

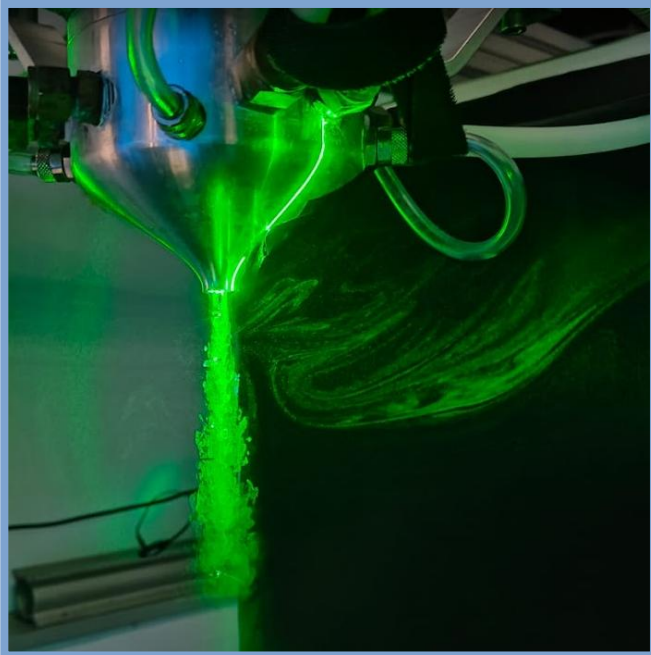
Measurement and prediction of flapping instability frequency in coaxial atomization

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

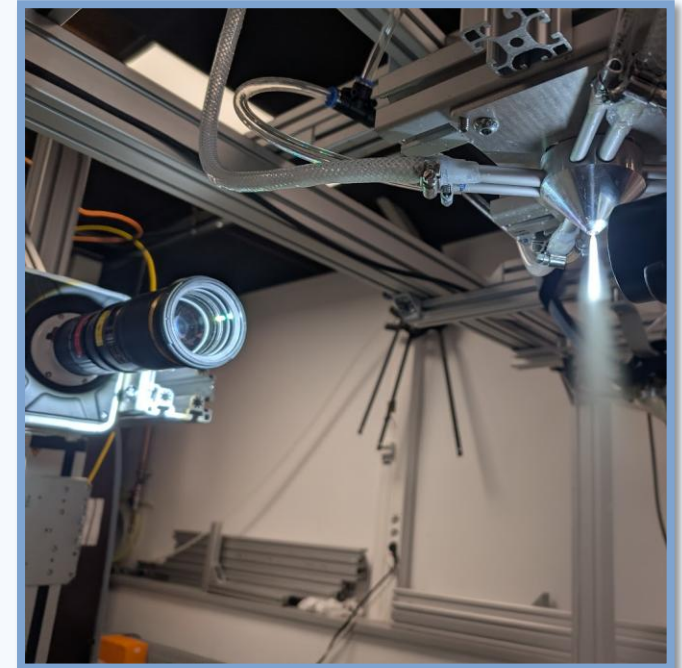
(1) Univ. Grenoble Alpes, CNRS, Institut Néel, Grenoble Cedex 9 38042, France

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

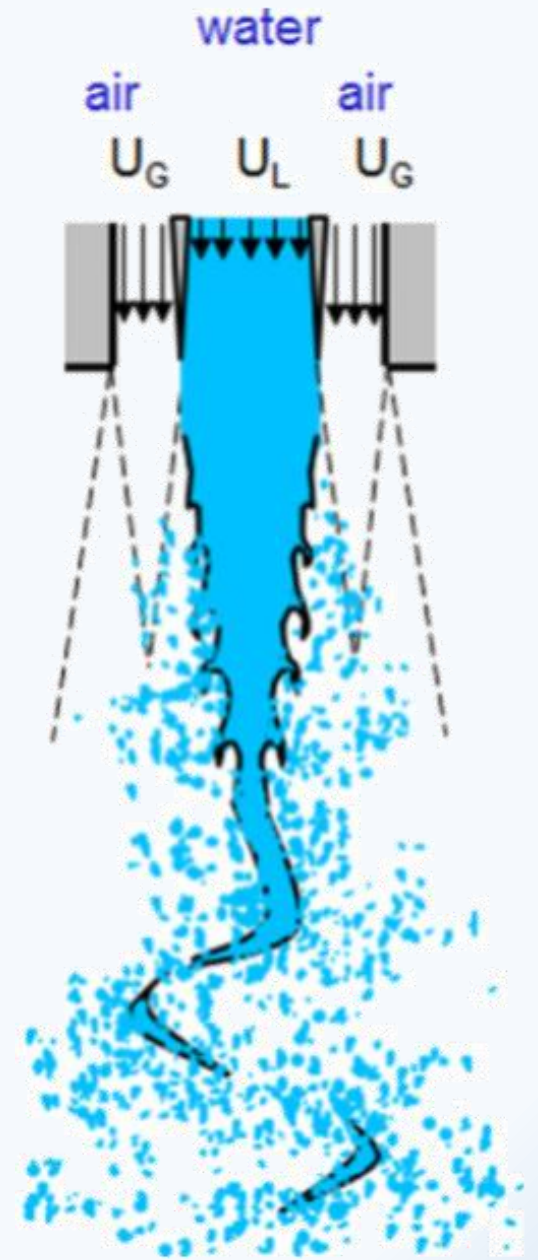
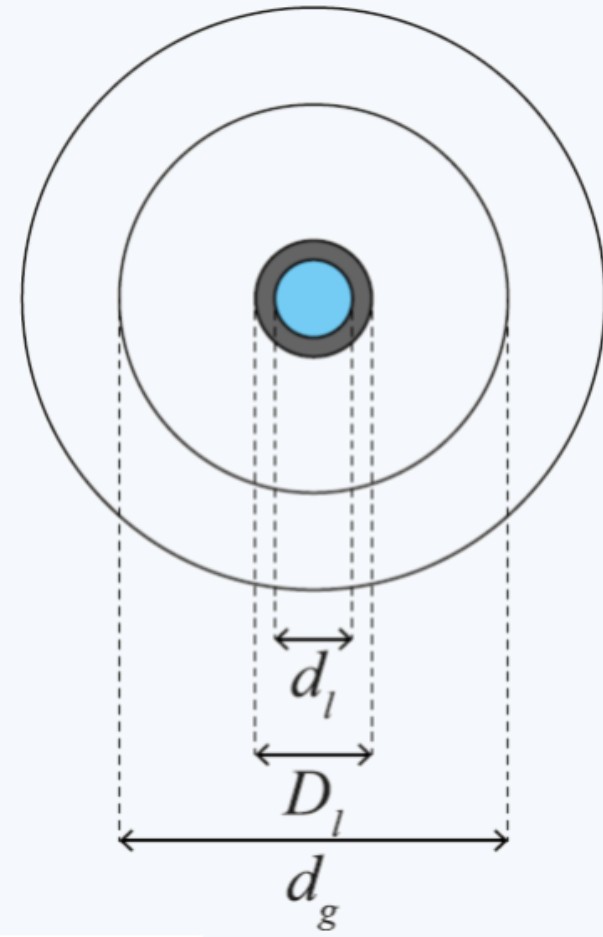
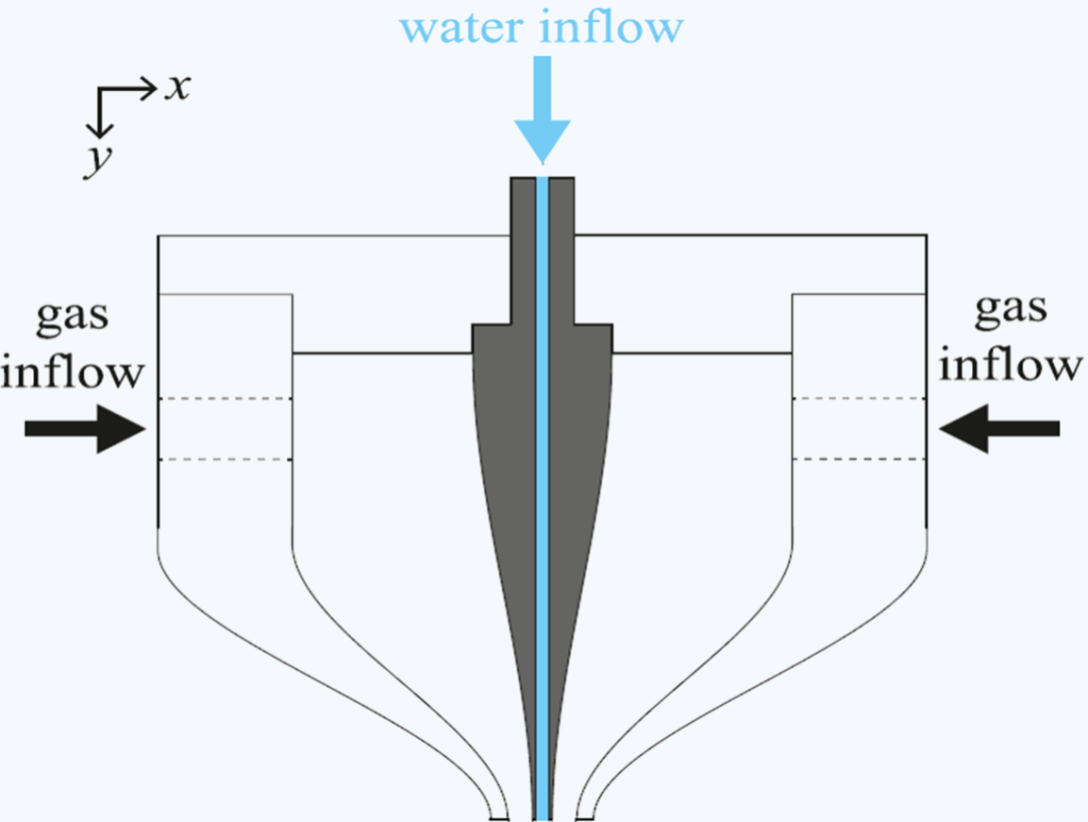
(3) Univ. Claude Bernard Lyon 1, LMFA, Villeurbanne, France



GdR TransInter April 5-7th 2026

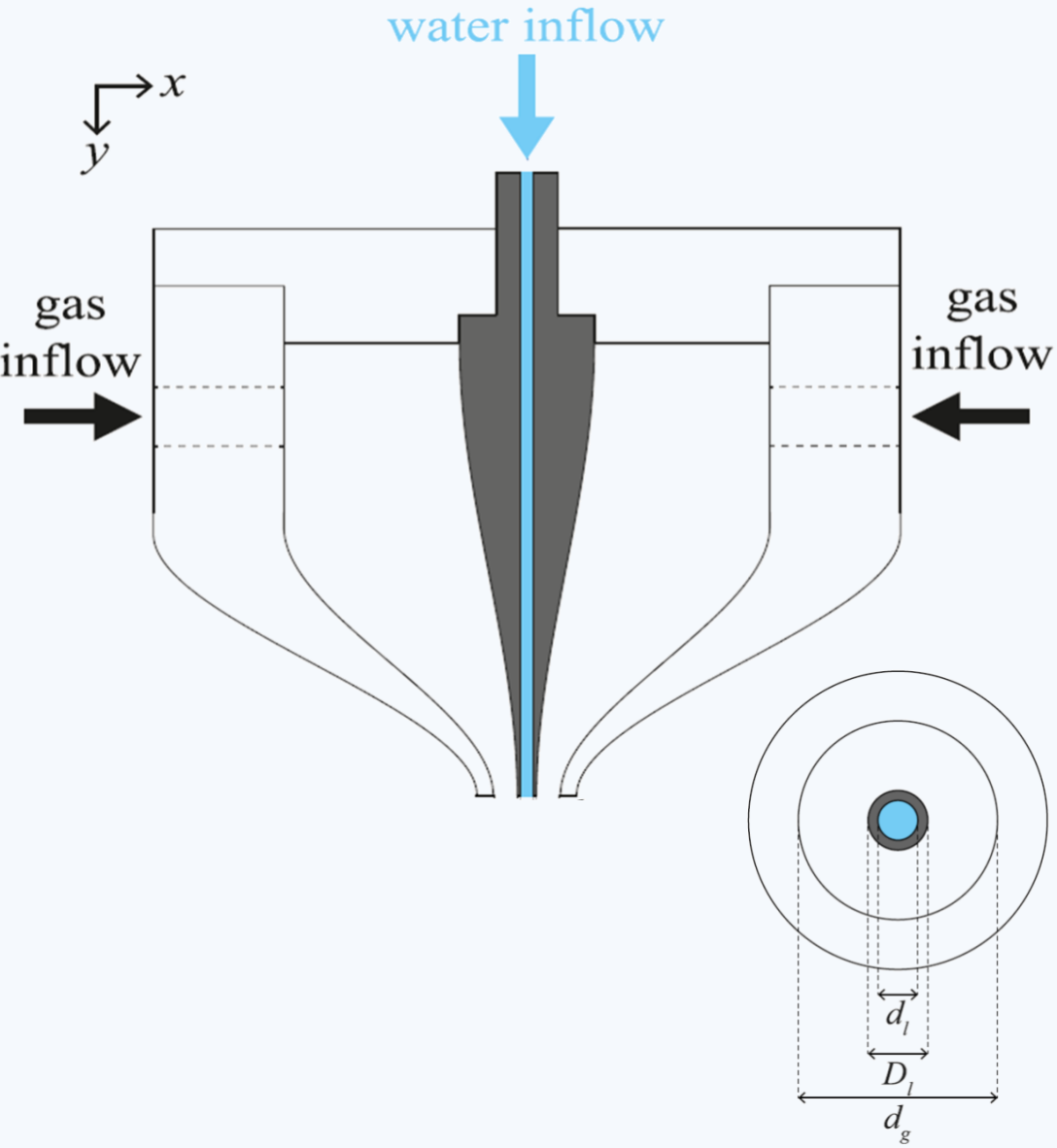


Coaxial Atomization

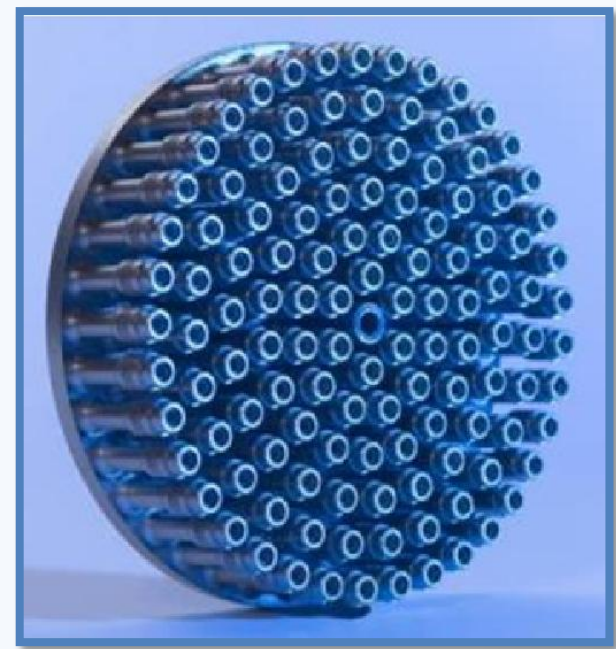


Nozzle scale S_{scale}	d_l [mm]	D_l [mm]	d_g [mm]
S_1	2	3	10

Coaxial Atomization



Vulcain engine



Vinci Injector plate

Soller, Sebastian & Behr, R & Beyer, S & Laithier, F & Lehmann, M & Preuss, A & Salapete, R. (2017). Design and Testing of Liquid Propellant Injectors for Additive Manufacturing.

https://www.esa.int/ESA_Multimedia/Videos/2020/09/Vulcain_2.1_roars

Better modeling of atomization processes

We study:

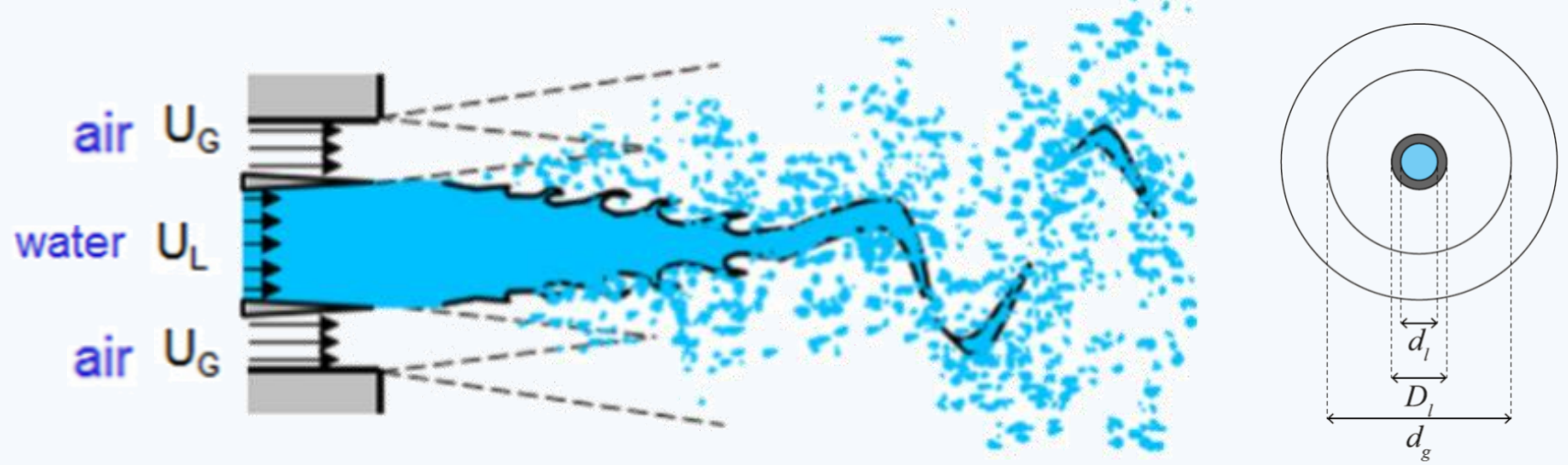
- Nozzle geometry and scaling
 - Cryogenic atomization
 - Instabilities
- Large scale fragmentation mechanisms

