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PaREGEn + PEMs 4Nano

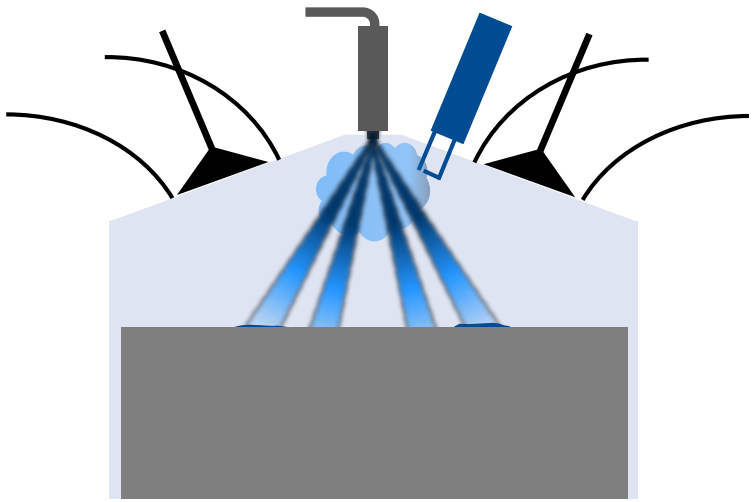
Development of laser-diagnostic techniques for liquid-film evaporation and soot formation

Sebastian Kaiser, Niklas Jüngst
University of Duisburg-Essen

See disclaimer

Motivation

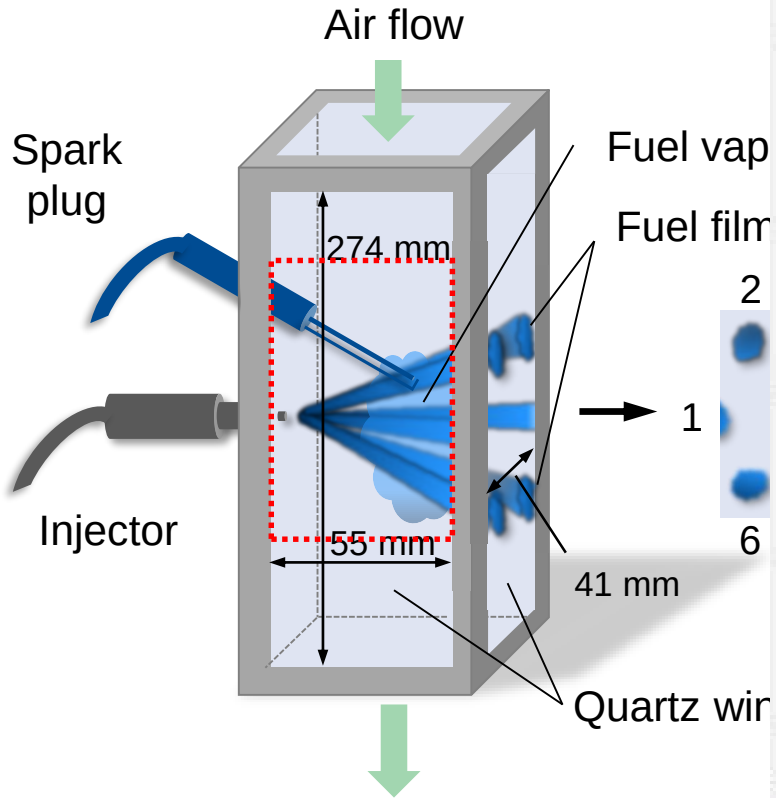
- Early fuel injection and cold-start conditions can cause the formation of fuel films in the combustion chamber
  - Evaporating fuel films on the piston surface during combustion
  - Soot formation (and oxidation)
  - Additionally: water injection -> films

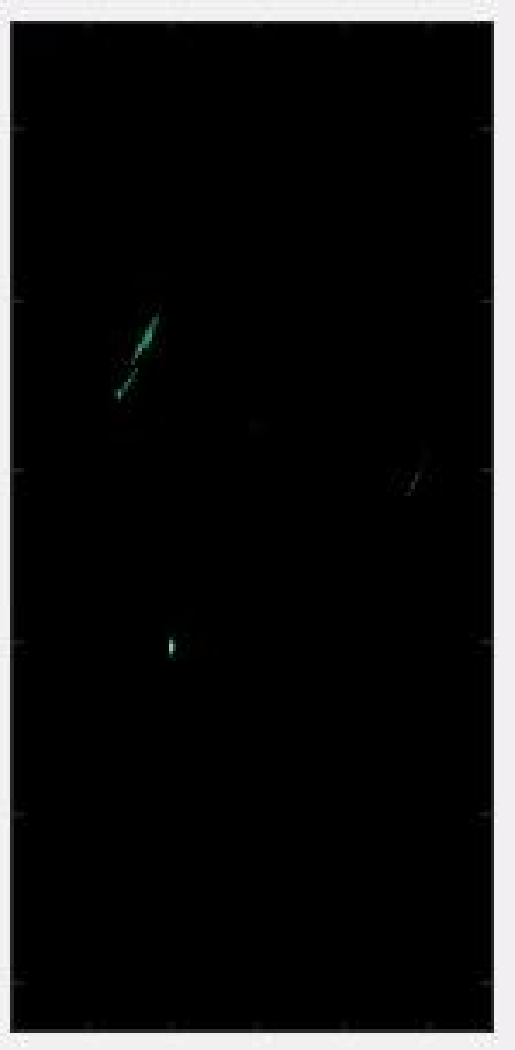


- Tasks:
  - Develop laser diagnostics to understand film formation, evaporation, combustion, soot formation
  - “Validate” 3D-CFD
  - Provide tools for future R&D

