Chapter 3: General Requirements for Laser Combustion Diagnostics

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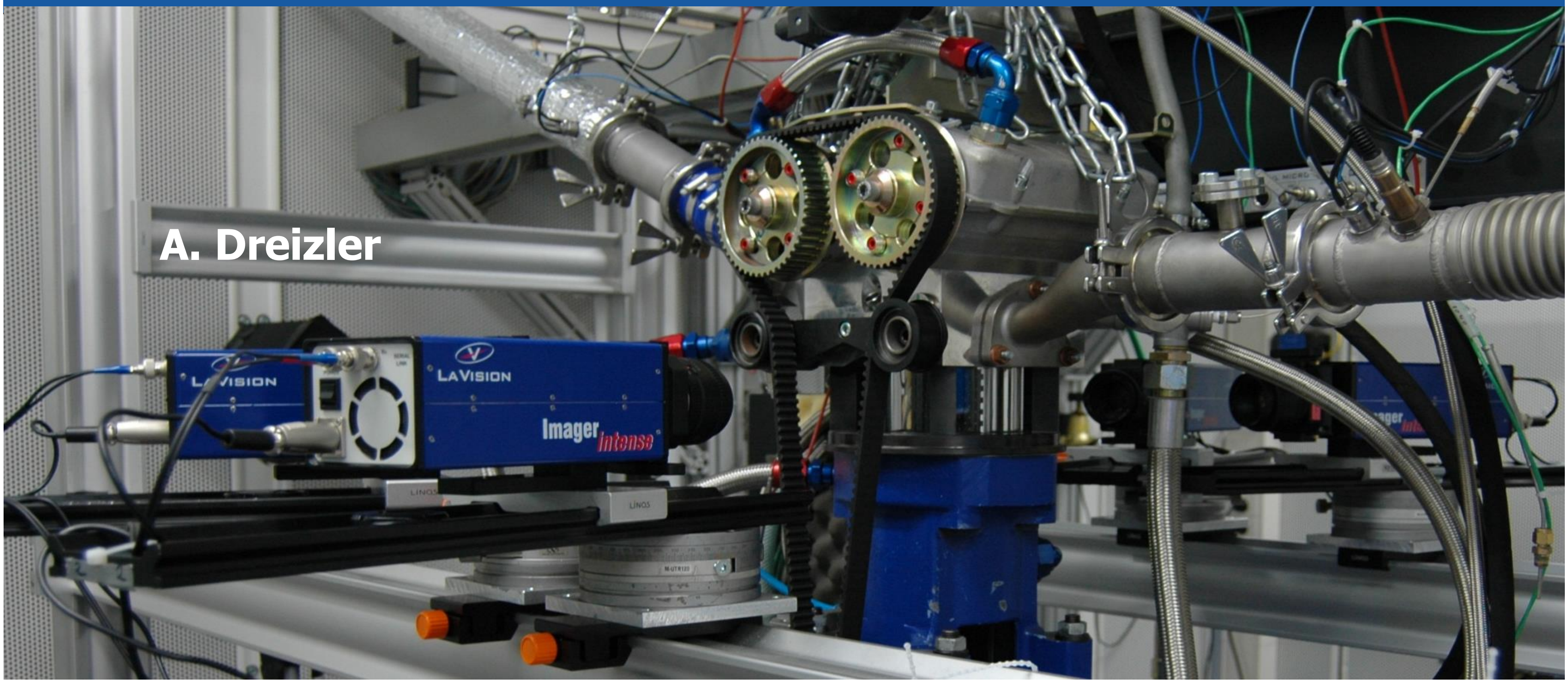