Better modeling of atomization processes

We study:

- Nozzle geometry and scaling
 - Cryogenic atomization
 - Instabilities
- Large scale fragmentation mechanisms

Parameters



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

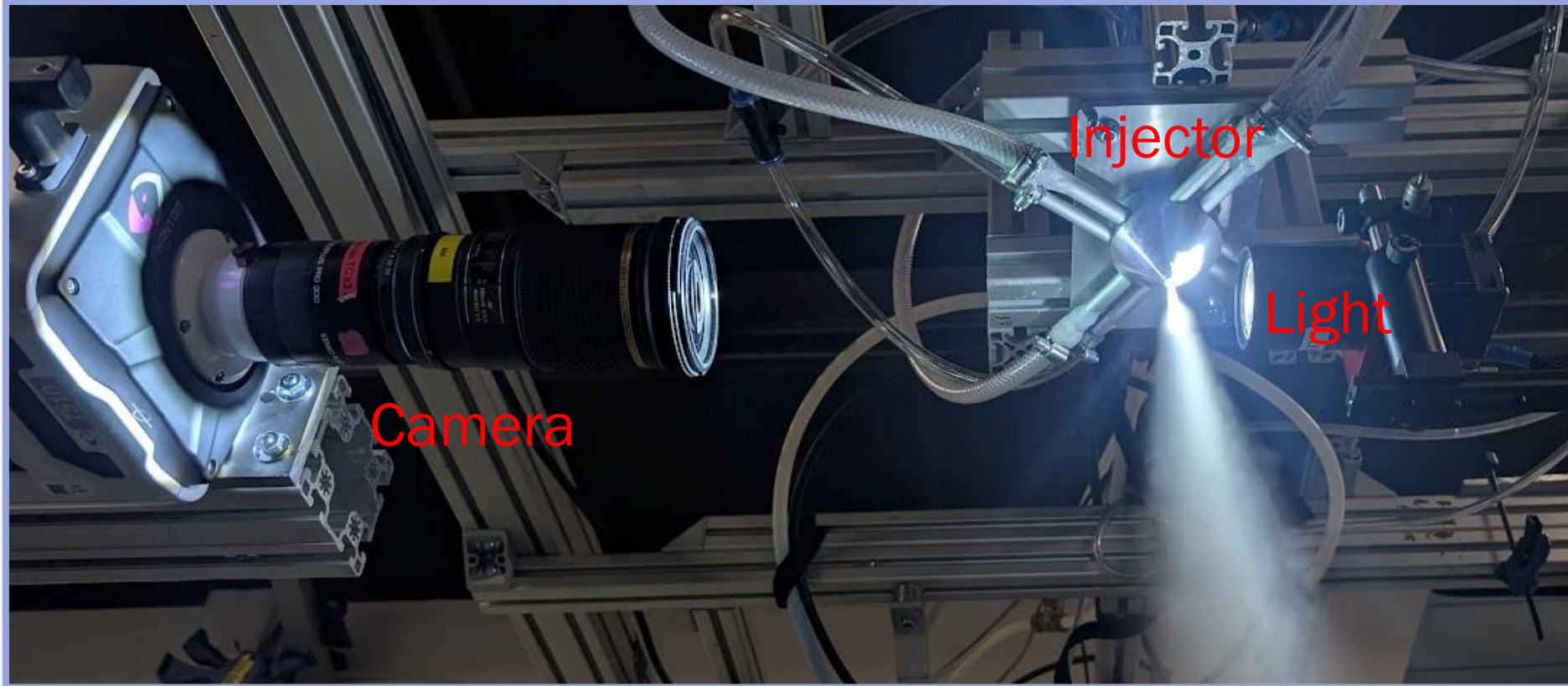
- Dynamic gas-to-liquid pressure ratio :
$$M = \frac{\rho_G u_G^2}{\rho_L u_L^2}$$

- 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 :
$$Re_L = \frac{4Q_L}{\nu_L \sqrt{4\pi A_L}} = \frac{u_G d_L}{\nu_G}$$

