How large particles filter the motions of ambient turbulence

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(not pictured) Laura J. Mazzaro and Yiheng Tao

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Motivation

Floc (including sediment aggregates)

Aquatic organisms with weak swimming

$1 \lesssim$ Aspect ratio $\lesssim 10$

Near neutral buoyancy

Can have scales within inertial subrange

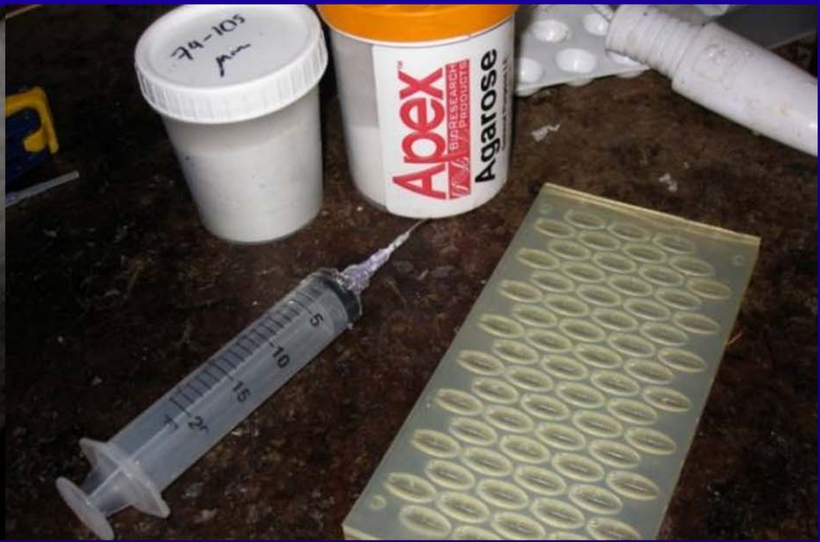
Q: Statistics of particle rotation?

Particle Fabrication

$1 \lesssim$ aspect ratio $\lesssim 10$

Near neutral buoyancy

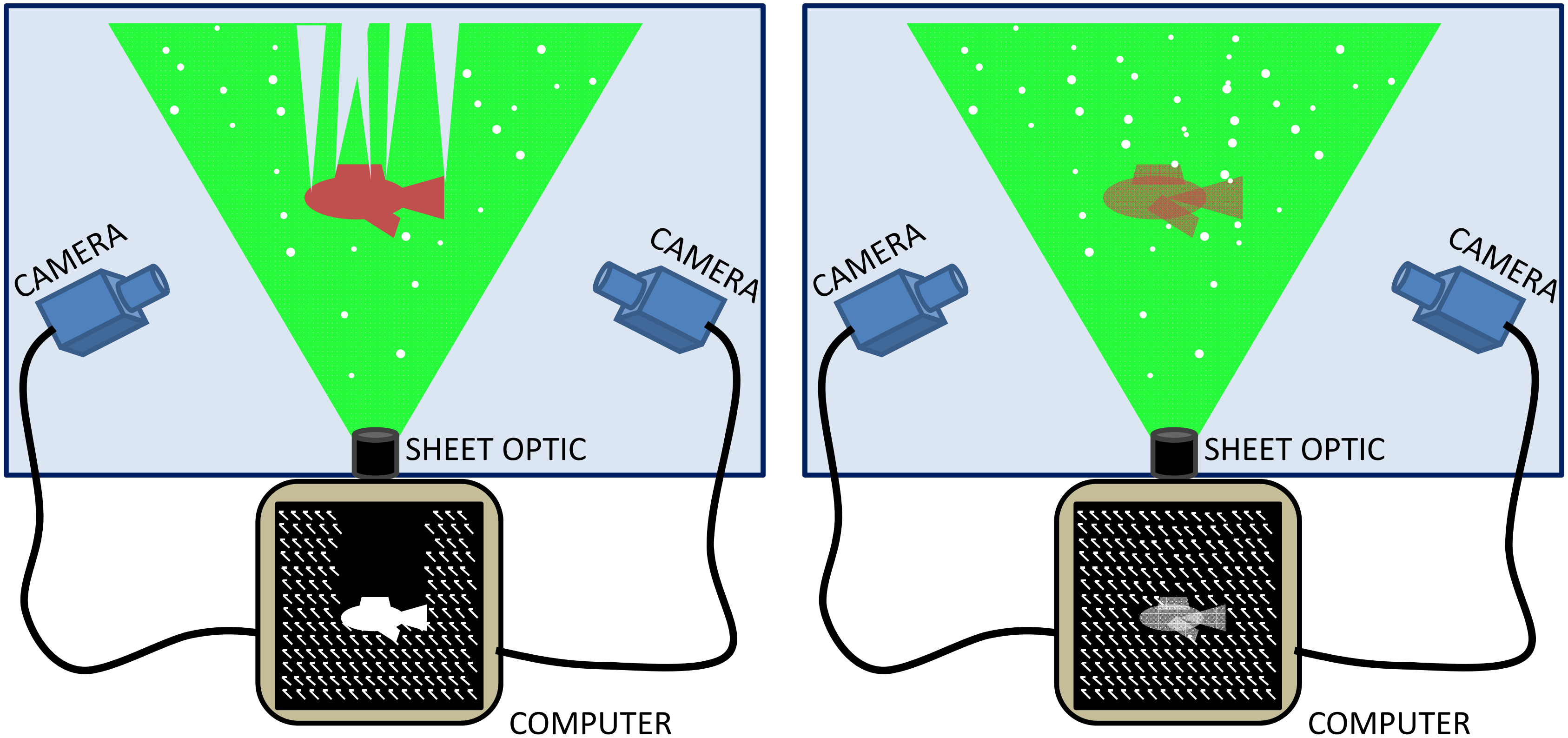
Can have scales within inertial subrange



Particle Fabrication

[Byron & Variano, Exp. Fluids 2013]

Technique: PIV through hydrogel



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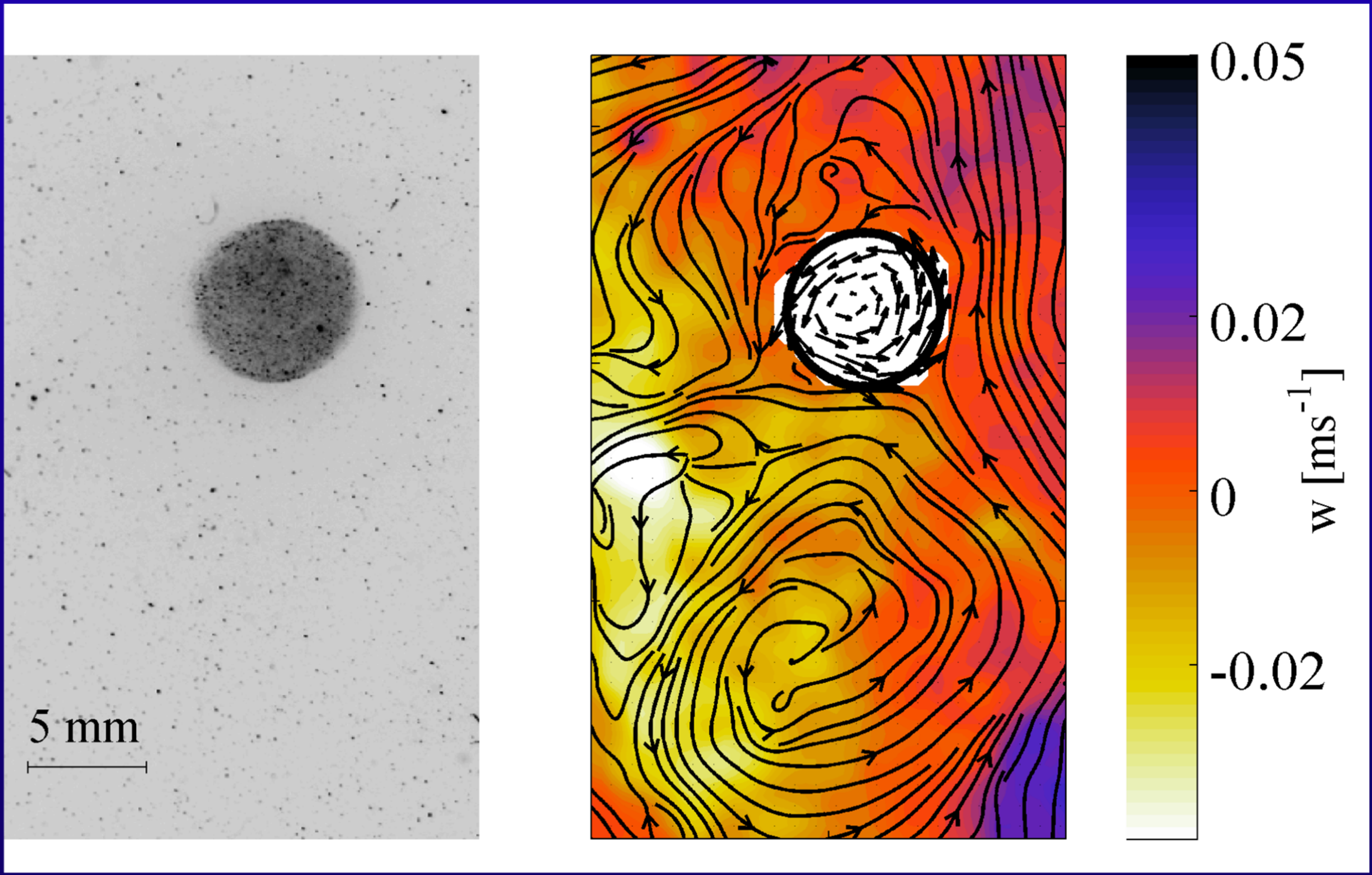

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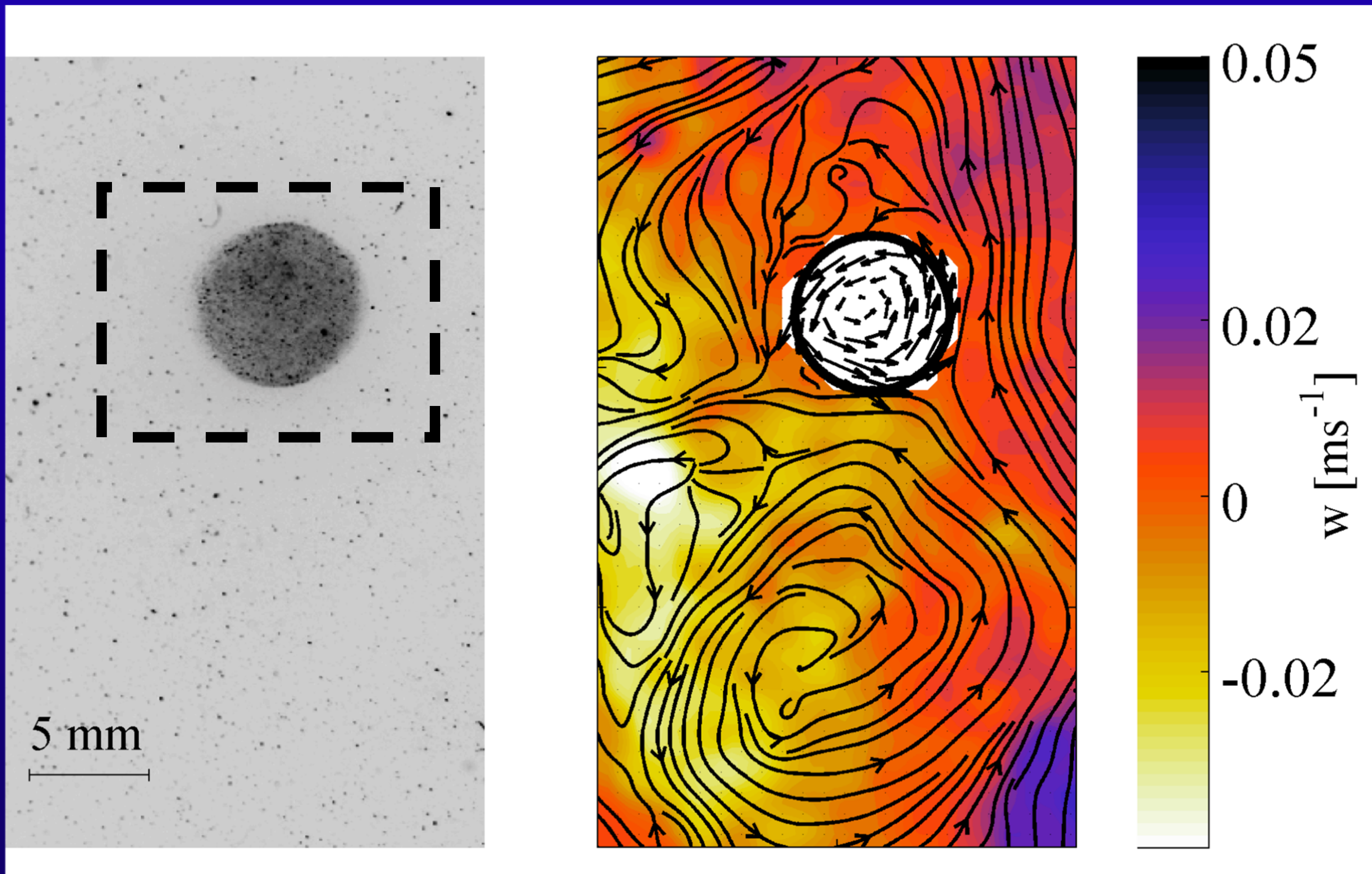

