Consiglio Nazionale delle Ricerche
Istituto per l'Energetica e le Interfasi

Orléans
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Combustion
Aérothermique
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Scattering/extinction measurements for soot particle formation and growth in a shock tube

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AIM of the work

Implementation of the well-known scattering/extinction technique and application to a shock tube.

few references (Kelleler et al. 1996-2000, di Stasio et al. 1996, 1998)

To obtain experimental database of C2H4 pyrolysis

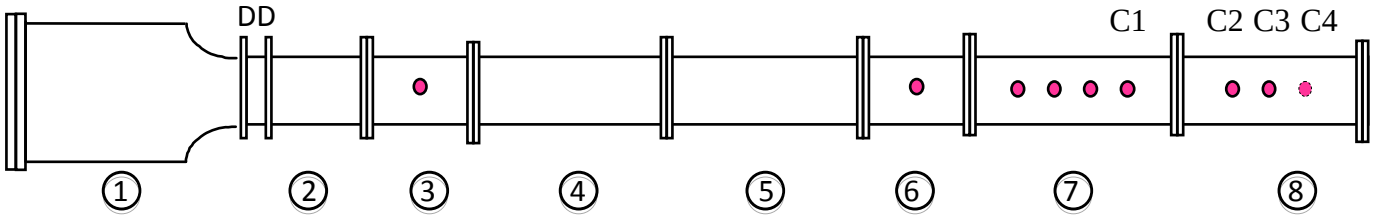
- Soot Volume Fraction
- Particle Mean diameter
- Agglomeration (?)
- Induction Delay Time
- Soot Yield
- Growth Constant

To study of the influence of hydrogen on soot parameters in C2H4 pyrolysis

SUMMARY

- Experimental set-up and procedure
- General background
- Time-resolved measurements for soot particles formation and growth
- Limitations and difficulties of the technique

Experimental set-up
(Ø = 78.4 mm)



N°	1	2	3	4	5	6	7	8
Volume (liter)	10.2	1.69	1.69	4.8	4.8	1.69	3.8	3.8
length (mm)	890	340	345	995	995	345	800	360
Calculated Pressure (bars)	70	50						

Mixture	Temperature (T5, K)	Pressure (P5, KPa)	[C] atom/cm^3
2%C_2H_4 + 98%Ar	1850-2100	500	$6.4*10^{17}$-$8.7*10^{17}$
2% C_2H_4 + 0.5%H_2+97.5%Ar	1850-2100	500	$6.6*10^{17}$ - $8.4*10^{17}$
2%C_7H_8+1%H_2+97%Ar	1850-2100	500	$6*10^{17}$-$7.9*10^{17}$