Experimental Setup

Experimental Setup

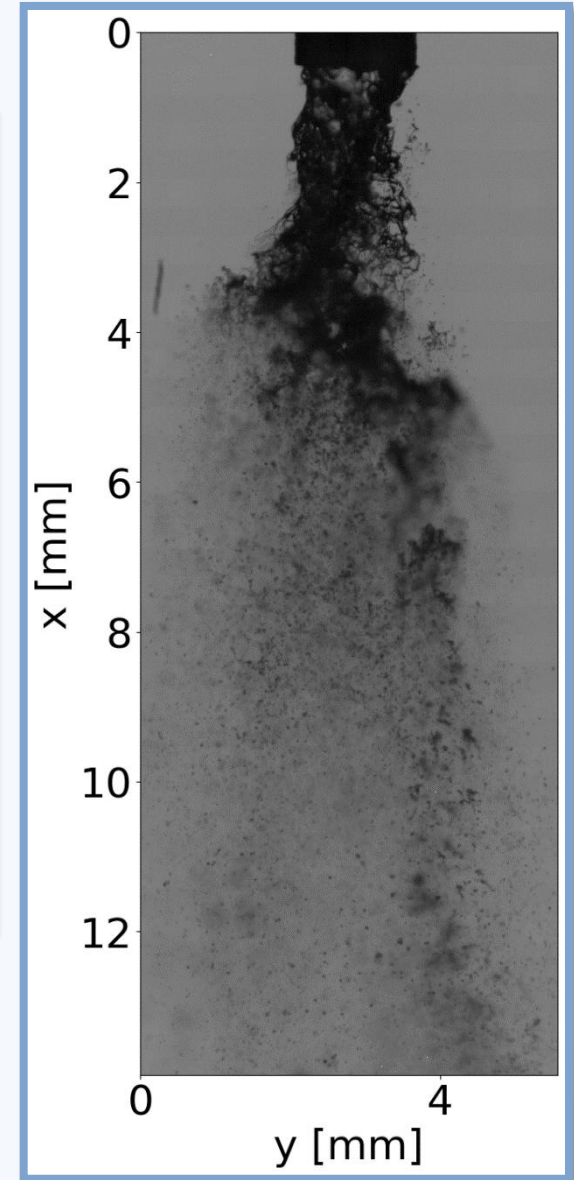


Camera

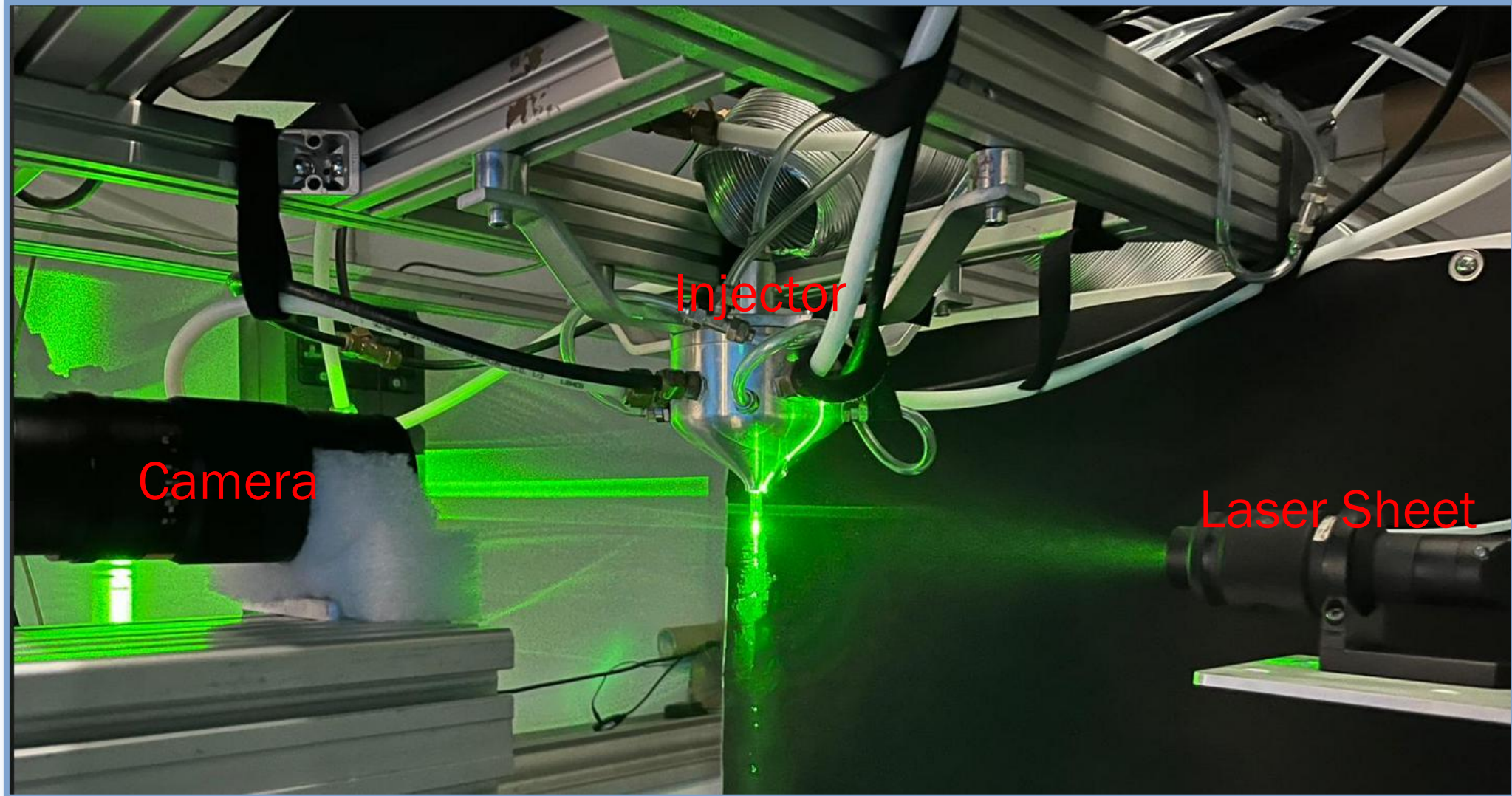
Injector

Light

Back-lit Imaging



Experimental Setup



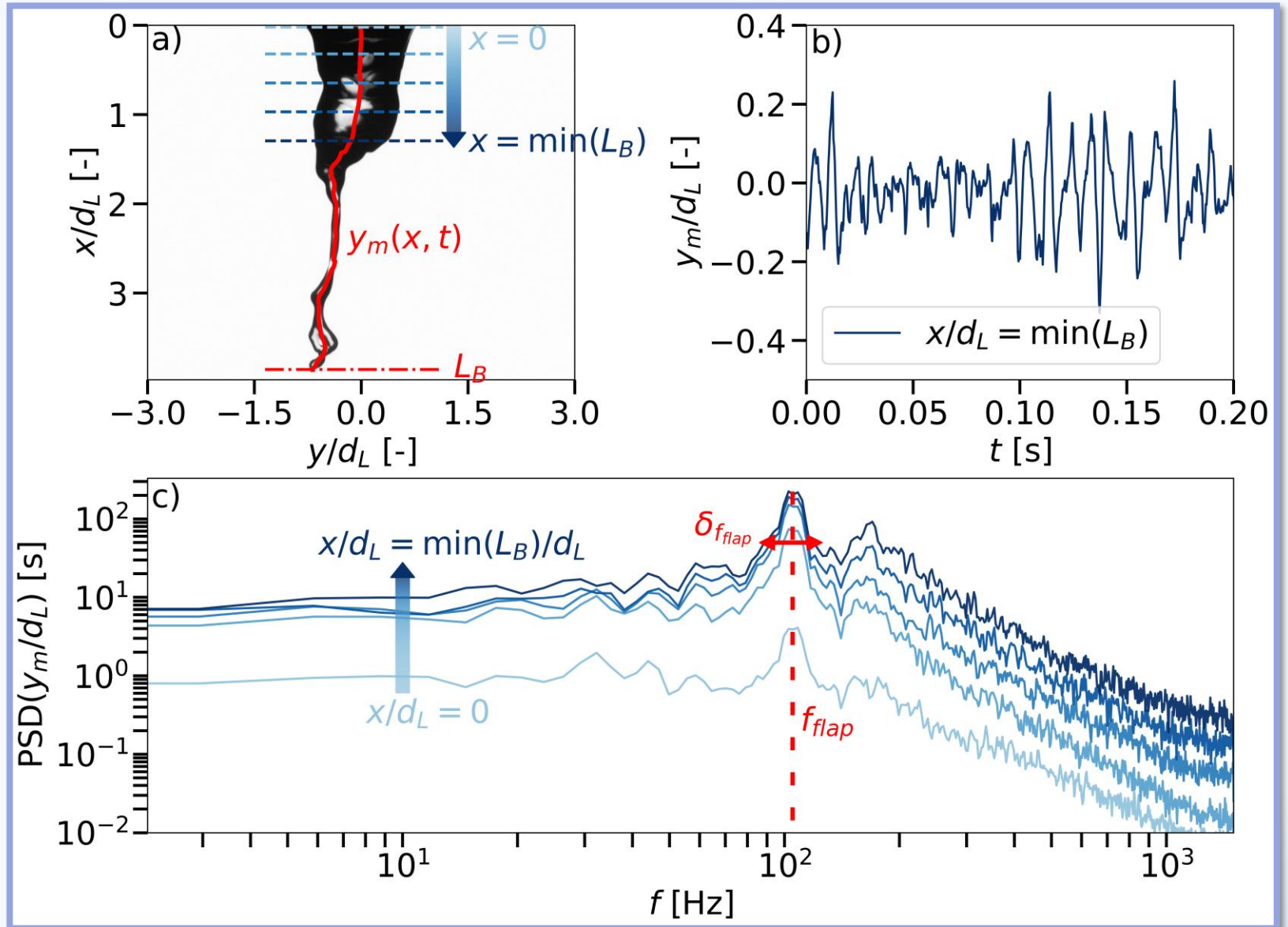
PIV Setup

Flapping Frequency

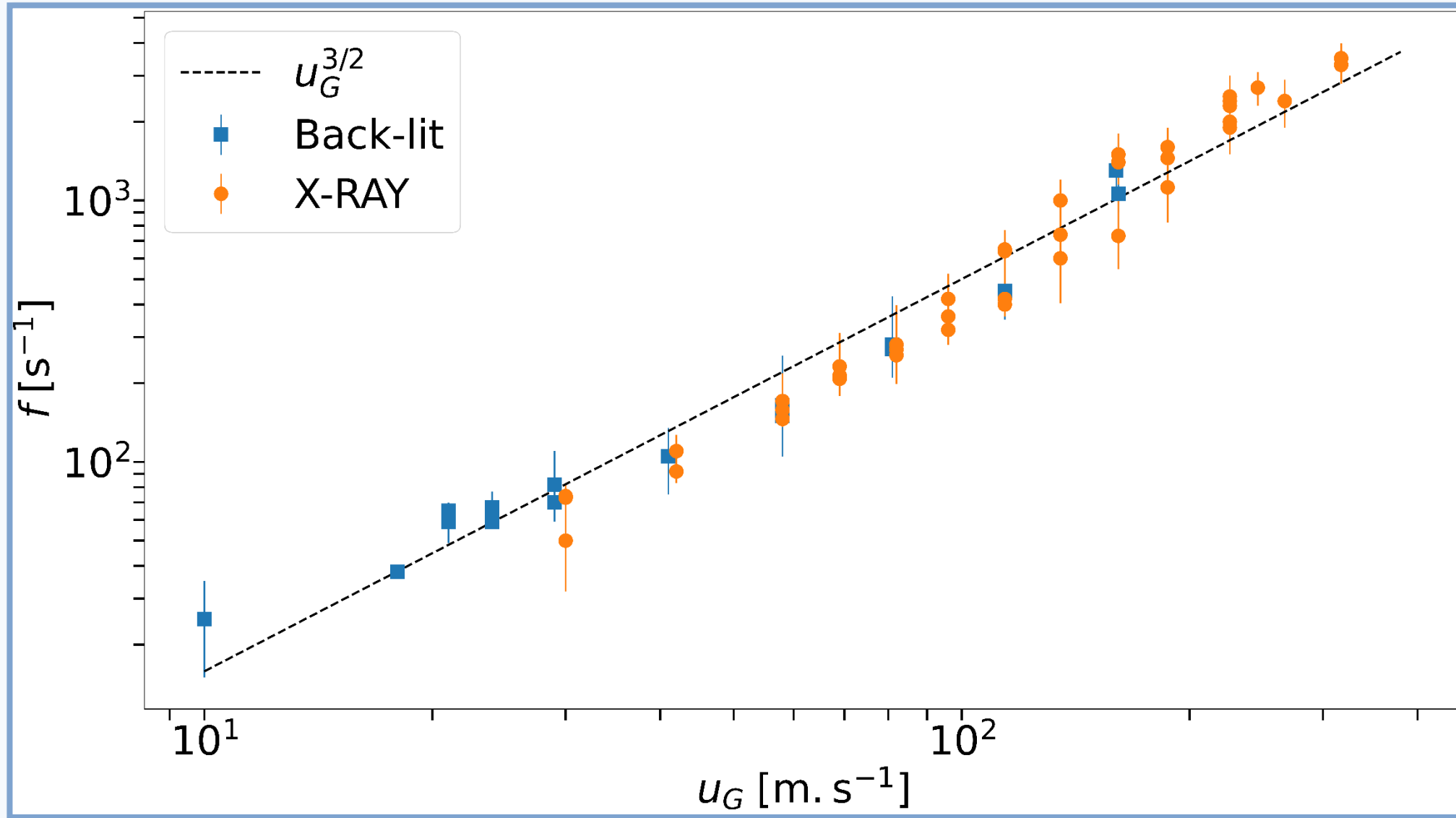
Flapping Frequency

Re_L	Re_G	We_G
620	2,7E4	56

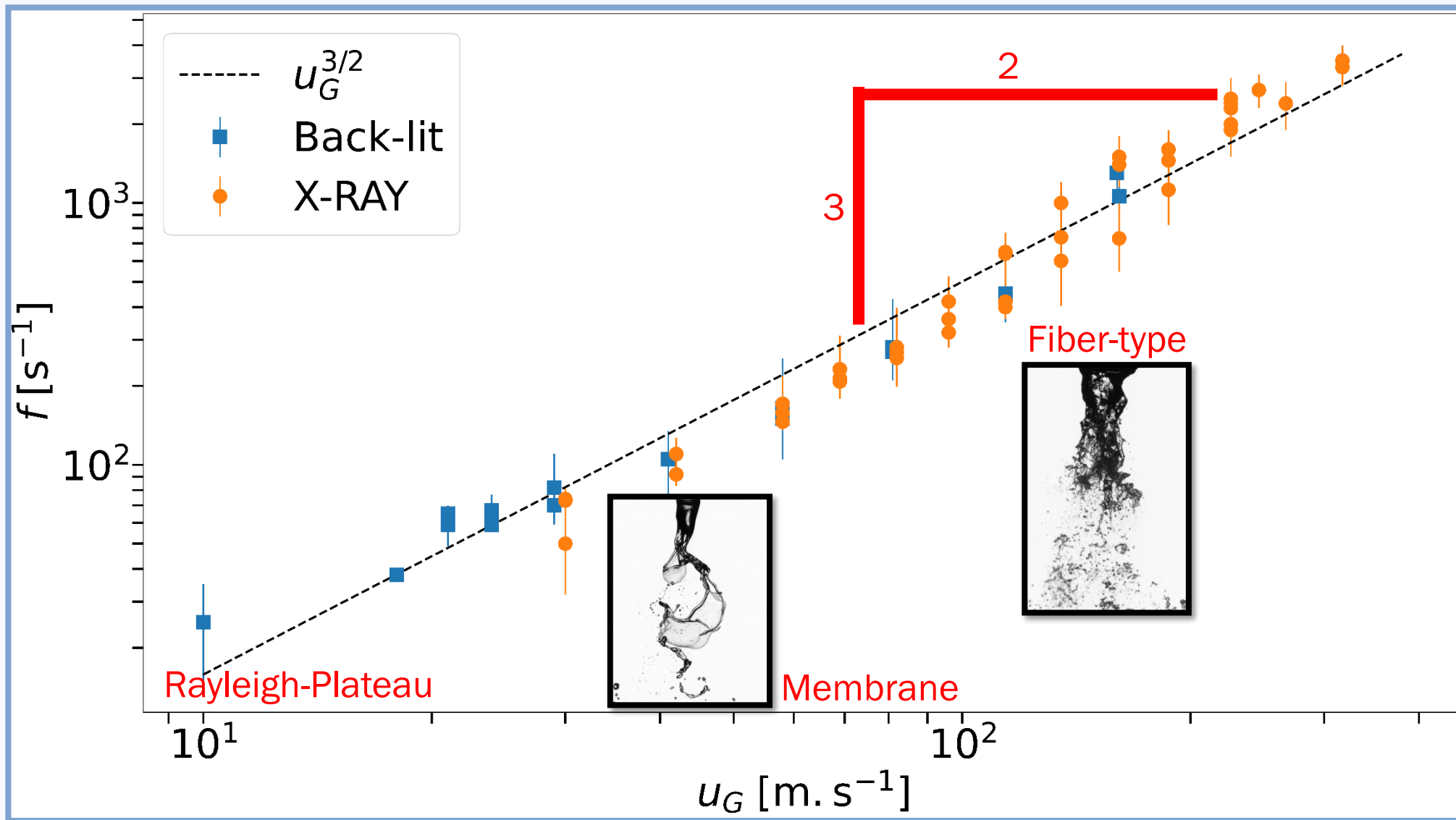
$L_B \equiv$ Intact jet length



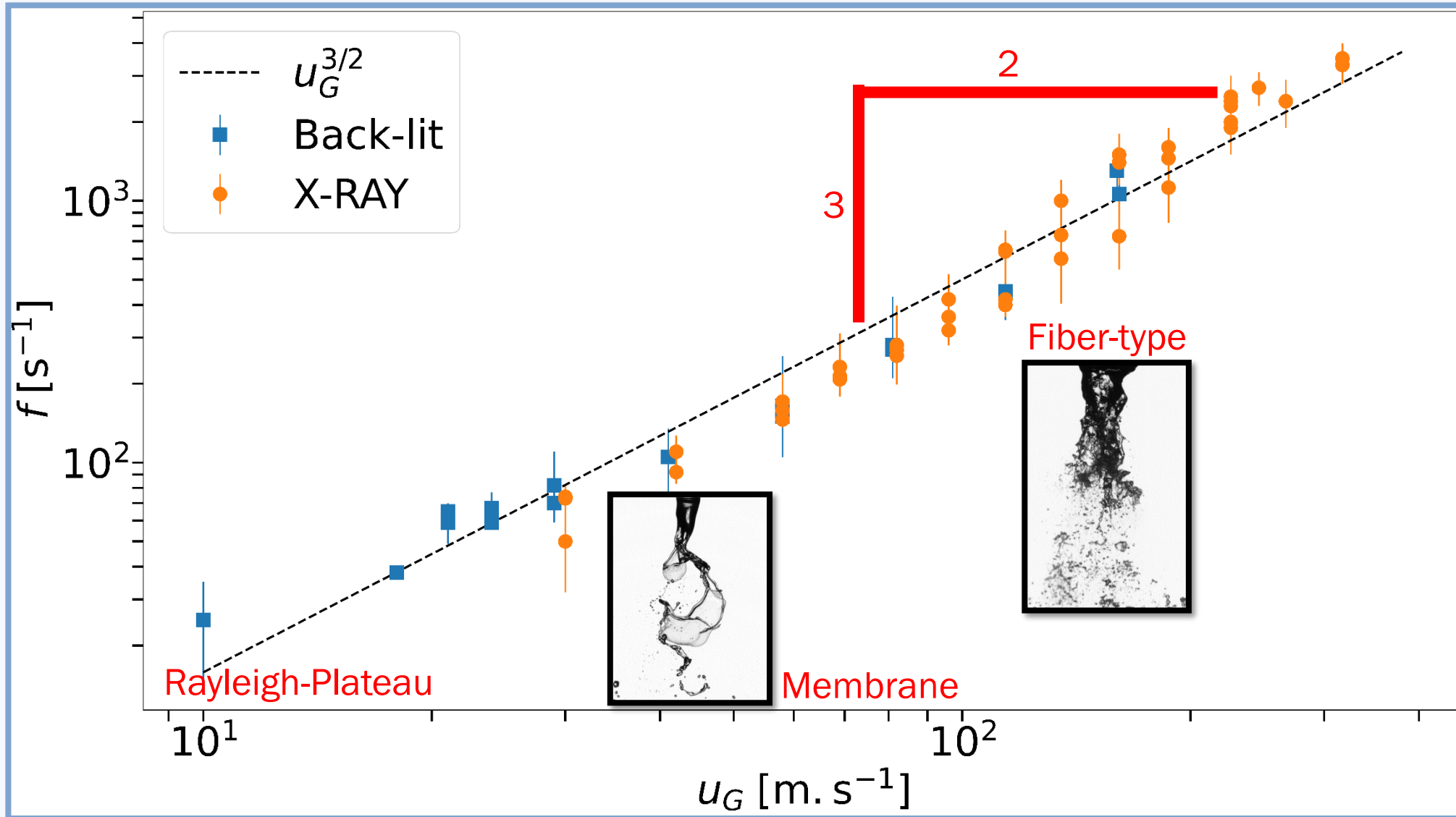
Flapping Frequency



Flapping Frequency



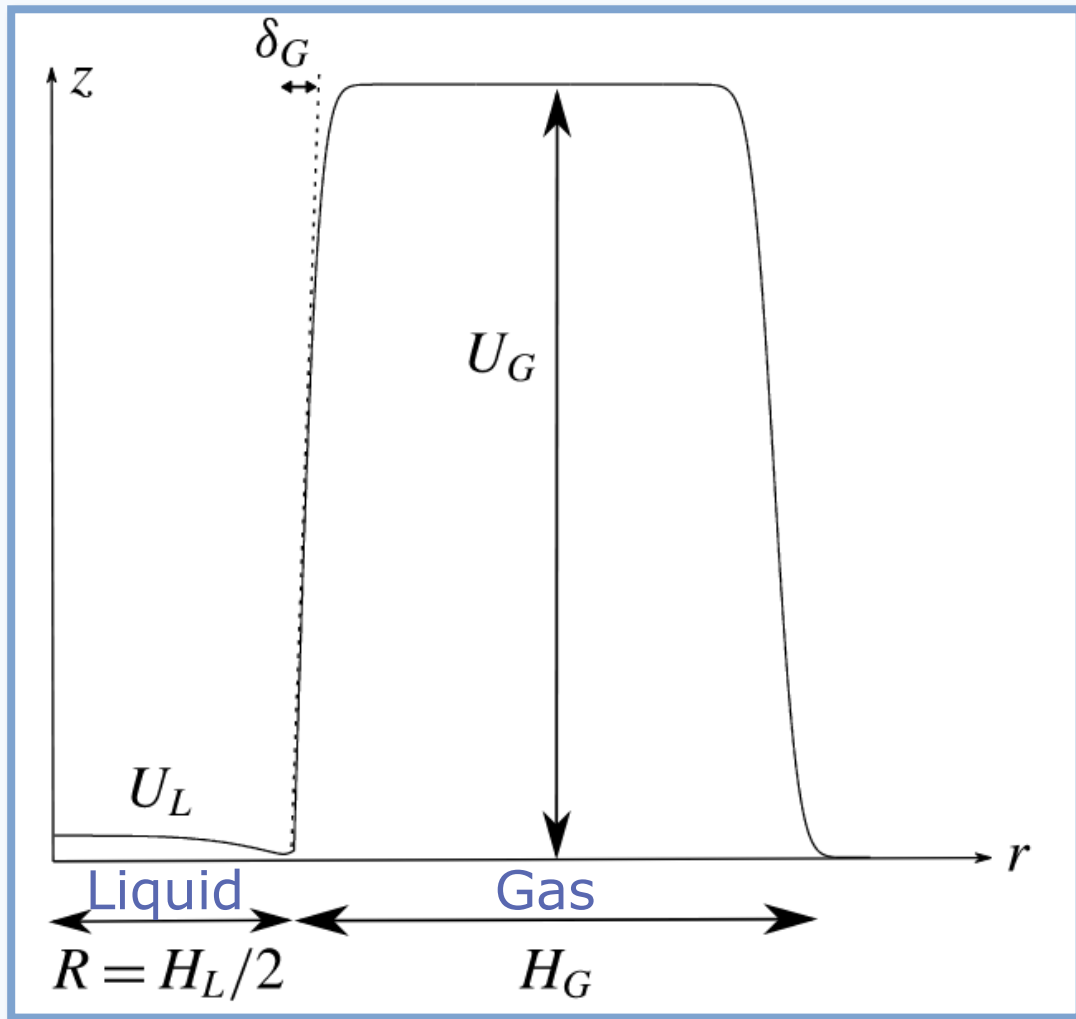
Flapping Frequency



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

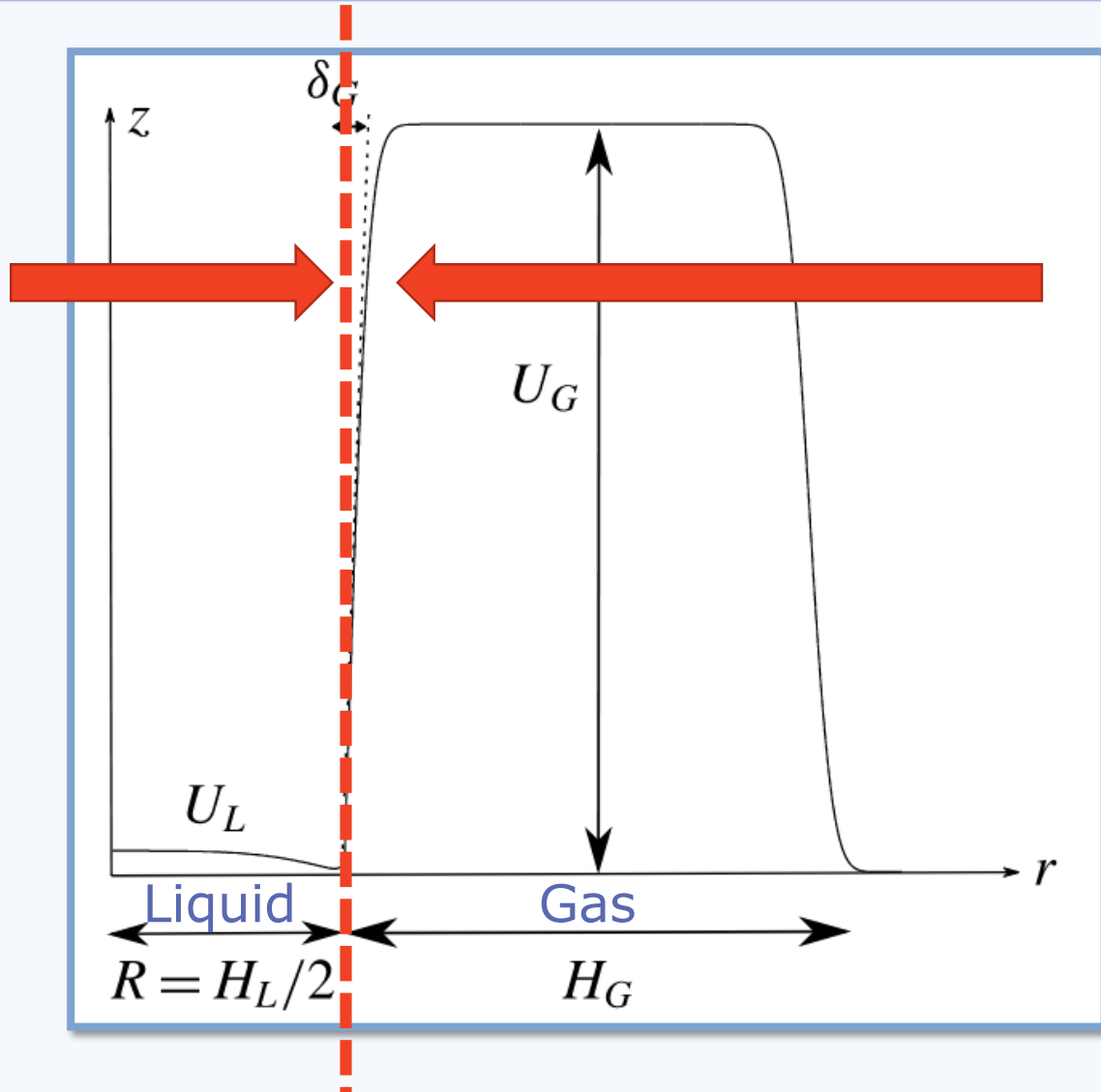
Linear Stability Analysis

Linear Stability Analysis (LSA)



- Linearized N-S equations in cylindrical referential
- Error function profile

Linear Stability Analysis (LSA)



- Linearized N-S equations in cylindrical referential + normal mode analysis
- Error function profile
- Shooting method : integration over both domains
- Validation of continuity conditions gives (\mathbf{k}, ω) solutions

