Instabilities and soot formation in high pressure, rich, iso-octane-air explosion flames

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Introduction

- Flame instabilities
- Schlieren and OH PLIF experiments in the Leeds Bomb
- Results
- LII experiments in the Shell Bomb
- Results
- Soot formation hypothesis
- Conclusion

Flame Instabilities

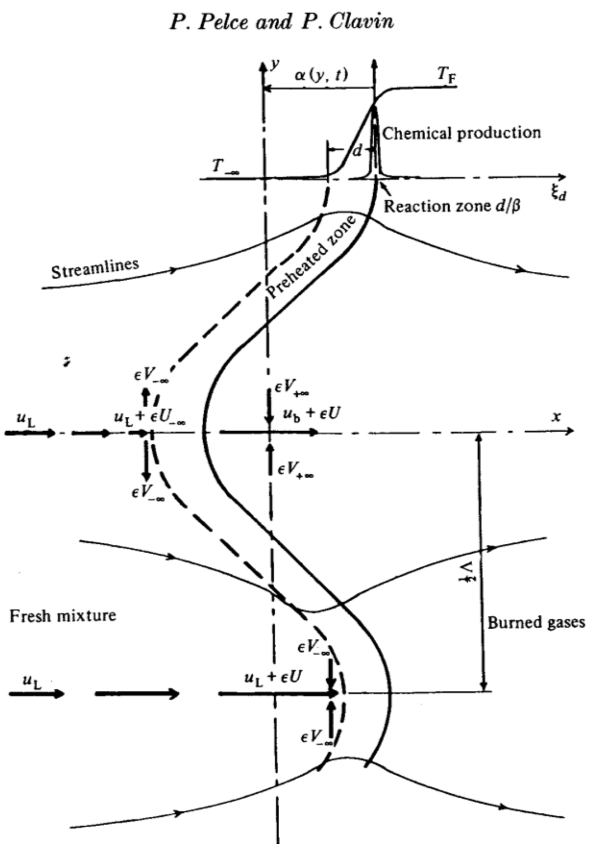
1. **Rayleigh-Taylor Instability**

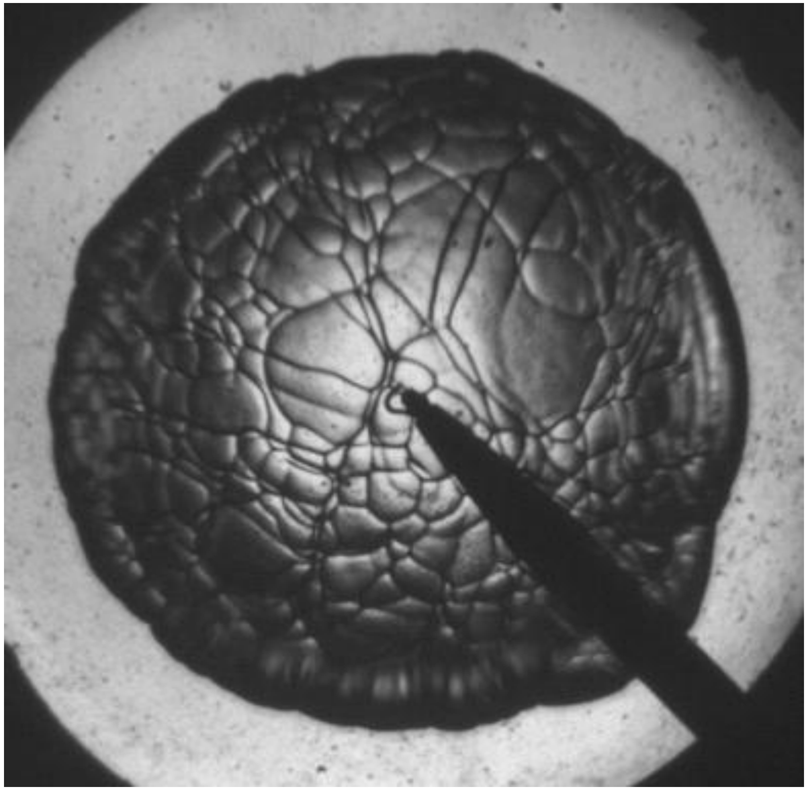
This instability is a result of a cold fluid above a hot fluid. The hot fluid is less dense than the cold fluid. Therefore the hot fluid is buoyant relative to the cold fluid.

Therefore irregularities at the interface of the two fluids grow, in order to achieve convection.