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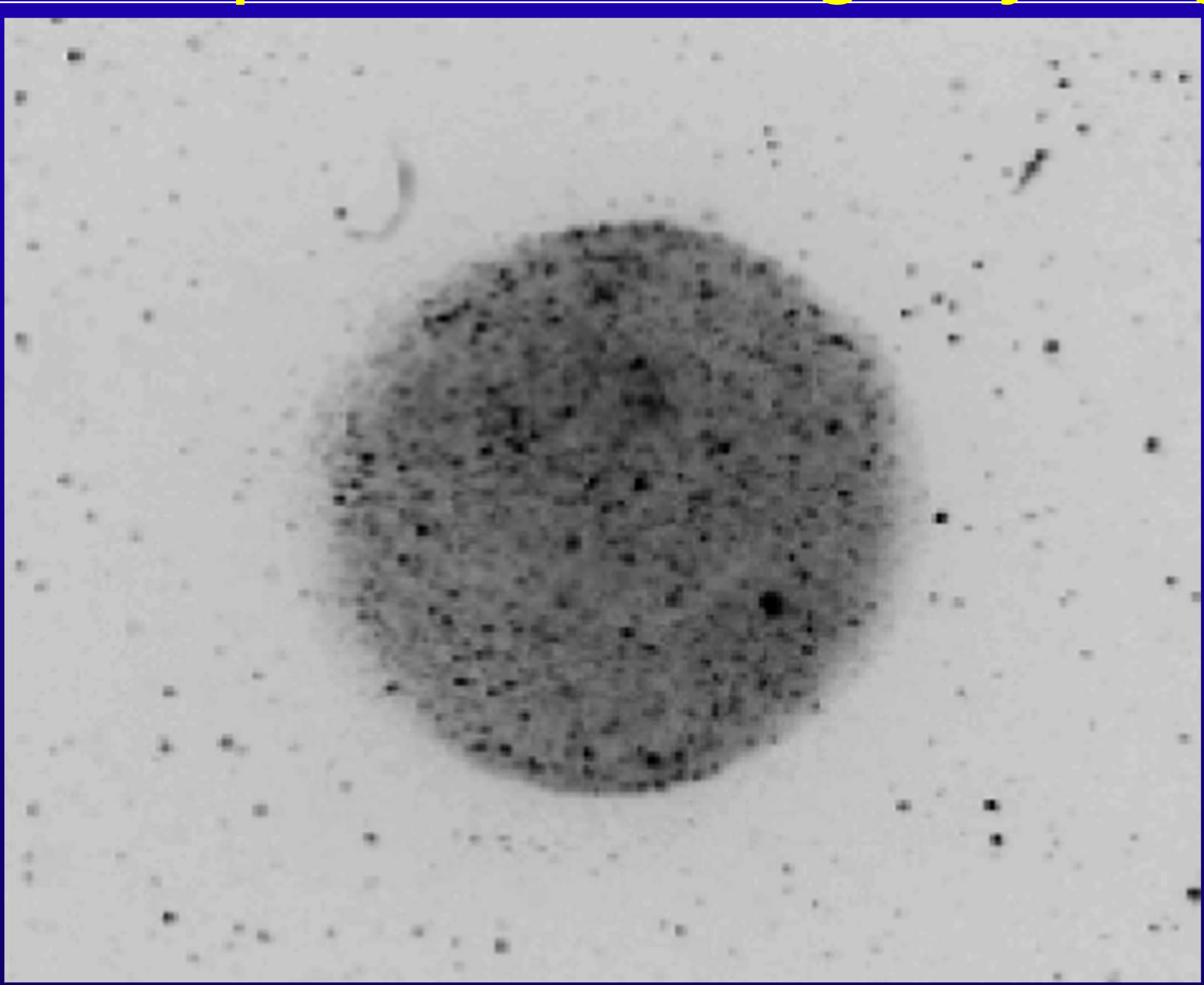


Technique: PIV through hydrogel

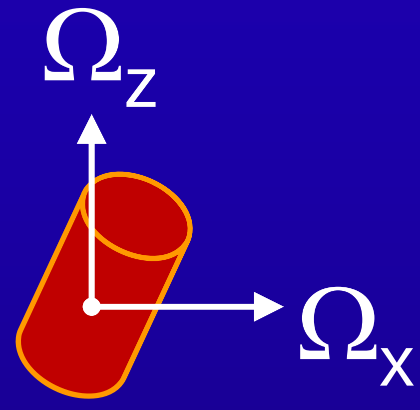
$$\underline{U}_m - \underline{U}_n = \underline{\Omega} \times (\underline{X}_m - \underline{X}_n)$$

Analysis: Particle Rotation

Solid body rotation:

$$\underline{U}_m-\underline{U}_n=\underline{\Omega}\times(\underline{X}_m-\underline{X}_n)$$

$$\underline{U}_m-\underline{U}_p=\underline{\Omega}\times(\underline{X}_m-\underline{X}_p)$$



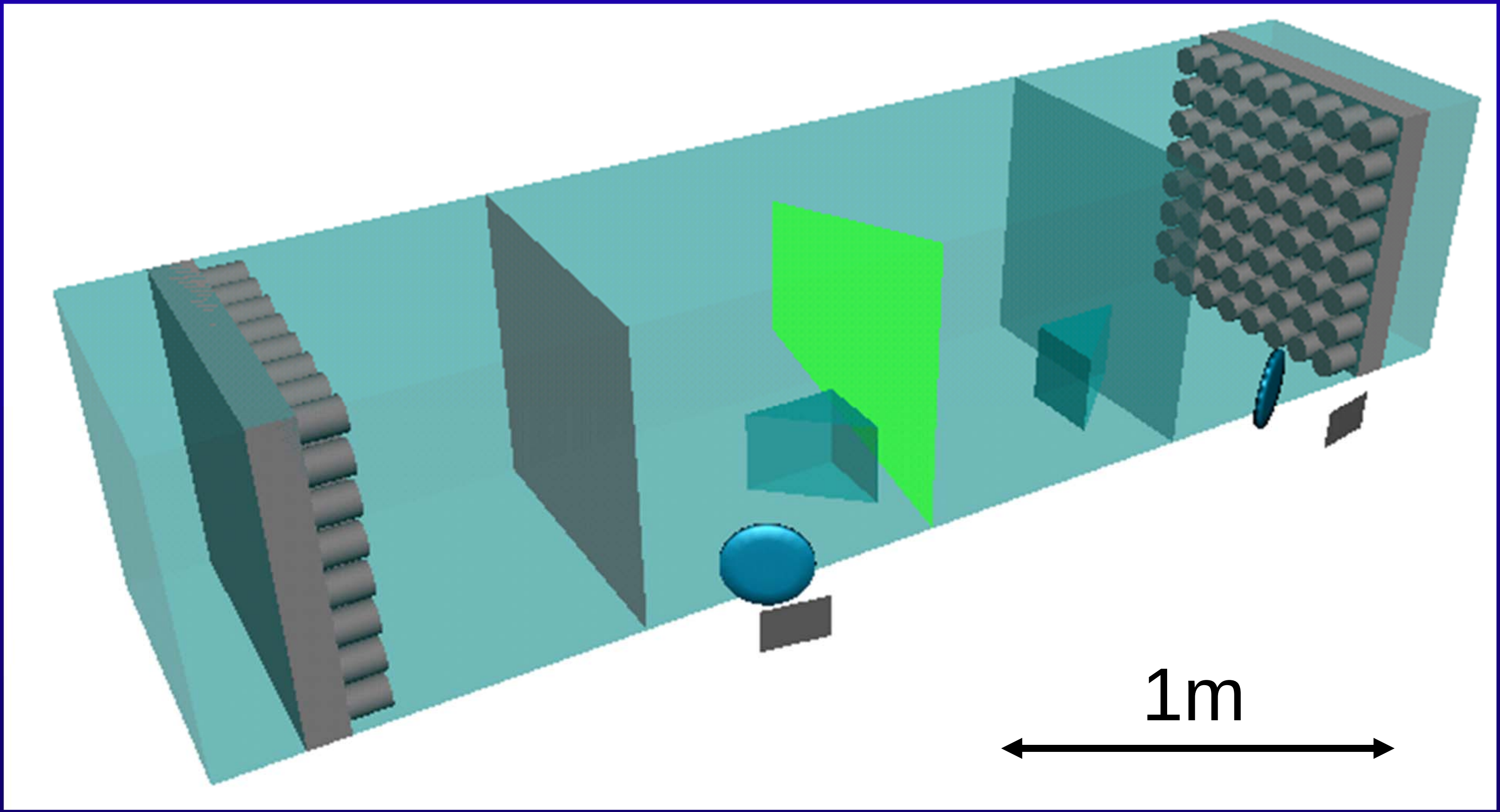
3 measured vectors within a particle give:

- 4 measurements of Ω_x
- 1 measurement of Ω_y
- 1 measurement of Ω_z

validation

[Bellani et al, JFM 2012]

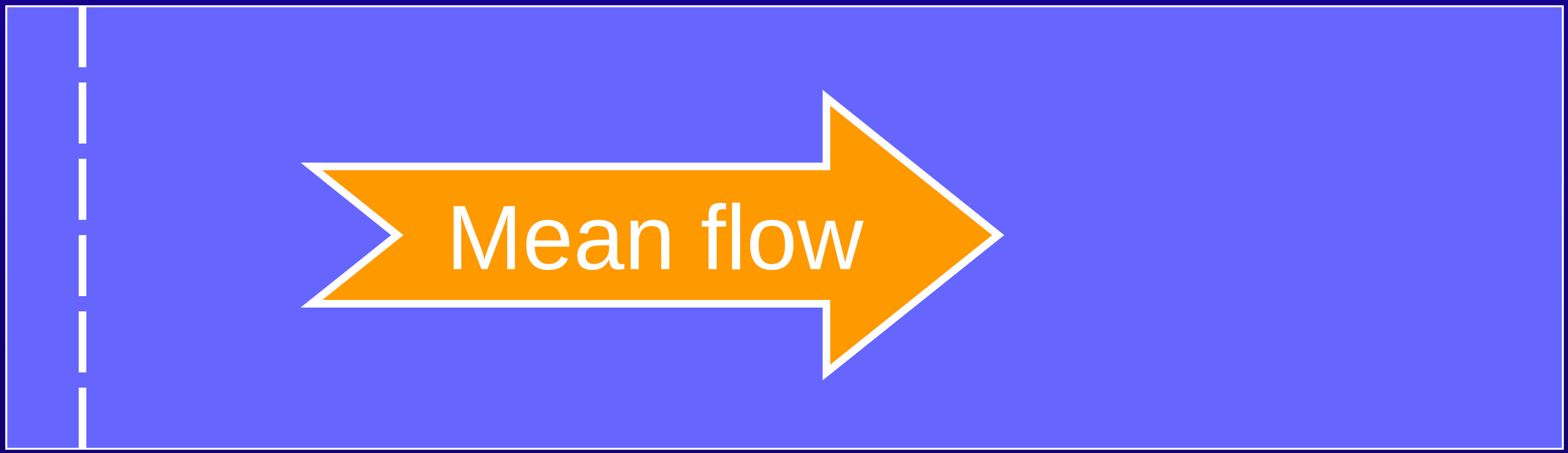
Stirred Tank



[Bellani and Variano, Exp. Fluids 2014]

Stirred Tank

Inspired by active grid wind tunnels
[Makita 1991, Mydlarski &Warhaft 1996]



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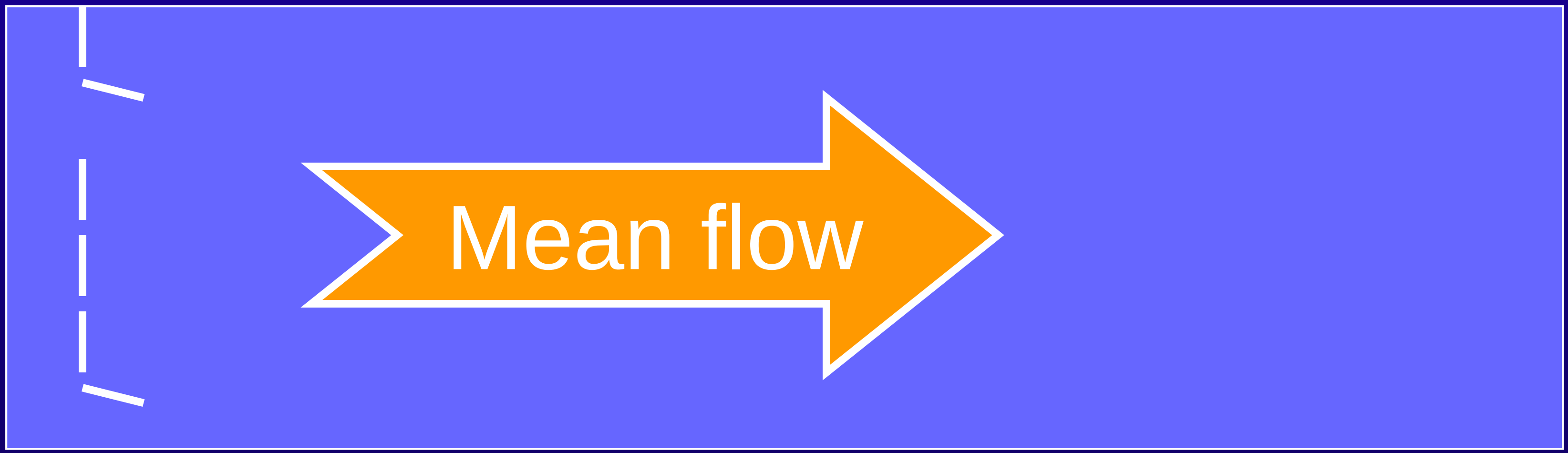

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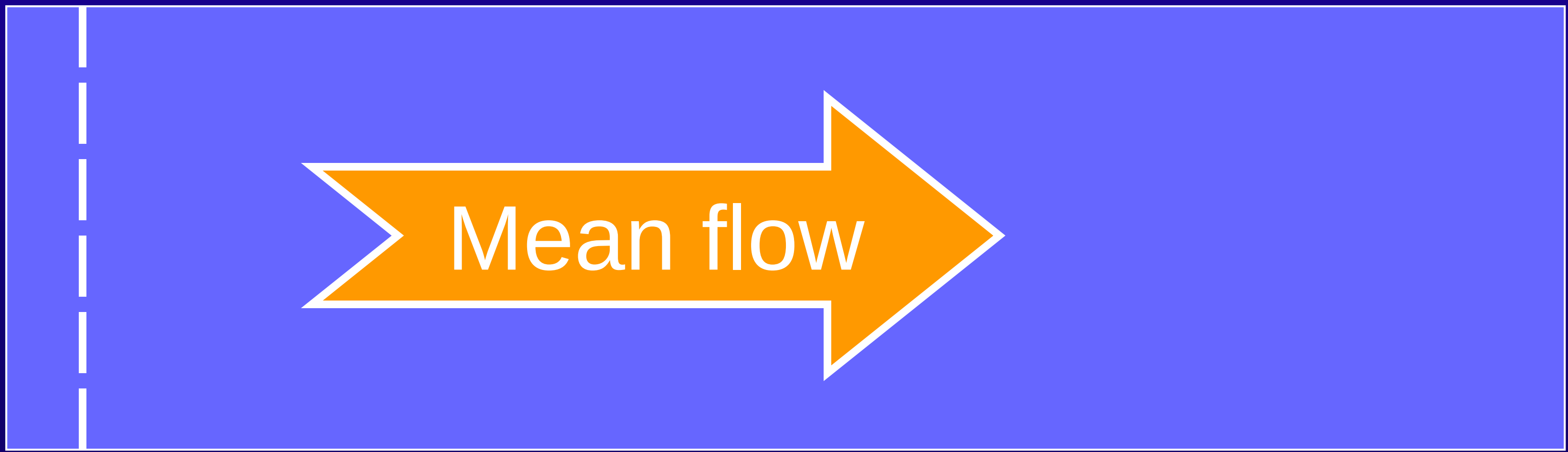