LSA : Inputs

Characterization methods of stability analysis input parameters

δ_G

Gas BL
thickness

δ_d

Velocity
deficit

R

Liquid
radius

H_G

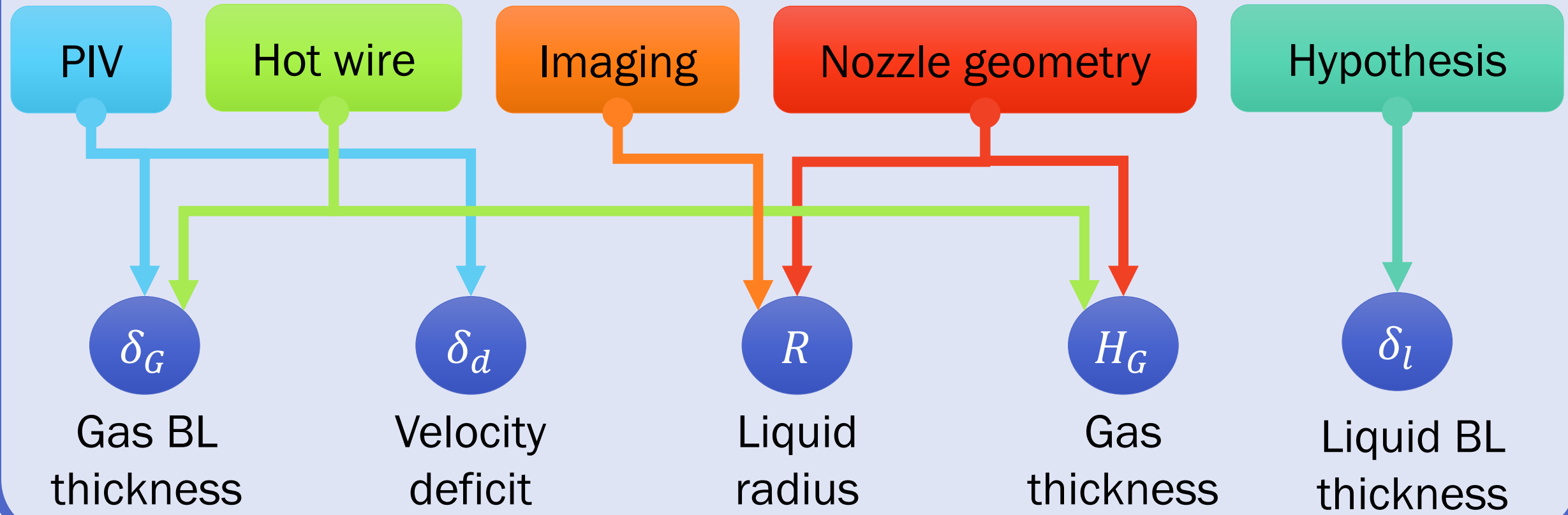
Gas
thickness

δ_l

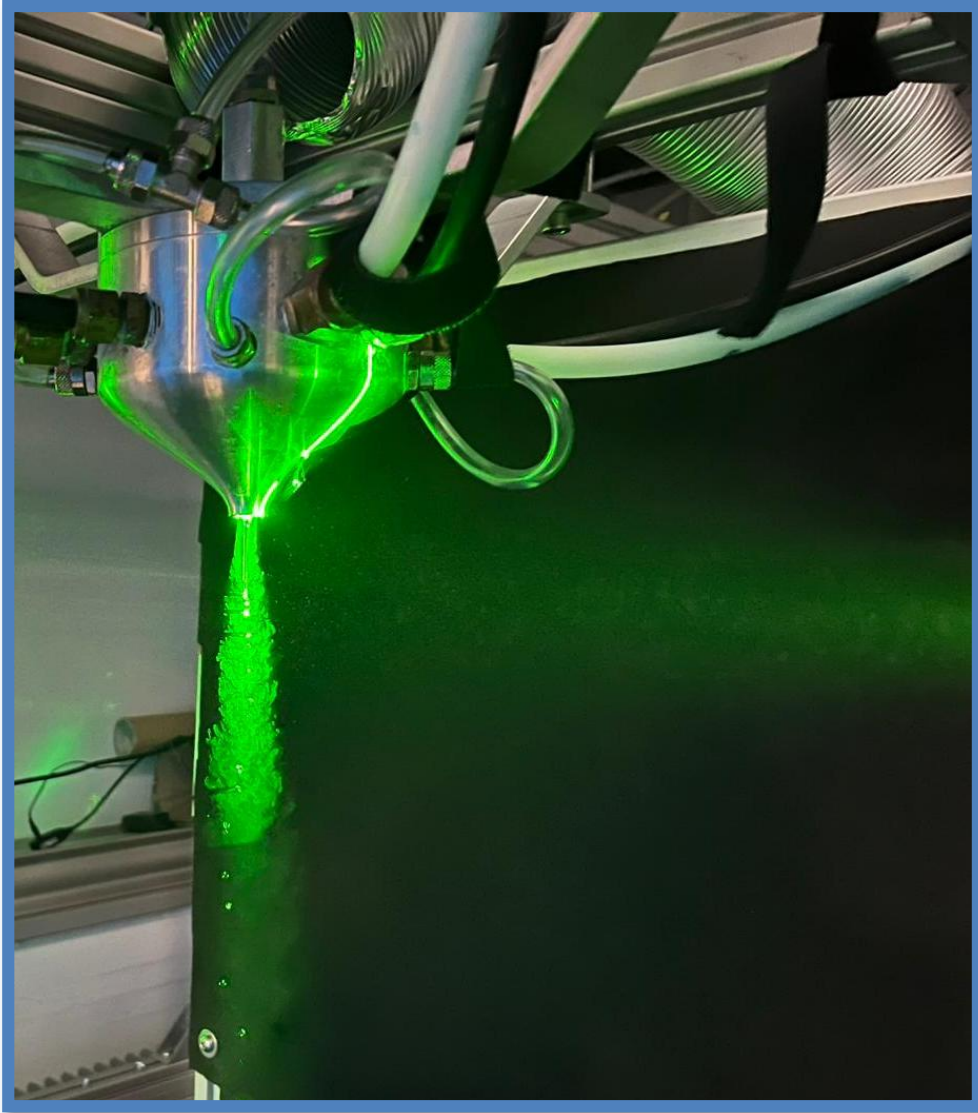
Liquid BL
thickness

LSA : Inputs

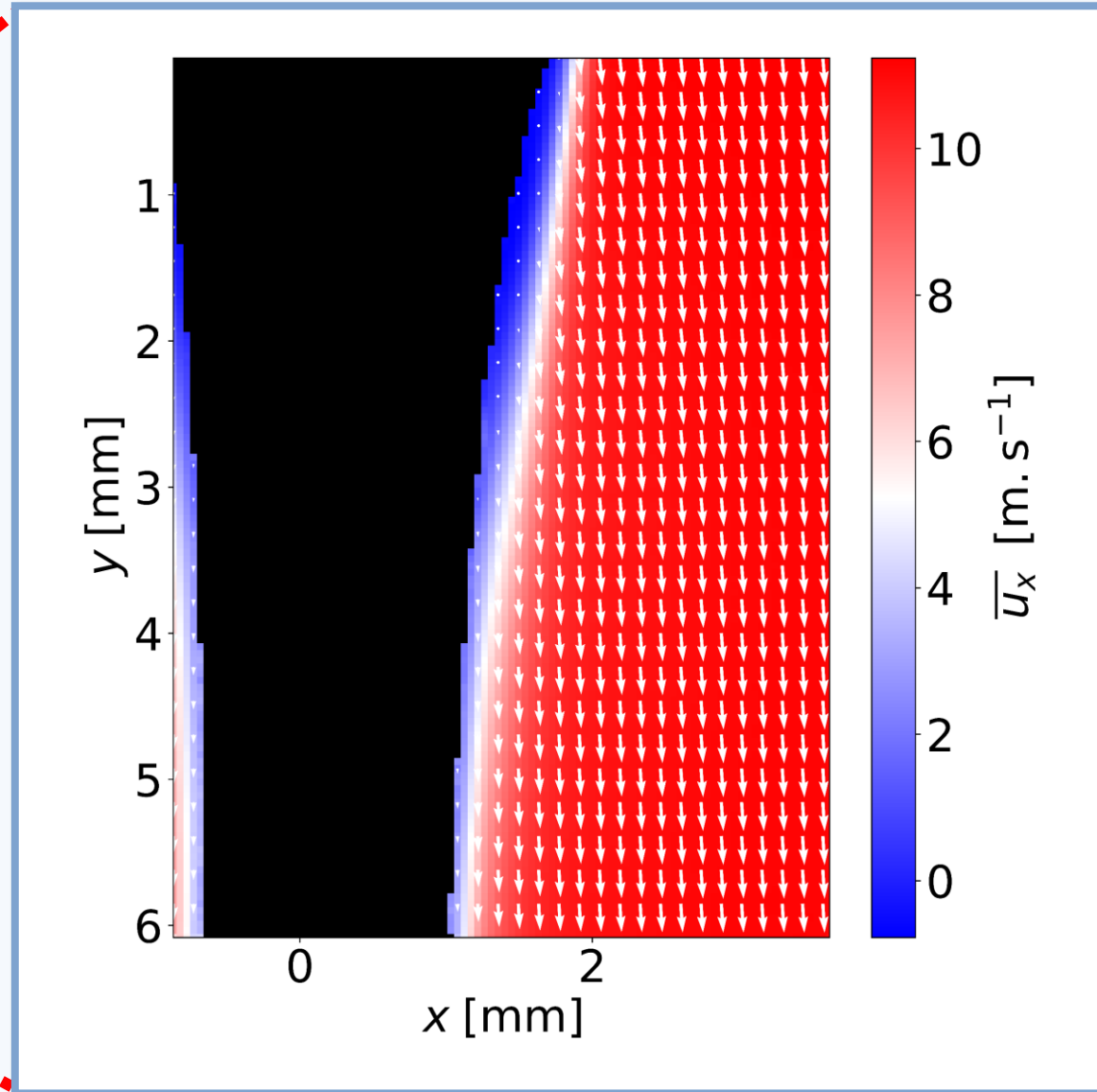
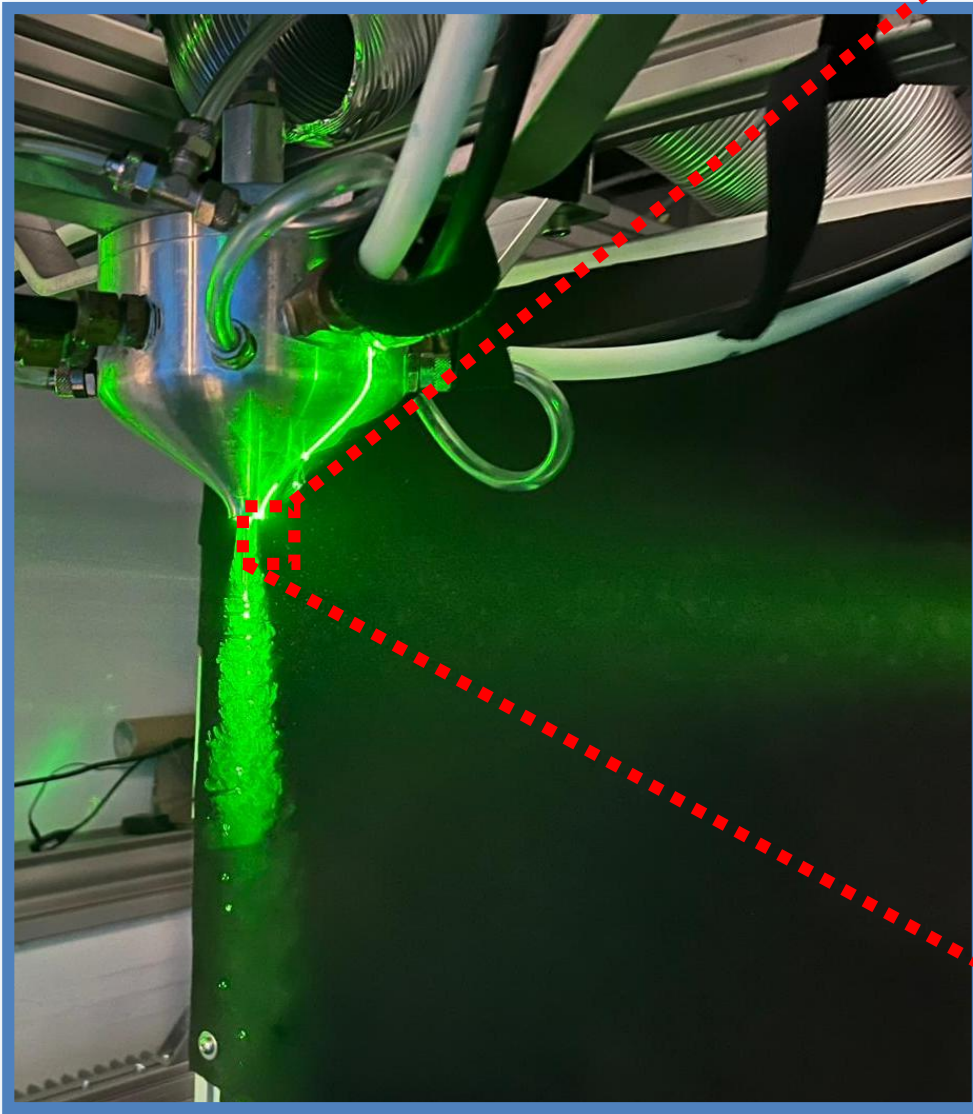
Characterization methods of stability analysis input parameters