Experiment

- Optically accessible const





	Iso-octane
	1.83 m/s
	381 K
	352 K
e	361 K
e	100 bar
	1 bar
	9.3 mg

nd ignite
film evaporation,
, and soot formation with
agnostics

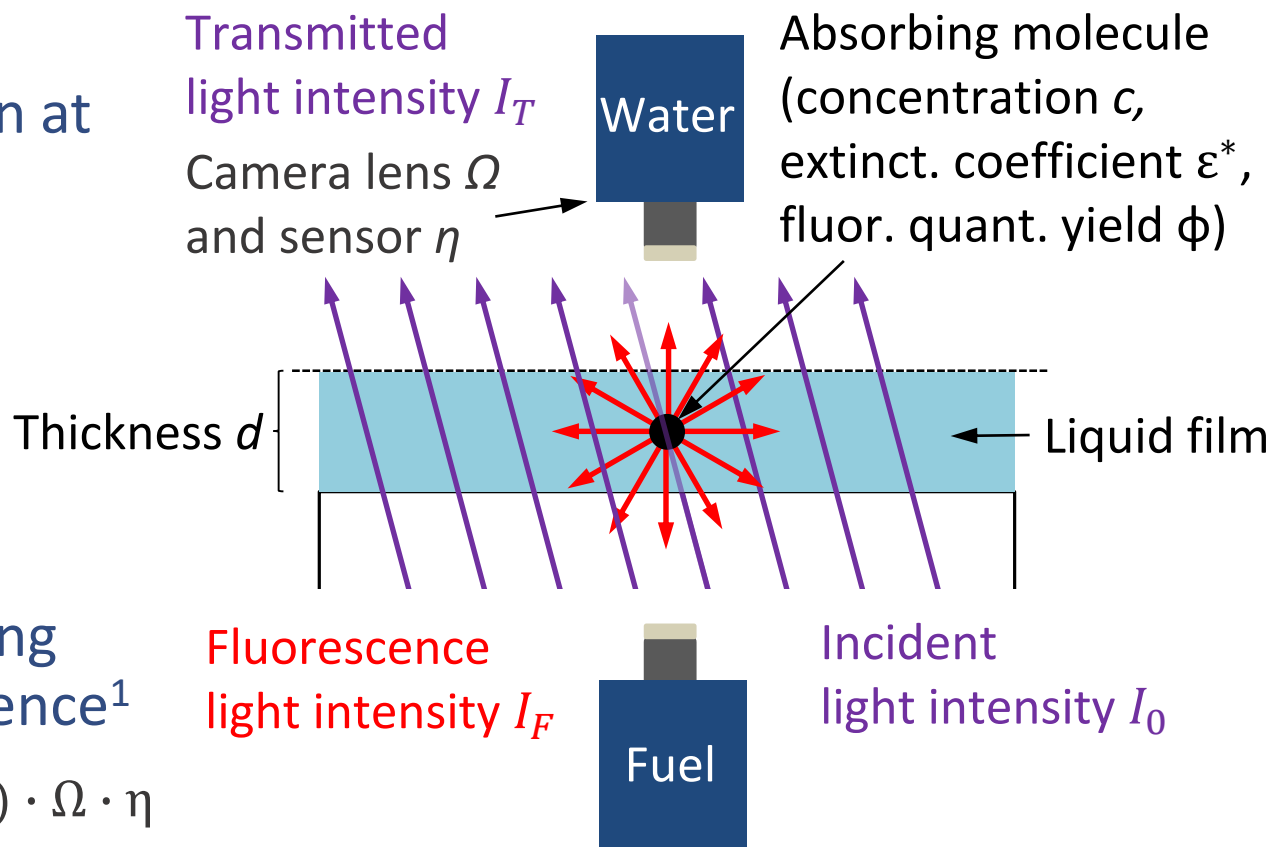
Liquid-film thickness imaging

- Water-film imaging
  - Infrared (IR) extinction at two wavelengths

$$I_T = I_0 \cdot e^{-\varepsilon^* \cdot c \cdot \boldsymbol{d}} \cdot \Omega \cdot \eta$$

- Fuel-film imaging
  - Tracer laser-induced fluorescence (LIF)
  - Temperature has strong influence on fluorescence[1]

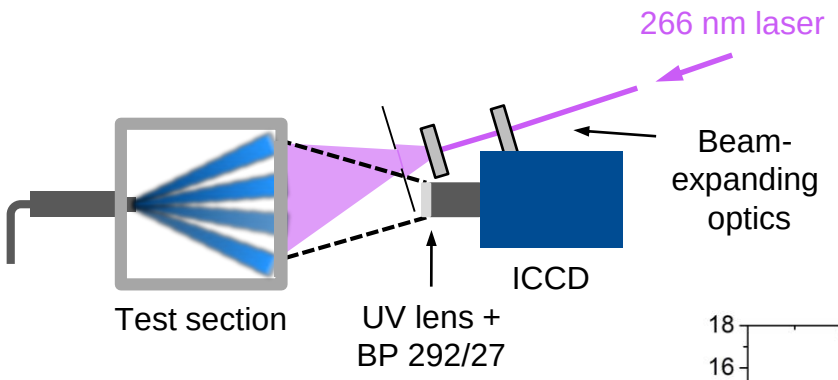
$$I_F = I_0 \cdot \left(1 - e^{-\varepsilon^* \cdot c \cdot \boldsymbol{d}}\right) \cdot \phi(T) \cdot \Omega \cdot \eta$$

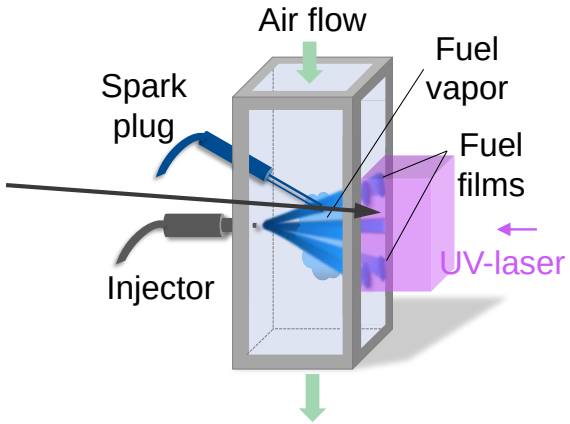


[1]Geiler, J.N., Grzeszik, R., Quaing, S., Manz, A., and Kaiser, S.A., "Development of laser-induced fluorescence to quantify in-cylinder fuel wall films," *International Journal of Engine Research* 19(33):134-147, 2018

