5.1 Speed, Forces and Torque

5.2 Exhaust Gas Analysis

5.3 Pressures, Temperatures and Flows

5.4 Combustion Analysis

Combustion Analysis

Value to be Measured
$v = f(x, y, z, t)$

Temperature

Chemical Composition
(including Particles)

Velocity Distribution

Physical Effects Useful for Measurement of v?

Technical Implementation of Measurement?

Alternatives:
CFD (Computational Fluid Dynamics),
Water Analog Engines

Physical Effects Useful for Measurement

Doppler Effect

Scattering

- Elastic Scattering
  - -- Rayleigh Scattering (particles small compared to wavelength)
  - -- Mie Scattering (particles large compared to wavelength)
- Inelastic Scattering
  - -- Raman Scattering

Fluorescence

Incandescence

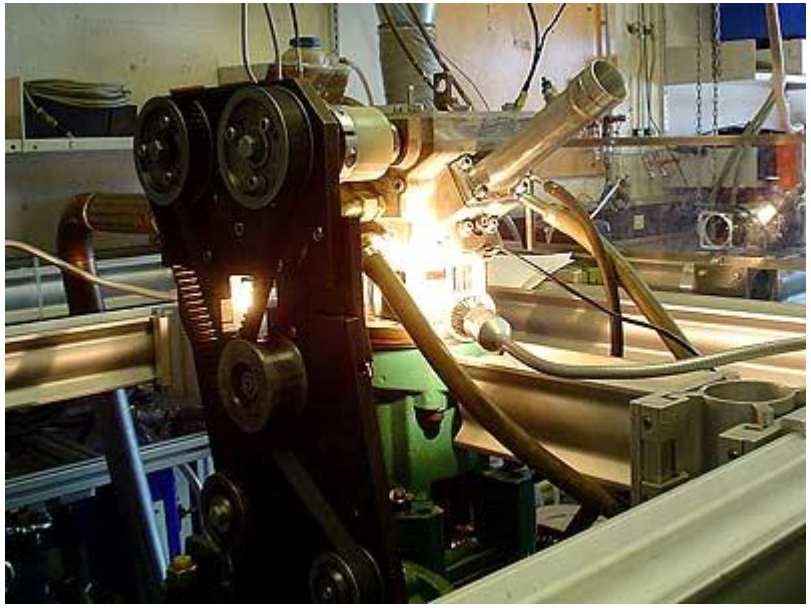
…

Practical Methods?

Practical Methods

- Endoscope, Optical Spark Plug, Glass Engine
- Ionization Sensors
- Indication (see Pressures)
- CARS (Coherent Anti-Stokes Raman Scattering)
- LDA (Laser Doppler Anemometry)
- QLS (Quantitatives Lichtschnittverfahren, Quantitative Light Section)
- PIV (Particle Image Velocimetry)
- LII (Laser Induced Incandescence)
- LIF (Laser Induced Fluorescence)
- …

Glass Engine



Glass Engine at AVL, Source: http://www.unplugged.at/krusche/feat01/txt03/txt114.htm