δ_G Measurement

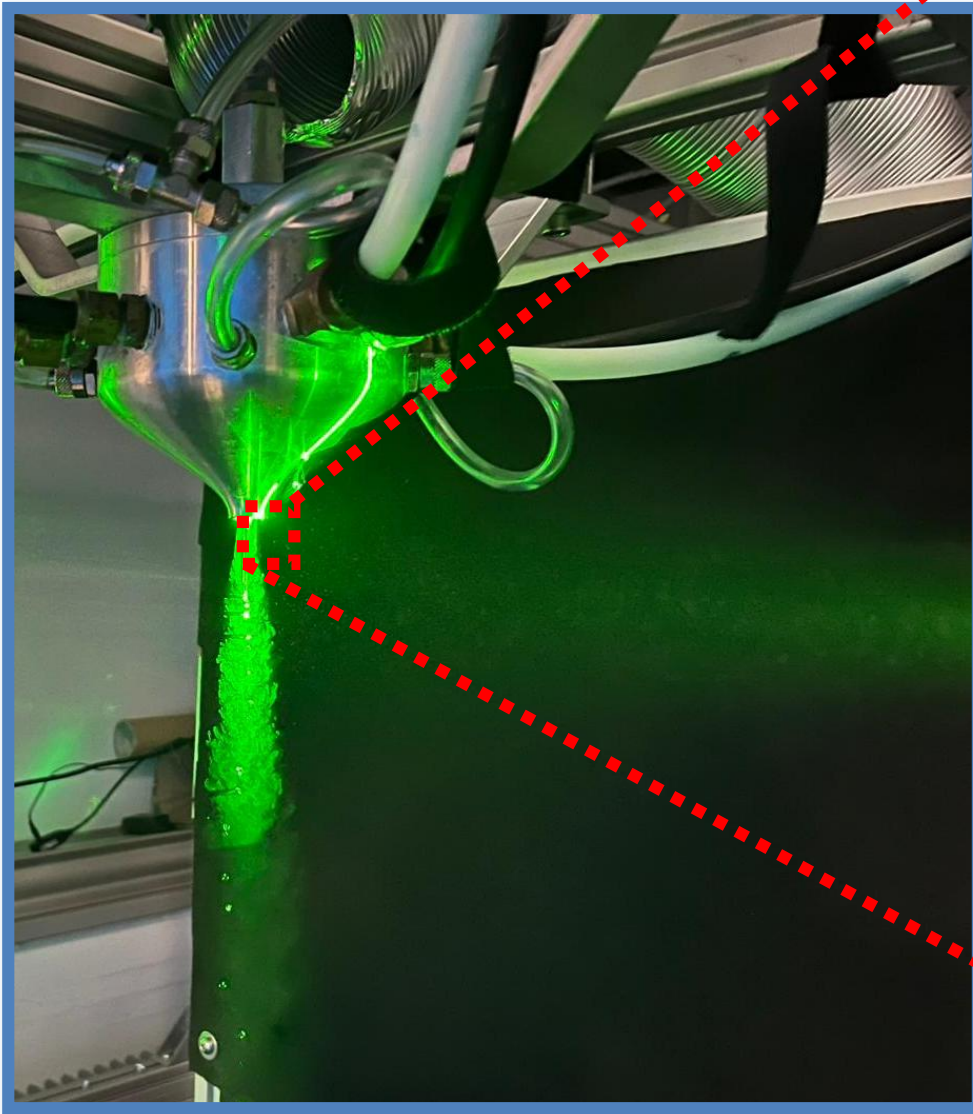


δ_G Measurement

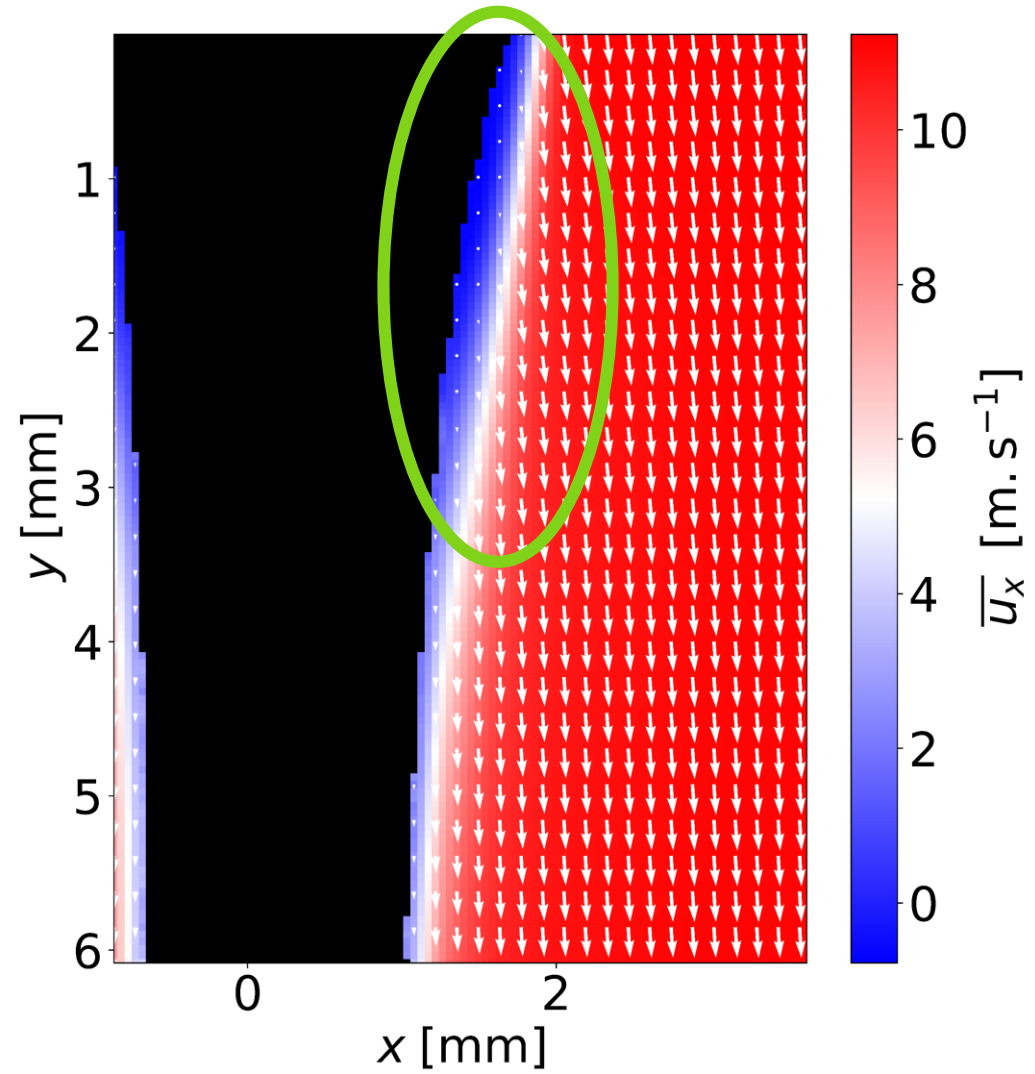


u_G (m/s)	u_L (m/s)
10.6	0.64

δ_G Measurement

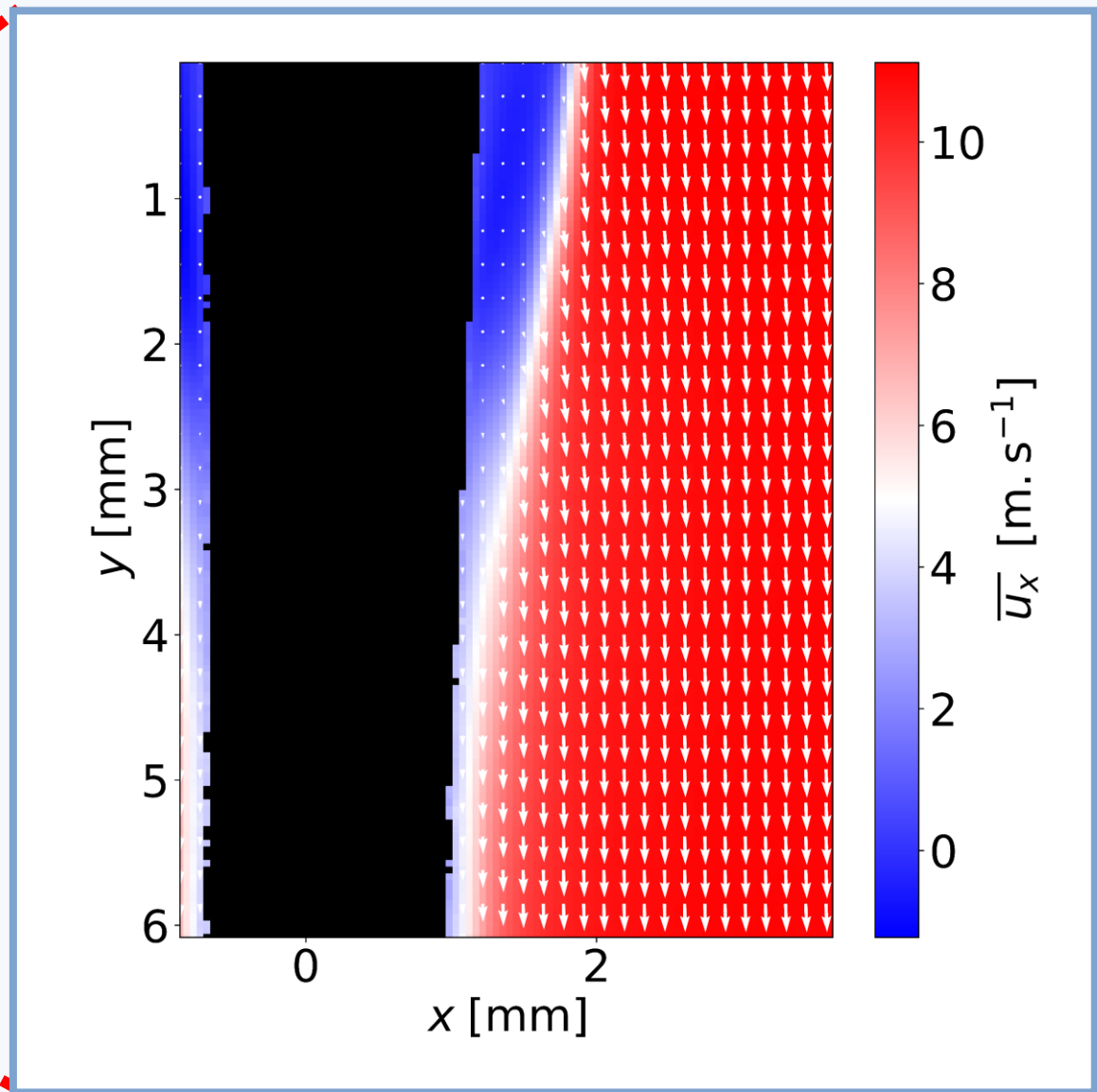
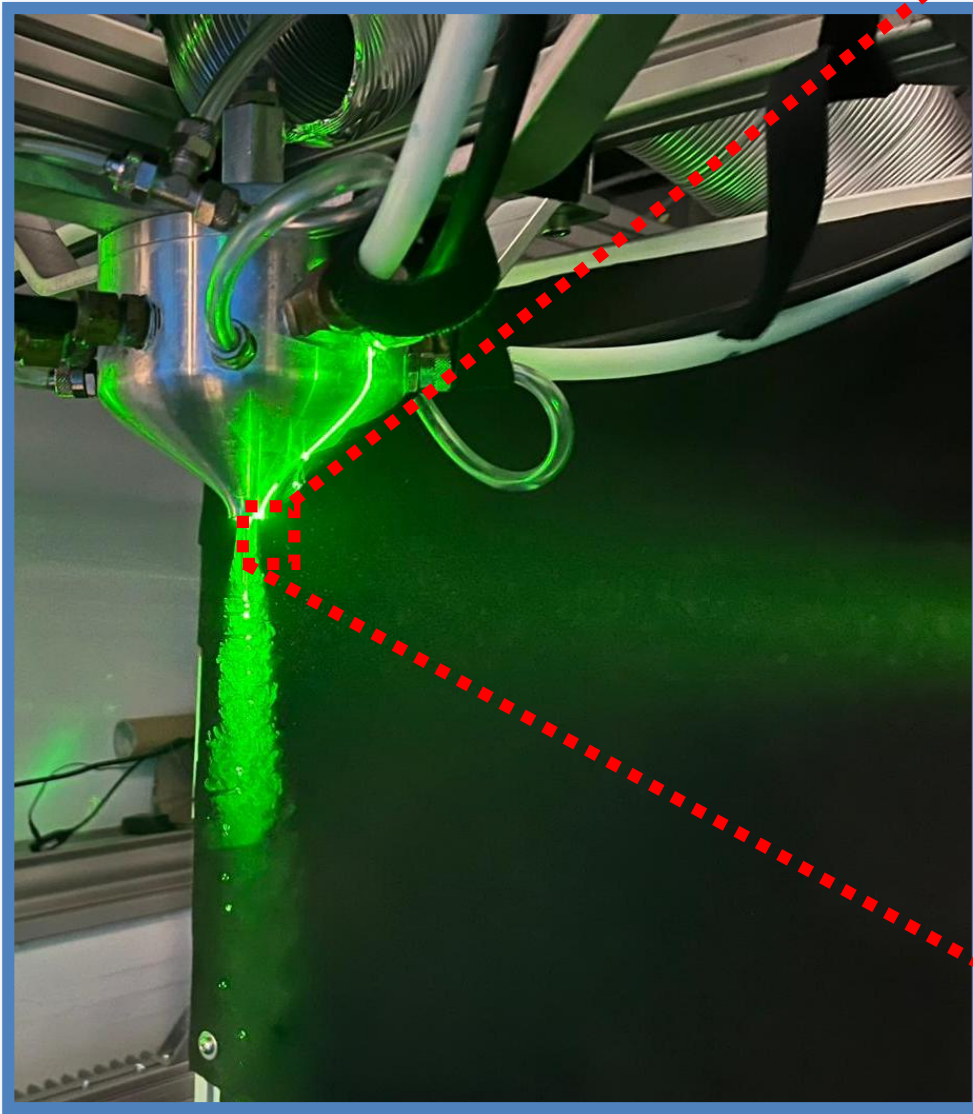


