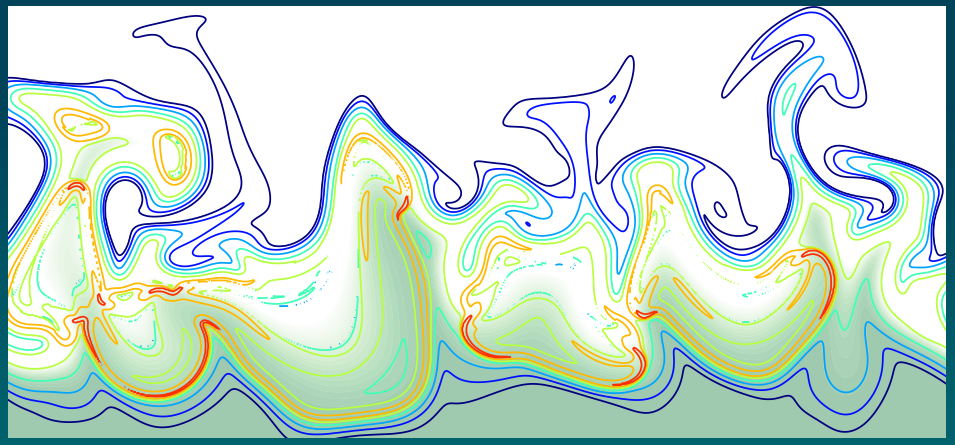
UNIVERSITY OF Southampton

DNS analysis of DME pilot-ignited methane-air combustion



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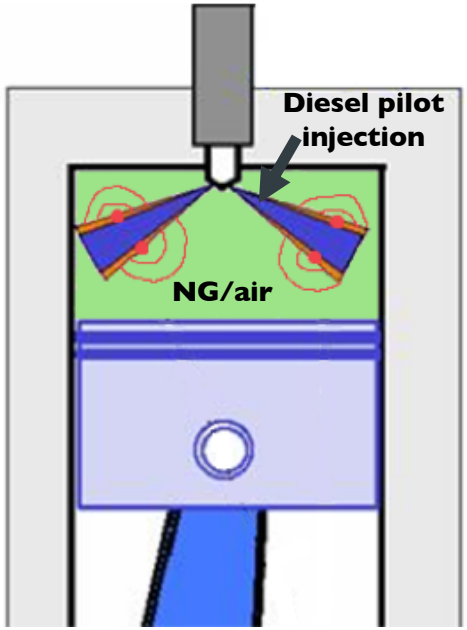
University of Southampton, UK