OPTICAL LAYOUT
Scattering/extinction section

m = mirror

d.m.= dichroic mirror

f = interferential filter

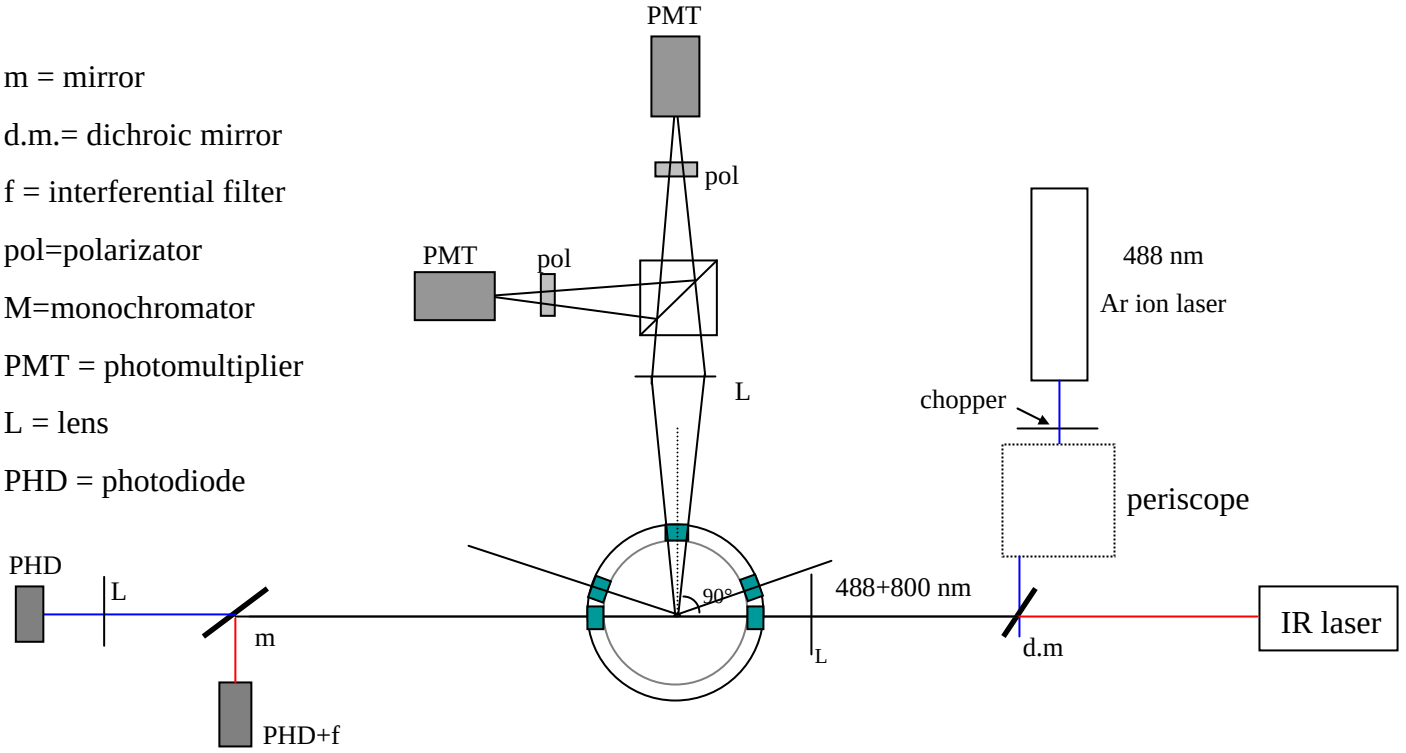
pol=polarizator

M=monochromator

PMT = photomultiplier

L = lens

PHD = photodiode



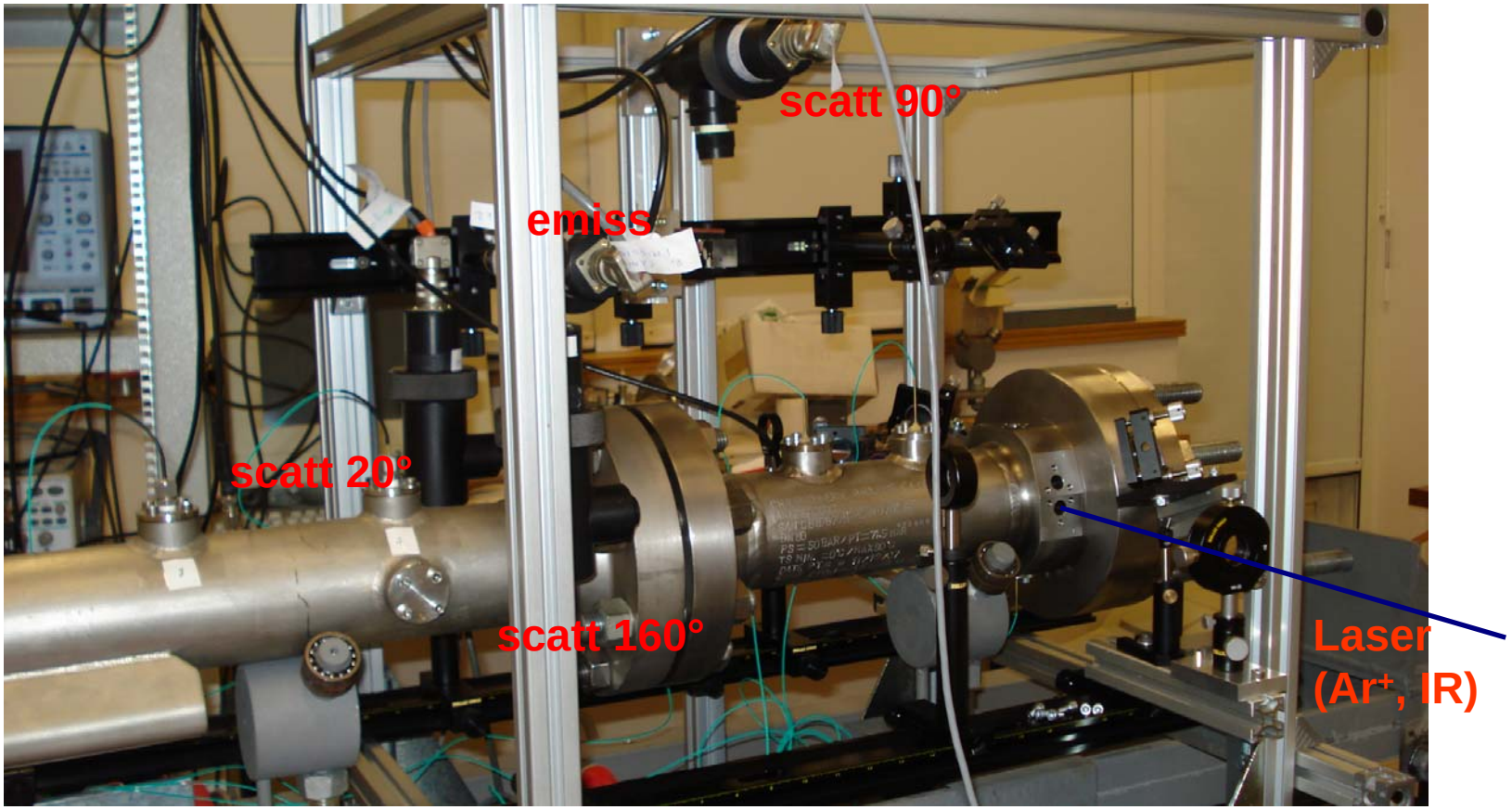
Mechanical chopper at 40KHz

