OPTICAL TECHNIQUES THAT CAN BE APPLIED TO INVESTIGATE GDI ENGINE COMBUSTION

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ICE 2017 – 13th International Conference on Engines & Vehicles

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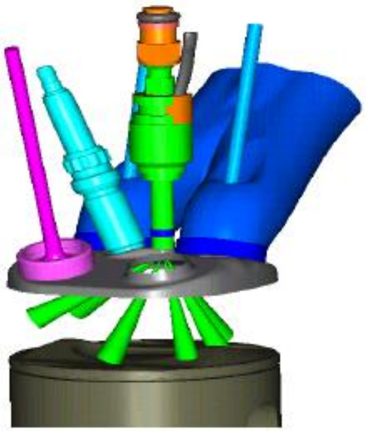
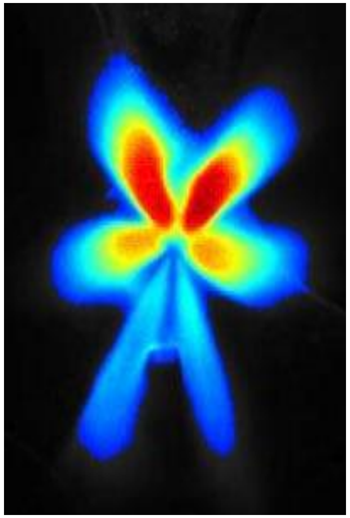
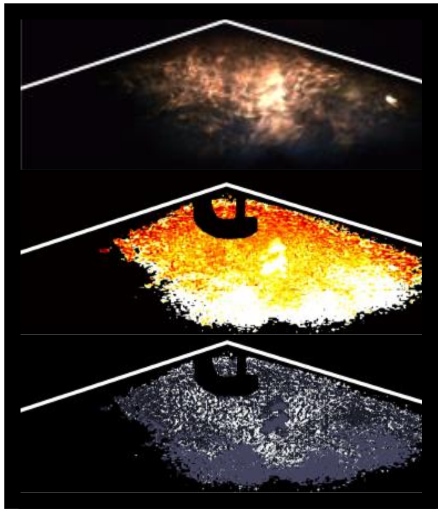
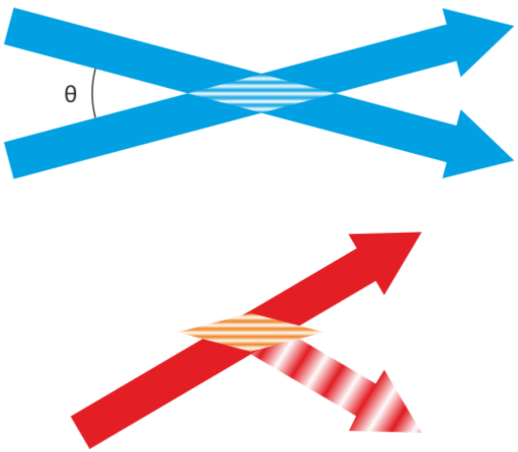
Overview

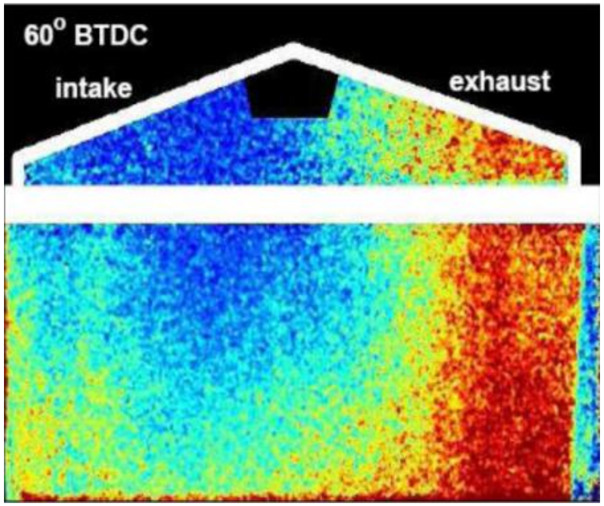


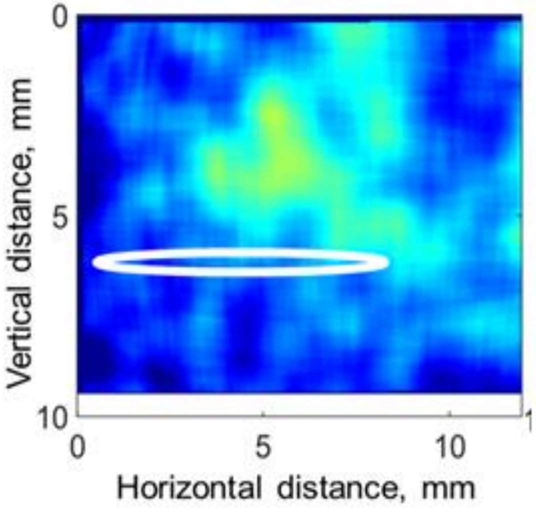
SAE 2009-01-1060





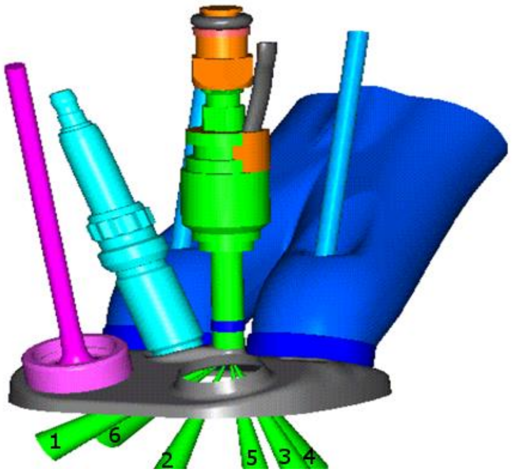




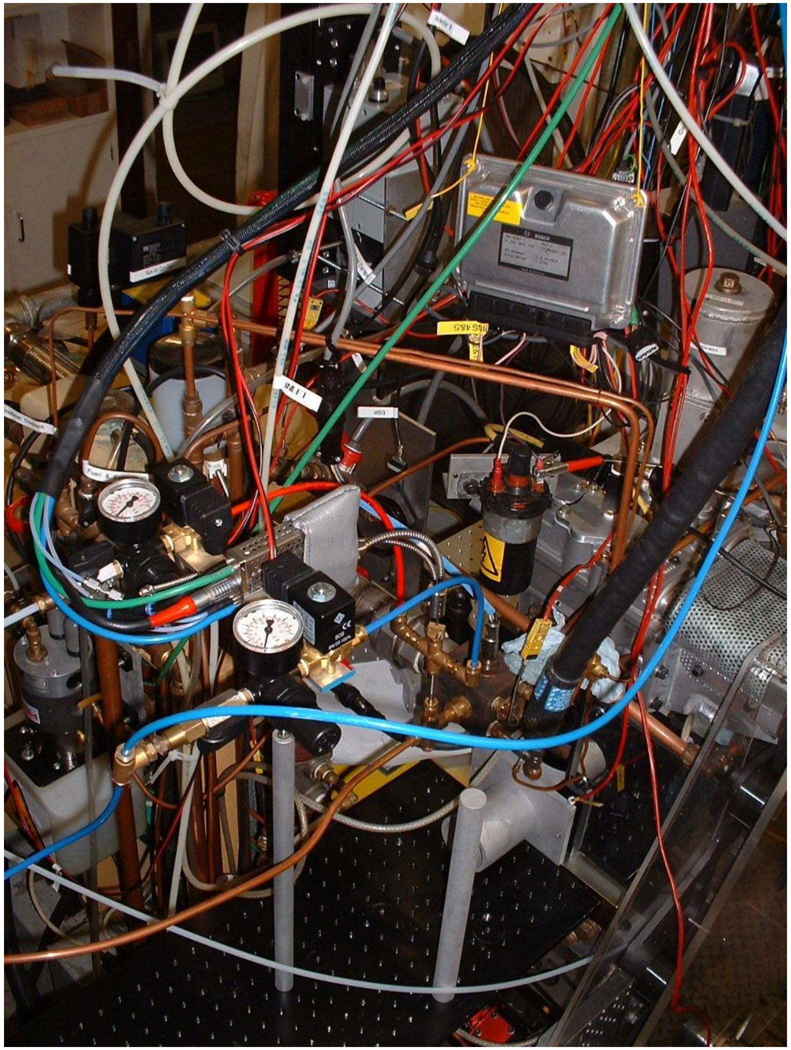


Single Cylinder Engine with Optical Access

• Bore	89 mm
• Stroke	90 mm
• Capacity	562 cc
• Compression Ratio	11.1
• Injection Pressure	150 bar