A. Dreizler

Quantities of primary interest in combustion

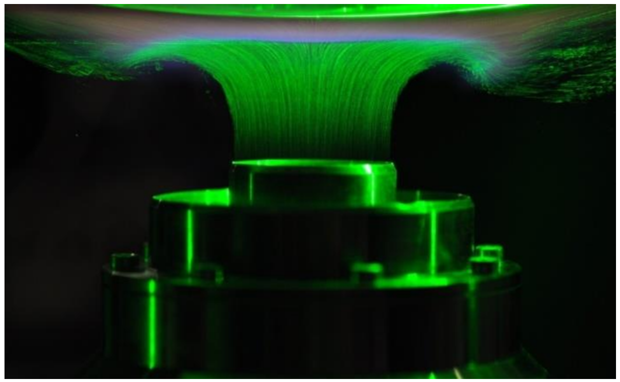
Methods from physics

⇩

Engineering sciences

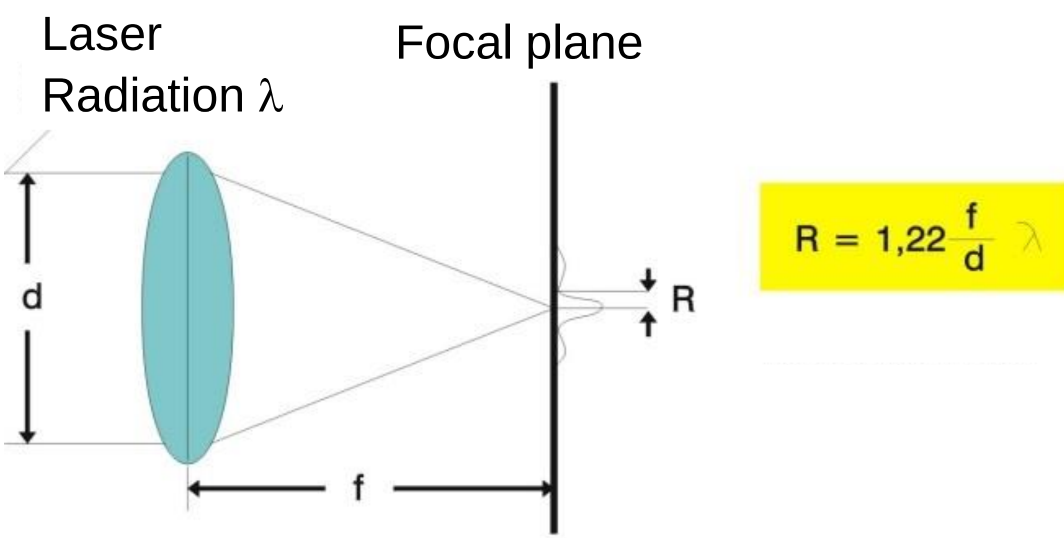
Transfer of methods

- Measuring by laser light
- Insitu-diagnostics → measuring inside combustors
- Non- or minimal intrusive
- High temporal resolution (~10^{-8}s)
- Reasonable spatial resolution (>10µm)



Spatial resolution

- **Laser properties**
  - Coherent radiation → well focusable → small spot sizes = small probe volumes
  - For TEM_{00}-mode operation:



  - Typical values f=350mm, d=10mm, λ=532nm

→ Spot size diameter 2R~45µm

  - In practice for pulsed lasers worse (~200µm)

Spatial resolution

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- **Typical spatial scales in turbulent flows**

  – Integral length scale $$L_{ij,k}(\vec{x},t) = \frac{1}{2}\int_{-\infty}^{\infty} \rho_{ij}(\vec{x},t,r_k,0)\,dr_k$$

  – Spatial covariance $$\rho_{ij}(\vec{x},\vec{r},t) = \frac{\overline{u'_i(\vec{x},t)u'_j(\vec{x}+\vec{r},t)}}{\sqrt{\overline{u'^2_i}(\vec{x},t)}\sqrt{\overline{u'^2_j}(\vec{x}+\vec{r},t)}}$$

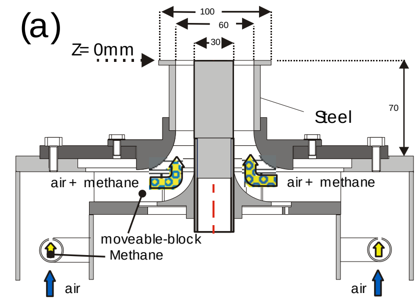
  – Kolmogorov (smallest) length scale
  (ν kinematic viscosity m^2/s)