⇨ fv ⇦ I/I_0 ⇦ Extinction diode laser λ = 800 nm

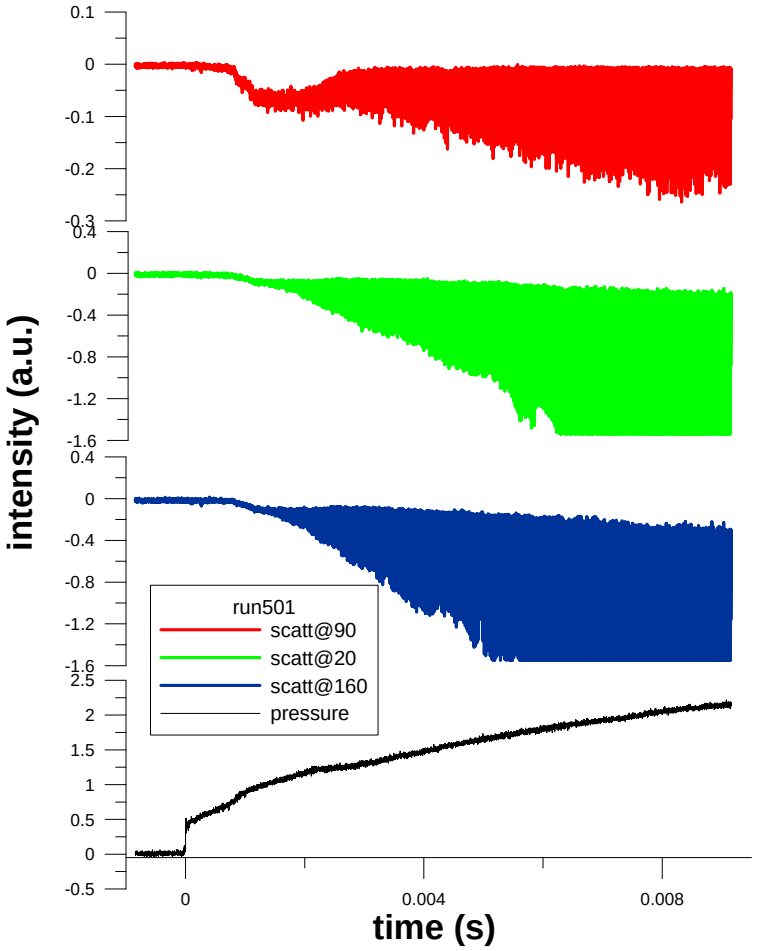
⇨ Scattering Ar^+ laser λ = 488 nm

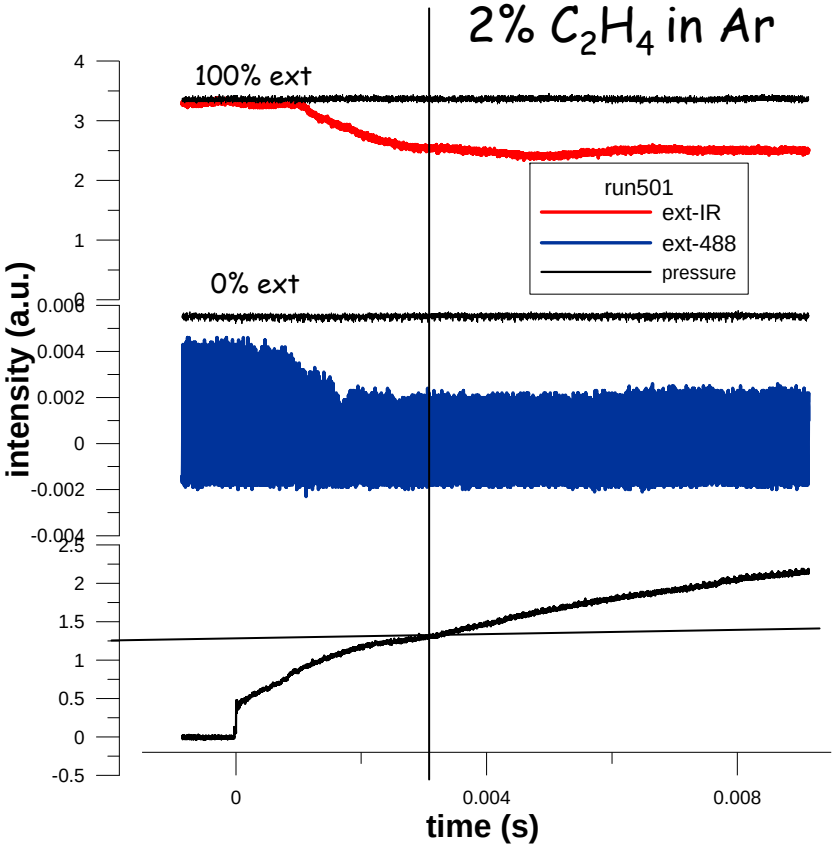
} ⇨ I_{scat} & I/I_0 ⇨ d_p

Shock tube with Ø = 78.4 mm



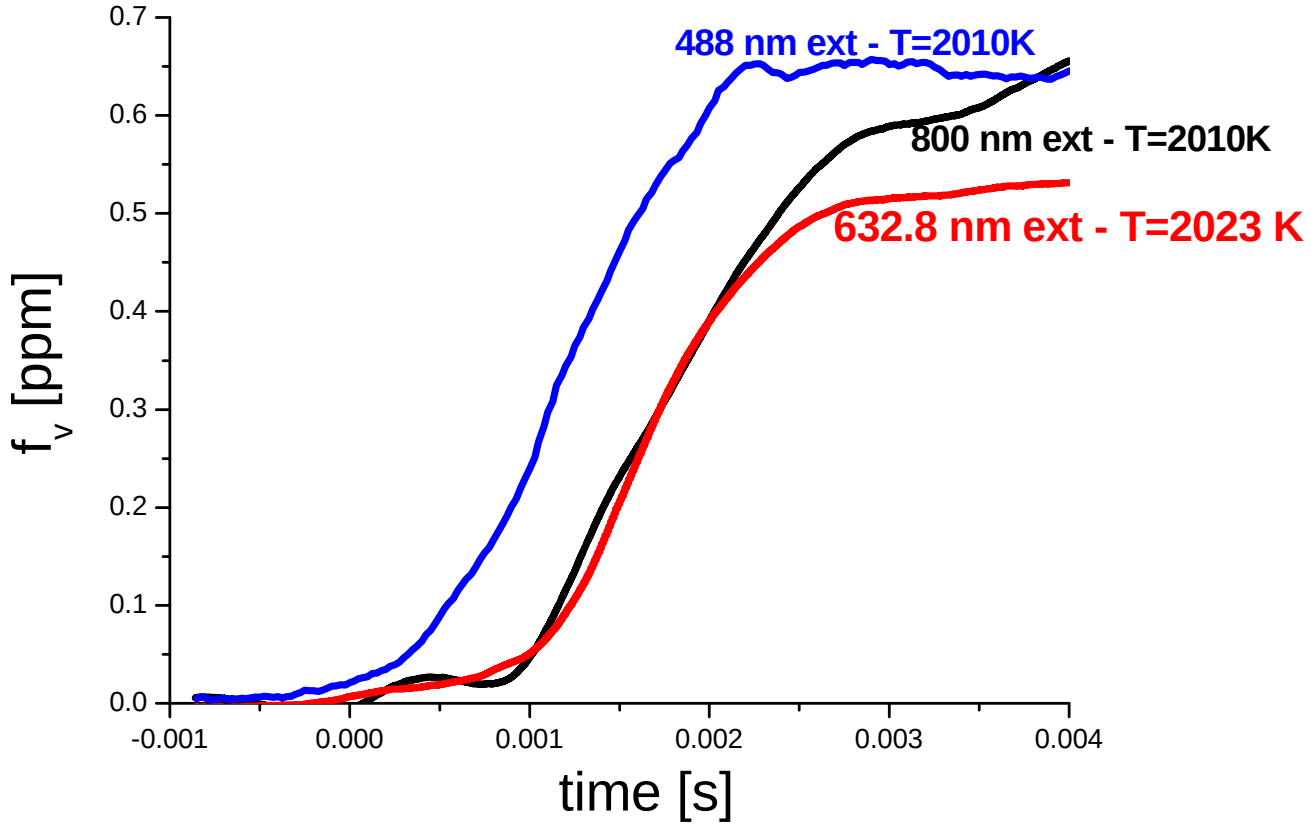
Typical time-resolved extinction/scattering measurements, raw data