UKCTRF annual meeting
Selwyn College, Cambridge, 13th September 2018

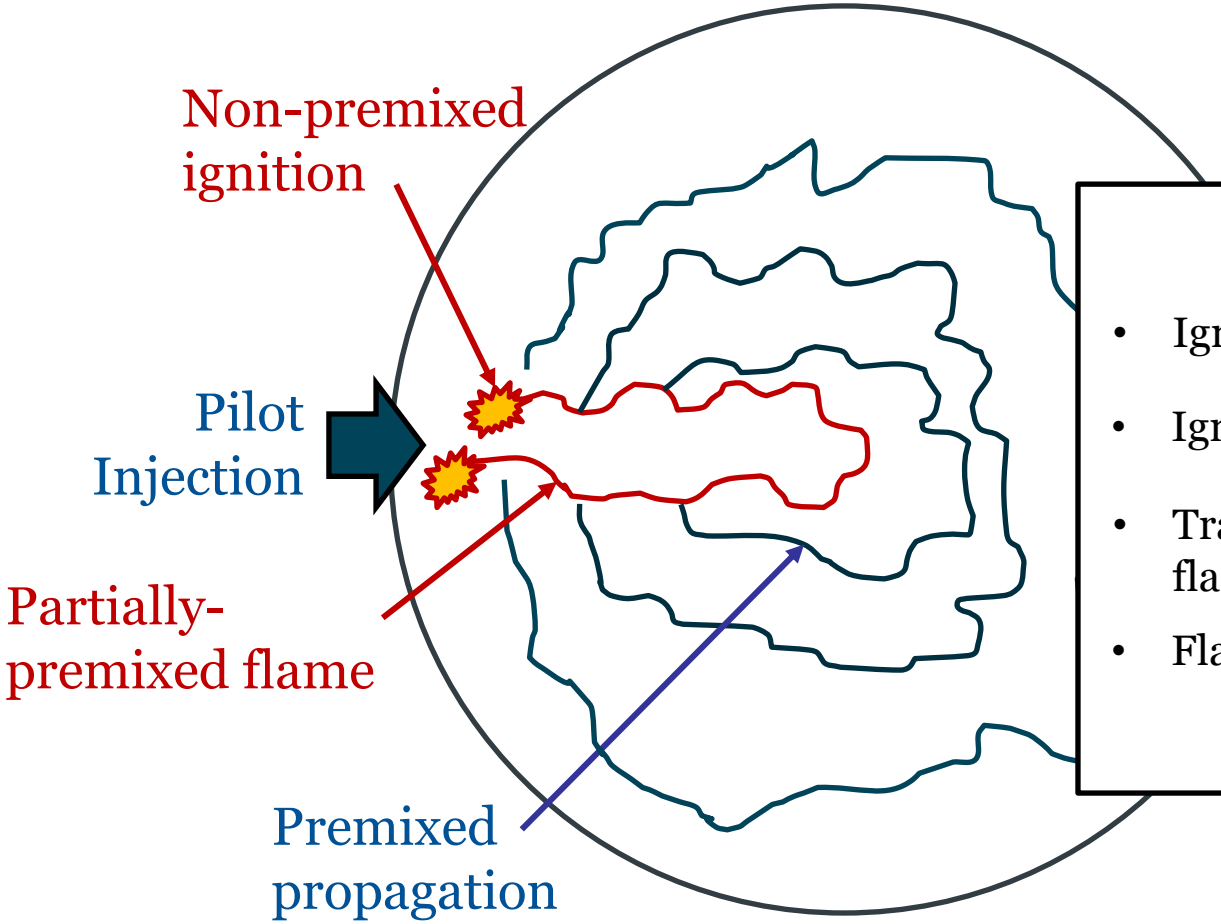
Dual-fuel engine concept

- Ultra-lean premixed natural gas (NG).
- Ignition from a pilot of a more reactive fuel.
- High efficiency and low NOx emissions.



Pilot-Ignited Combustion Phenomena

- Initiation – ignition and transition, propagation, (detonation), flame-wall interaction



Questions:

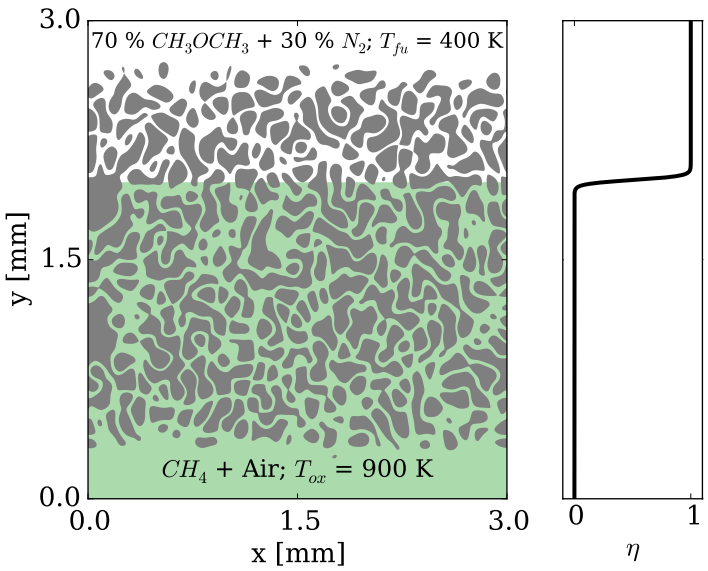
- Ignition delay time?
- Ignition location?
- Transition to premixed flame?
- Flame speed?

DNS setup

- Based on Krisman et al. 2016.
- Relevant engine conditions.
- Resolution: 1 μm and 10^{-9} s.
- Chemical mechanism: 30-species Lu et al.
- Unity Lewis number.
- S3D DNS code [Chen et al. J. Comput. Disc. 2009].
- High order numerical schemes:
  - 8th order finite differences.
  - 4th order Runge-Kutta.
- Limited to 2D pseudo-turbulent and 1D laminar.

