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Investigating fuel staging influence on the stabilization process of a turbulent swirling flame using two-phase flow large eddy simulation

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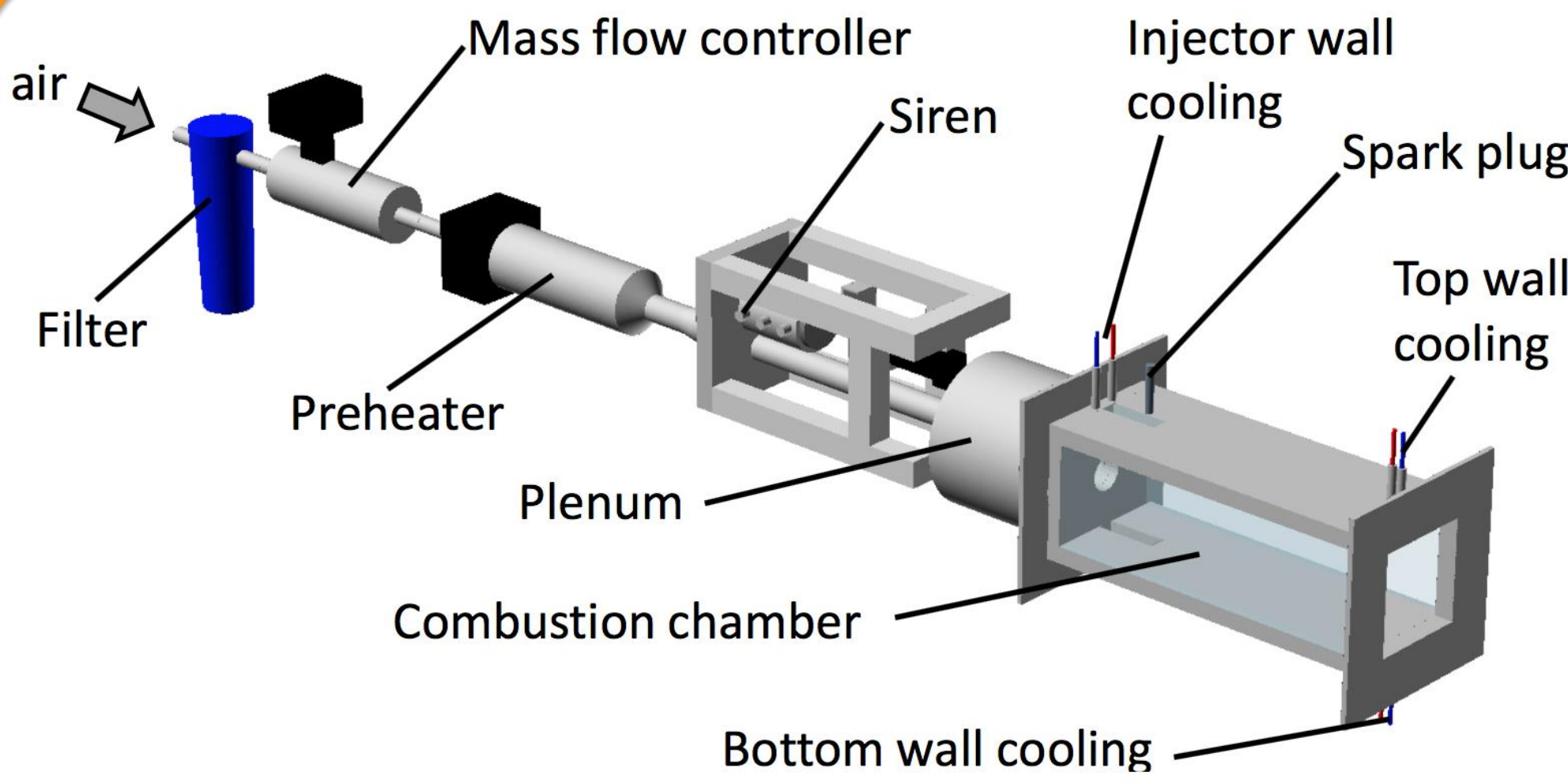
