Detonability of Binary $H_2/CH_4 - Air$ Mixtures

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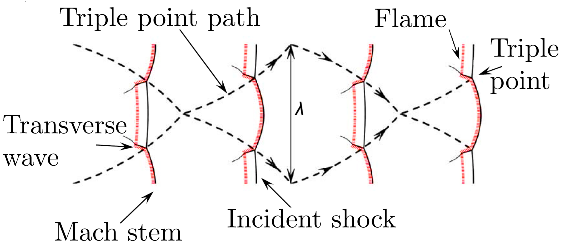
Outline

1. Background
2. Experimental Set-Up
   - Detonation tubes
   - DDT tubes
3. Experimental Results
   - Detonation Parameters
   - Correlation with induction length L_i
   - DDT Parameters
4. Conclusion

Introduction

- H_2 is the most valuable candidate for fossil combustible replacement
- The H_2/air mixture is more sensitive (to detonate) than classical hydrocarbon/air ones.
- Safety concerns are engaged

Detonation cells

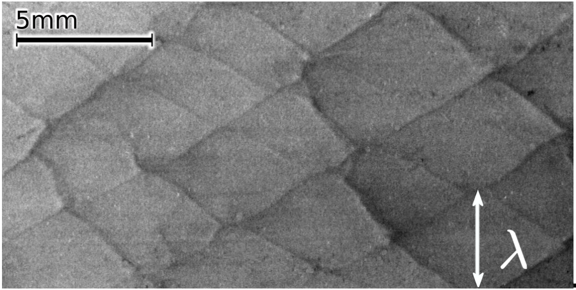


Detonation front is 3D unsteady but globaly 1D steady

$D \approx D_{CJ}$

$H_2 + \frac{1}{2} O_2$

$p_0 = 0.3$bar



Why λ is important ?

Detonation cell size (λ) is characteristic of a mixture.

λ is linked to chemistry (Induction length after the leading shock L_i)

λ is important for :

- Detonation limits
  - marginal propagation in tubes (i.d. d) : $\lambda = \pi d$ (C_nH_m/O_2 mix.) (spinning regime is the last steady regime observed)
  - critical tube diameter for transmission to open-space : $d_c = 13\lambda$ (C_nH_m/O_2 mix.)
  - critical initiation energy : $E_c \approx B\rho_0 D_{CJ}^2 \lambda^3$ (Zel'dovich criterion, $B = 500$)
- DDT studies with obstacle-laden tubes

Looking literature

Fuel	H_2	$C_nH_{2n+2}(n \geq 2)$	CH_4
Detonation cell size λ	1cm	5-6cm	30cm
DDT length L_{DDT}	0.37m	2m	12-15m

Mixture with air in obstacle-laden tubes, ϕ=1, p_0=1bar, T_0=293K

If current designs using usual hydrocarbon/air meet the detonation risk acceptance (i.e. $\lambda \geq$5cm), H_2/air may NOT.

It is possible to desensitize the H_2/air mixture by adding CH_4.

What are the effects of adding CH_4 on the detonation and DDT parameters ?

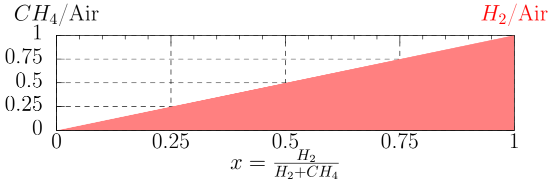
Objectives and notations

Experimental work to give new data on

- self-sustained detonations characteristics (D, p, λ)
- DDT in obstacle-laden tubes (L_{DDT})