Malcolm Sandford, Graham Page and Paul Crawford, SAE Paper: 2009-01-1060

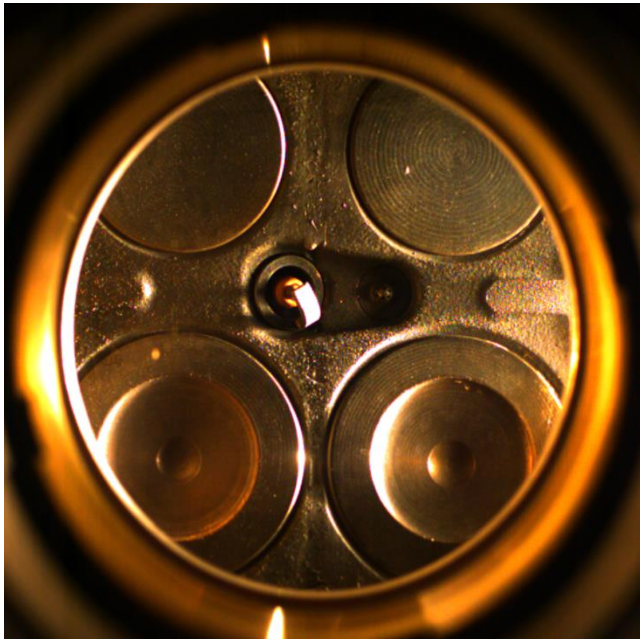


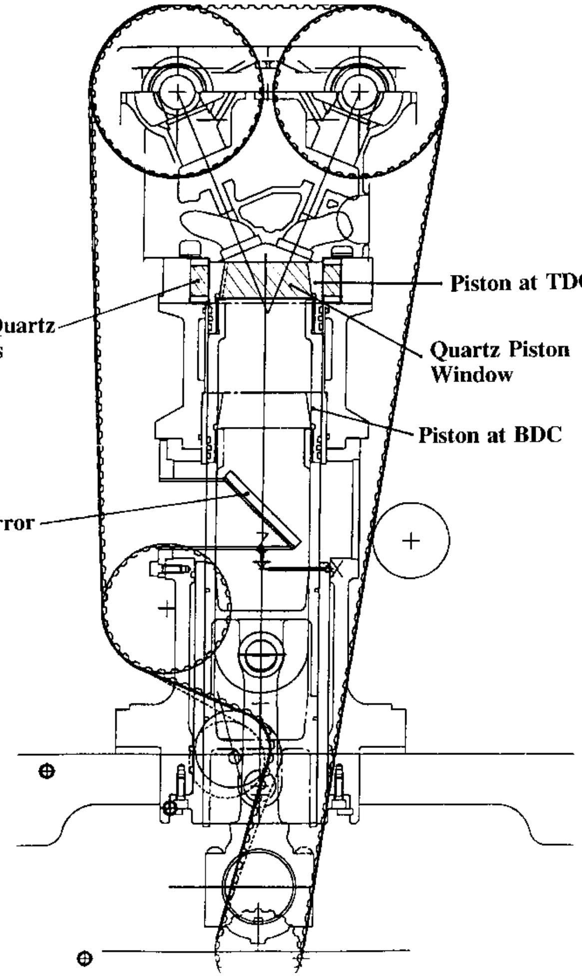
High Speed Imaging – Bowditch Piston

- Photron FASTCAM-1024PCI model

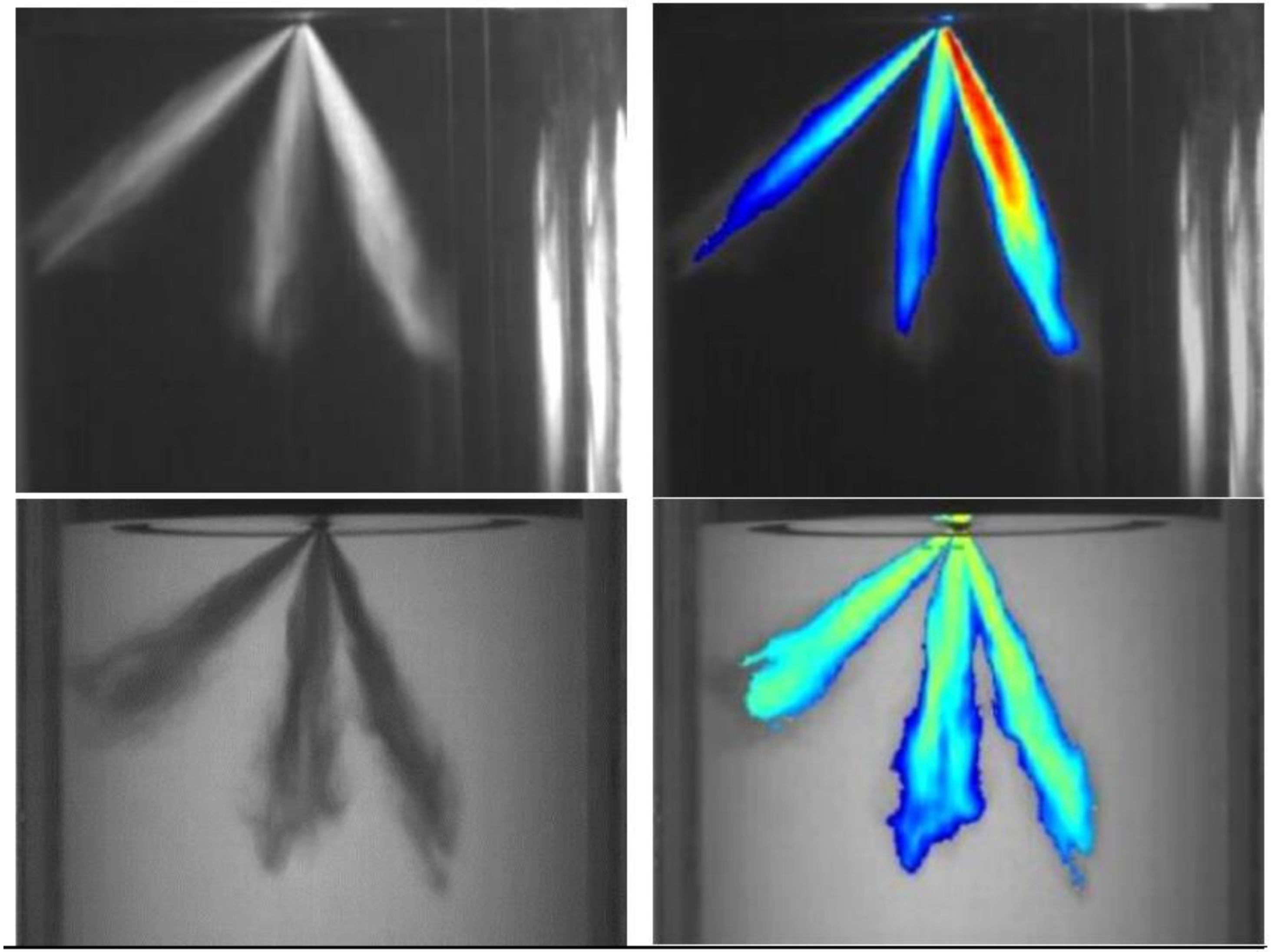
  100K Colour Camera

- Resolution: 1024x1024 pixels



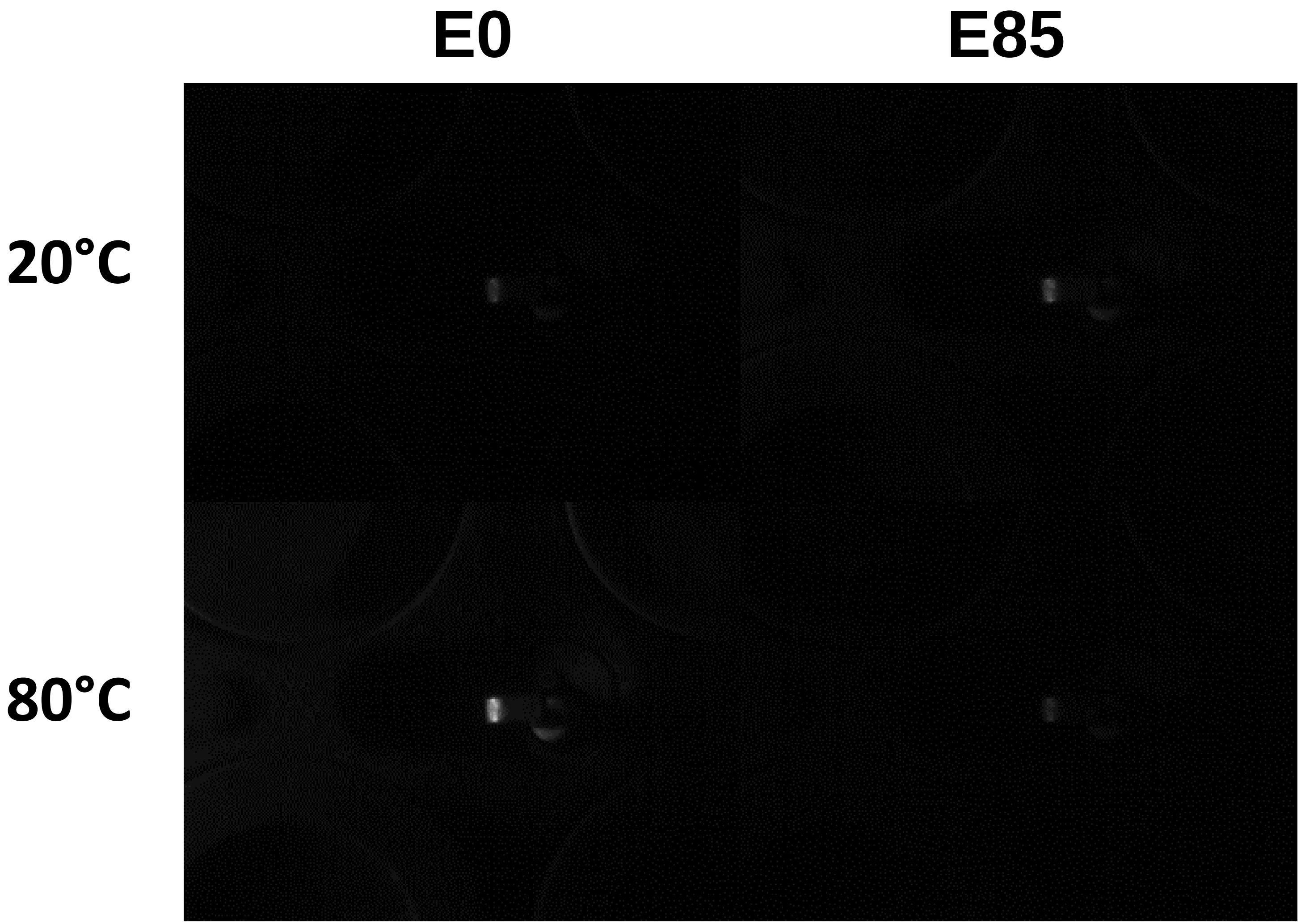


Mie Scattering (upper) and Shadowgraphy (lower) of Fuel Spray



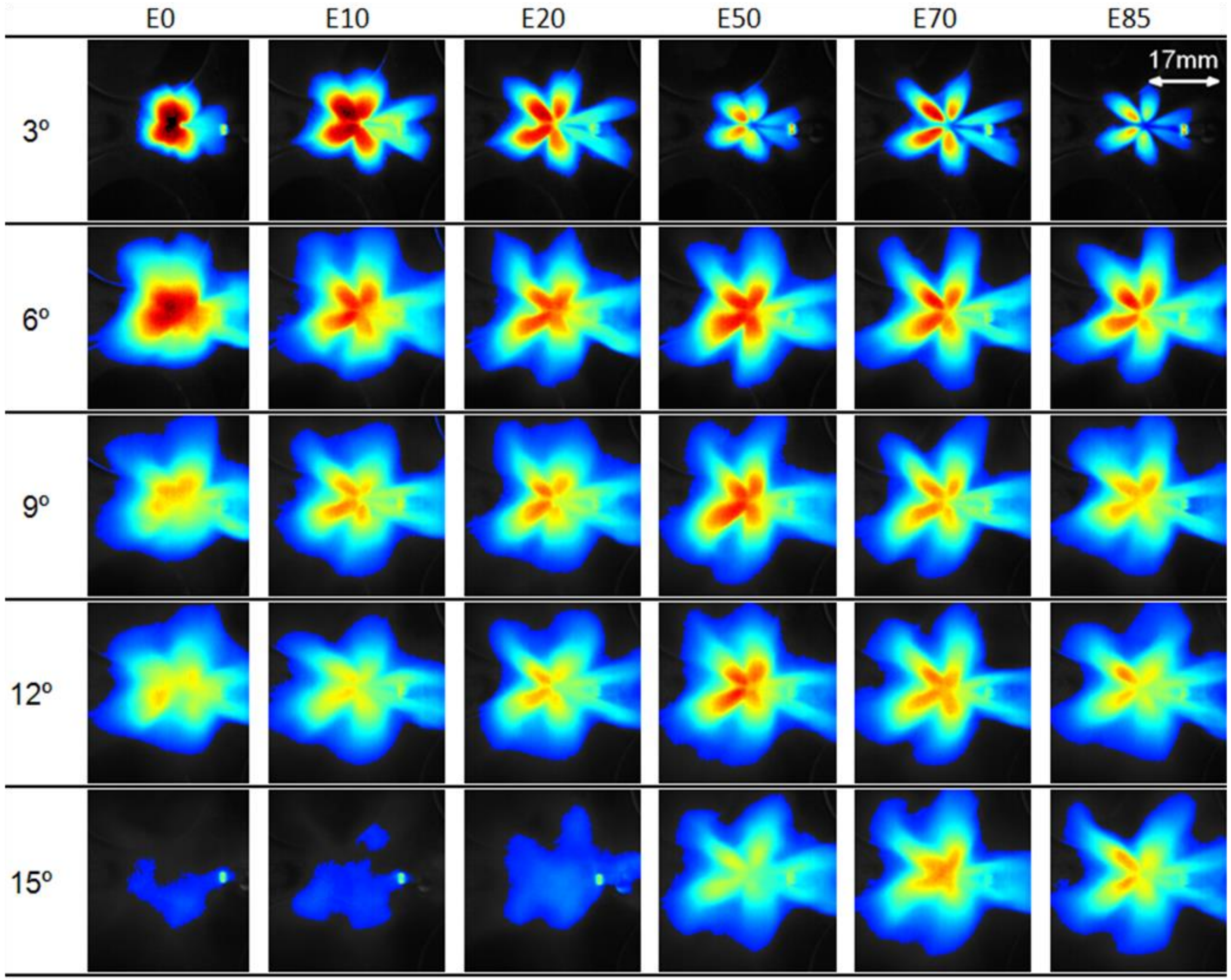
Murad, S. H. M, Camm, J., Davy, M., Stone, R., et al. “Spray Behaviour and Particulate Matter Emissions with M15 Methanol/Gasoline Blends in a GDI Engine”. SAE Technical Paper 2016-01-0991, 2016

Mie Scattering Images

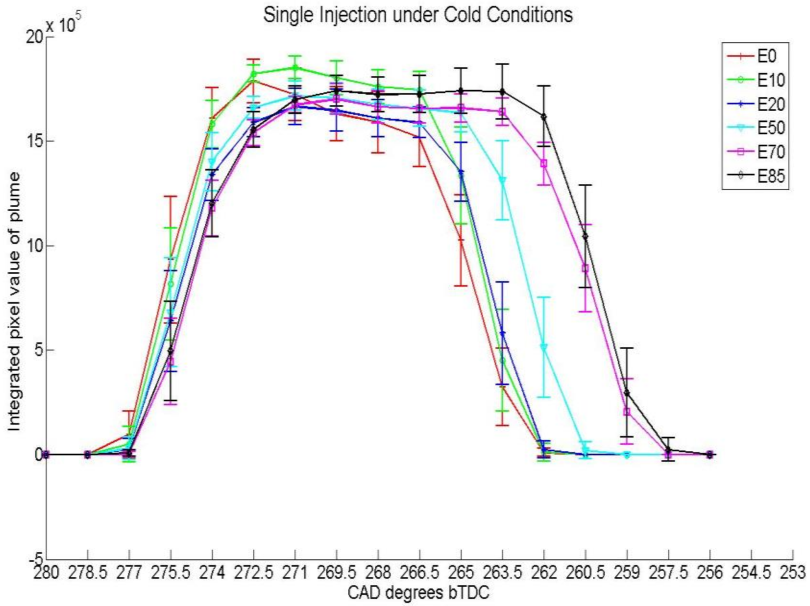


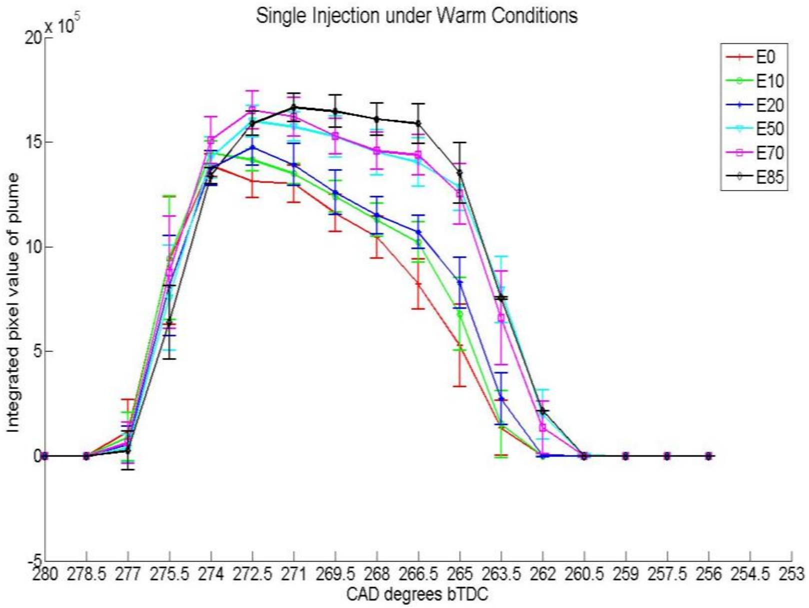
