Evidence of anisotropy of small scale turbulence in the laboratory model of an atmospheric cloud

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Motivation
How is warm rain formed?

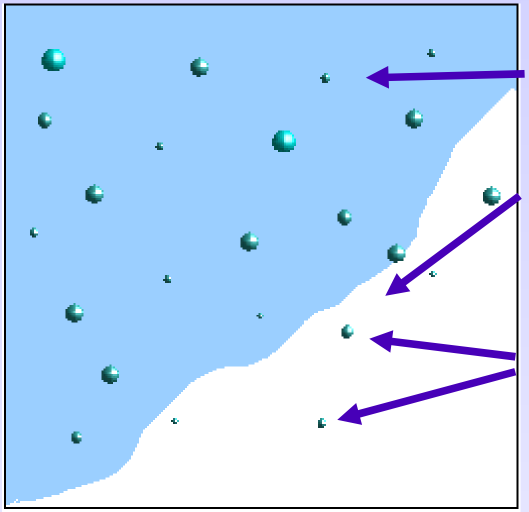
- „Warm rain initiation problem” – formation of rain in clouds without ice crystals – how is it possible?
- Is turbulence responsible for higher aggregation rate?
- Lack of high resolution measurements of cloud droplets turbulence interactions.
- Aims:

– measurement of the velocity fields down to Kolmogorov scale for the laboratory model of a cloud

– validation of DNS model.

Mixing of cloud and clear air

Transport mechanisms of water across the interface:
-molecular diffusion (vapor),
-sedimentation of droplets

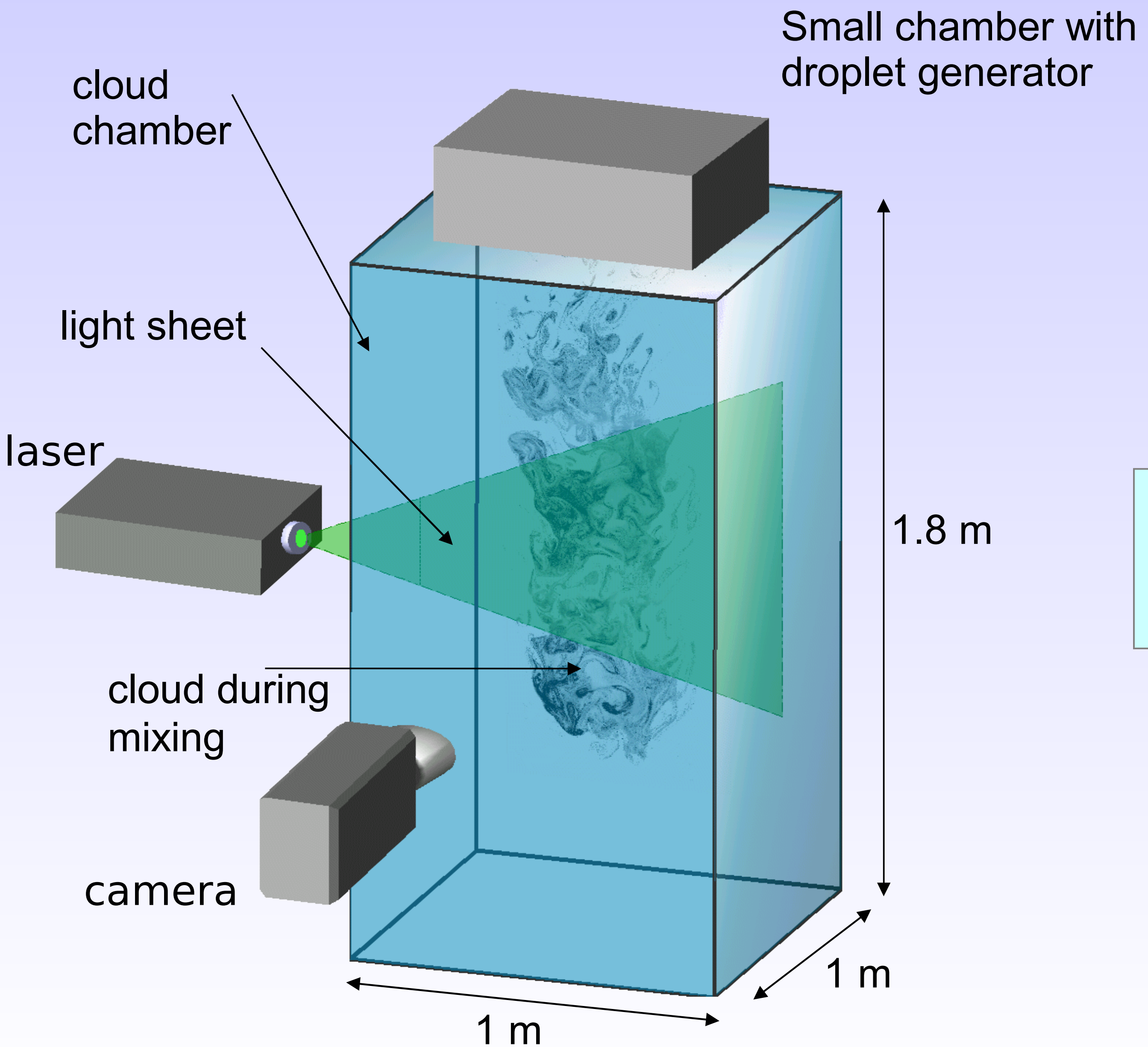


At the interface:
-evaporation of droplets,
-evaporative cooling,
-buoyancy fluctuations

Processes possibly important for:
-droplet collisions,
-evolution of droplet spectra
-warm rain formation

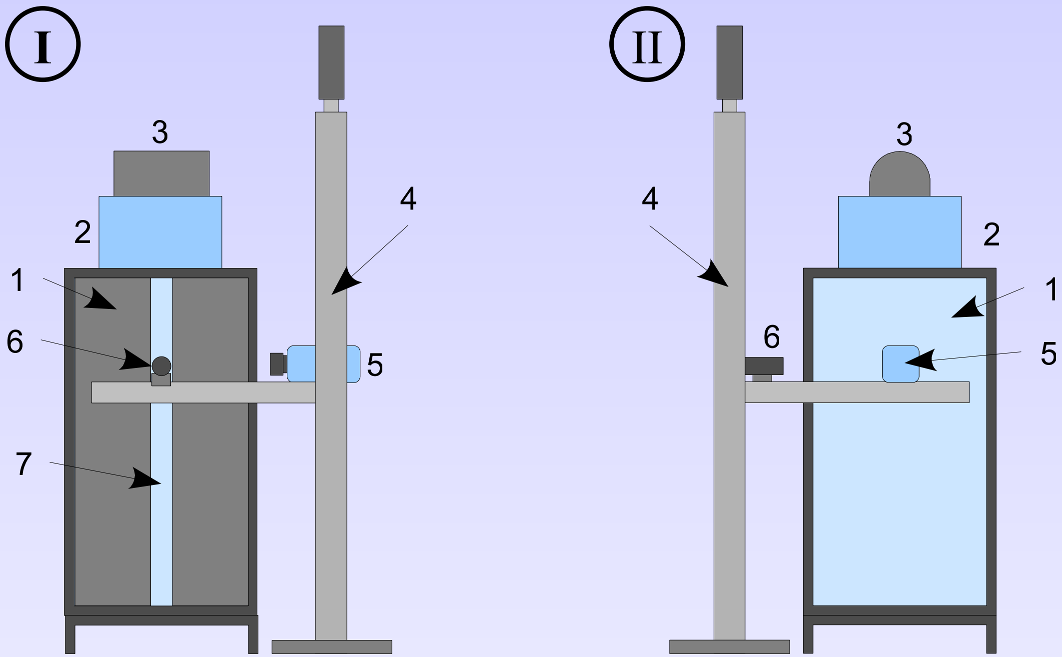
Main questions:
- is the turbulence isotropic?
- can evaporation substantially influence structure of turbulence?