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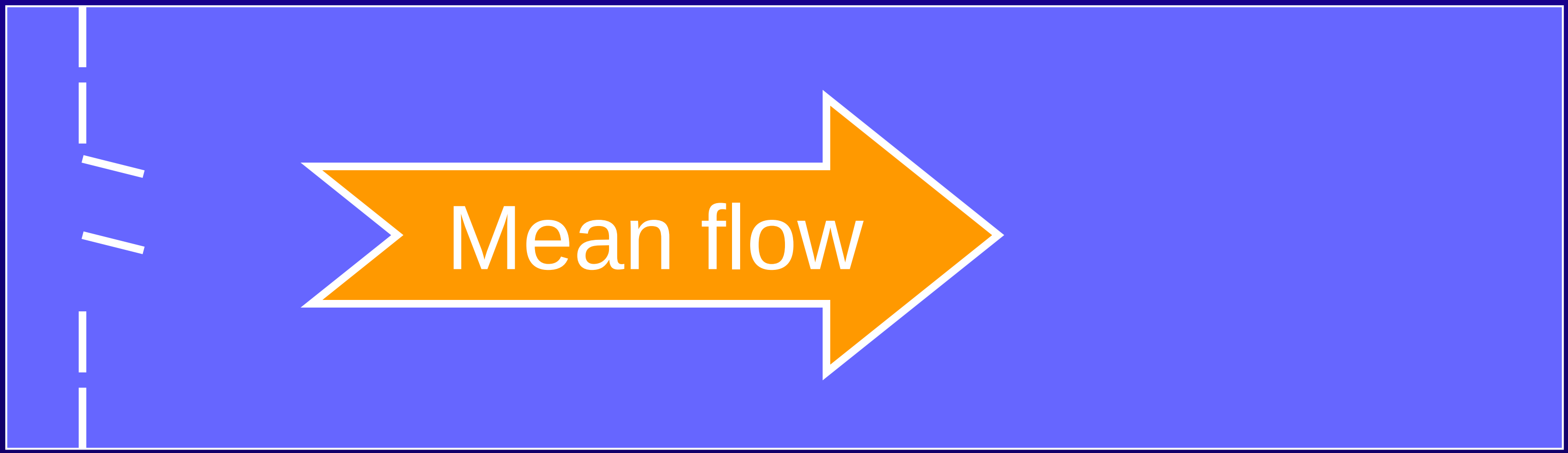

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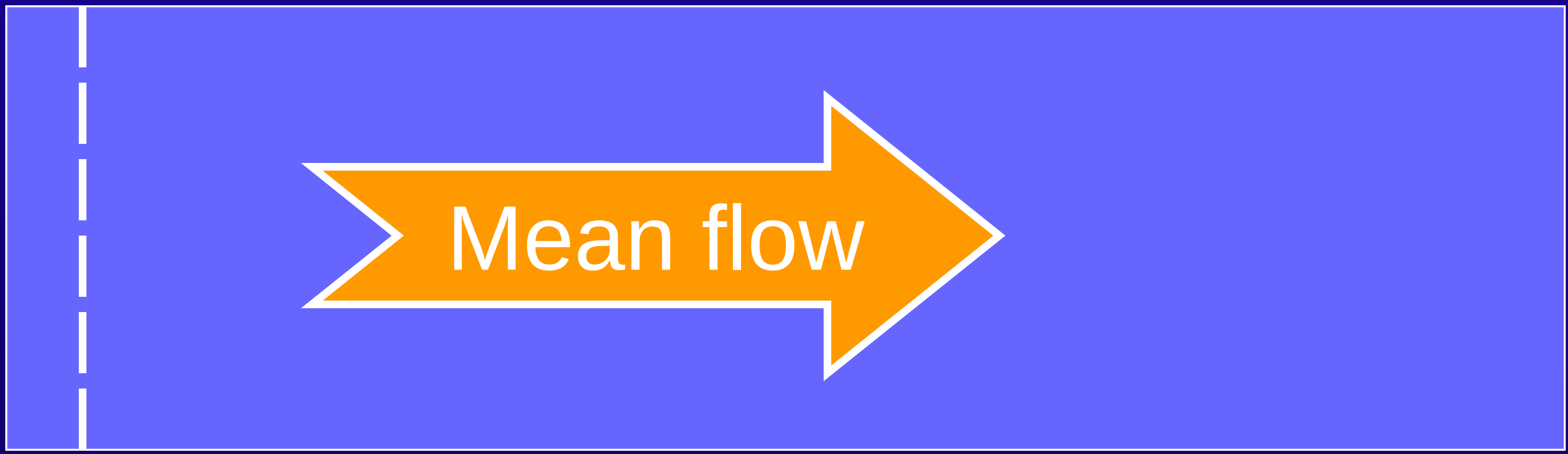

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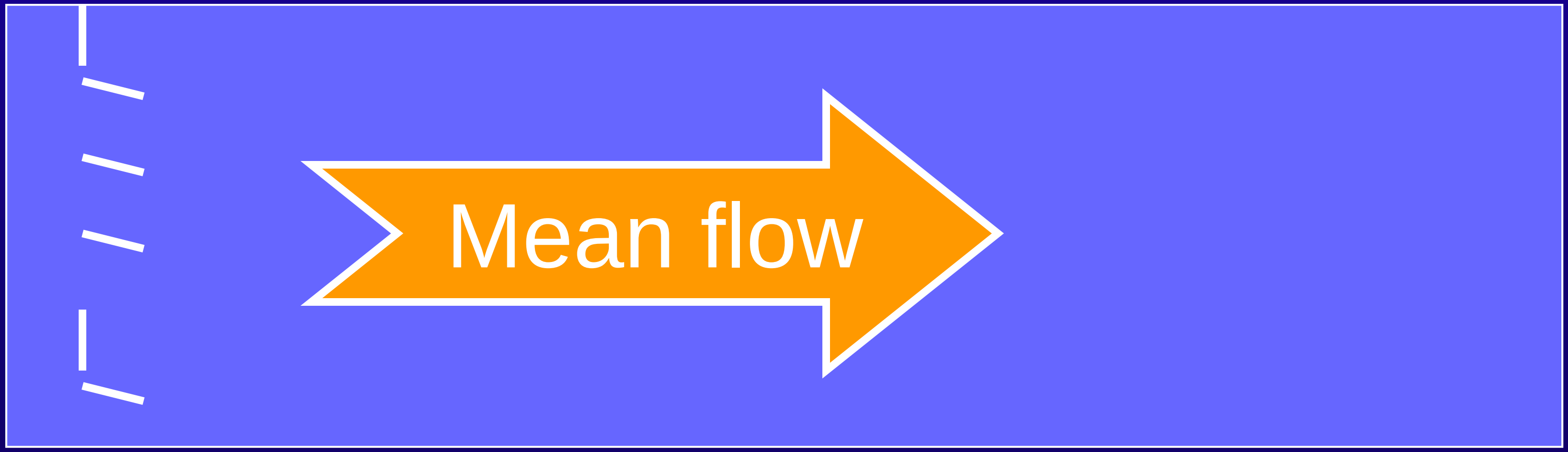

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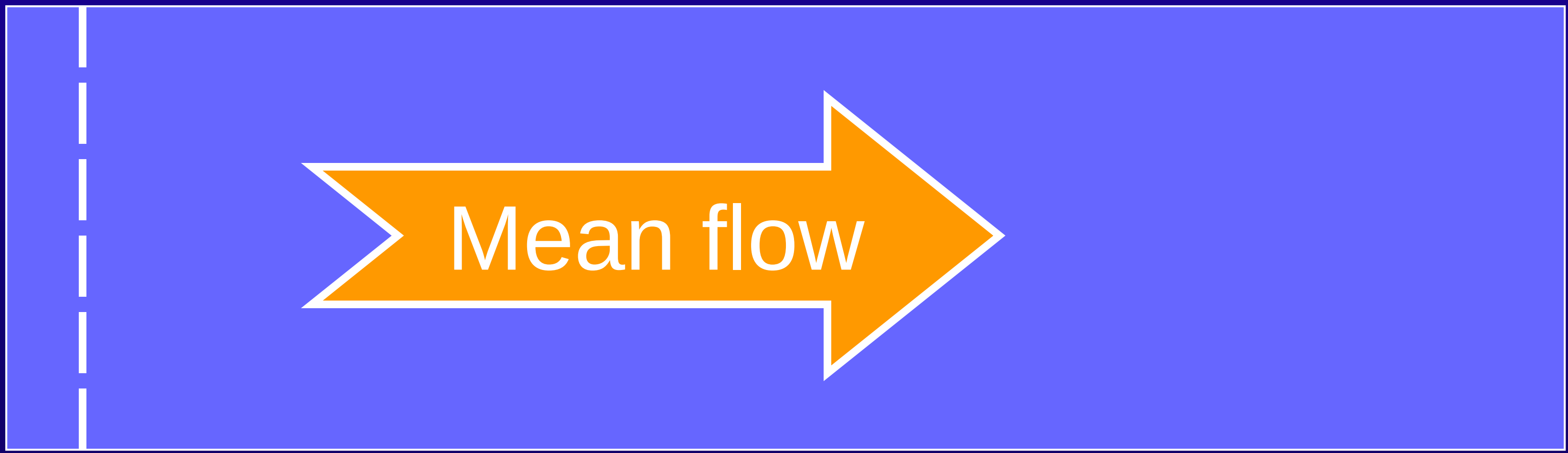

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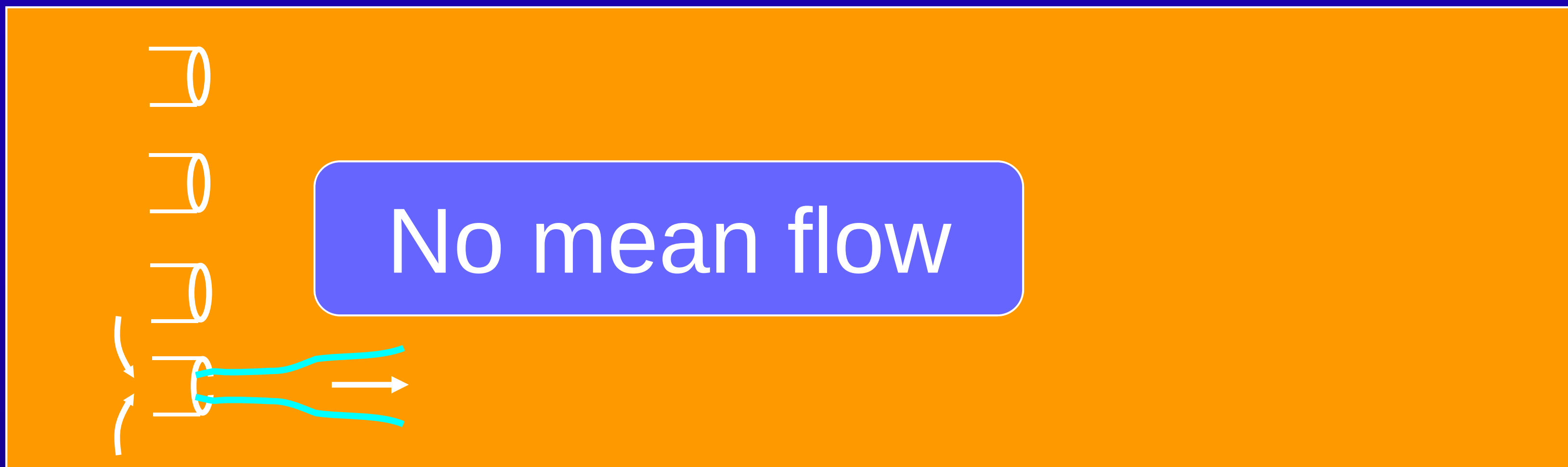

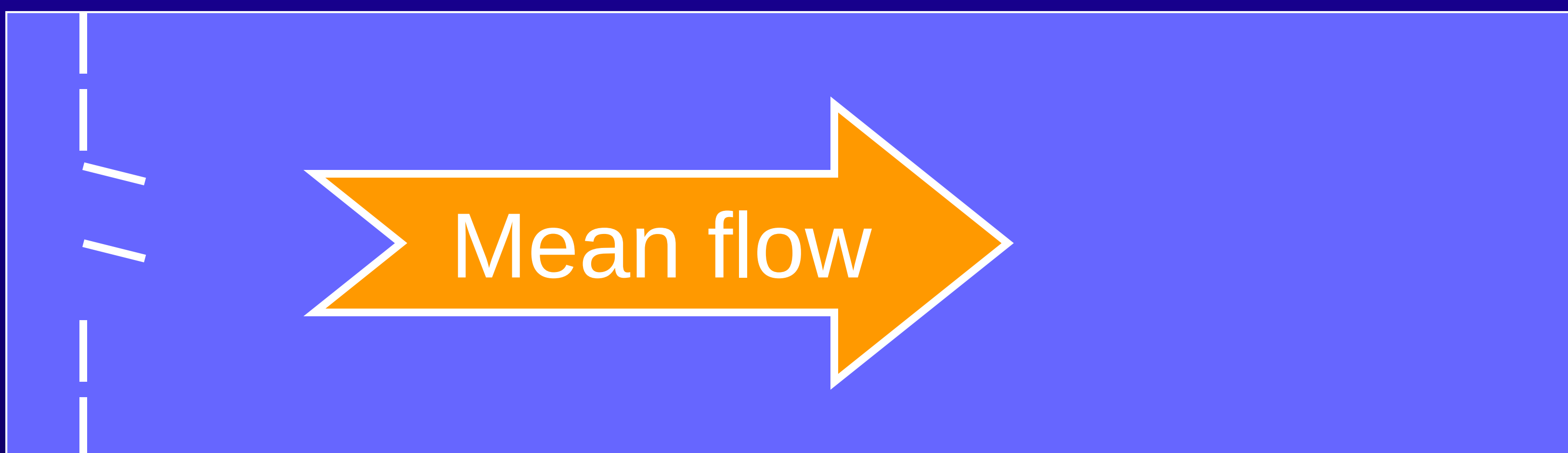

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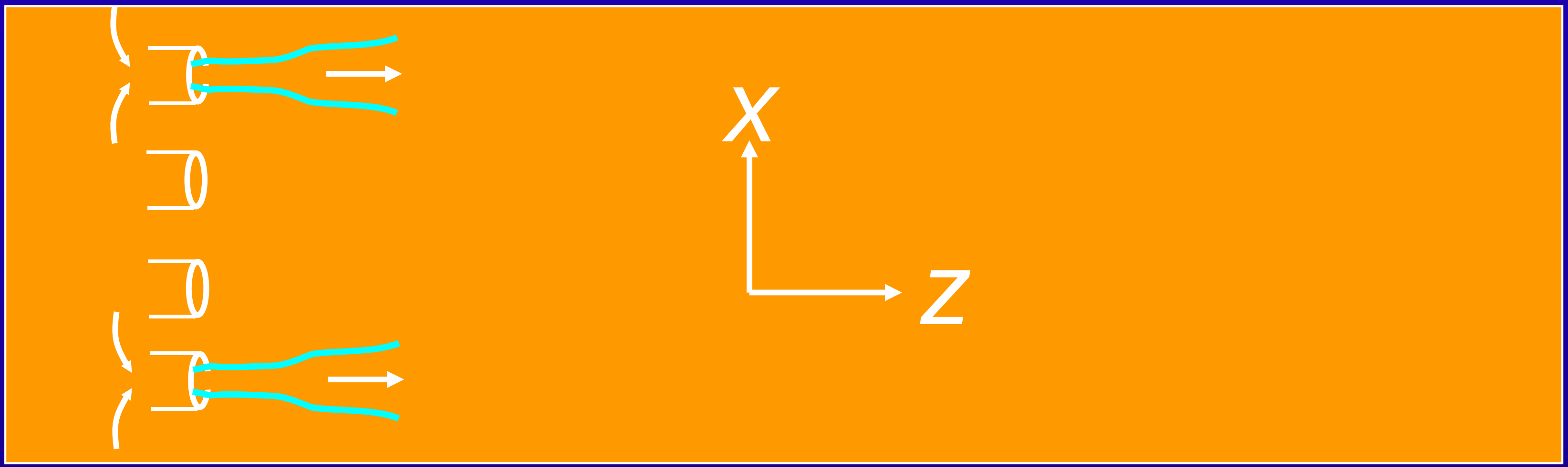

