Fast flames and their transition to detonations

Matei Radulescu

University of Ottawa

Invited Talk
65th UKELG One Day Discussion Meeting on
Explosion Research of Yesterday, Today and Tomorrow
Thursday 27th November 2025
BP International Centre for Business and Technology
Sunbury-on-Thames, UK TW16 7LN

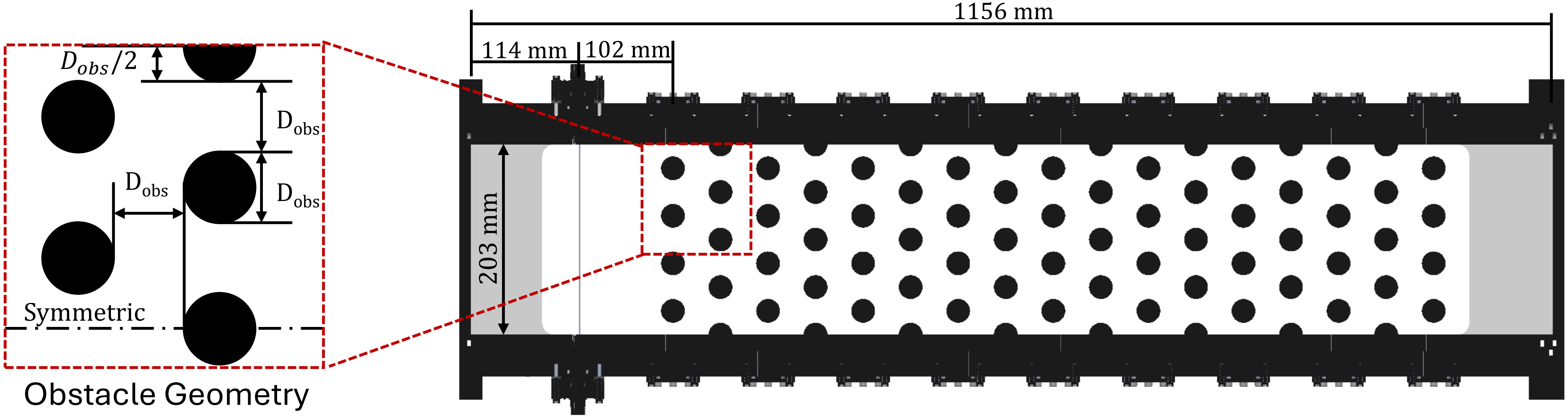
A criterion for detonation based on the speed of a “fast” flame?

Example of industrial piping

Pekalski et al. (2015)

Davis et al. (2018)

Experimental Method



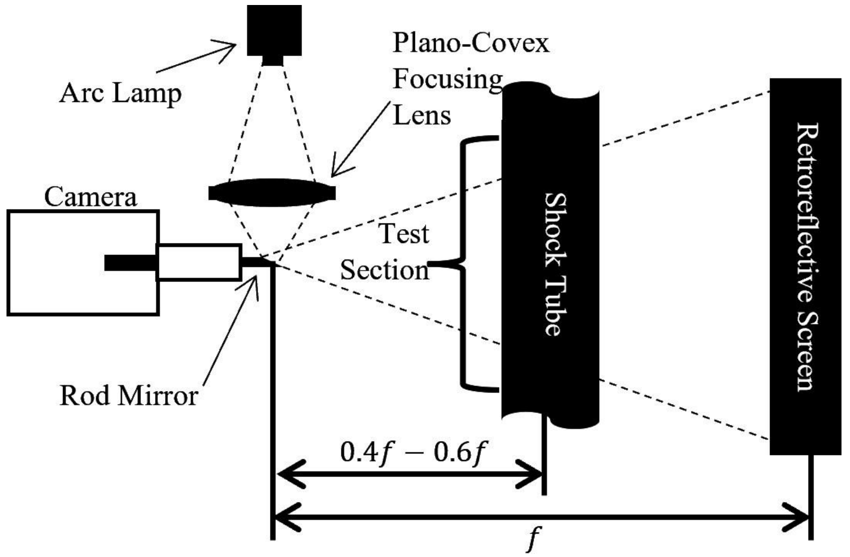
Obstacle Geometry

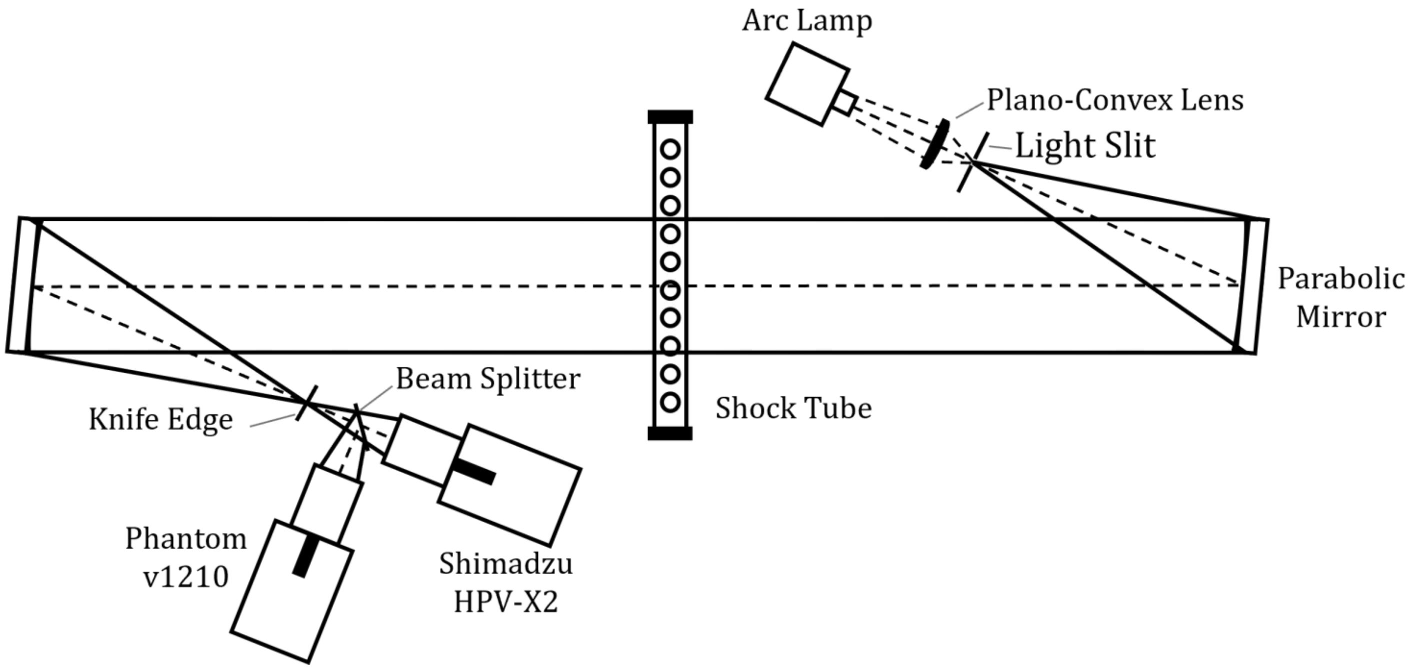
Mixtures :

- $2H_2 + O_2 + 1.29N_2$ 19.0 kPa
- $CH_4 + 2O_2$ 10.3 kPa

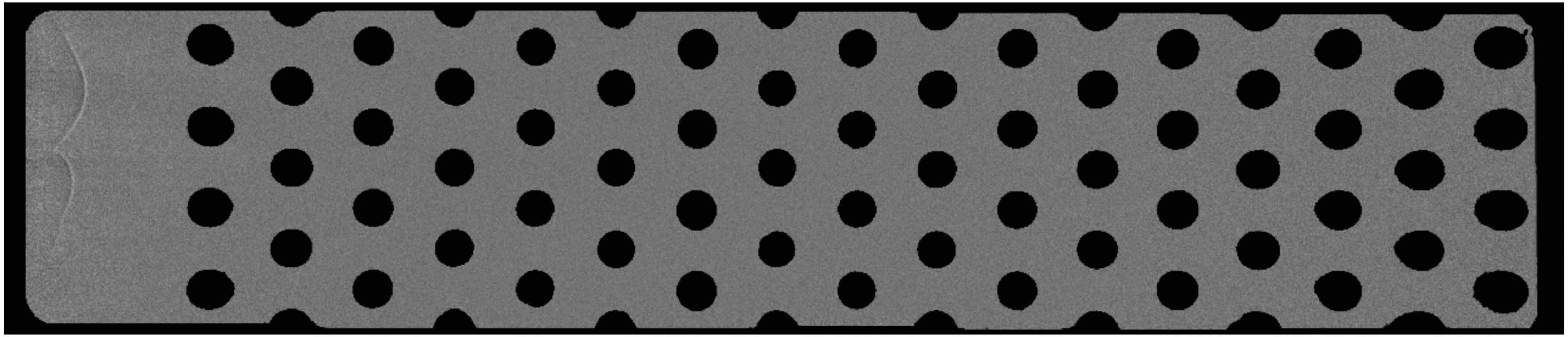
Cheevers et al. ICDERS 2025

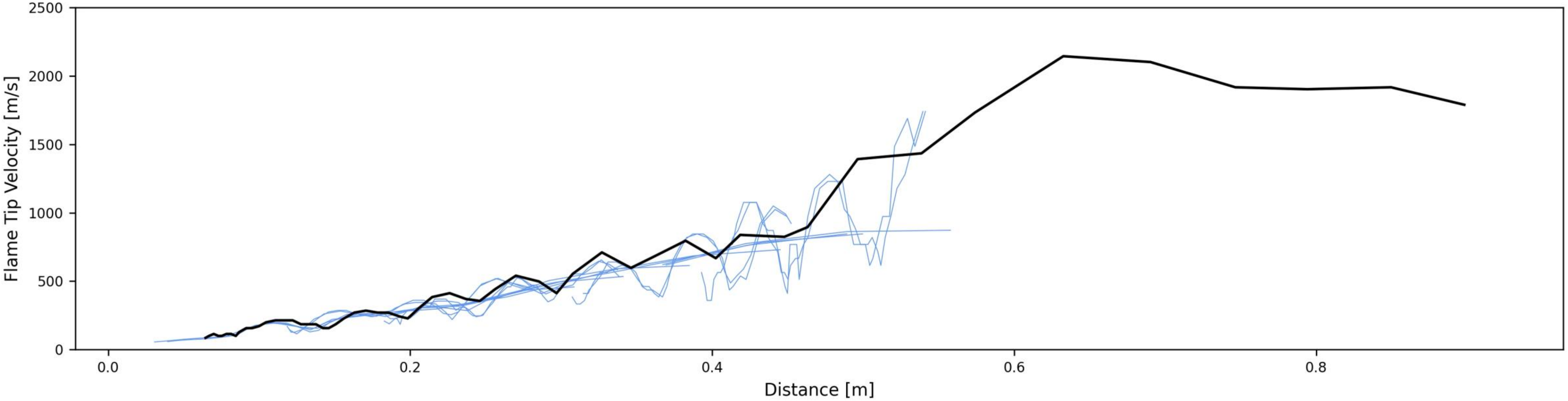
Visualisation Setup





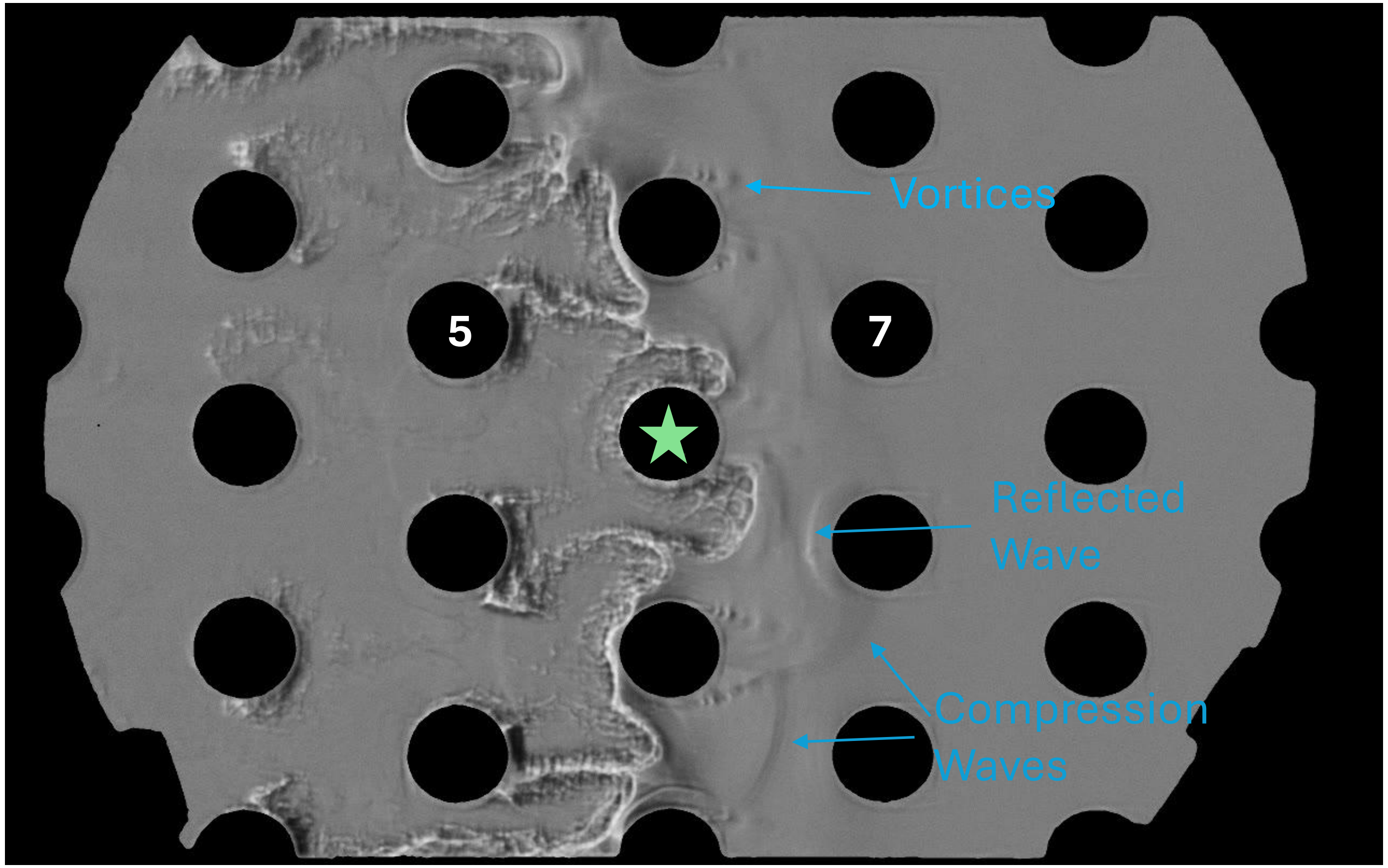
Hydrogen Shadowgraph Video and Velocity Plot