Optical Spark Plug

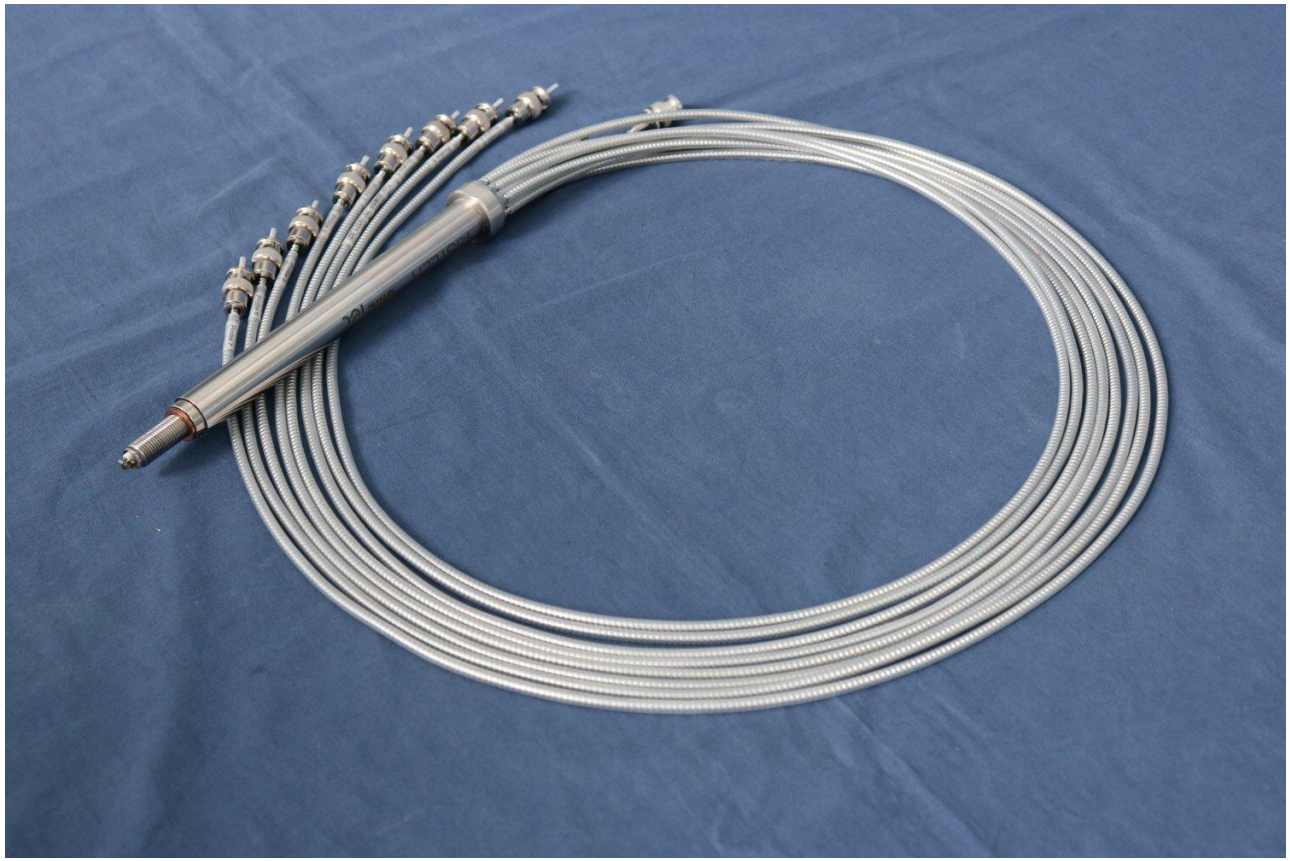
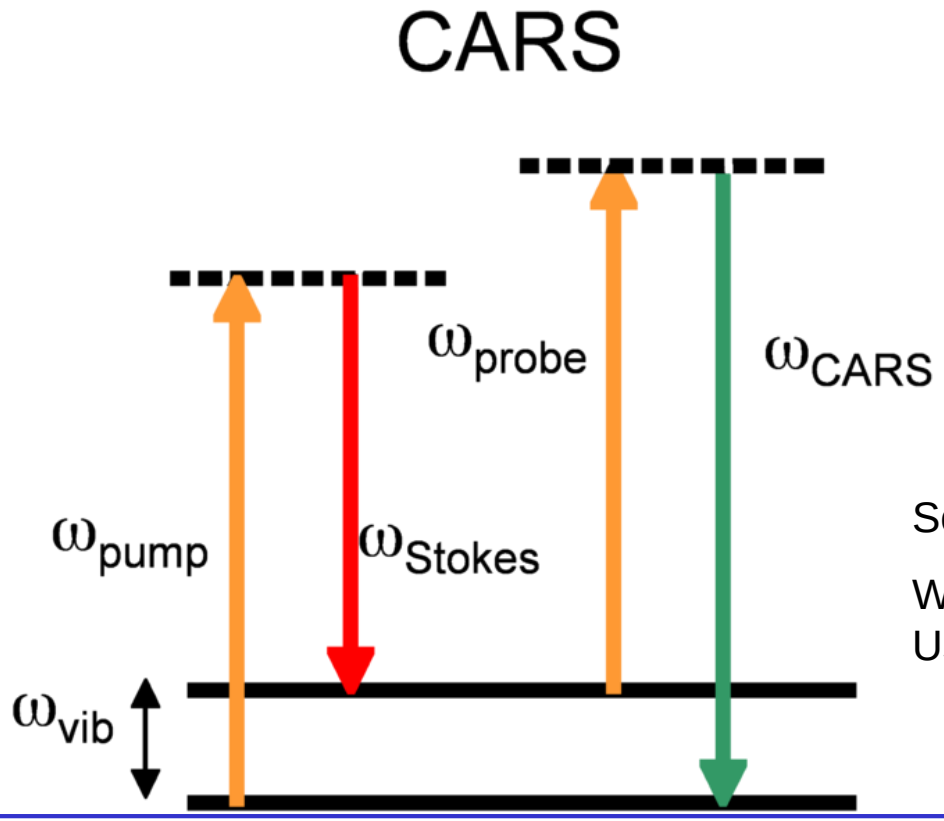


