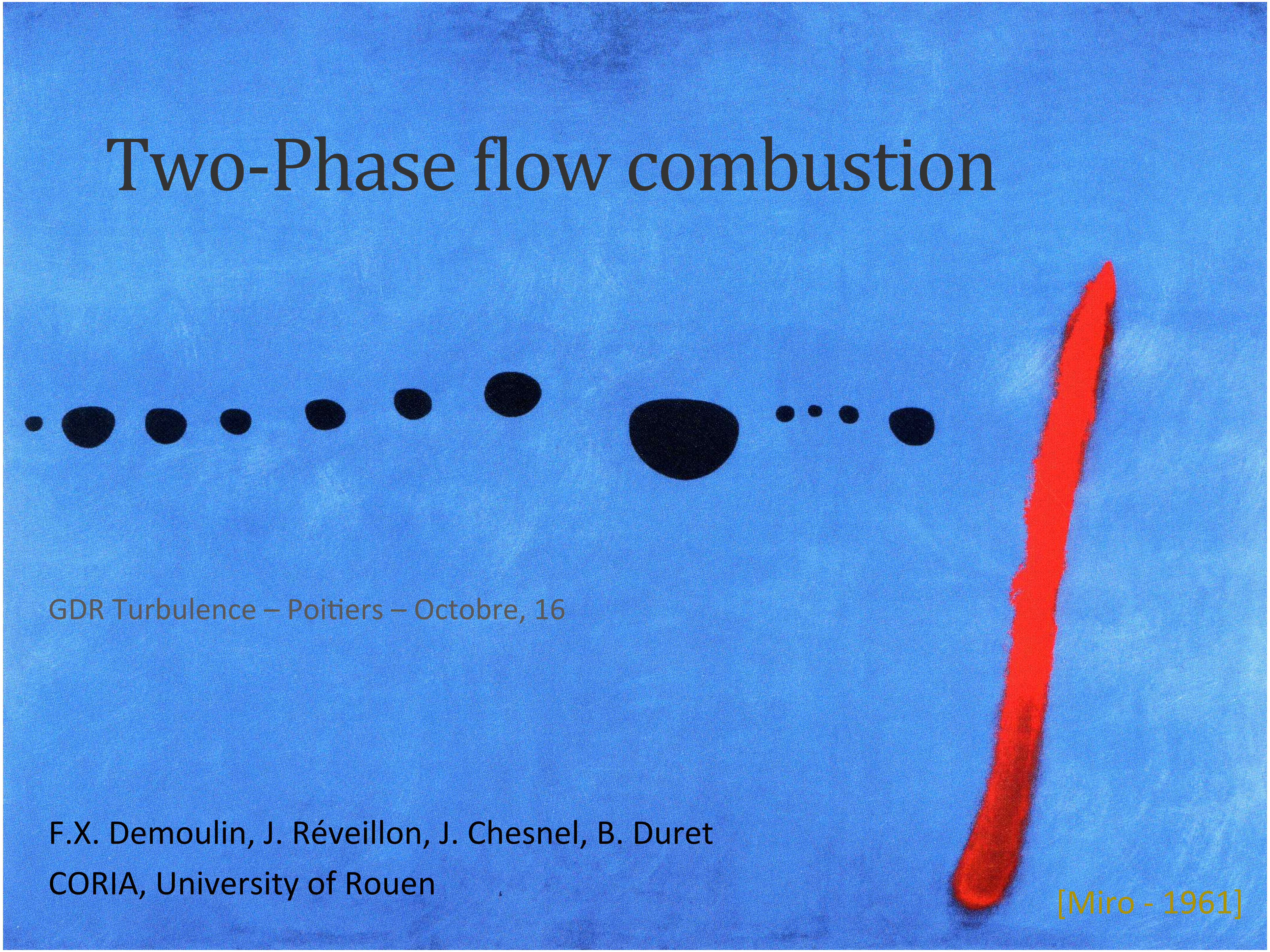
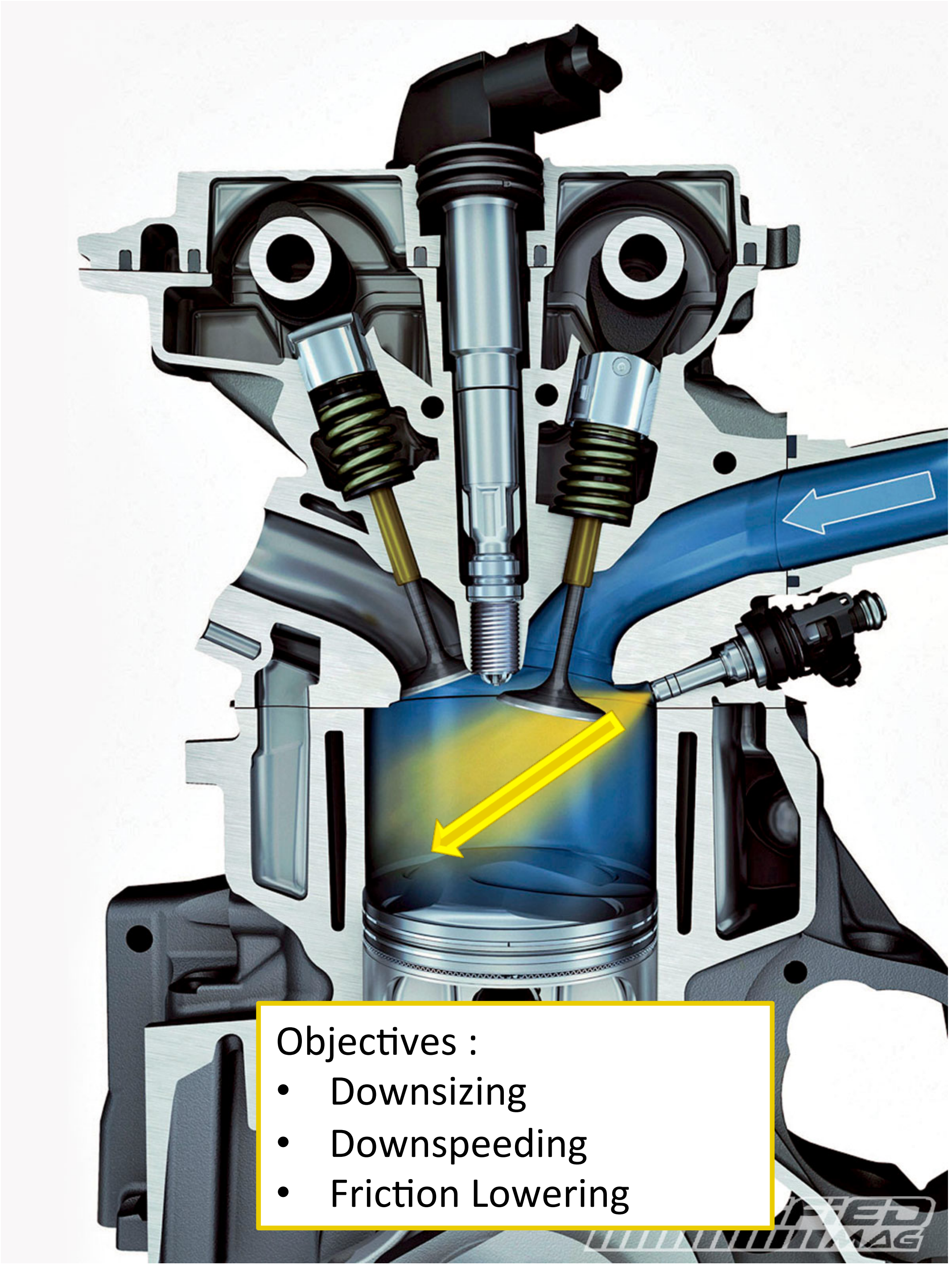
Two-Phase flow combustion

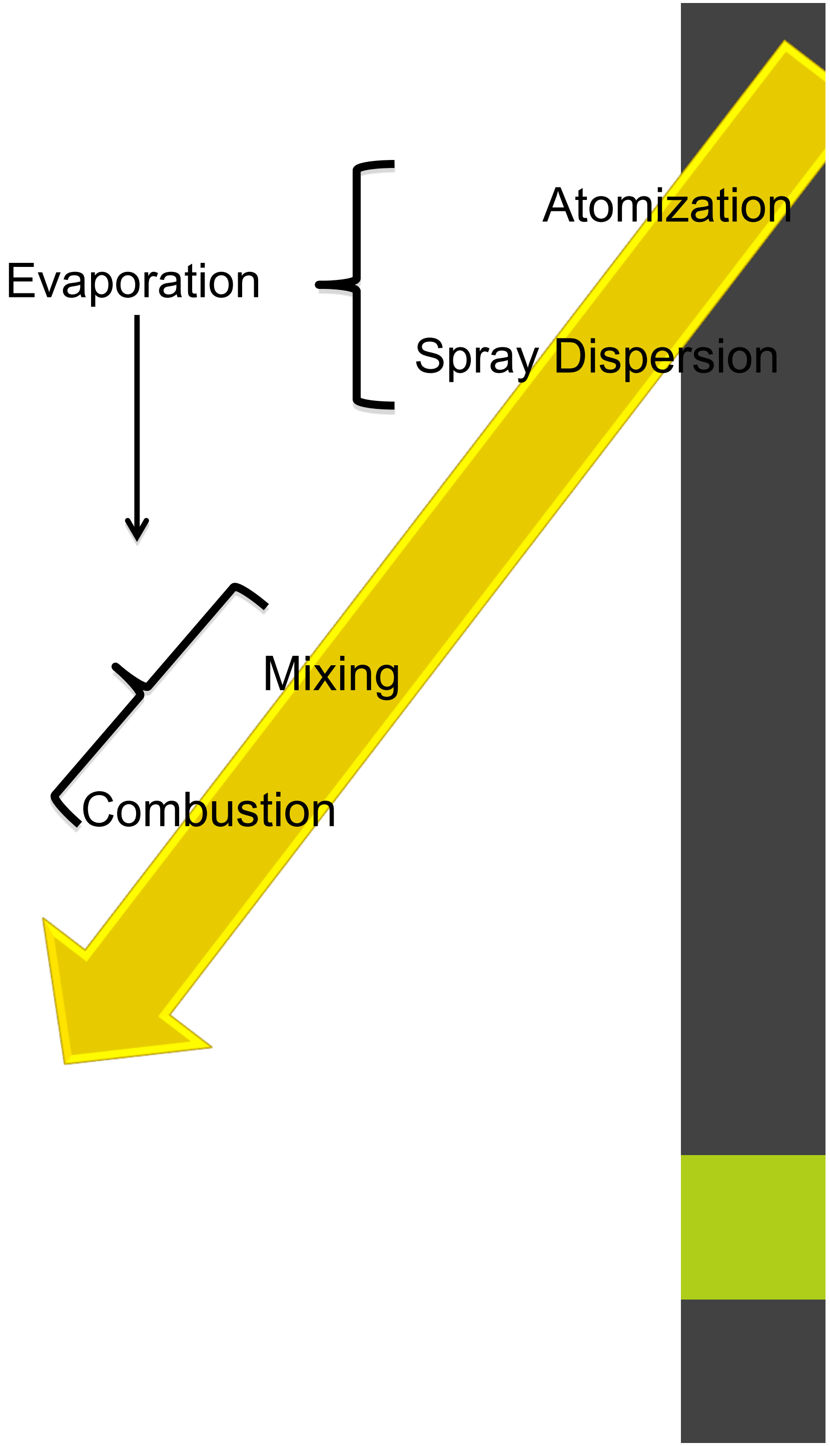
GDR Turbulence – Poitiers – Octobre, 16

F.X. Demoulin, J. Réveillon, J. Chesnel, B. Duret
CORIA, University of Rouen



[Miro - 1961]