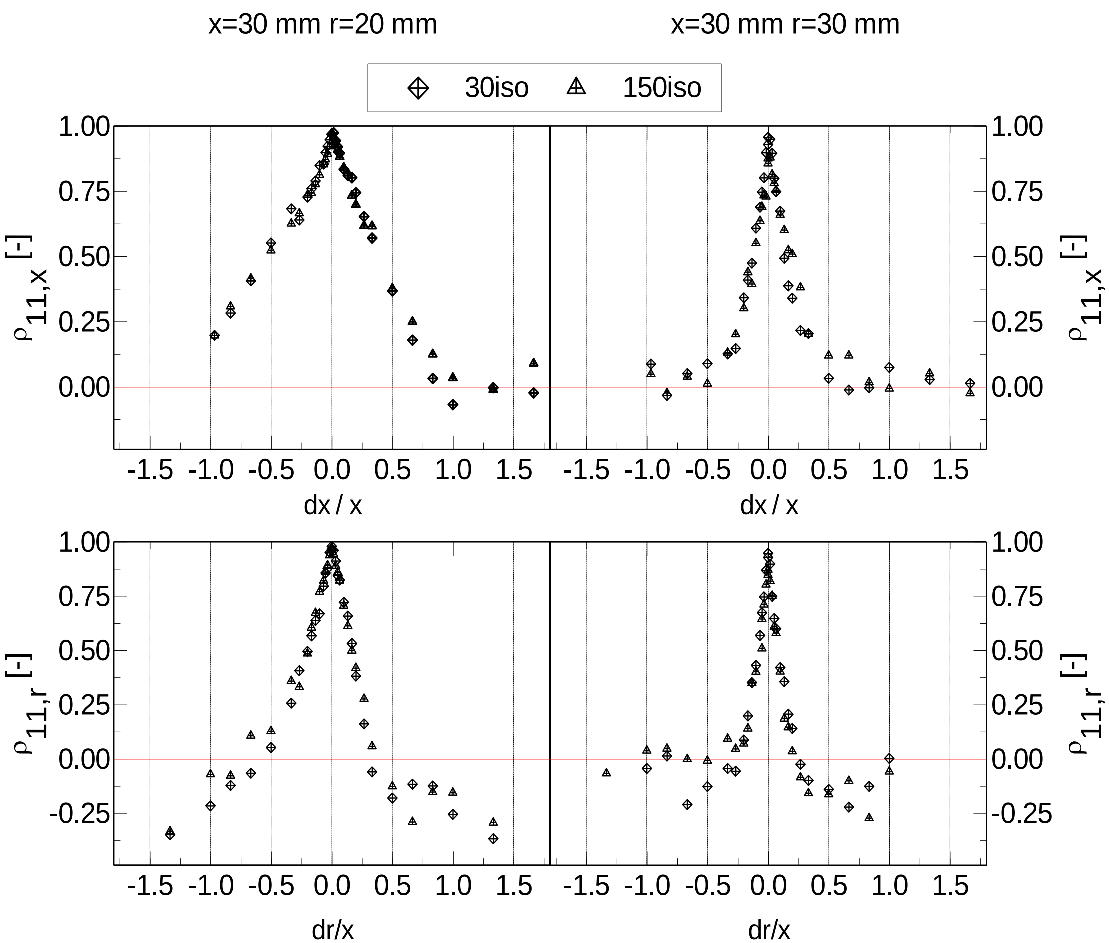
$$\eta_k = \left(\frac{\nu^3}{\varepsilon}\right)^{1/4} \qquad \varepsilon = \frac{k^{\frac{3}{2}}}{L}$$

$$\eta_k = \frac{L}{Re_t^{0.75}} \qquad Re_t = \frac{k^{\frac{1}{2}}L}{\nu}$$

Spatial resolution

- **Full optical resolution:**
  2R (spot diameter) ≤ η_k (Kolmogorov scale)
- **Example non-reacting swirling flow**





30iso (Re=10000)
$L_{11,x}$=10mm

30iso (Re=10000)
$L_{11,r}$=6mm

⇨ η_k~50µm

Schneider et int. Dreizler. Flow Turbulence and Combustion (2005) 74:103 – 127

Spatial resolution

- **Comparison optical resolution and Kolmogorov scale**
  - Spot size **2R~45µm** (f=350mm, d=10mm, λ=532nm)
  - Kolmogorov scale **η_k~50µm** (swirled air flow at Re=10000)
  - → Same order of magnitude but in practice often not fully resolved

→ **To be considered when comparing experimental data to numerical results**

  - Smoothing of measurands is an important issue but not yet any commonly agreed advice for best practice when comparing "filtered" measurands with "filtered" quantities from CFD

