Tracking the rotation of light magnetic particles in turbulence

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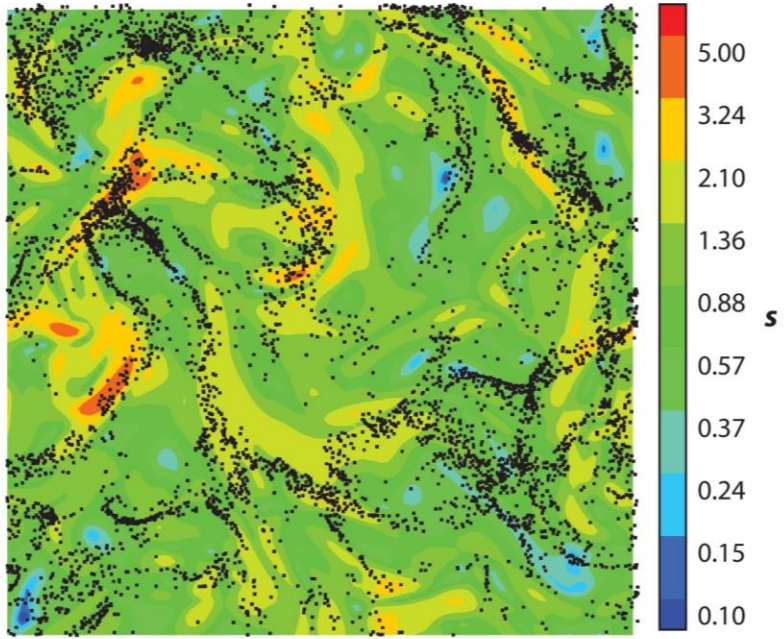
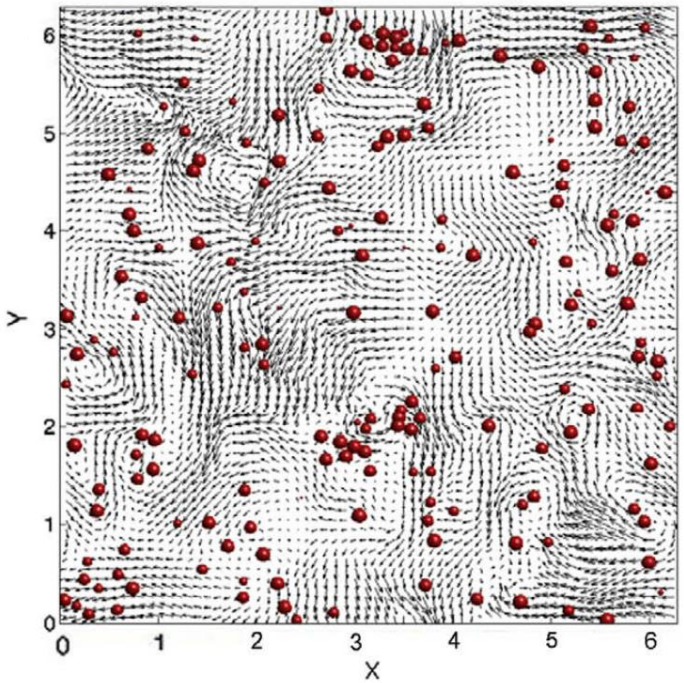
Preferential concentration



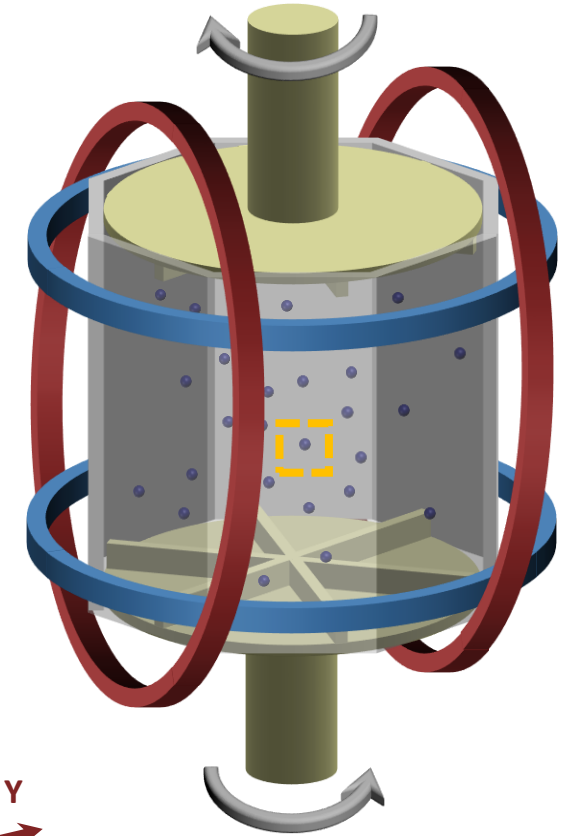
Heavier-than-fluid particles accumulating in regions of high strain rate (Brandt L, Coletti F. 2022)