Selection of Spray Images at 20° C

- Variation of the spray area at 3° after SOI is due to shot-to-shot variations in injection;
- Spray area and evaporation duration increase as the ethanol content increases.
- Spray area and evaporation duration increase as the ethanol content increases.



Semi-Quantitative Data from Mie Scattering

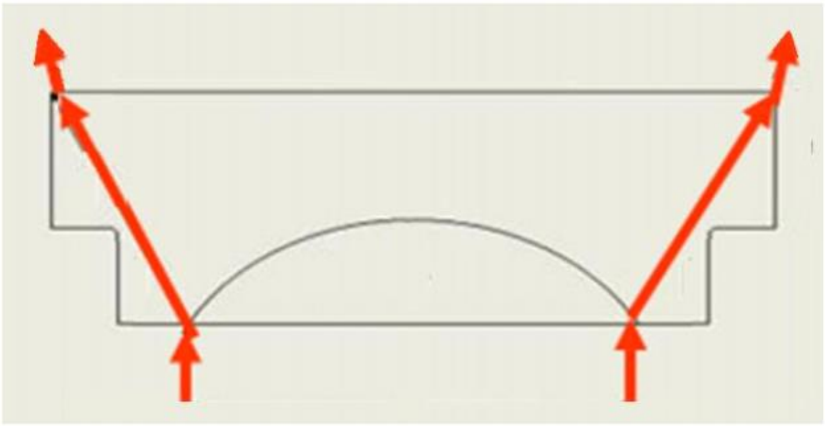


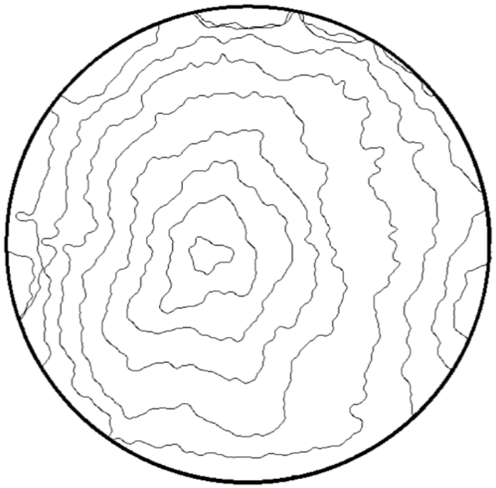


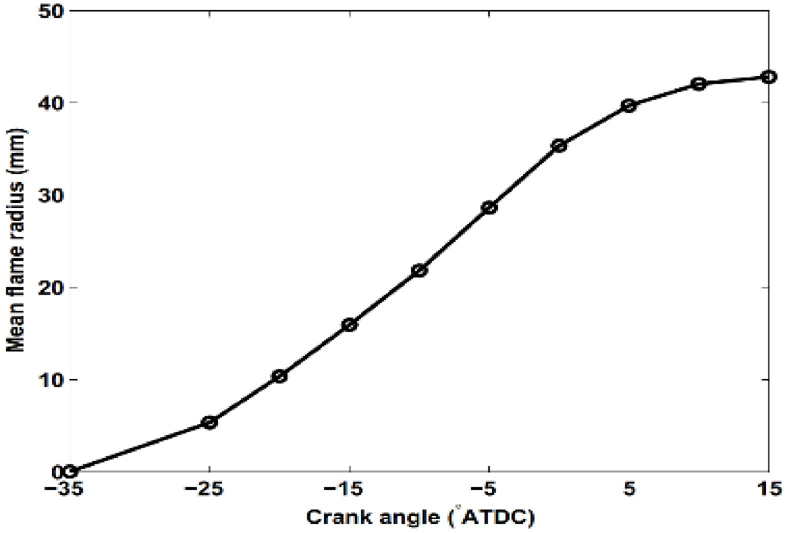
- In general, warm fuel plumes exhibit smaller integrated pixel values than cold plumes;
- The evaporation duration of warm plumes is shorter than for cold plumes;
- The spray duration increases as the ethanol content increases;
- Standard deviations in the ‘plateau’ region are always smaller than at both ends.

