Settling dynamics of oloids

Physics of Fluids Group

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MAX-PLANCK-GESELLSCHAFT

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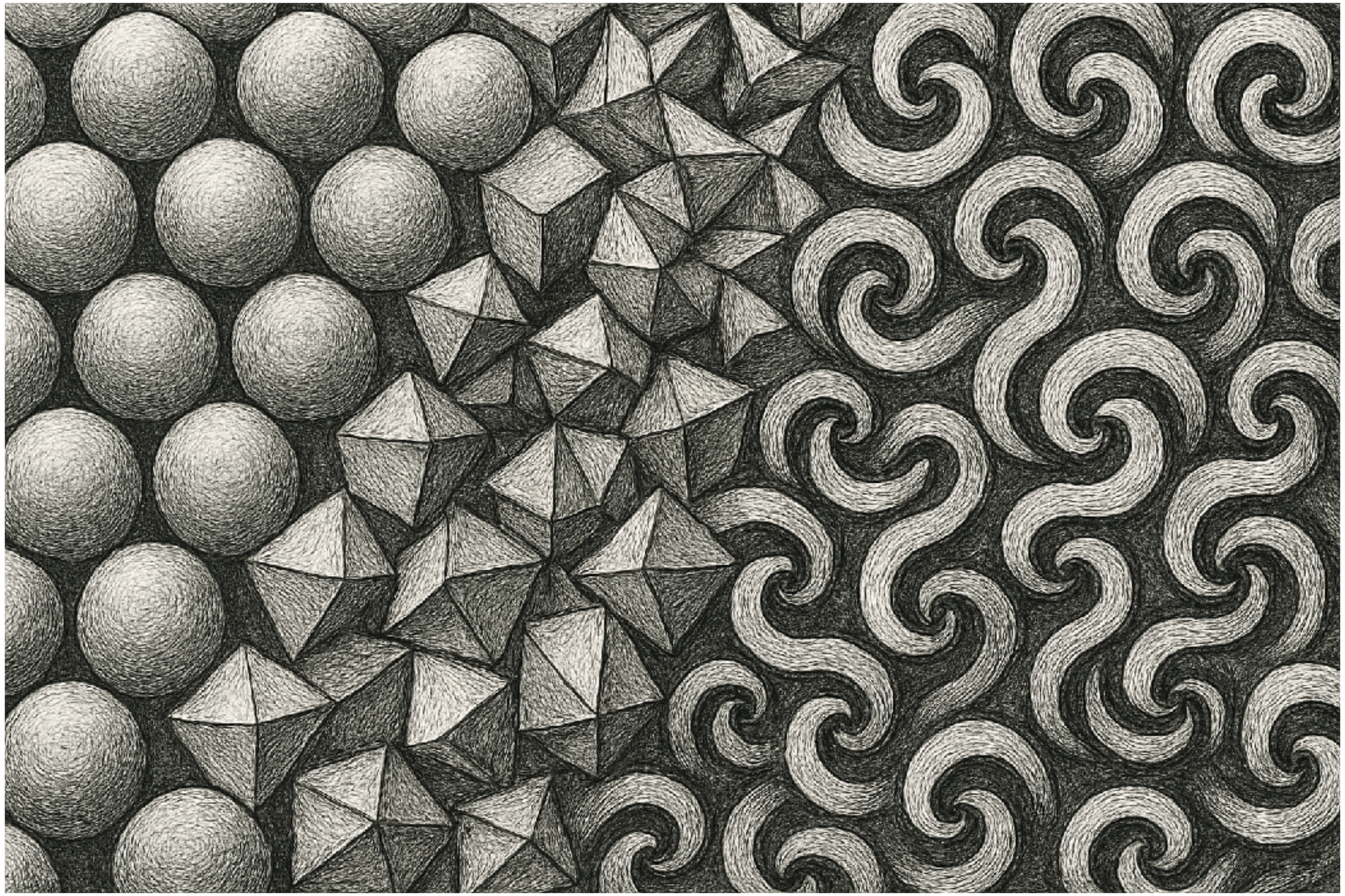
Chiral particles and odd fluids

12-14 January 2026, at Eindhoven University of Technology



Physics of Fluids

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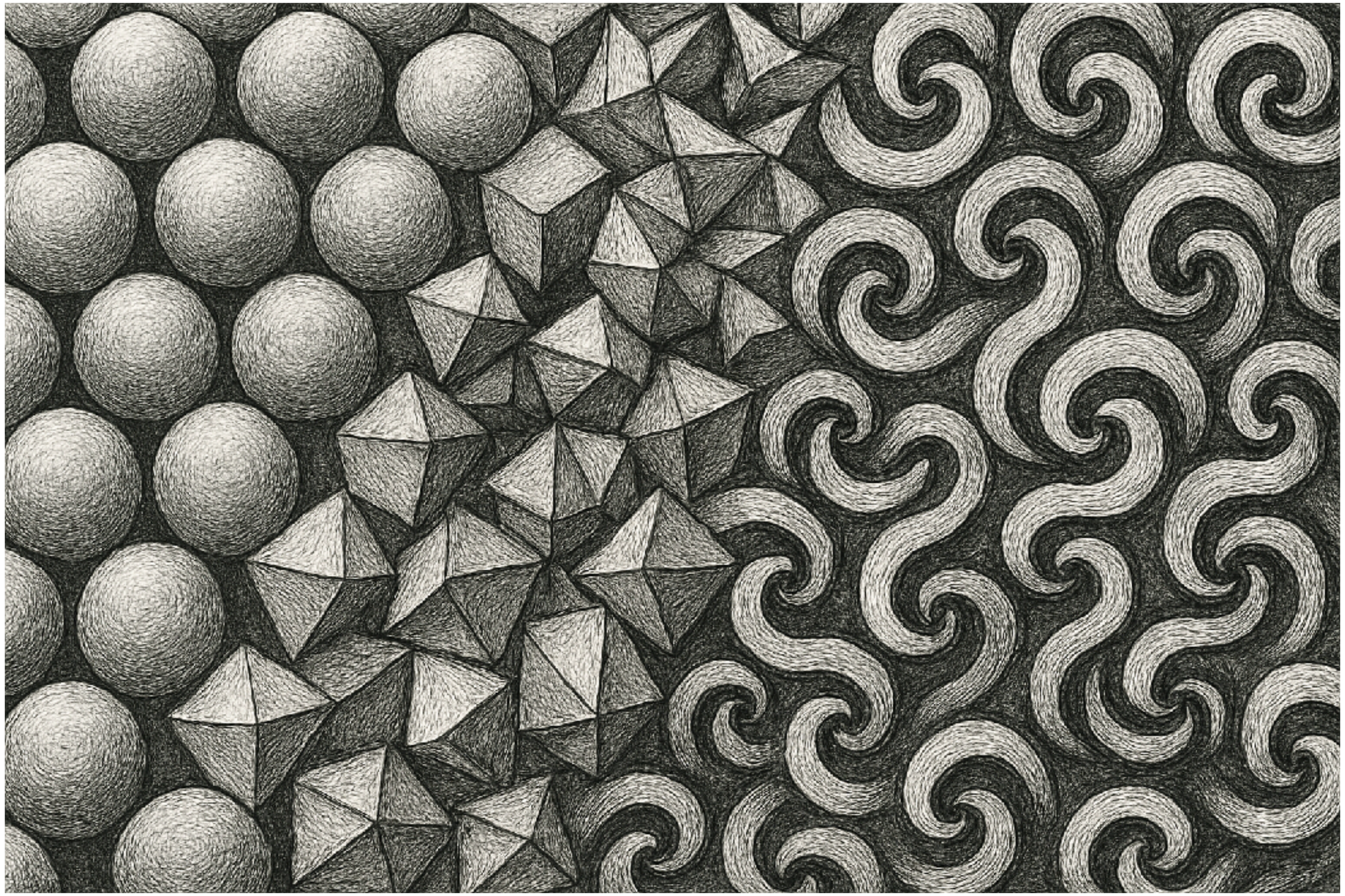
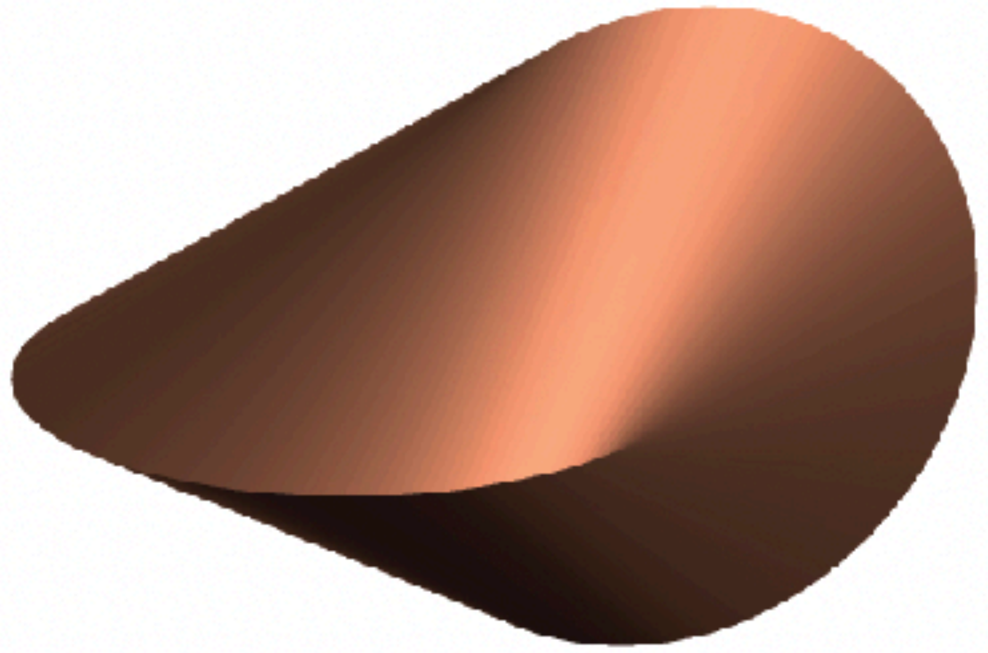


Physics of Fluids



Odd particles

Settling dynamics of oloids

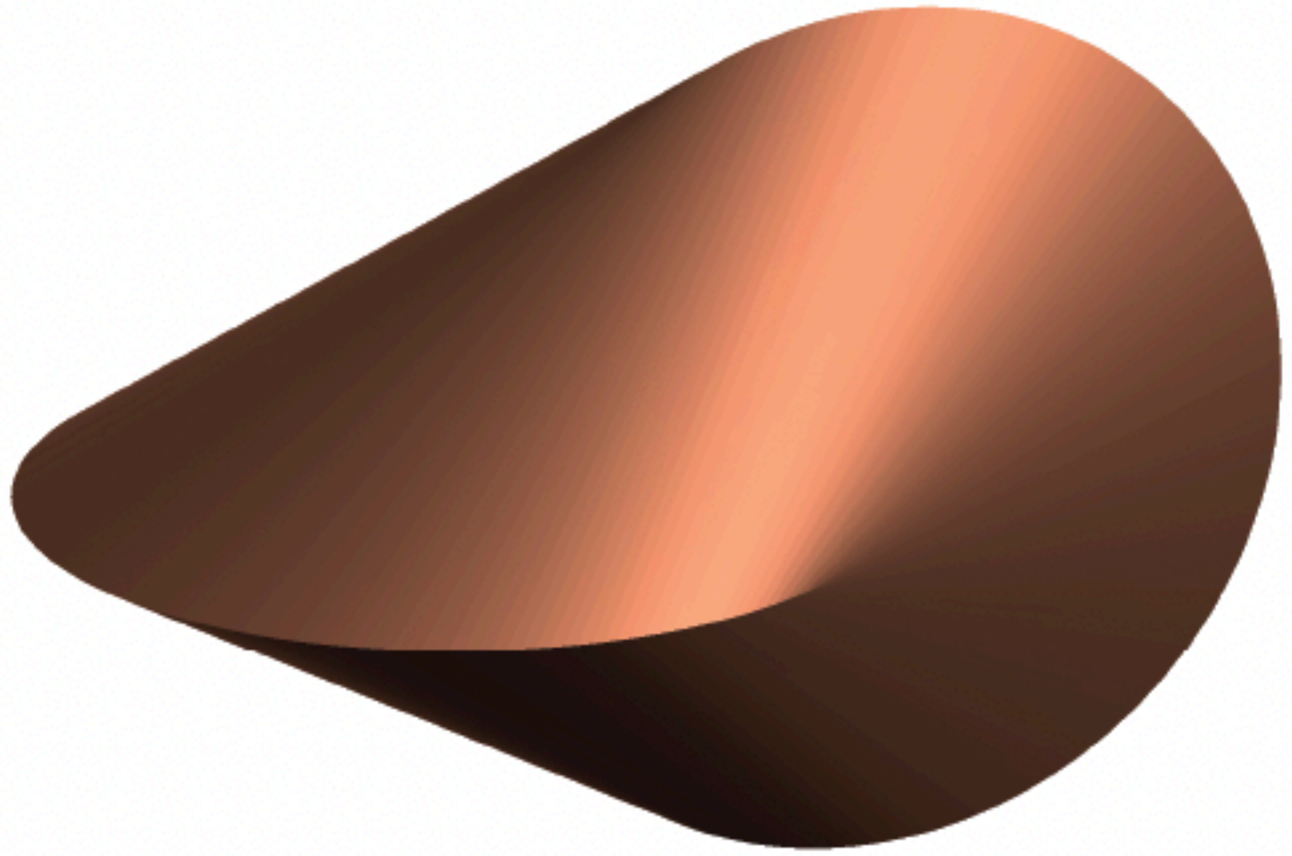
Mees Flapper

Sander Huisman

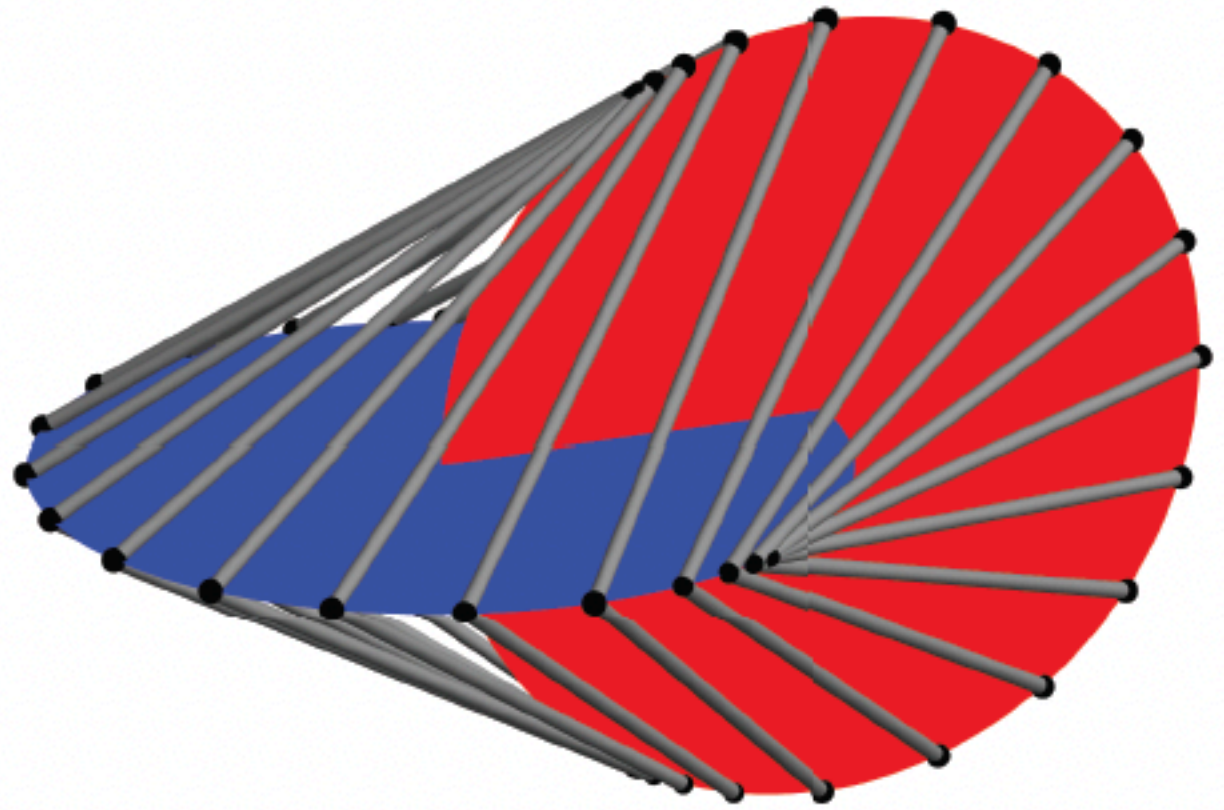
Giulia Piumini

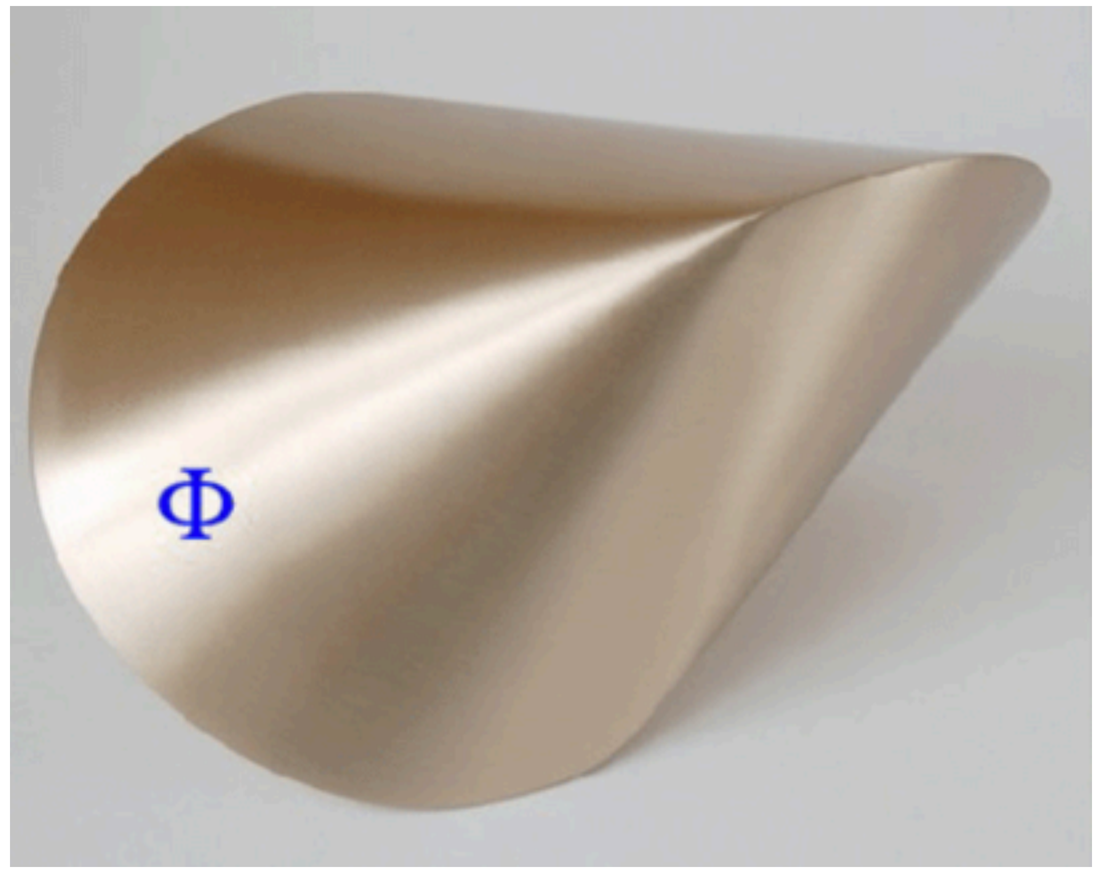
Roberto Verzicco

Physics of Fluids

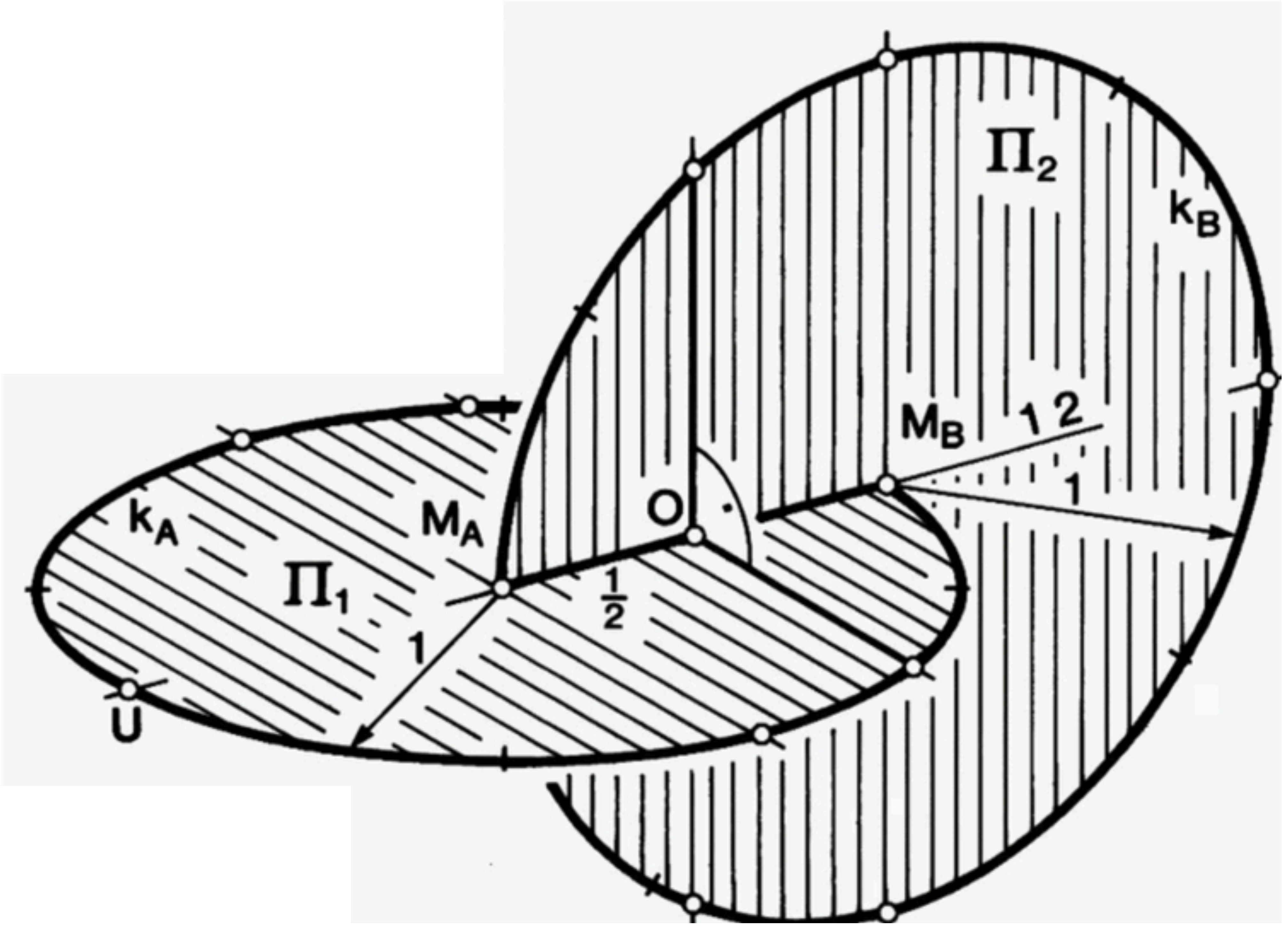


What is an oloid?





- Defined by two congruent circles of radius R
- Circles lie in perpendicular planes
- Each center lies on the other circle’s circumference
- The oloid is the convex hull of the two circles



How does an oloid roll?

- Rolls smoothly on a flat surface
- Center of mass remains at constant height
- Motion alternates contact between the two circles
- Unique example of constant-height rolling

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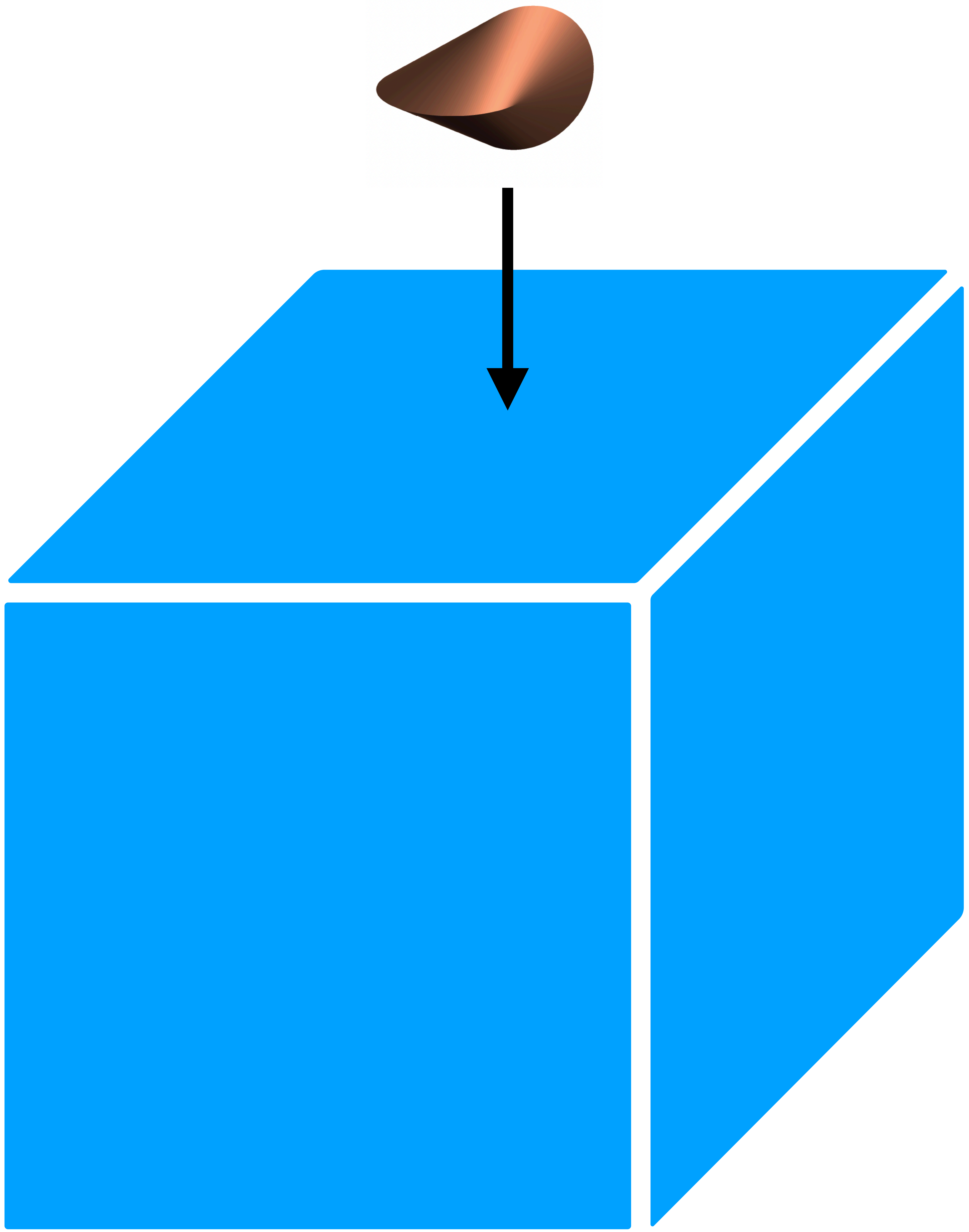
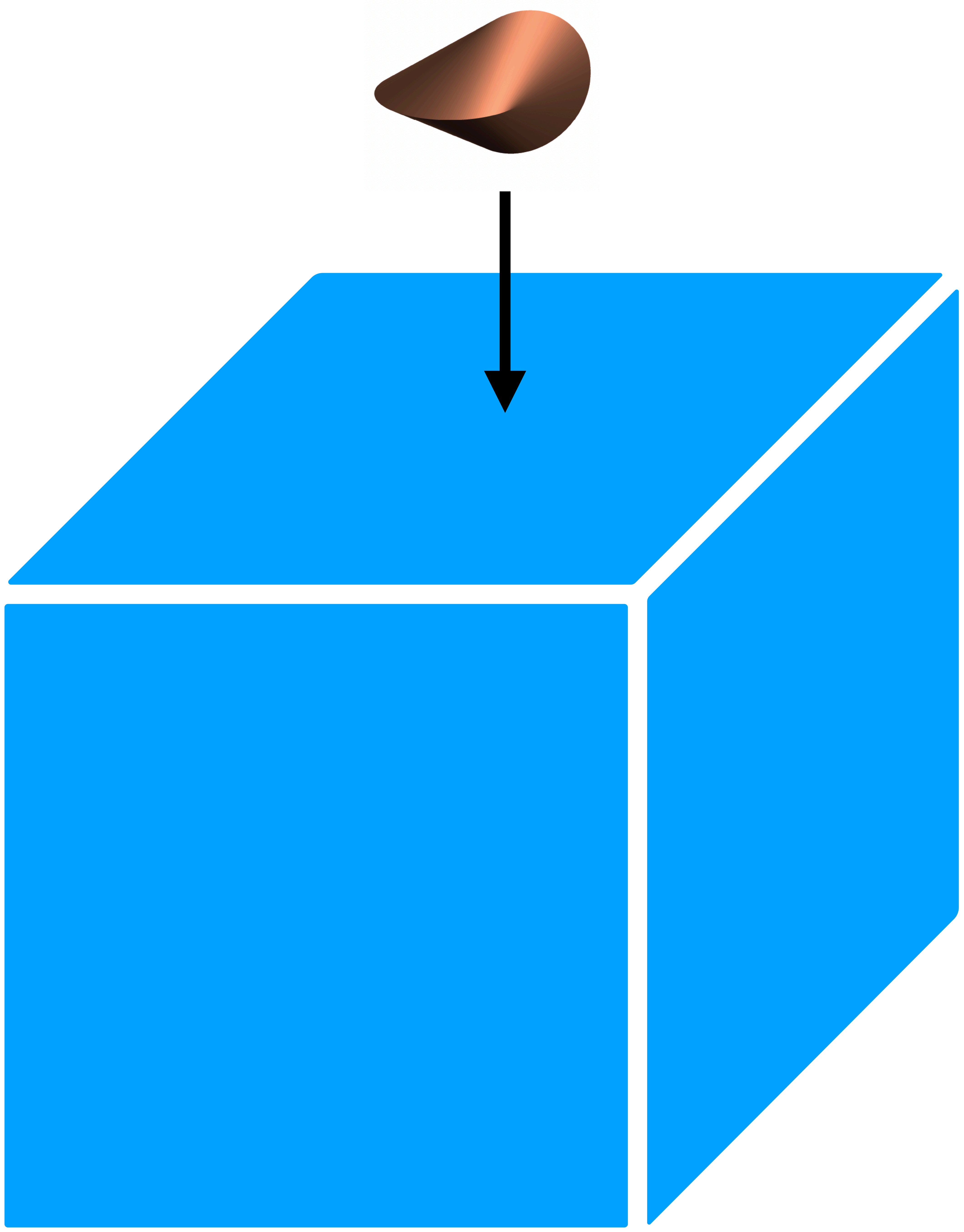
How does an oloid settle in still water?

