Large-scale instabilities in coaxial two-fluid atomization

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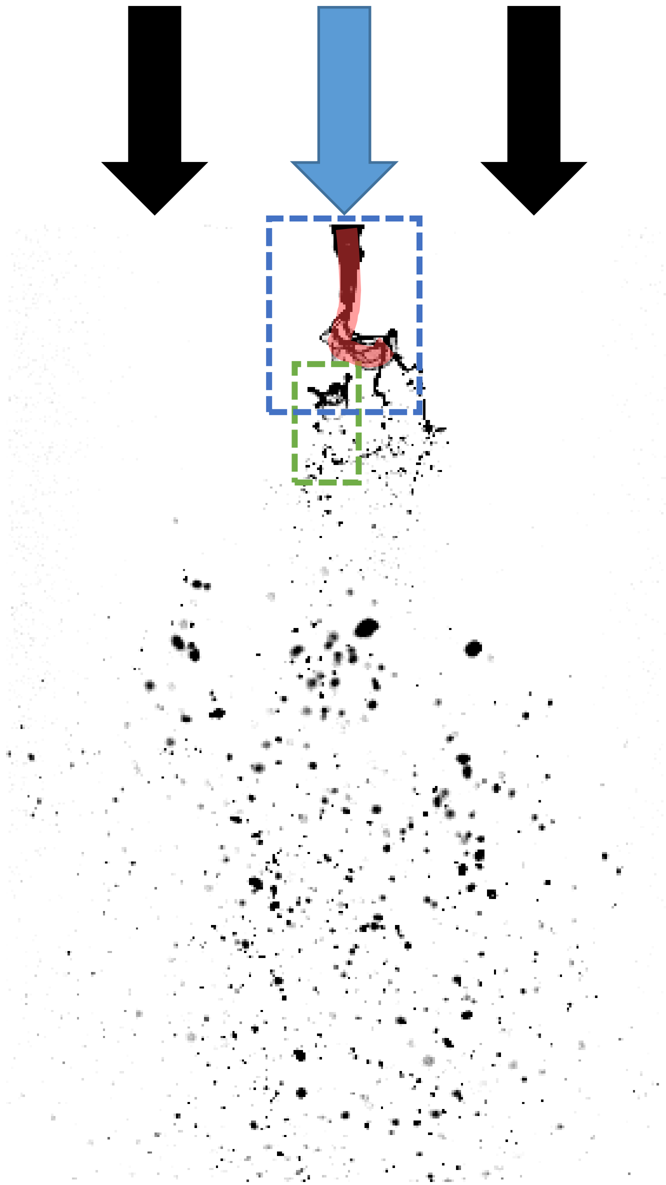
Gas-assisted Atomization Phenomena

gas liquid gas



Near field

Mid field

Assisted atomization: breaking of a liquid jet into a spray (droplet cloud) by a gas co-flow

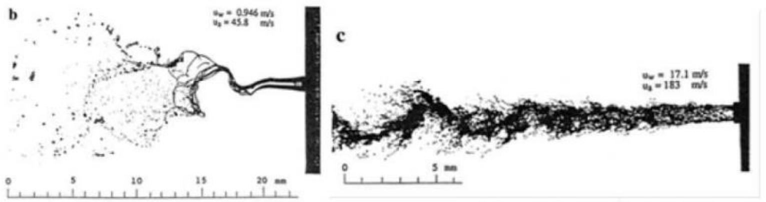
Spray formation:
- Interfacial instabilities
- Primary break-up

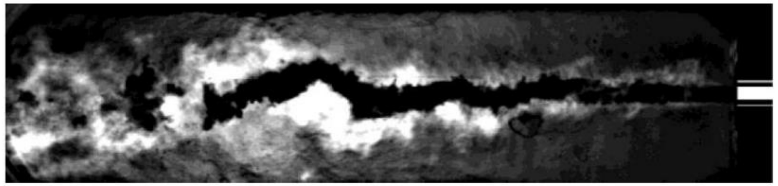
Drops/ligaments in turbulence:
- Secondary break-up
- Turbulent dispersion

Droplets in turbulence:
- Turbulent dispersion
- Evaporation

FLAPPING

Farago & Chigier, 1992





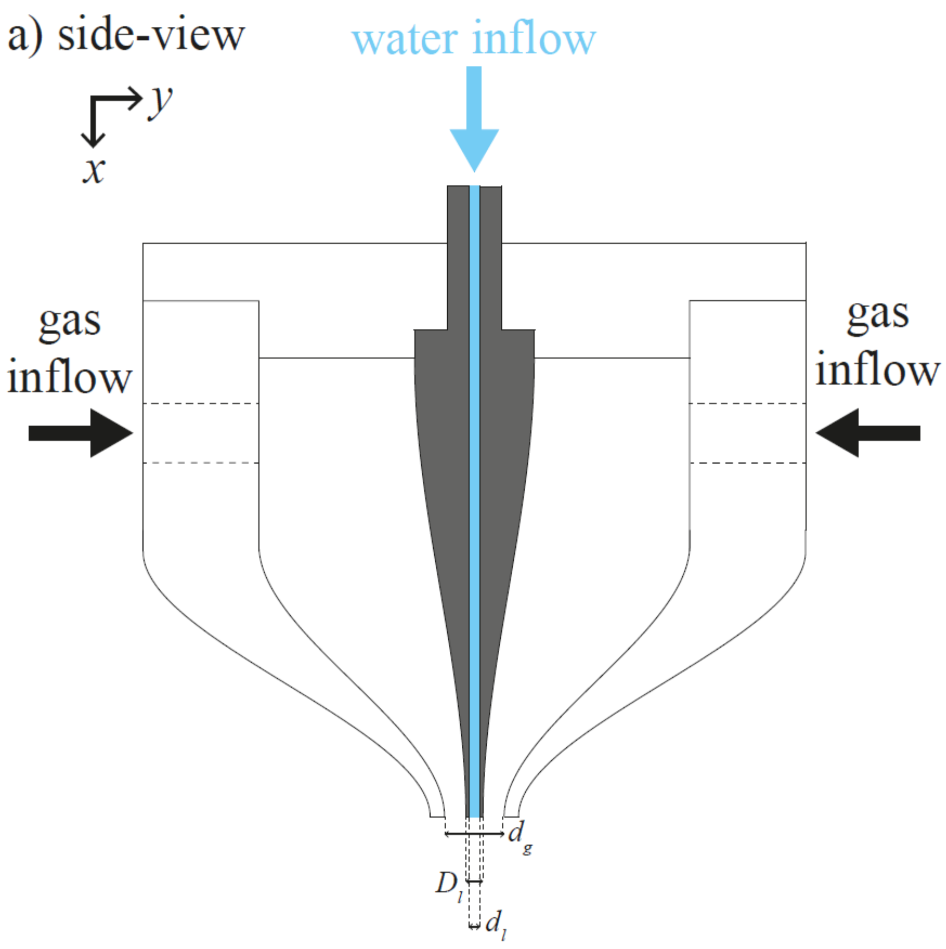
Cryogenic, *Locke at al. 2010*

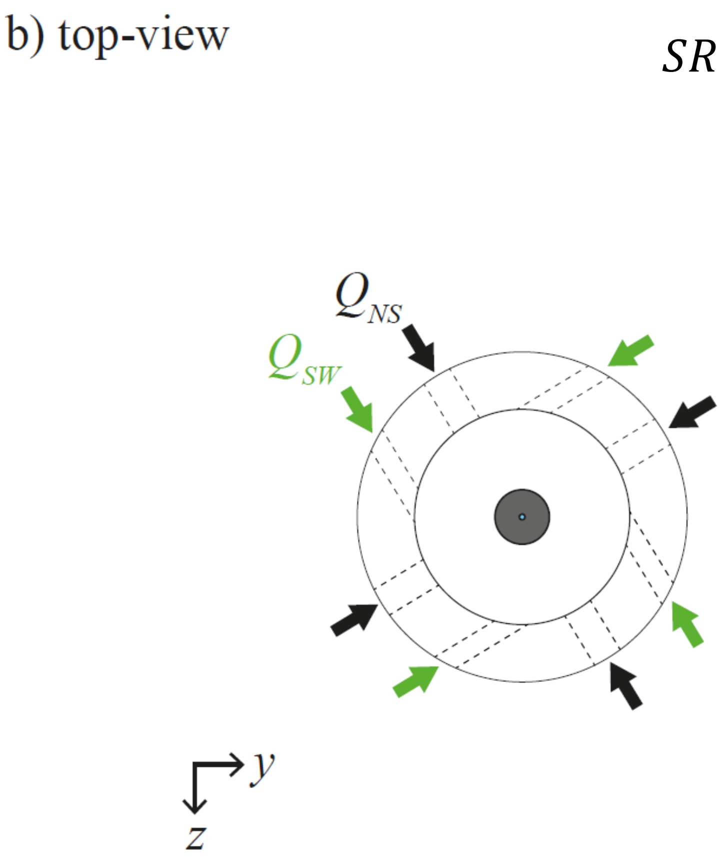
- Frequency well modeled (Delon et al., 2018)
- Flapping affects the cascade of mechanisms, up to droplet spatiotemporal distributions
- Dimensionality yet to be explored

