The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

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Winter College on Optics in Environmental Science

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Combustion basics, Laser diagnostics of combustion
Part II

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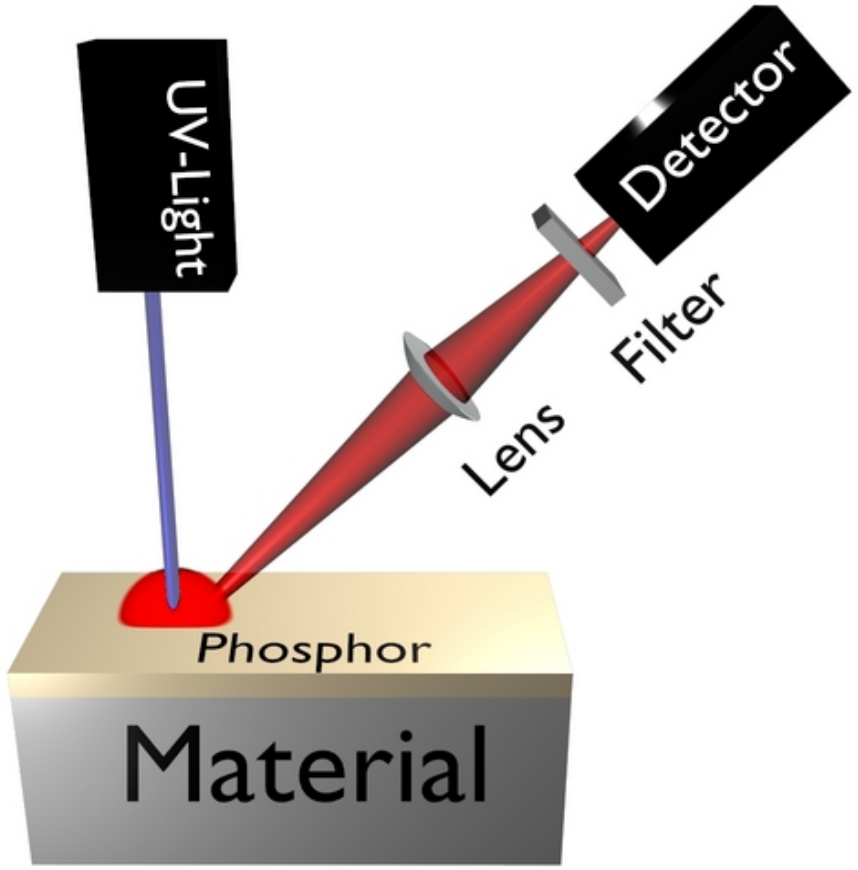
Thermographic phosphors

- Introduction/Background/Theory
- Thermometry methods
  - Temporal approach
  - Spectral approach
  - Calibration
  - 2D measurements
- Applications
  - Fires
  - Decomposing material
  - IC engines
  - Aero engines
  - Droplets/Sprays
  - SImultaneous velocity/temperatures

Thermographic phosphors for temperature measurements

- Industrial and scientific applications.
- Powder(1-10µm), sensitivity from cryogenic to 2000K.
- Excitation: UV (light), laser, e-beam.



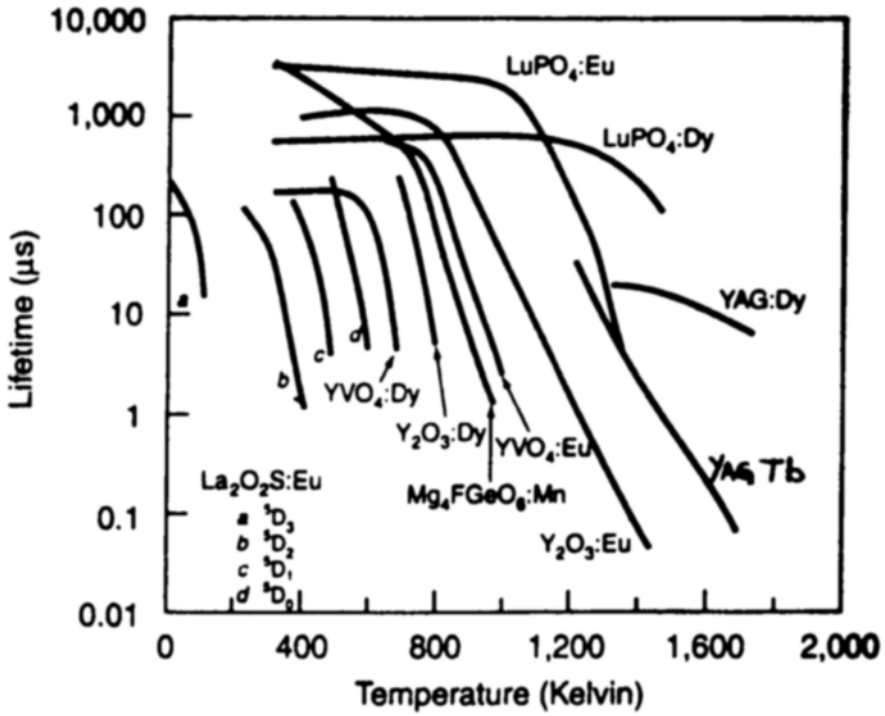
Physical description

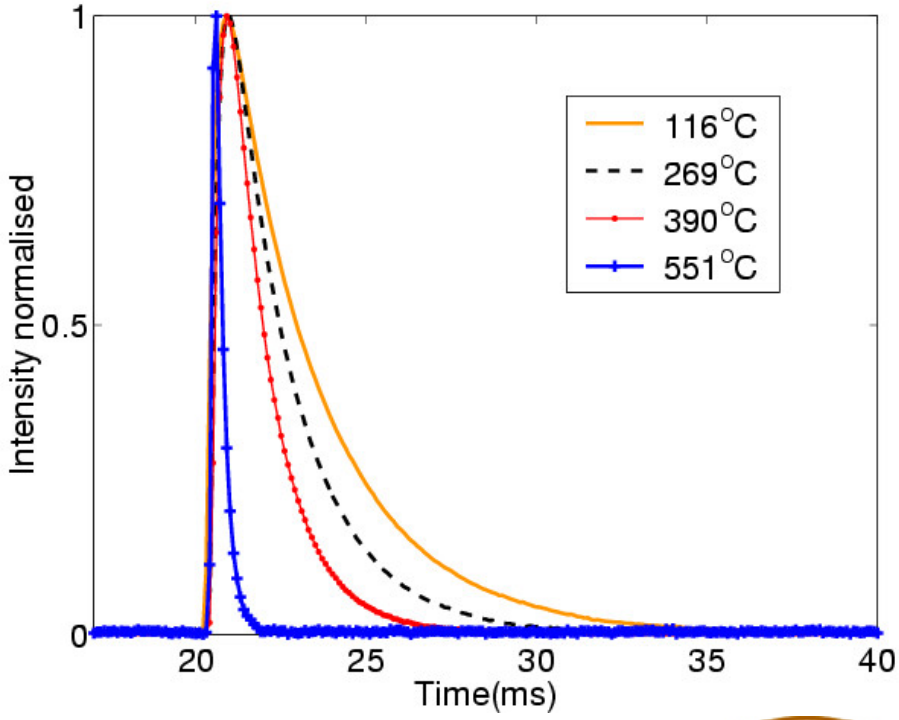
- Host inorganic material (ceramic) doped with and an activator (rare earth metal)~1 %.
- Host material transparent, laser energy absorbed by the activator.
- Through complex interactions in the electronic configuration of the activator and the host, temperature will influence the spectral and temporal behaviour of the emission

Thermometry Methods

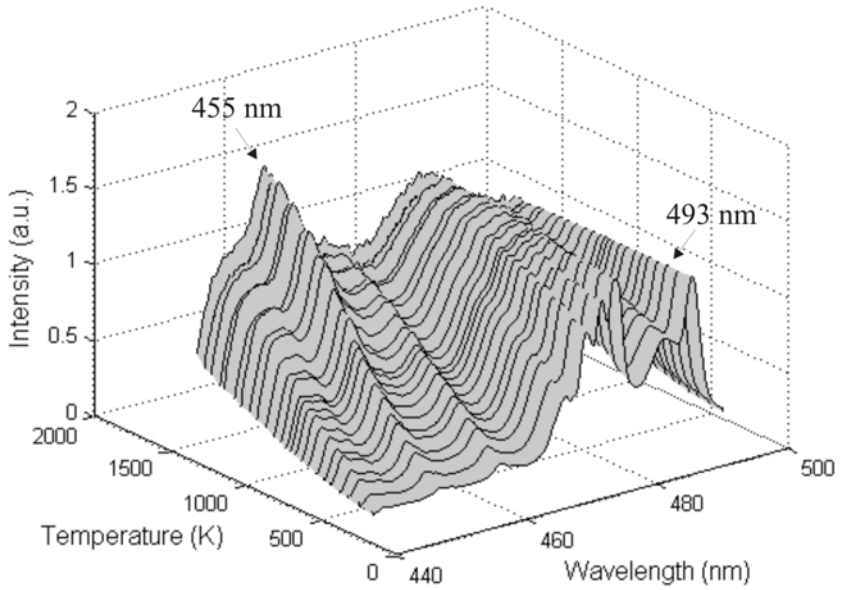
- Lifetime method: Decay time.
- Spectral method: Ratio between emission lines.
- Emission line shift and line broadning.
- Absorption
- Excitation

Lifetime method: Decay time

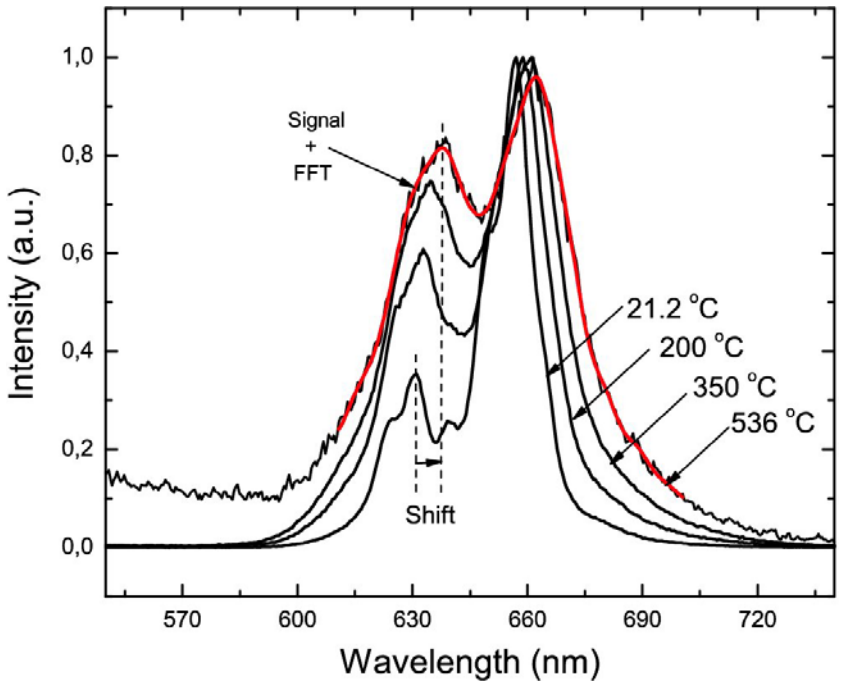




Spectral method: Ratio between emission lines.