Objectives :
• Downsizing
• Downspeeding
• Friction Lowering


Atomization
Evaporation
Spray Dispersion
Mixing
Combustion

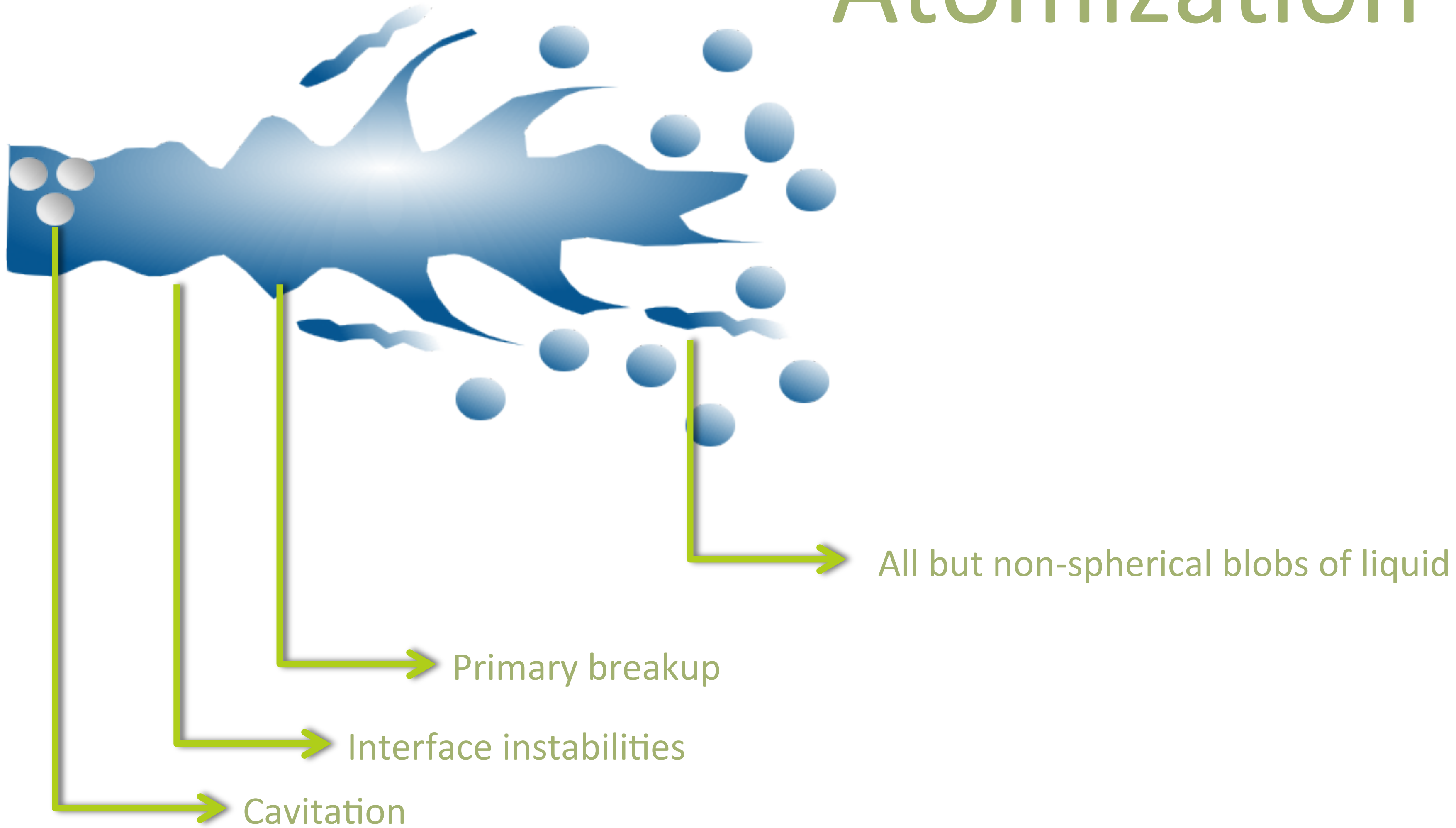
Combustion chamber atomization

As simple as…
holes

Yet, impossible to predict…

Combustion chamber

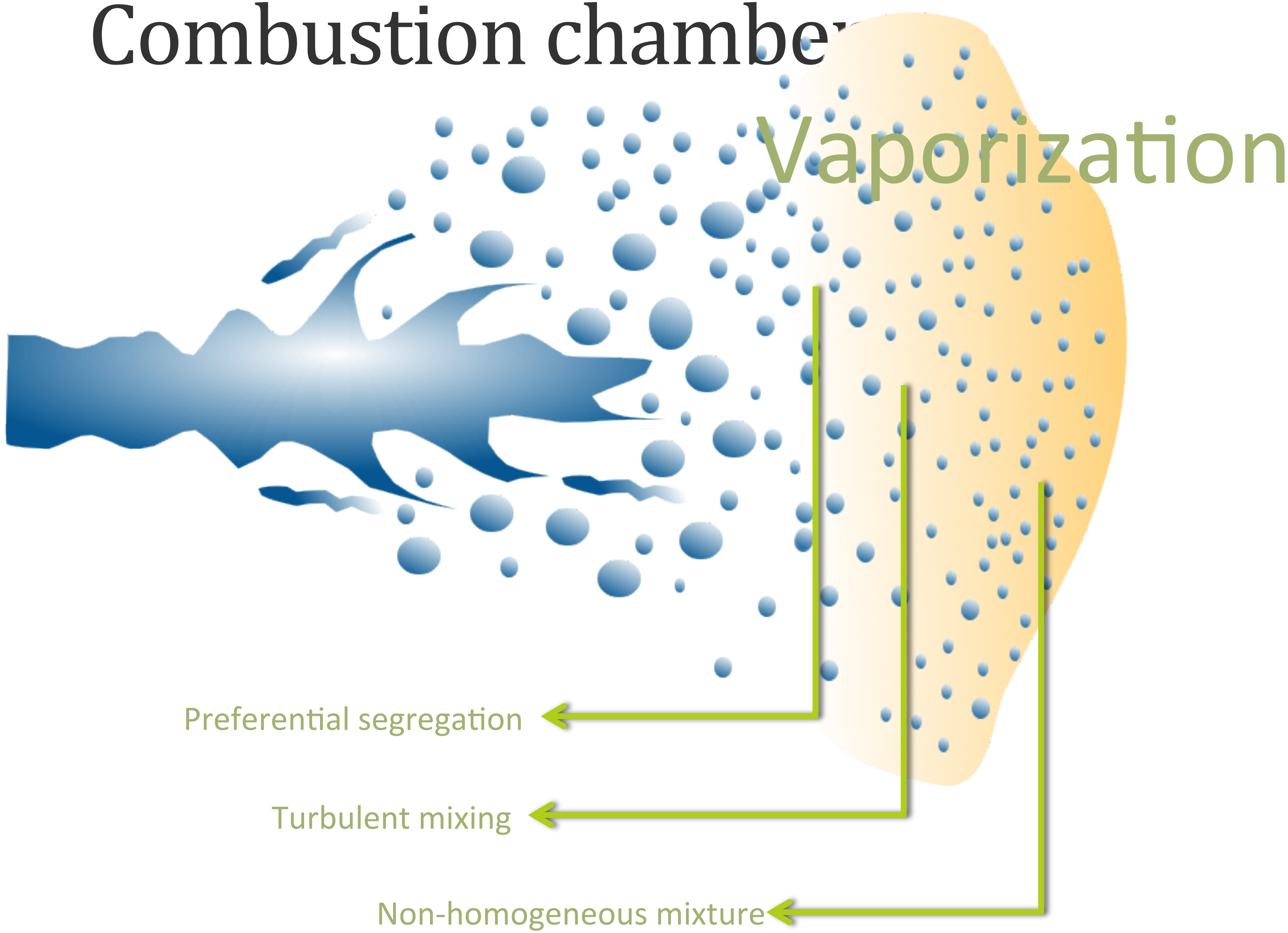
Atomization



Dispersion

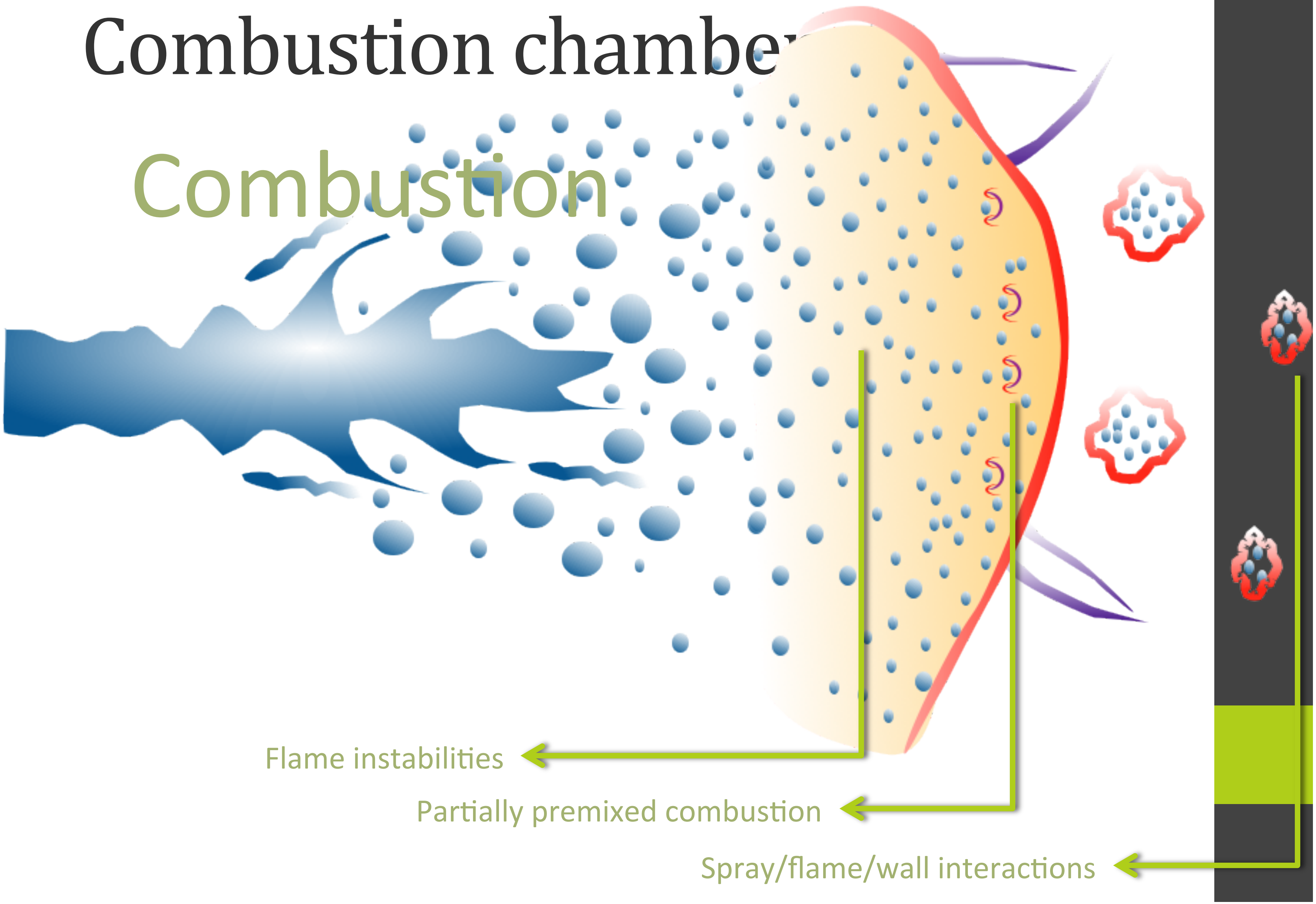