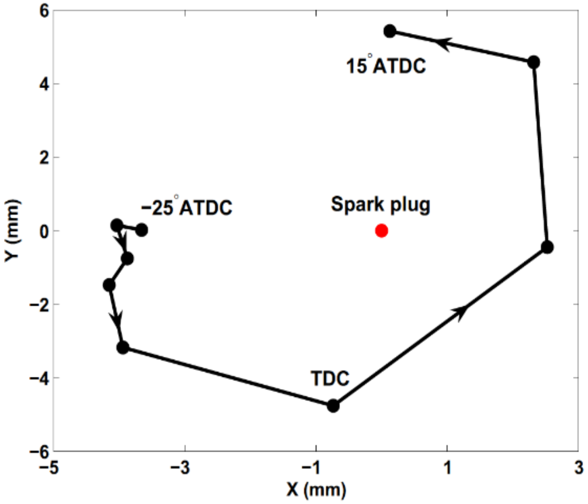
L Chen, F Xu, R Stone and D Richardson. ‘Spray Imaging, Mixture Preparation and Particulate Matter Emissions Using a GDI Engine Fuelled With Stoichiometric Gasoline-Ethanol Blends’, IMechE, London, C1328/002, pp 43-52, 2011

Flame Front Imaging









Ma, H., Marshall, S., Stevens, R., and Stone, R. "Full-bore crank-angle resolved imaging of combustion in a four-stroke gasoline direct injection engine." Proc. IMechE Part D: Journal of Automobile Engineering 221, no. 10: 1305-1320, 2007.

Soot Pyrometry

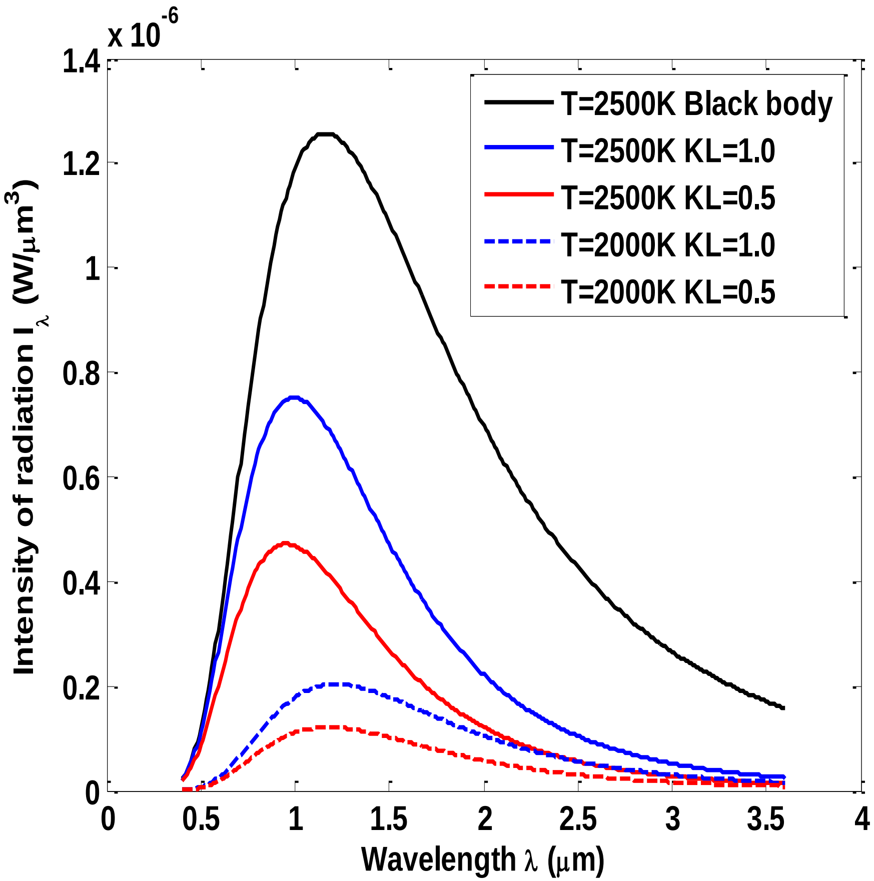
$$I_{\lambda b} = \frac{2C_1}{\lambda^5 \left[\exp\left(C_2/\lambda T\right) - 1\right]}$$

Black Body Radiation, C_1, C_2 are Planck's constants

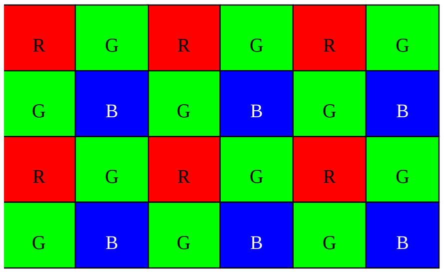
$$\varepsilon_\lambda = 1 - \exp\left(-KL/\lambda^\alpha\right)$$

K is the absorption coefficient per unit flame thickness, and *L* is the geometric flame thickness along the optical path length of the detection system.

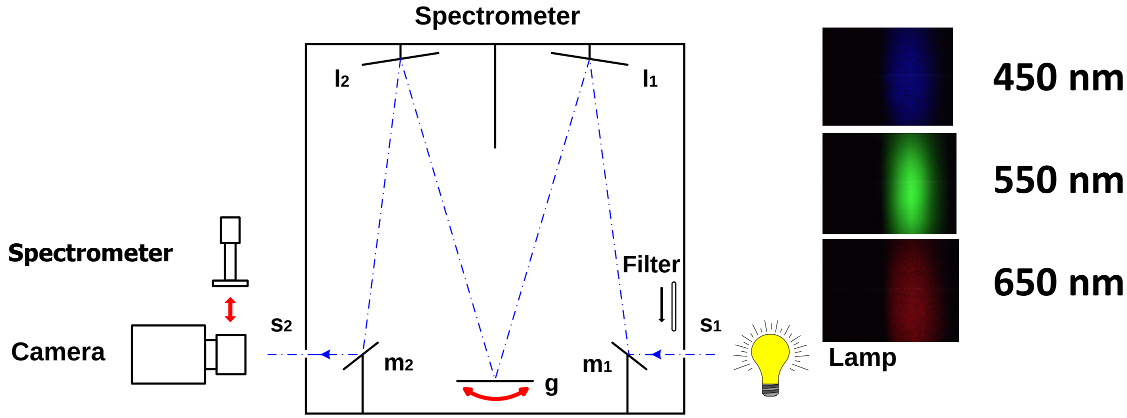
Hottel and Broughton: $\alpha = 1.39$.



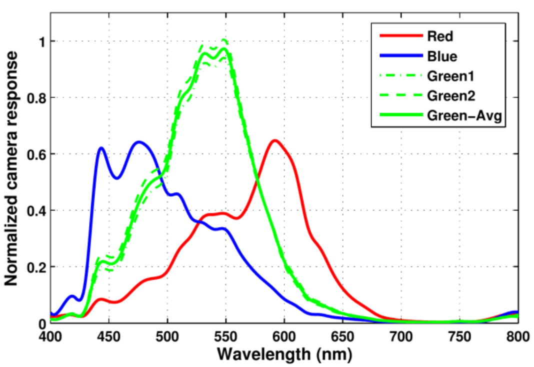
Three-Colour Pyrometry



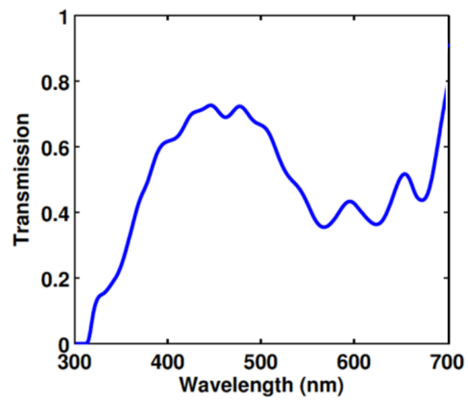
Bayer Colour Filter Array



Colour Filter Array Calibration Procedure



X



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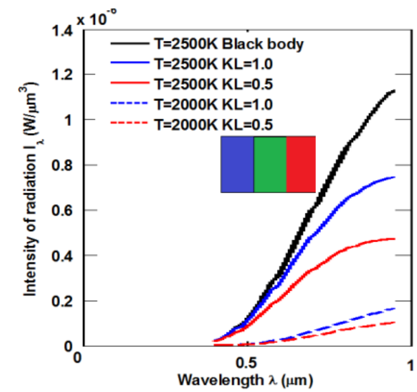
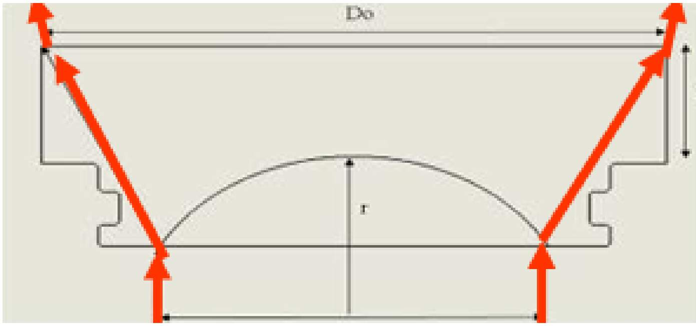
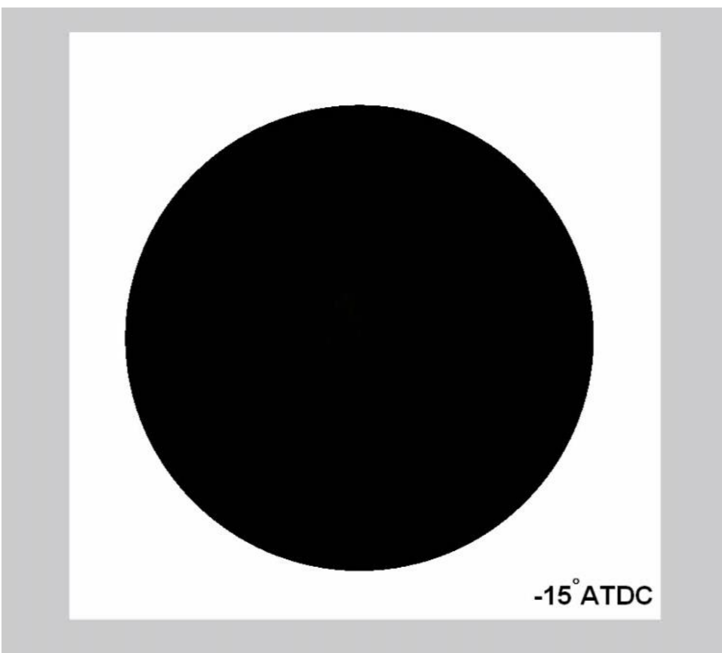