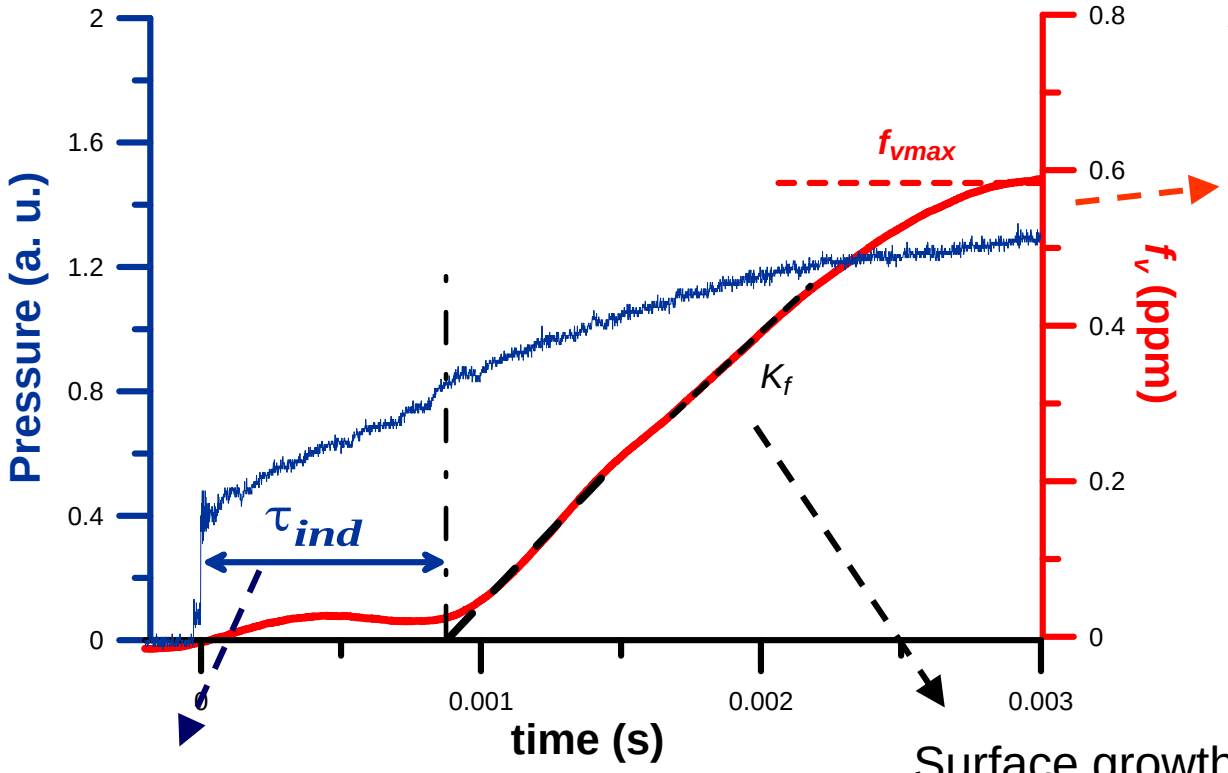
P5= 555 kPa and T5 = 2010 K

Extinction signal Measurement



- ✓ From extinction: time-resolved behavior of K_{ext} and fv
- ✓ Maximum value of f_v reached behind the reflected shock wave

Soot kinetic parameters



$$Y_{soot} = \frac{[C]_{soot}}{[C]_{tot}}$$

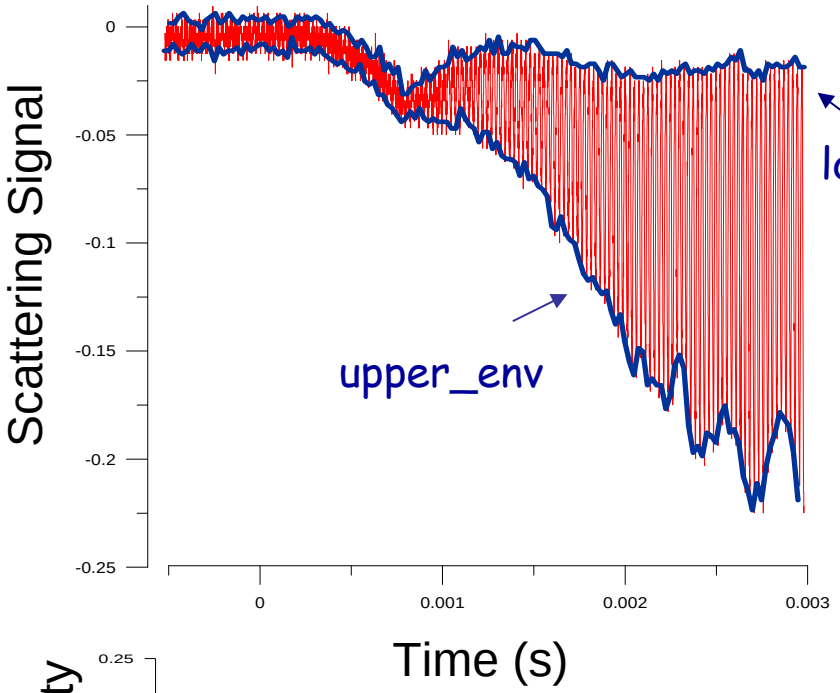
$$Y_{soot} = \frac{N_{av}\rho}{12\pi[C]_{tot}} f_{v\max}$$