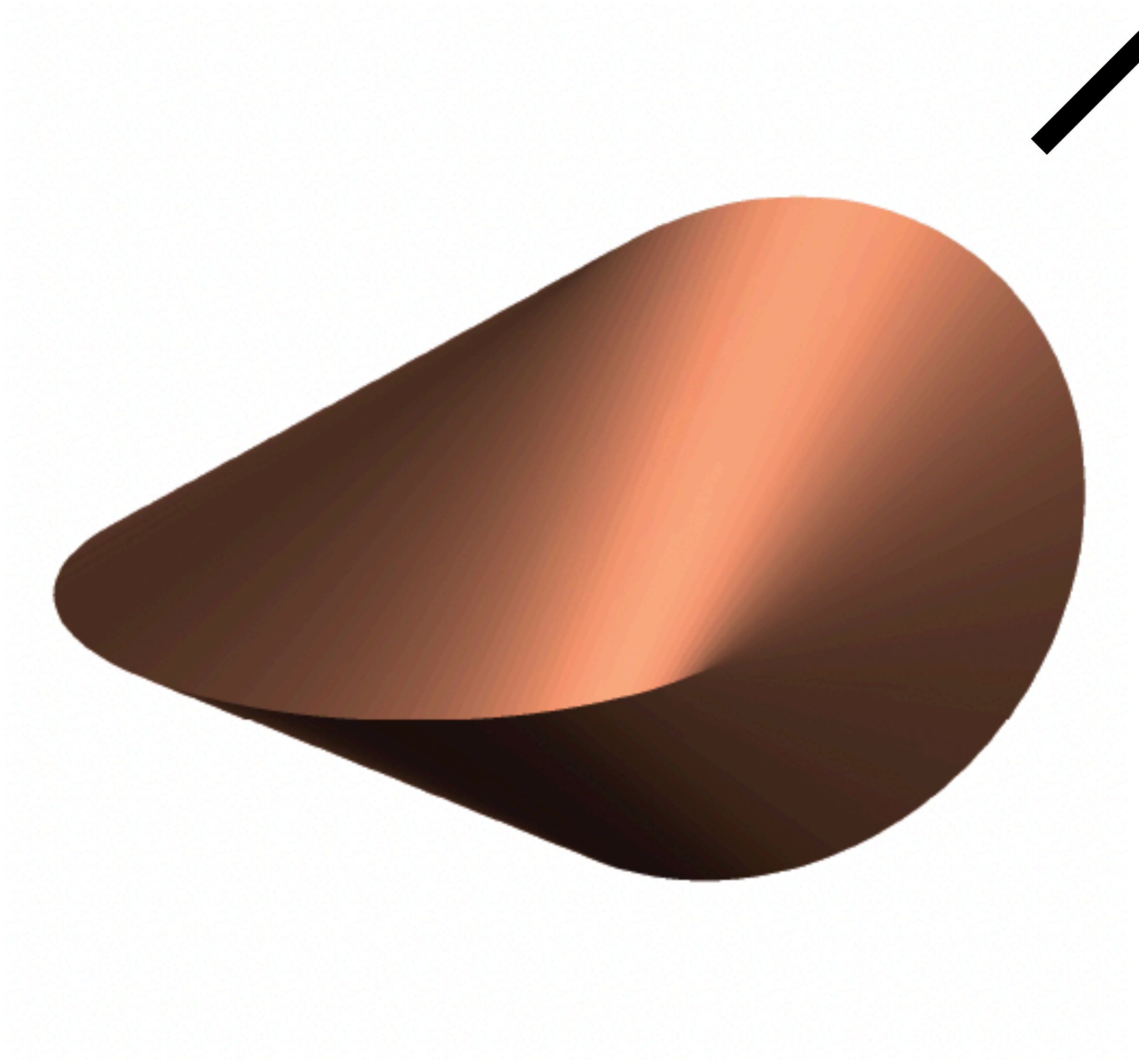


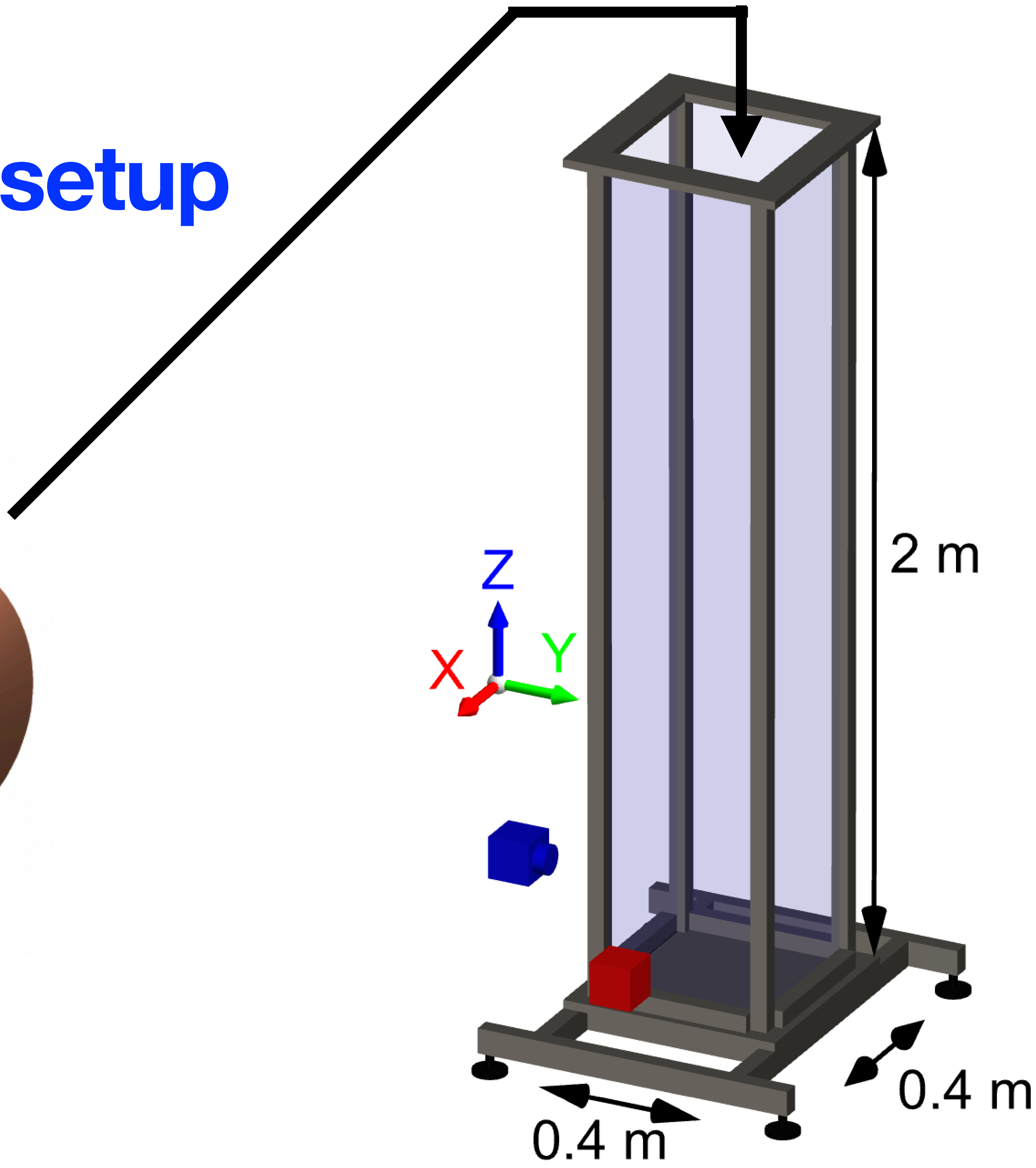
How does an oloid settle in still water?

We are in fluid dynamics after all!

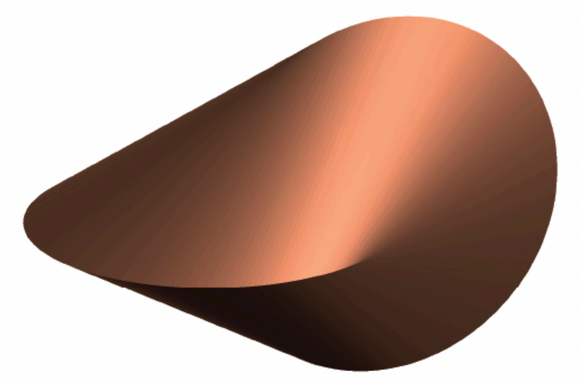


Oloid settling: Experimental setup





Oloid settling experiment: Control parameter



Dimensional:

•Densities of liquid & oloid

•Kinematic viscosity

•Volume (sphere-equivalent diameter)

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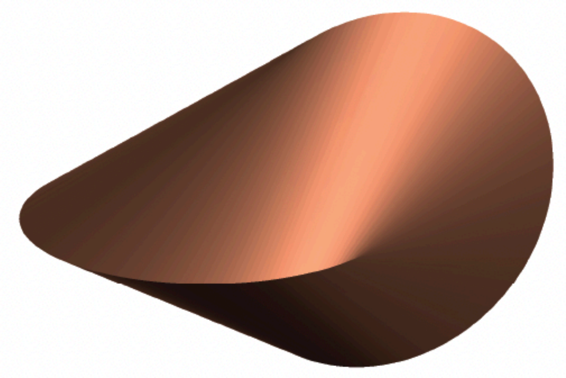

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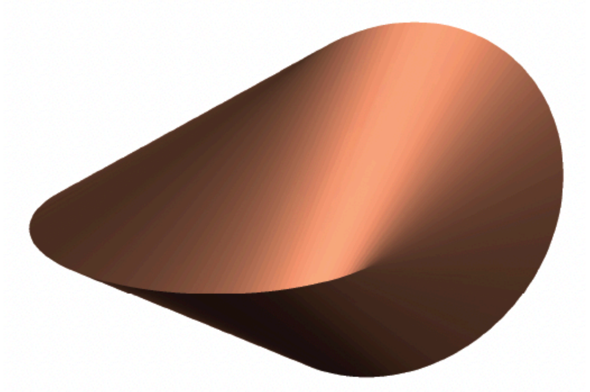
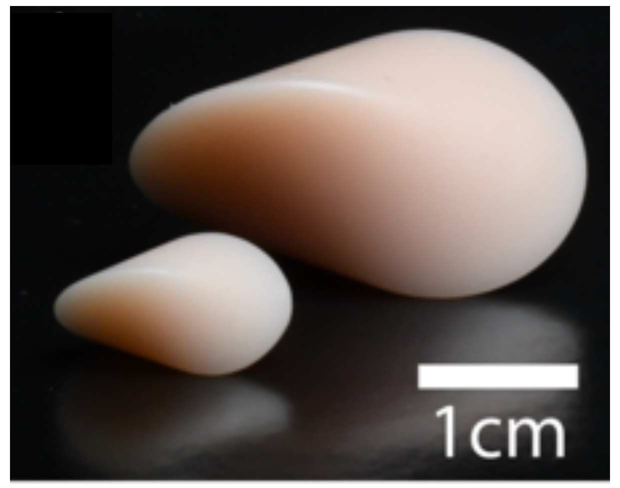
Non-dimensional: **Galileo number:**

$$Ga = \frac{D_{eq}\sqrt{gD_{eq}(\frac{\rho_p}{\rho_f} - 1)}}{\nu}$$

Oloid settling experiment: Control parameter





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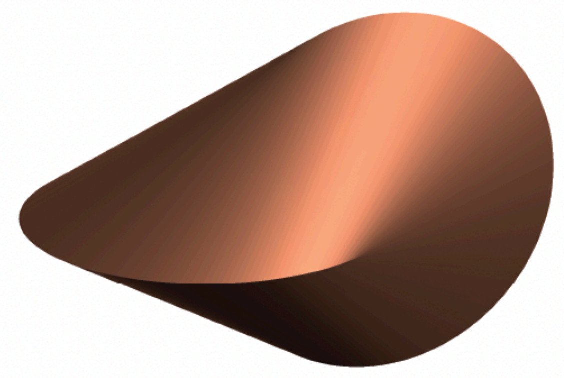
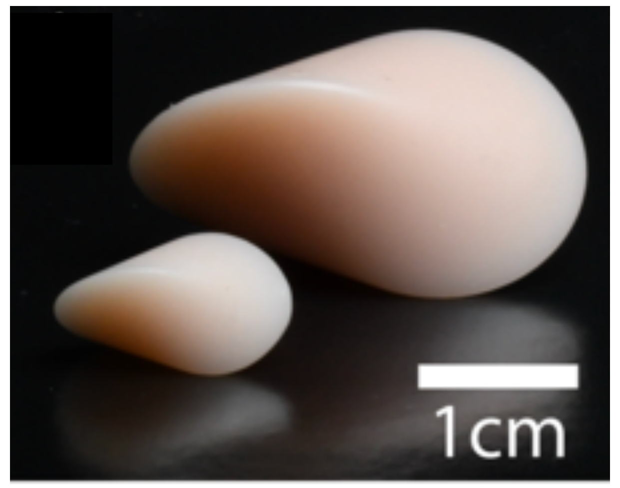
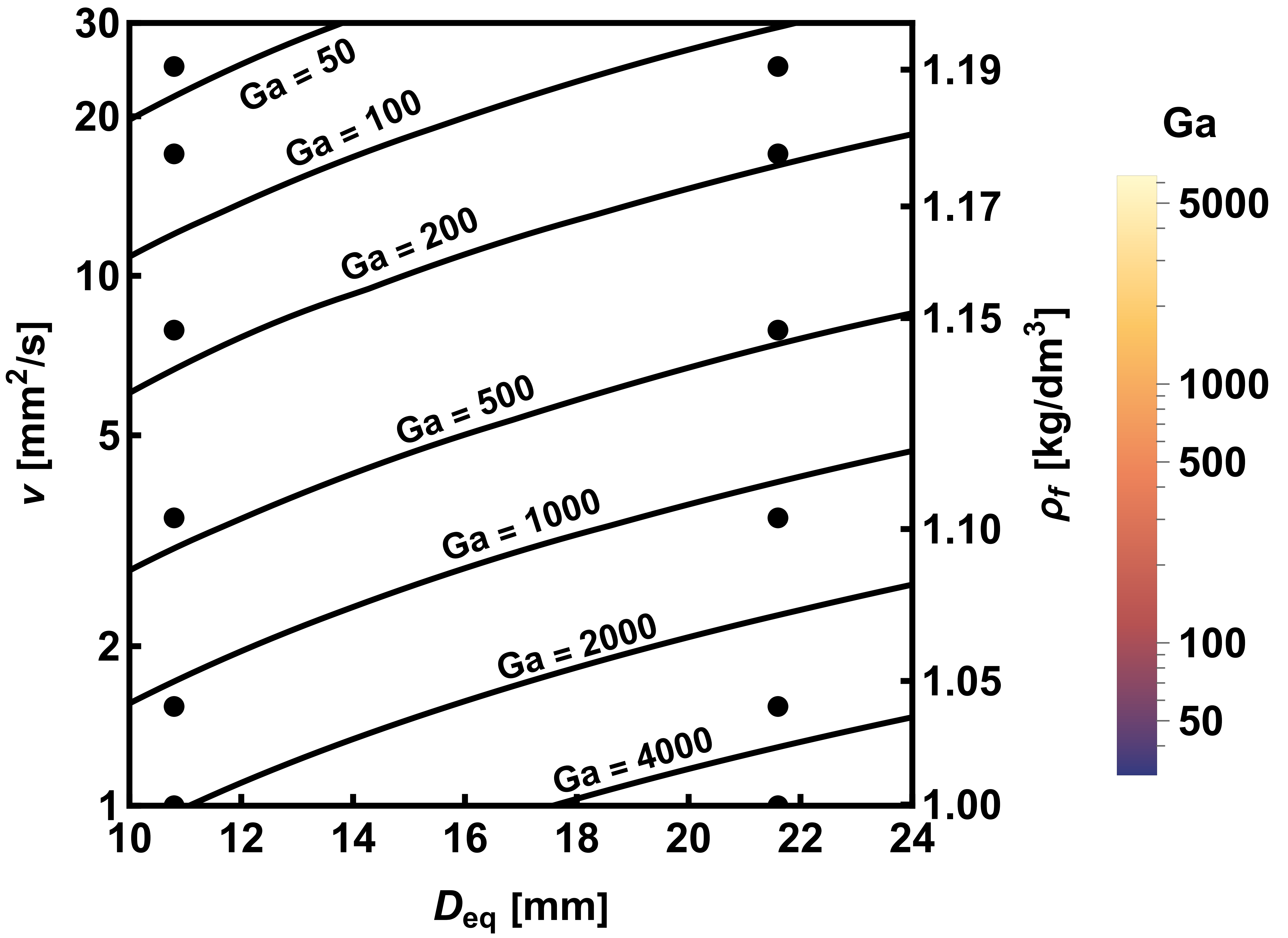
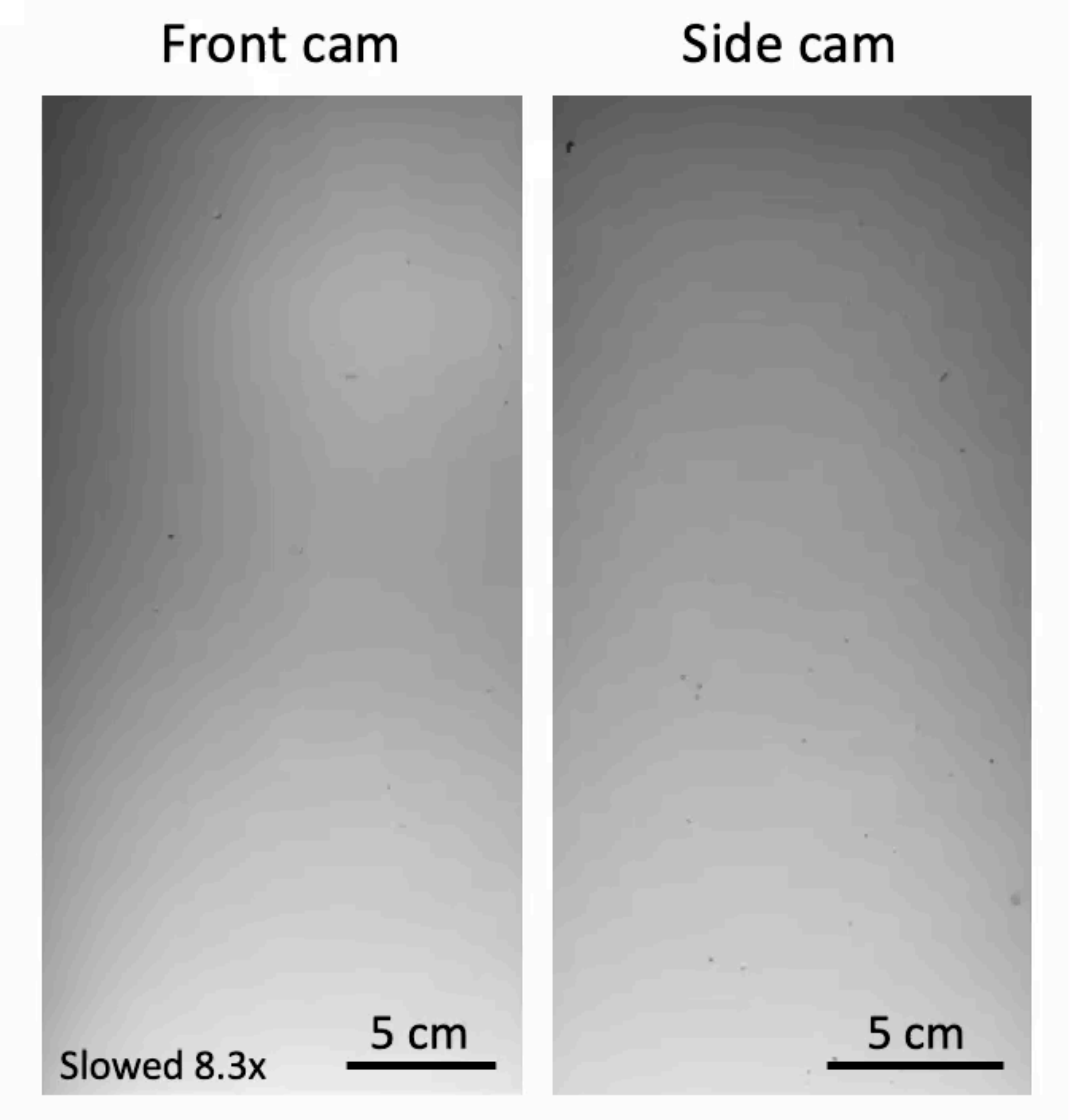






Oloid settling: Typical recordings



17% Glycerol
Ga = 3500

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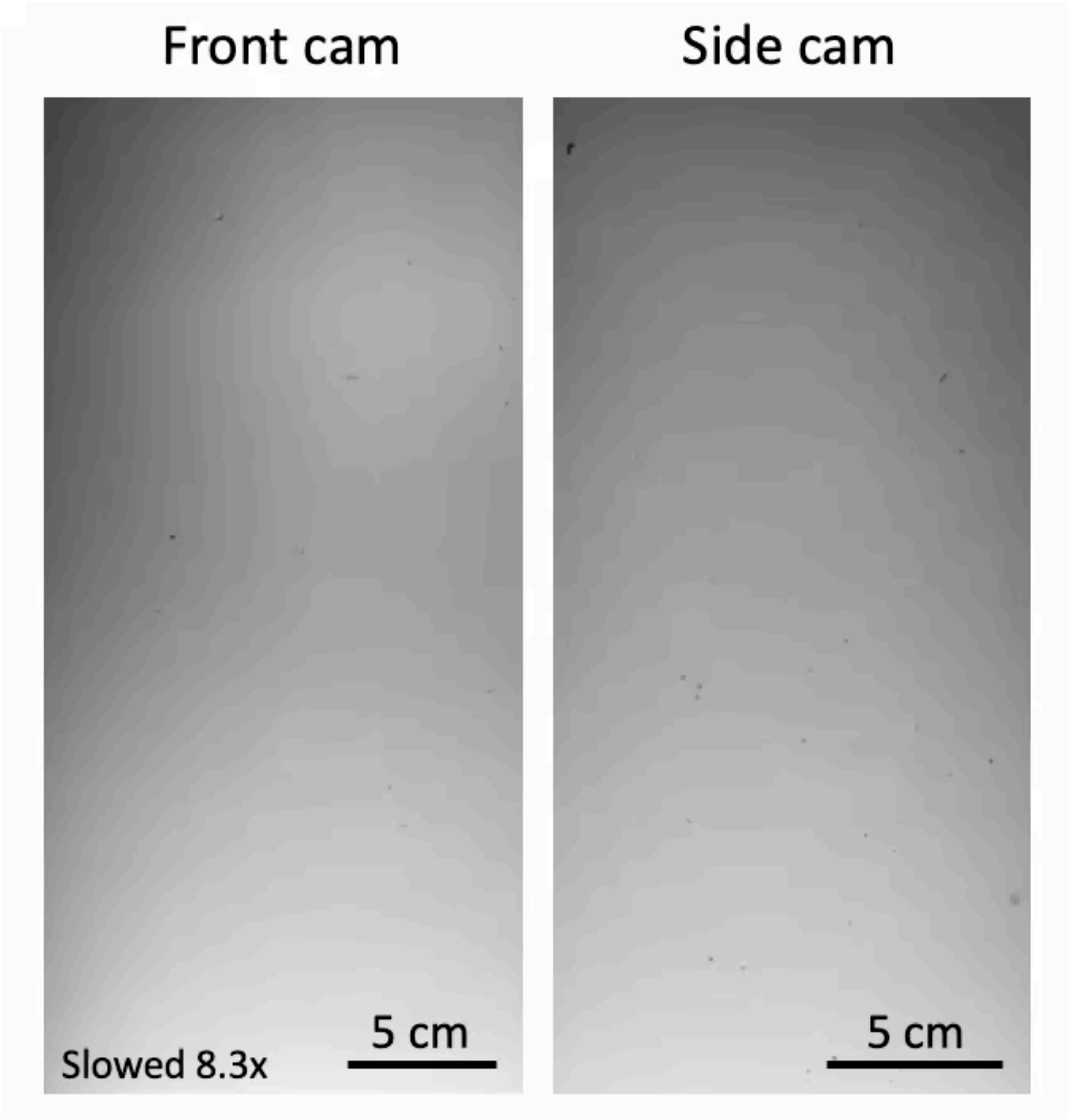

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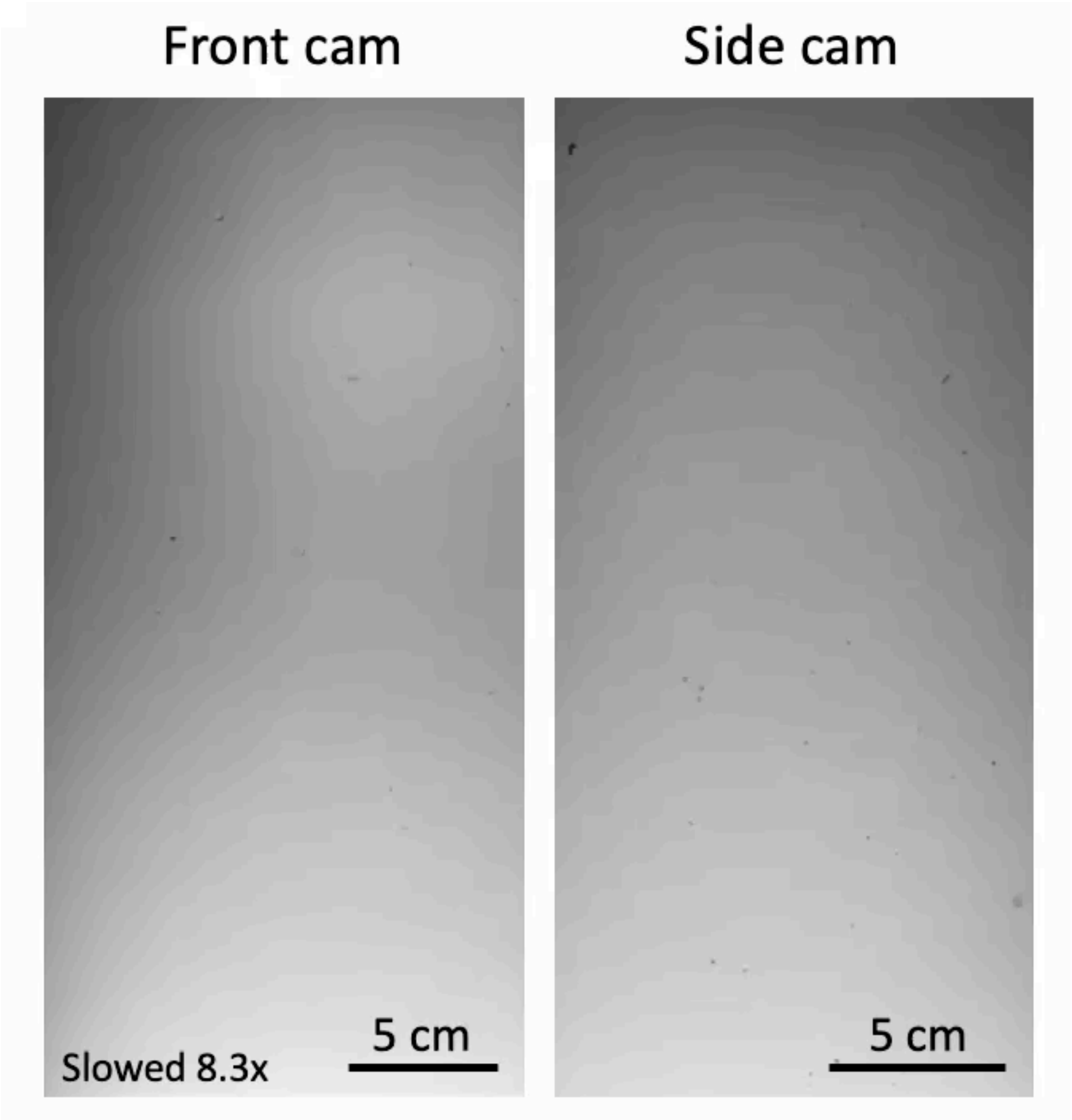

Tumbling !