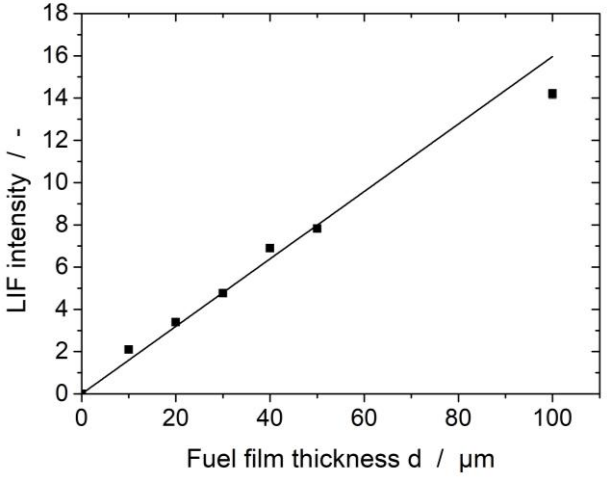
Fuel-film imaging

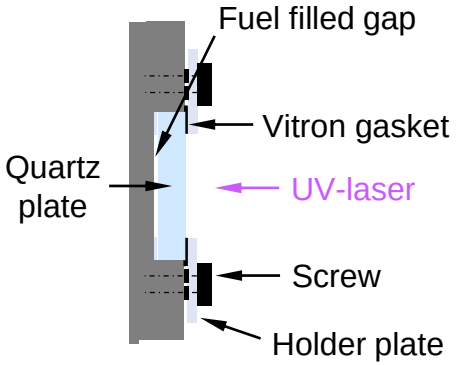
- Optical layout and calibration





- Can detect thin fuel films, down to 10 µm

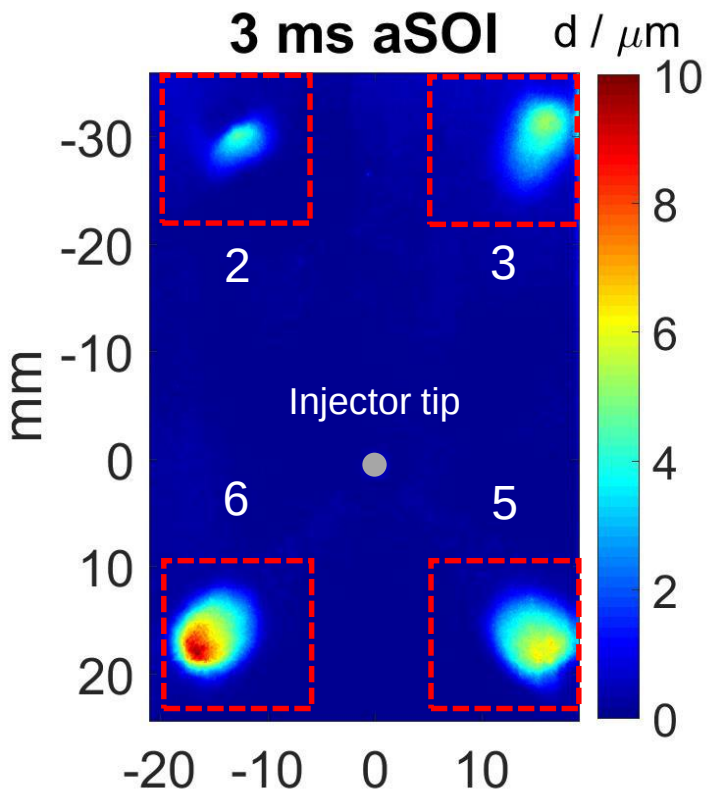


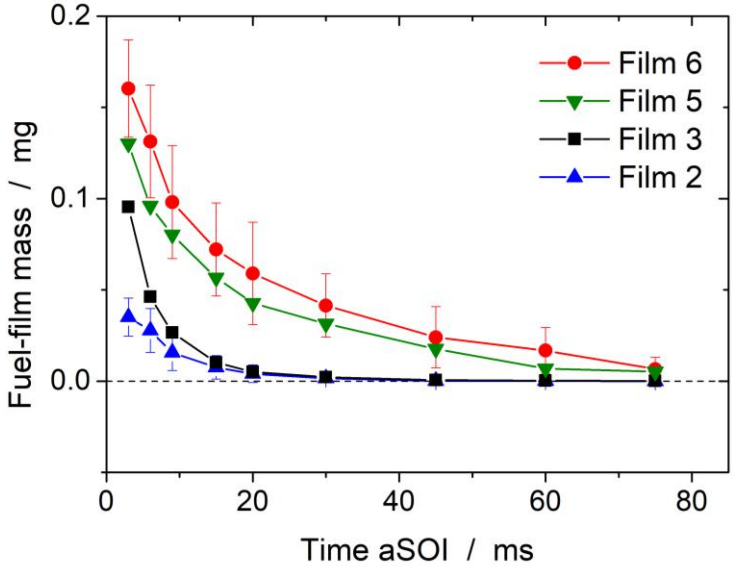


Fuel-film evaporation

- Accumulation of fuel in the outer parts of the wetted area
- Films 2 and 3 on average thinner than 5 and 6