$$\tau_{ind} = A \cdot \exp\left(\frac{E_{ind}}{R \cdot T}\right)$$

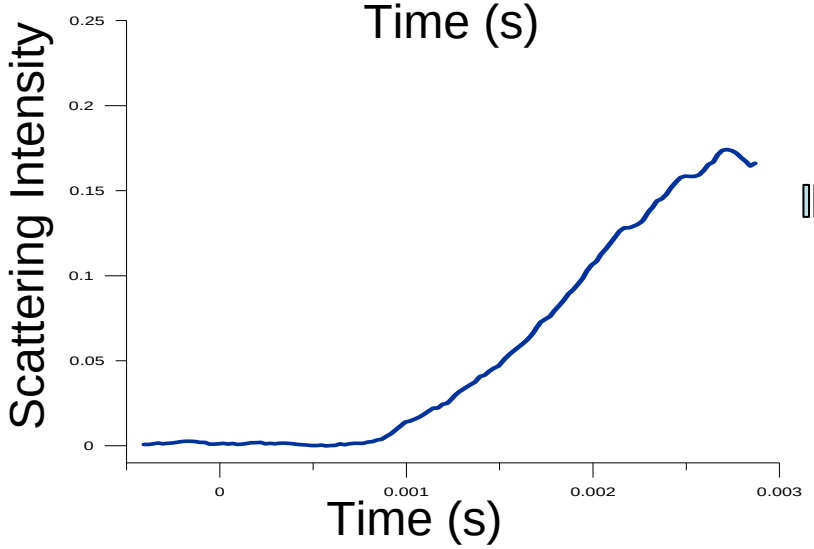
Surface growth rate

$$k_f = A \cdot \exp\left(-\frac{E_{ind}}{R \cdot T}\right)$$

Scattering signal Measurement (1/2)



(upper_env) – (lower_env)

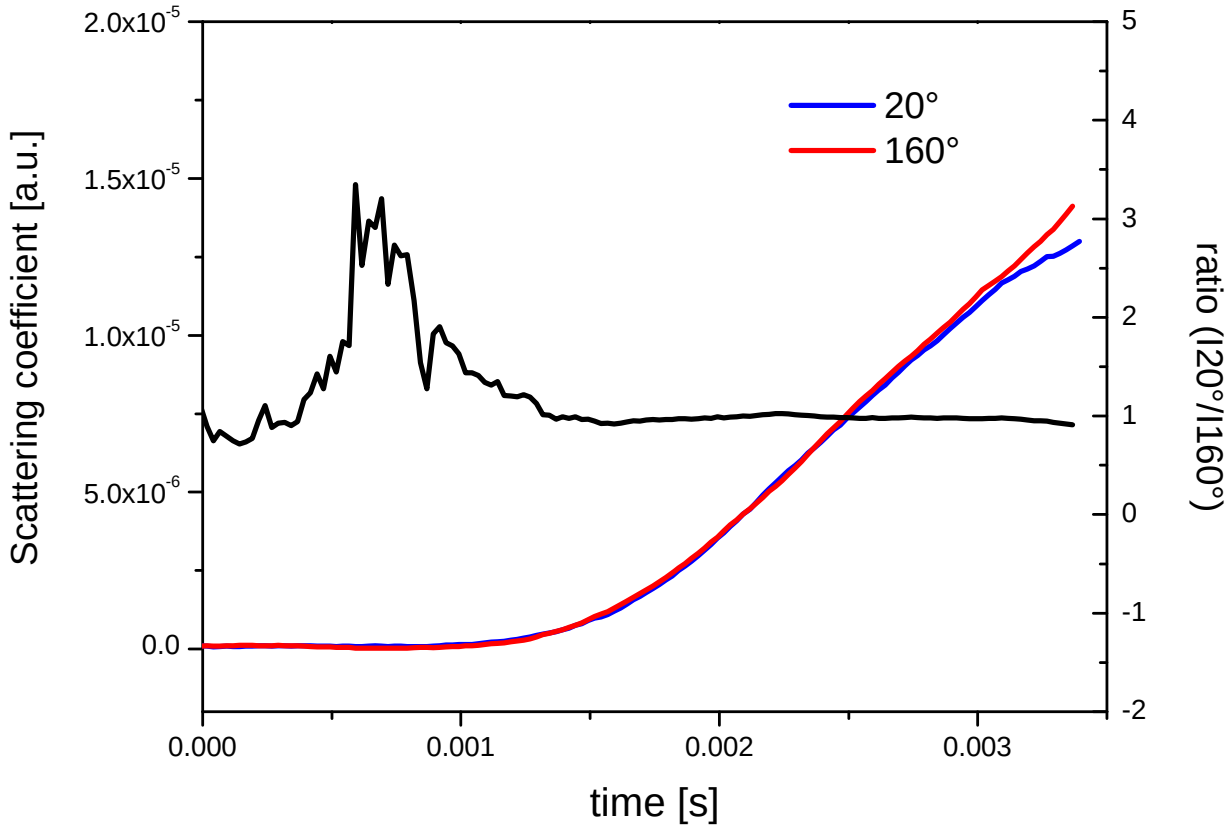


+ Propane Calibration

⇩

K_{vv}

Scattering signal Measurement (2/2)