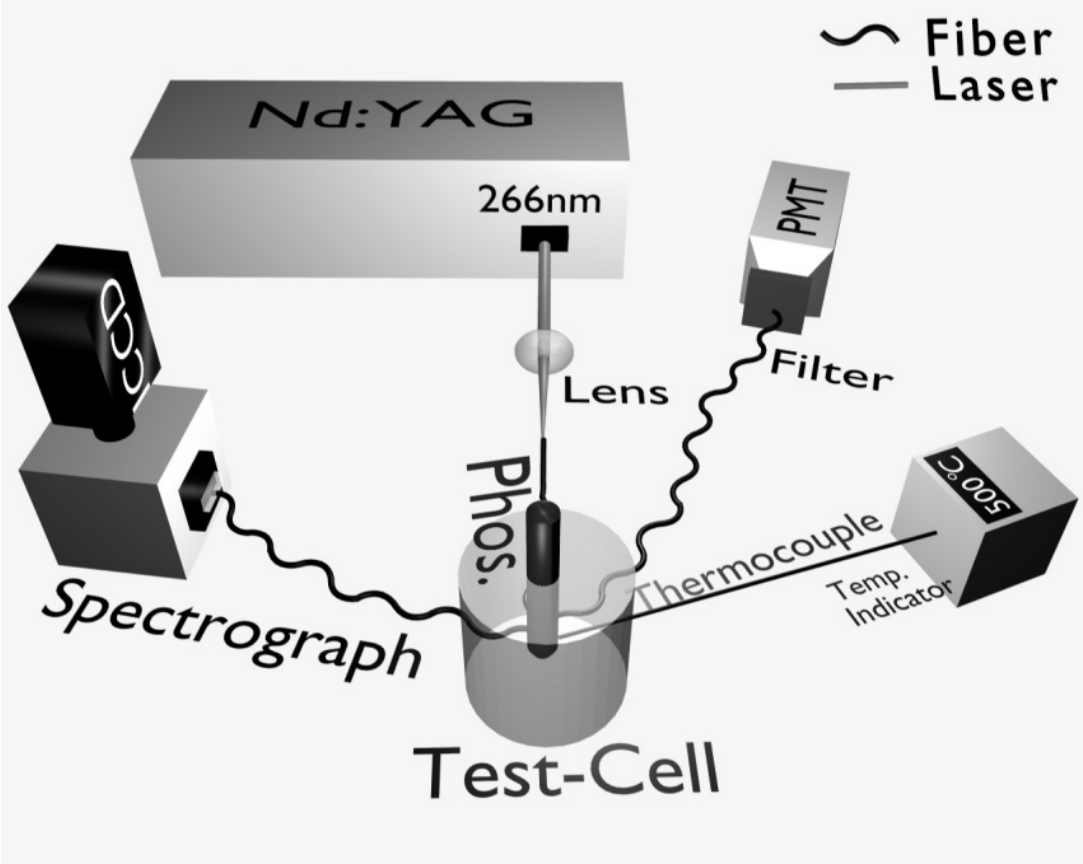


YAG : Dy

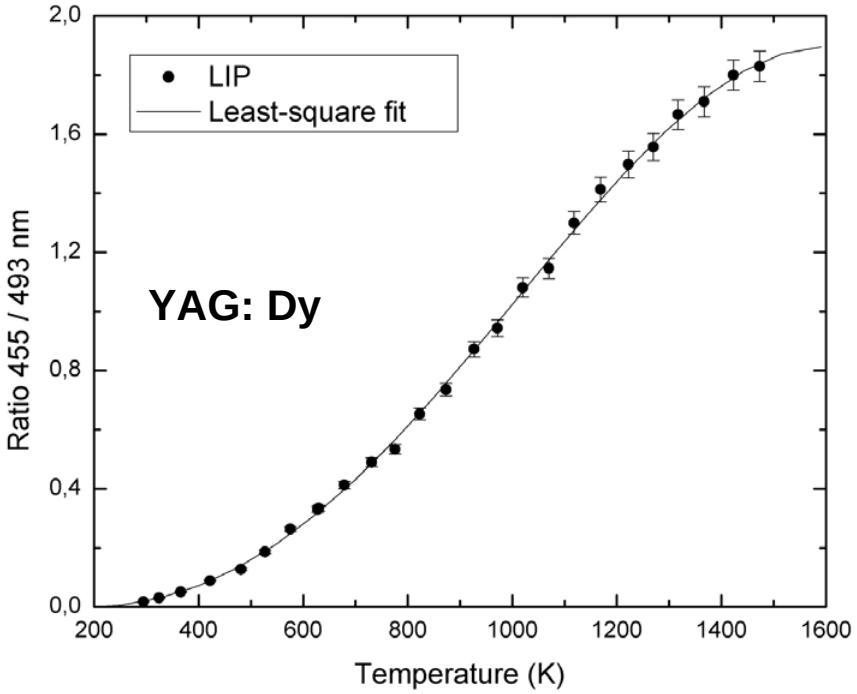


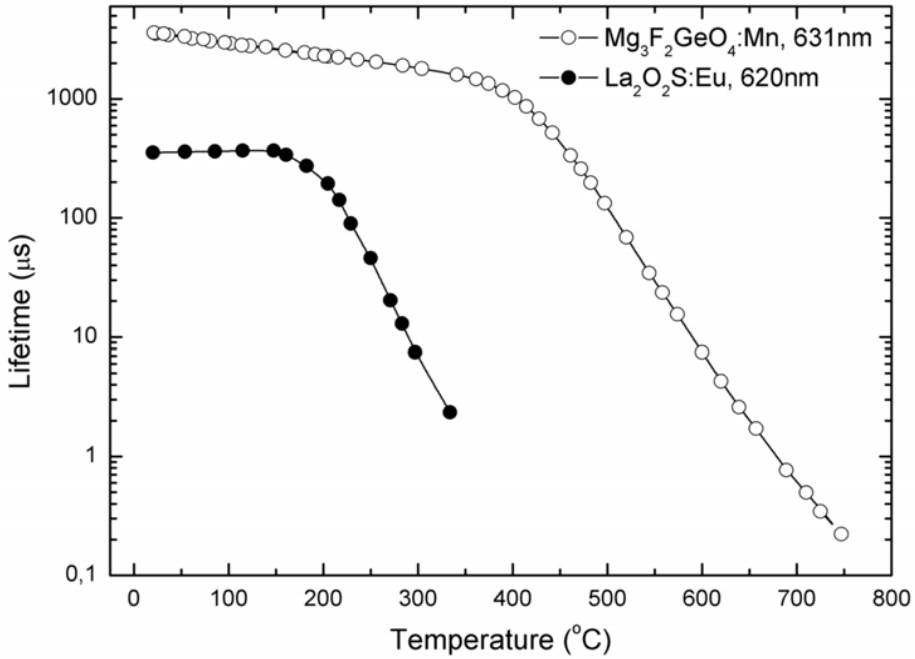
$Mg_3FGeO_4 : Mn$

Calibration procedures

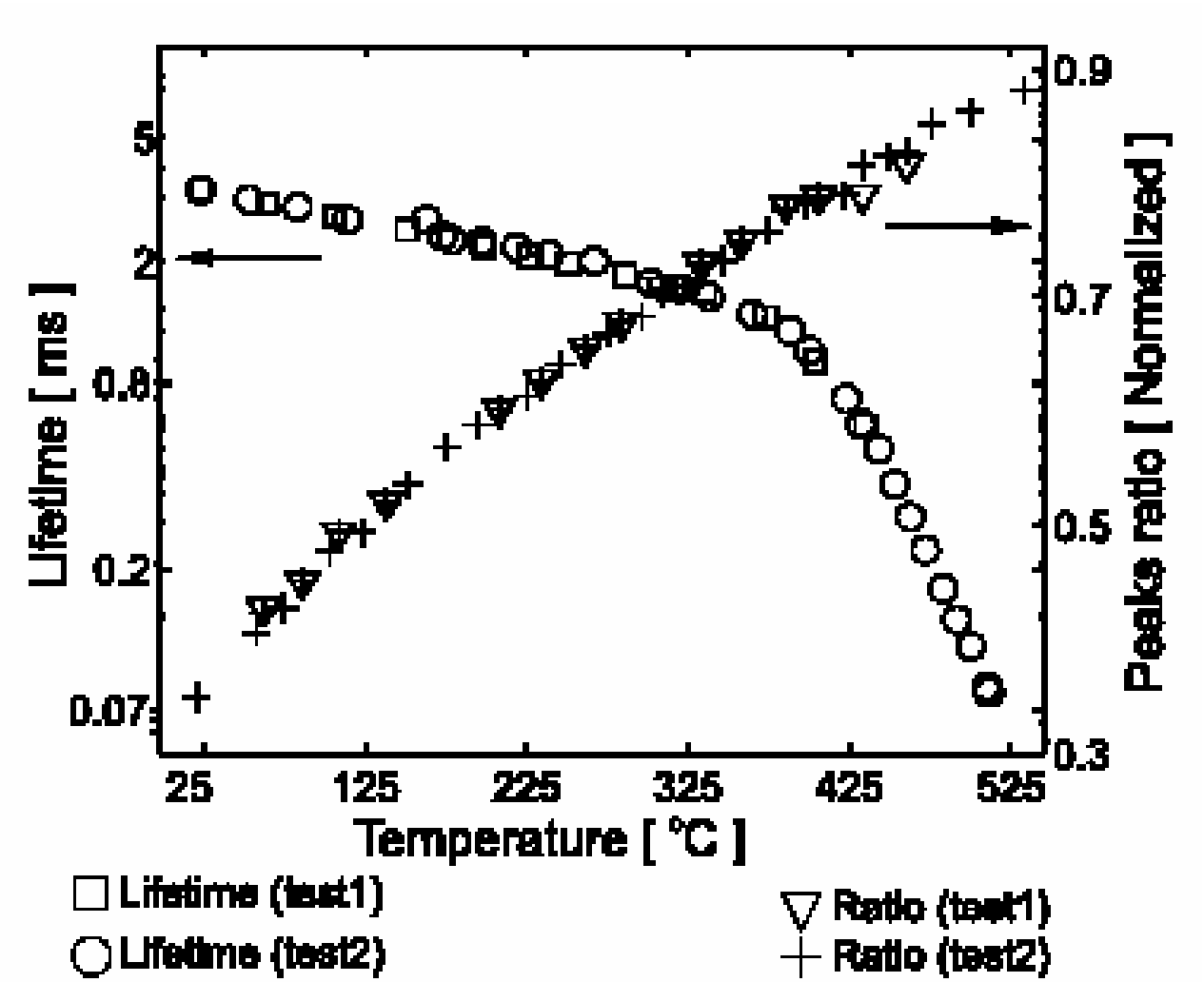


Calibration procedures

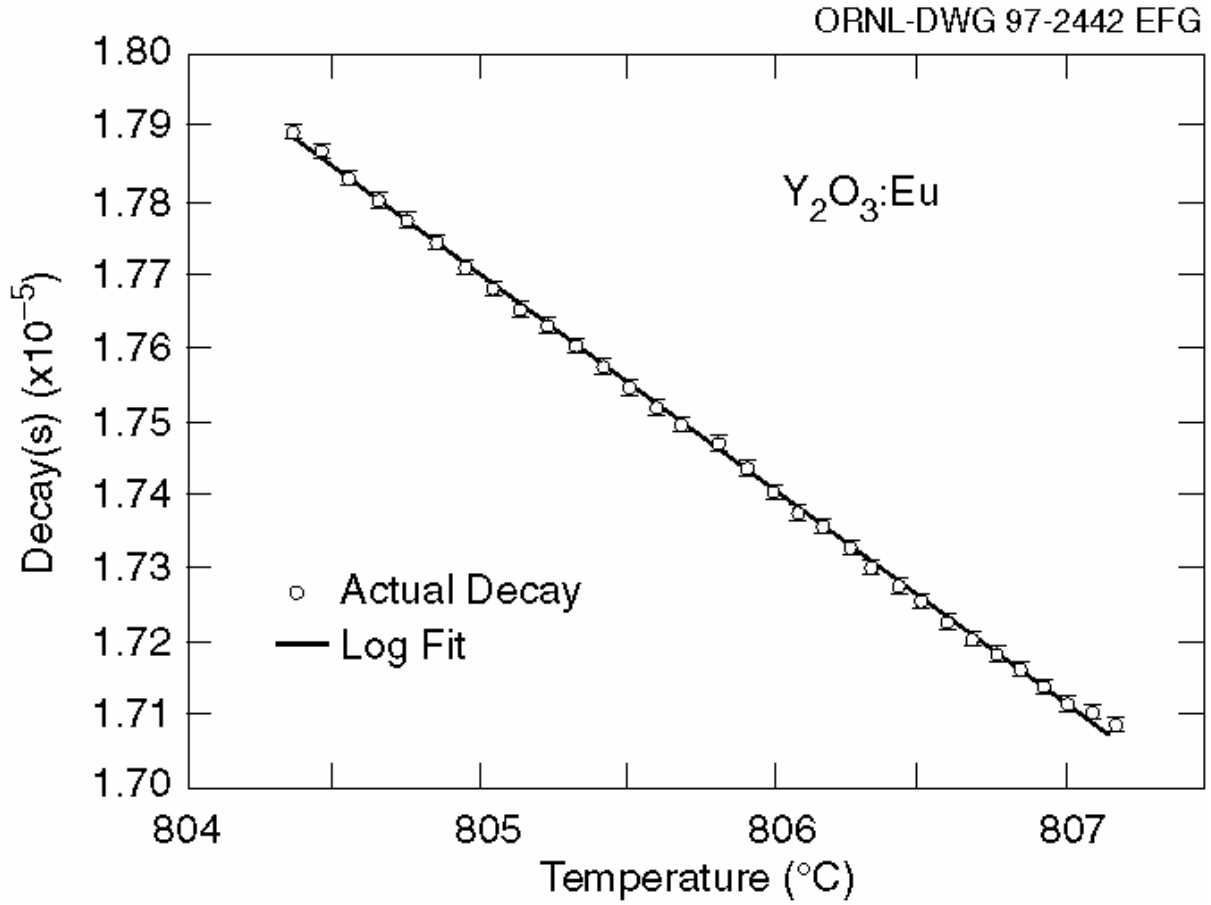




Calibration procedures

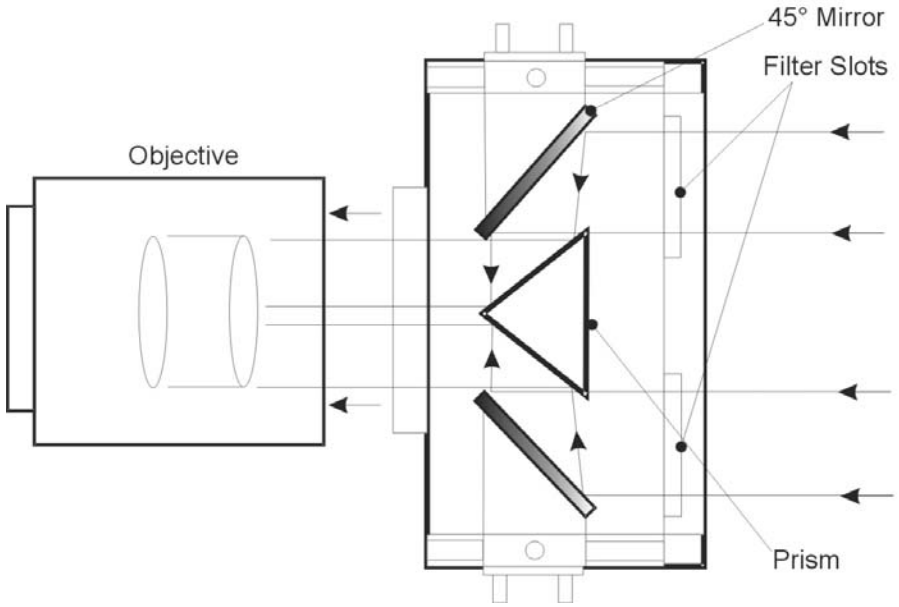


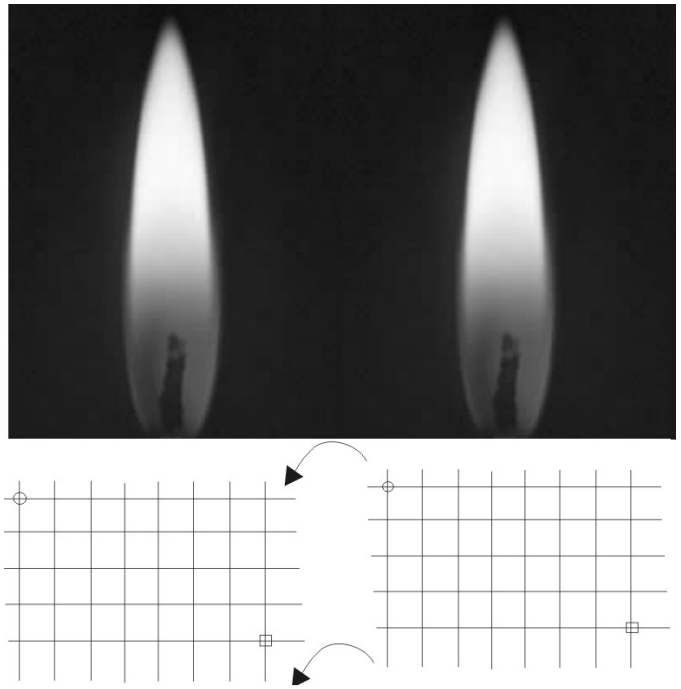
Precision limits are <10 mK for some phosphors and conditions



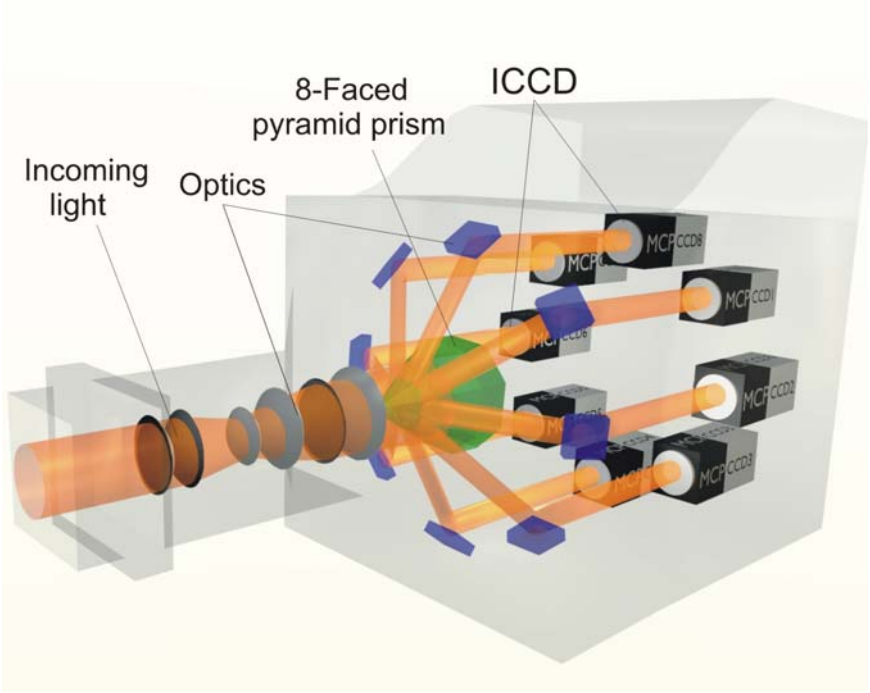
Cates, M.R., et al "Ultra High Precision Phosphor Thermometry Near 1100 K," *Proceedings of The 8th Symposium on Temperature, Chicago, IL USA, NIST, American Institute of Physics (AIP), College Park, MD USA, 10/21/2002-10/24/2002.*

