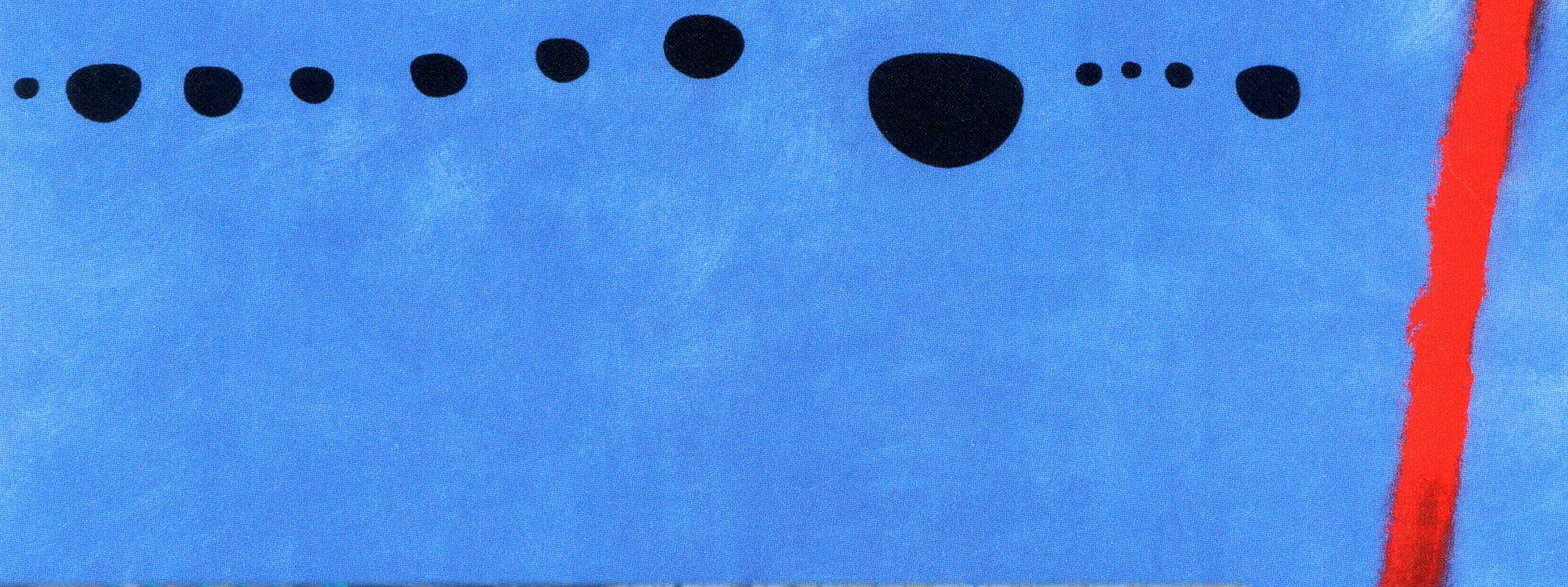
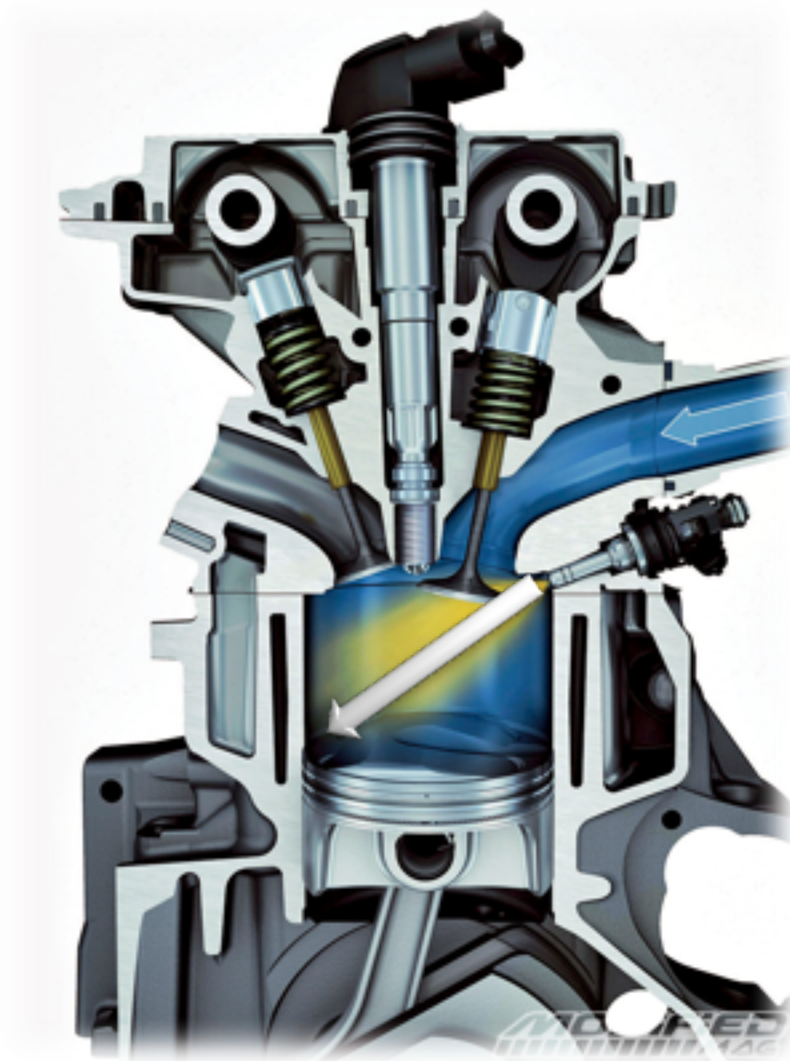
Modeling of liquid atomization using a surface density function

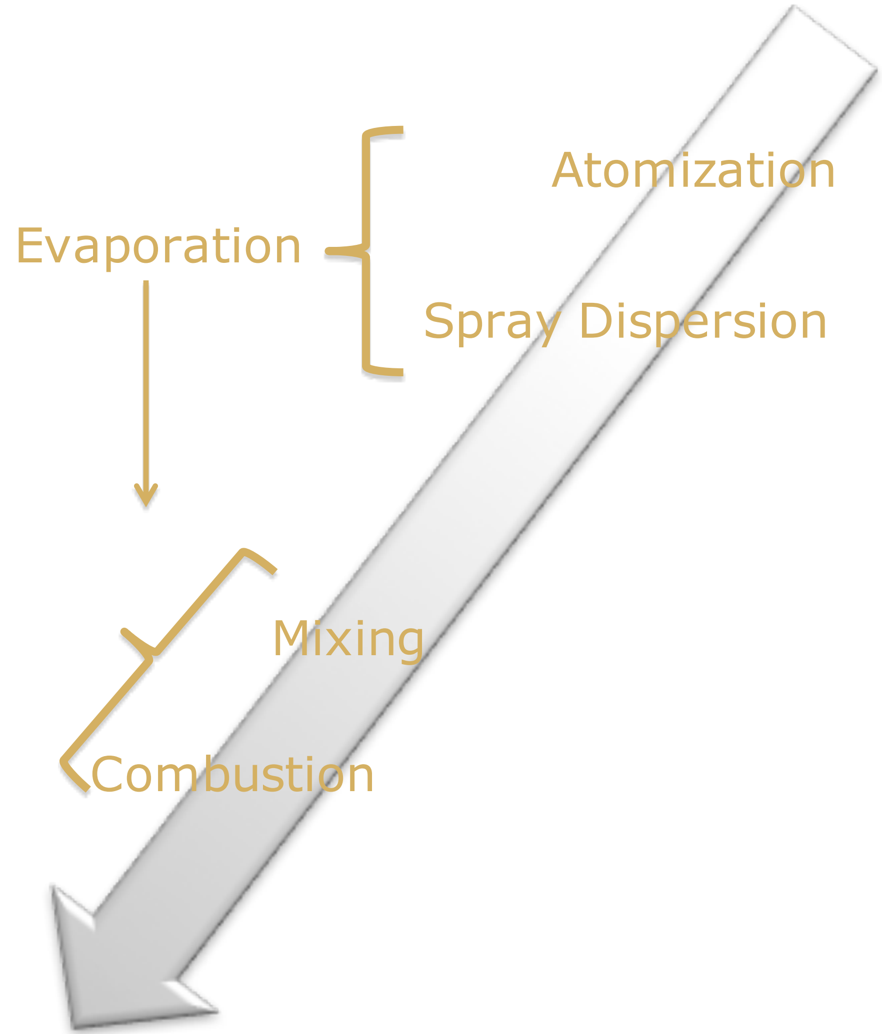
Hecht, N., Perdomo J.A., Reveillon J. and Demoulin F.X.
CORIA – UMR CNRS 6614 – Normandie Université