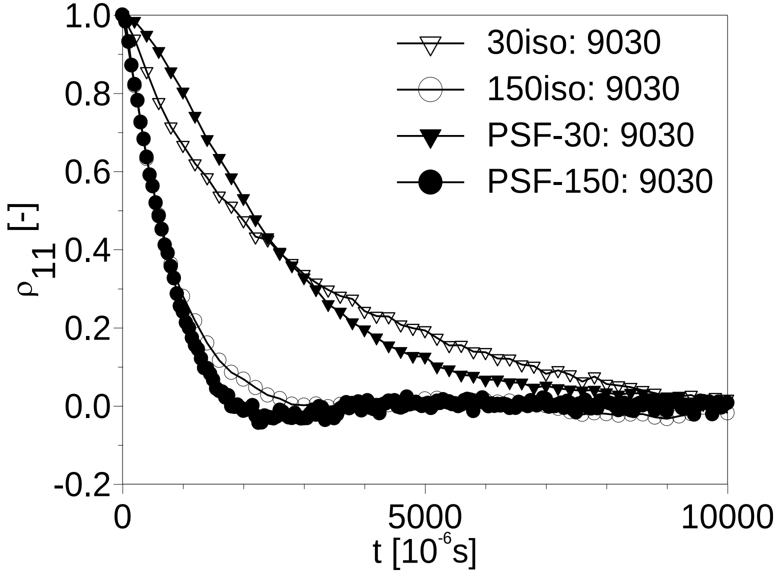
Temporal resolution

- **Pulsed laser operation**
  - Quality (q-) switch allows ns-pulses (10^{-9} s)
  - 1ns pulse corresponds to ~30cm
  - Pulsed operation increases intensity dramatically → non-linear optical methods become feasible (most prominent method CARS)
- **Typical time scales in turbulent flames**
  - Integral time scale $T_{ij}(\vec{x},t) = \frac{1}{2}\int_{-\infty}^{\infty} \rho_{ij}(\vec{x},t,0,\tau)d\tau$
  - Temporal auto-covariance $\rho_{ij}(\vec{x},t,0,\tau) = \frac{\overline{u_i'(\vec{x},t)u_j'(\vec{x},t+\tau)}}{\sqrt{\overline{u_i'^2}(\vec{x},t)}\sqrt{\overline{u_j'^2}(\vec{x},t+\tau)}}$
  - Kolmogorov time scale $\tau_k = \left(\frac{\nu}{\varepsilon}\right)^{1/2}$

$$\varepsilon = \frac{k^{\frac{3}{2}}}{L}$$

Temporal resolution

- **Example reacting swirling lean premixed flame**



PSF-30 (Re=10000)

T=1.2ms

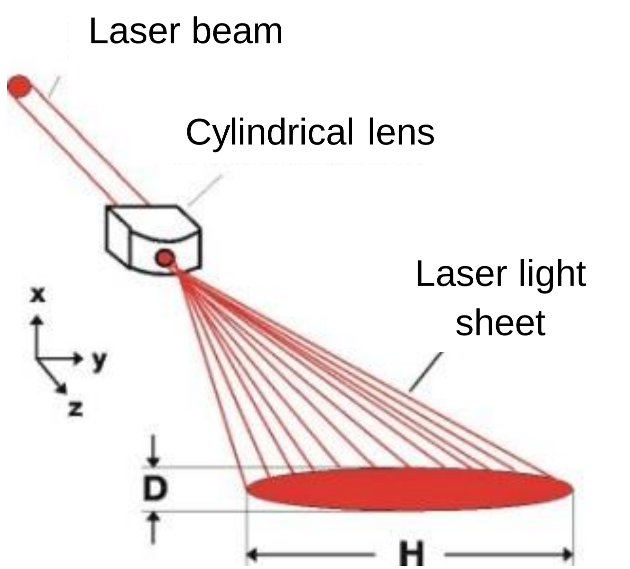
⇨ τ_k~170μs

- **Comparison optical resolution and Kolmogorov time scale**
  - Laser pulses are much shorter than any time scales in turbulent flames
  - Temporal resolution is no problem

→ Comparison of calculated and measured power spectra better in frequency domain

0D – 3D measurements by laser diagnostics

- **Up to 3 spatial dimensions are observable**
  - 0D/ 1D: generation of a thin laser beam
  - 2D: generation of a laser light sheet



  - Quasi-3D: multiple and parallel laser light sheets
  - 3D: Volumetric illumination