Experimental setup

$$Q_{Total} = Q_{SW} + Q_{NS} = cst$$

$$SR = \frac{Q_{SW}}{Q_{NS}}$$

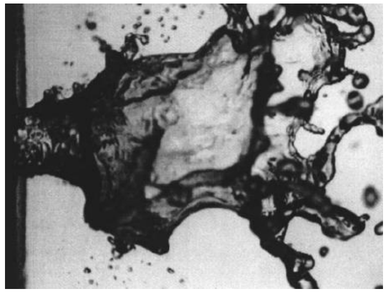




2-view high-speed back-lit imaging

high-speed camera

Threshold of angular to longitudinal momenta ratio



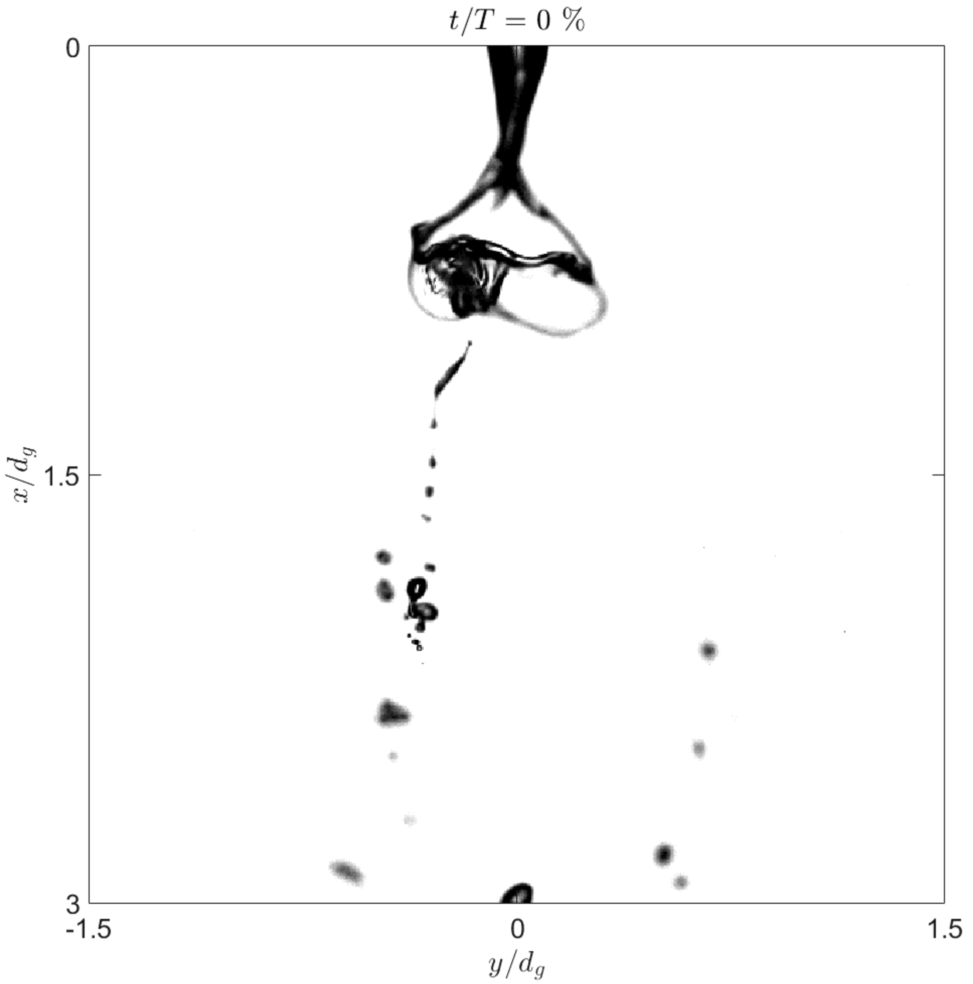
Lasheras & Hopfinger ARFM 2000

Synchronized two-view back-lit imaging

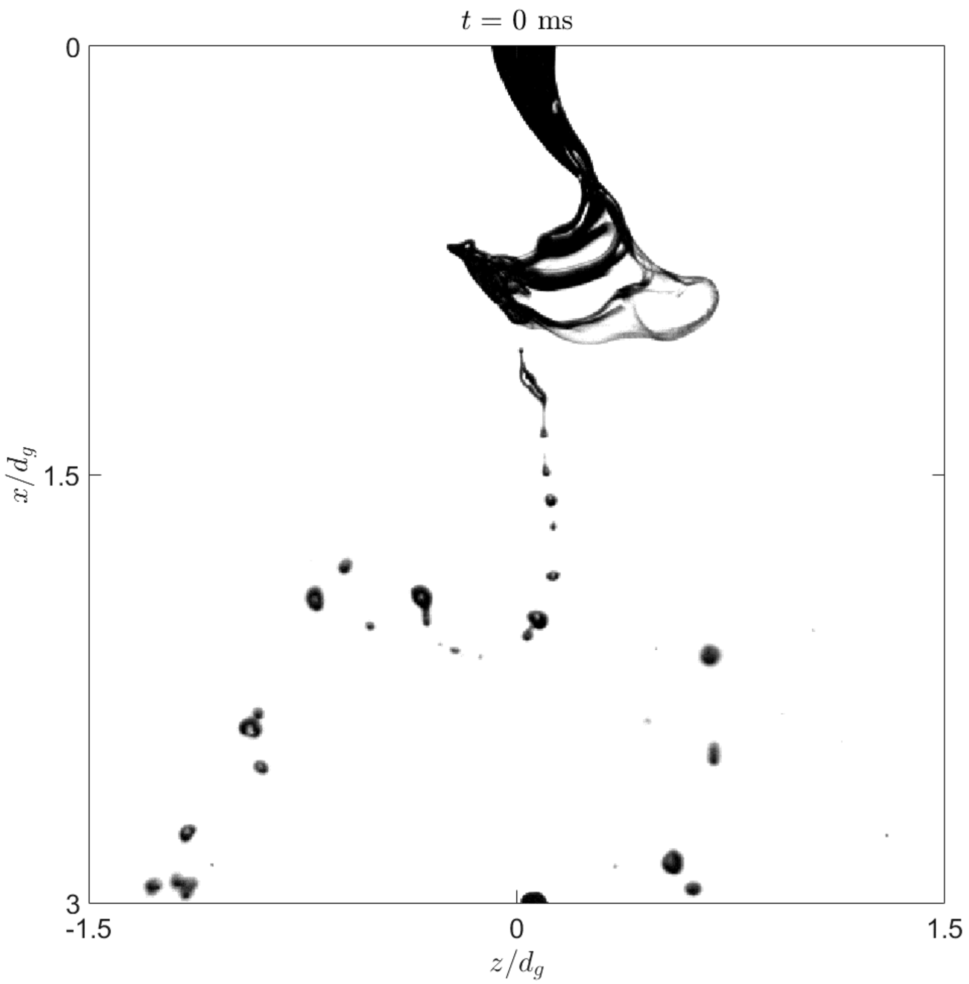
$Re_l = \frac{u_l d_l}{\nu_l} = 1200$ $10^4 < Re_g = \frac{u_g d_{eff}}{\nu_g} < 3\ 10^4$ $2 < M = \frac{\rho_g u_g^2}{\rho_l u_l^2} < 12$

$M = 2$

Camera “1”: (x, y) plane

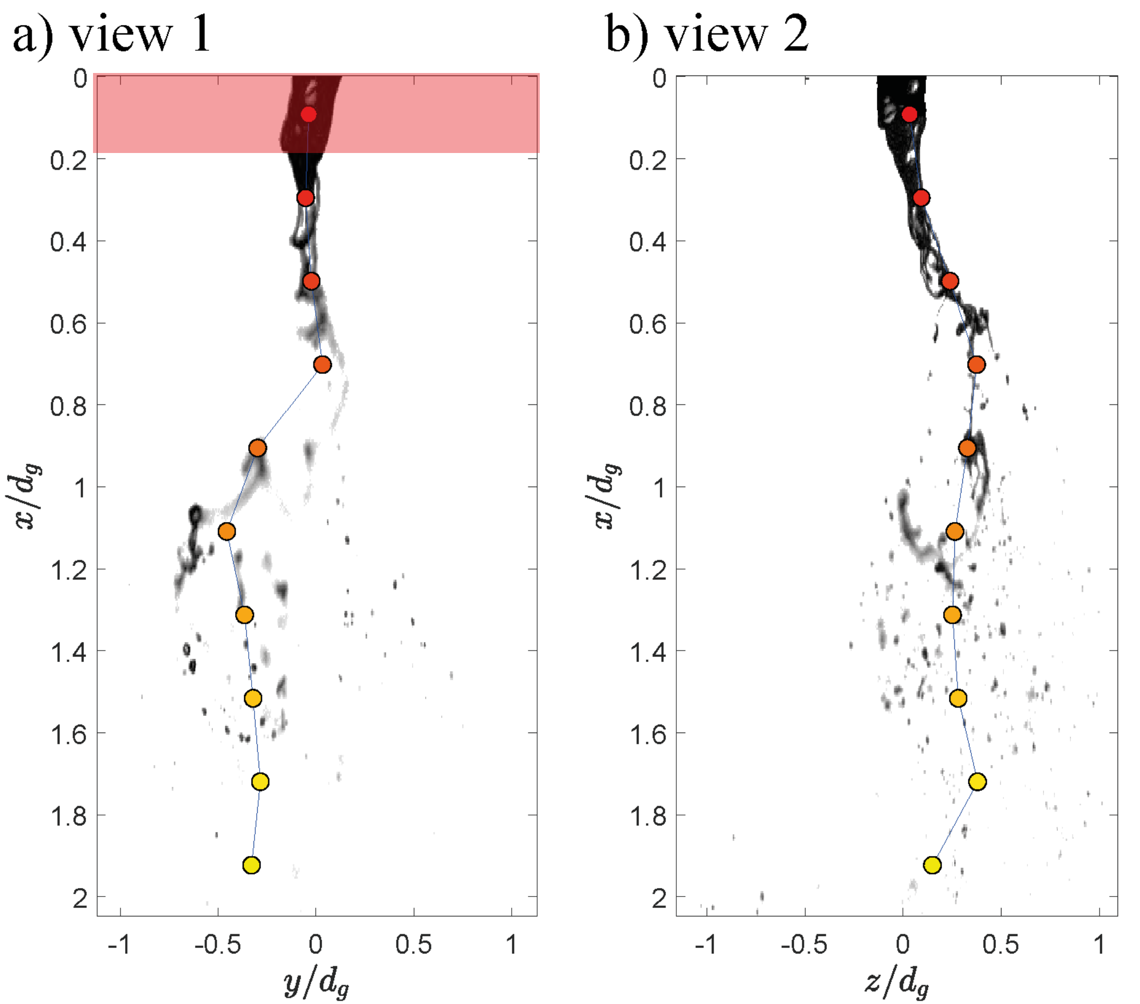


Camera “2”: (x, z) plane



3D reconstruction of the liquid jet's barycenters

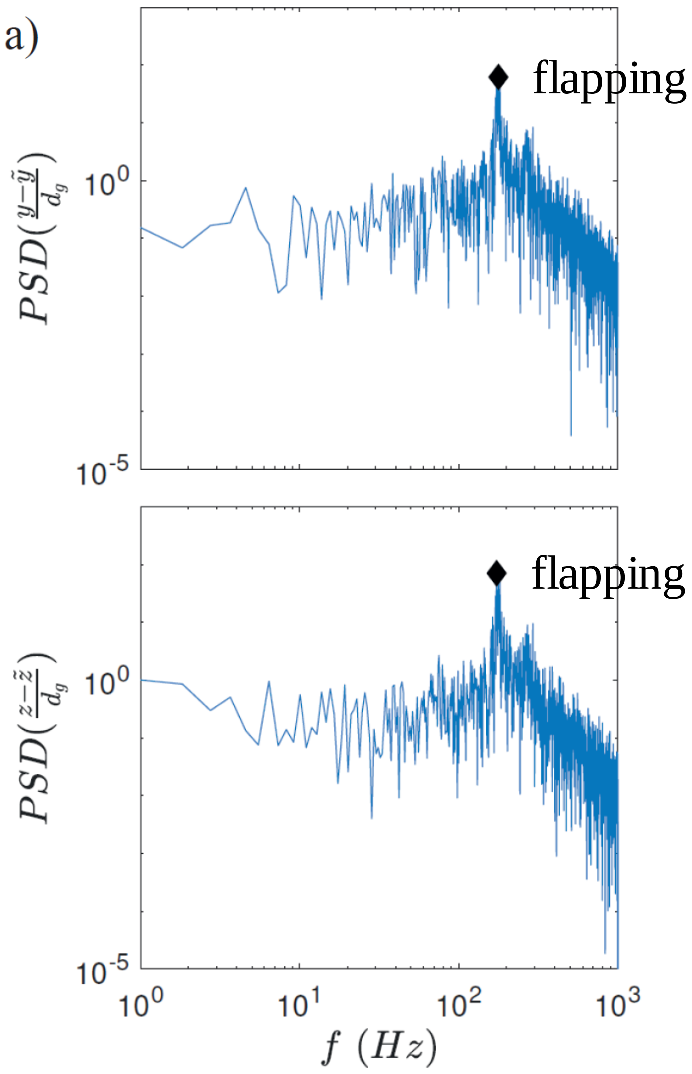
Barycenter of the liquid pixel in a band of pixel



