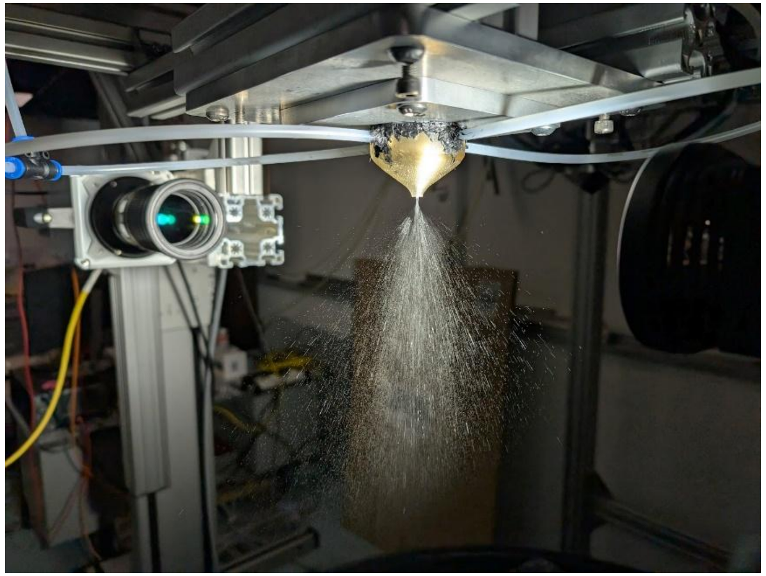
Scale effect in coaxial two-fluid atomization

Corentin Bourjaillat(1,2), Mathieu Gibert(1), Nathanaël Machicoane(2), Jean-Philippe Matas(3)

(1) Univ. Grenoble Alpes, CNRS, Institut Néel, Grenoble Cedex 9 38042, France

(2) Univ. Grenoble Alpes, CNRS, Grenoble INP, LEGI, 38000 Grenoble, France

(3) Université Claude Bernard Lyon 1, LMFA, Villeurbanne, France



GdR TransInter June 10th 2025

Atomization

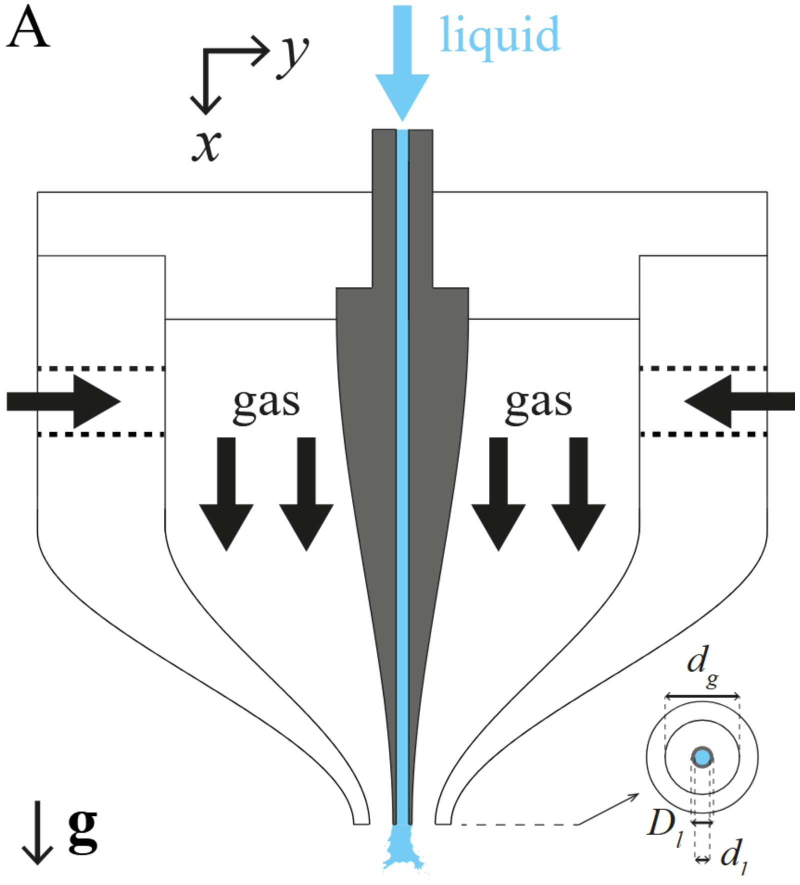
Fuel mixing

Industrial coating

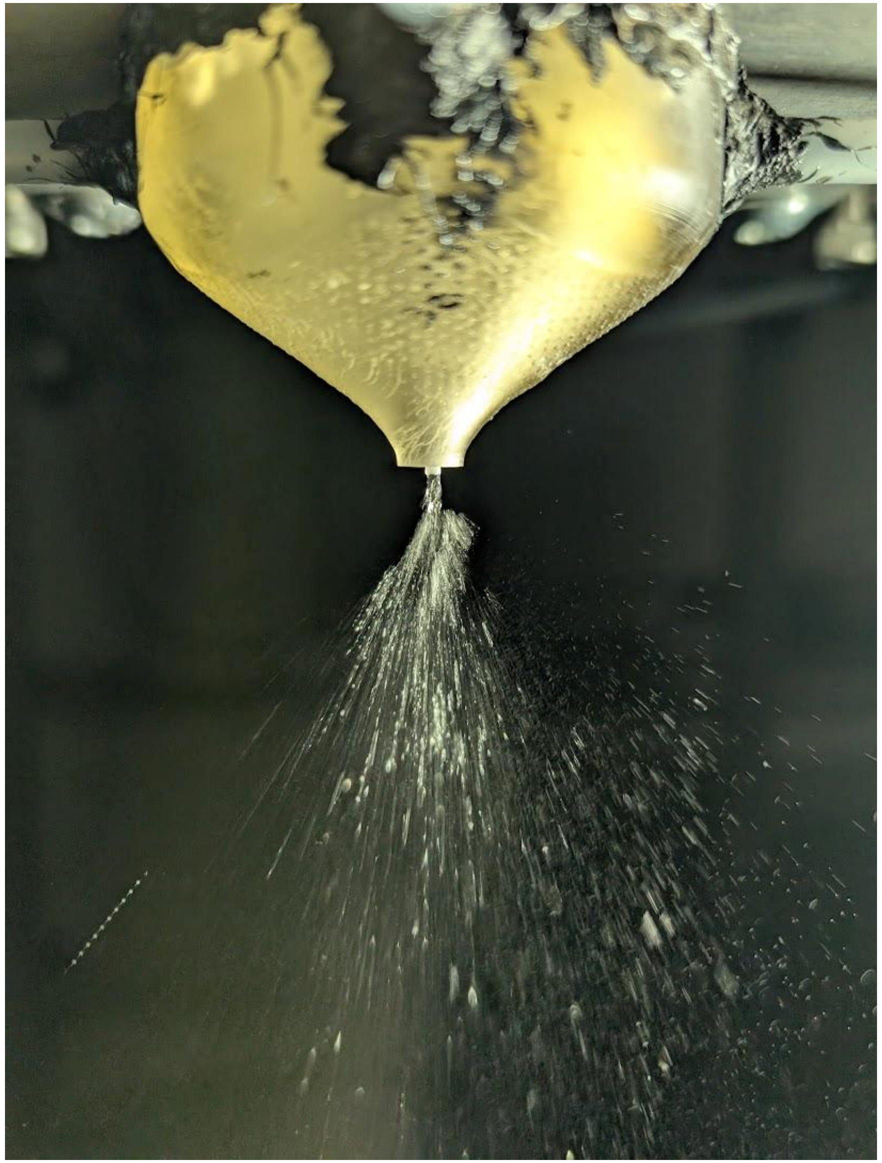
Oceanic spray

https://www.spray.com/enau/applications/coating
https://www.lsxmag.com/tech-stories/fuel-cooling-ignition-tech/taking-the-guesswork-out-with-fuel-injector-clinic/
https://cpo.noaa.gov/uncovering-the-links-between-surfactants-sea-spray-and-tropical-cyclone-intensification/

Atomization

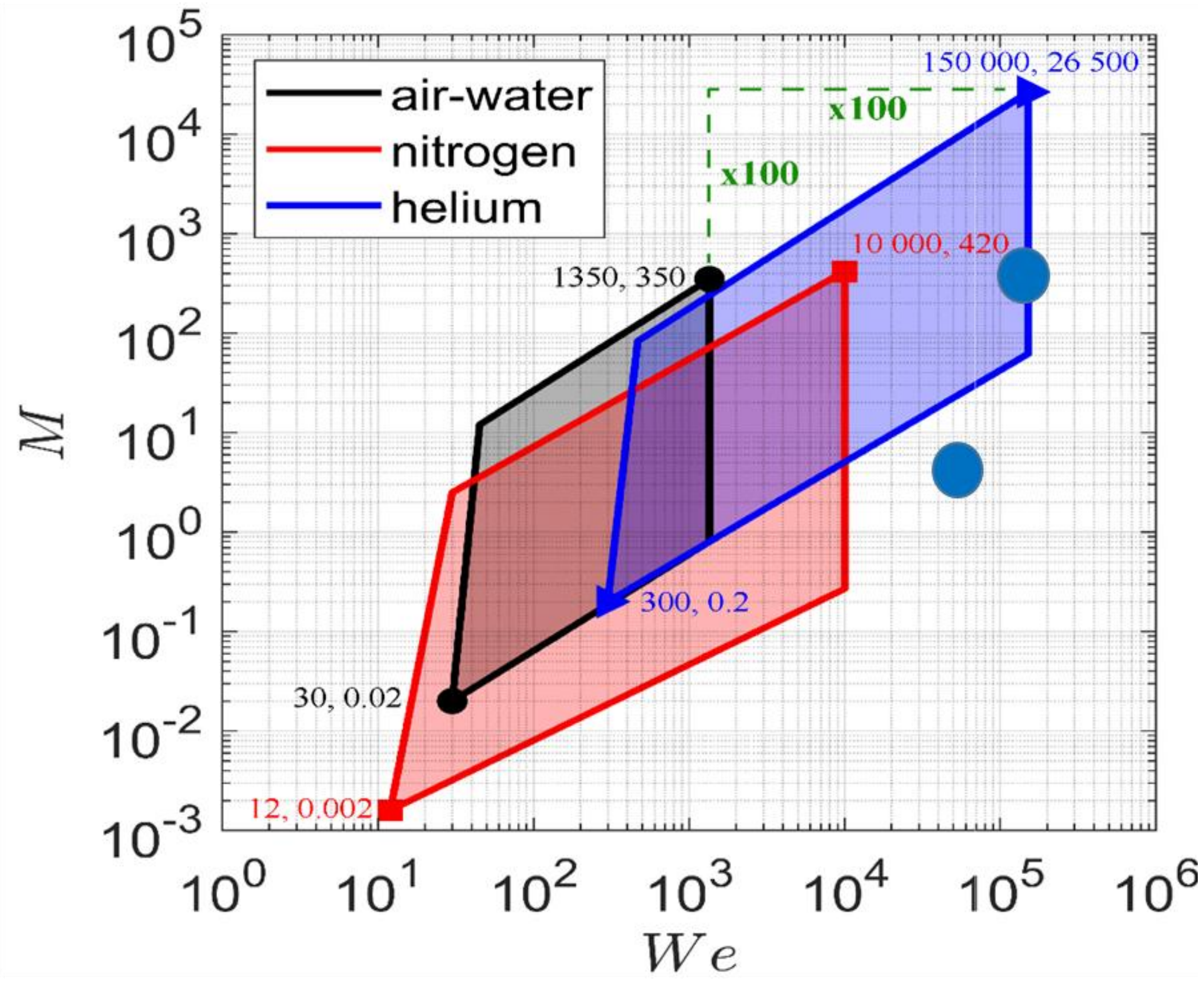


Coaxial two-fluid atomizer



Motivations

- ANR Cryospray
- Scale down needed
- Implementation in LN_2 and LHe cryostat



Will the downscaling of the nozzle impact the atomization mechanisms ?

Motivations

- Collaboration with J-P Matas

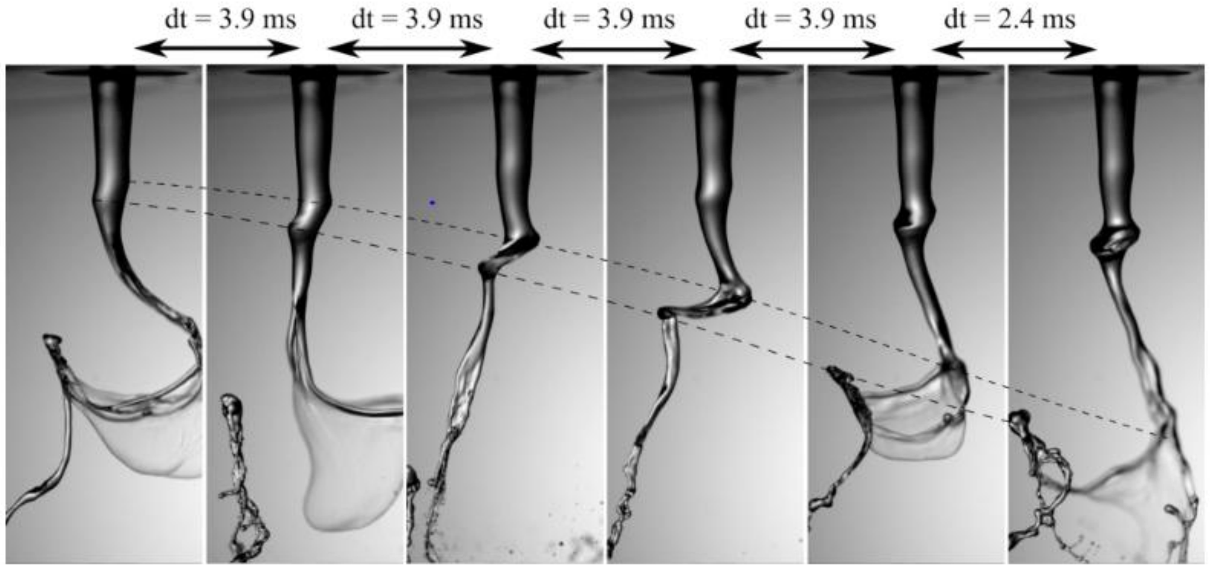
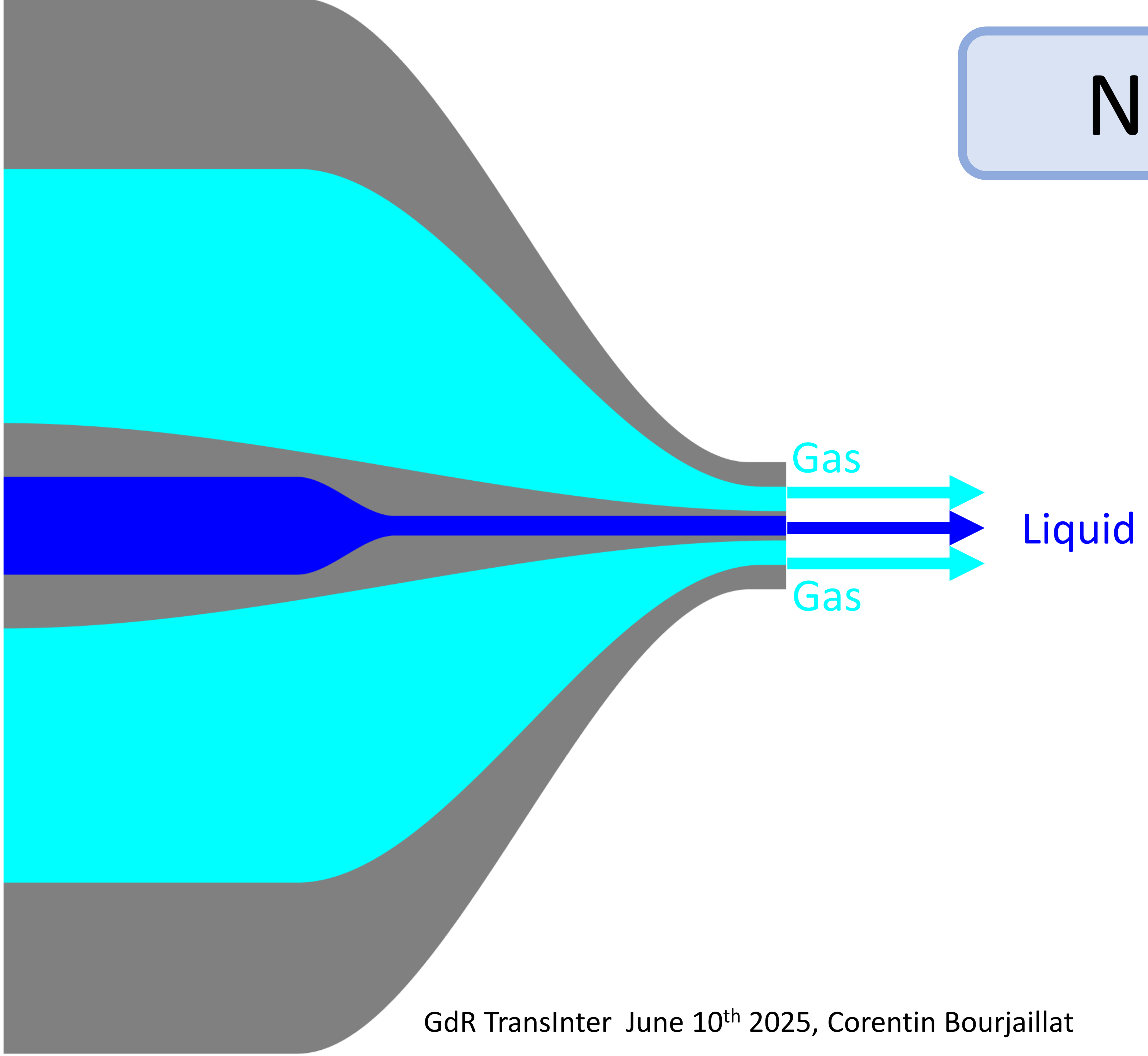