DNS setup

- Methane (CH4) and dimethyl ether (CH3OCH3): surrogate for natural gas and diesel.



Decaying turbulence

- *Passot-Pouquet isotropic kinetic energy spectrum*
- *u' = 0.49 m/s*
- *L_t = 0.1 mm*

Numerical experiment

	Case A	Case B
CH_4	Reactive	Inert
ø	0.4	
P [bar]	40	

- CH4 replaced by passive scalar
- Thermal properties conserved
- Test chemical effect

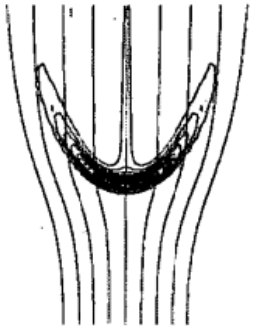
Results

Questions:

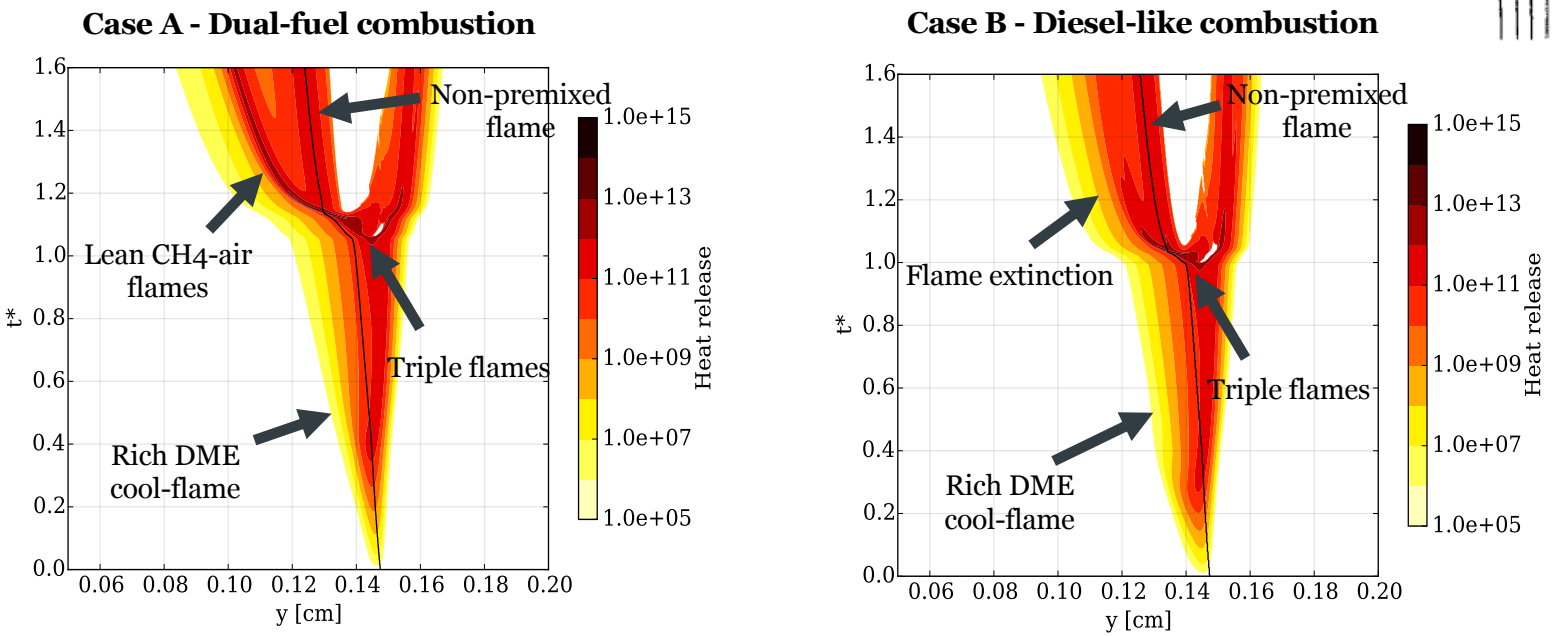
- Ignition delay time?
- Ignition location?
- Transition to premixed flame?
- Flame speed?