for binary fuels H_2/CH_4 with air at T_0=293K

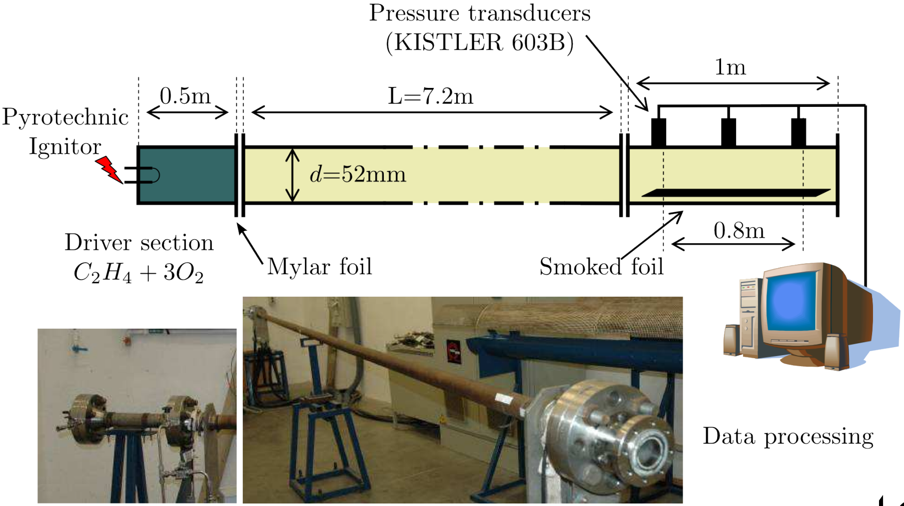
$$\phi\,[xH_2 + (1-x)CH_4] + (2-1.5x)(O_2 + 3.76N_2)$$



Equivalence ratio : $0.6 \leq \phi \leq 3$,
H_2 molar fraction in fuel : $0.5 \leq x \leq 1$,
Initial pressure : $0.2\text{bar} \leq p_0 \leq 2\text{bar}$

Outline

Experimental device for detonation study



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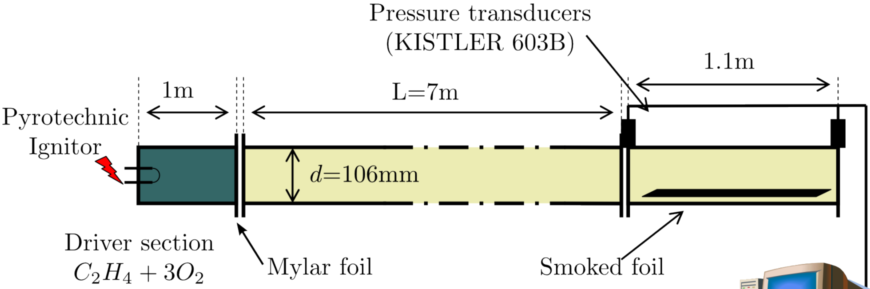
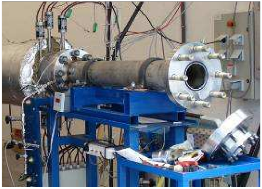
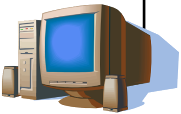