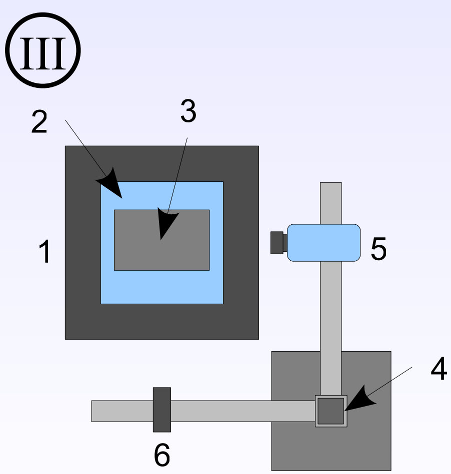
Experimental setup



The same configuration was used in DNS model

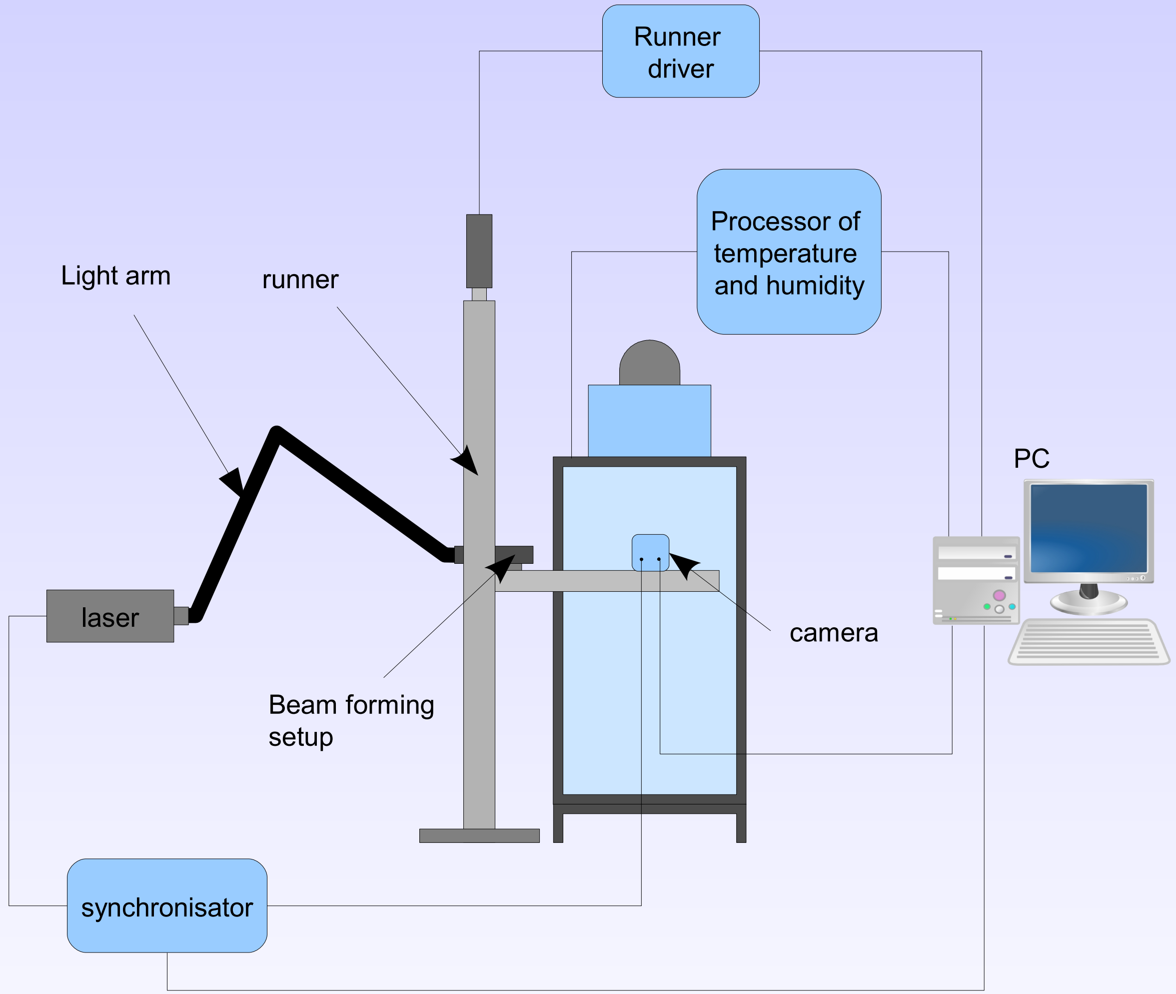
Experimental setup

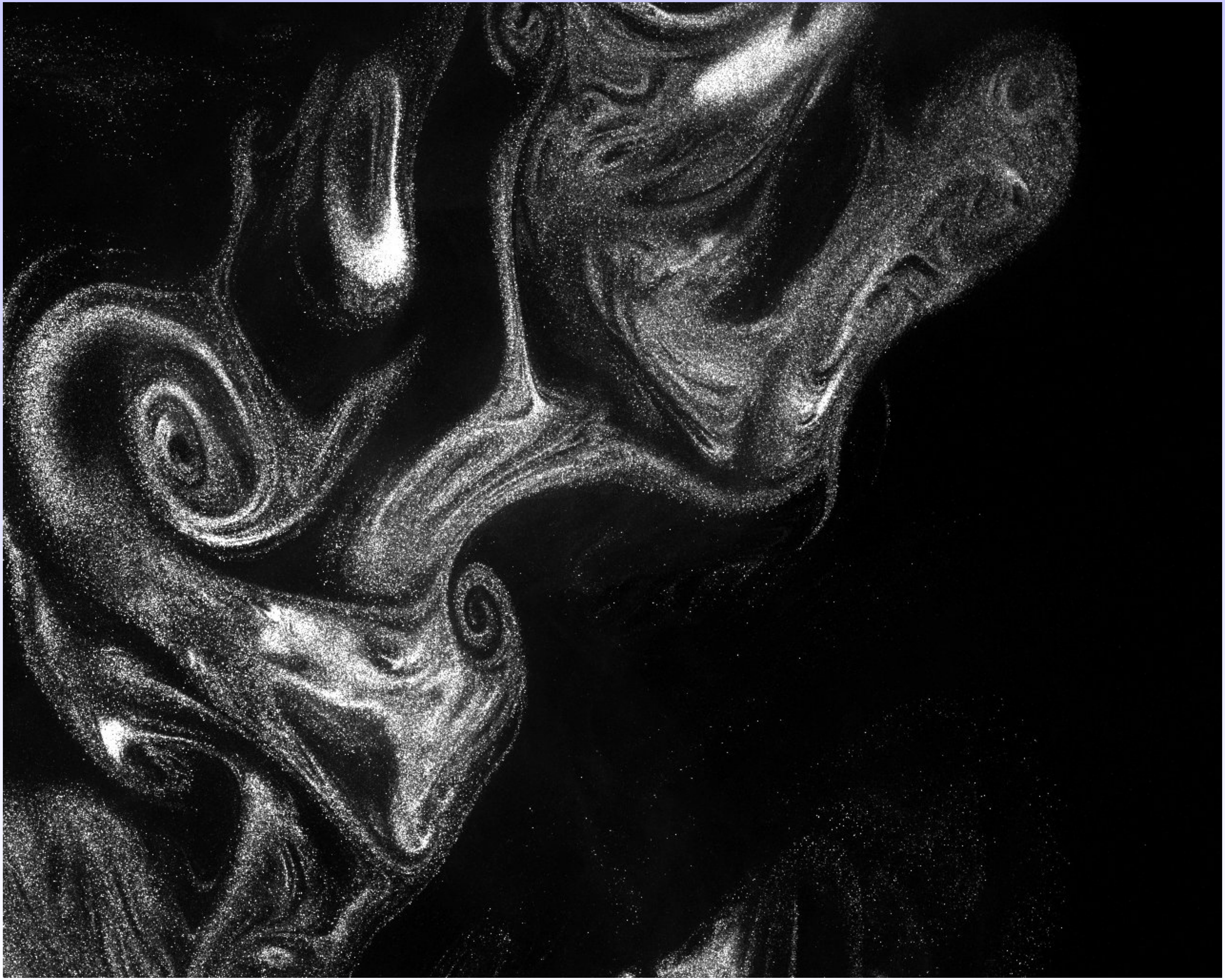


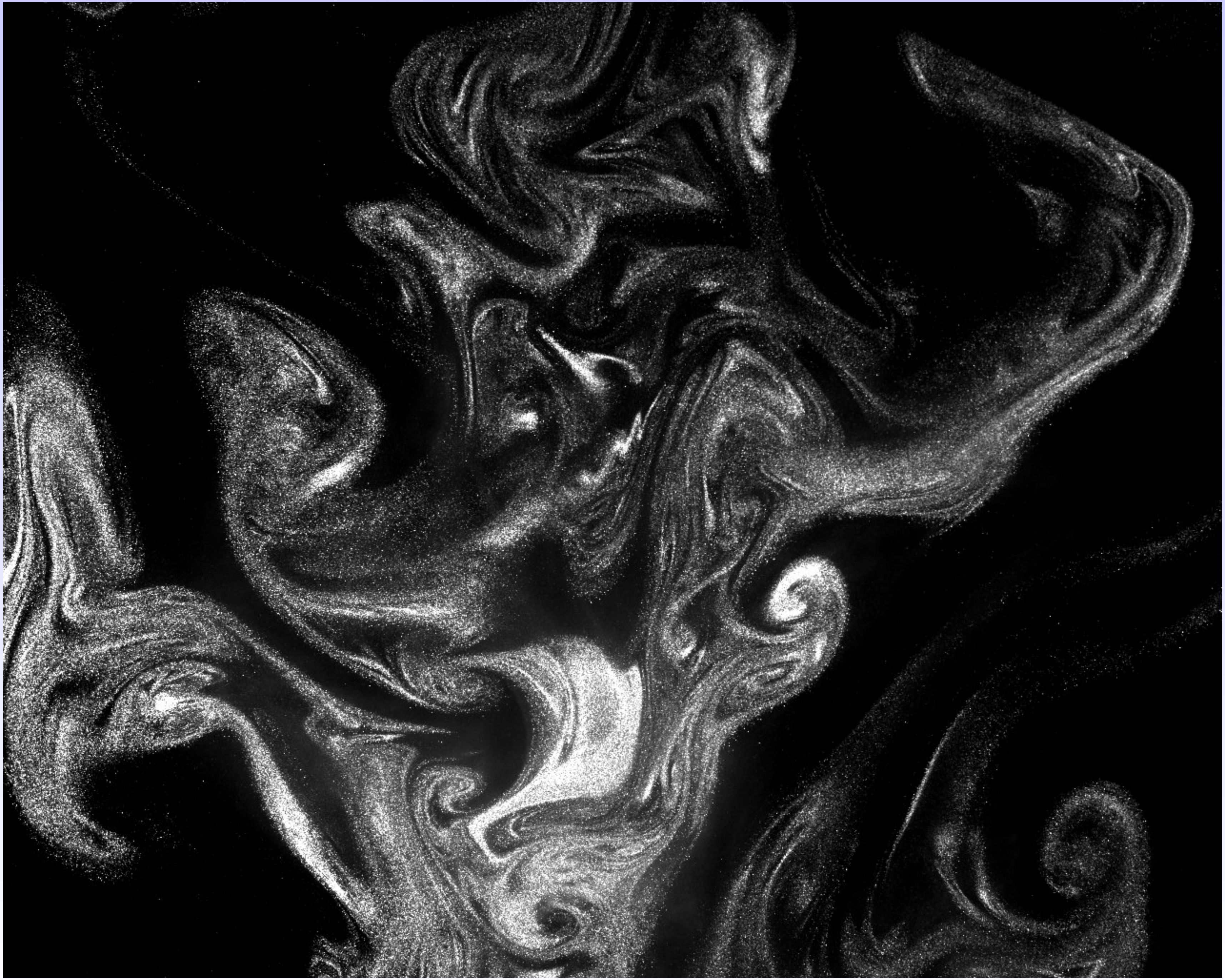


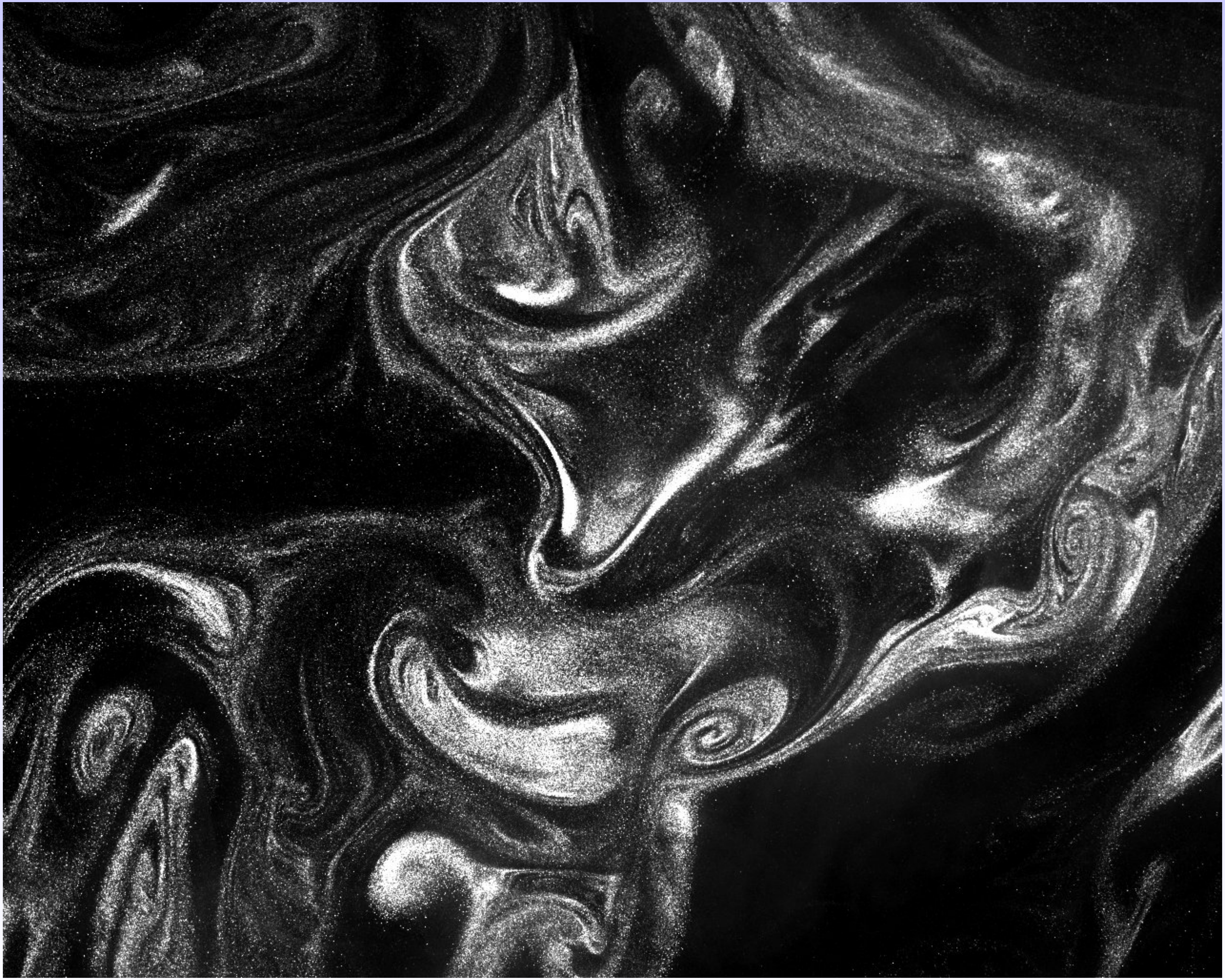
1 – main chamber, 2- small chamber, 3 – droplets generator, 4 – runner, 5 – camera, 6 – light forming setup coupled with laser by means of light arm