Flame Instabilities

2. Landau-Darrius (Hydrodynamic) Instability



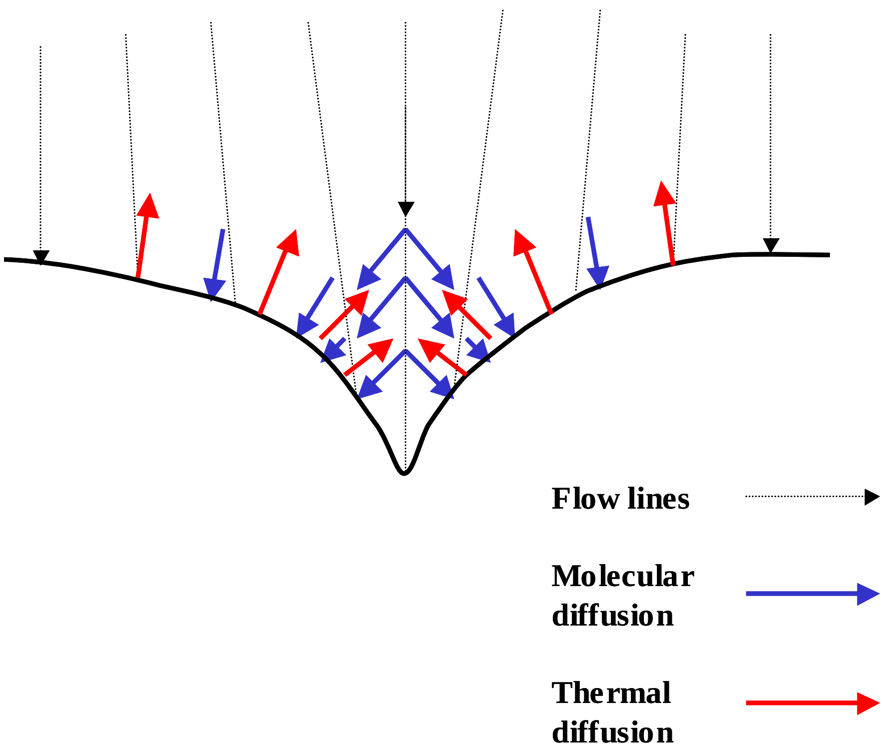


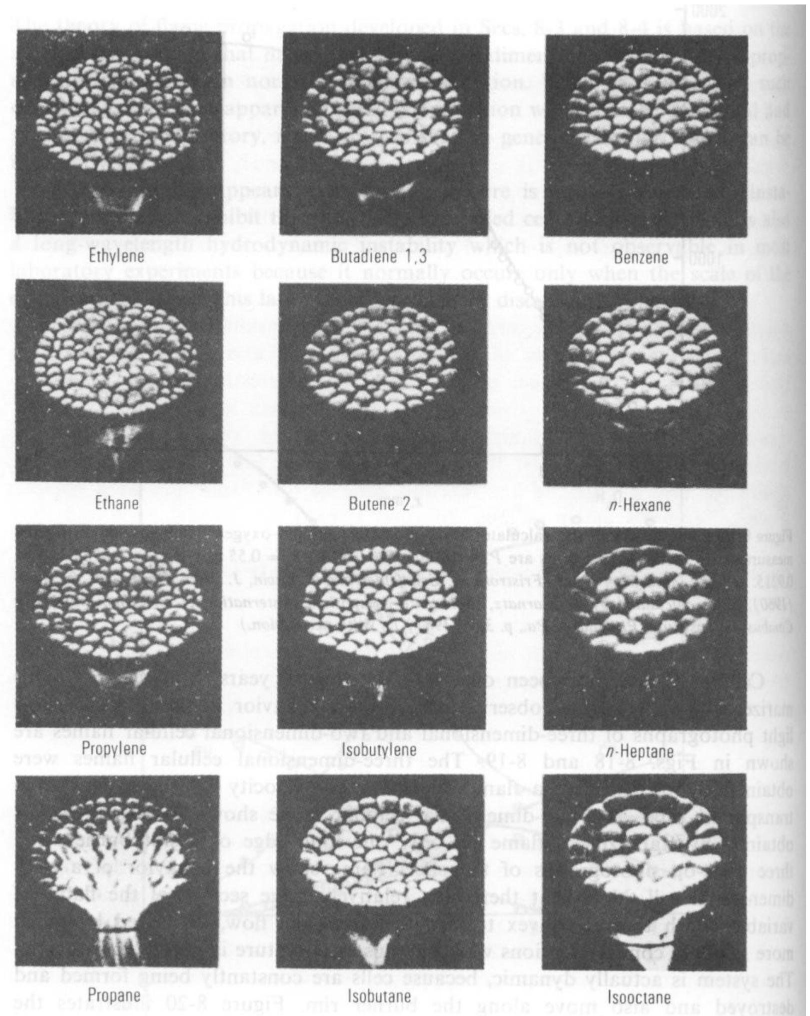
Courtesy of R. Woolley, Univ. of Leeds

Flame Instabilities

3. Thermal-Diffusive Instability

$$Le = \frac{\alpha}{D} < Le^{*} \equiv O(1)$$





Copied from “Combustion Fundamentals”, R. Strewlow, 1985

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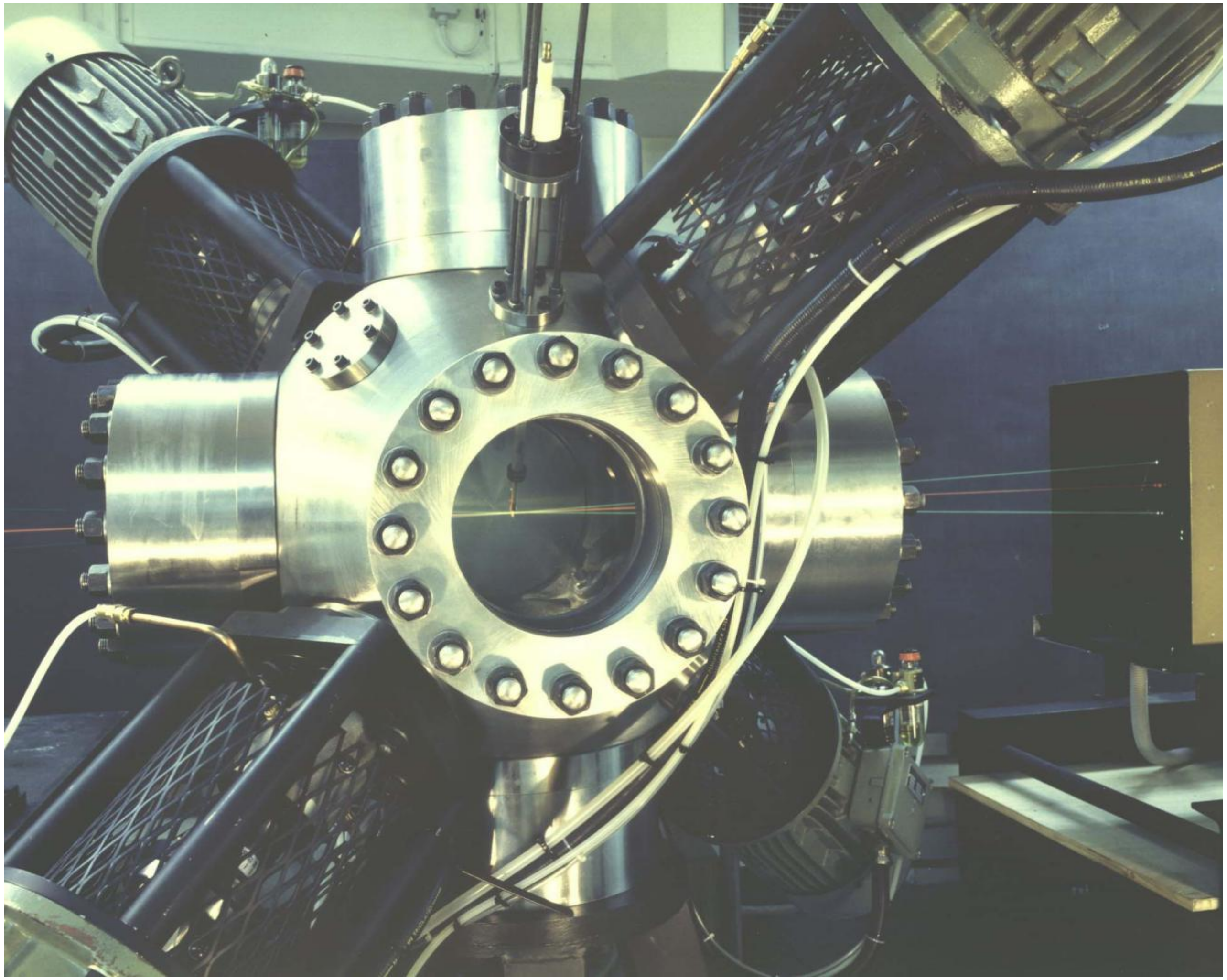
The Leeds Bomb

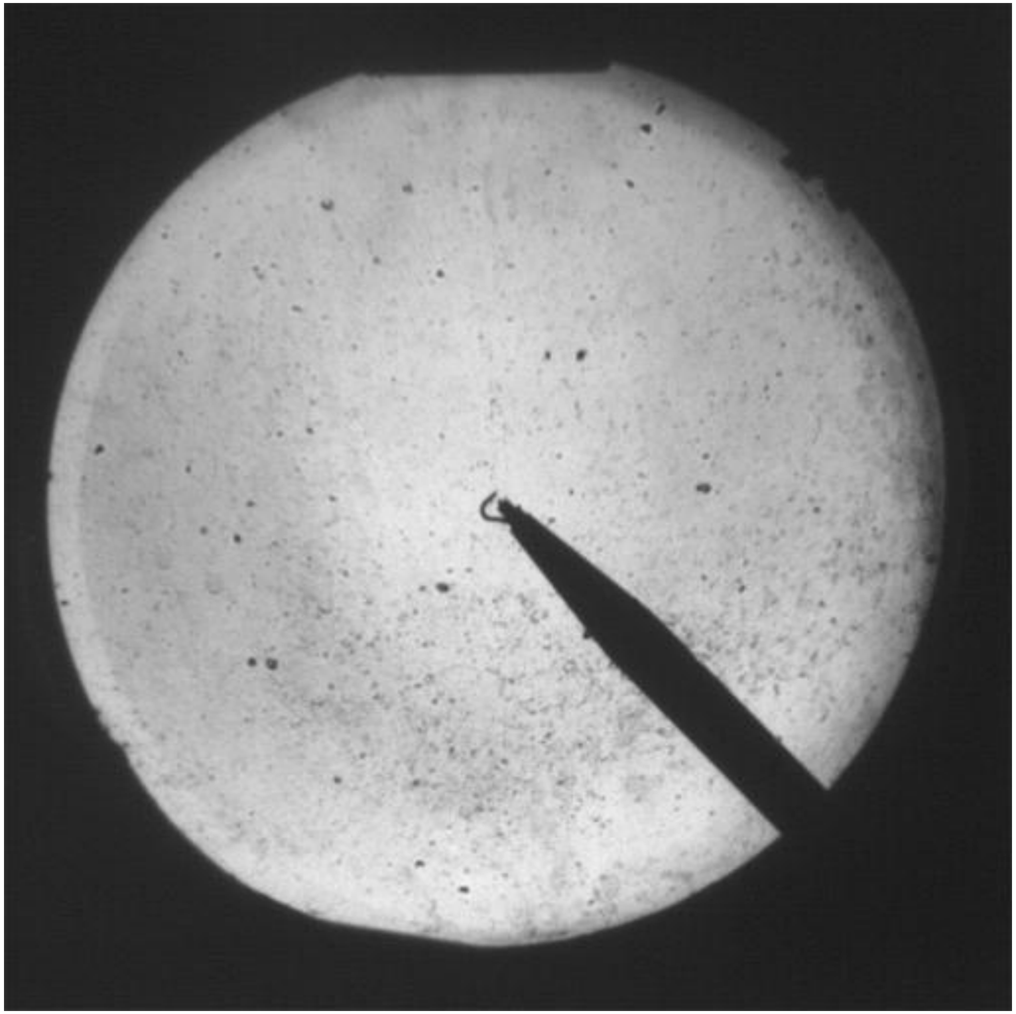


Schlieren Cinematography in the Leeds Bomb

Conditions:

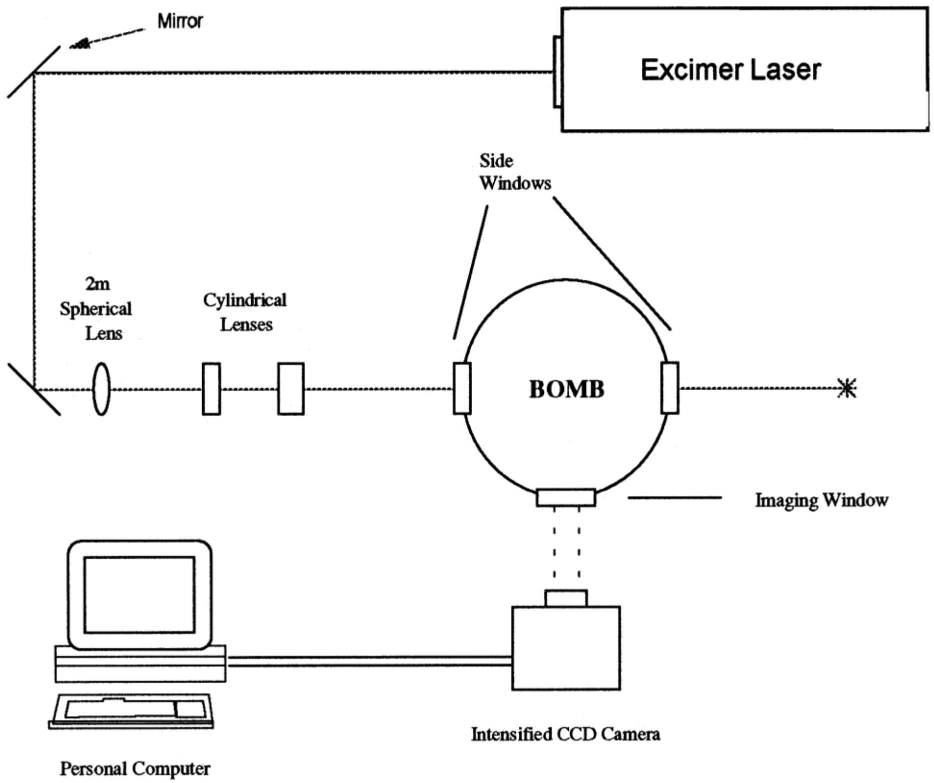
Iso-octane-air mixture
$\varphi = 1.0$, $p = 5$ bar

Viewing diameter
D = 15 cm



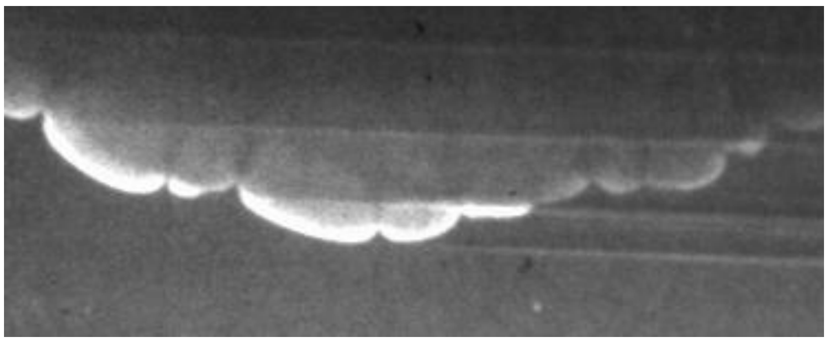
Courtesy of R.Woolley,
Univ. of Leeds, 2005

OH PLIF in the Leeds Bomb



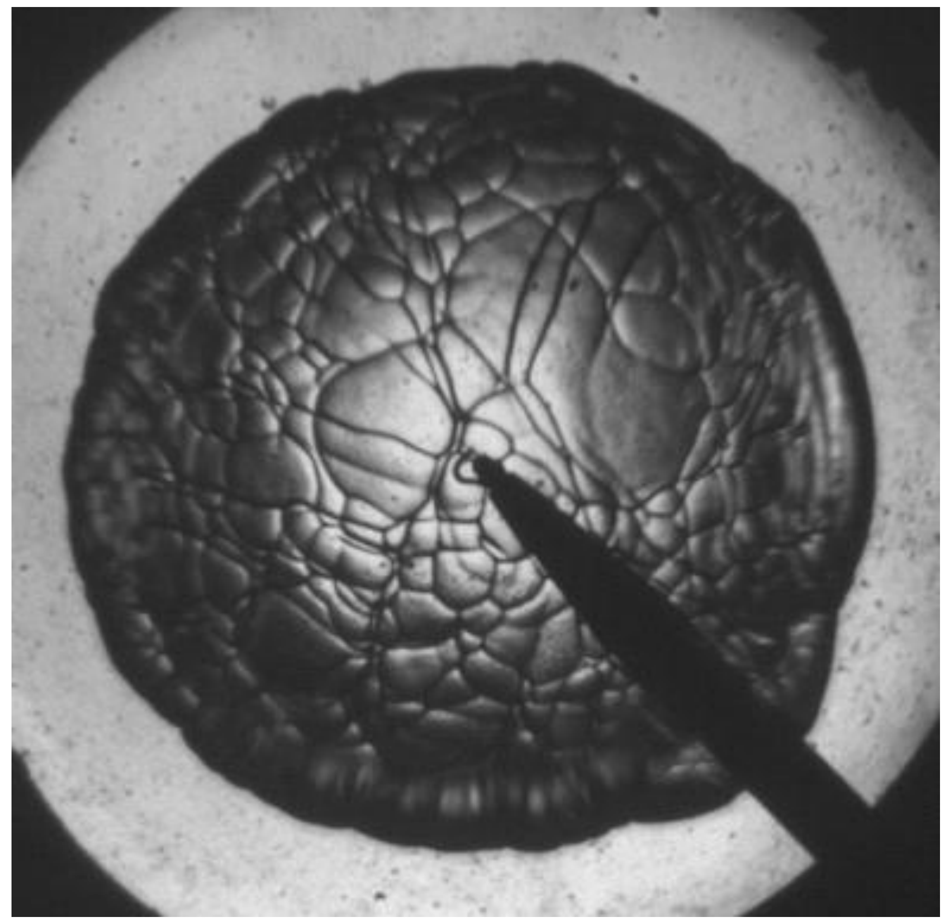
OH PLIF in the Leeds Bomb

5.5 cm



Unprocessed OH PLIF Image of a $\varphi = 1$ 5 bar Iso-octane-Air Explosion Flame obtained in the Leeds Bomb (Flame radius ≈ 60 mm, Pe ~ 600)

This reveals the influence of the Darrius-Landau (hydrodynamic) instability.

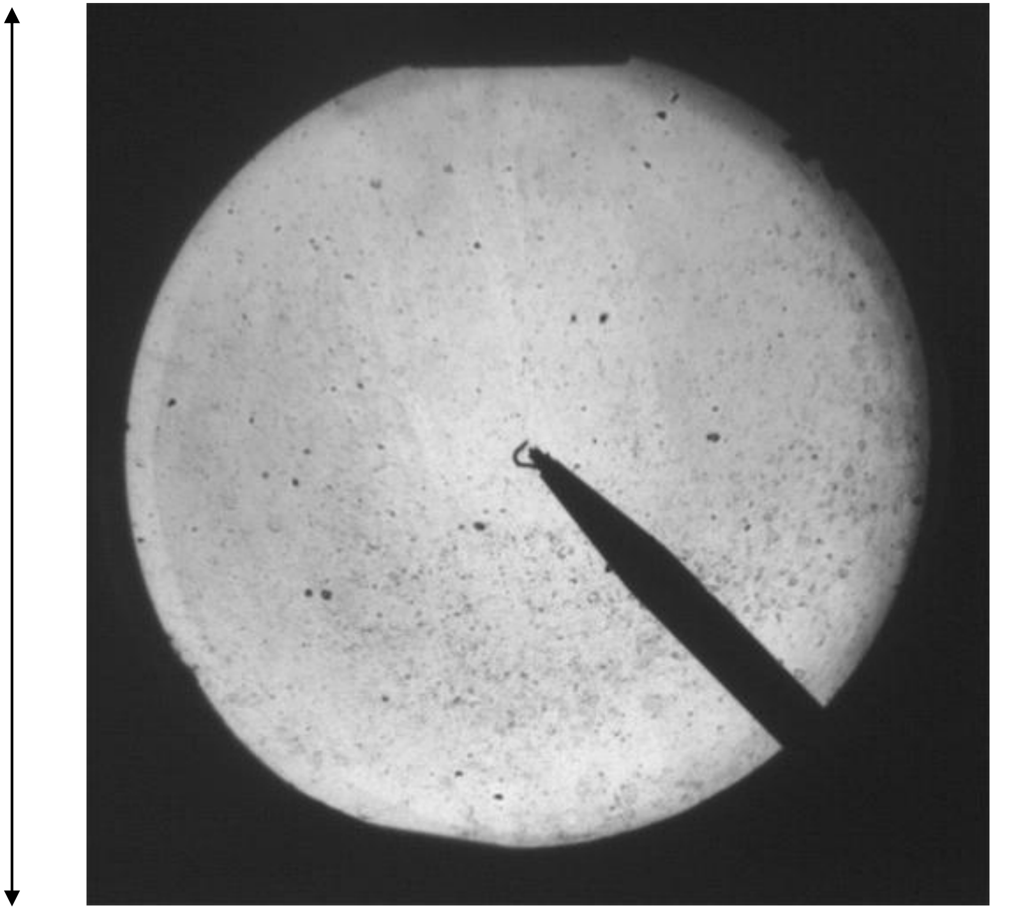


Schlieren Cinematography in the Leeds Bomb

Conditions:

Iso-octane-air mixture
$\varphi = 1.4$, $p = 5$ bar

Viewing diameter
D = 15 cm



Courtesy of R.Woolley,
Univ. of Leeds, 2005

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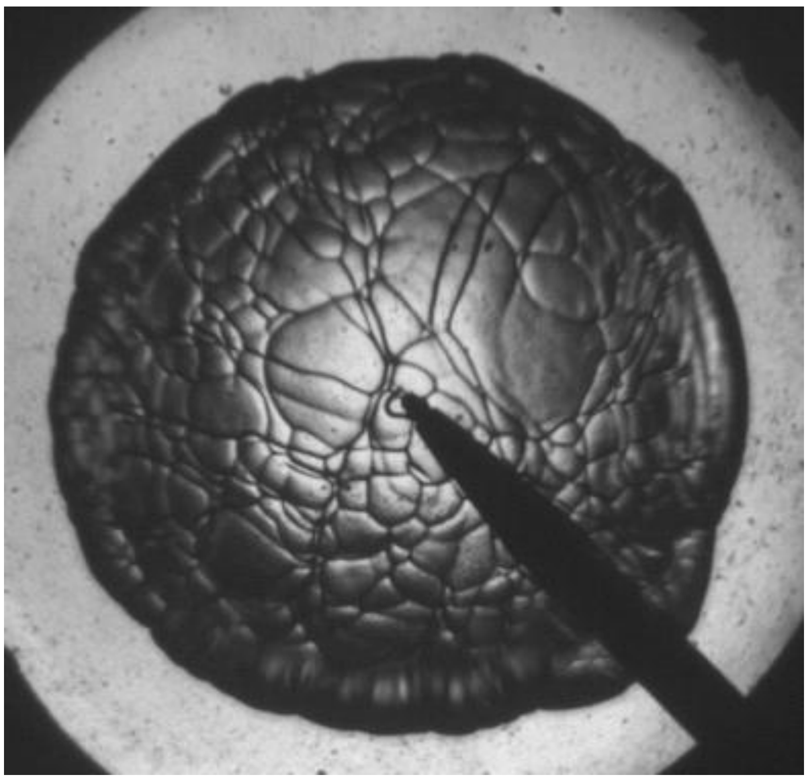
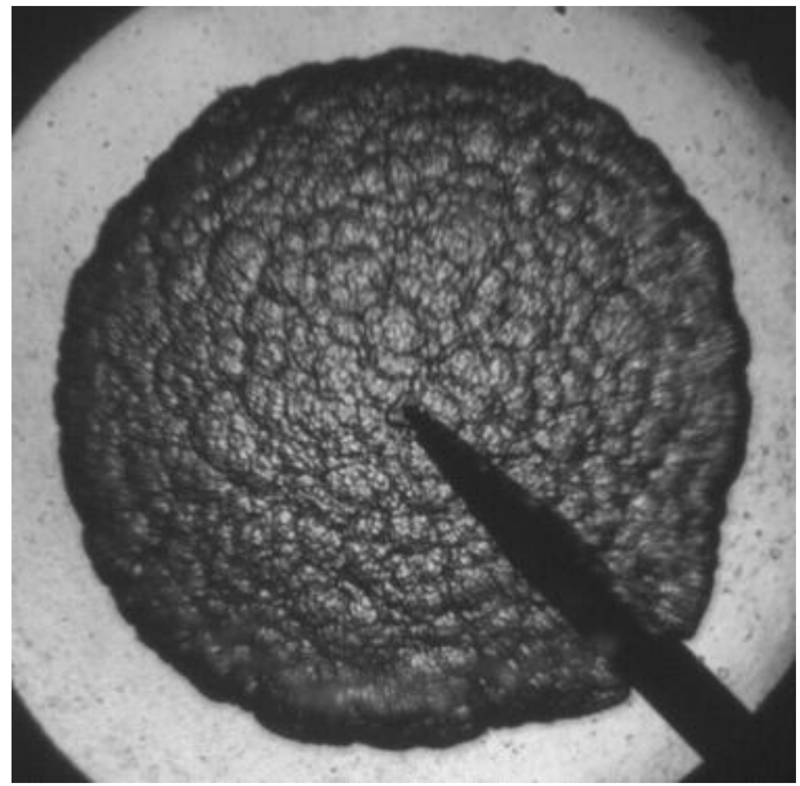
Schlieren Images of Iso-octane-Air Explosion Flames
(flame radius ~ 60 mm, Pe ~ 600)

P = 5 bar, $\varphi = 1.0$



P = 5 bar, $\varphi = 1.4$



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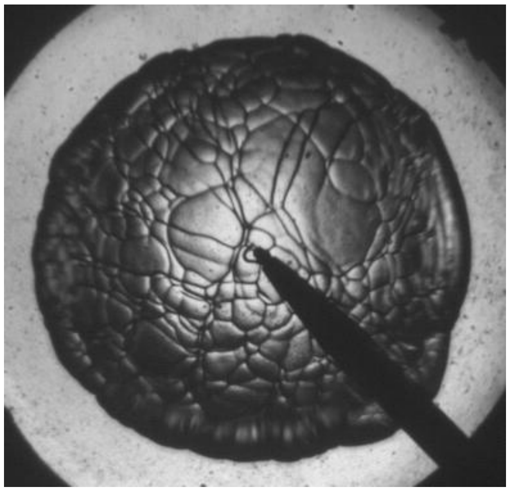
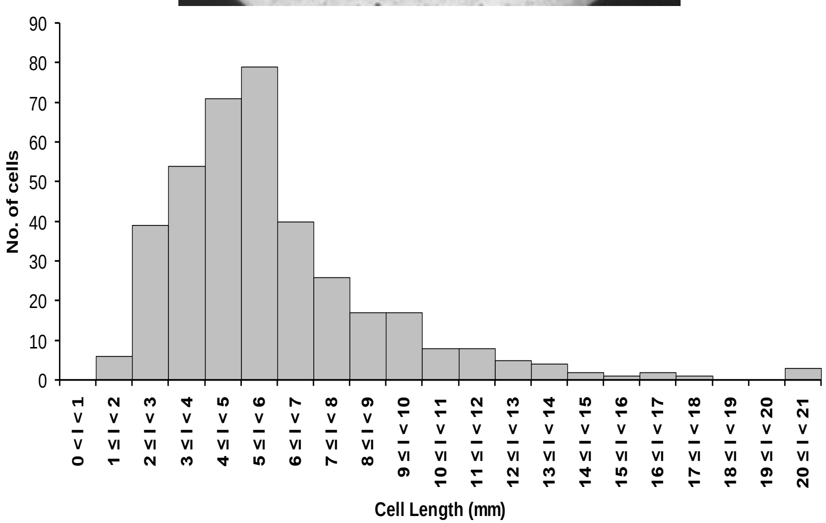
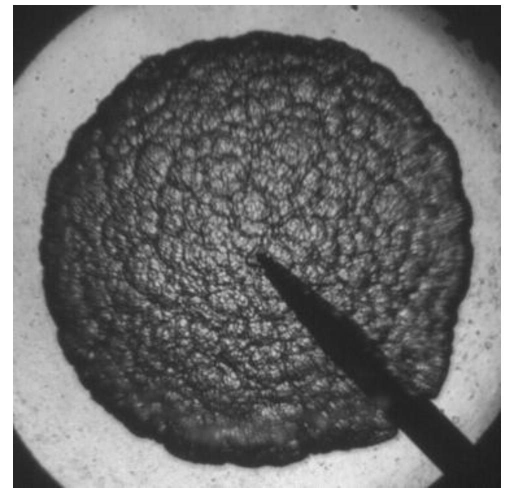
Schlieren Images of Iso-octane-Air Explosion Flames
(flame radius ~ 60 mm, Pe ~ 600)

