Stabilisation and blow-off of turbulent flames

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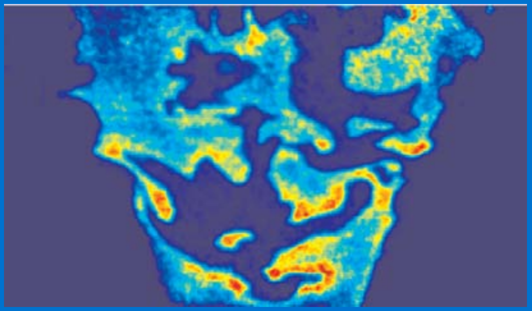

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Outline of presentation

The questions

- What are we trying to answer?
- Why is this important?
- How did we try to answer the question?
- What did we find out?
- What are the implications of our findings?

What are we trying to answer?

The research question

- What are the characteristics of flames near-to and during their low fuel-air ratio (lean) limit?

Luminous non-premixed flame

- Incomplete burning of fuel

Blue lean premixed flame

- More complete burning of fuel

Why is this important?

Factors driving lean-burn technology

Sooty non-premixed flame
‘bad’

http://www.zmescience.com/ecology/environmental-issues/fighting-against-soot-more-important-than-ever/

http://www.disputeabout.eu/clanek/26359

Blue lean premixed flame
‘good’

http://villageofjoy.com/33-cool-and-creative-ads-part-i/

http://www.reportage-enviro.com/2010/09/carbon-taxes-support-from-ets/

How did we try to answer the question? (1/3)

Background and approach

- Factors known to affect flame behaviour and extinction:
    - Mixture chemistry
    - Fluid mechanics
    - Heat loss
- What do we need to observe and measure?
- Where (global vs. local)?
    - Air-fuel composition
    - Velocity
    - Flame shape (location, structure)

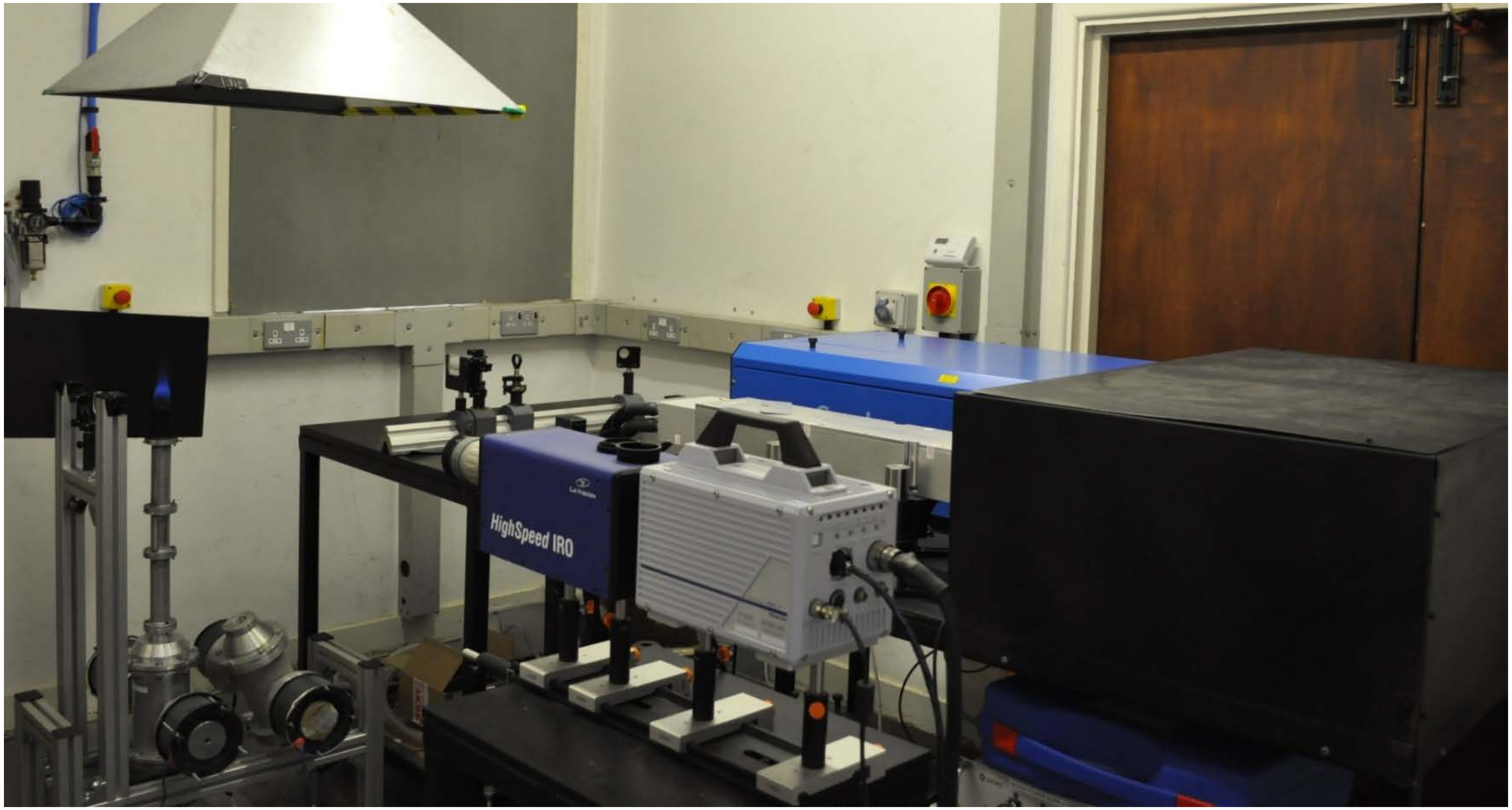
How did we try to answer the question? (2/3)