Characterization of soot formation and growth

Extinction Measurements
(time-behavior)

- Soot Volume Fraction
  - Induction delay time
  - Soot Growth Costant
  - Soot Yield

+ scattering
measurements

- Particles Characterisation
  - ratio (20°/160°) for aggregation
  - dp,
  - Np

Some expressions of the extinction/scattering technique

extinction

$$\tau_\lambda = \ln\left(\frac{I_L}{I_0}\right) = -K_{ext} L$$

$$K_{abs} = -\frac{\pi^2}{\lambda}\,\mathrm{Im}\left\{\frac{m^2-1}{m^2+2}\right\} N_p \int_0^\infty p(d_p) d_p{}^3 d(d_p)$$

$d_{30}{}^3$

$$fv = \frac{\pi}{6} N d_{30}{}^3$$

scattering

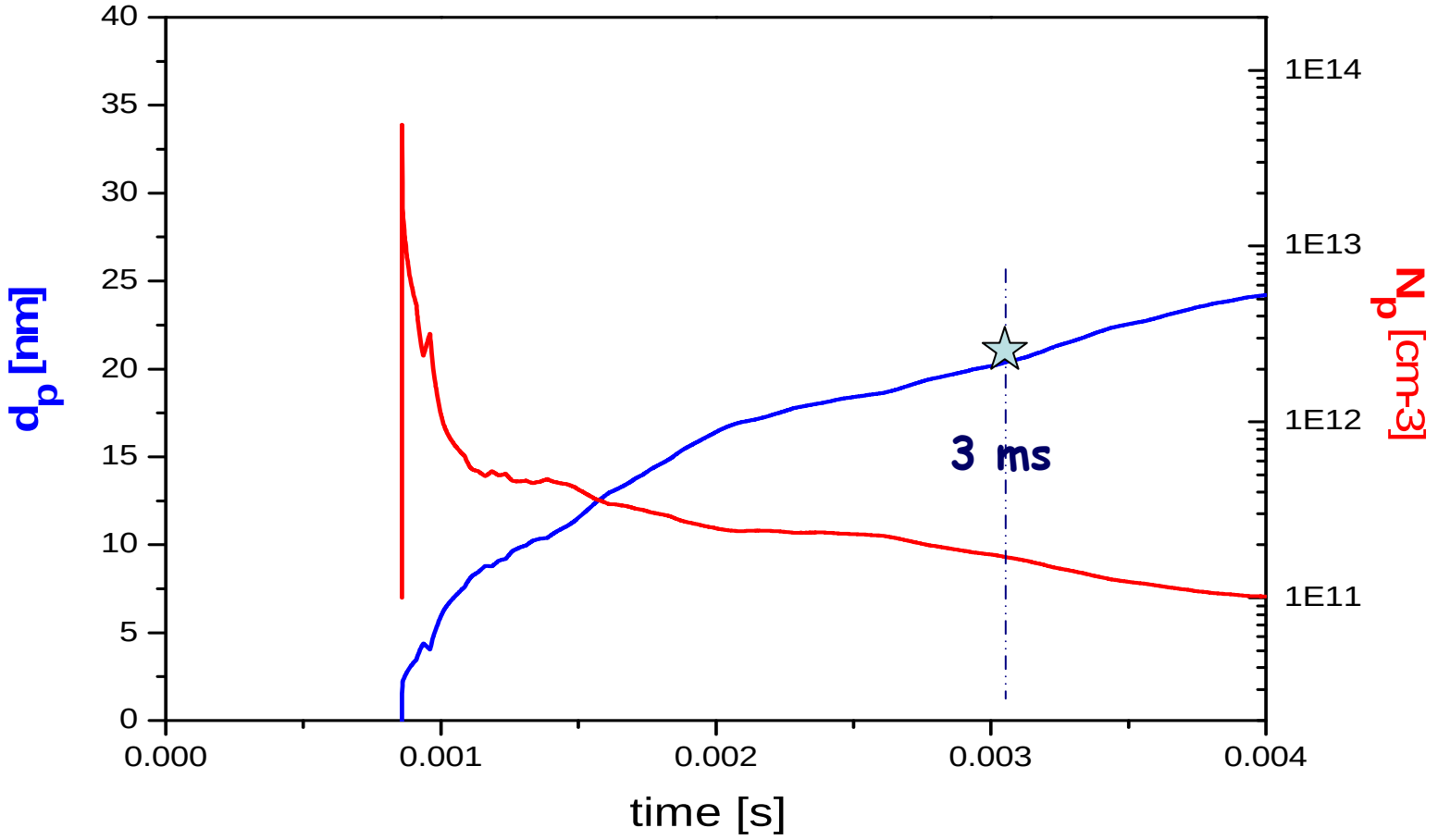
$$S_{VV}^P = \eta I_0 N_p C_{VV}^P$$

$$C_{vv} = \frac{F(m)}{4}\left(\frac{\pi}{\lambda}\right)^4 N_p \int_0^\infty p(d_p) d_p{}^6 d(d_p)$$

$d_{60}{}^6$

$$d_{30} = d_m = \lambda\left(\frac{4\,E(m)\,C_{vv}}{\pi^2 F(m)\,K_{abs}}\right)^{1/3} \qquad N_p = \frac{12\,f_v}{\pi\,d_m^3}$$