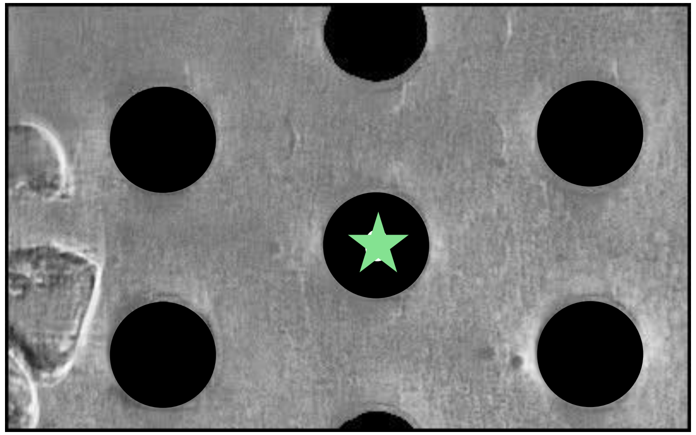




Hydrogen Flame – Shock Formation

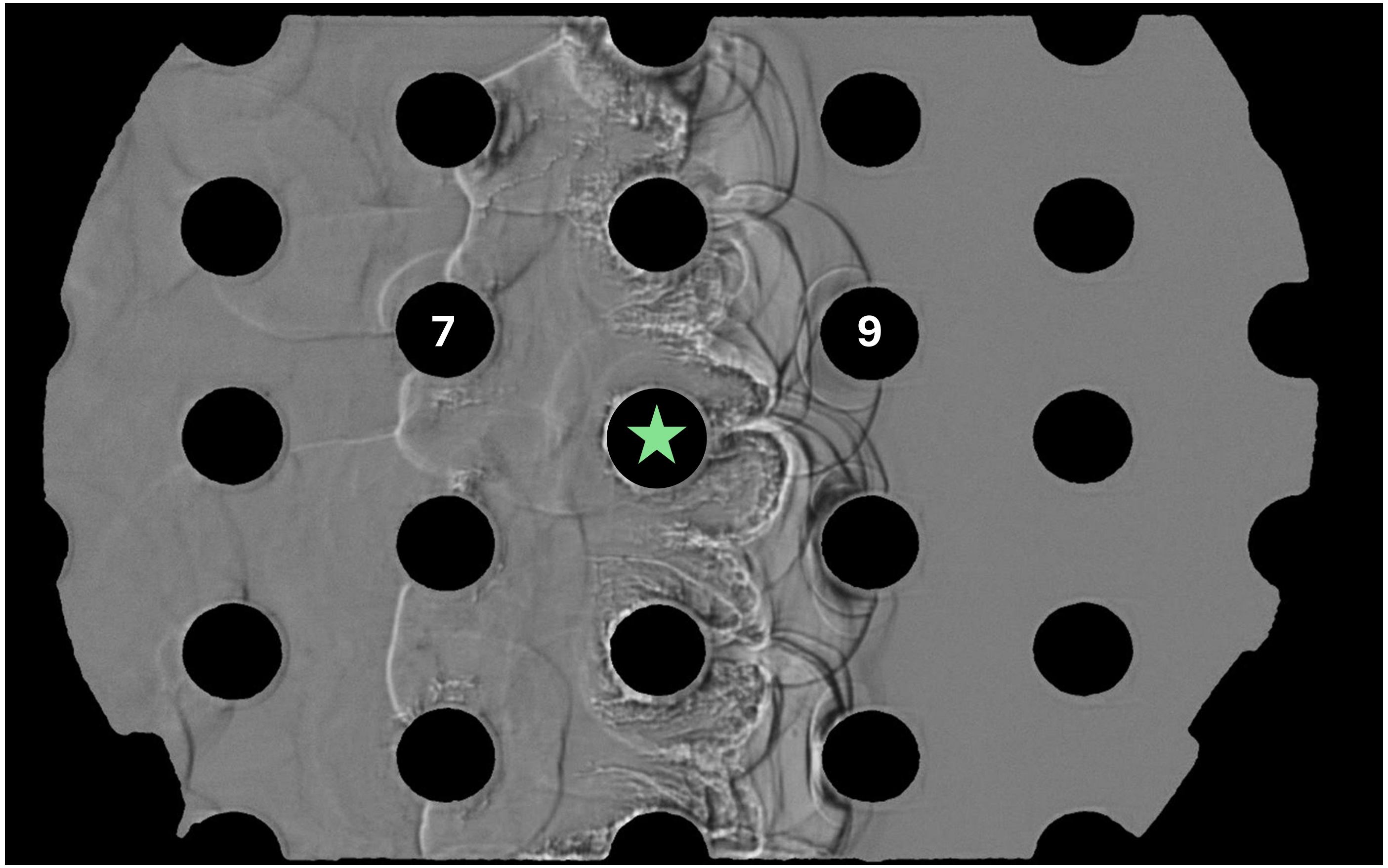
~750 m/s

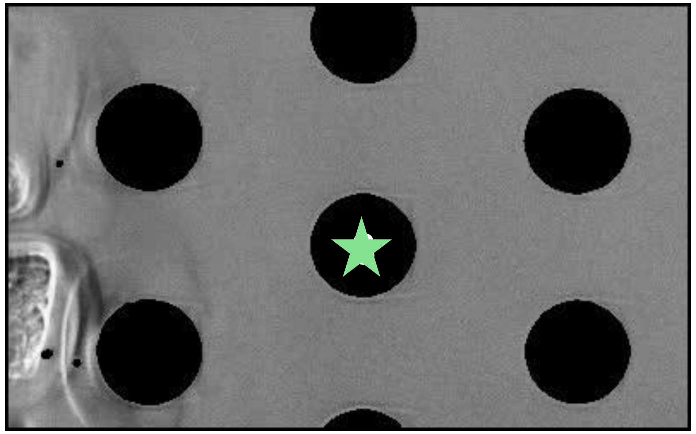




Hydrogen Flame – Shock Formation

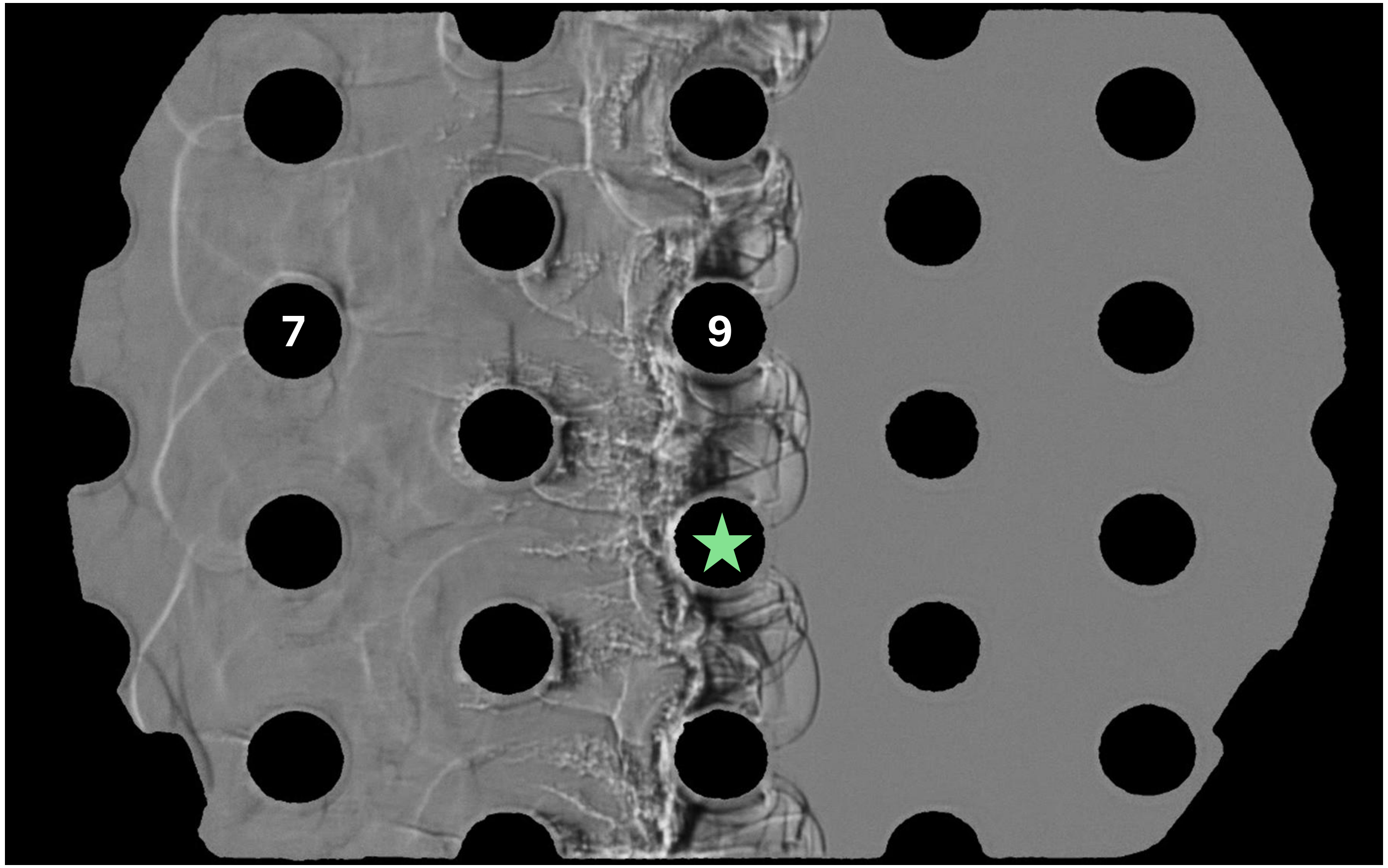
~1000 m/s

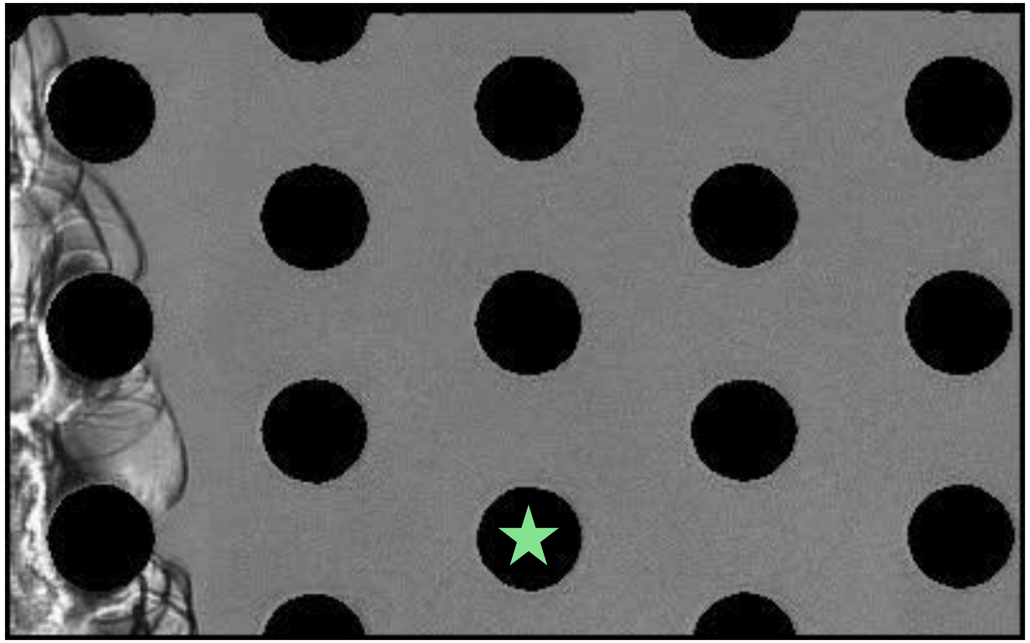




Hydrogen Flame – Detonation Initiation

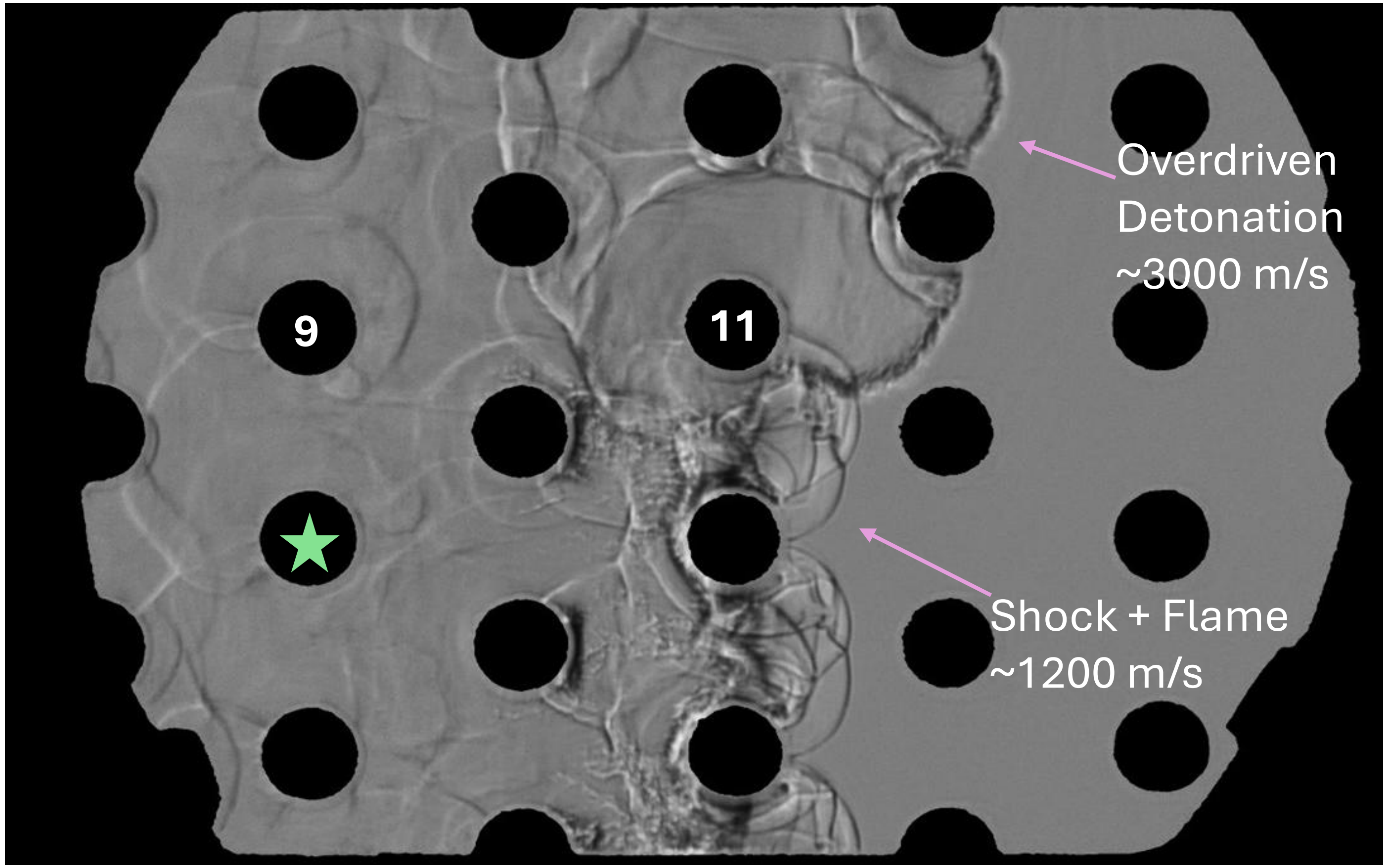
~1000 m/s