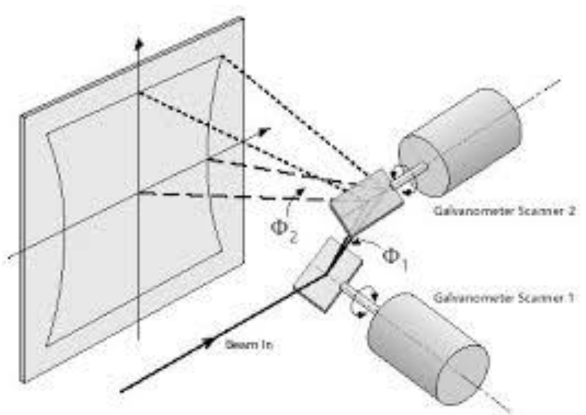
Scanning devices

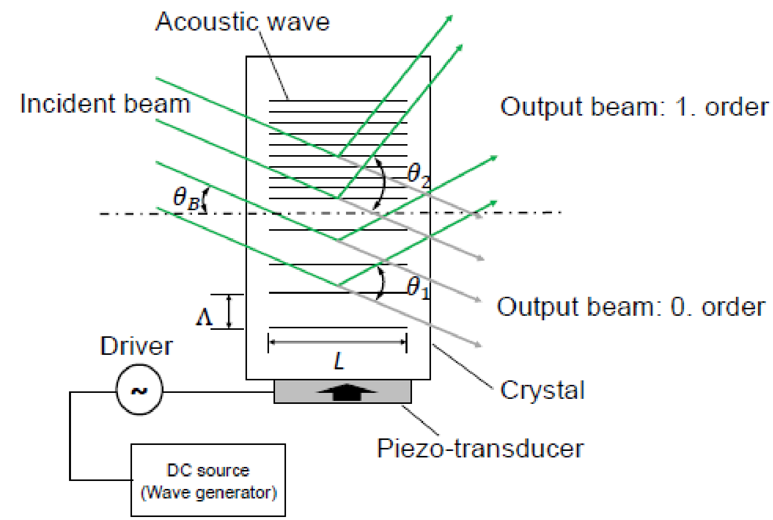
Galvanic mirror

Scan-speed

Polygon scanner

Acousto-optic deflector





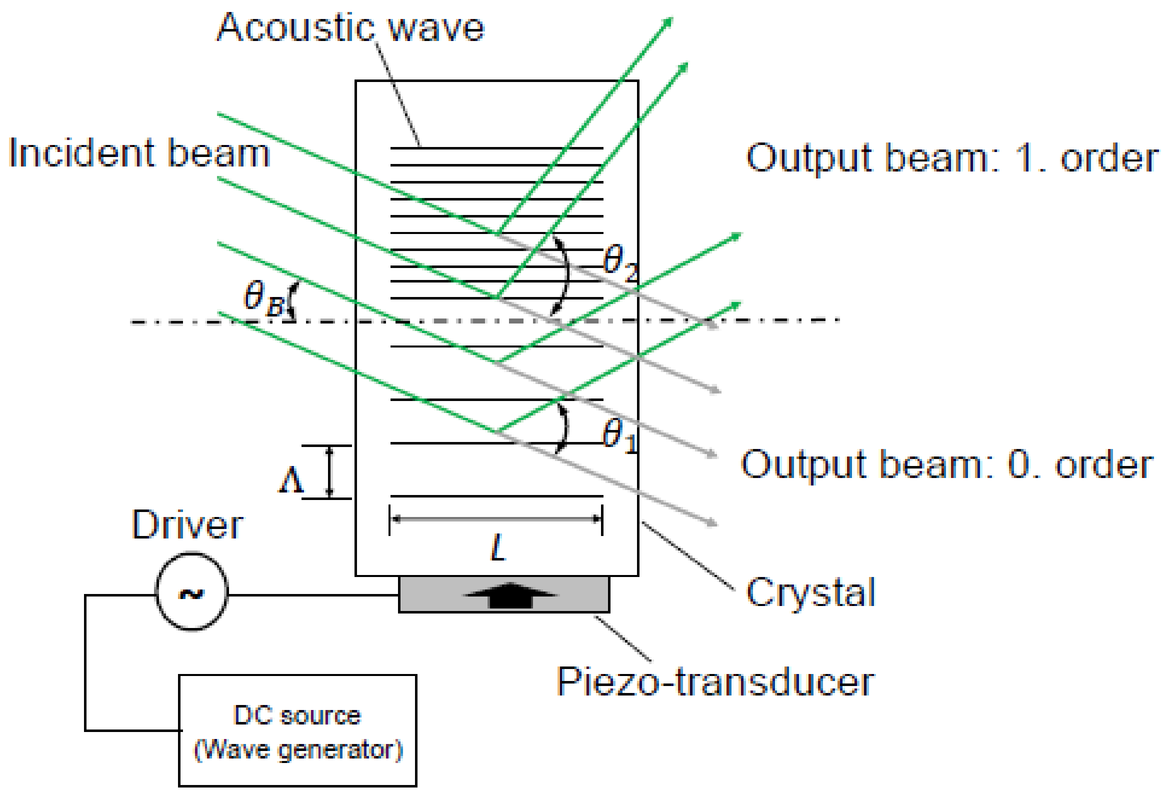
Weinkauff et int. Dreizler, Böhm. Meas. Sci. Technol. (2015) 26:105201

Li et int. Dreizler, Böhm. Appl. Phys. B (2017) 123:78

Acousto-optic deflector

- Faster than any mechanical device
- No moving parts
- Use of Bragg reflection
- Changing acoustic wavelength (frequency) → change of Bragg angle