Combustion chamber

Combustion chamber

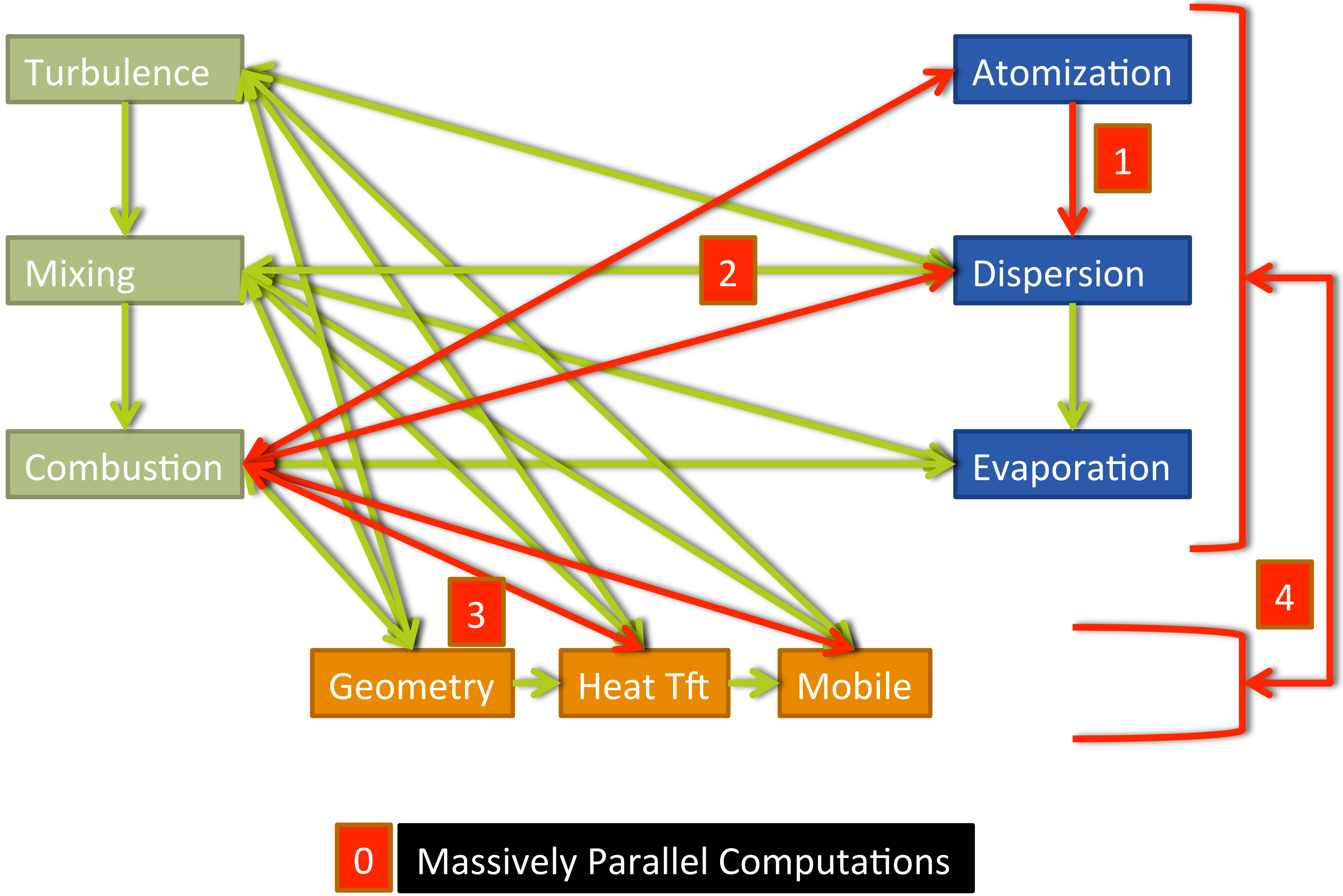


Combustion chamber

Combustion



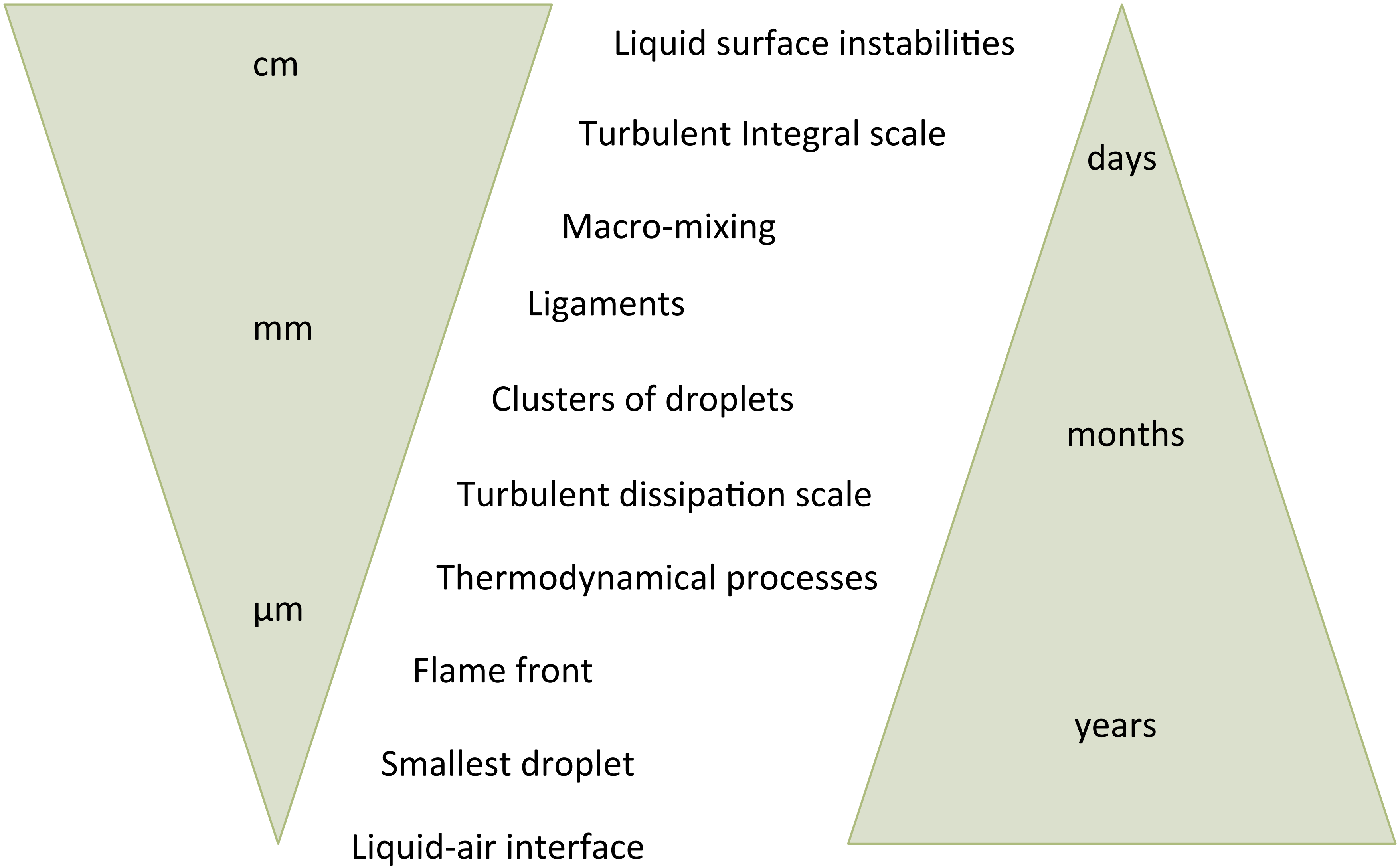
Combustion chamber modeling



Two-phase flows : size matter !

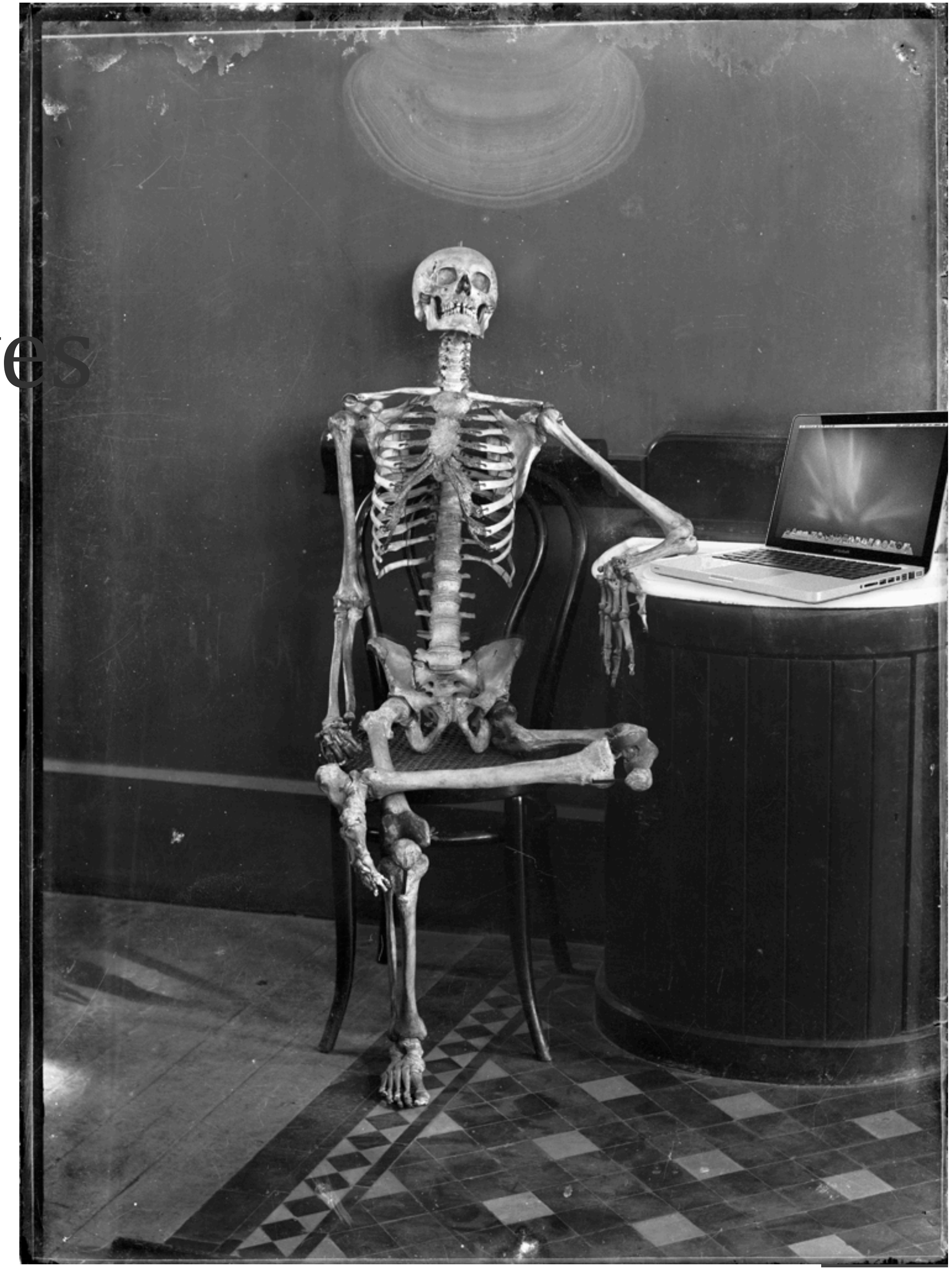
... a lot !

A wide range of scales



Complete DNS : dark perspectives

?



Actual ways out ...