Small recirculation zone



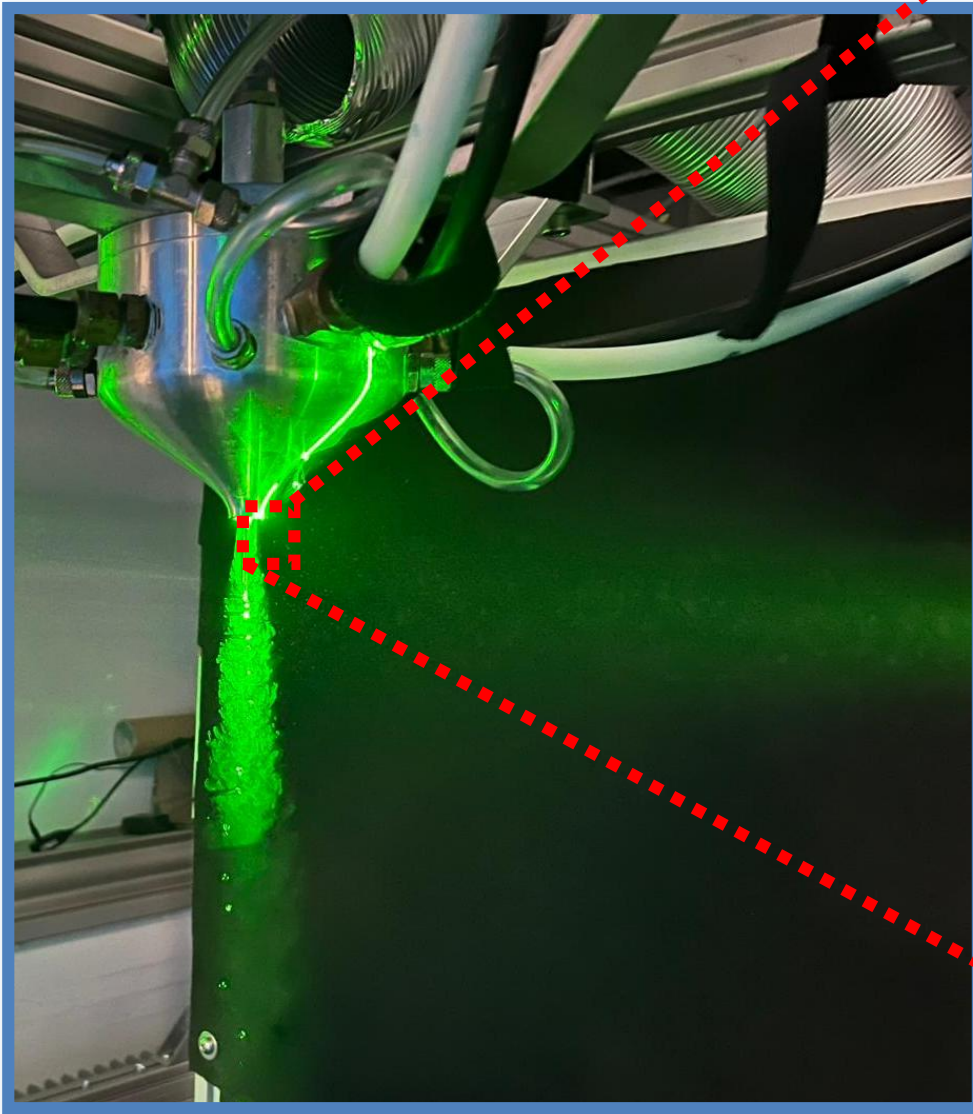
u_G (m/s)	u_L (m/s)
10.6	0.64

δ_G Measurement

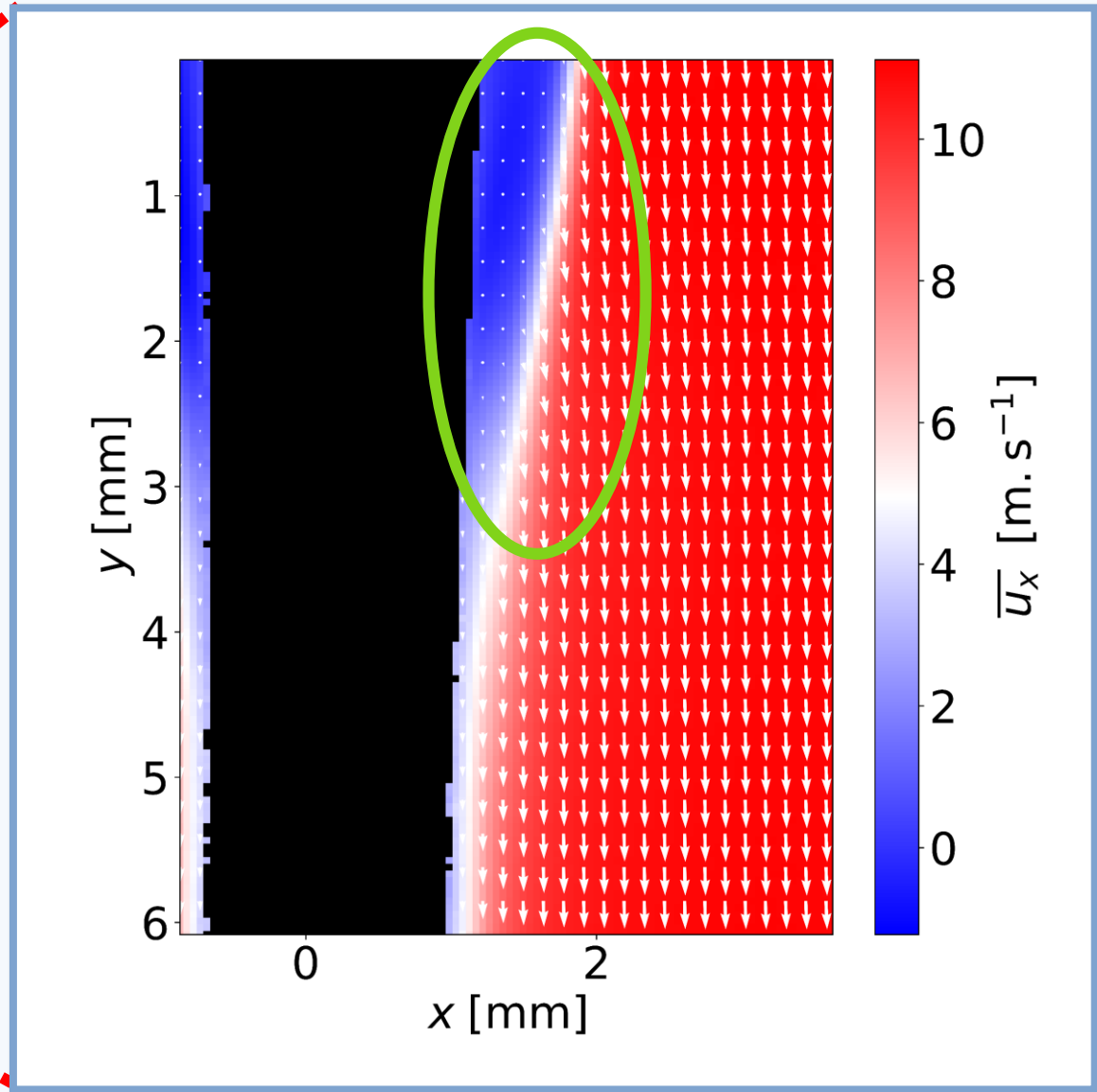


u_G (m/s)	u_L (m/s)
10.6	2.64

δ_G Measurement

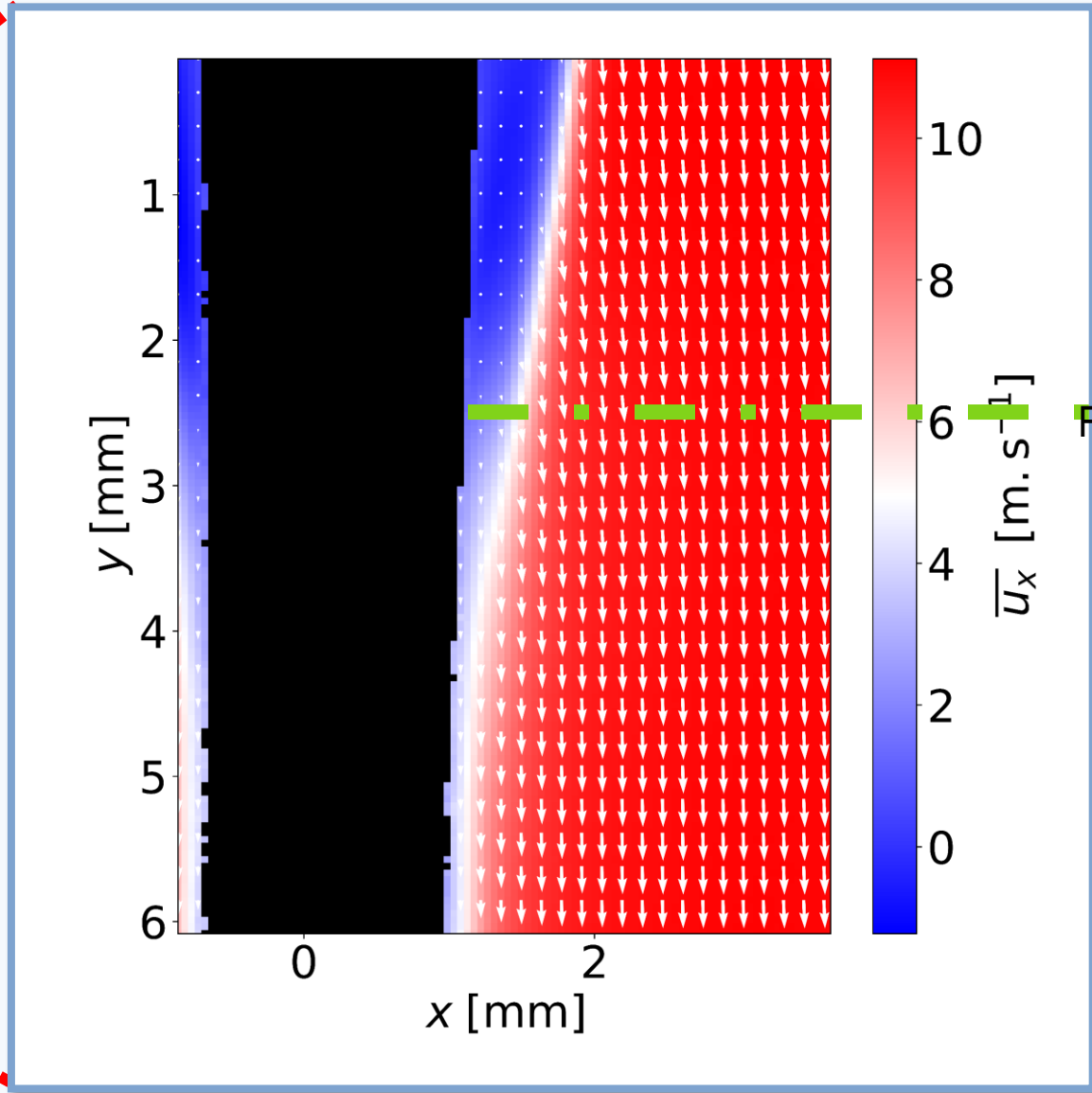
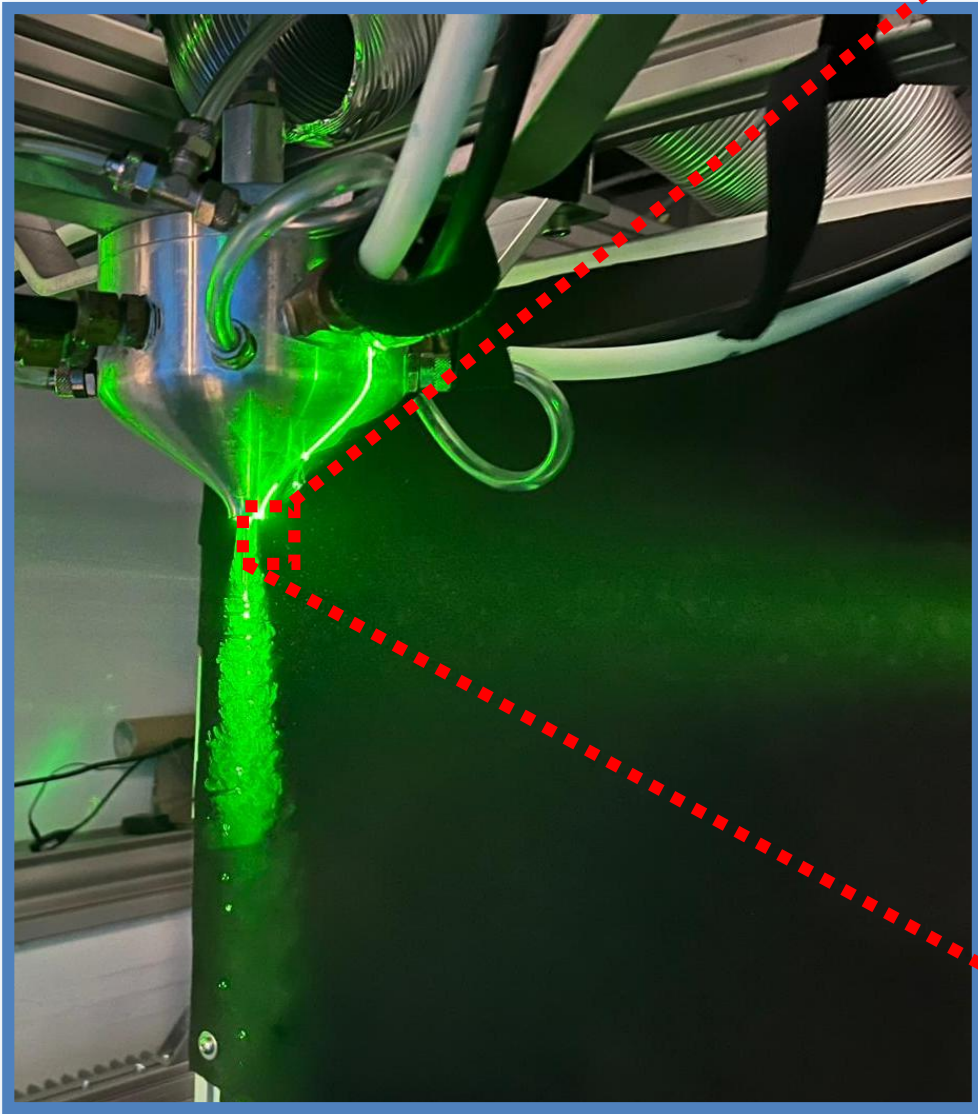