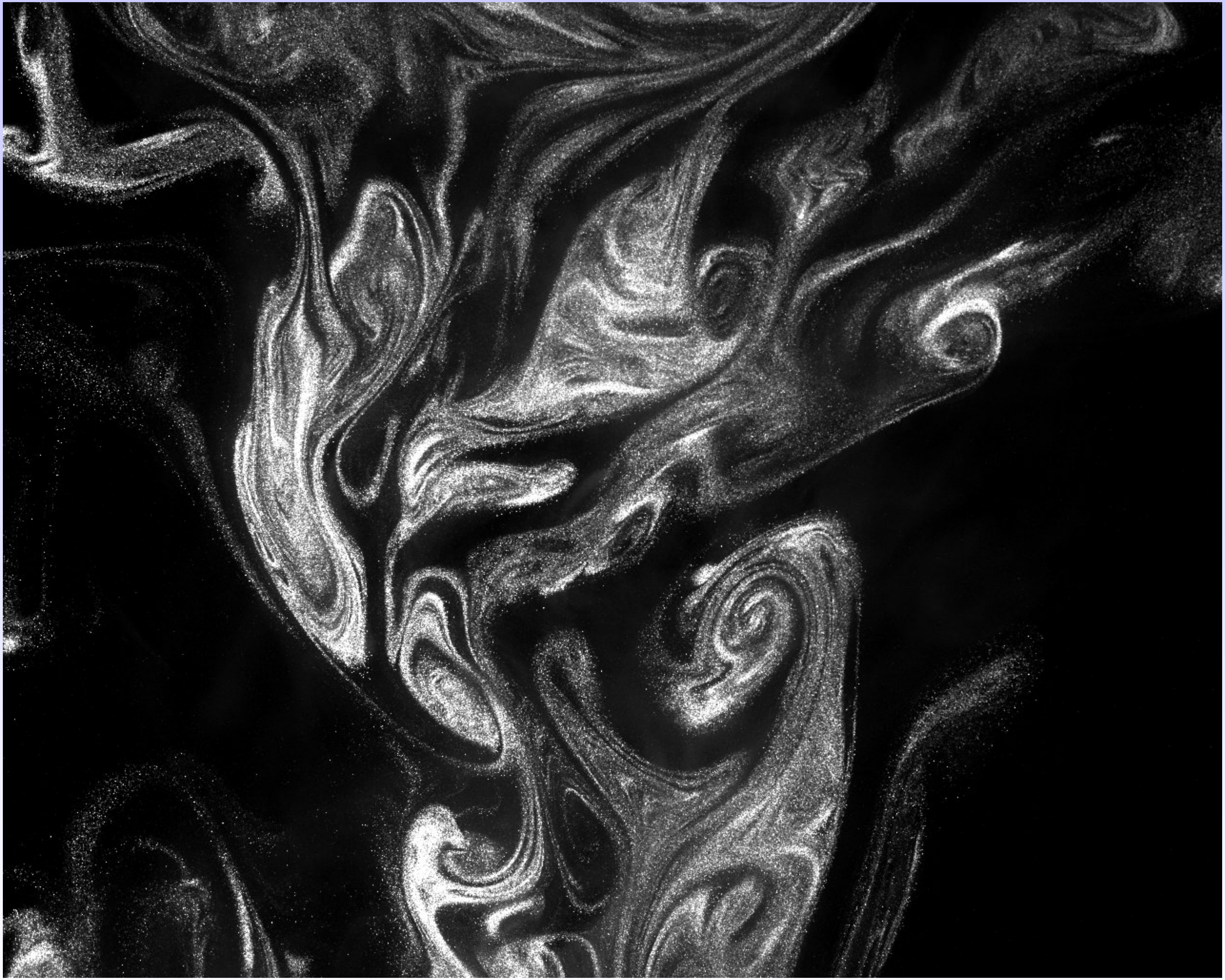
Experimental setup

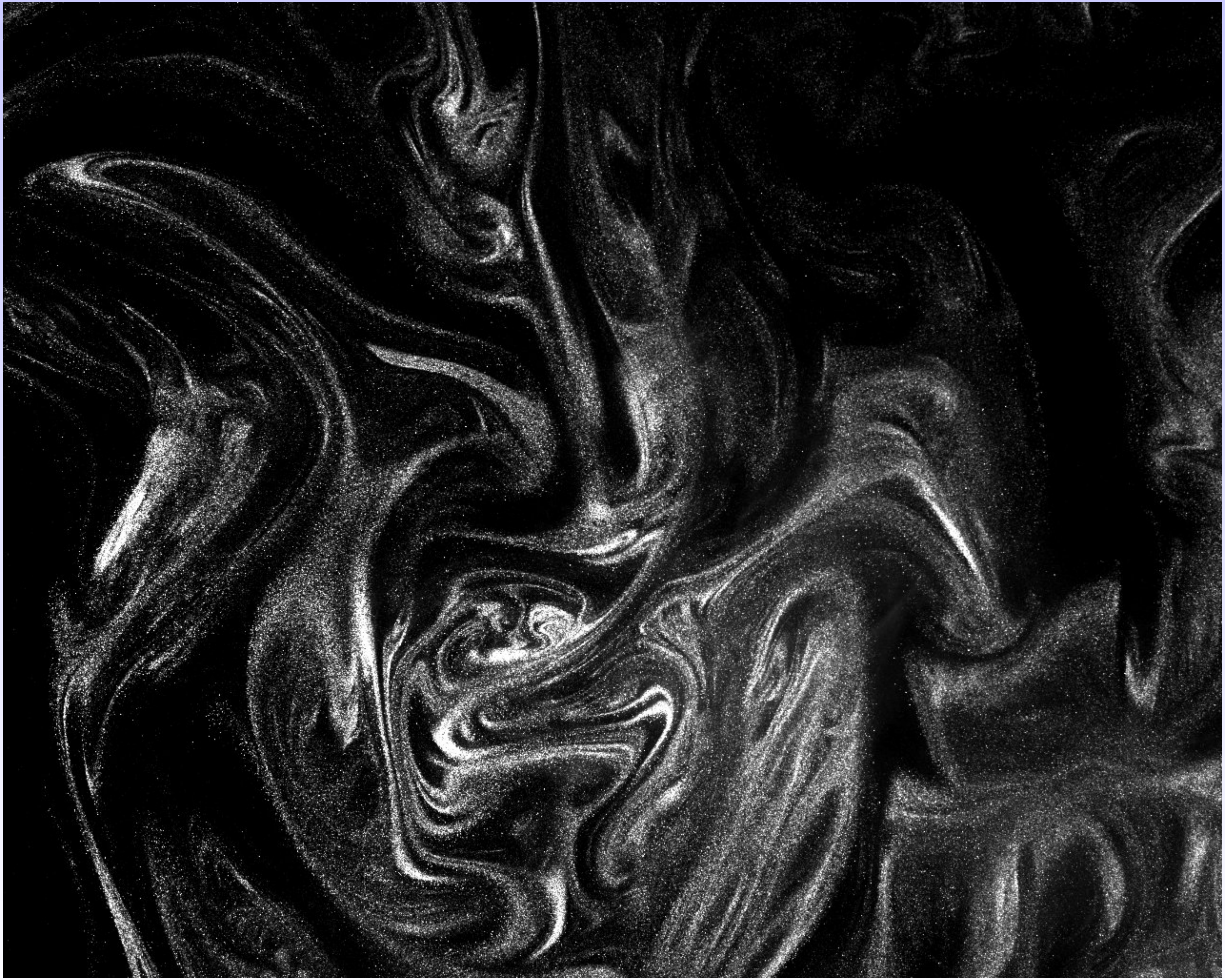


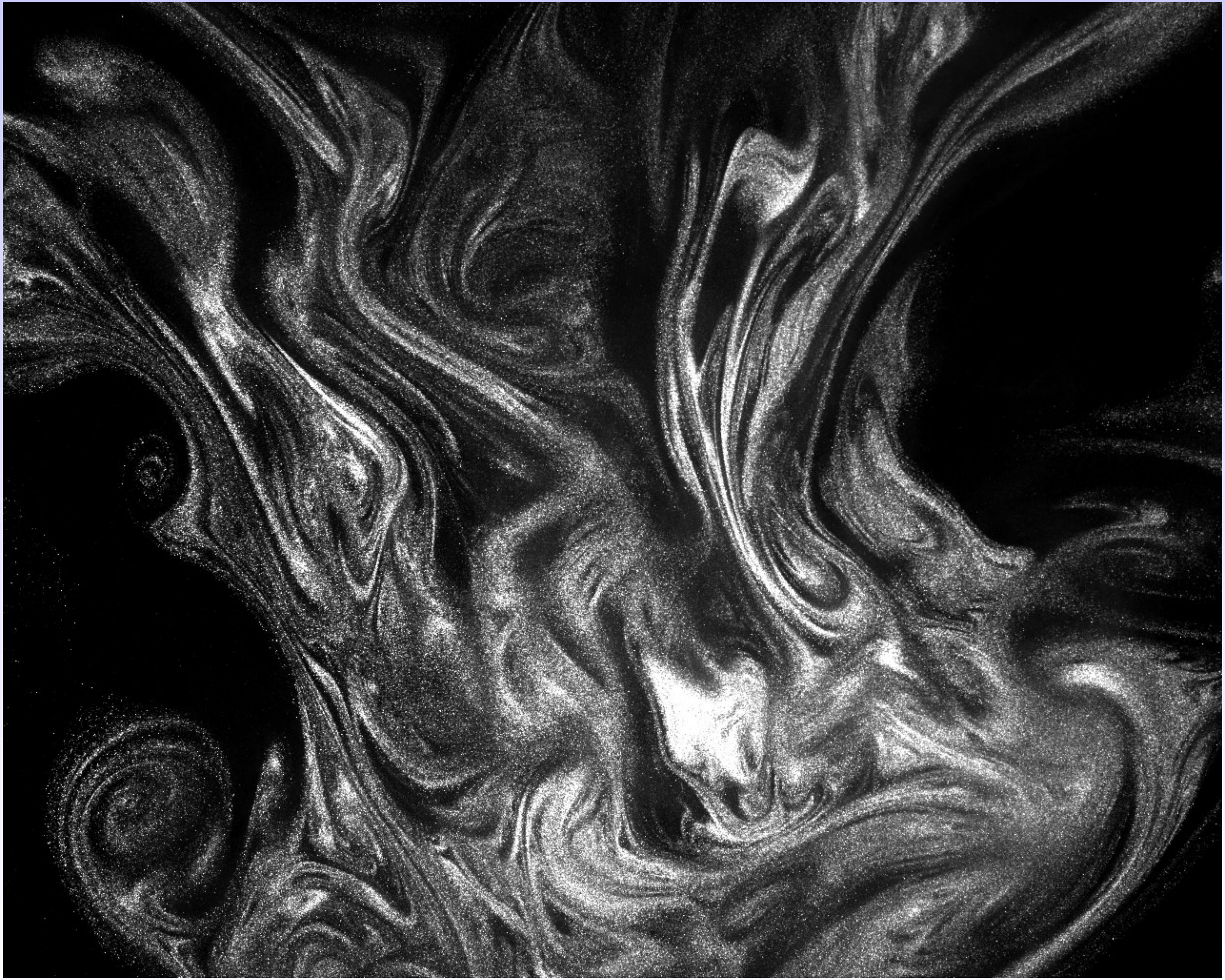


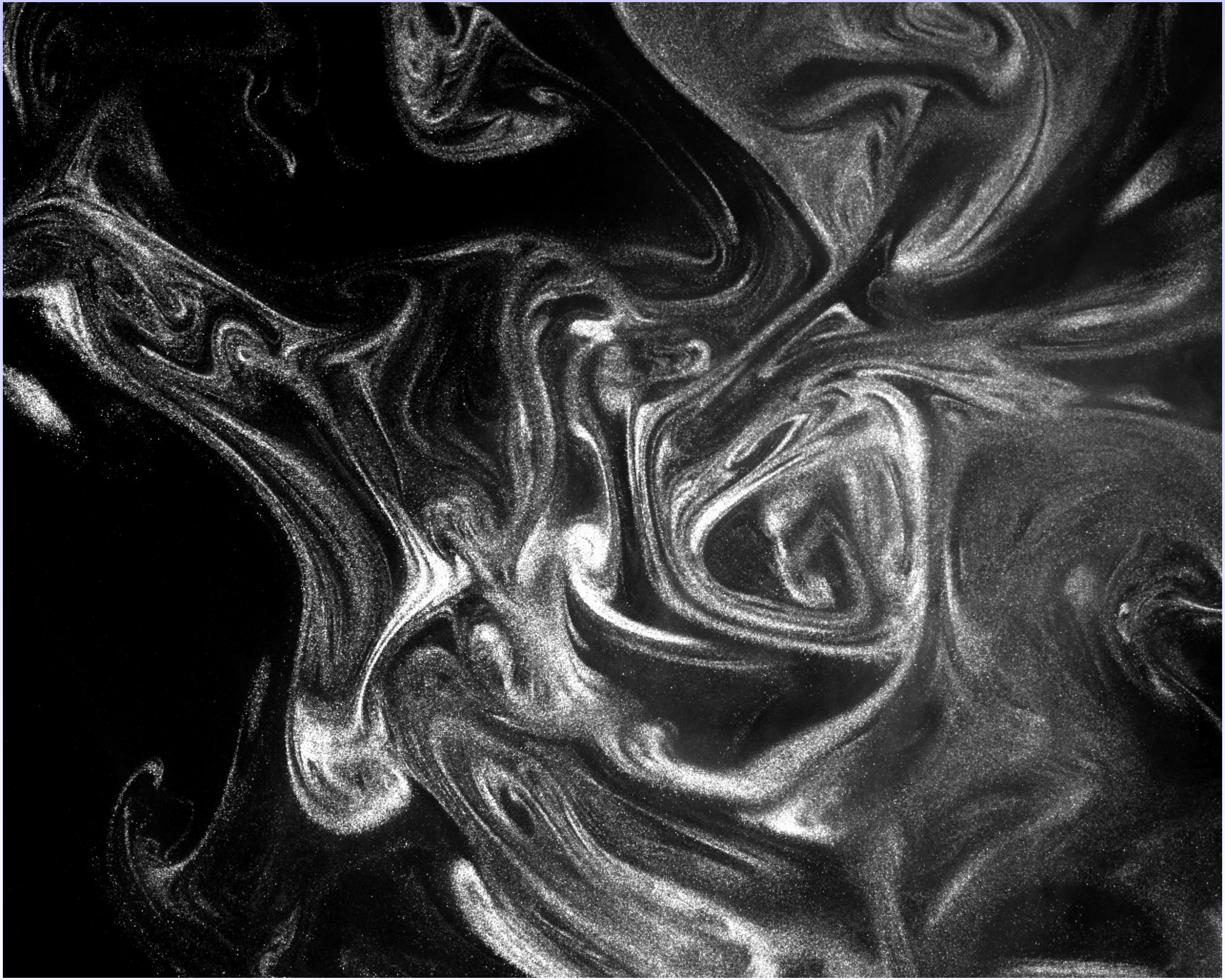












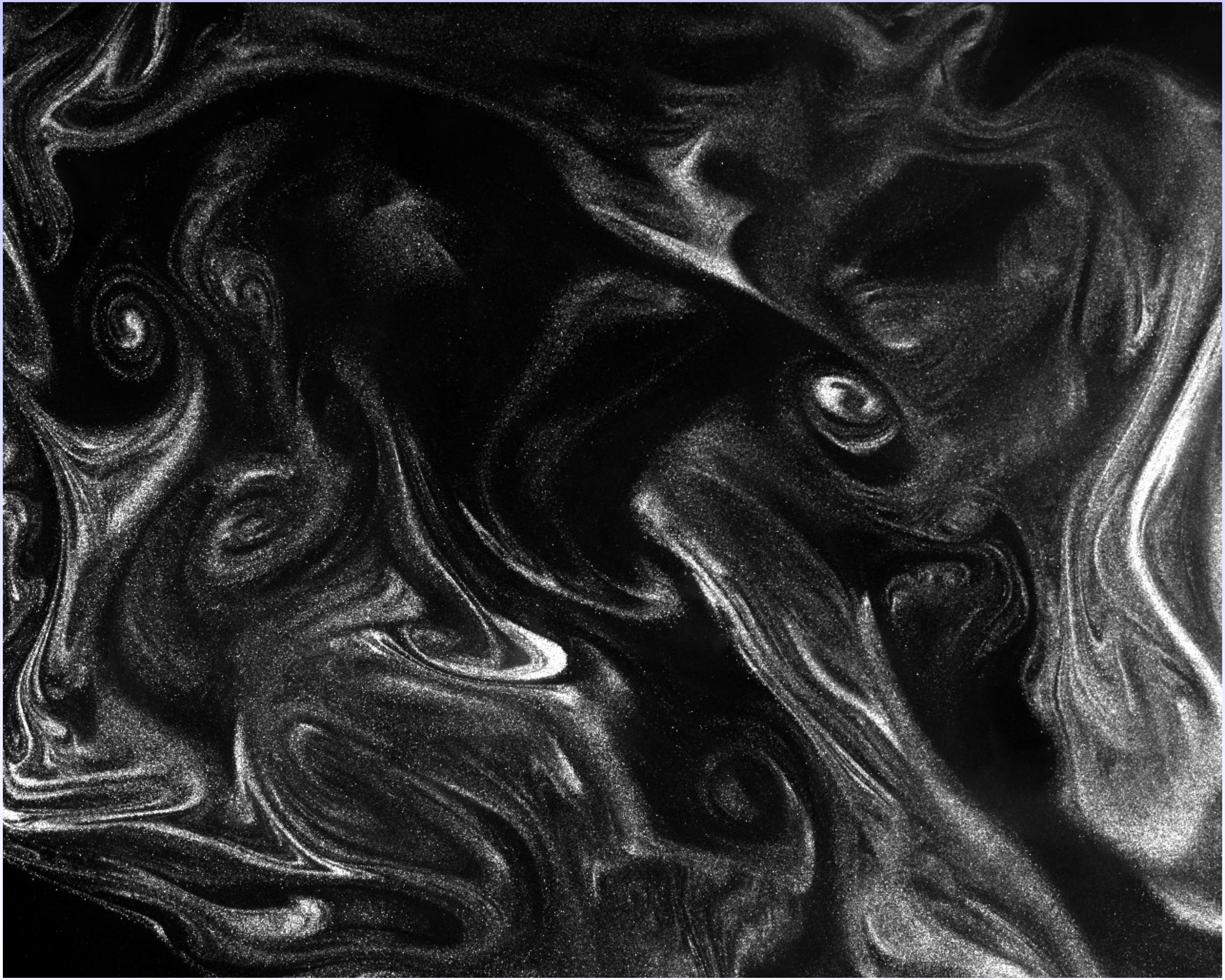
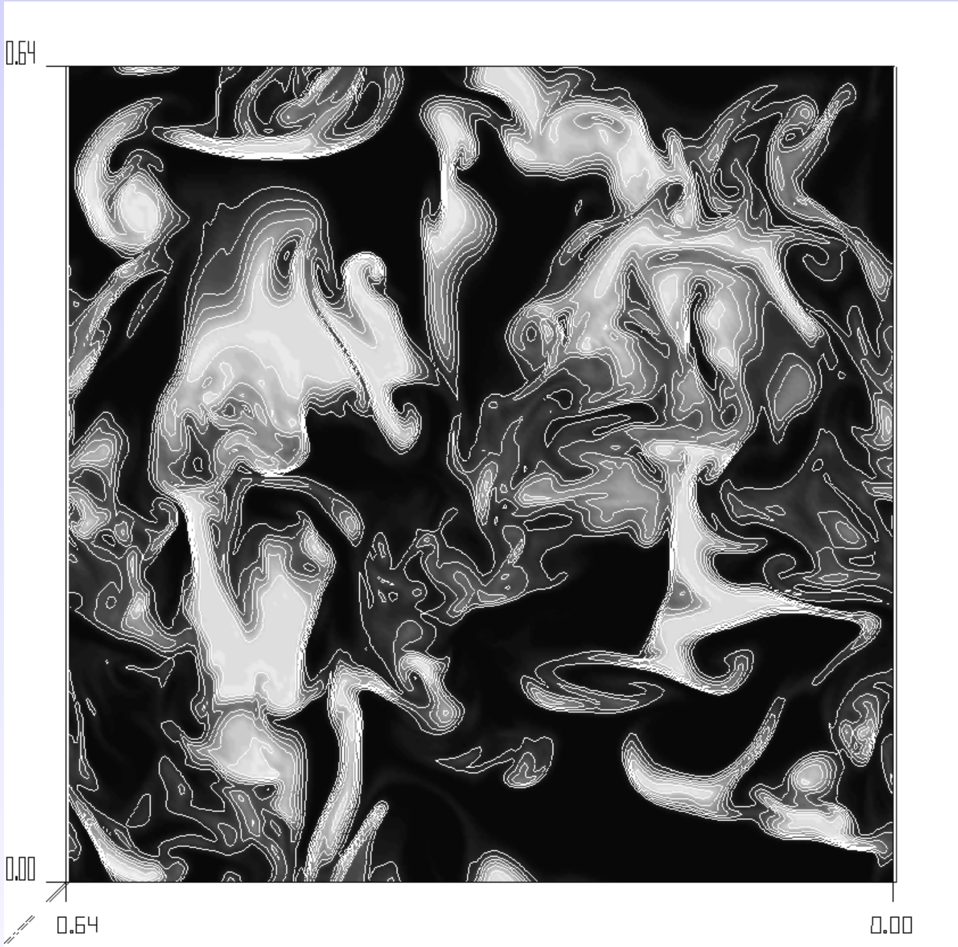


Image from DNS computations



Laboratory and modeling studies of cloud-clear air interfacial mixing: anisotropy of small-scale turbulence due to evaporative cooling, Sz. Malinowski, M. Andrejczuk, W. W. Grabowski, P. Korczyk, T.A. Kowalewski, P. Smolarkiewicz, New Journal of Physics 10, 075020, 2008.