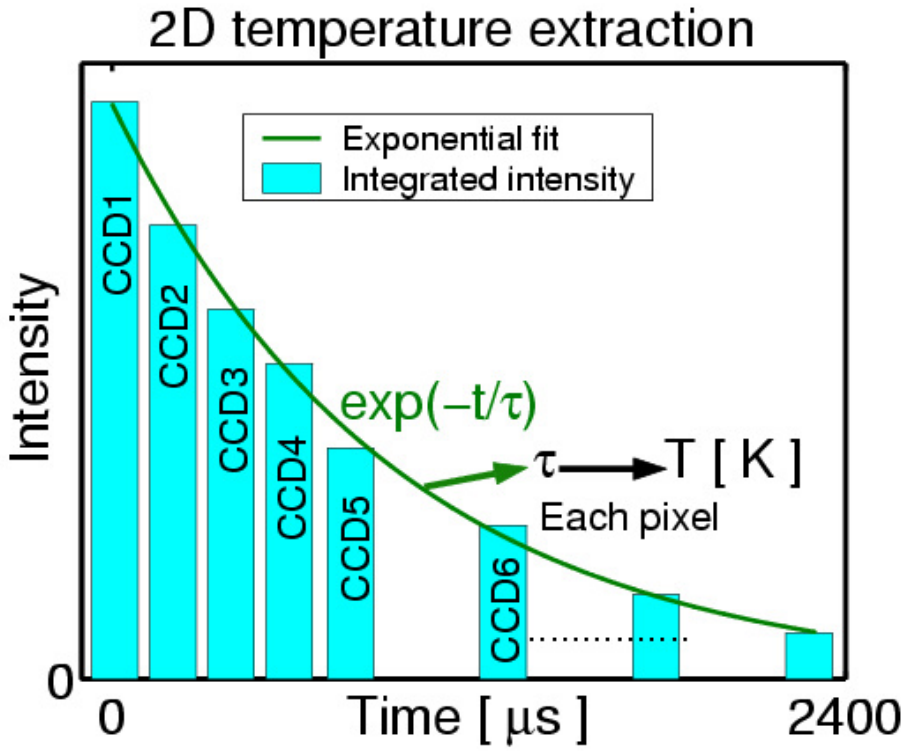
2D measurements: Spectral method



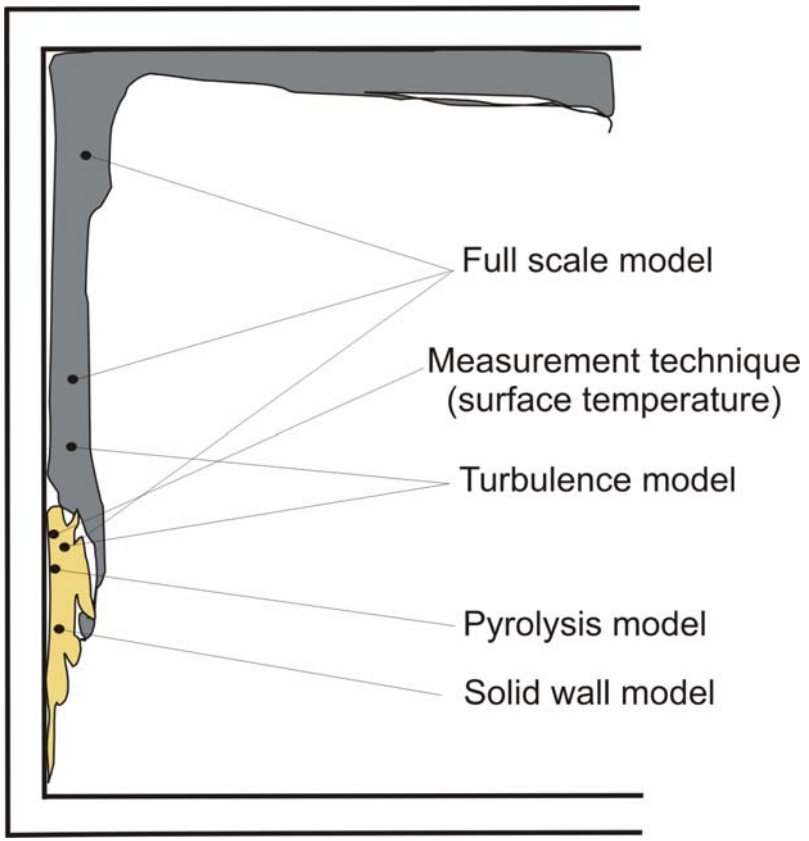


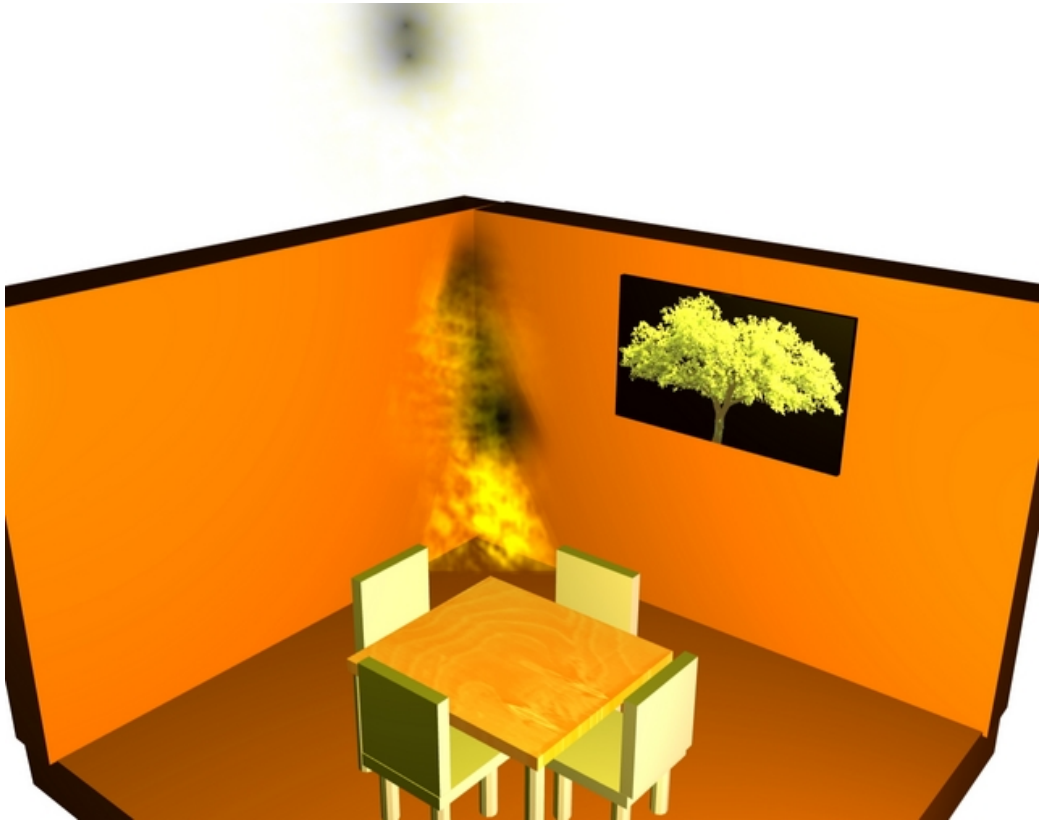
2D measurements: Temporal method



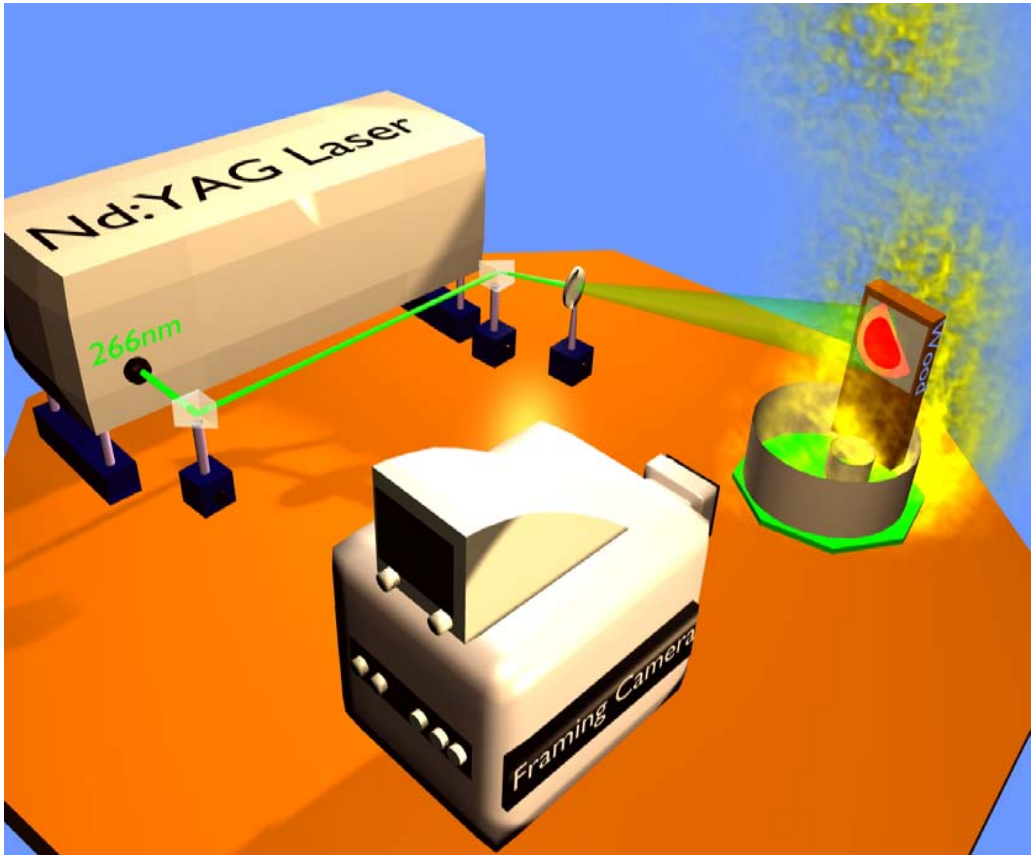


Application 1: Fire studies



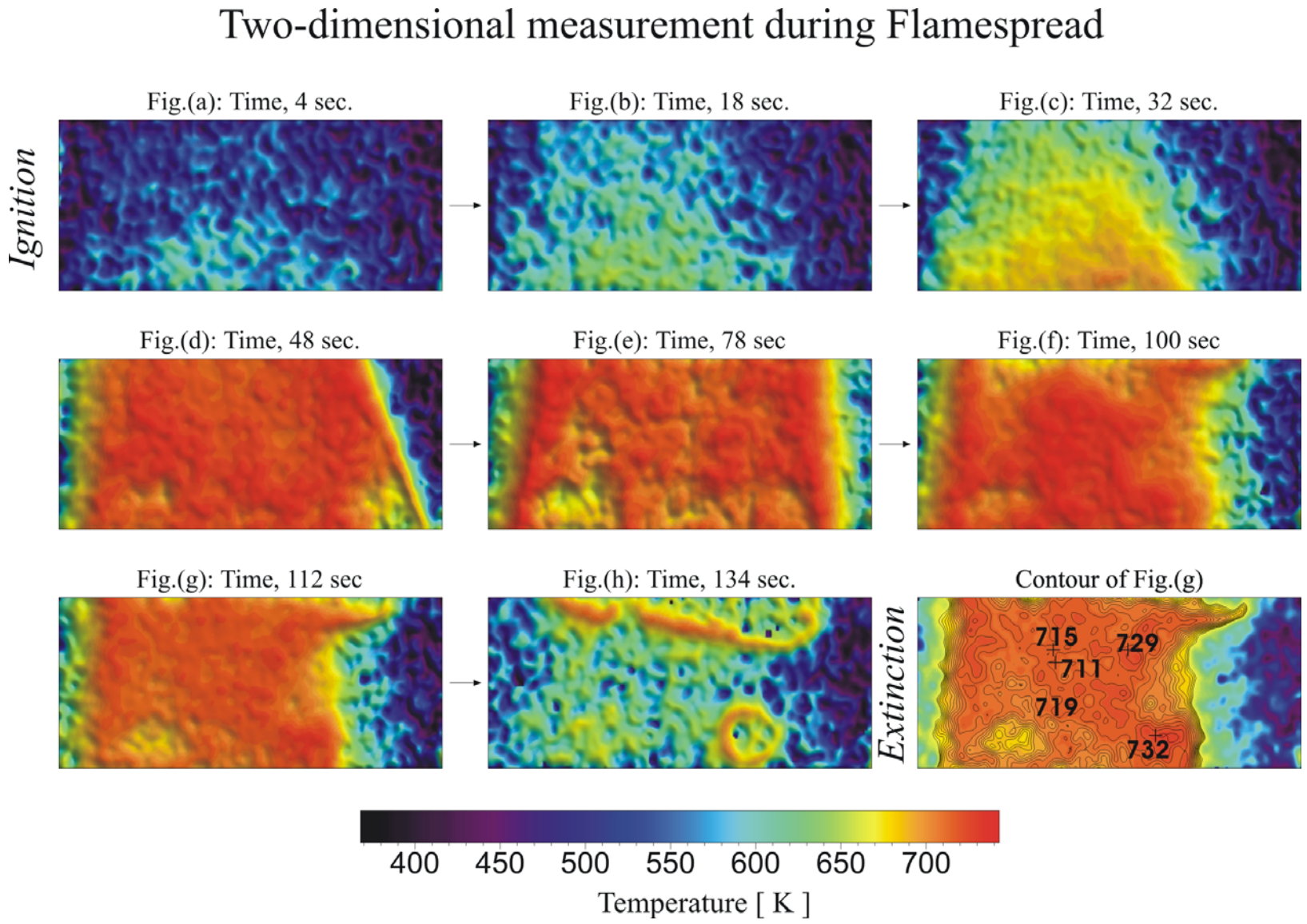


Experimental setup

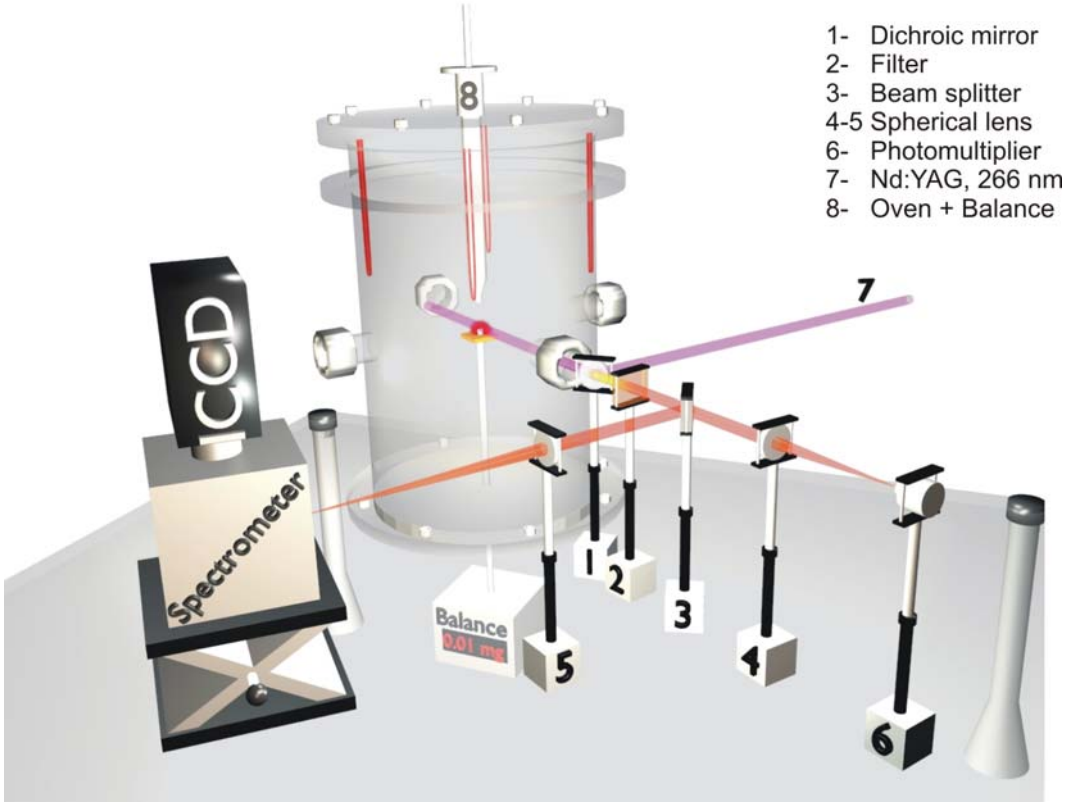


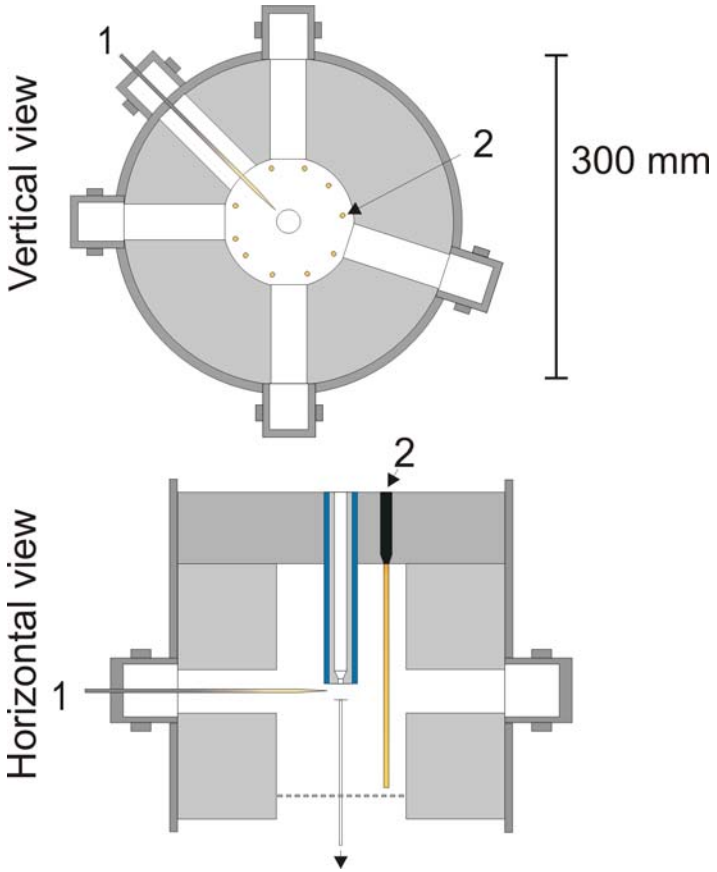
- Excitation 266 or 355 nm
- Fuel: Alcohol and Heptane.
- Detection: Framing Camera.
- Material: LDF and PMMA.

Results

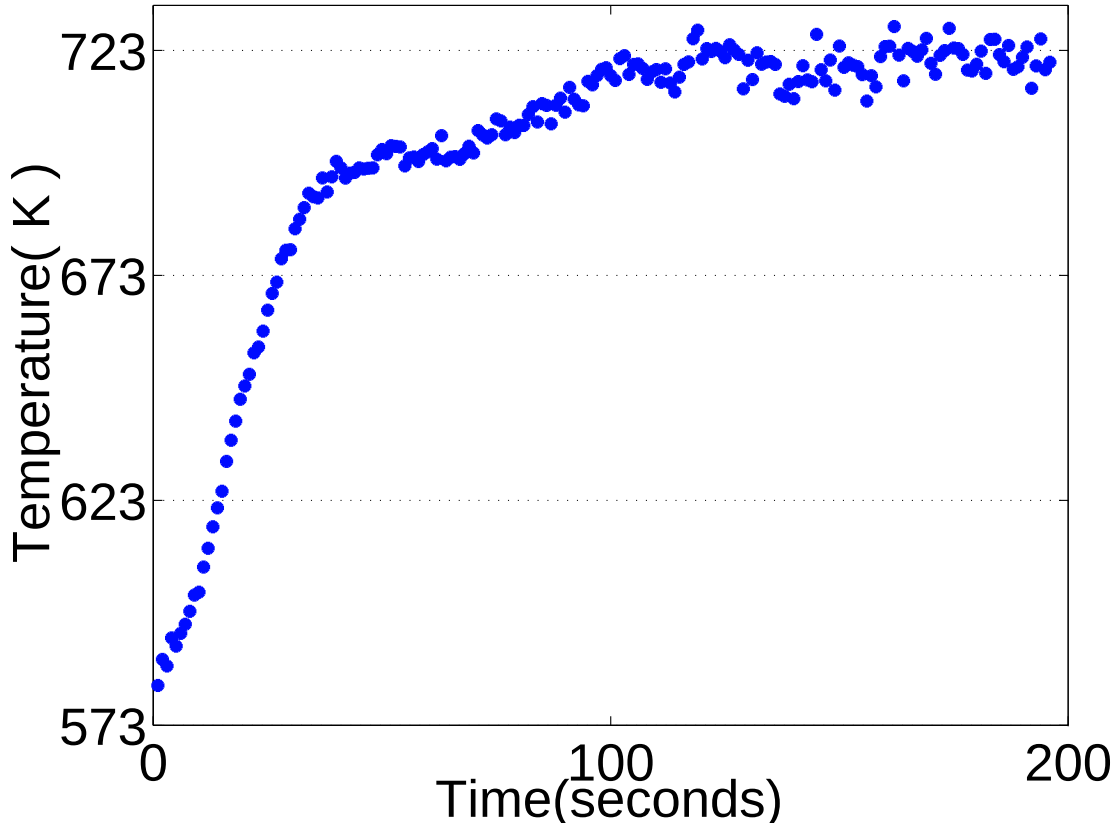

Two-dimensional measurement during Flamespread
Fig.(a): Time, 4 sec.
Fig.(b): Time, 18 sec.
Fig.(c): Time, 32 sec.
Ignition
Fig.(d): Time, 48 sec.
Fig.(e): Time, 78 sec
Fig.(f): Time, 100 sec
Fig.(g): Time, 112 sec
Fig.(h): Time, 134 sec.
Contour of Fig.(g)
Extinction
715
729
711
719
732
400
450
500
550
600
650
700
Temperature [K]