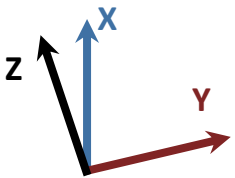


Lighter-than-fluid particles accumulating in regions of high vorticity (Yeo K, Dong S. 2010)

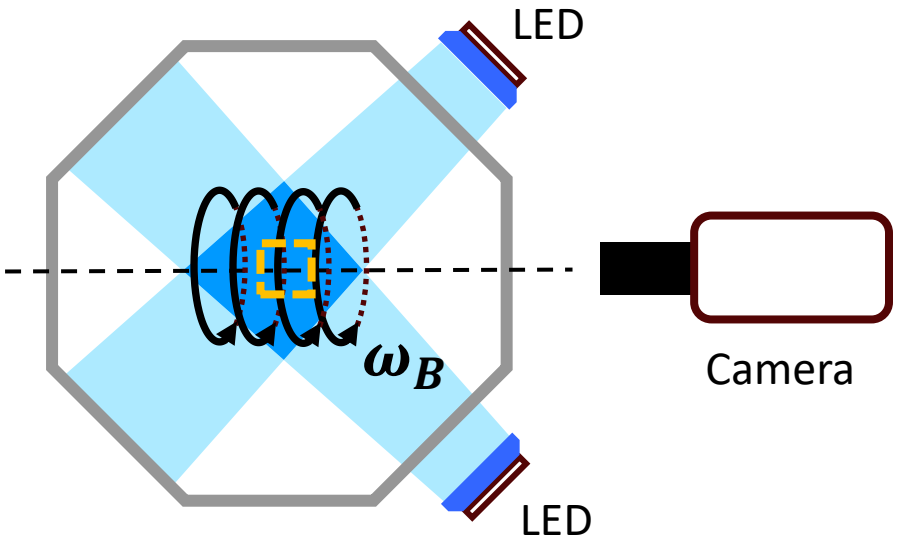
Can we affect the turbulence from within, by exerting an external force/torque on light particles?

Experimental setup





Measurement volume



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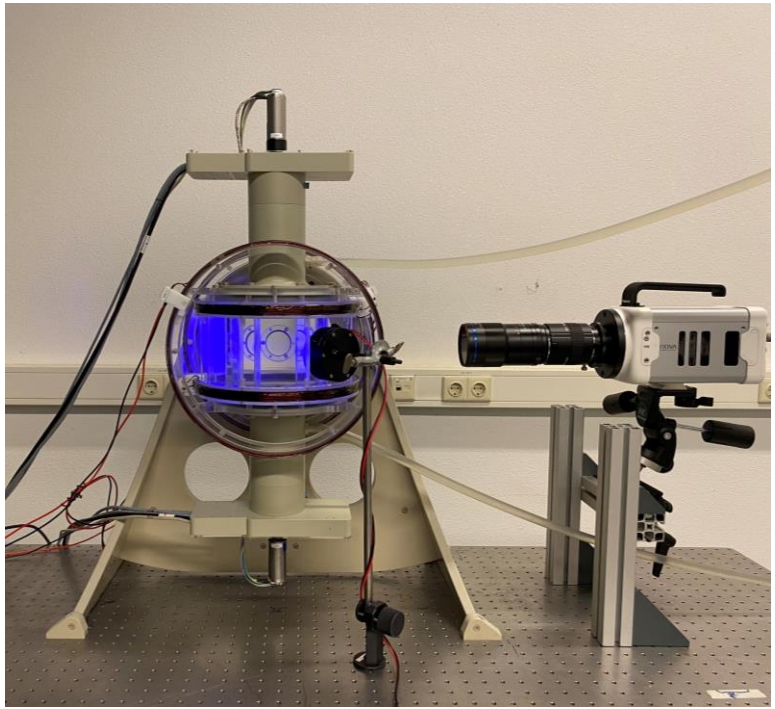
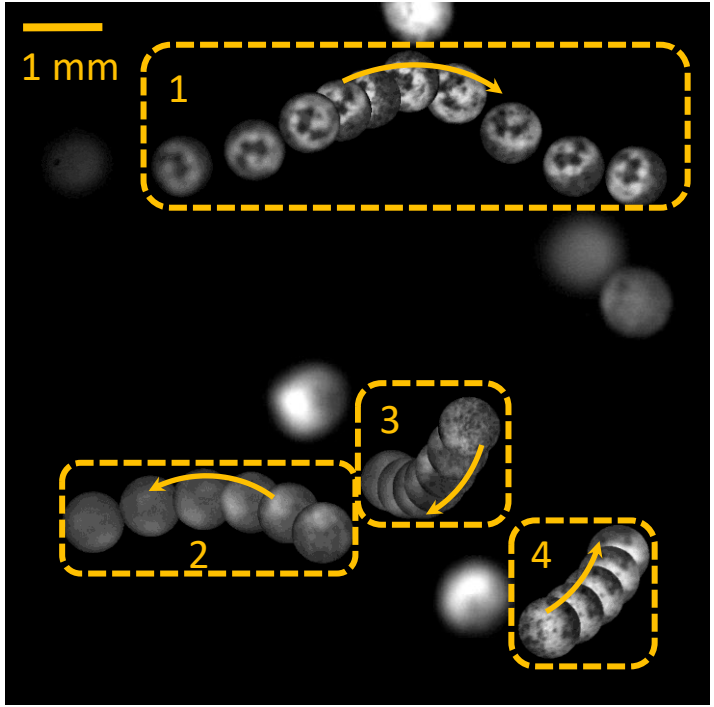
Experimental setup