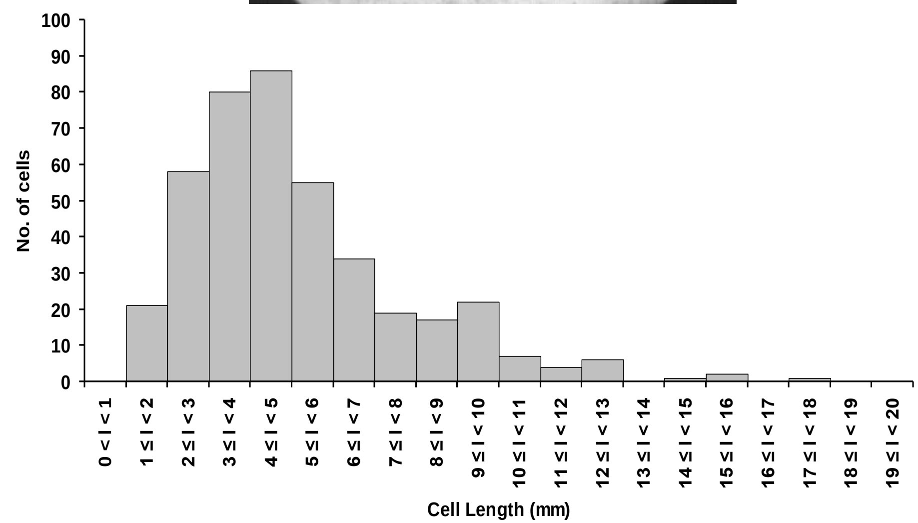
P = 5 bar, $\varphi = 1.0$



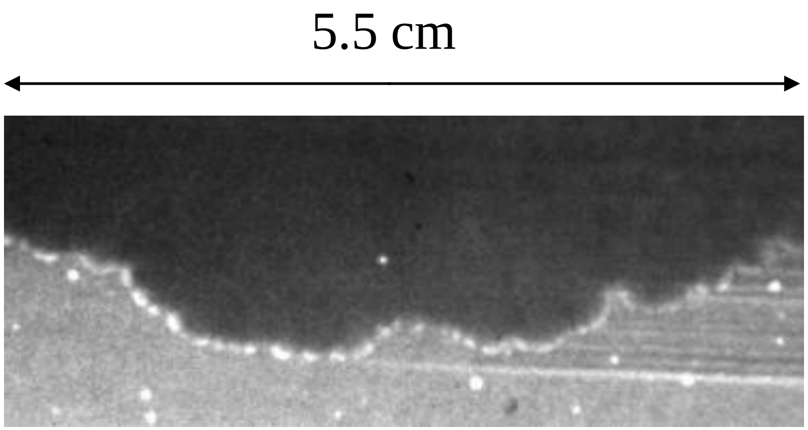


P = 5 bar, $\varphi = 1.4$



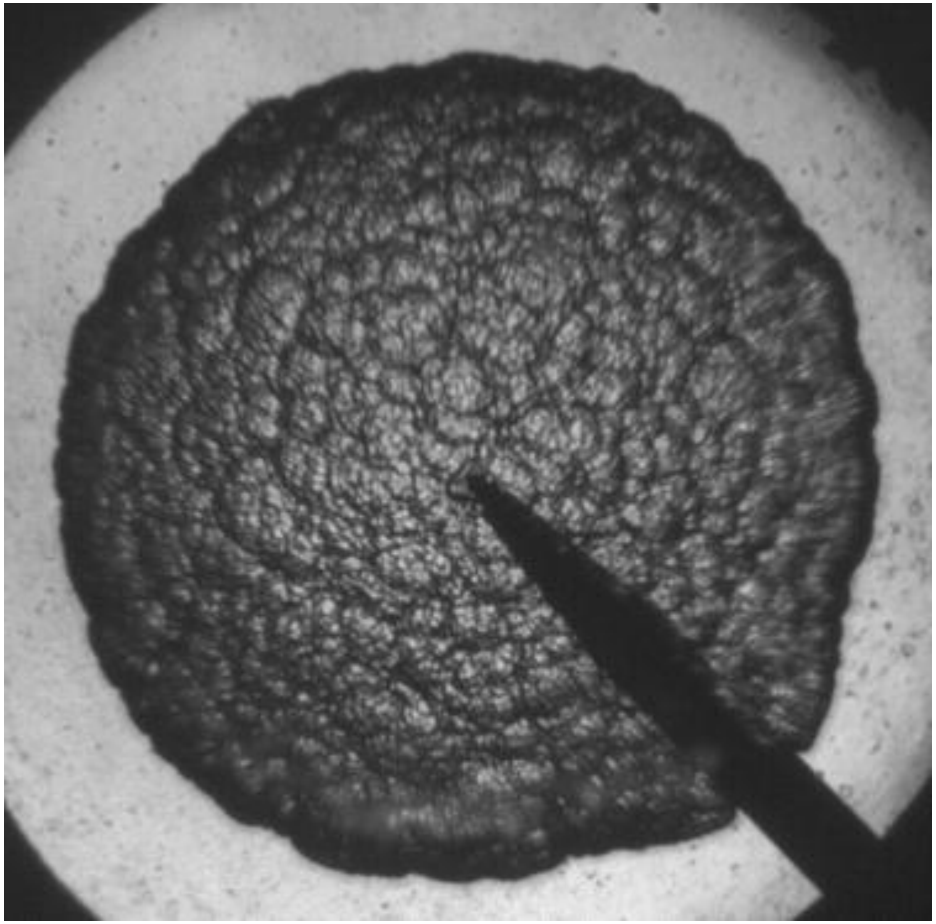


OH PLIF in the Leeds Bomb



Unprocessed OH PLIF Image of a $\varphi = 1.4$, 5 bar Iso-octane-Air Explosion Flame obtained in the Leeds Bomb (Flame radius ≈ 60 mm, Pe ~ 600)

This reveals the influence of the Darrius-Landau (hydrodynamic) instability and the thermal-diffusive instability.



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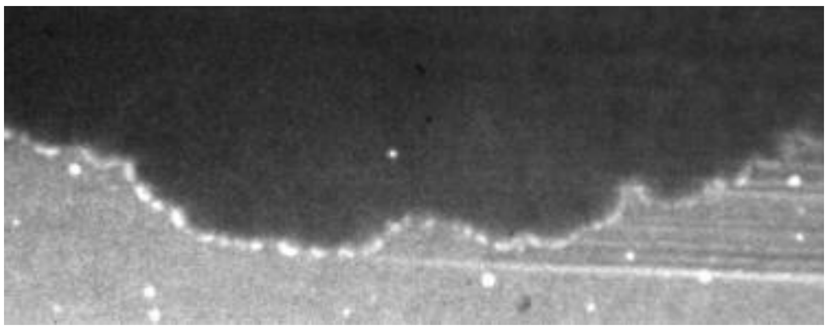
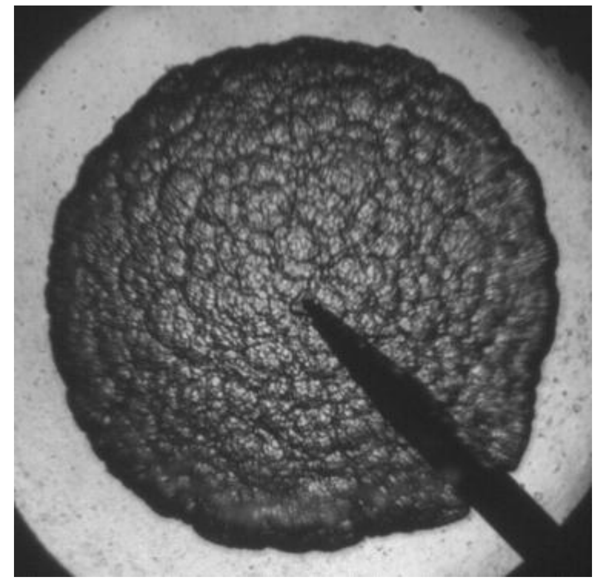
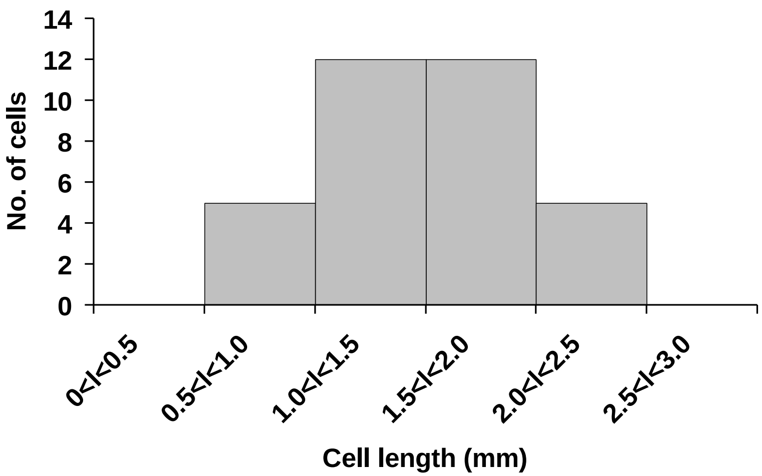
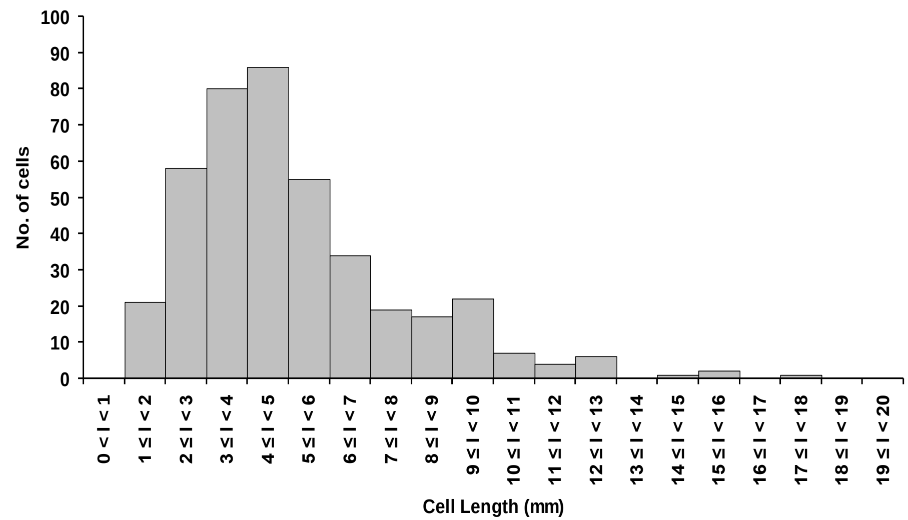
Cell Length Scale Analysis