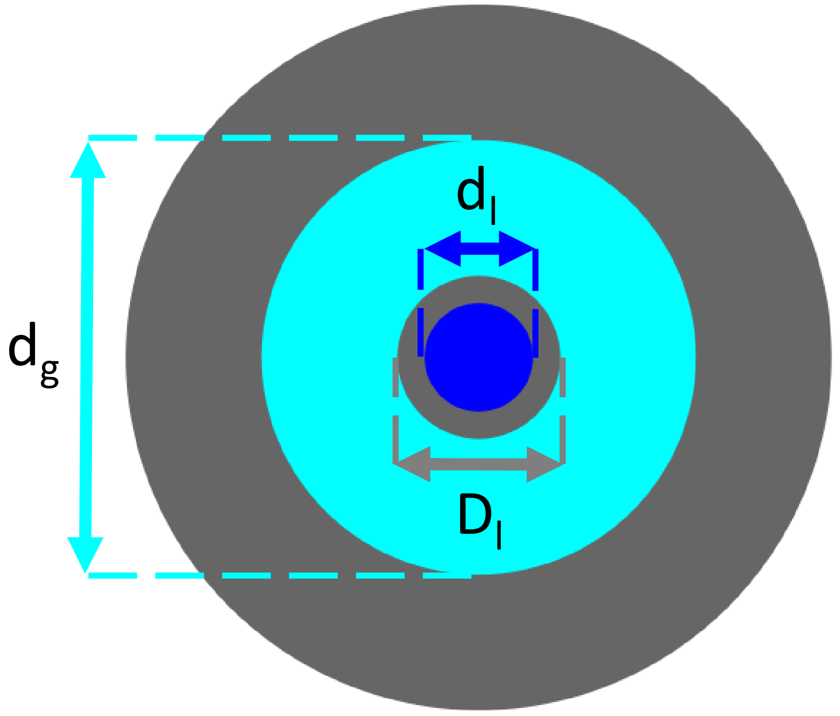
FIG. 11. Time evolution of an oblique shear instability wave, for $H_L = 5$ mm, $H_G = 5$ mm, $U_L = 0.28$ m/s, and $U_G = 22$ m/s.

Which scales govern the instabilities ?

Matas, J. P. (2015). Inviscid versus viscous instability mechanism of an air–water mixing layer. *Journal of Fluid Mechanics*, *768*, 375-387.

Nozzle geometry



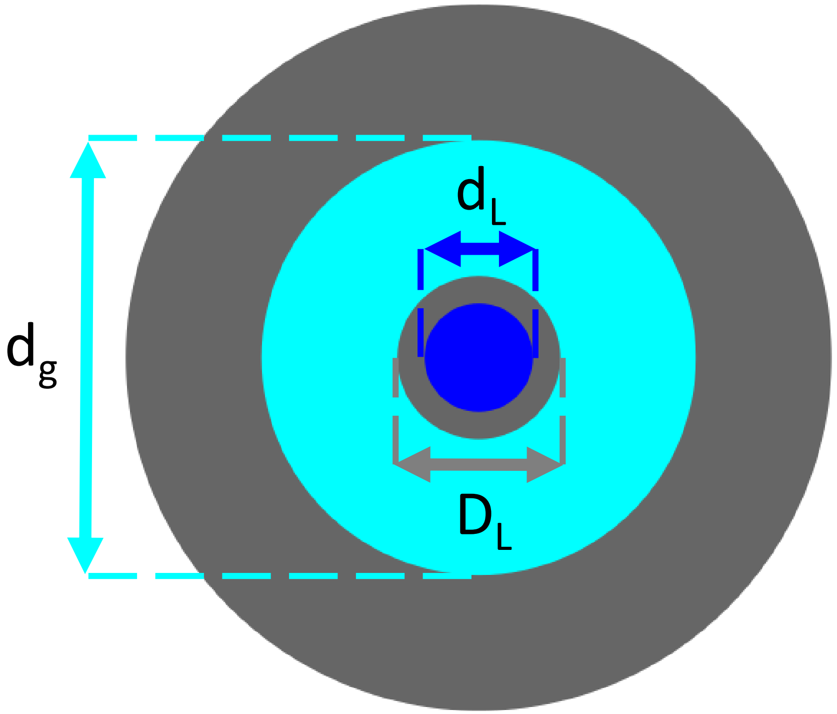


Nozzle geometry

ALUMINUM NOZZLE

Nozzle	d_l [mm]	D_l [mm]	d_g [mm]
N_{1,V_0}	2	3	10
N_{1,V_1}	2	2,5	8
$N_{1/2,V_1}$	1	1,5	4

NEW, 3D PRINTED NOZZLES

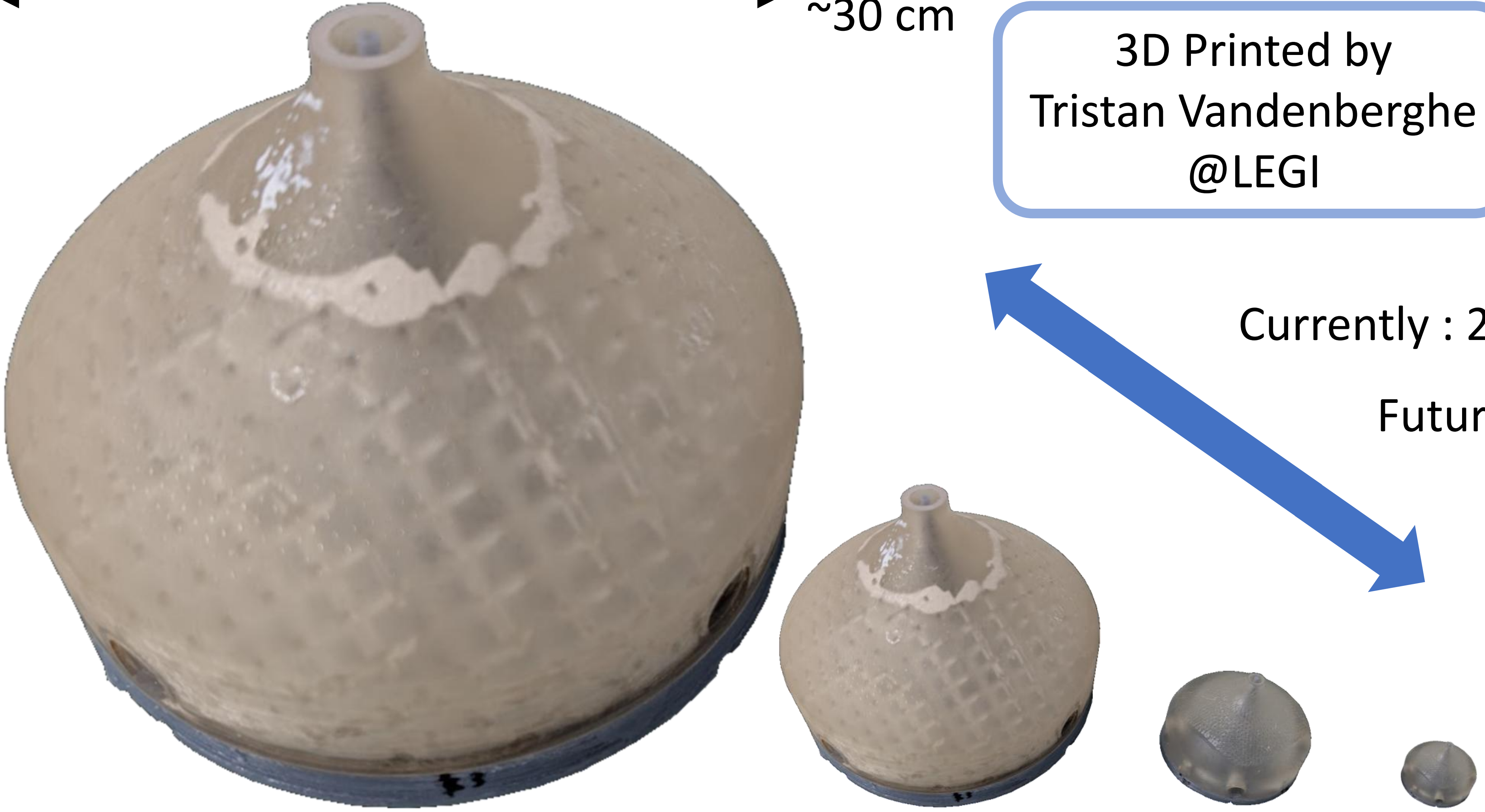


$N_{1/2,V_1}$: "$\frac{1}{2}$ scale nozzle, version 1"

Nozzles

3D Printed by
Tristan Vandenberghe
@LEGI

~30 cm



Currently : 2× scaling

Future : full decade range ?

~3 cm

2.5× scale | 1× scale | $\frac{1}{2}\times$ scale | $\frac{1}{4}\times$ scale

Parameters

- Weber number : $$We = \frac{\rho u_G^2 d_l}{\sigma} = \frac{Inertia}{Surface\ tension}$$

- Dynamic gas-to-liquid pressure ratio : $$M = \frac{\rho_G u_G^2}{\rho_L u_L^2}$$

- Gas Reynolds number : $$Re_G = \frac{4Q_G}{\nu_G\sqrt{4\pi A_G}} = \frac{u_G\sqrt{d_g^2 - D_l^2}}{\nu_G}$$

- Liquid Reynolds number : $$Re_L = \frac{4Q_L}{\nu_L\sqrt{4\pi A_L}} = \frac{u_G d_l}{\nu_G}$$