Application 2. Decomposing material

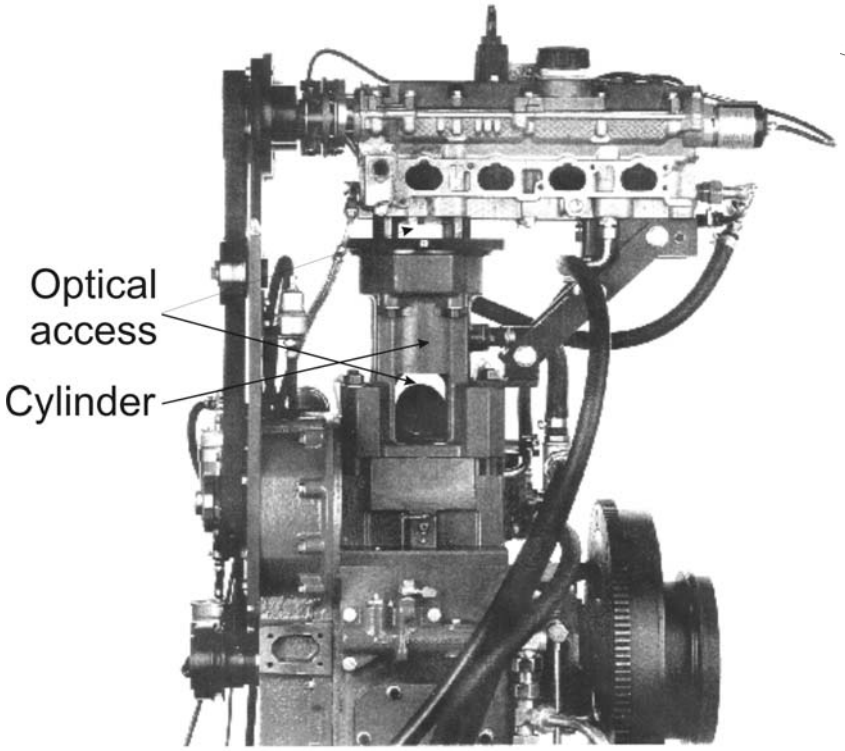


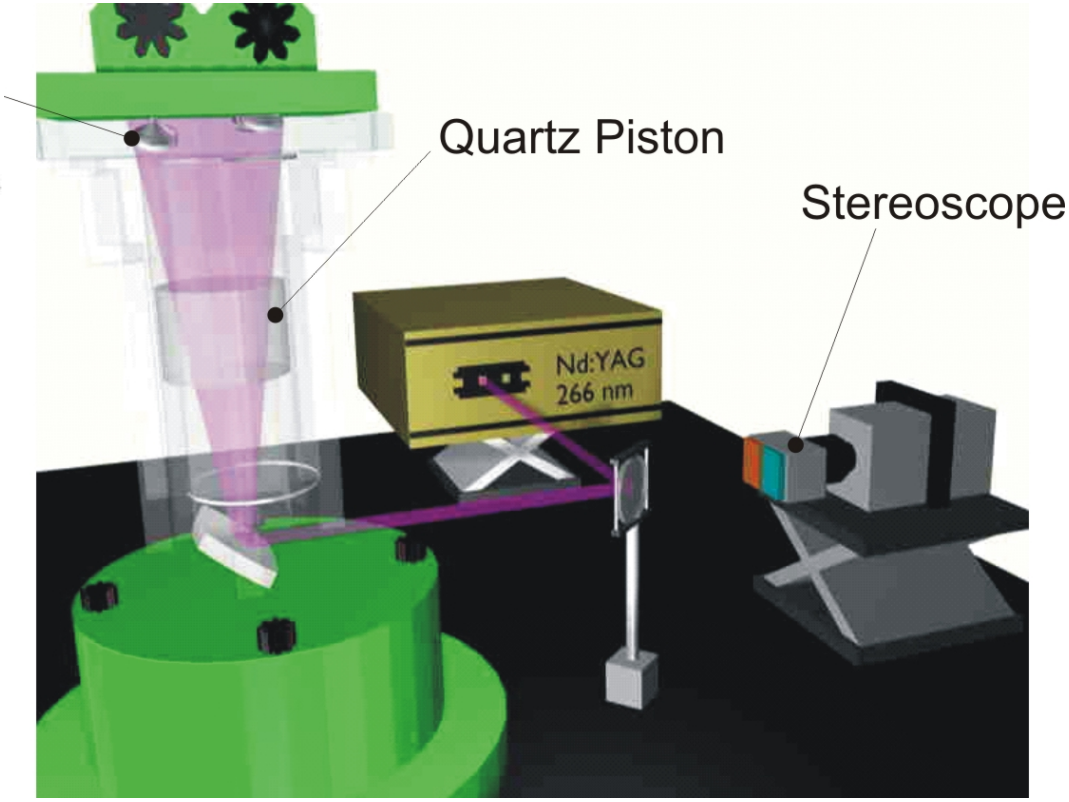


Surface temperature of a woodparticle during pyrolysis

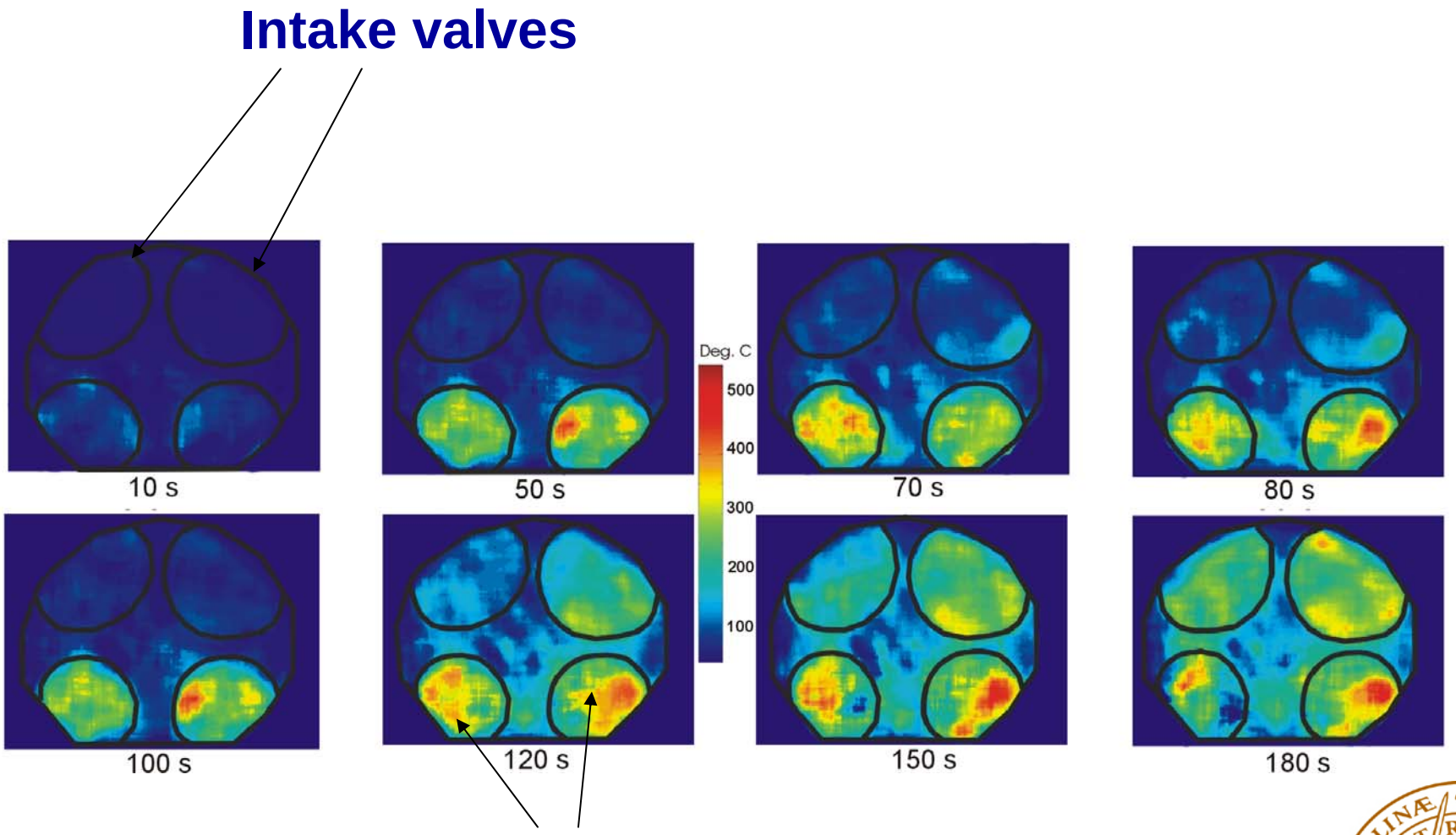


Application 3: IC engines

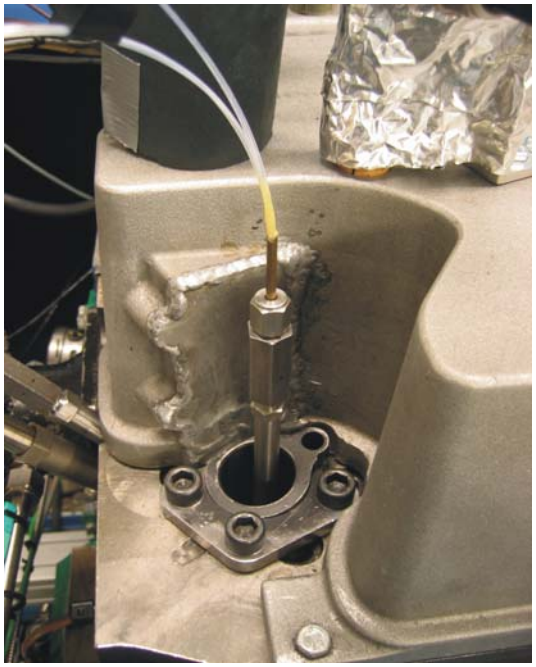


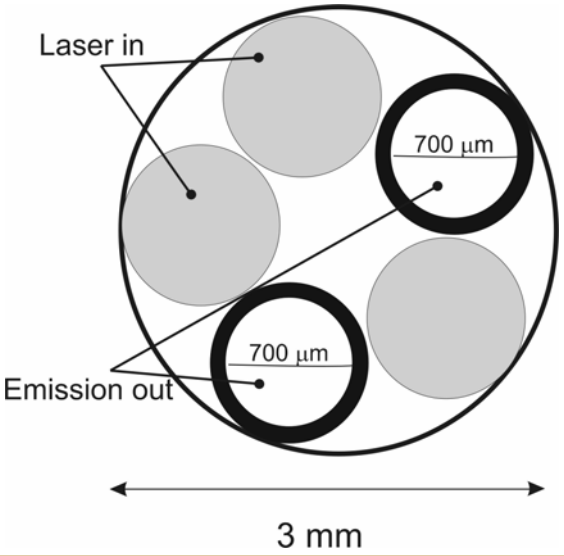


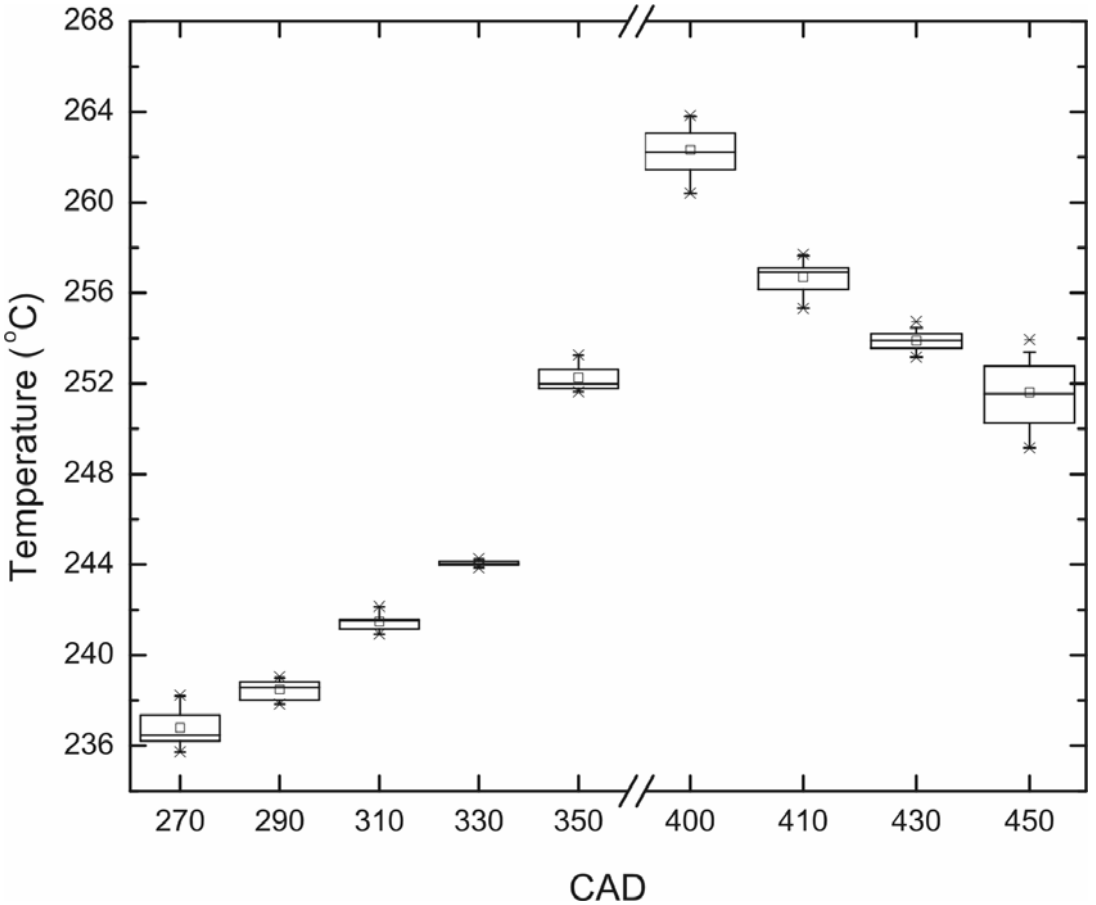
Results


Intake valves
10 s
50 s
70 s
80 s
Deg. C
500
400
300
200
100
100 s
120 s
150 s
180 s
Exhaust valves

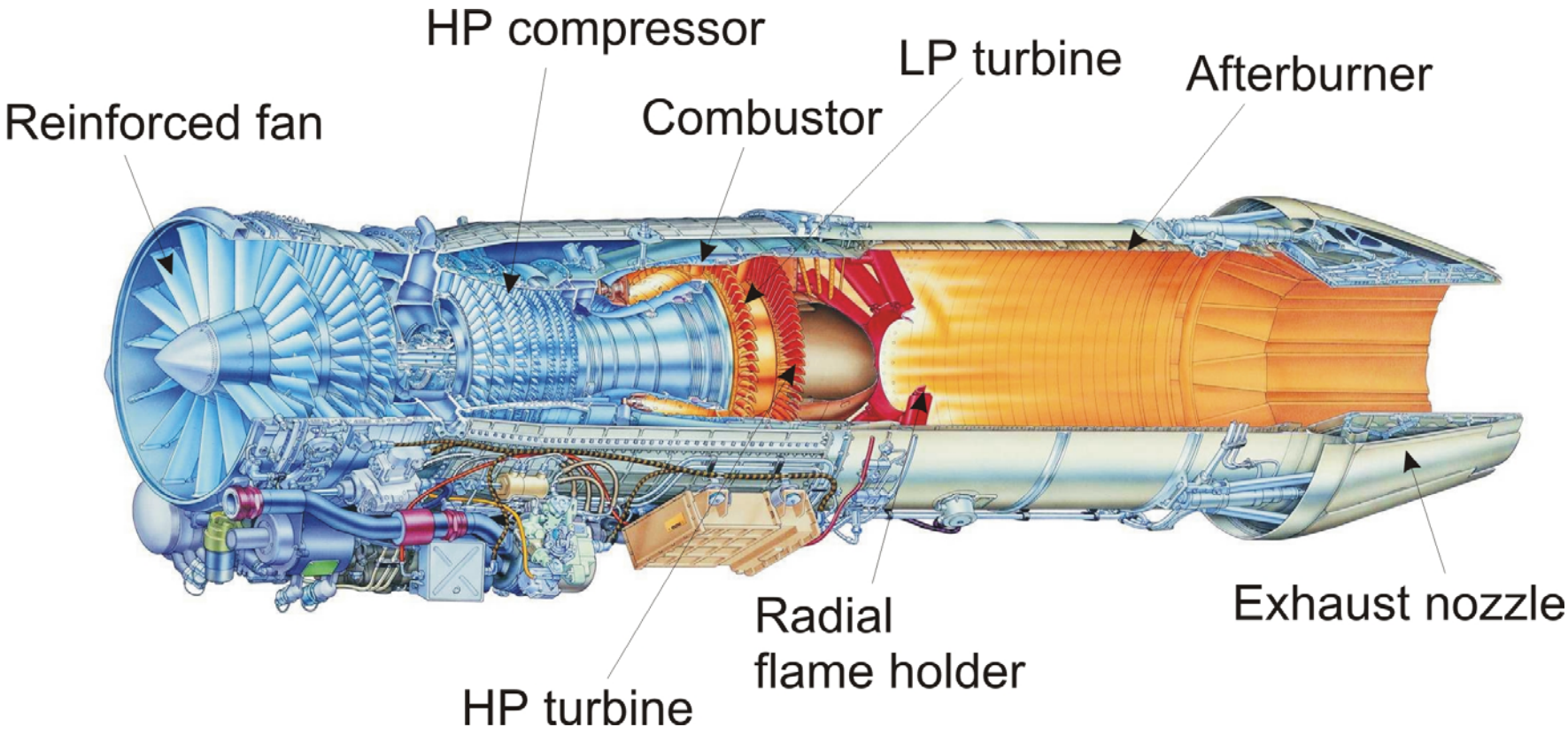
Surface measurements in a “production” diesel engine using thermographic phosphors and optical fibers