Larger recirculation zone



u_G (m/s)	u_L (m/s)
10.6	2.64

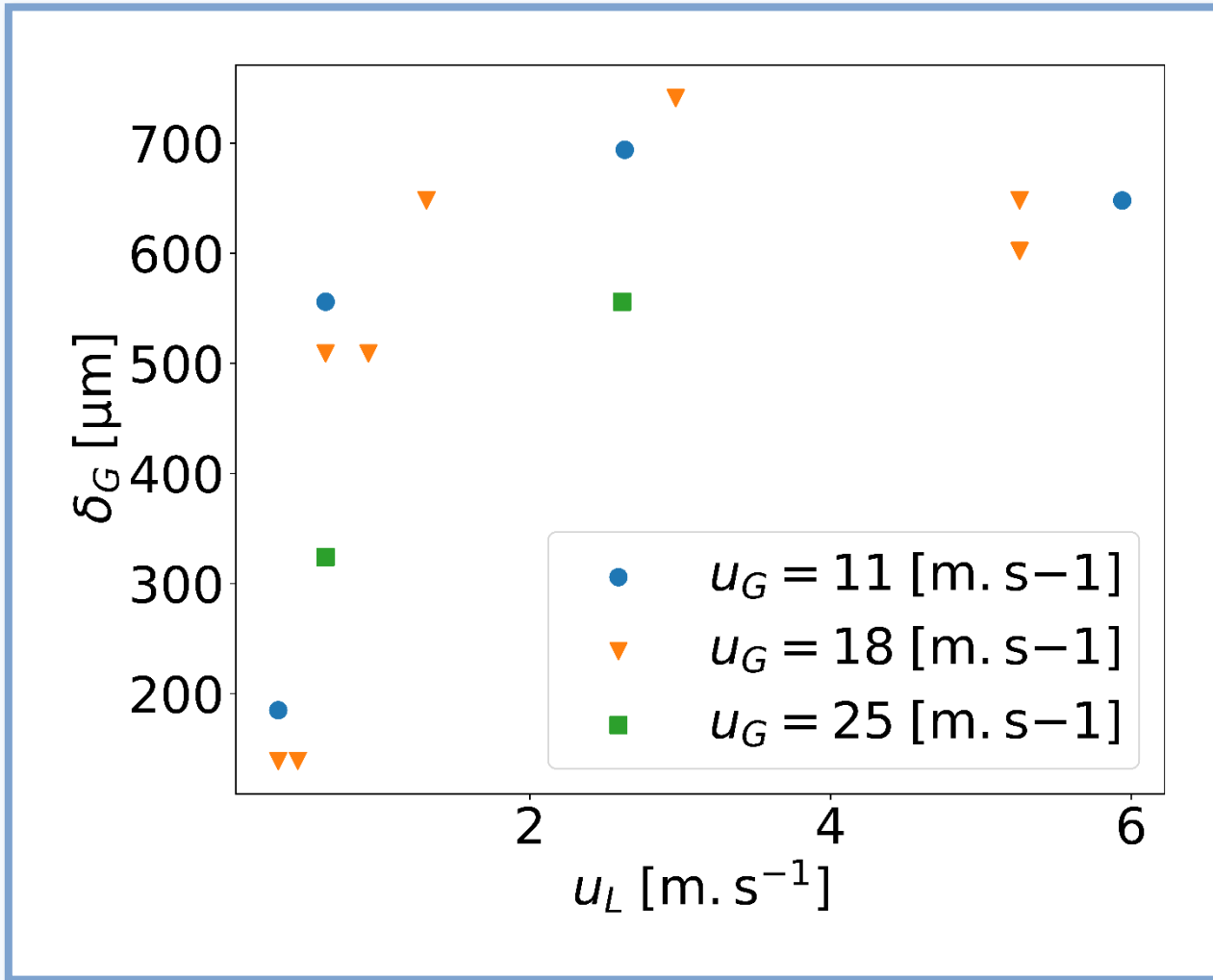
δ_G Measurement



Reattachment point

u_G (m/s)	u_L (m/s)
10.6	2.64

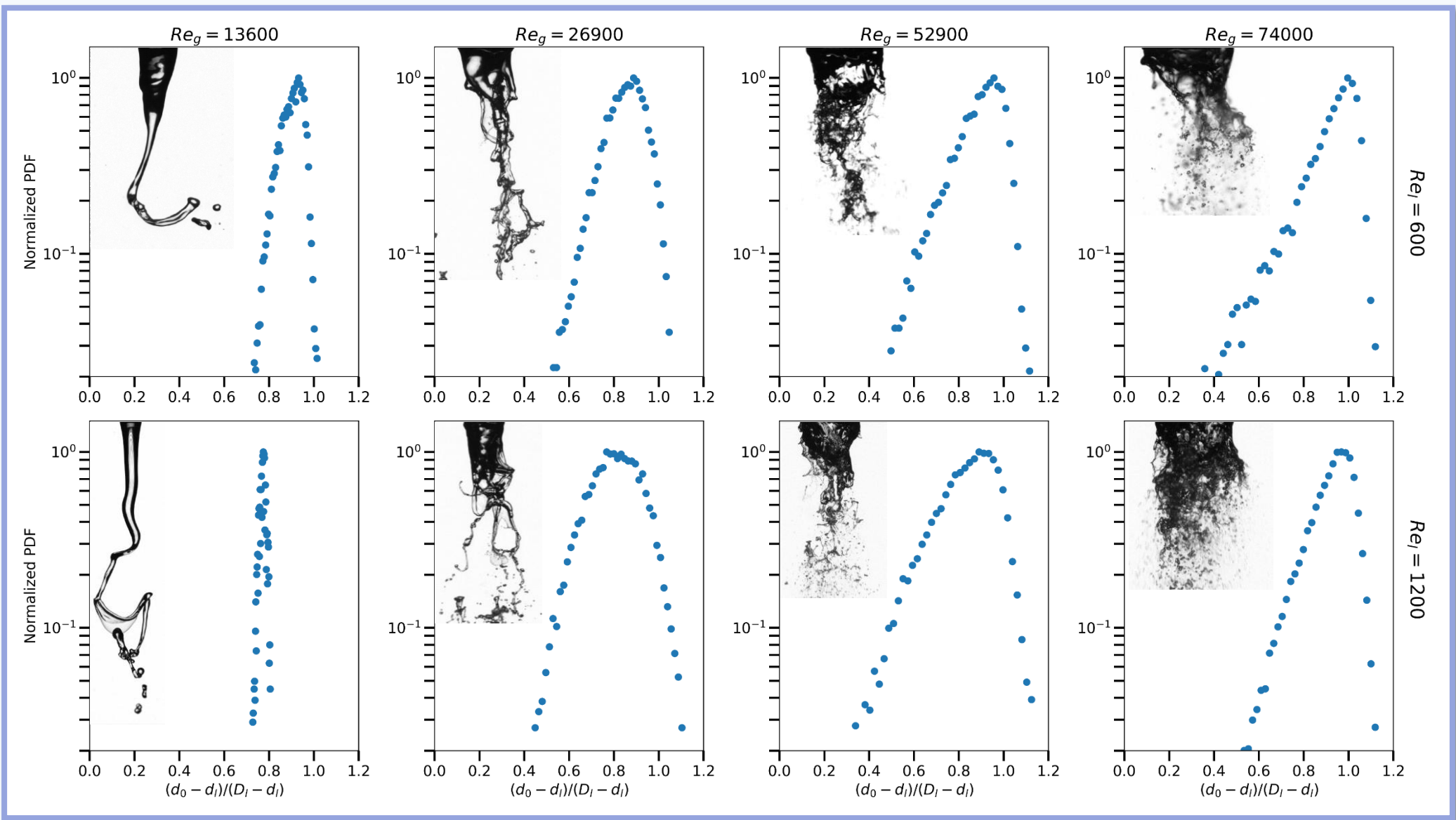
δ_G Measurement



δ_G measured at reattachment point

Wetting evaluation

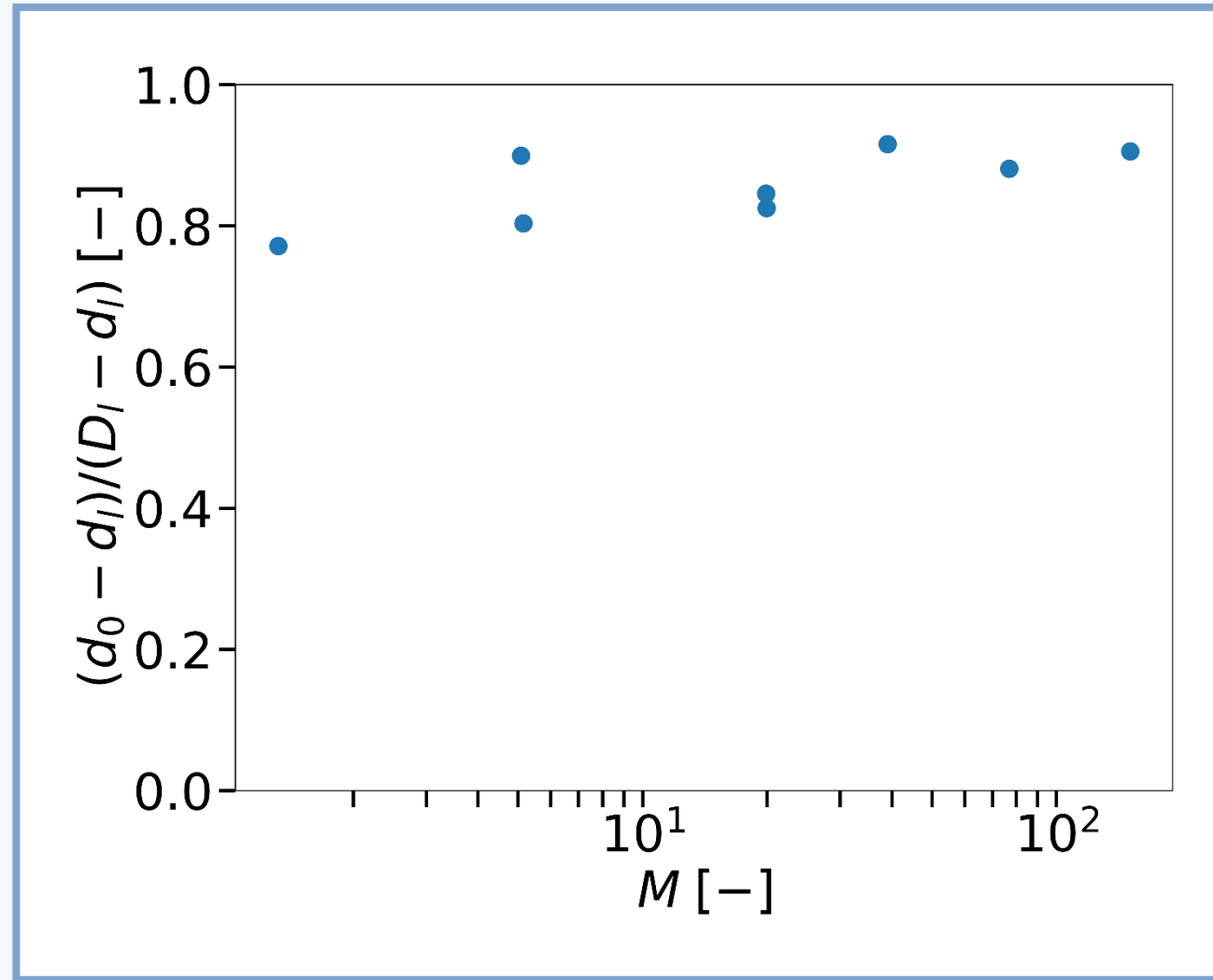
0 = Fully dry
1 = Fully wet



Wetting evaluation

0 = Fully dry
1 = Fully wet

$$M = \frac{\rho_G u_G^2}{\rho_L u_L^2}$$



=> Lip
mostly
wet

LSA Results

LSA : Instability Mechanisms

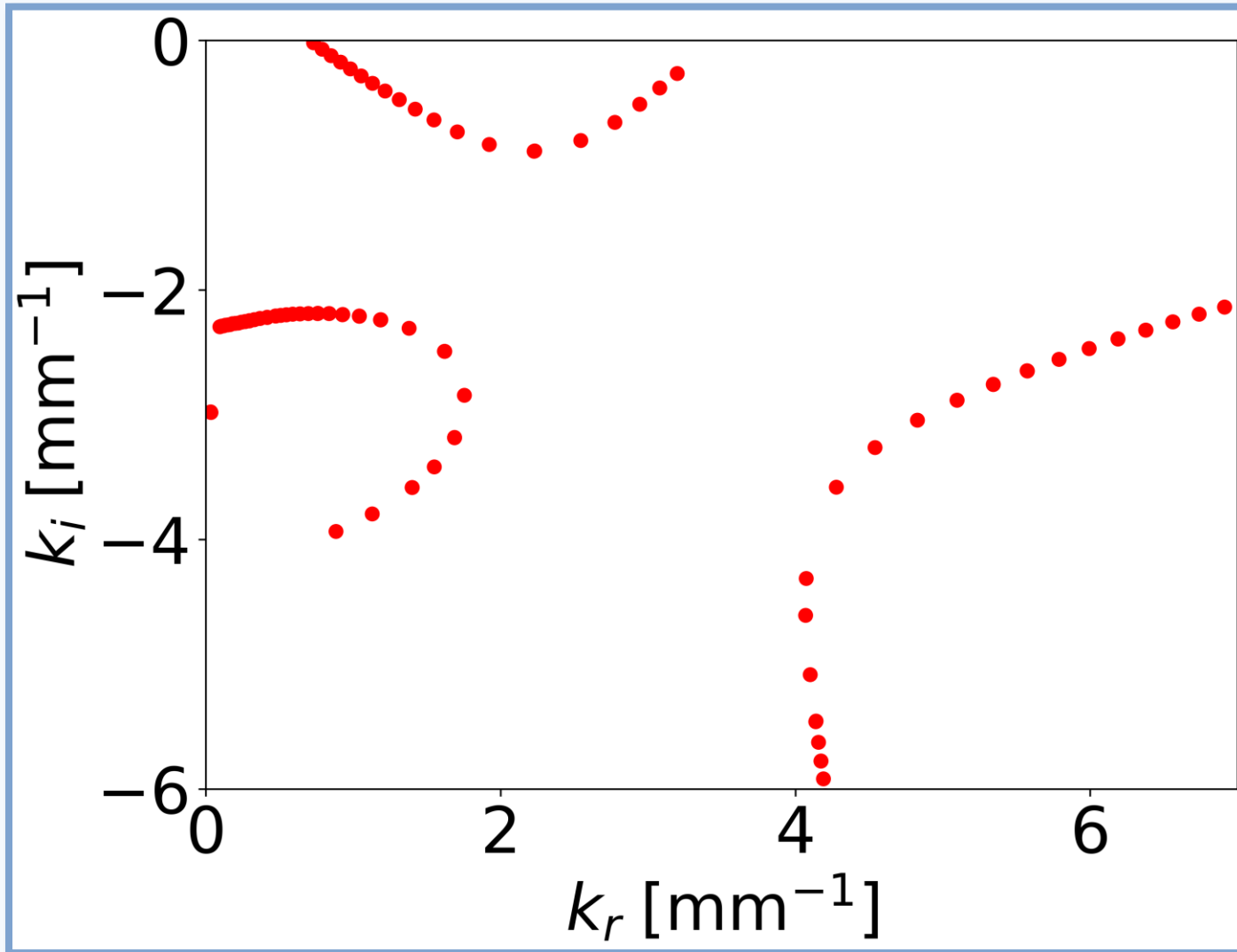
Plot (\mathbf{k}, ω) solutions :

Select ω_i

Cut in (k_r, k_i) plane

Curves parametrized in ω_r

LSA : Instability Mechanisms



Re_L	Re_G	We_G
550	2.7E4	55

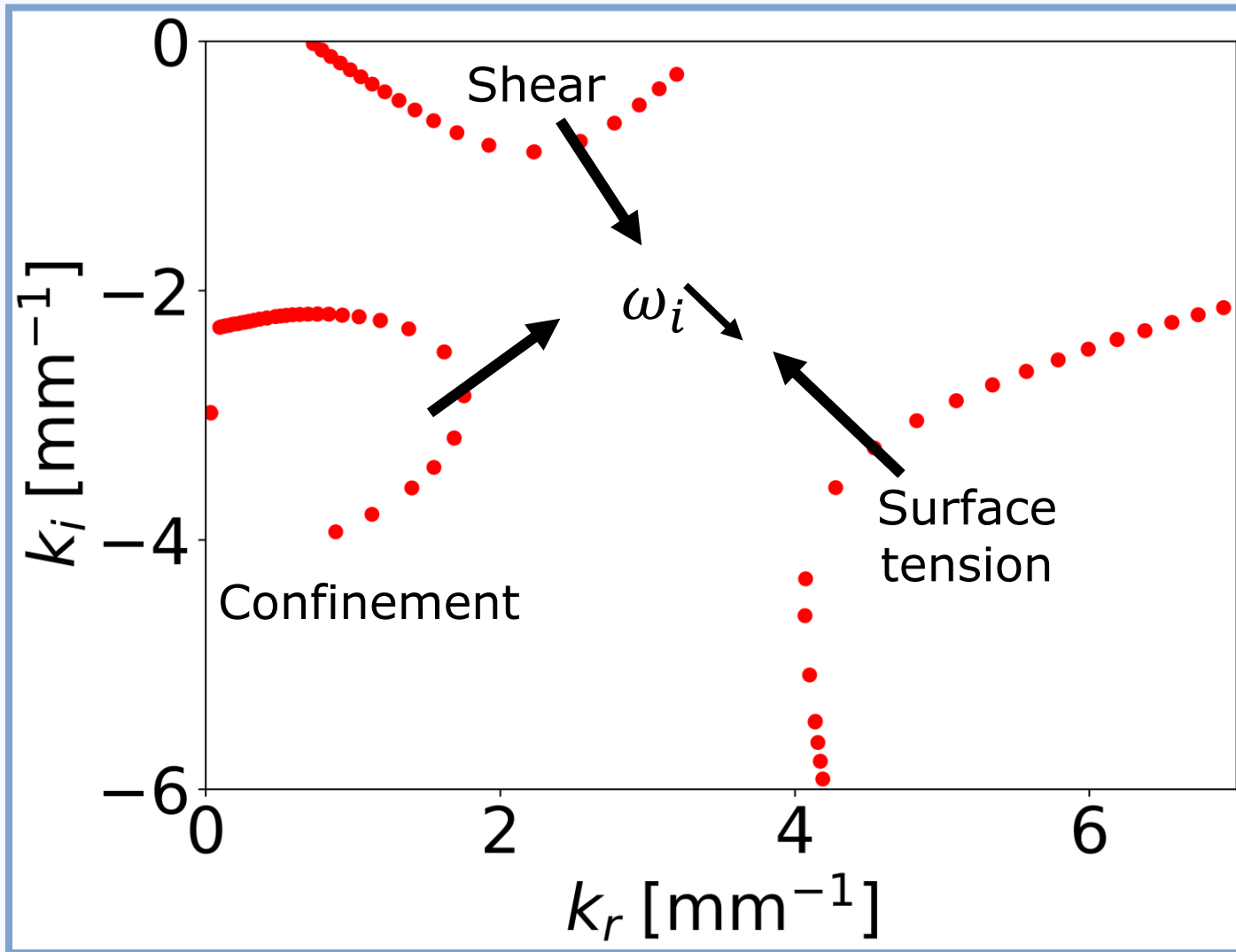
Plot (\mathbf{k}, ω) solutions :

$$\omega_i = 250 \text{ rad. s}^{-1}$$

Cut in (k_r, k_i) plane

Curves parametrized in ω_r

LSA : Instability Mechanisms



Re_L	Re_G	We_G
550	2.7E4	55

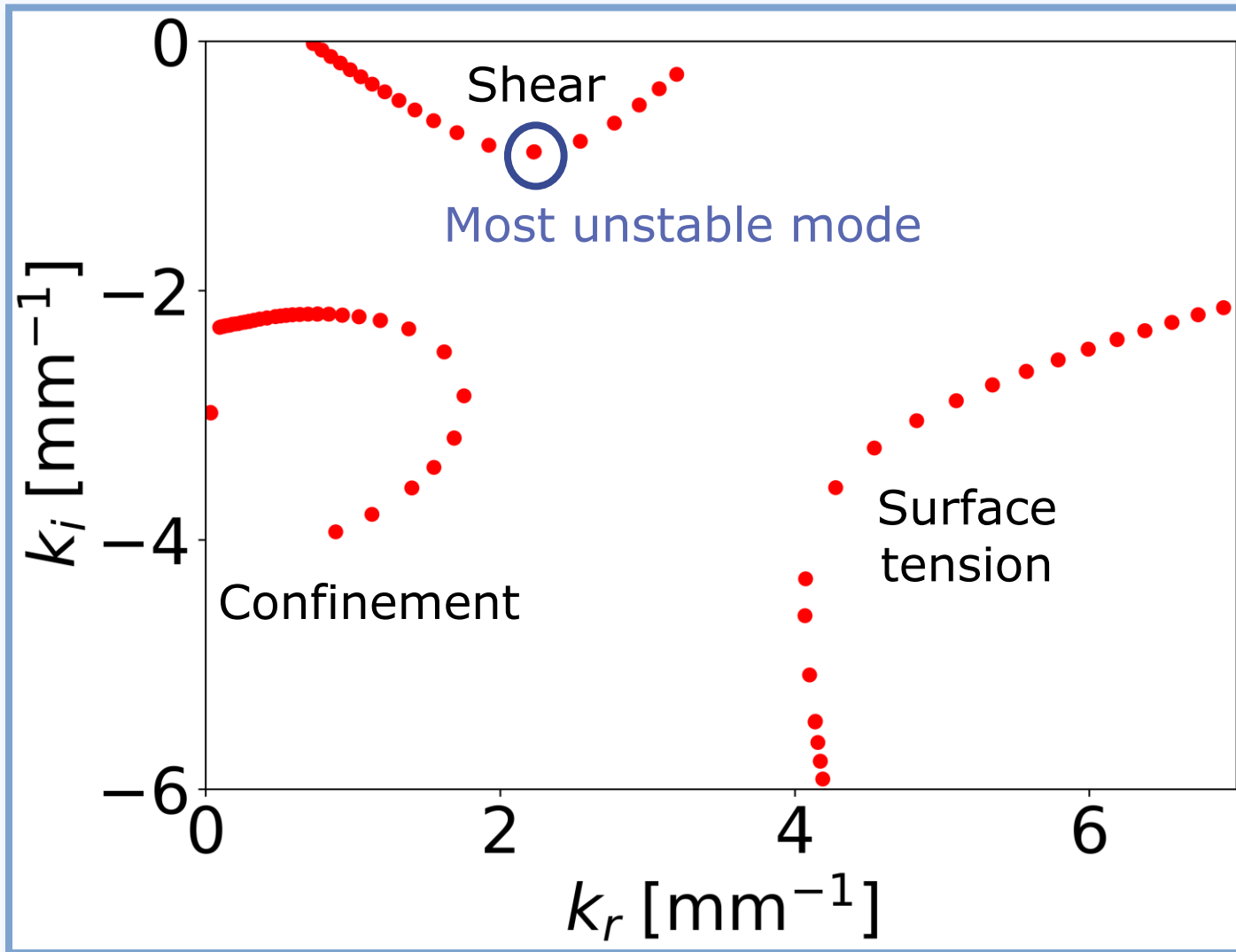
Plot (\mathbf{k}, ω) solutions :