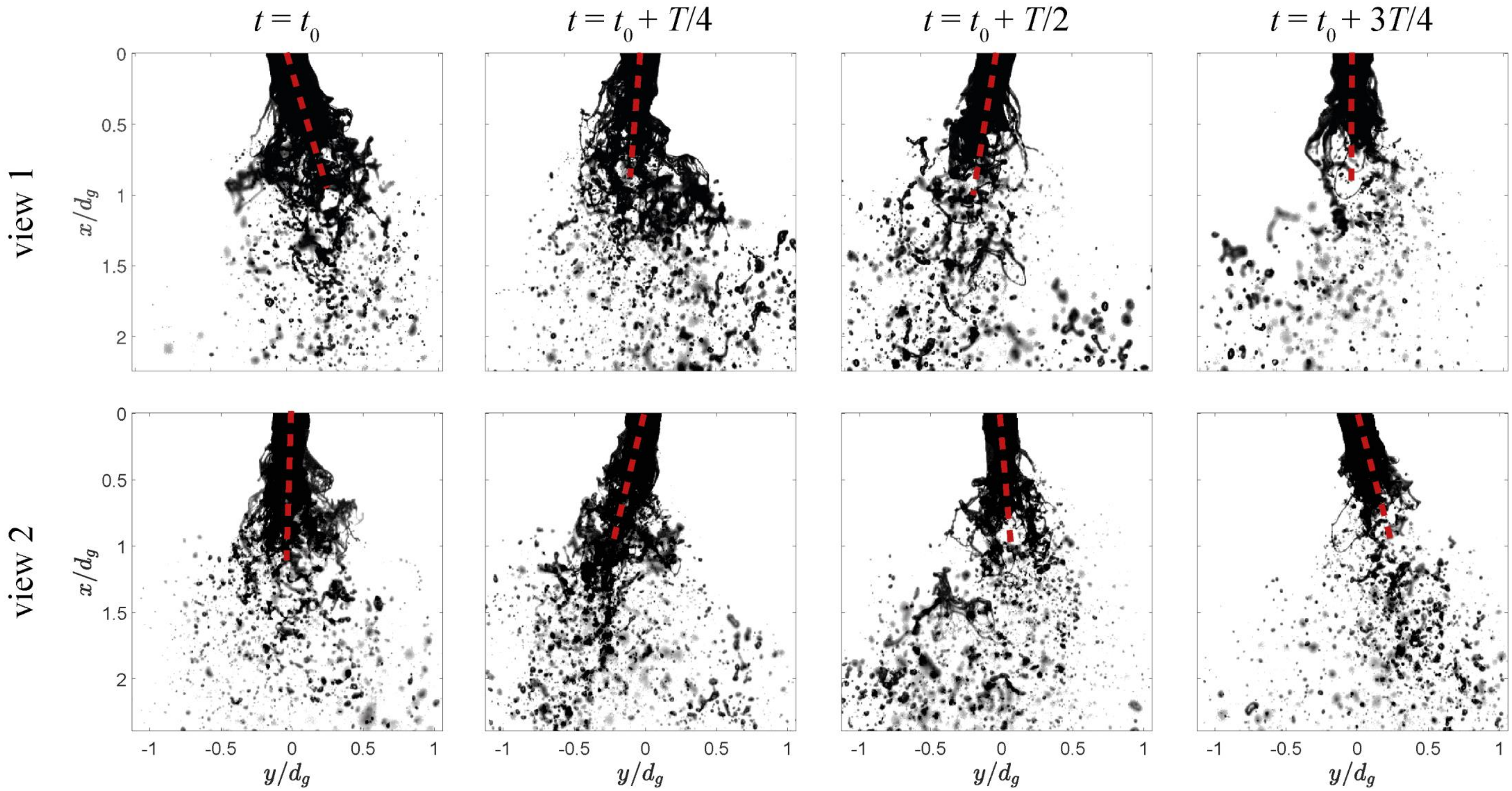
➔ 2D coordinate (y, z) of the barycenter in each x plane

Phase-averaging at the flapping frequency

Power spectra of the barycenter (y, z)