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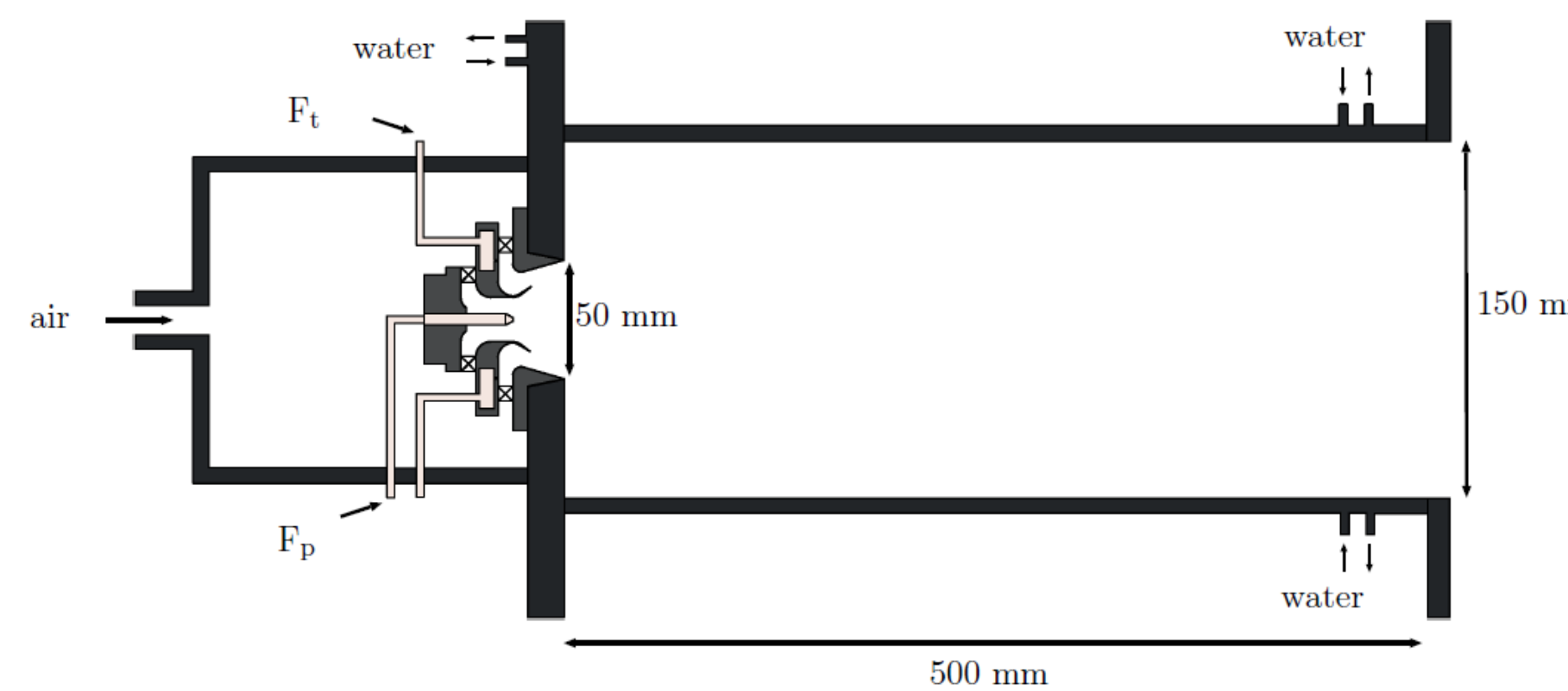
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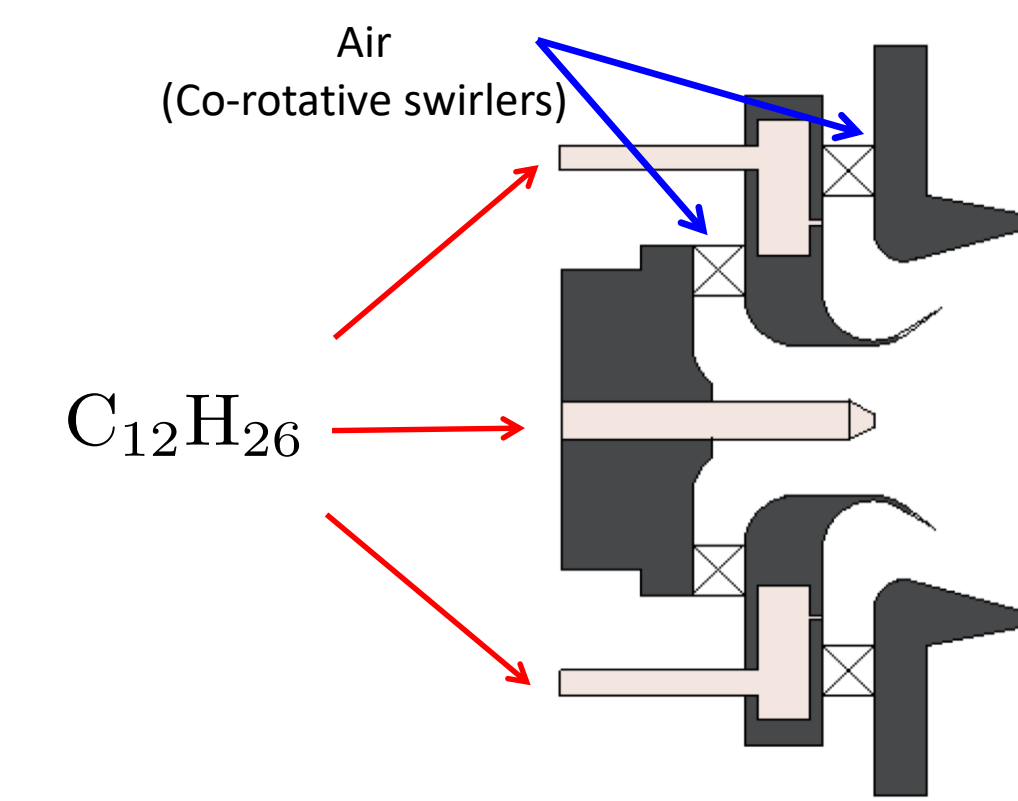
The two stage BIMER combustor^{1,2,3}