Photo: SMETEC GmbH

Coherent Anti-Stokes Raman Scattering

Location Dependant Identification of Substances

**(pumped by Laser,
different release spectra characteristic of molecules)**



Source:

Wikimedia Commons,
User: epotma

Laser Doppler Anemometry

Uses Doppler Shift for Velocity Measurement
(**P**lanar **D**oppler **V**elocimetry, **L**aser **D**oppler **V**elocimetry, **L**aser **D**oppler **A**nemometry)

uses Mie Scattering with **Optical** Doppler effect

Single Ray Reflection (unusual)

$$\frac{f - f_0}{f_0} \approx 2\frac{v}{c}\cos\varphi$$

f_0	Original Laser Frequency
f	Scattered Frequency
v	Particle Velocity **(to be measured)**
φ	Angle between Laser and Particle Flight

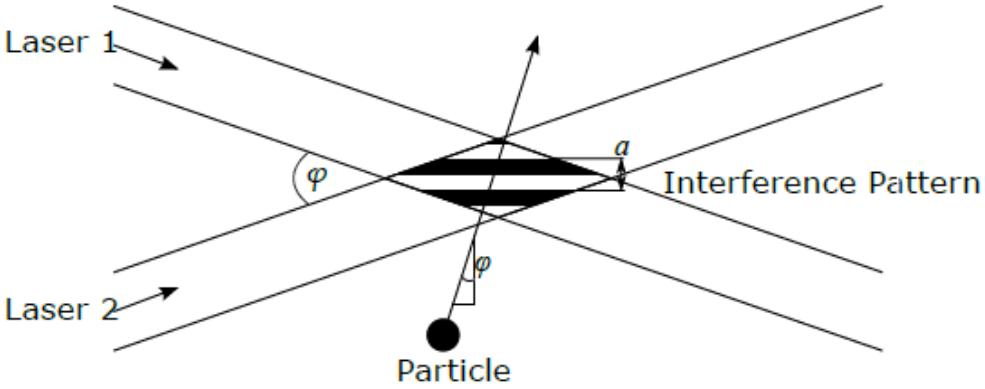
Laser Doppler Anemometry

Uses Doppler Shift for Velocity Measurement
(**P**lanar **D**oppler **V**elocimetry, **L**aser **D**oppler **V**elocimetry, **L**aser **D**oppler **A**nemometry)

Uses Mie Scattering with **Optical** Doppler Effect

Dual Ray

(both lasers have same wavelength λ)