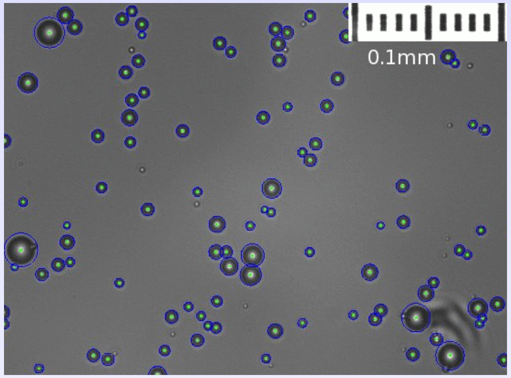
Measurements

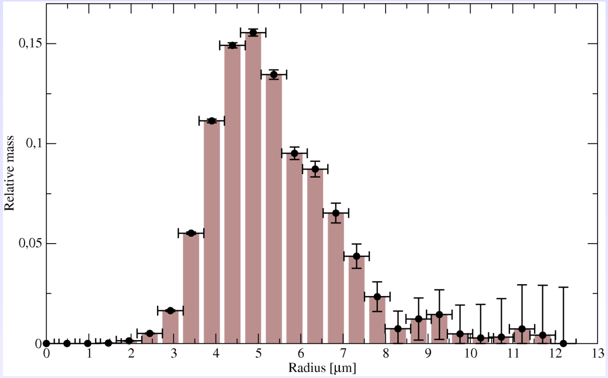
Initial conditions:

• Temperature and humidity – a set of sensors connected with computer

•Liquid water content ~20g/kg (the ratio of mass of liquid water containing certain portion of air to the mas of this portion)

•Droplets spectra – processing of microscopic images of droplets





Main measurements:

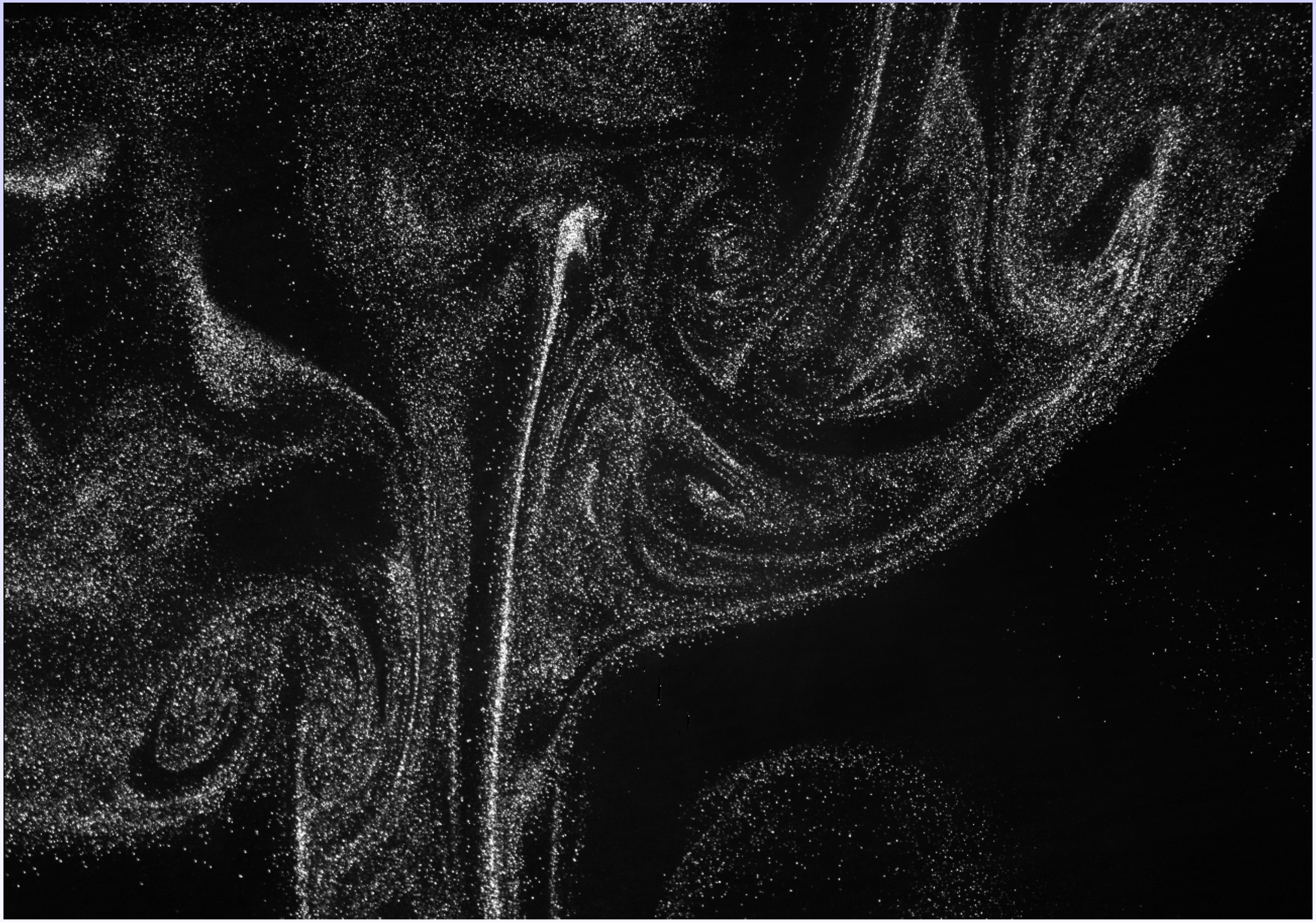
• Velocity fields

•Mean dissipation rate

•Kolmogorov scale

•Structure function

Pair of experimental images



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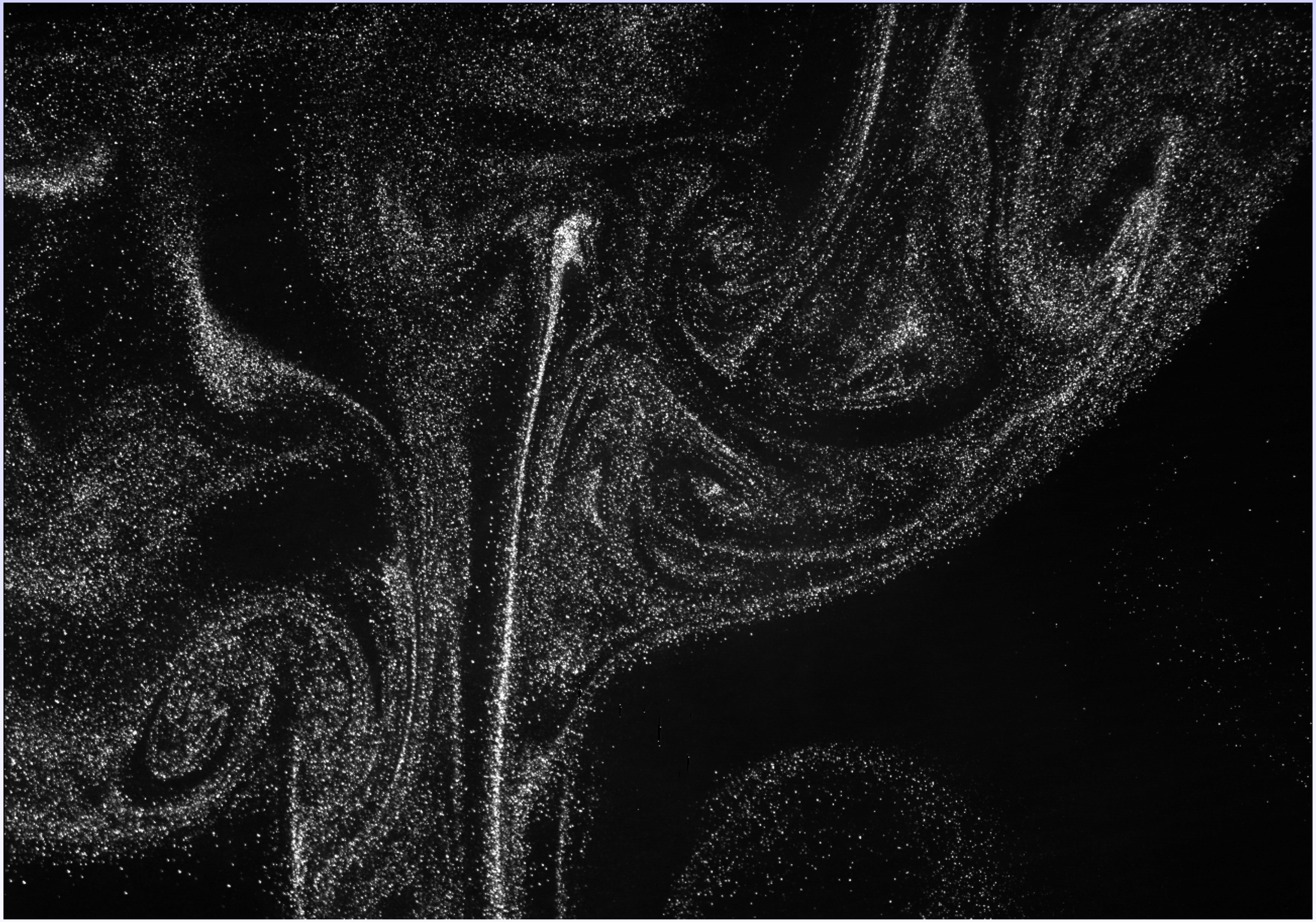
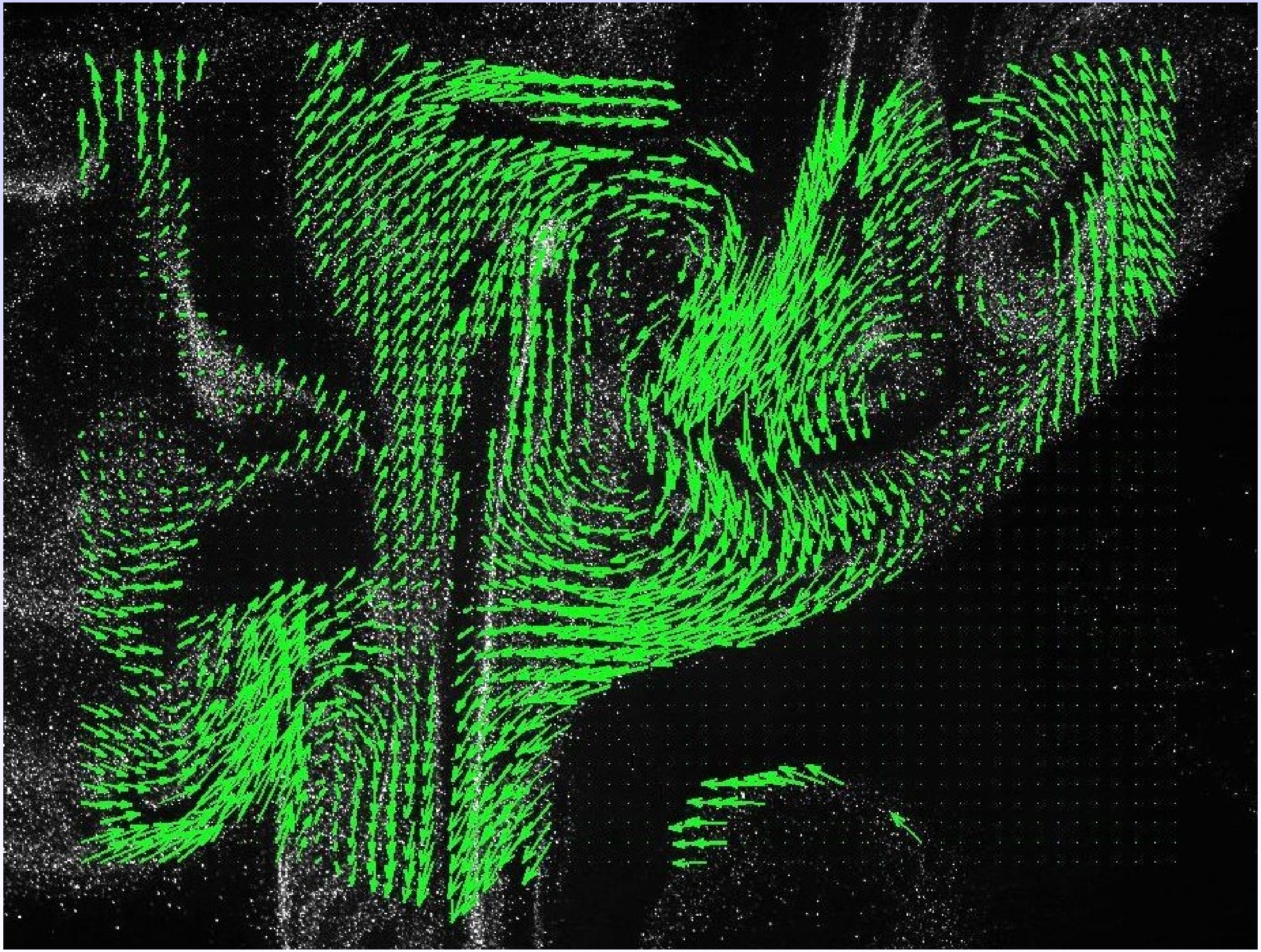