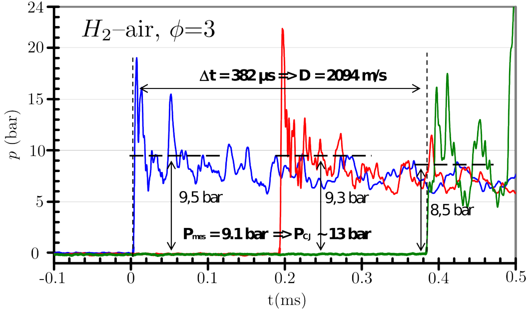




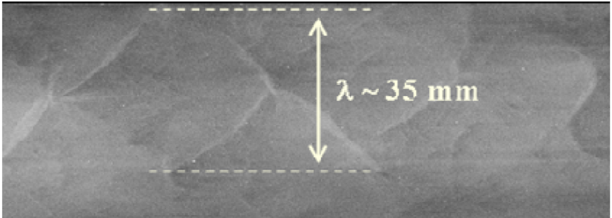
Data processing

Detonation parameters measurements

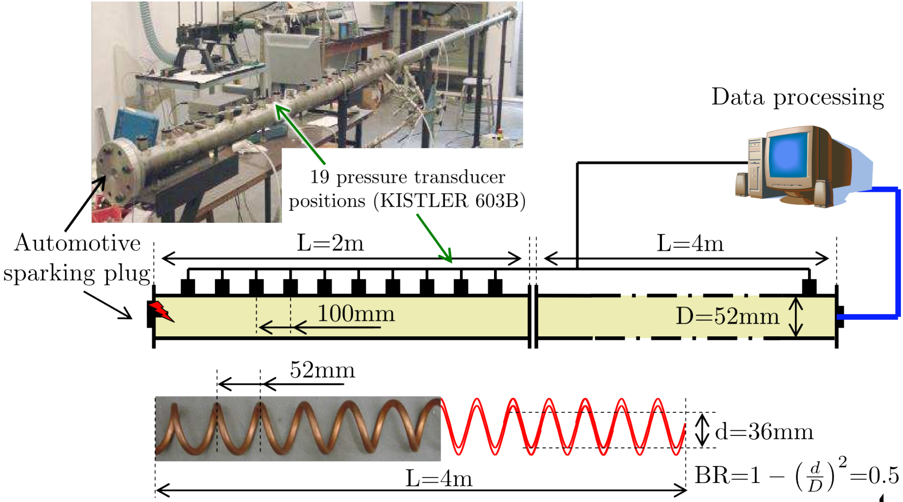
- Pressure signals give p and D



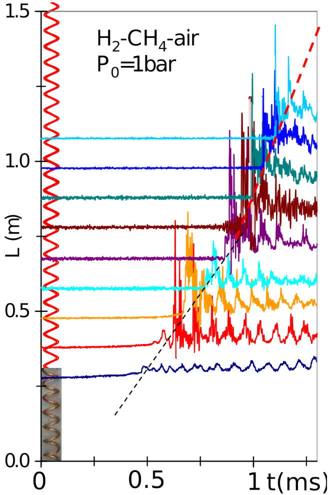
- Smoked foils : 80% H_2–20% CH_4, p_0=1bar, ϕ=1

