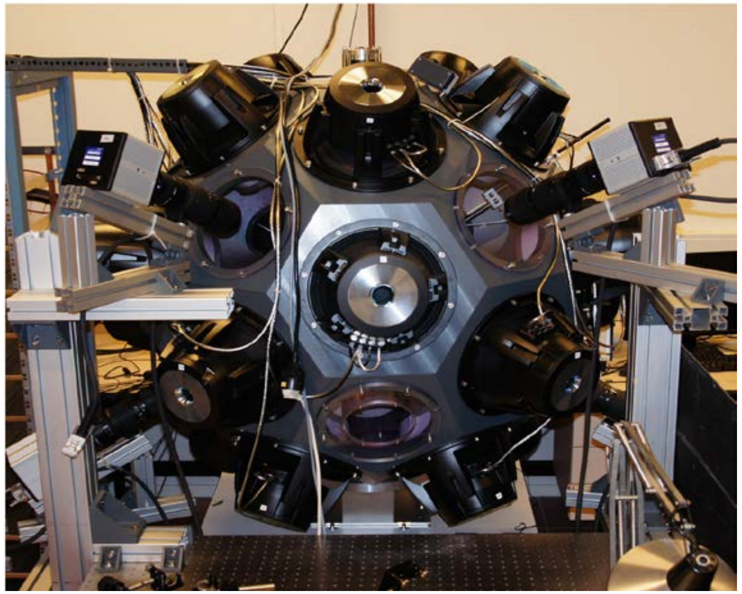
Hydrodynamic clustering of droplets in turbulence



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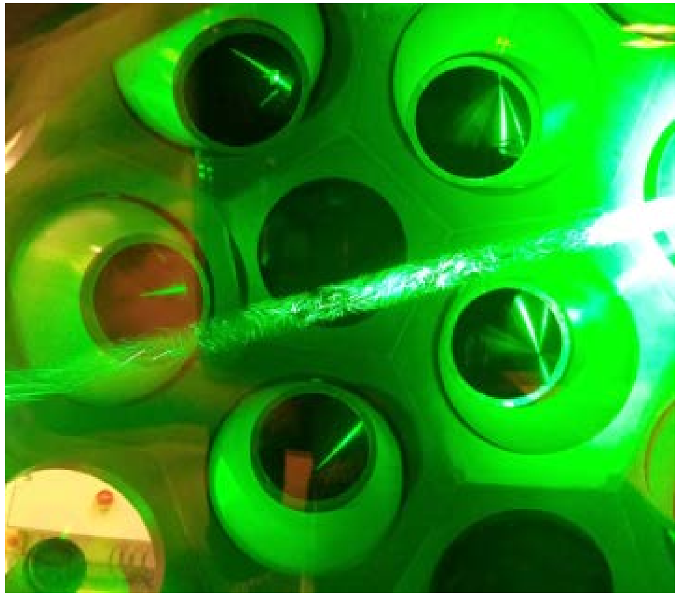
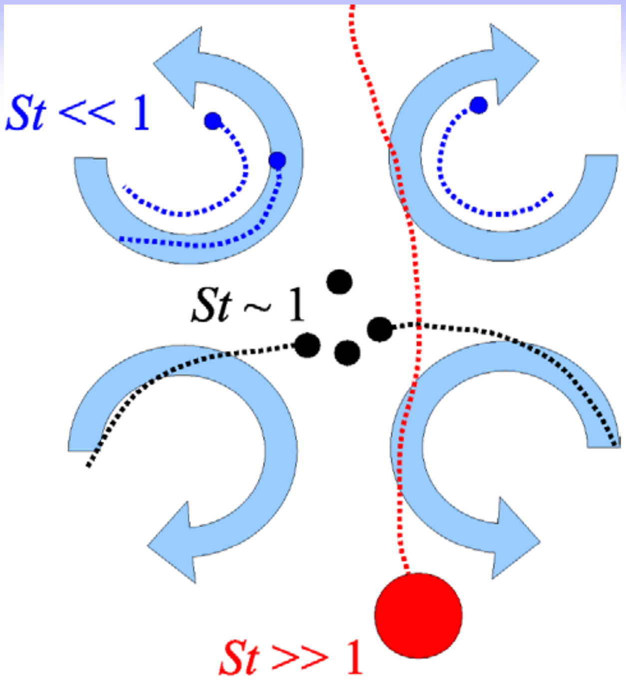
22 November 2017