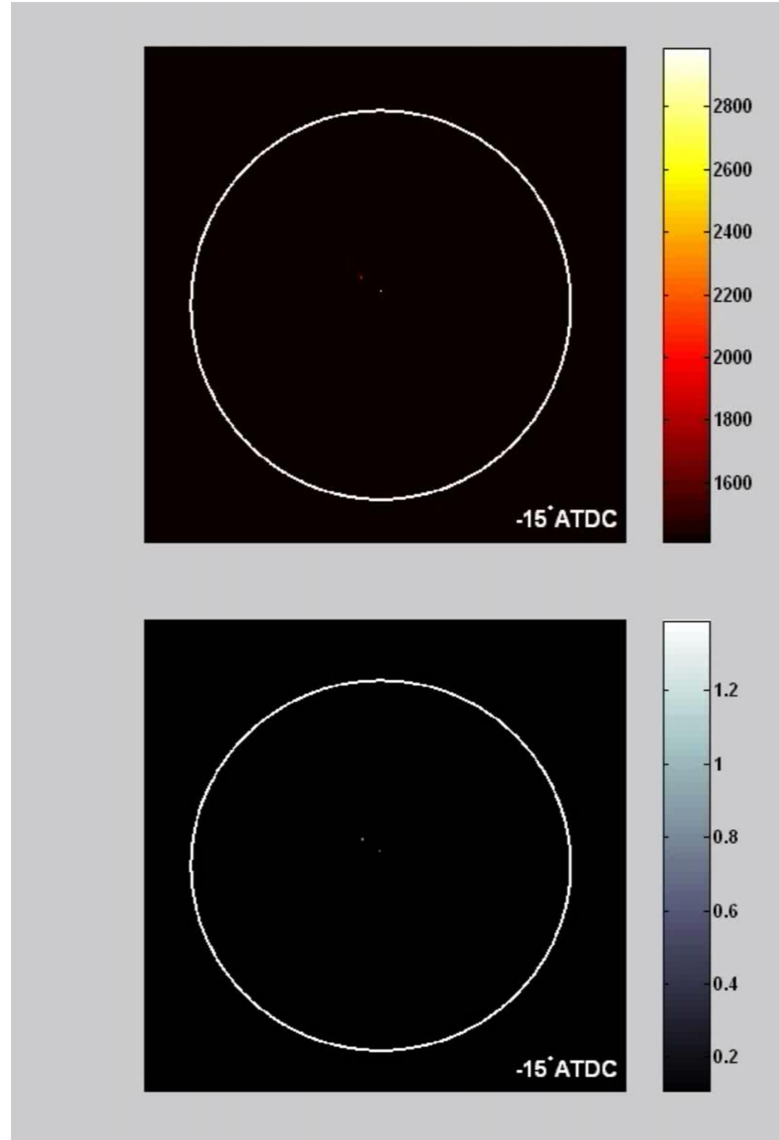
Colour Filter Array Calibration | Blue Filter | Integrate: ∫Blue, ∫Green, ∫Red

Simonini, S., Elston, S. J., and Stone, C. R. "Soot temperature and concentration measurements from colour charge coupled device camera images using a three-colour method." Proc. IMechE Part C: Journal of Mechanical Engineering Science 215, no. 9: 1041-1052, 2001.

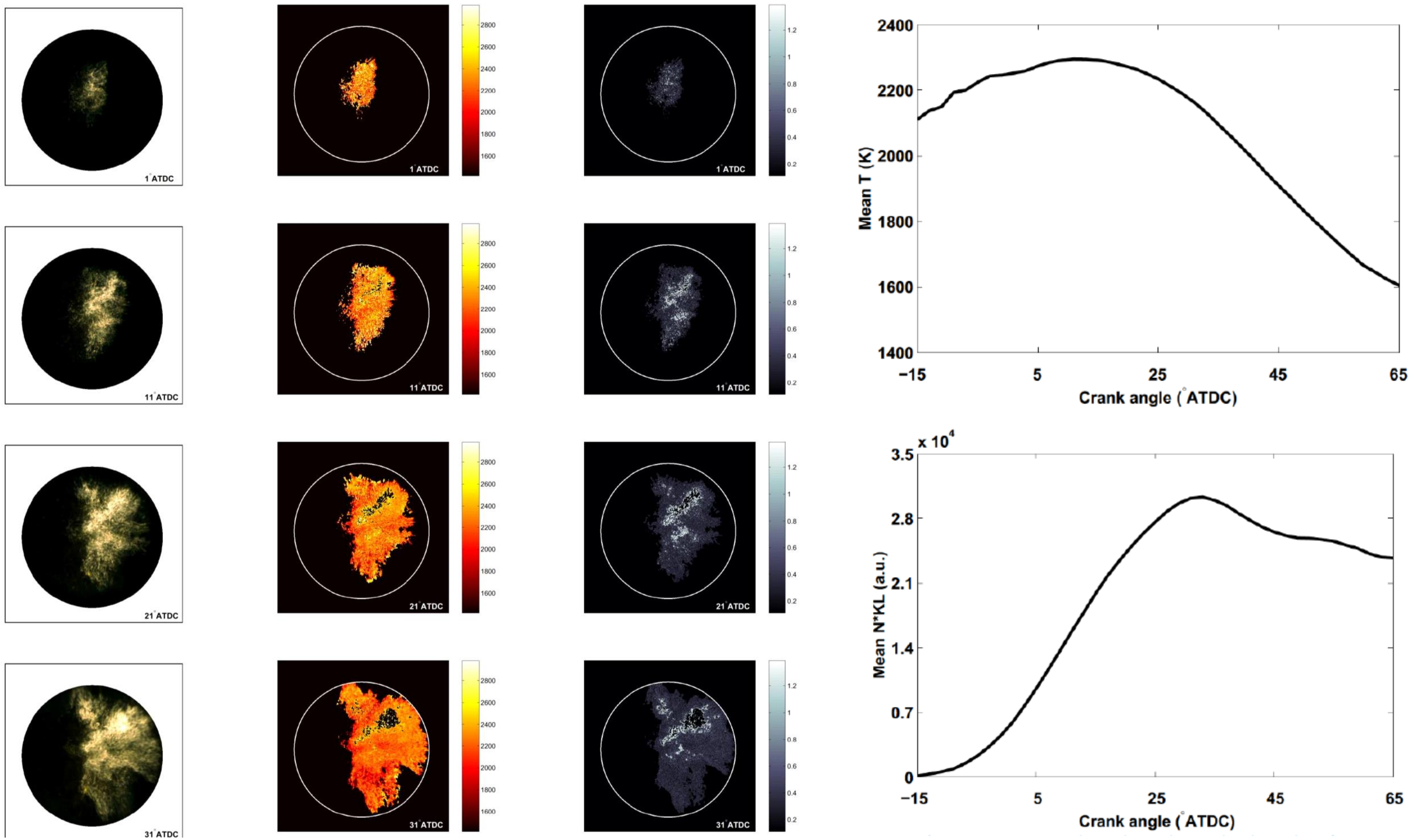
Toluene, Lambda = 0.9







Three-Colour Pyrometry; Toluene with Lambda = 0.9



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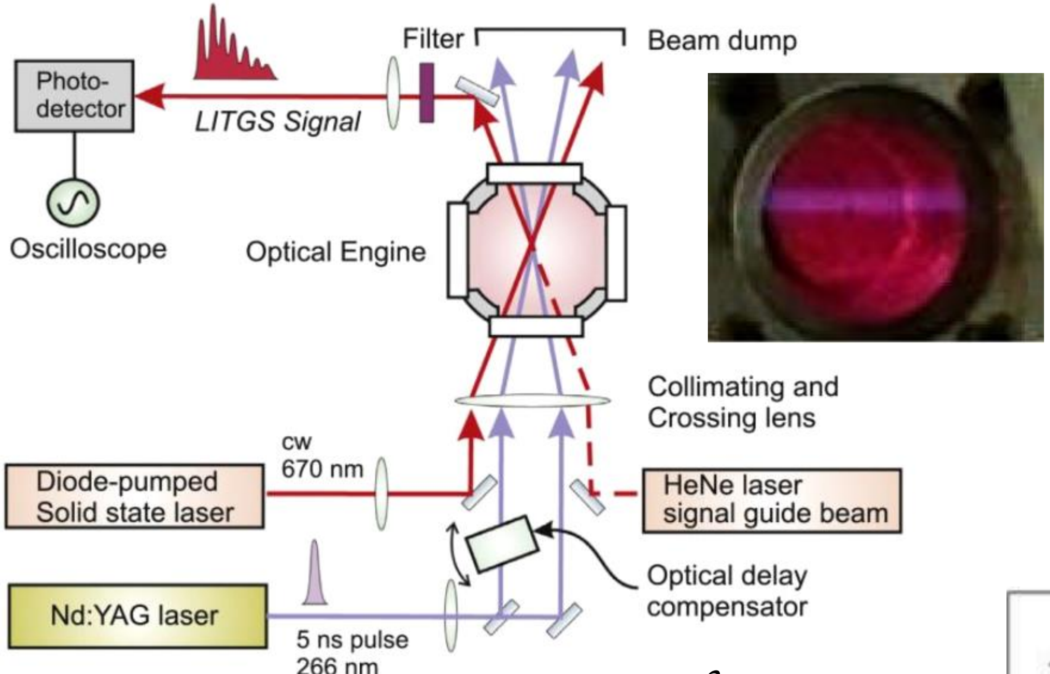
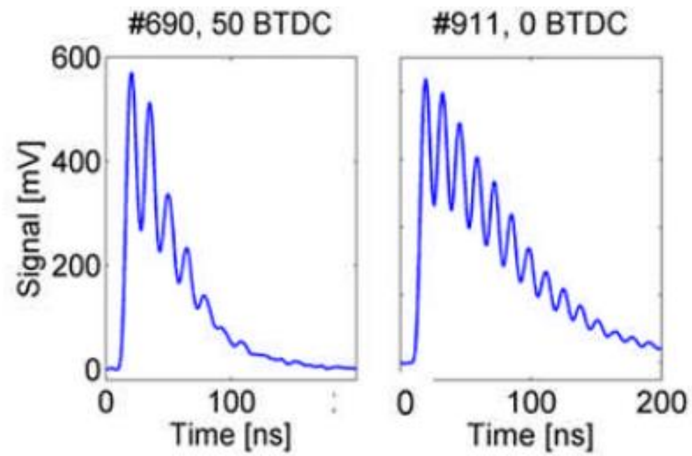
Laser Induced (Thermal) Grating Specroscopy - LIGS