DNS results

[Ruetsch et al. 1995]



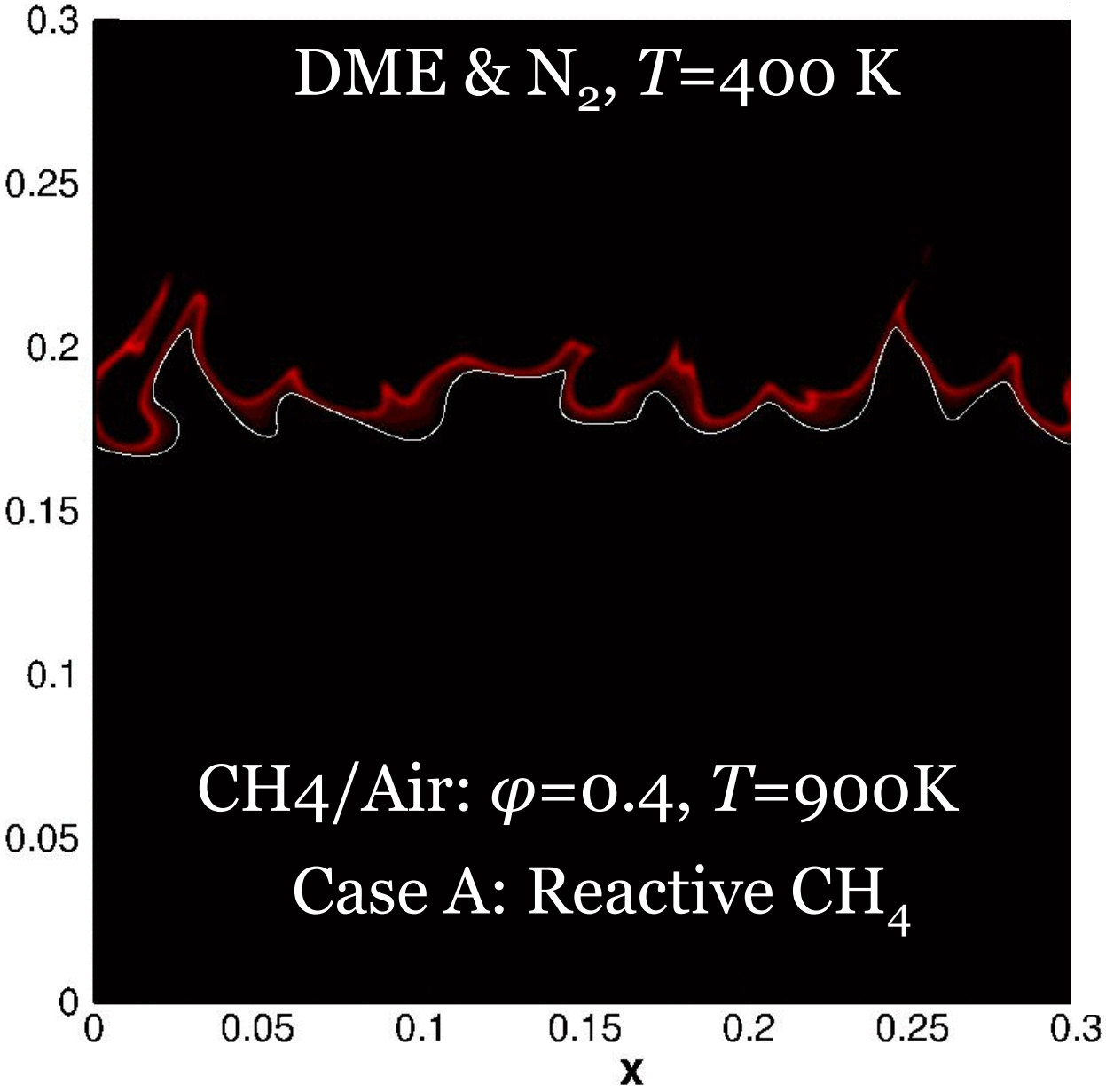
- Temporal evolution of a 1D mixing layer



