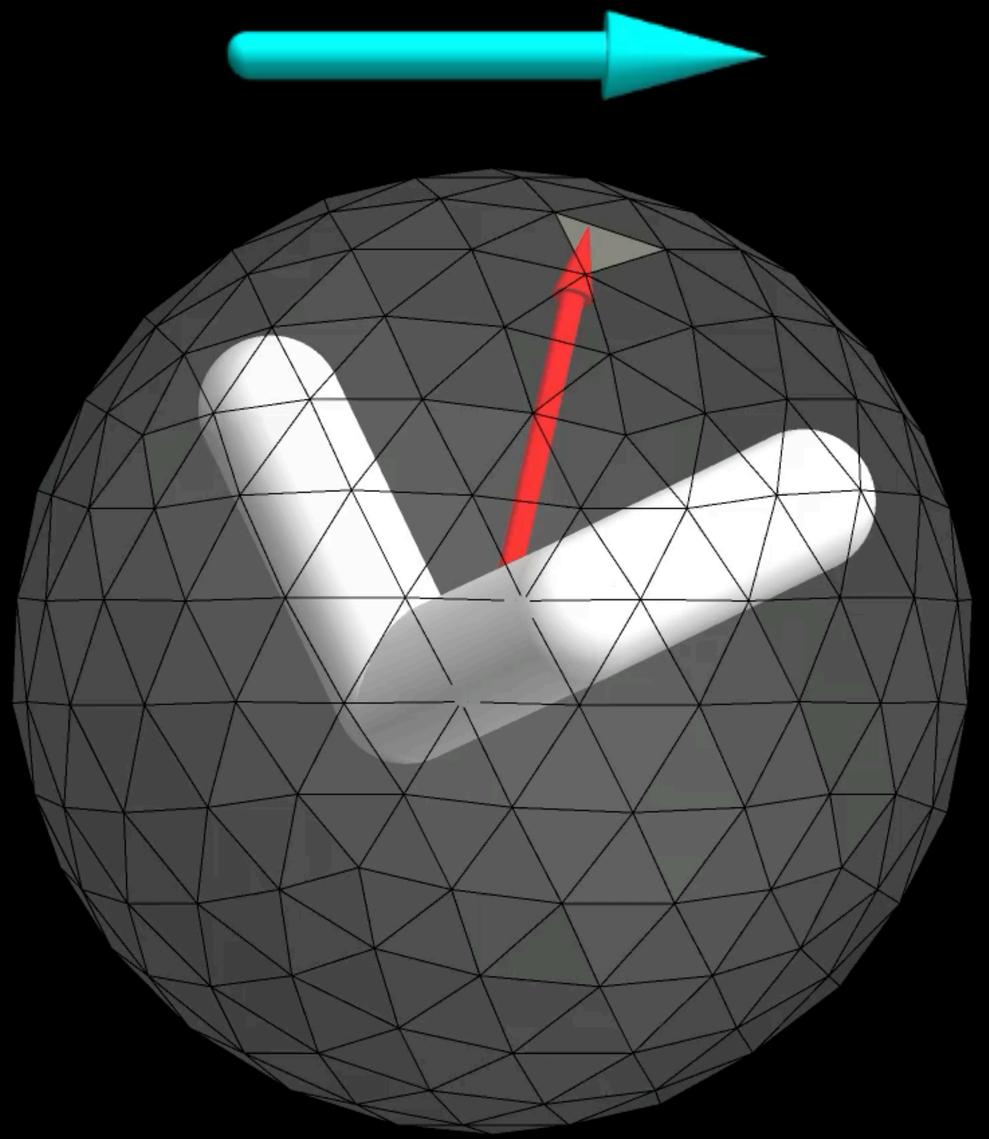
- Follow particle in Lagrangian frame
- Find orientation statistics