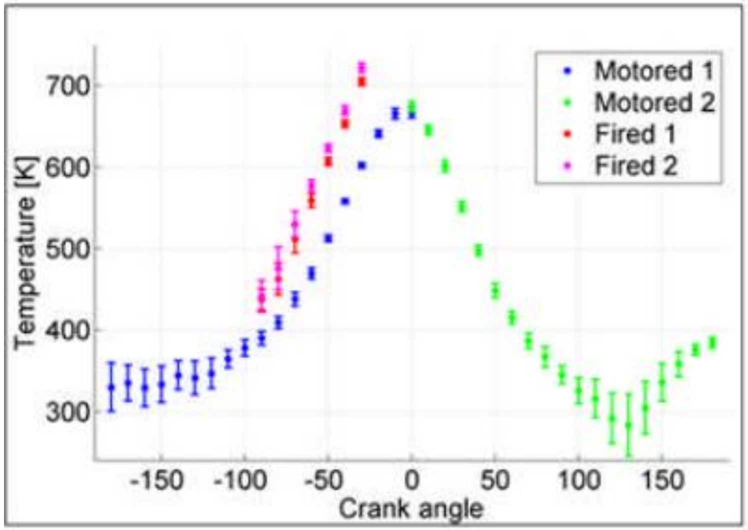




Fringe spacing: $\Lambda = \dfrac{\lambda}{2\sin(\theta/2)}$

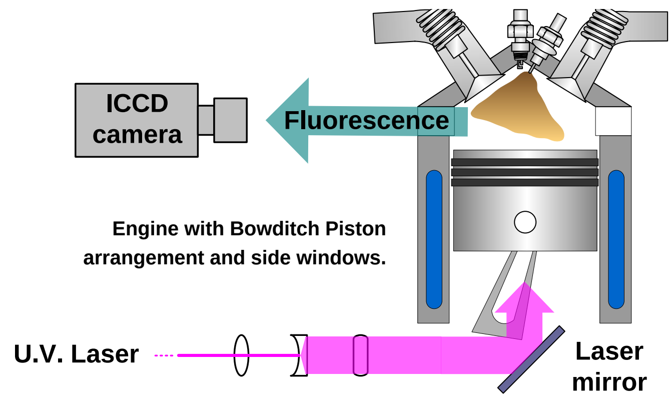
Bragg Angle: $\theta_B = \sin^{-1}(\lambda_P / 2\Lambda)$

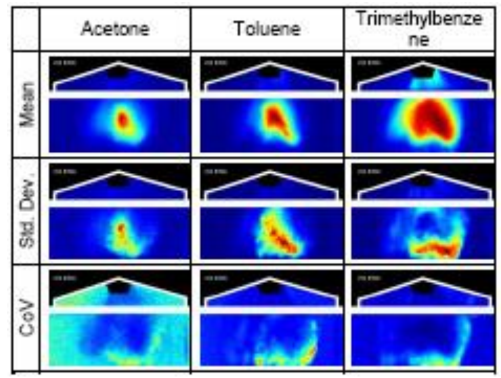
$$f_{osc} = c_S / \Lambda \qquad c_S = \left(\frac{\gamma R_o T}{M} \right)^{1/2}$$



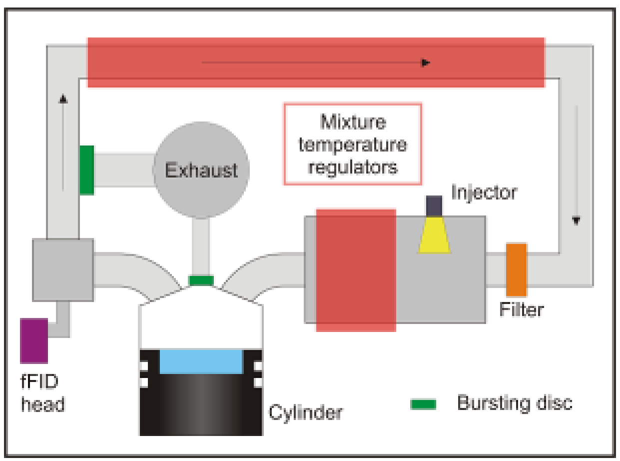
Williams, B, Edwards, M., Stone, R., Williams, J., and Ewart, P., "High precision in-cylinder gas thermometry using Laser Induced Gratings: Quantitative measurement of evaporative cooling with gasoline/alcohol blends in a GDI optical engine," Combustion and Flame 161, 270–279, 2014

In-Cylinder AFR from PLIF





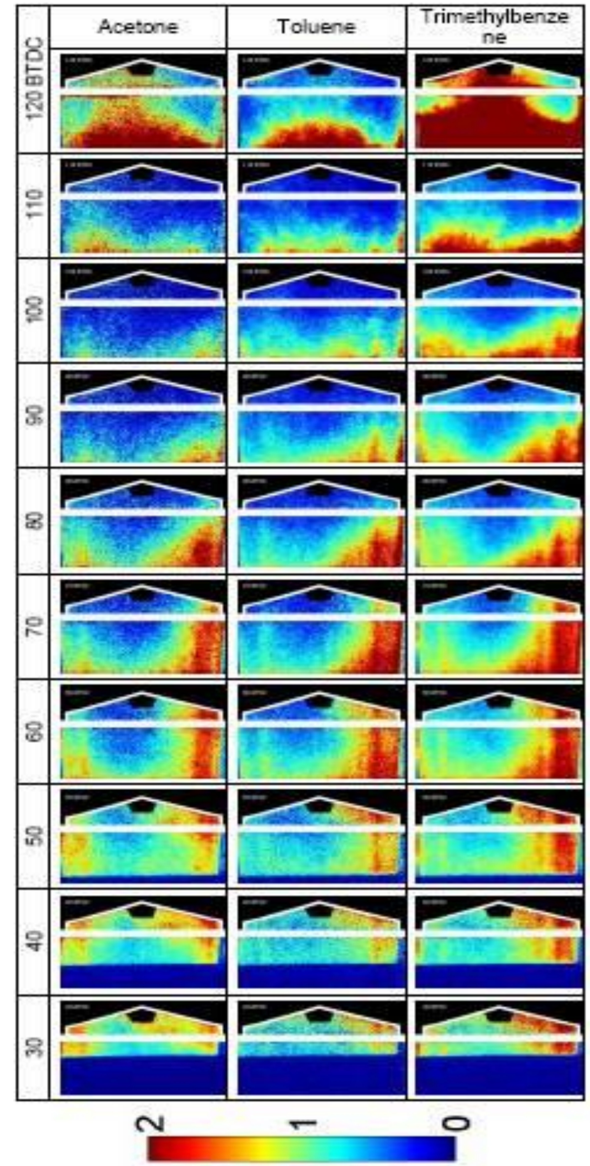
Spray Imaging



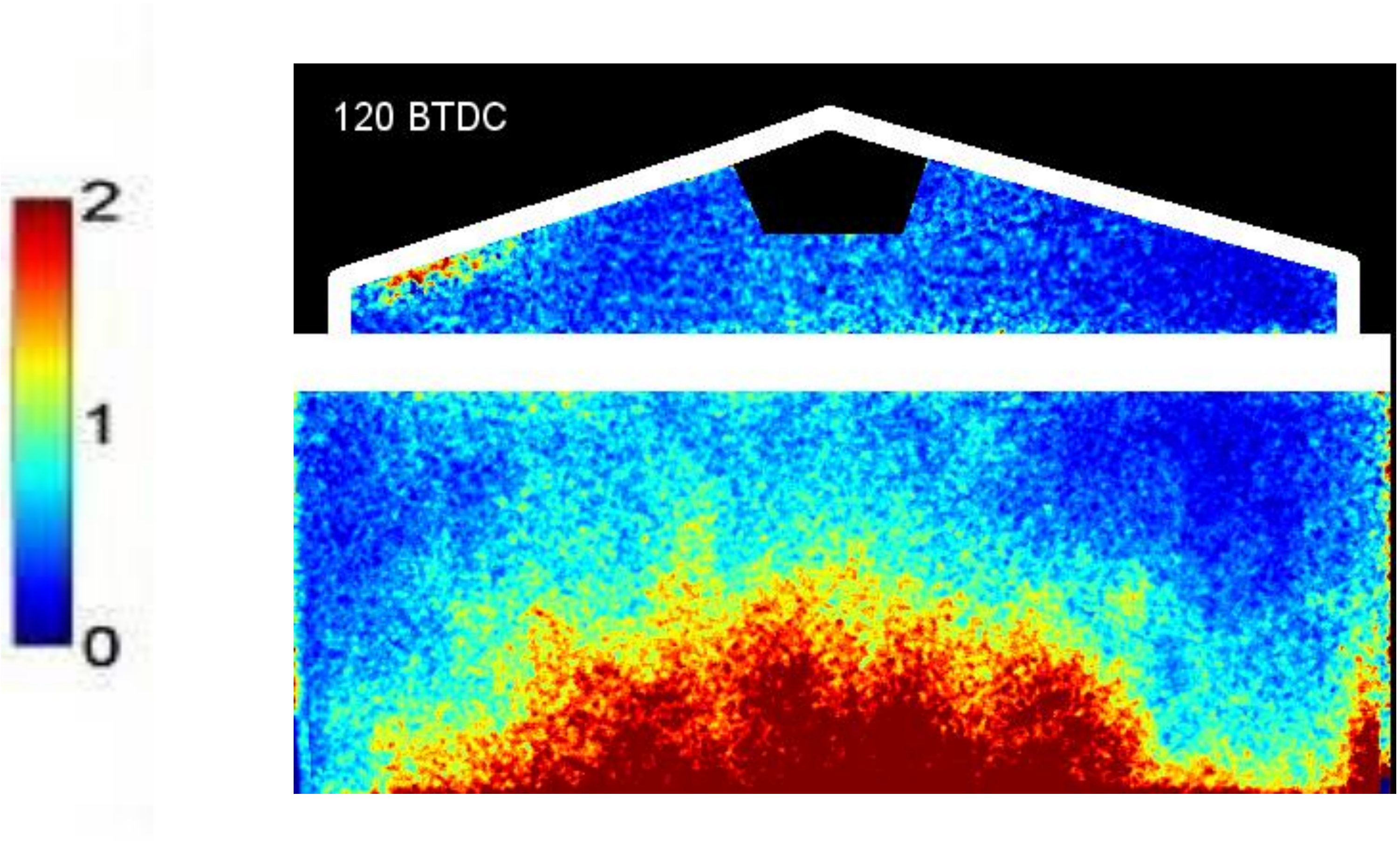
Calibration Loop

Williams, B., Ewart, P., Wang, X., Stone, R., et al., "Quantitative planar laser-induced fluorescence imaging of multi-component fuel/air mixing in a firing gasoline-direct-injection engine: effects of residual exhaust gas on quantitative PLIF," Combustion and Flame, 157(10), pp.1866-1878, 2010.