Velocity field



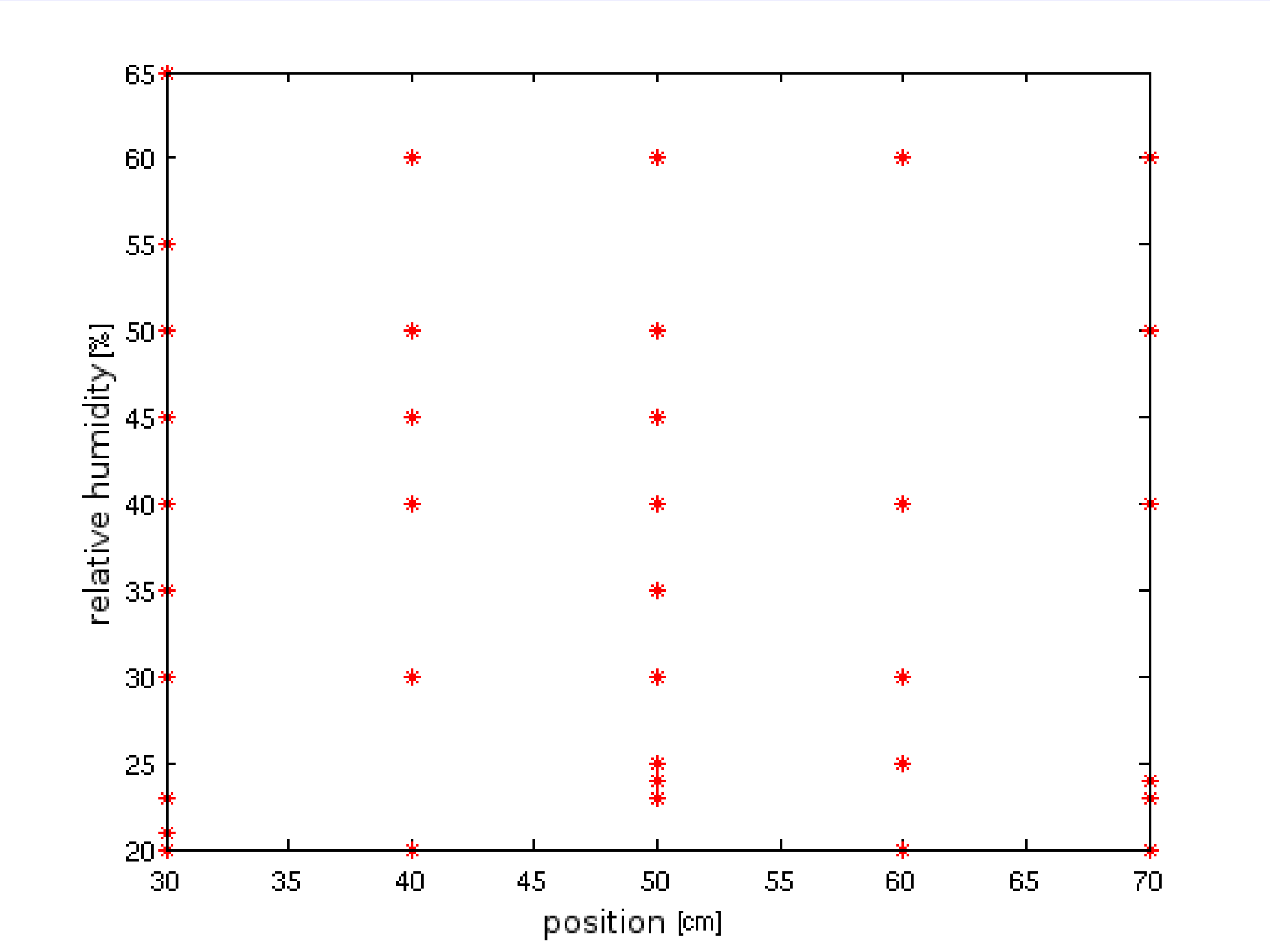
Experiments with evaporative and non evaporative droplets

	water	DEHS
Chemical formula	H_20	$C_{26}H_{50}O_4$
Density	1000 kg/m^2	912 g/m^2
Vapour Pressure (25 ºC)	2,3 kPa	<<1Pa
Mass content in experiments	24 g/m^3	8 g/m^3
viscosity	895 10^{-6} Pa s	0,23 10^{-3} Pa s
Surface tension (25 ºC)	7,2 10^{-2}N/m	3,2 10^{-2}N/m

Measurements in positions 30cm, 50cm and 70cm

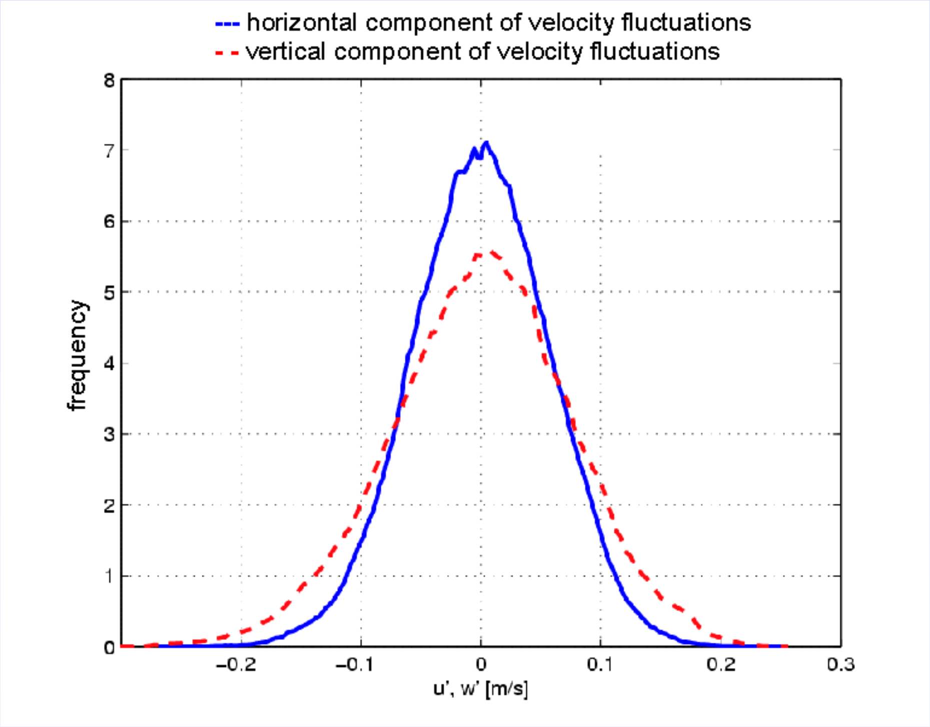
Map of experimental cases with evaporation