APS-DFD 2017 Denver



Clustering of droplets in turbulence

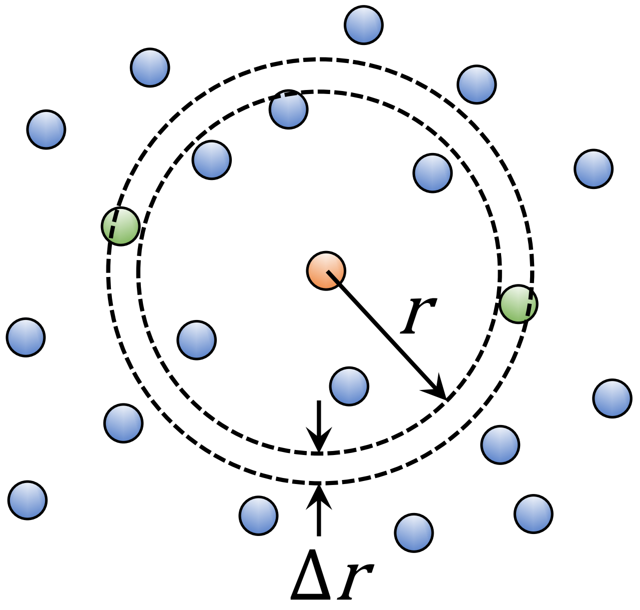


Stokes number: $$St = \frac{\tau_p}{\tau_\eta}$$

Droplets with $St \sim 1$ experience
preferential concentration

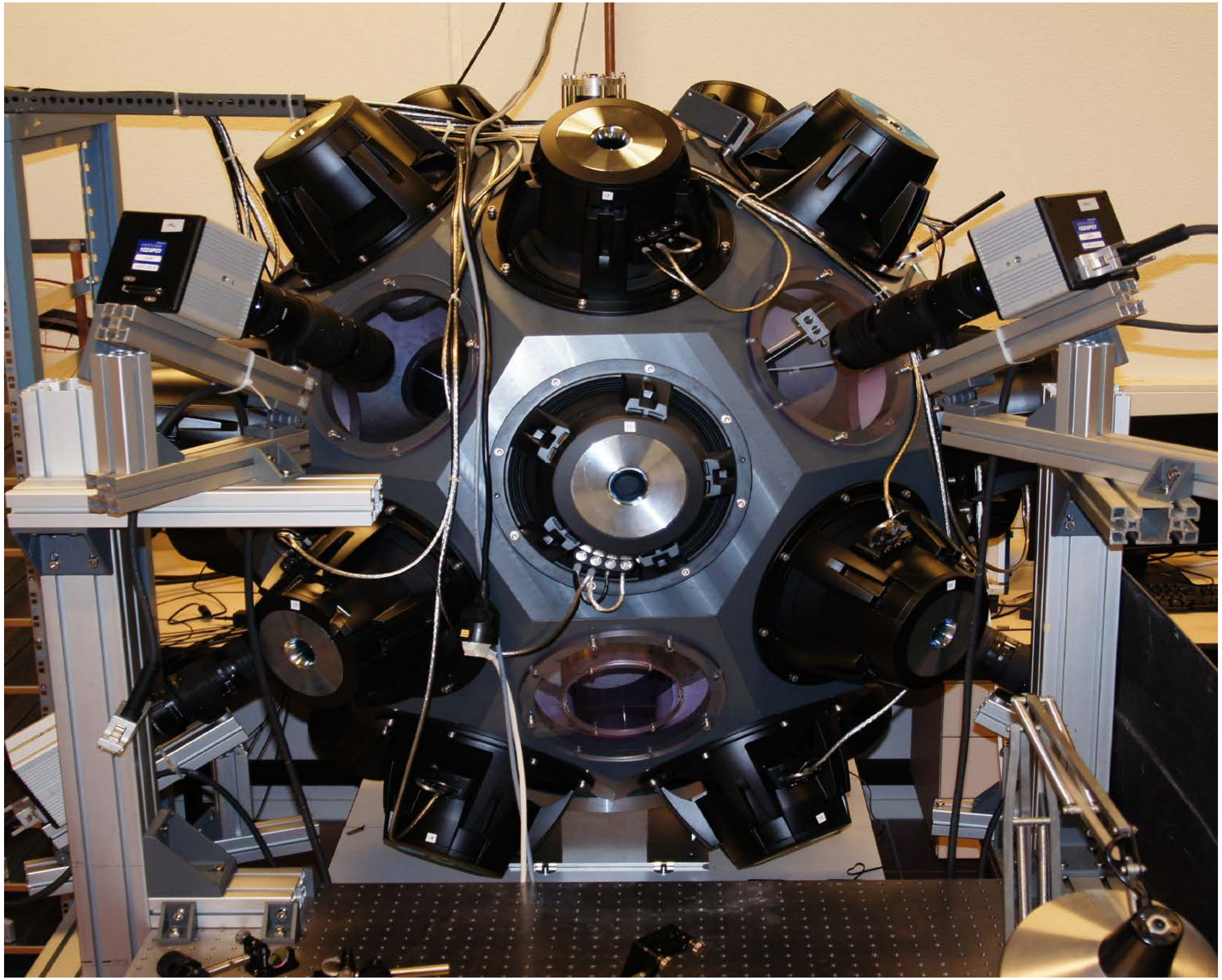
Goal: study droplet clustering in an experiment
→ radial distribution function (RDF)

$$g(r) = \frac{\text{particle pair concentration in shell } r}{\text{mean particle pair concentration}}$$