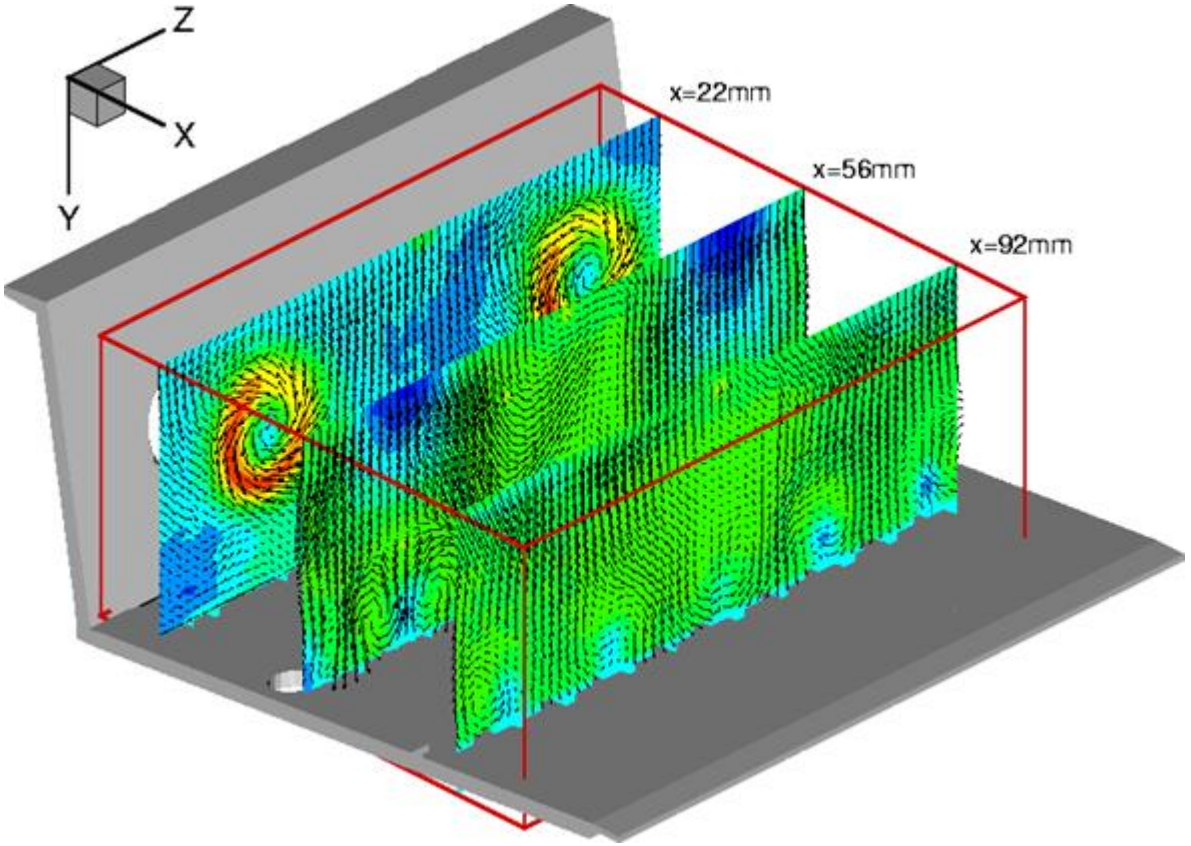
Interference Pattern $$a = \frac{\lambda}{2\sin(\phi/2)}$$

Scattered Frequency $$f = \frac{2v\cos(\varphi)\sin(\phi/2)}{\lambda}.$$

Laser Doppler Anemometry

Uses Doppler Shift for Velocity Measurement
(**P**lanar **D**oppler **V**elocimetry, **L**aser **D**oppler **V**elocimetry,
Laser **D**oppler **A**nemometry)