DNS since 30 years

J. Shinjo and A. Unemura, International Journal of Multiphase Flow, 2010

Domingo, Vervisch, Proc. Symp. Comb 1996


Progress in Energy and Combustion Science 38 (2012) 846–887

Contents lists available at SciVerse ScienceDirect

Progress in Energy and Combustion Science

journal homepage: www.elsevier.com/locate/pecs

ELSEVIER

Review

Modeling of turbulent dilute spray combustion

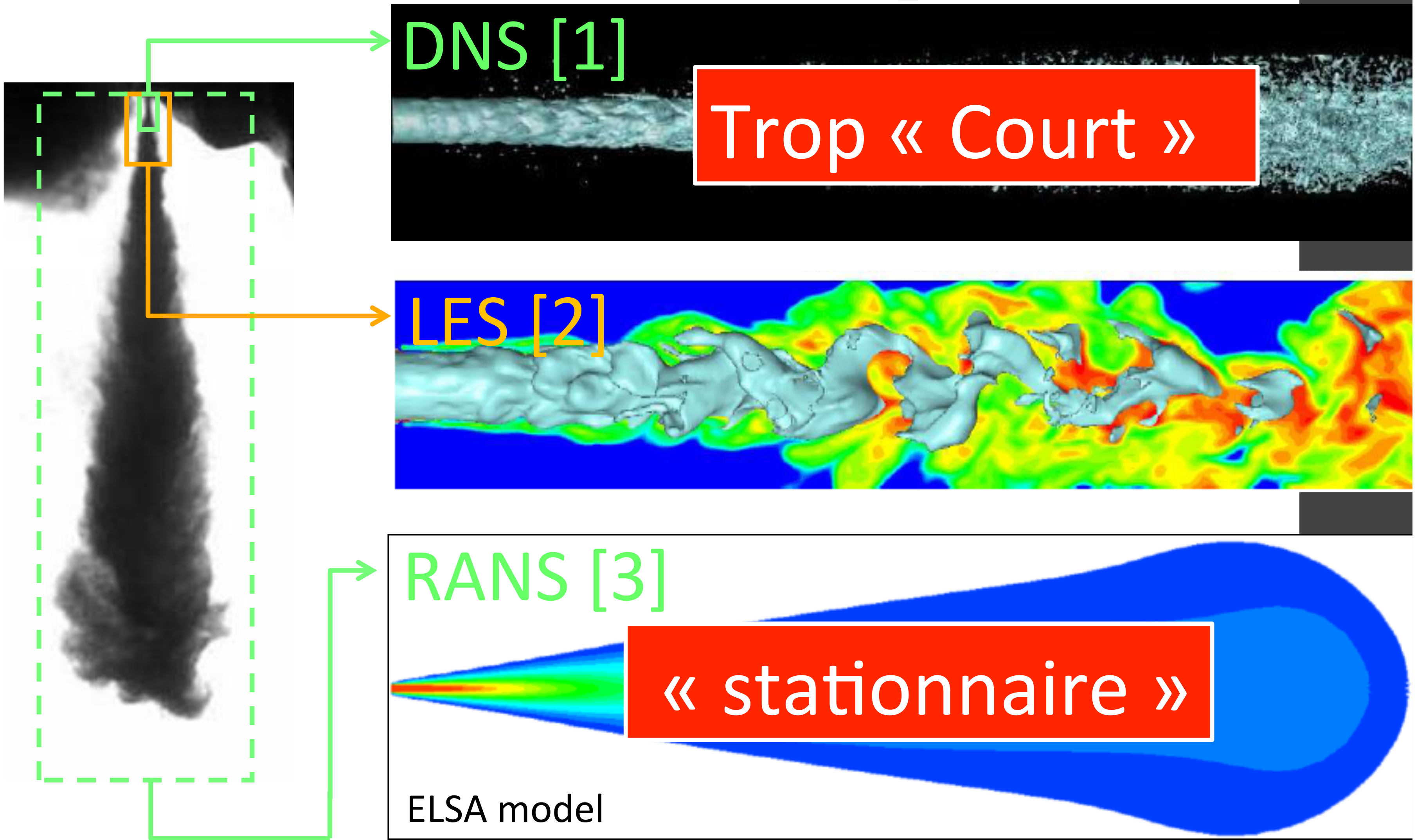
Patrick Jenny [a], Dirk Roekaerts [b,*], Nijso Beishuizen [c]

[a] ETH Zurich, Sonneggstrasse 3, 8092 Zurich, Switzerland
[b] Delft University of Technology, Leeghwaterstraat 39, 2628 CB Delft, The Netherlands
[c] Bosch Thermotechnology, P.O Box 3, 7400 AA Deventer, The Netherlands

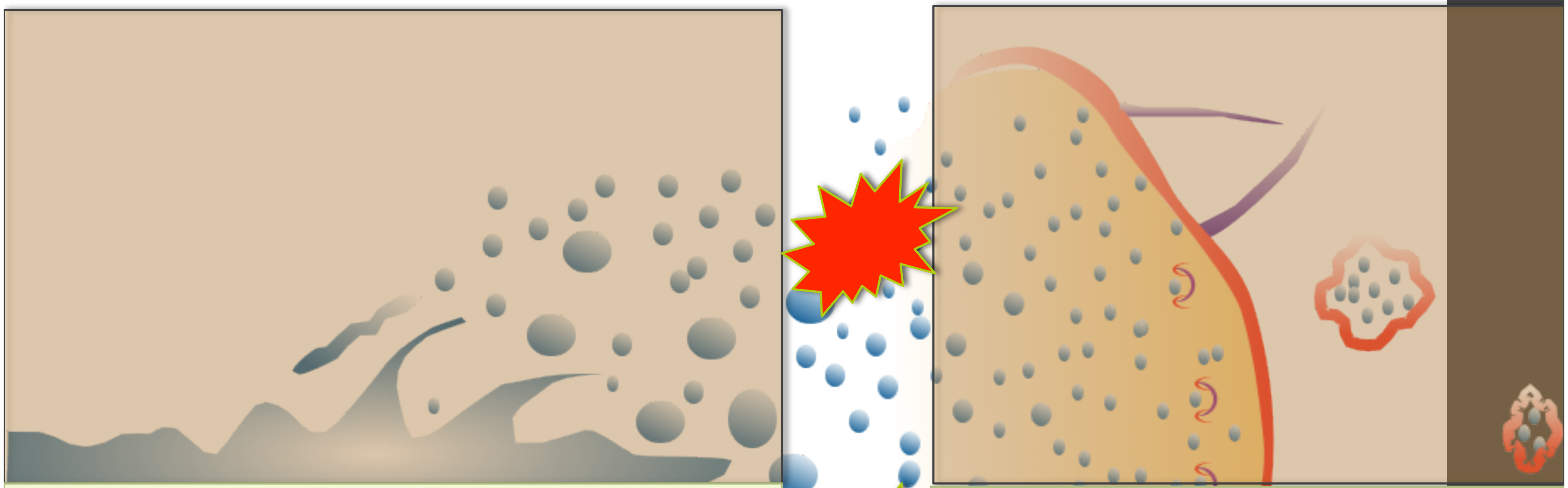
Multiphase Flow, 2010

Reveillon, Vervisch, JFM 2005

Simulation of the whole process



[1] T. Menard et al, International Journal of Multiphase Flow, 2007.
[2] J. Chesnel et al, Atomization and Spray, 2011
[3] R. Lebas et al, International Journal of Multiphase Flow, 2009



- 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 !!!

→ Junction stumblingblock

First steps to fil the gap

LES

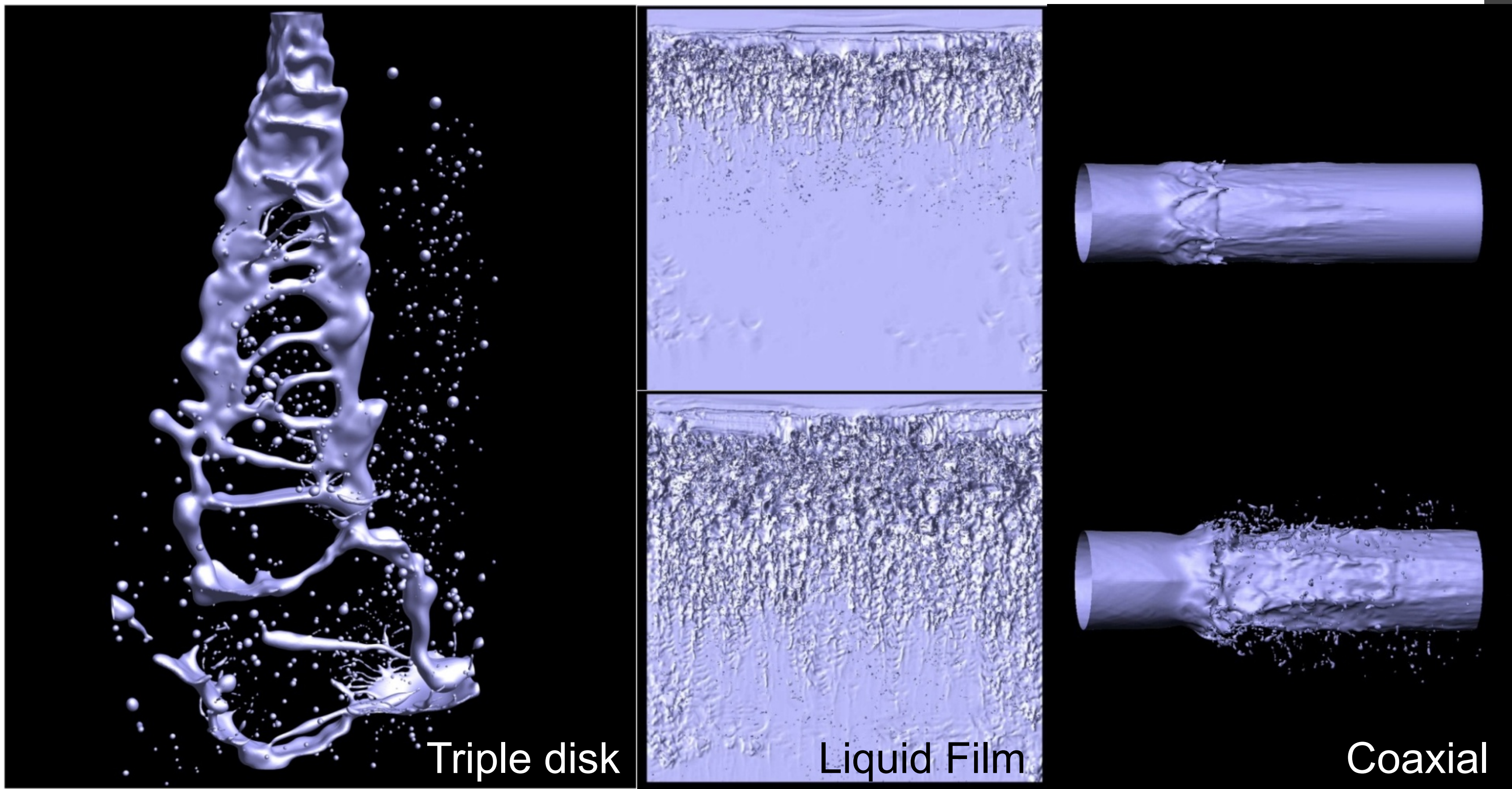
characterization of the

Subgrid Spray

+

Evaporation of the liquid interface

ARCHER Code : DNS



ARCHER code :

- DNS/LES code, MPI parallelization
- Level Set/VOF/Ghost Fluid method coupling
- Solve incompressible NS equations

[T. Menard et al, International Journal of Multiphase Flow, 2007]

LES formulation

$$\frac{\partial \overline{\rho}\ \overline{u}_i}{\partial t} + \frac{\partial \overline{\rho}\ \overline{u}_i\ \overline{u}_j + \tau_{\rho u_i u_j}}{\partial x_j} = -\frac{\partial \overline{P}}{\partial x_i} + \frac{\partial \overline{D}_{ij}}{\partial x_j} - \sigma \overline{\kappa}^r\ \overline{n}_i^r \delta_\Gamma^r$$

Interface tracking

$$\frac{\partial \phi}{\partial t} + u_i \frac{\partial \phi}{\partial x_i} = 0$$

Filtering process

$$\frac{\partial \overline{\phi}}{\partial t} + \overline{u}_i \frac{\partial \overline{\phi}}{\partial x_i} = -\left(\overline{u_i\ \frac{\partial \phi}{\partial x_i}} - \overline{u}_i\ \frac{\partial \overline{\phi}}{\partial x_i} \right)$$