Confirmation of flapping frequency

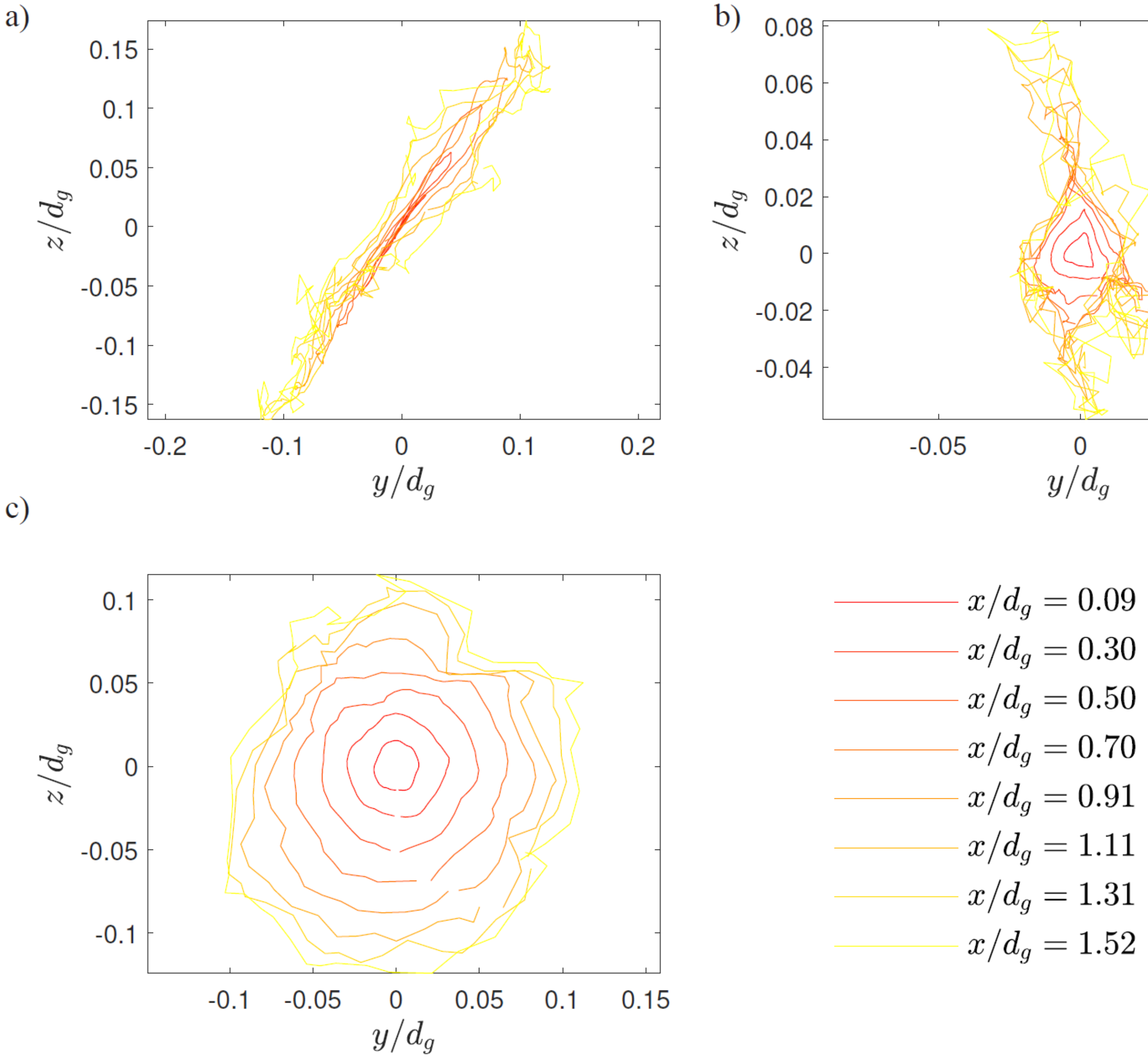


Flapping dimensionality/shape

planar

ellipsoidal

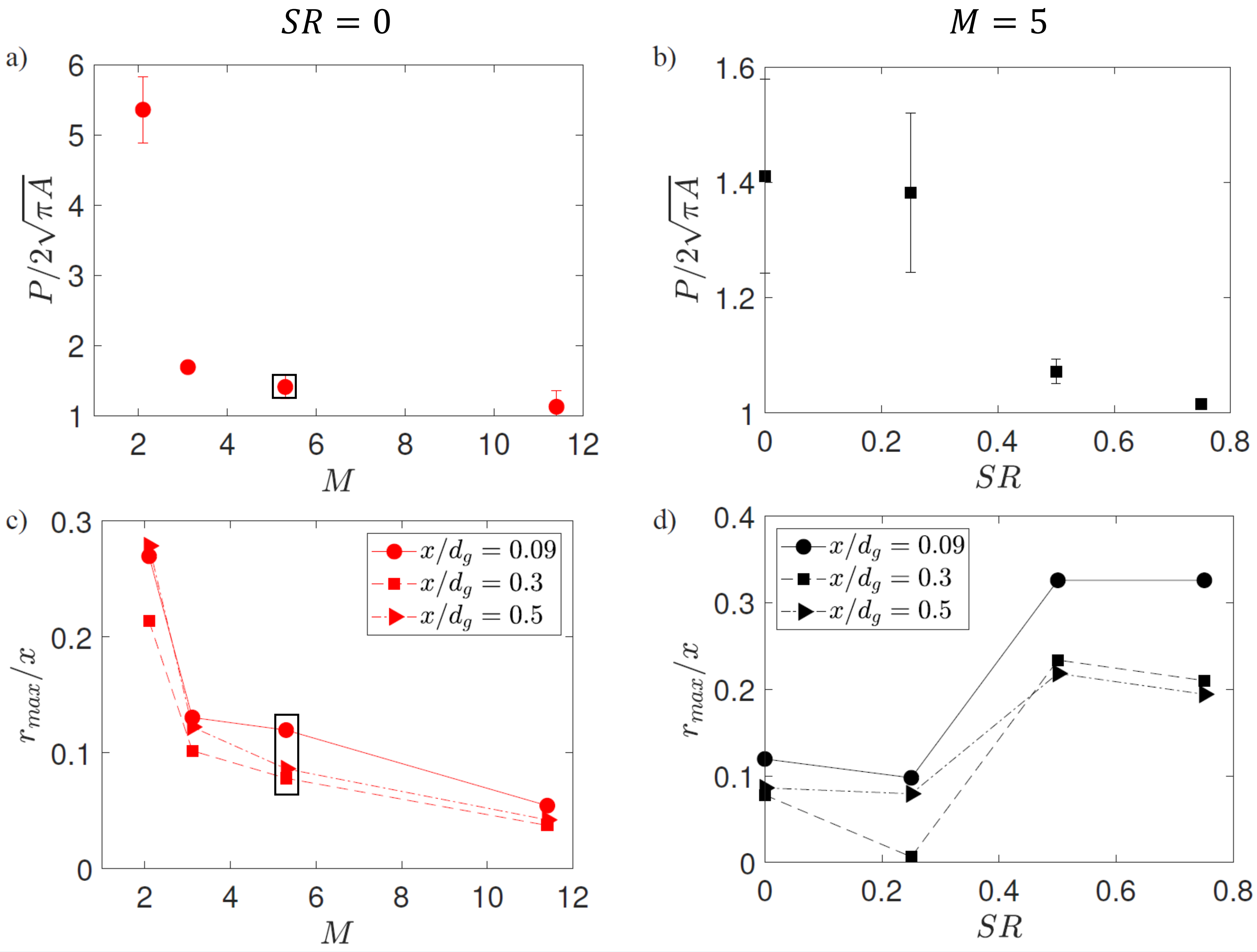
circular



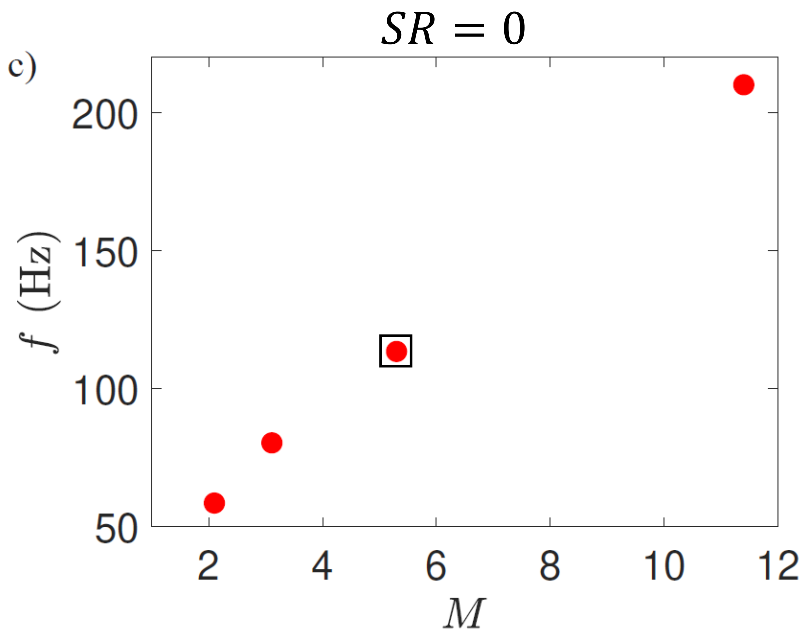
Evolution with parameters

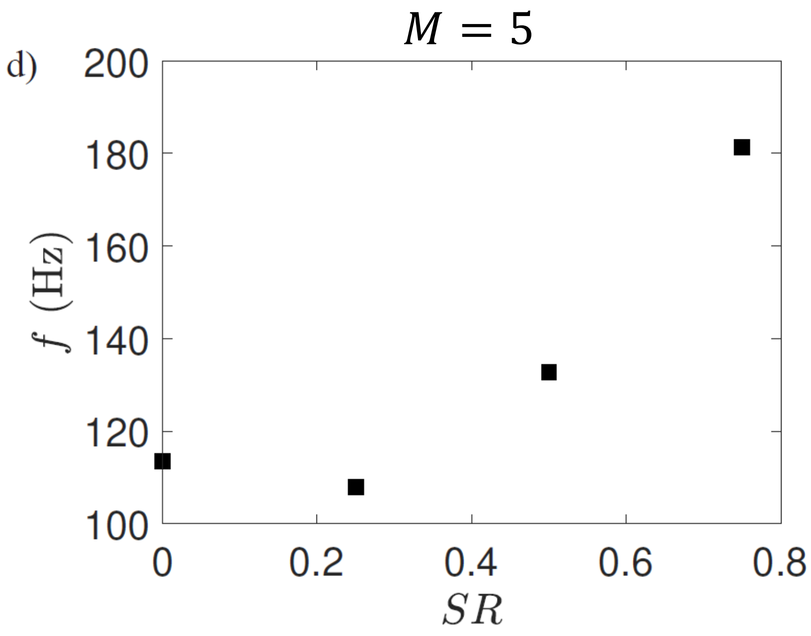
Shape factor

Flapping amplitude

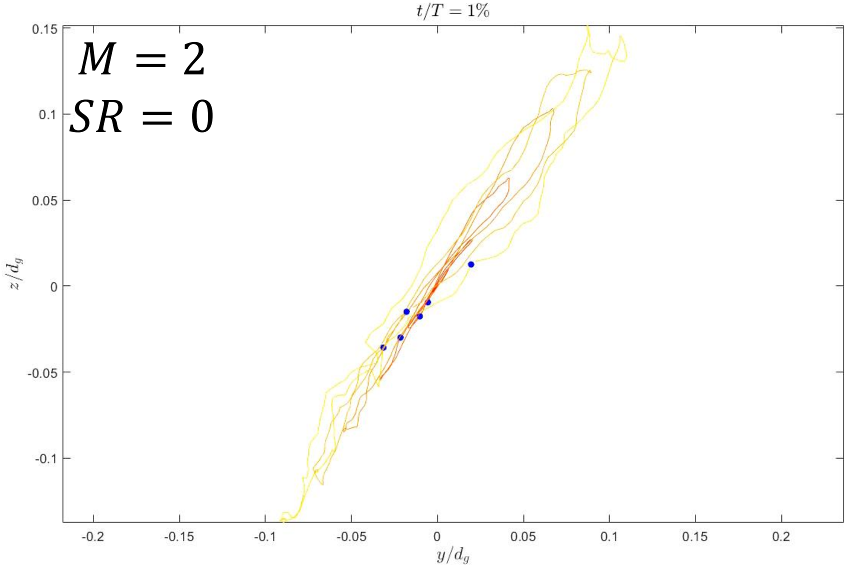


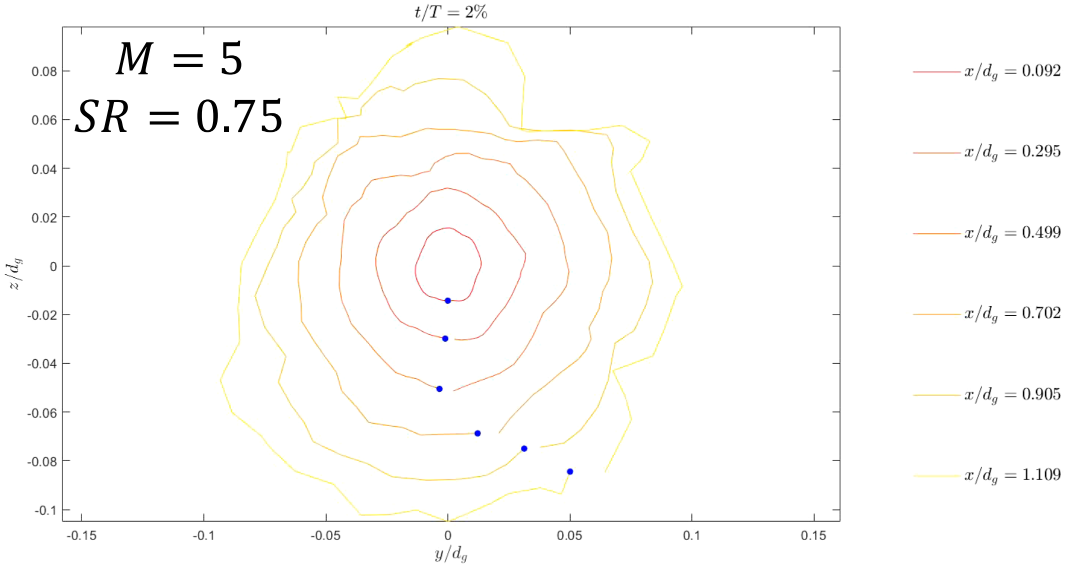
Flapping frequency



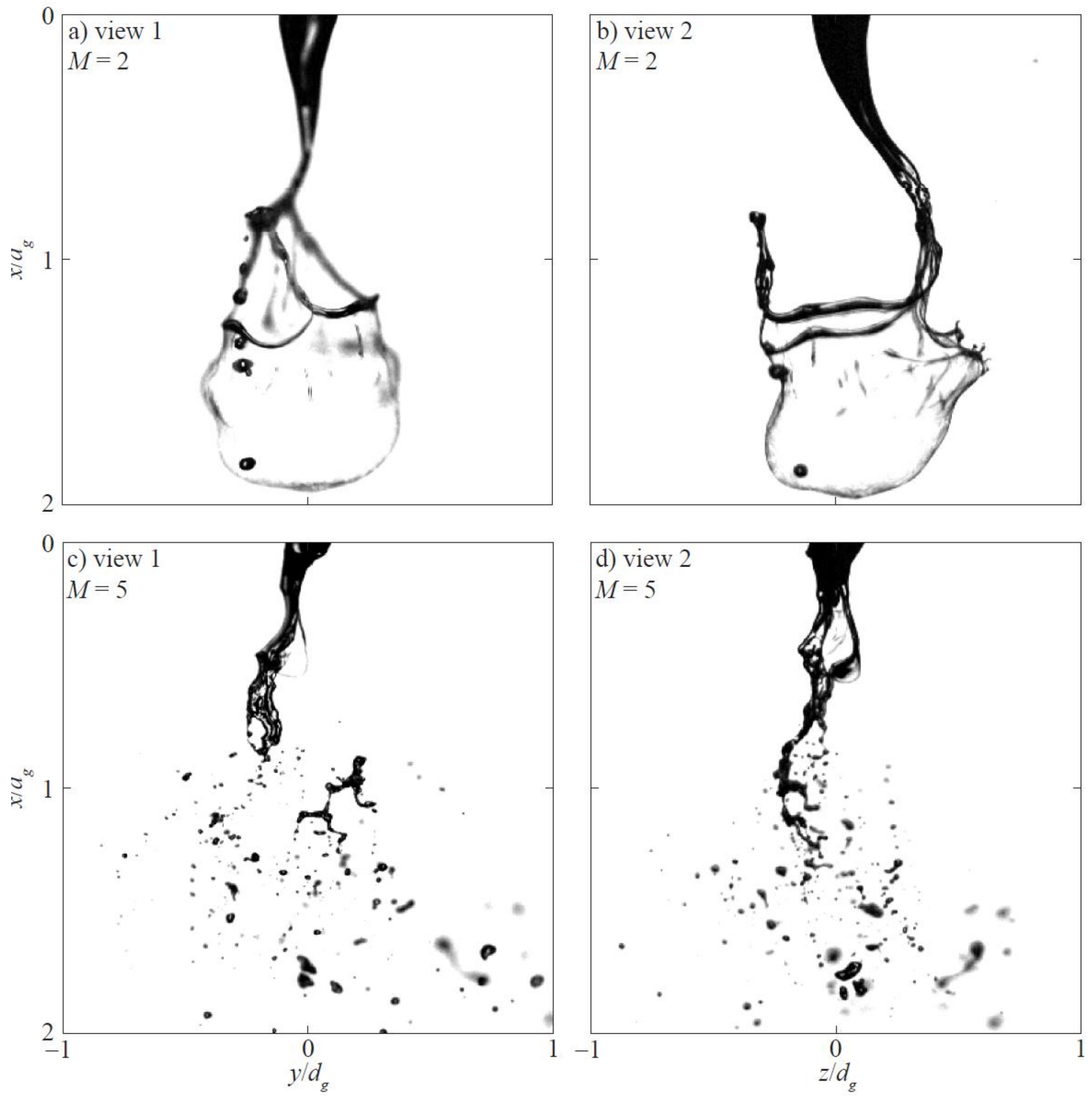


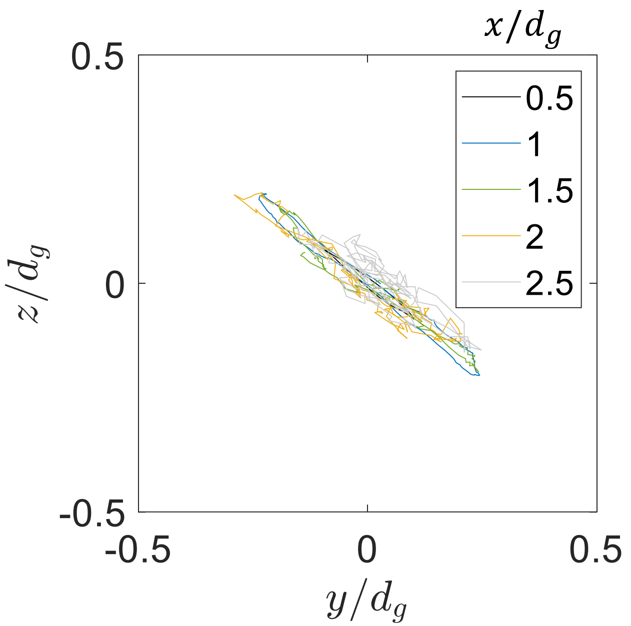
Phase shift

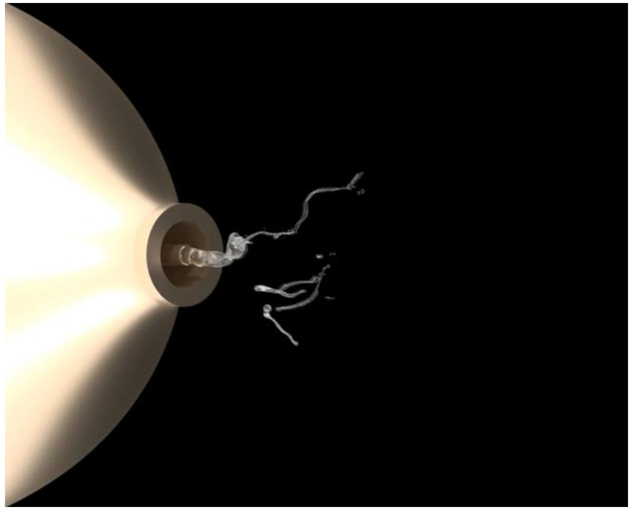




From hook bags to side bags



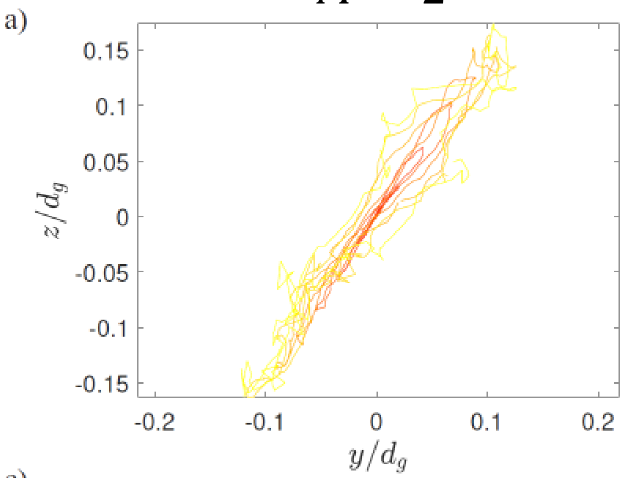




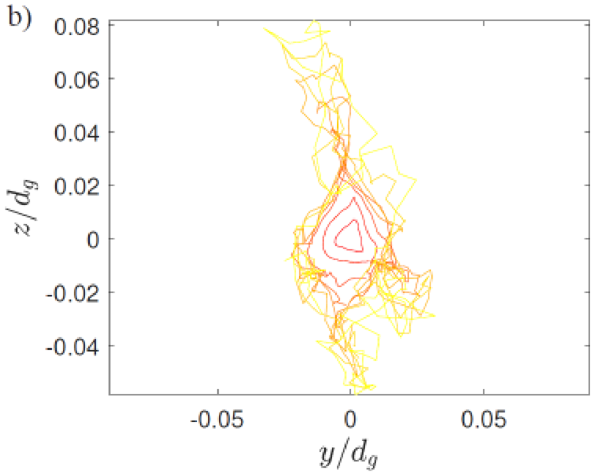