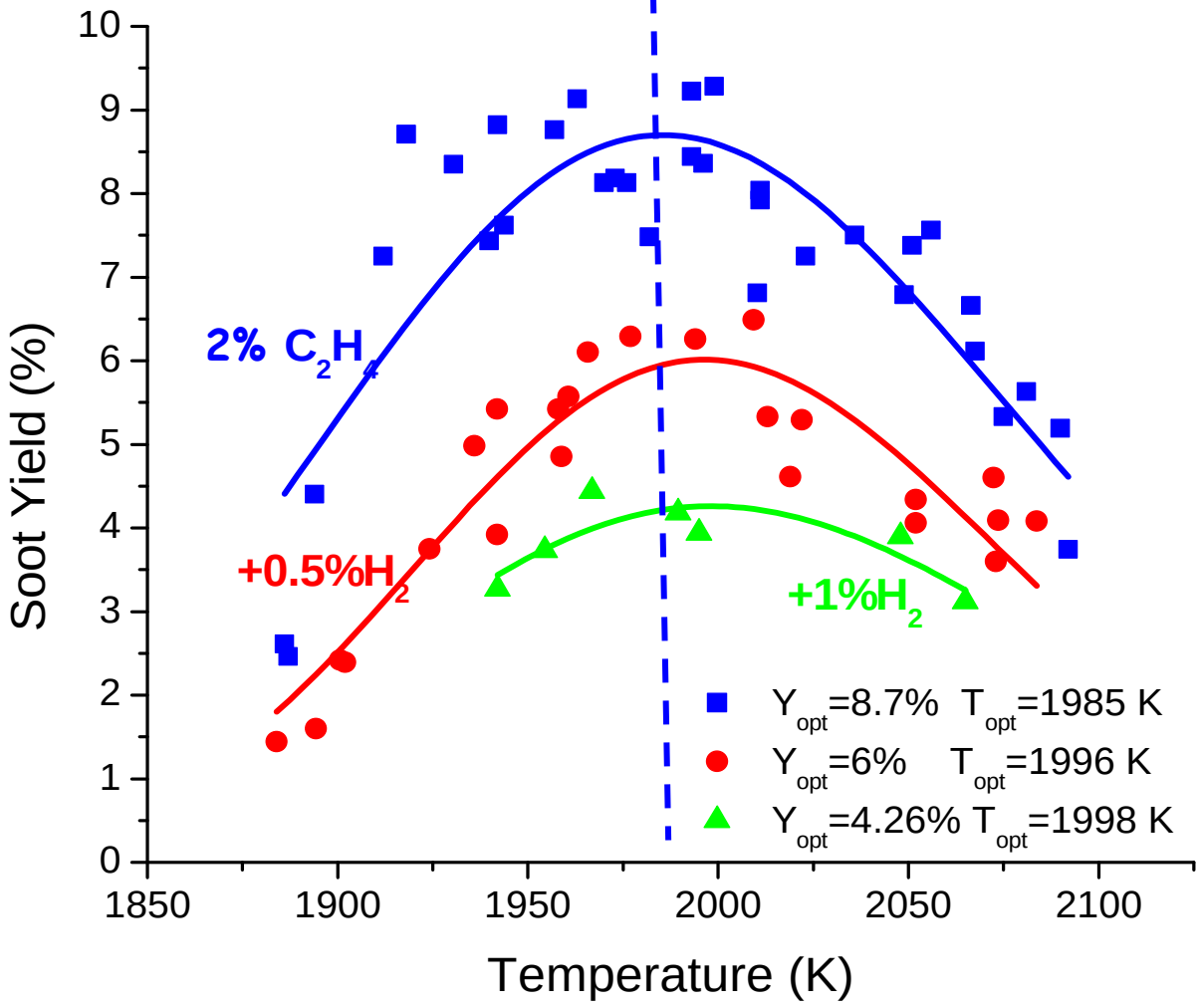
Soot Particles Parameters : N_p, d_m



✓ Growth characterized by two different rates (the faster at the beginning of soot nucleation).

✓ The number density presents a fast increase due to soot nucleation, followed by a decrease due to coagulation mechanisms.