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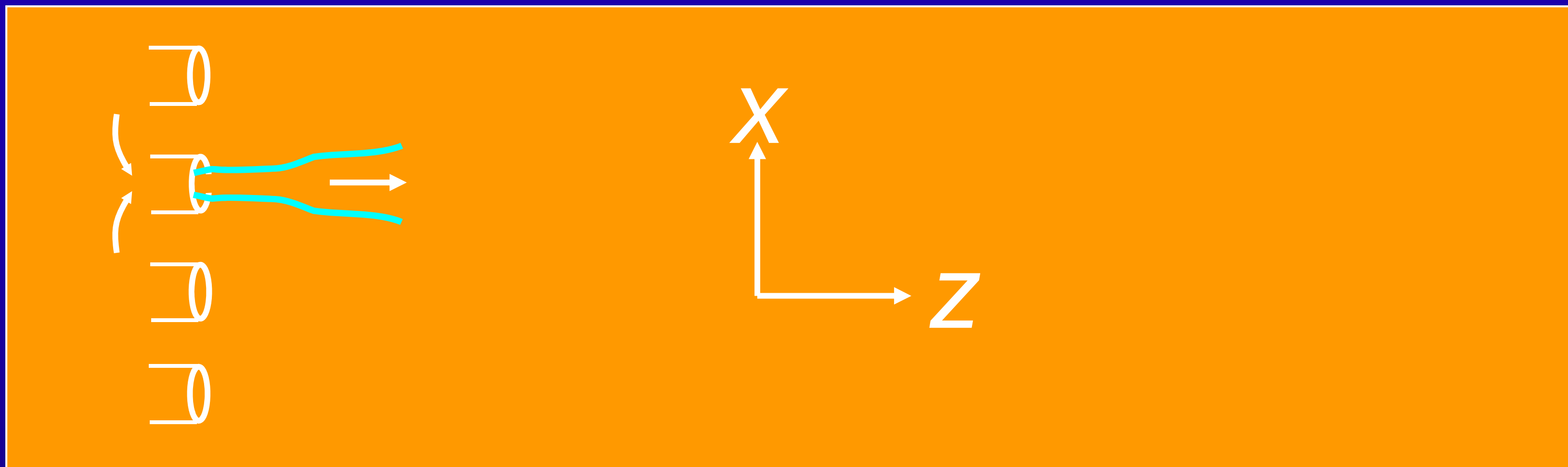

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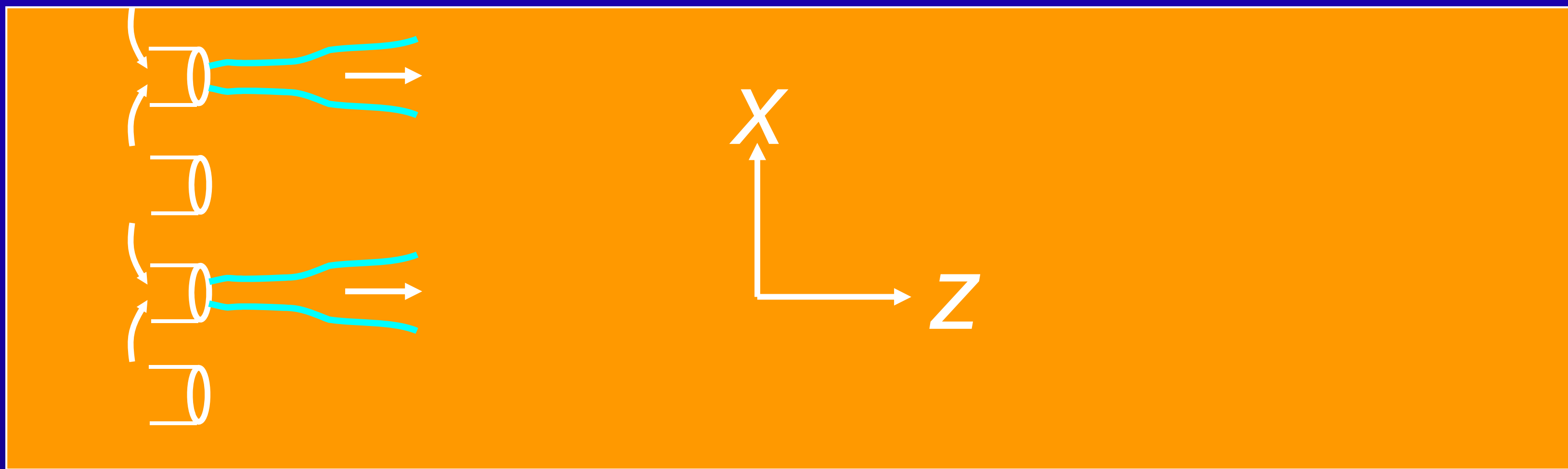

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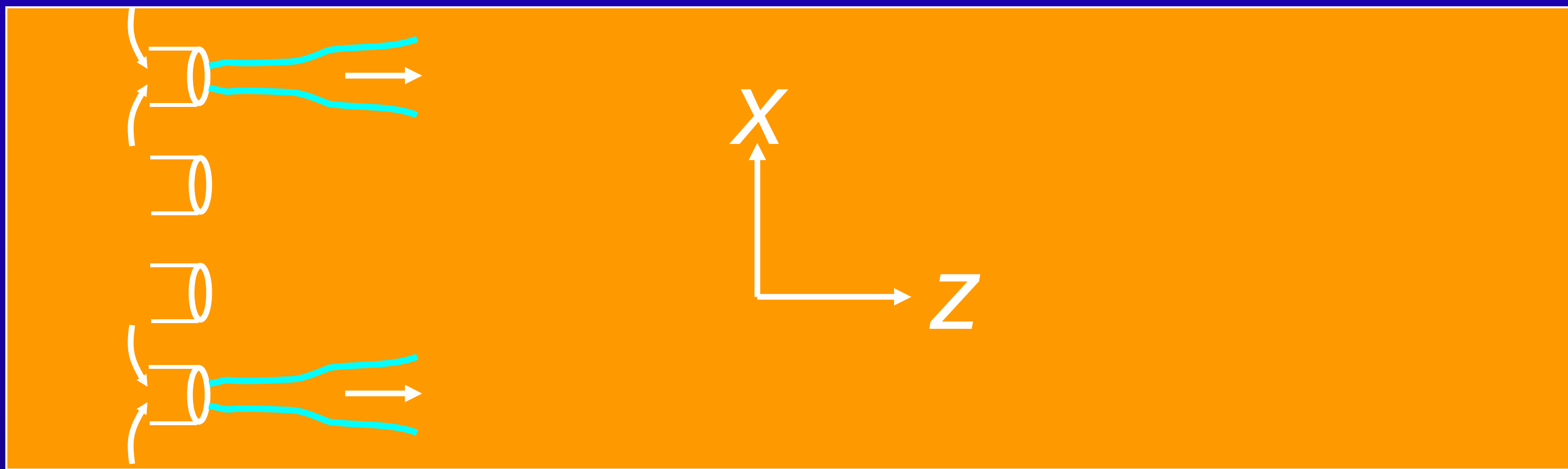

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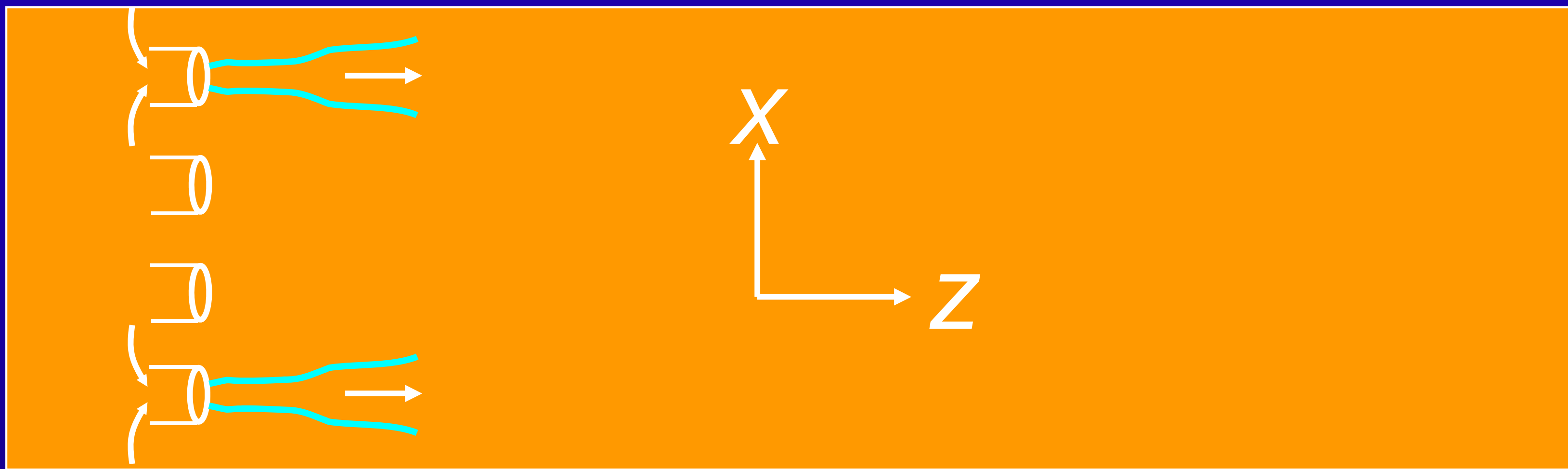

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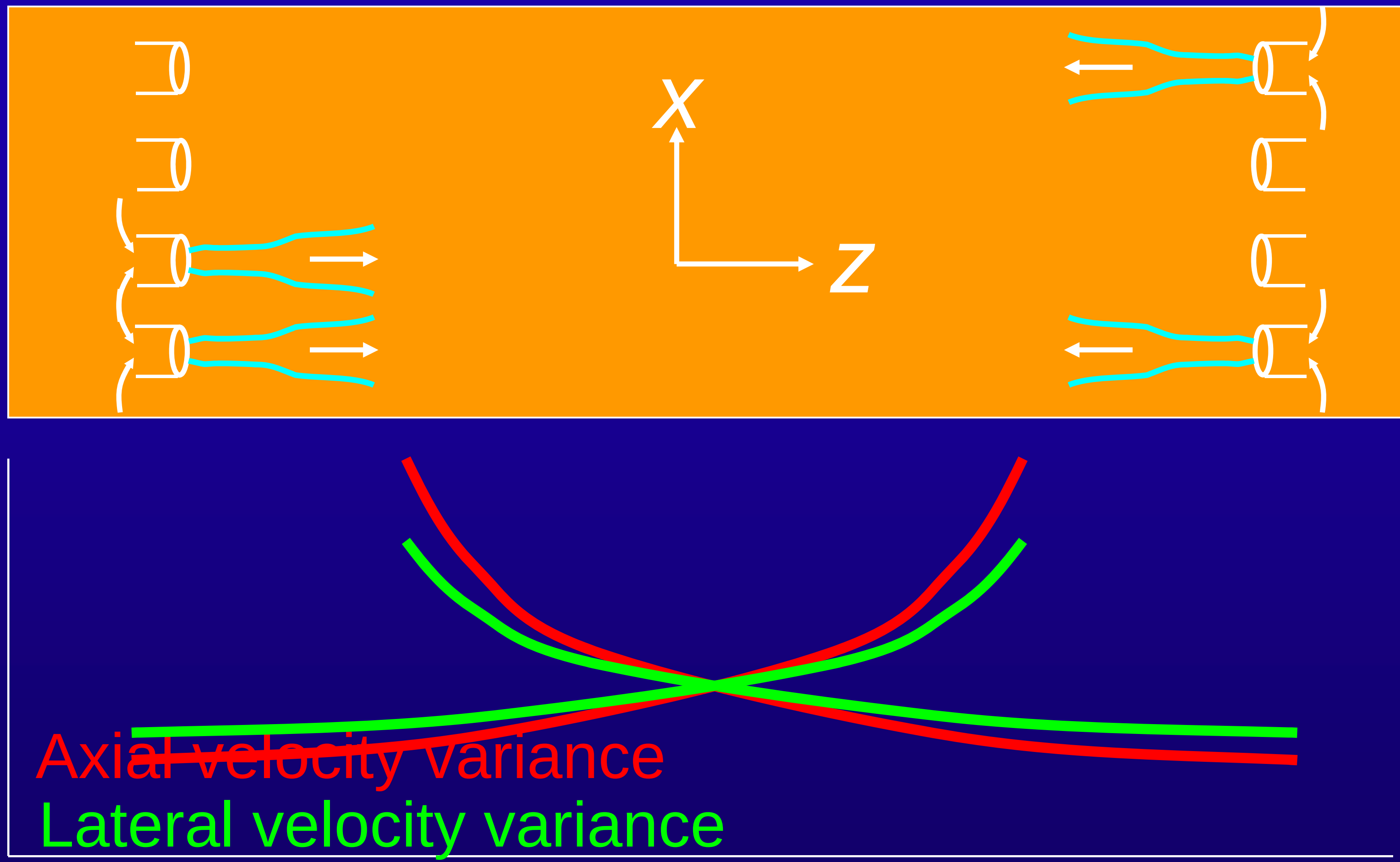