O. Desjardins

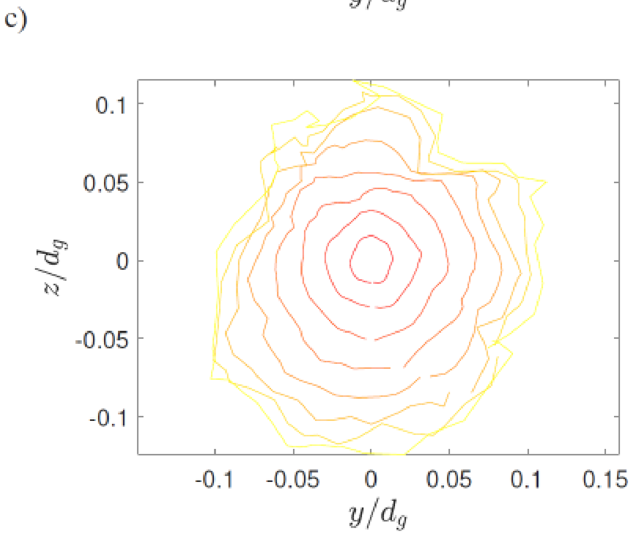
1st conclusions

$M = 2$



$M = 5$

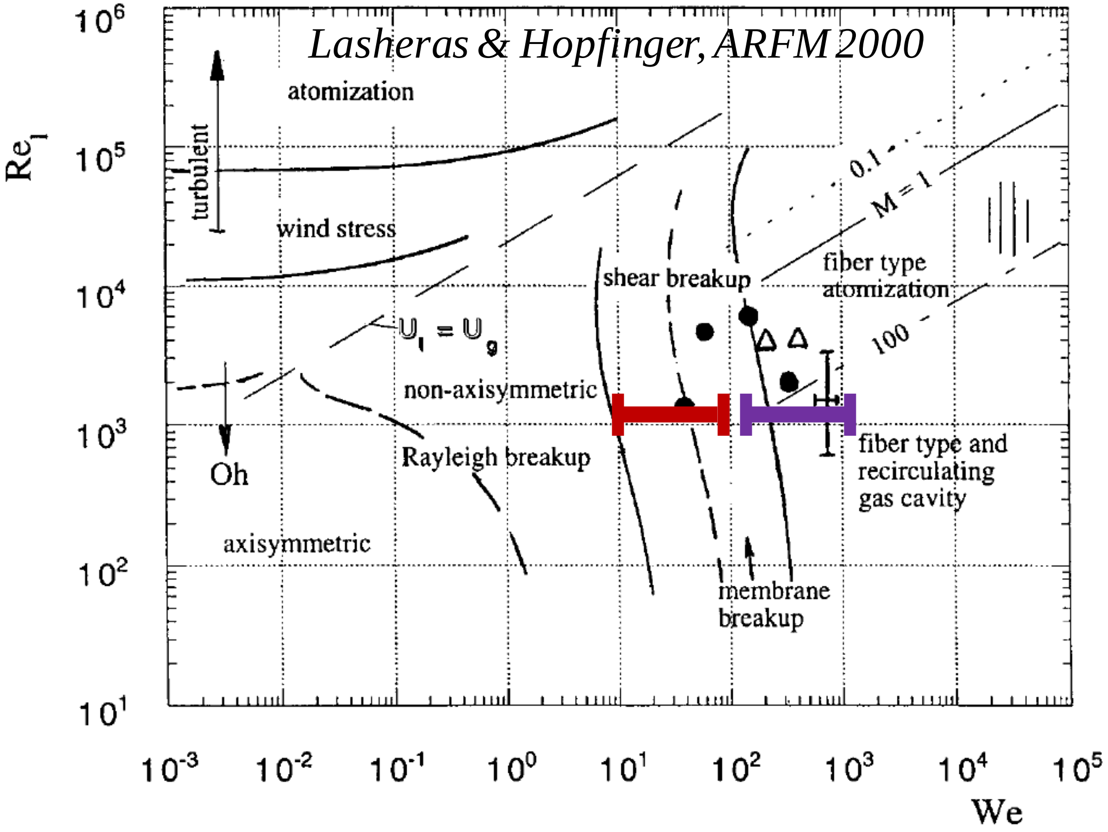




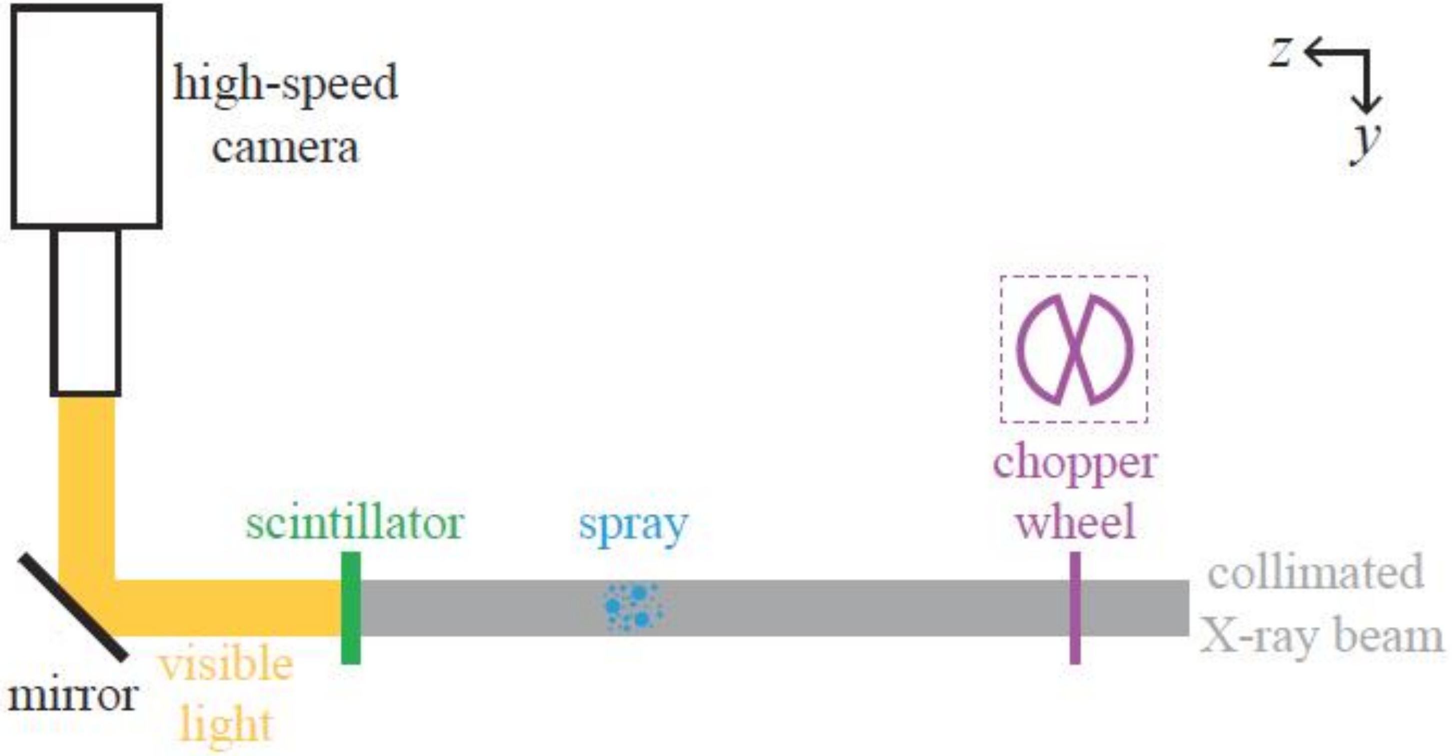
$M = 5$
$SR = 0.5$

- 3 modes of flapping reported
- Planar flapping only at low M / circular at high M
- Swirl is very efficient at transitioning towards circular orbits
- No apparent change in flapping frequency scaling with changes in dimensionality

<u>Open questions</u>:
Is the flapping direction random in planar mode?
What happens in high-speed sprays (fiber-type regime)?



X-Ray Radiography



Beer-Lambert law:

$$I = I_0 e^{\mu l}$$

→

Measure liquid
equivalent path length (EPL)