aSOI: after start of injection

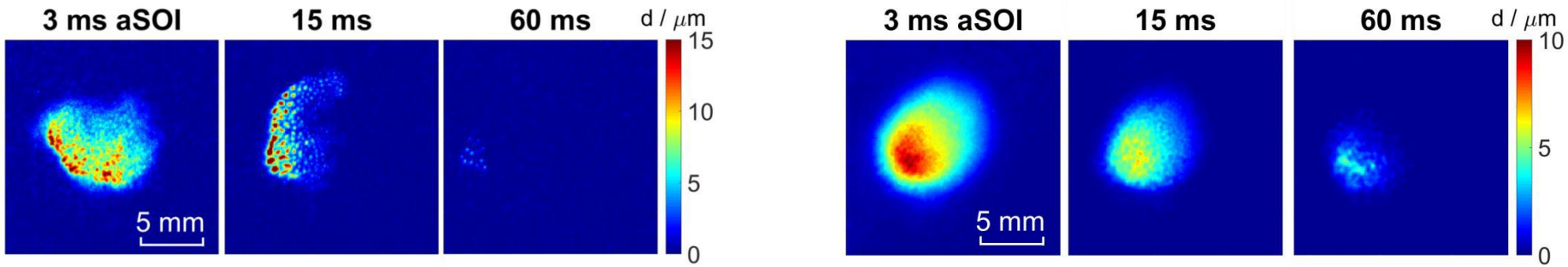




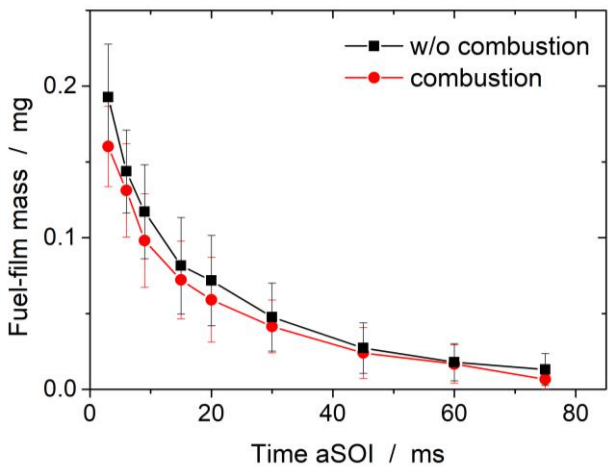
- High evaporation rates in the beginning
  - Strong turbulence
  - Evaporation of thin parts

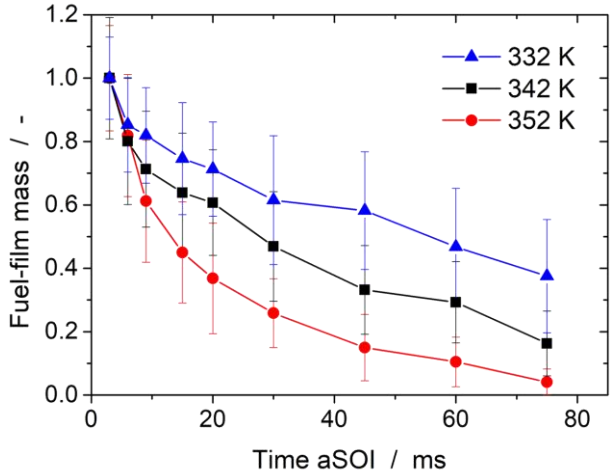
Fuel-film evaporation

- Single shots and means of evaporating film 6



- Combustion has **little**, wall temperature **much** influence on evaporation



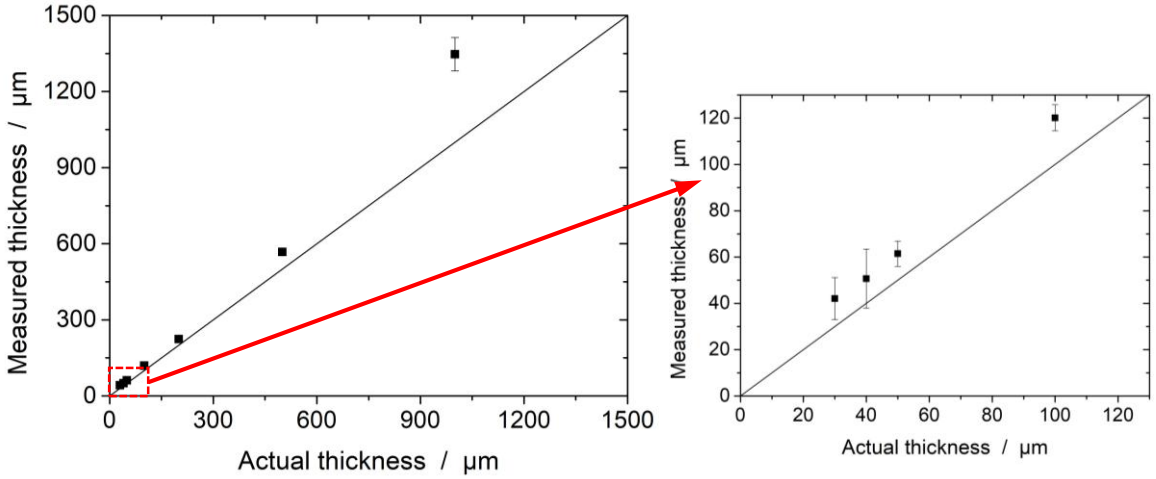


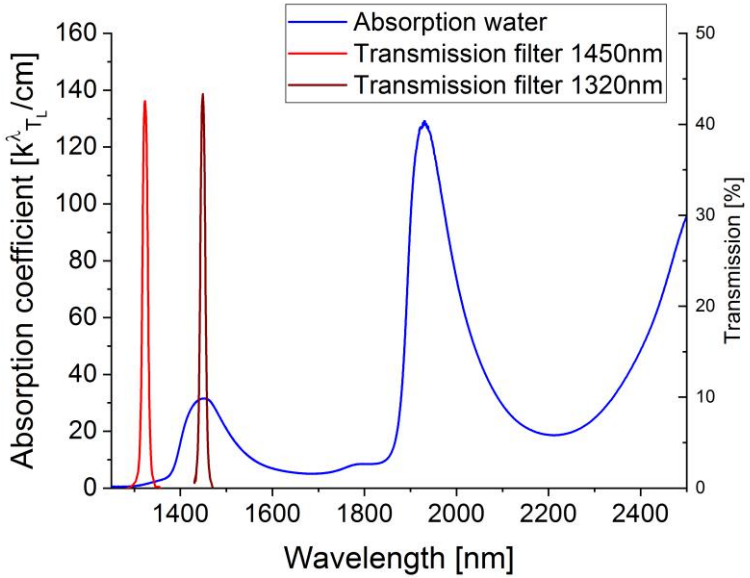
Water-film imaging by IR absorption

- Problem: Extinction = absorption + scattering, but only absorption = f(d)
- Measure extinction at two wavelengths with **a** and **d** unknown