Experimental techniques

- Flame photographs
- Measurements of reactive species - OH radical
  - Chemiluminescence: light emission from chemical reactions
    - Good for global flame shape
    - Accuracy limited by spatial smearing
  - Fluorescence: light emission induced by electromagnetic radiation
    - Control over spatial region illuminated by the laser
    - Increased spatial detail and sharpness of edges
- Flow and velocity measurements: laser illumination of tracer particles
  - Mie Scattering, Particle Image Velocimetry

How did we try to answer the question? (3/3)

Experimental set-up

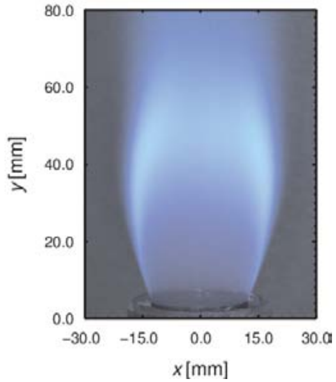


Photograph of the experimental facility.

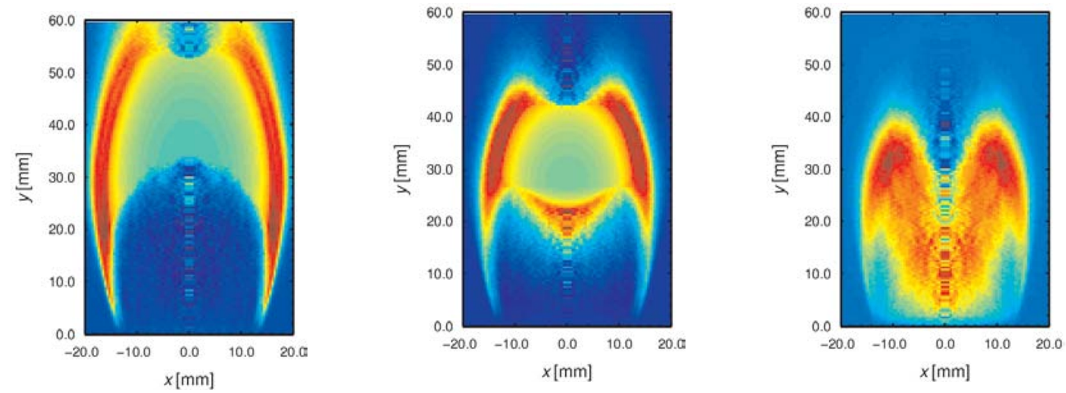
What did we find out? (1/7)