$$sin\theta_B = \frac{\lambda}{2\Lambda}$$



Acousto-optic deflector

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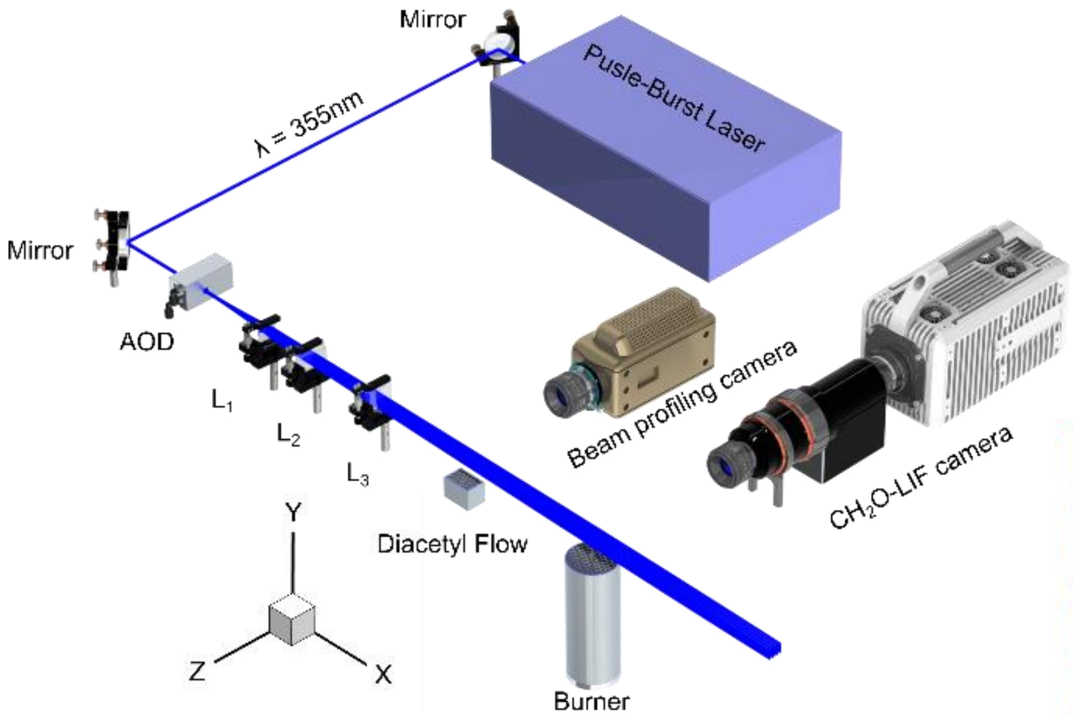
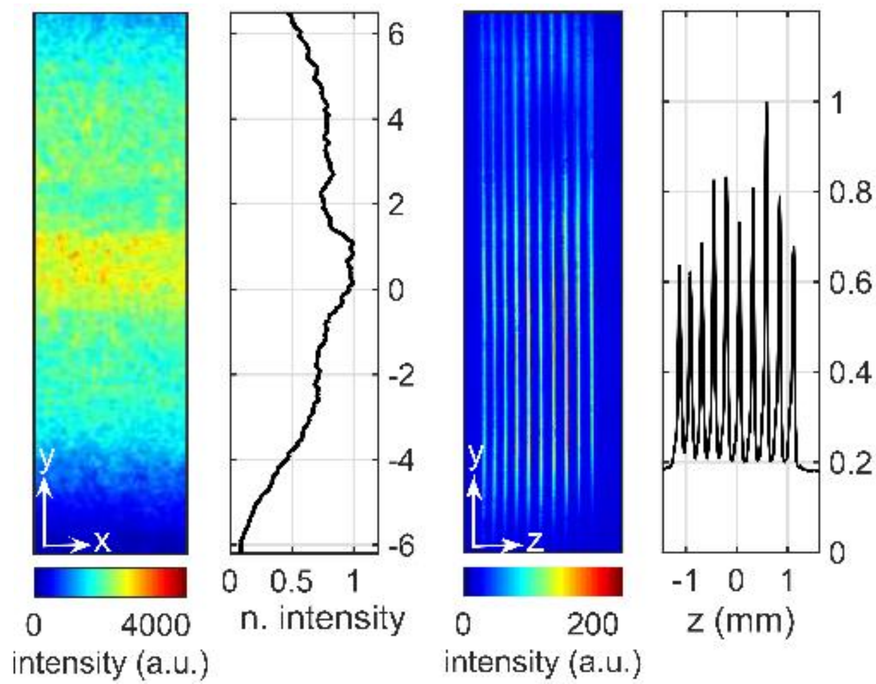
Setup