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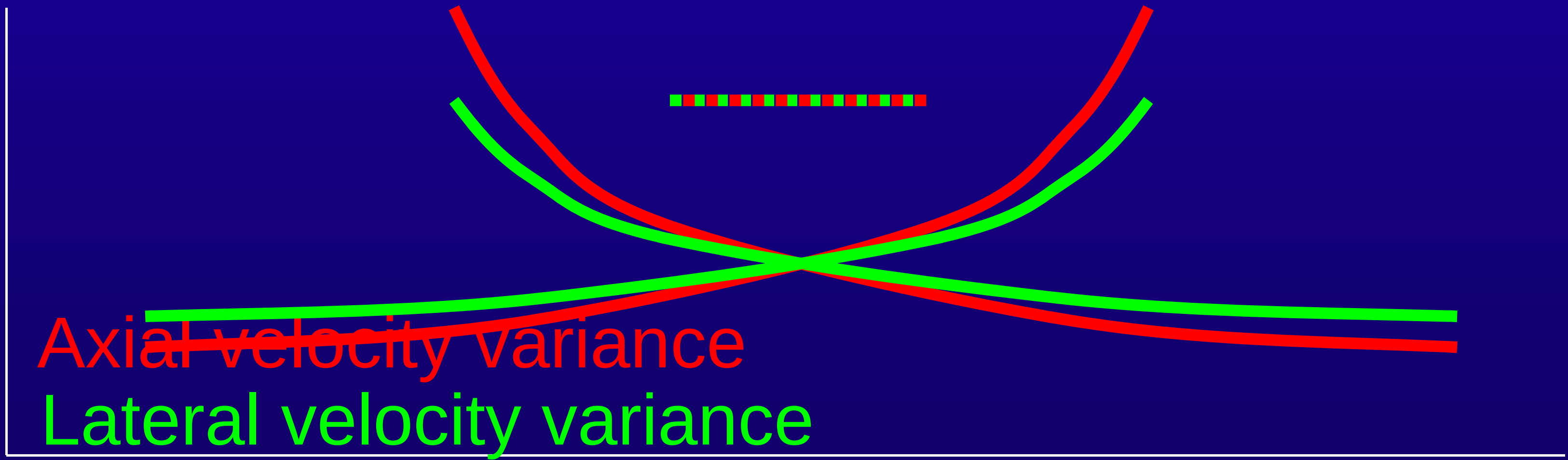


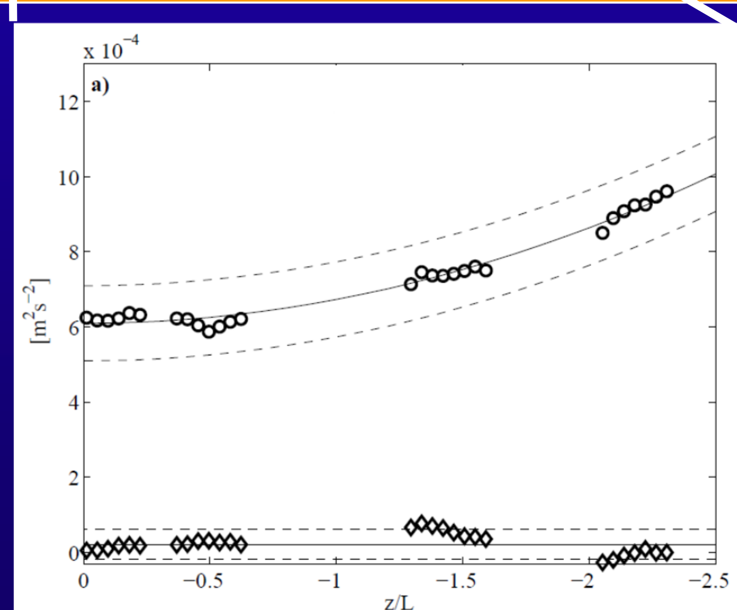
Stirred Tank

$R_\lambda = 270$

$L = 72$ mm

$\eta = 0.4$ mm

$\varepsilon = 4.6\ cm^2/s^3$



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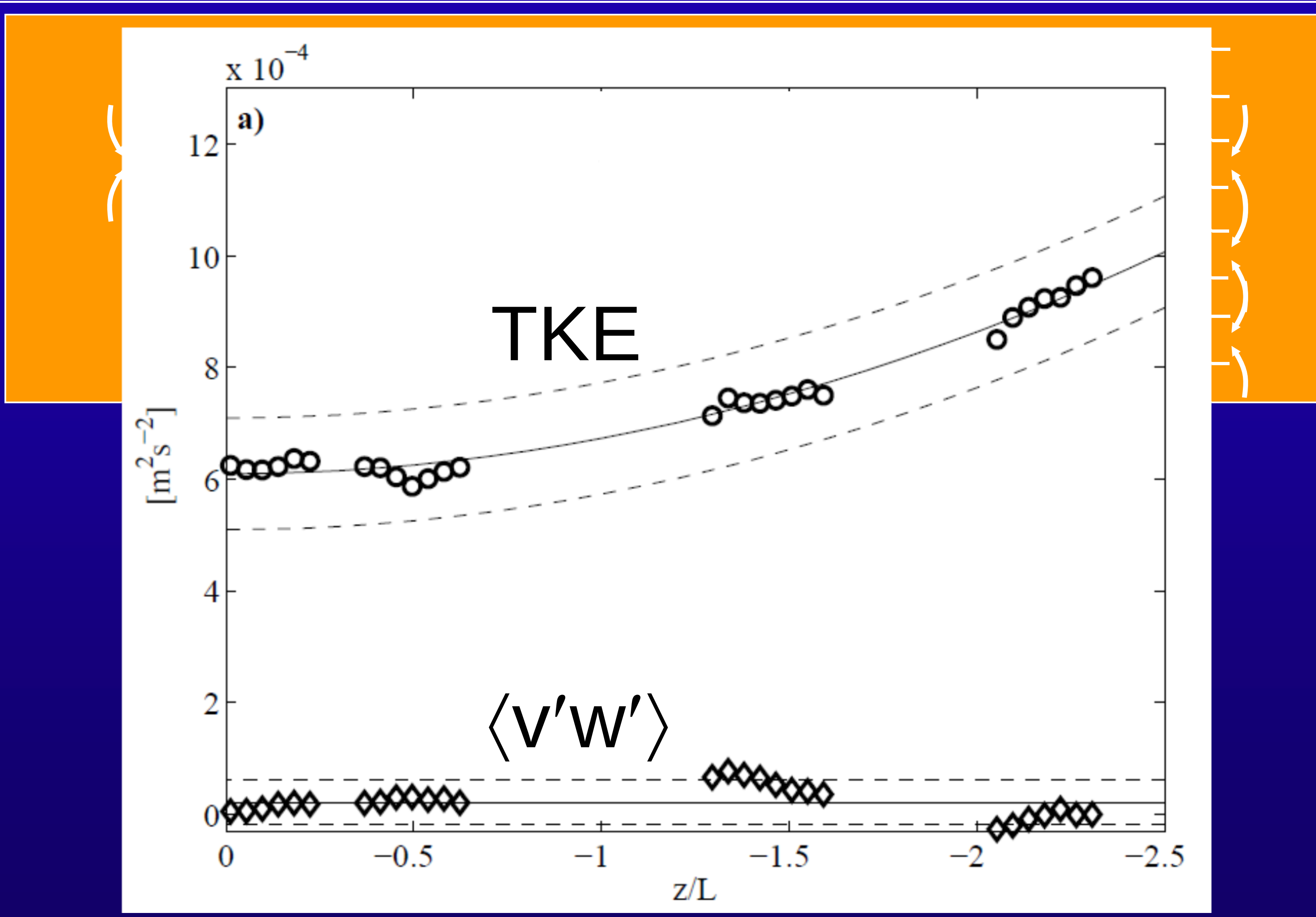

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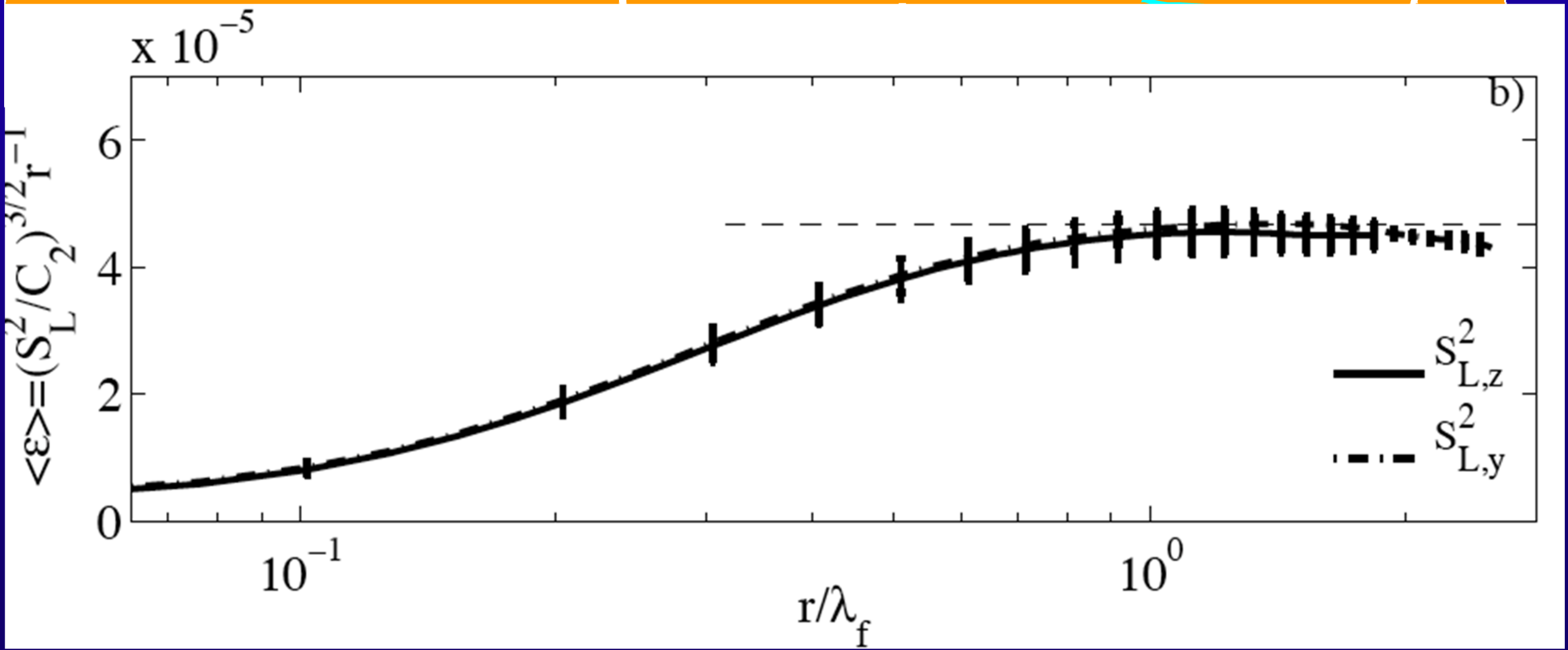


Stirred Tank

$R_\lambda = 270$

$L = 72$ mm

$\lambda = 12$ mm

$\eta = 0.4$ mm

$w_{rms} = 2$ cm/s

$\varepsilon = 4.6\ cm^2/s^3$

[Bellani and Variano, Exp. Fluids 2014]