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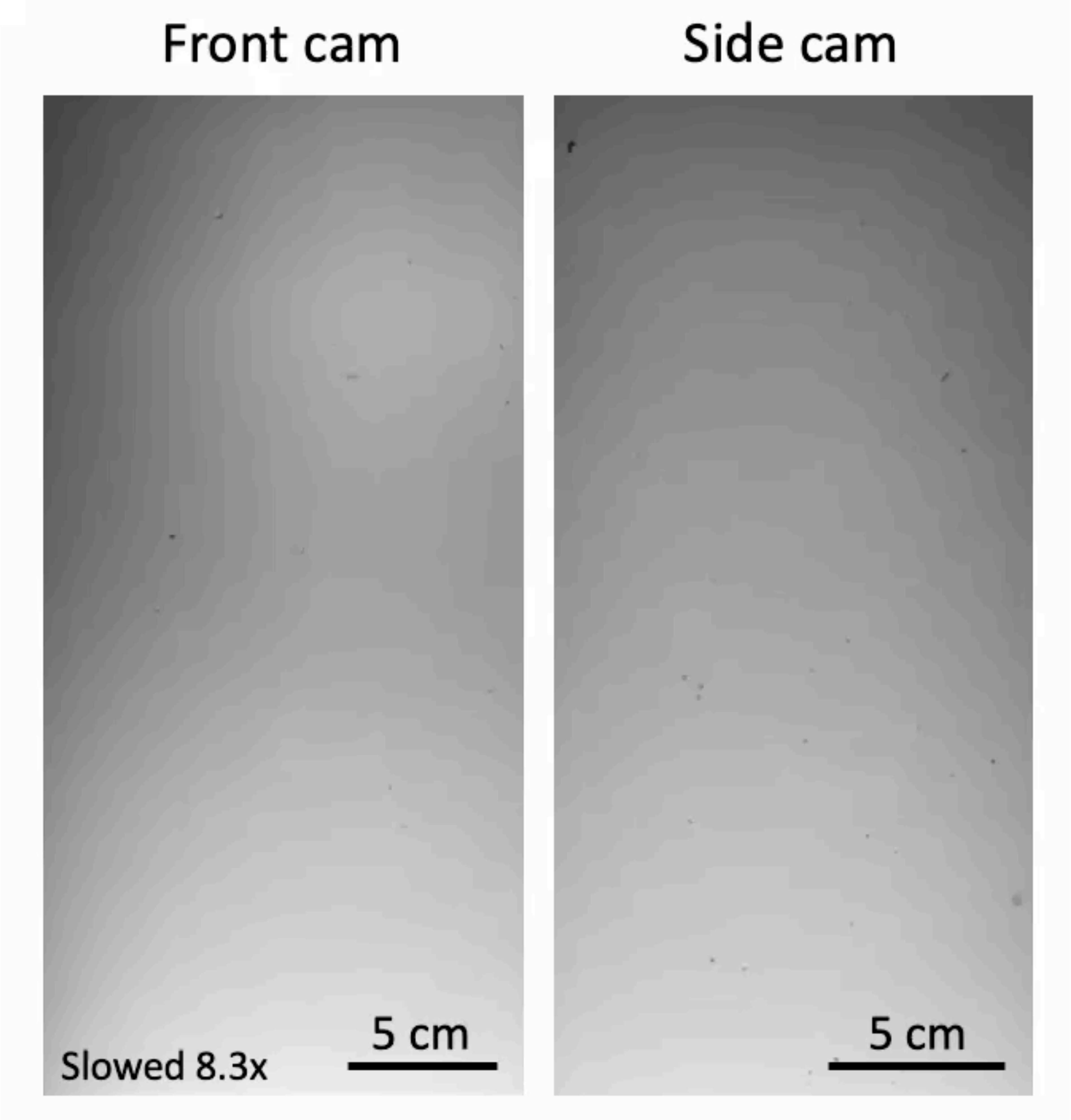
Dependence on Ga: tumbling vs stable



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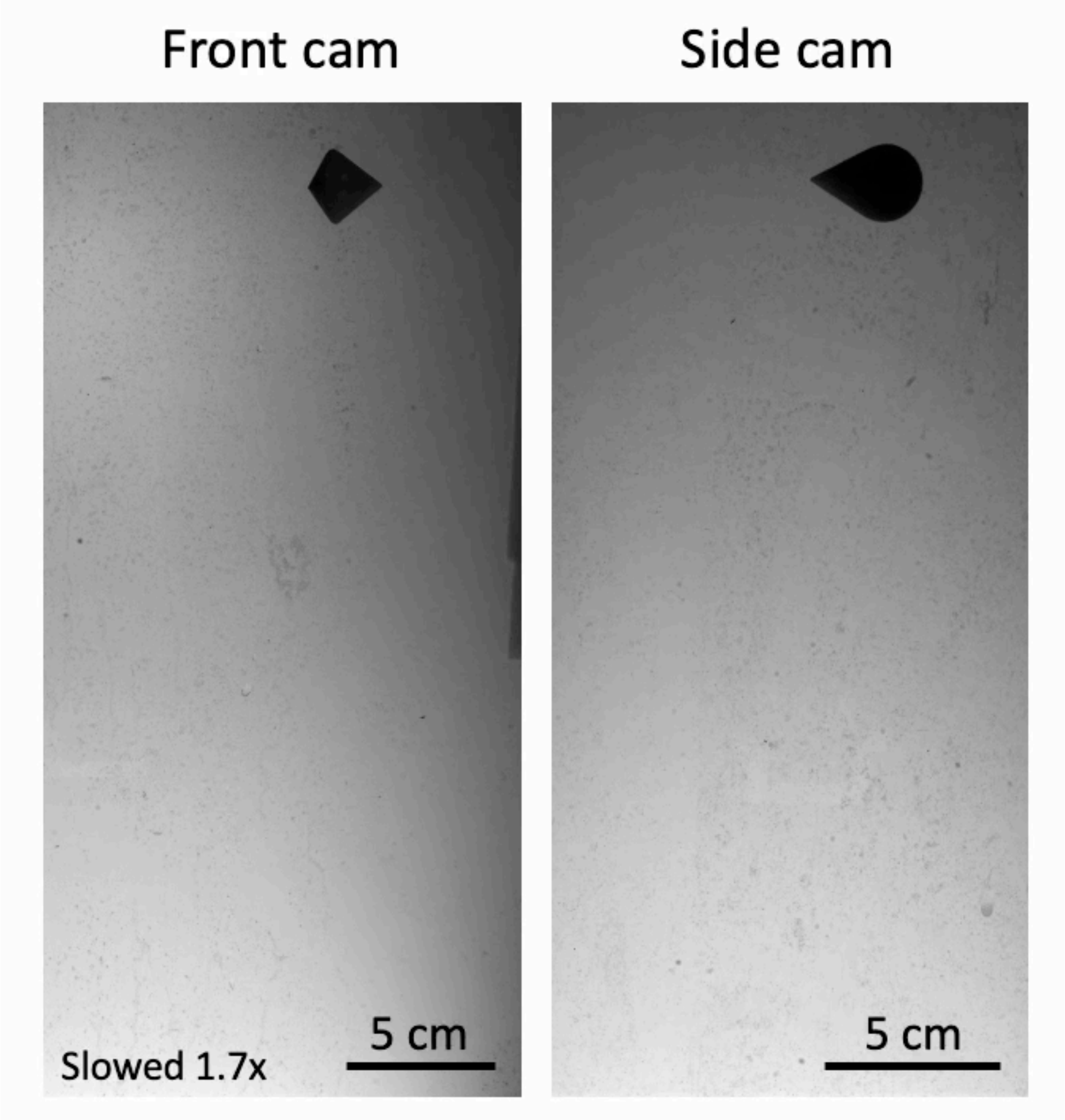

74% Glycerol
Ga = 130

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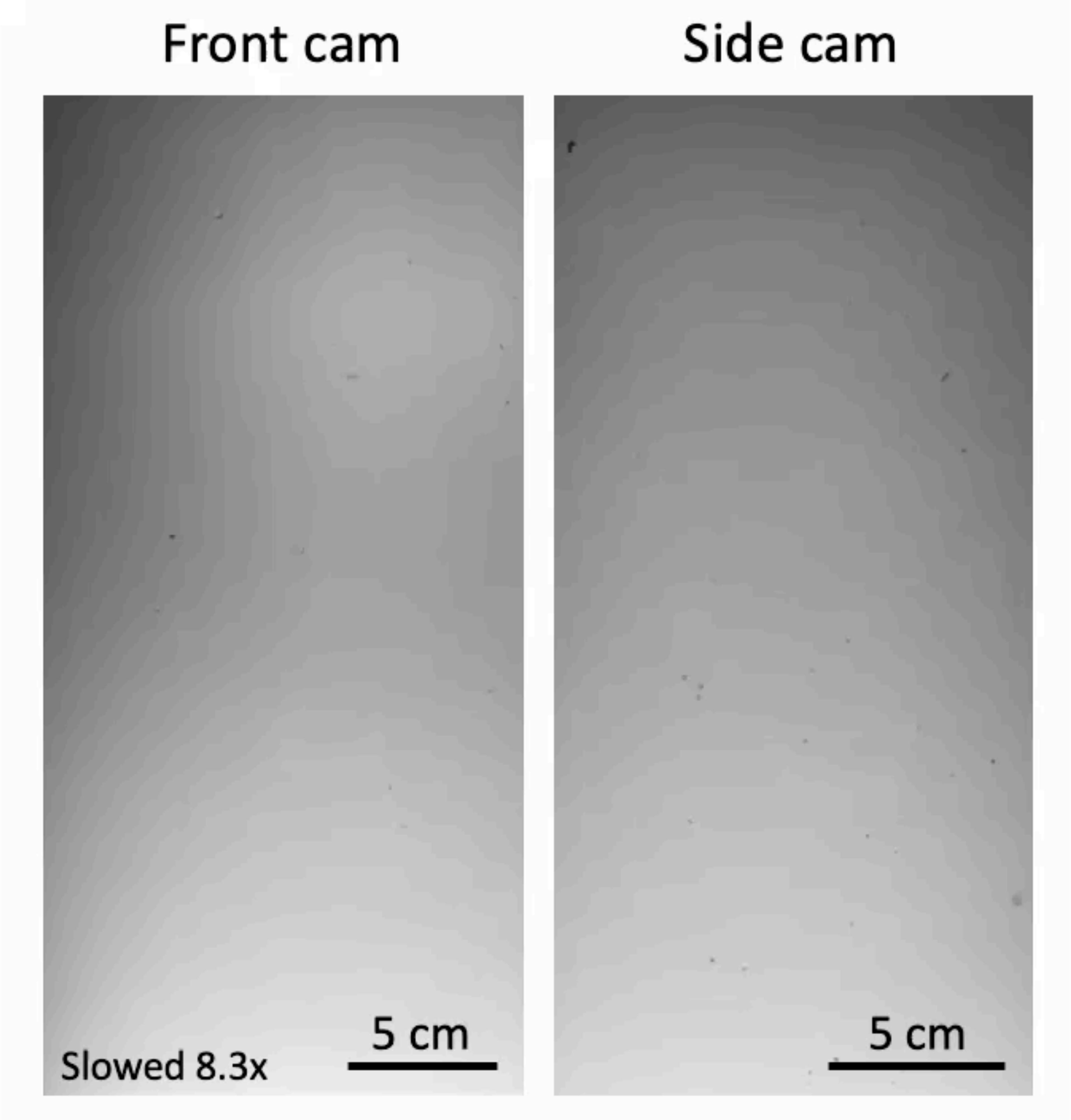

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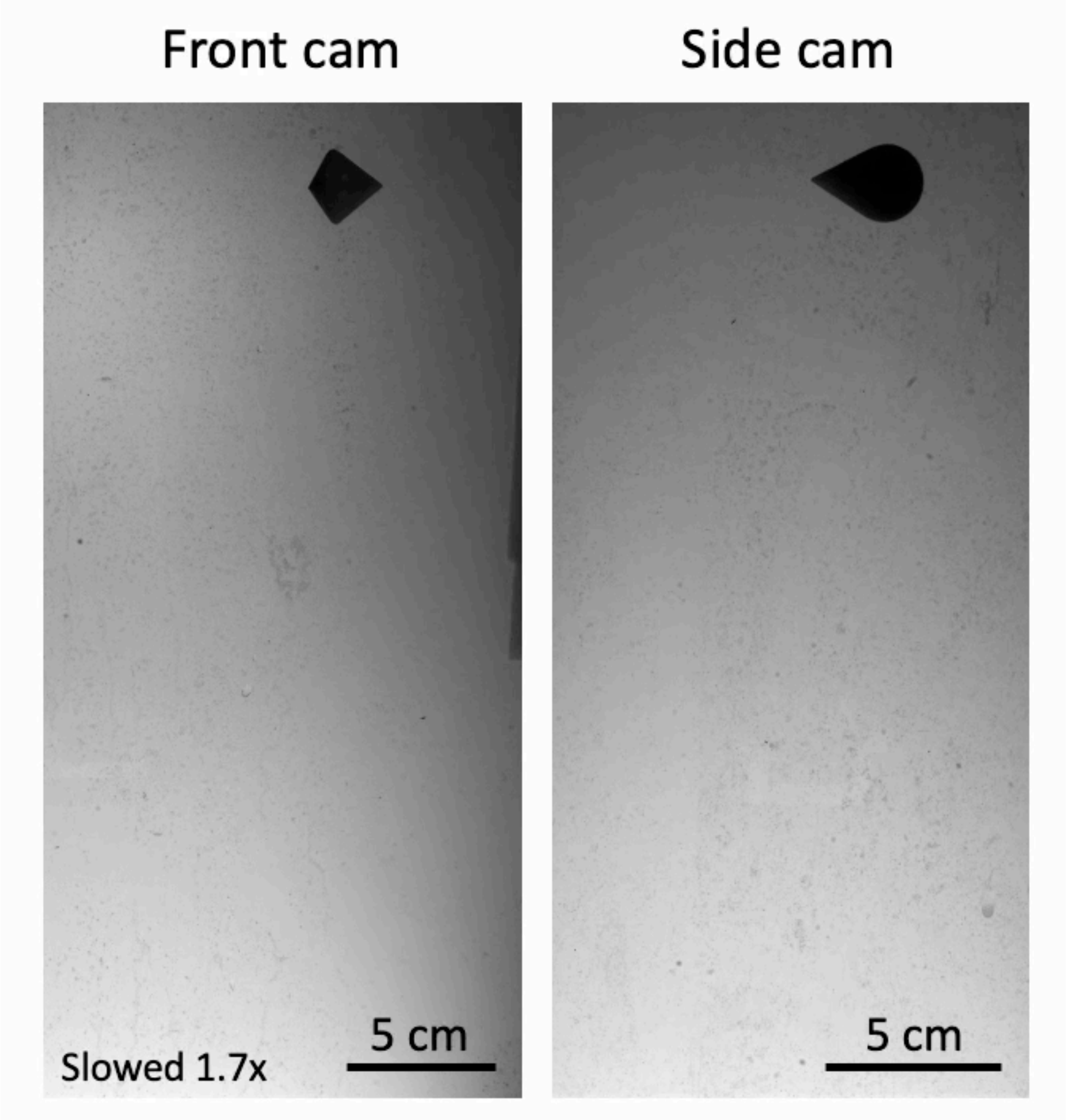

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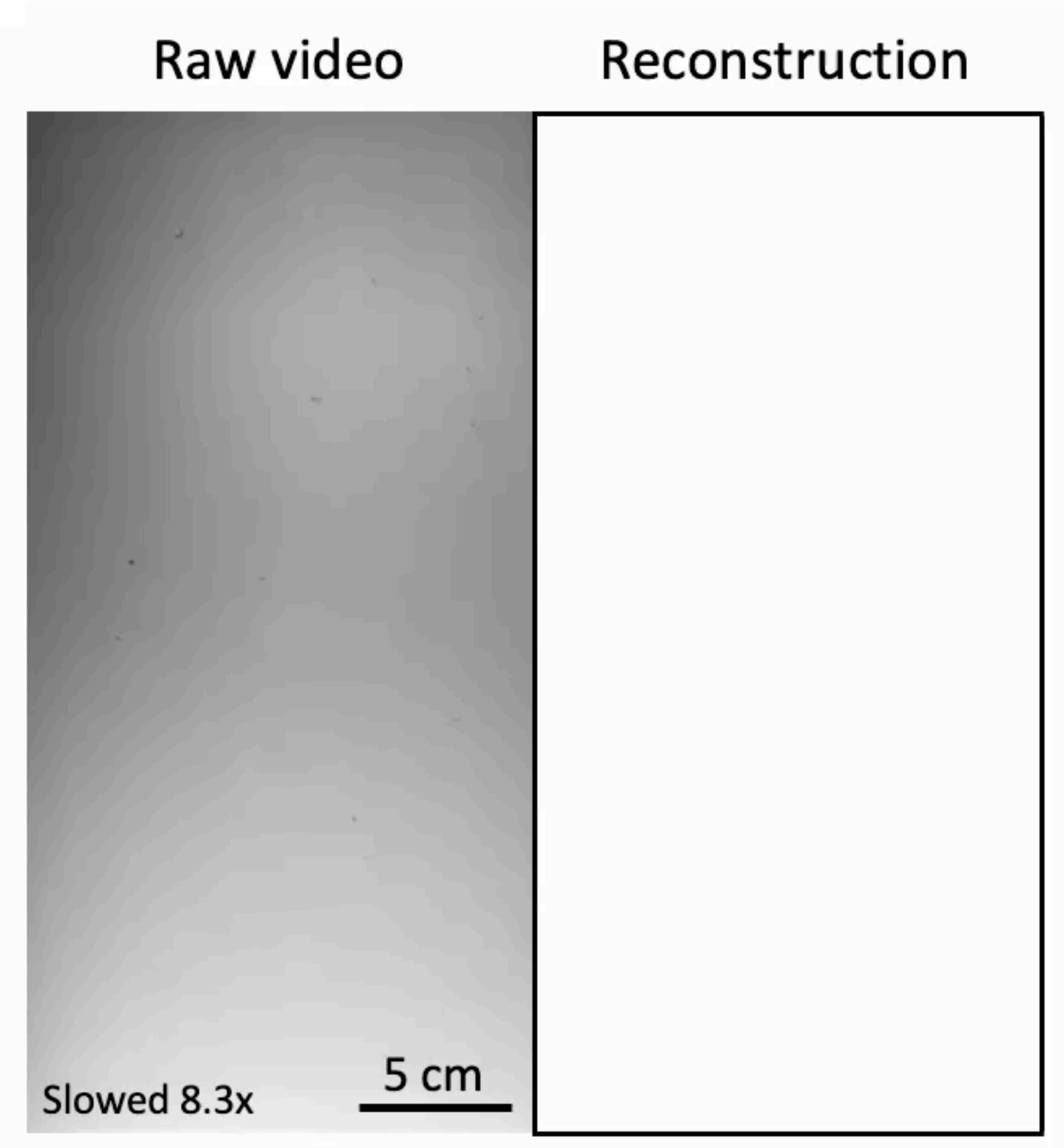
Reconstruction of path

Flapper, Benard & Huisman,
Rev. Sci. Instr. 96, 065207 (2025)



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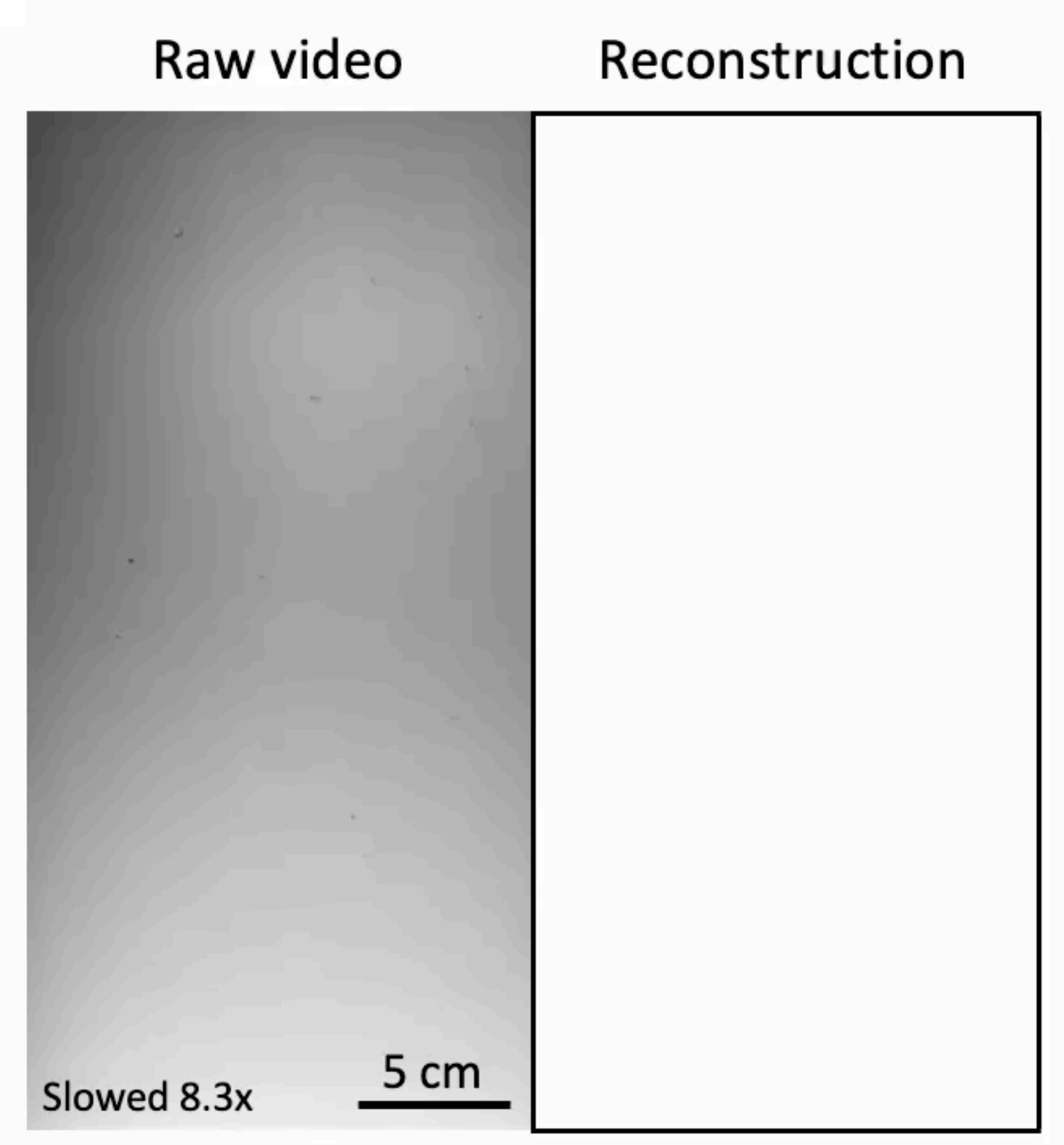

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Oloid settling: Direct numerical simulations

Method: AFiD + IBM

The Method: Carrier phase

DNS of incompressible Navier-Stokes equations using our AFiD code *(www.afid.eu)*.

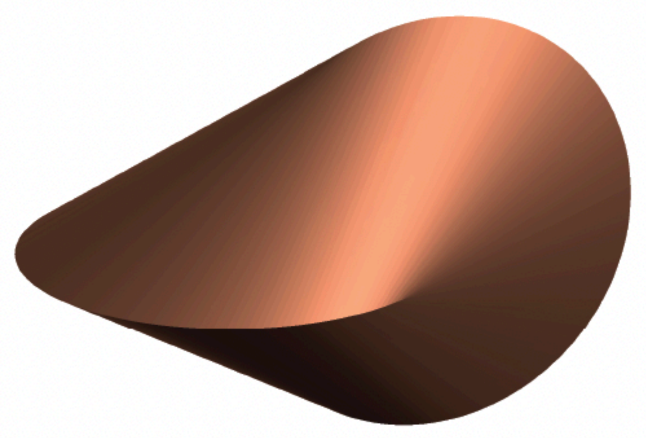
Volume forces used to account for effect of oloid on flow (immersed boundary method).