5.5 cm

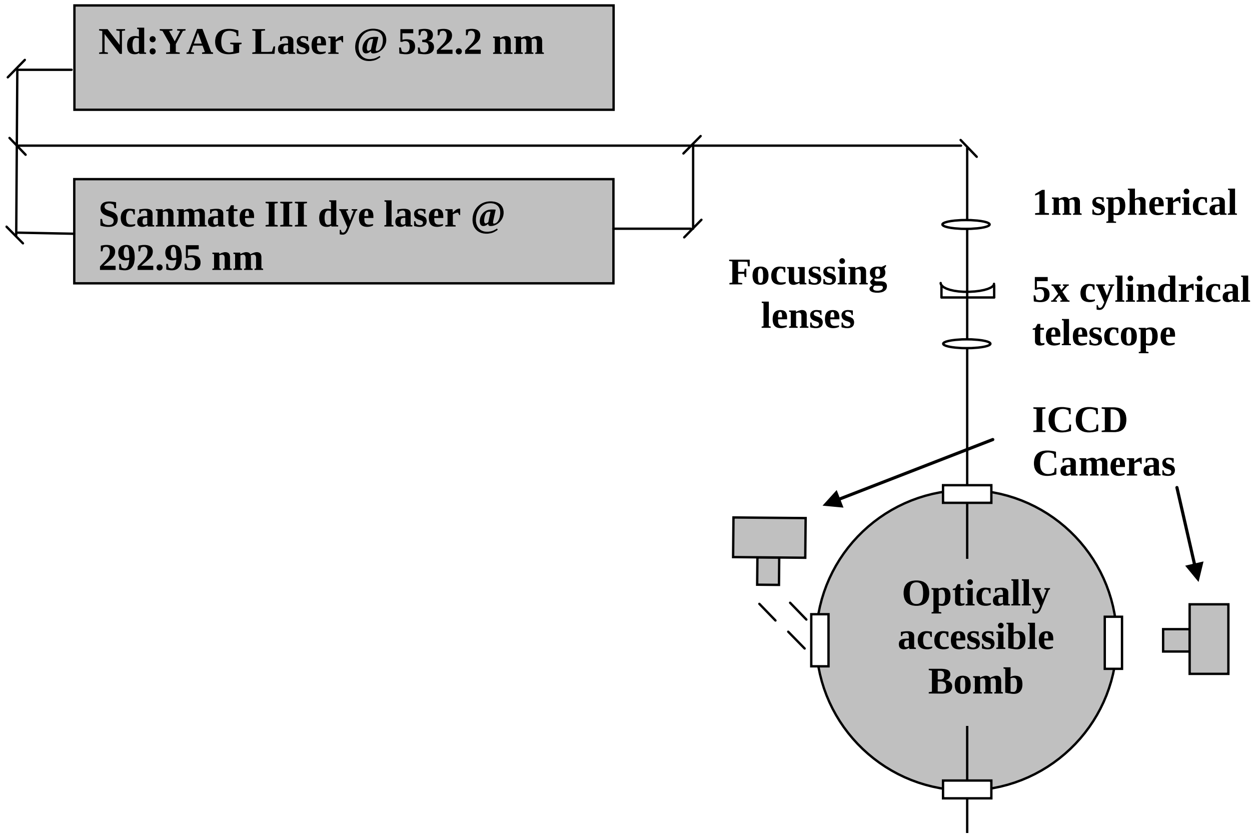








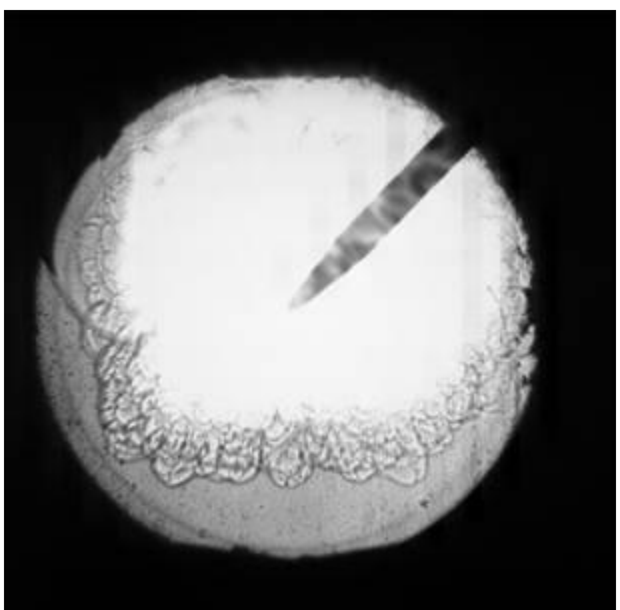
Soot Formation Measurements in the Leeds Bomb Simultaneous Rayleigh/OH PLIF Spectroscopy



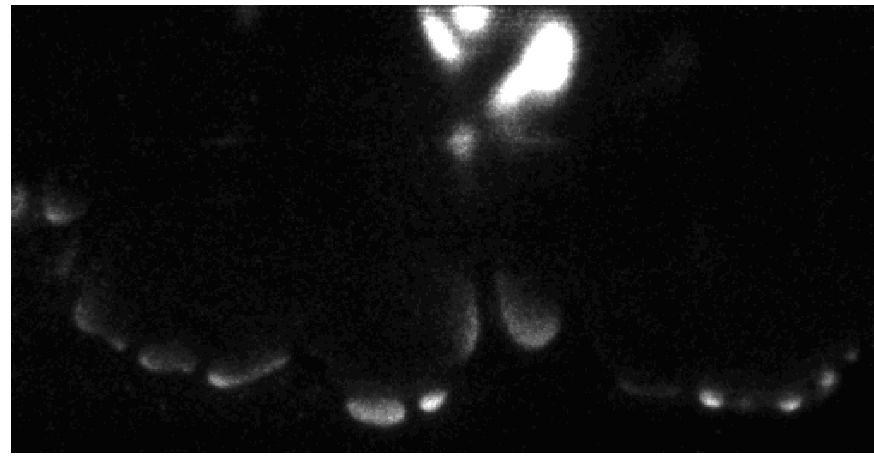
Soot Formation in the Leeds Bomb

Soot formation in a 2 bar, φ = 2.0 iso-octane-air flame.

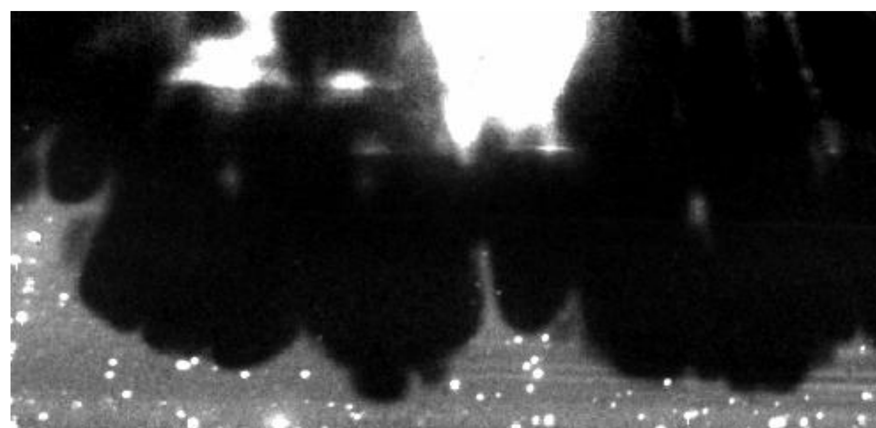
Note the soot formed behind deep cracks in the flame.