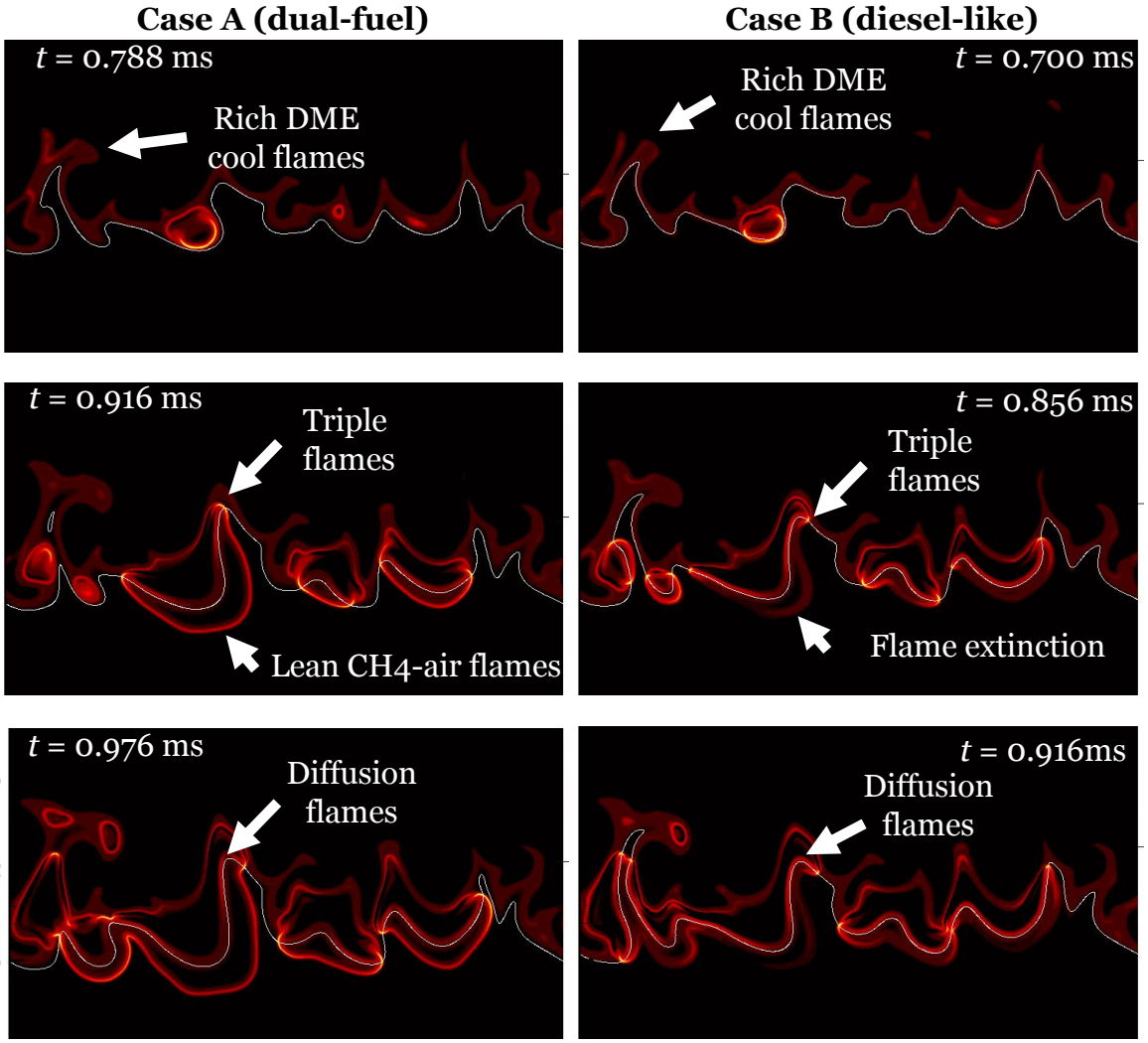
Space-time map of heat release for 1D mixing layer

- 'Poly-brachial' structure
- CH4-air flame initiated from the lean-branch of the triple flame.