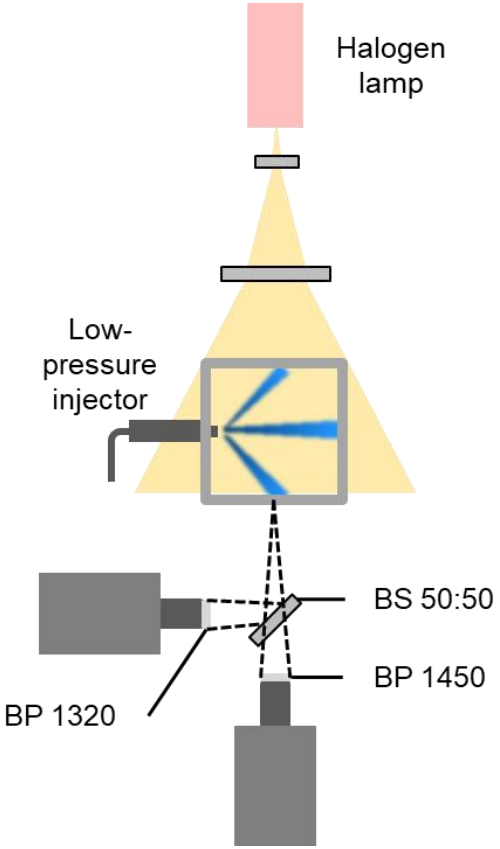
$$\frac{I_{1450}}{I_{1320}} = \cdot \underbrace{\frac{(1-a)}{(1-a)}}_{\text{Non-absorption losses}} \cdot \frac{I_{0,1450}}{I_{0,1320}} e^{-d\,(\tilde{k}_{T,1320}-\tilde{k}_{T,1450})}$$

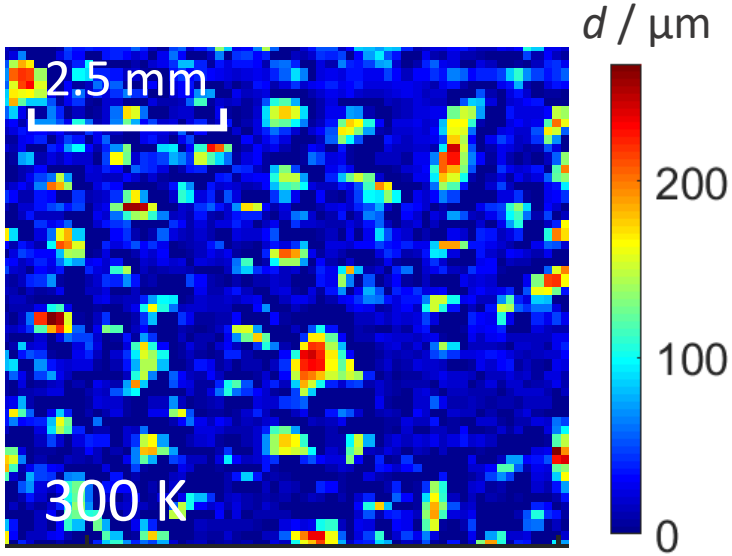
Thickness





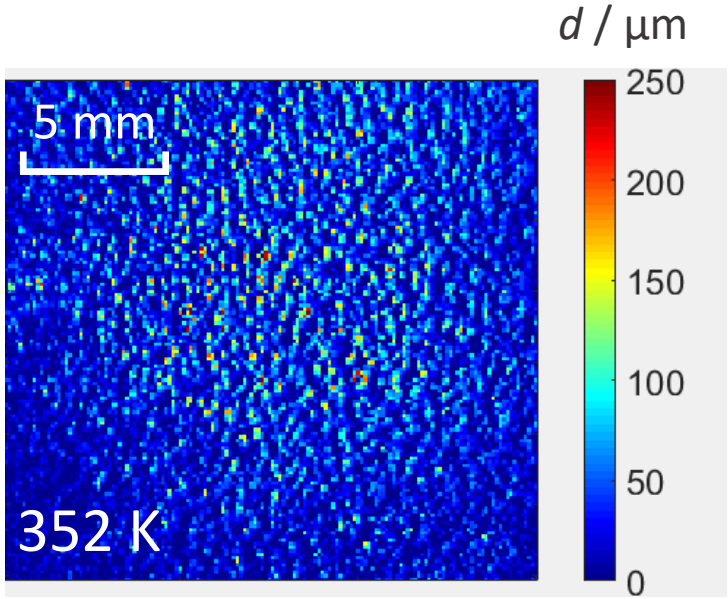
Water-film imaging by IR absorption





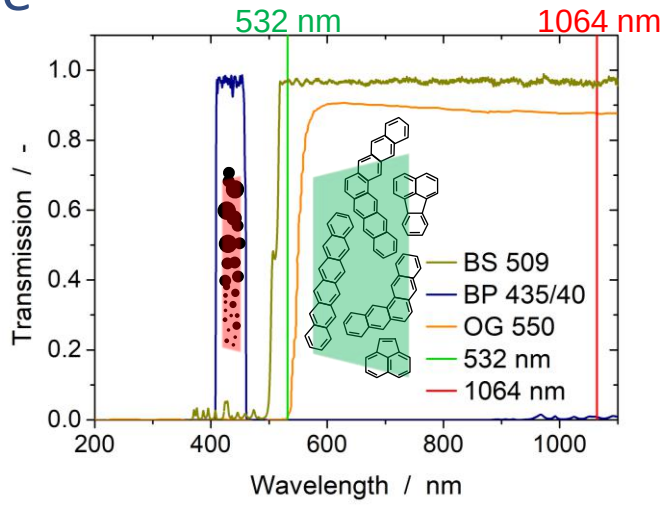
- Close-up image of water-film thickness (T_{wall} = 300 K)