- Built to better understand LPP burners
- Two swirling stages with two types of liquid fuel injection:
 - Multipoint: 85% of air mass flow and 10 fuel jets in cross-flow to achieve LPP regime
 - Pilot: 15% of air mass flow and hollow cone fuel spray to stabilize combustion
- High swirl numbers ($S \approx 1$)
- **Liquid fuel:** Dodecane ($C_{12}H_{26}$) as kerosene surrogate

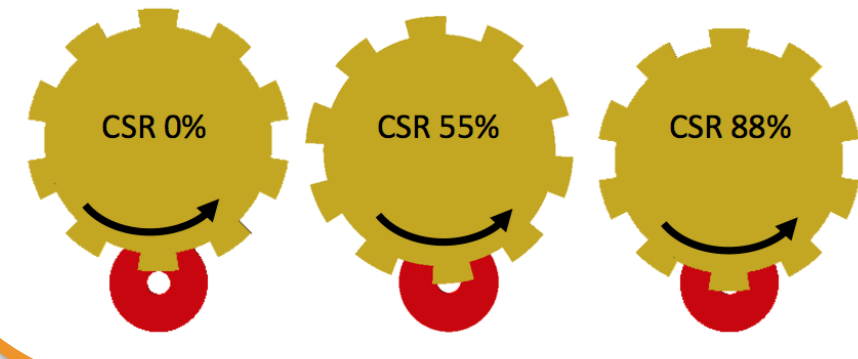


Schematic view of the injection device:



Staging parameter:

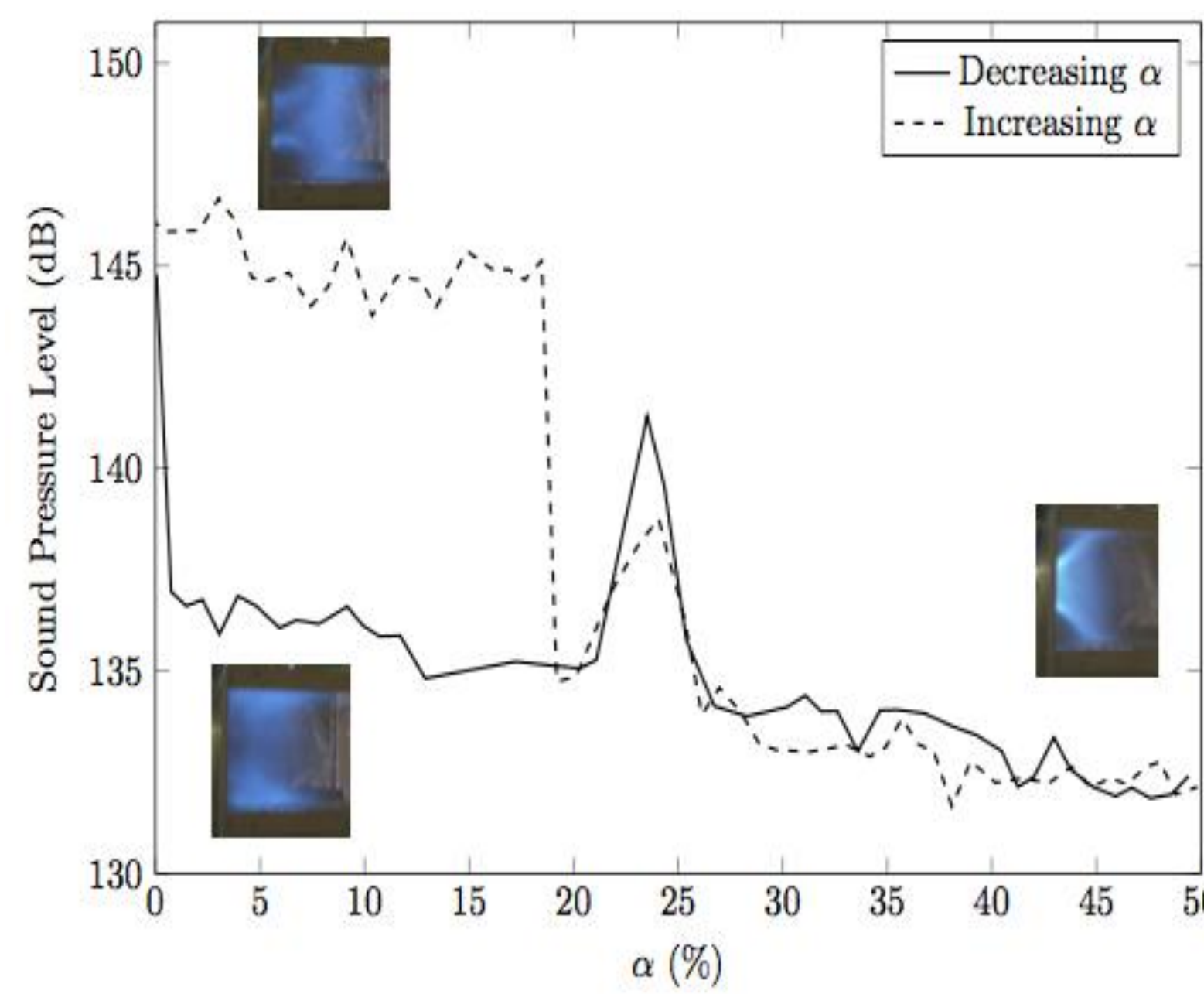
$$\alpha = \frac{\text{PILOT INJECTION Fuel mass flow rate}}{\text{TOTAL Fuel mass flow rate}}$$