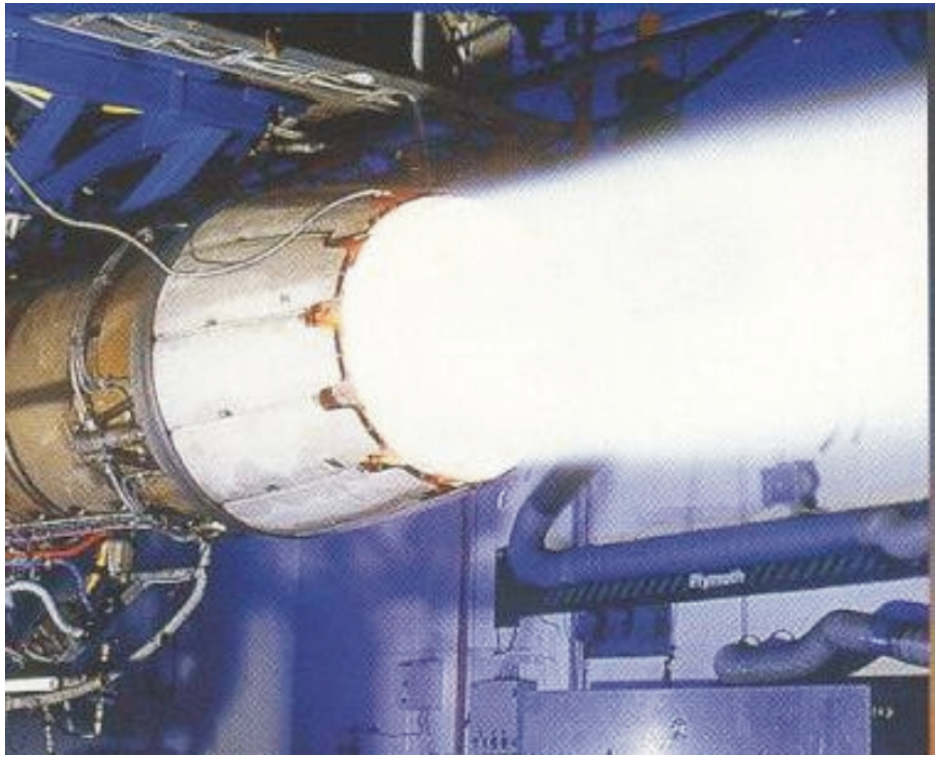


Application 4: Aircraft engine

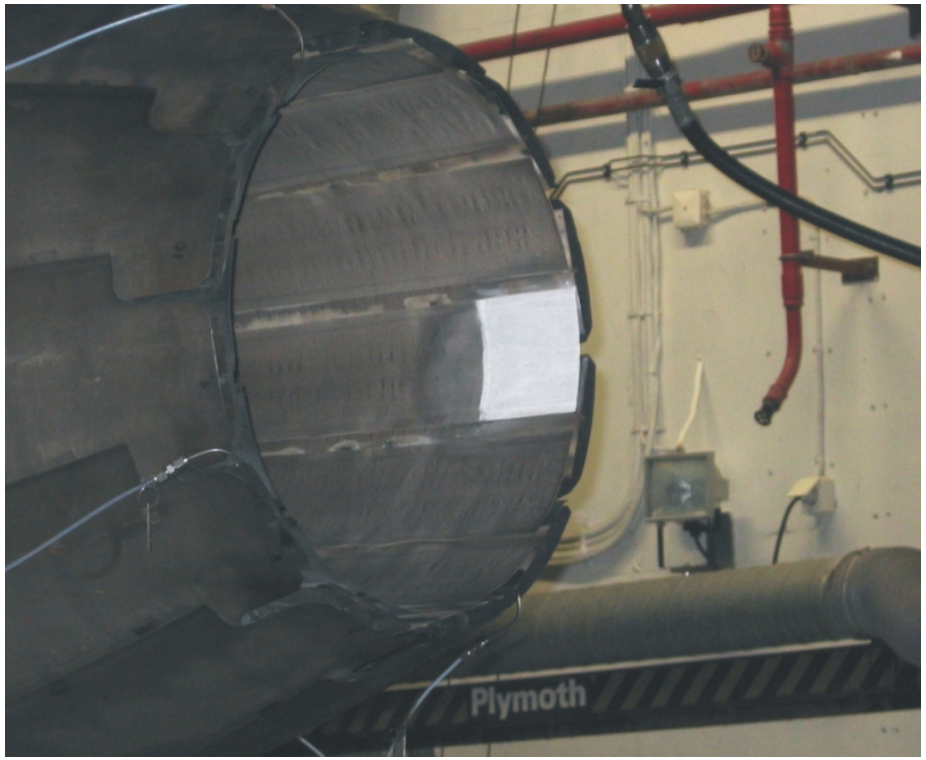


Experimental

Engine at full load



Investigated Surface

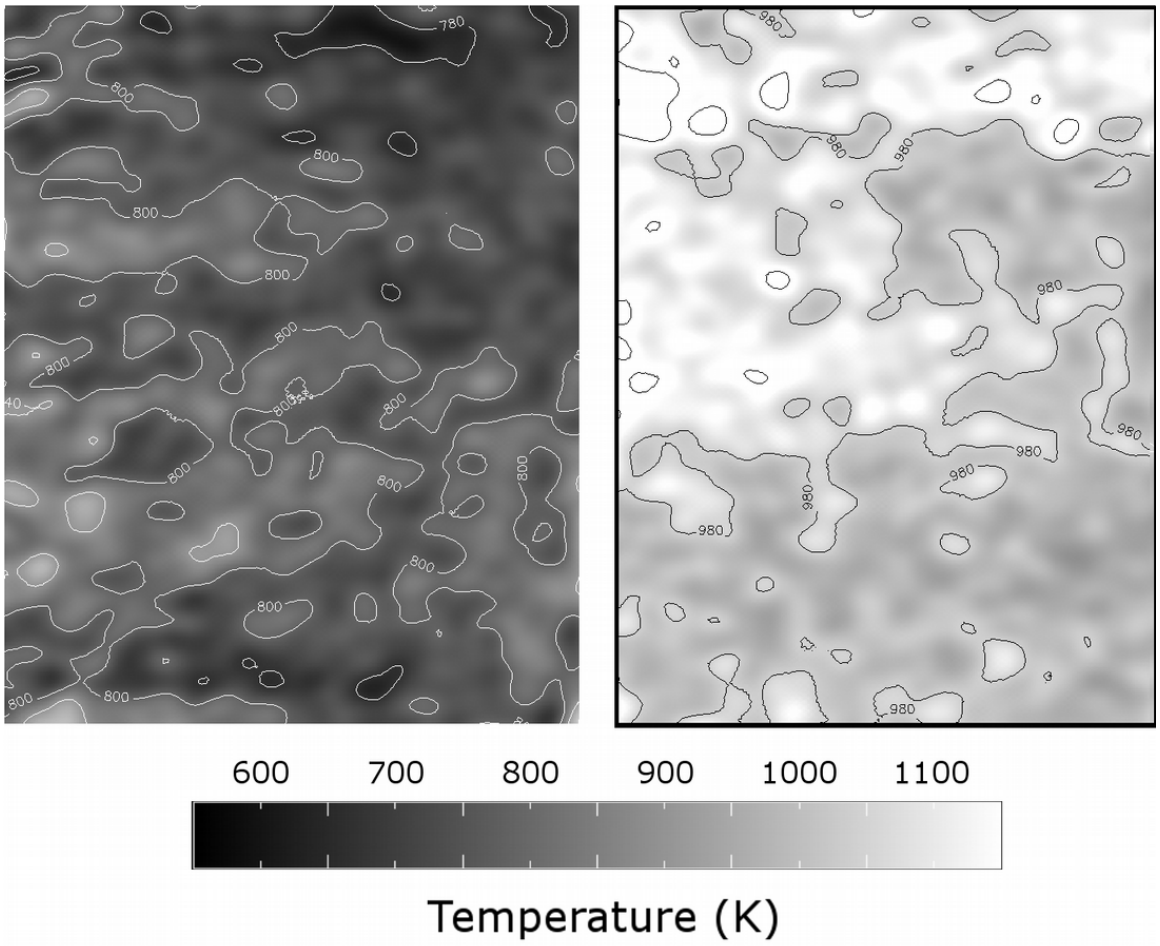


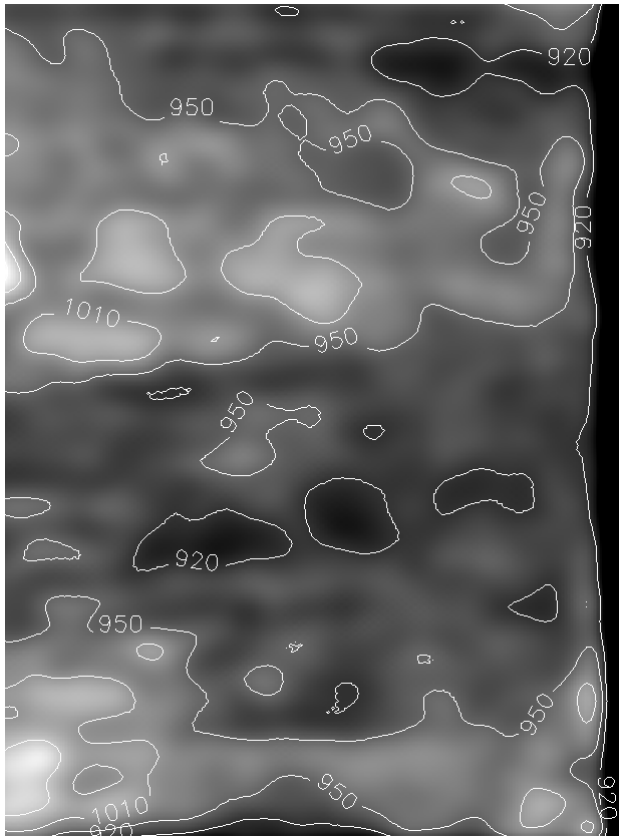
- Use of YAG:Dy
- Excitation at 355 nm
- Emission at 458 and 493 nm

Experimental

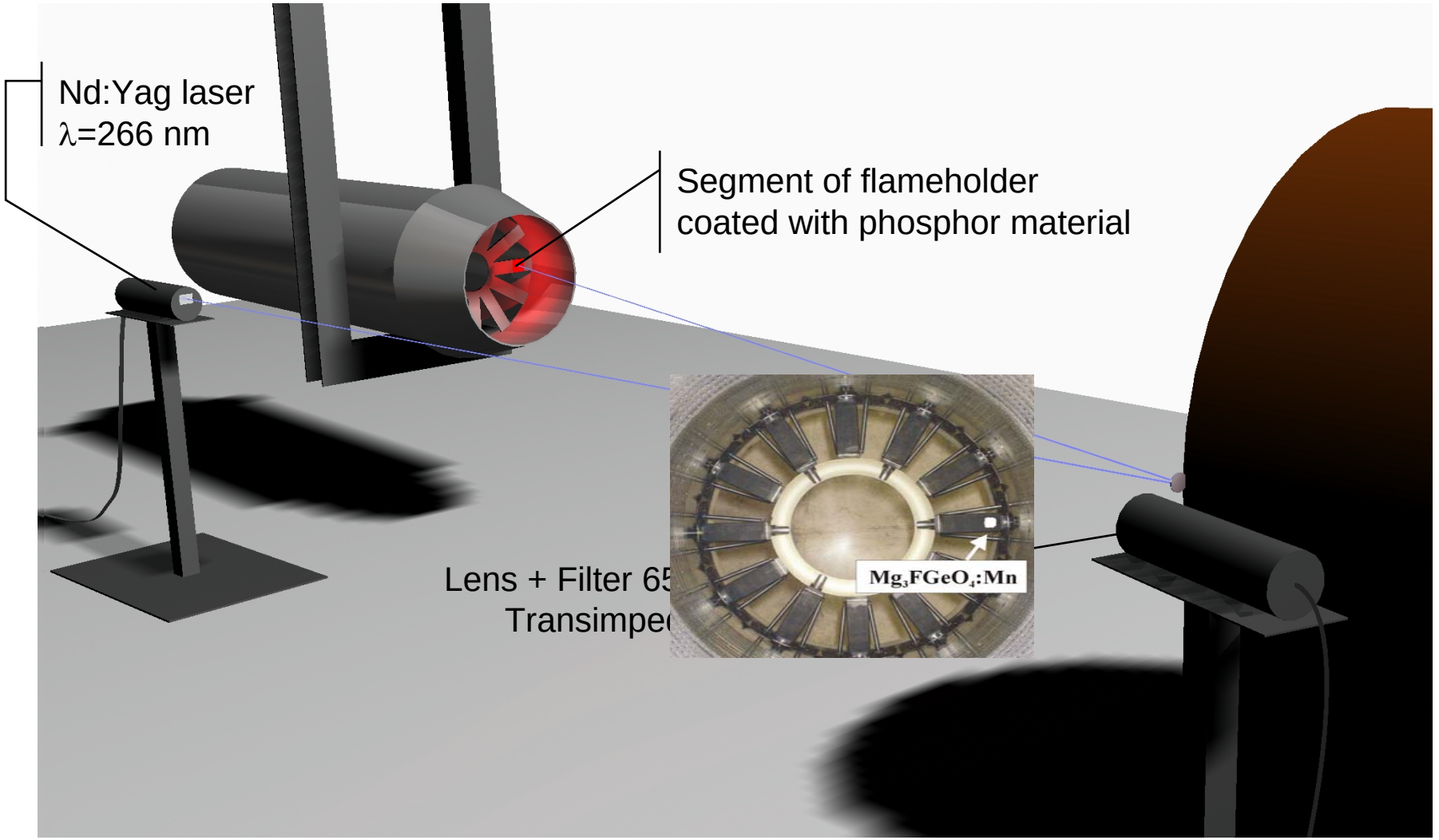
Single Shot

Averaged Temperature Image





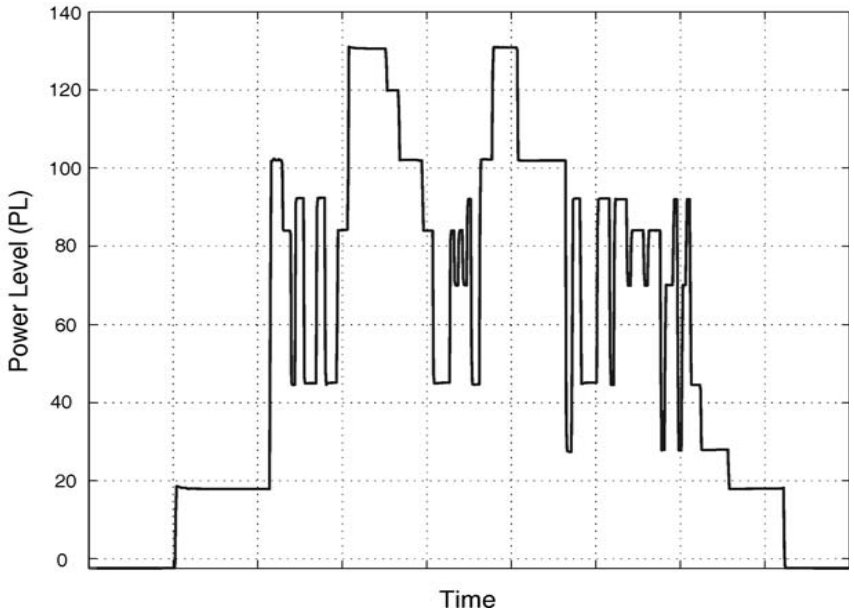
Experimental arrangement



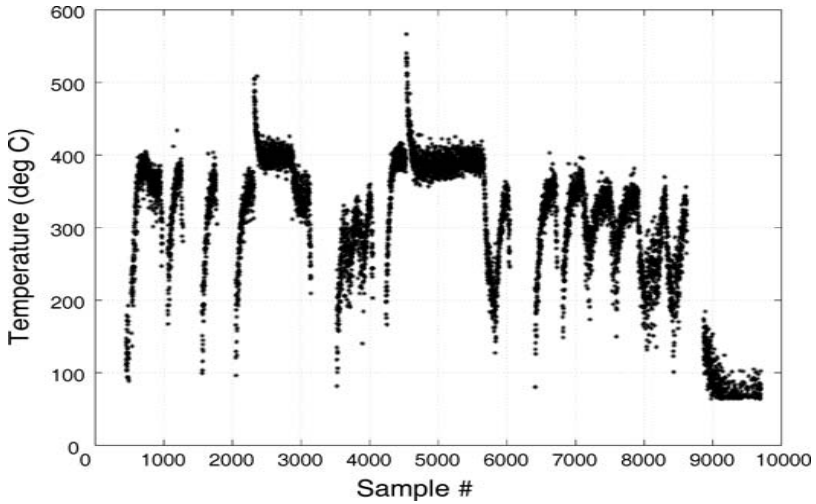
Results

Temperature data (lifetime decays) was recorded at the repetition rate of the excitation laser (10 Hz).

Signals were sampled using a 1 GHz bandwidth oscilloscope (LaCroy).

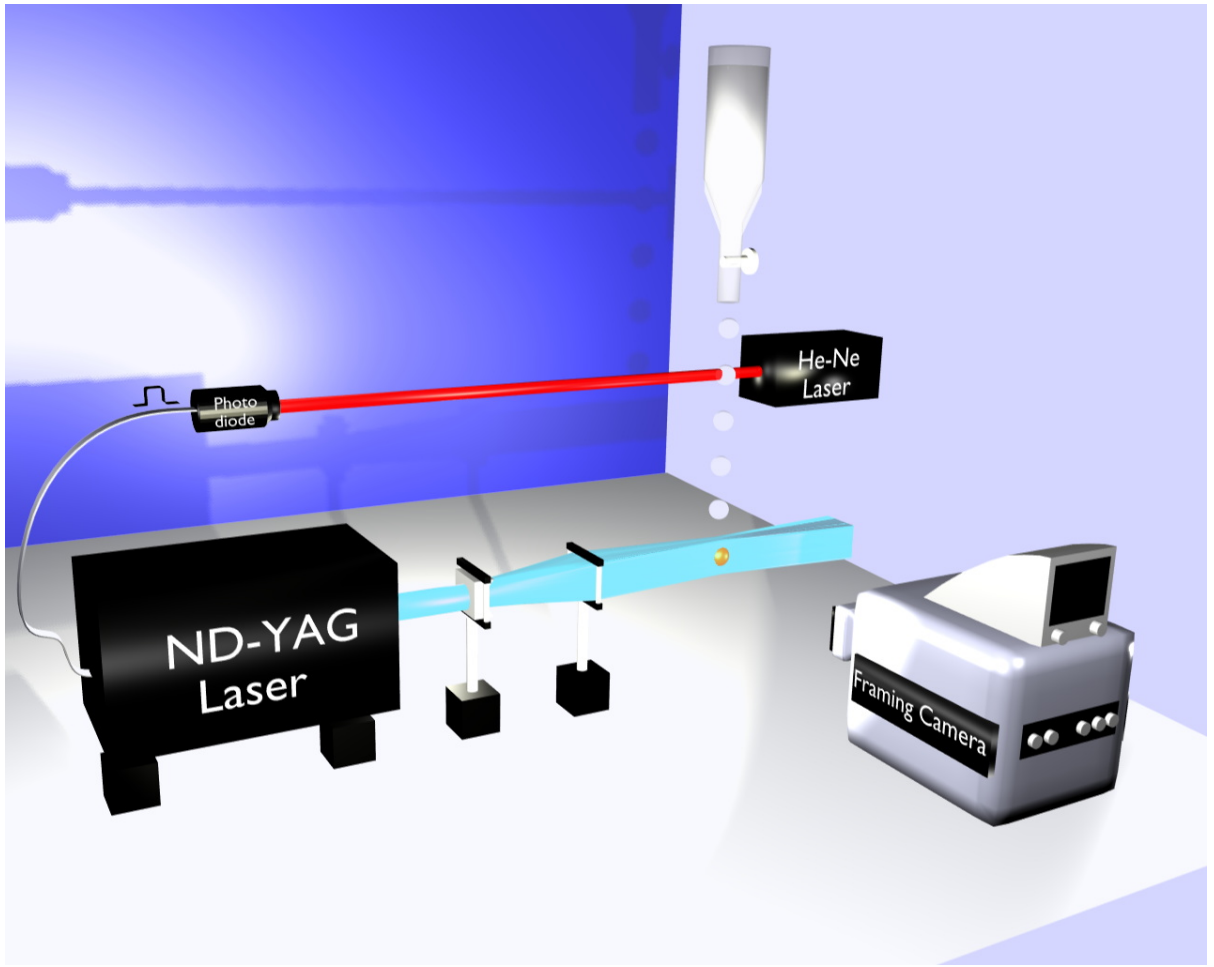


Power Level (PL) versus time for test cycle B.