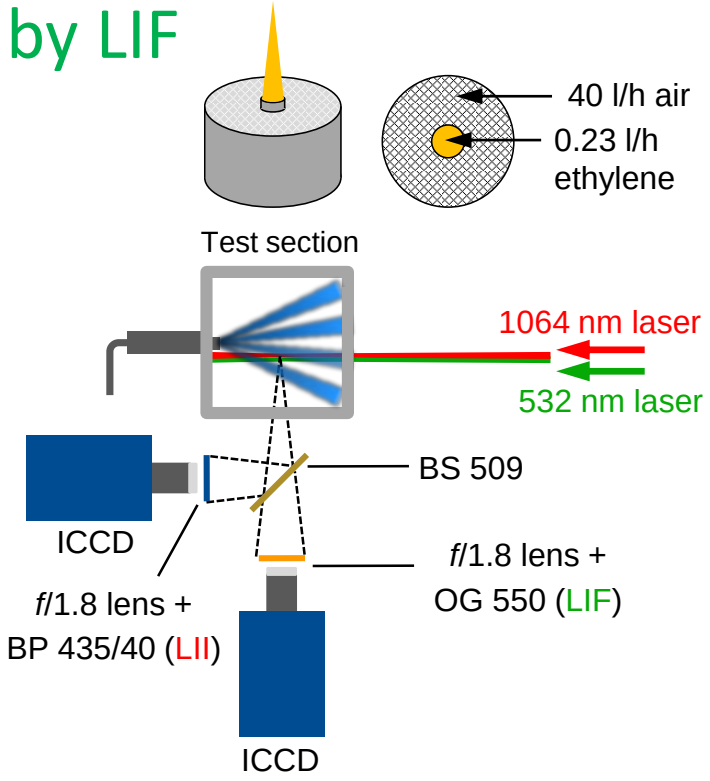
- Evaporation from wall (T_{wall} = 352 K)



Visualization of soot and soot precursors

- Visualize soot by laser-induced incandescence (LII) and polycyclic aromatic hydrocarbons (PAH) by LIF
  - LII: Laser heats soot particles => incandescence
  - PAH LIF: Many size-classes of PAH fluoresce when excited at 532 nm[1,2,3]

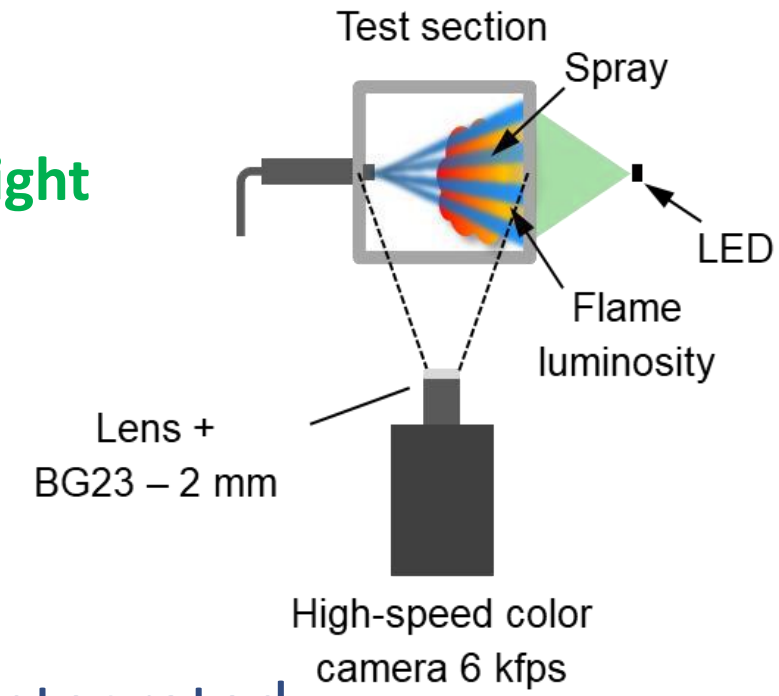




[1] Bejaoui, S., Mercier, X., Desgroux, P., and Therssen, E., *Combustion and Flame* 161(10):2479-2491, 2014.
[2] Liu, P., He, Z., Hou, G.L., Guan, B., Lin, H., and Huang, Z., *J Phys Chem A* 119(52):13009-17, 2015.
[3] Desgroux, P., Mercier, X., and Thomson, K.A, *Proceedings of the Combustion Institute* 34(1):1713-1738, 2013.

High-speed colour combustion imaging

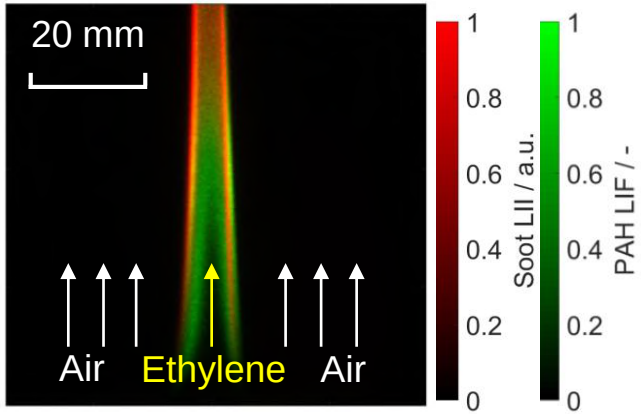
- Visualize spray, flame front, and soot incandescence with high-speed color camera
  - Spray and wall films by **Mie-scattered light** of green LED
  - Flame front by **chemiluminescence**
  - Soot by **natural incandescence**
- Simple and robust, but line-of-sight integrated