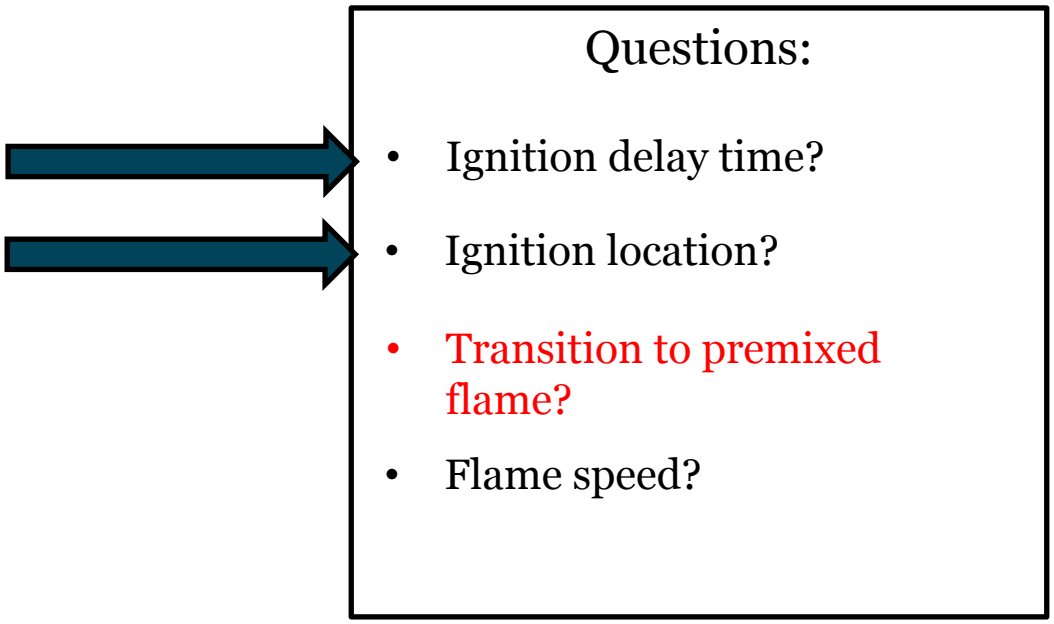
2D evolution of heat release



2D flame structure



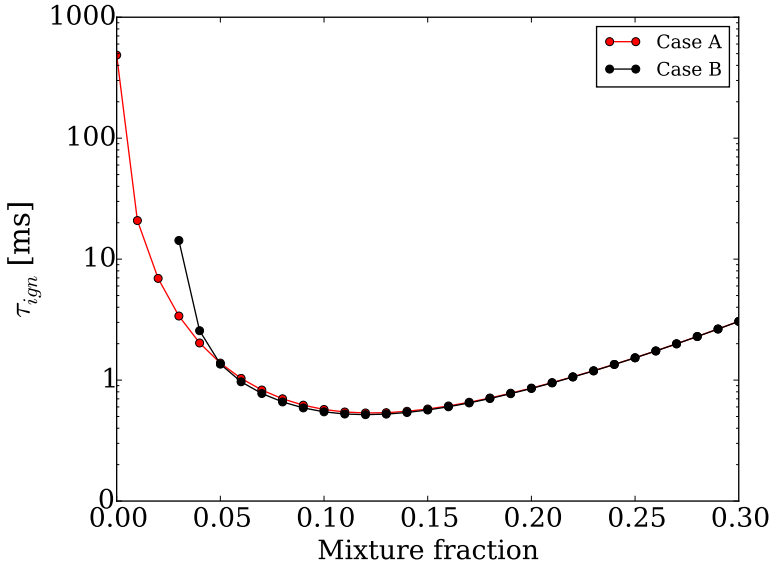
Contour maps of heat release rate during ignition & stoichiometric iso-line (white)