Back-lit imaging

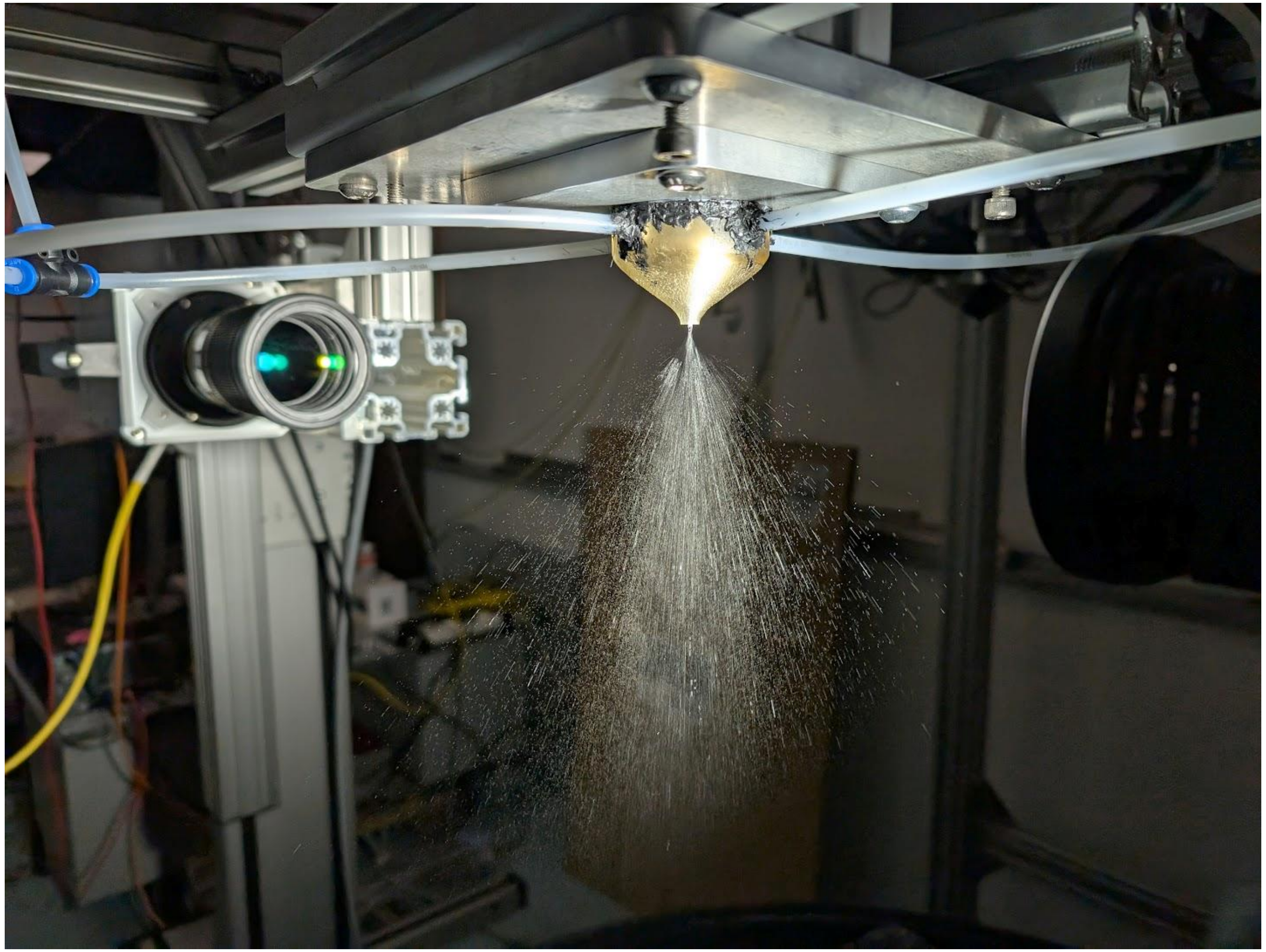


Image processing

- Raw image

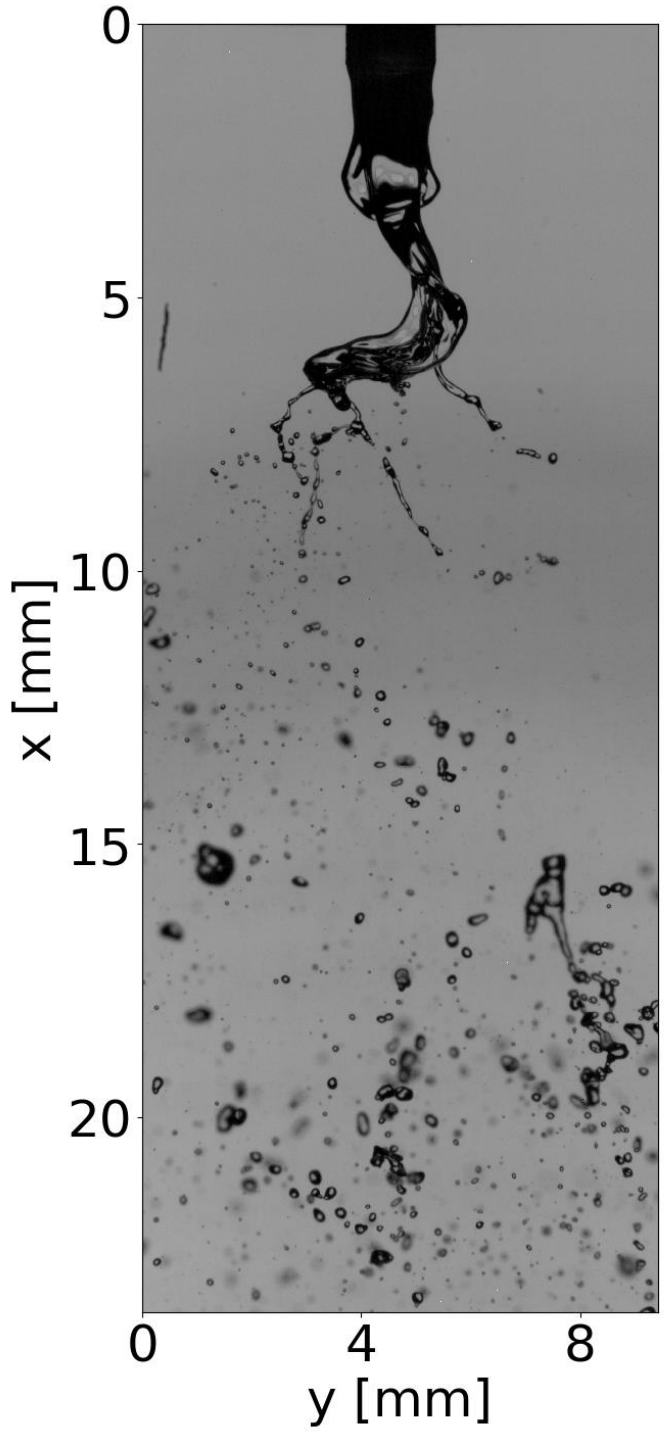


Image processing

- Background removal

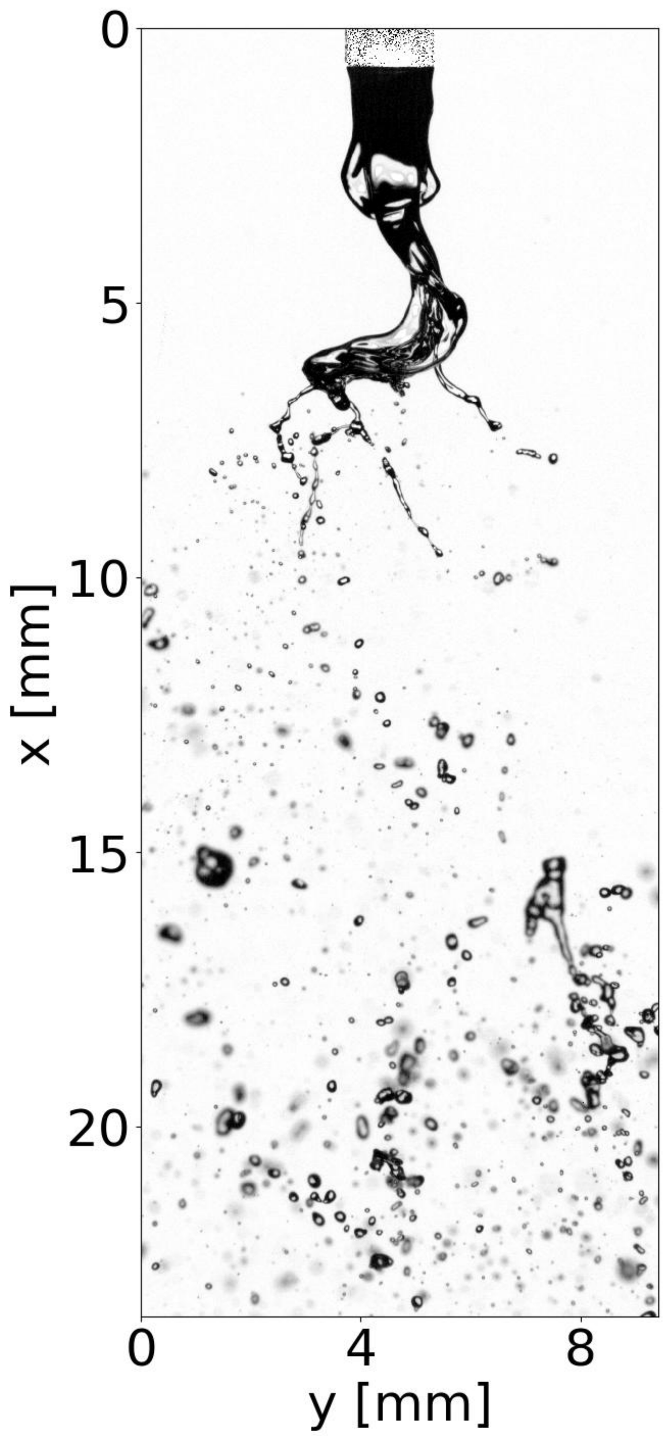


Image processing

- Thresholding

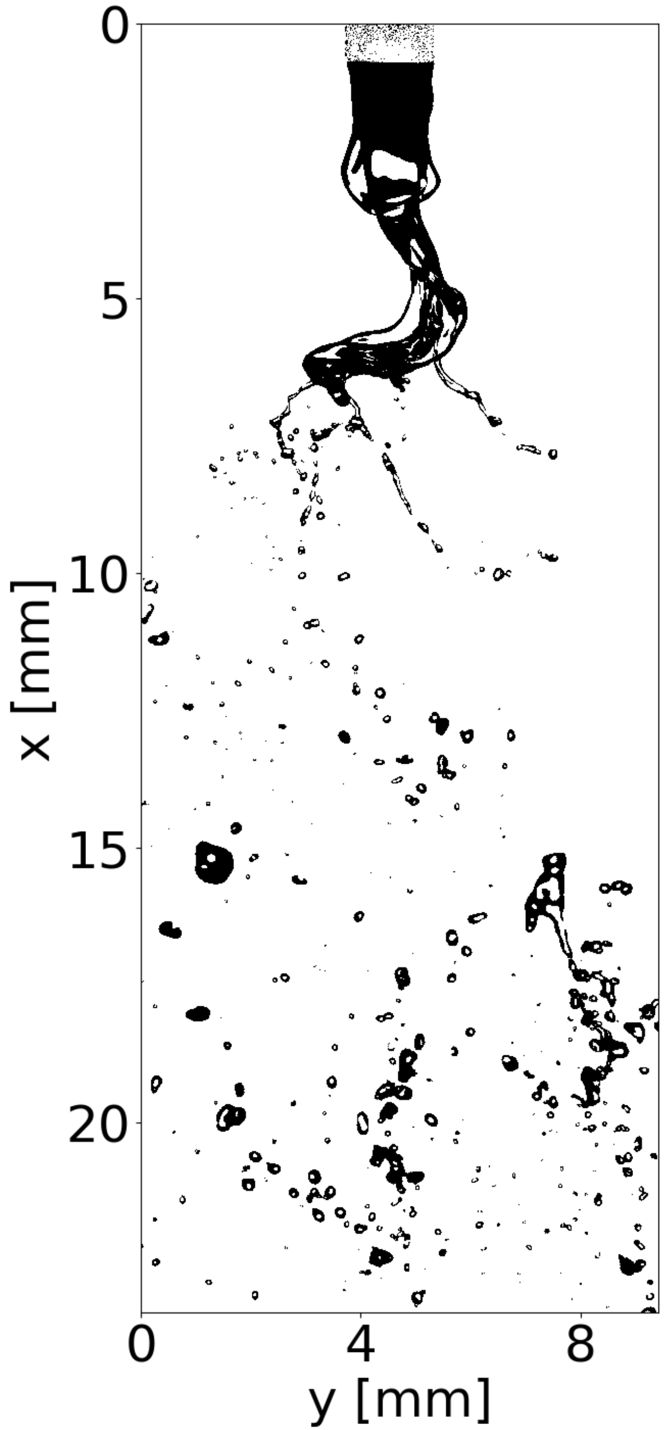


Image processing

- Fill holes

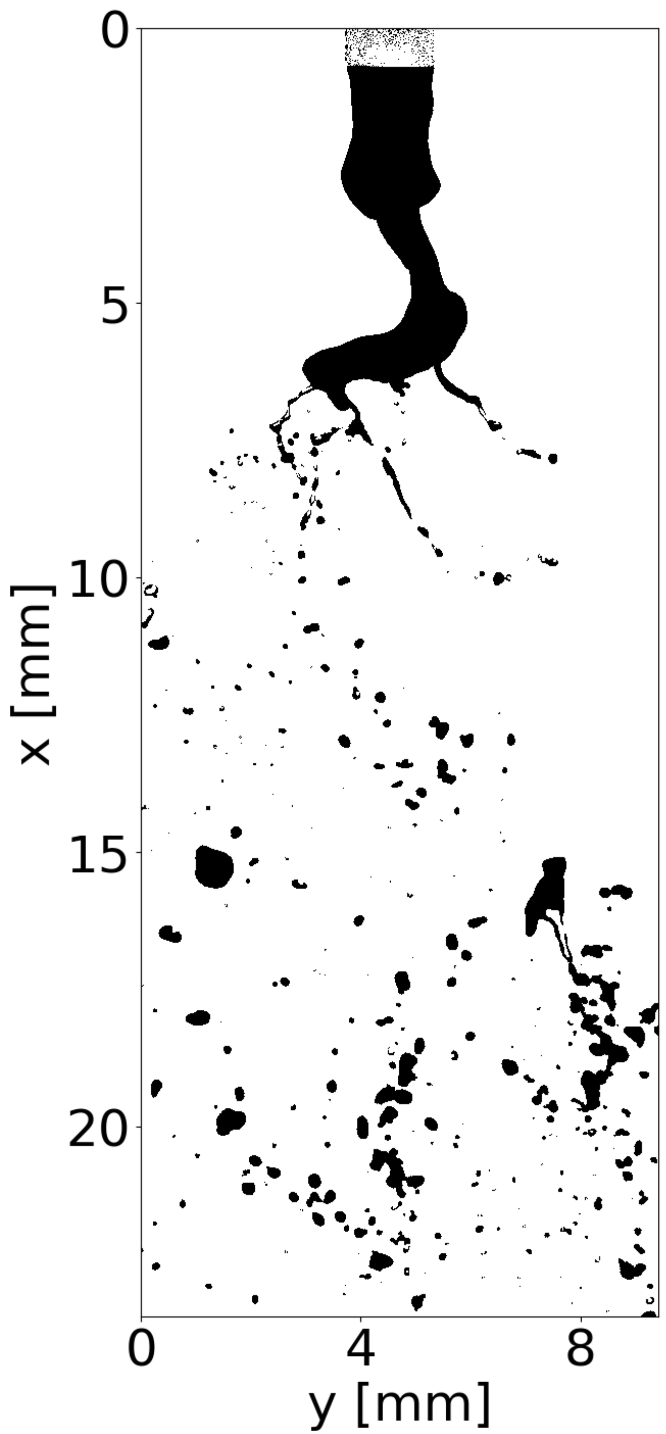