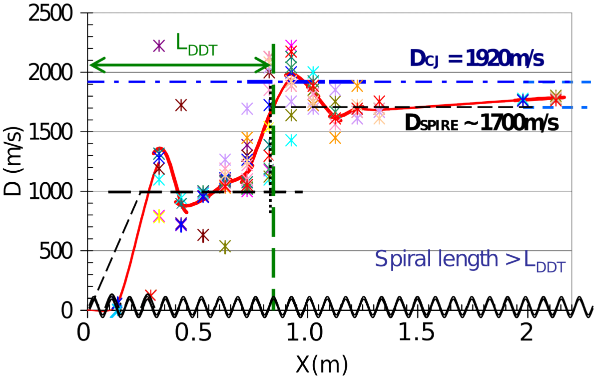


Experimental device for DDT study



Typical pressure signals for DDT and interpretation



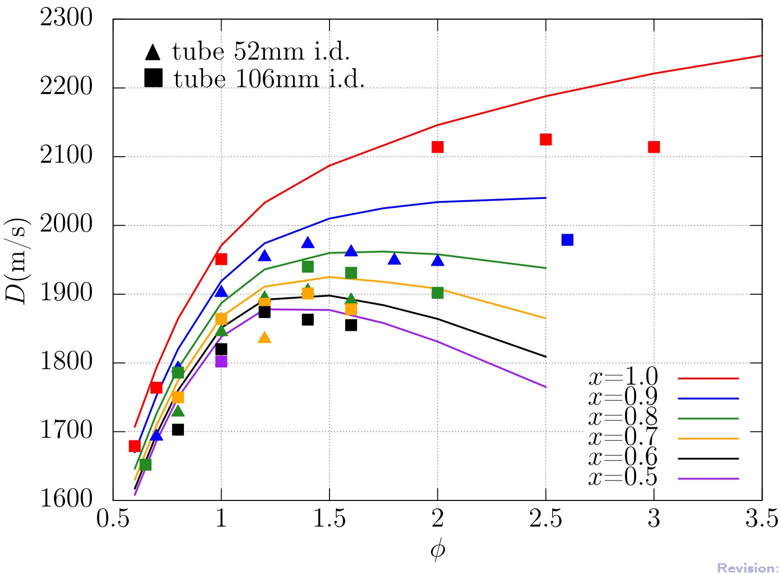


Choking regime 1000m/s ($\approx 0.5 D_{CJ}$)

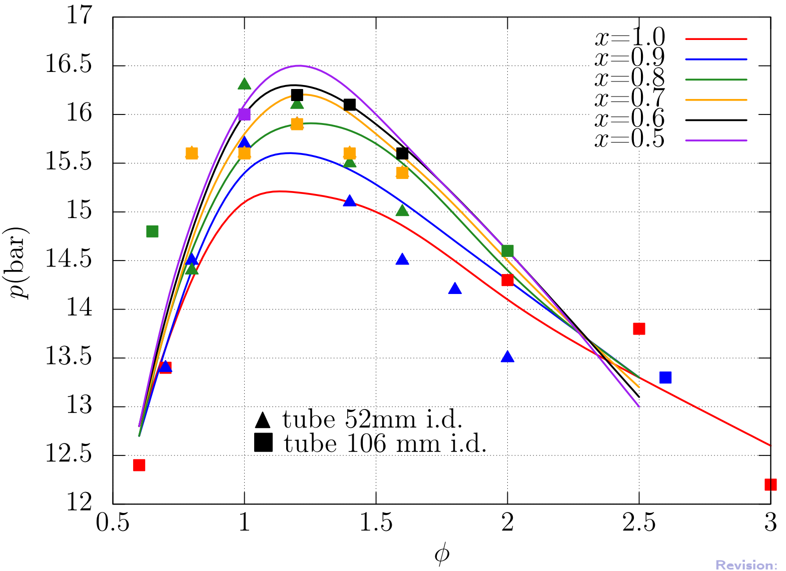
Then, suddently, detonation regime at $0.85 D_{CJ}$