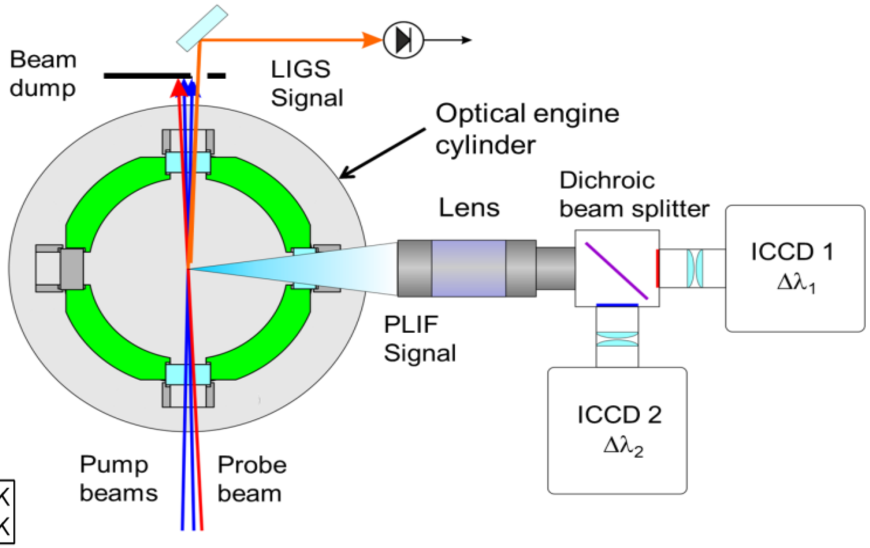
Sequence of PLIFimages - evolution of the fuel distribution with crank angle and fuel fraction. The late injection timing for this sequence was 140 BTDC. Each image is an average of 32 single shots

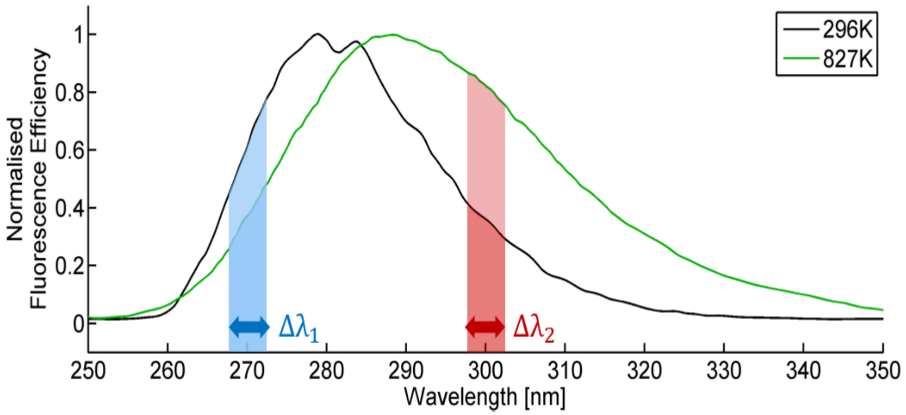


In-Cylinder AFR from PLIF



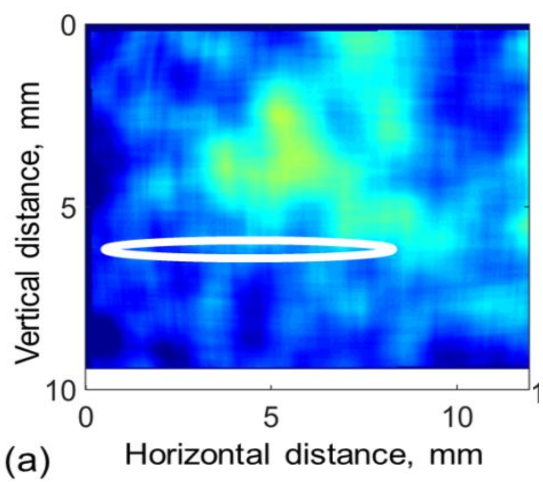
T-PLIF:- Frequency quadrupled Nd:YAG 266 nm





Number of photons absorbed *Optical efficiency* *Fluorescence quantum efficiency*

$$\frac{S_1}{S_2} = \frac{\cancel{N(\gamma)}\cancel{n_o}\cancel{\sigma}_{abs}\,\eta_{opt1}\,\varphi_1}{\cancel{N(\gamma)}\cancel{n_o}\cancel{\sigma}_{abs}\,\eta_{opt2}\,\varphi_2}$$



(a)

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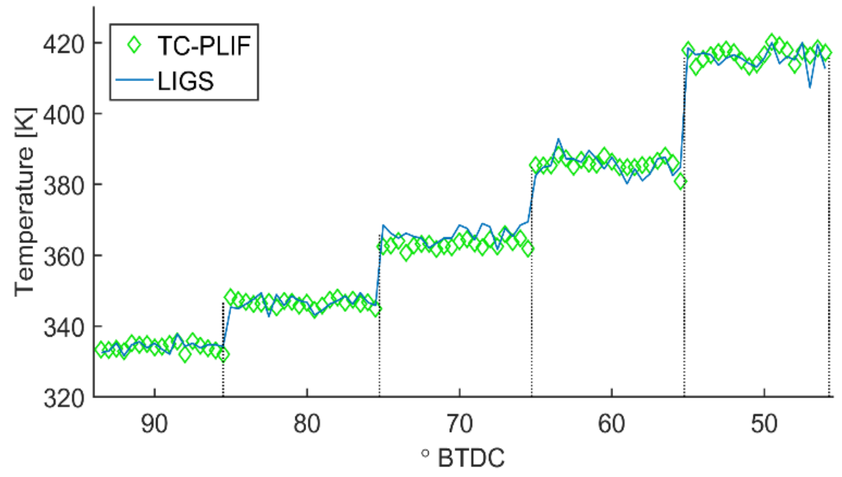
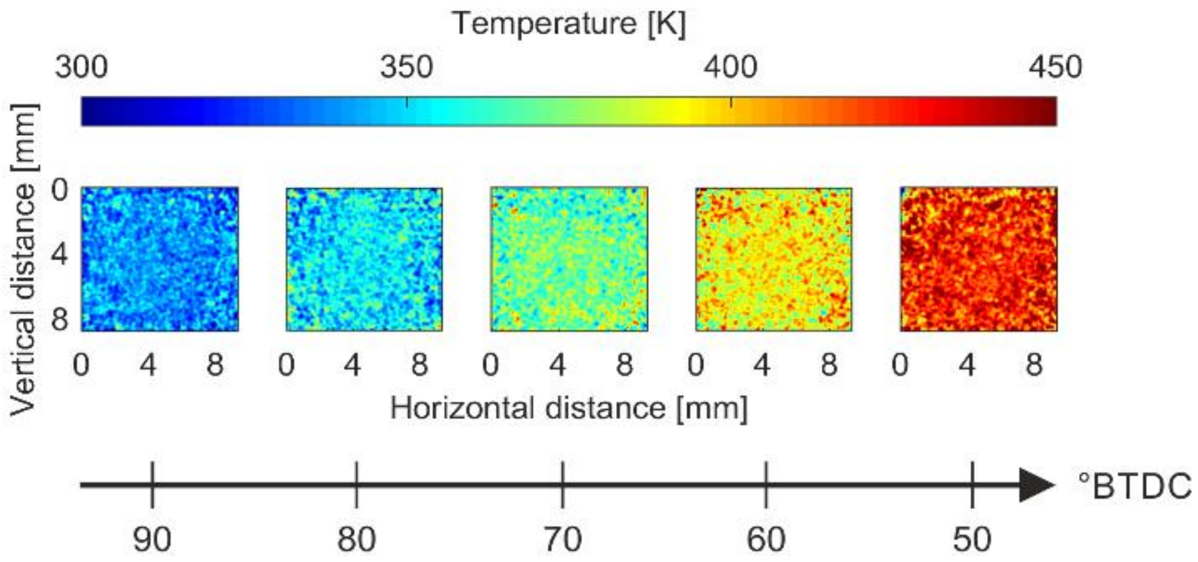
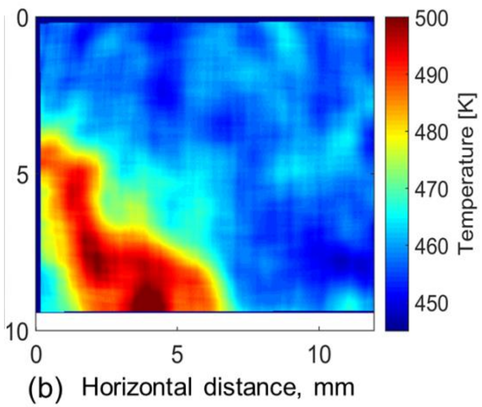
Two Colour PLIF (T-PLIF)

20 sequential LIGS signals at crank angles between 90º and 50º BTDC at intervals of 10º