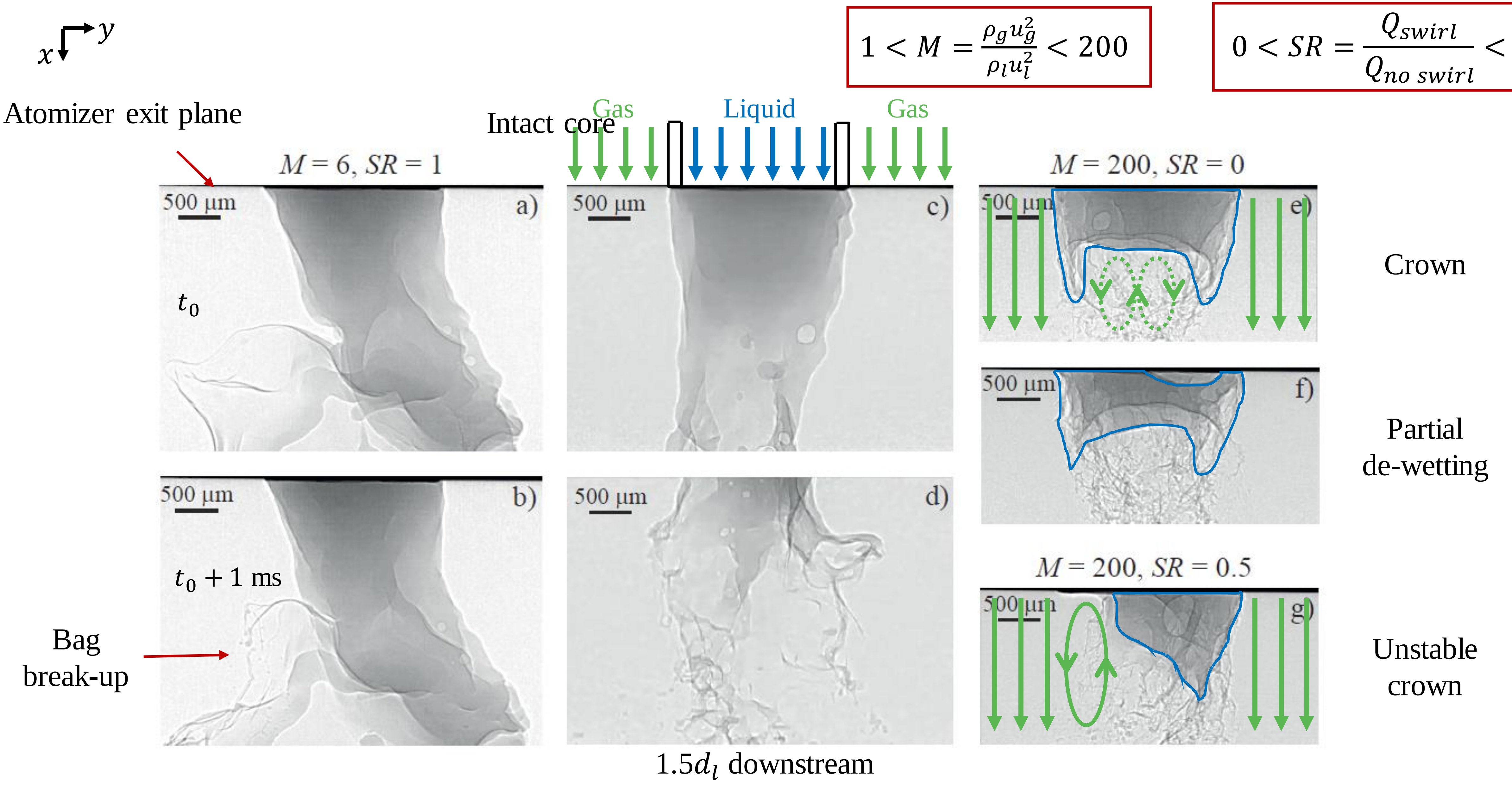
$$EPL(x, y) = \int l \, dz$$

Advanced Photon Source, Argonne National Lab

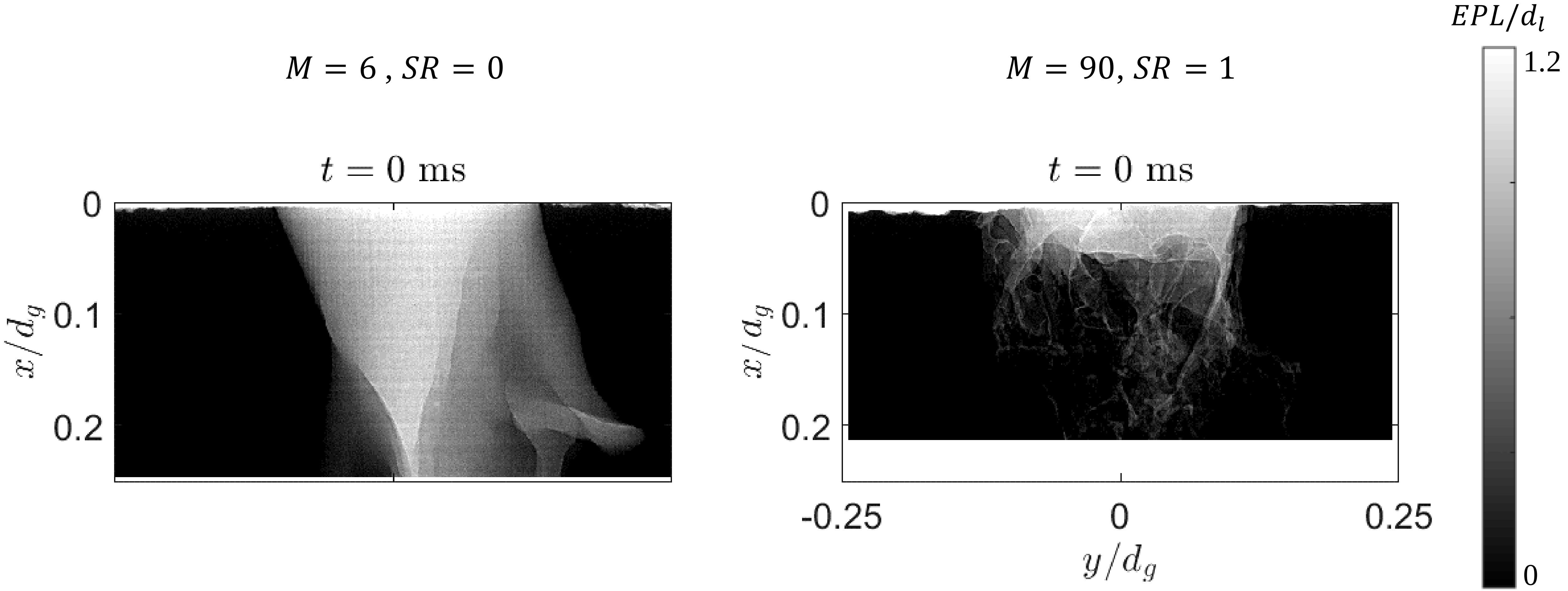
X-Ray Images

$$1 < M = \frac{\rho_g u_g^2}{\rho_l u_l^2} < 200$$

$$0 < SR = \frac{Q_{swirl}}{Q_{no\ swirl}} < 1$$



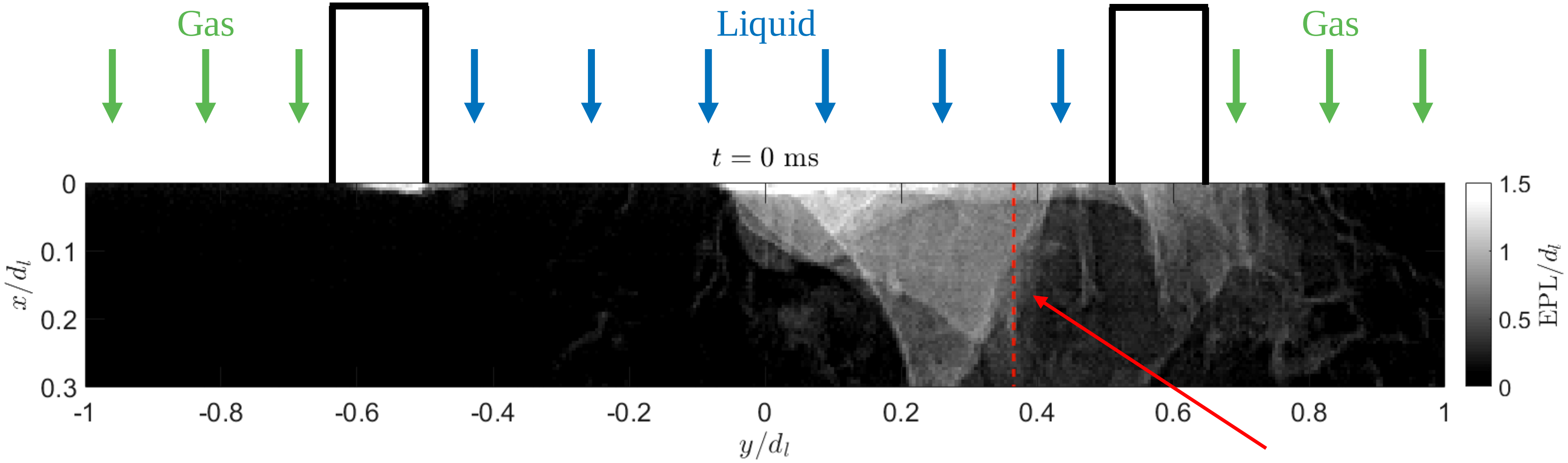
X-Ray Liquid EPL Movies



Unstable Crown

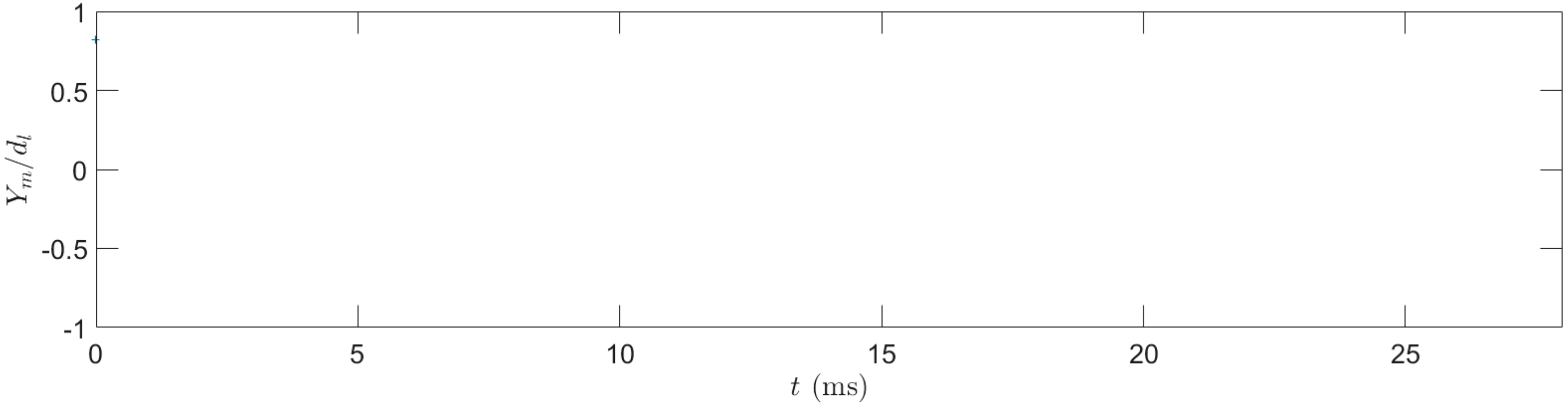
$M = 200, SR = 1$

$$SR = \frac{Q_{swirl}}{Q_{no\ swirl}}$$



Y position of the liquid core center of mass

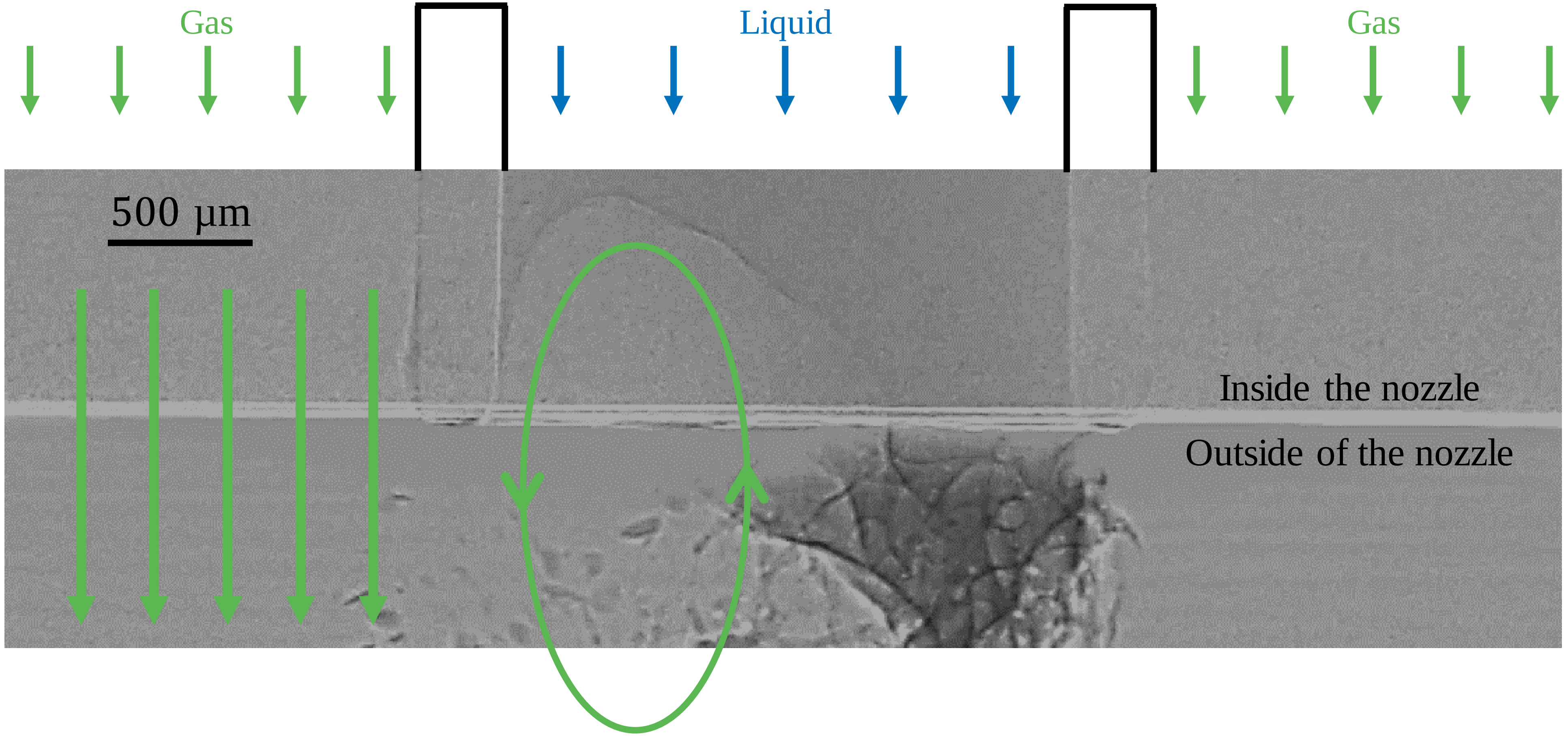
Center of mass of the liquid crown



Unstable Crown

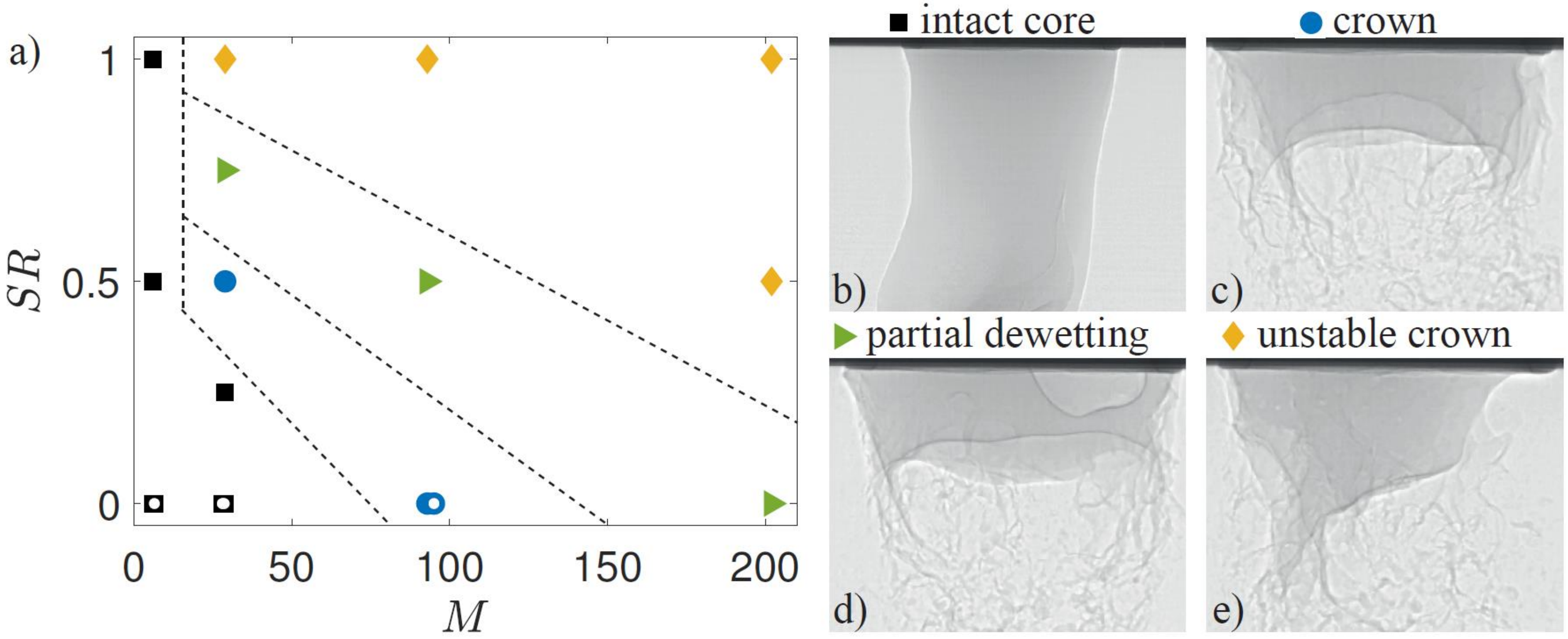
$$M = 200, SR = 1$$

$$SR = \frac{Q_{swirl}}{Q_{no\ swirl}}$$

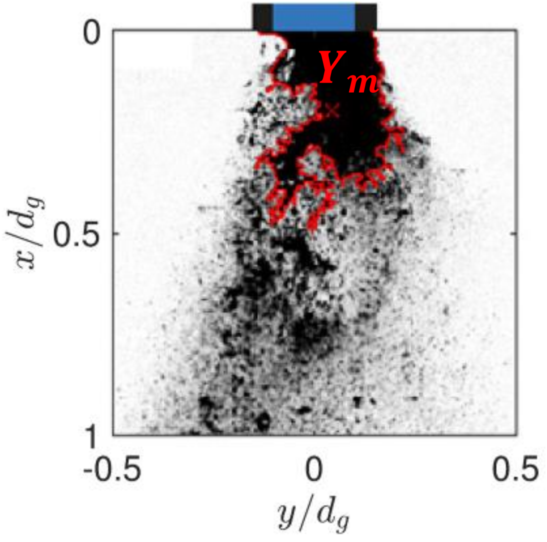


- Gas recirculates behind the liquid nozzle and penetrates inside it
- Instability of the recirculation cavity ➔ drastic de-wetting and unstable crown