Neutrally buoyant large spheroids

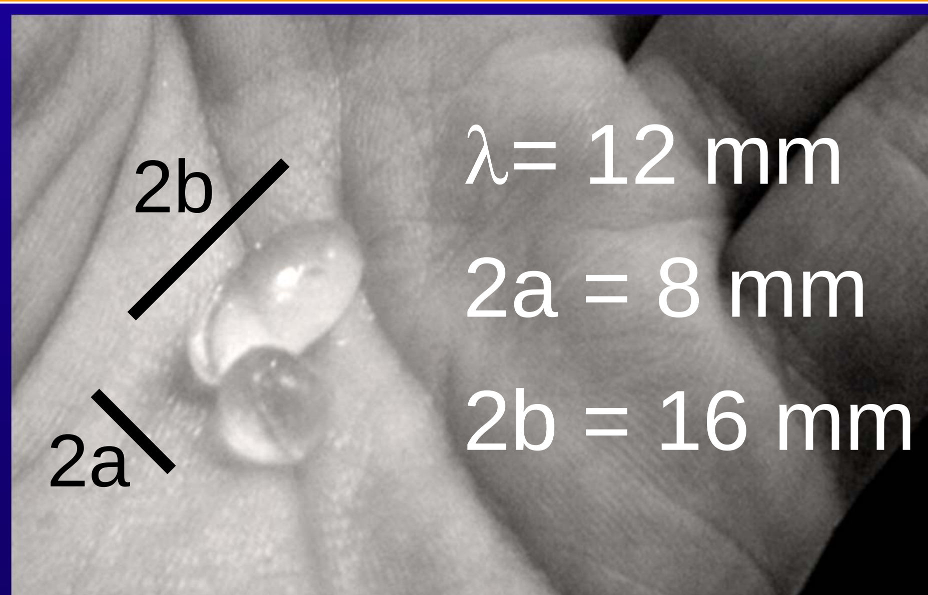
Neutrally Buoyant Spheroids

$R_\lambda = 270$

$L = 72$ mm

$\eta = 0.4$ mm

$\varepsilon = 4.6\ cm^2/s^3$



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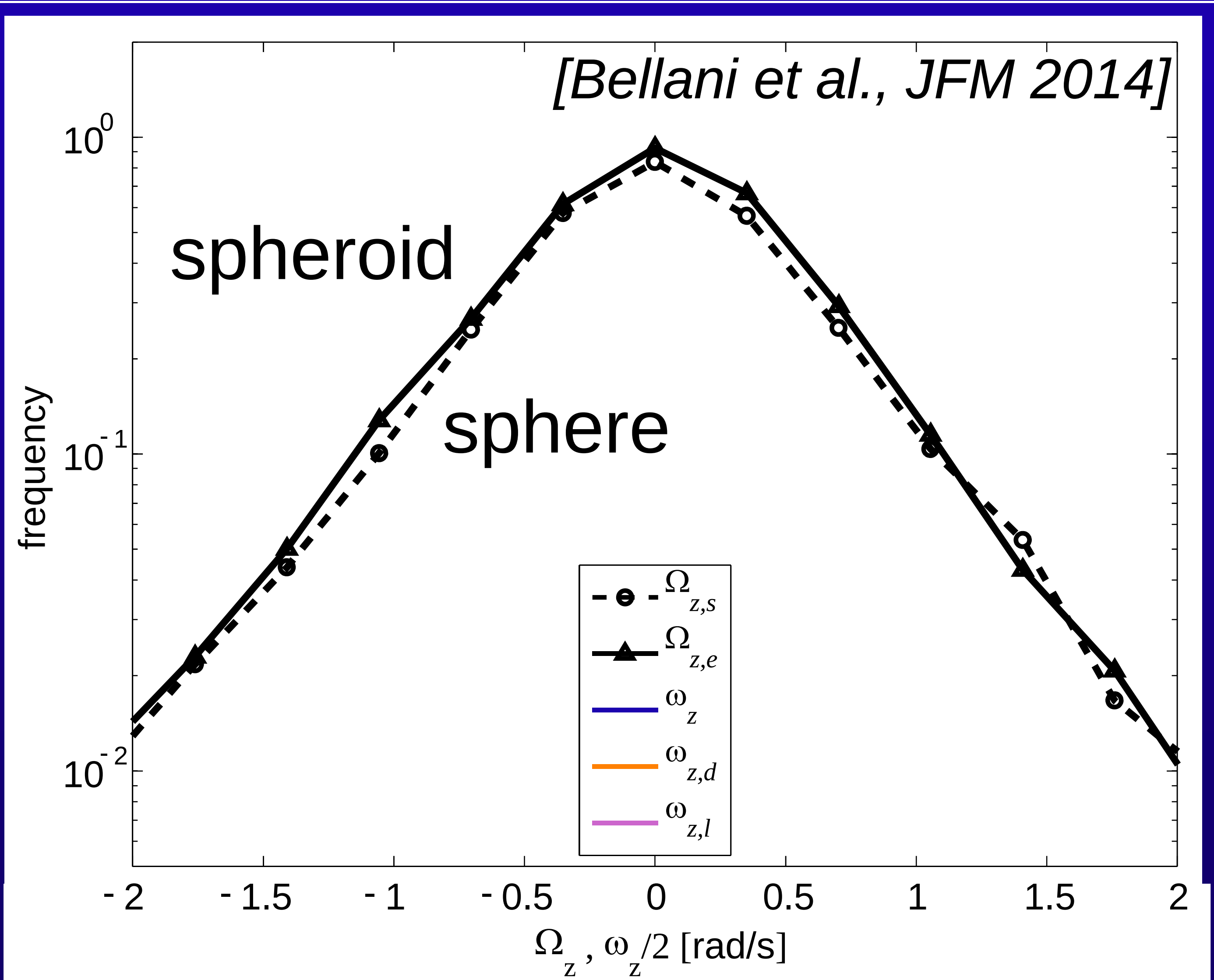

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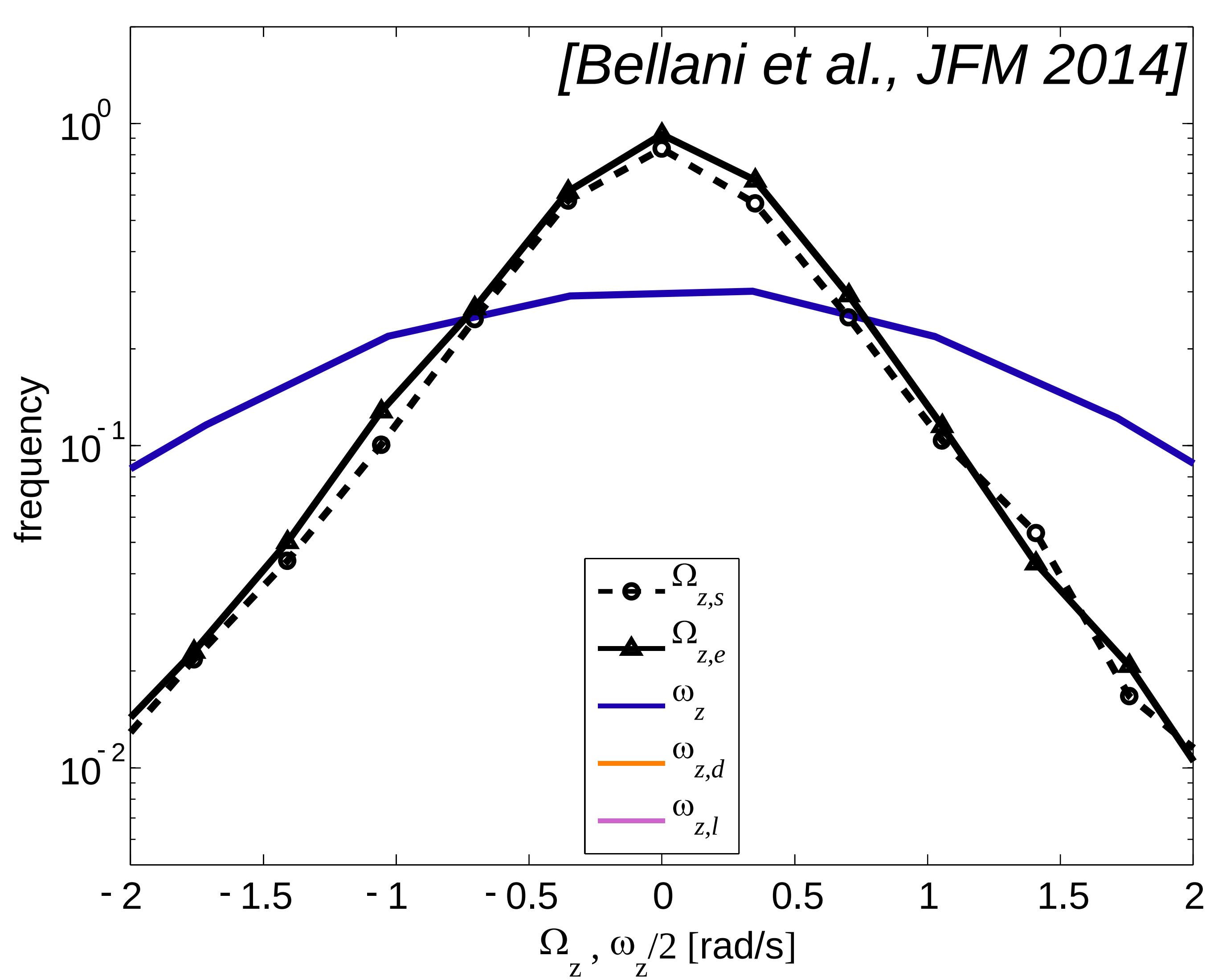

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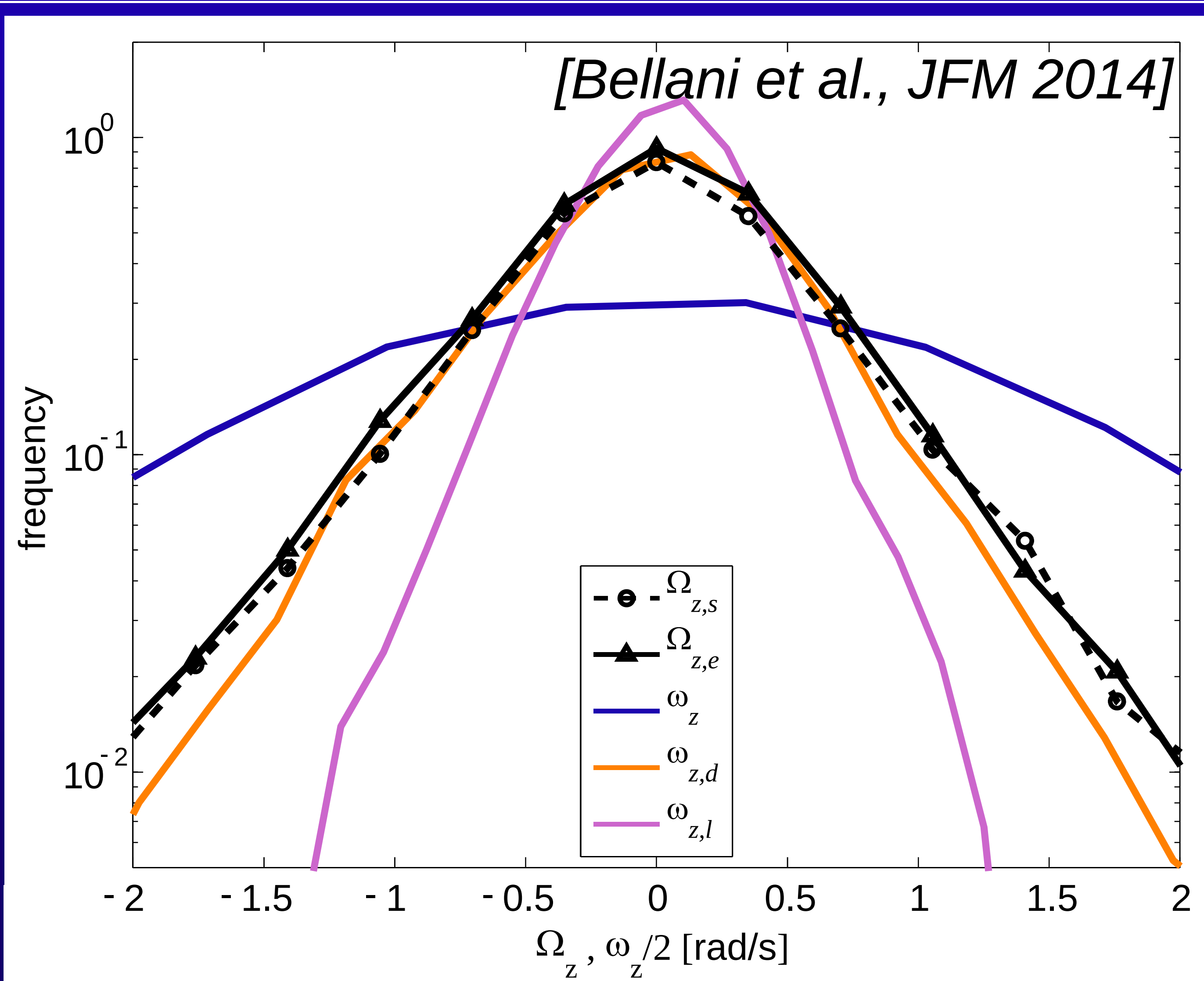


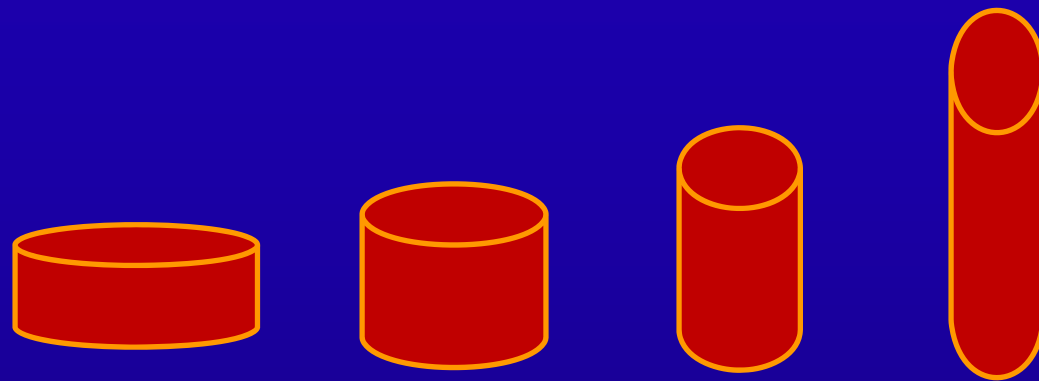
Neutrally Buoyant Spheroids

- Vorticity rms matches that predicted by filtered turbulent field ($\approx$1 s^{-1})
- Vorticity autocovariance timescale matches that predicted by filtered turbulent field ($\approx$0.5 s)

- Weak shape dependence for quantities measured in the lab frame (and also weak size dependence)

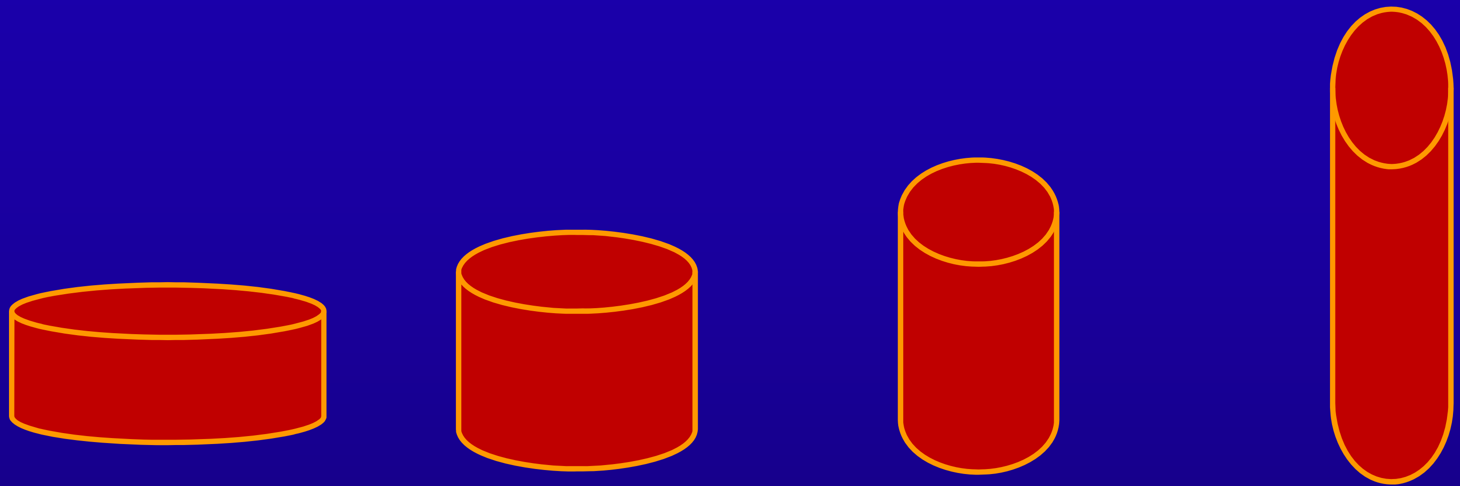
Neutrally buoyant large cylinders

Neutrally Buoyant Cylinders



Aspect Ratio	0.5	1	2	4
Minimum length	3 mm	4.8 mm	7.5 mm	6 mm
maximum length	12 mm	9.5 mm	7.5 mm	12 mm
Equivalent sphere diameter (d_e)	8.6 mm	8.6 mm	8.6 mm	8.6 mm
Kolmogorov scale	0.4 mm	0.4 mm	0.4 mm	0.4 mm
Integral scale	72 mm	72 mm	72 mm	72 mm

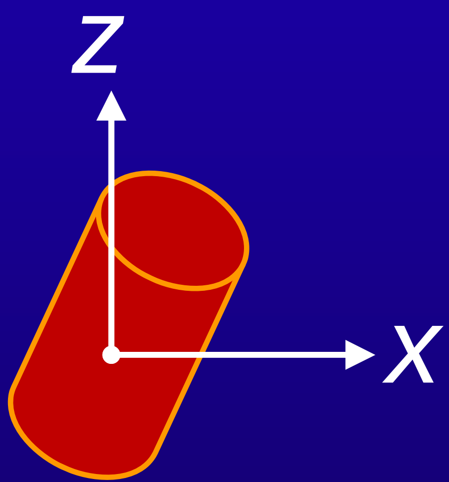
Neutrally Buoyant Cylinders

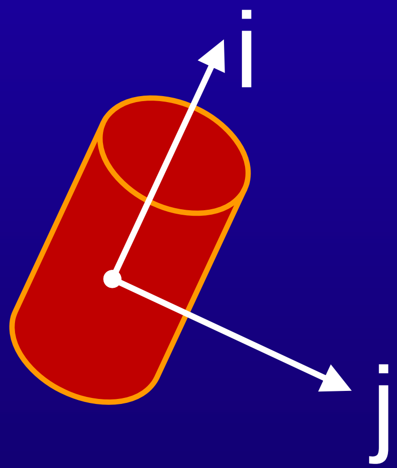


All cylinders have the *same* angular velocity, within measurement error.