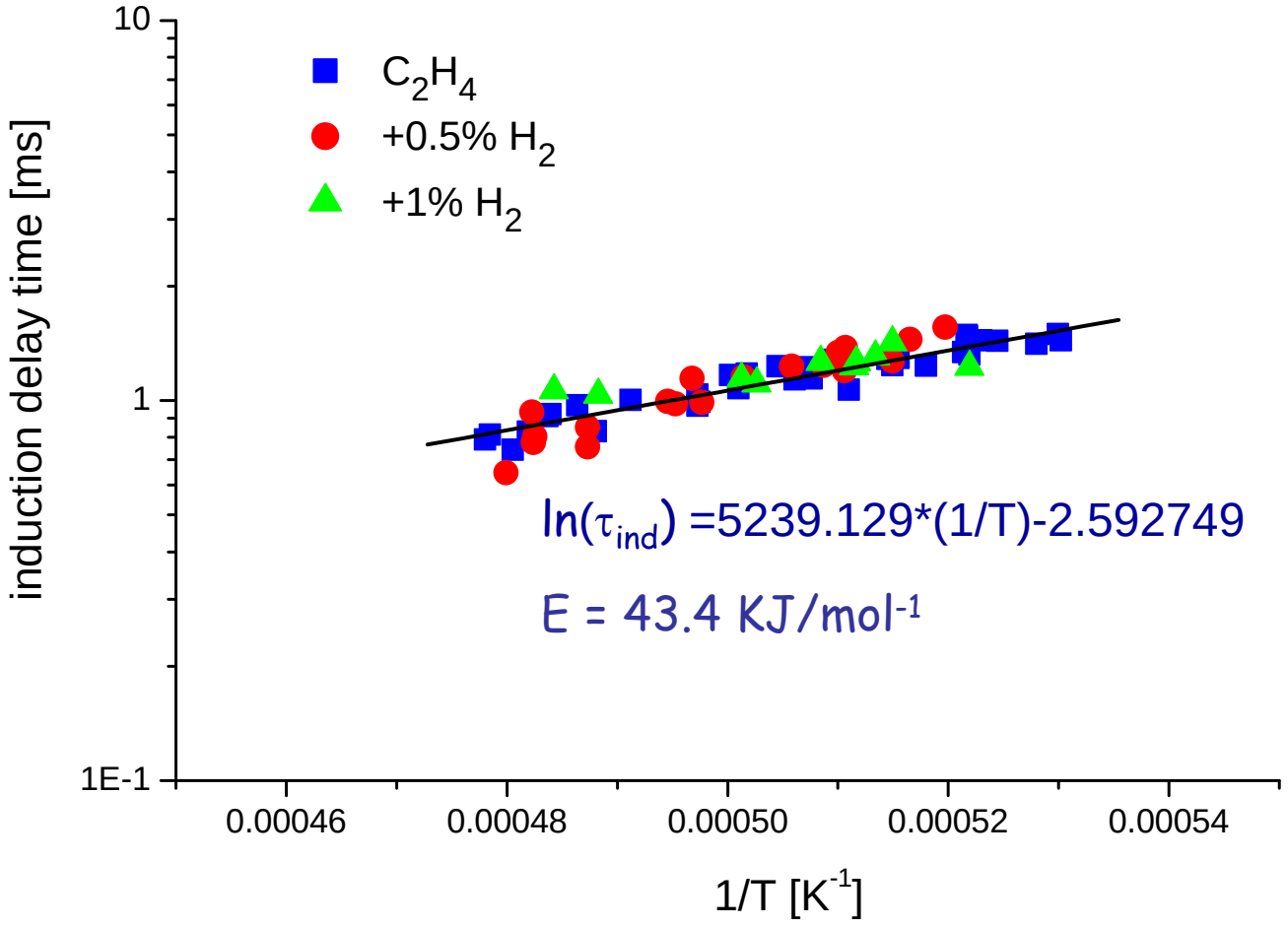
Results: Soot Yield



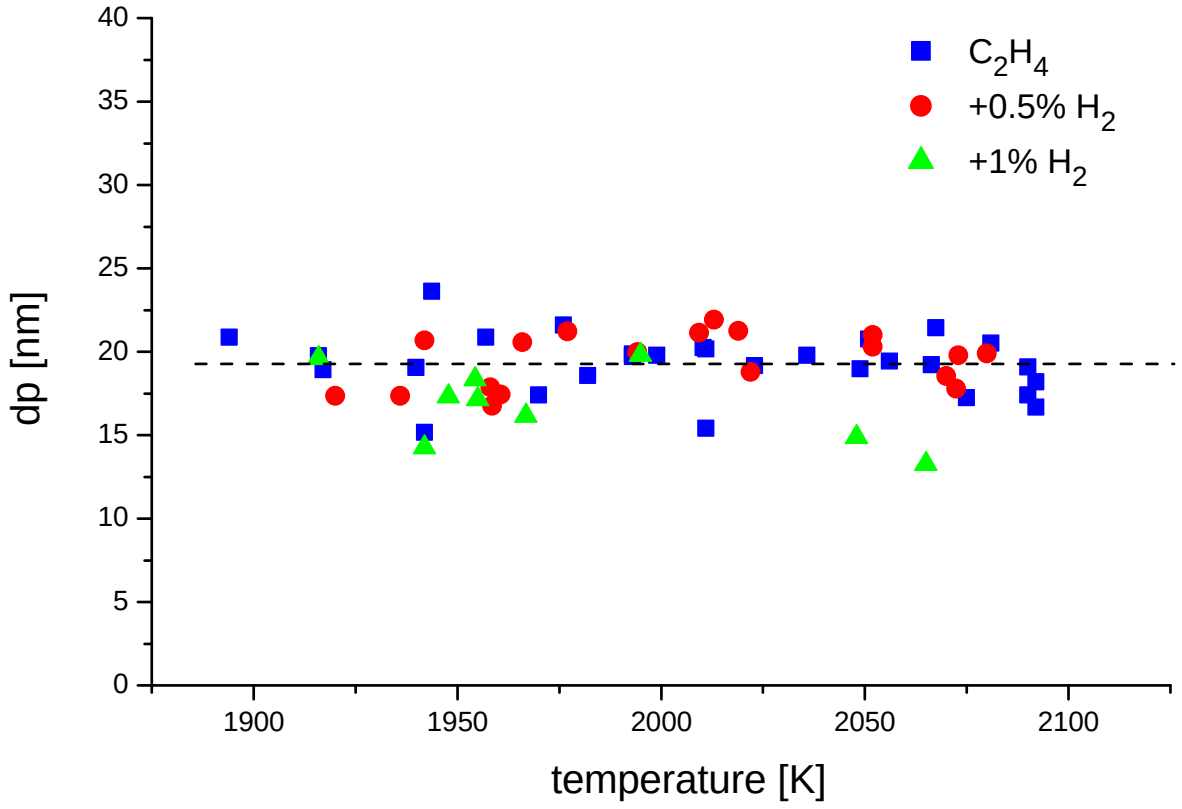
$$Y = Y_{opt} \exp\left[A_y \left(\frac{T_{opt} - T}{T} \right)^2 \right]$$

O. Mathieu et al. 31st Symposium (Inter.) on Combustion

Results: Induction delay time



Results: soot particle diameter vs temperature



Conclusions

For the technique:

✓ No aggregation effects occur in the range of temperature and pressure investigated

✓ He-Ne laser as well as the IR one can be used for f_v measurements by extinction

With H_2 addition:

✓ The soot yield curves present the same optimum temperature (around 1990K) but exhibit a strong decrease in the maximum value (less than the half by adding 1%H_2)

✓ No influence is detected on the induction delay time and the particle diameters.

Thanks for your attention!