Flame shape – unconfined flame

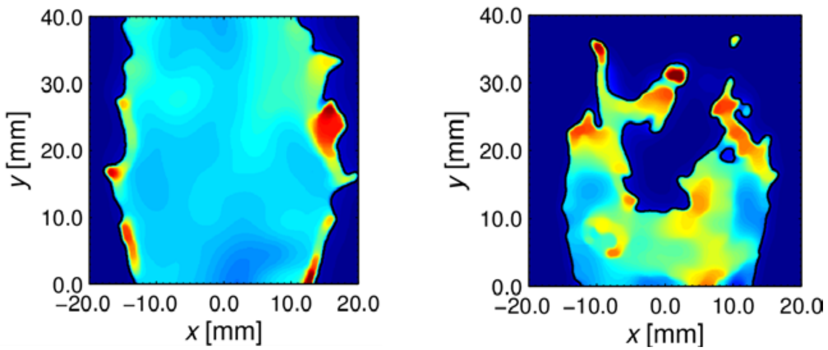
- Flame shape changes as lean blow-off condition is approached



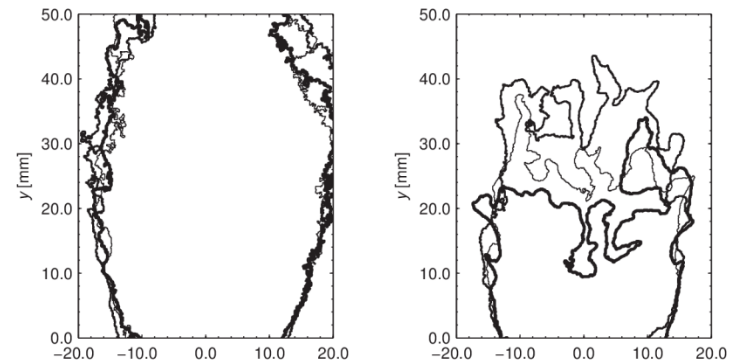
Photograph of the stable flame.



Time average OH* chemiluminescence images (after Abel transform) approaching blow-off (left to right)



Instantaneous OH-PLIF images with the local flame front superimposed.



Arbitrary chosen instantaneous contours of the flame front at conditions far-from and close-to blow-off.

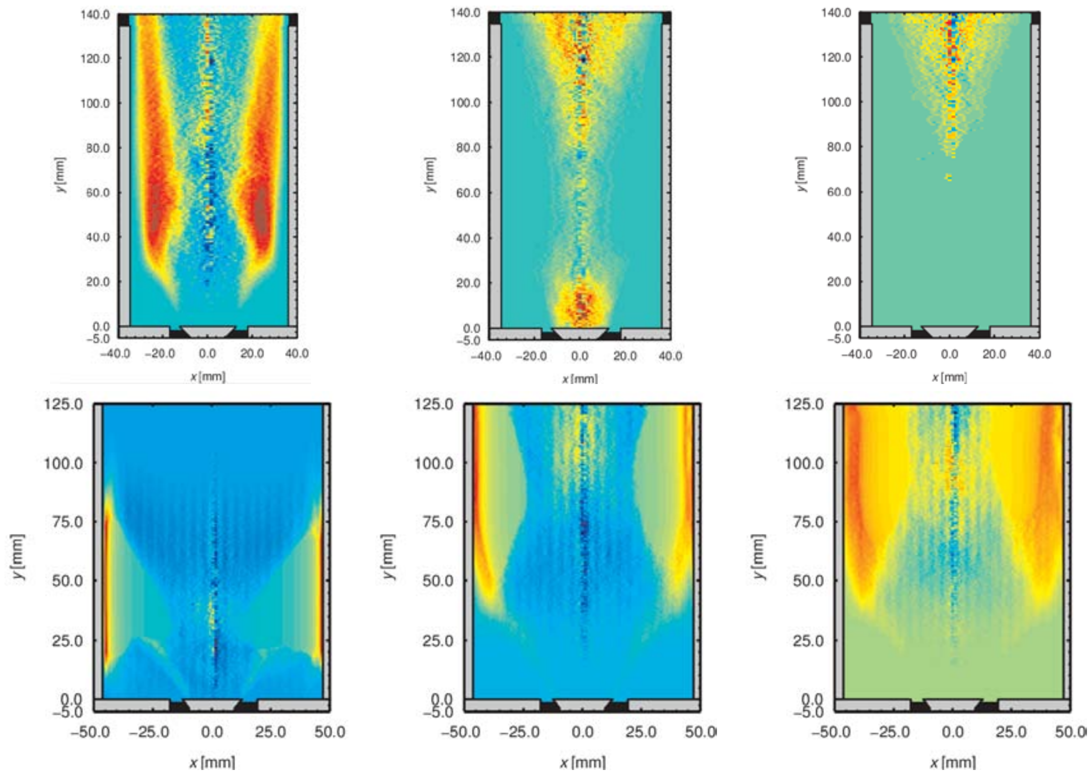
What did we find out? (2/7)