Actual « LES » : U-LES

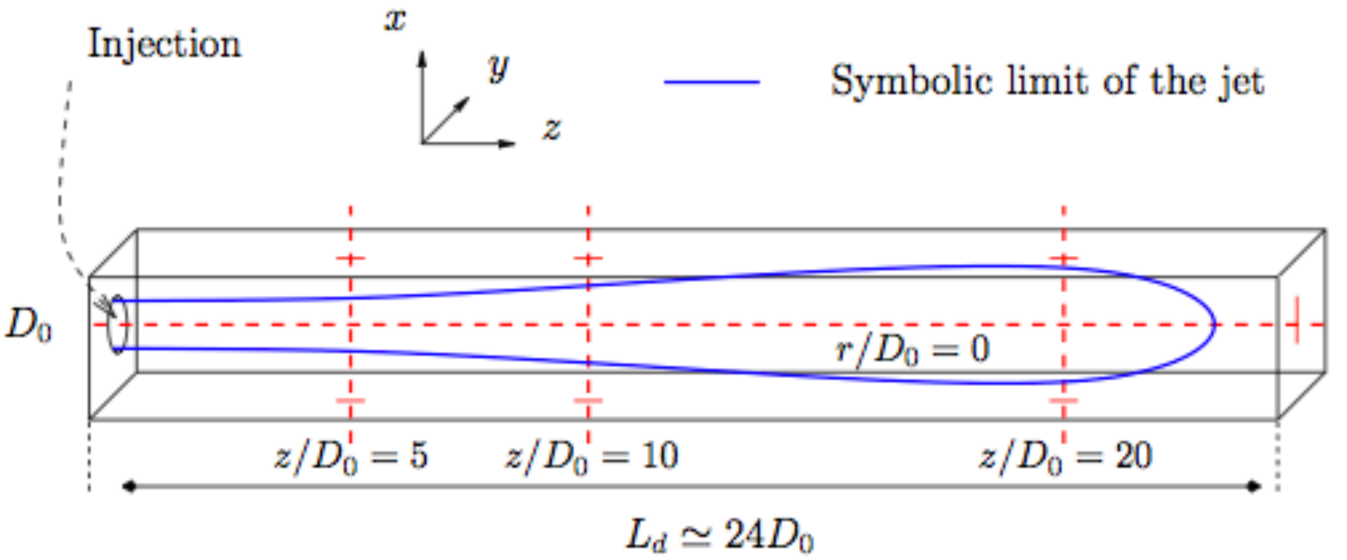
- Momentum : standard LES
- Interface : coarse DNS

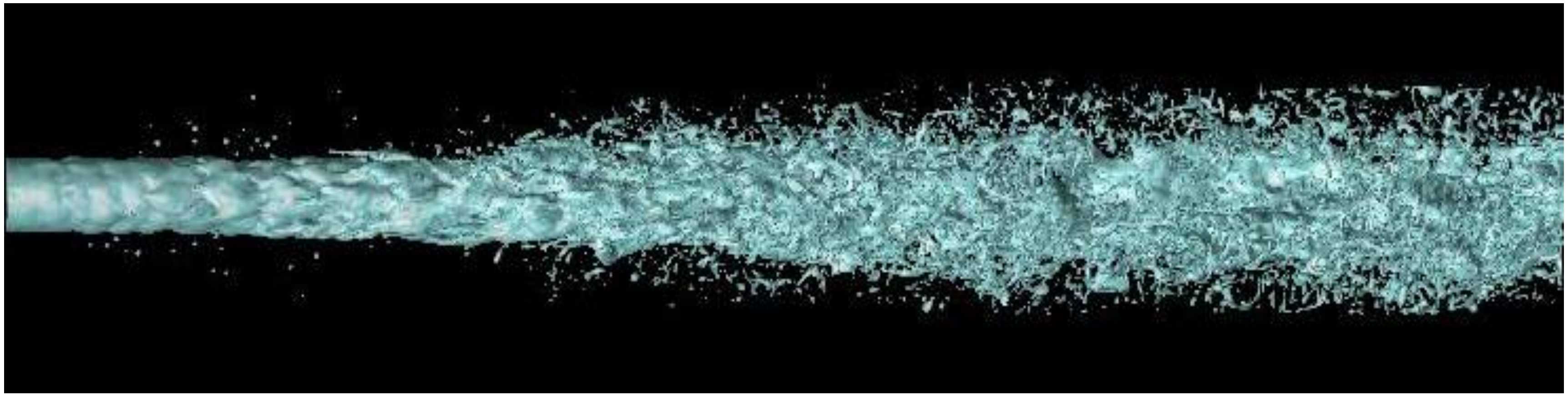
$$\frac{\partial \overline{\rho}\,\overline{u}_i}{\partial t}+\frac{\partial \overline{\rho}\,\overline{u}_i\,\overline{u}_j+\tau_{\rho u_i u_j}}{\partial x_j}=-\frac{\partial \overline{P}}{\partial x_i}+\frac{\partial \overline{D}_{ij}}{\partial x_j}-\sigma\overline{\kappa}^r\,\overline{n}_i^r\delta_\Gamma^r$$

$$\frac{\partial \overline{\phi}}{\partial t}+\overline{u}_i\frac{\partial \overline{\phi}}{\partial x_i}=-\left(\overline{u_i \ldots} \ldots \frac{\partial \overline{\phi}}{\partial x_i}\right)$$

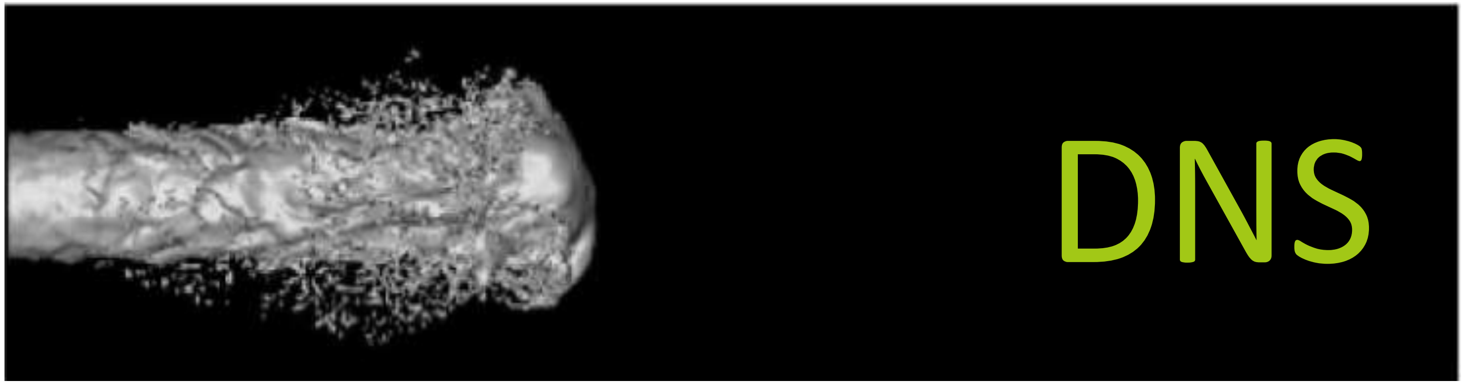
No subgrid liquid phase characterization

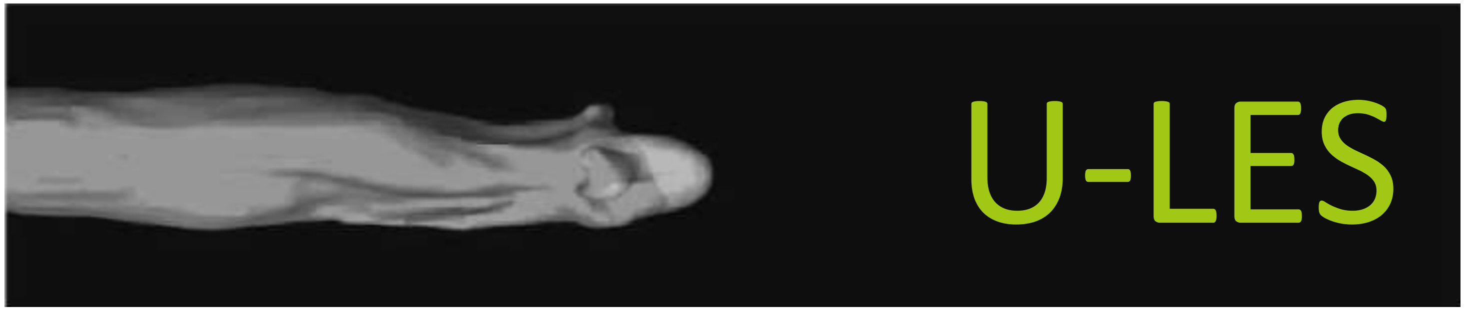
Configuration





Actual « momentum only LES »





SG interfacial terms need a model

UΦ-LES

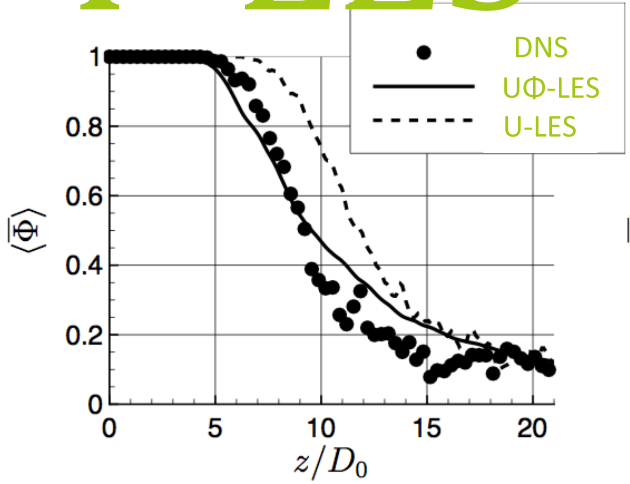
$$\frac{\partial \overline{\Phi}}{\partial t} + \frac{\partial \overline{u}_i\, \overline{\Phi}}{\partial x_i} + \frac{\partial \tau_{\Phi_i}}{\partial x_i} = 0$$

Scale Similarity Model

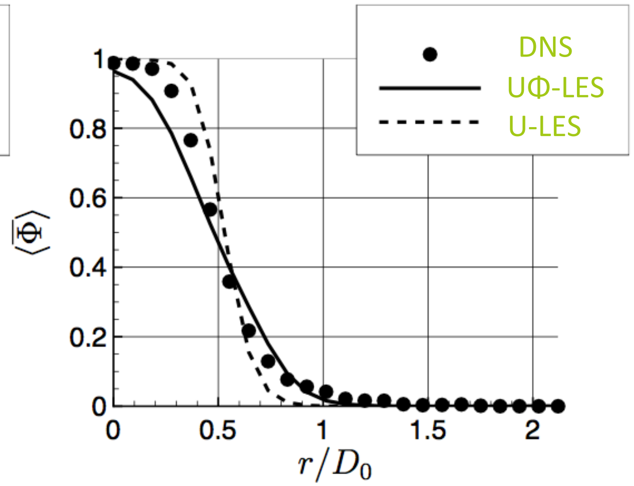
$$\tau_{\Phi_i} \simeq C_{\Phi}\left(\widehat{\overline{\Phi}\,\overline{u}_i} - \widehat{\overline{\Phi}}\,\widehat{\overline{u}_i}\right)$$

[*Chesnel et al., Atomization and spray, 2011*]