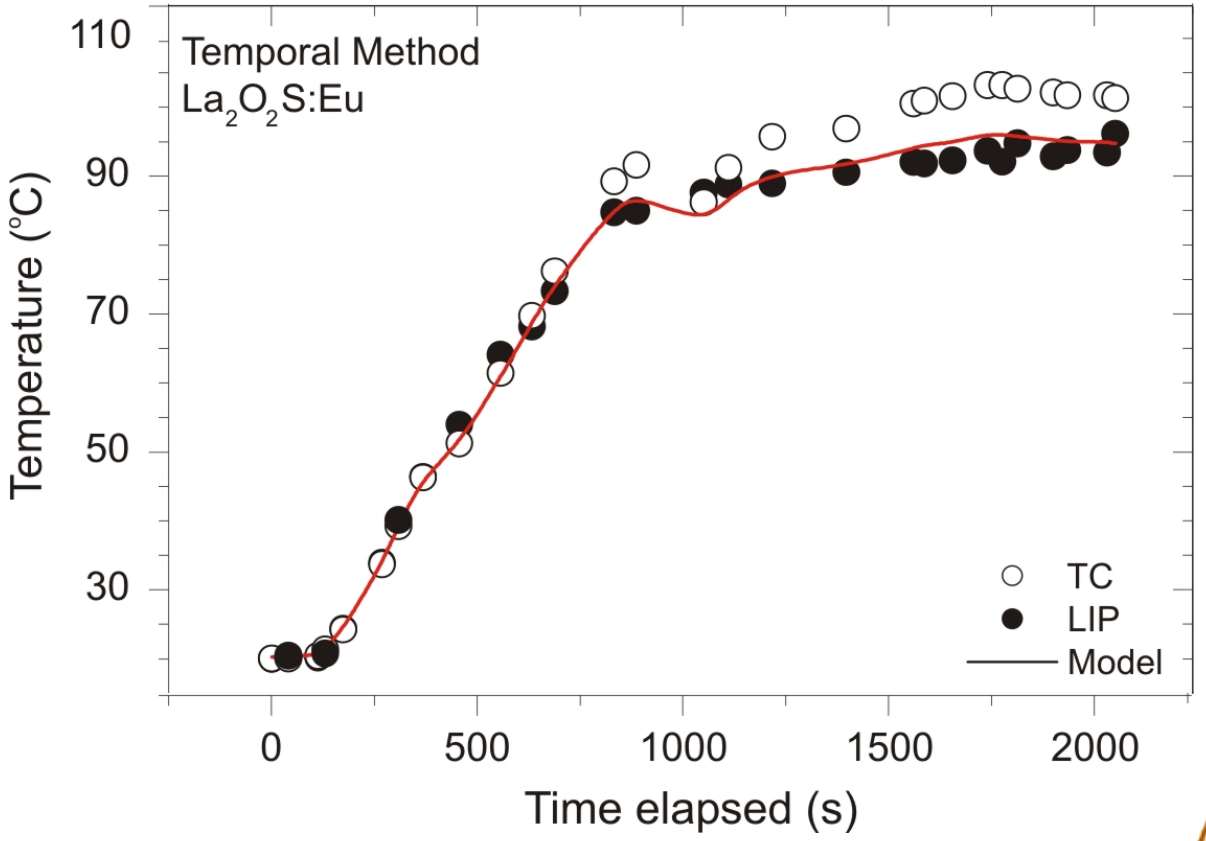


Temperature data measured for test cycle B.