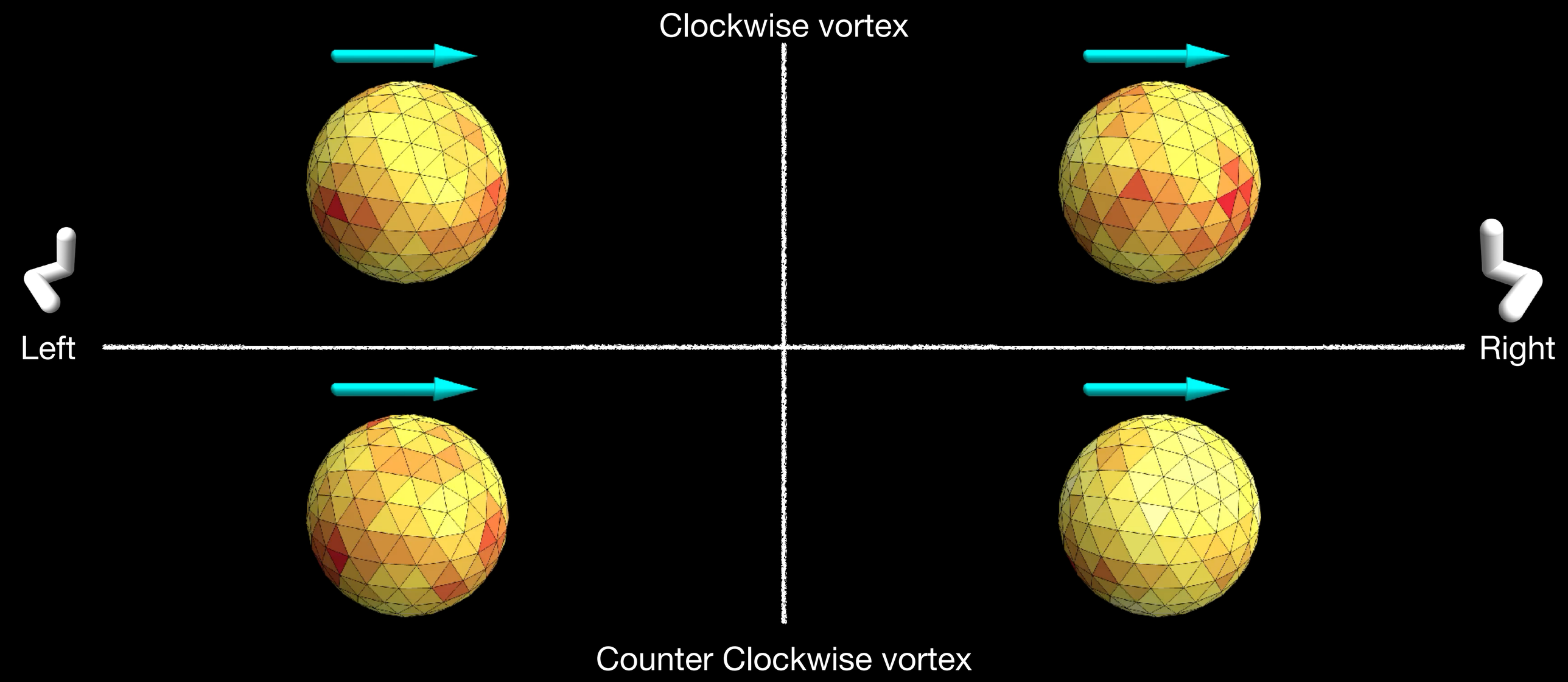


Orientation statistics

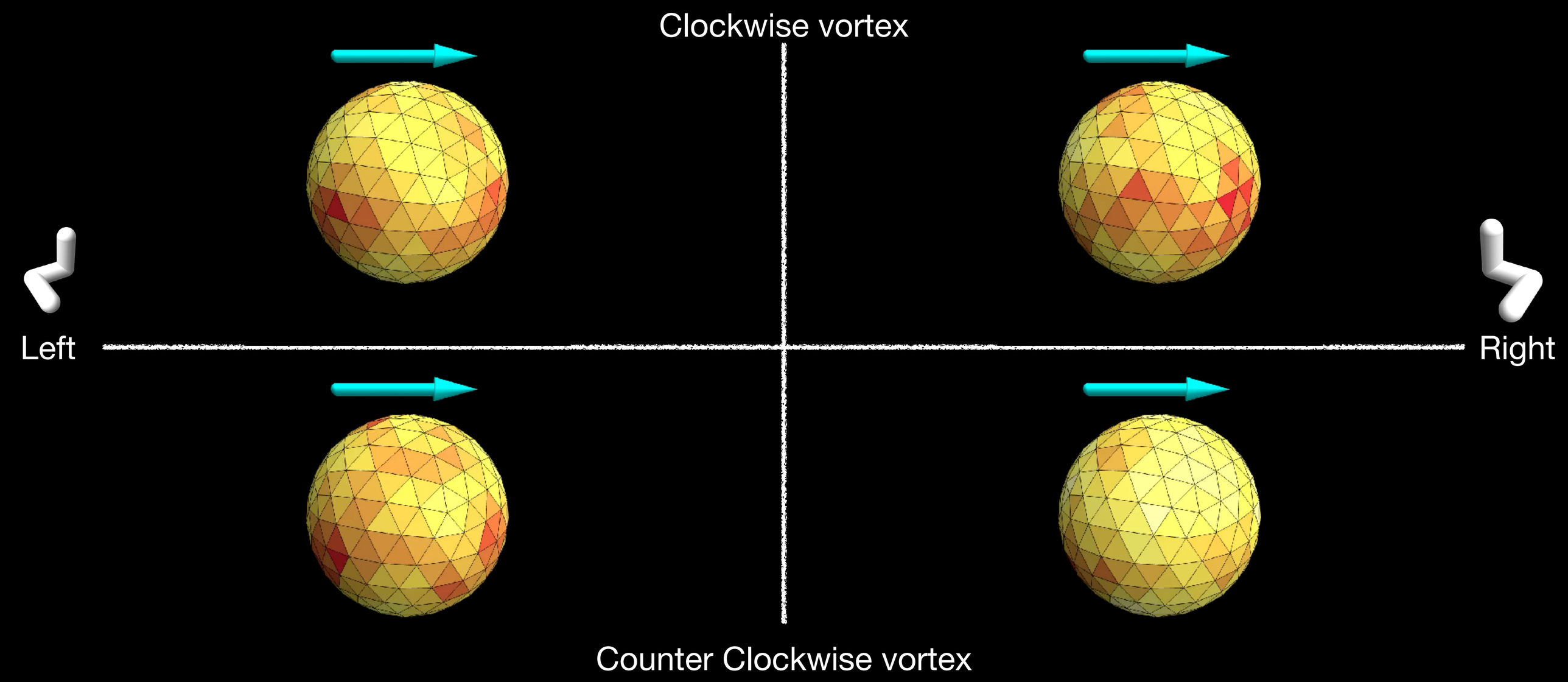
- Follow particle in Lagrangian frame
- Find orientation statistics