Water tank inner diameter: 150 mm
Coils diameters: 250 mm, 300 mm
Kolmogorov scale: $\eta \approx 0.07$ mm, $\tau_\eta \approx 5$ ms



Random, unique surface patterns enable rotation tracking.
No predefined designing is required.

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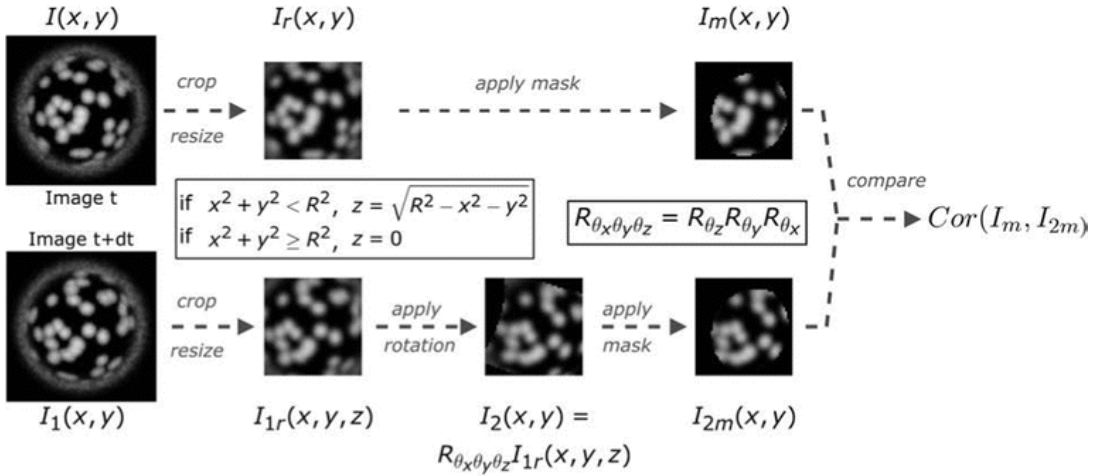
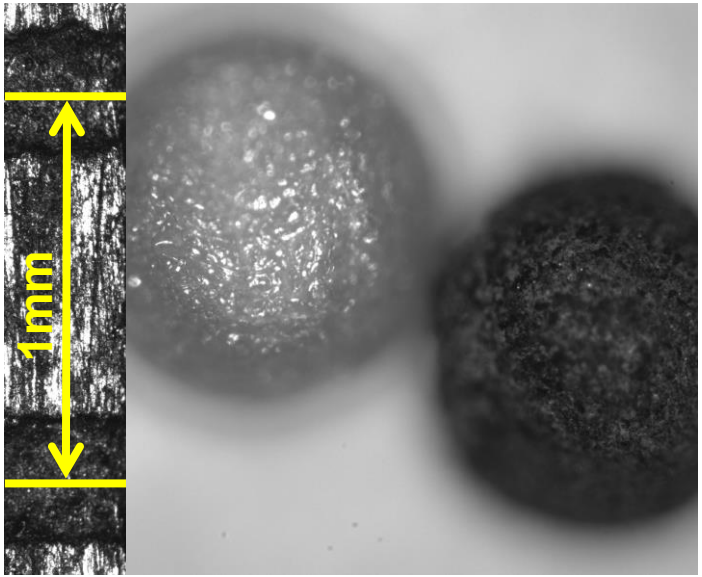
3D rotation tracking by 2D images*



1. Capture two consecutive images of the particle with a **single camera** (t and t+Δt).
2. **Project** the particle's circular surface pattern from each image onto a **hemispherical surface**.
3. Search angles on the hemisphere and use **cross-correlation** to find the peak, yielding the optimal orientation change.