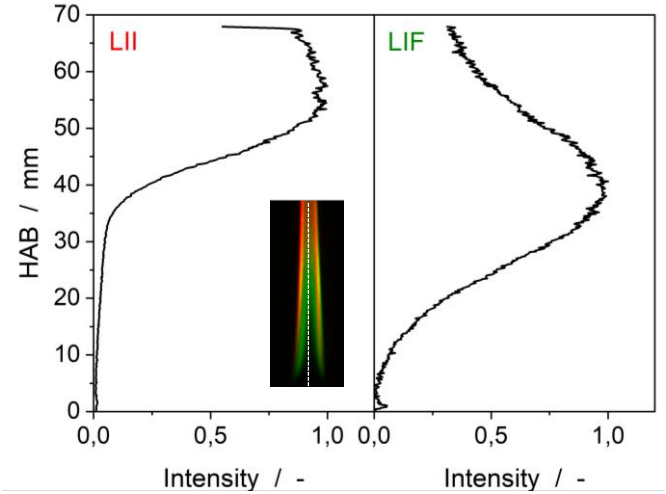


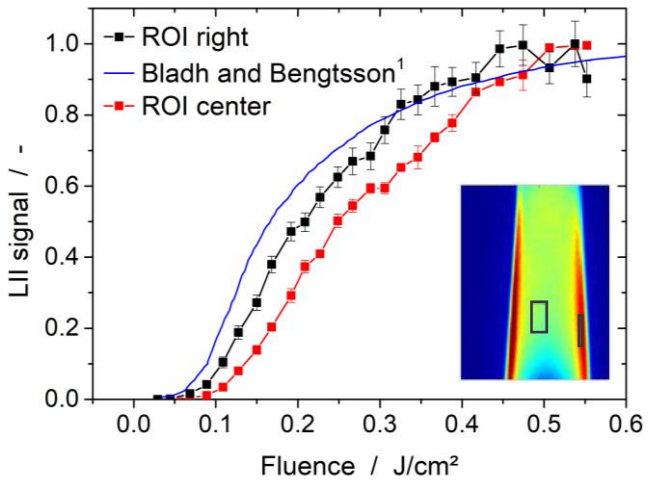
Preliminary measurements in laminar flame

- Simultaneous detection of PAH LIF and soot LII in Santoro burner
- PAH LIF in a hollow cone region enclosed by LII

- Choice of laser fluences
  - LII @ 1064 nm: **0.5 J/cm²**
  - LIF @ 532 nm: **0.008 J/cm**