“Soccer ball” turbulence chamber

20 speakers drive homogeneous isotropic turbulent airflow



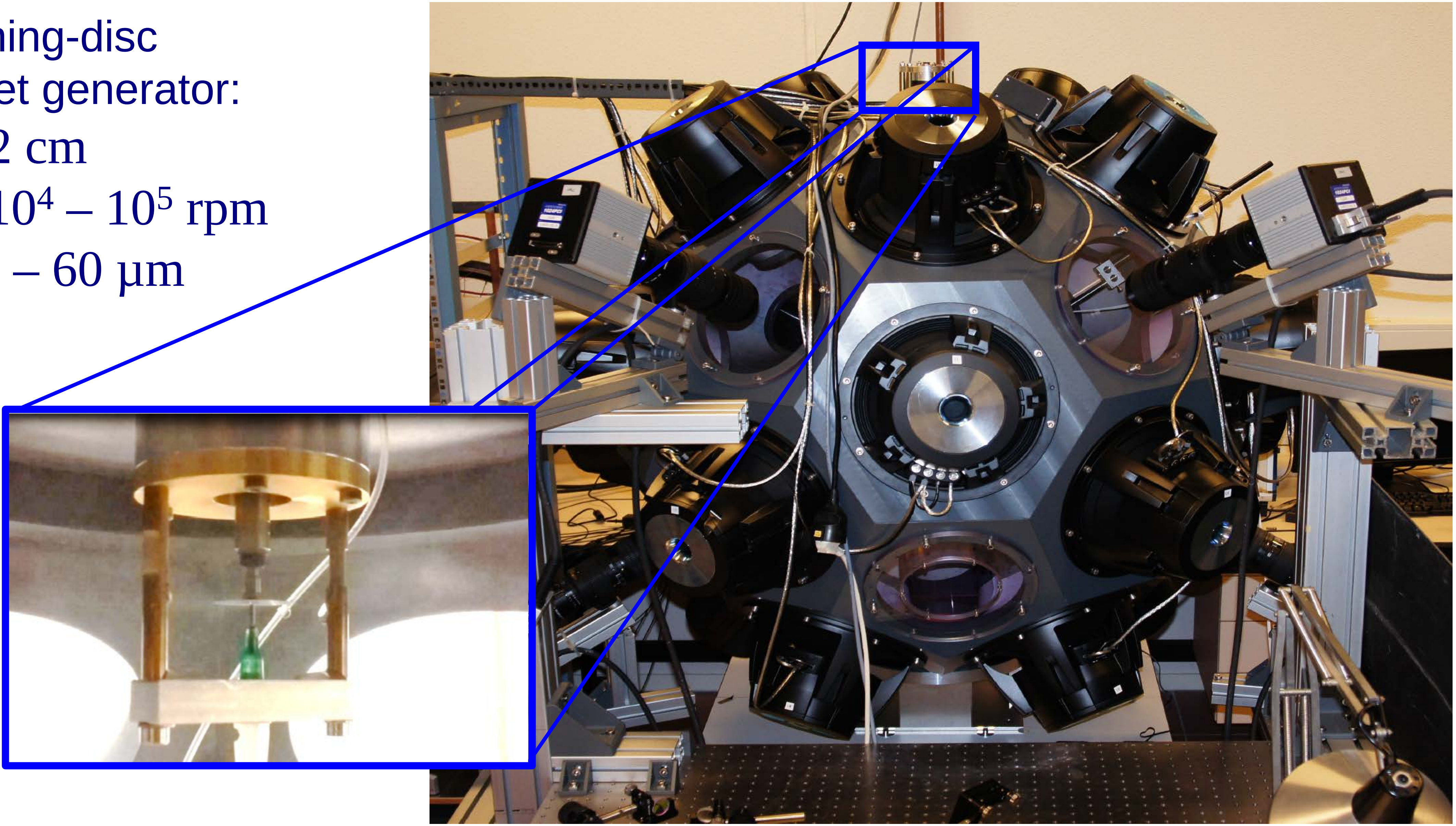
“Soccer ball” turbulence chamber

Spinning-disc
droplet generator:

$D = 2$ cm

$\omega = 10^4 – 10^5$ rpm

$a = 5 – 60$ μm

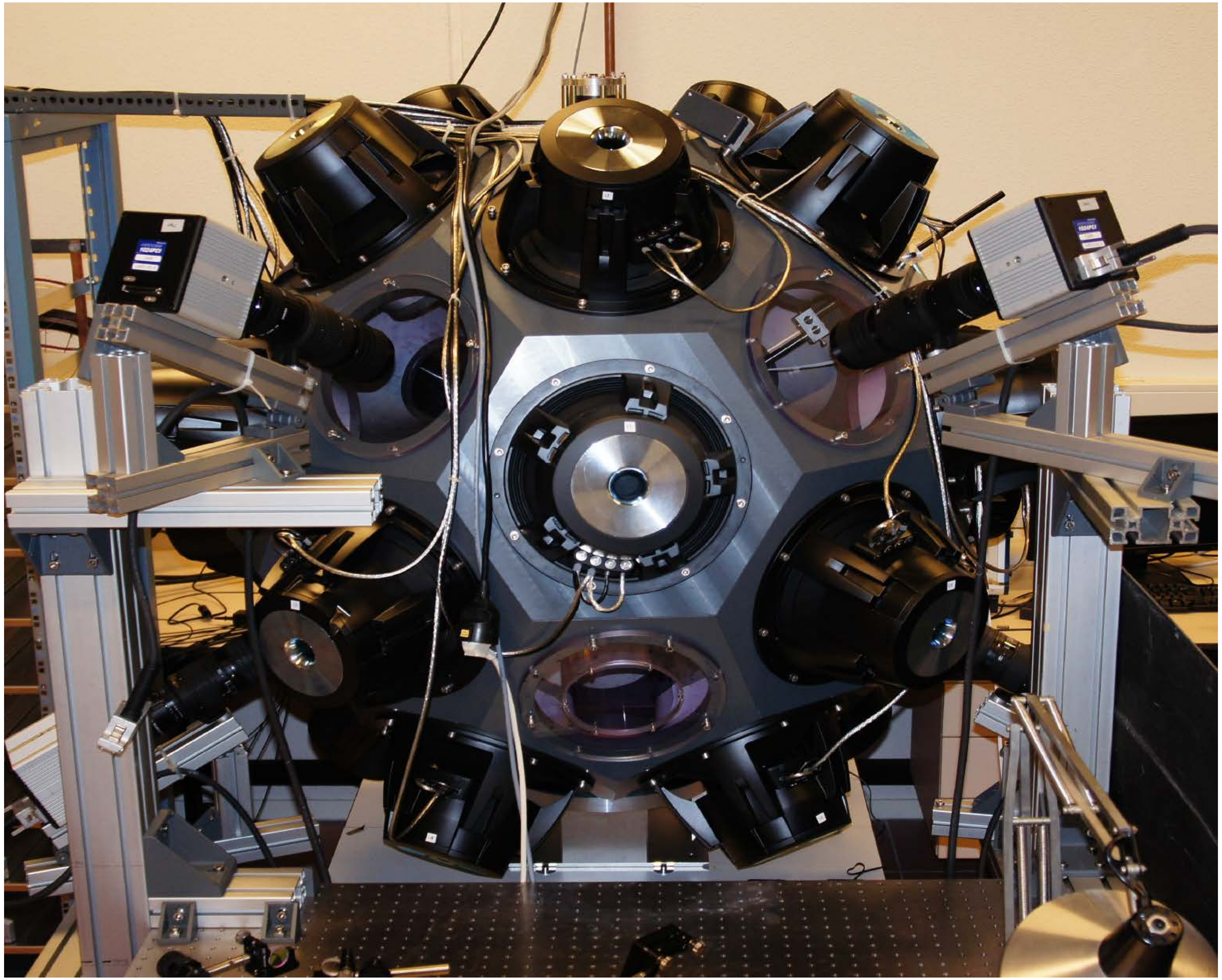


“Soccer ball” turbulence chamber

20 speakers drive homogeneous isotropic turbulent airflow

3D particle tracking: 4 hi-speed