Magnetic particles



Styrofoam particles coated by magnetic paint

- Diameter: $D_P \approx 0.8$ mm
- Density: $\rho_P \approx 0.2$ g/cm^3
- Magnetic anisotropy: $\Delta\chi \approx 0.01$

*Niggel, V., Bailey, M. R., Van Baalen, C., Zosso, N. & Isa, L. 3-D rotation tracking from 2-D images of spherical colloids with textured surfaces. *Soft Matter* 19, 3069–3079 (2023).

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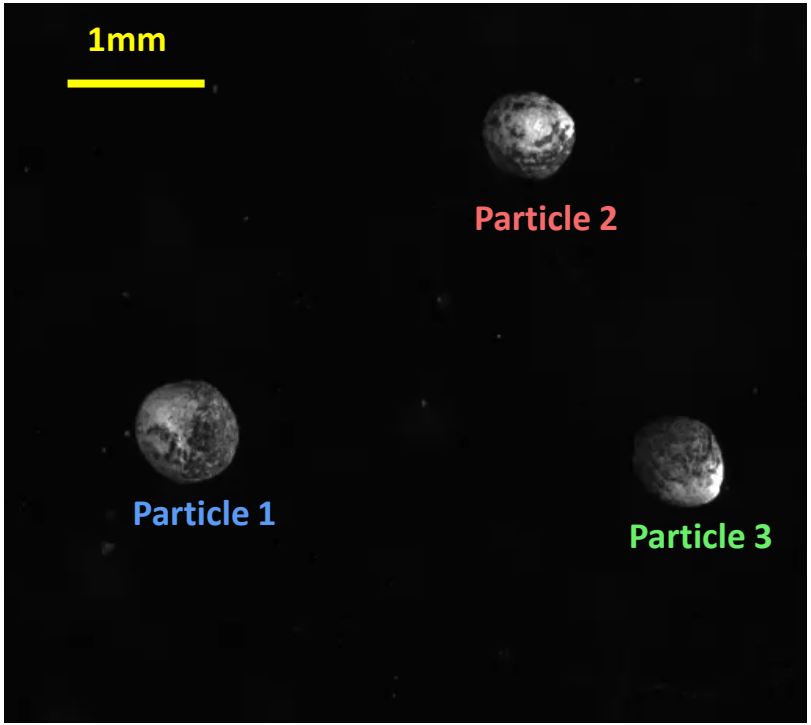
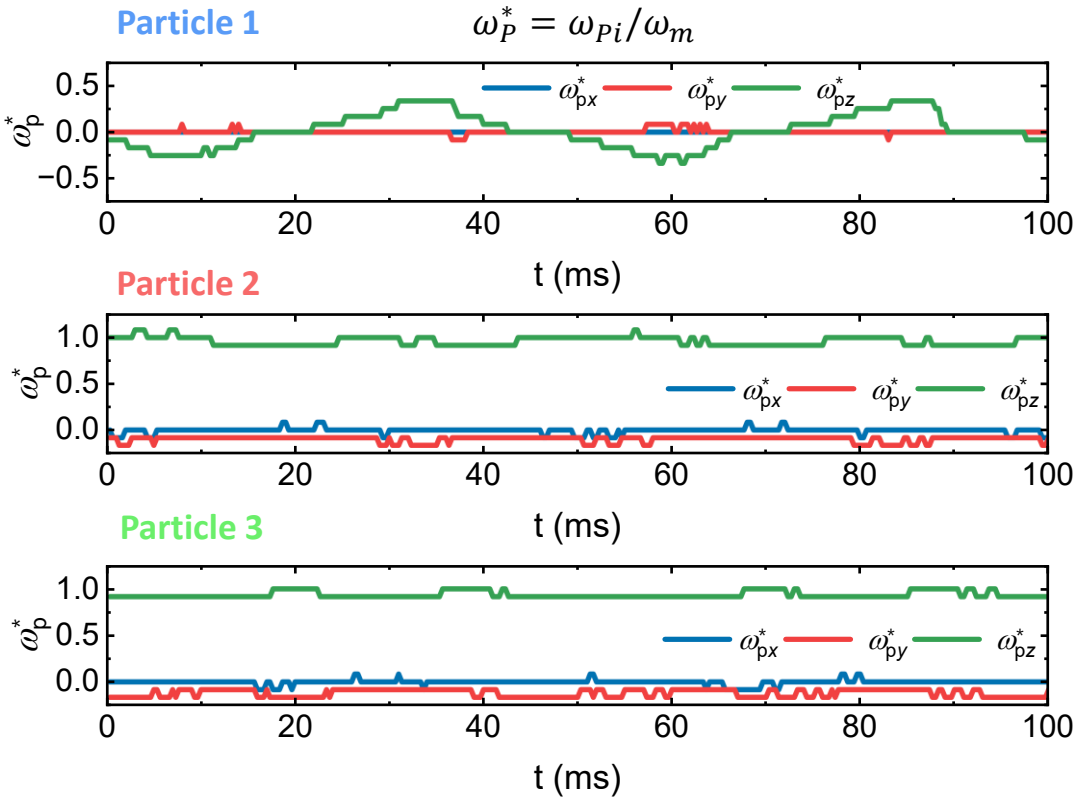
Rotation tracking of magnetic particles