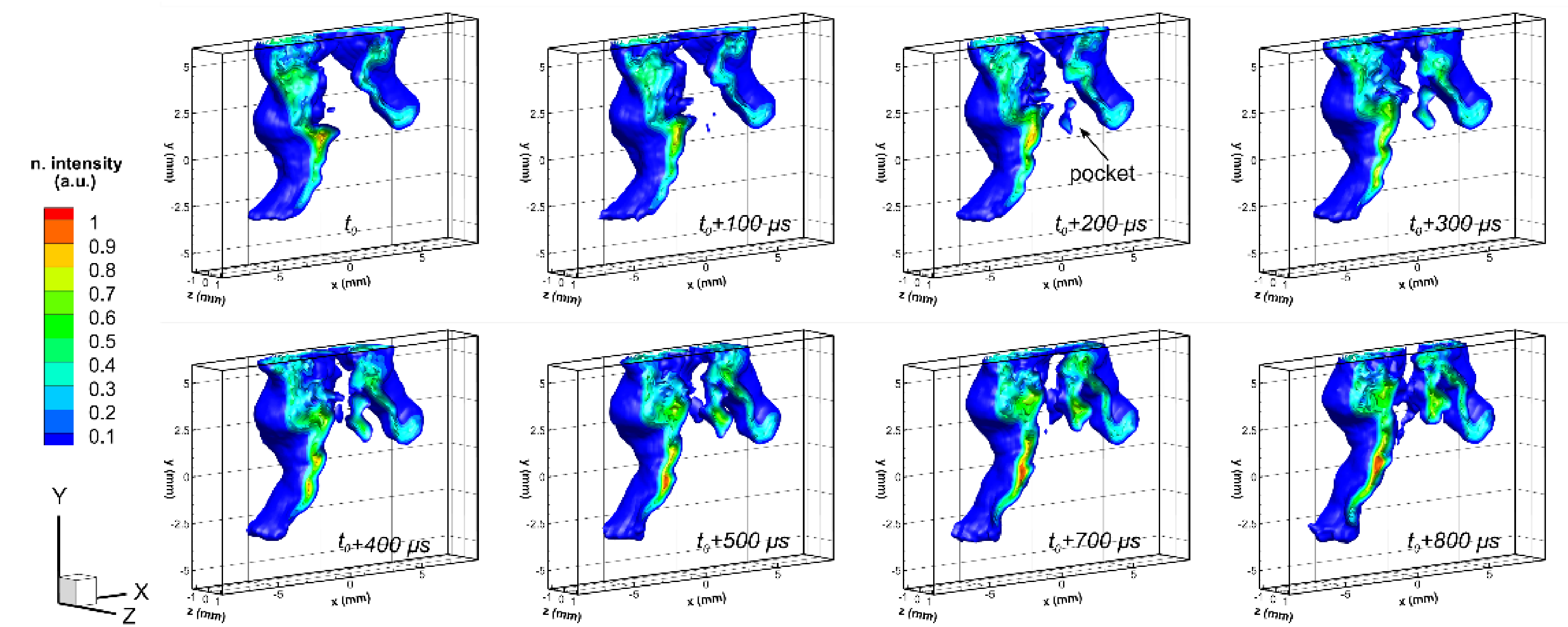


Intensity profiles

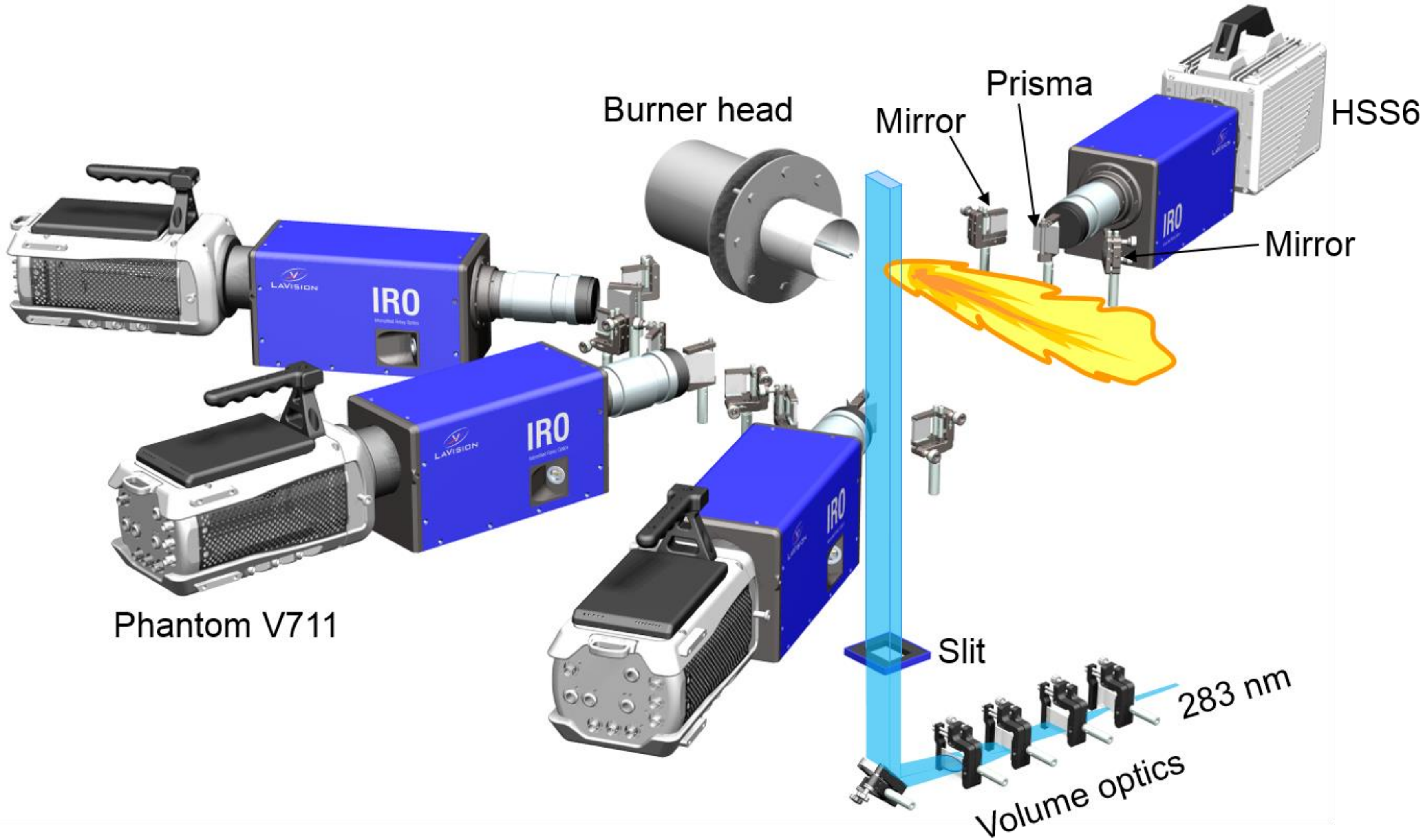


Acousto-optic deflector: Application example

- Base of lifted flame
- Volumetric distribution of formaldehyde
- Temporal sequence

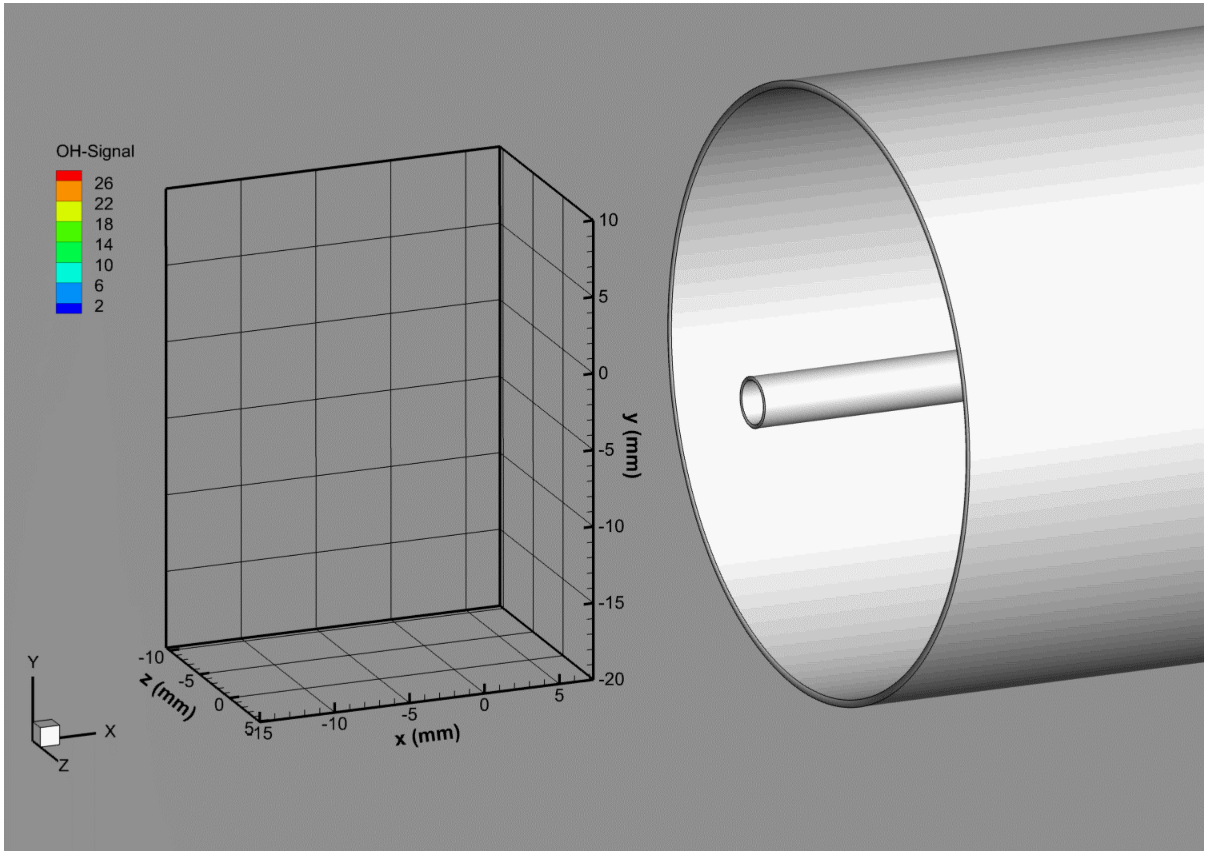


Volumetric Laser-induced fluorescence: 8 views



Pareja et int. Dreizler, Böhm. Proc. Combust. Inst. (2019) 37 (2):1321-1328

Volumetric imaging of auto-ignition



	Co-flow	Jet
Fluid	Air	CH_4
T (°C)	1100	530
Re (-)	10000	3700

4D-diagnostics: 3 spatial dimensions & time