Flame shape – confined swirling flame

- Change in flame shape is dependent on the burner geometry and flow conditions.

- Circular enclosure (70 mm diameter, 135 mm height)
- Weaker swirl

- Square enclosure (95 mm width, 145 mm height)
- Stronger swirl



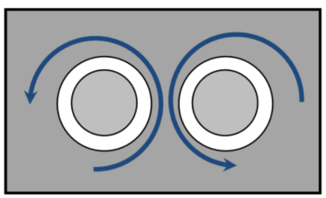
Time average OH* chemiluminescence images (after Abel transform) approaching blow-off (left to right)

What did we find out? (3/7)

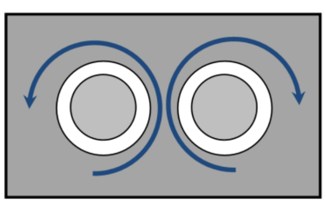
Flame shape – adjacent confined swirling flames

- Flame shape is more complicated for more practical burners

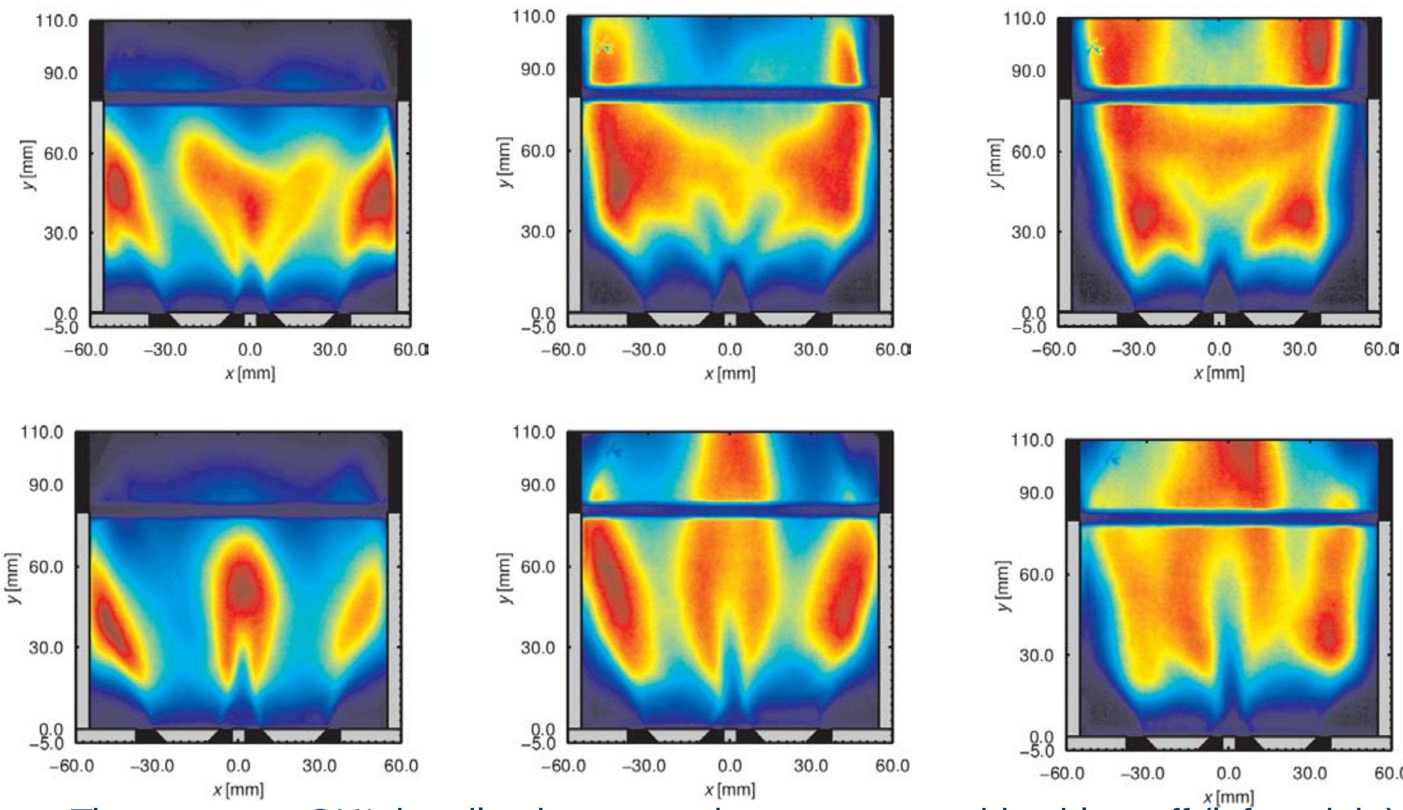
Arrows indicate direction of swirl



Co-swirl



Counter-swirl

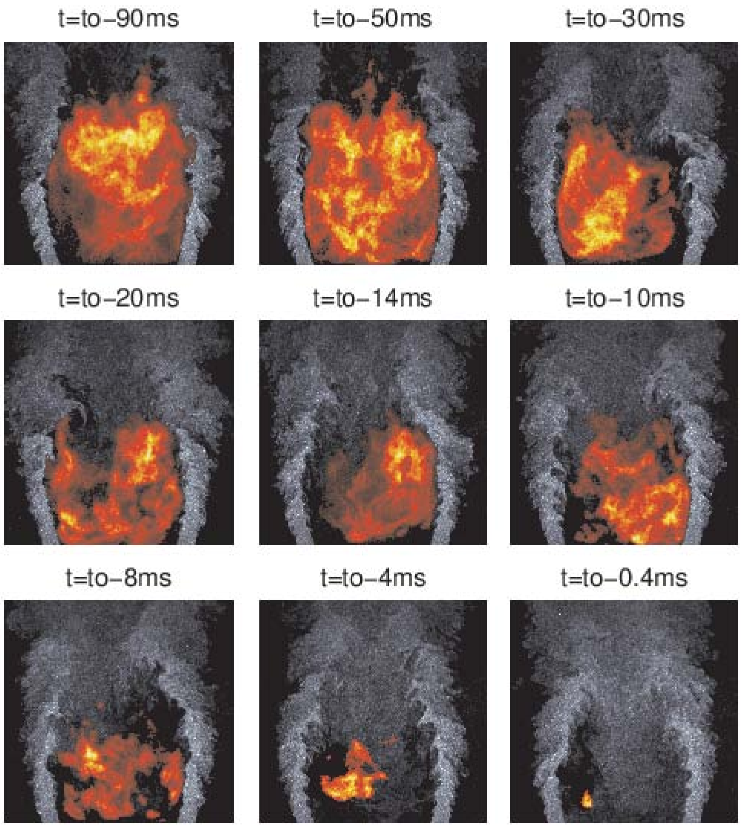


Time average OH*chemiluminescence images approaching blow-off (left to right)