1.6 mT 20 Hz magnetic field, in quiescent water



Rotation tracking results

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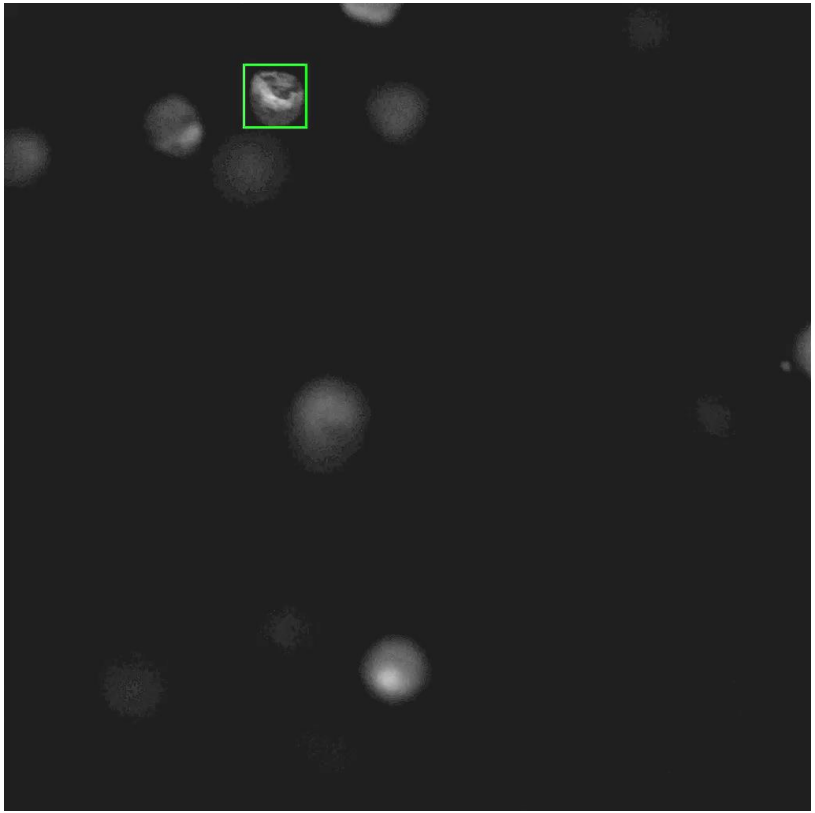
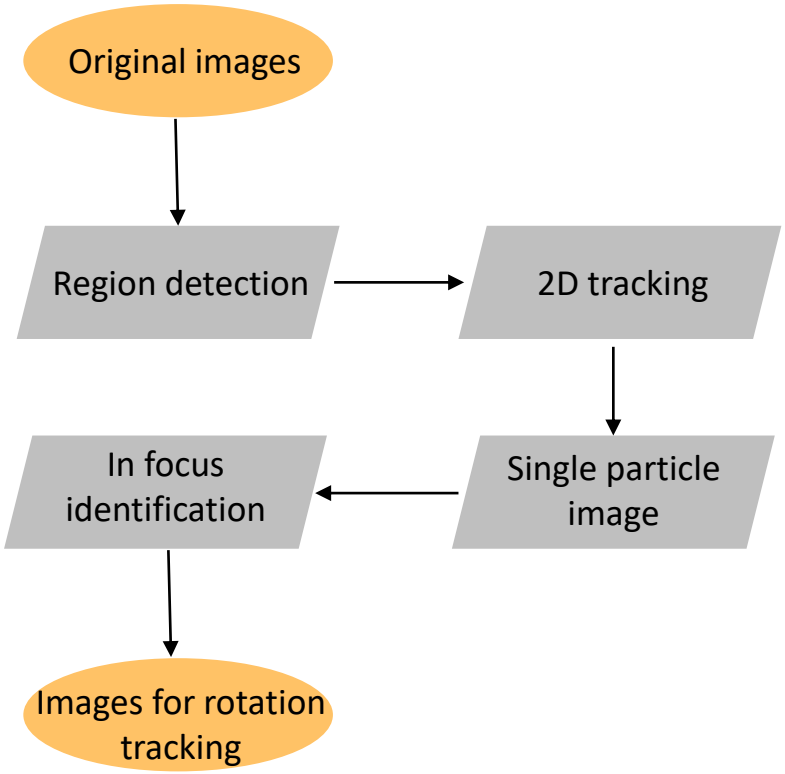
Image processing & single particle image extraction