Outline

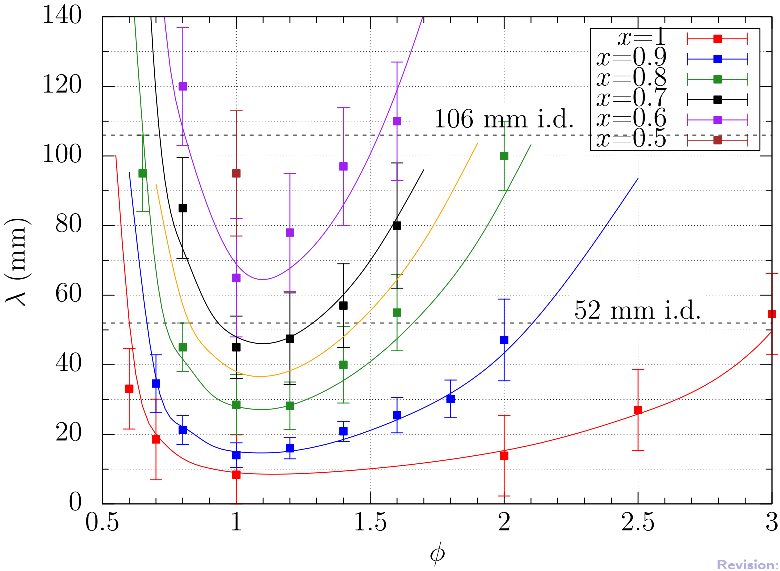
Detonation Velocity



Detonation Pressure



Detonation Cell Size (λ) with ϕ, x



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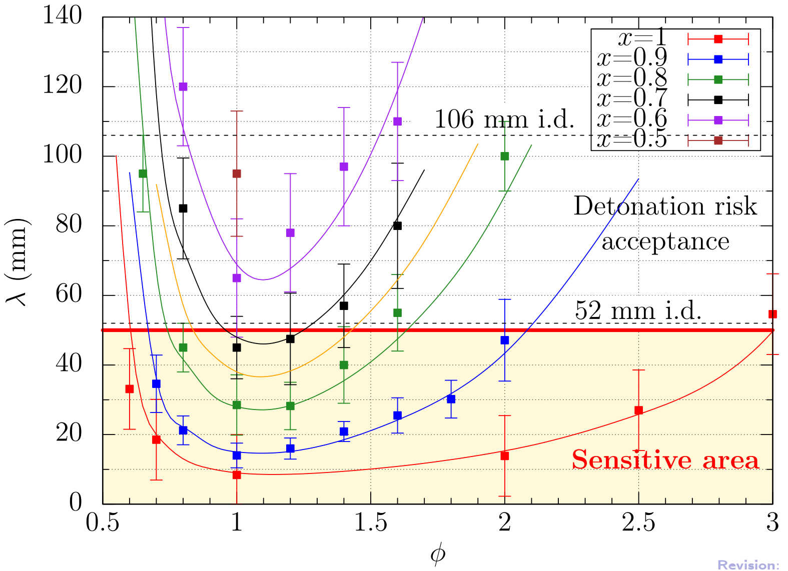
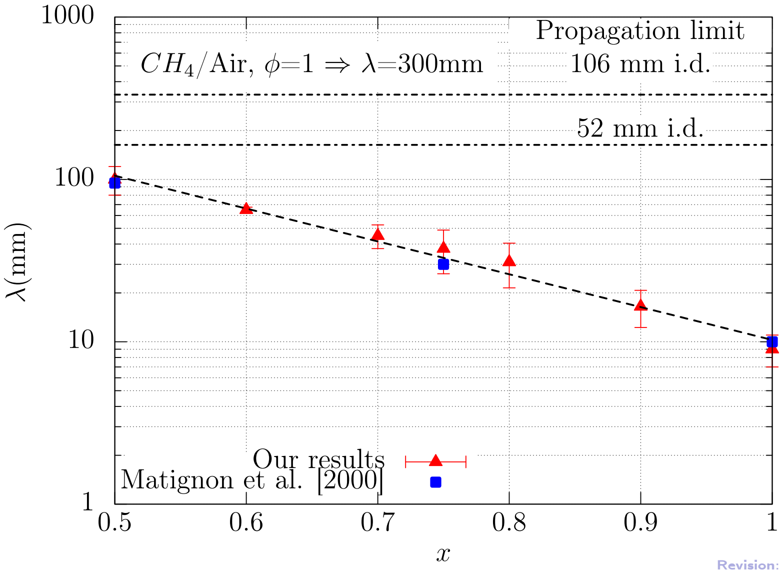
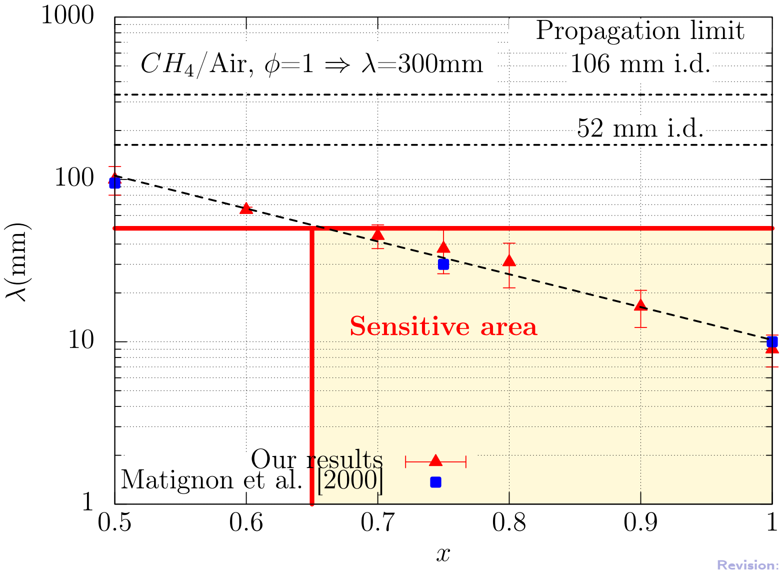