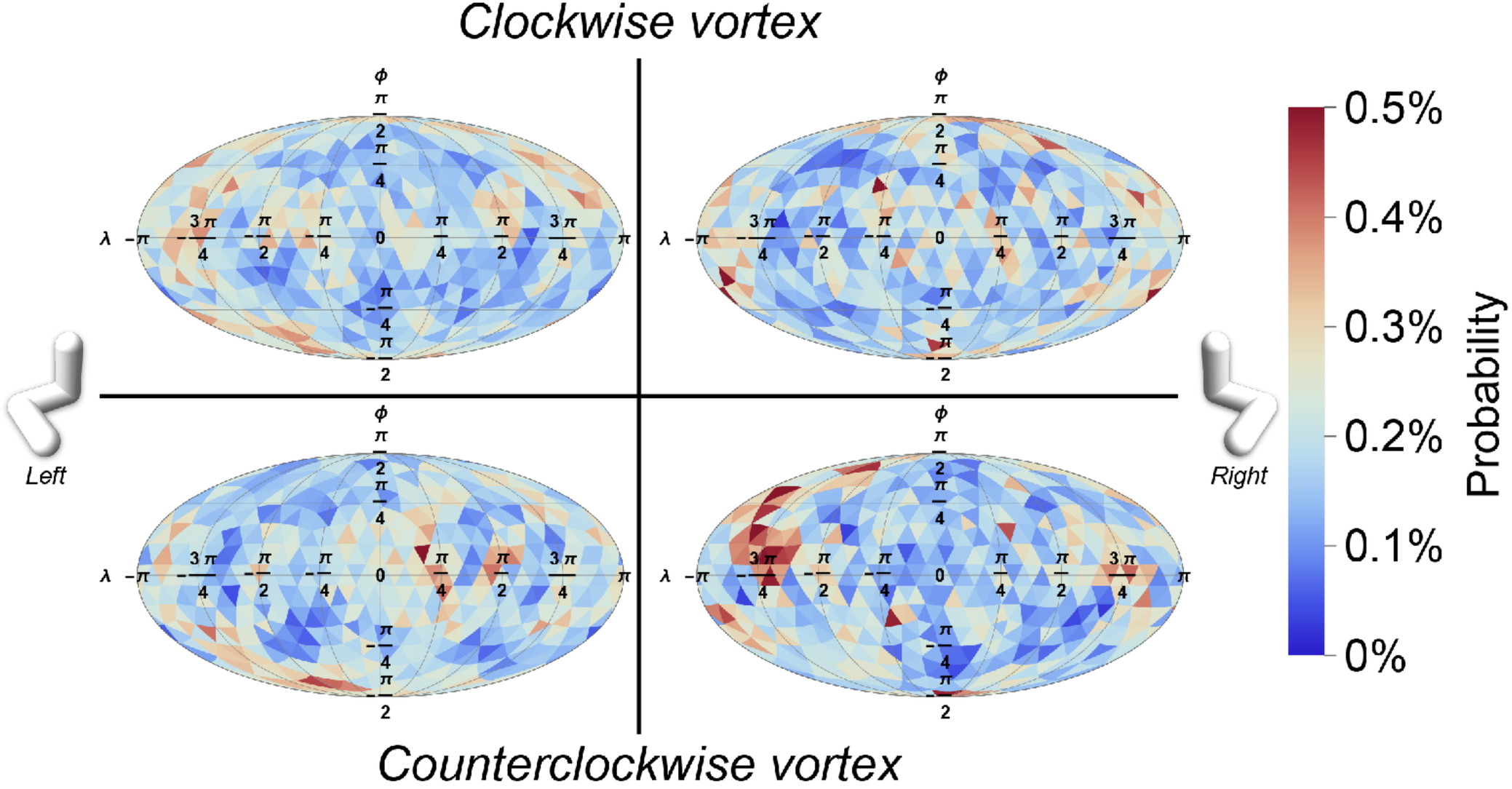
Orientation statistics



Orientation statistics

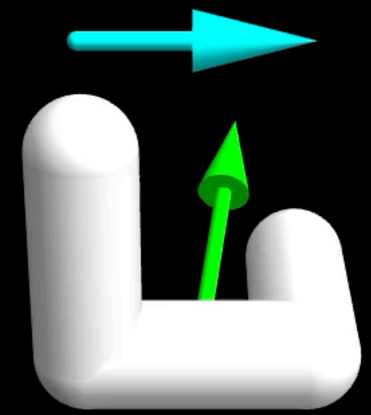


Orientation statistics



Rotation statistics

- Is there a preferred rotation direction?
- Find most occurring rotation directions