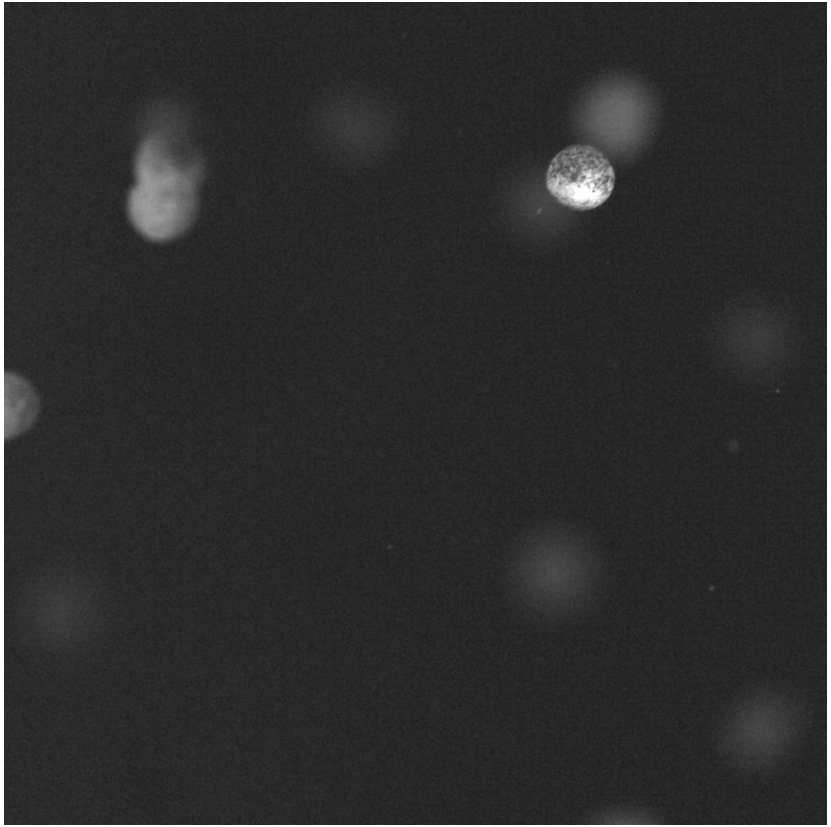


Region properties detection based on **area, mean brightness, eccentricity**

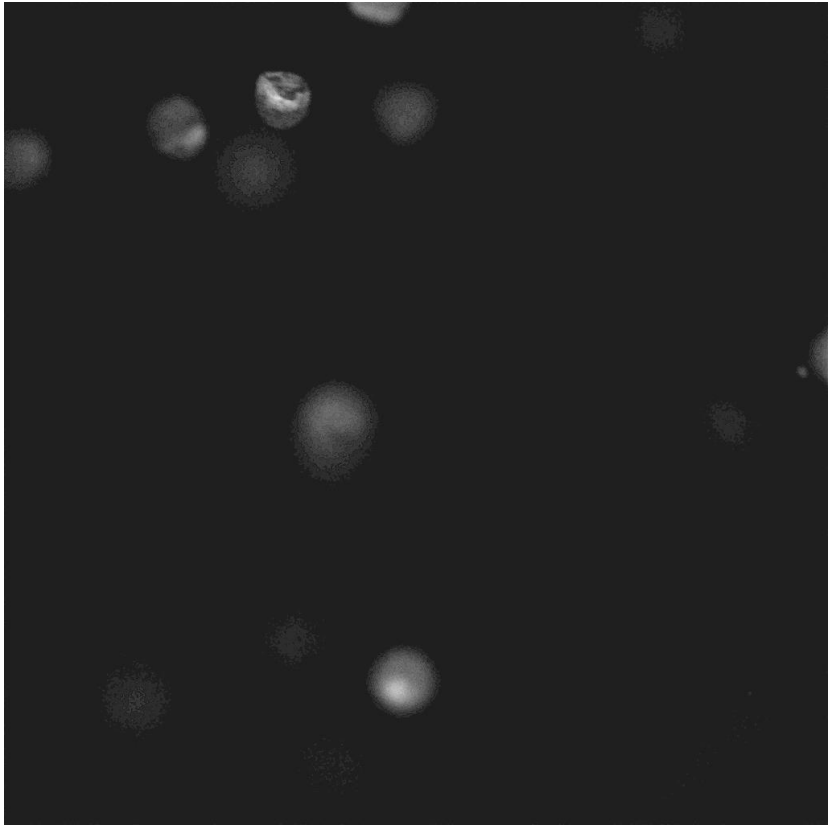


Flow chart of the image processing

Magnetic particles rotation in turbulence (recording at 3000fps, playing at 60 fps)