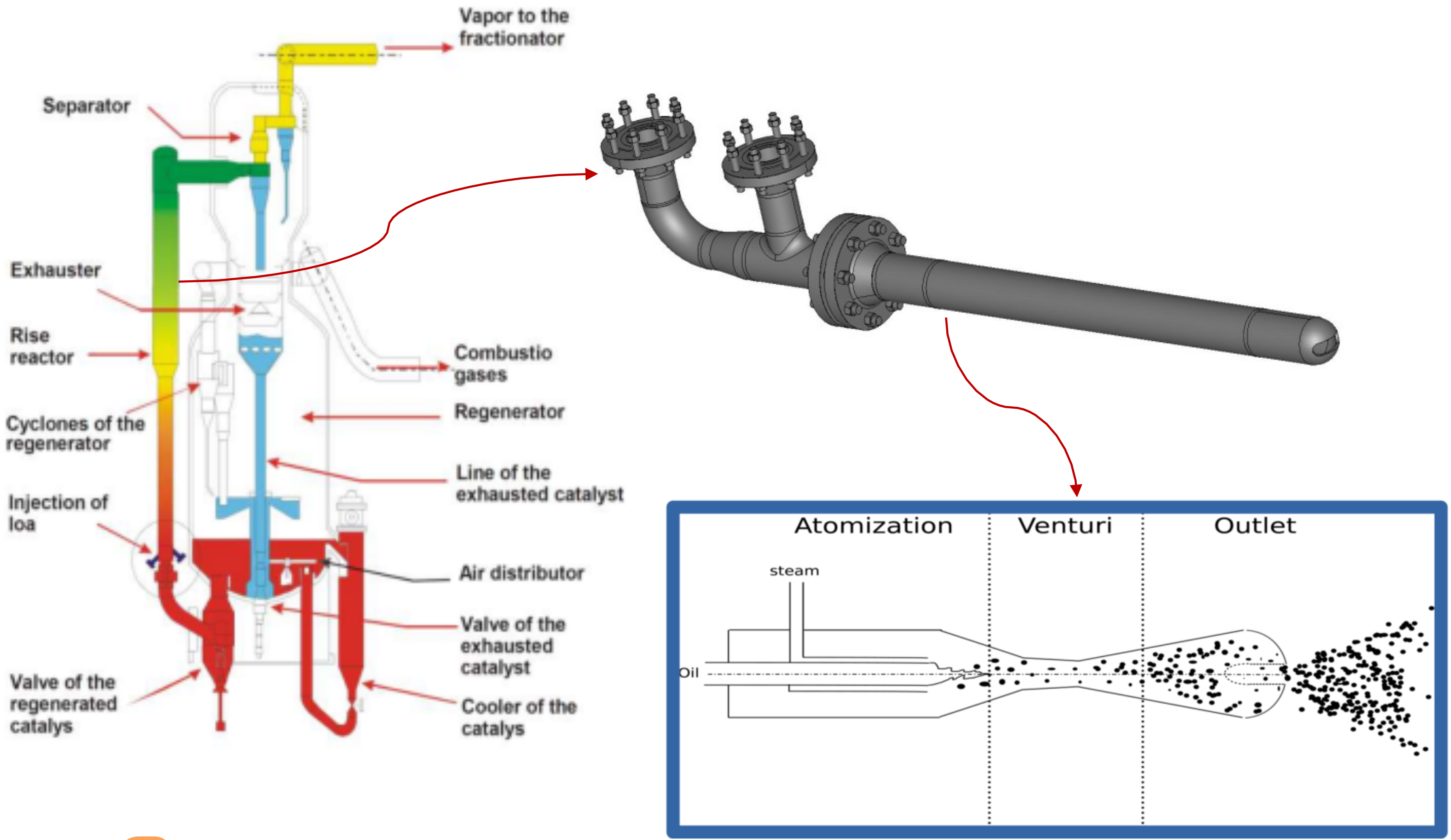
[Miro - 1961]

Atomization in combustion chamber





Atomization in FCC injector

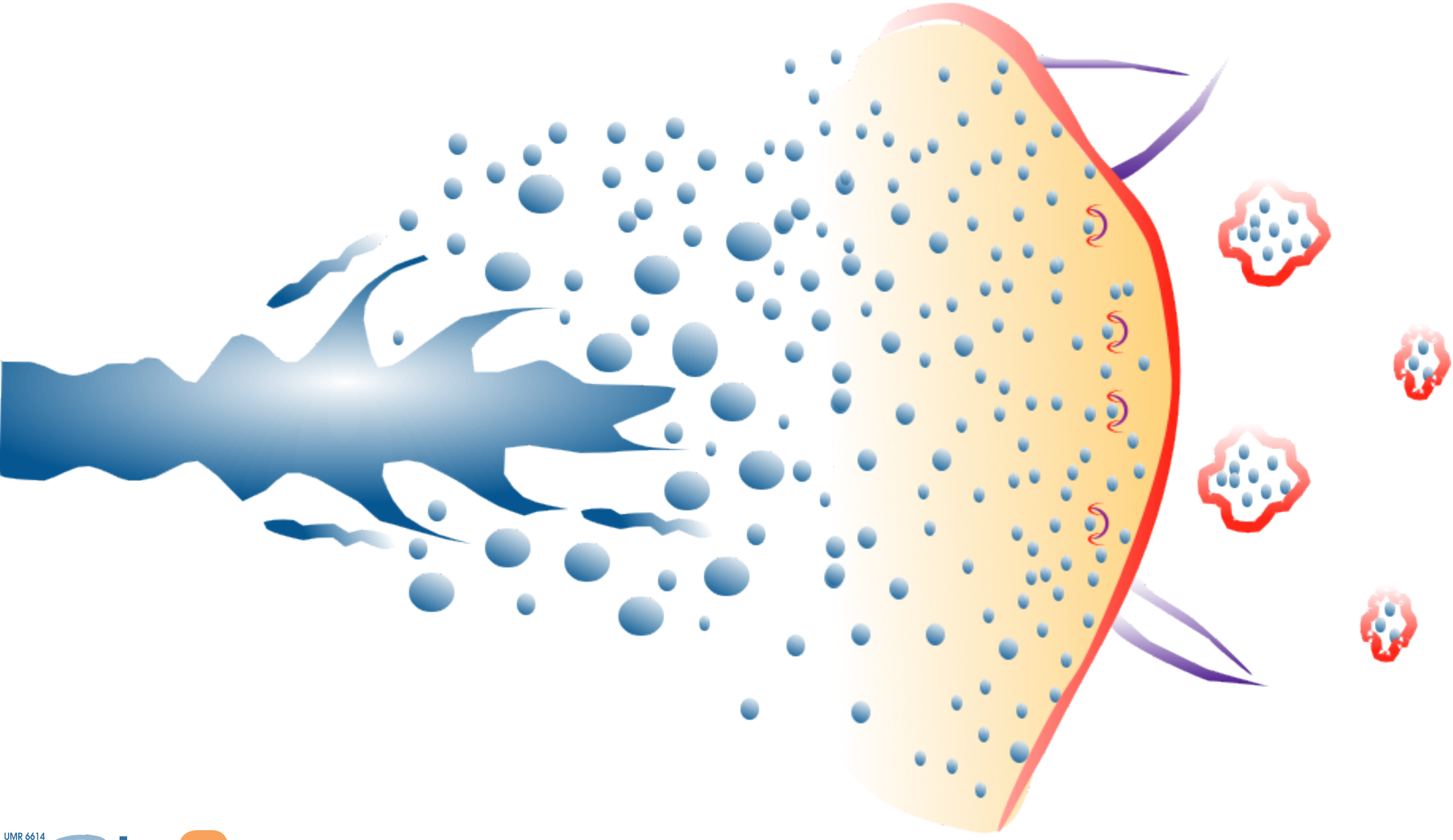


Atomization process:

As simple as…holes

Yet, impossible to predict…

Combustion chambers



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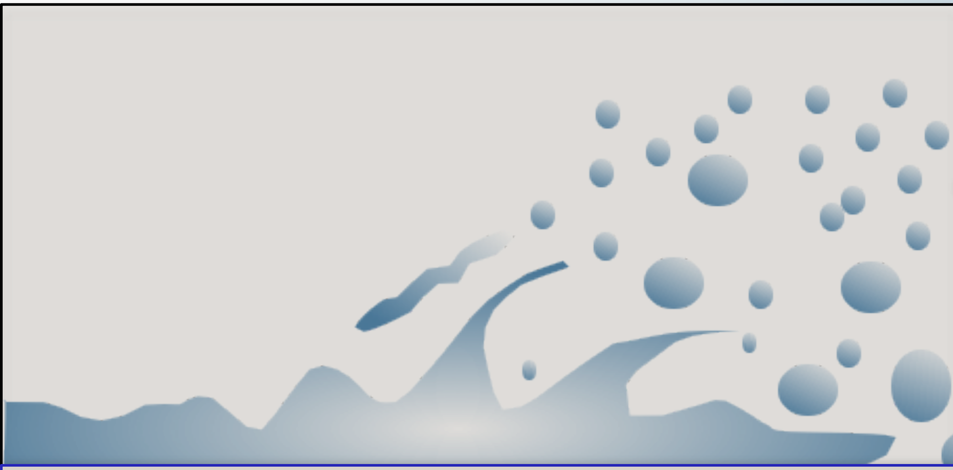
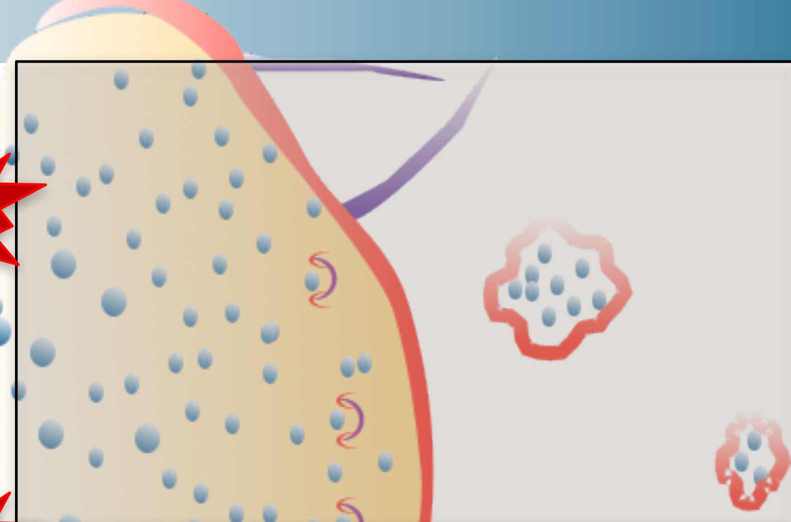
Junction stumblingblock



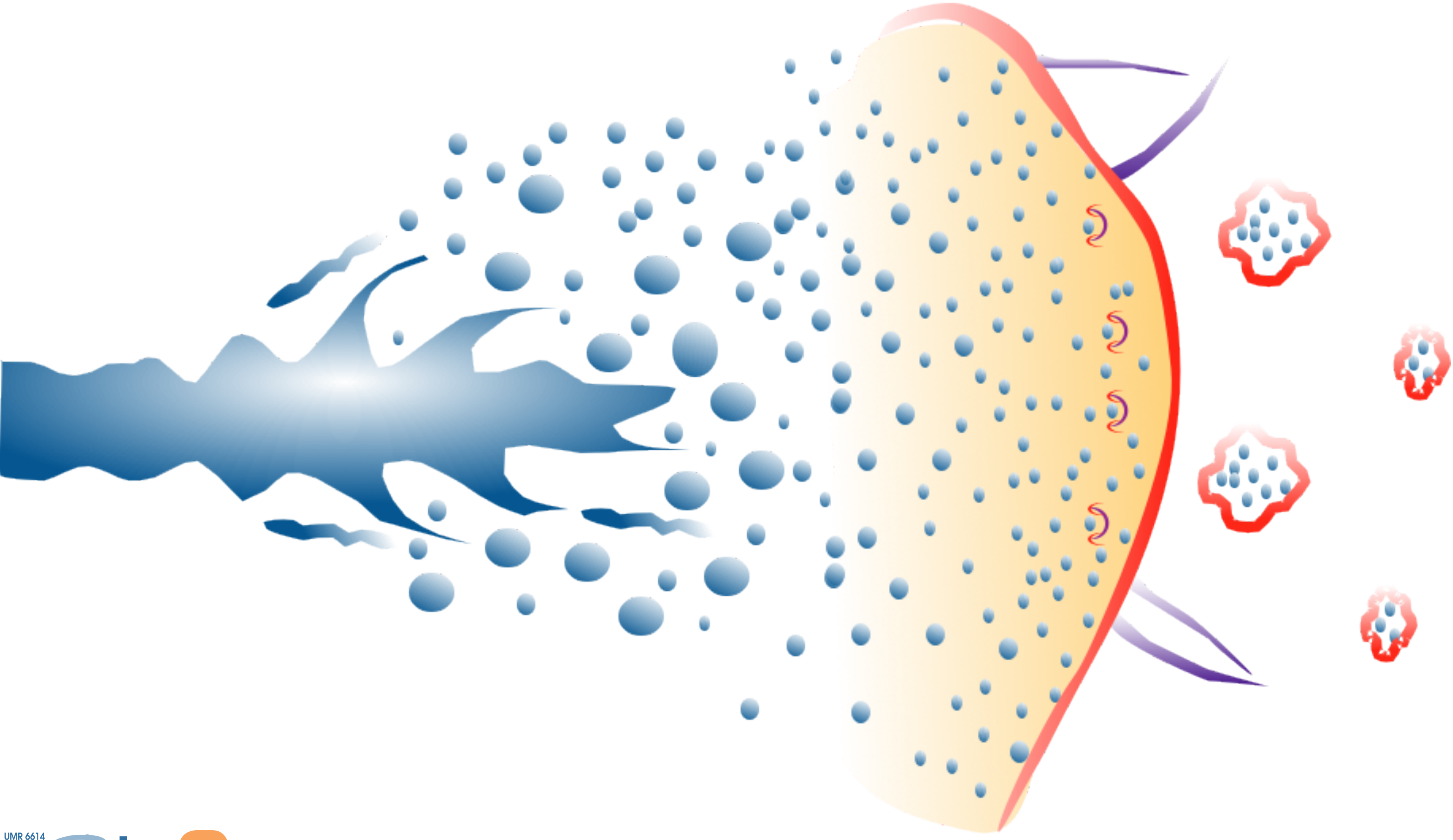
- Incompressible flows
- Level-Set / VOF / SPH
- Non-Vaporizing
- m and cm scales