Neutrally Buoyant Cylinders

All cylinders have the *same* angular velocity, within measurement error.

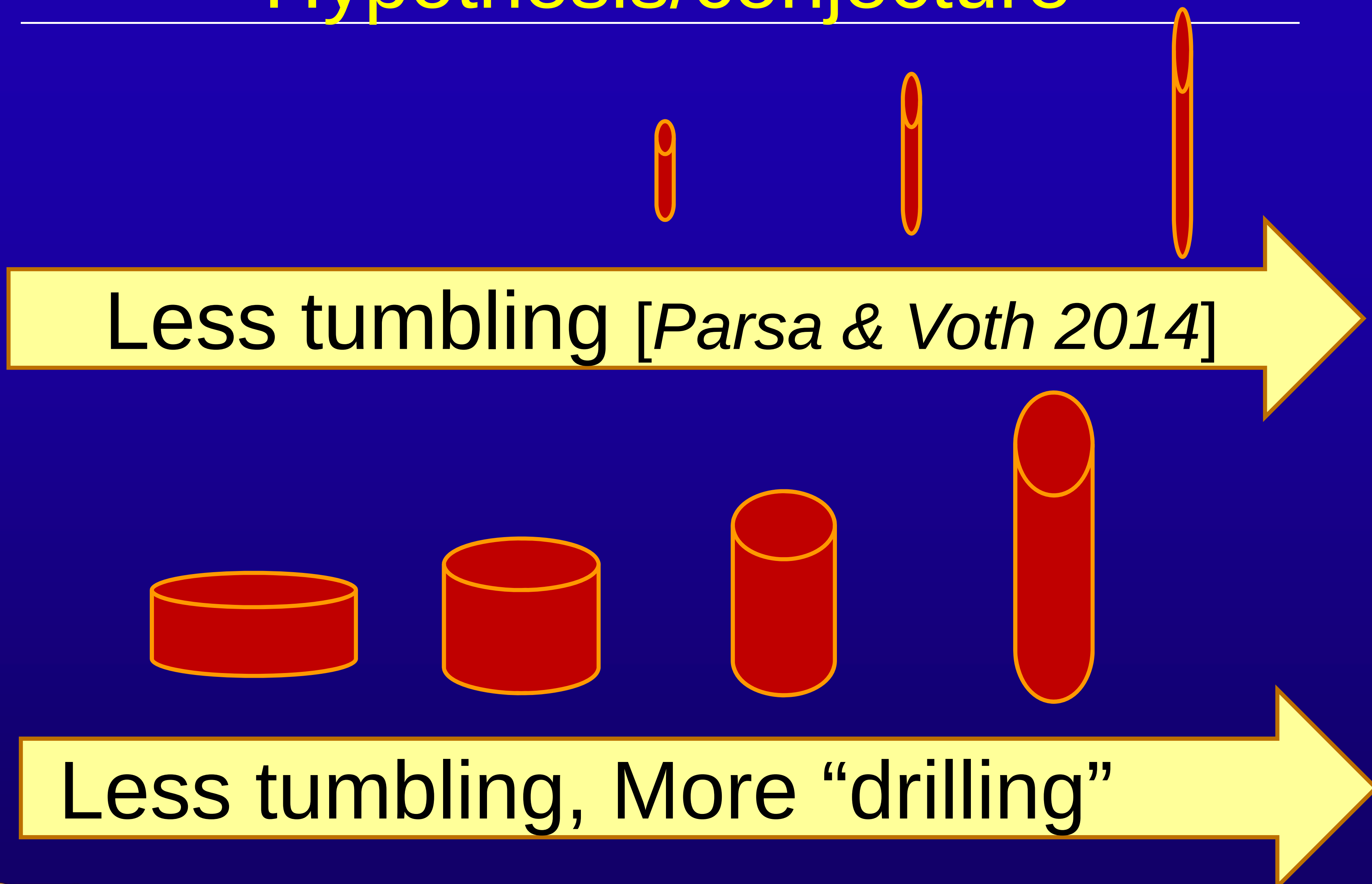




$\Omega_x = \Omega_y = \Omega_z$

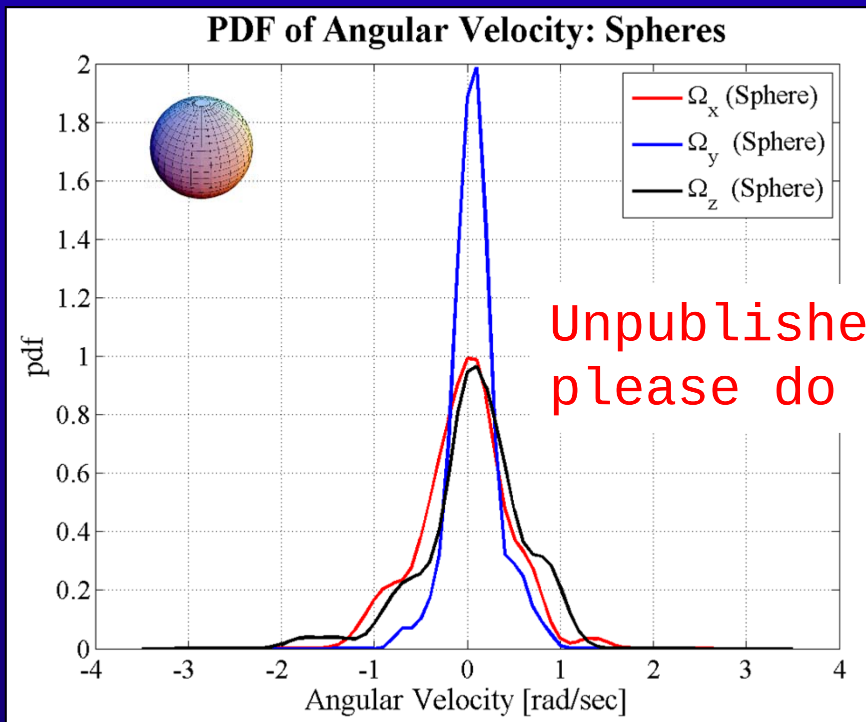
$\Omega_i \neq \Omega_j = \Omega_k$

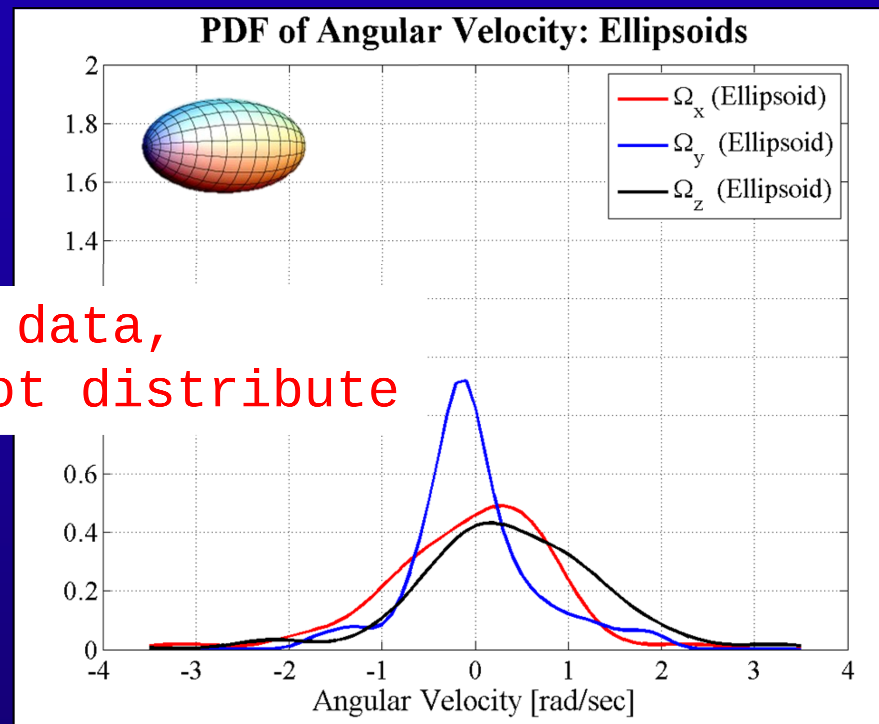
Hypothesis/conjecture



Buoyant (inertial) large spheroids

Buoyant Spheroids



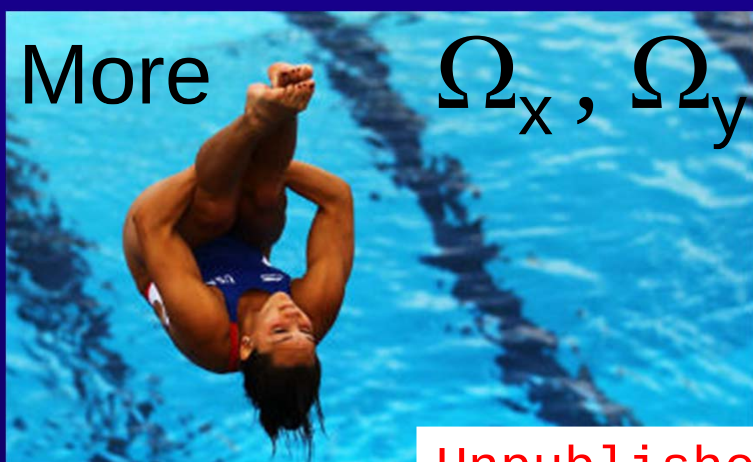


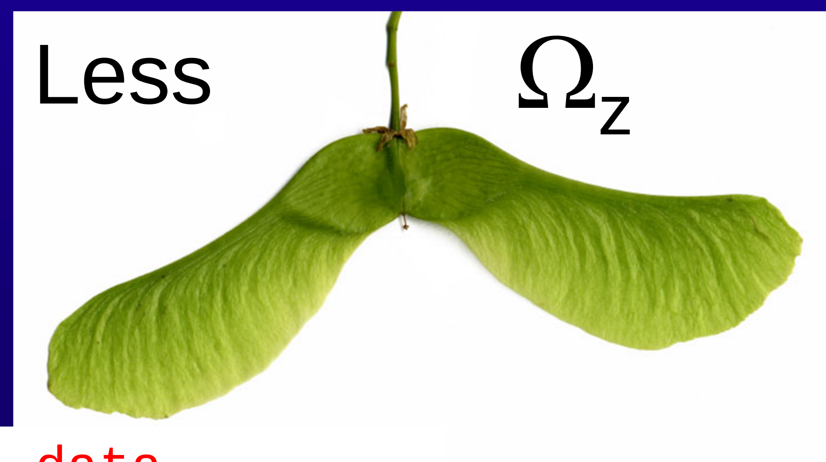
Unpublished data,
please do not distribute

Gravity breaks symmetry
and introduces shape-dependence

Buoyant Spheroids

	Spheres [95% CI], n=65	Ellipsoids [95% CI], n=59
$Var(\Omega_x)$ [sec^{-2}]	0.21 [0.14, 0.29]	0.74 [0.40, 1.34]
$Var(\Omega_y)$ [sec^{-2}]	0.28 [0.16, 0.42]	1.20 [0.56, 2.03]
$Var(\Omega_z)$ [sec^{-2}]	0.06 [0.04, 0.10]	0.45 [0.26, 0.66]





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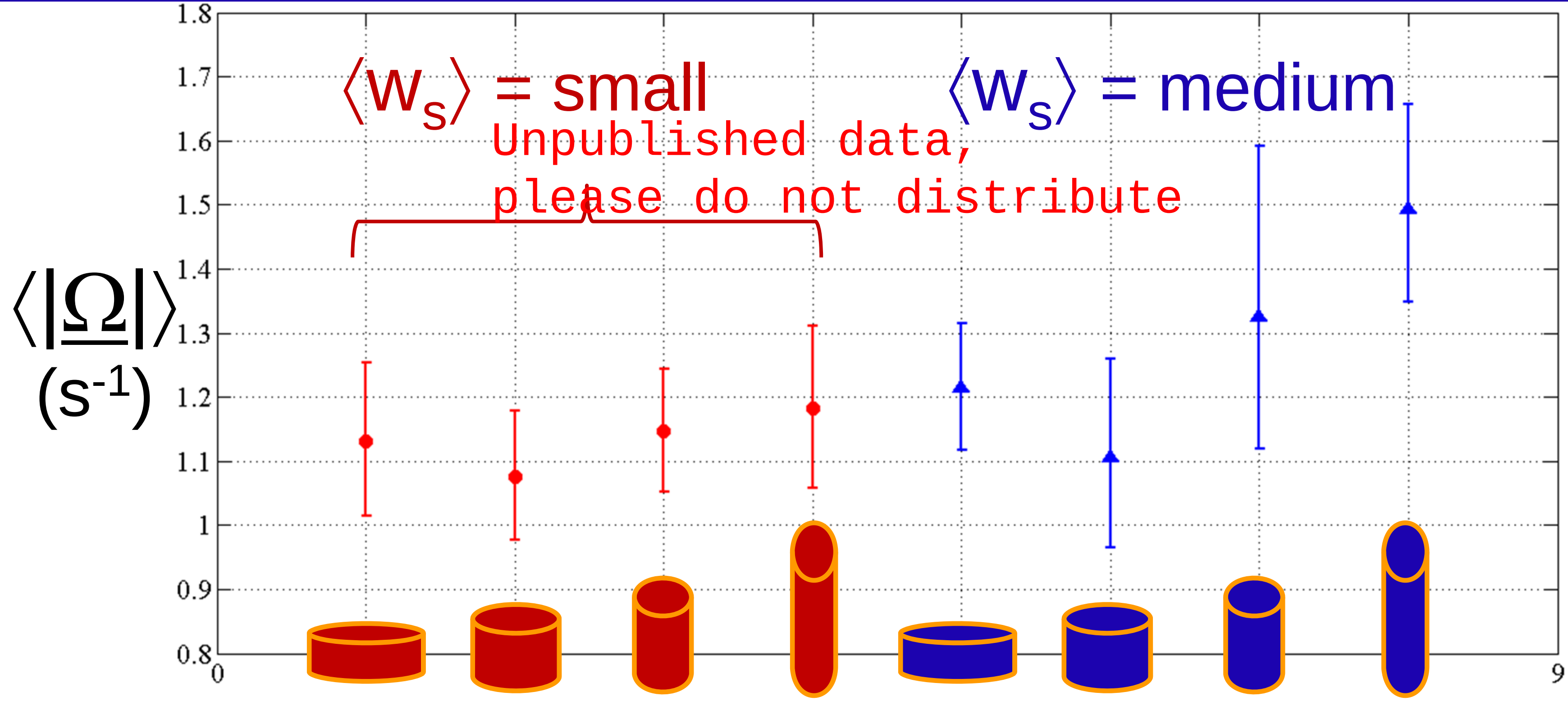
Buoyant (inertial) large cylinders

Buoyant Cylinders



Buoyancy increases angular velocity, especially for aspherical particles

Hypothesis/conjecture

Angular velocity for buoyant elongated particles in turbulence

¿=?