Image processing

- Identify core

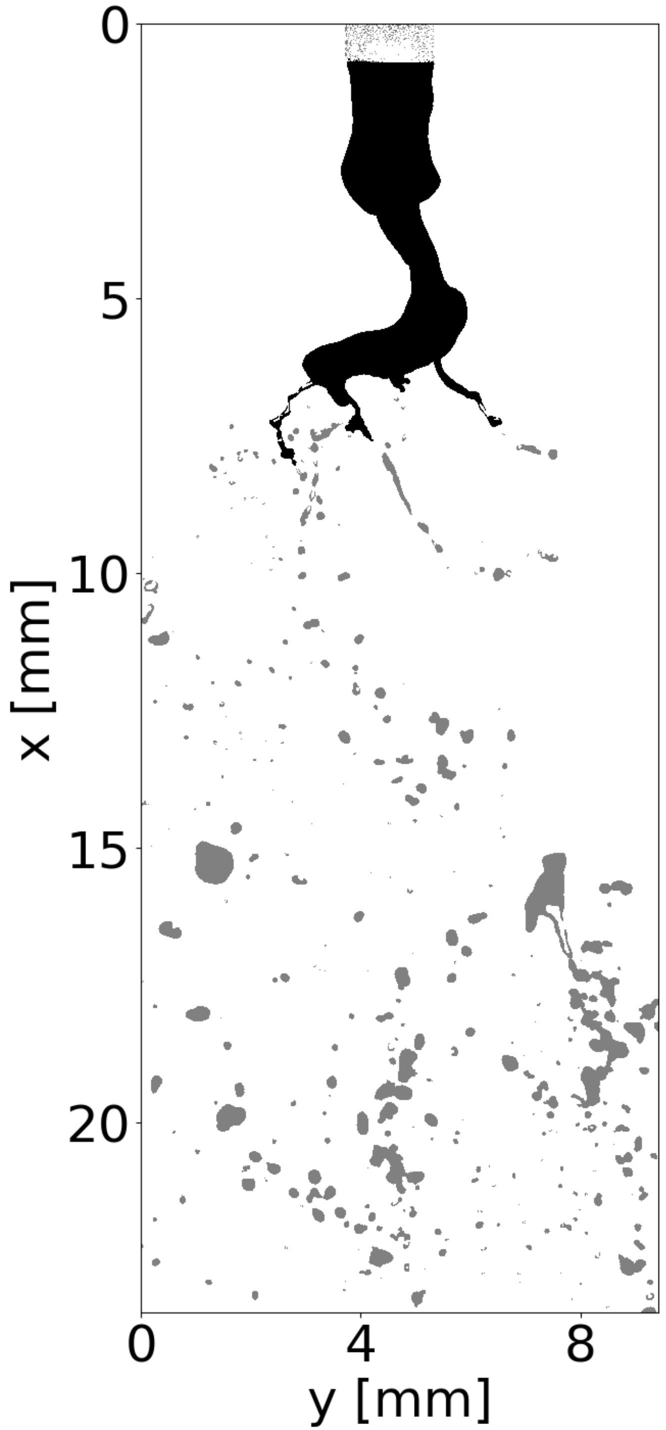


Image processing

- Identify core

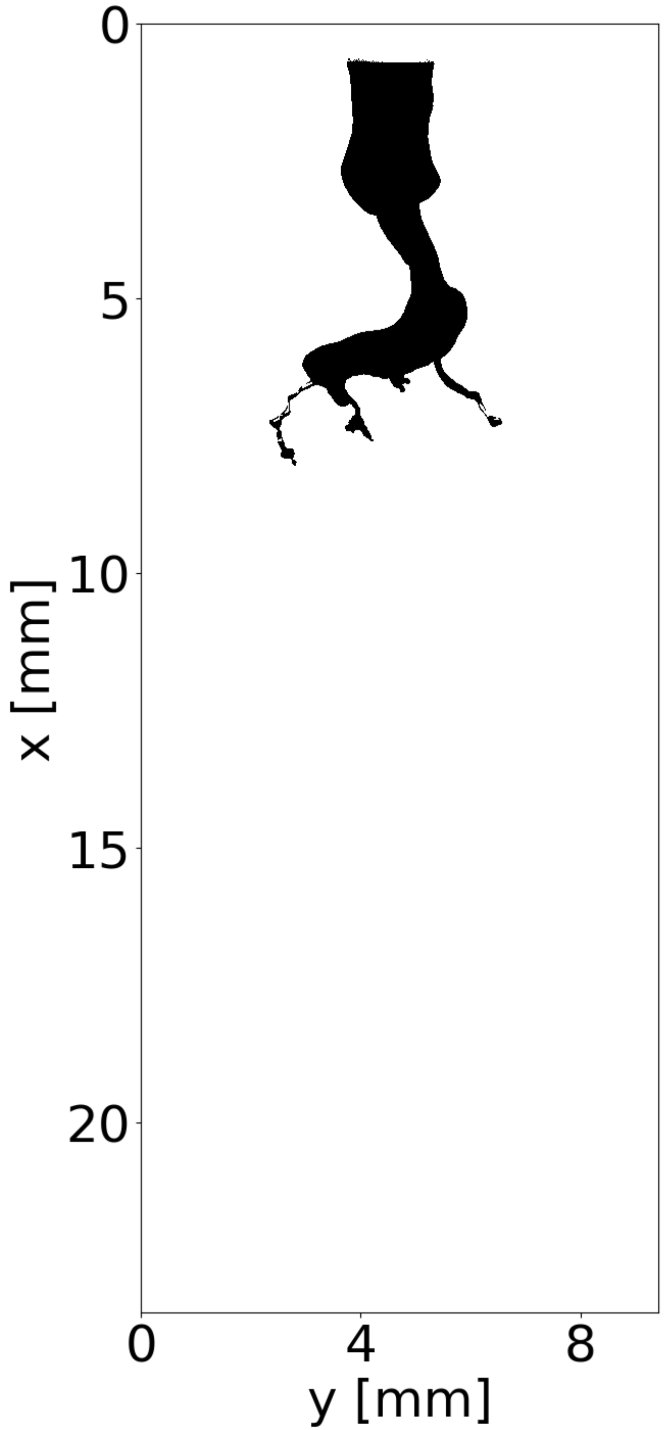
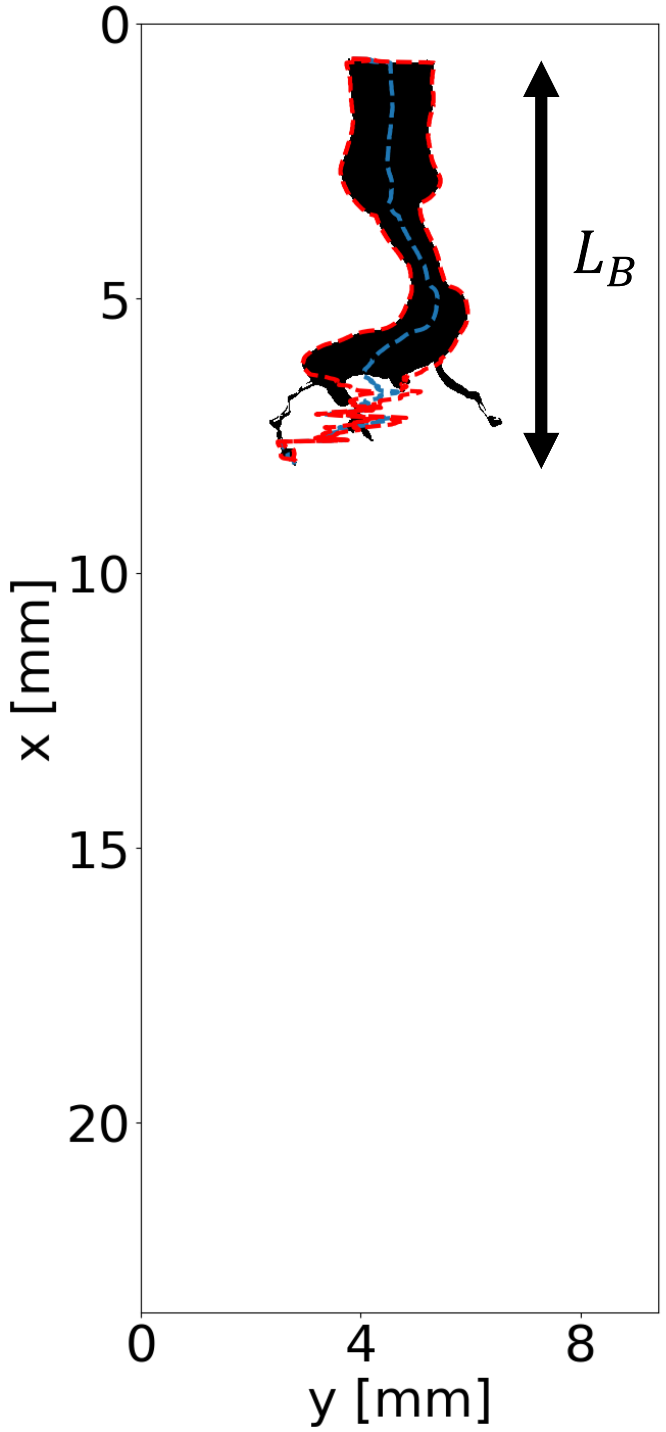


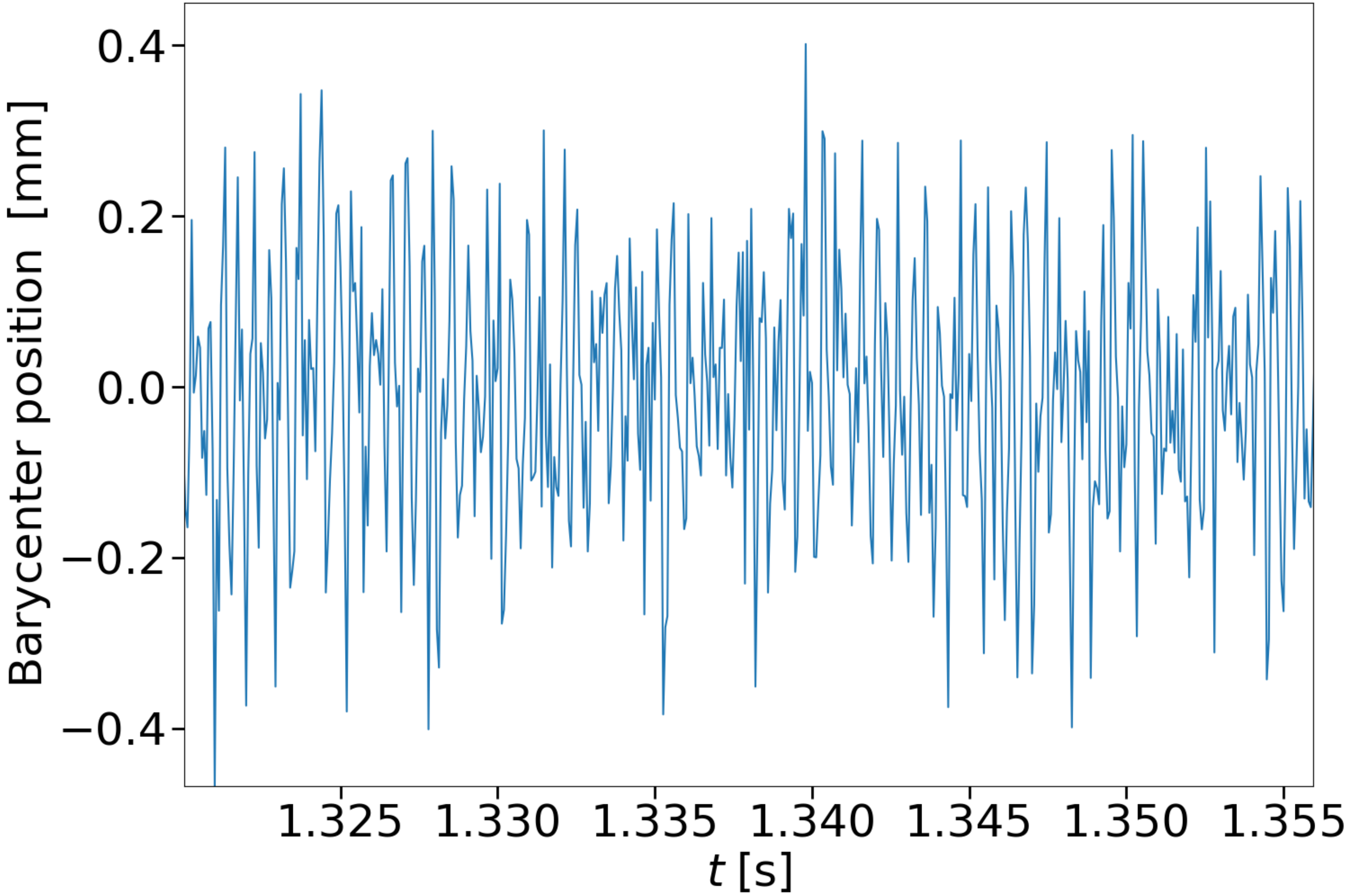
Image processing

Measure :

- Core length : $L_B\ (t)$
- Barycenter (x, t)
- Width (x, t)