- Siren mechanism used to produce air flow rate modulations
- Flow can be blocked from 0% to 88% by a rotating toothed wheel

Most recent experimental data^{1,2} and numerical comparisons

- Staging factor α varied from 100% to 0% and back
- Hysteresis cycle below $\alpha = 20\%$
- The flame is stabilized in a V shape throughout all operating points with decreasing α
- However, when pilot injection is ceased, the flame detaches and stabilizes in a M lifted shape
- This flame transition can also be forced by the operation of the siren
- Two operating points were extensively studied:
 - $\alpha = 15\%$: two states, sV or Lifted
 - $\alpha = 100\%$: V flame



Experimental data available:

Air: $m_{\text{air}} = 43.1 \text{ g/s}$, $T = 433 \text{ K}$
Fuel: $m_{\text{fuel}} = 1.64 \text{ g/s}$, $T = 300 \text{ K}$

- $\alpha = 15\%$ (non-reacting and reacting)
 - Mie-scattering spray
 - PIV (velocity)
 - PDA (SMD, size distribution, velocity)
 - CH^* chemiluminescence (Abel)
- $\alpha = 20\%$ (reacting)
 - Mie-scattering spray
 - PIV (velocity)
 - PDA (SMD, size distribution, velocity)
 - CH^* chemiluminescence (Abel)

Air: $m_{\text{air}} = 32.3 \text{ g/s}$, $T = 473 \text{ K}$
Fuel: $m_{\text{fuel}} = 1.02 \text{ g/s}$, $T = 300 \text{ K}$

- $\alpha = 100\%$ (non-reacting and reacting)
 - Mie-scattering spray
 - PIV (velocity)
 - PDA (SMD, size distribution, velocity)
 - CH^* chemiluminescence (Abel)