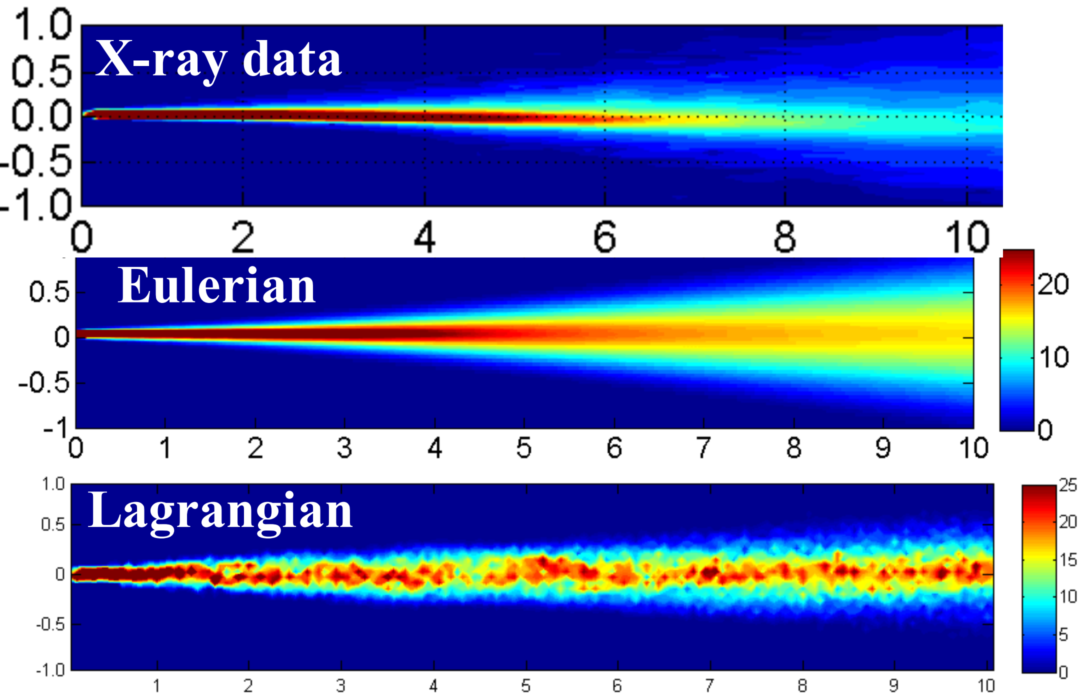
- Compressible or dilatable flows
- Simple or complex chemistry
- Dispersed phase (Lagrangian or Eulerian)
- Small spherical droplets
- mm and µm scales

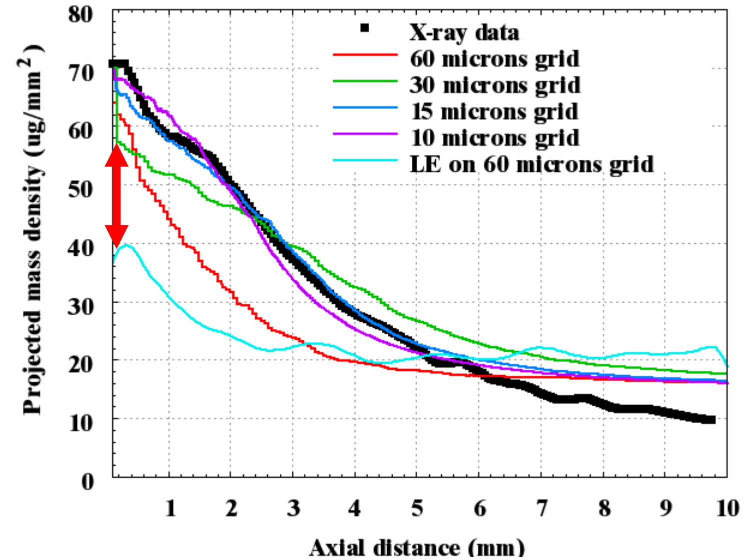
Different numerical methods, physical outcomes and communities !!!

Solution ? Interface ? LES ? Euler ? Lagrange ?

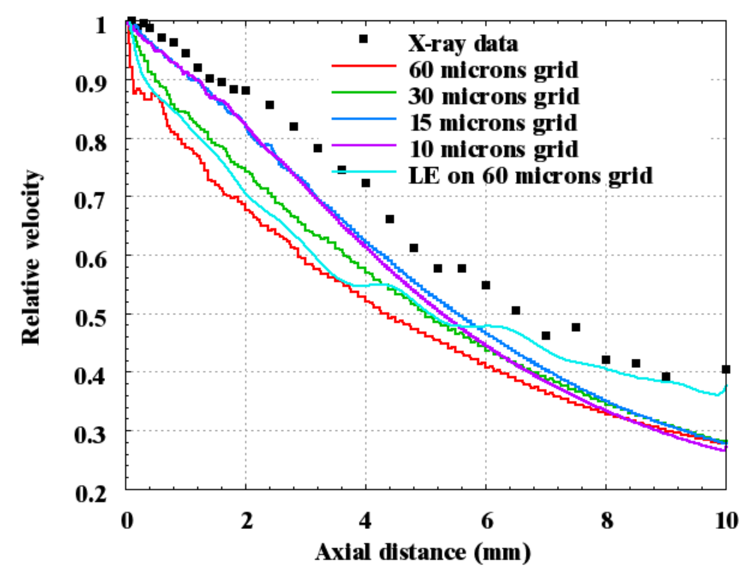


Spray A: EE vs. LE at Argonne





Projected mass density along spray axis



Mass-averaged velocity along axis

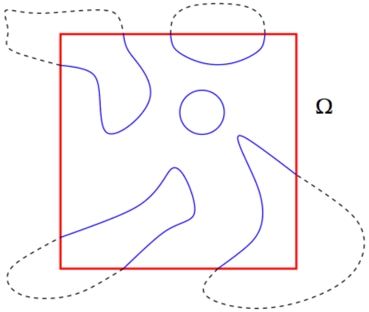
- Eulerian model is better than traditional Lagrangian approach in the near nozzle region
- Lagrangian simulations: 62.5μm minimum resolution, blob injection model, 300,000 parcels

Interface + SG Surface density (E/E)

Description of the subgrid spray :

- Eulerian description
- Multiple objects characterization (drops, blobs, ligaments, liquid sheets, etc)

$$\text{Interface density}\,\overline{\Sigma} = \frac{\text{Interface area}}{\text{Control volume}}$$