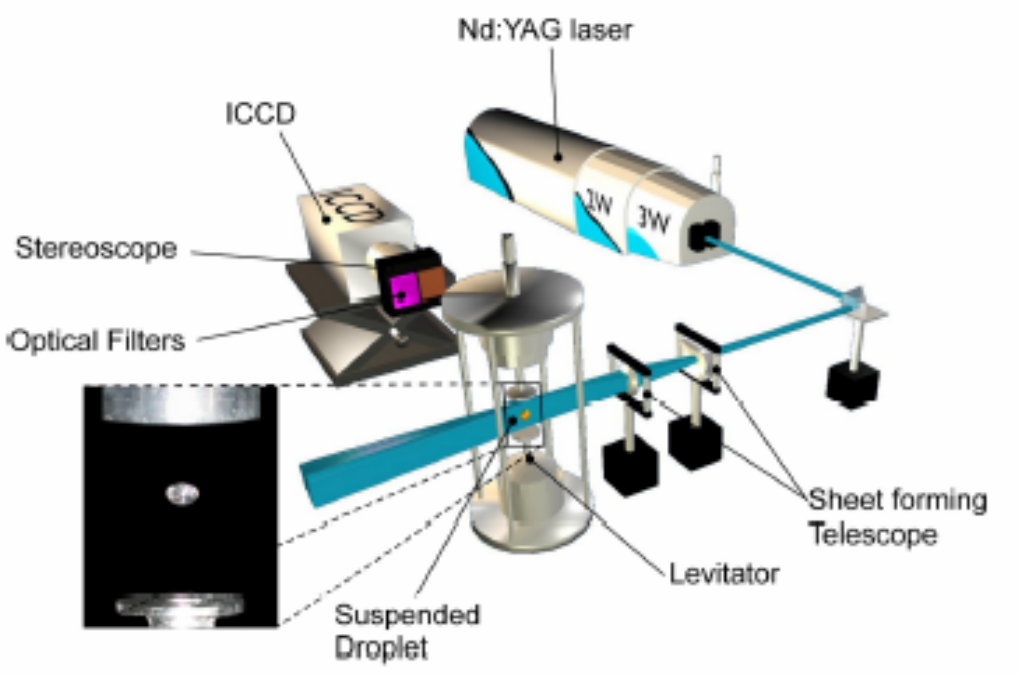
Application 5: Droplet/spray

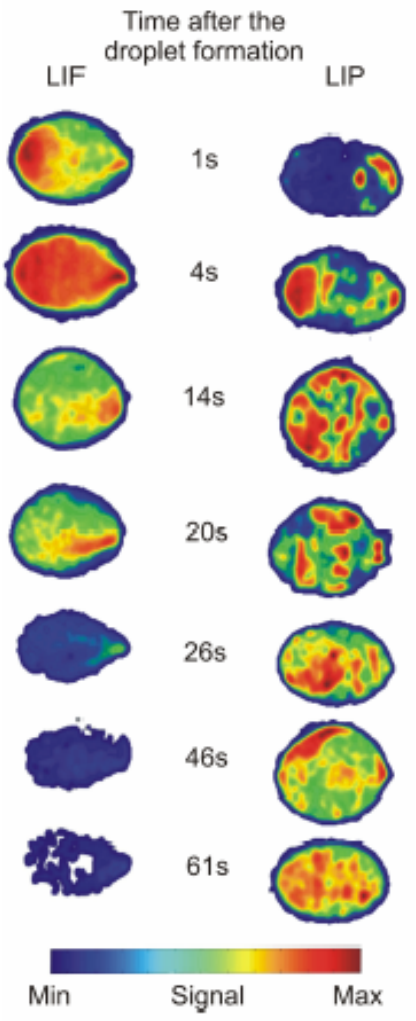


One-point measurements

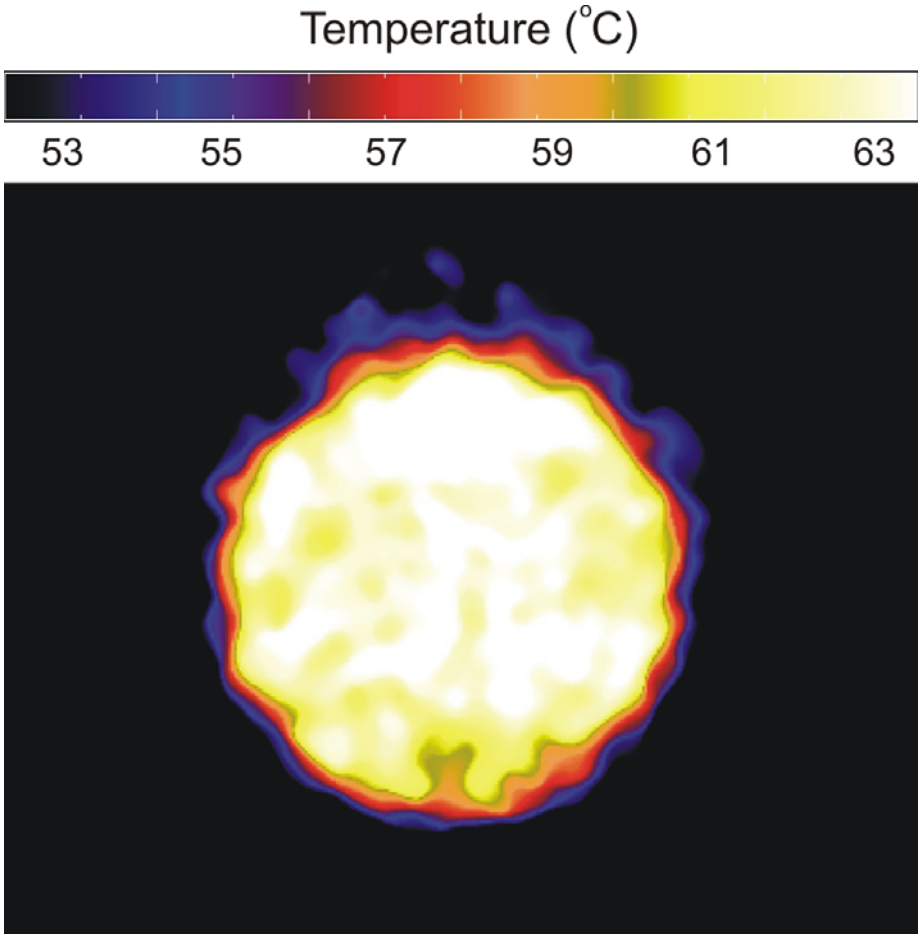


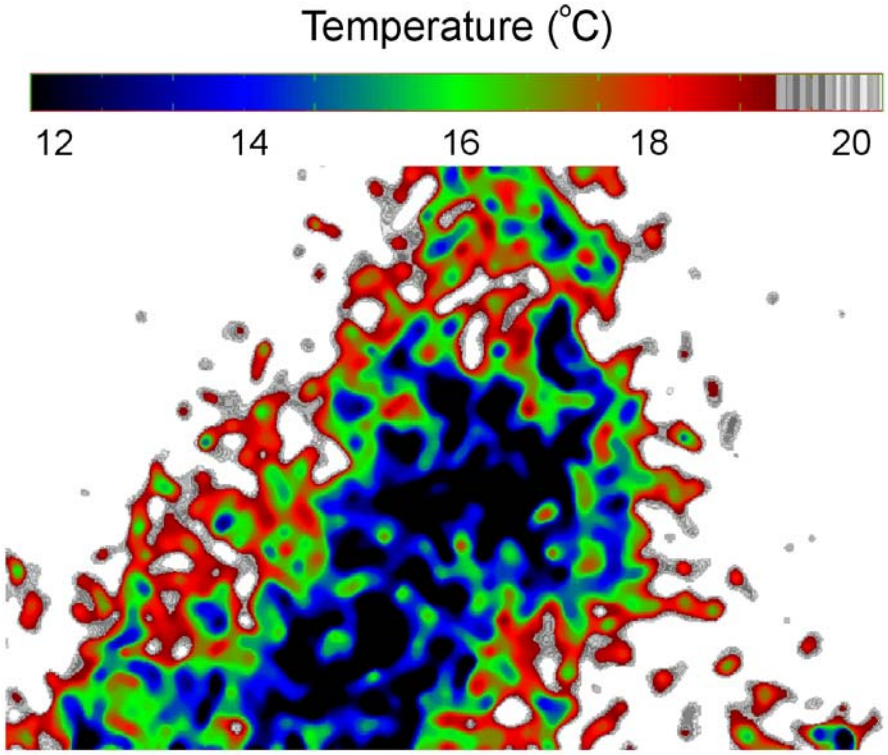
Droplets in acoustic levitation



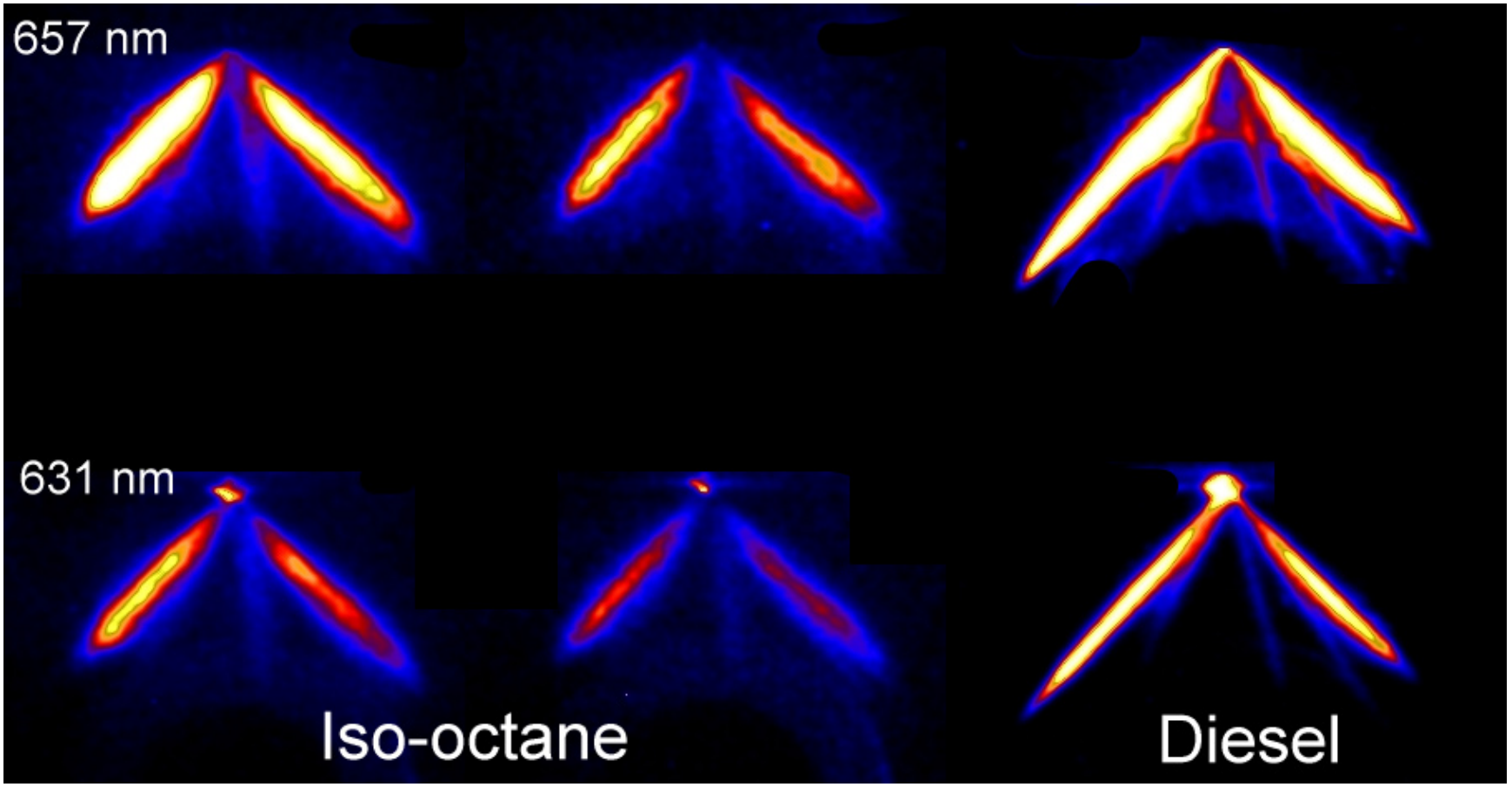


Results: Droplets and Sprays

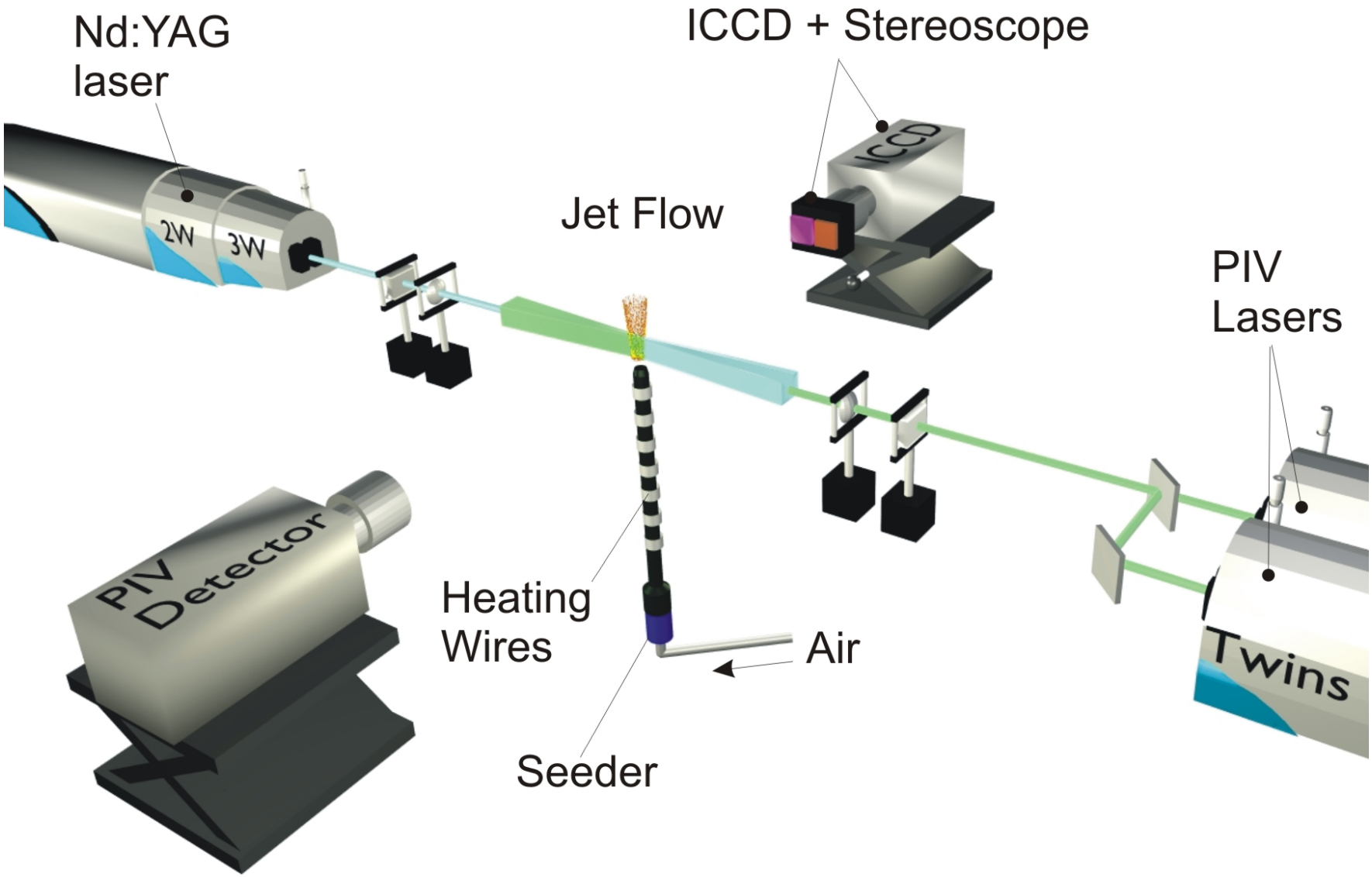




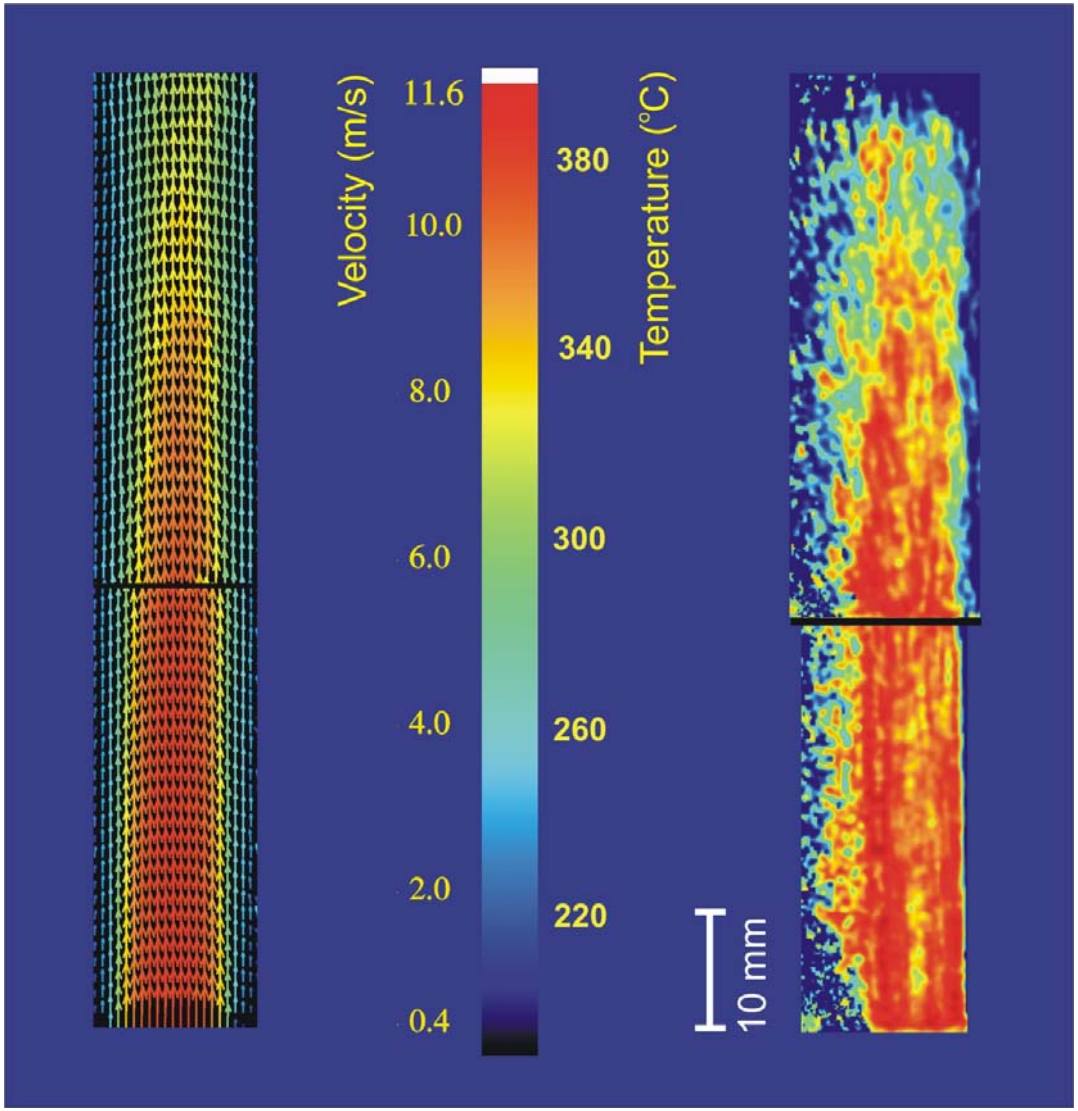
Results: Realistic spray



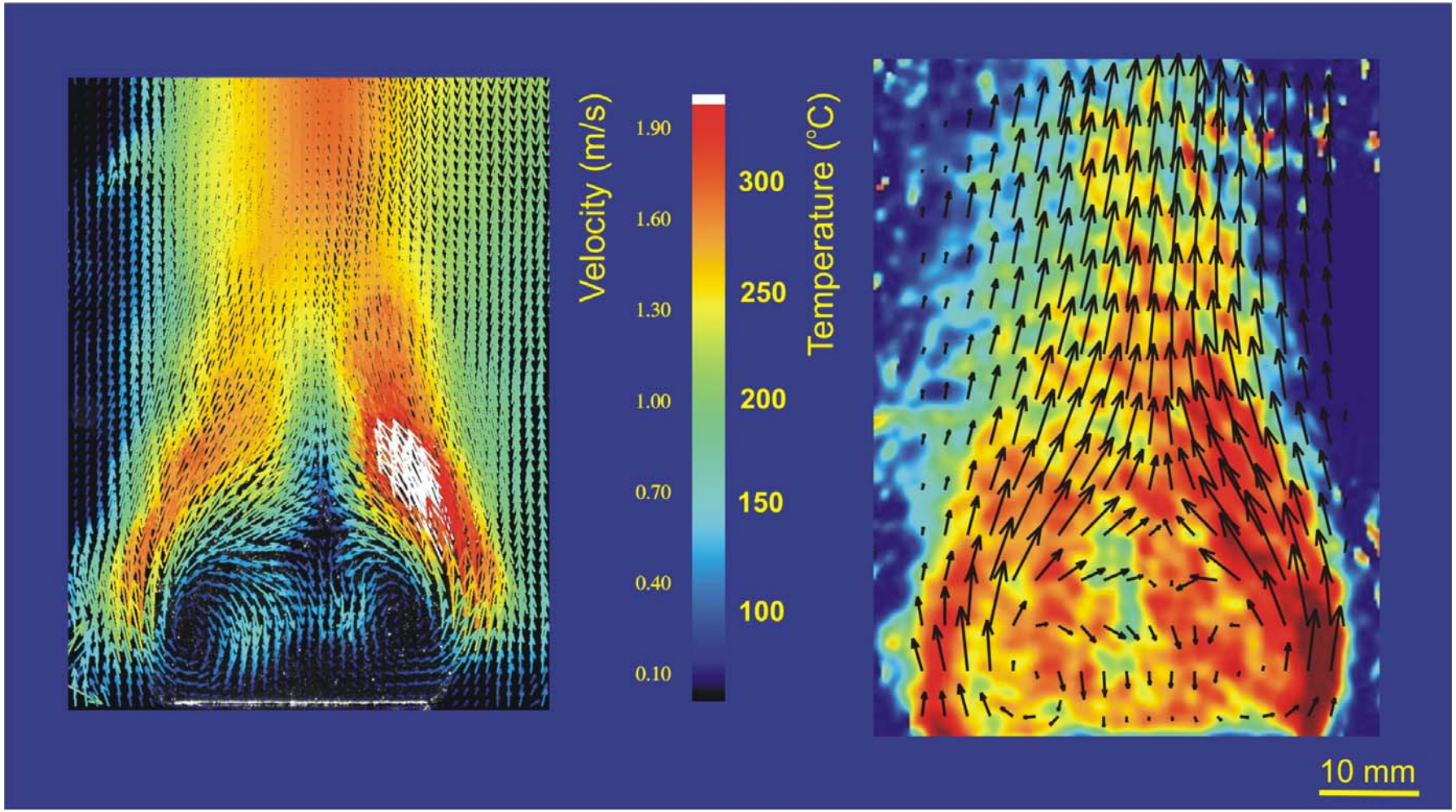
Simultaneous temperature/velocity: LIP + PIV



Laminar flow: Average of 50 images



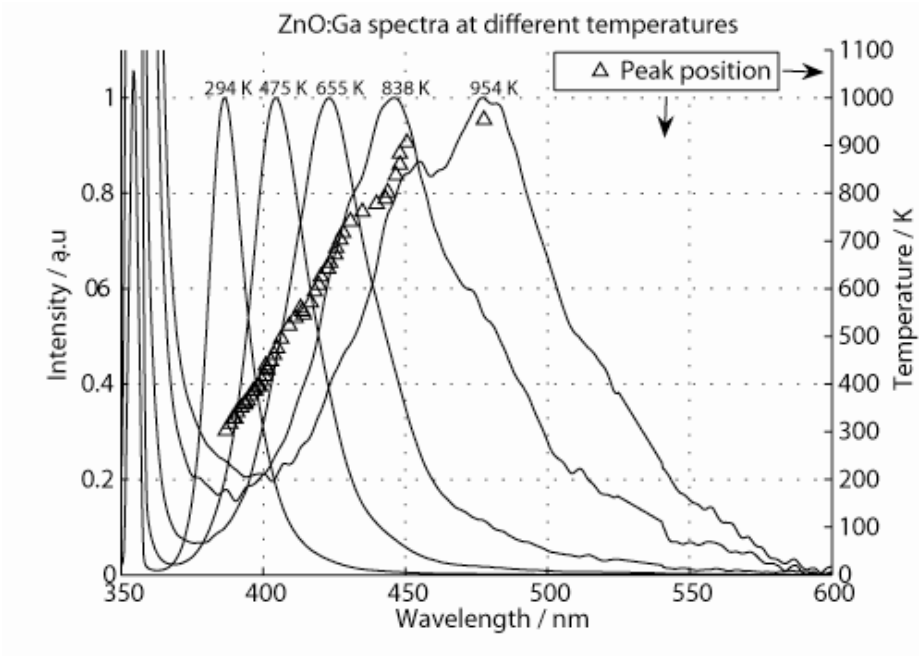
Turbulent flow: Average of 50 images

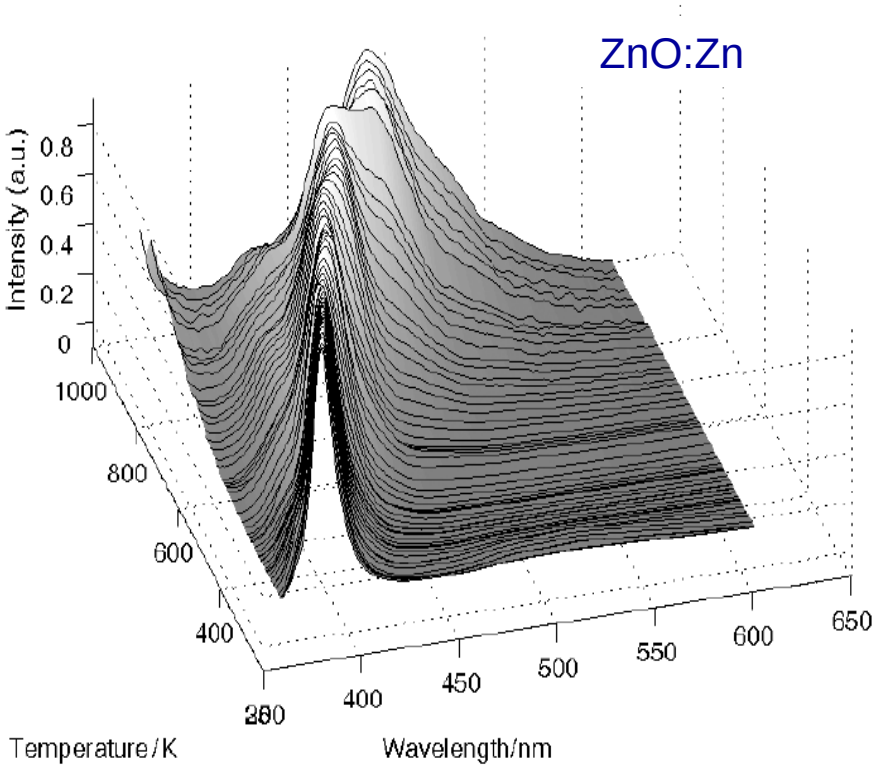


Further development and application needed

- UV and blue emitting phosphors
- Short decay time
- Nano phosphors
- Phosphors for high temperature

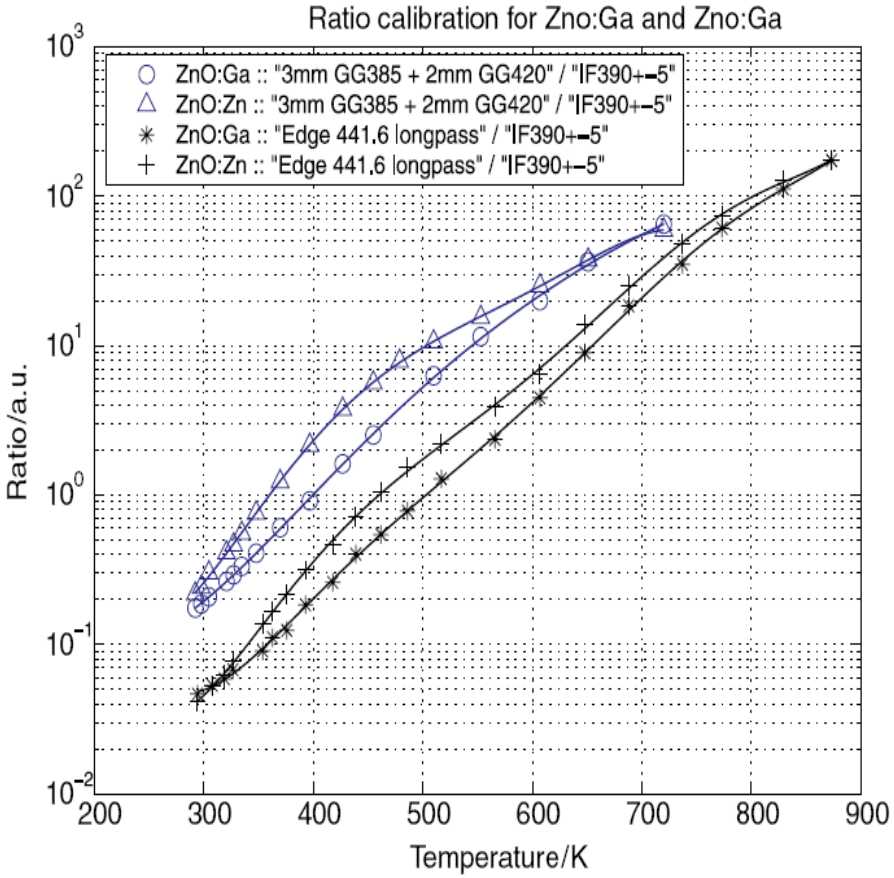
New phosphors: Blue, fast and very temperature sensitive!