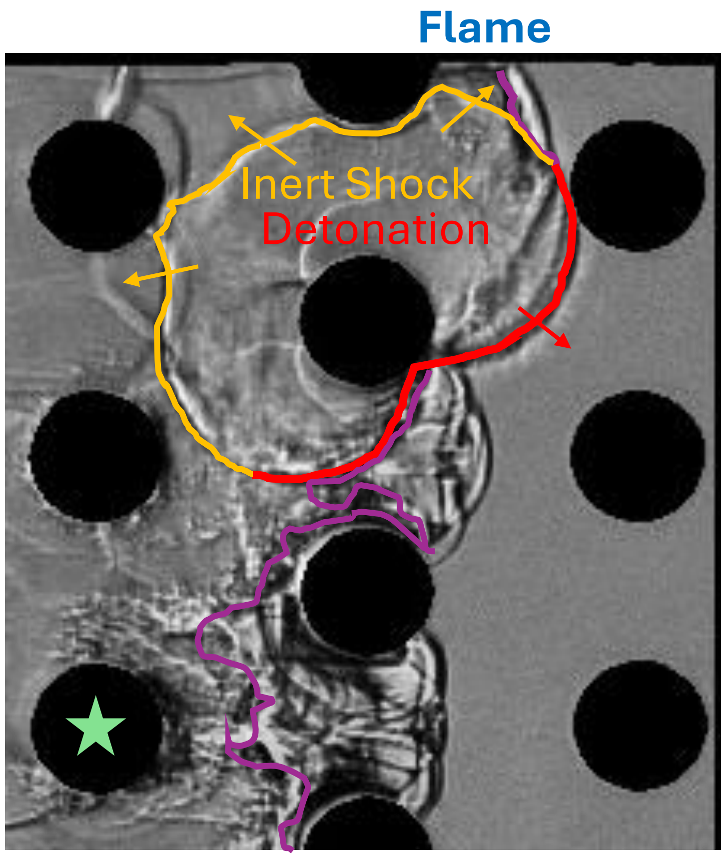




Hydrogen Flame – Detonation Initiation

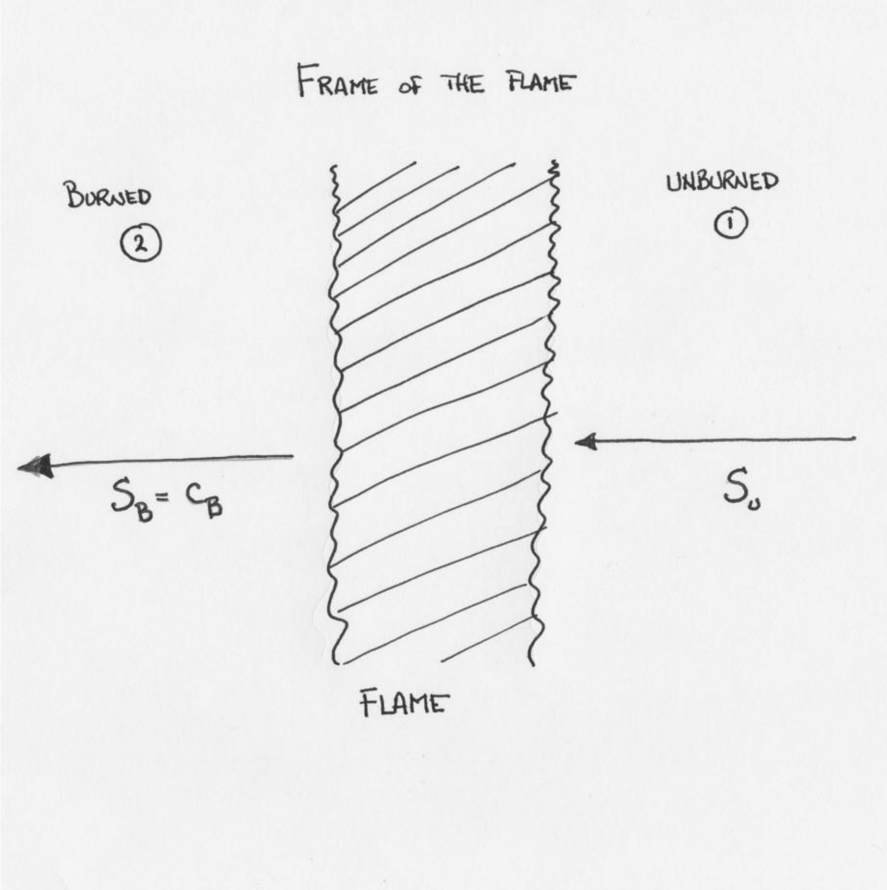
~1000-1400 m/s

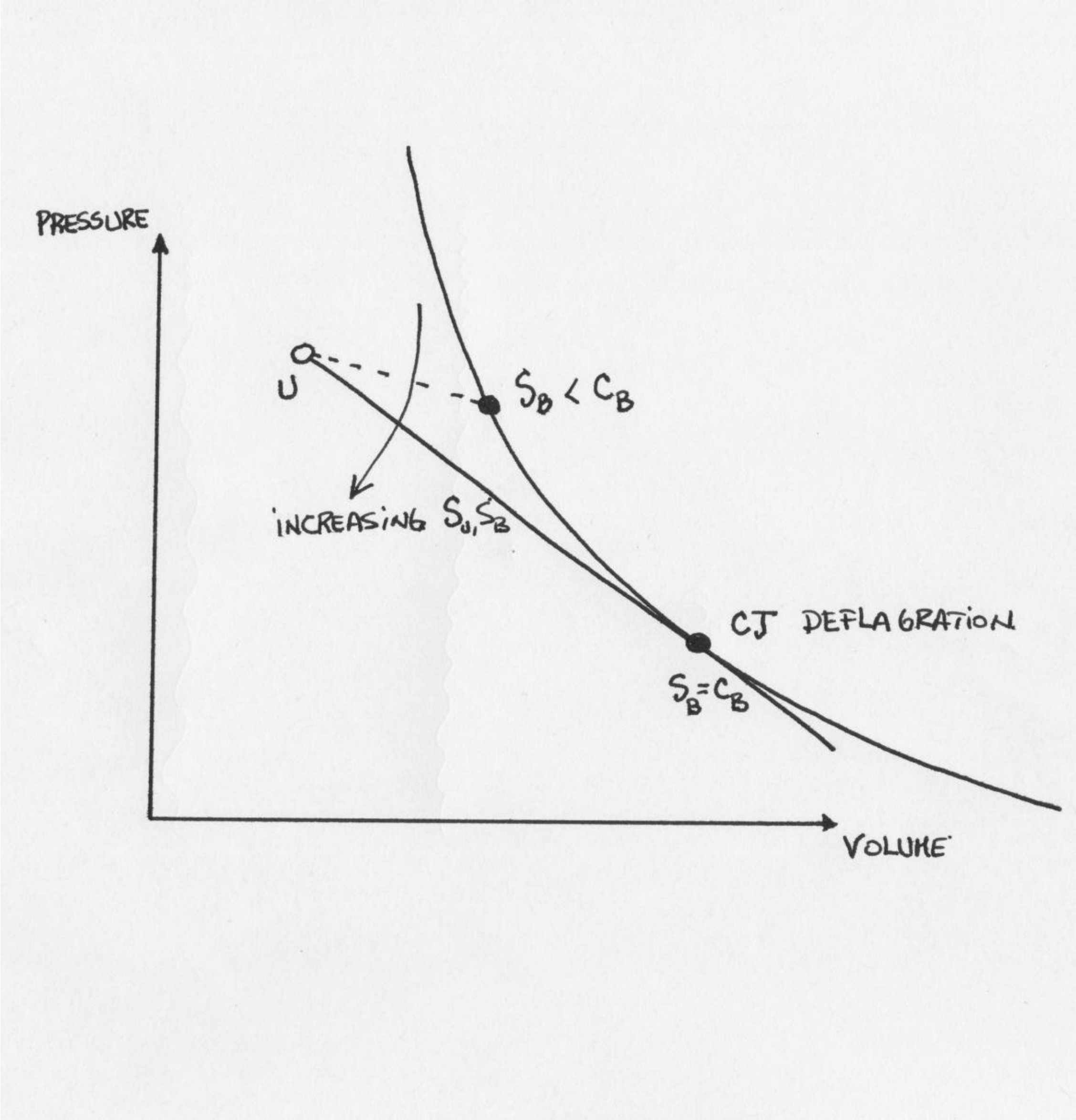




What is special about the CJ deflagration condition?

- max. burning rate S_u
- Sonic outflow



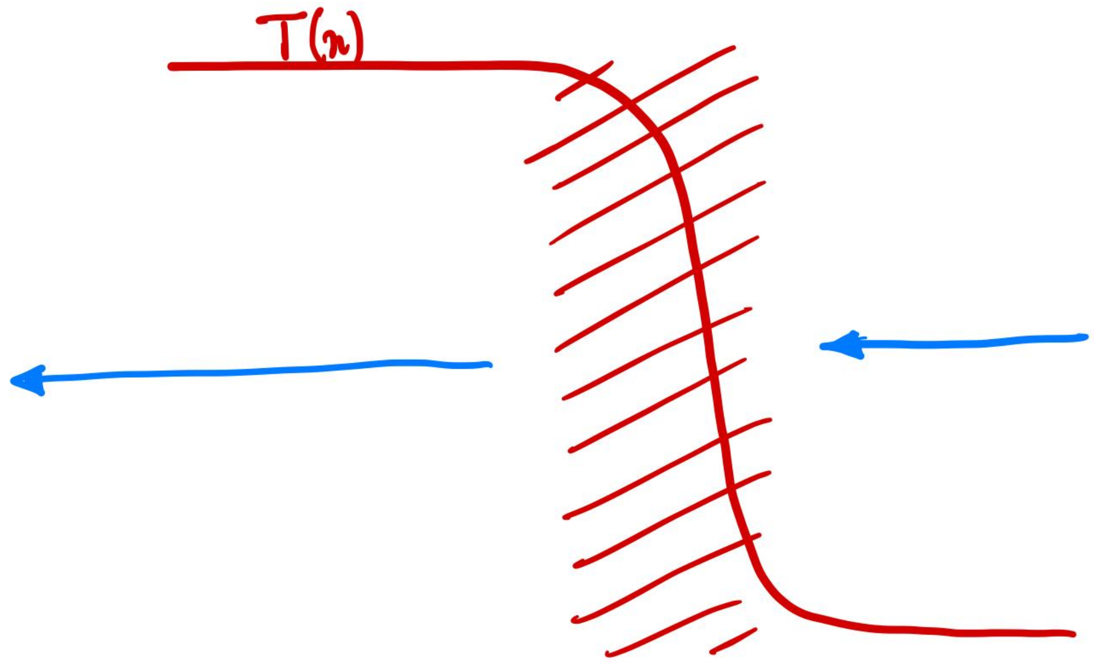


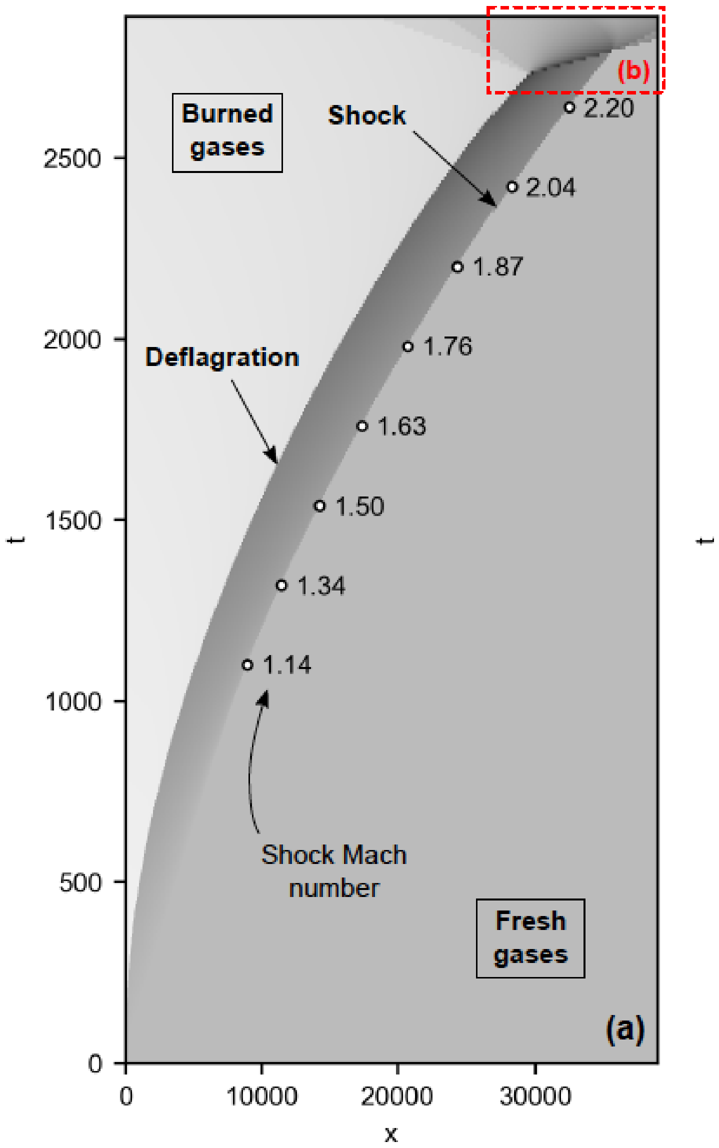
What's so special about CJ deflagrations?