- **Principles of the approach**

A. Vallet and R. Borghi. C. R. Acad. Sci, 1999

- **First application to Co-axial injector**

A. Vallet, A.A. Burluka, and R. Borghi, Atomization and Sprays, 2001

- **First transition to Lagrangian ➔ name ELSA**

G. Blokkeel, R. Borghi, and B. Barbeau, 2003

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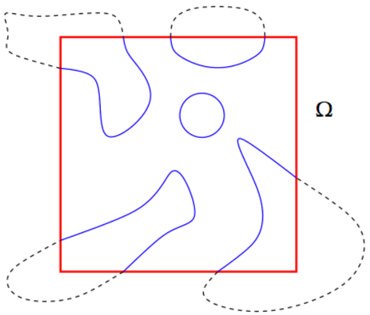
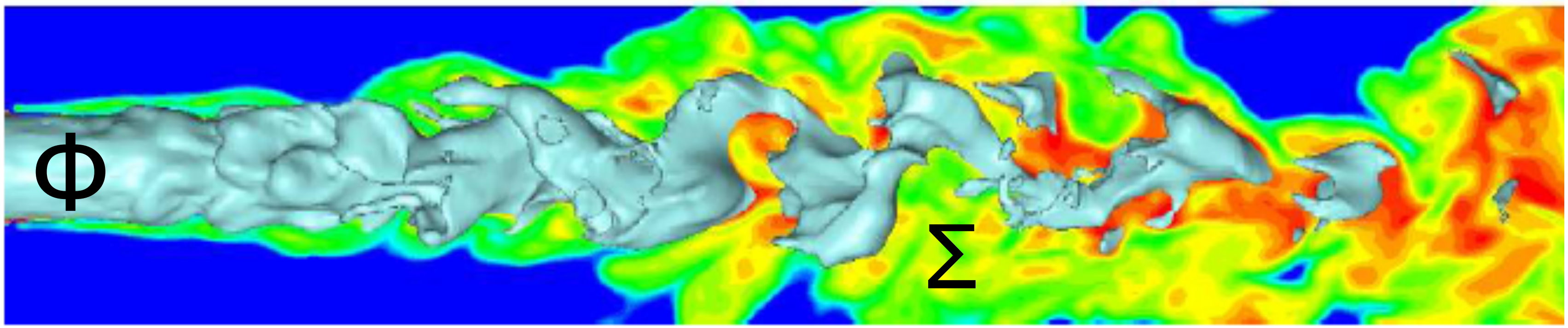
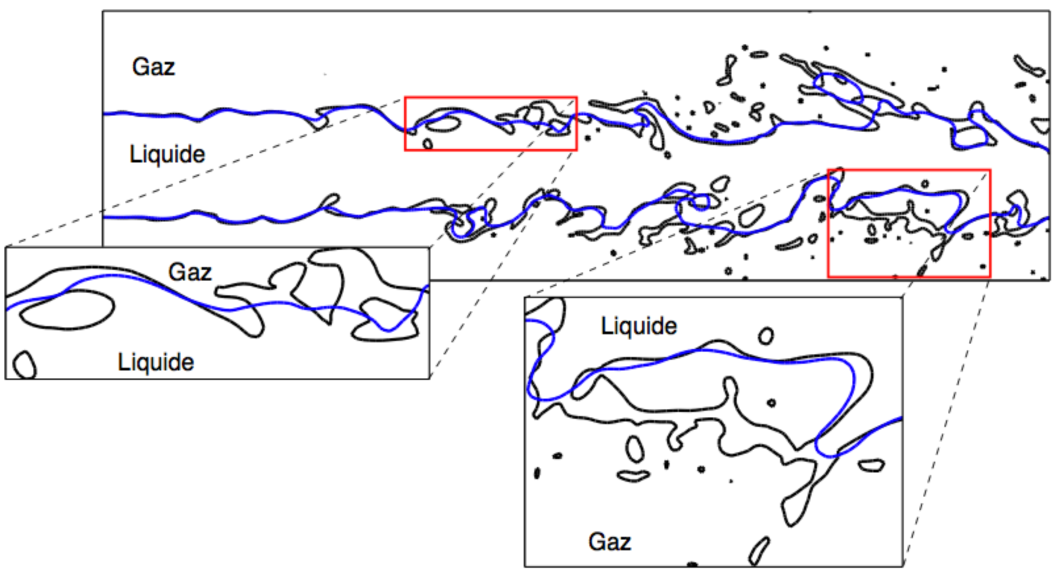


$$\frac{\partial \overline{\Sigma}}{\partial t} + \frac{\partial \overline{u}_j \overline{\Sigma}}{\partial x_j} = \frac{\partial}{\partial x_\alpha}\left(\overline{\Sigma}(\overline{u}_\alpha - \overline{u}_{\Gamma\alpha})\right) + \dot{\overline{\Sigma}}$$

Interface + SG Surface density (E/E)

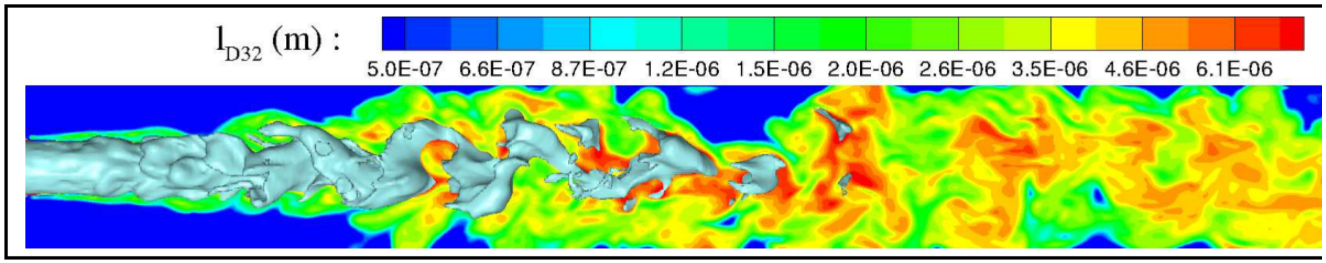
- Subgrid interface density

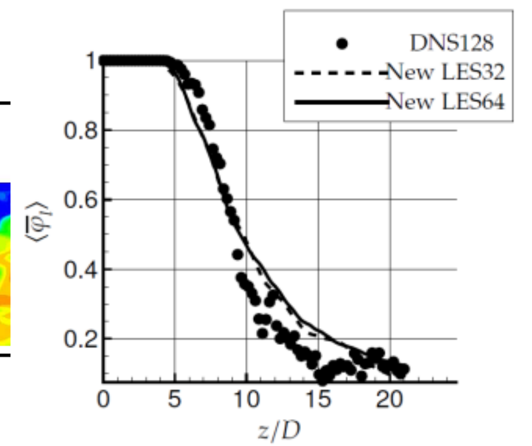




To combine resolved and under resolved approaches

J. Chesnel et al., Atomization and Spray, 2011





! Incompatibility issue !

Subgrid term ⇔ICM

$$\tau_{\varphi j} = \underbrace{Random\ motion}_{Diffusion}$$

$$\frac{\partial \overline{\varphi_l}}{\partial t} + \frac{\partial \overline{u_j}\,\overline{\varphi_l}}{\partial x_j} = \underbrace{\frac{\partial \tau_{\varphi j}}{\partial x_j}}_{\text{Subgrid Term}}$$

←ICM Method VOF, Level Set

$$\frac{\partial \varphi_l}{\partial t} + \frac{\partial u_j \varphi_l}{\partial x_j} + \underbrace{\frac{\partial C_\alpha u_{Cj} \varphi_l (1-\varphi_l)}{\partial x_j}}_{\text{ICM}-\text{interFoam}} = (1-\ C_\alpha)\tau_{\varphi j}$$

1/0 ? Criteria needed !

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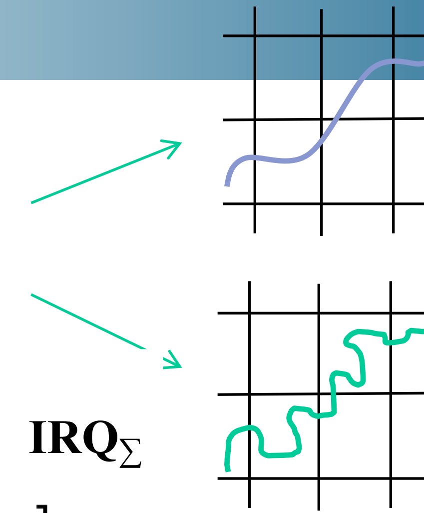
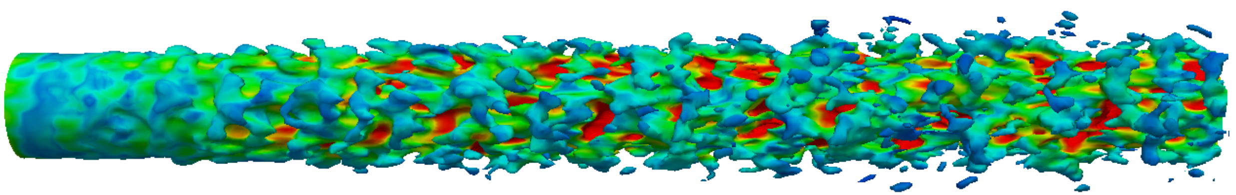
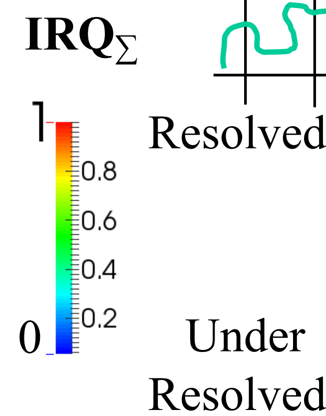
Interface Resolution Quality : IRQ_{Σ}