Incompressible Navier-Stokes equations

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\partial p + \frac{1}{Re}\nabla^2 \mathbf{u} + \mathscr{F}_{\boldsymbol{HIT}} + \mathscr{F}_{\boldsymbol{IBM}}$$

$$\nabla \cdot \mathbf{u} = 0$$

Two-way Coupled



***HIT**: Chouippe and Uhlmann Physics of Fluids **27**, 123301 (2015)*

***IBM**: De Tullio and Pascazio, Journal of Computational Physics **325** 201–225 (2016)*

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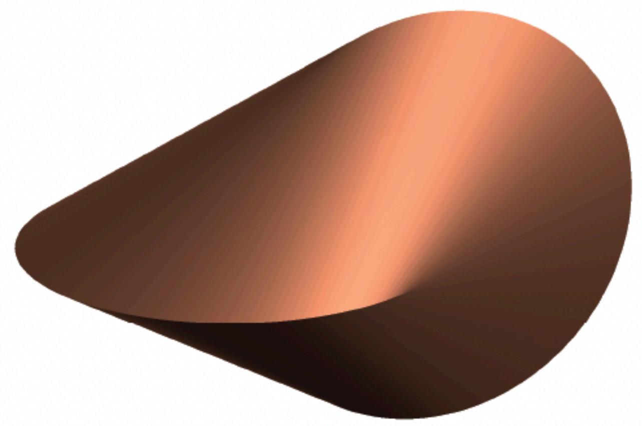

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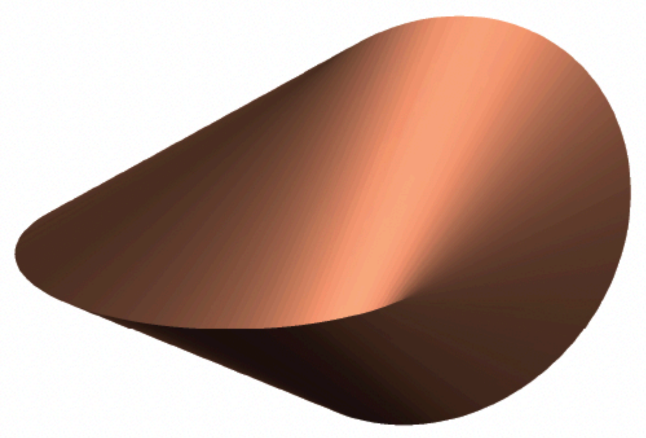

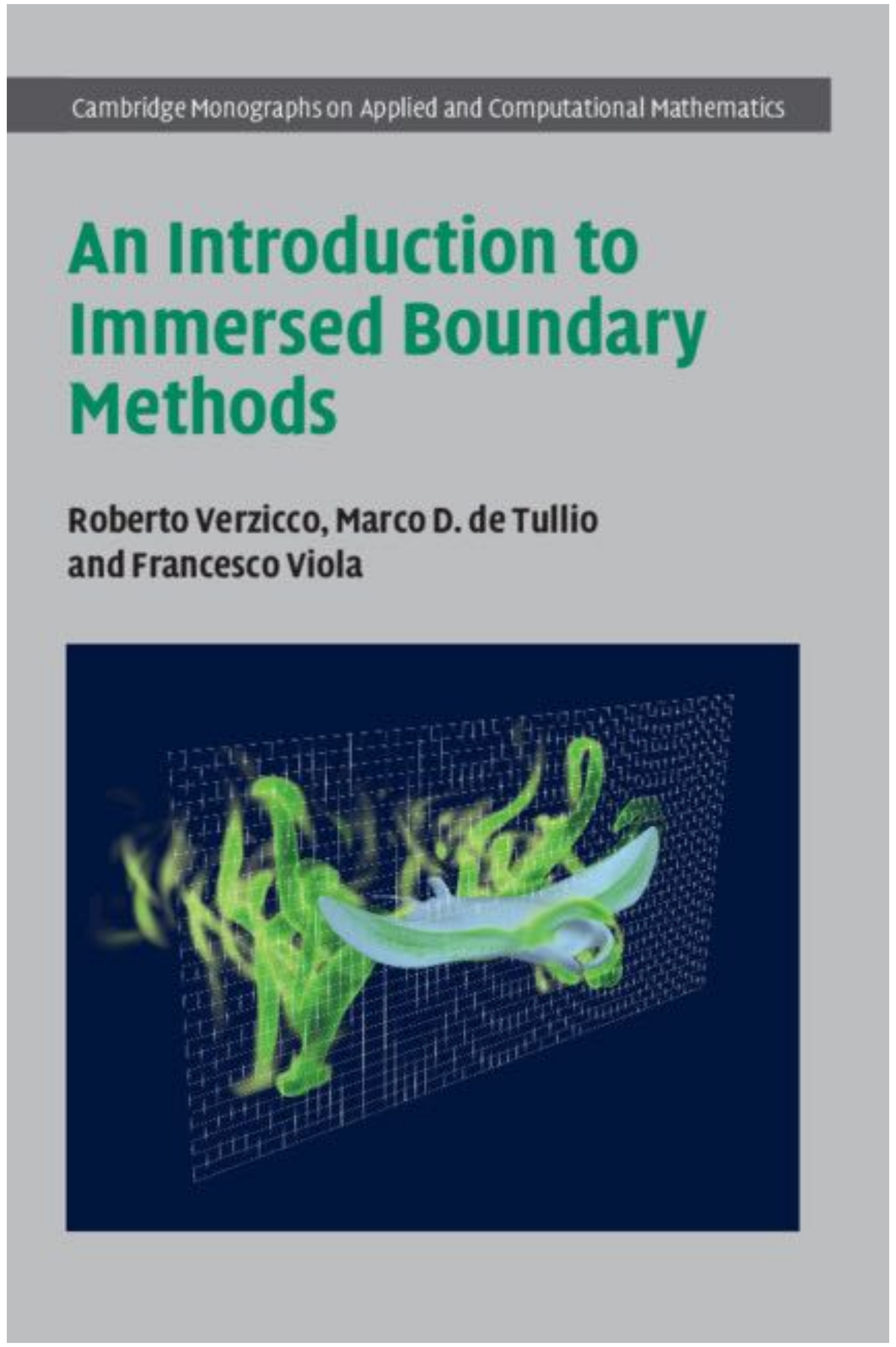

The Method: Dispersed phase: Translation and rotation

Oloid dynamics is evolved by Newton-Euler equations integrated using quaternions

$$\rho_p V_p \frac{d\boldsymbol{u}_c}{dt} = \oint_{A_p} \boldsymbol{\tau} \cdot \boldsymbol{n} dA + (\rho_p - \rho_f) V_p \boldsymbol{g} + \boldsymbol{F}_c \qquad \boldsymbol{I}_p \frac{d\boldsymbol{\omega}_c}{dt} + \boldsymbol{\omega}_c \times (\boldsymbol{I}_p \boldsymbol{\omega}_c) = \oint_{A_p} \boldsymbol{r} \times (\boldsymbol{\tau} \cdot \boldsymbol{n}) dA + \boldsymbol{T}_c$$

Non-dimensionalized Newton-Euler equations

$$\frac{d\boldsymbol{u}_c}{dt} \approx \frac{\rho_f}{\rho_p} \frac{6}{\pi} \left(-\sum_{i=1}^{N_l} \boldsymbol{f}_i \Delta V_i + \frac{d}{dt} \int_{V_p} \boldsymbol{u} dV \right) - \frac{\widehat{\mathbf{k}}}{Fr} + \frac{\rho_f}{\rho_p} \frac{6}{\pi} \boldsymbol{F}_c$$

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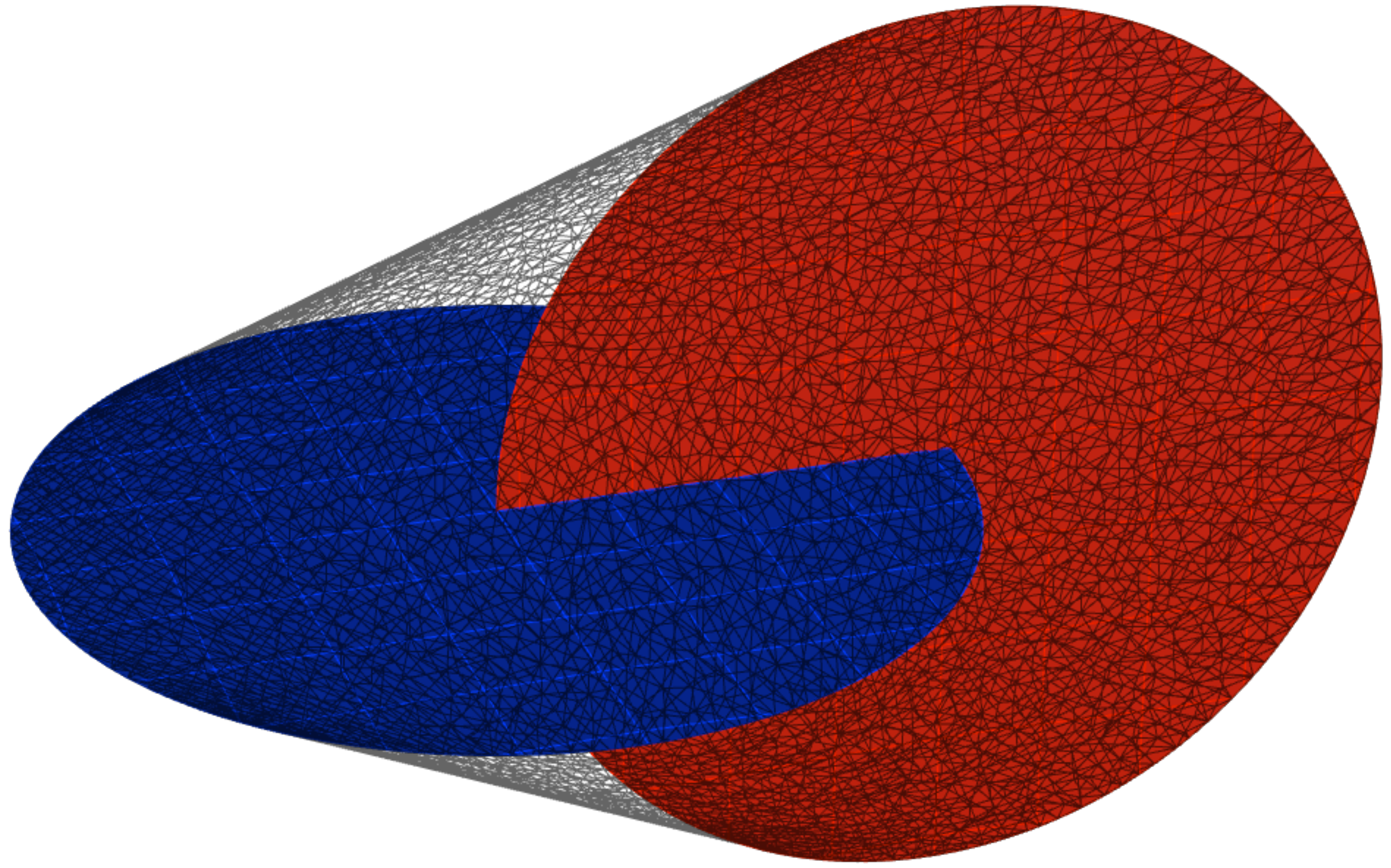

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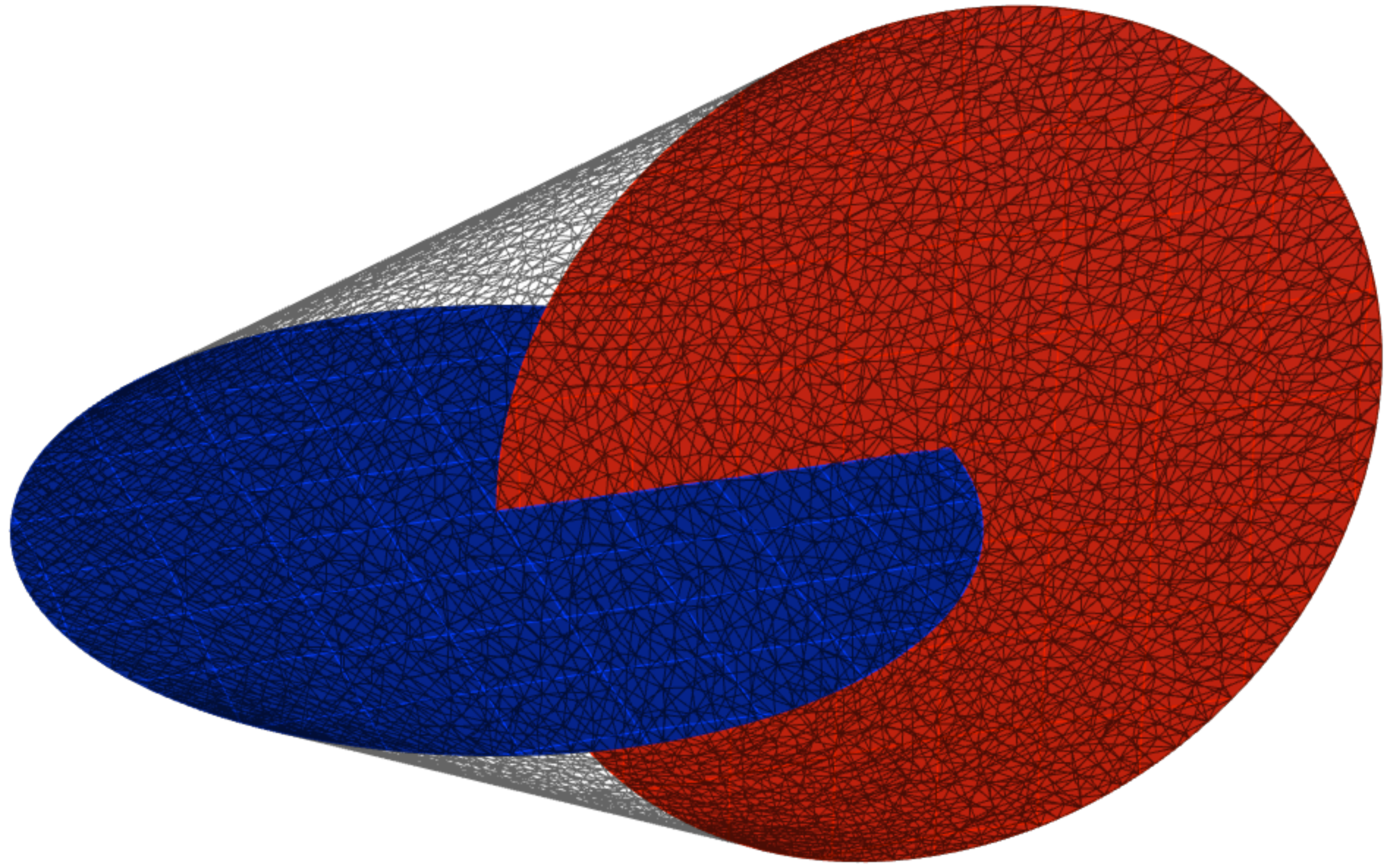
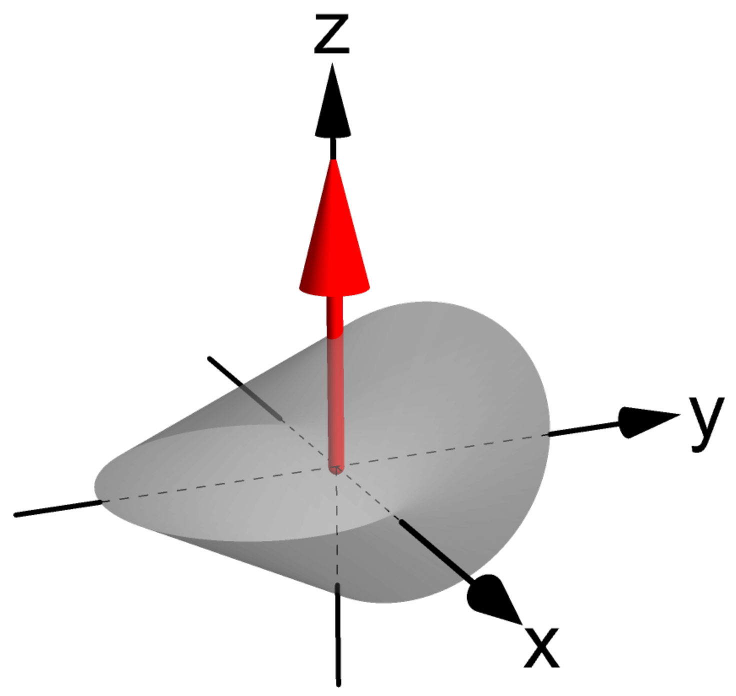
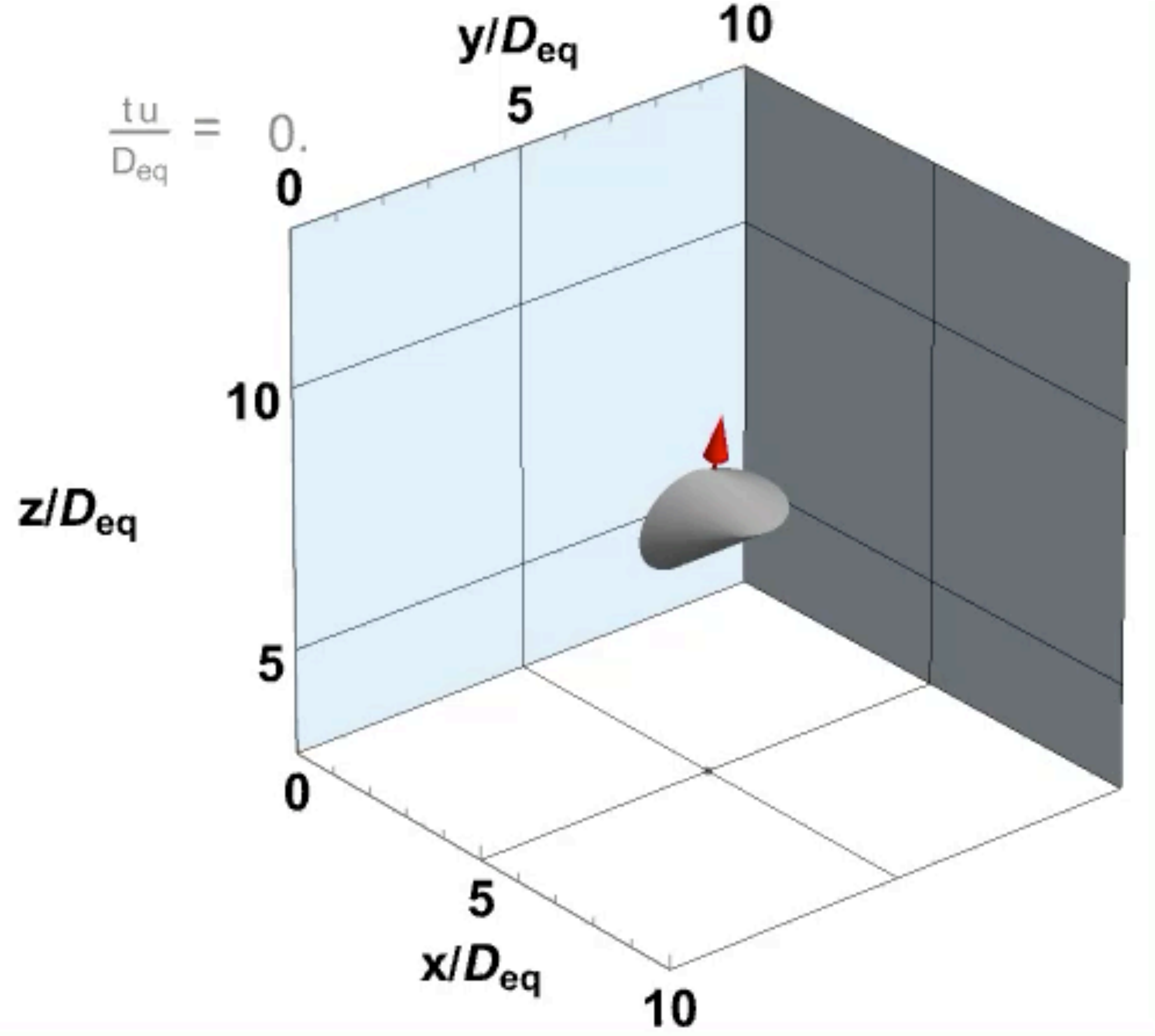
$$Fr = \frac{U}{\sqrt{gD_{eq}\left(1 - \frac{\rho_p}{\rho_f}\right)}}$$



Oloid settling: Direct numerical simulations

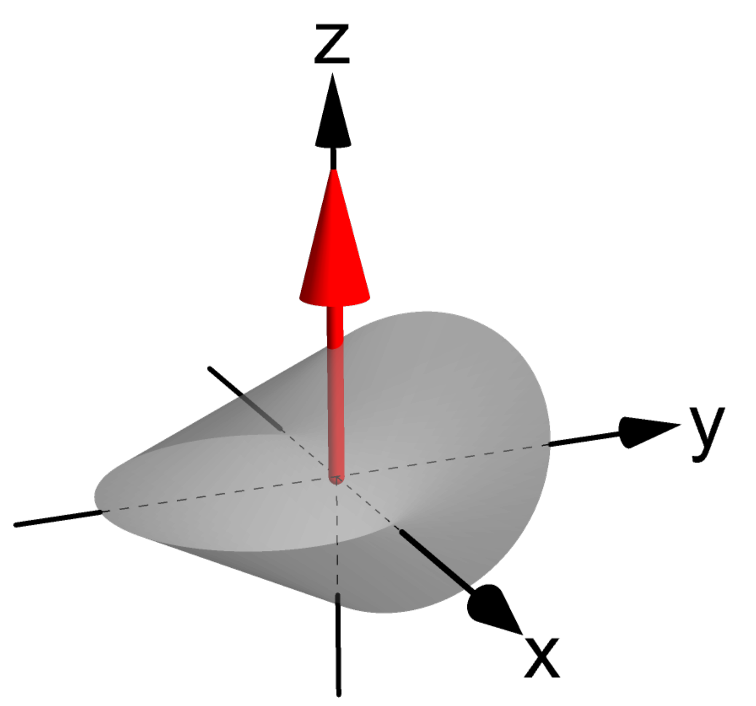


Poynting vector

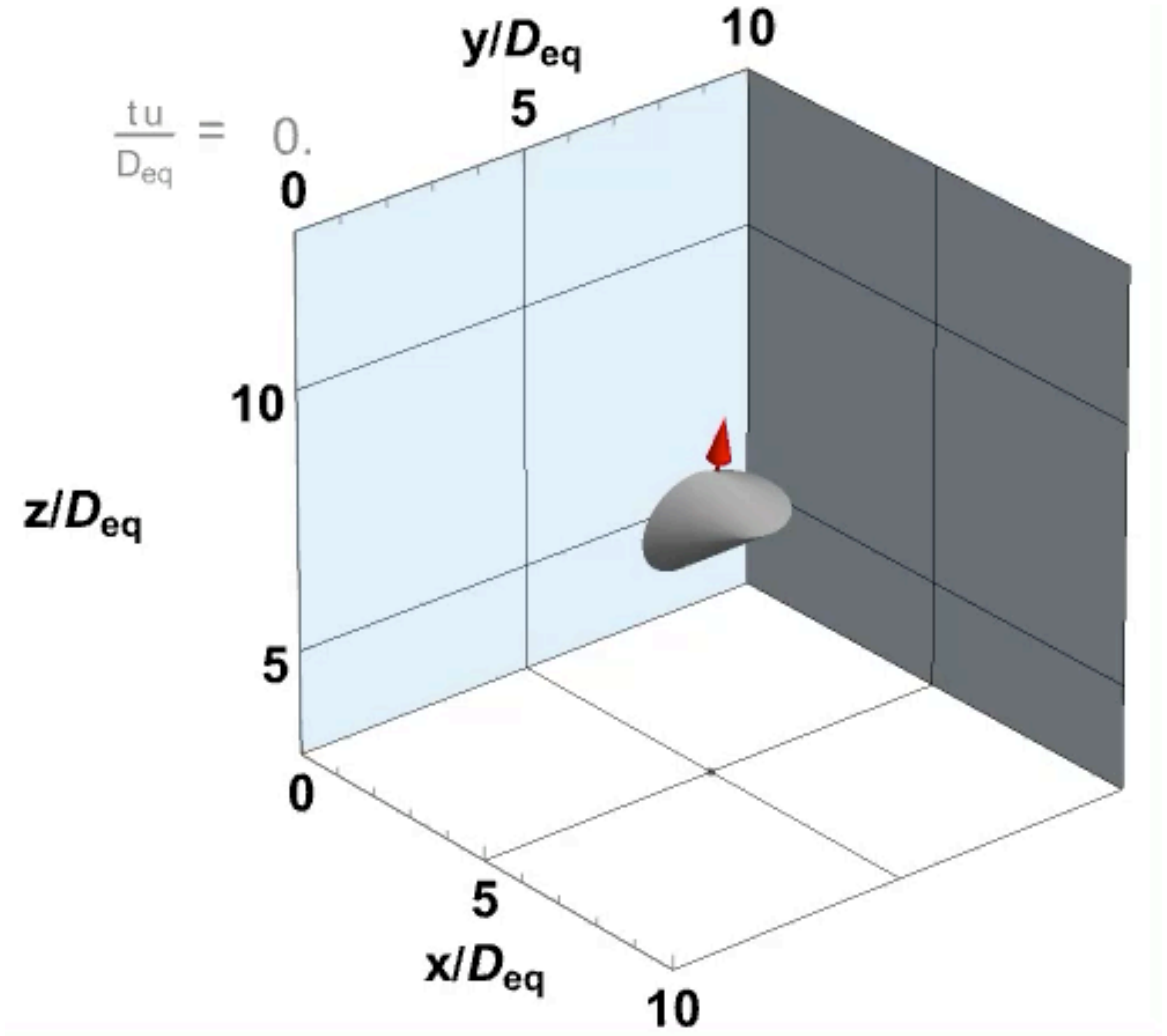


Ga = 10

Oloid settling: Direct numerical simulations



Poynting
vector



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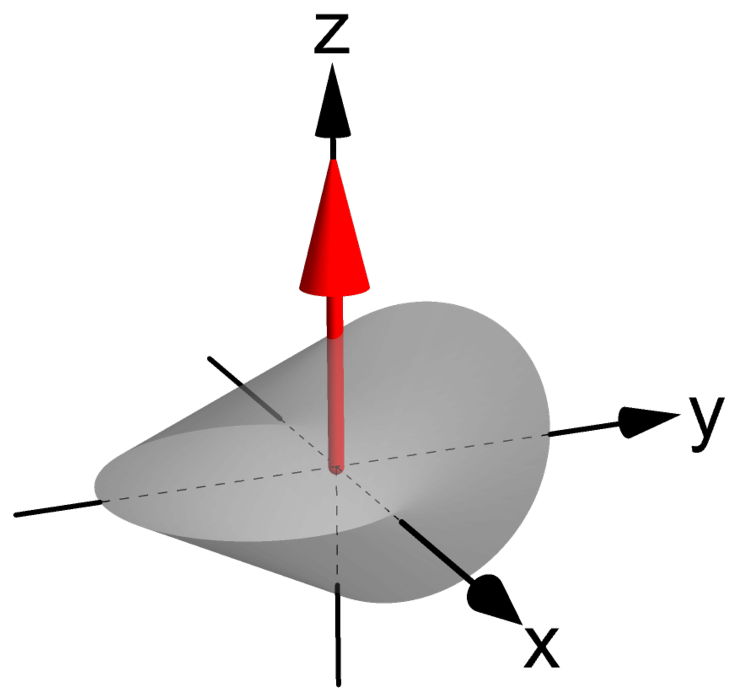