cameras monitor volume of 2.5 x 2.5 x 2.5 cm^3

Laser illumination



Droplets in turbulence

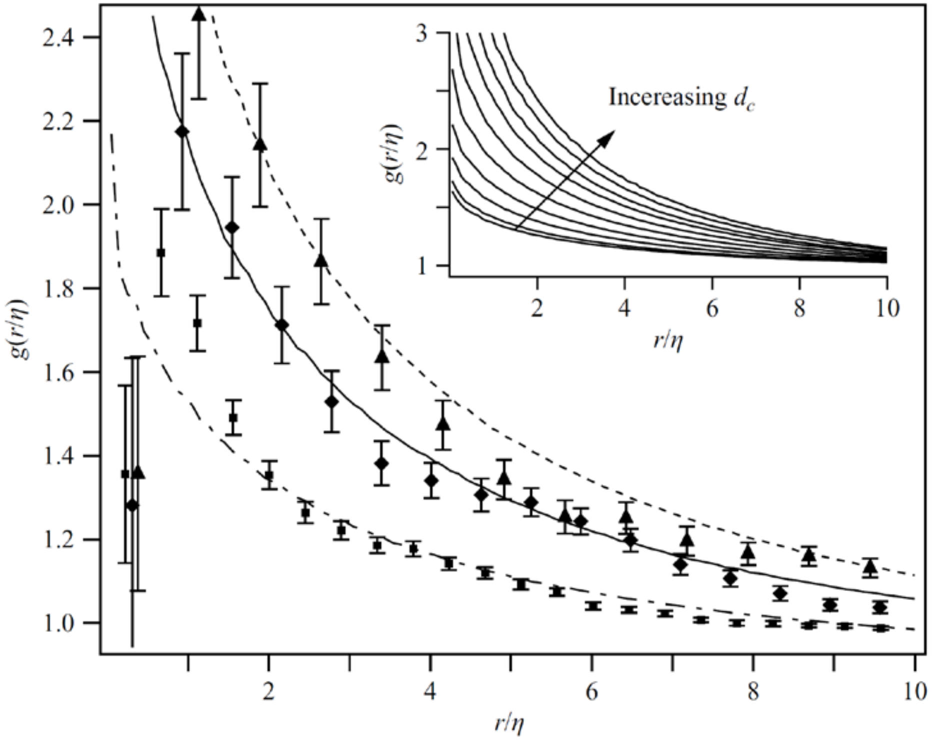
TU/e

Earlier RDF results

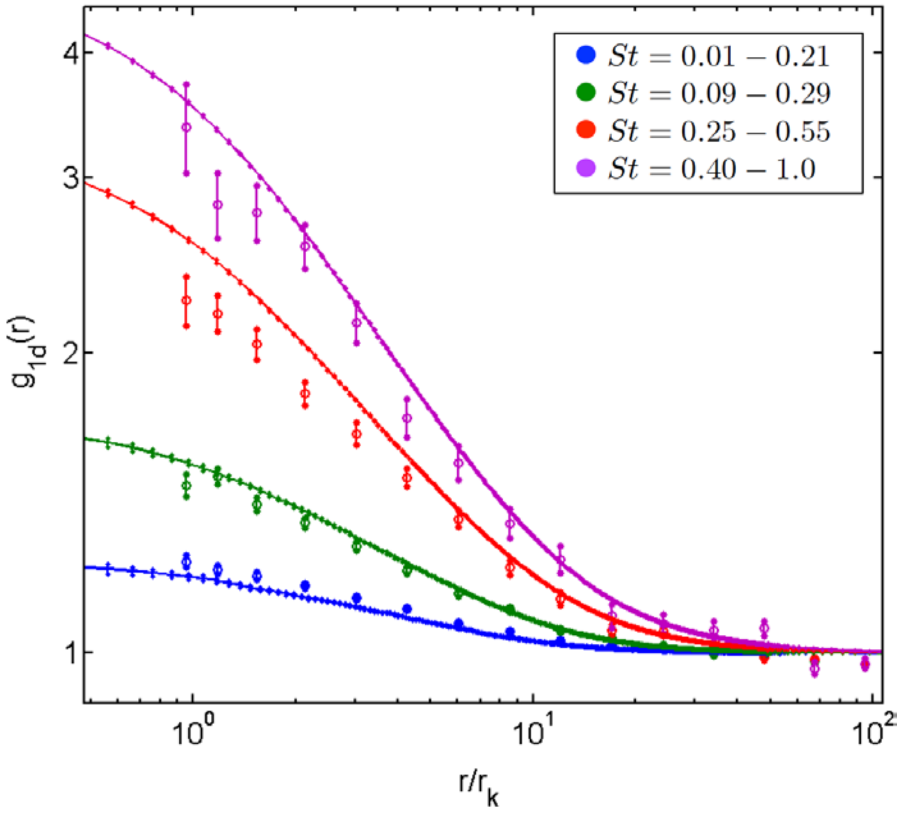
Chun *et al.* (2005) derive:

$$g(r) \propto r^{-c_1\, St^2}$$

Salazar *et al.* (2008): exp & DNS

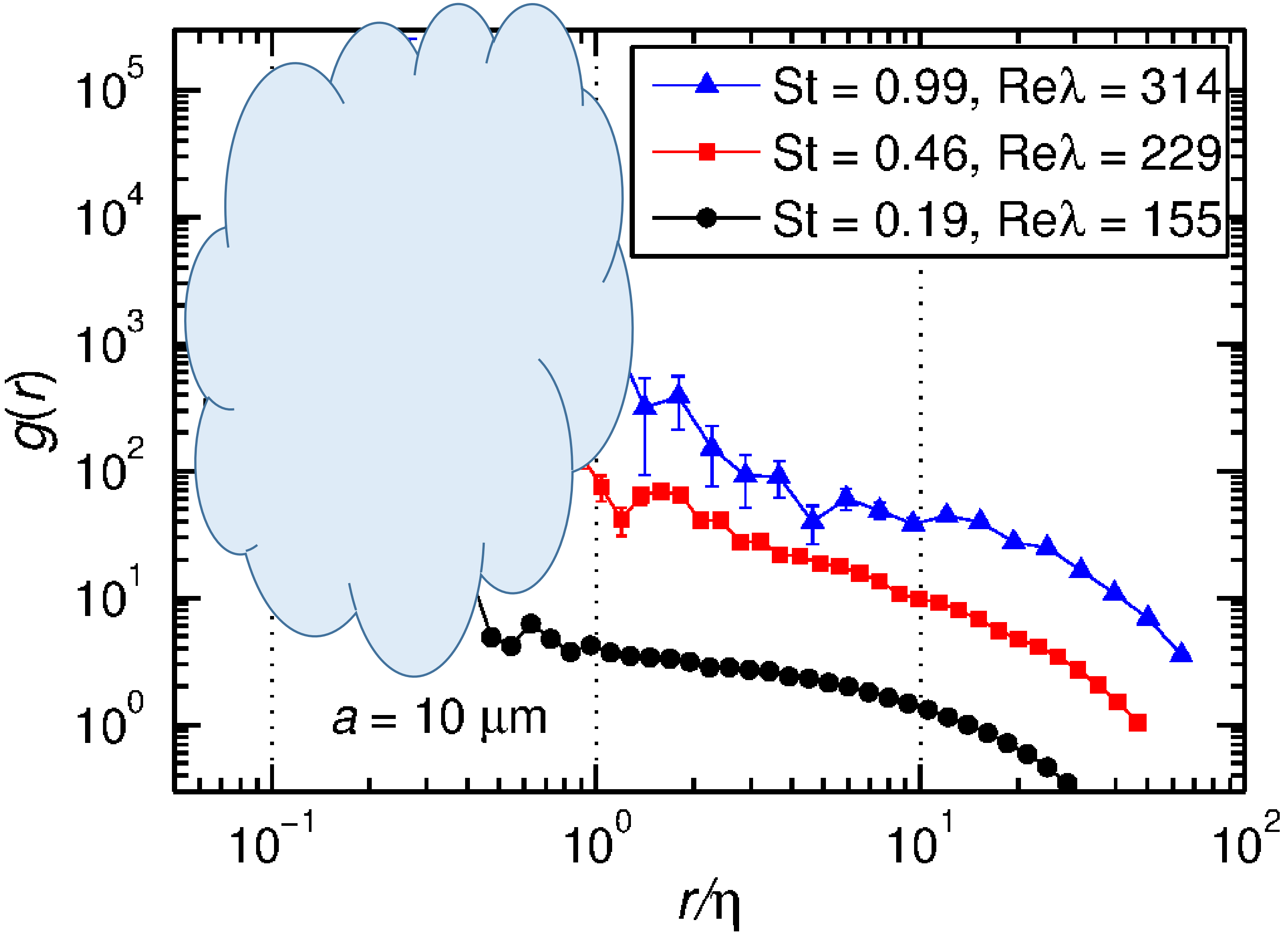


Saw *et al.* (2012): exp & DNS

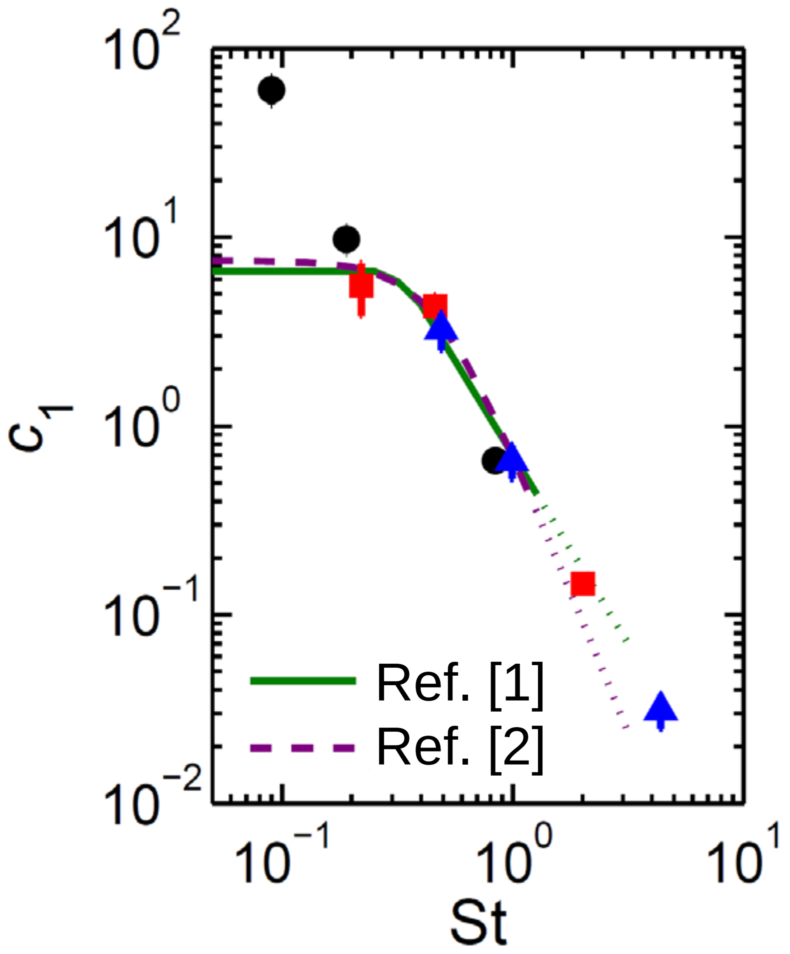


J Chun et al *J Fluid Mech* **536**, 219 (2005)
JPLC Salazar et al *J Fluid Mech* **600**, 245 (2008)
E-W Saw et al *New J Phys* **14**, 105031 (2012)

Current RDF results



$$g(r) \propto r^{-c_1\, St^2}$$

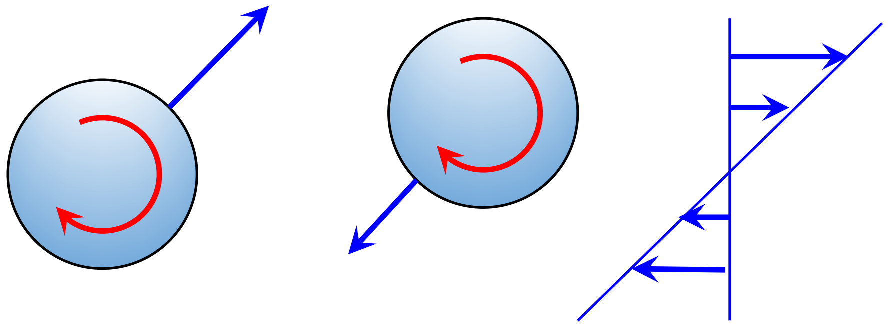


[1] E-W Saw et al *New J Phys* **14**, 105030 (2012)
[2] G Falkovich & A Pumir *J Atmos Sci* **64**, 4497 (2007)

Hydrodynamic interaction

Stokes flow of two spheres in linear background flow: attraction!

(Batchelor & Green 1972)



Brunk *et al.* (1997):

Tracers in turbulence: attraction!