Particles rotating in turbulence with
no magnetic field



Particles rotating in turbulence with
1.6mT 20Hz magnetic field

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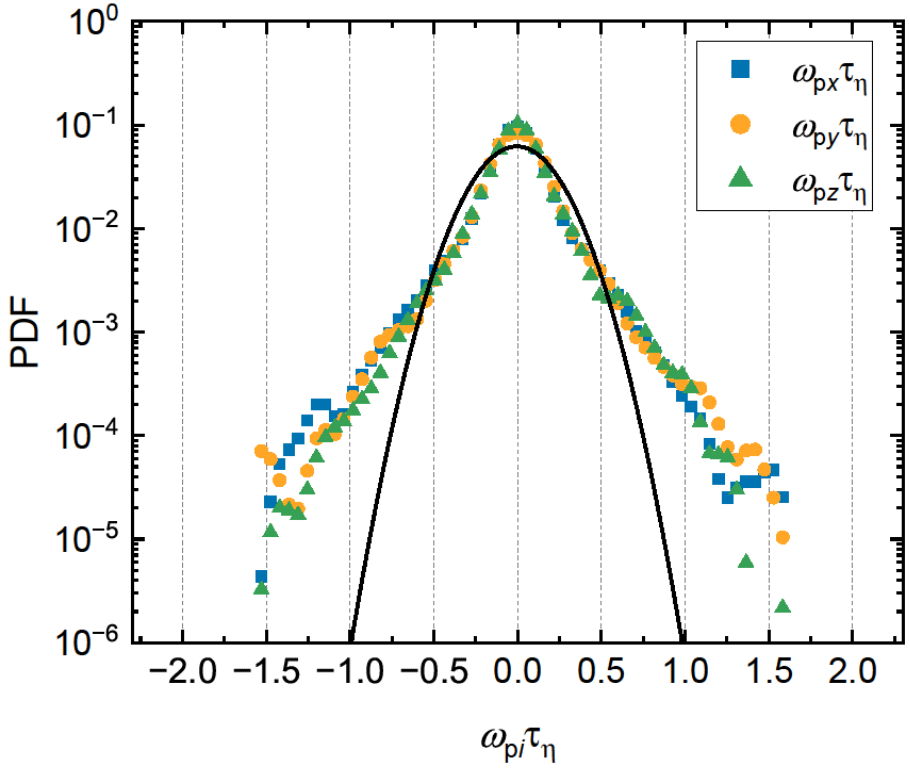
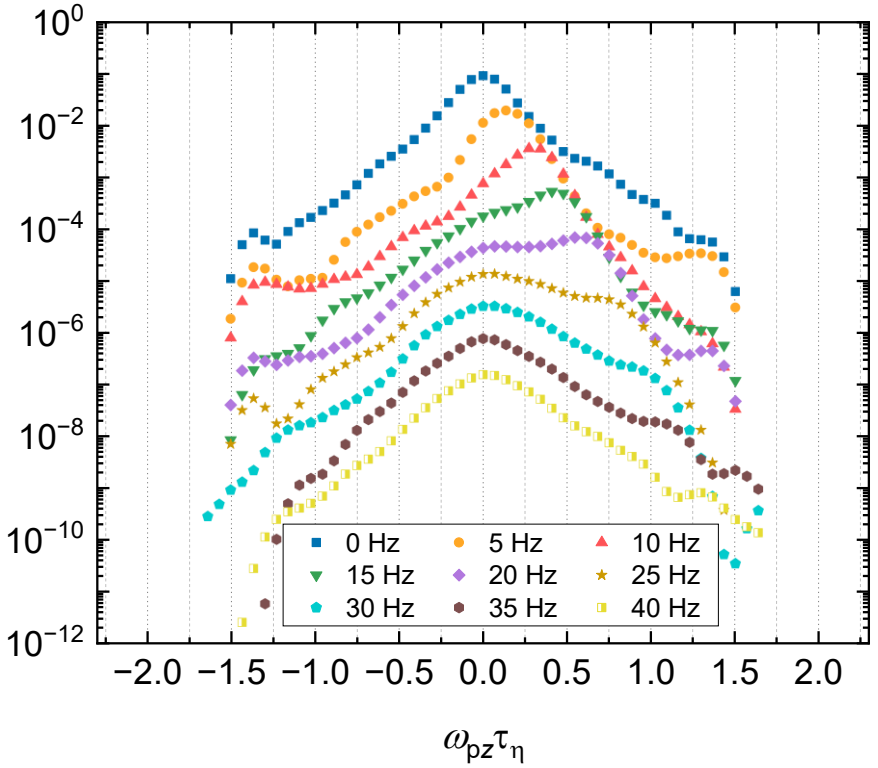
Particles' angular velocities without & with magnetic field