Barycenter dynamics

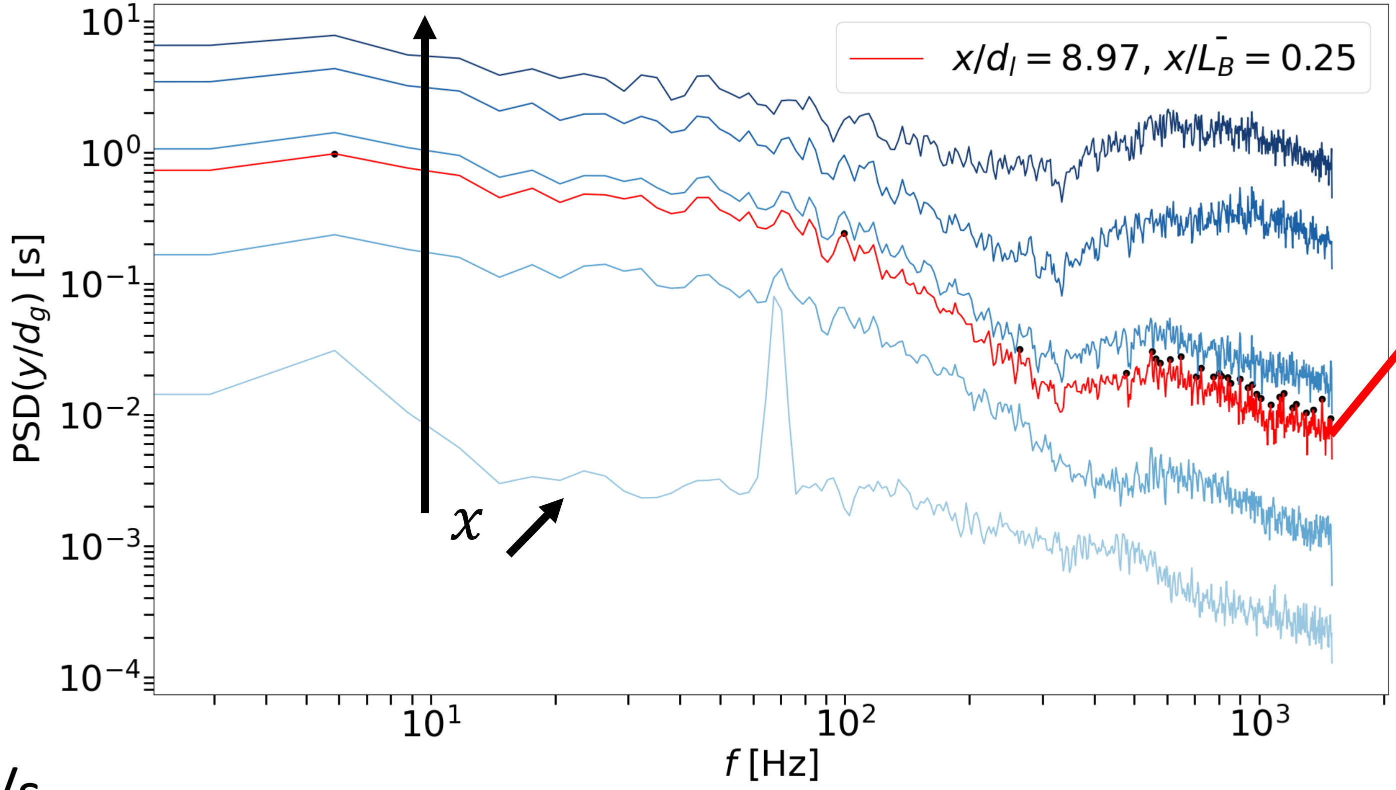


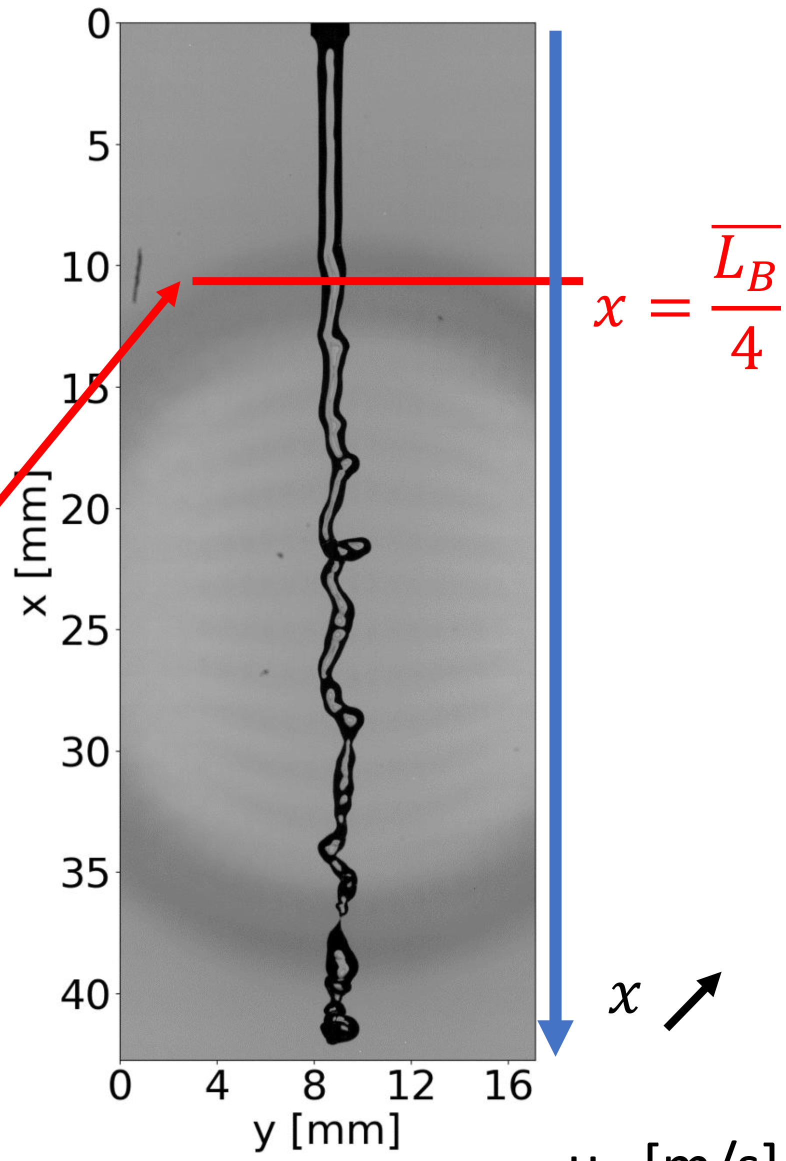
Barycenter time series at one x position

Spray Regimes

$Re_L = 2500$

Very low u_G : Rayleigh-like breakup, no small drop production





30 m/s

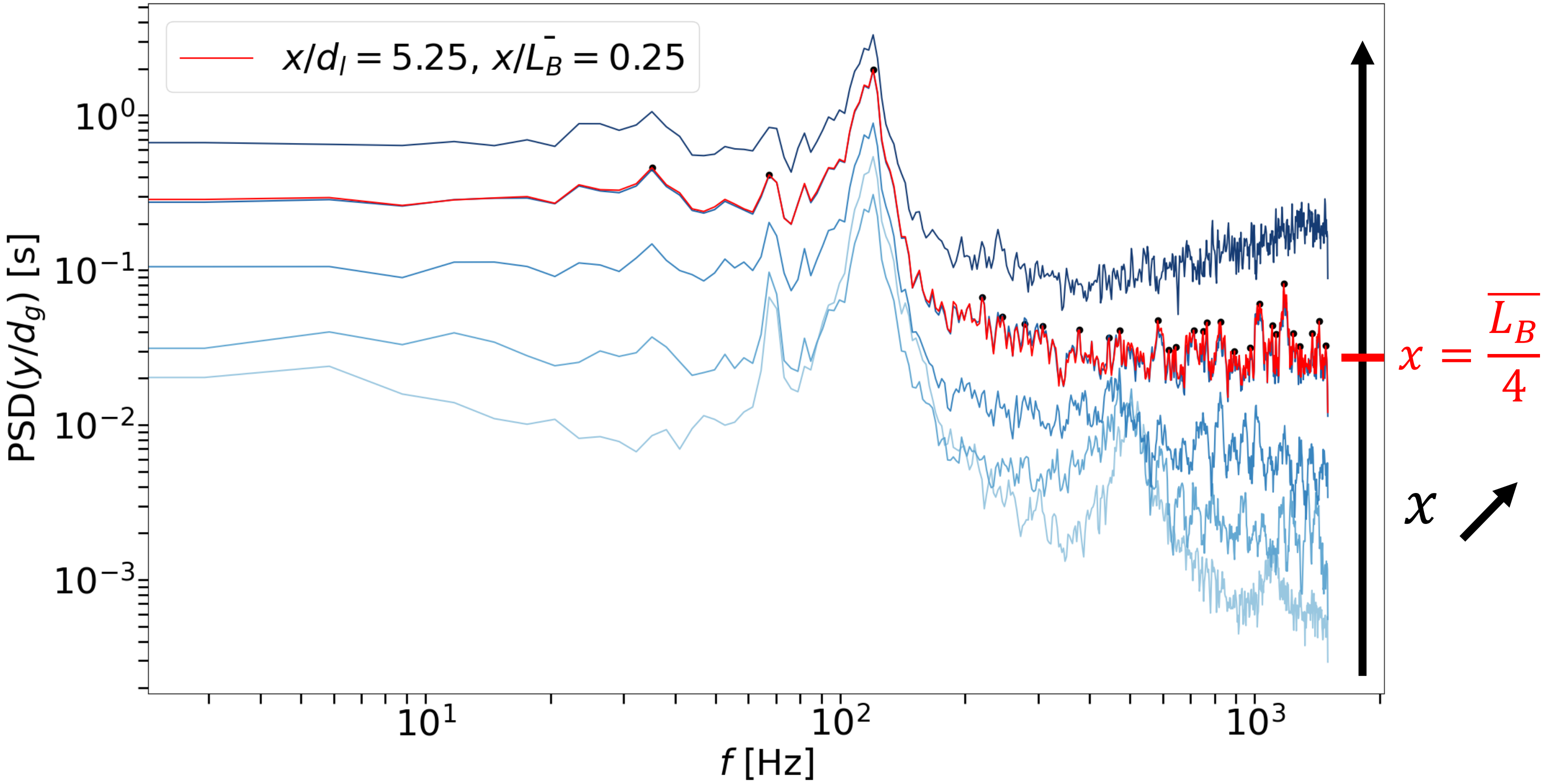
u_G [m/s]

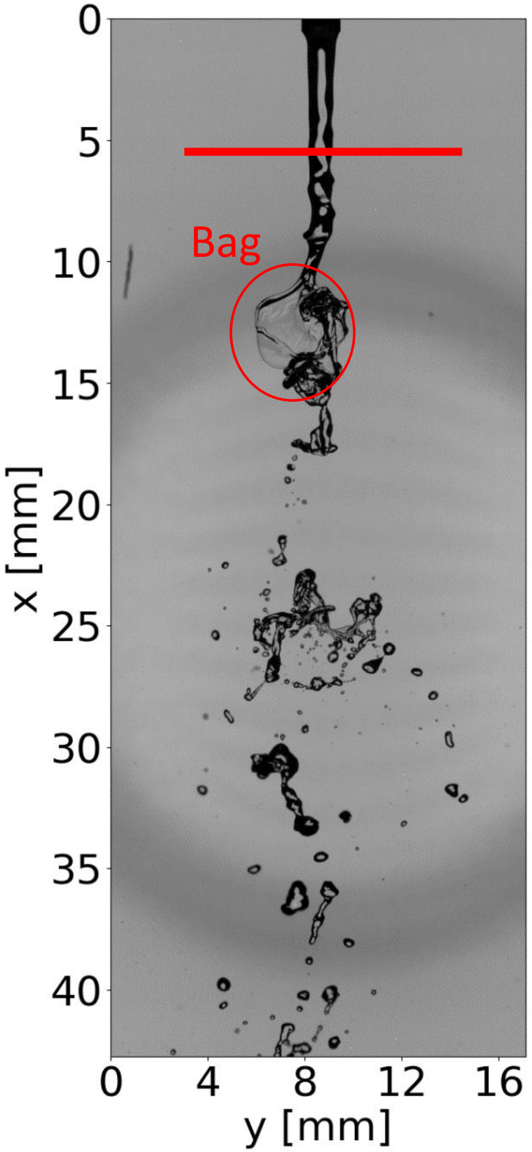
$We = 12$

Spray Regimes

$Re_L = 2500$

Low-medium u_G : Bag breakup





u_G [m/s]