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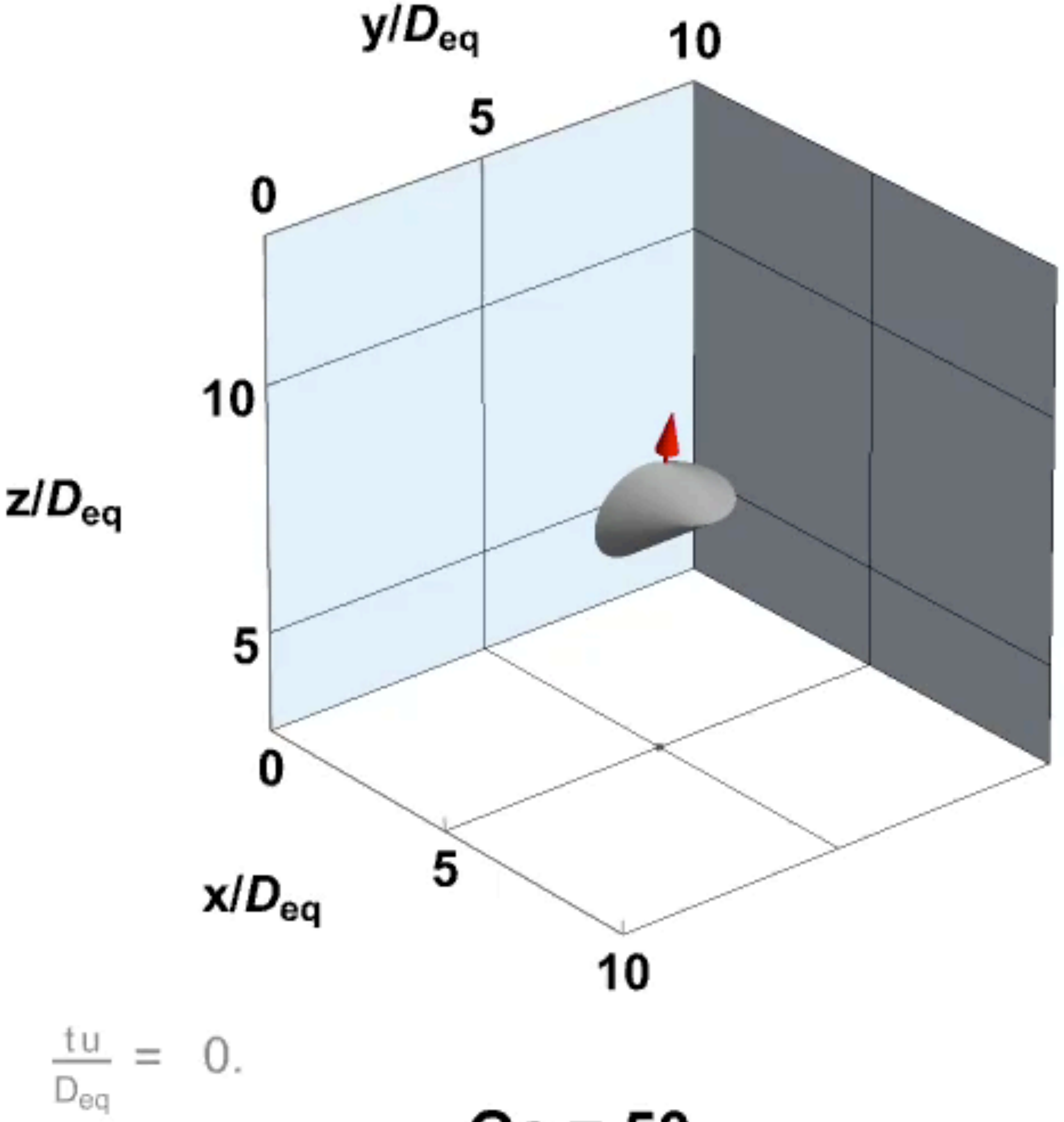

Ga = 50

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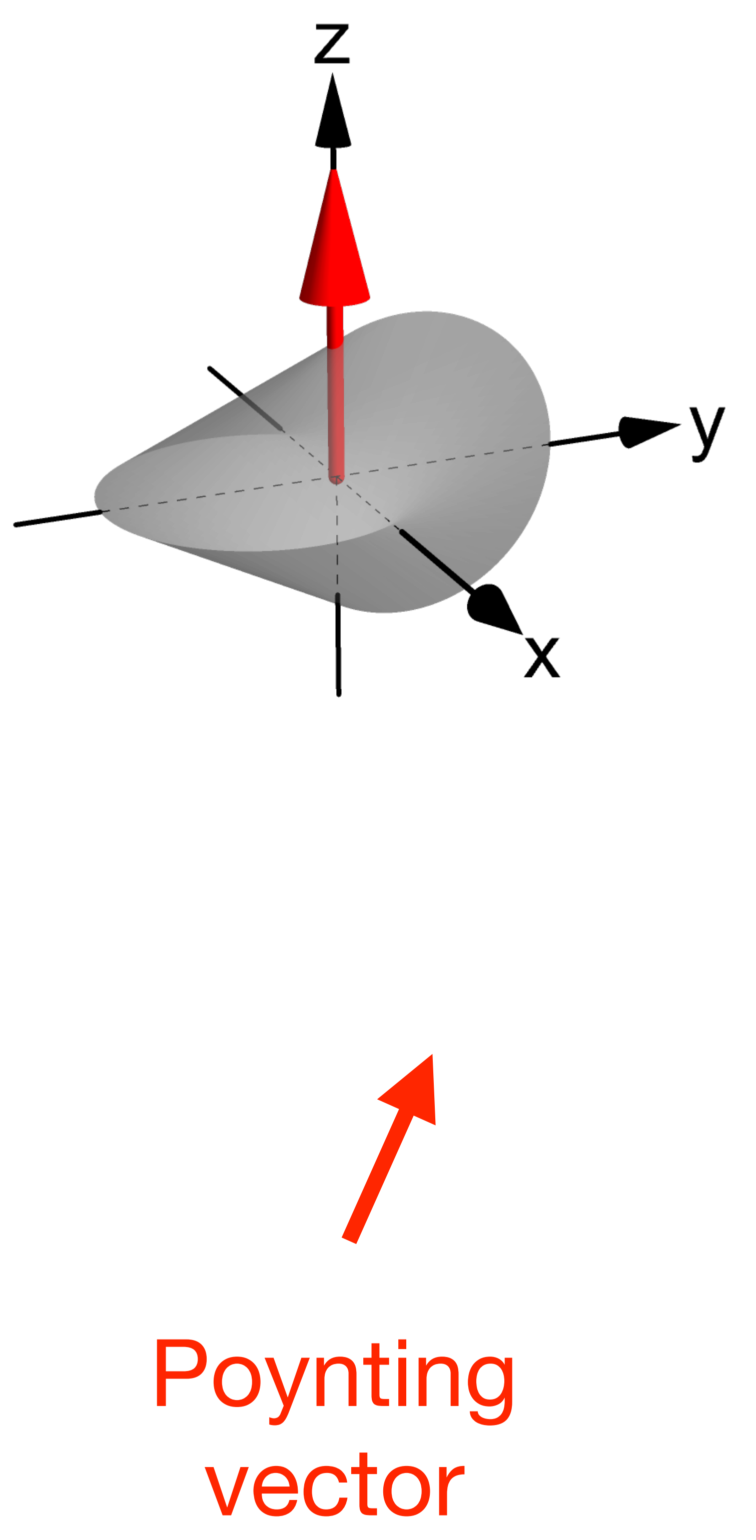

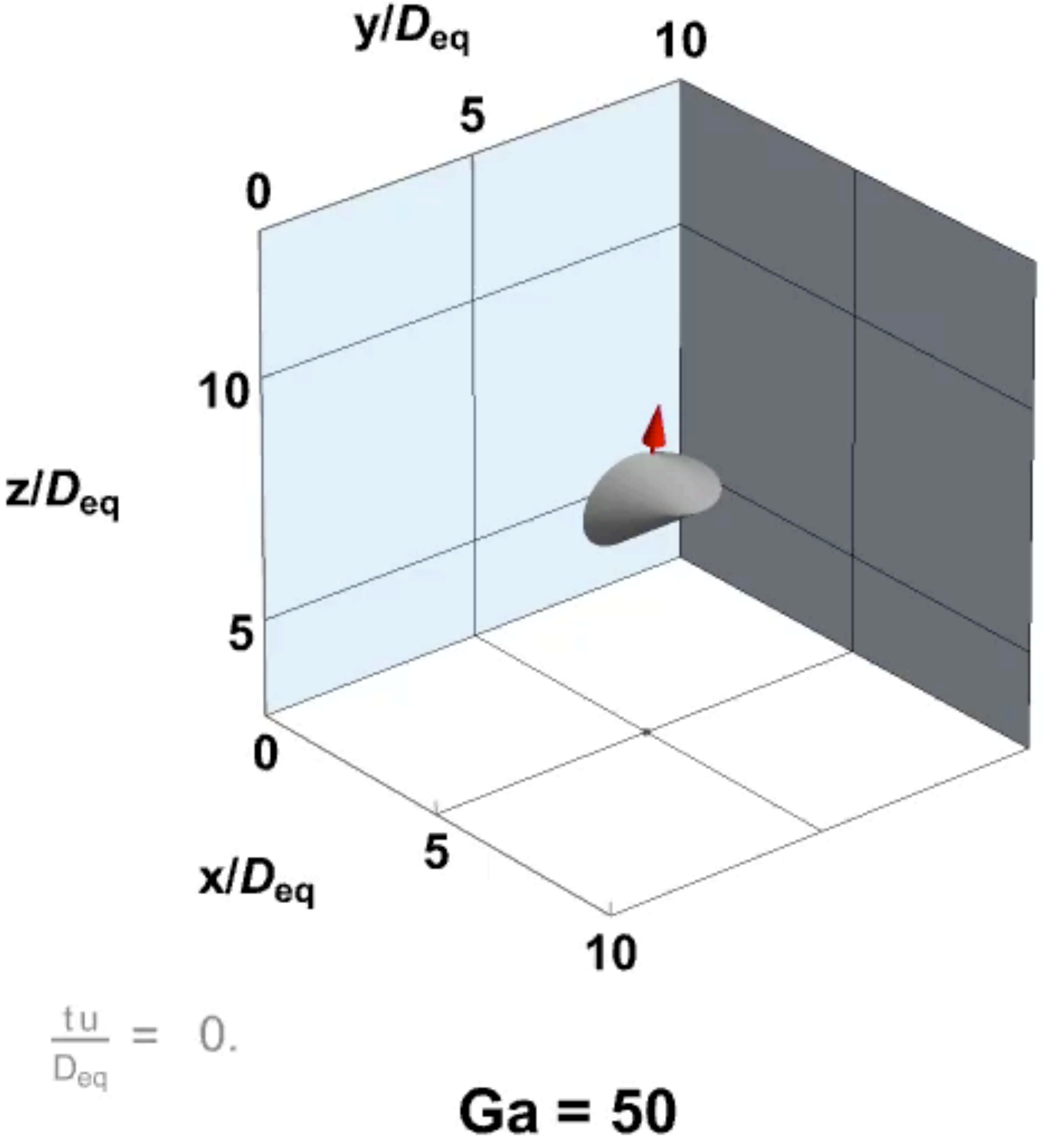

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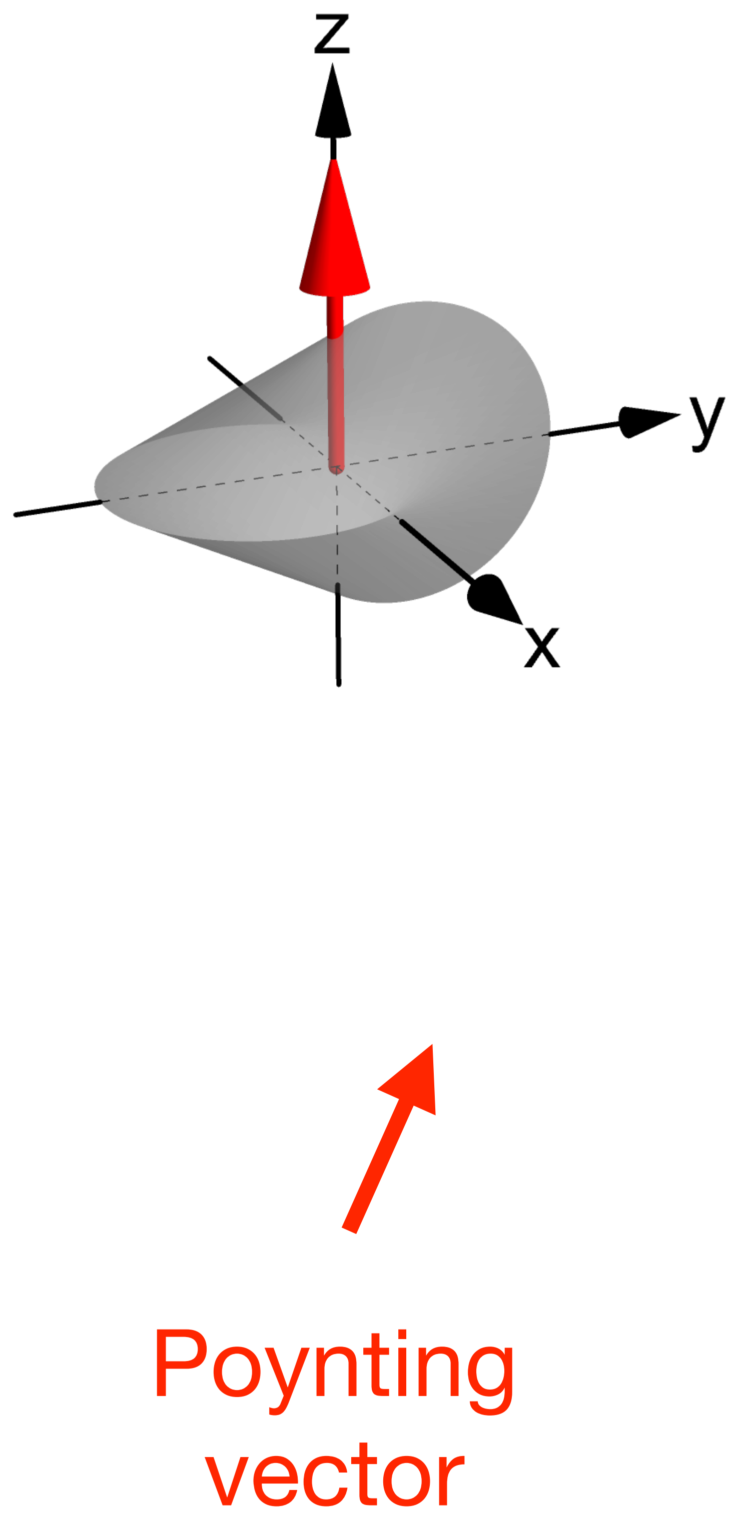

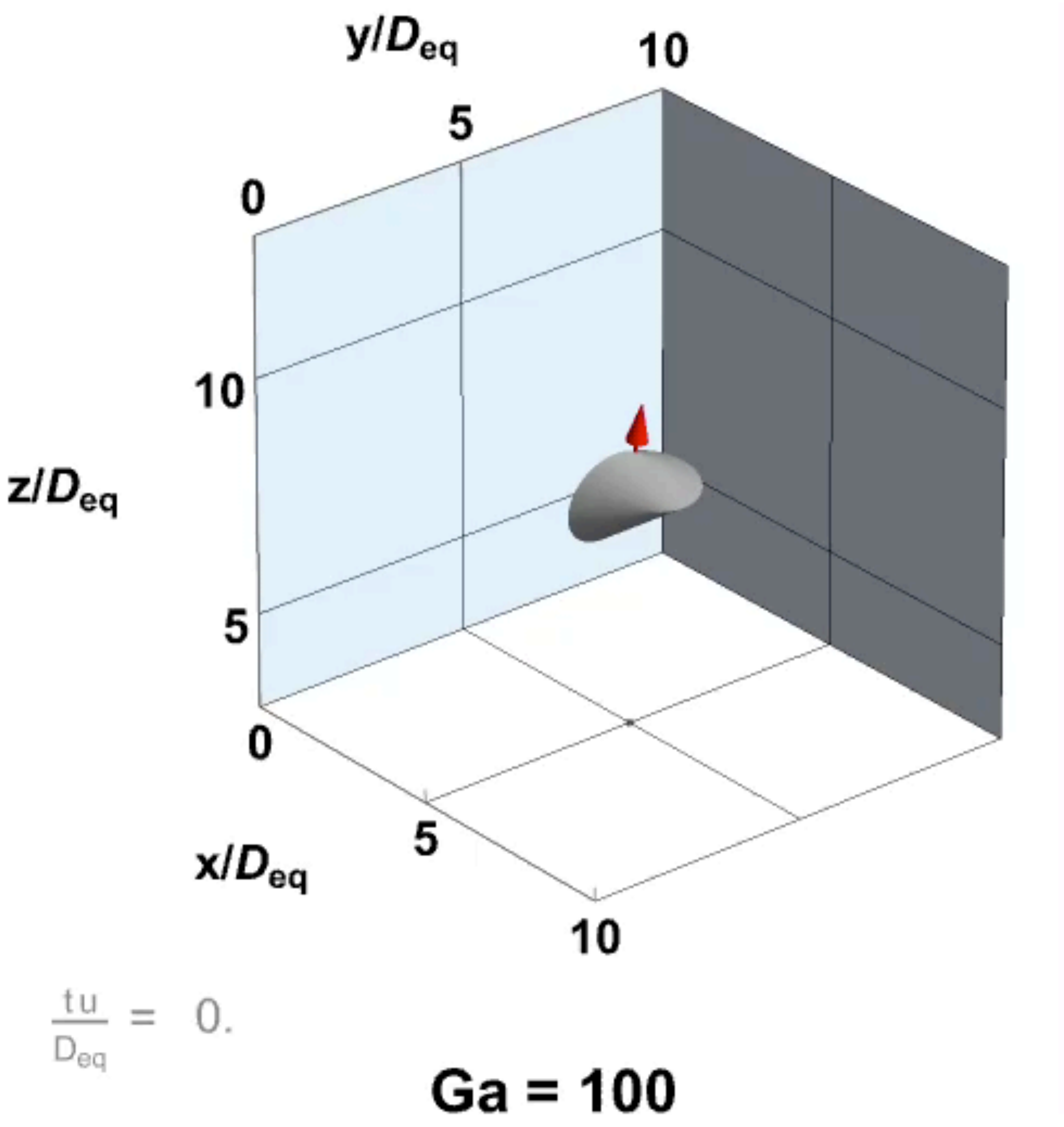

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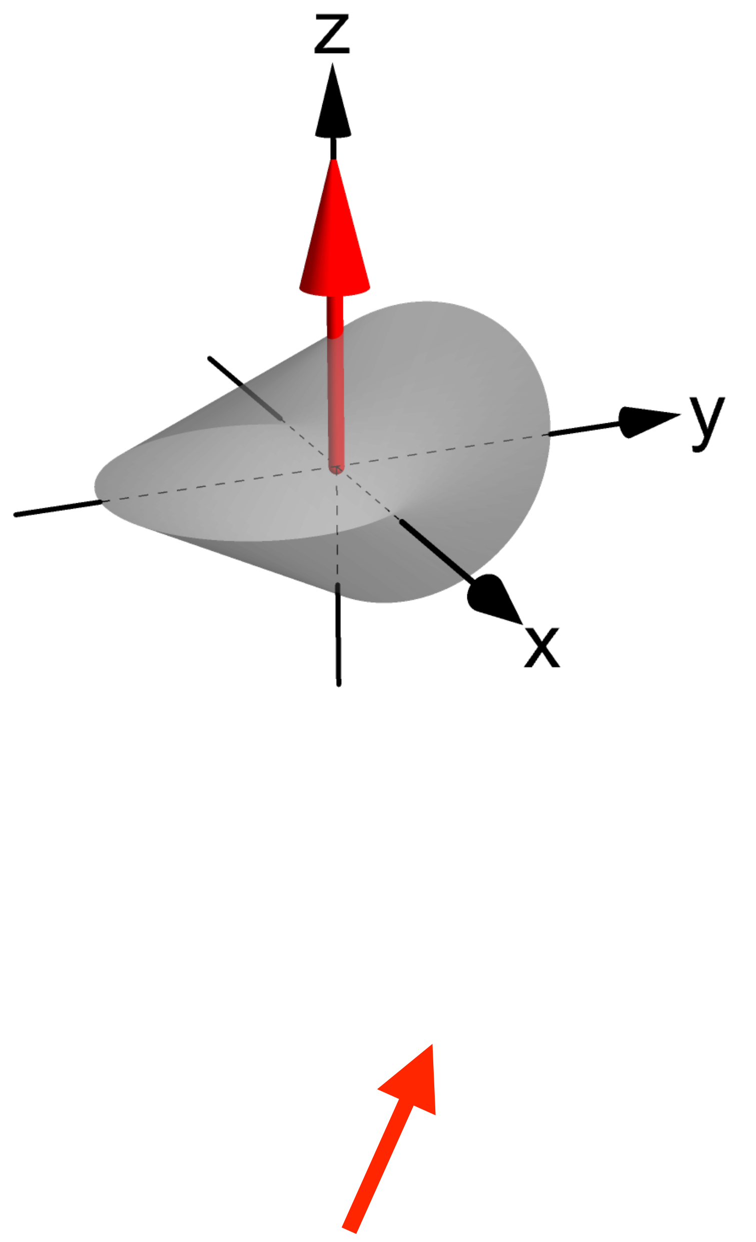

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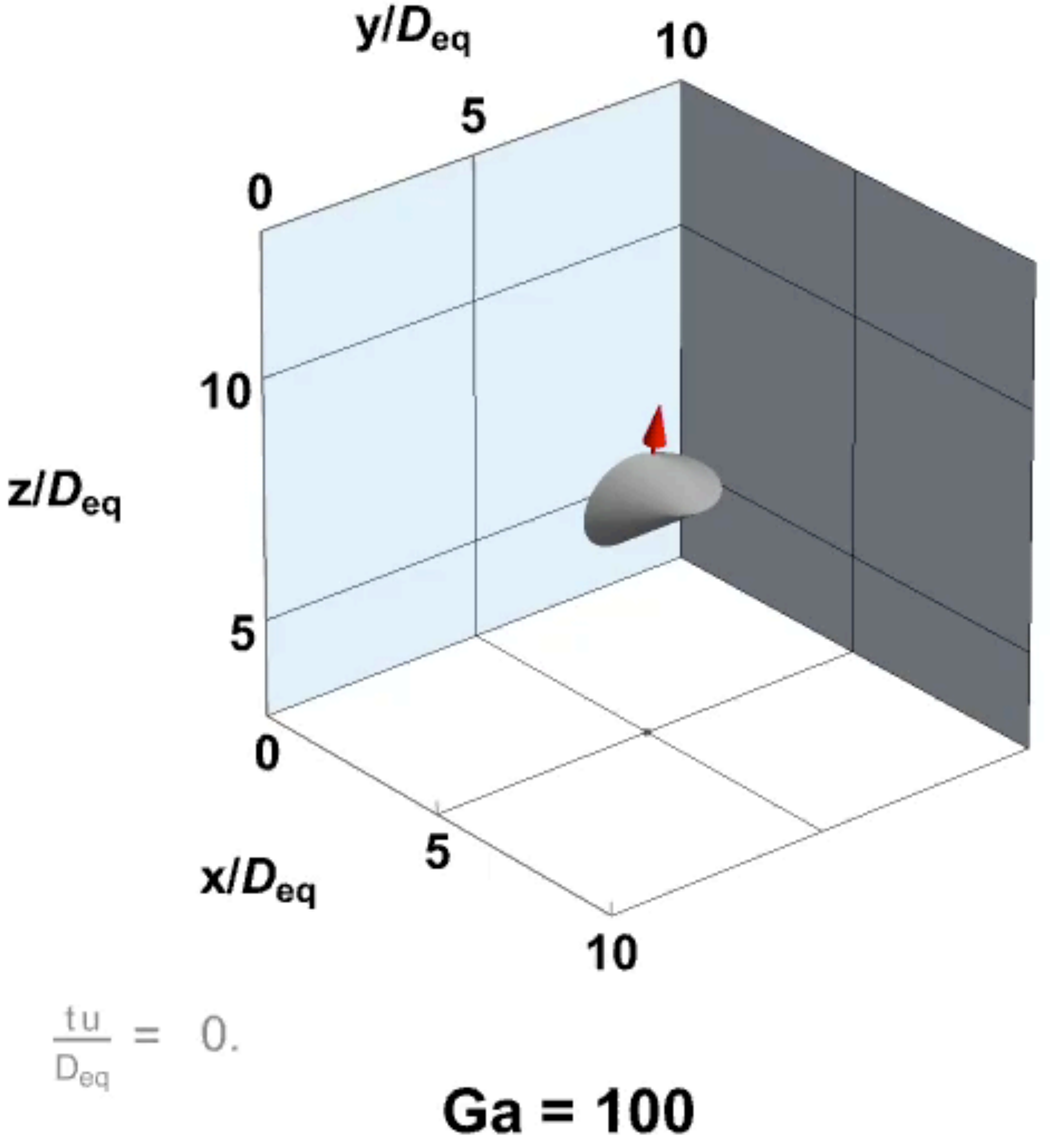
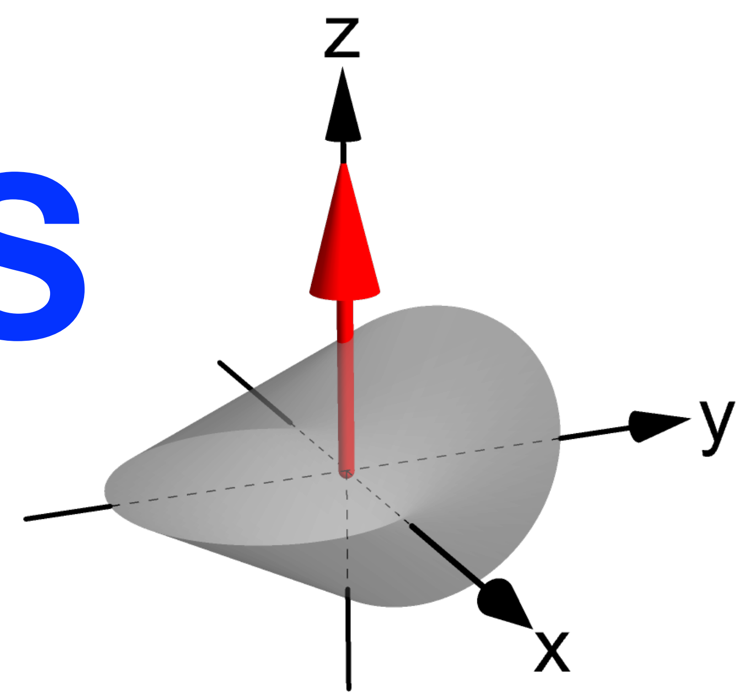
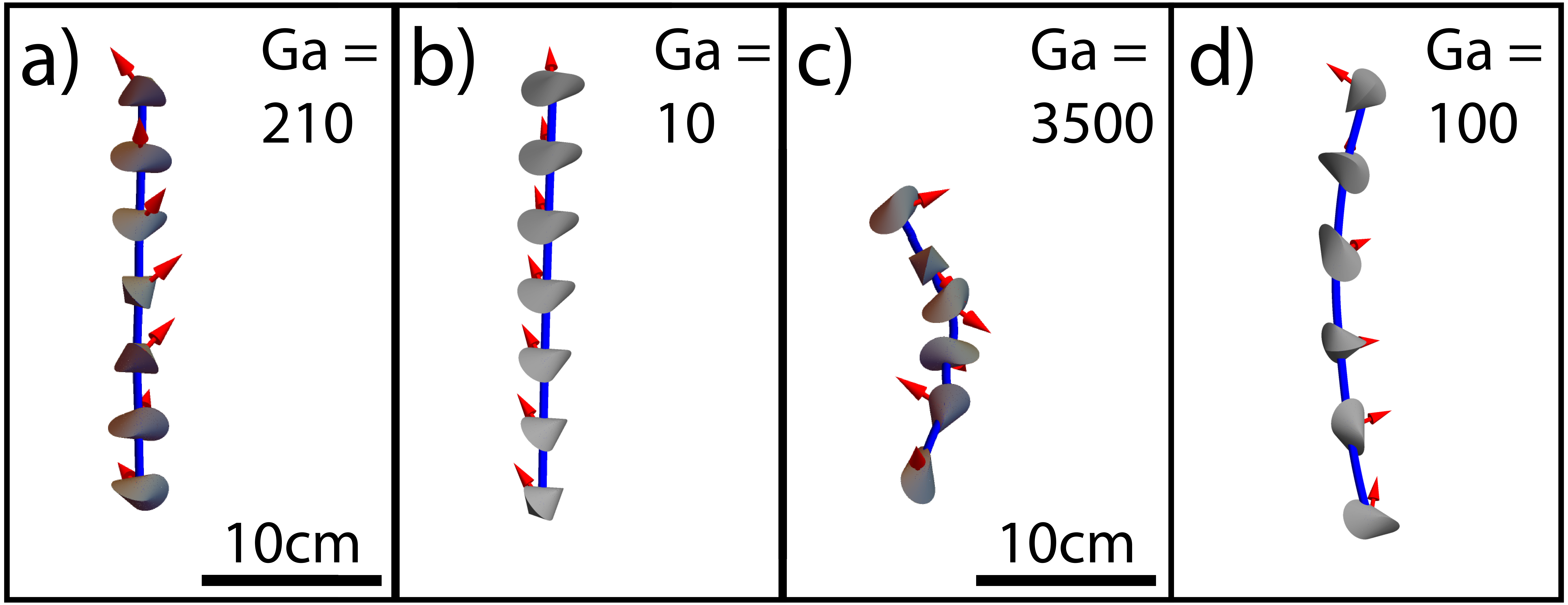