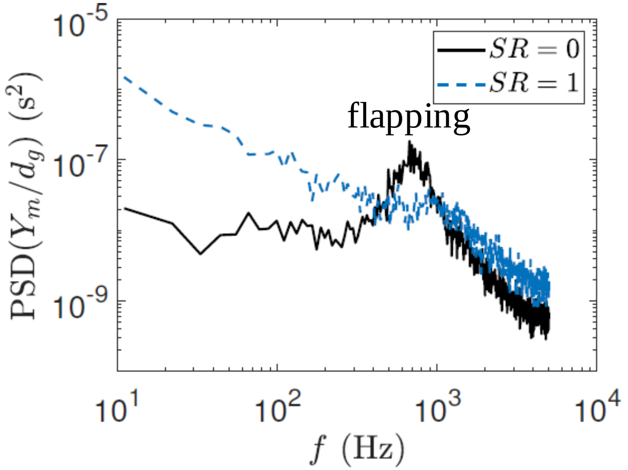
Phase Diagram of Break Up Modes



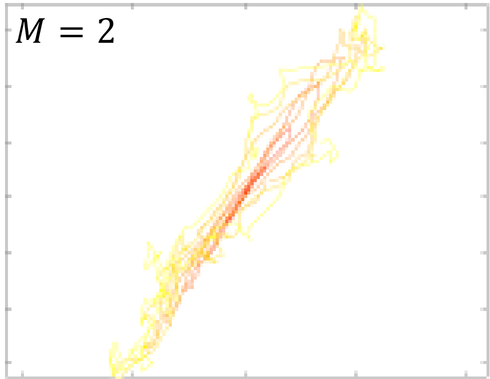
Shadowgraph:
center of area

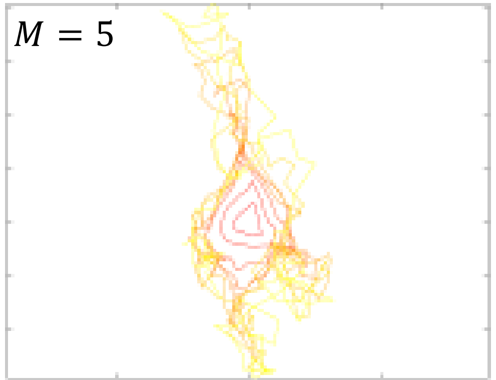


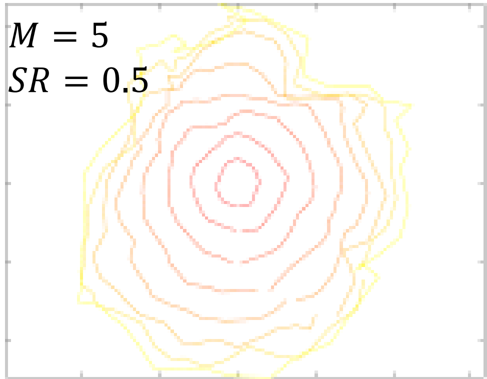
- Unstable crown only in the presence of swirl
- Swirl permits transition to more active states at lower values of *M*
- Strong signature on the temporal dynamic of the liquid jet

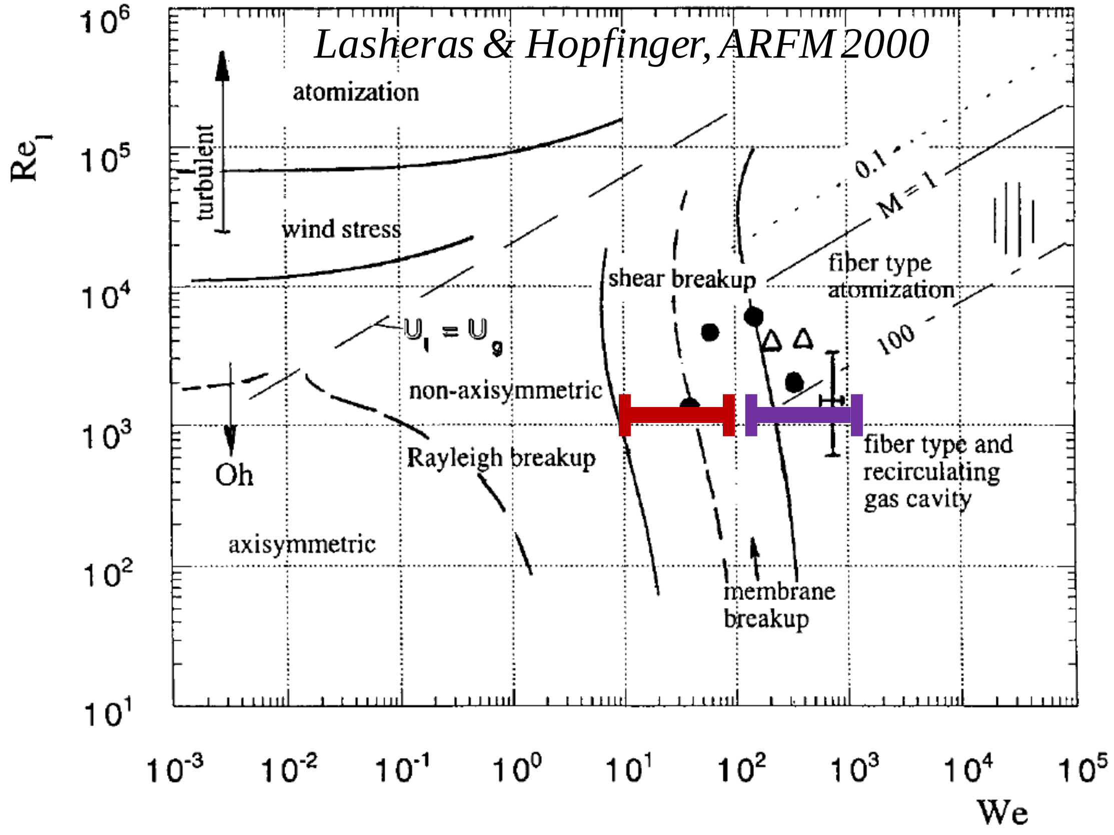


Conclusion







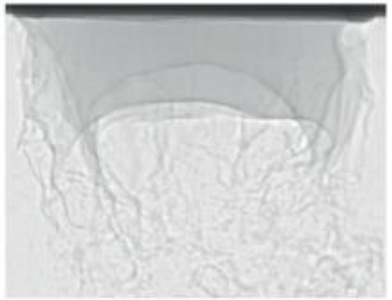


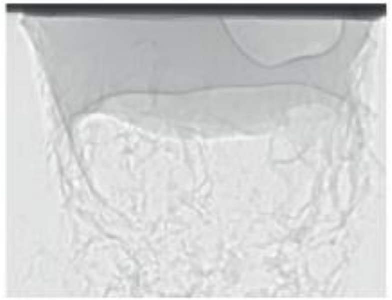
Low M

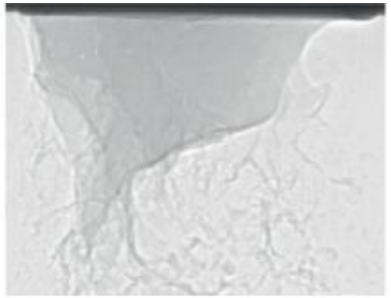
- 3 modes of flapping reported
- Swirl is very efficient at transitioning towards circular orbits

High M

- Crown/recirculating gas
- Unstable crown only for $SR > 0$
  - ➢ Vortex within liquid nozzle
  - ➢ Long-time dynamic