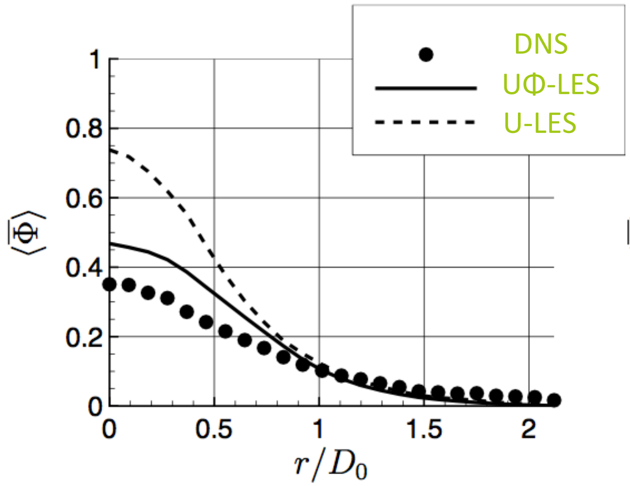
UΦ-LES



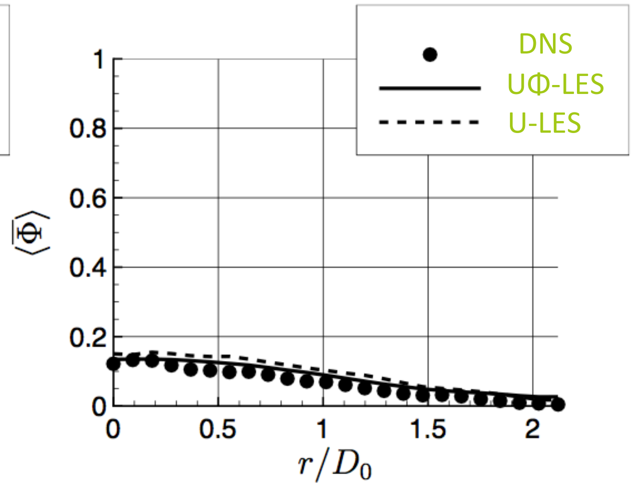
Axial profile



Radial profile, 5 d



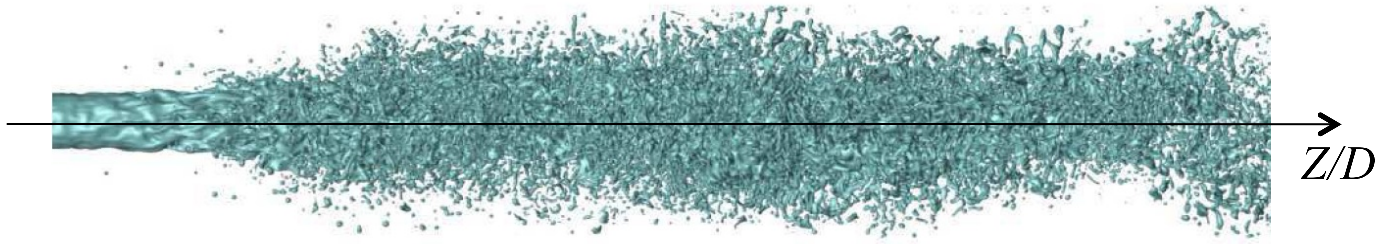
Radial profile, 10 d



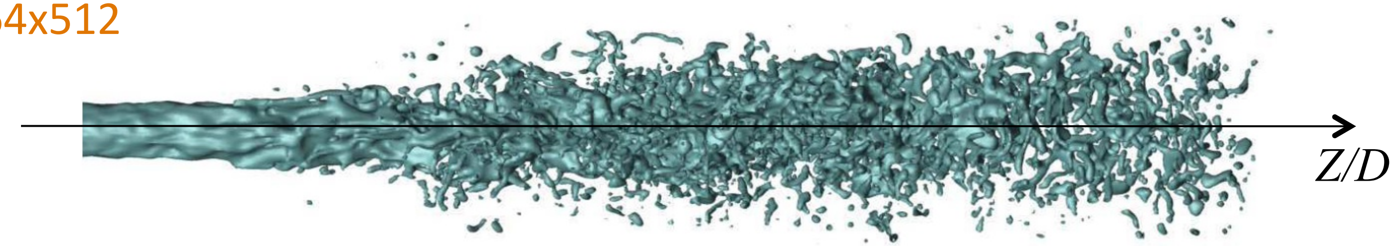
Radial profile, 20 d

U-LES, grid impact

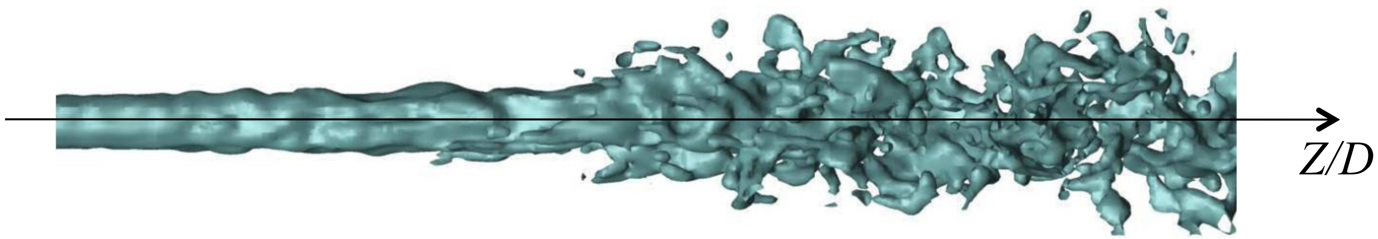
128x128x1024



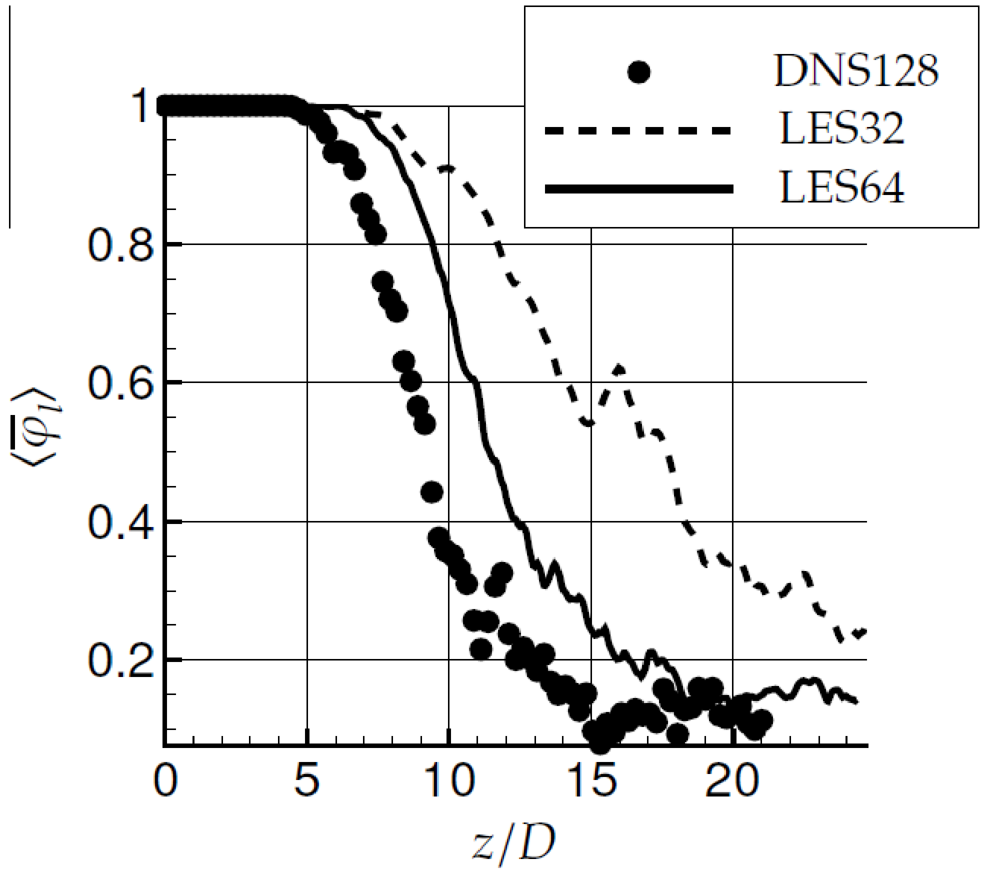
64x64x512



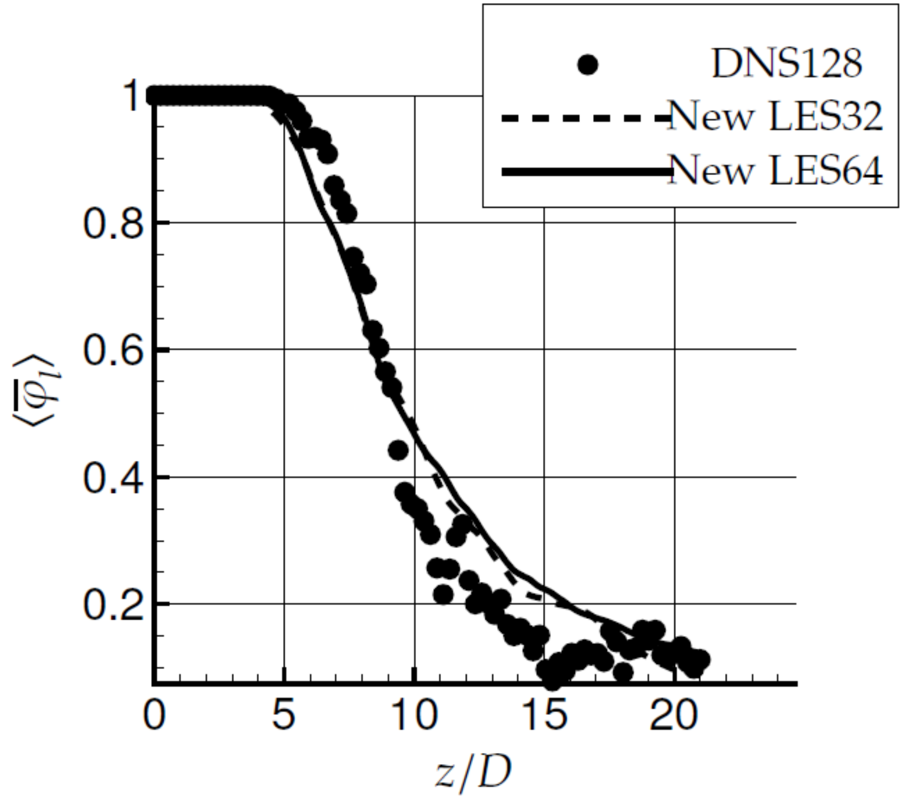
32x32x256



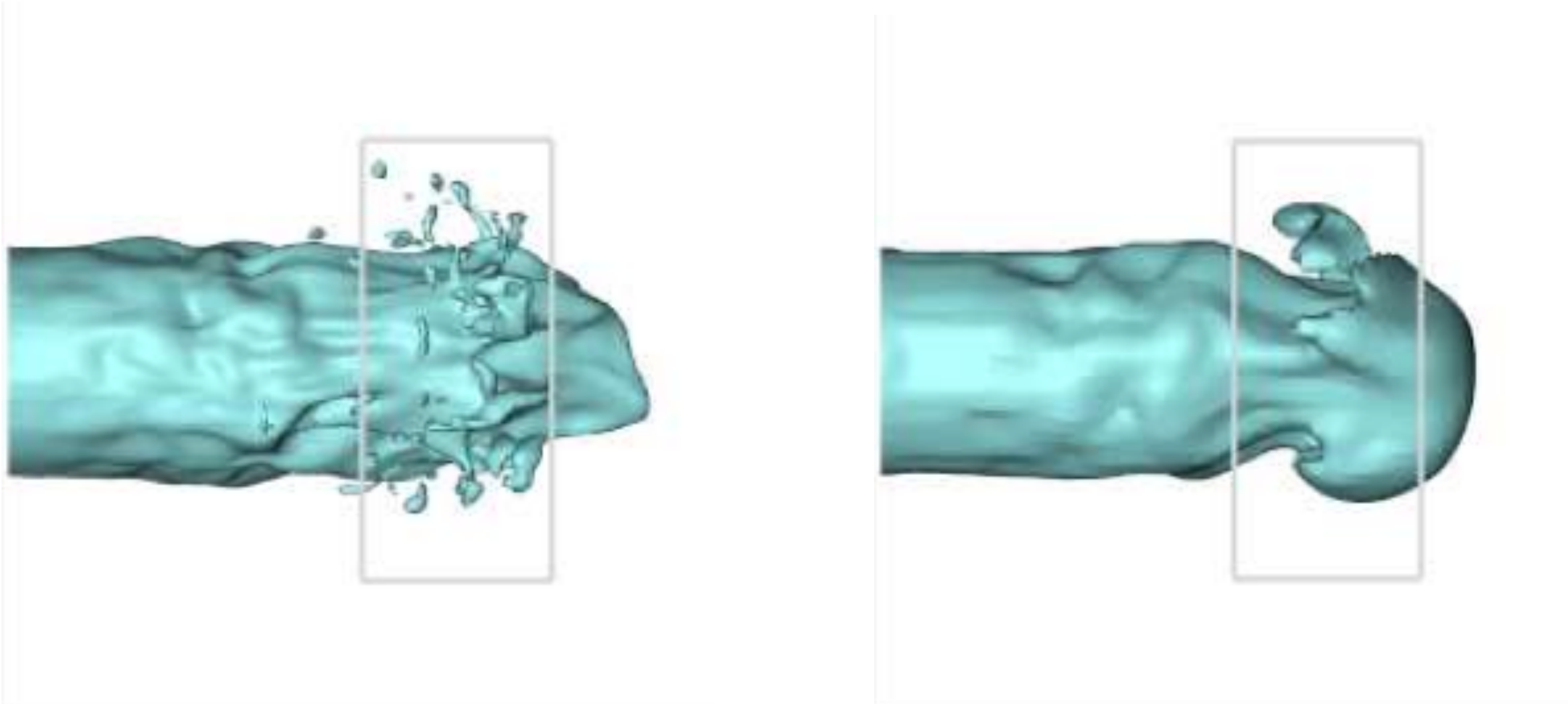
U-LES, grid impact



UΦ-LES, grid impact

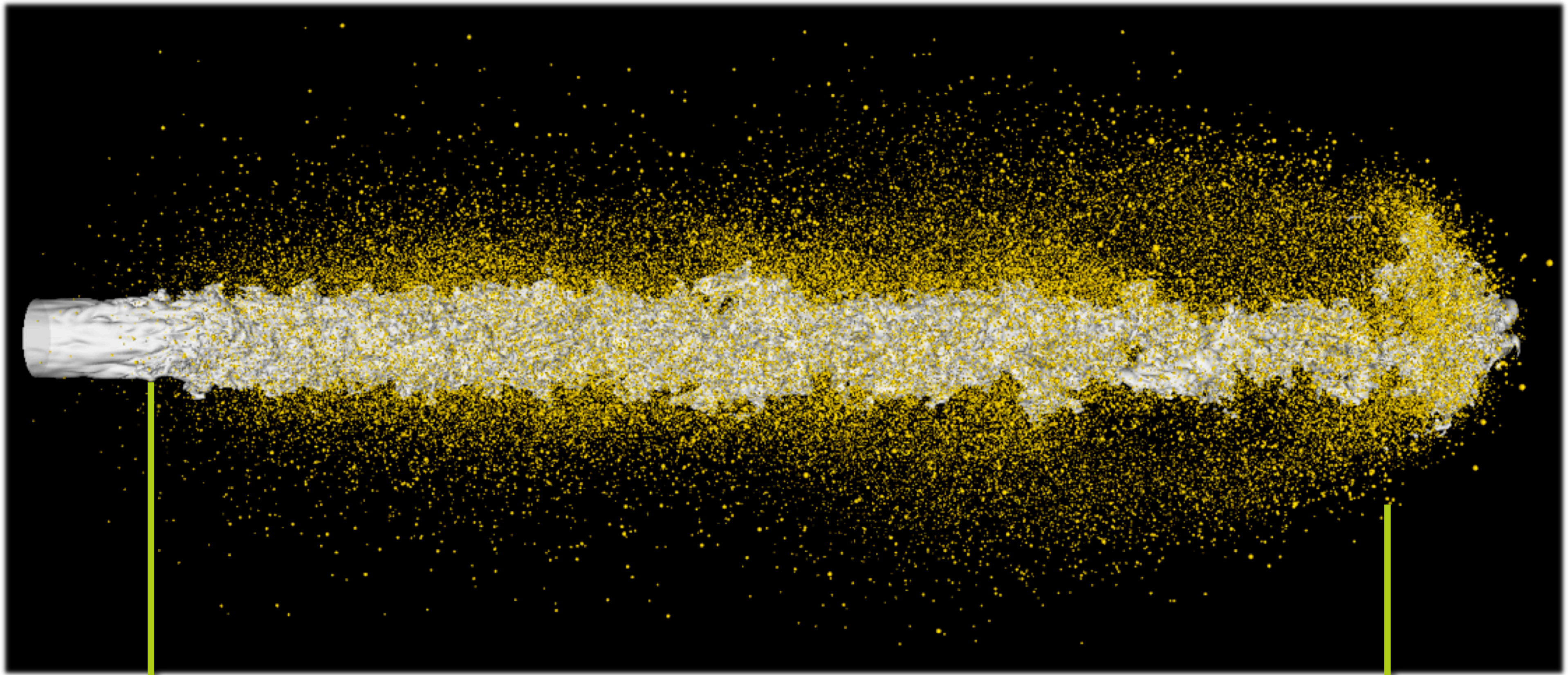


What about the subgrid spray ?



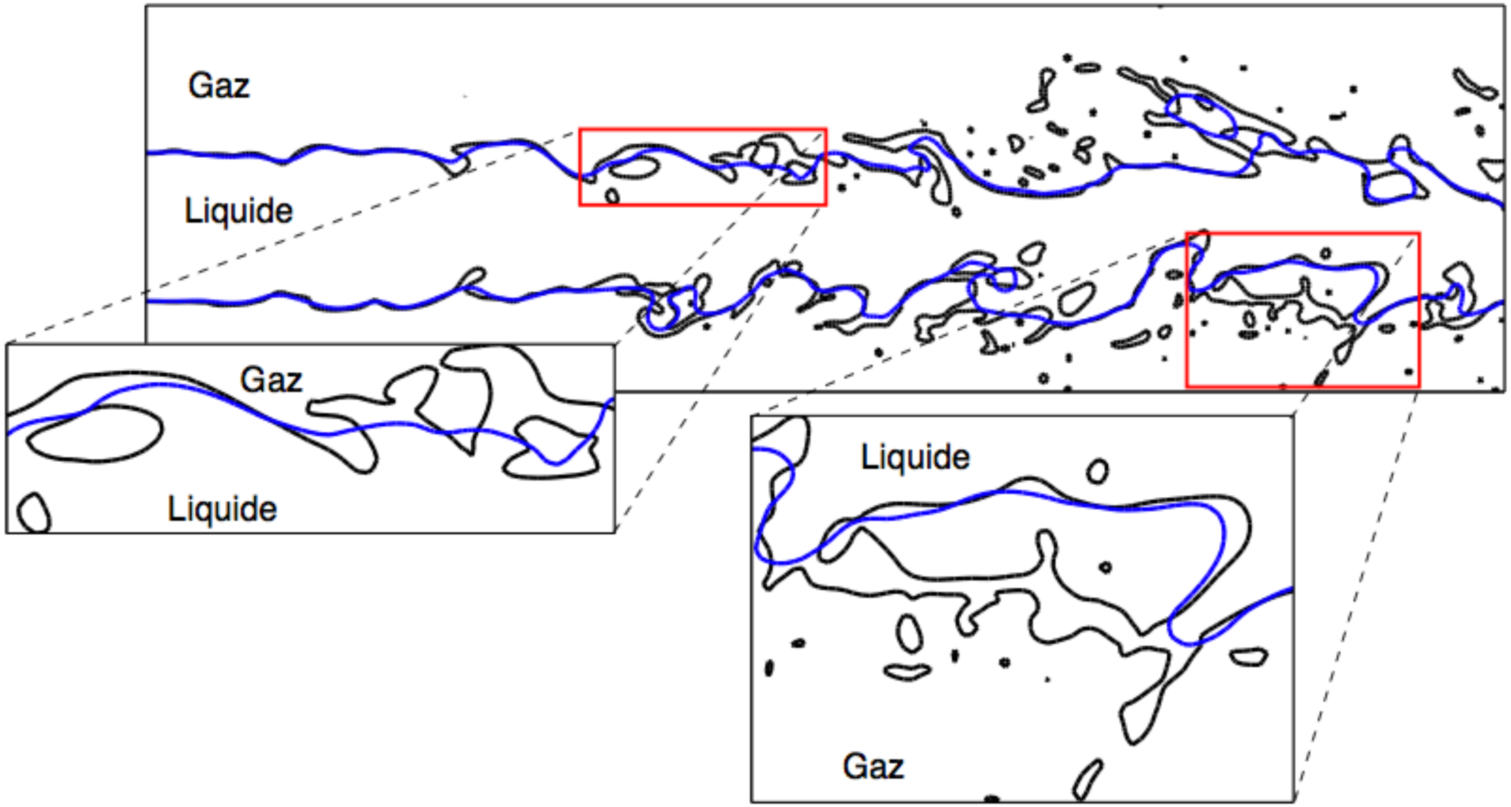
[M. Herrmann, J. Comput. Phys., 229, pp. 745-759, 2010]

LES Interface + SG Dispersed (E/L)



Large scale : Refined Level Set Grid Method

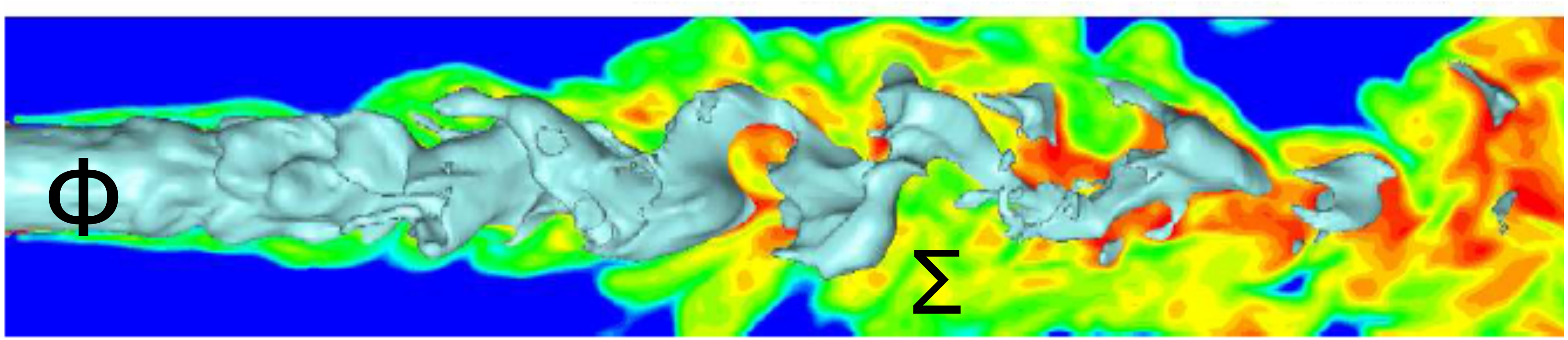