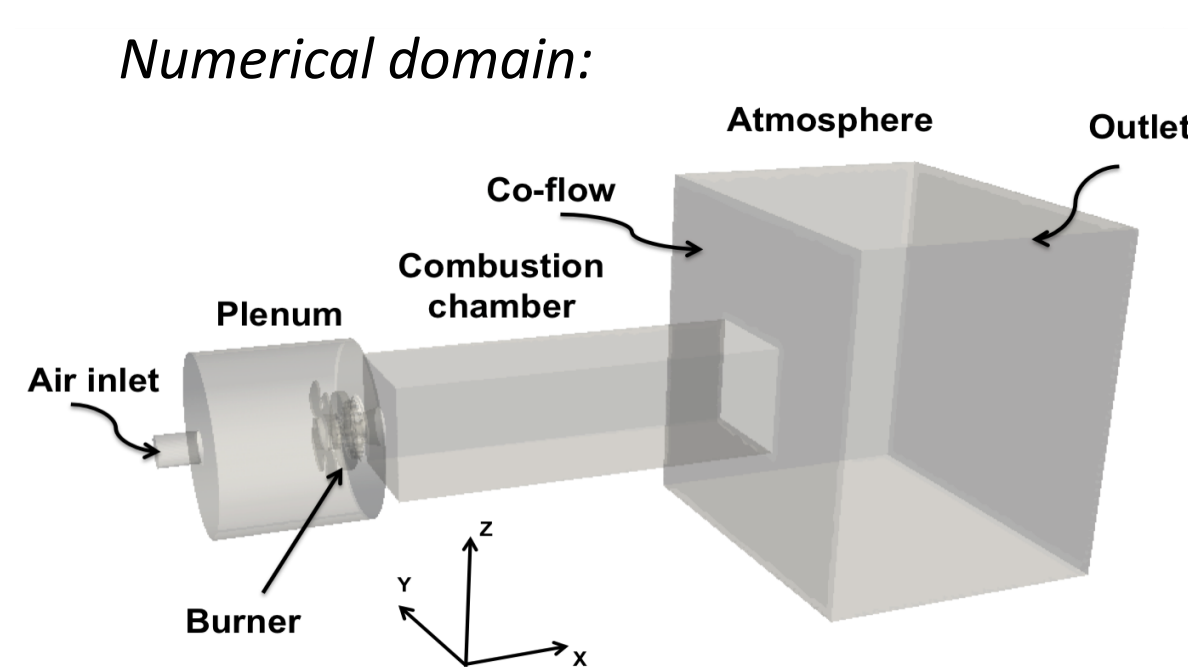
AVBP LES compressible solver^{4,5,6}

Modeling

- WALE for subgrid scale modeling
- Polydisperse Lagrangian modeling for the liquid phase
- BFER two-step chemistry model
- DTF-LES combustion model