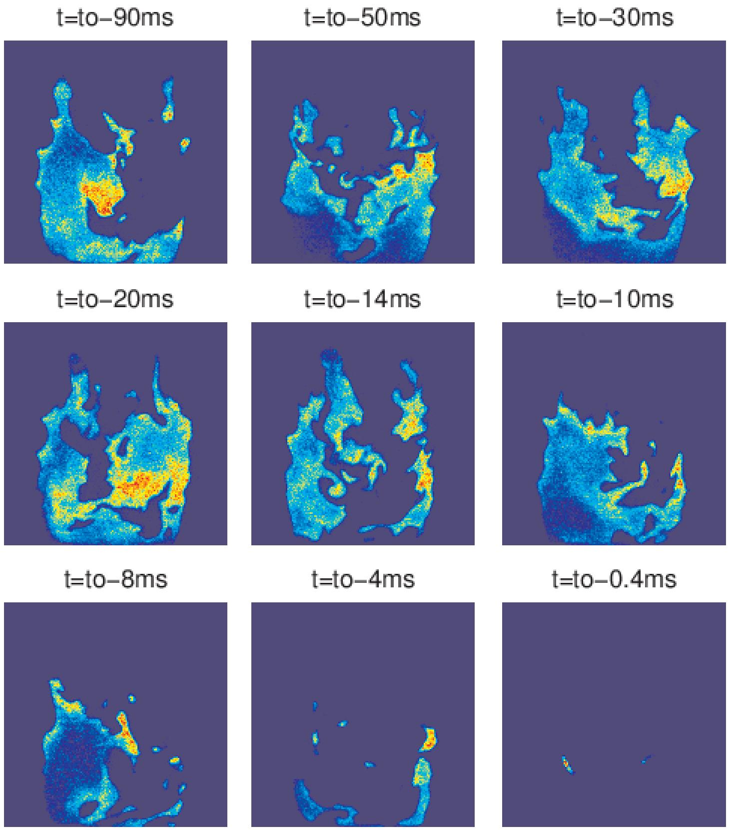
What did we find out? (4/7)

Flame structure during blow-off – unconfined flame

- Blow-off is a gradual process



Sequences of simultaneous instantaneous OH* chemiluminescence (red) and Mie scattering (gray)

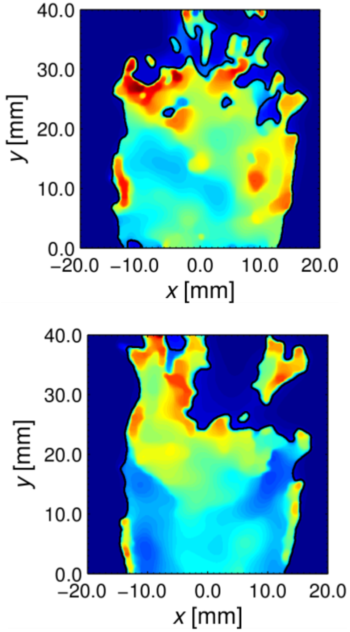


Sequences of instantaneous OH-PLIF

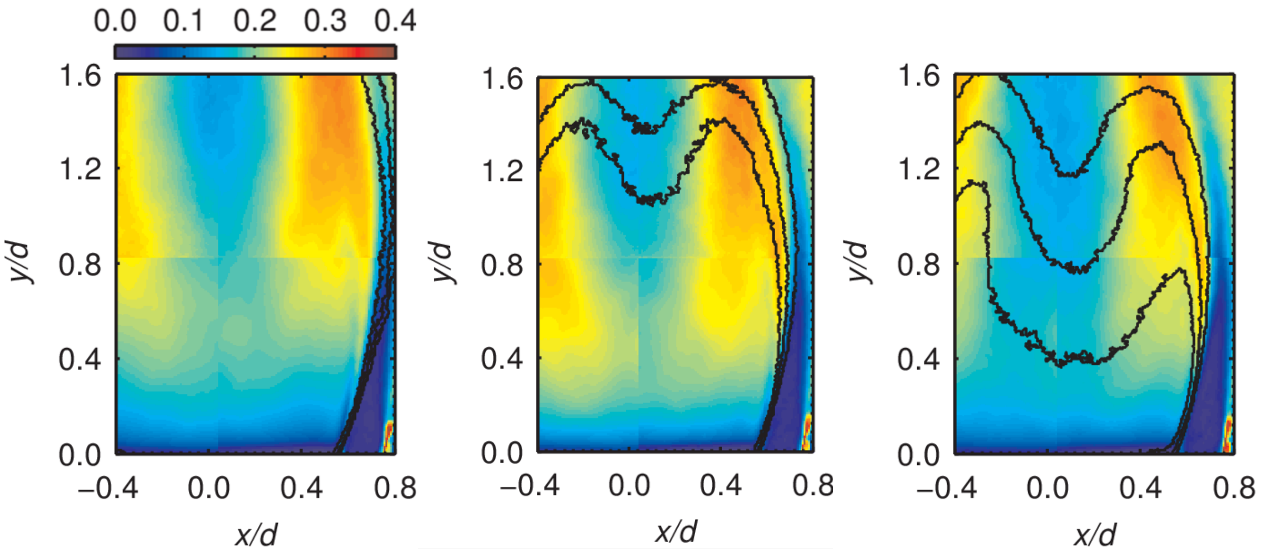
What did we find out? (5/7)