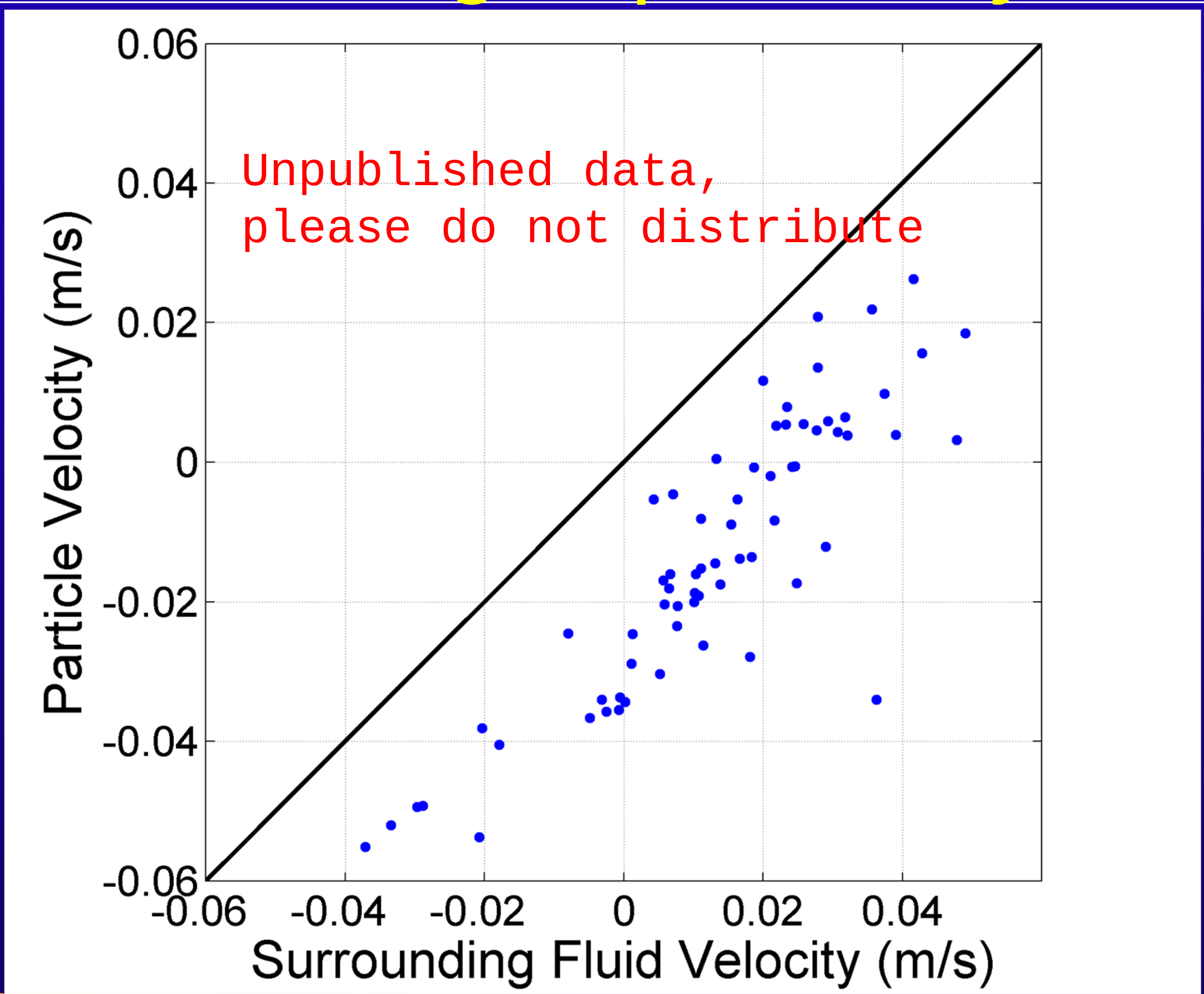
Angular velocity for neutrally buoyant elongated particles in turbulence

+

Angular velocity for buoyant elongated particles in quiescent flow [Example]

Buoyant (inertial) large spheroids

Settling Slip Velocity



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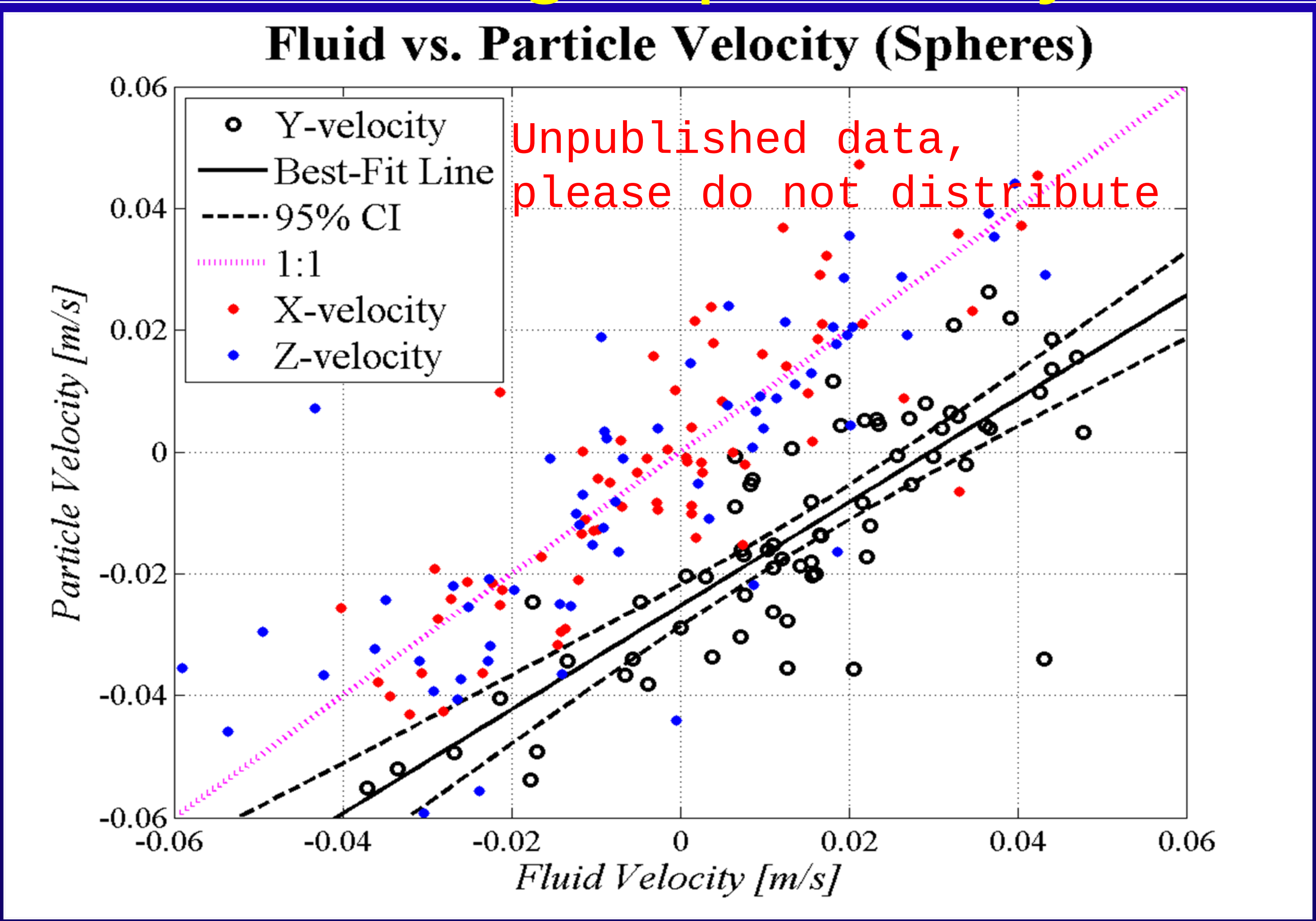

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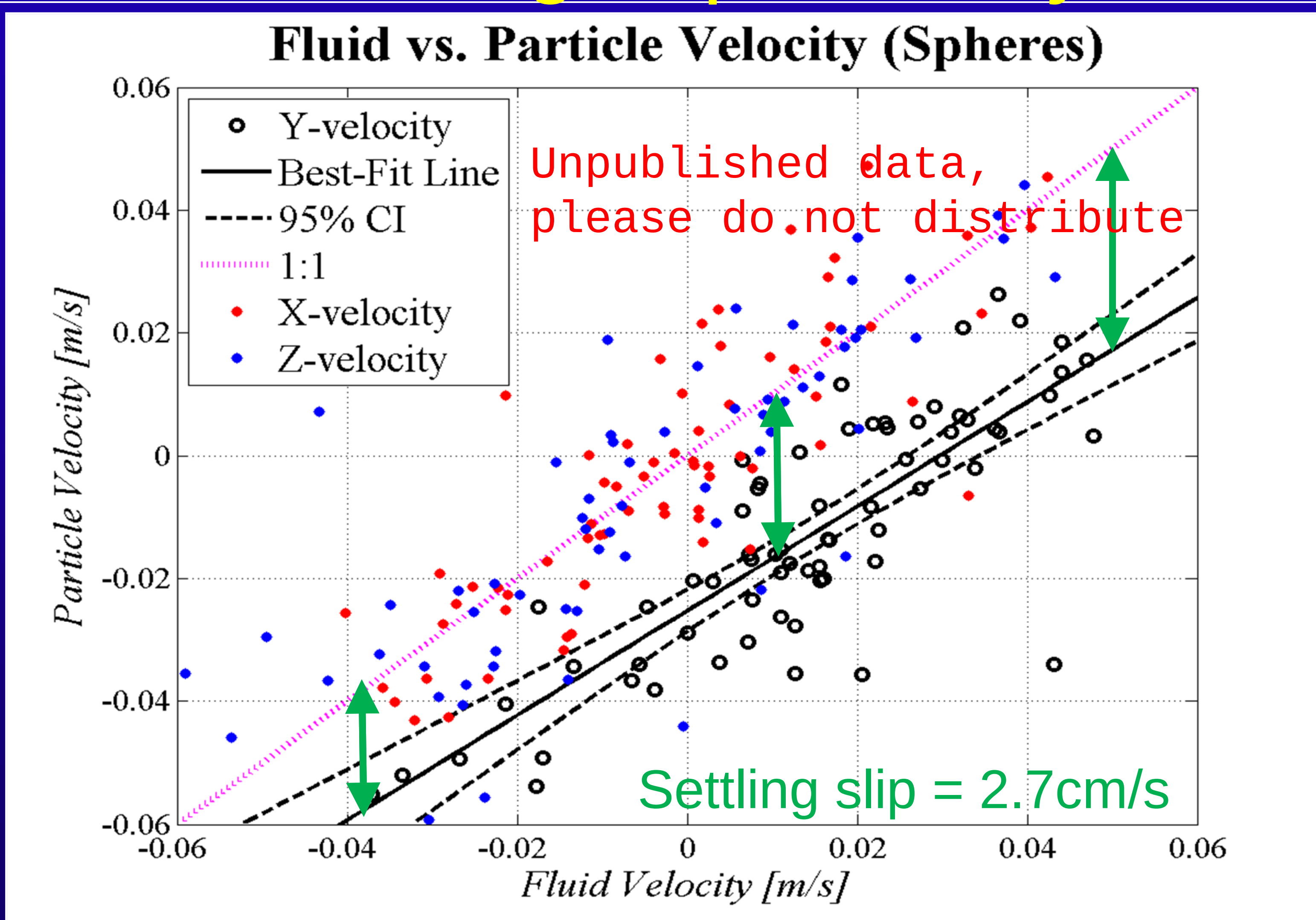

Settling Slip Velocity

Unpublished data, please do not distribute	Spheres	Ellipsoids
Settling Slip Velocity	-0.027 ± 0.002 ms^{-1}	-0.028 ± 0.001 ms^{-1}
Quiescent Settling Rate **Modified Clift-Gauvin approximation [*Loth 2008*]**	-0.069 ms^{-1}	-0.070 ms^{-1}
Stokes # (St), Settling # (Sv)	{7.2, 3.5}	{9, 3.5}

Strong evidence of altered settling; systematic study with cylinders underway

Conclusions

Neutrally buoyant large particles have very weak shape dependence for angular velocity in the lab frame.

Buoyancy causes additional angular velocity which is shape-dependent in the lab frame and also anisotropic in the lab frame.

Large particles show altered settling (“loitering”)

Thank you!

$$\underline{U}_m - \underline{U}_n = \underline{\Omega} \times (\underline{X}_m - \underline{X}_n)$$