Increase in burning speed modifies upstream state via shocks in order to remain CJ deflagration.

- Poludnenko et al. *Physical Review Letters* 2011, *Science* 2019
- Rakotoarison (PhD thesis, ICDERS 2023)

Rakotoarison 1D study





Establish laminar flame and increase the reaction rate

Rakotoarison 1D study

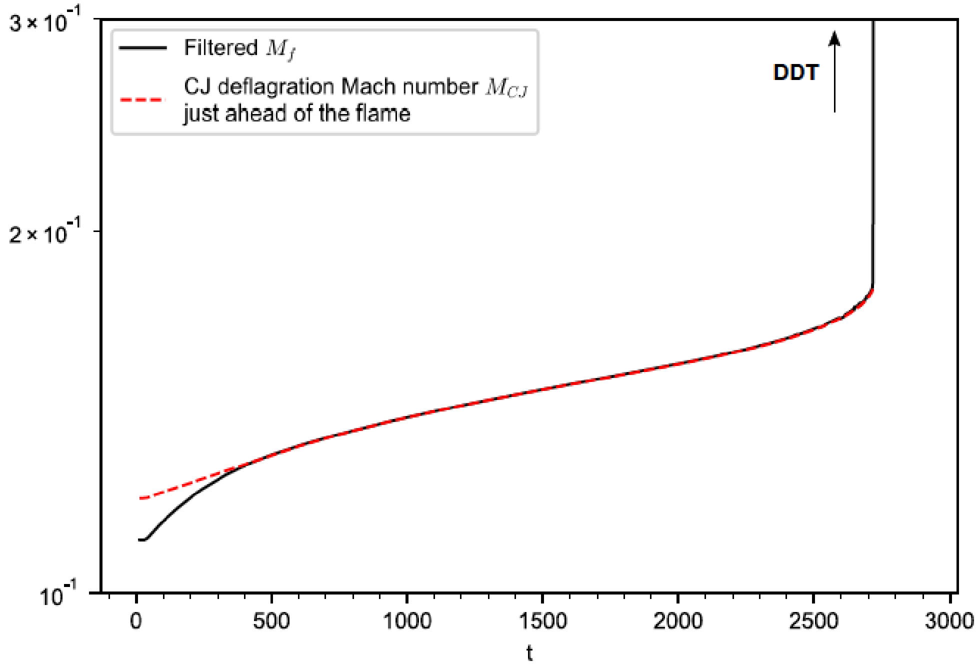
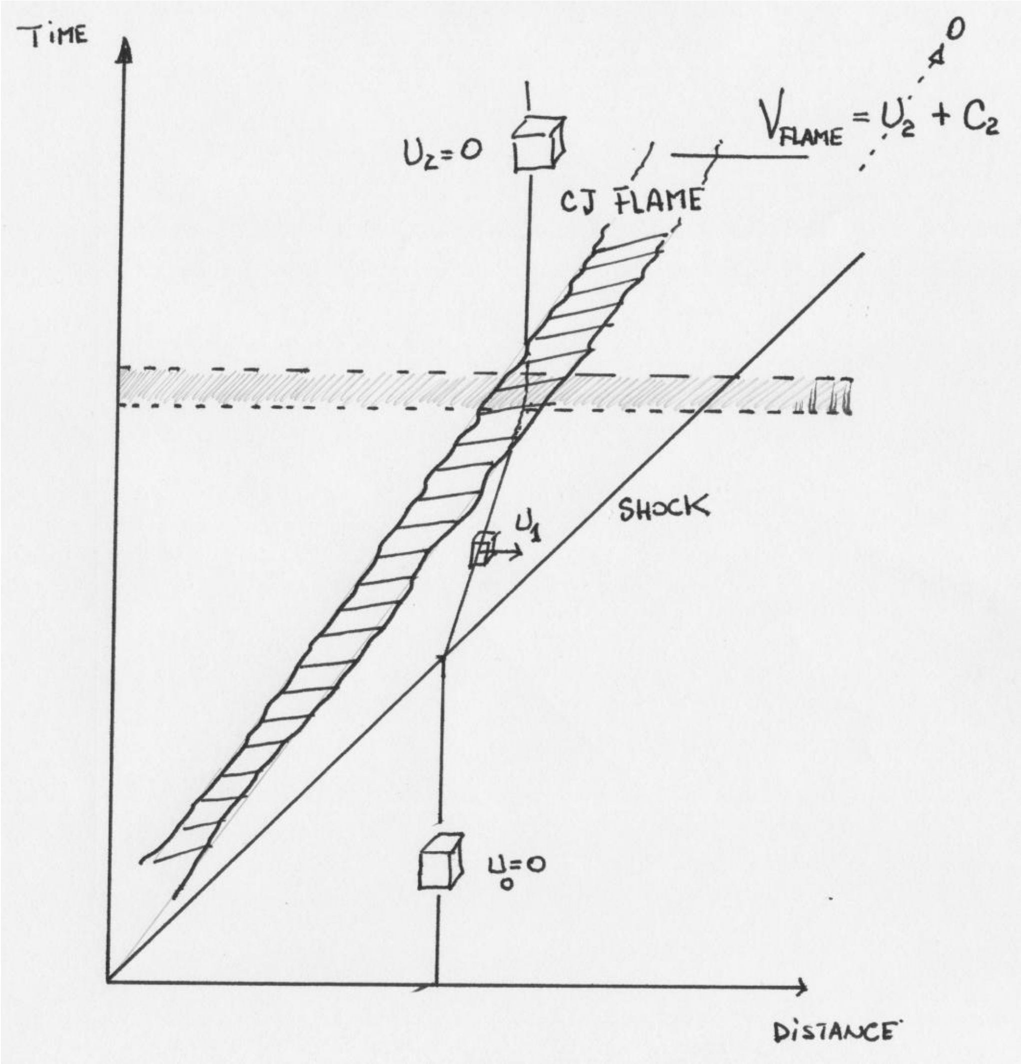
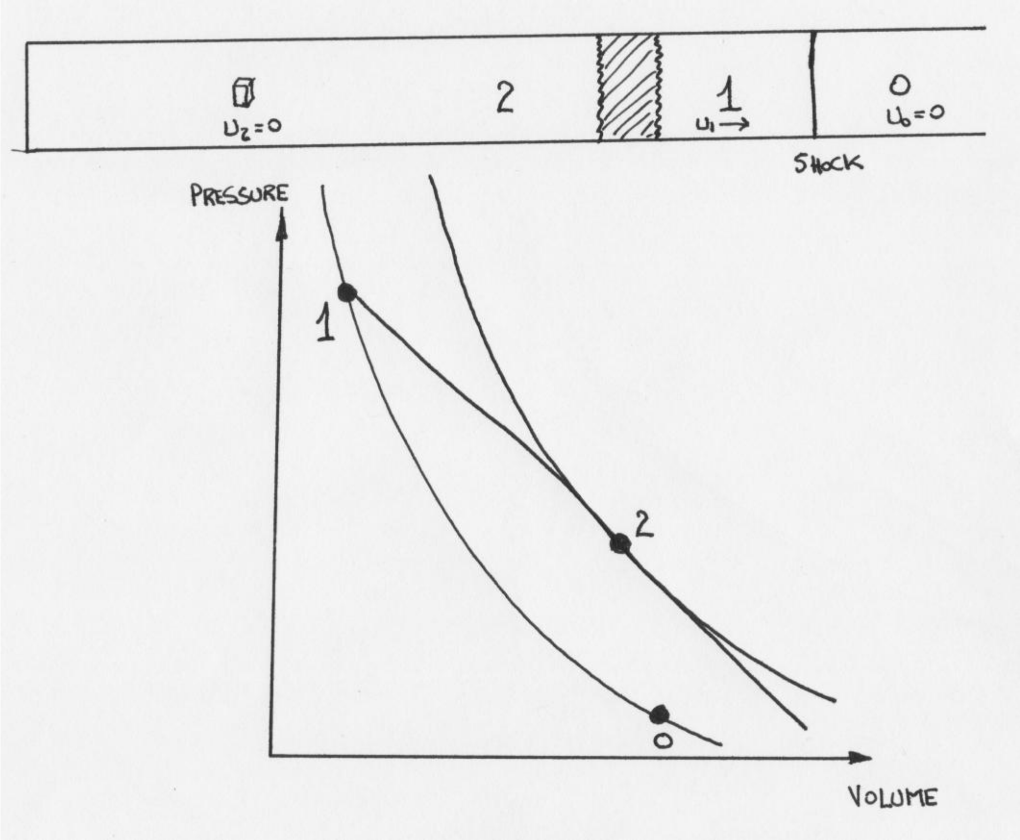


Figure 3: Evolution of the flame Mach number and the expected CJ deflagration Mach number over time.

Flame remains CJ deflagration but modifies upstream state via shock

Chapman-Jouguet deflagrations in closed tubes





R. S. Chue, J. F. Clarke, and J. H. Lee, "Chapman-Jouguet deflagrations," *Proc. Roy Soc. A*, 1993.

Critical Speed for DDT : Sound speed in products

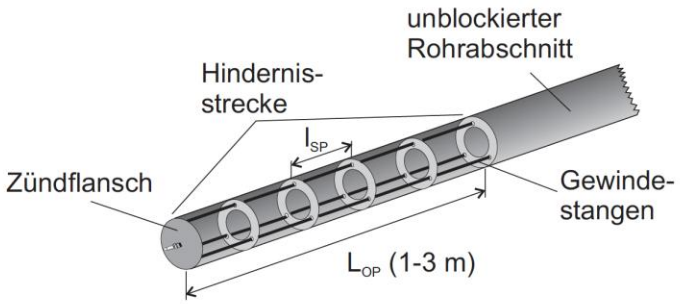
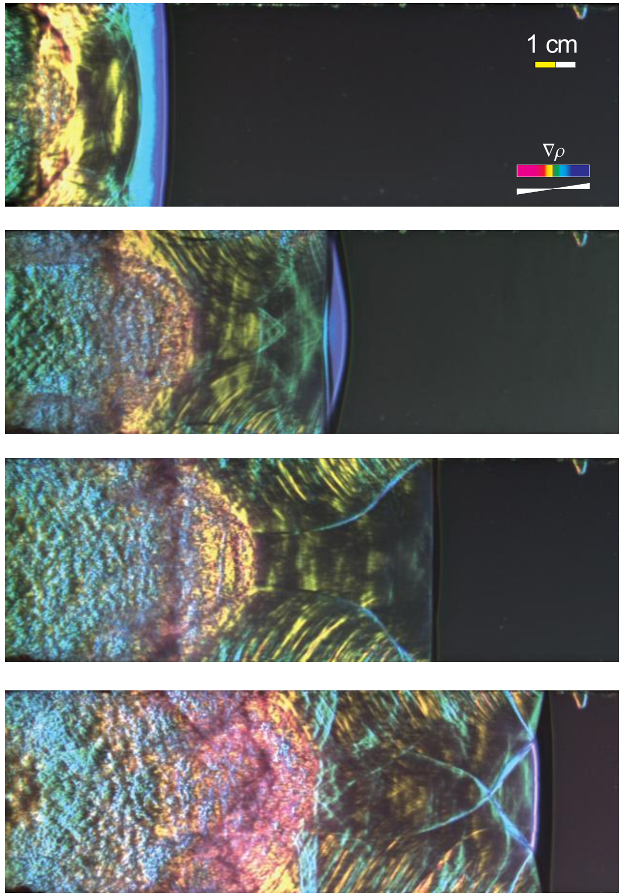


Abbildung 3.2: Geometrie der eingesetzten Blenden sowie Anordnung der Hindernisse im Explosionsrohr.