Detonation Cell Size (λ) with x



Detonation Cell Size (λ) with x



Link with chemical induction length (L_i)

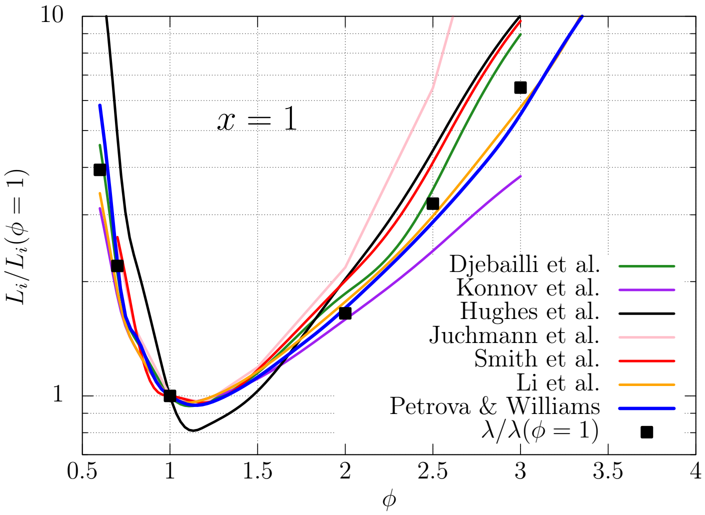
The ZND reaction zone is calculated with Chemkin Code.

L_i= maximum heat release rate.

The detailed kinetics tested :

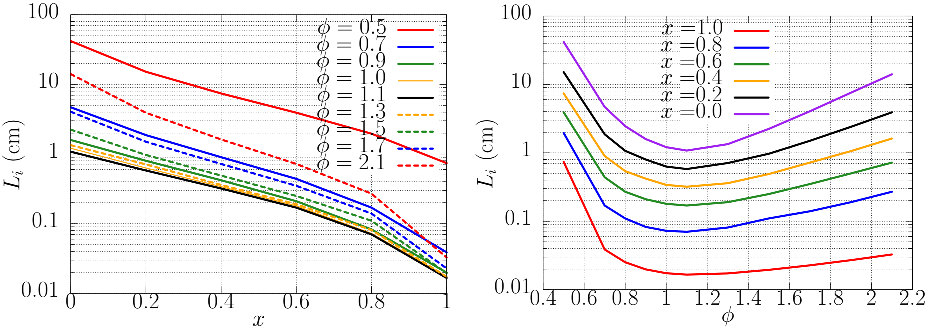
- Djebaili et al. [Symp. Shock Wave, 1997]
- Konnov et al. [2000]
- Hughes et al. [2001]
- Juchmann et al. [Symp. Combustion, 2001]
- Smith et al. [2002] (GRIMech)
- Li et al. [2004]
- Petrova and Williams [Comb.& Flame, 2006]