The blow-off mechanism

- Near blow-off, fragmentation begins at the downstream parts of the flame
- where the weaker burning flame interacts with large velocity fluctuations



Images of instantaneous OH-PLIF near blow-off



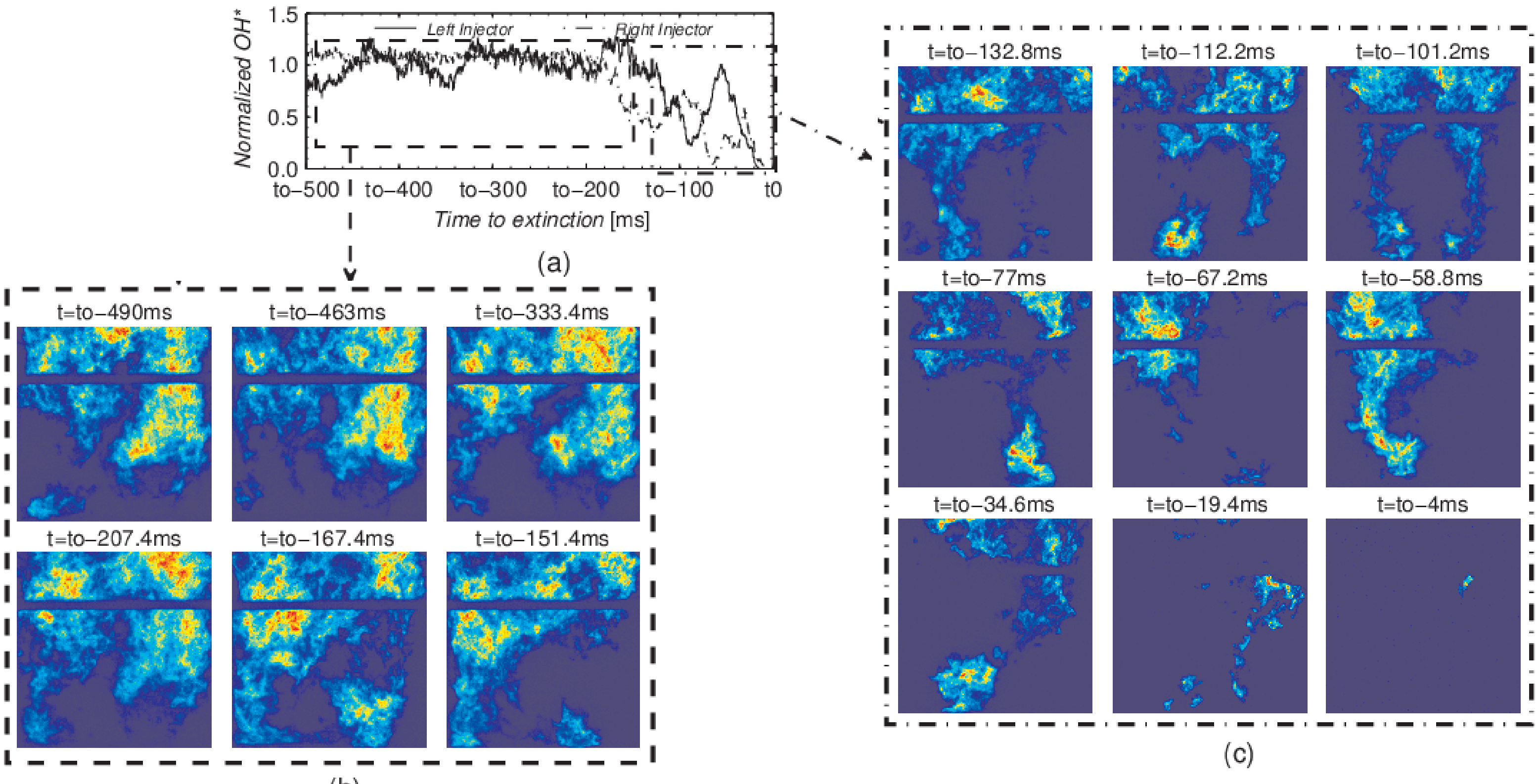
Images of u_{RMS}/U_b with contours of the flame brush superimposed as blow-off is approached (left to right).