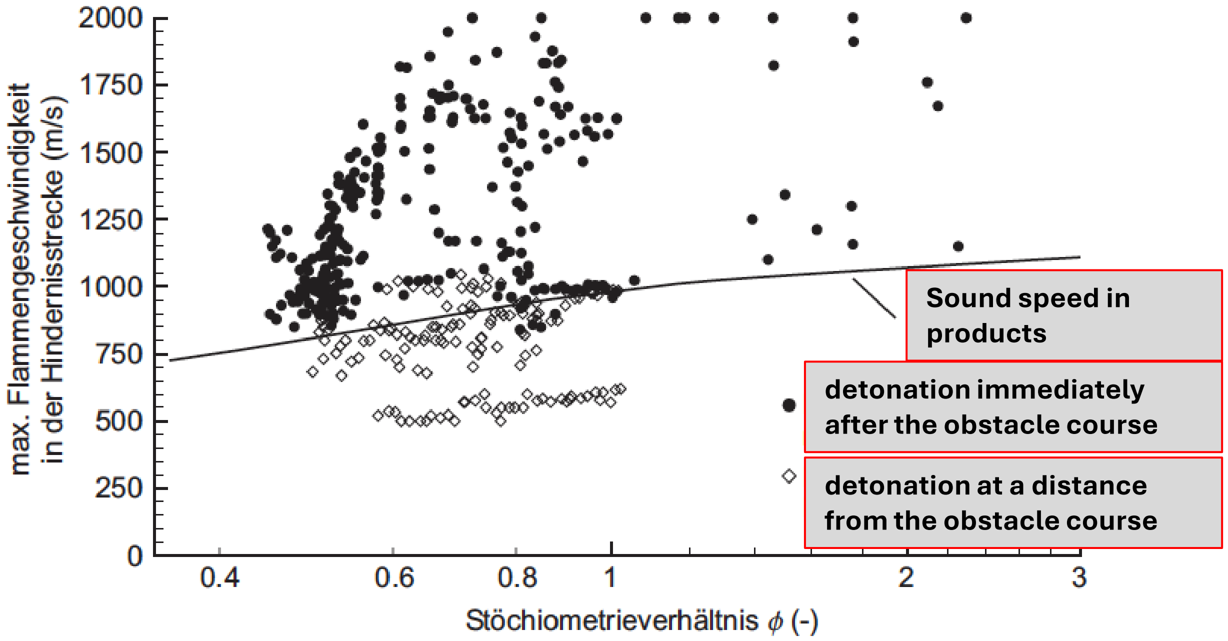
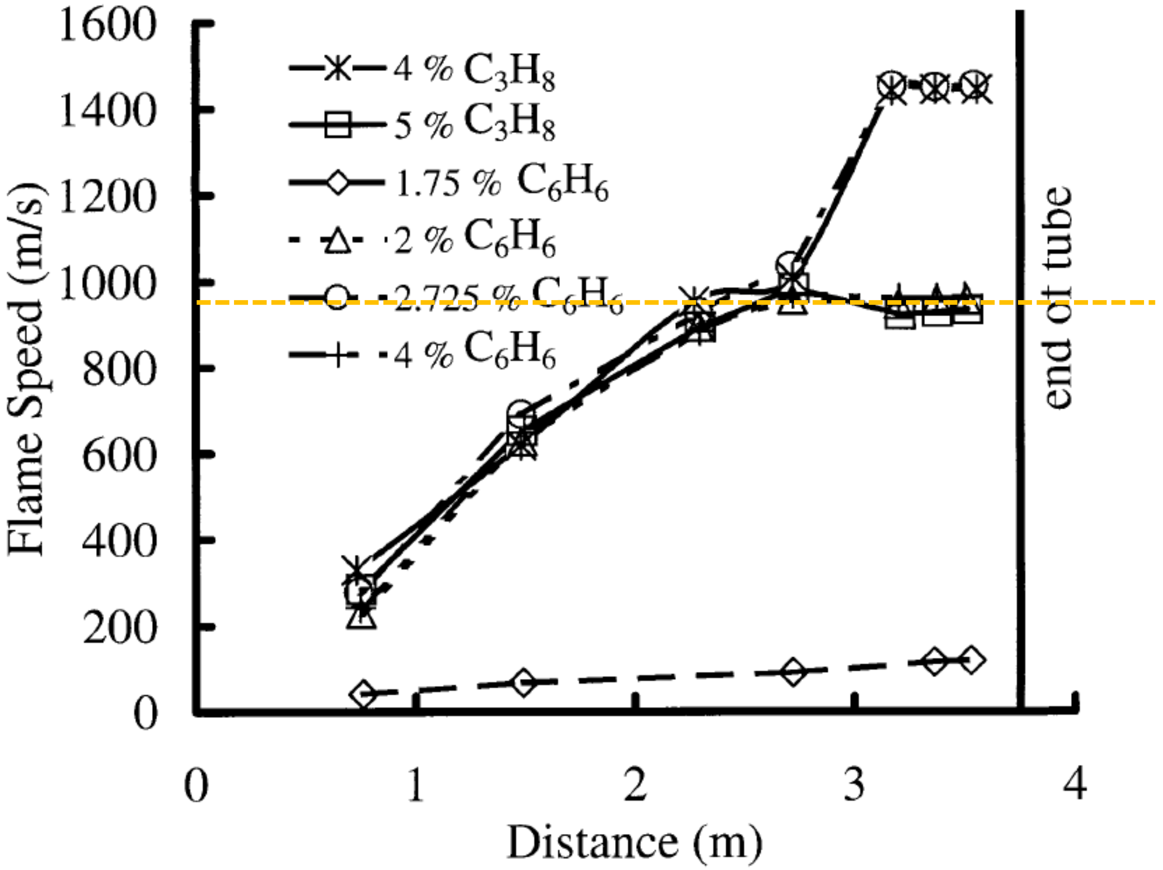


Abbildung 5.11: DDT-Prozesse unmittelbar nach und in Abstand von der Hindernisstrecke in Abhängigkeit der maximalen Flammengeschwindigkeit in der Hindernisstrecke.

A. Eder, 2001, **Brennverhalten schällnaher und überschall-schneller, Wasserstoff-Luft Flammen**, PhD Thesis, Technische Universitat München.

Compatible with other empirical data

Knystautas, R., Lee, J.H.S., Shepherd, J. E. and A. Teodorczyk, **Flame Acceleration and Transition to Detonation in Benzene–Air Mixtures**, *Combustion and Flame* 115:424–436 (1998)



Sound speed in products

Simulations

Xiao, H., Oran, E.S. **Shock focusing and detonation initiation at a flame front,** *Combustion and Flame 203* (2019) 397–406.

Pinos T. , Ciccarelli, G., **Combustion wave propagation through a bank of cross-flow cylinders**, *Combustion and Flame* 162 (2015) 3254–3262 .

H_2-air

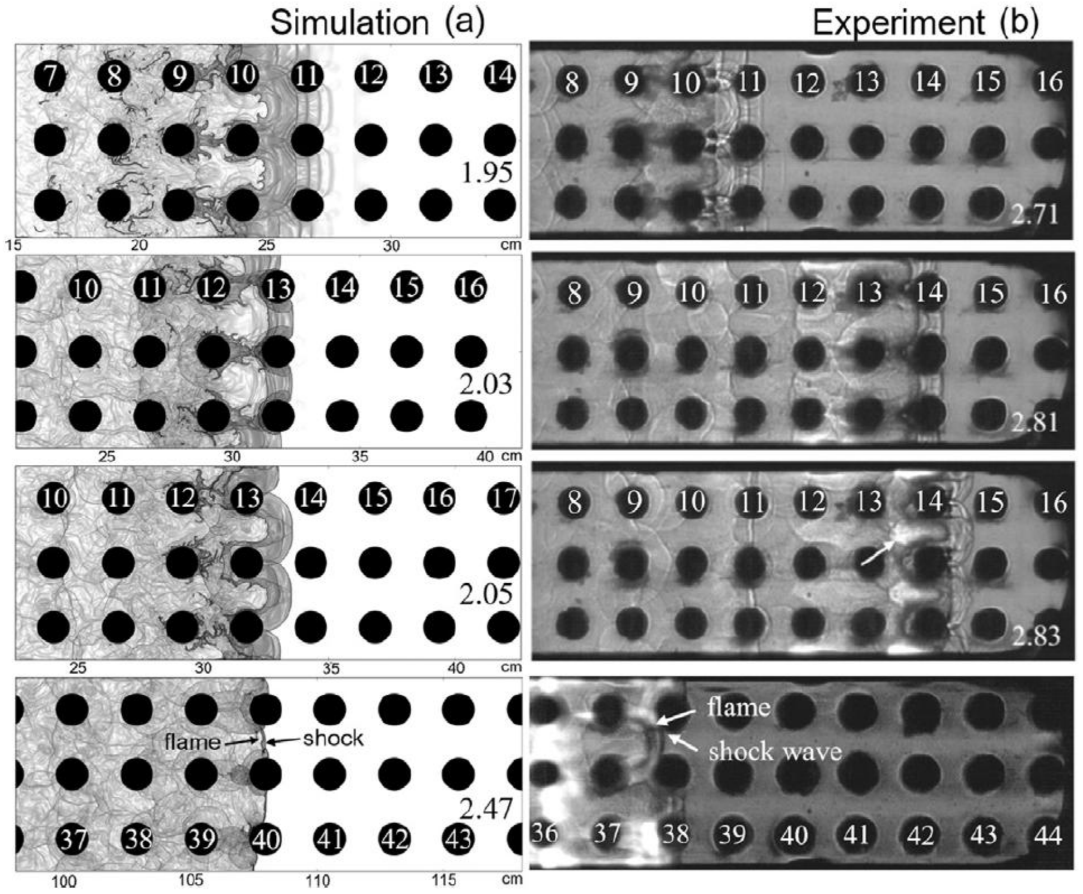


Fig. 4. Schlieren images at later stage of flame acceleration and detonation propagation. (a) Simulation. (b) Experiments by Pinos and Ciccarelli [20]. Time in milliseconds in the right-bottom corner of each frame.

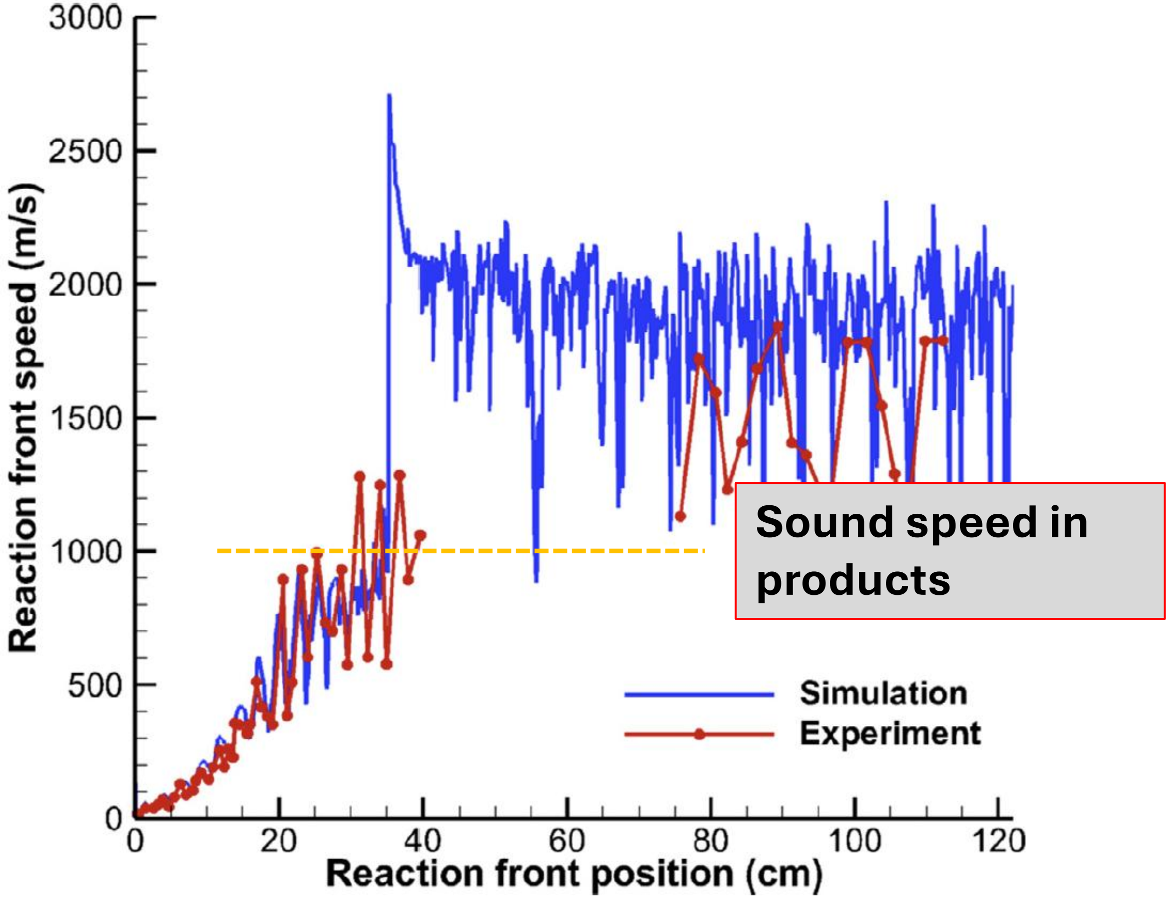
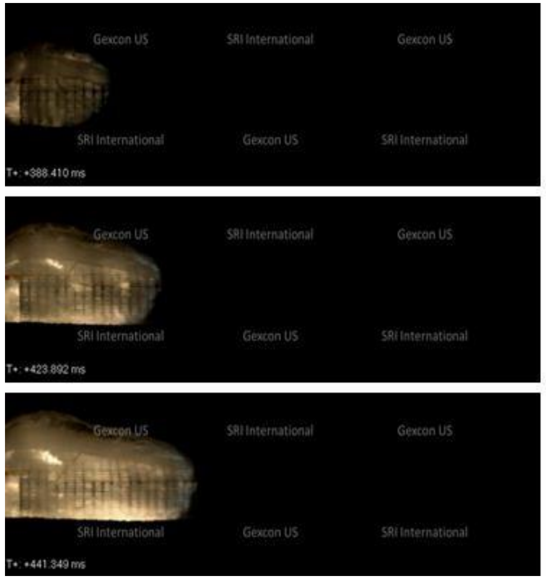
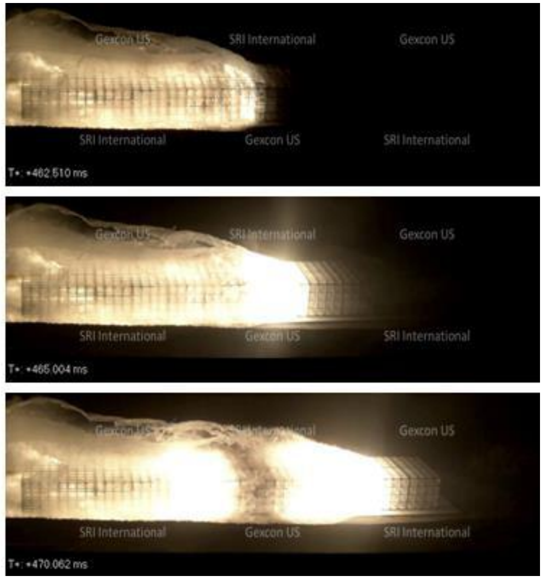


Fig. 5. Computed and measured [20] reaction-front propagation speed as a function of position. The gap in the experimental data curve arises because the initial DDT process was not captured by the experiment.