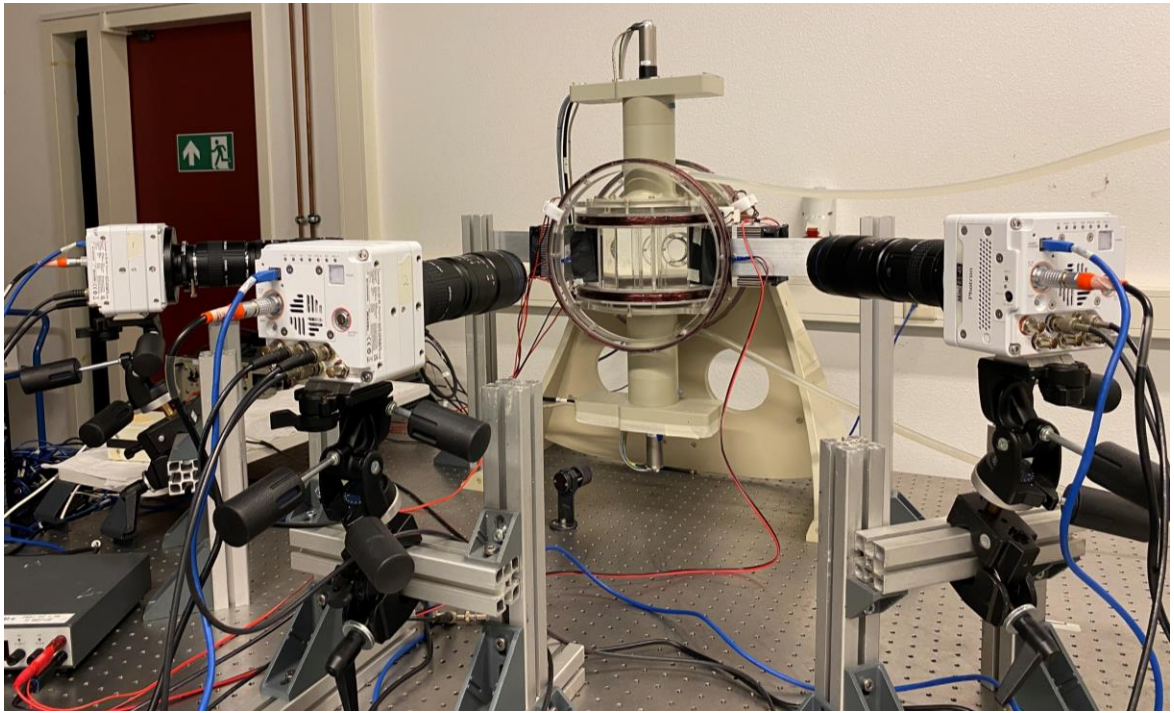


PDFs of angular velocity with
no magnetic field



PDFs of angular velocity with
1.6 mT 0 - 40 Hz magnetic field

Three-camera configuration for LPT



Summary :

- An experimental method to track the 3D rotational motion of light magnetic particles in turbulent flow was developed.
- A rotation tracking algorithm was implemented that relies solely on 2D images from a single camera, estimating three-component angular velocity.

Next stage work :

- The method enables detailed studies of magnetically modulated turbulence at small scales using light magnetic particles. Future work will integrate Lagrangian Particle Tracking (LPT) to enable simultaneous measurement of both translational and rotational motions, offering deeper insight into particle–turbulence interactions.

*Wu, C., Kunnen, R. P. J., Wang, Z., de Wit, X. M., Toschi, F., & Clercx, H. J. H. (2025). Tracking the rotation of light magnetic particles in turbulence. *Physical Review Fluids*, *10*(11), Article 114903. https://doi.org/10.1103/xsj2-fvk8

*Wang, Z., de Wit, X. M., Benzi, R., Wu, C., Kunnen, R. P. J., Clercx, H. J. H., & Toschi, F. (2025). Stochastic resonance of rotating particles in turbulence. *Nature Communications*, *16*, Article 10376. https://doi.org/10.1038/s41467-025-65316-8

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Thanks for listening!

PRFluids Journal Club presentation and discussion

This Thursday, Jan 15, at 16:00 hrs CET

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