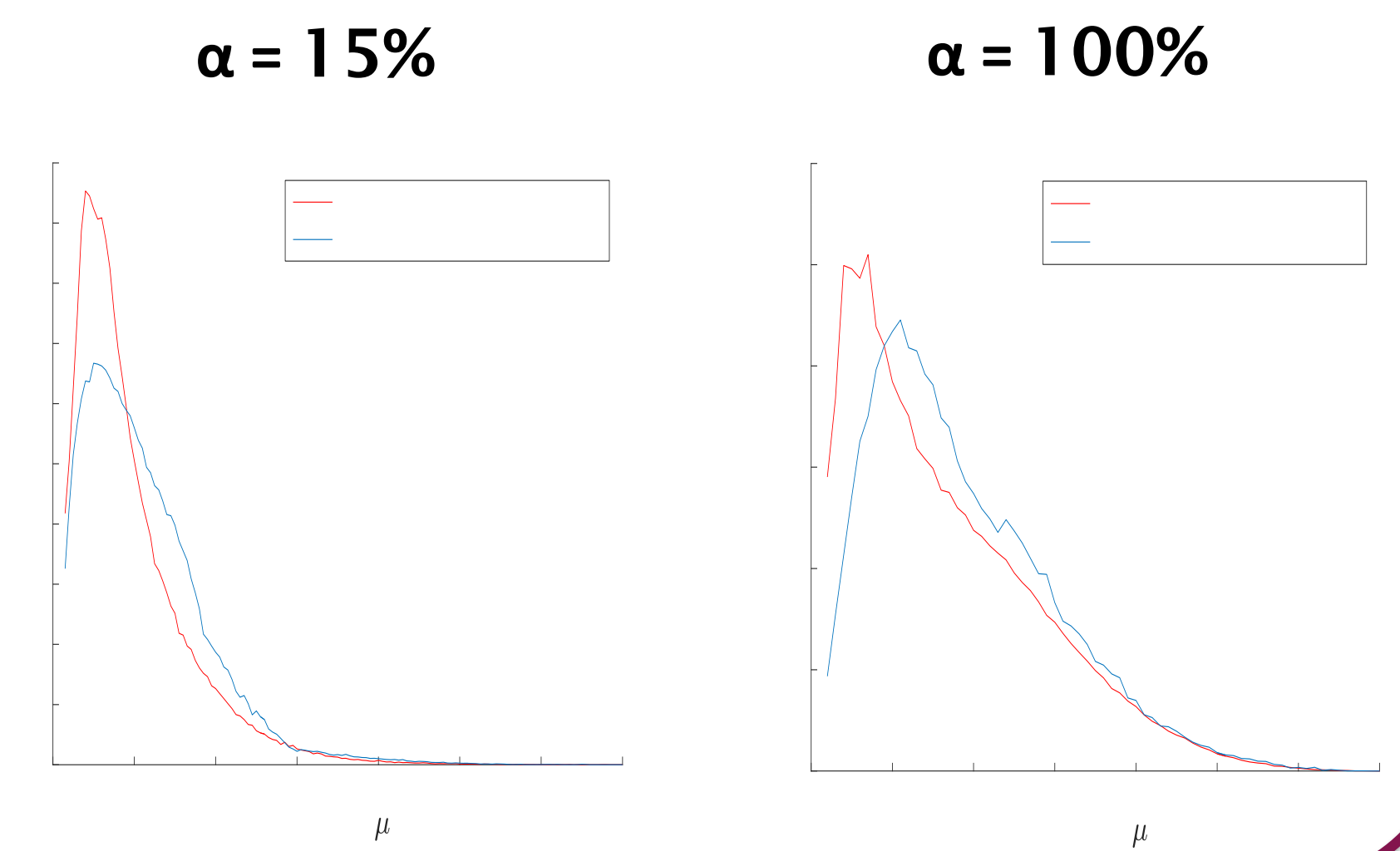
Numerics & boundary conditions

- 26 M tetrahedra mesh
- TTGC scheme for both gas and liquid phases
- Pilot injection: FIMUR injection model
- Multipoint injection: imposed mass flow rate
- NSCBC boundary conditions for inlets and outlets



Polydisperse Lagrangian modeling for the liquid phase

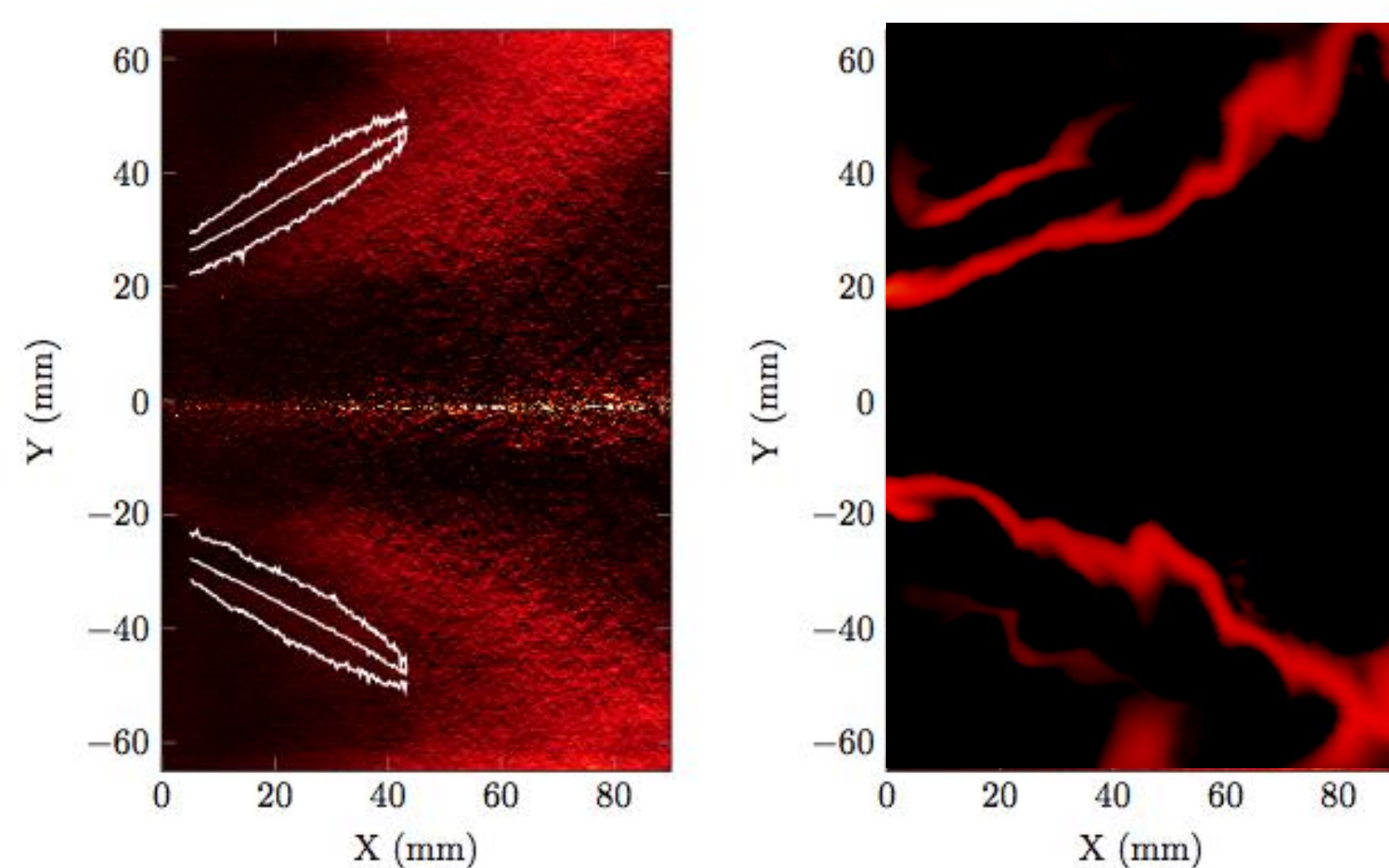
- Non-reacting data used
- For the pilot injector distribution
 - Experimental PDF available
- For the multipoint distribution
 - Only mixed injection point $\alpha = 15\%$ available
 - Pilot injector PDF is known and considered unchanged with regime
 - Multipoint PDF is deduced by subtraction