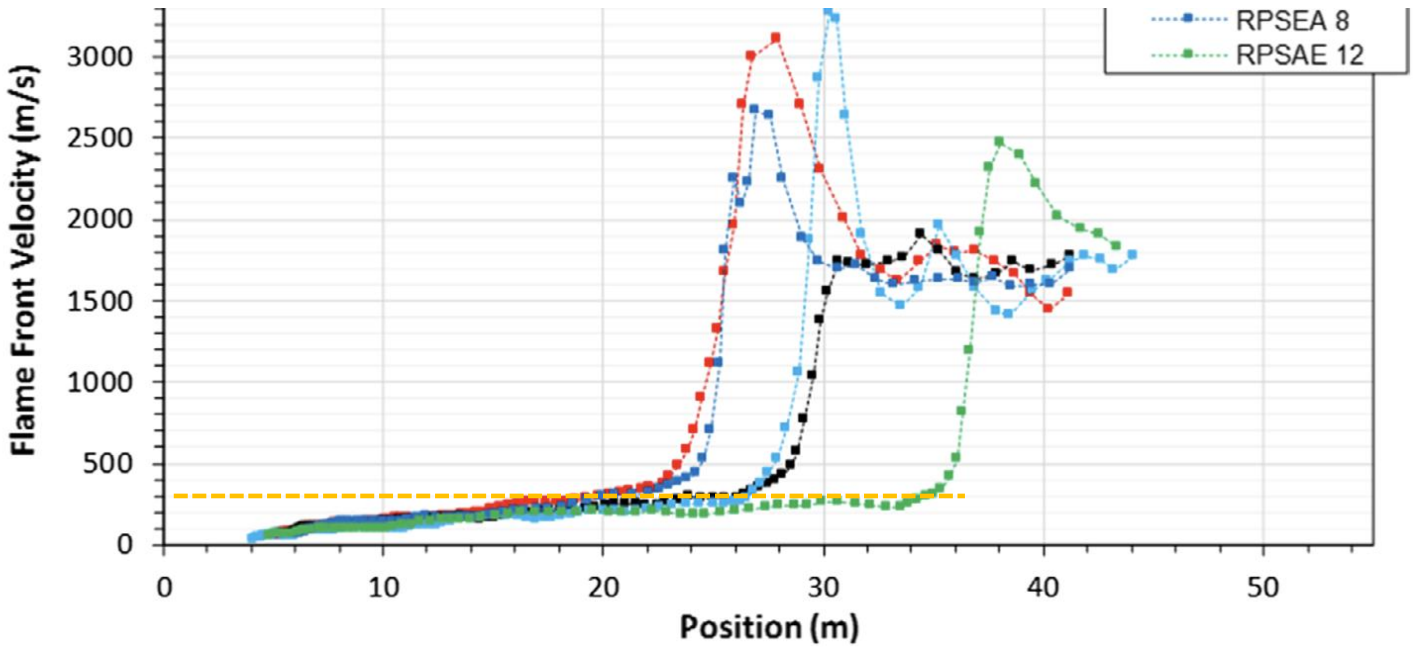
Non-confined DDT with congestions

Davis, S., Engel, D., van Wingerden, K. and Merilo, E. **Can gases behave like explosives: Large-scale deflagration to detonation testing**, *Journal of Fire Sciences* 2017, Vol. 35(5) 434–454

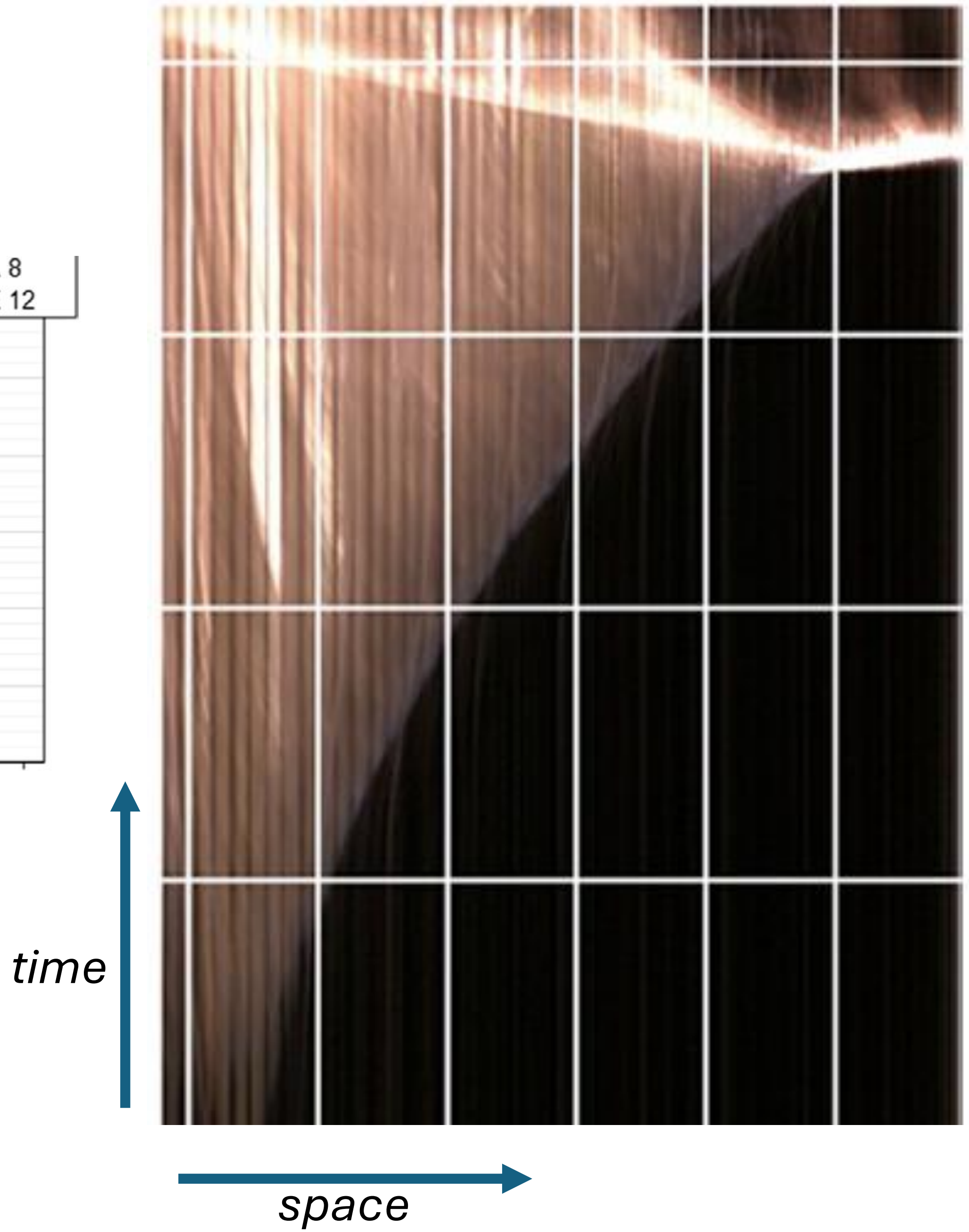




Propane-air

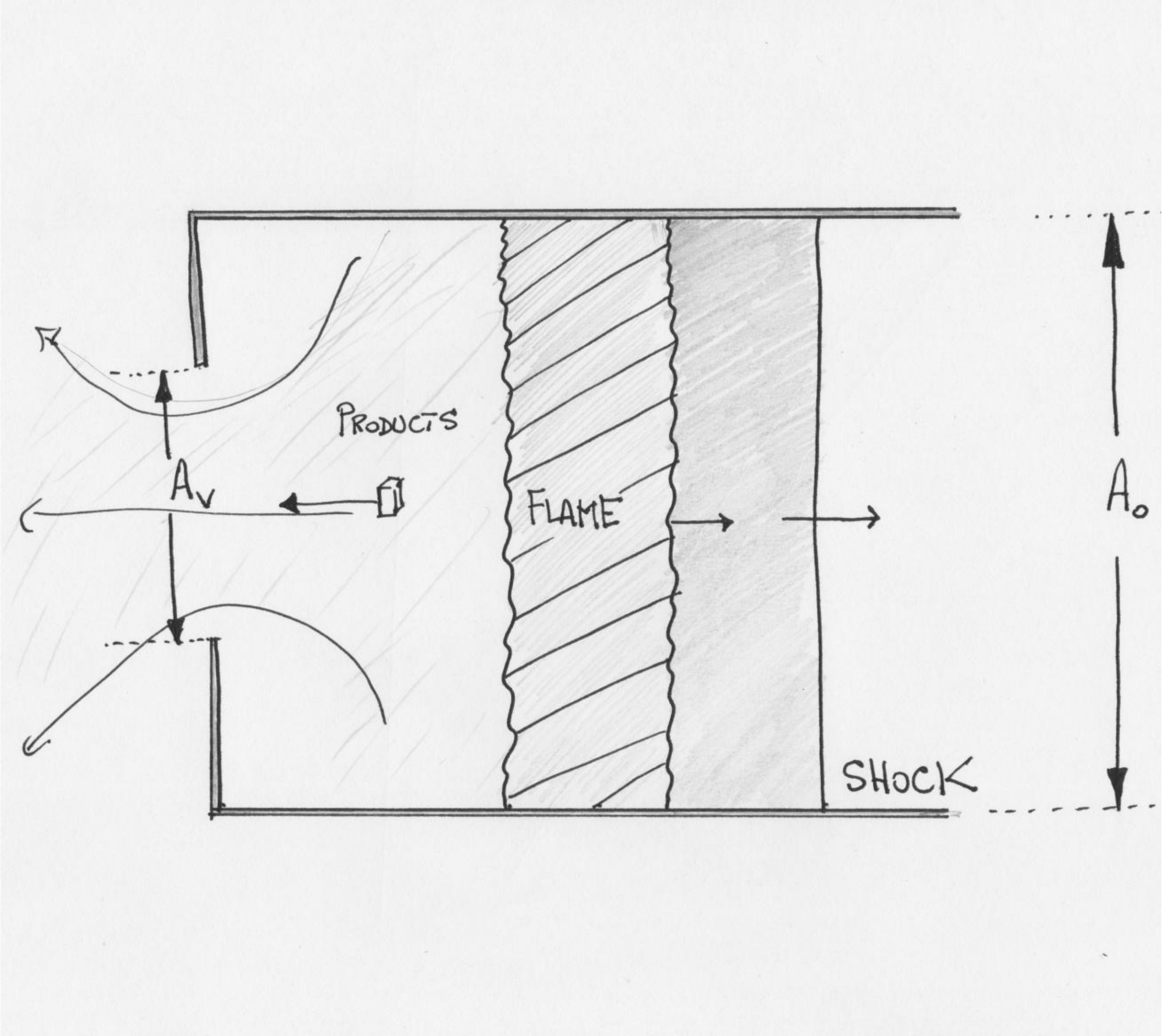


$$V^*_{FLAME} \approx 300 - 400 \text{ m/s}$$

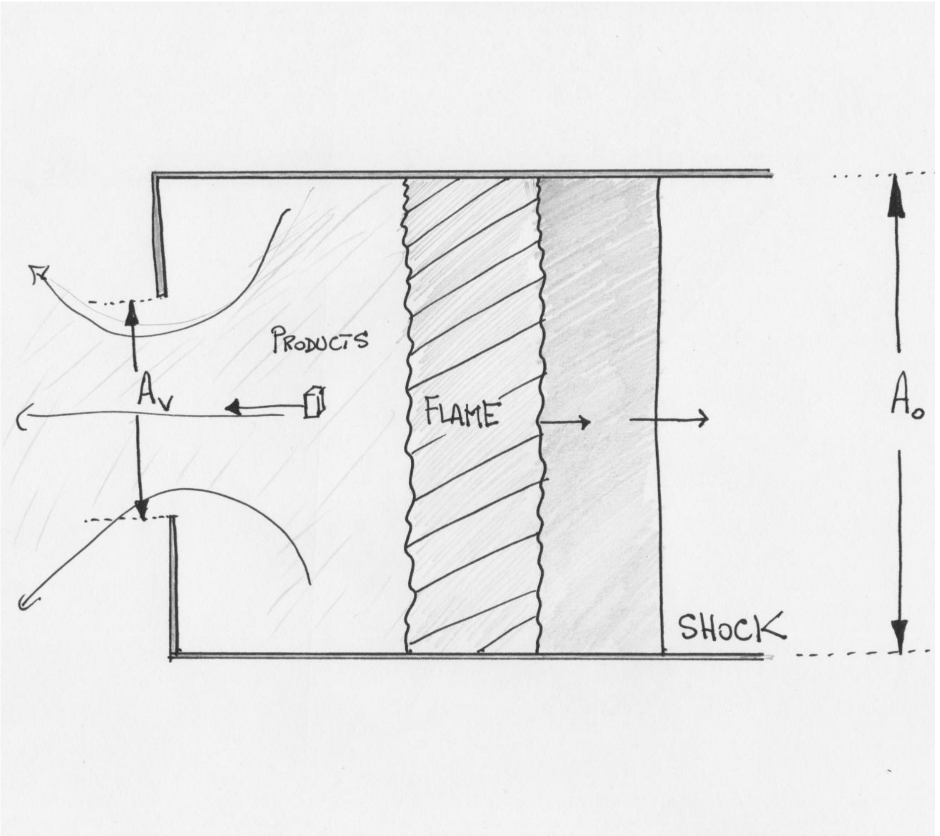


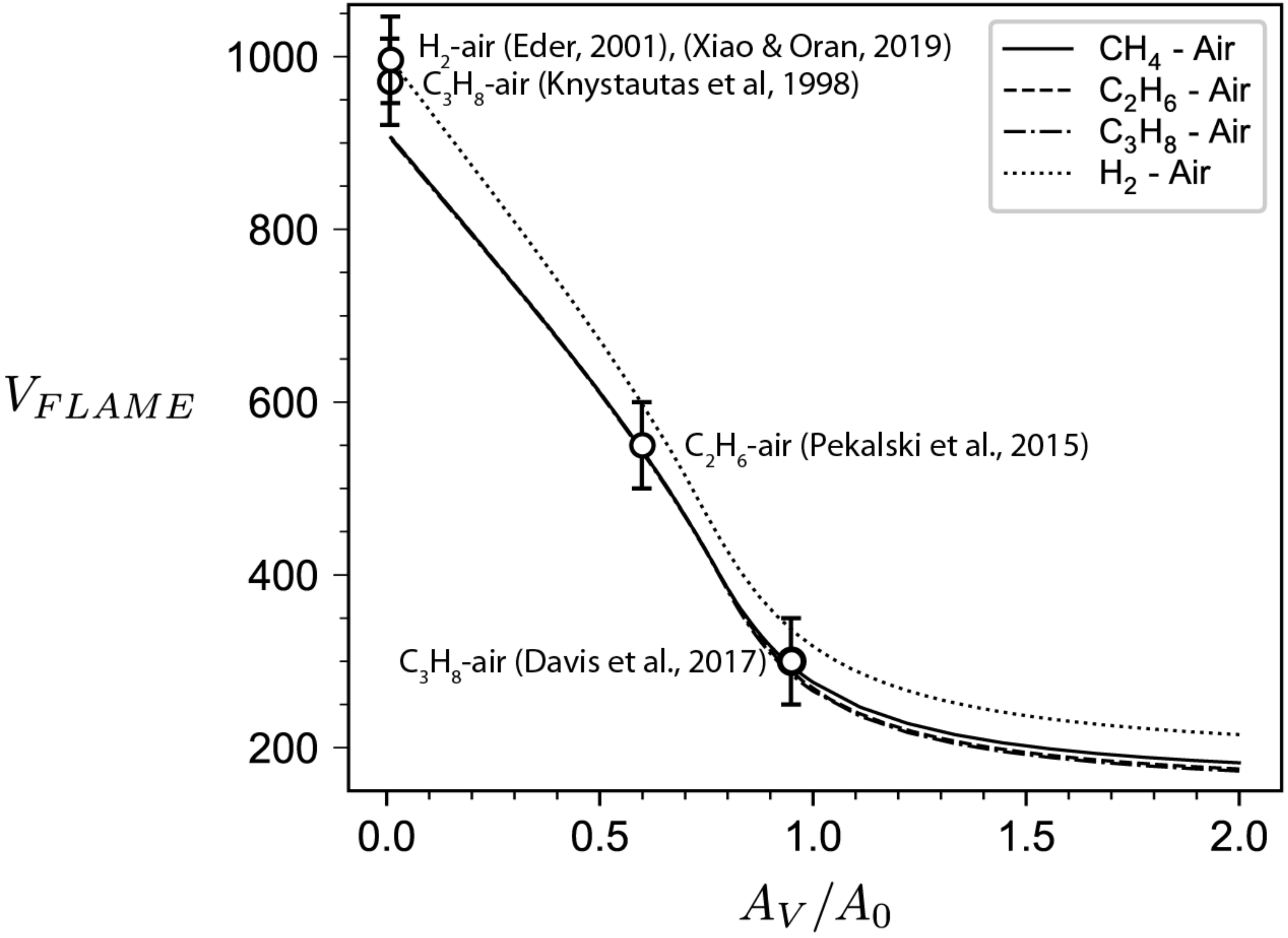
DDT with venting compatible with CJ deflagrations

Rakotoarison, W., Vilende, Yohan, Radulescu, M.I. (2024) **Model for Chapman-Jouguet deflagrations in open ended tubes with varying vent ratios**. *Combustion and Flame*.