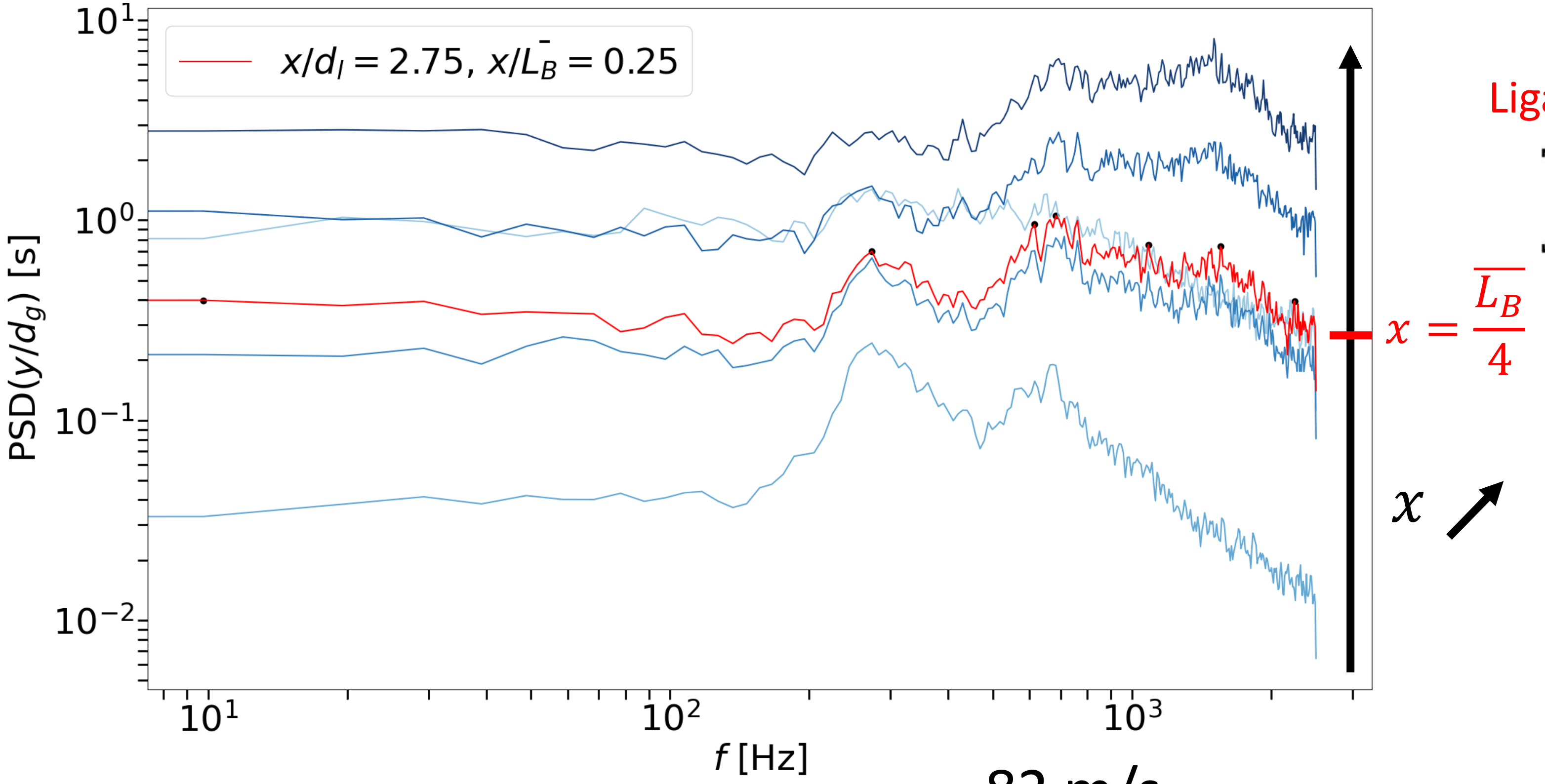
42 m/s

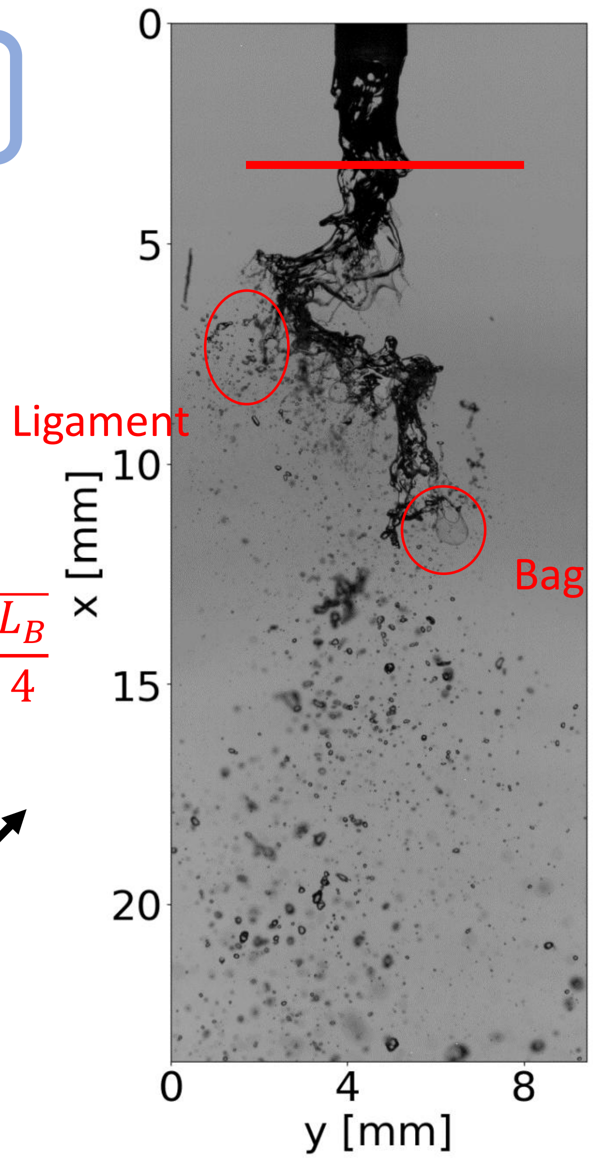
$We = 23$

Spray Regimes

$Re_L = 2500$

Low-medium u_G : Intermediate regime





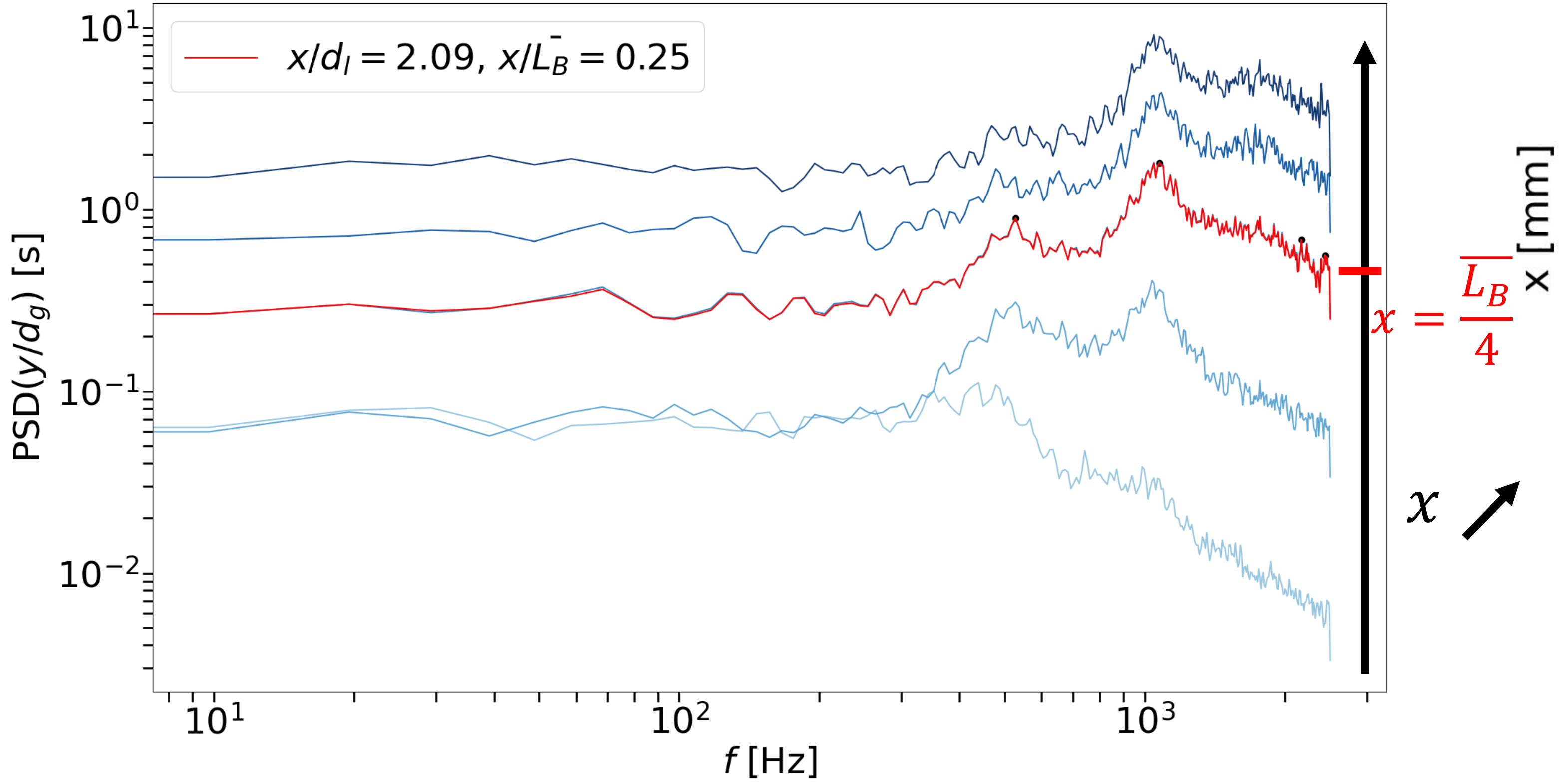
82 m/s

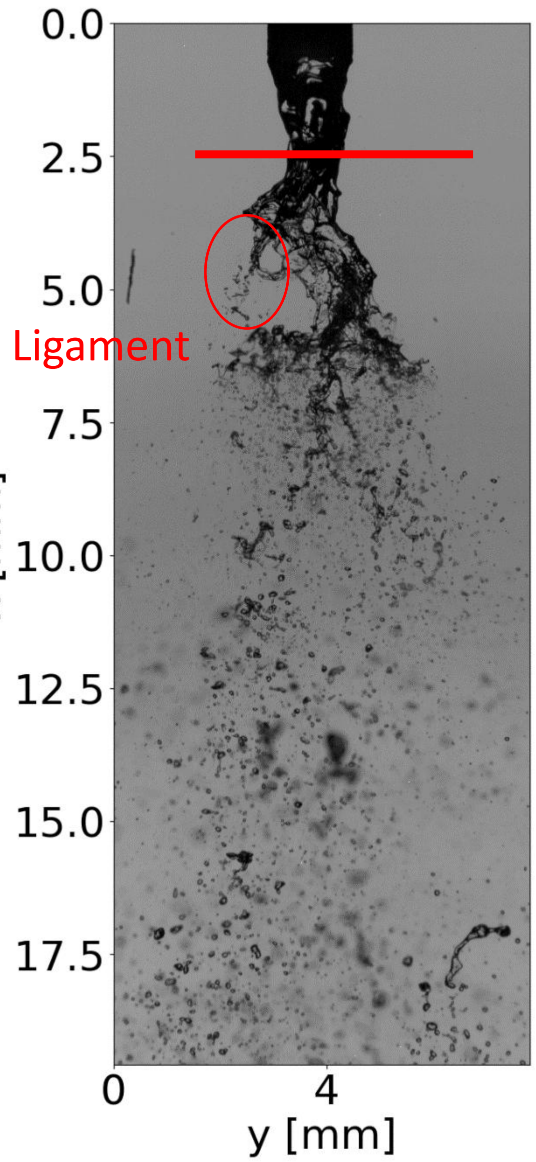
u_G [m/s]

$We = 89$

Spray Regimes

High u_G : Fiber-type atomization





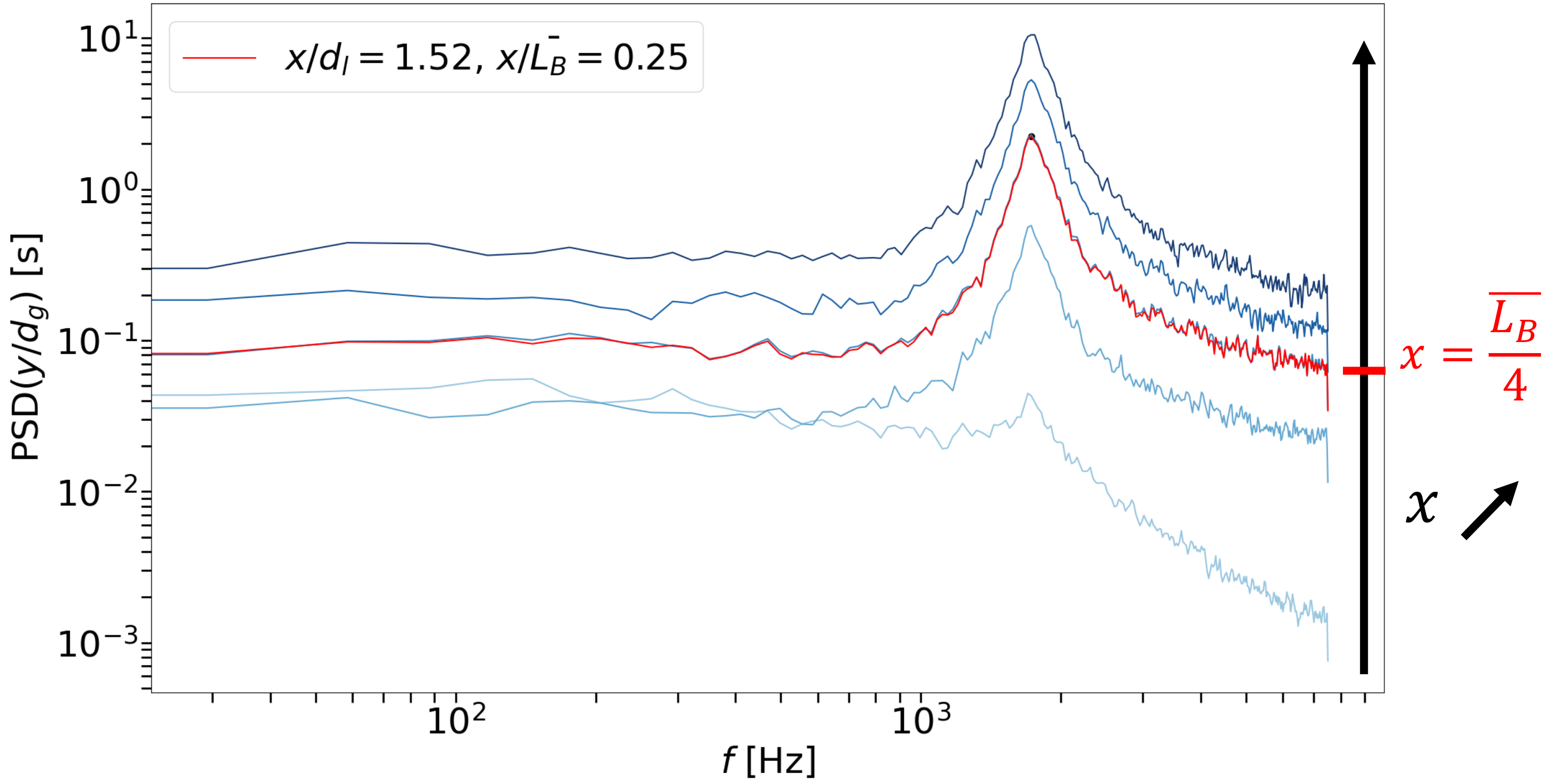
u_G [m/s]

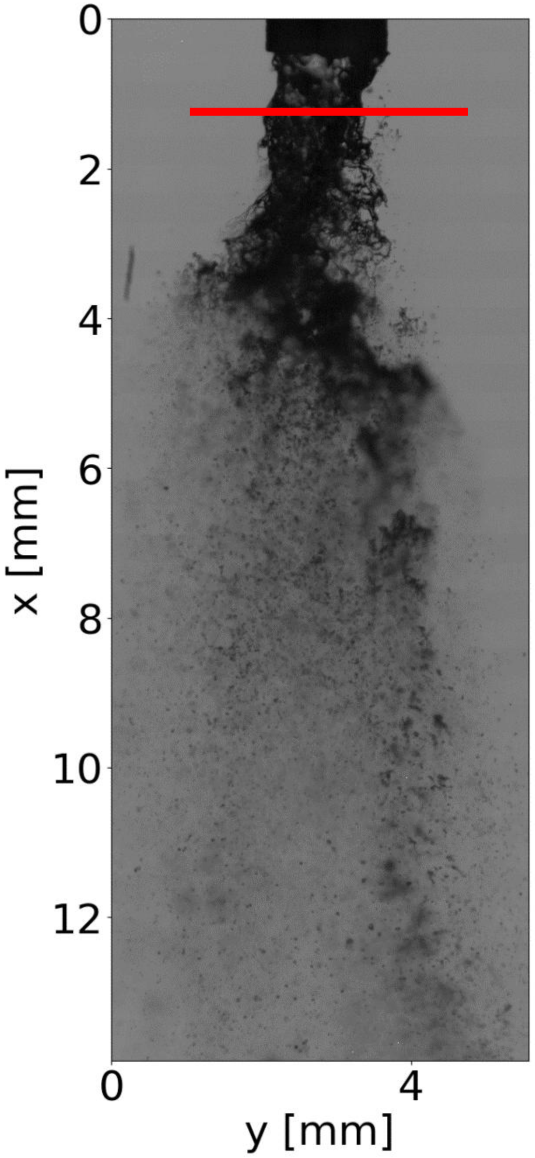
116 m/s, $We = 190$

Spray Regimes

$Re_L = 2500$

High u_G : Fiber-type atomization

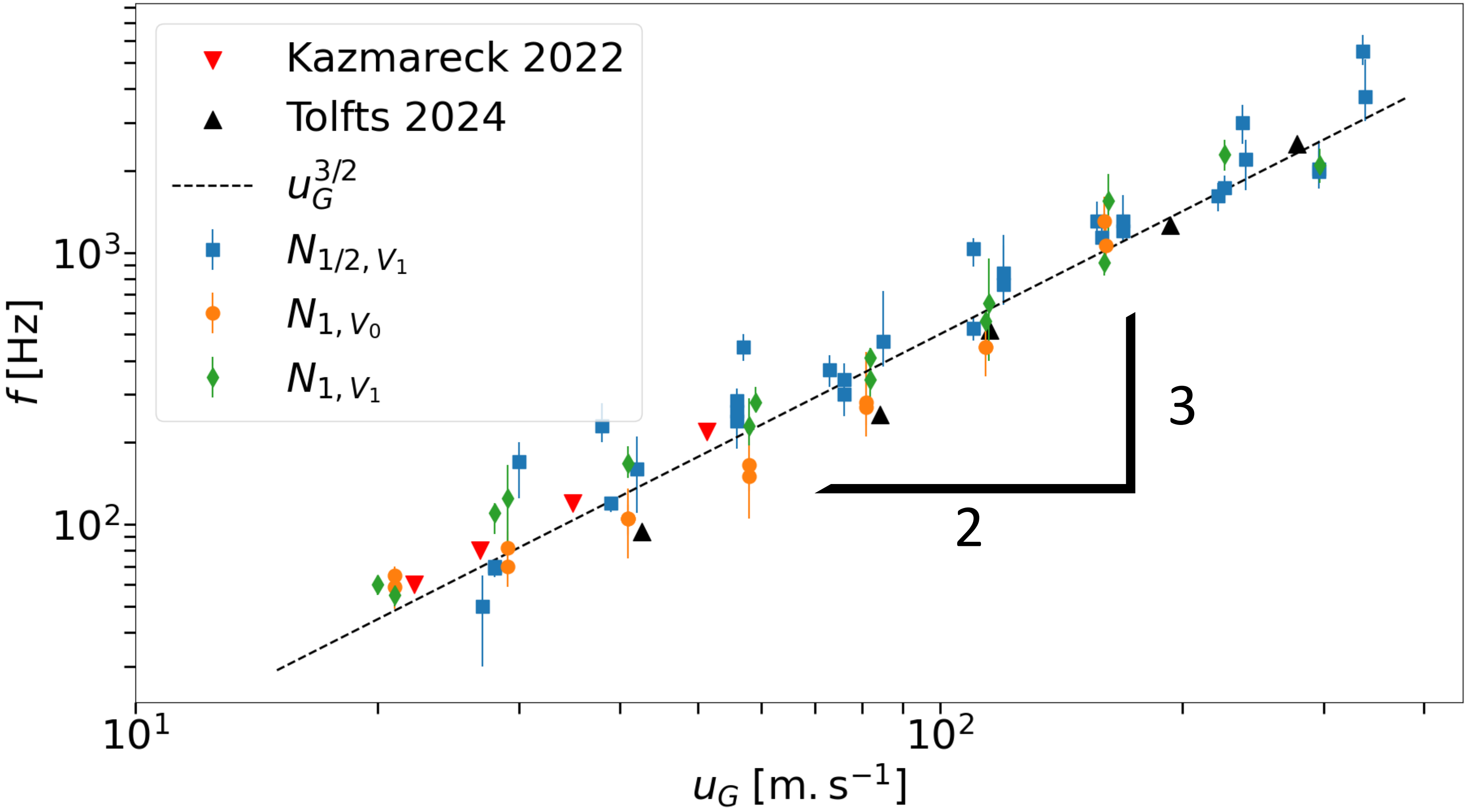




u_G [m/s]