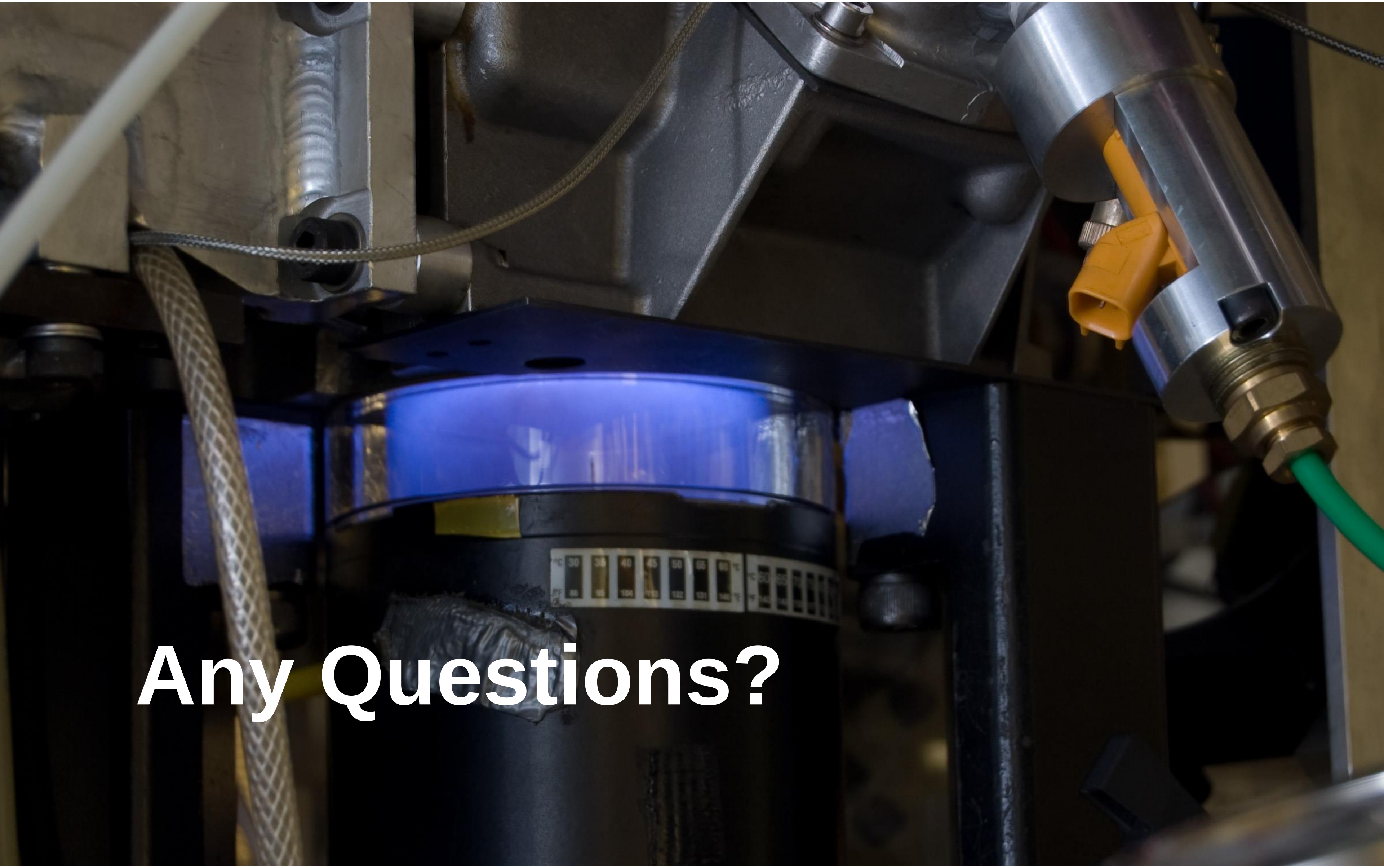






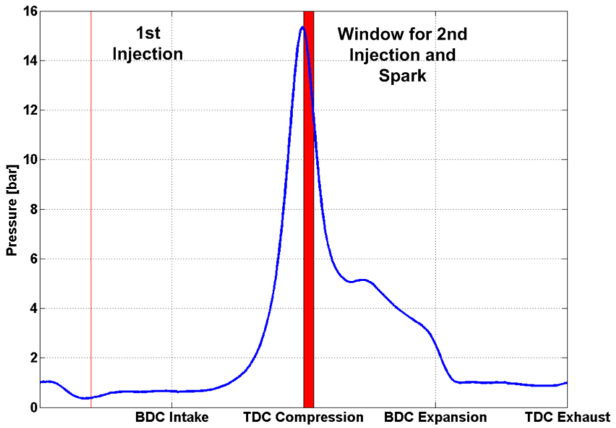
Conclusions

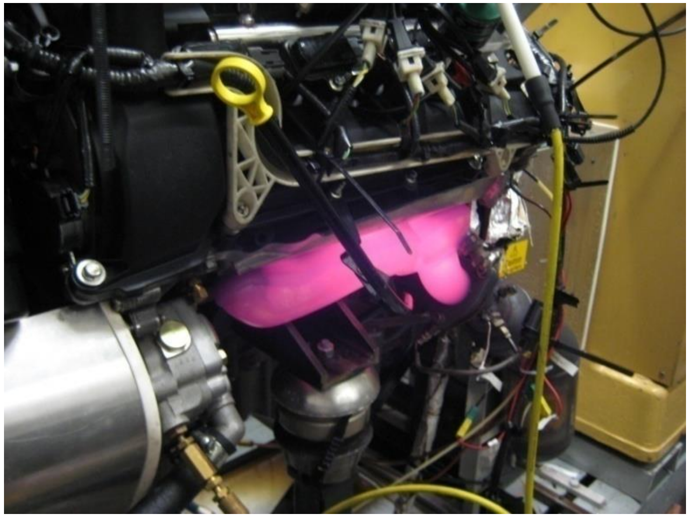
- High Speed Videoing
  - Cameras are becoming faster, more sensitive, with greater resolution and a larger dynamic range
  - LED illumination is readily controllable and low cost
  - Computing resources (hardware and software) continue to improve
- Laser-Based Techniques
  - Lasers are reducing in cost and size
  - Lasers are becoming faster, and more powerful
  - Companies offer turn-key solutions with dedicated software
    - But applications to engines are not always straightforward
- Optical access engines will continue to be important for the validation of computer modelling


Any Questions?

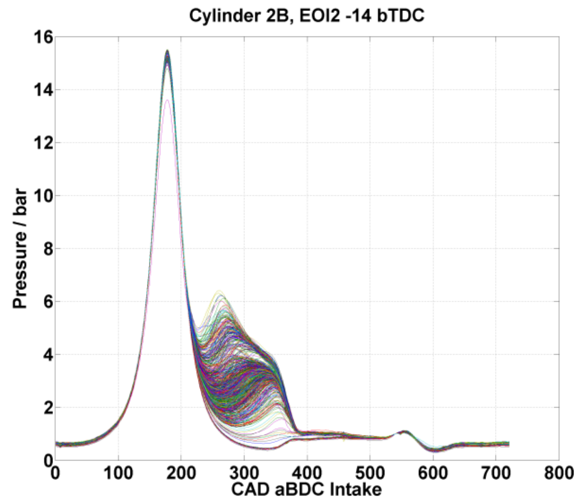
Catalyst Light-Off Strategy

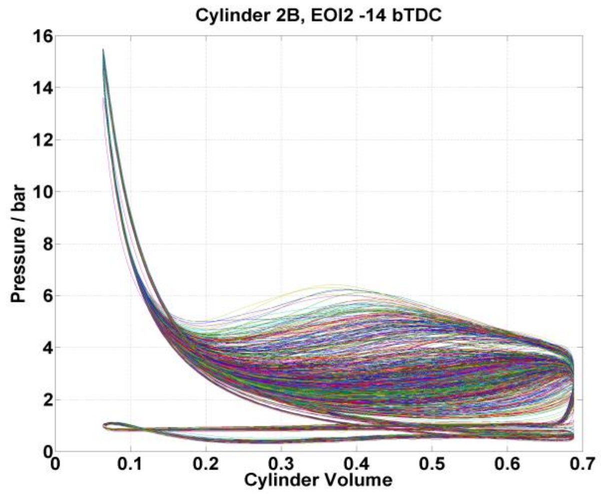
- 80% of Emissions Occur During the first 100s of a drive cycle.
- Essential to Have Fast Catalyst Light-Off
- Strategy
  - 1st Injection during induction - relatively well mixed but lean mixture in the cylinder before ignition,
  - 2nd Injection close to ignition - stratified fuel rich mixture in the central region of the combustion chamber.
  - Ignition after top dead centre

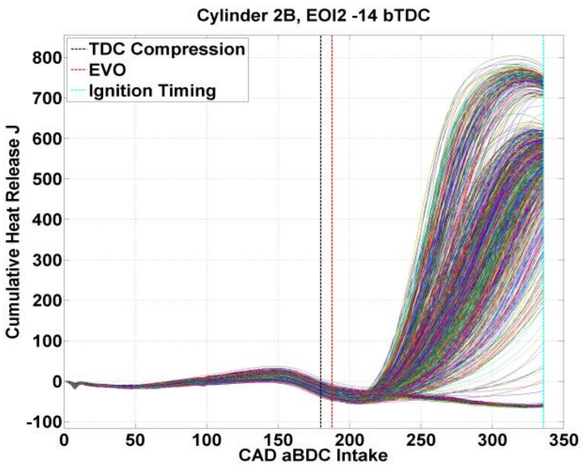


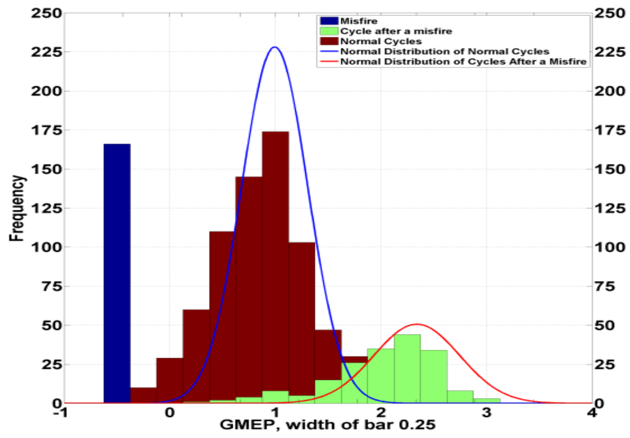


Combustion with Split Injection









with Split Injection – 6000 pps

- Misfire

- Normal

- Slow-burn