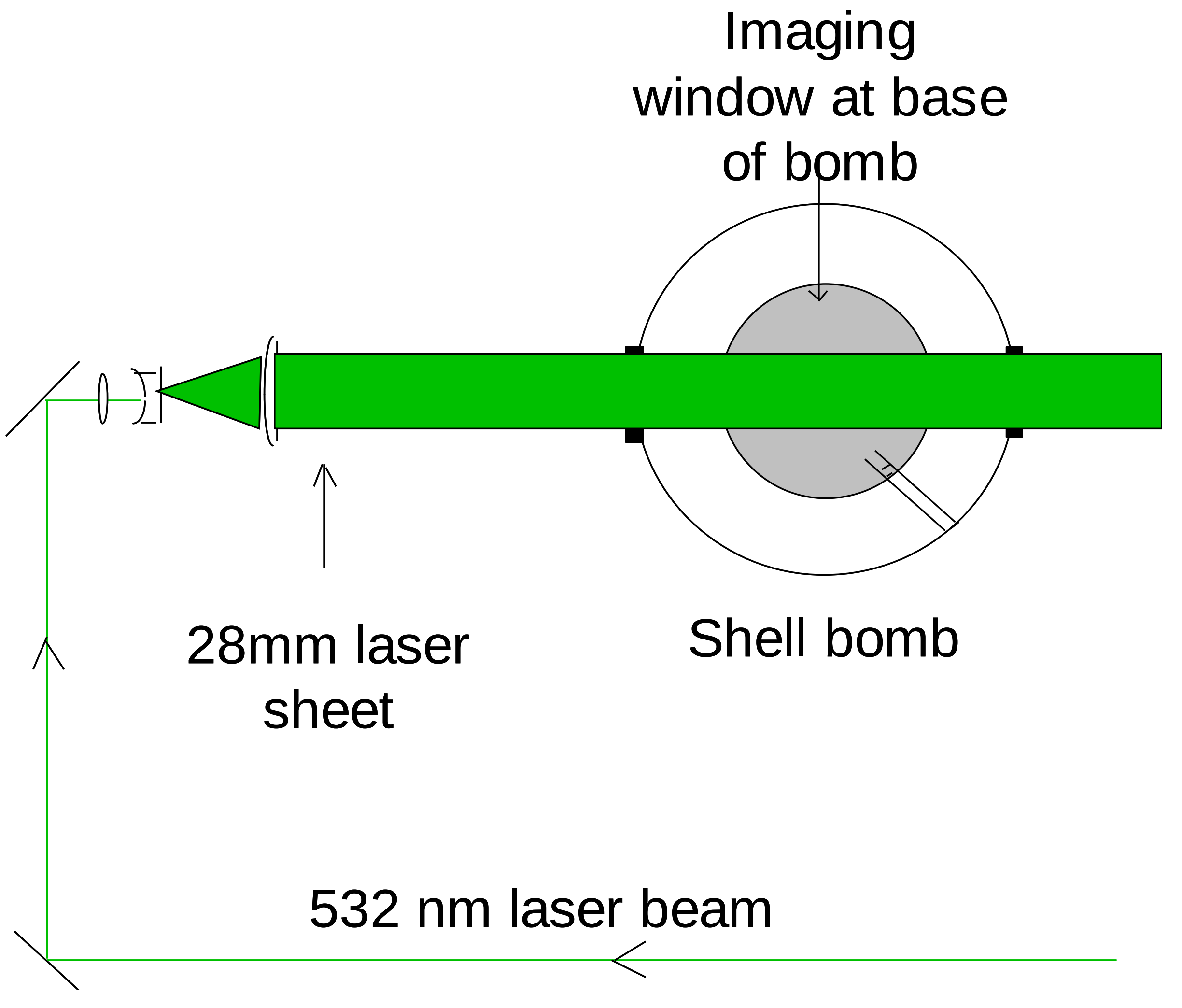
4.6 cm **OH PLIF**



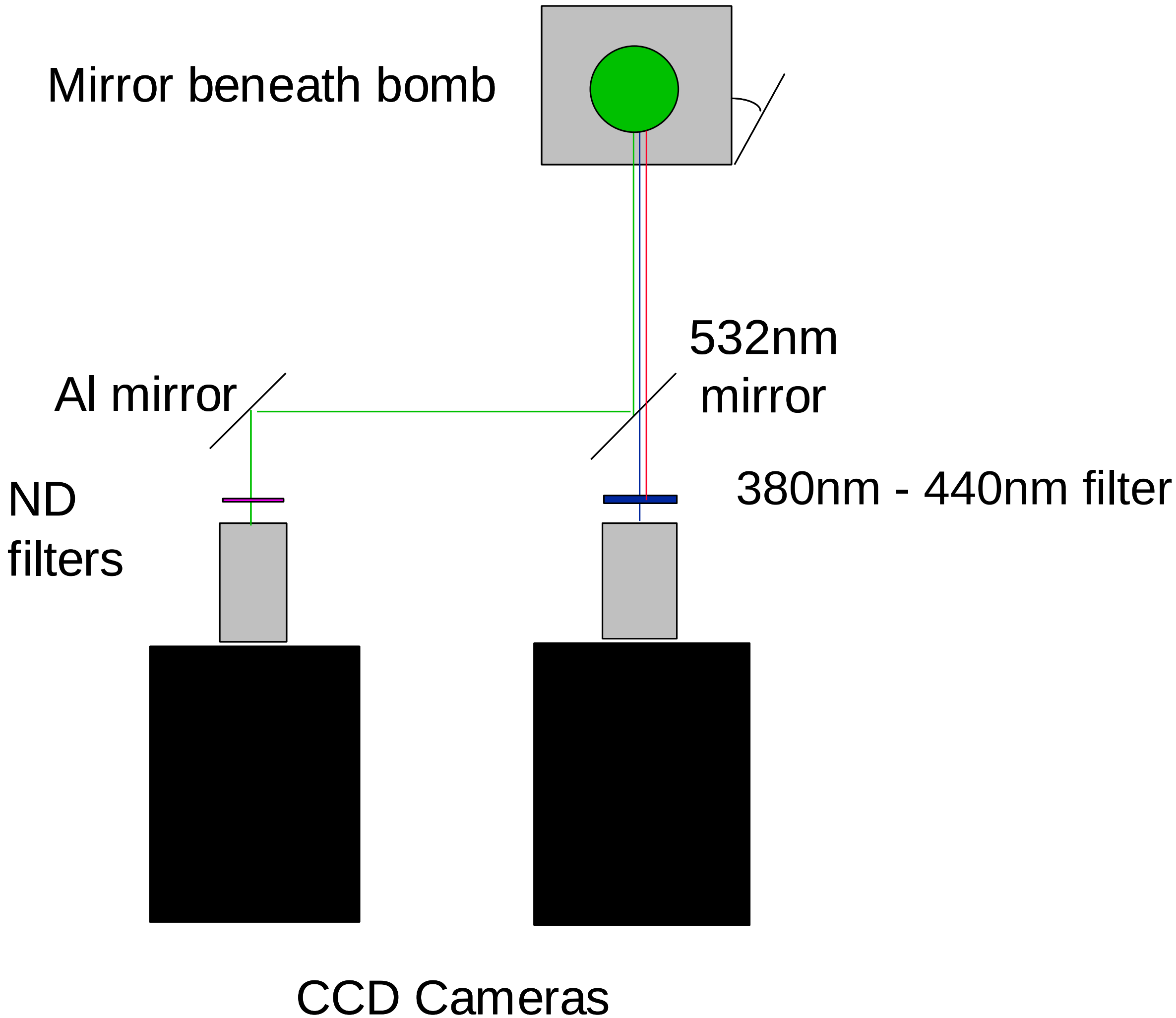
Rayleigh scattering



LII/Mie Scattering in the Shell Bomb



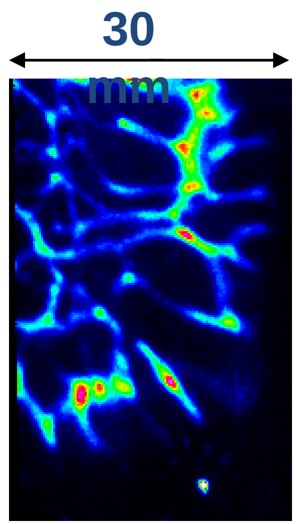
LII/Mie Scattering in the Shell Bomb



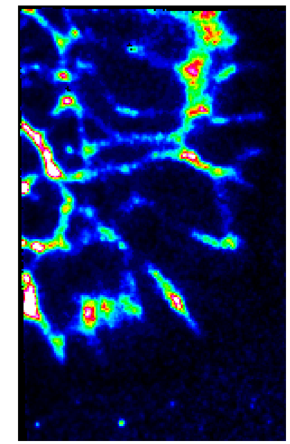
LII/Mie Scattering in the Shell Bomb

Processed LII image obtained from a $\varphi = 1.8$, 5 bar, iso-octane-air flame (flame radius ~ 60 mm)