Subgrid : dispersed flow solver (LagrangianTracking)



- Stumbling blocks
  - Extremely expensive + usual drawbacks of Lagrangian description on massively parallel computers
  - Fine grid necessary in the secondary break up zone : how to represent ligaments and non spherical liquid blobs ?

Interface + SG Surface density (E/E)

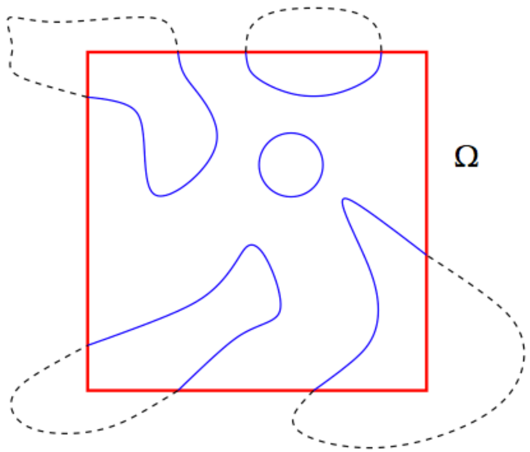
- Subgrid interface density



UΦΣ-LES

Interface + SG Surface density (E/E)

- Description of the subgrid spray :
  - Eulerian description
  - Multiple objects characterization (drops, blobs, ligaments, liquid sheets, etc)



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

- LES transport equation

(1) (2)

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

[Adaptation of ELSA model, Vallet et al 2001]

Interface + SG Surface density (E/E)