Both modes in both experiment & DNS



stable | tumbling

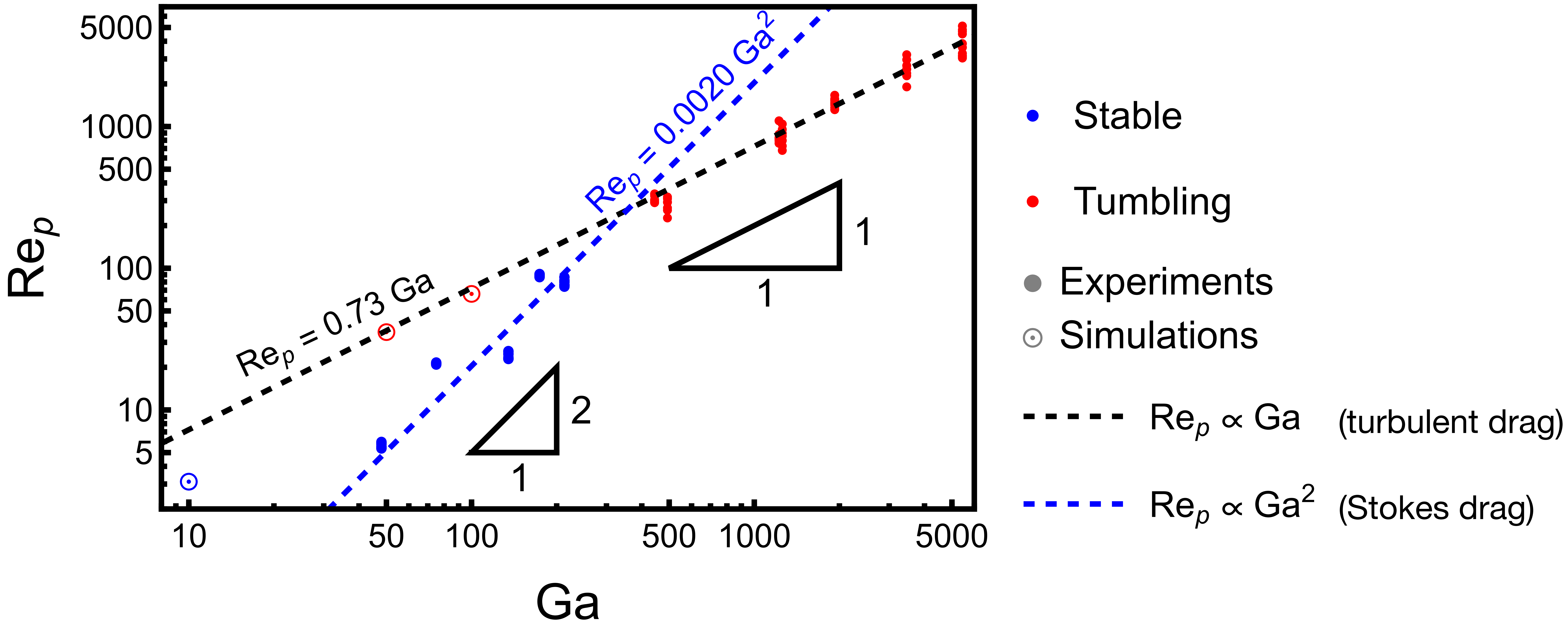
Experiment | Simulation | Experiment | Simulation



Experiments have $\Gamma = \rho_p/\rho_f \approx 1.2$

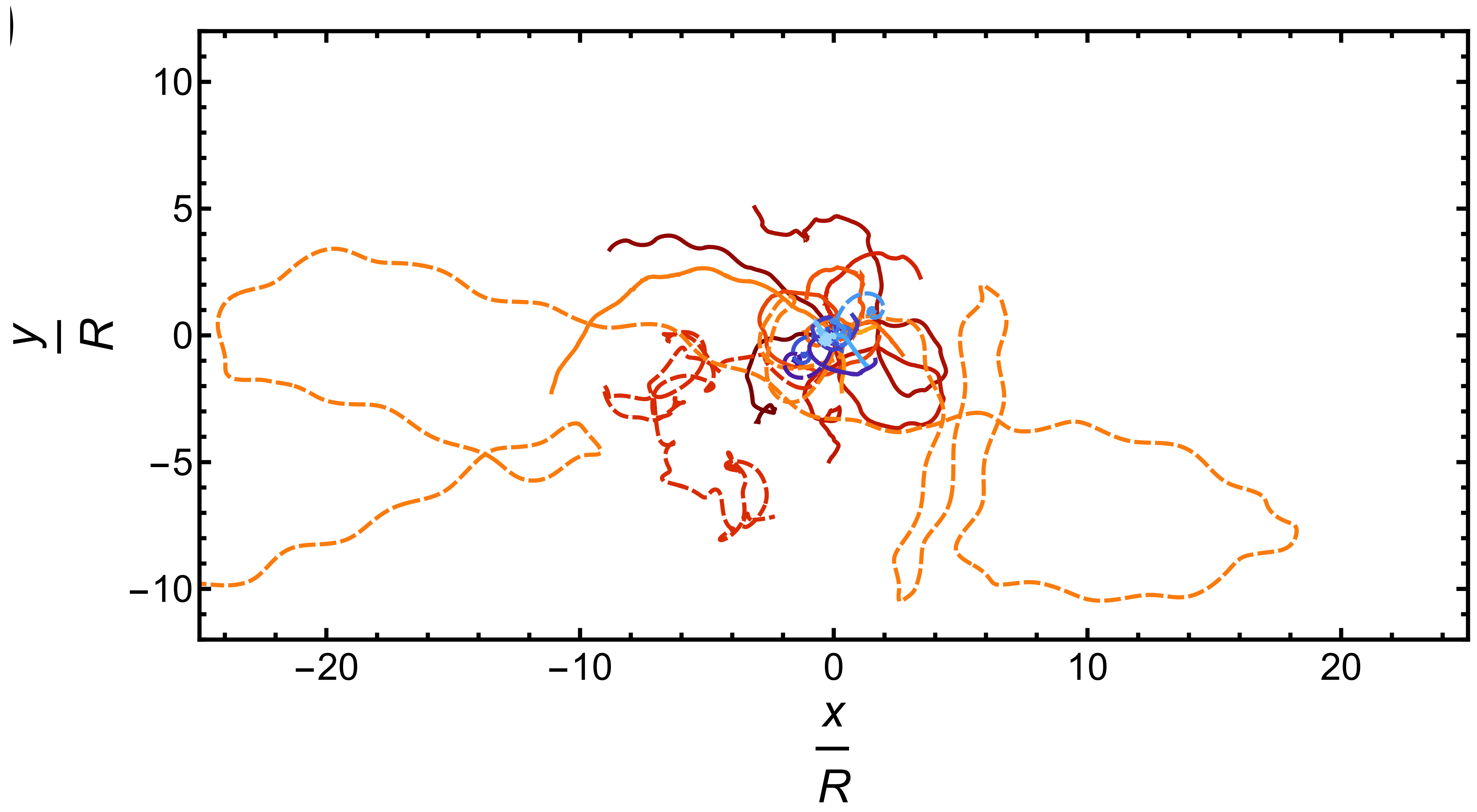
Simulations have $\Gamma = \rho_p/\rho_f \approx 2$

Results on settling velocity: two regimes



Top view: horizontal trajectories

blue: stable
red: tumbling



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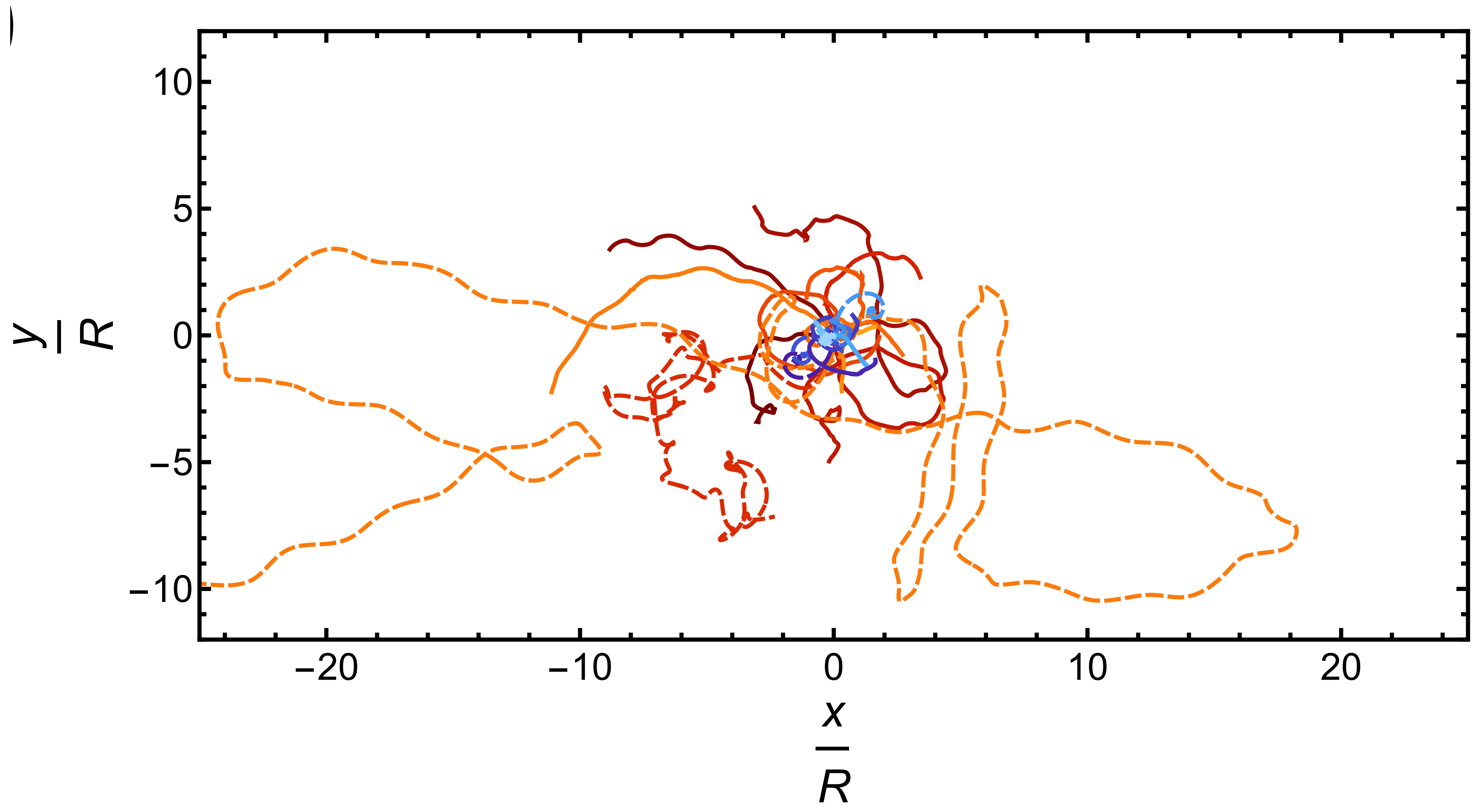
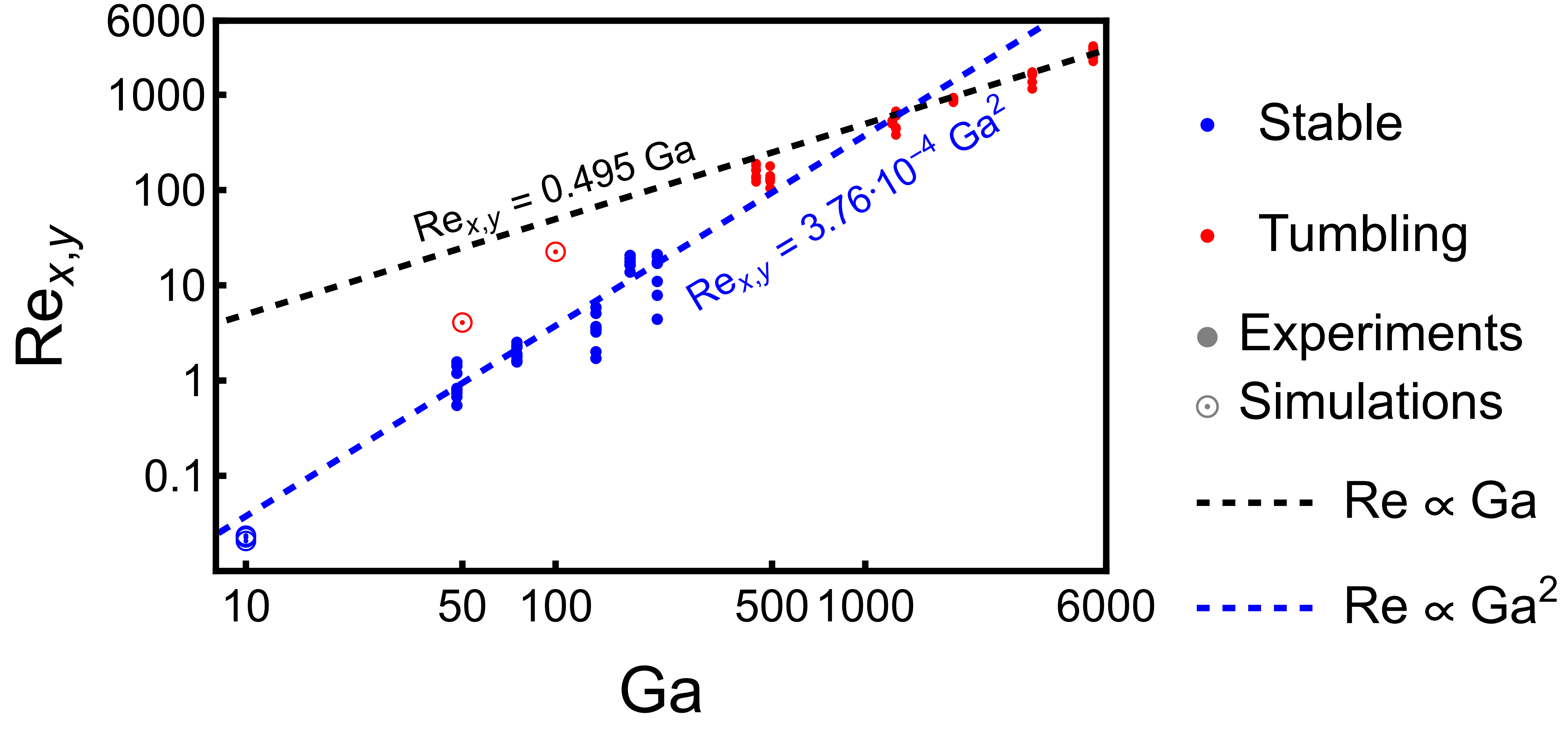
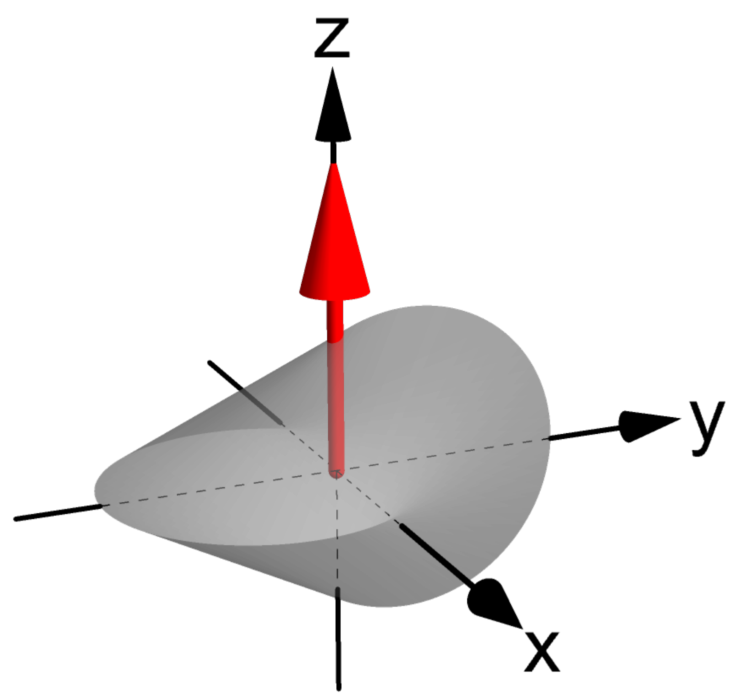




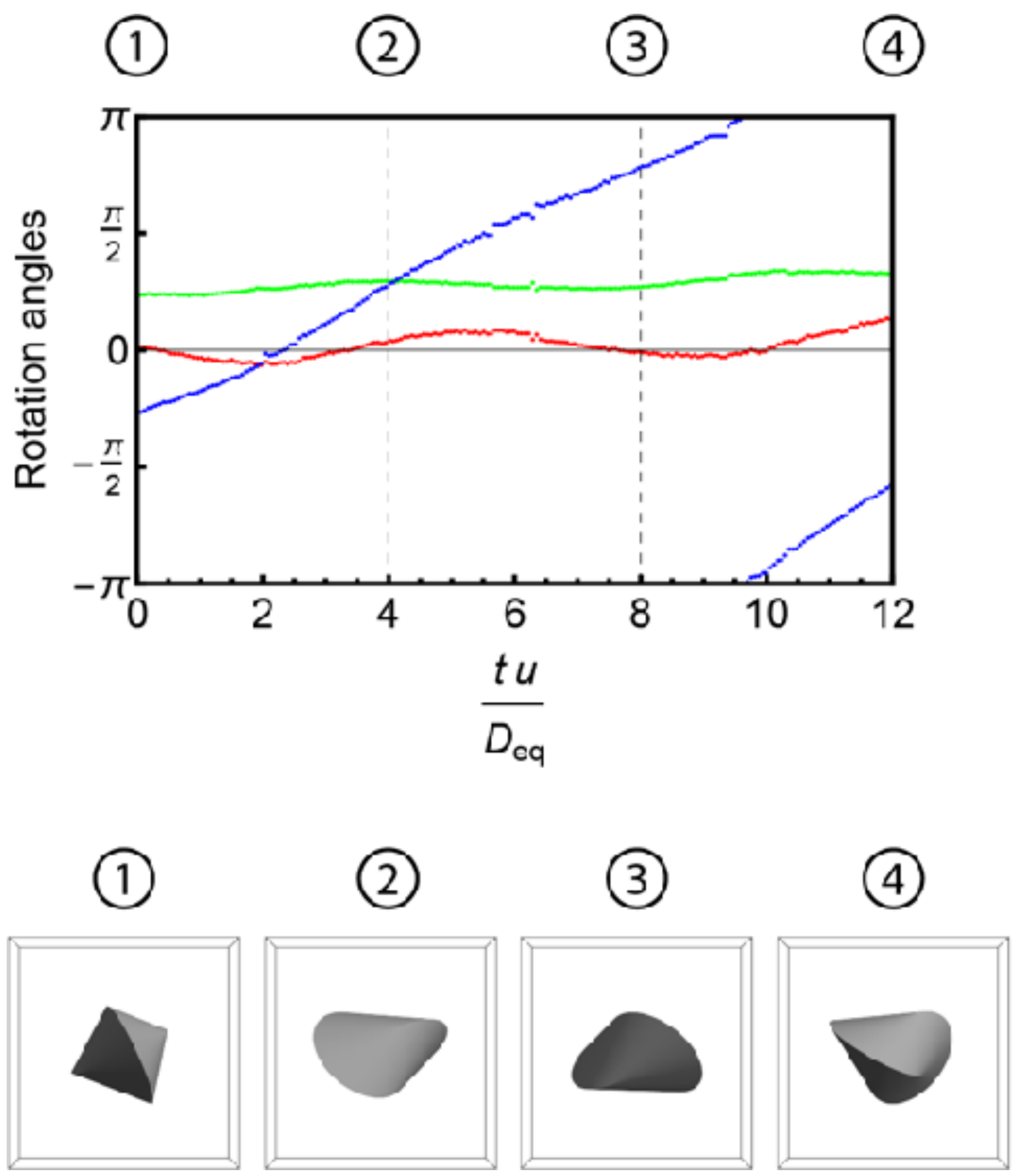
Results on orientation: stable mode



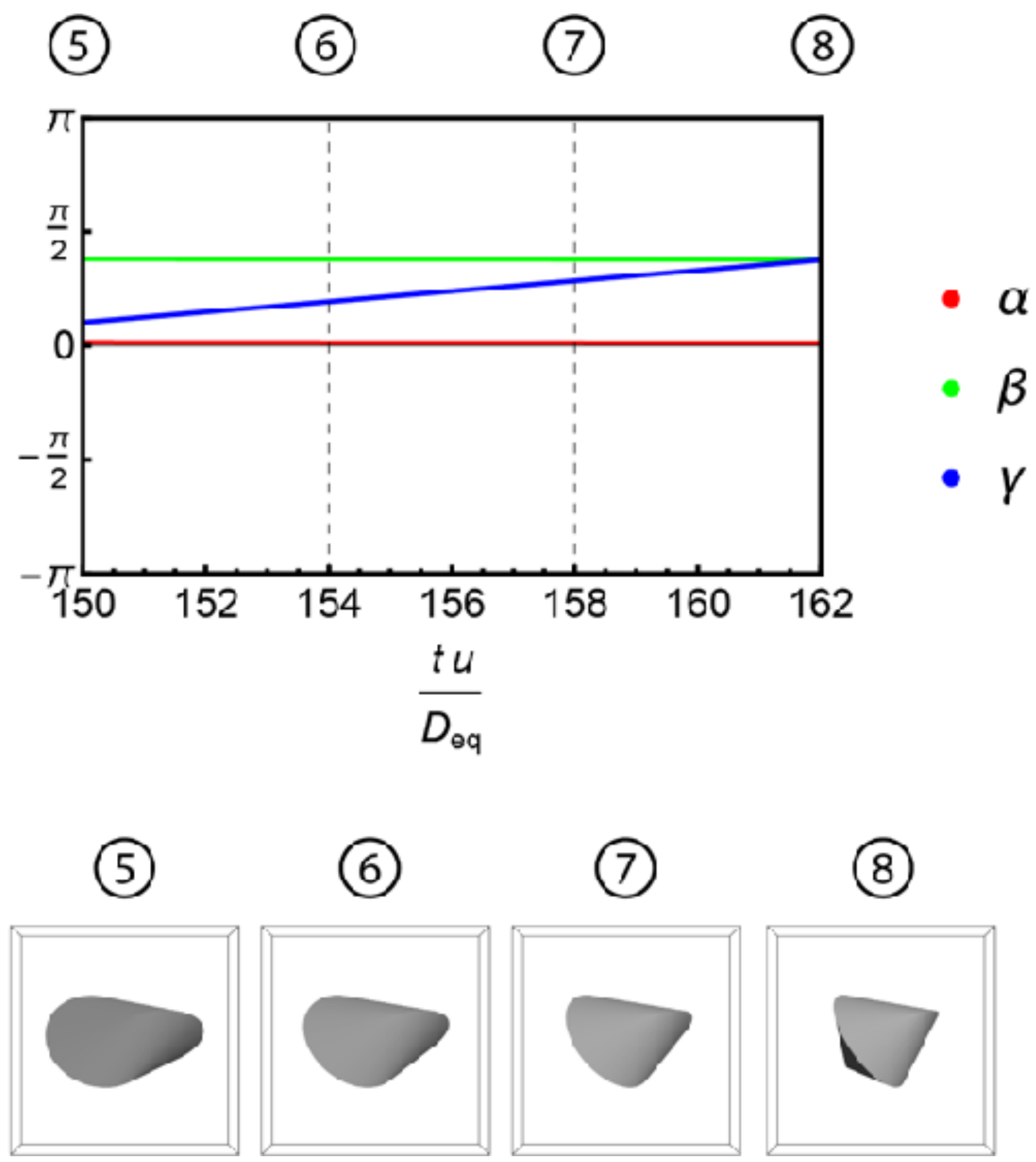
Stable

only rotation
around
z-axis

Experiment: Ga = 210

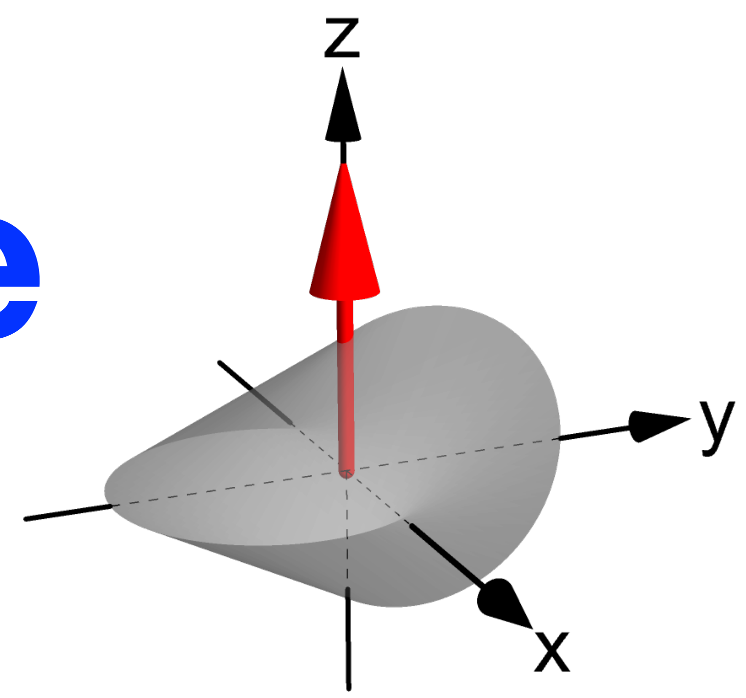


Simulation Ga = 10



α (around x-axis)
β (around y-axis)
γ (around z-axis)