DDT with venting compatible with CJ deflagrations

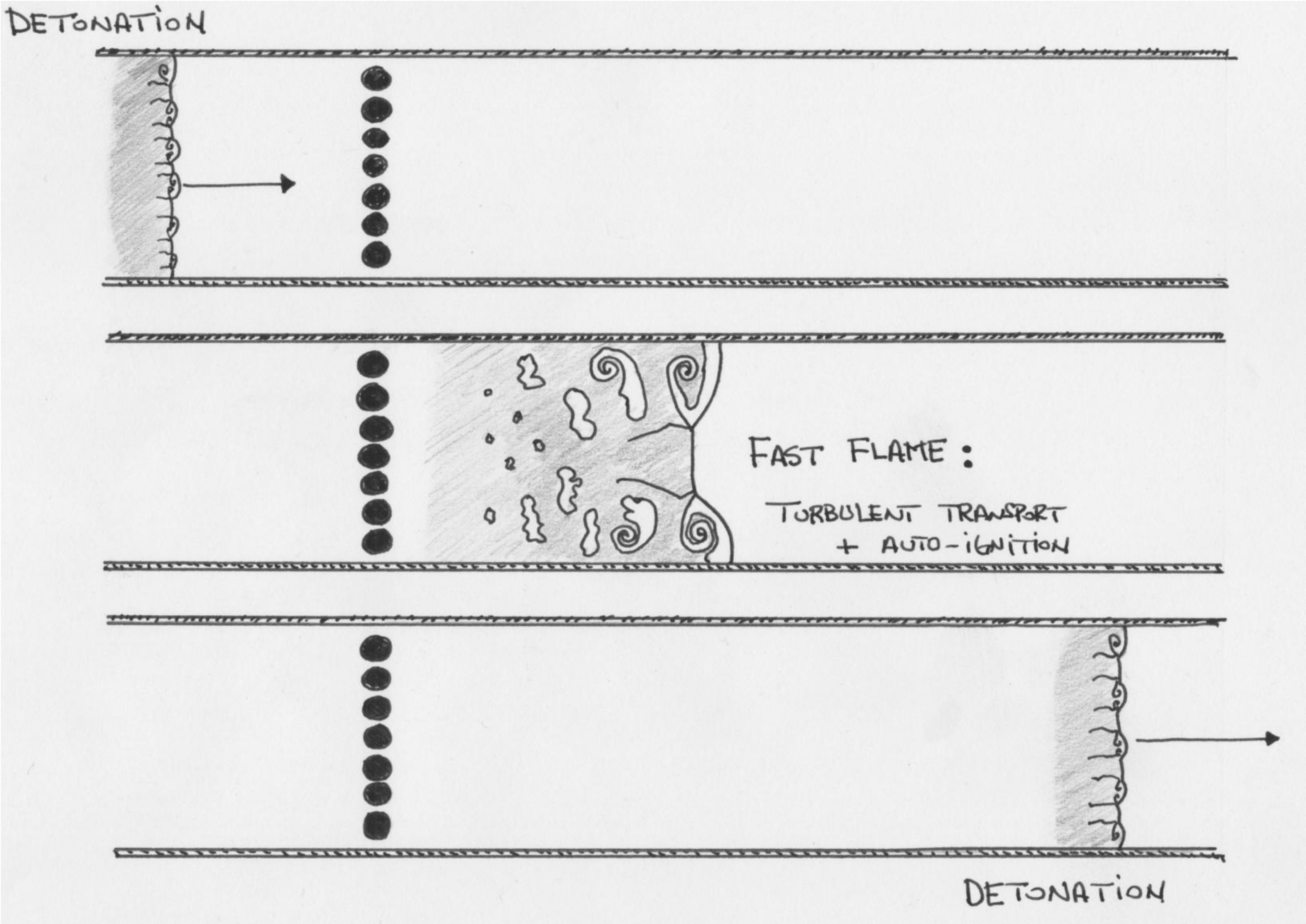




CJ deflagration robust “necessary condition” for DDT

What is the amplification length of a CJ deflagration if congestion stops?

Piston supported CJ deflagrations

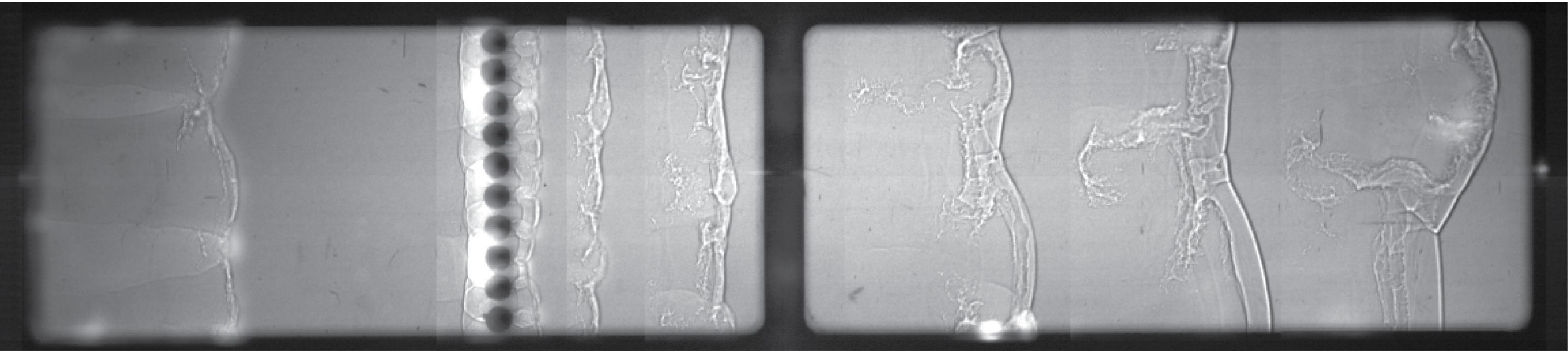


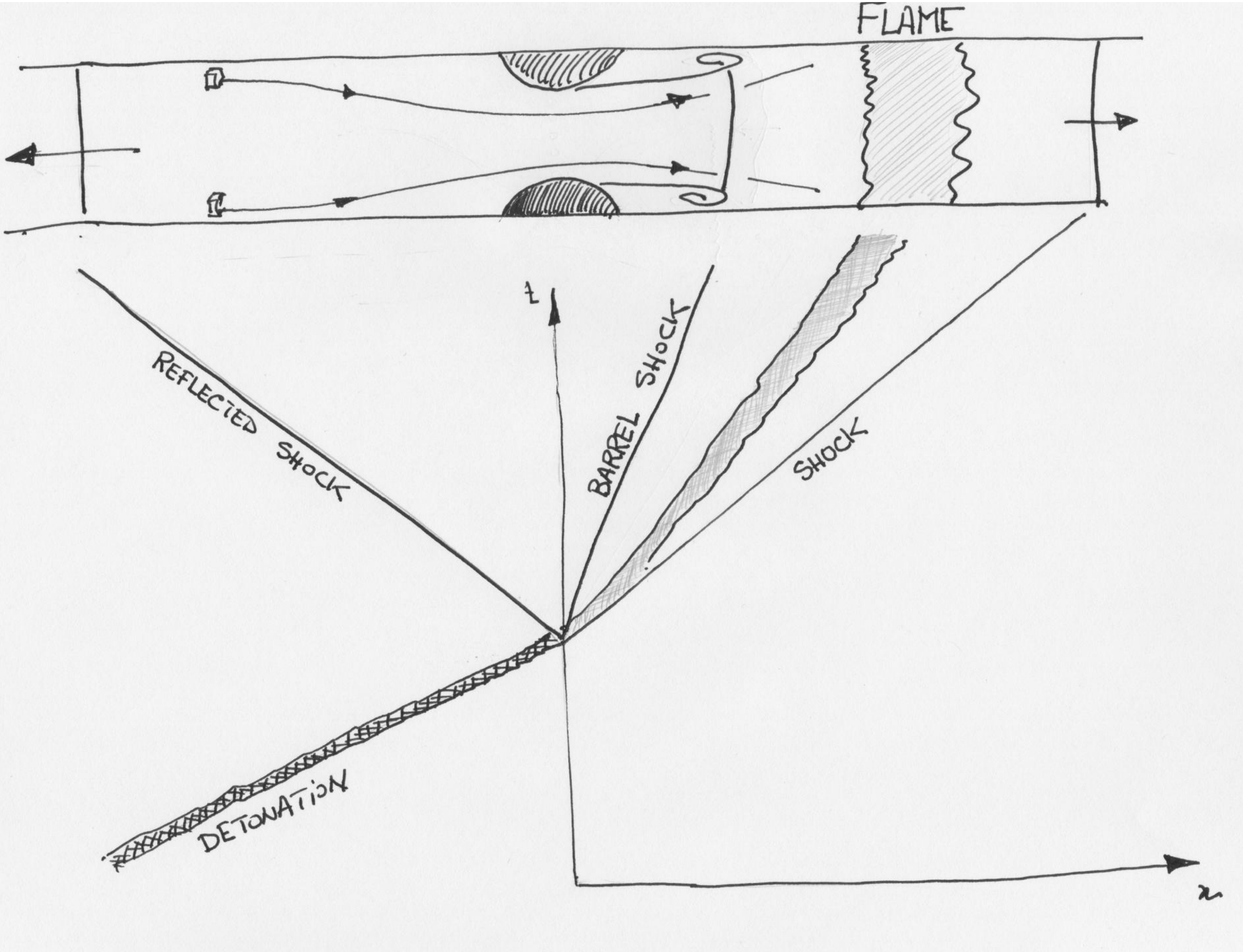
Chao, J. C. , **Critical deflagration waves that lead to the onset of detonation**, Ph.D. thesis, McGill University, 2006.

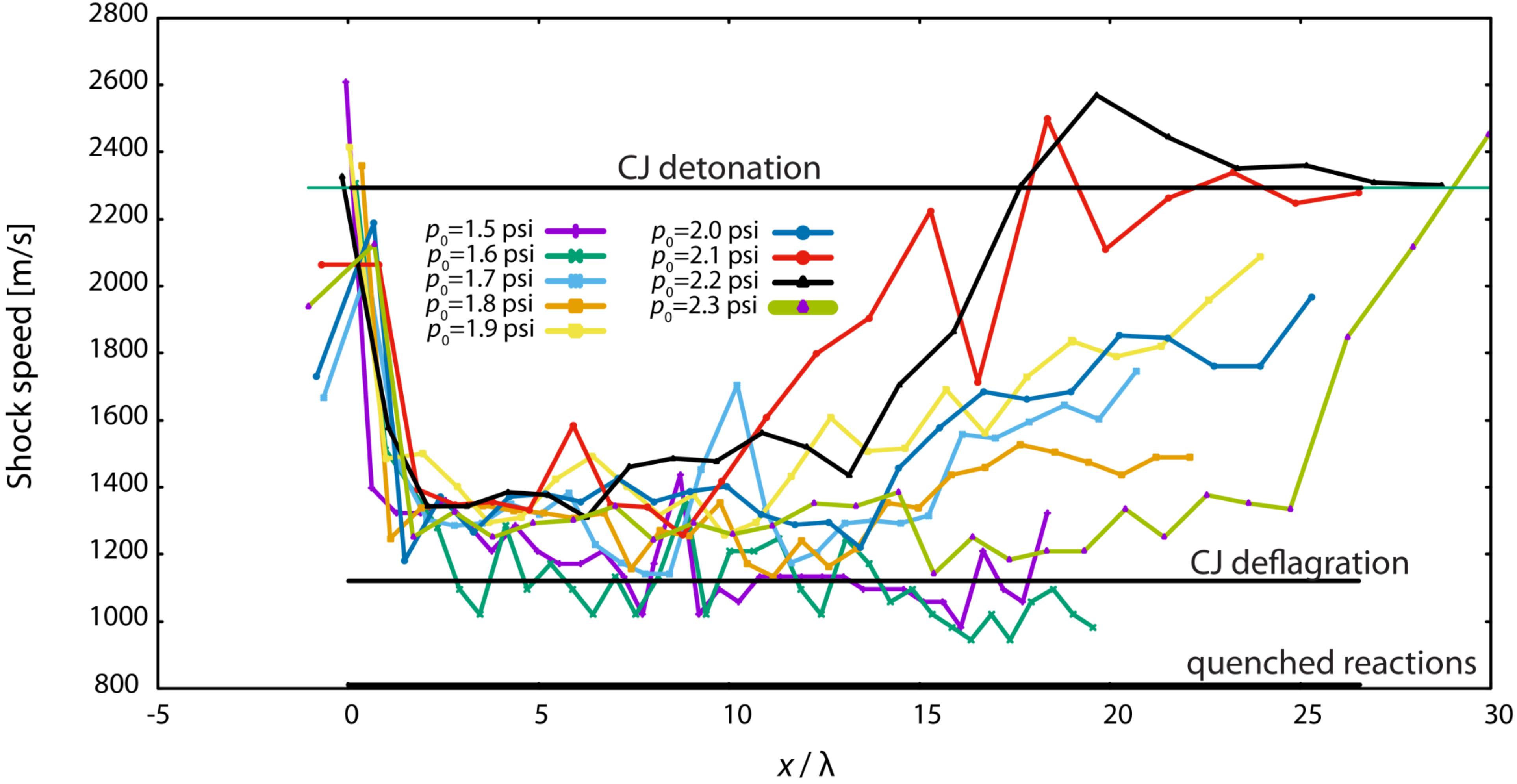
Grondin, J.-S., Lee, J.H.S. , **Experimental observation of the onset of detonation downstream of a perforated plate**, Shock Waves, 20, p. 381386, 2010.