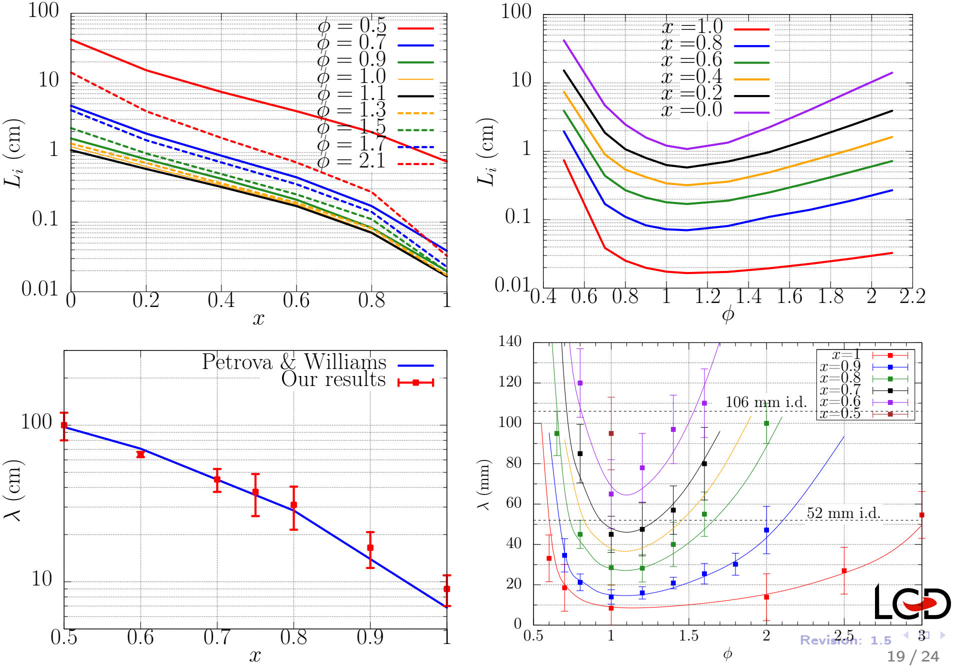
Detailed kinetics comparision



The Petrova & Williams kinetic best correlates experimental data.

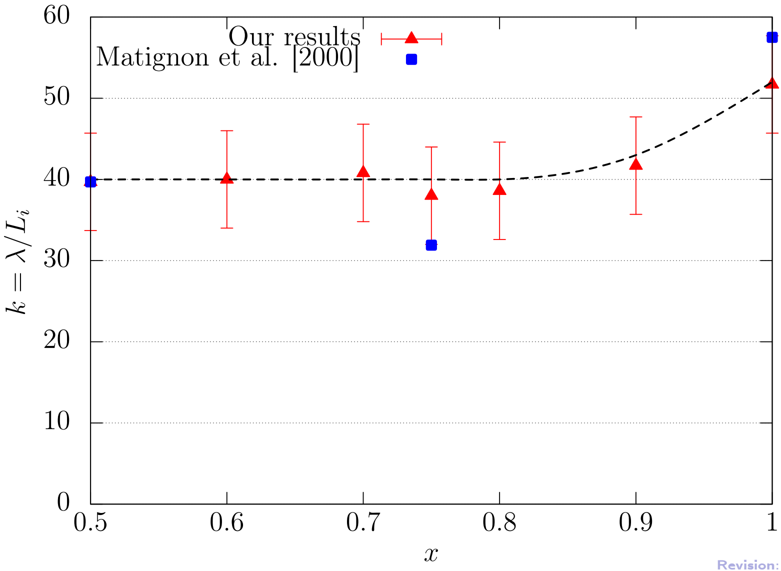
Link with chemical induction length (L_i)



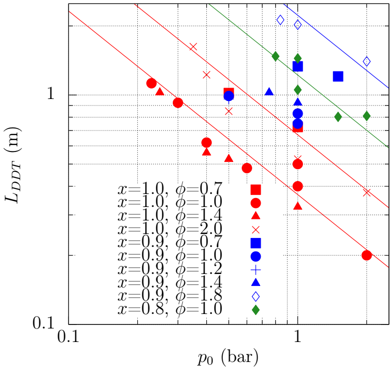


L_i (cm)
x
$\phi = 0.5$
$\phi = 0.7$
$\phi = 0.9$
$\phi = 1.0$
$\phi = 1.1$
$\phi = 1.3$
$\phi = 1.5$
$\phi = 1.7$
$\phi = 2.1$
L_i (cm)
ϕ
x =1.0
x =0.8
x =0.6
x =0.4
x =0.2
x =0.0
λ (cm)
x
Petrova & Williams
Our results
λ (mm)
ϕ
x=1
x=0.9
x=0.8
x=0.7
x=0.6
x=0.5
106 mm i.d.
52 mm i.d.