Results on orientation: tumbling mode

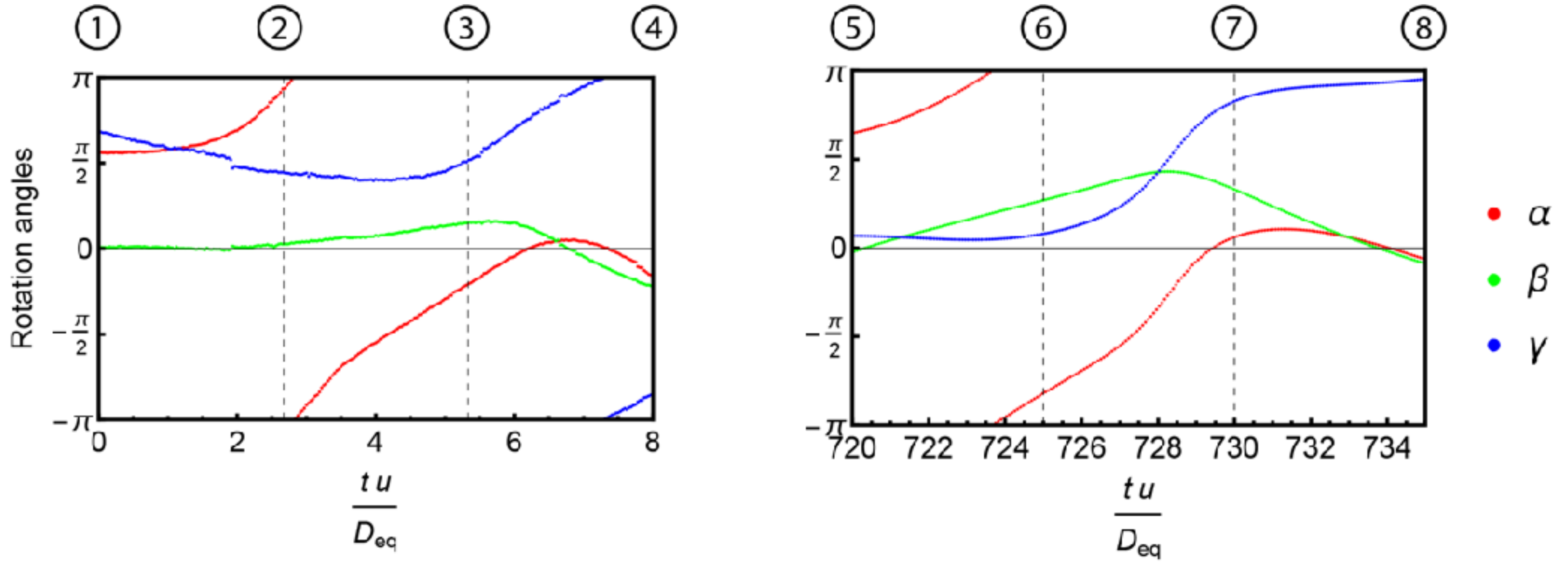


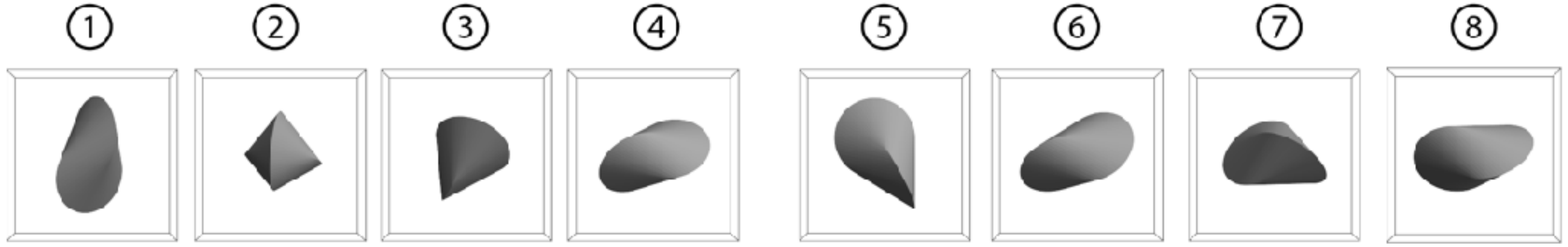
Experiment (Ga=1300)

Simulation (Ga=100)