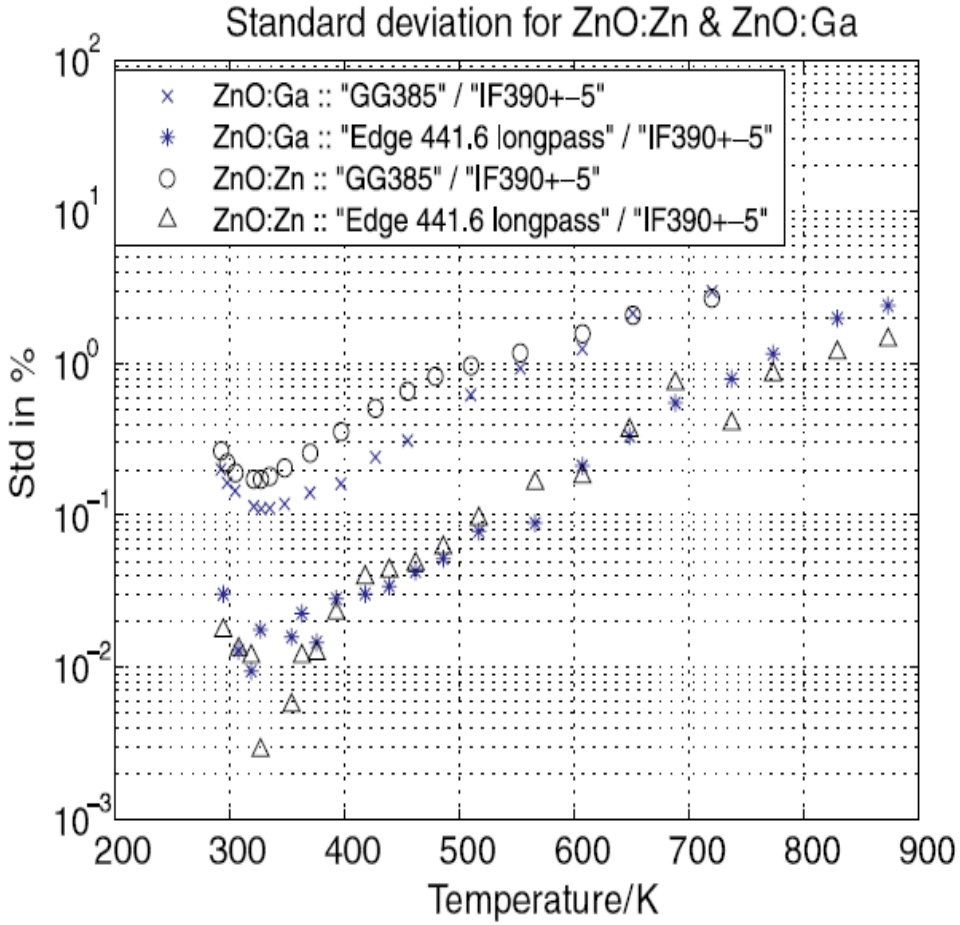




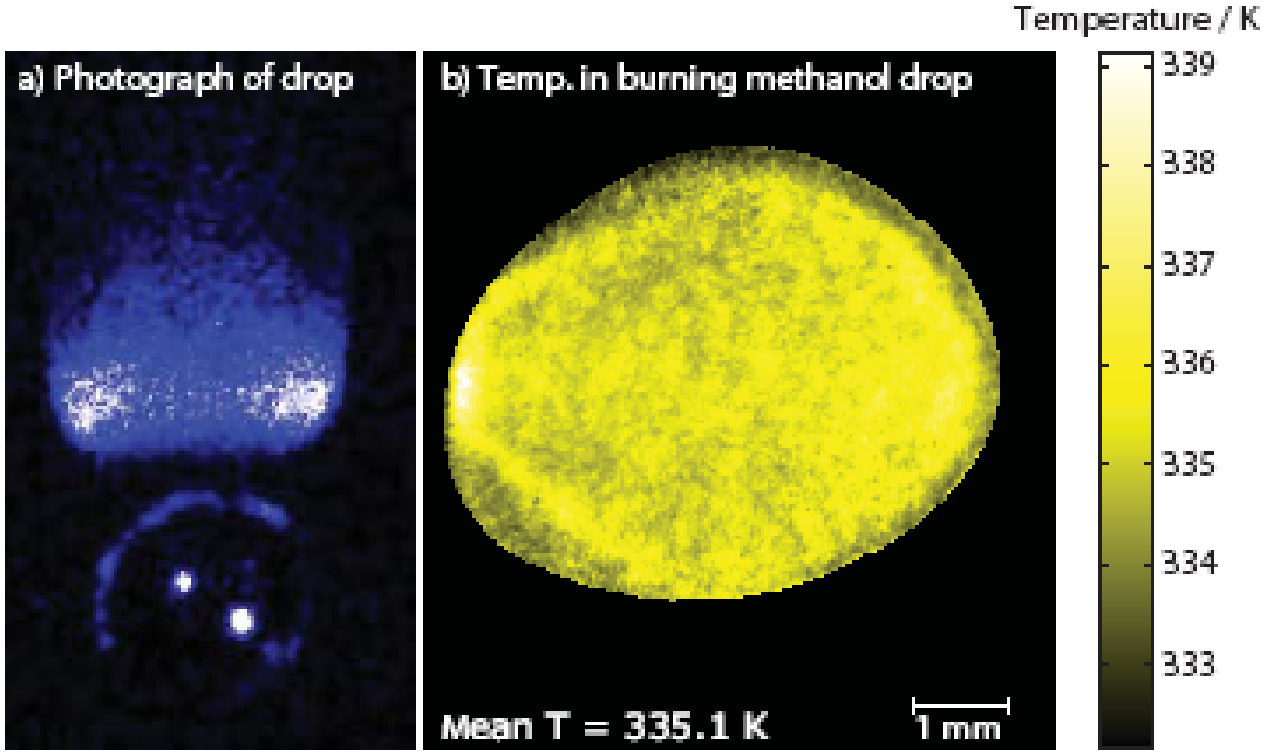
Laser wavelength:	355 nm
Laser rep. rate:	10 Hz
Laser energy:	~18 mJ
Camera:	ICCD 512*512 px + stereoscope
Exposure time:	10 ns
Filter:	HP Edge 442nm / IF 390nm ±10

Calibration/precision curves

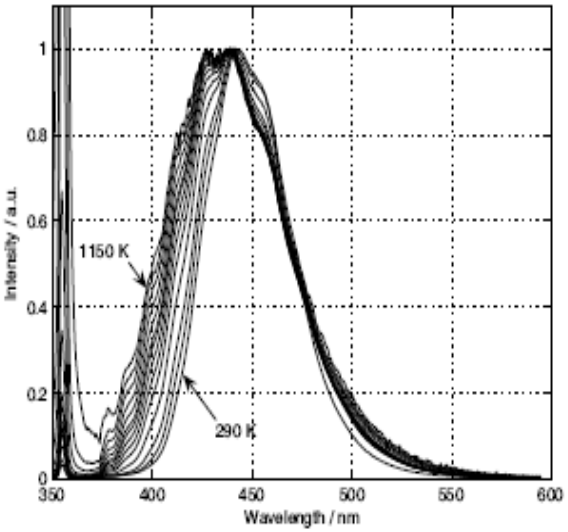


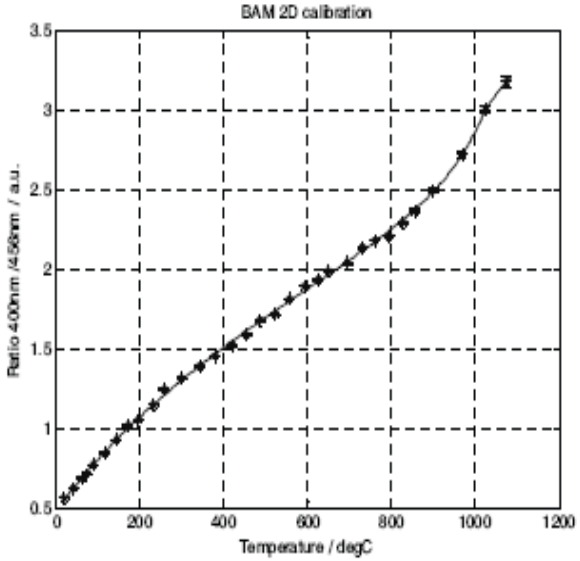


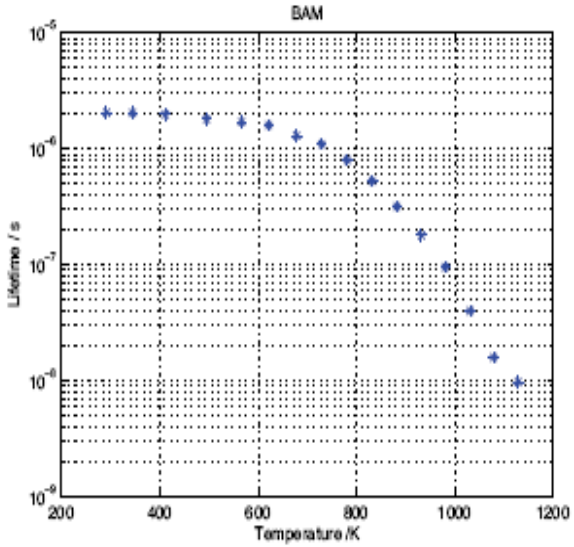
2D temperature measurements in a burning droplet usin ZnO:Ga



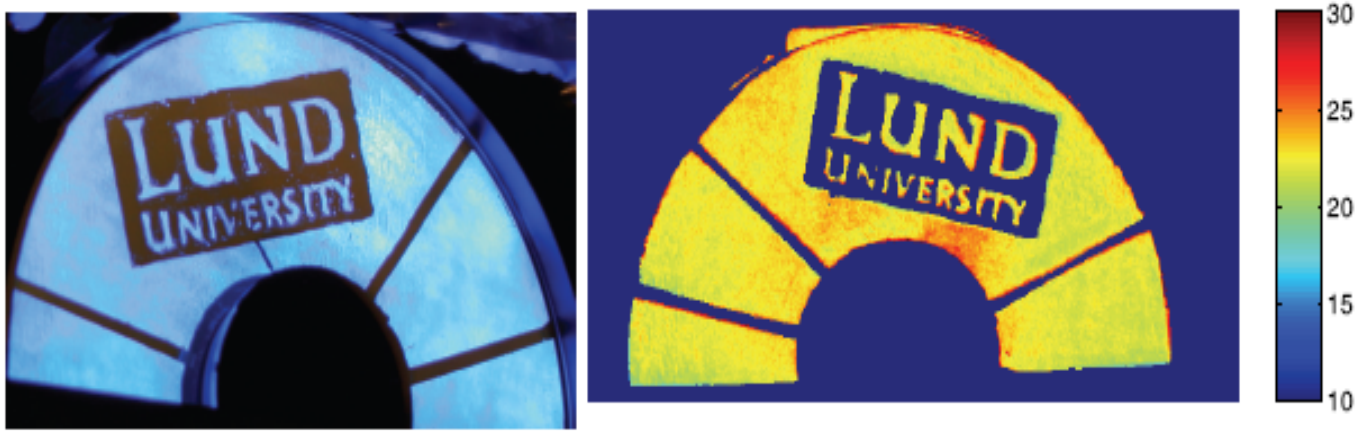
$BaMg_2Al_{10}O_{17}$:Eu (BAM)





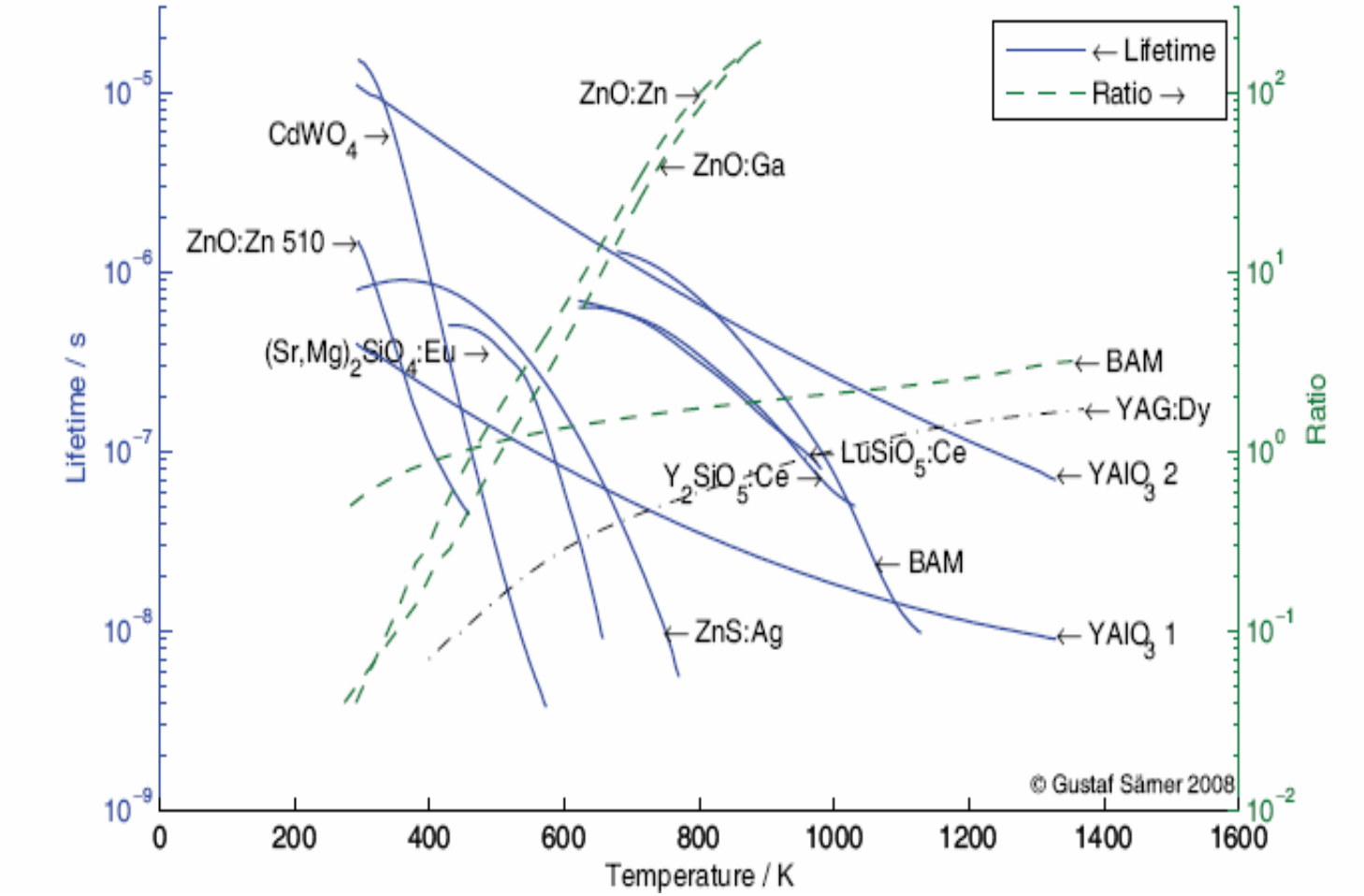


LIP on a moving target (7200 rpm) using BAM

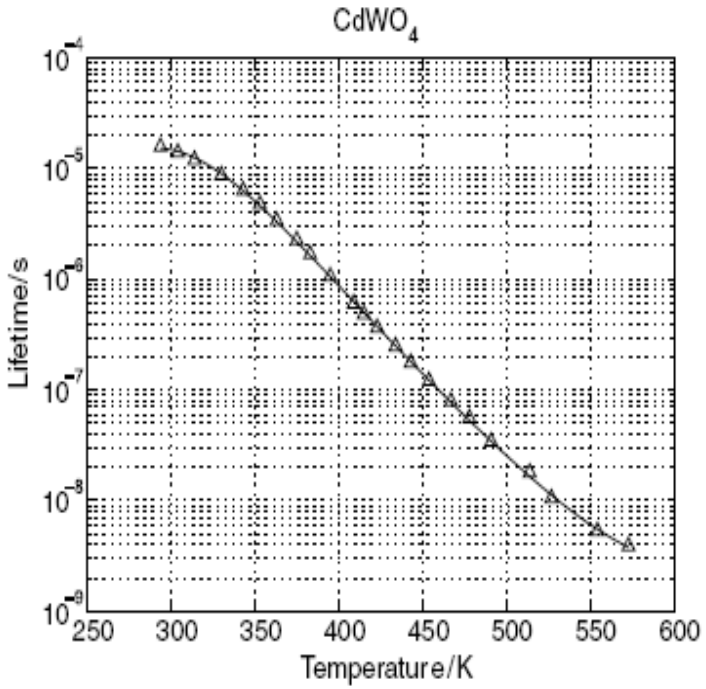


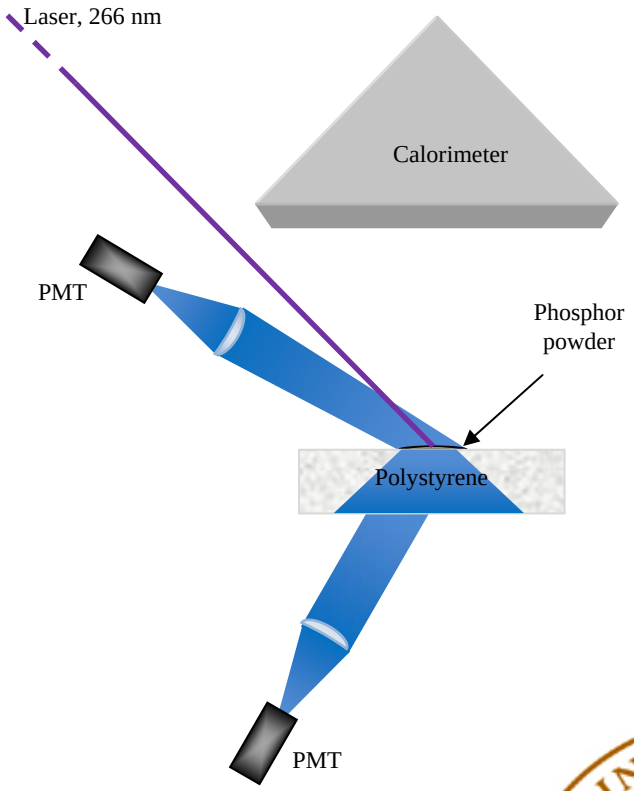
Exposure time~1µs

Summary of investigated phosphors



Fire experiments:
TIP through scattering media





Fire results