- (1) Difference between surface and mixture velocity

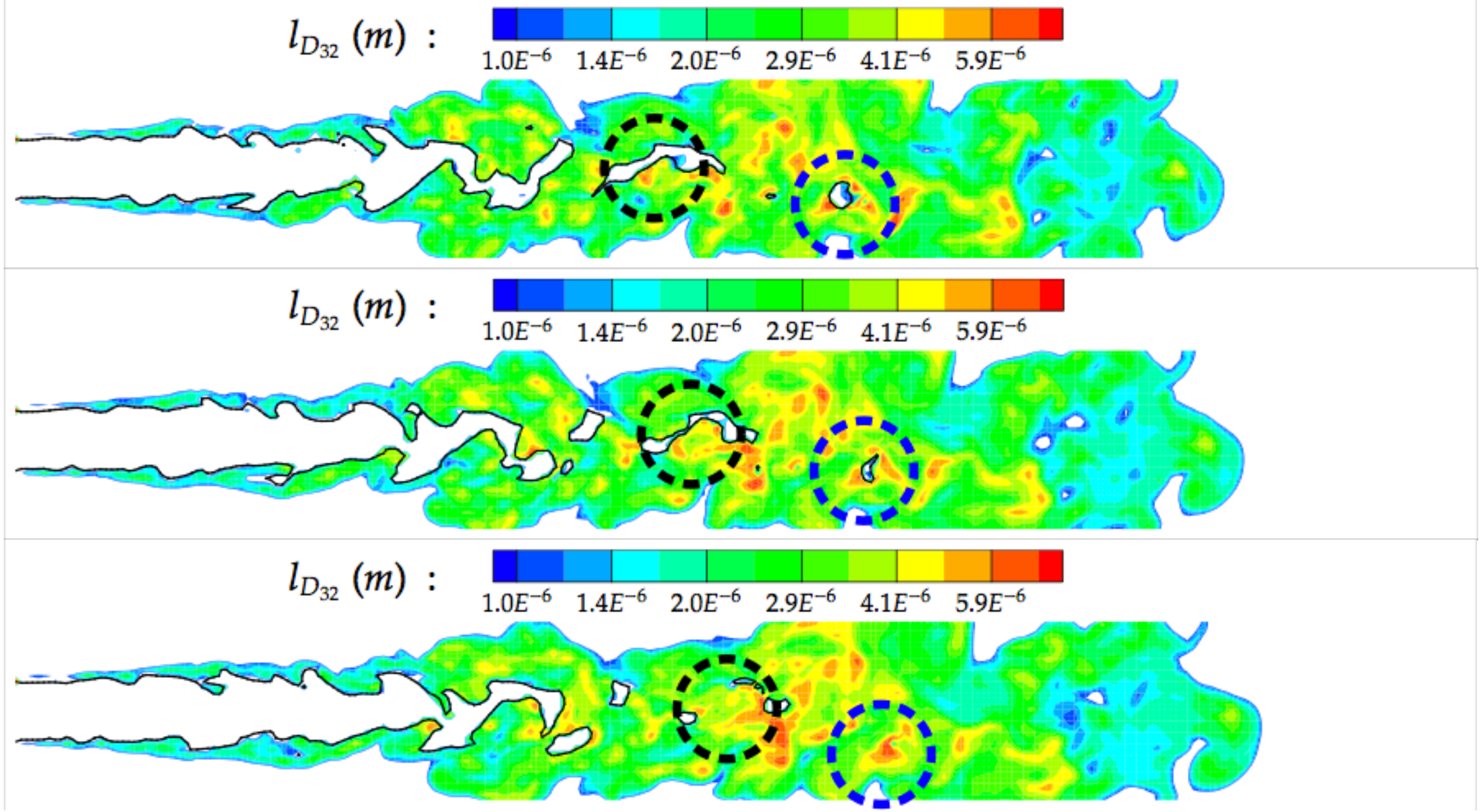
$$\overline{\Sigma}(\overline{u}_\alpha - \overline{u}_{\Gamma\alpha}) \simeq -2C_s\overline{\Delta}^2|S|\frac{\partial\overline{\Sigma}}{\partial x_\alpha}$$

- (2) Source term

$$\dot{\overline{\Sigma}} = \dot{\overline{\Sigma}}_{vap} + \dot{\overline{\Sigma}}_{mix} + \dot{\overline{\Sigma}}_{int}$$

  - To ensure $\Sigma > \Sigma_{min}$
  - Production/destruction : air/liq and liq/liq interactions
  - Closures not straightforward. One needs We^*_{eq} and Σ^*_{eq}

UΦΣ-LES



$l_{D_{32}}$ (m) :
1.0E−6 1.4E−6 2.0E−6 2.9E−6 4.1E−6 5.9E−6
$l_{D_{32}}$ (m) :
1.0E−6 1.4E−6 2.0E−6 2.9E−6 4.1E−6 5.9E−6
$l_{D_{32}}$ (m) :
1.0E−6 1.4E−6 2.0E−6 2.9E−6 4.1E−6 5.9E−6

Conclusion

SG interfacial term has to be accounted for : Scal. Sim. Mod.

SG spray has been characterized through the interface density

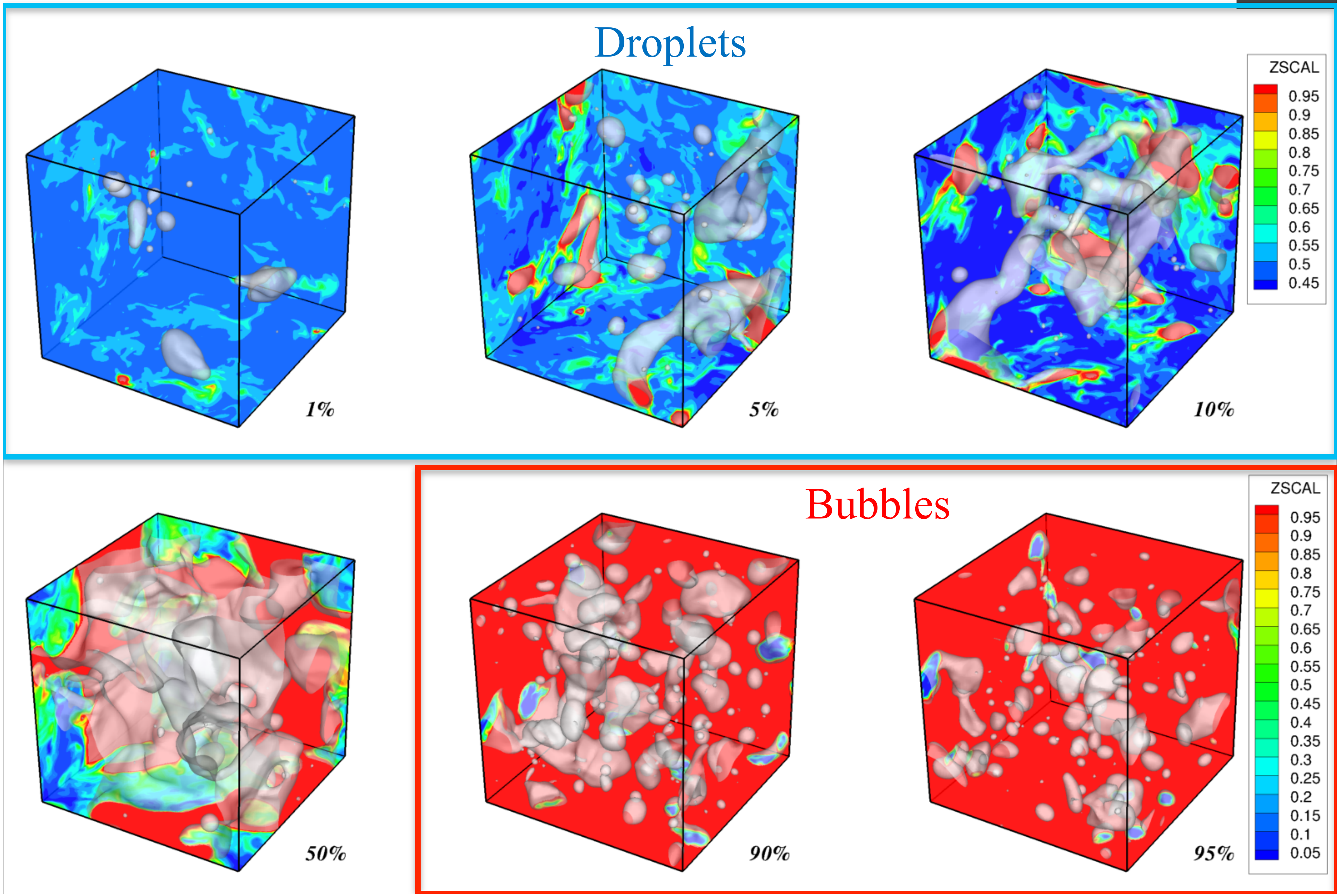
How to account for vaporization ?

To go further : Interface evaporation

Mixture fraction

Linear forcing, k=cst

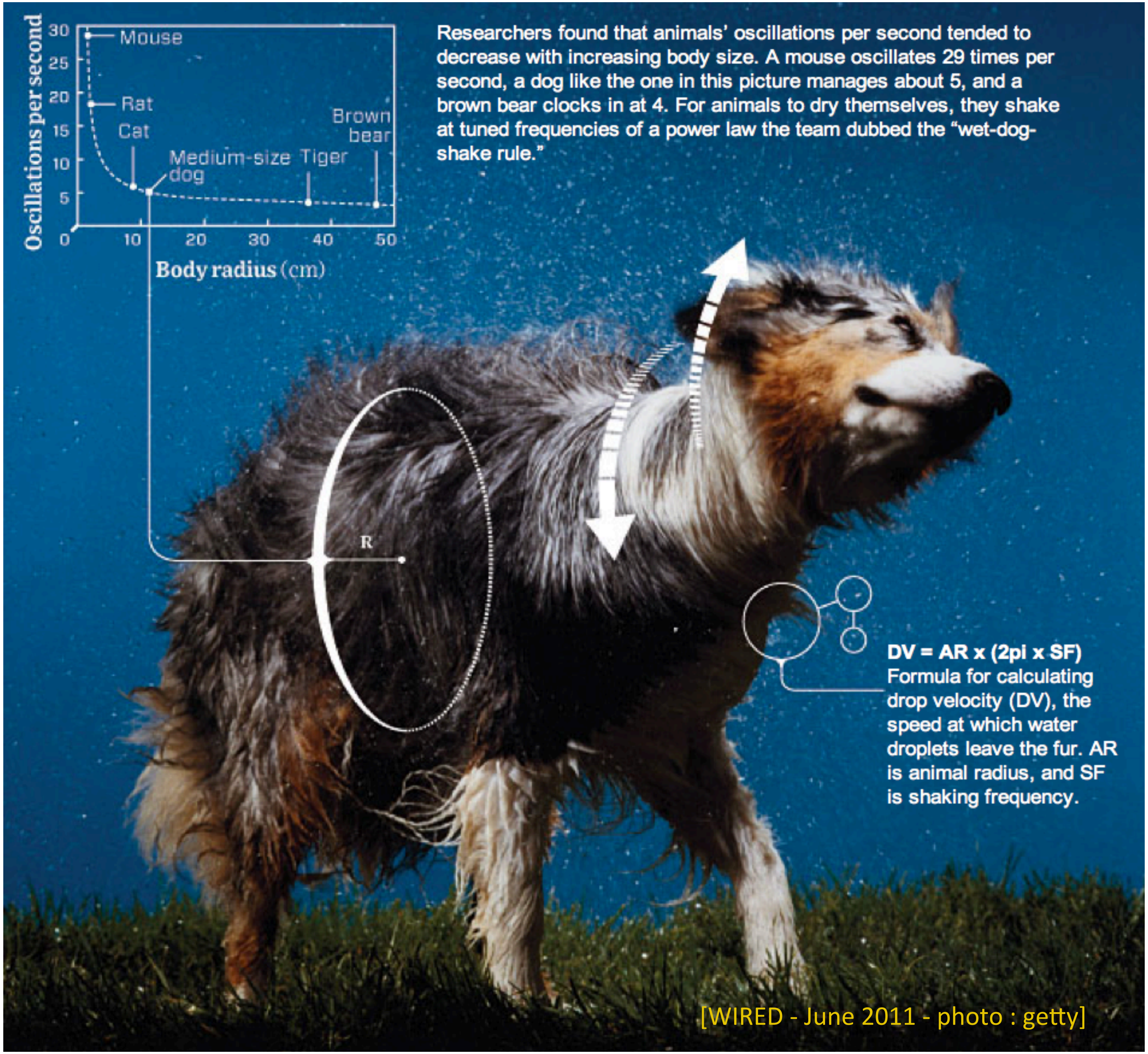
[Rosales, et al., Physics of Fluids, 2005]



Summary

- [1] Closure to account for the interfacial term is necessary
  - Scale similarity. Works fine, needs DNS to determine a constant.
  - Smagorinsky model not satisfactory.
  - Another dynamic model ?
- [2] Subgrid spray has to be accounted for
  - E/L Closure (Herrmann et al)
  - E/E Closure (Chesnel et al)
  - Others ?
- [3] Vaporization needs to be characterized
  - 0^{th} order method has been shown (Z=1 at the surface)
  - 1^{th} and 2nd orders methods are under development (See last ILASS proceedings) but very expensive.
- [4] Combustion [?]
  - Solvers ? Compressibility ? Heat transfers ? Etc.

Human best friend atomizer



[WIRED - June 2011 - photo : getty]