Link with chemical induction length (L_i)

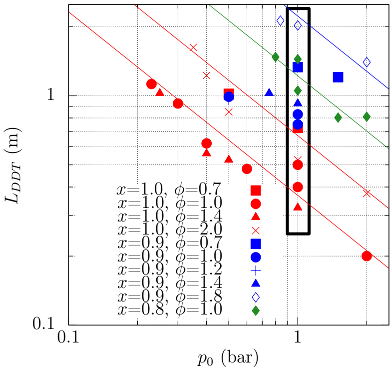


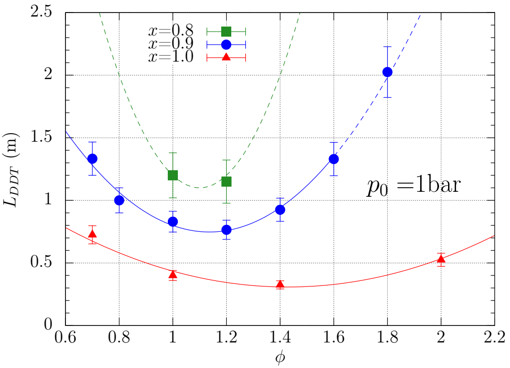
Length of transition (L_{DDT}) with p_0 or ϕ



$$L_{DDT} \propto p_0^{-0.8}$$

Length of transition (L_{DDT}) with p_0 or ϕ

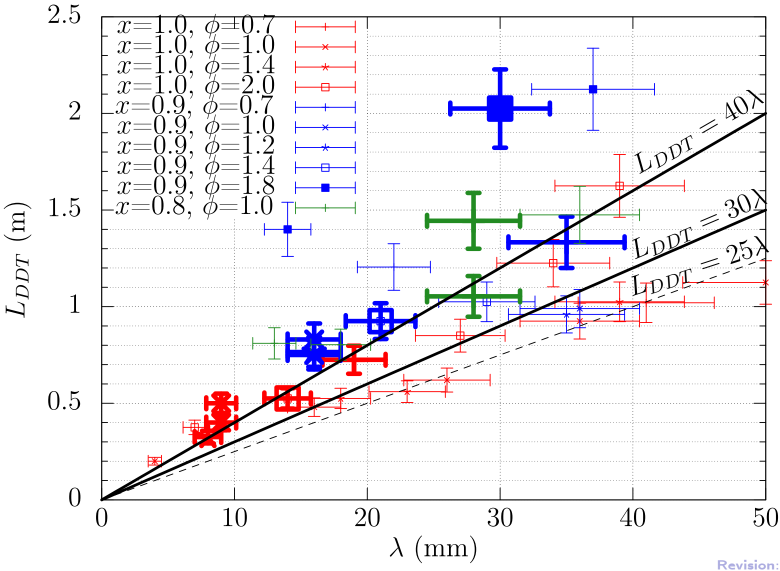




$L_{DDT} \propto p_0^{-0.8}$

(p_0=1bar)

Length of transition (L_{DDT}) with λ



Outline

Conclusion

Detonation study :

- p, D are close to the CJ values
- $\lambda(\phi)$ has classical U-shape (at x given)
- At given ϕ, x increases $\Rightarrow$ λ decreases

DDT study :

- Sensitive area (i.e. $\lambda < 50$mm) when few CH_4 is added to H_2/Air mixture (up to 35% CH_4)
- $L_{DDT} \sim p_0^{-n}$, $n \approx 0.8$
- $L_{DDT} \sim$ 30–40 λ

	x=1 (H_2/air)	x=0.8	x=0.5
λ (cm)	1	3	10
L_{DDT} (m)	0.4	1.25	

(ϕ=1)

Acknowledgement

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HYDROMEL

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