50 experiments with 100 velocity fields for each experiment

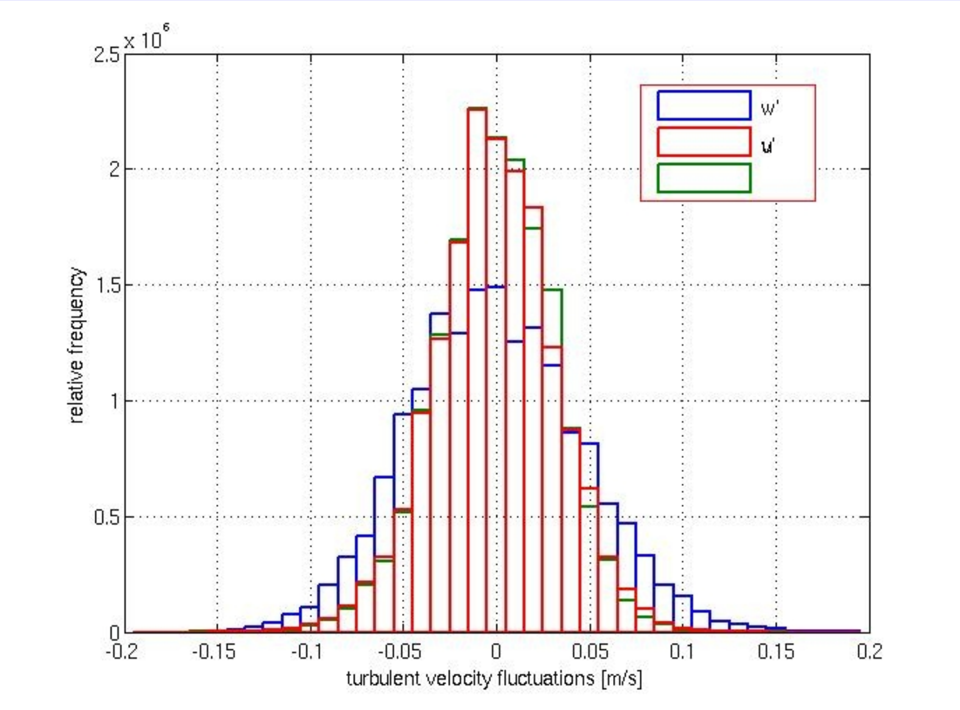


Statistics of velocity fluctuations - anisotropy

Experiment for water



DNS



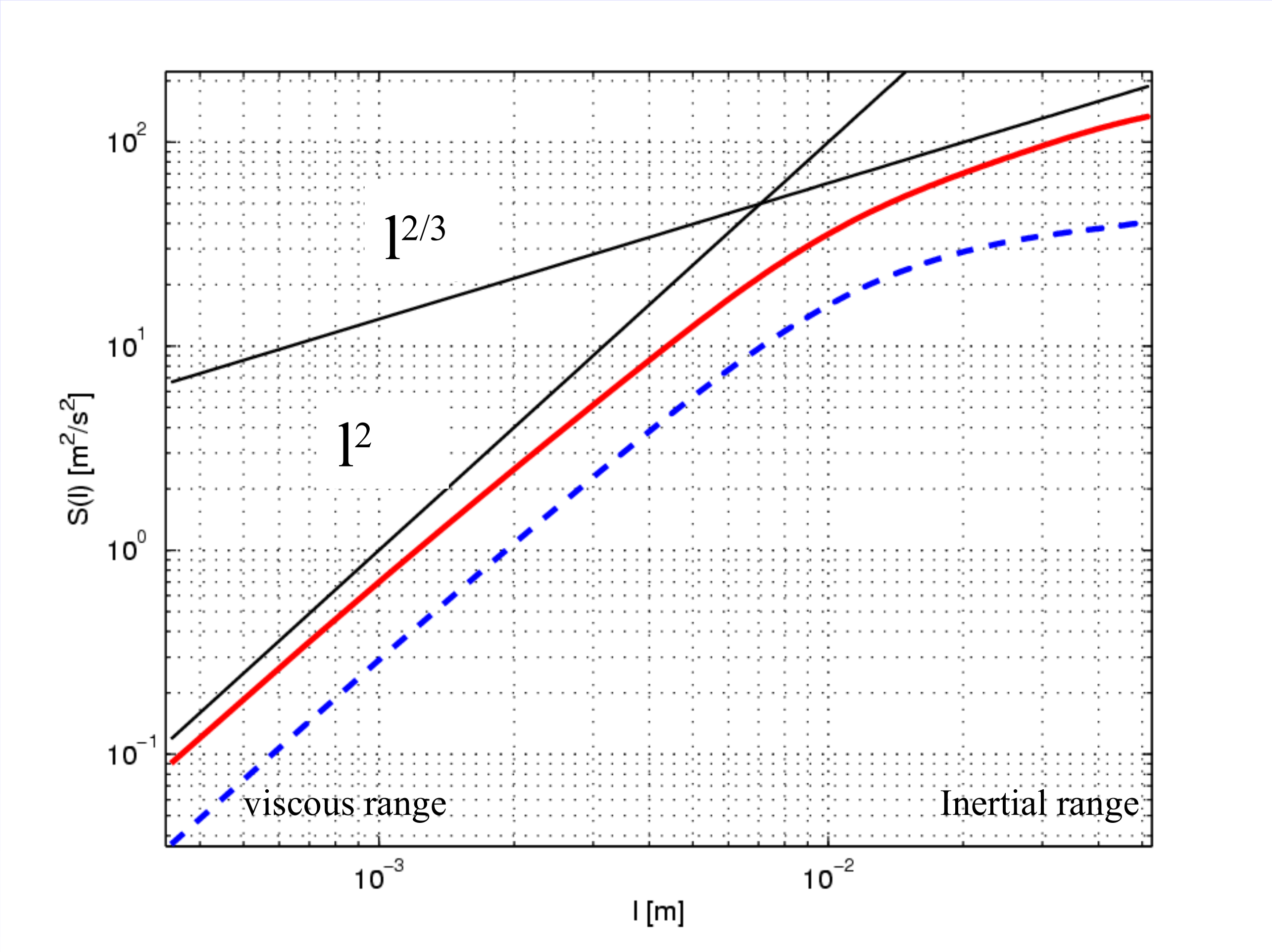
	Standard deviation [cm/s]	*Skewness*	*Kurtosis*
horizontal	4.6	-0.01	3.2
vertical	5.8	-0.2	3.1

	Standard deviation [cm/s]	*Skewness*	*Kurtosis*
horizontal	3.19	-0.07	3.3
vertical	4.56	0.15	3.0

Second order longitudinal structure function

$$S_u^{\parallel}(l) = \langle [u(x+l, z) - u(x, z)]^2 \rangle$$

$$S_w^{\parallel}(l) = \langle [w(x, z+l) - w(x, z)]^2 \rangle$$



Is anisotropy caused by evaporation?

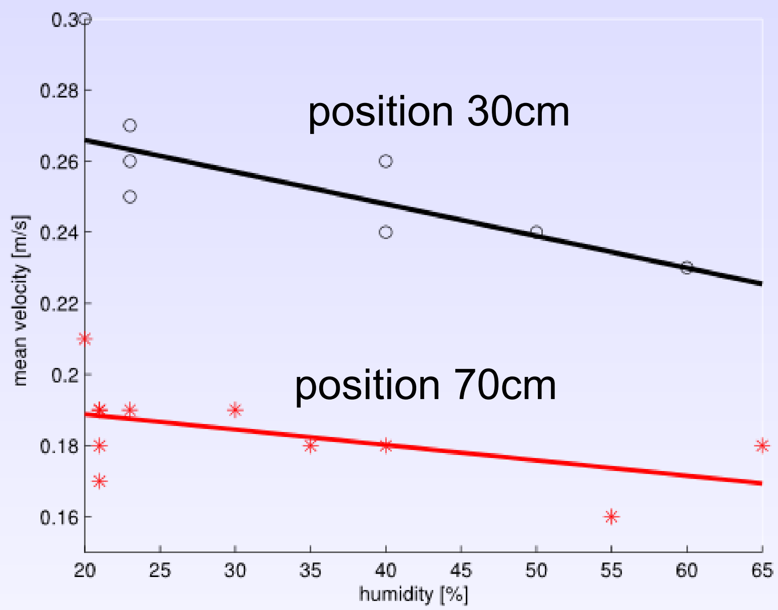
- Mean ratio of vertical and horizontal standard deviation in experiments with water droplets does not depend on humidity and is about 1.14±0.05

- Mean ratio of vertical and horizontal standard deviation in experiments with DEHS is about 1.16±0.05

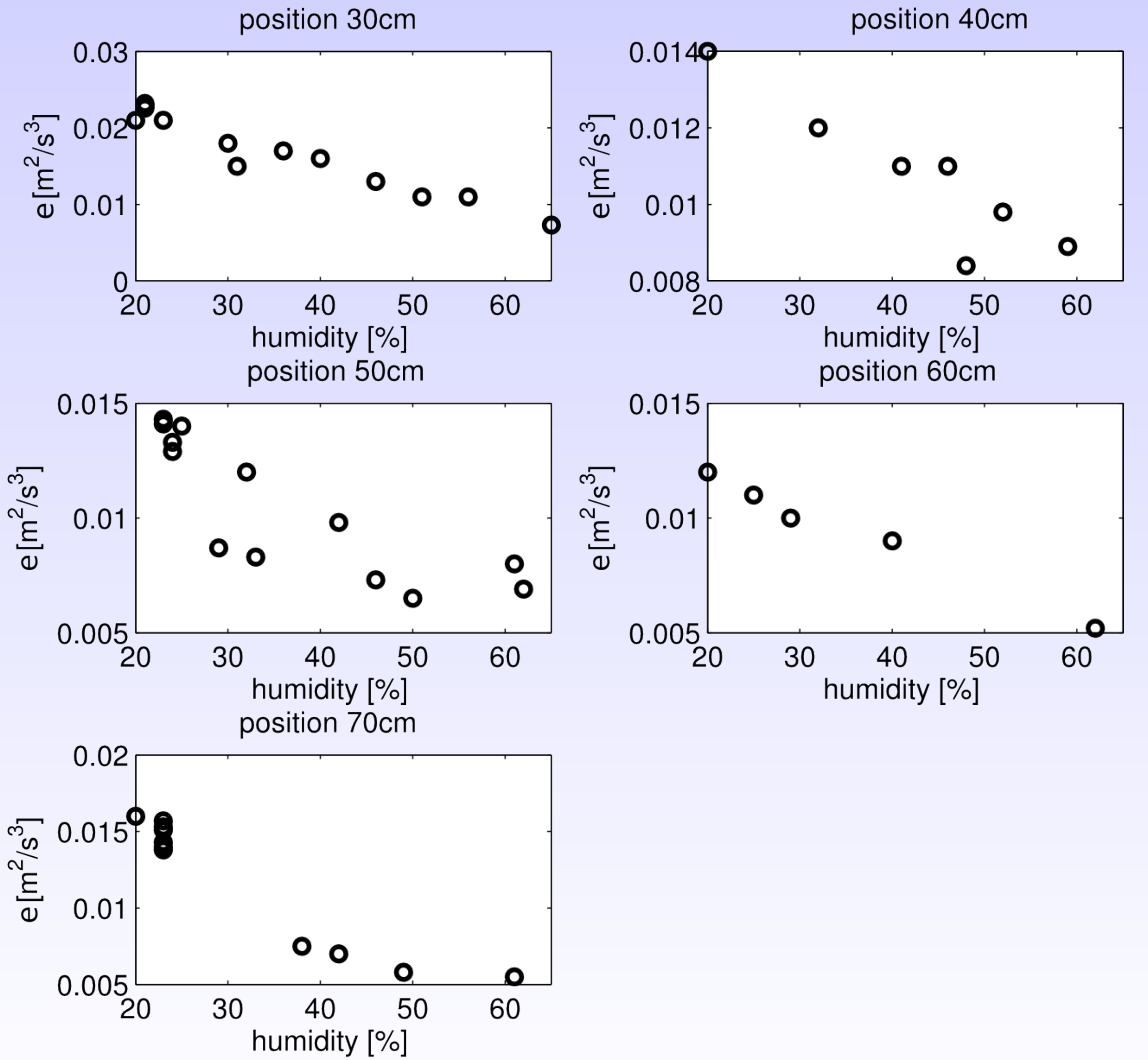
Anisotropy is caused by gravity and geometry of experimental setup

Can evaporation influence motion of fluid?