Maley, L. , Bhattacharjee, R. , Lau-Chapdelaine, S.-M., and Radulescu, M. I. , **Influence of hydrodynamic instabilities on the propagation mechanism of fast flames**, Proceedings of the Combustion Institute, 35, 2117–2126, 2015

Saif, M., Wang, W., Pekalski, A., Levin, M., Radulescu, M.I. (2017). **Chapman-Jouguet deflagrations and their transition to detonation**. Proceedings of the Combustion Institute, 36(2), 2771-2779




FLAME
REFLECTED SHOCK
BARREL SHOCK
SHOCK
DETONATION
t
x



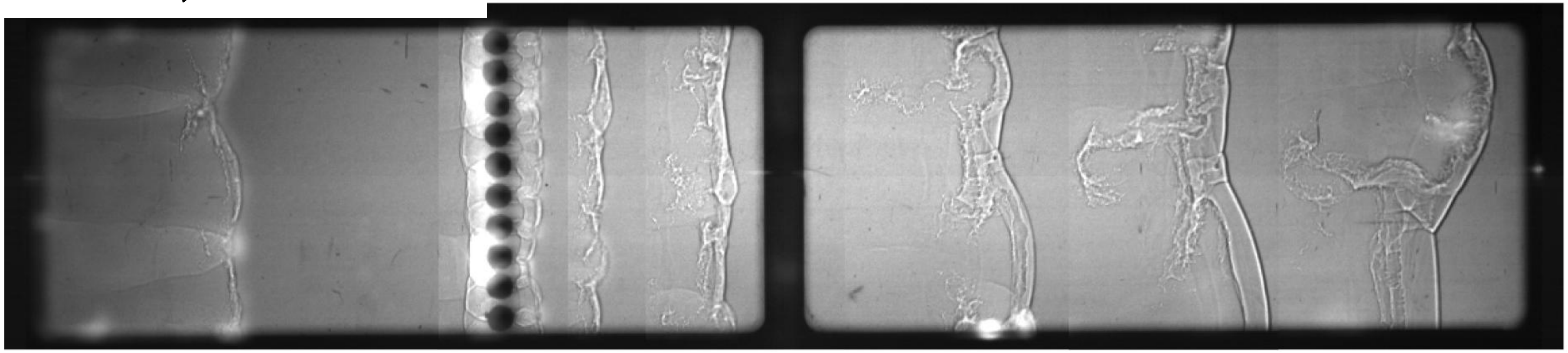
Shock speed [m/s]
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
-5
0
5
10
15
20
25
30
x / λ
CJ detonation
CJ deflagration
quenched reactions
p0=1.5 psi
p0=1.6 psi
p0=1.7 psi
p0=1.8 psi
p0=1.9 psi
p0=2.0 psi
p0=2.1 psi
p0=2.2 psi
p0=2.3 psi

What is the mechanism?

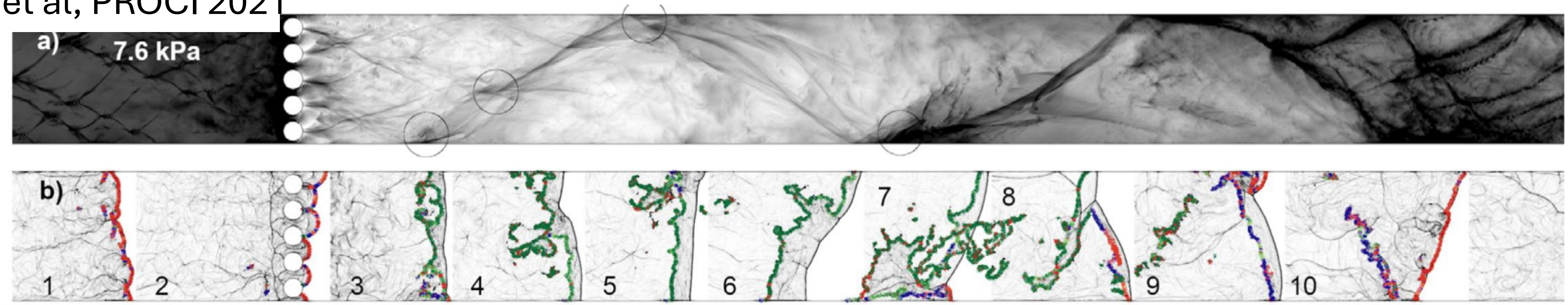
My speculation based on evidence so far:

Landau-Darrieus instability coupled with the shock motion

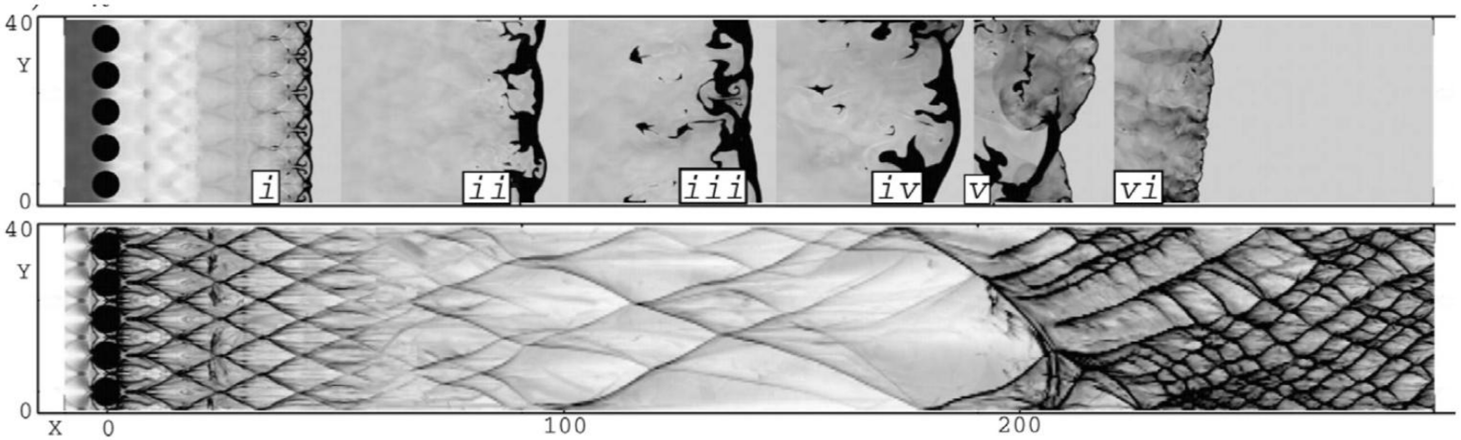
Saif et al, PROCI 2017



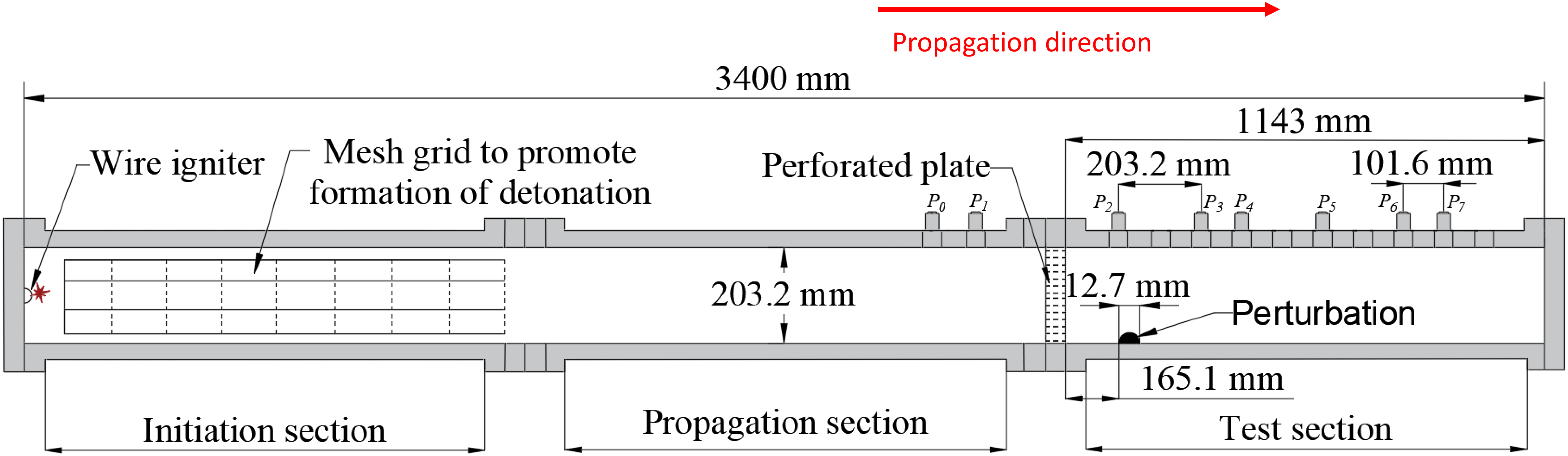
Jaravel et al, PROCI 2021



Maxwell, Pekalski & Radulescu C&F 2018



High blockage ratio, suppress auto-ignition



- Stoichiometric C_3H_8-$5O_2$
- Blockage ratio: 96%

Miri et al.: ICDERS 2025, Combustion Symposium 2026

Flame self-corrugates at large scales

Miri et al.: Combustion Symposium 2026

Growth of perturbations compatible with Landau-Darrius growth rate (factor of 2-3 slower)

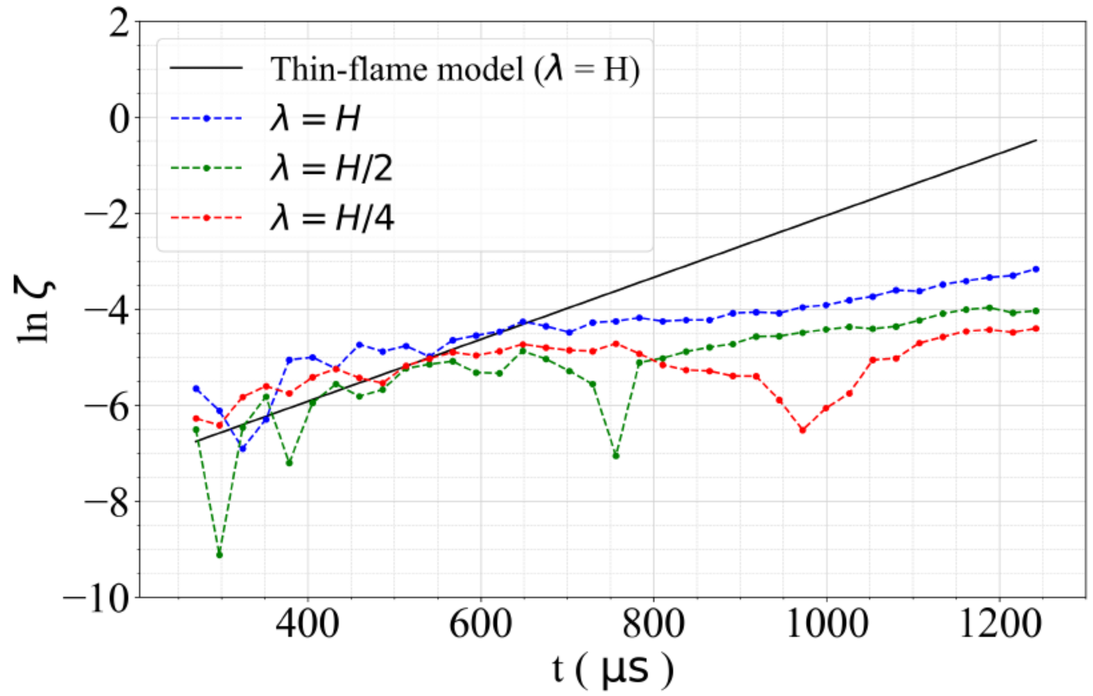
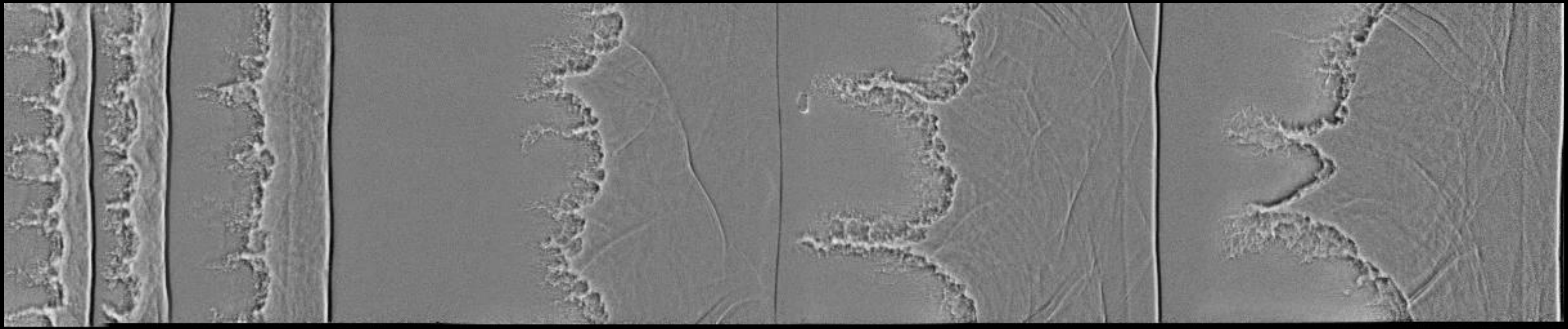


Fig. 4: Flame surface amplitude as a function of time, $\zeta(t)$, for different wavelengths obtained experimentally, and compared to the thin-flame DL instability model [7].

Miri et al.: Combustion Symposium 2026

Role of perturbations

Without perturbation



With perturbation

Summary

- CJ deflagration necessary condition for DDT.
- Dependence on rear boundary condition (closed/open)
- Amplification length $\vartheta(10)\lambda$.
- Mechanism compatible with Landau-Darrieus instability coupling with lead shock dynamics.

Collaborators

Logan Maley (Masters)
Mohamed Saif (Masters)
Brian Maxwell (Phd, now Assoc. Prof. at U. Ottawa)
Hongxia Yang (PhD, postdoc)
Willstrong Rakotoarison (PhD)
Kevin Cheevers (PhD ongoing)
Samaneh Miri Jafroudi (PhD ongoing)

Andrzej Pekalski (Shell)
Judy Jeevarajan (UL)

Sponsors

- NSERC
- Shell
- UL