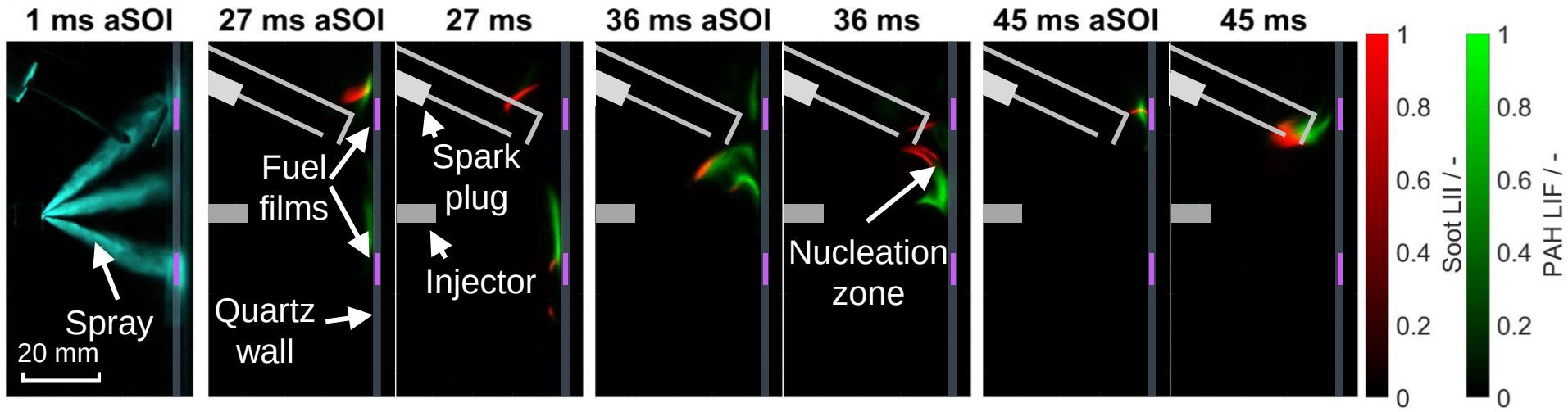






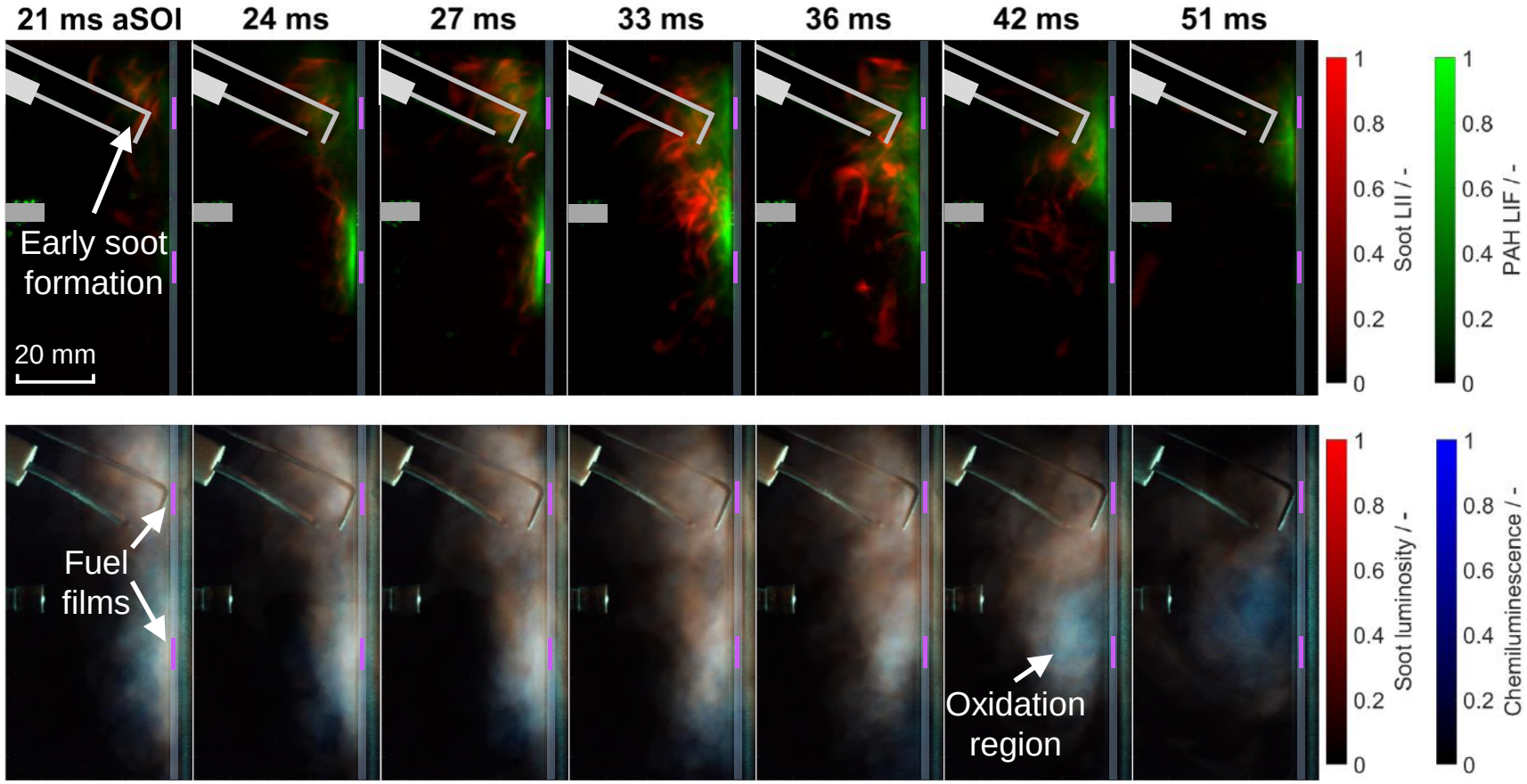
[1]H. Bladh, P.E. Bengtsson, Characteristics of laser-induced incandescence from soot in studies of a time-dependent heat- and mass-transfer model, Applied Physics B 78 (2) (2004) 241-248.

Single-shot LII + LIF near fuel films



- PAH and soot found in spatially separate but often adjacent regions
- Both close to fuel films, PAH closer
- ETH simulation predicts flame evolution and soot formation in good agreement with experiment

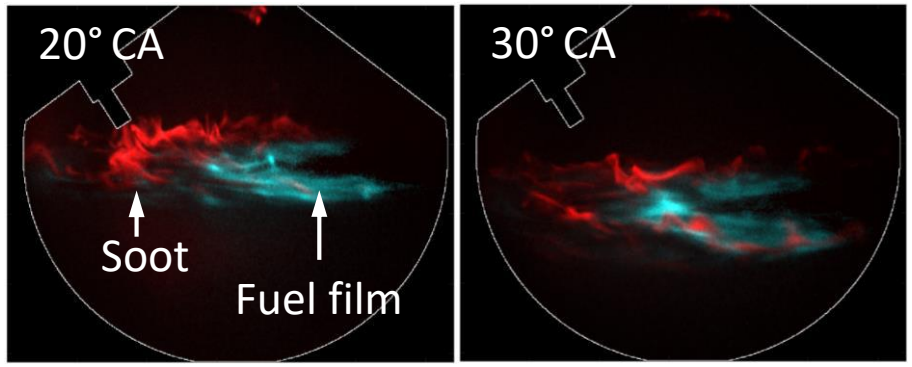
Mean LII + LIF vs. VIS flame luminosity



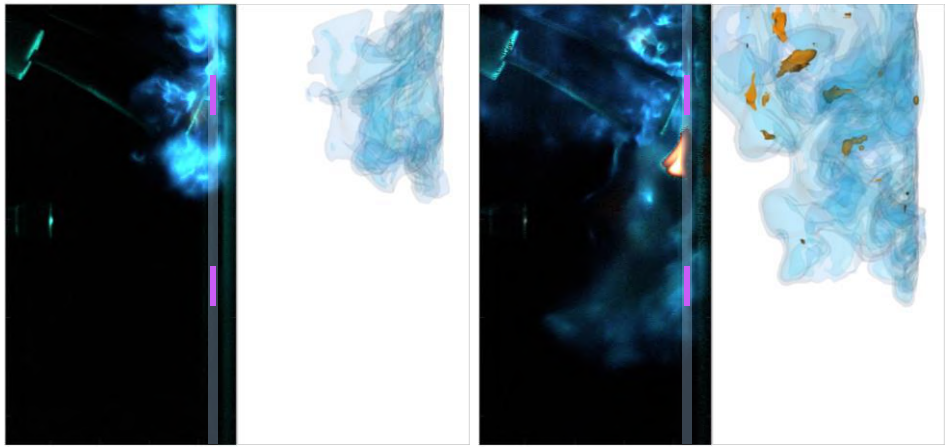
Conclusions

- Techniques for imaging multiple phenomena in wall-film formation, evaporation, combustion and soot formation were developed or refined
- Here: constant-flow model experiment at ambient pressure

Apply diagnostics in single-cylinder engines -> BOSCH



Validate 3D-CFD -> ETH



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