Resulting 3D
Velocity Image



Source: DLR

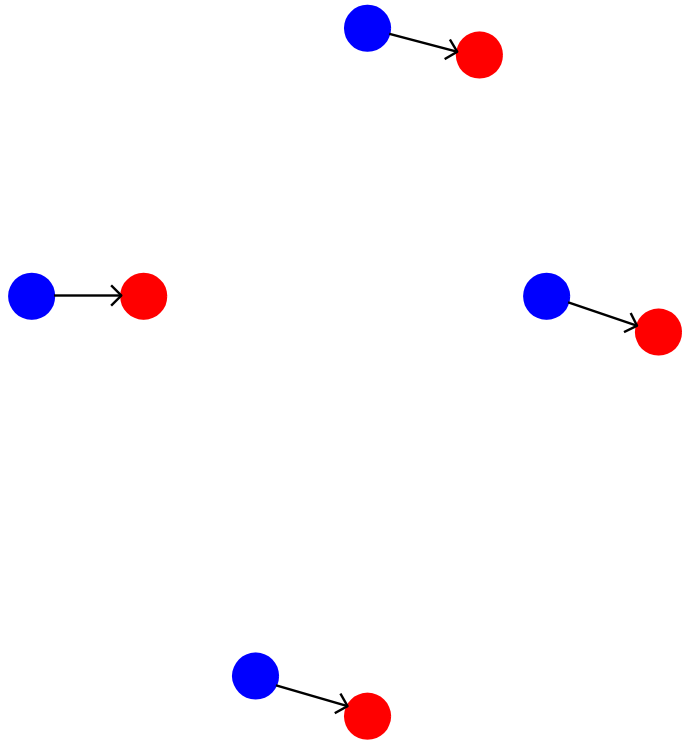
Quantitative Light Section

(also **D**oppler **G**lobal **V**elocimetry)

Measures Volume Flow in a light plane in one step

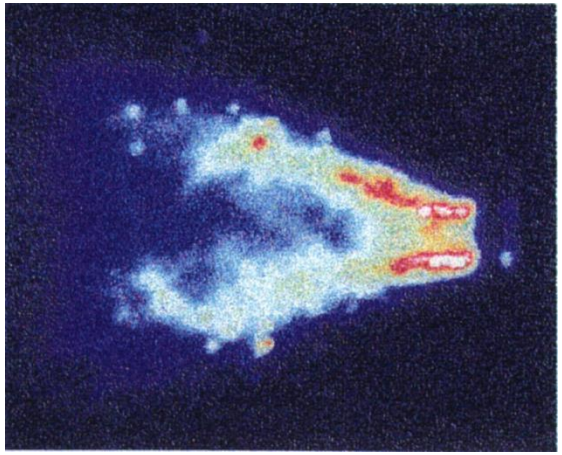
Effect: Mie Scattering

Particle Image Velocimetry (**P**article **I**mage **V**elocimetry)



Snapshot 1 Snapshot 2

Analysis of Mixture Processes in Combustion Chamber (e. g. Fuel Sprays)



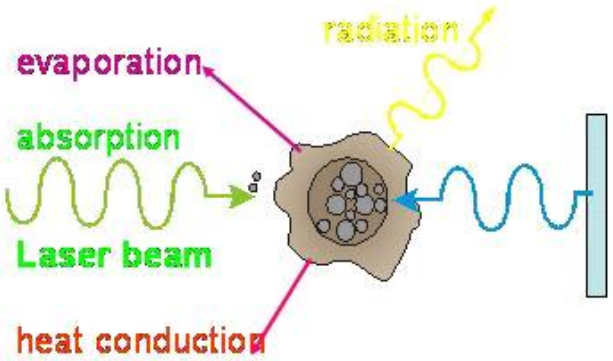
Source:
University of Warwick

Particulate Matter Analysis in Combustion Chamber

Thermodynamic processes during LII of soot particulates

Mass loss:

$$\frac{dM_s}{dt} \propto C_{abs} q \frac{W_v}{\Delta H_v}$$



Energy balance:

$$r^3 \rho_s C_{p,s} \frac{dT}{dt} \propto C_{abs} I_{laser} - \frac{T - T_0}{\lambda_{gas}} r^2 - \sigma_{SB} r^2 (T^4 - T_a^4) - \Delta H_v \rho_v U_v r^2$$

internal energy | Laser Absorption | Conduction | Radiation | Evaporation

Source:
Paul-Scherer-Institute,
Villigen (CH)