Rotation statistics

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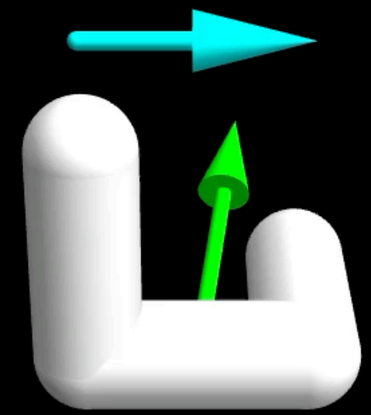
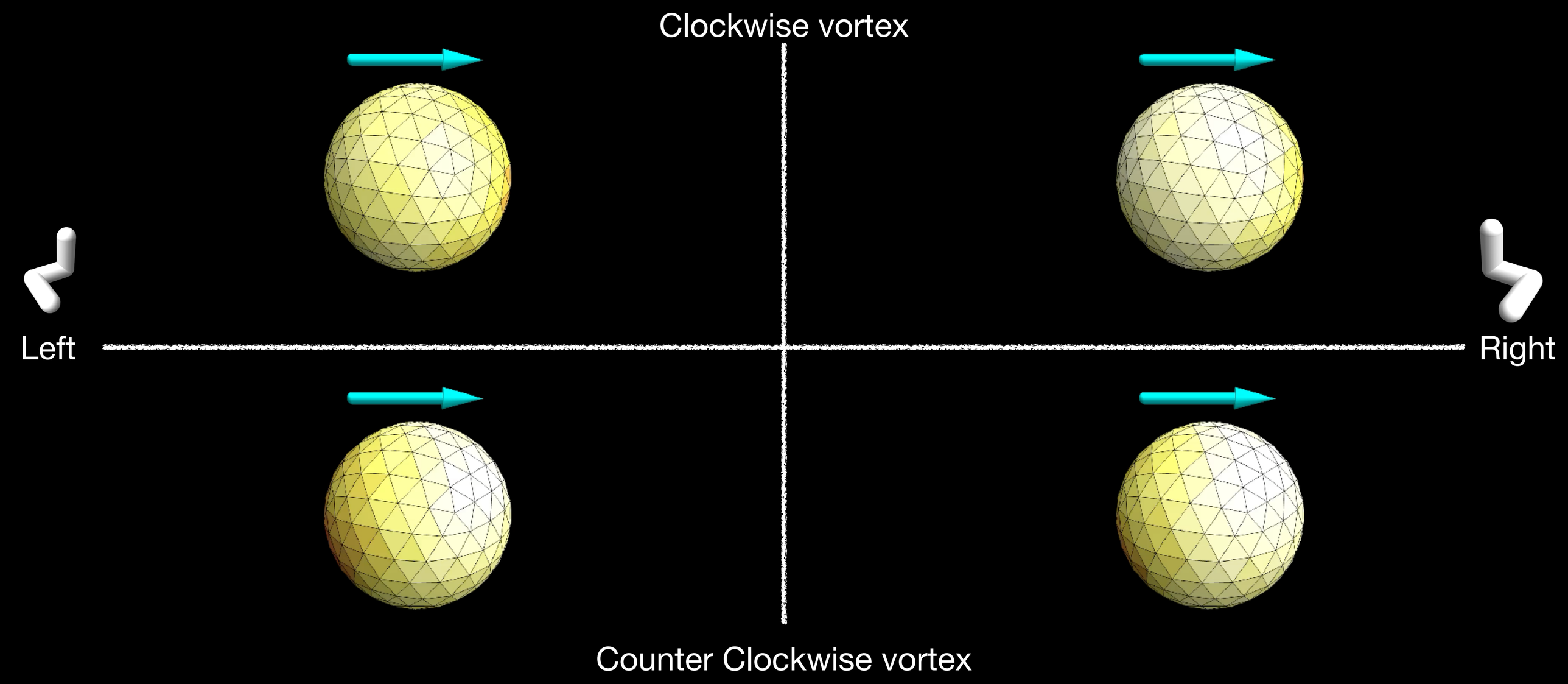
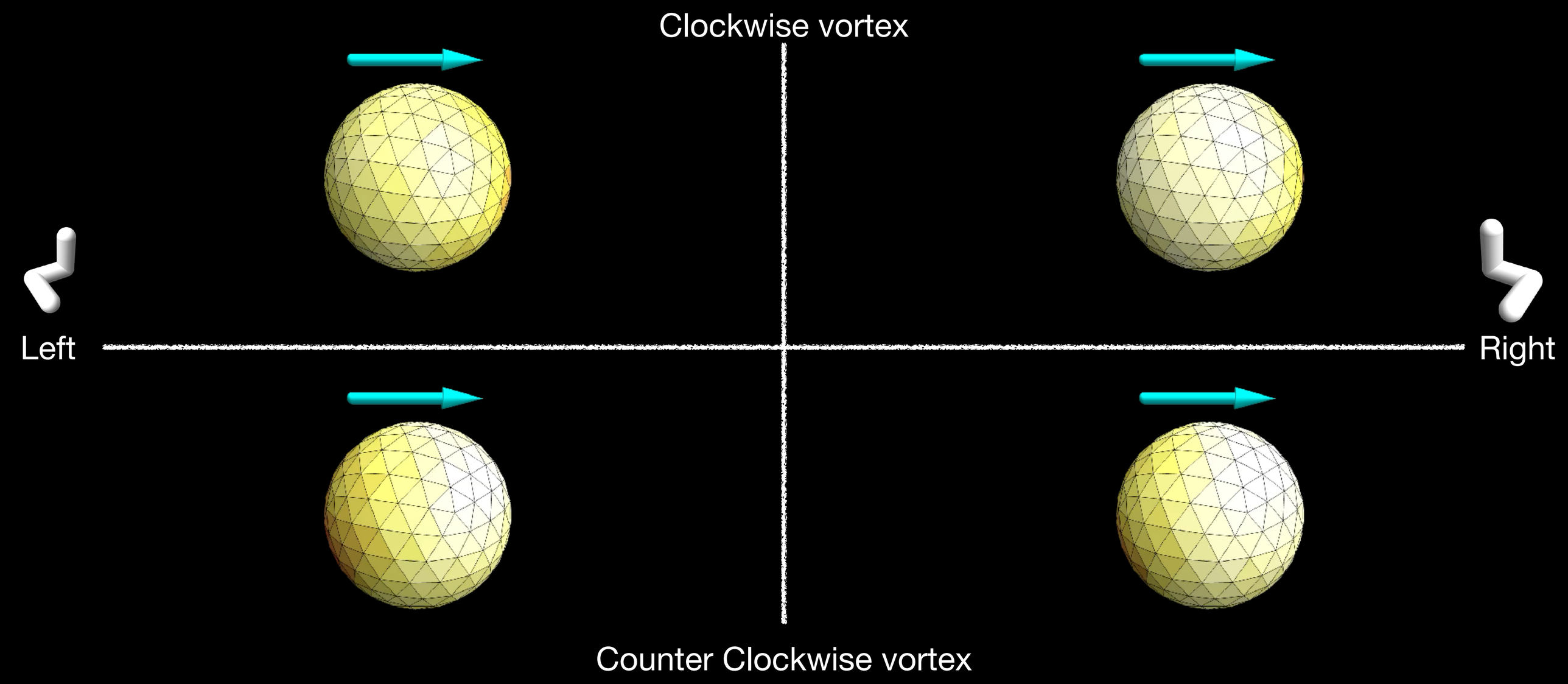