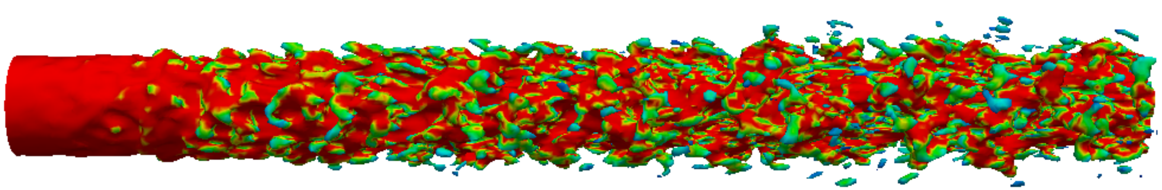
$$IRQ_{\Sigma} = \frac{\Sigma_{min}}{\Sigma} : \frac{\text{Resolved Interface}}{\text{Total Interface (ELSA)}}$$

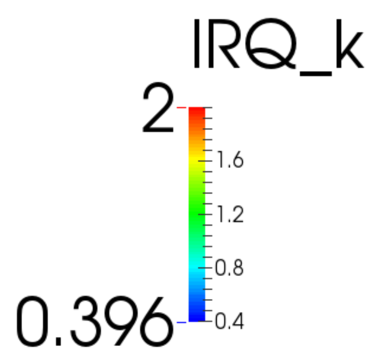




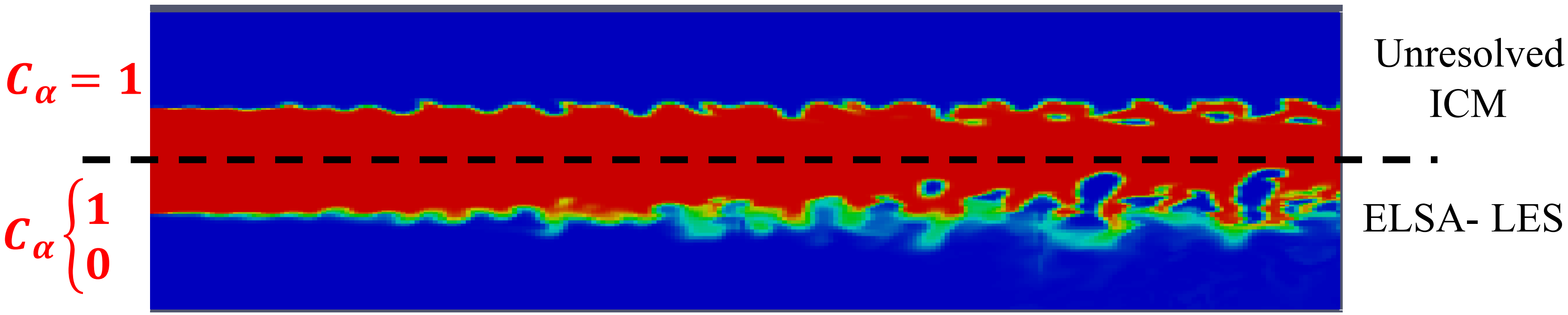


$$IRQ_{\kappa} = \frac{1}{\Delta\kappa} = \frac{R}{2\Delta}$$

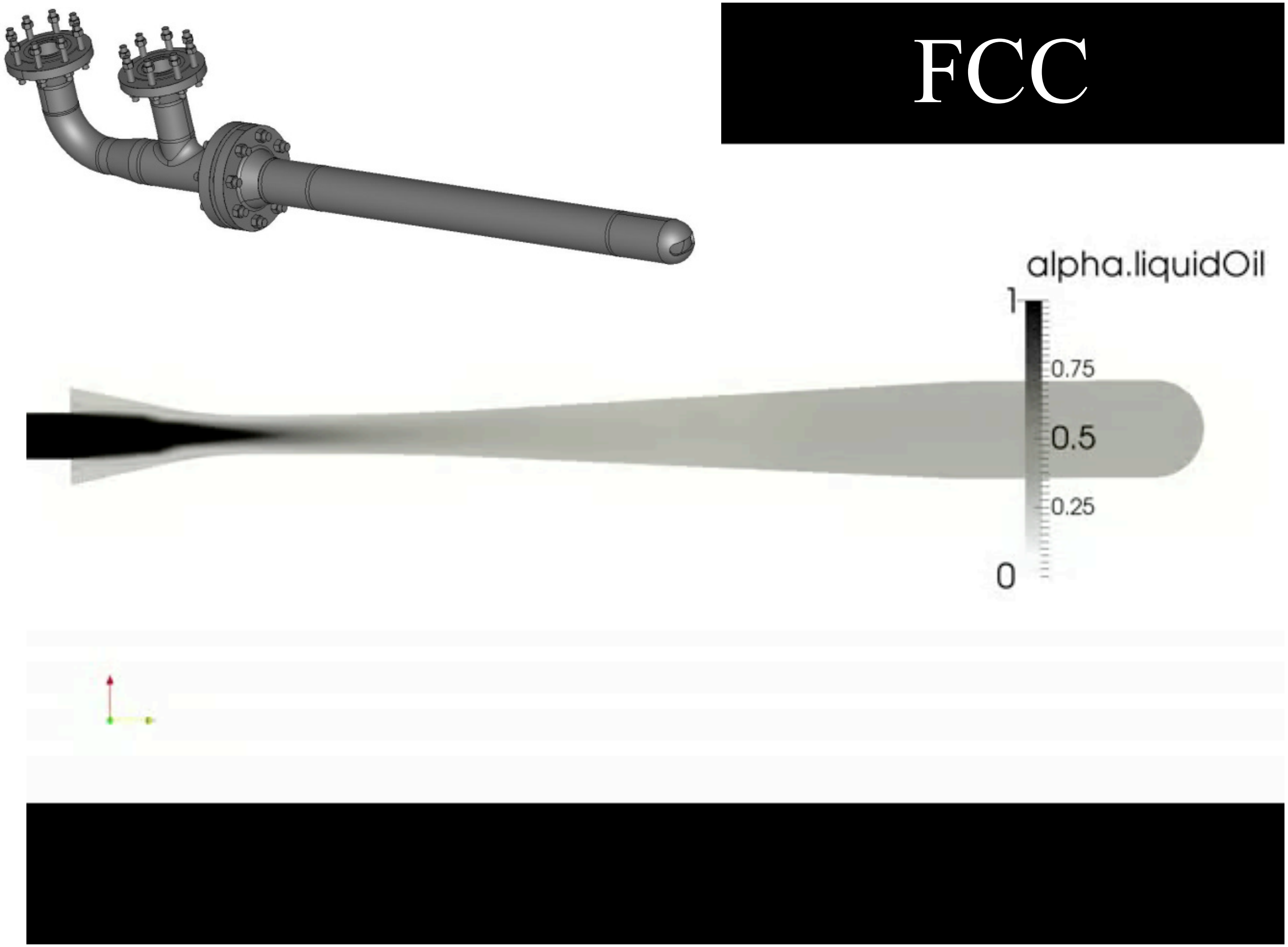




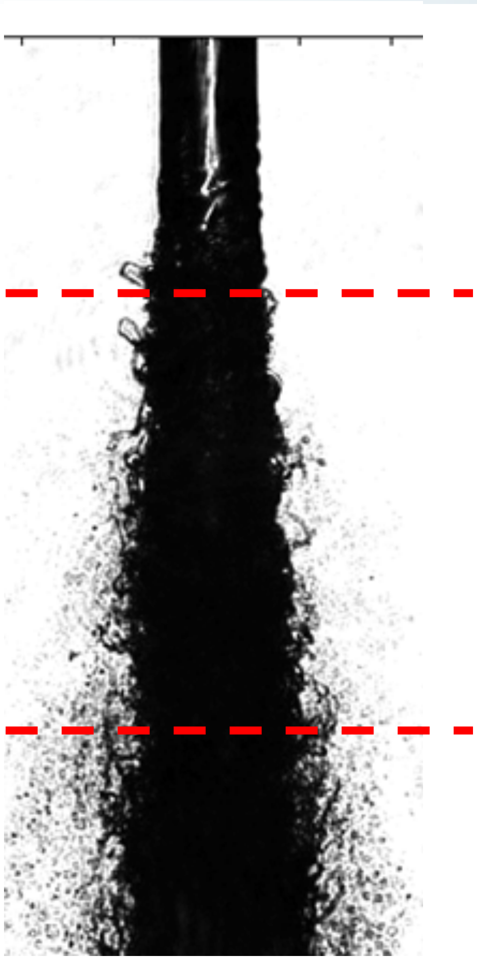
ICM combined with subgrid modeling