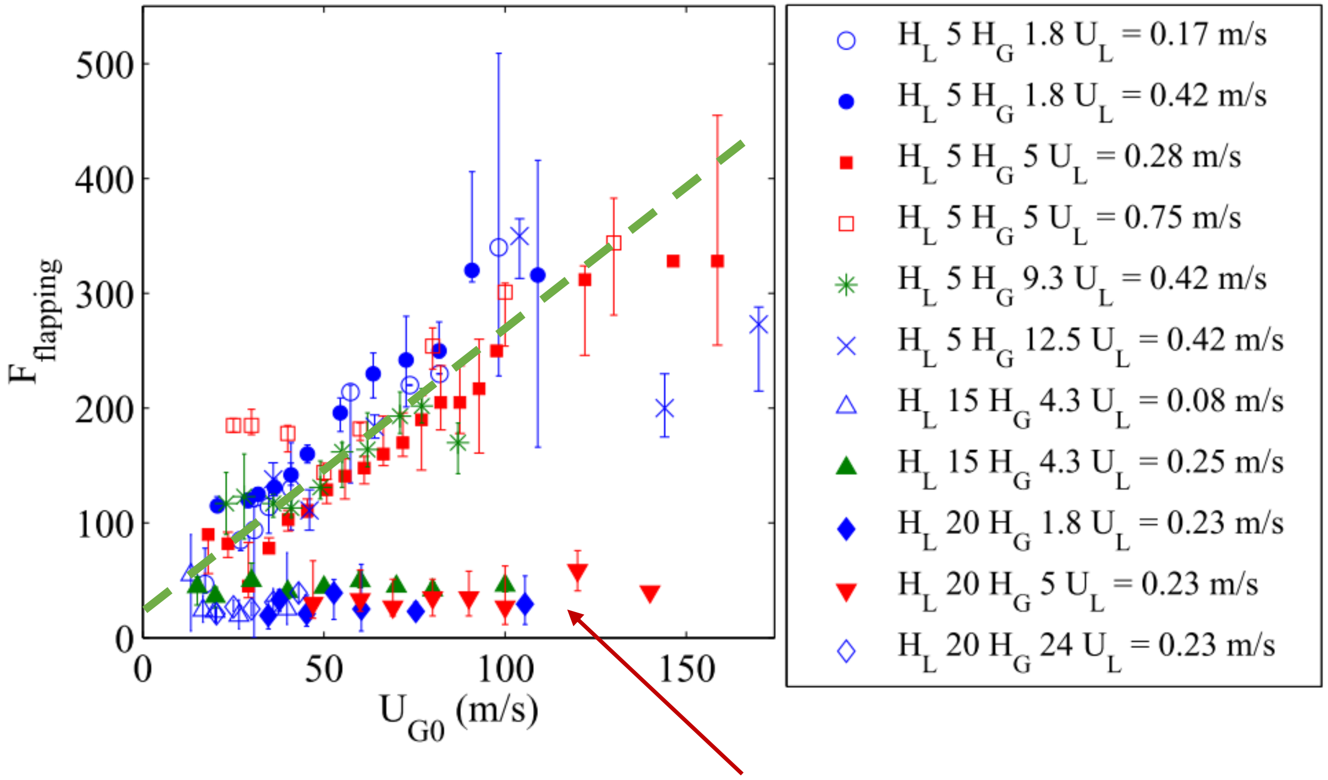


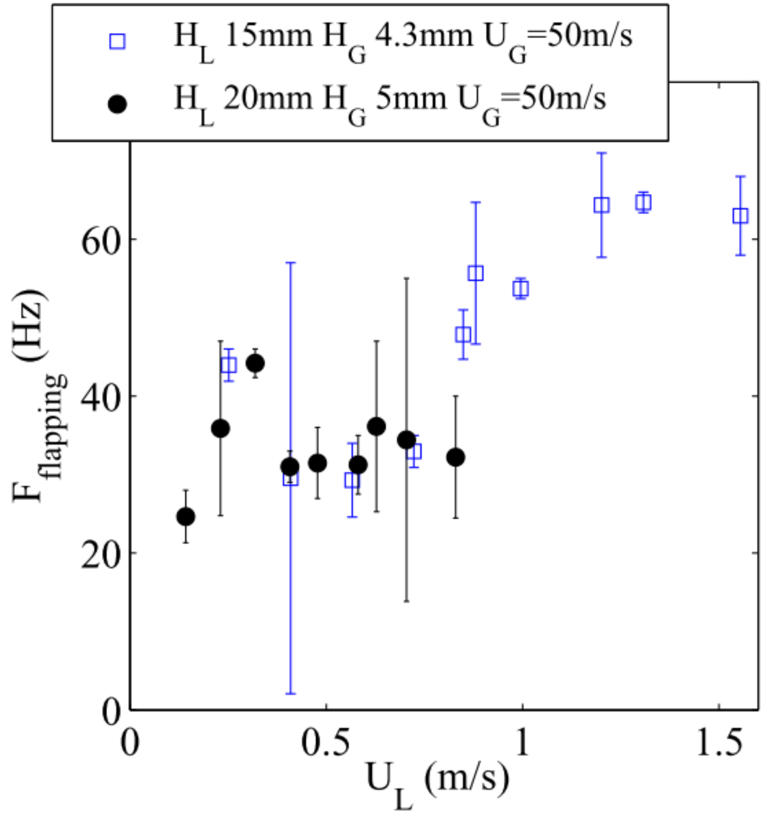




Flapping frequency dependency

Delon et al., 2018





Shear instability with wavelength shorter than liquid jet diameter

X-Ray Radiography

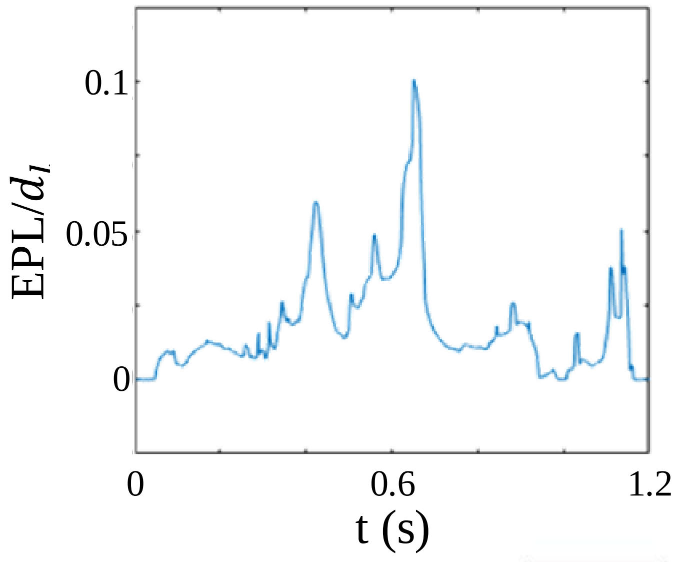
Focused beam measurements:
- Monochromatic
- Point-like (5 x 6 μm)
- High-speed (0.3 MHz)

Beer-Lambert law:

$$I = I_0 e^{\mu l}$$

↓

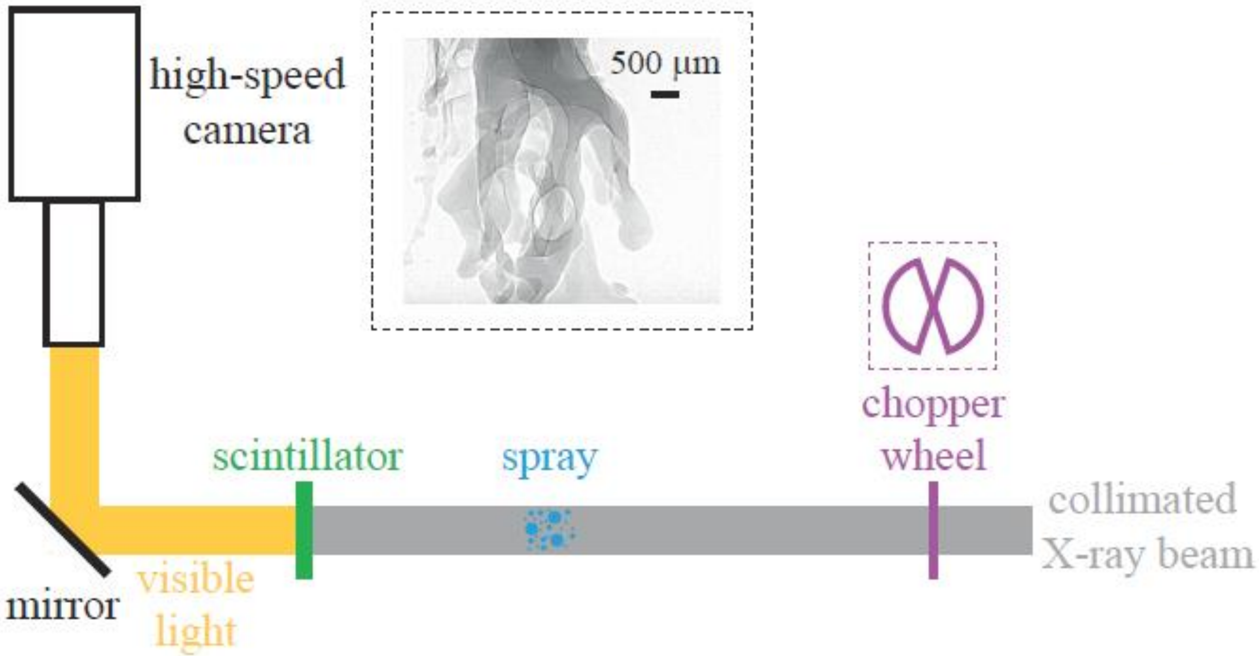
Measure liquid equivalent path length (EPL)



White beam imaging:
- Polychromatic
- Large field of view ~ (10mm)²
- High temporal resolution ~ 10kHz

→ Measure Optical Density (OD)

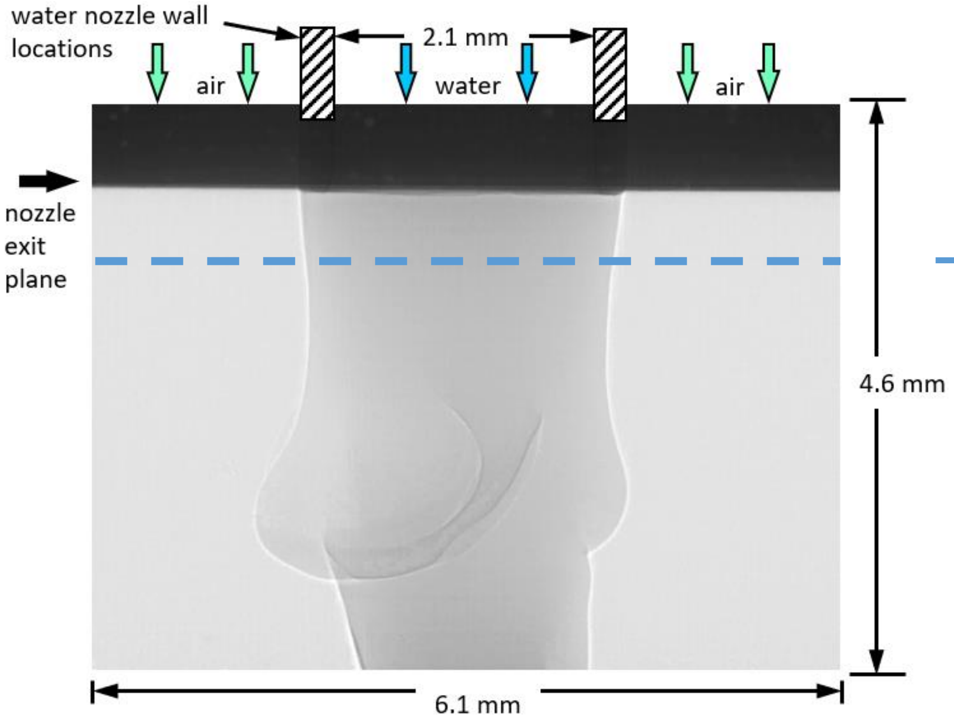
Advanced Photon Source, Argonne National Lab



X-Ray Optical Density Conversion to Liquid Equivalent Path Length

White beam imaging:
- Polychromatic
- Large field of view ~ $(10mm)^2$
- High temporal resolution ~ 10kHz

Optical Density (OD)



Focused beam measurements:
- Monochromatic
- Point-like (5 x 6 µm)
- High-speed (0.3 MHz)

➔ Liquid equivalent path length (EPL)

$$\frac{x}{d_l} = 0.25$$