Mean velocity

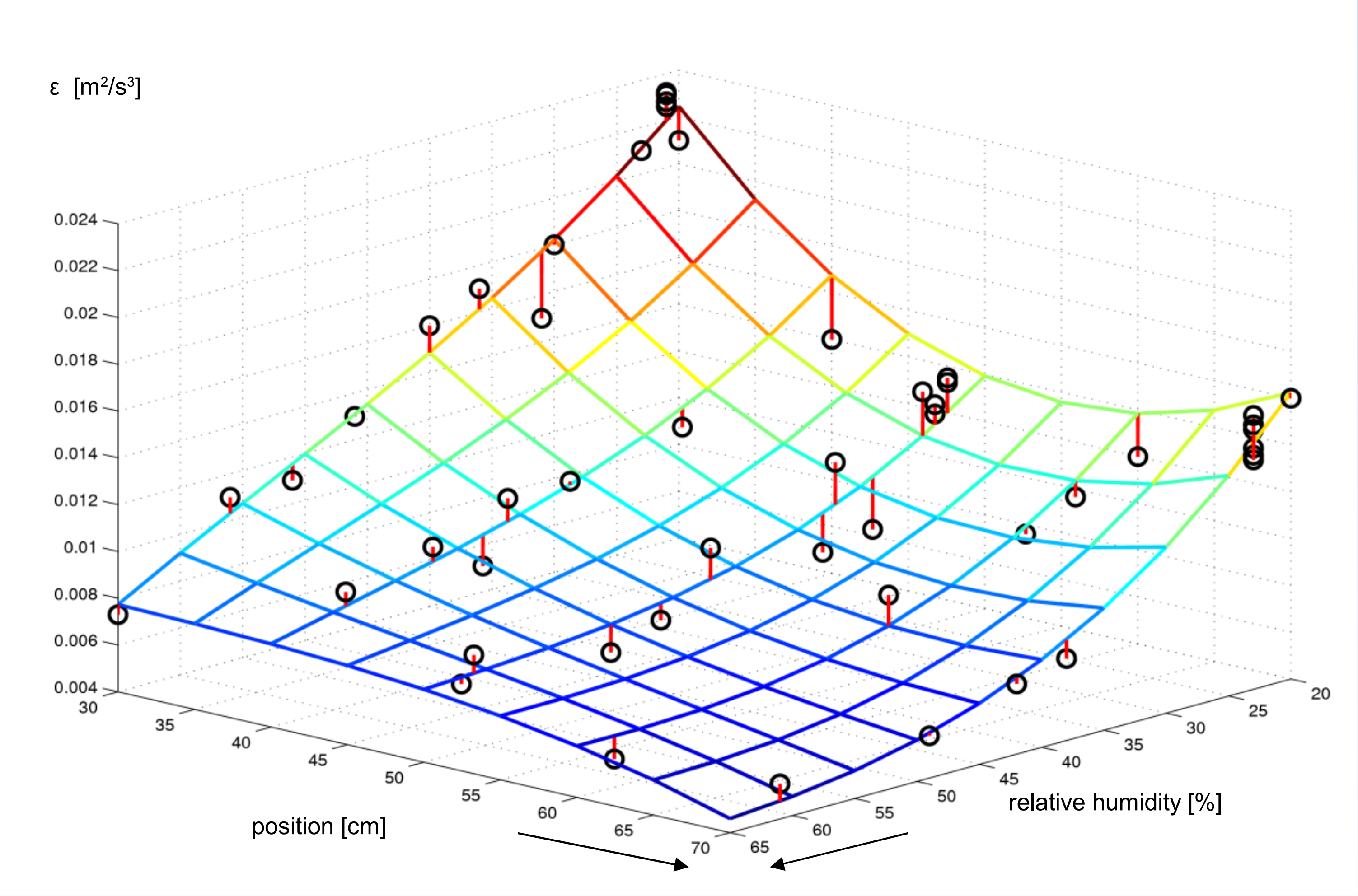


Energy dissipation rate calculated from PIV

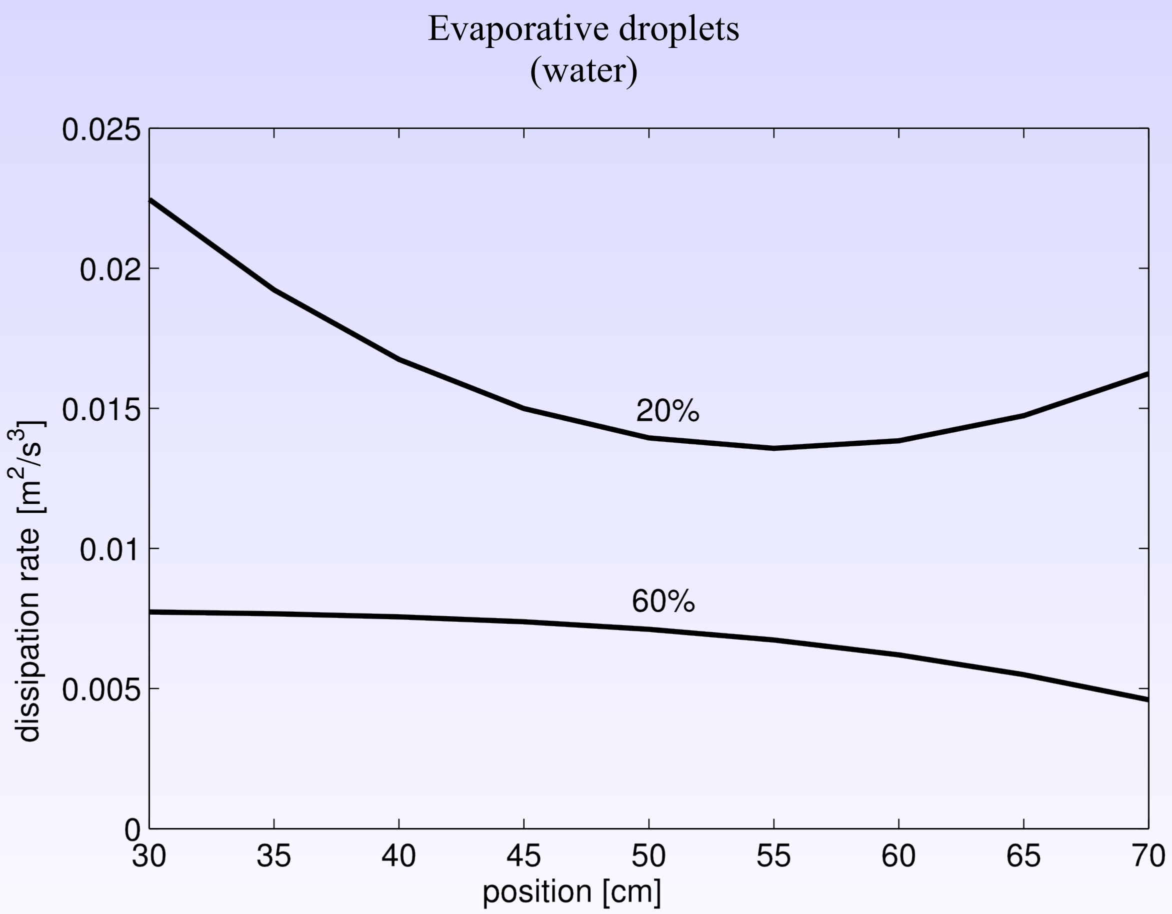


Energy dissipation rate calculated from PIV

$$\varepsilon = \nu \left\langle \left(\frac{\partial u_i}{\partial x_j} \right)^2 \right\rangle$$



Energy dissipation rate with and without evaporation

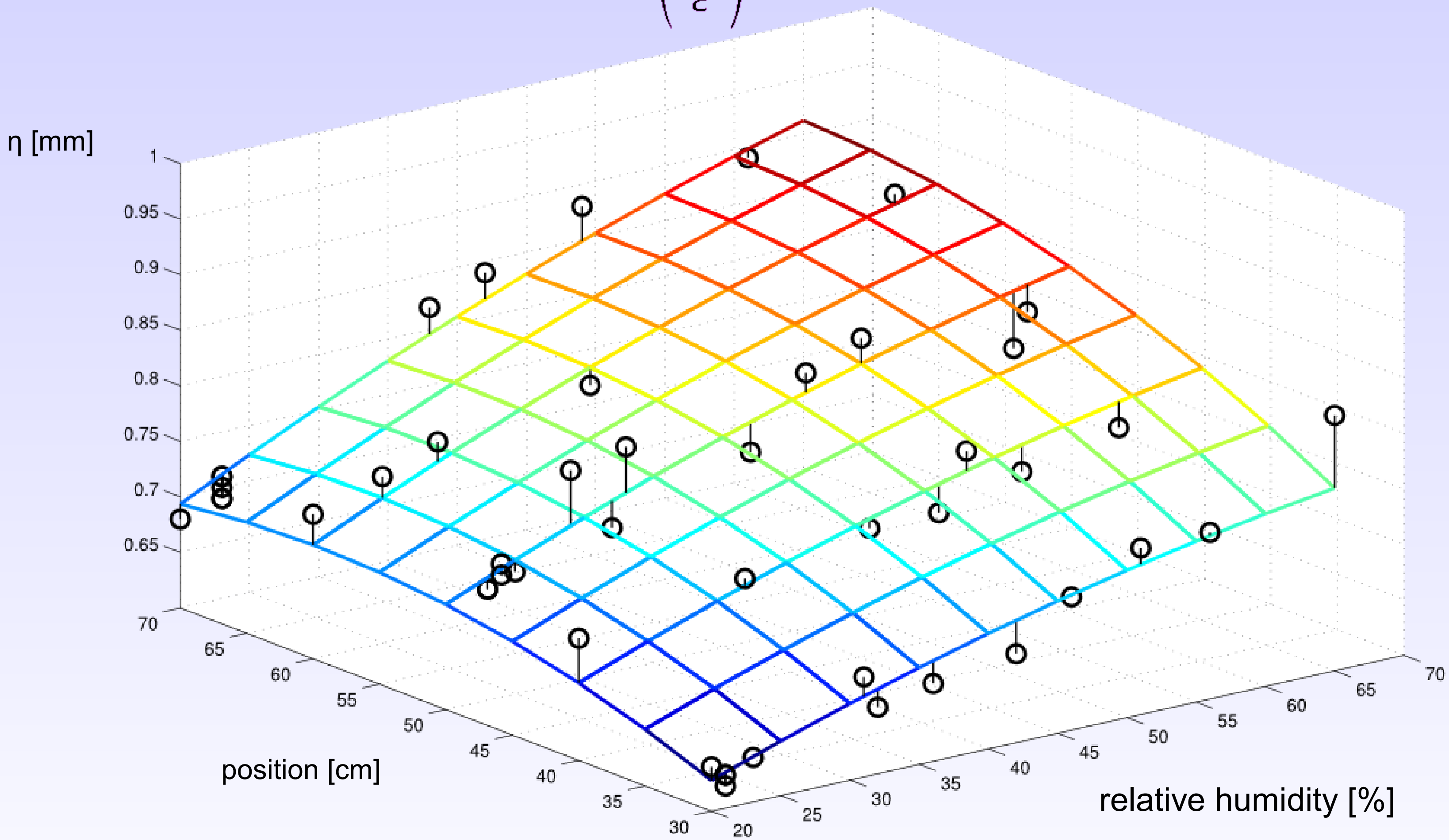


Non evaporative droplets
(DEHS)

position [cm]	ε [m^2/s^3]
30	0,00020
50	0,00006
70	0,00001

Kolmogorov length calculated from PIV

$$\eta = \left(\frac{\nu^3}{\varepsilon} \right)^{1/4}$$



Conclusions

• Our study demonstrates the possibility of using Particle Image Velocimetry for quantitative analysis of cloud droplets motion inside the cloud chamber

•Statistical analysis of the retrieved velocity field confirms suggestion of earlier numerical simulations, that small scales anisotropy of the turbulence takes place in regions of entrainment and mixing of cloud filaments with clean air. This anisotropy is caused by gravity force and does not depend on evaporation.

•Evaporating droplets should not be treated as passive particles. They may significantly influence small scales of turbulence relevant for clustering and collisions of droplets.