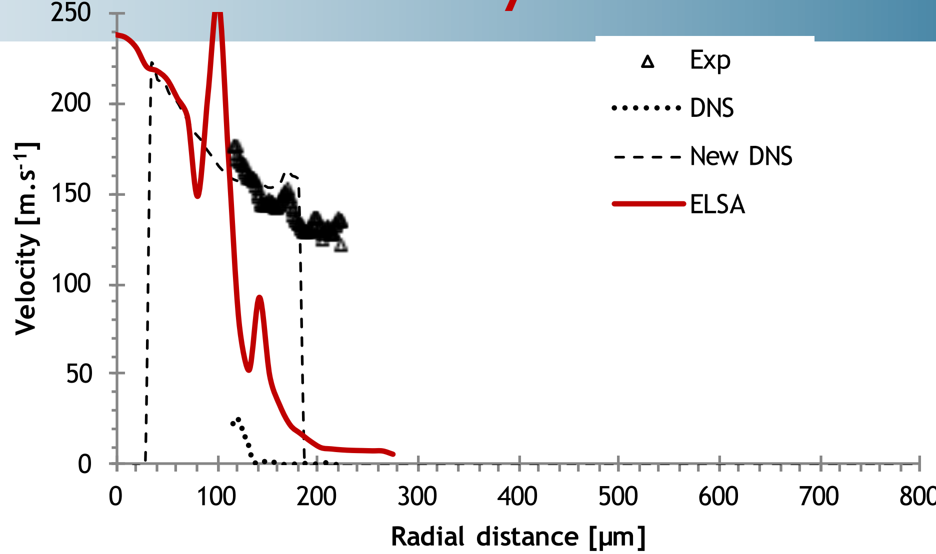
ICM combined with subgrid modeling

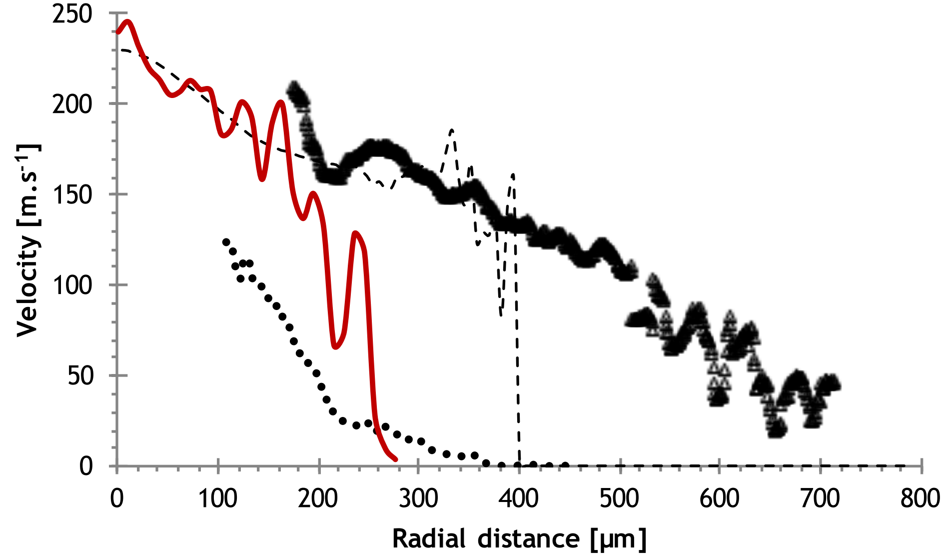


DNS/ELSA-LES/Experiment : Velocity



K. Lounnaci et al., Atomization and Sprays, 2015.





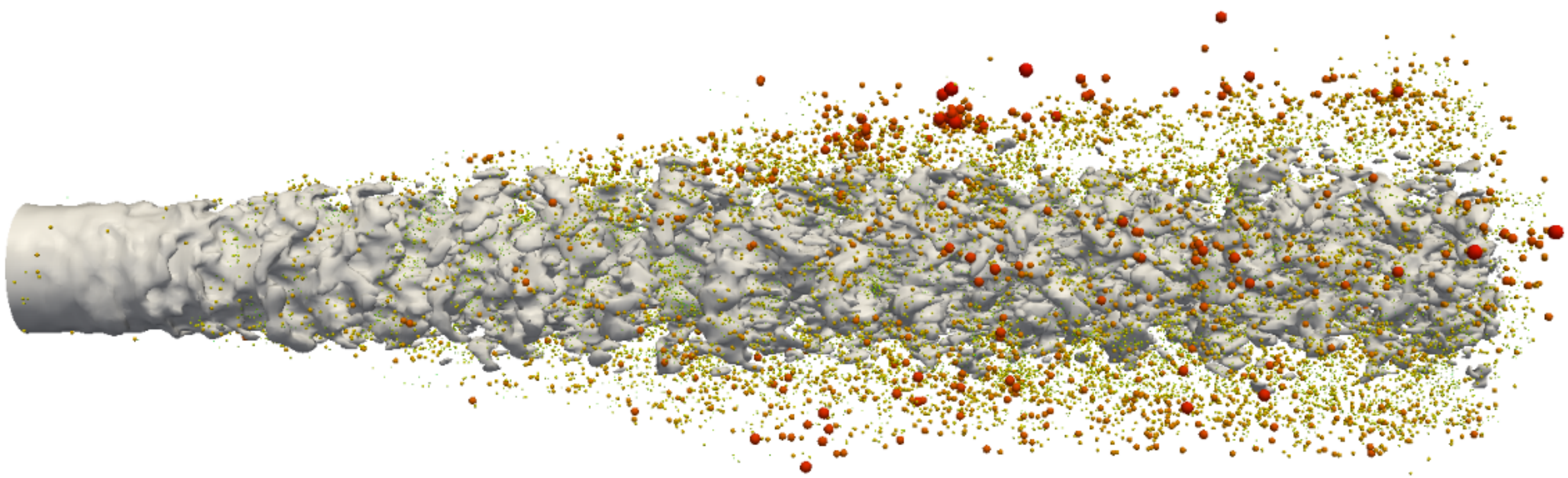
ICM + ELSA + Lagrange
Dynamic adaptive numerical methods

In the dispersed aera: lack of Information

- Very small liquid volume fraction
- Wrong description of the velocity (slip velocity needed)

Solution:

- Addition of a Lagrangian description (diluted aera <10%)
- To transport information and correct Eulerian formulation



Work in Progress

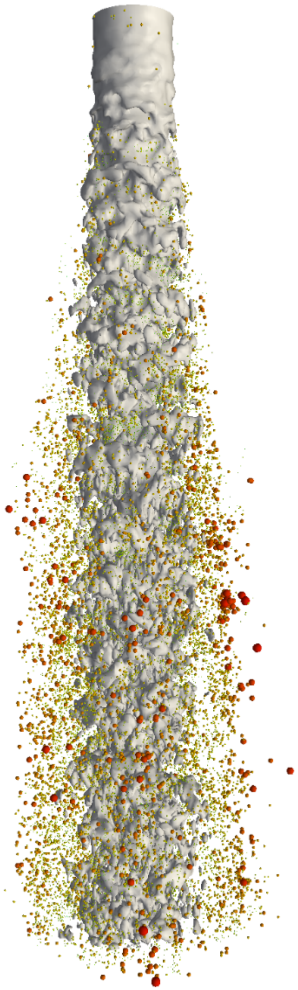
- **Foam ELSA family of Solvers**

Based on : twoLiquidMixingFoam, interFoam, compressibleInterFoam, cavitatingFoam + Lagrangian

ELSABaseFoam:

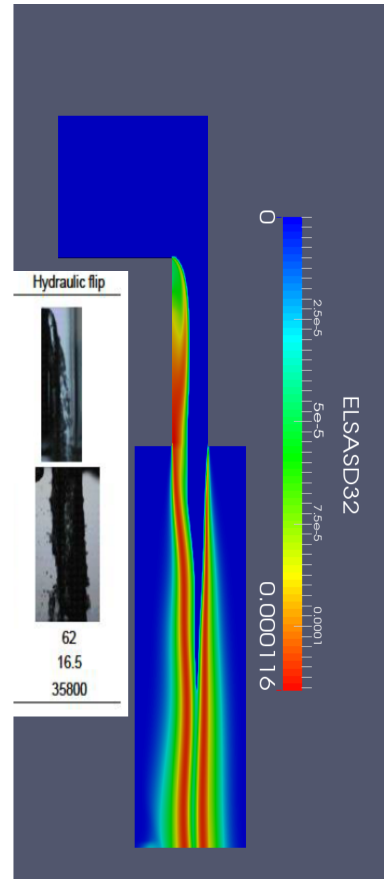
Javier Perdomo

ELSALESInterFoam:



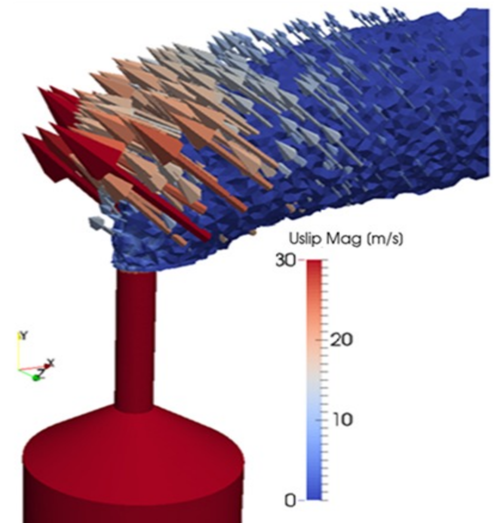
Nicolas Hecht (2016)

ELSACavitationFoam:



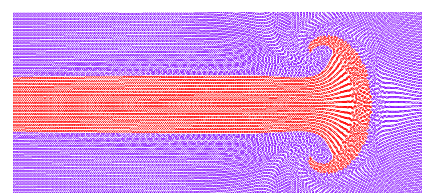
Yan Meslem (2013)
Raghavan Lakshmanan

ELSAQMEFoam:



Stefano Puggelli

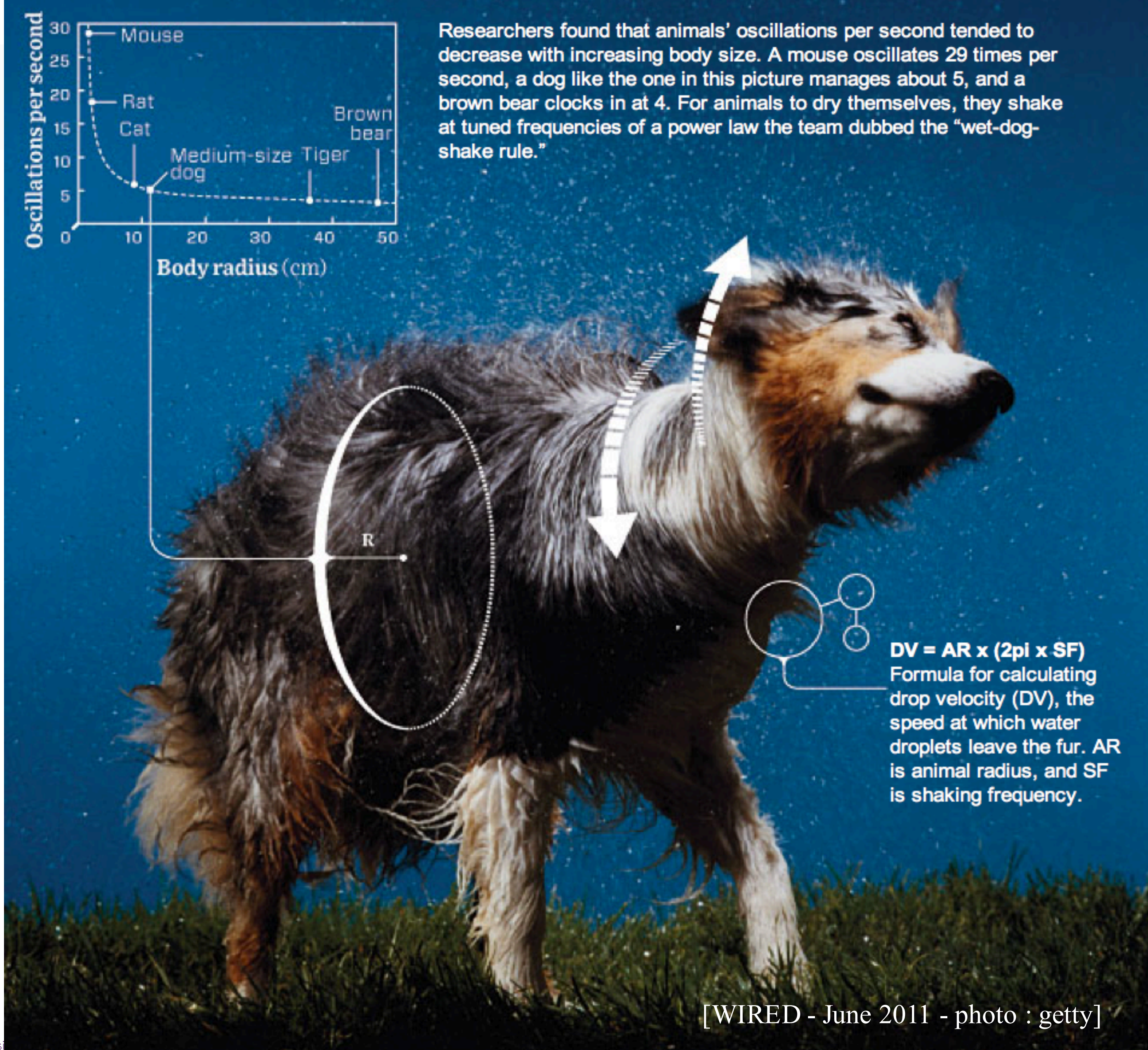
ELSASPHFoam:



Félix Dabonneville

➔ Many thanks to Foam Community and Developers ☺

Other Atomization systems



[WIRED - June 2011 - photo : getty]