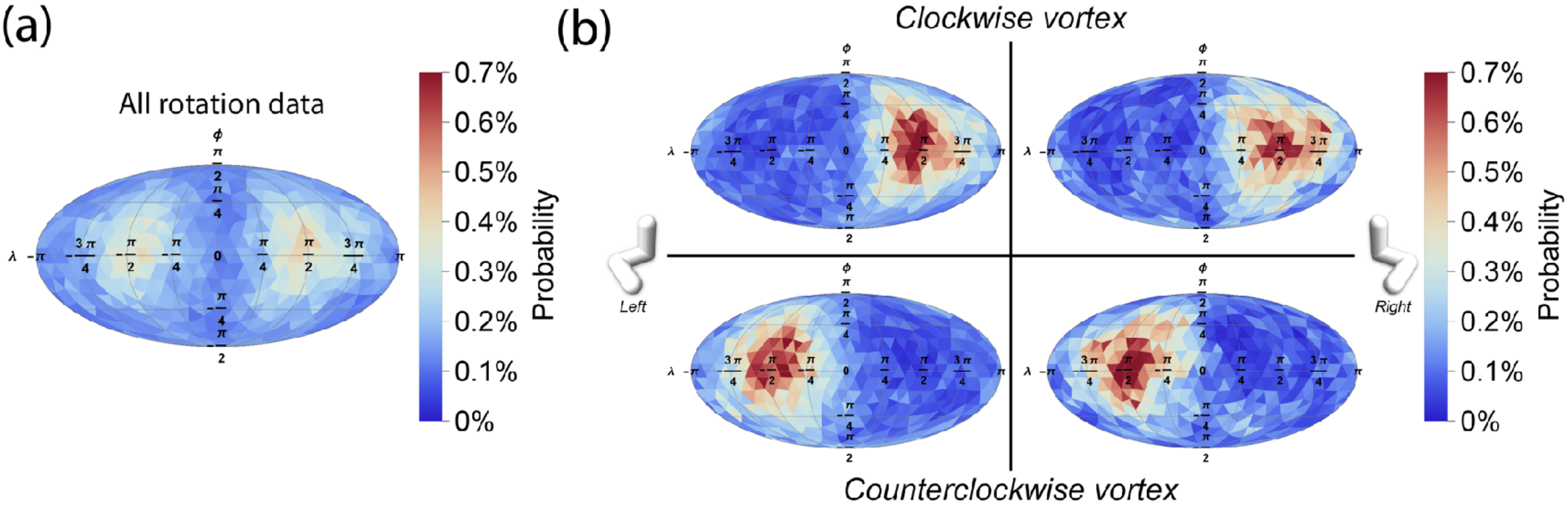
Rotation statistics



Rotation statistics

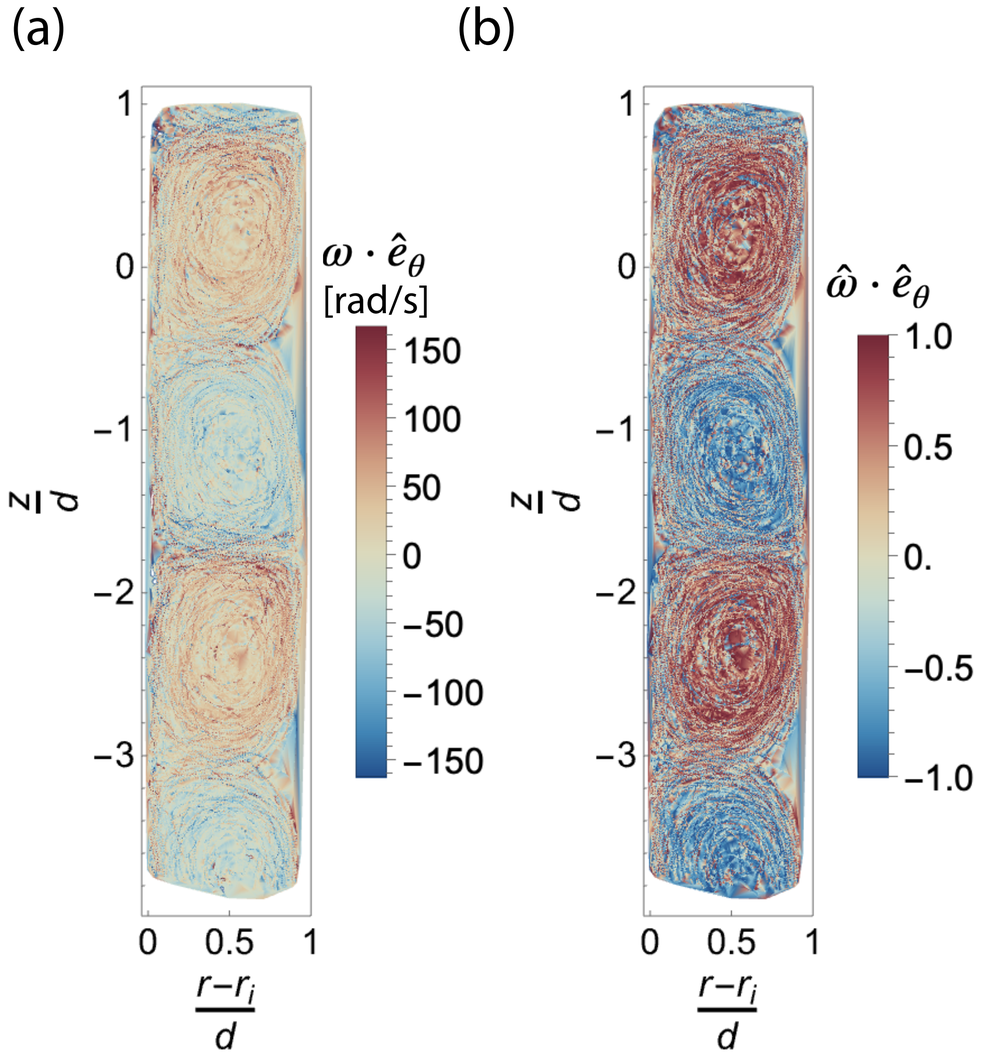


Rotation statistics



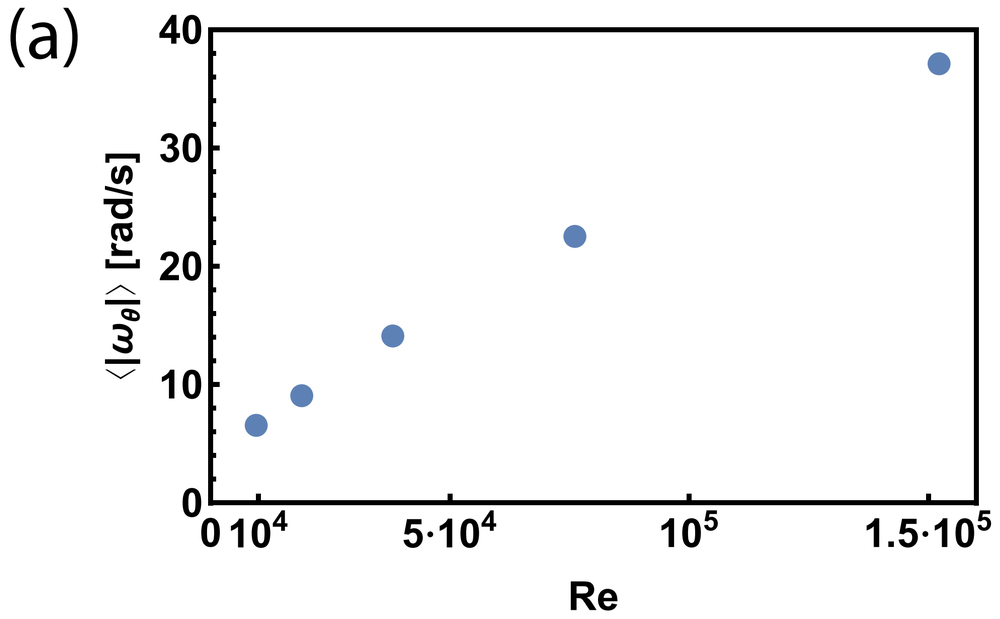