$$\omega_i = 250 \text{ rad. s}^{-1}$$

Cut in (k_r, k_i) plane

Curves parametrized in ω_r

LSA : Instability Mechanisms

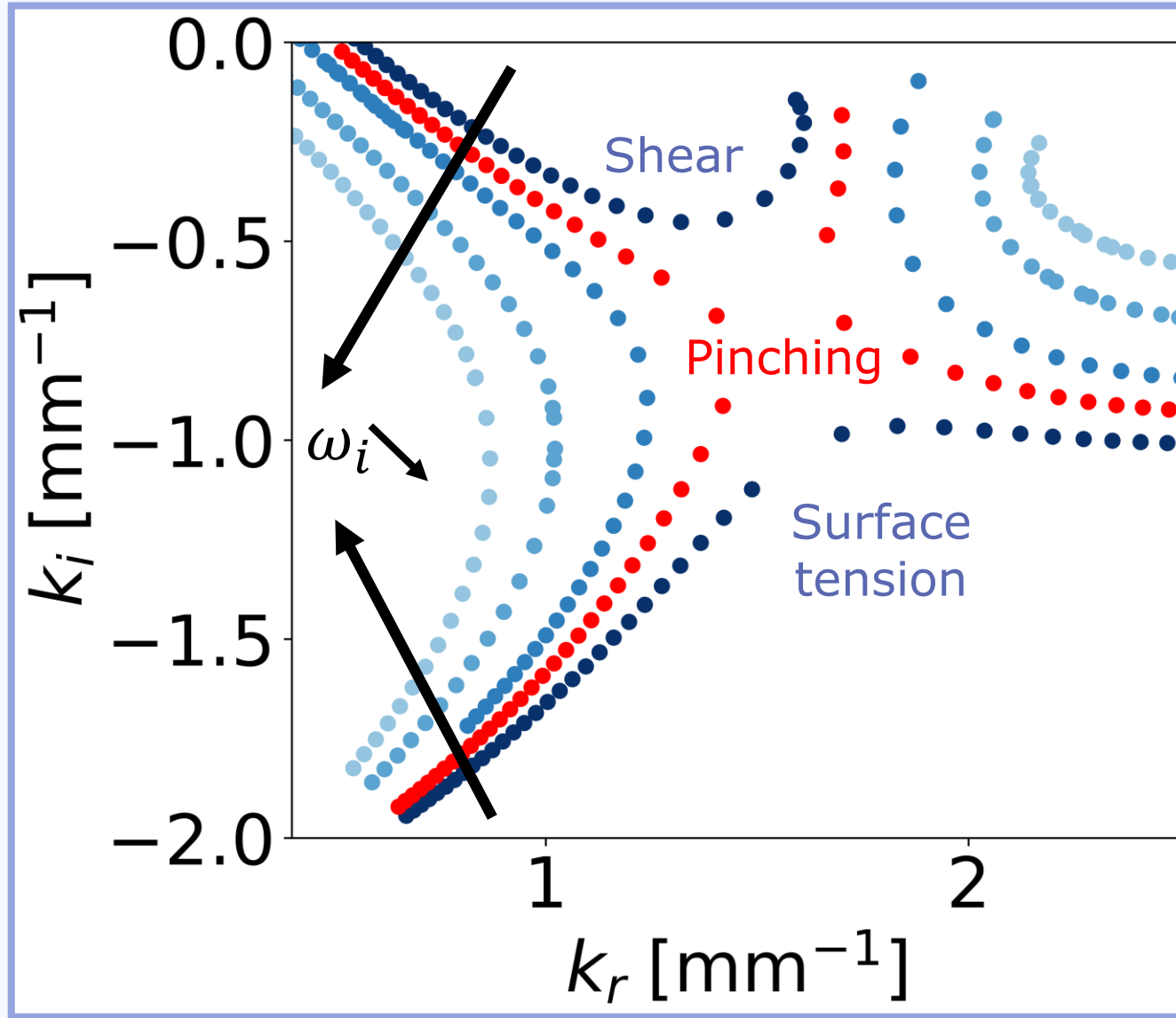


Re_L	Re_G	We_G
550	2.7E4	55

No pinch for $\omega_i > 0$
=> Convective (shear) instability

LSA : Instability Mechanisms

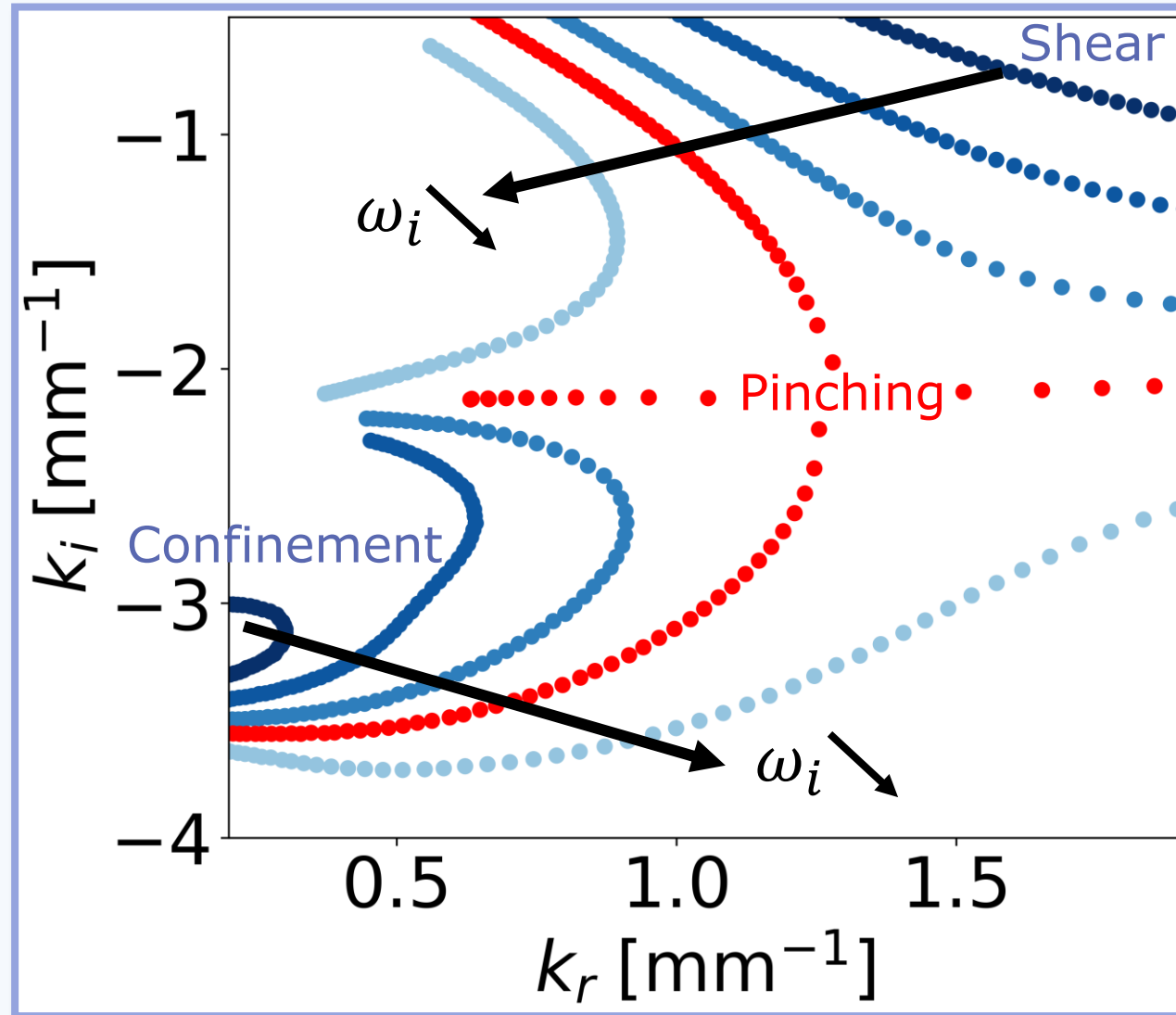
Re_L	Re_G	We_G
550	1.8E4	27



=> Absolute Instability 1

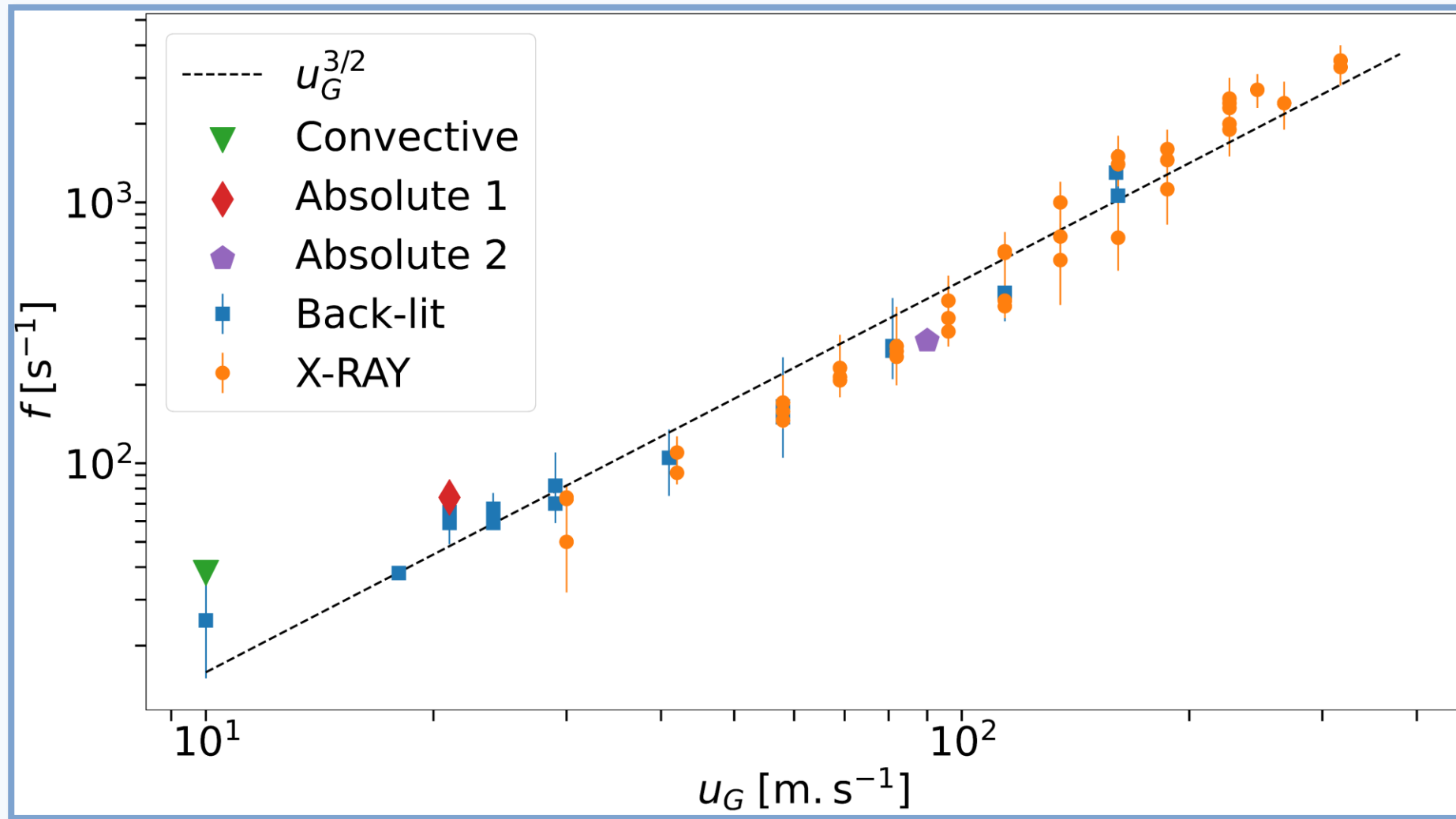
LSA : Instability Mechanisms

Re_L	Re_G	We_G
550	5.7E4	260



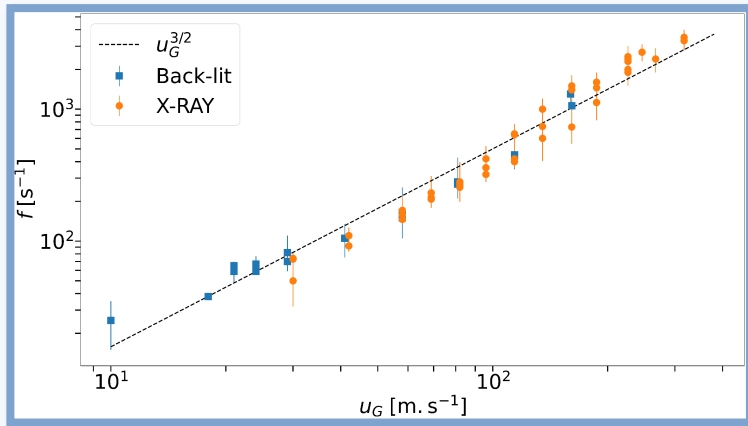
=> Absolute Instability 2

LSA : Comparison with experiments



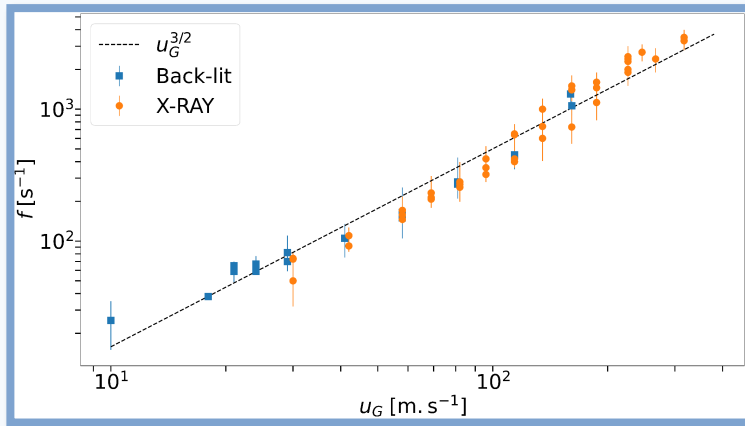
Conclusion

Conclusion

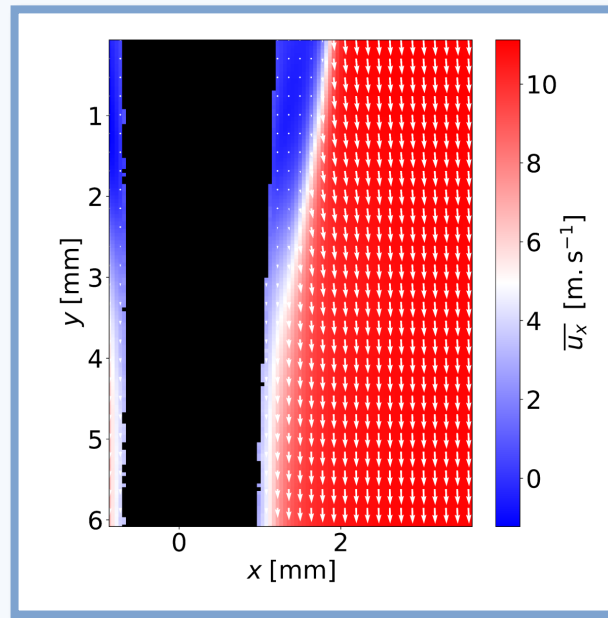


Flapping frequency

Conclusion

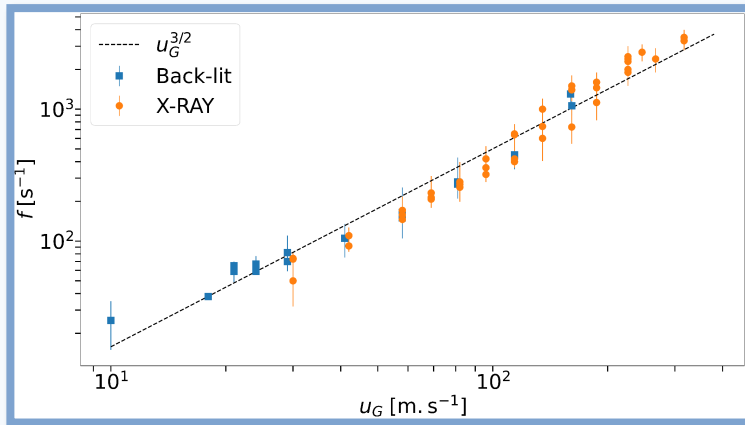


Flapping frequency

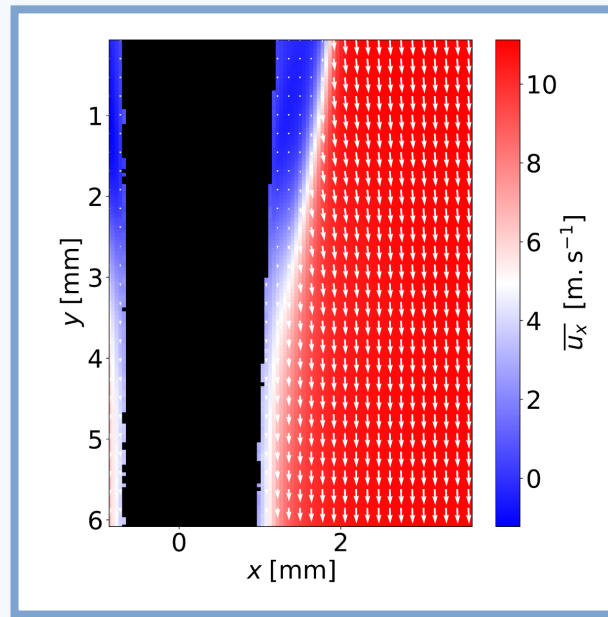


Flow Characterization

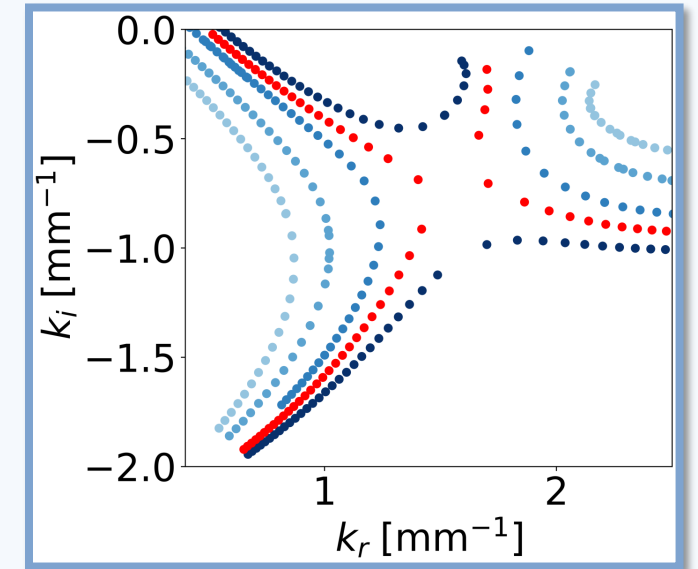
Conclusion



Flapping frequency

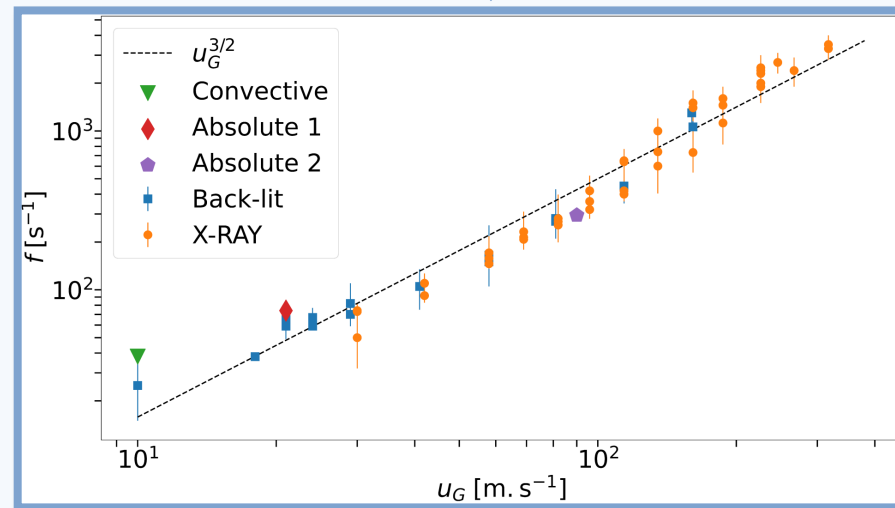
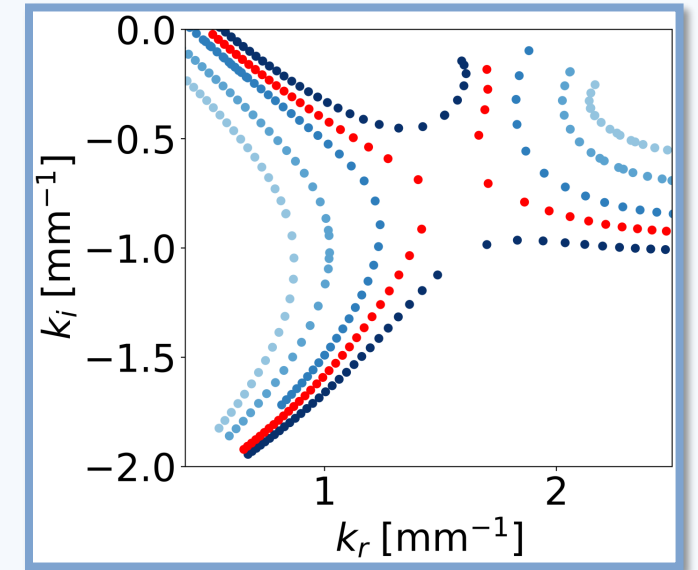
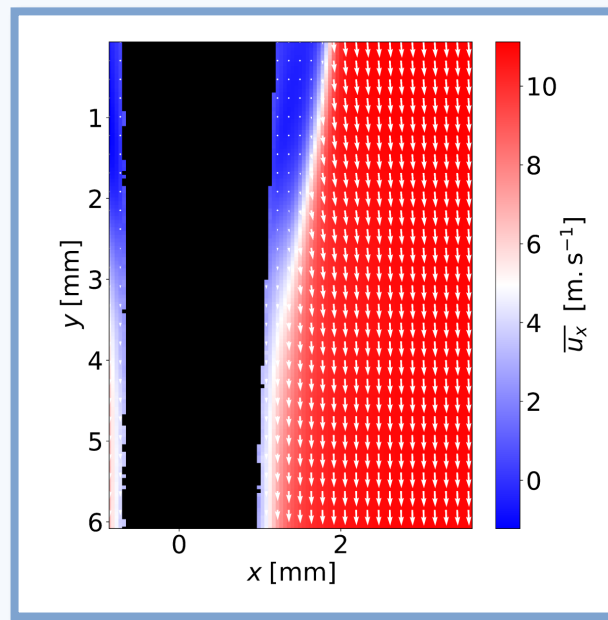
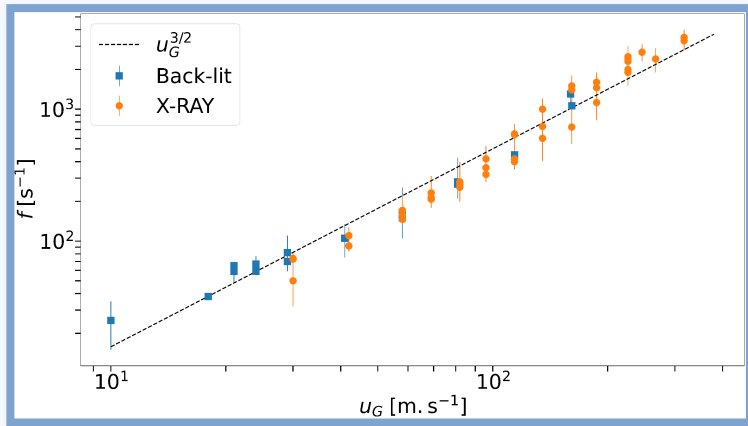


Flow Characterization



Stability Analysis

Conclusion



Perspectives



Cryospray



Coming
Soon !