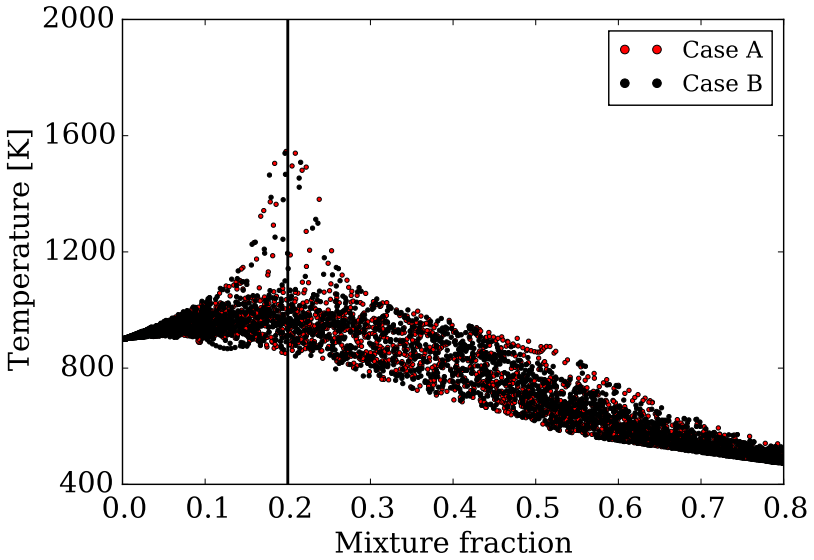

Questions:
• Ignition delay time?
• Ignition location?
• Transition to premixed flame?
• Flame speed?

Ignition analysis

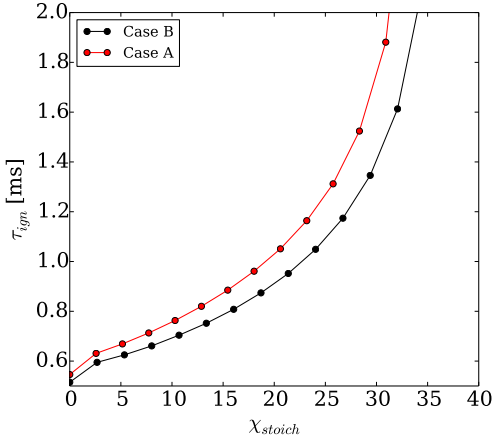
- Most reactive mixture fraction and ignition delay: small change by CH_4-reactivity.

  ➔ Ignition occurs at the same mixture fraction.





Case	Case A	Case B
τ_{2D-DNS} [ms]	0.738	0.676
τ_{1D-DNS} [ms]	0.870	0.782
τ_{HR} [ms]	0.535	0.518

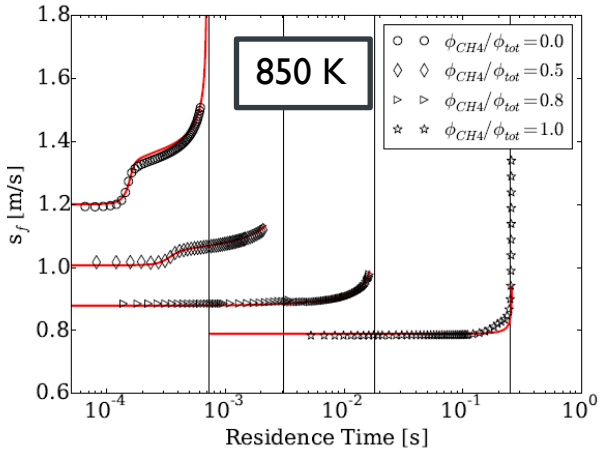


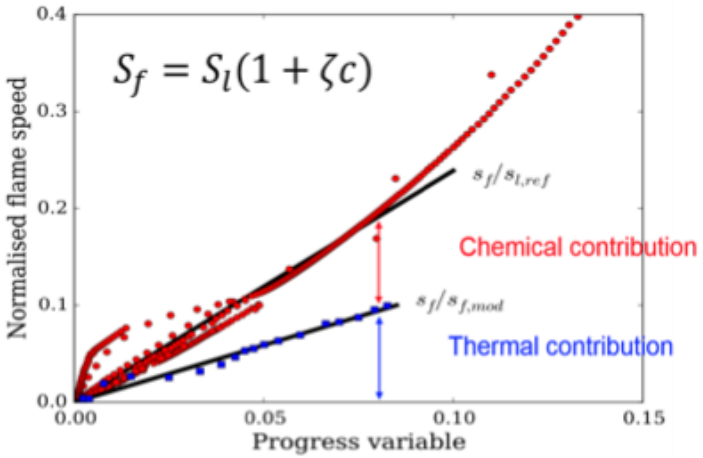
Questions:

- Ignition delay time?
- Ignition location?
- Transition to premixed flame?
- Flame speed?