- Colder unburned gases then penetrate inside and cool the hot recirculating gas region critical for flame stabilisation.

What did we find out? (6/7)

Flame structure during blow-off – multiple flames

- Flame shape during blow-off is dependent on the burner and flow pattern.

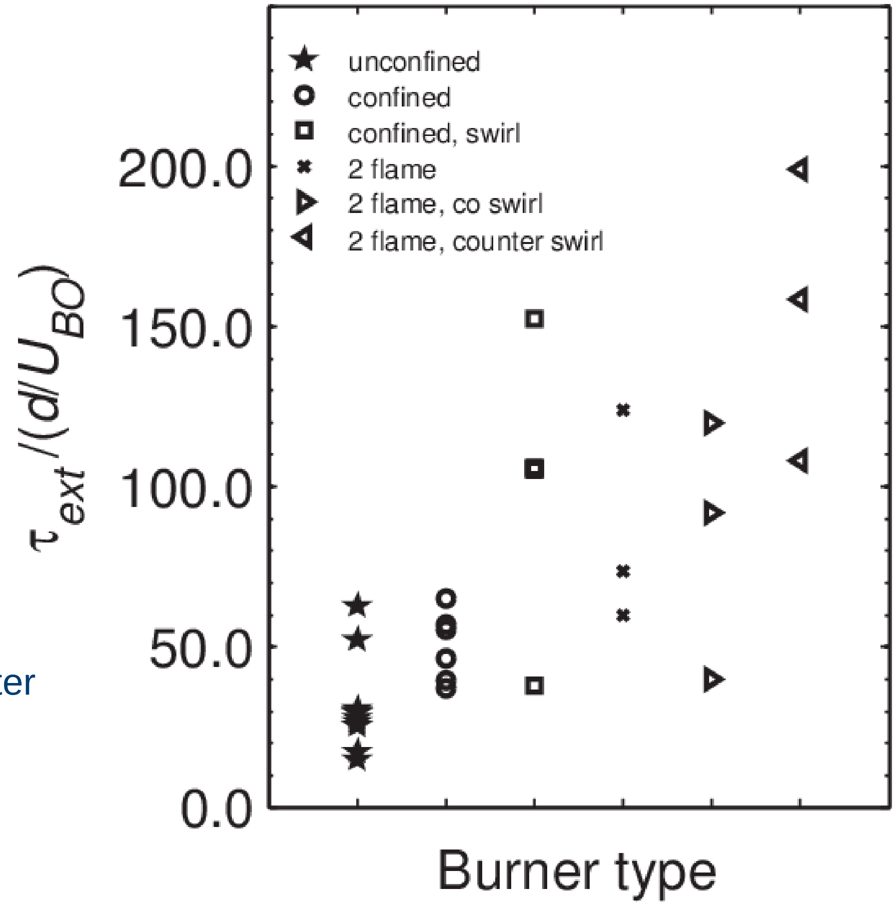


(a) Time series of the area integrated OH* signal during blow-off, and sequences of OH* images during the (b) intermediate and (c) final stages of the blow-off transient for two adjacent flames with counter-swirl.

What did we find out? (7/7)

Average duration of the blow-off event

- The blow-off event lasts an average time (τ_{ext}) of the order of tens to hundreds of milliseconds.



d – flame holder diameter

U_{BO} – bulk mixture velocity at blow-off

What are the implications of our findings?

The main conclusions

- New information provided on the flame behaviour both near-to and during the low fuel-air ratio extinction limit.
  - for both simple and more practical burner geometries
- Qualitative and quantitative information available for:
  - flame shape, structure, flow-field, duration of extinction transient
- Data is useful for:
  - further research on flame stabilisation and extinction
  - validation of computational models