230 m/s, $We = 1400$

Flapping frequency



Power law only partially explained by models, e.g. Marmottant & Villermaux 2004

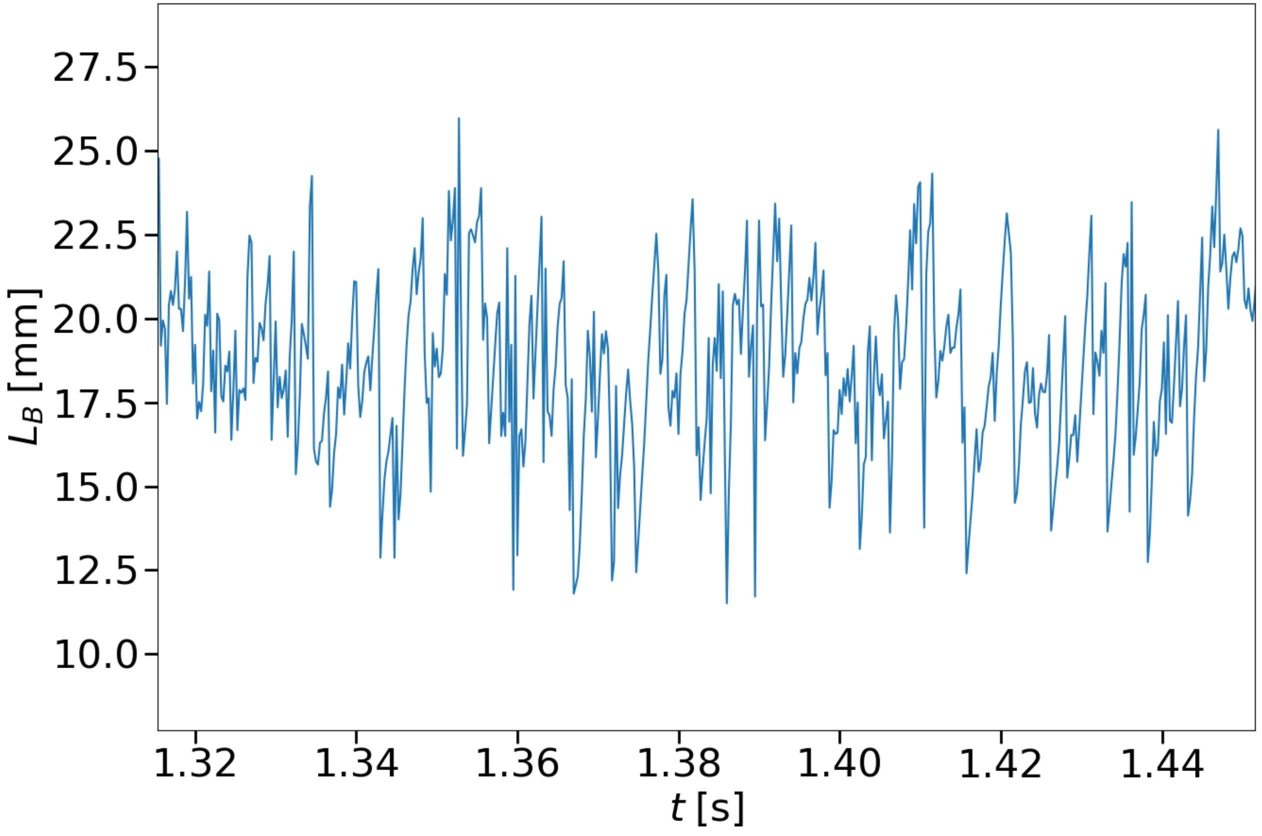
Marmottant, P., & Villermaux, E. (2004). On spray formation. *Journal of fluid mechanics*, *498*, 73-111.

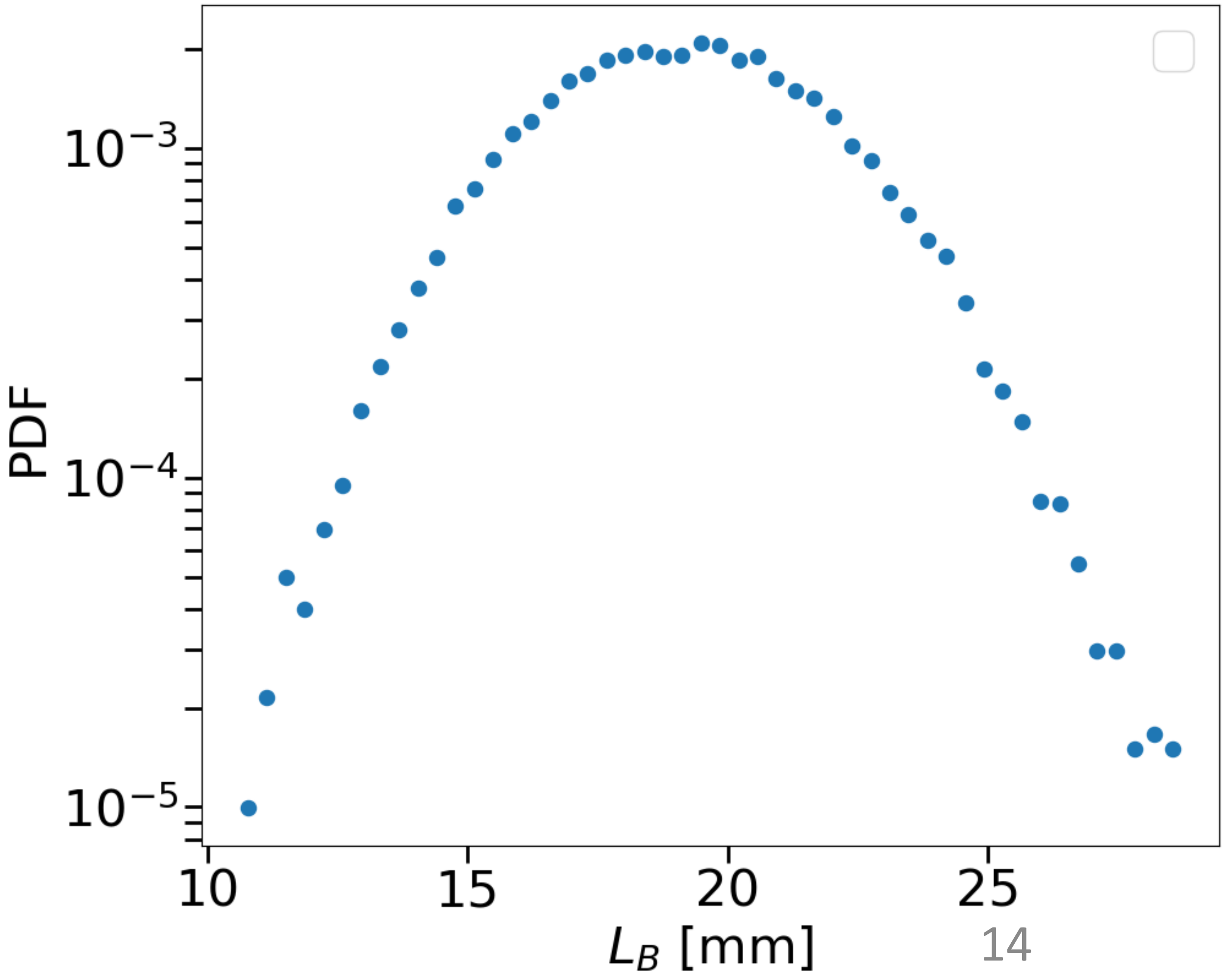
Kaczmarek, M., Osuna-Orozco, R., Huck, P. D., Aliseda, A., & Machicoane, N. (2022). *International Journal of Multiphase Flow*, *152*, 104056.

Tolfts, O., Rack, A., & Machicoane, N. (2024). *International Journal of Multiphase Flow*, *181*, 105004.

L_B statistics

Nozzle	d_L [mm]
N_{1,V_0}	2
N_{1,V_1}	2
$N_{1/2,V_1}$	1





L_B statistics

Nozzle	d_L [mm]
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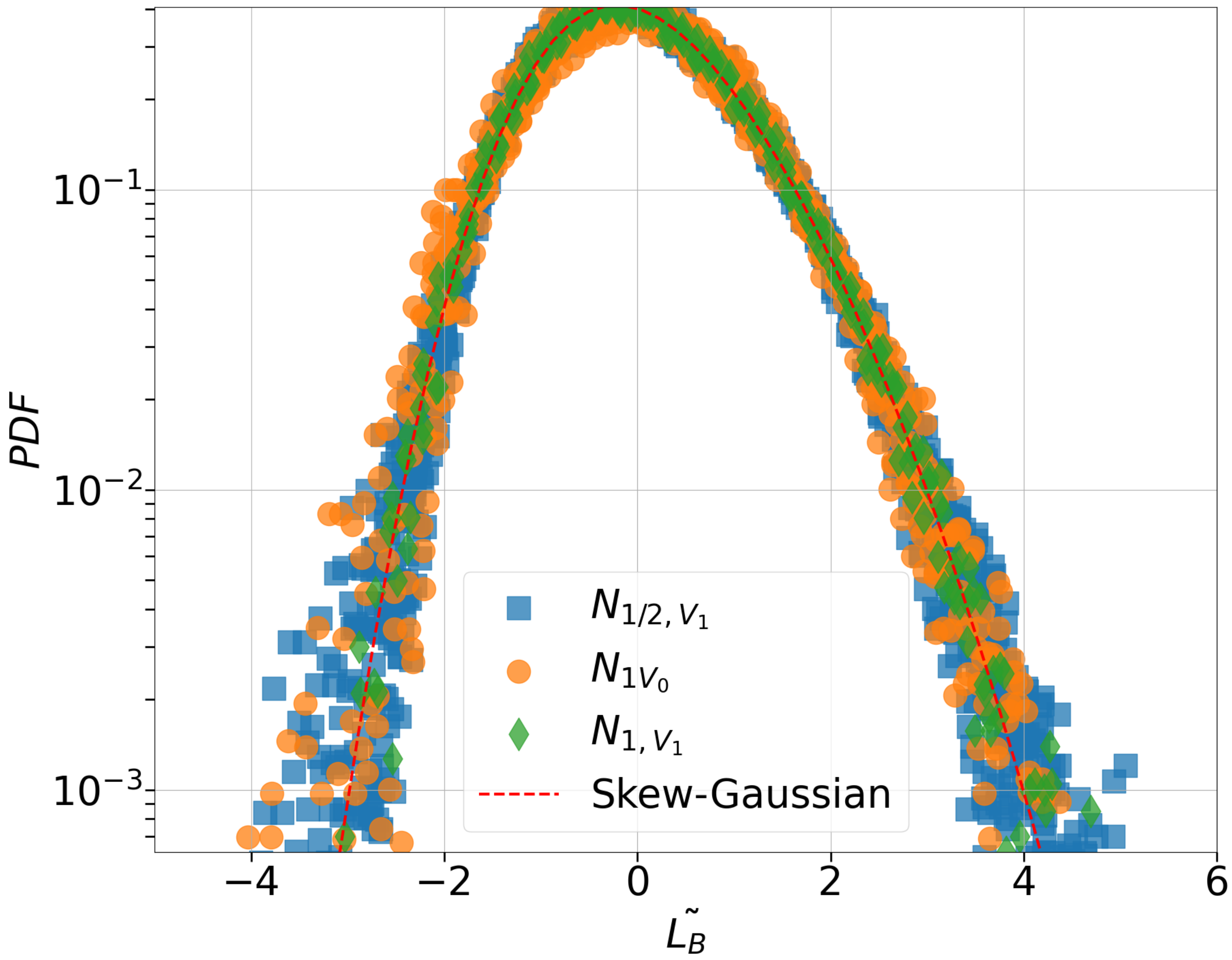
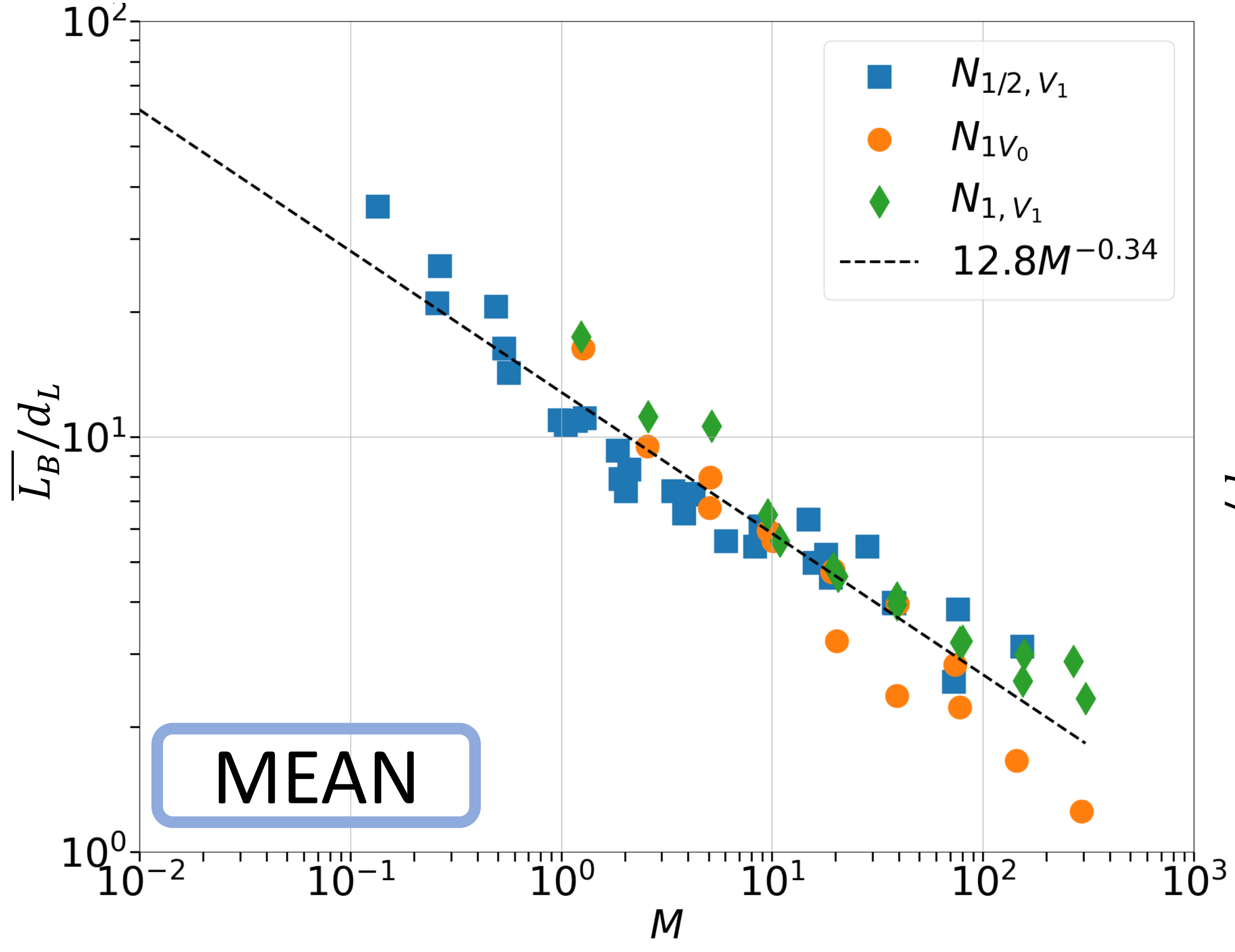