GK Batchelor & JT Green *J Fluid Mech* **56**, 375 (1972)

BK Brunk et al *Phys Fluids* **9**, 2670 (1997)

J Chun et al *J Fluid Mech* **536**, 219 (2005)

HERE: combine perturbative *St* expansion of Chun *et al.* (2005)

$$\mathbf{x} = \mathbf{x}^{[0]} + St\,\mathbf{x}^{[1]} + St^2\,\mathbf{x}^{[2]} + \cdots$$
$$\mathbf{v} = \mathbf{v}^{[0]} + St\,\mathbf{v}^{[1]} + St^2\,\mathbf{v}^{[2]} + \cdots$$
$$\boldsymbol{\omega} = \boldsymbol{\omega}^{[0]} + St\,\boldsymbol{\omega}^{[1]} + St^2\,\boldsymbol{\omega}^{[2]} + \cdots$$

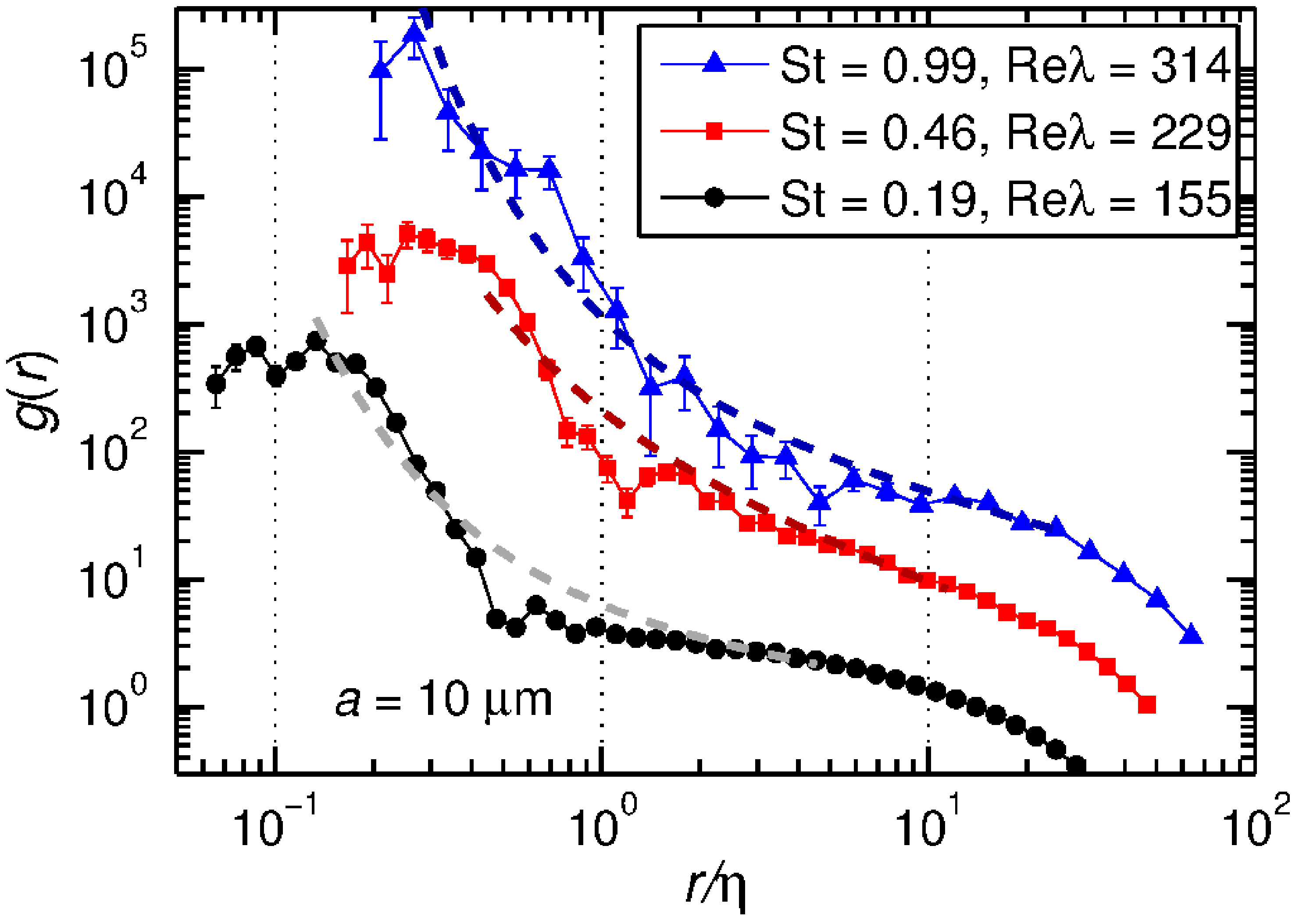
with interaction and turbulence treatment as in Brunk *et al.* (1997)

Result:

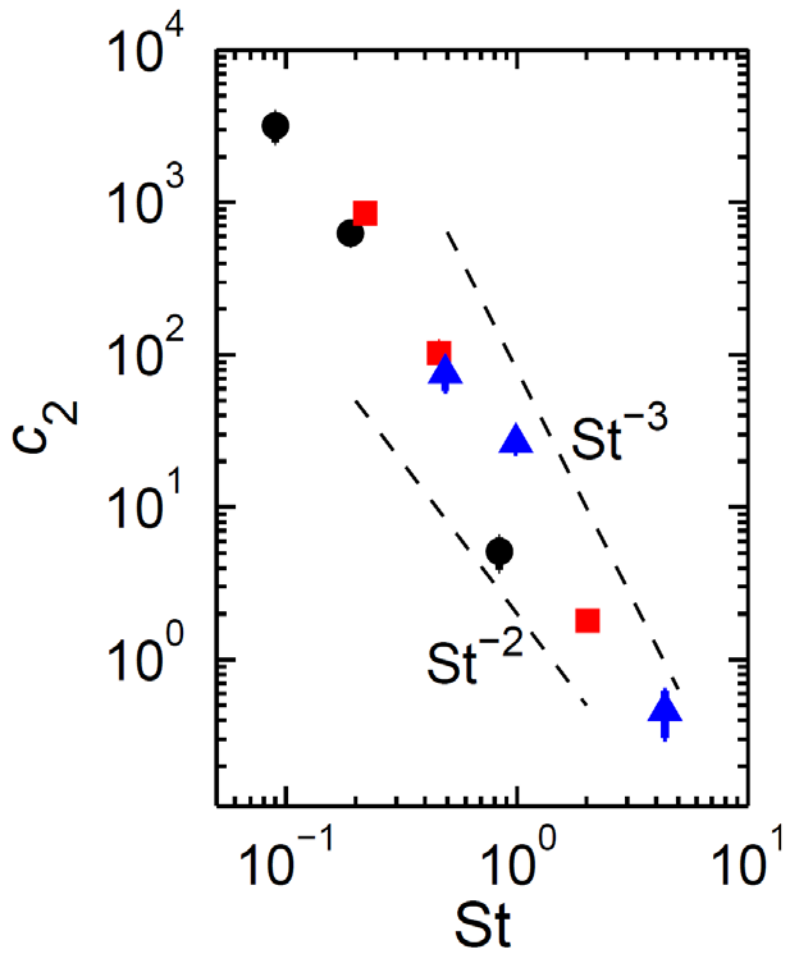
$$g(r) \propto \exp\left(St^2 \frac{c_2}{r}\right) r^{-c_1 St^2}$$

TU/e

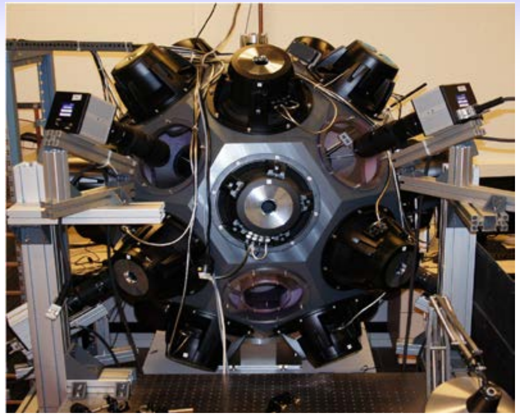
RDF with hydrodynamic interaction



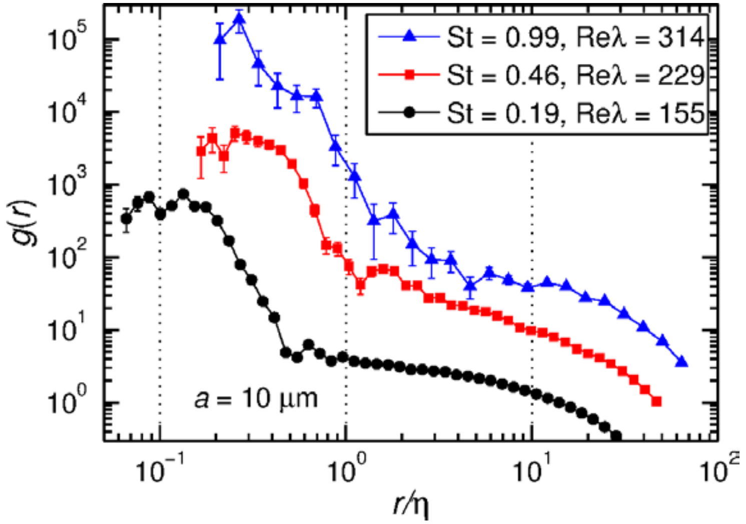
$$g(r) \propto \exp\left(St^2 \frac{c_2}{r}\right) r^{-c_1 St^2}$$



Conclusion

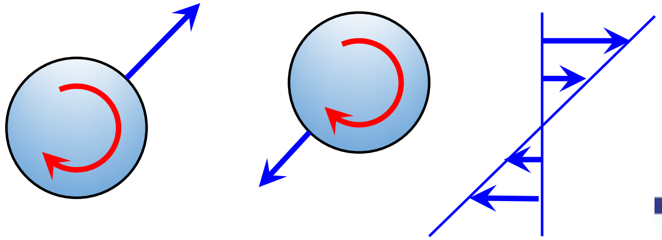


- We have tracked the 3D positions of droplets in turbulence



- High-precision ($r << \eta$) measurements of the RDF reveal extreme droplet clustering at small scales

- Hydrodynamic interactions are the cause of extreme clustering



Droplet and turbulence parameters

Re_λ	ϵ	η	τ_η	Stokes number St per droplet radius		
	(m^2/s^3)	(mm)	(ms)	$a = 7.1 \pm 0.3\ \mu m$	$a = 10.0 \pm 0.6\ \mu m$	$a = 20.7 \pm 0.7\ \mu m$
155	0.30	0.33	7.1	0.09 ± 0.01	0.19 ± 0.02	0.84 ± 0.04
229	2.1	0.20	2.7	0.22 ± 0.01	0.46 ± 0.04	2.02 ± 0.10
314	9.7	0.14	1.2	0.49 ± 0.03	0.99 ± 0.08	4.38 ± 0.21

All RDF measurements