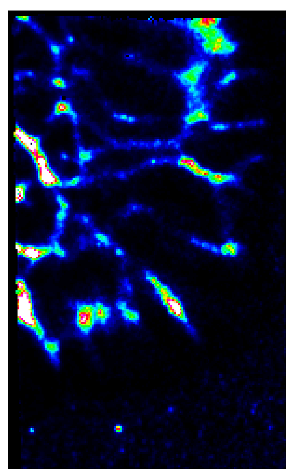
(relative soot volume fraction)



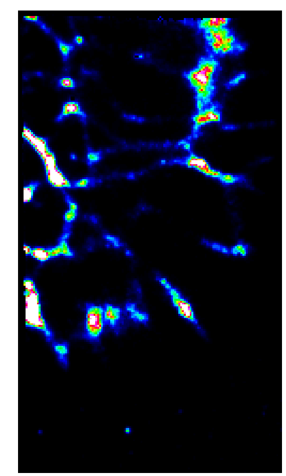
Processed Mie scattering image obtained from a $\varphi = 1.8$, 5 bar, iso-octane-air flame

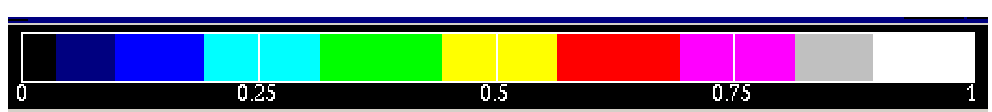


Relative soot particle size distribution d_{63}



Relative soot particle number density





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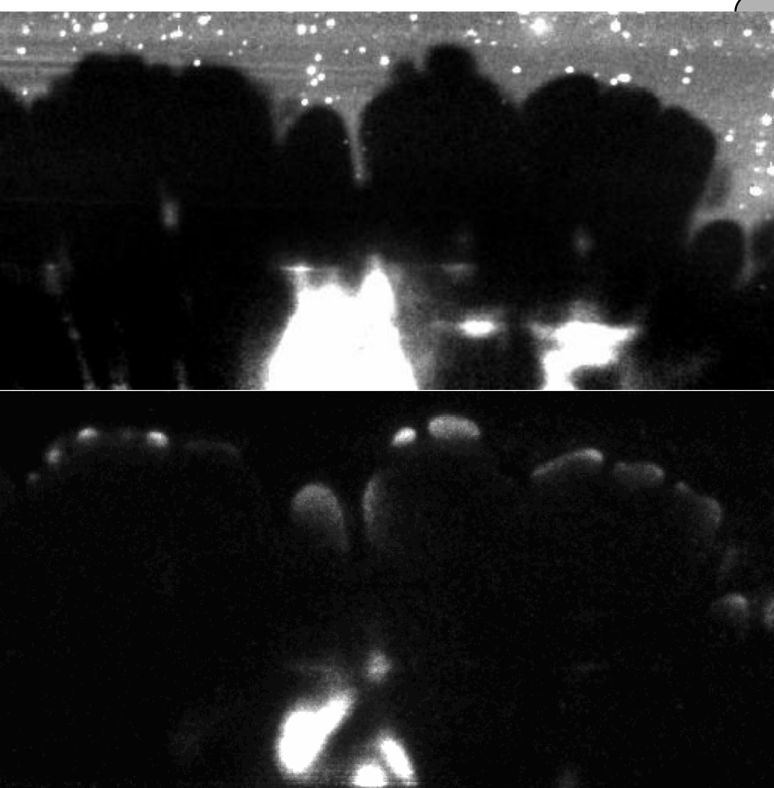
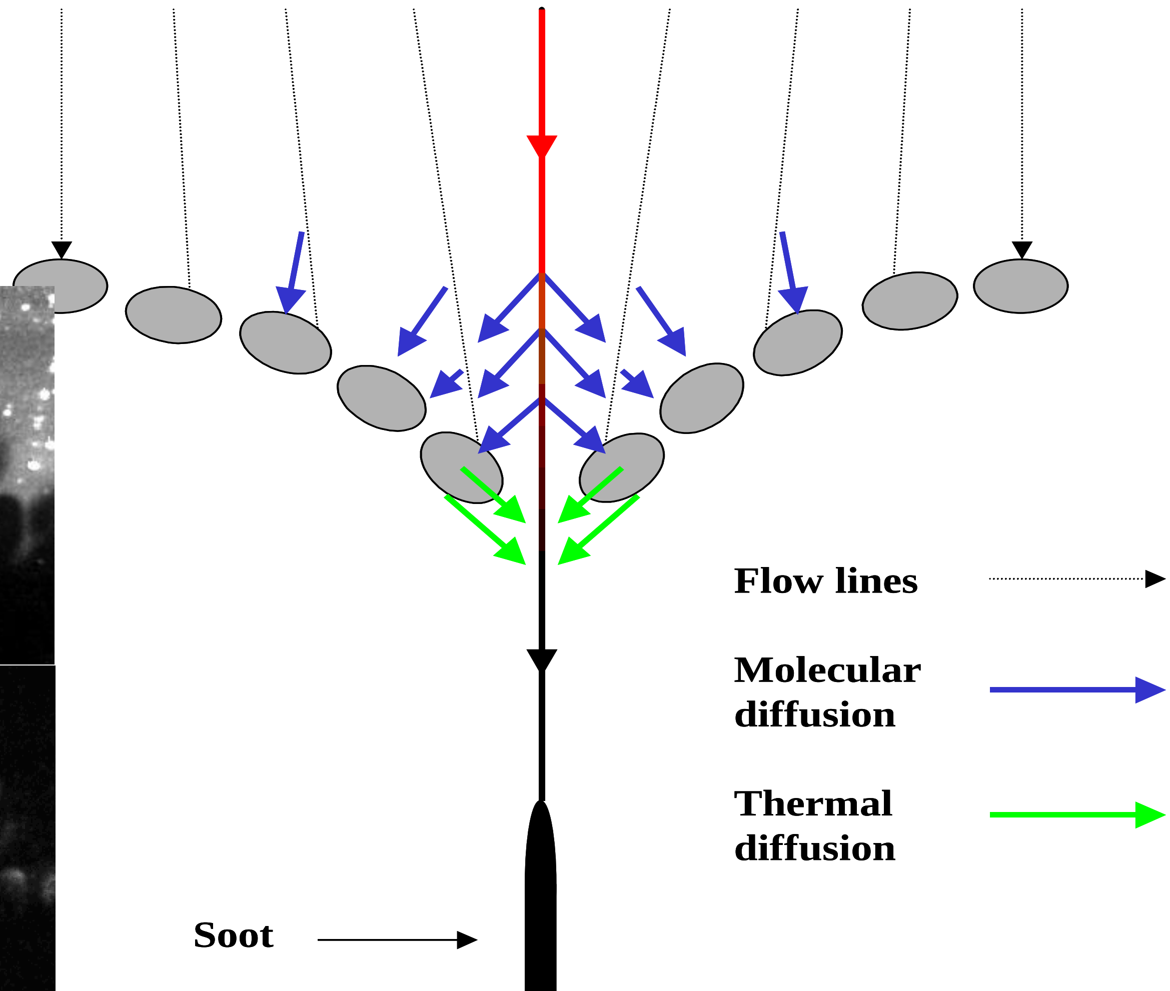
Soot Formation in Rich, High Pressure, Spherically Expanding Explosion Flames





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Conclusions

1. Two distinct length scales associated with flame cracking have been observed from the Schlieren images and the OH PLIF images.

2. These length scales are identified with hydrodynamic effects and thermal-diffusive effects. The large length scale cracking (5 mm to 1 cm) is associated with the hydrodynamic instability, while the small length scale cracking is associated with the thermal-diffusive instability (~ 1 mm).

3. High pressure flames that are stable to thermal-diffusive cracking develop hydrodynamic cracks which do not develop into discrete cells, while high pressure flames unstable to thermal-diffusive cracking exhibit full cellular structure and hydrodynamic perturbations.

4. Flame reaction quenching has been observed in the regions between the smaller length scale flame cells.

Conclusions Cont.

5. In highly enriched, high pressure explosion flames ($\varphi > 1.8$), soot was observed to be formed in a honeycomb-like structure behind the flame.

6. The soot cell size was observed to be of the order of 5 mm to 1 cm, which corresponded with the larger length scale cellularity, determined by the hydrodynamic instability.

7. A plausible hypothesis for the formation of soot in highly enriched, spherical explosion flames has been suggested.