$\alpha = 15\%$

sV flame

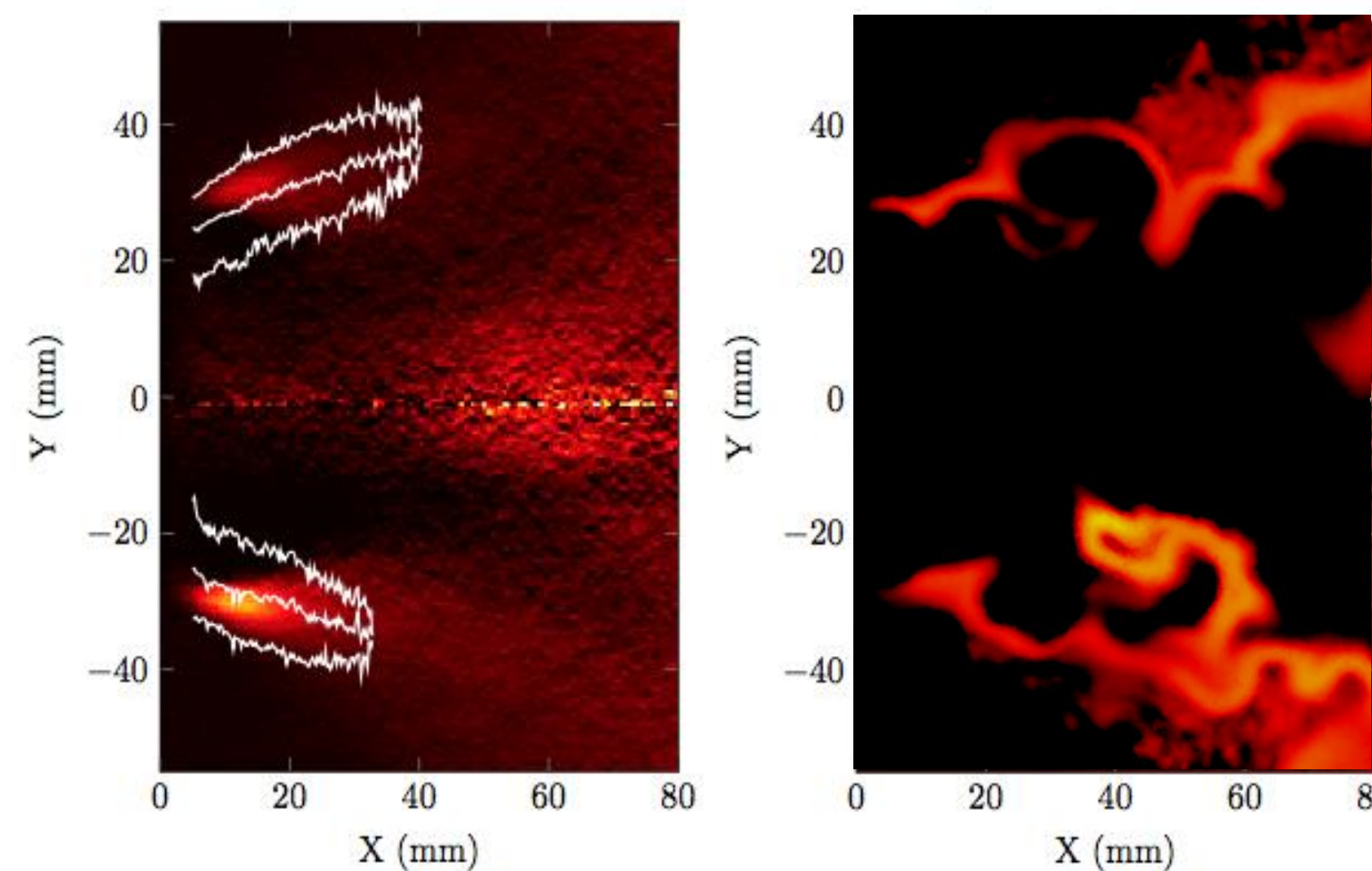
- Mostly in premixed regime
- Pilot flame at injectors exit stabilizes combustion
 - Multi-regime flame



Abel inverted mean CH^* chemiluminescence image for the sV flame (left). Heat release for the sV flame (right).