Rotation statistics

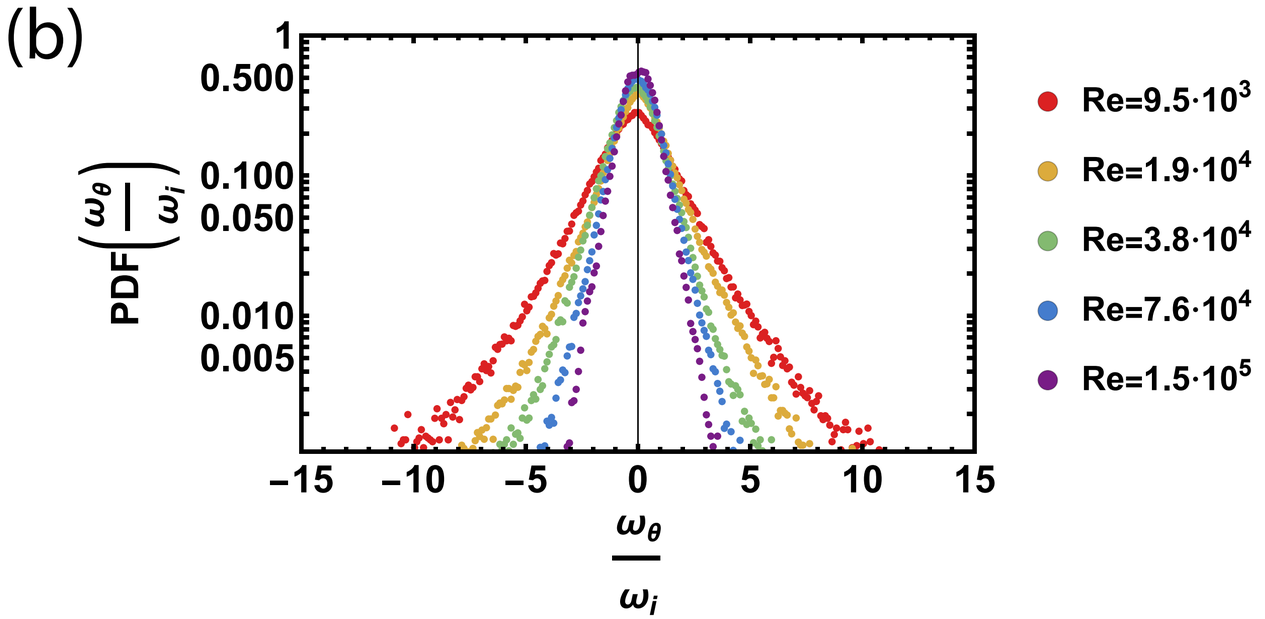
Angular velocities



Rotation statistics

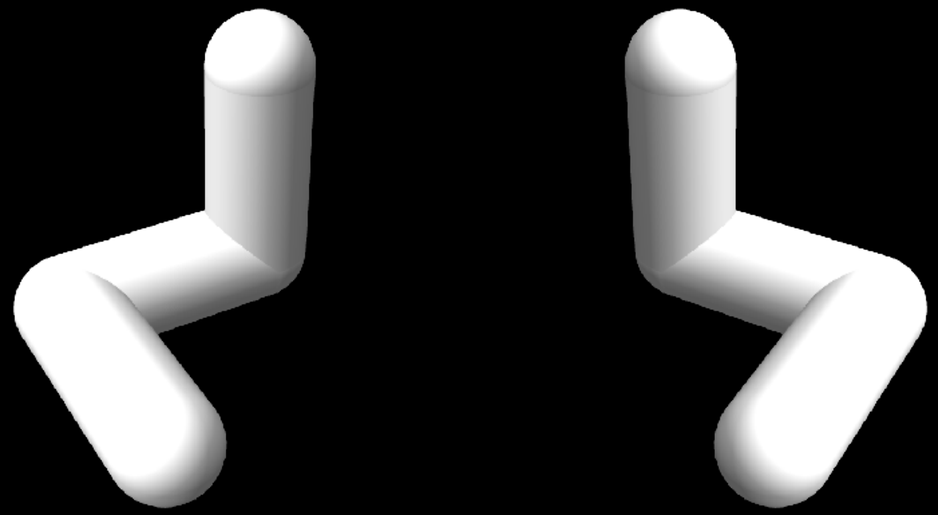
Angular velocities





Conclusion

- Particles rotate with flow
- No difference in orientation and rotation statistics between chiralities for high Reynolds numbers



Acknowledgments

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