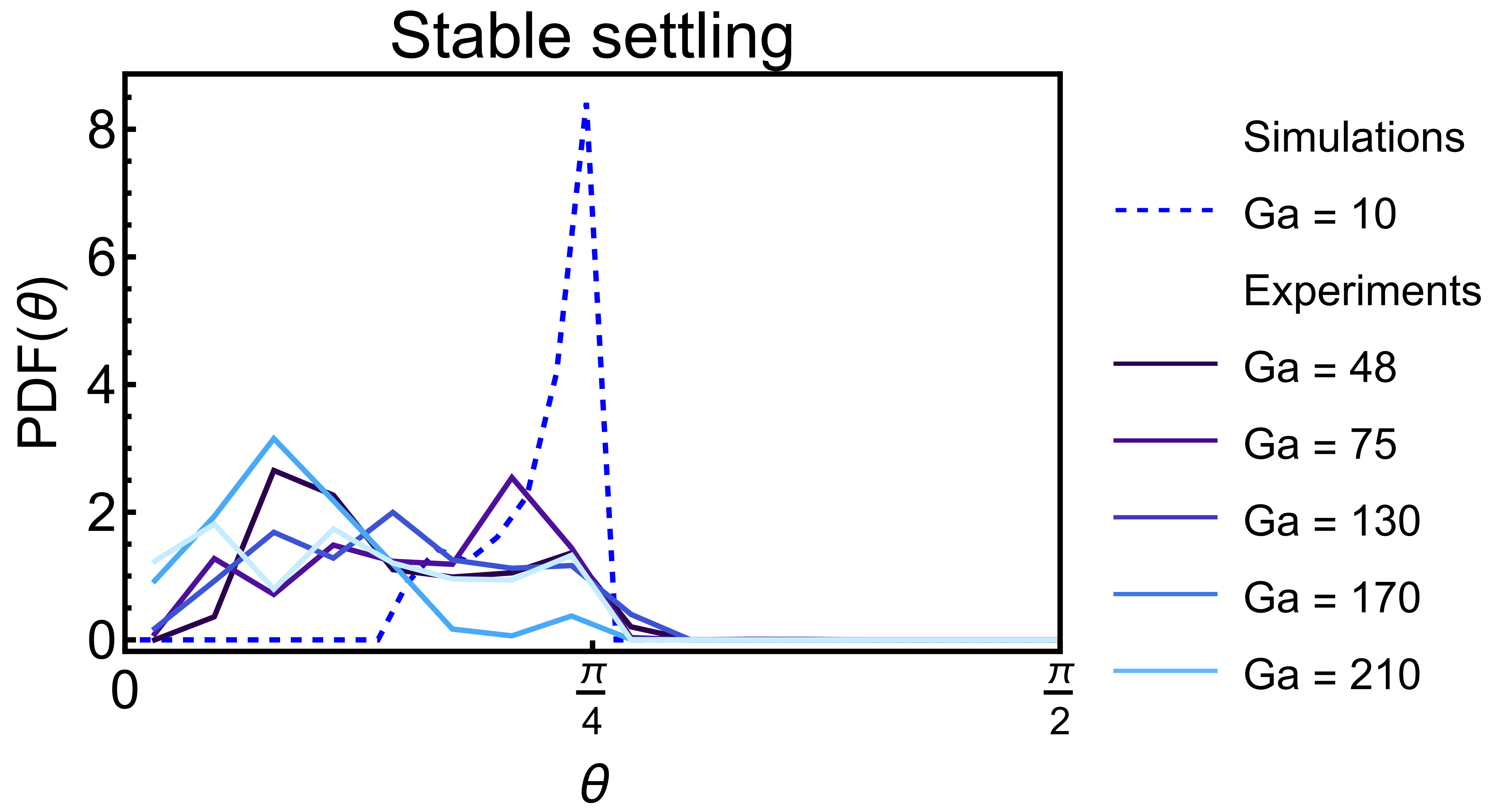
Tumbling

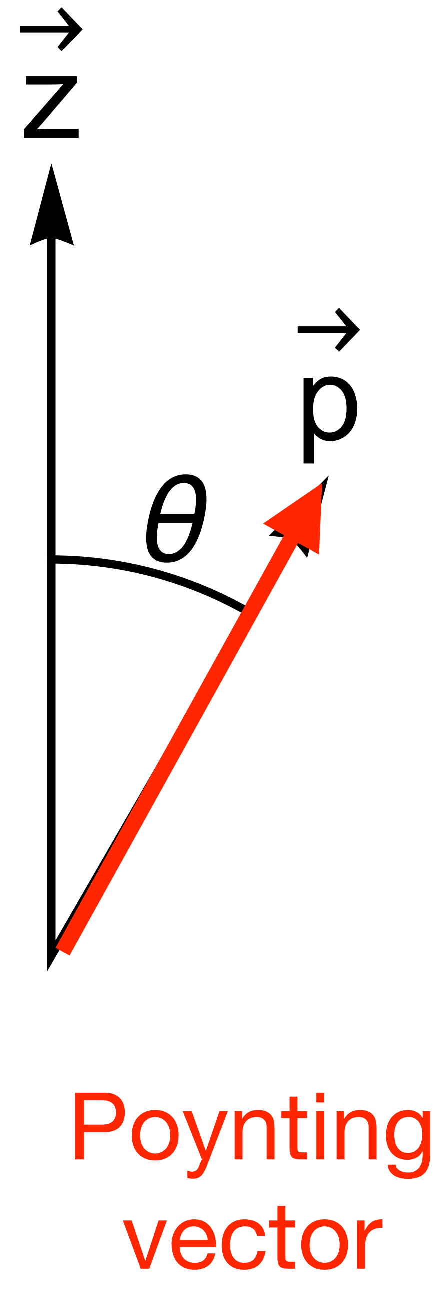
all angles kind of random

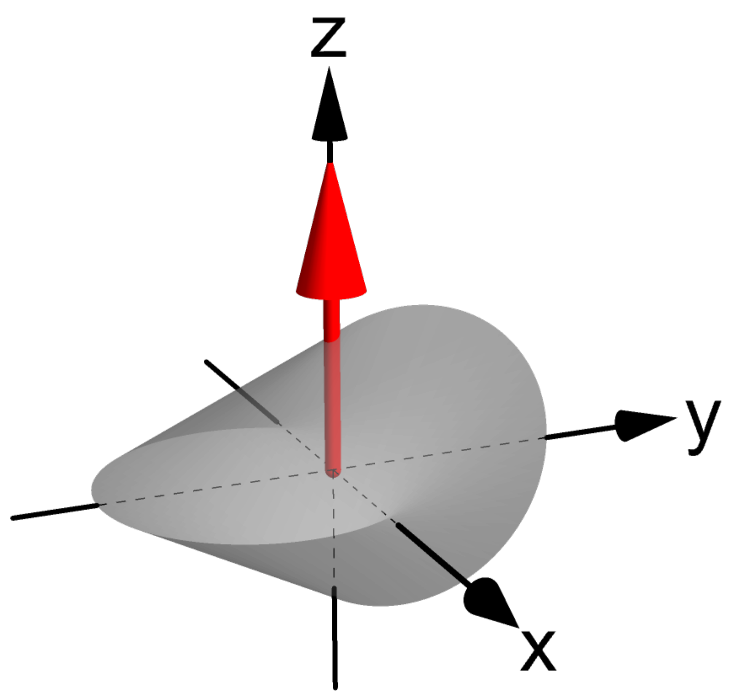


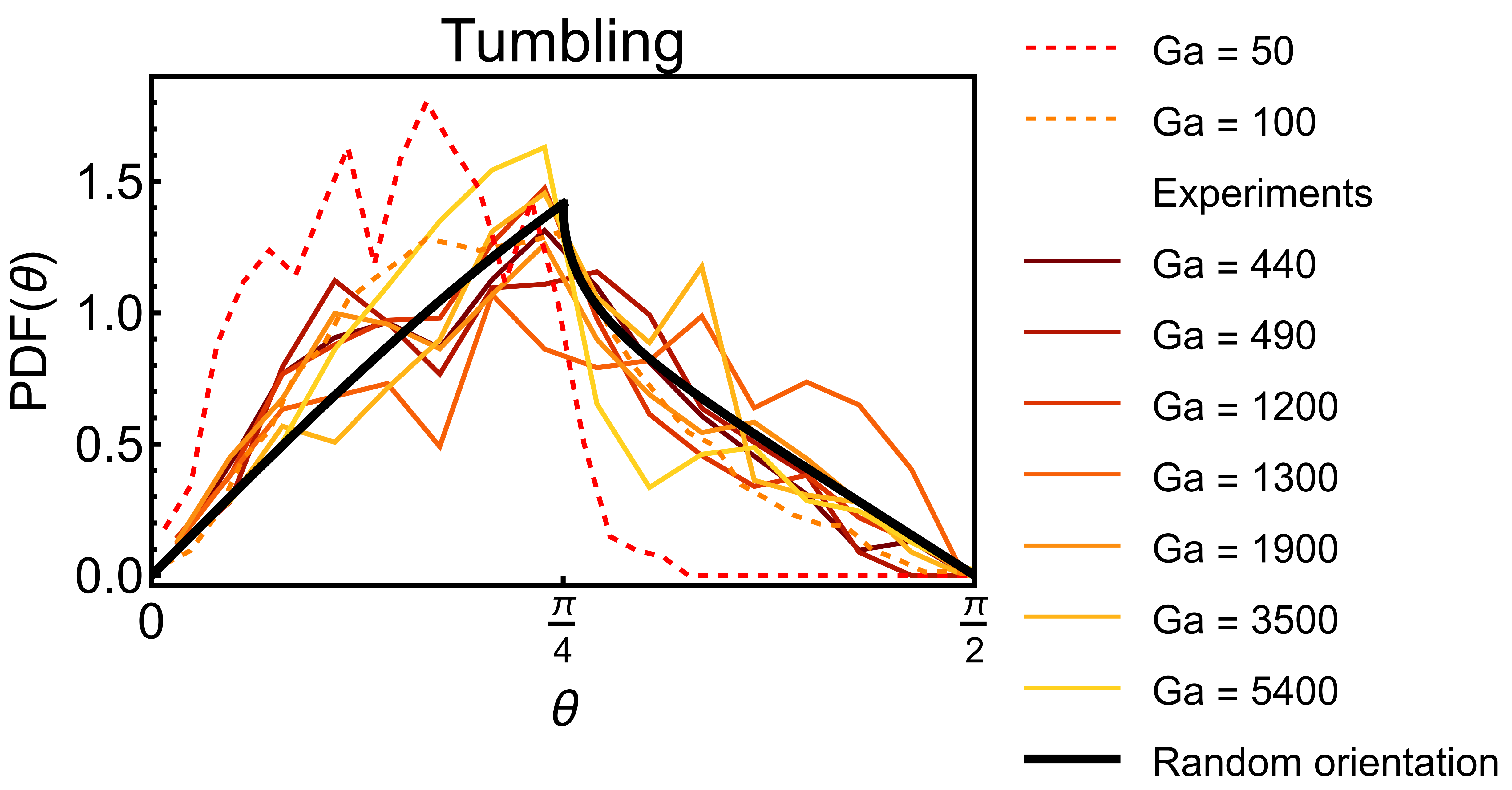


Results on alignment

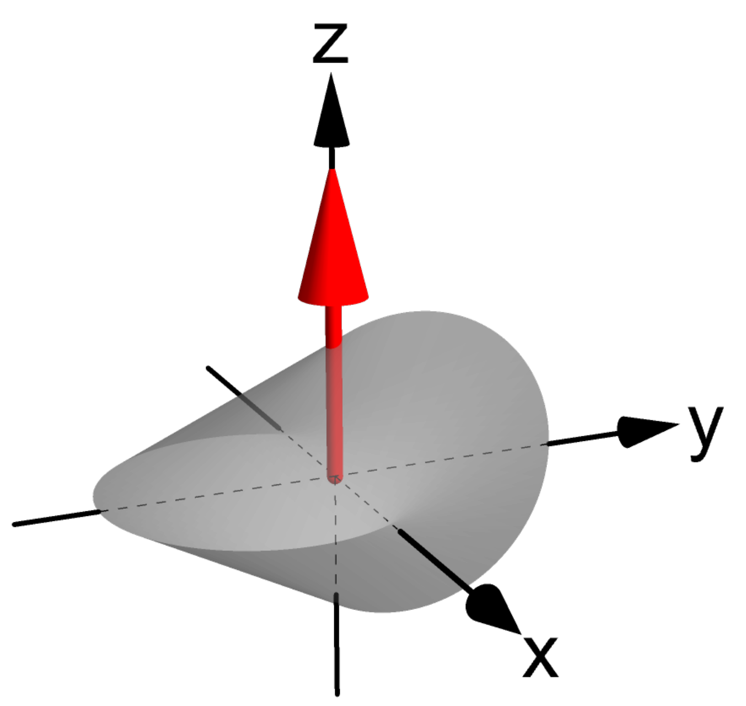


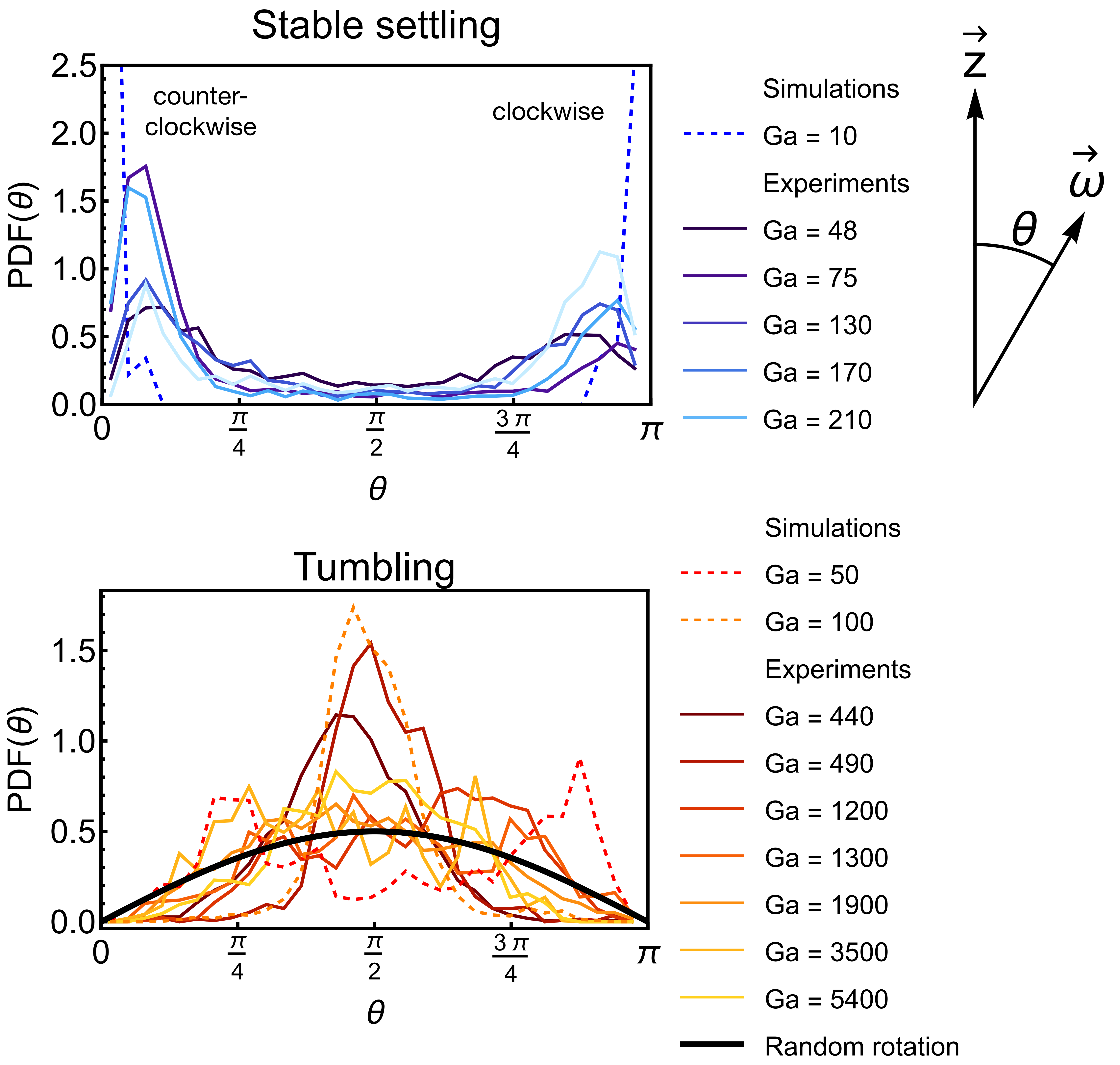






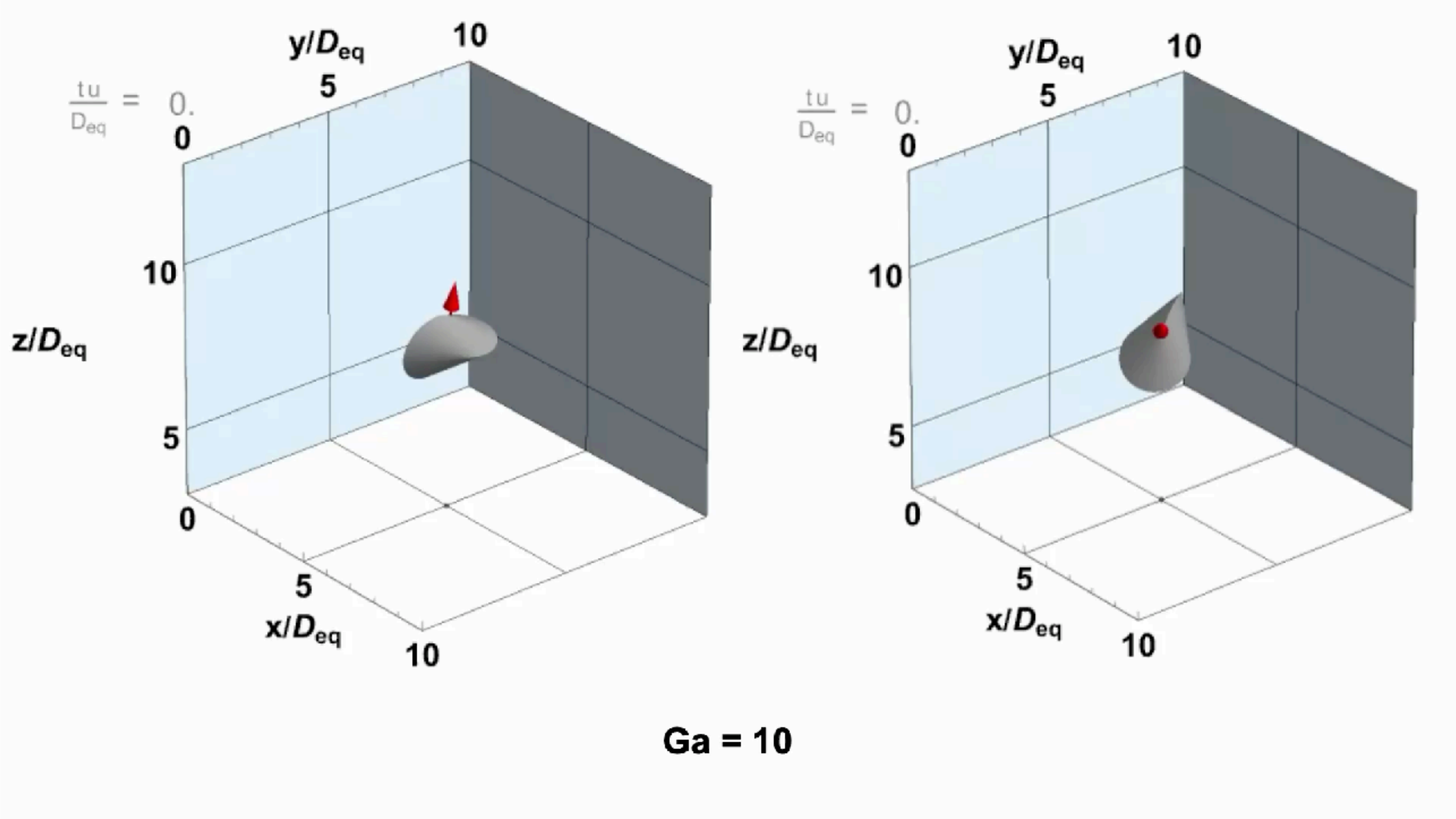
Results on rotation





DNS results on rotation: both orientations

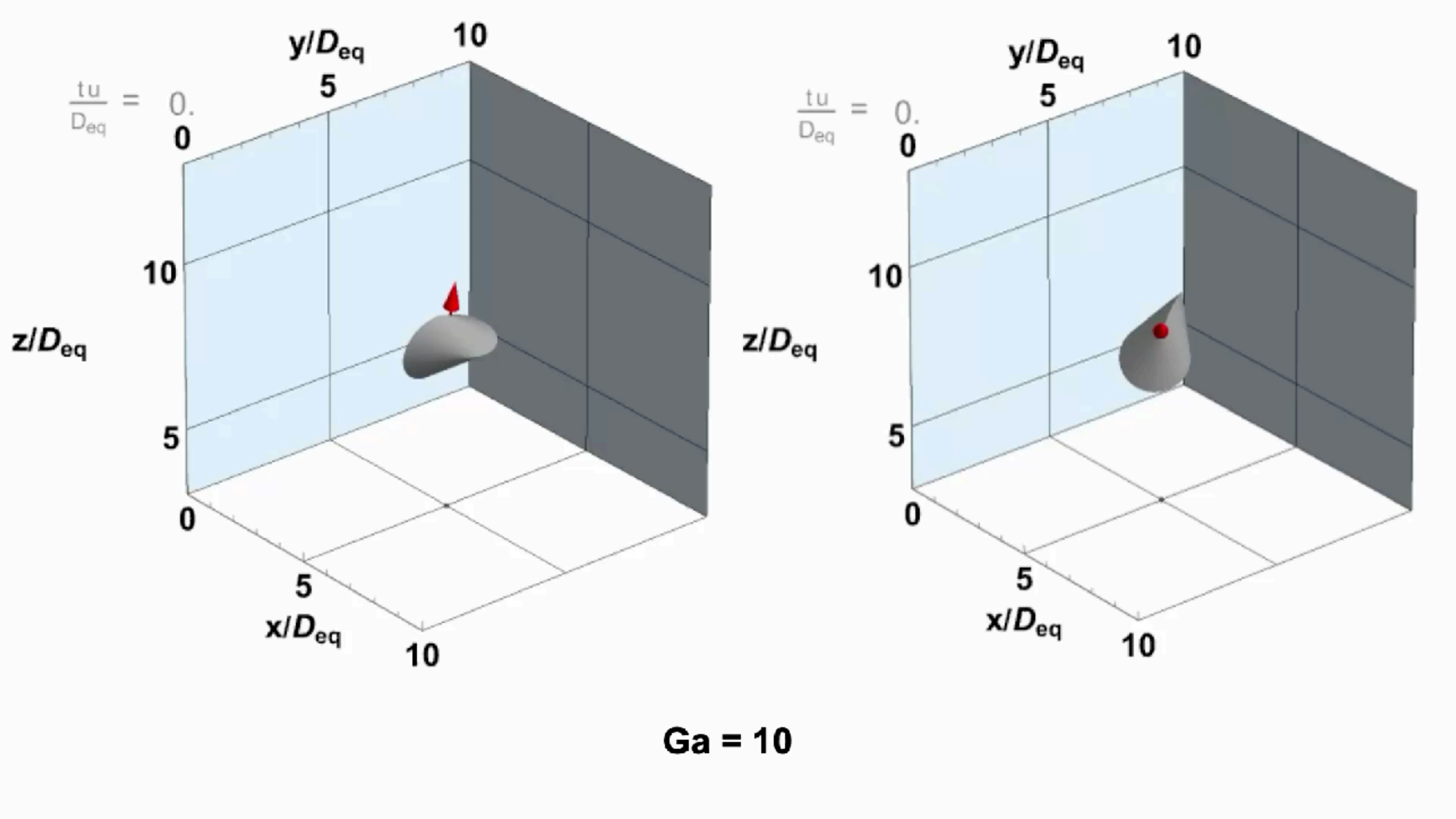
clockwise



counter-clockwise

DNS results on rotation: both orientations

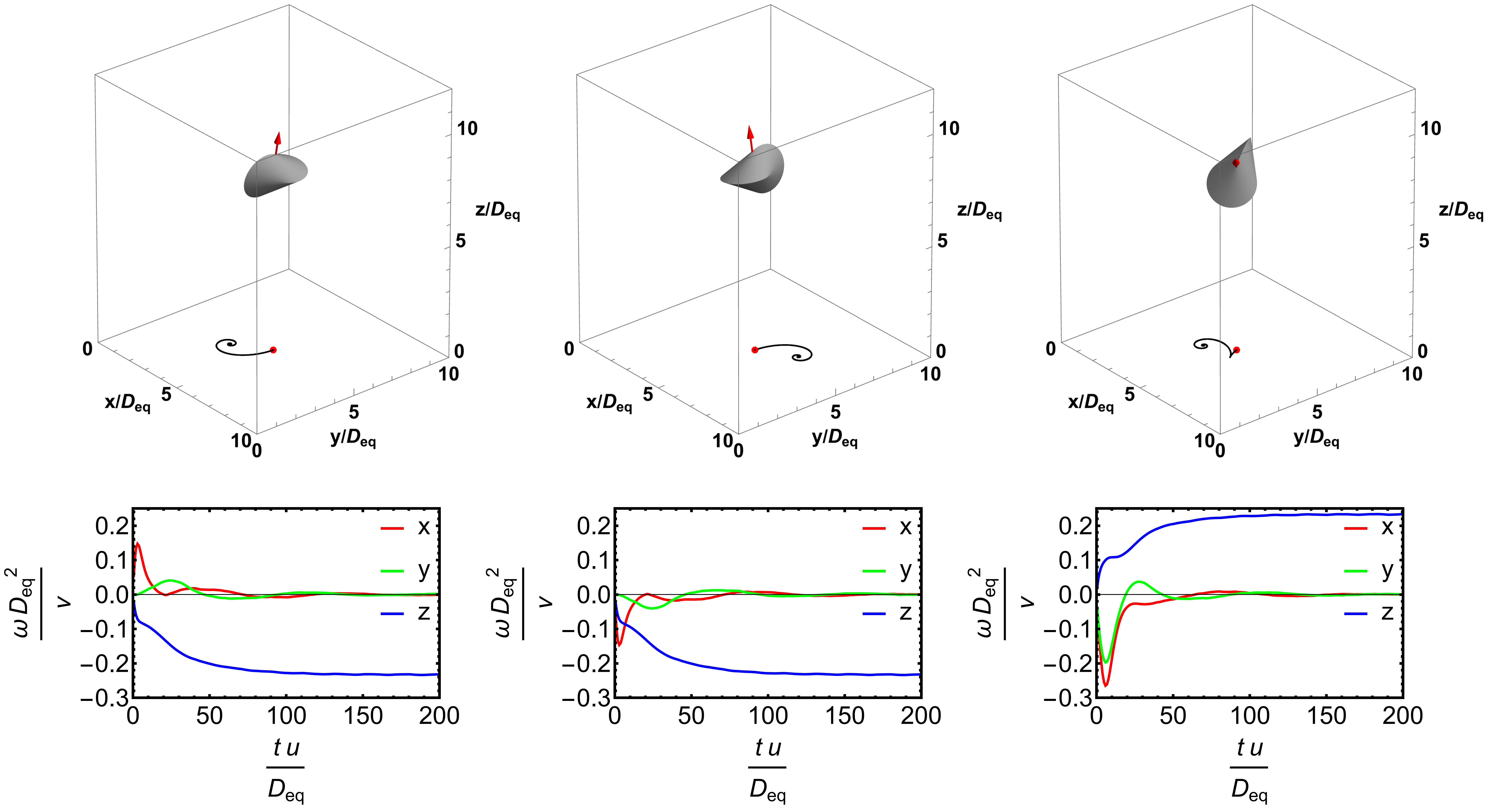
clockwise



counter-clockwise

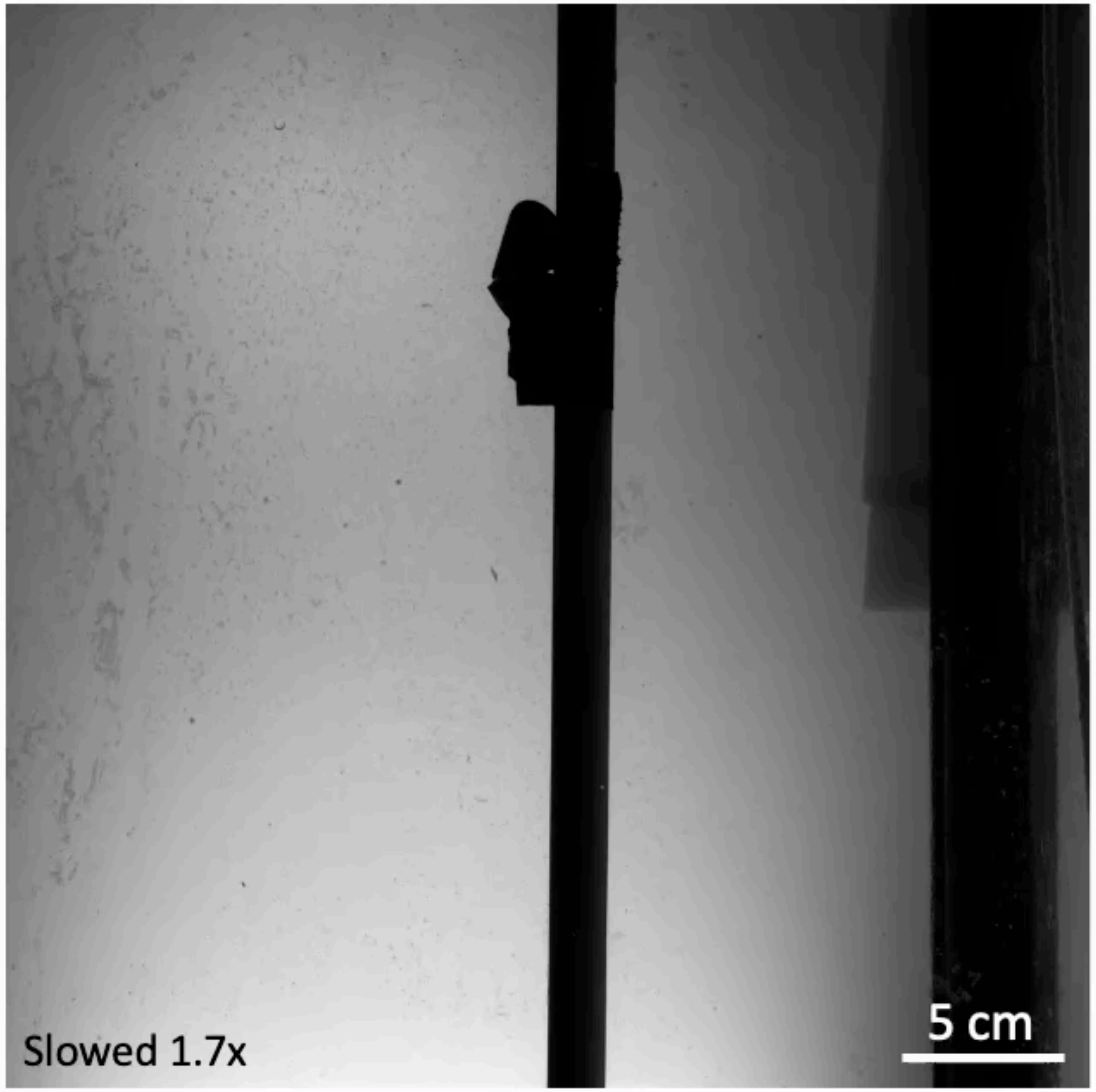
Results on rotation: dependence on initial conditions

Ga = 10



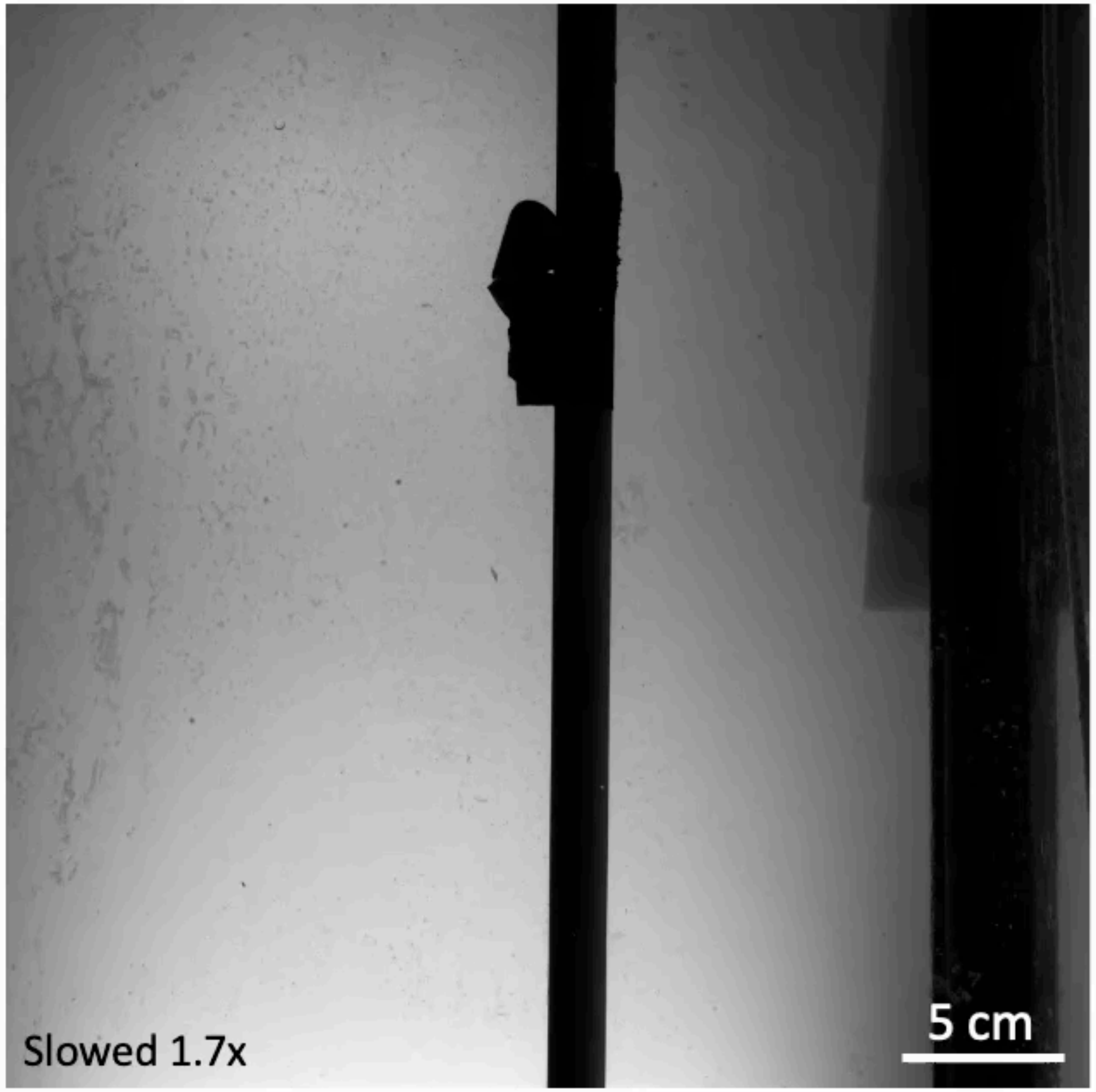
Transients towards preferential orientation

Ga = 130



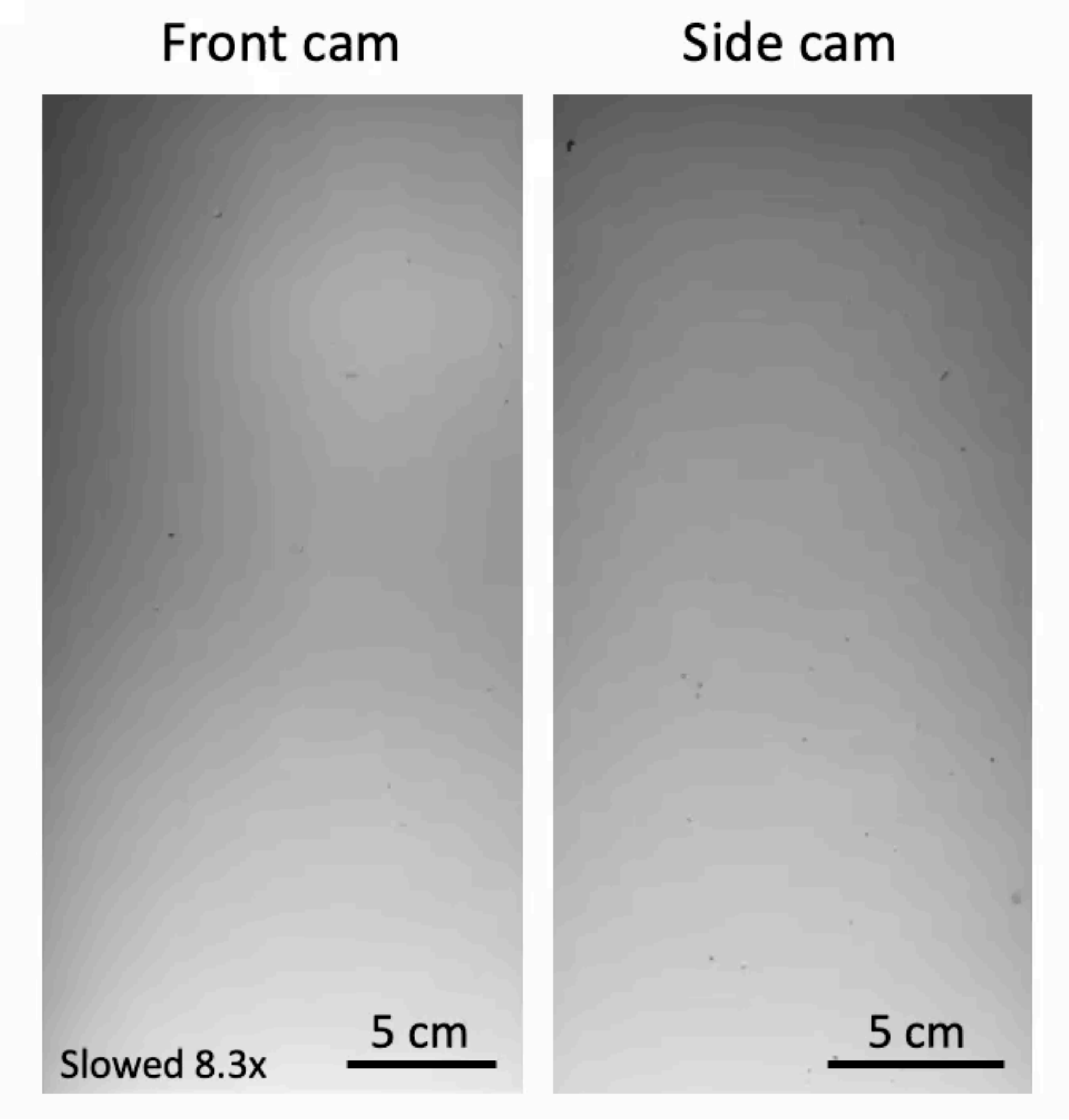
Transients towards preferential orientation

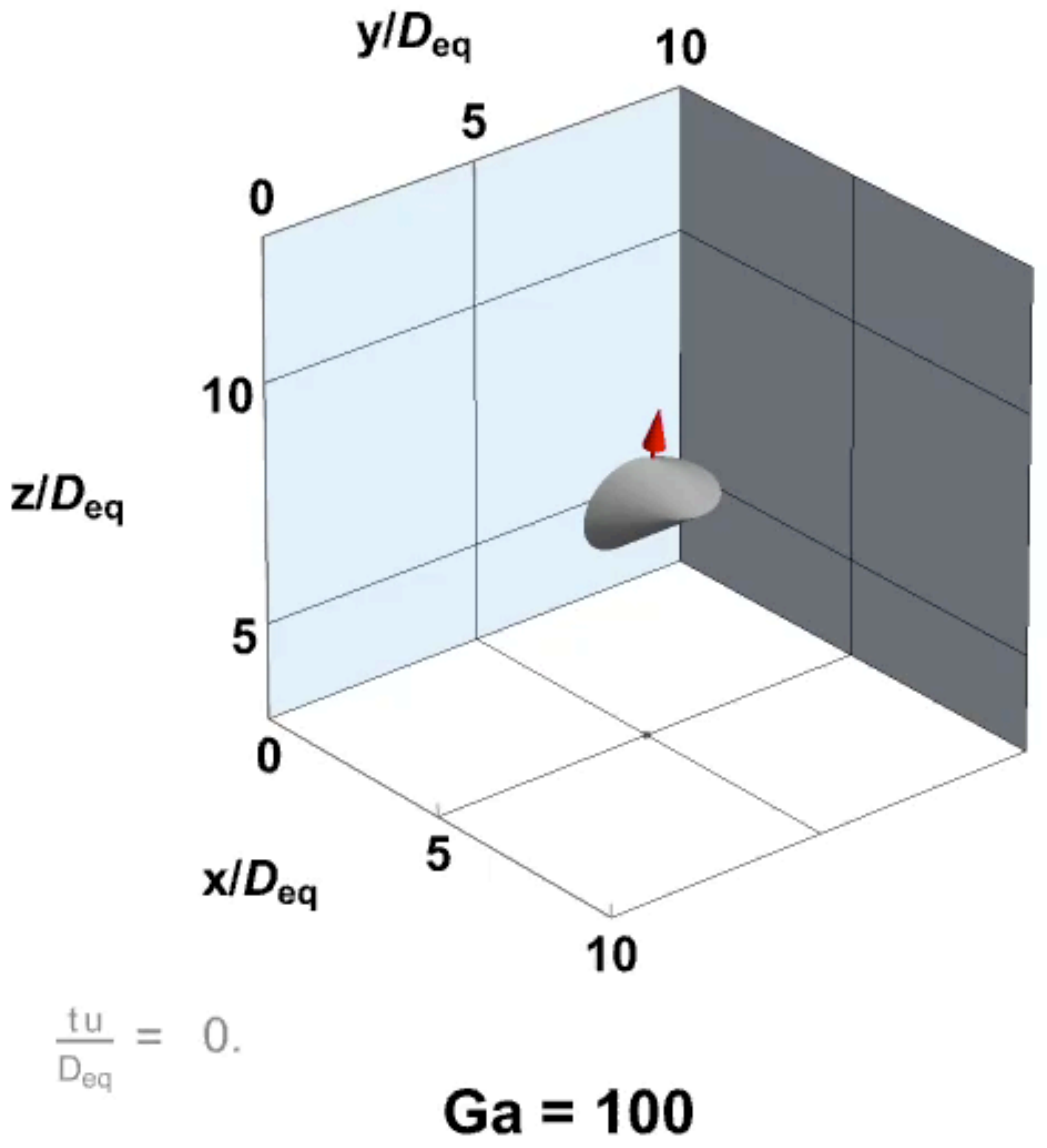
Ga = 130



Oloid settling: Conclusions

- Distinct stable and tumbling regime
- Stable settling in Stokes regime, tumbling outside Stokes regime
- Rotation direction determined by initial orientation





Oloid settling: Conclusions

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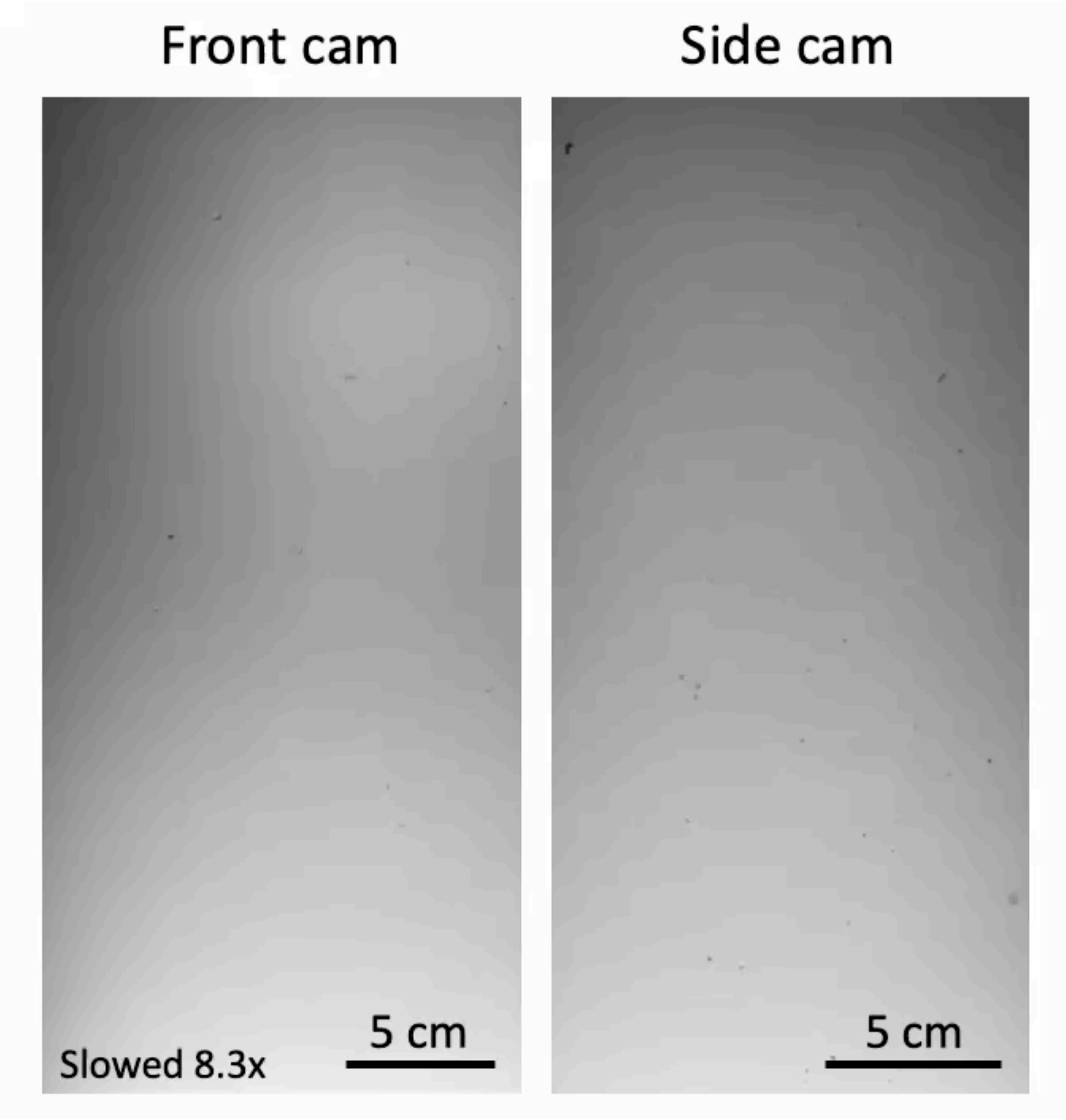

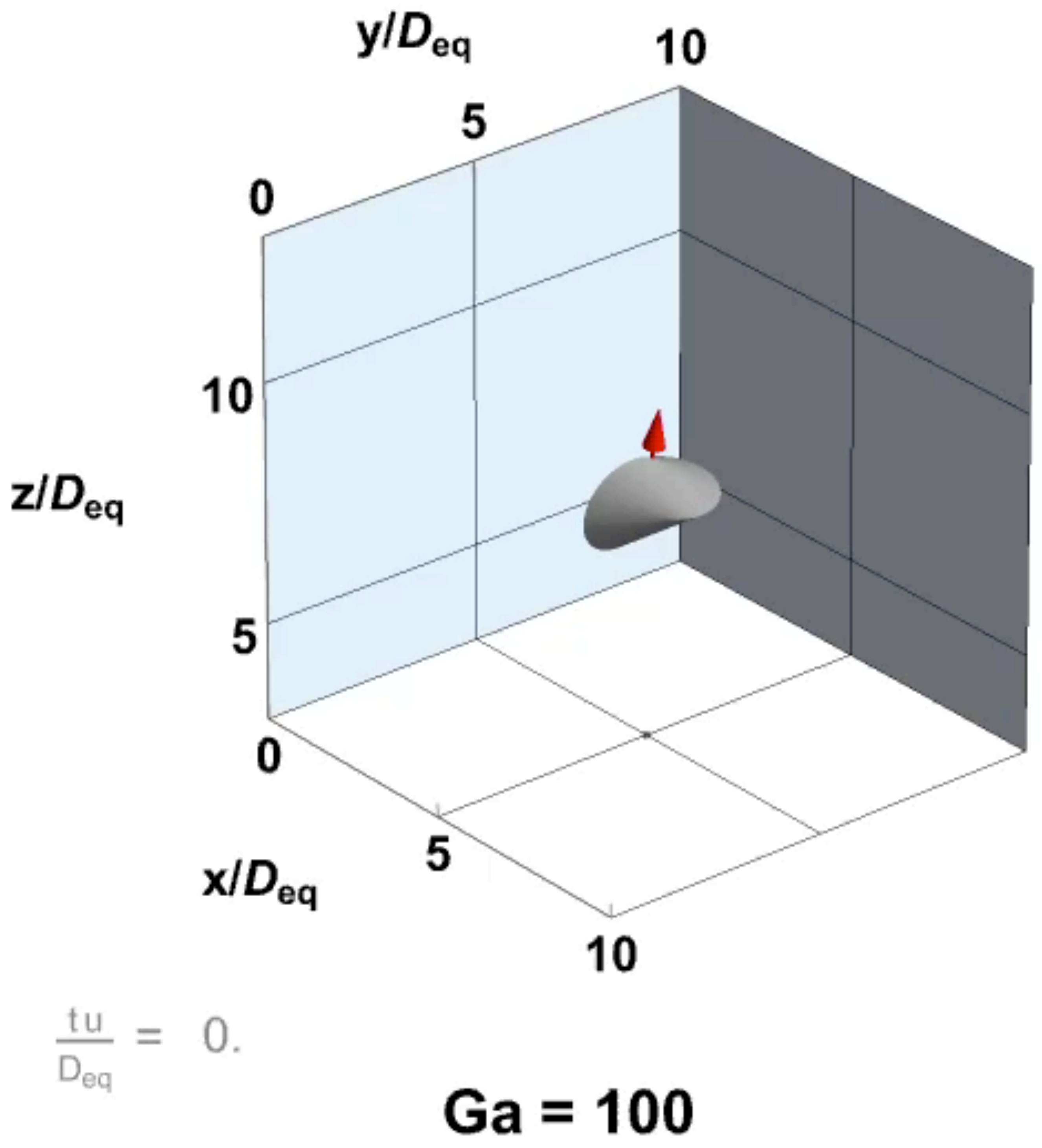

Settling dynamics of an oloid: experiments and simulations

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JFM,
under revisions

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This study presents a combined experimental and computational investigation of an oloid-shaped particle settling in a quiescent fluid. The oloid, a unique convex shape with anisotropic geometry, provides a distinctive model for exploring how a particle's shape and orientation affect its settling dynamics. The settling oloids are tracked experimentally for Galileo numbers $48 \leq Ga \leq 5.4 \cdot 10^3$, using two particle sizes ($D_{\mathrm{eq}} = 21.6$ mm, and $D_{\mathrm{eq}} = 10.8$ mm). The density ratio between the particle and fluid $\Gamma = \frac{\rho_p}{\rho_f}$ ranges from $1.11 \leq \Gamma \leq 1.30$ in the experiments. Computationally, the Galileo numbers $10 \leq Ga \leq 100$ are simulated, with $\Gamma = 2$. The experimental findings and numerical