Lifted flame

- Mostly in premixed regime
- Strong combustion instability observed
 - Longitudinal 300Hz mode

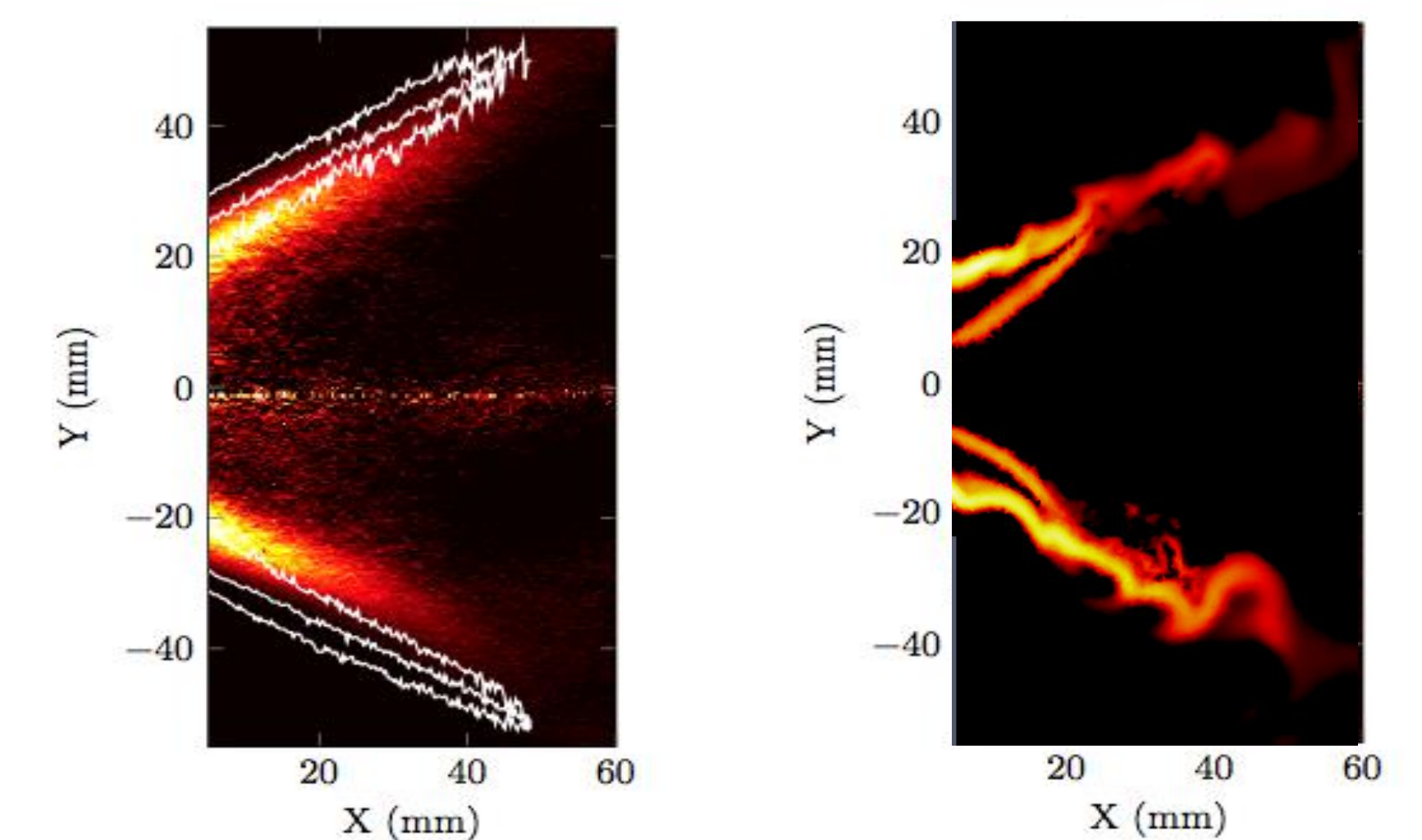


Abel inverted mean CH^* chemiluminescence image for the lifted flame (left). Heat release for the lifted flame (right).

$\alpha = 100\%$

V flame

- Strong interaction between spray, flame and recirculation zone
- Two flame zones according to spray penetration or not in the recirculation zone



Abel inverted mean CH^* chemiluminescence image for the pilot-only V flame (left). Heat release for the V flame (right).

To summarize

- A laboratory-scale two-stage swirling burner fueled with liquid dodecane has been studied experimentally and numerically using large eddy simulations
 - Using lagrangian polydispersed approach
 - Other studies⁷ were done using eulerian monodispersed approach
- Simulations were compared to existing experimental results
- The simulated flames show different shapes and dynamics

Future developments:

- Investigating flame dynamics to determine the physics of the hysteresis phenomenon evidenced in the experiments

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