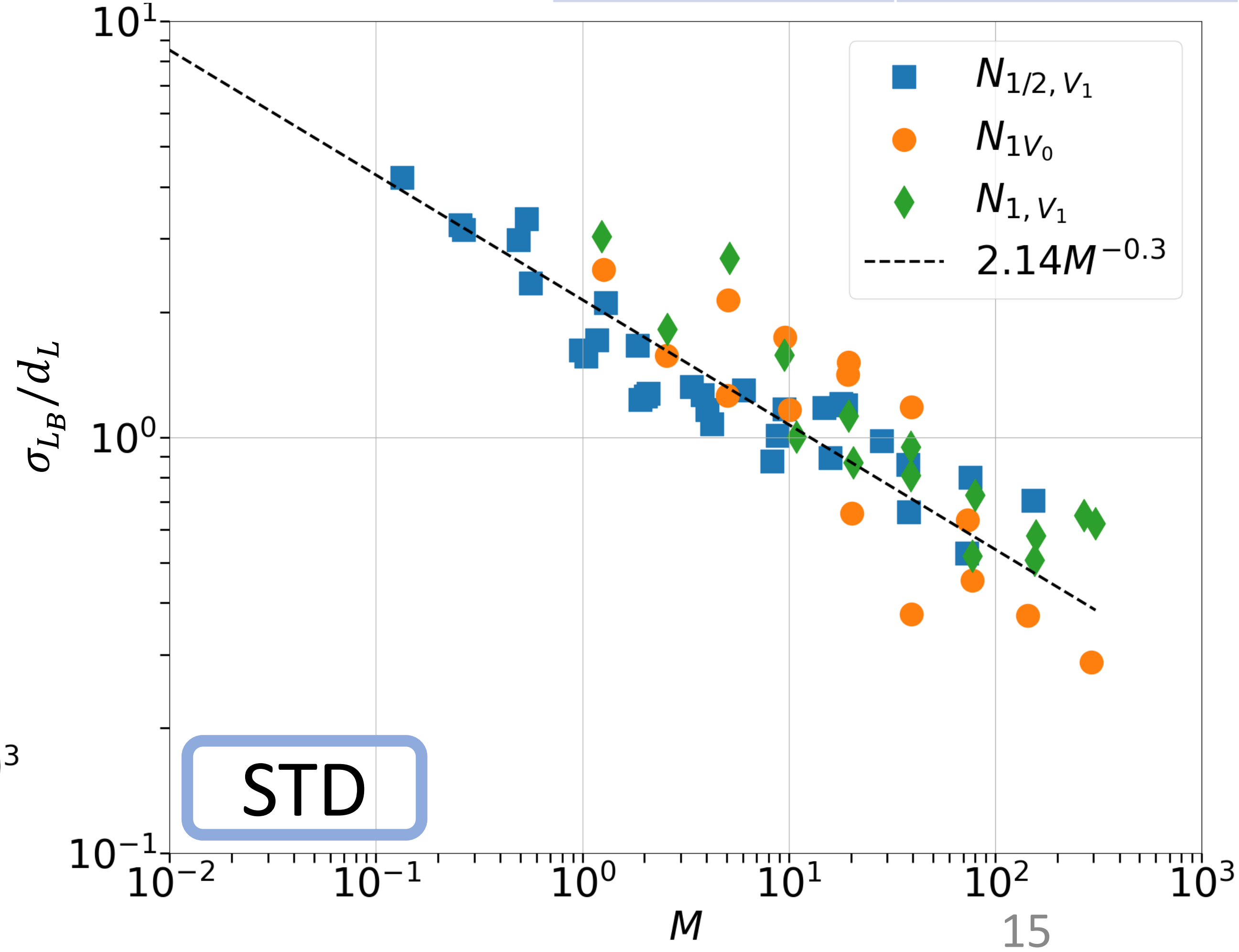
$$\widetilde{L_B} = \frac{L_B - \overline{L_B}}{\sigma_{L_B}}$$

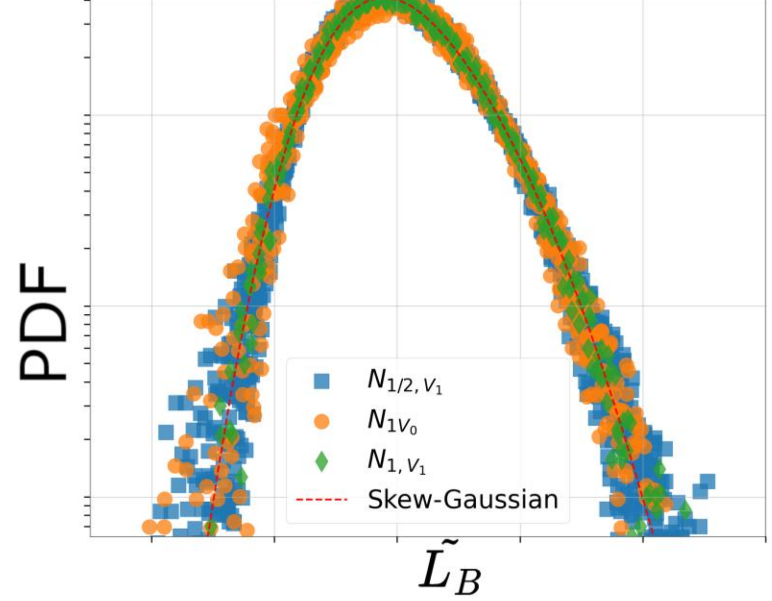
L_B statistics

Tolfts, O., Rack, A., & Machicoane, N. (2024). Morphology and dynamics of the liquid jet in high-speed gas-assisted atomization retrieved through synchrotron-based high-speed X-ray imaging. *International Journal of Multiphase Flow*, *181*, 105004.

Nozzle	d_L [mm]
N_{1,V_0}	2
N_{1,V_1}	2
$N_{1/2,V_1}$	1

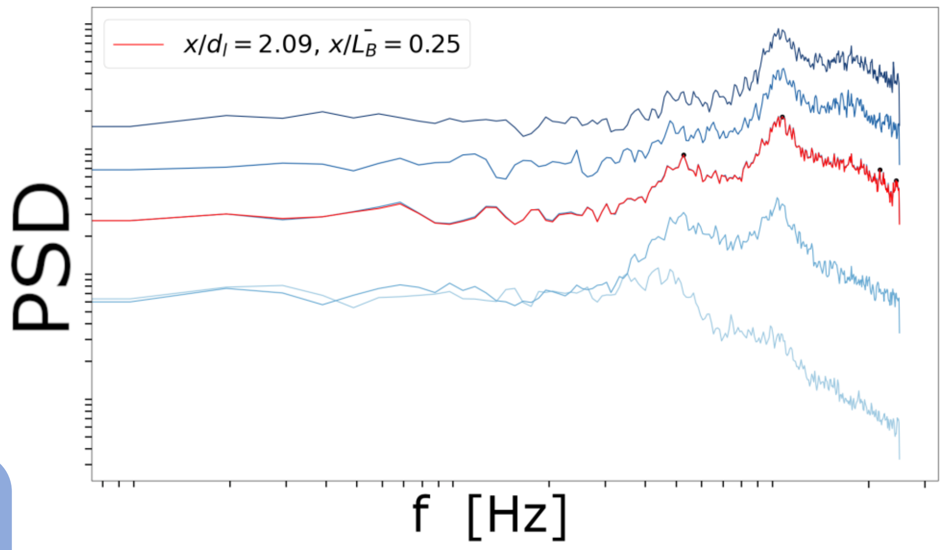




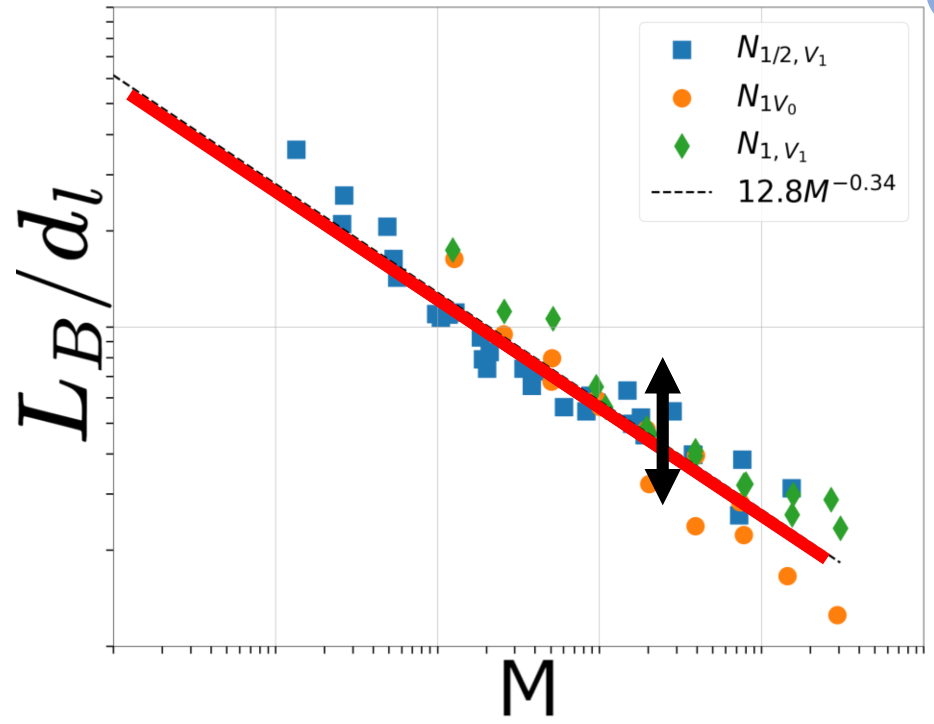


Scale invariant centered normalized PDF

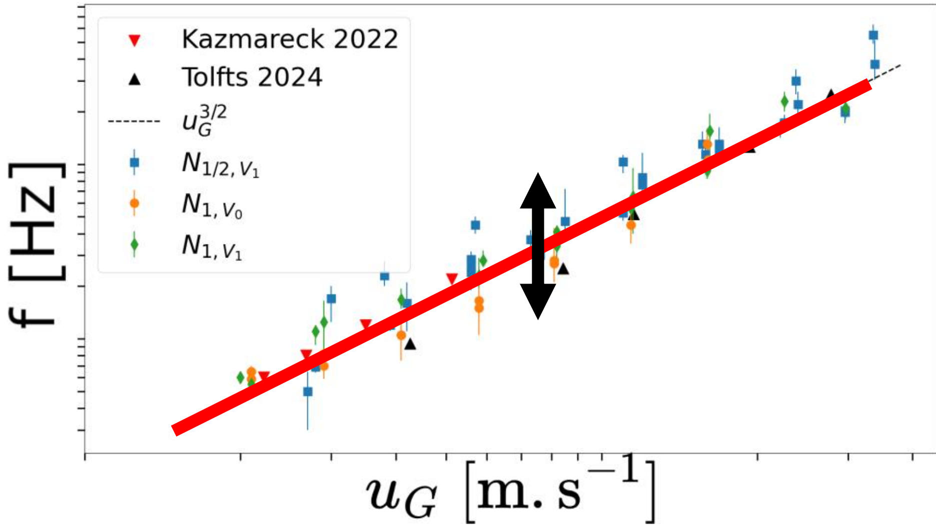
Rich spectra to understand



Conclusions



Trends preserved at different scales



Imperfect collapse

Perspectives

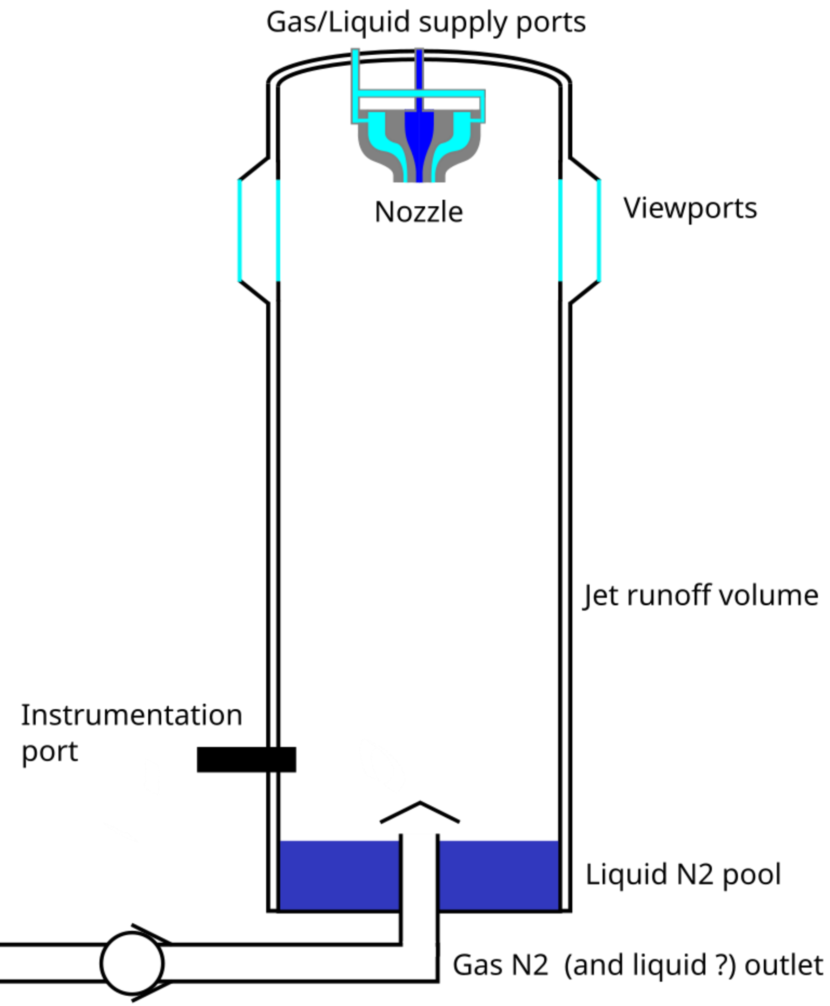
Analysis :

- Measure other quantites e.g. interface positions
- Linear Stability analysis with J-P Matas

Setup development :

- Expand range of scales
- Study other geometric variations, e.g. lip thickness
- Nitrogen cryostat in construction
- Helium setup in development

Perspectives



Design by
Grégory Garde
@Institut Néel