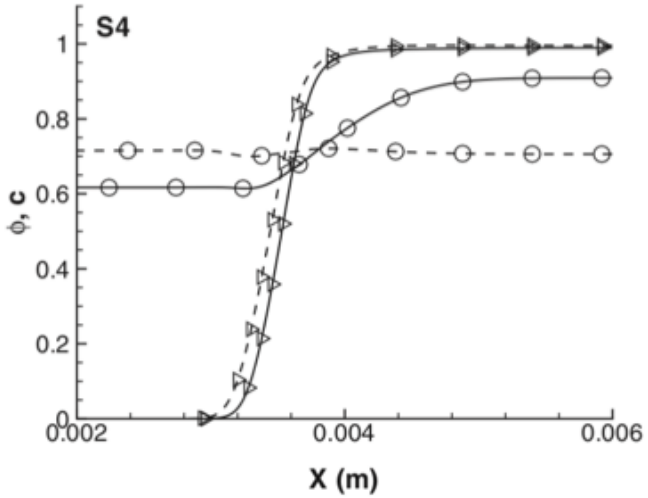
Flame speed analysis

- Pre-ignition reactions?
- Gradient of mixture fraction through the flame?





[Soriano, Richardson, *Submitted* 2018]

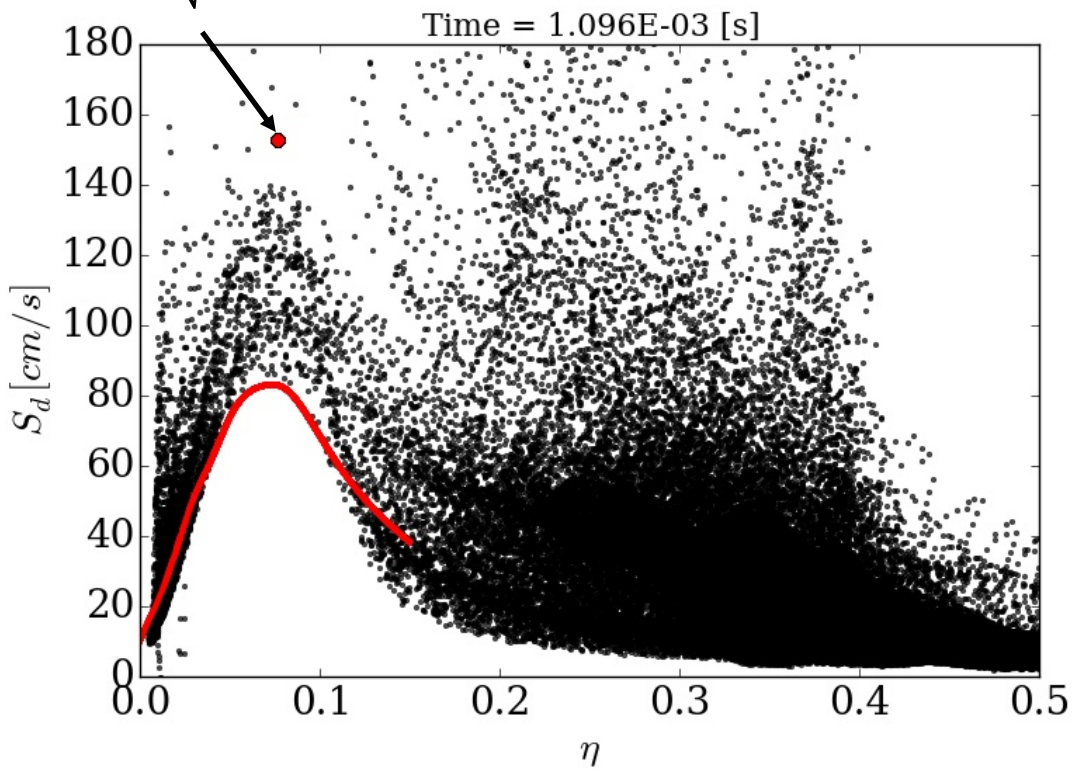


[Richardson et al, *2010*]

Displacement speed

S_d of the progress variable surface with greatest heat release

$$S_{r,edge} = S_r \sqrt{\frac{\rho_u}{\rho_b}}^{*}$$



Progress variable $c(\underline{x},t) = \dfrac{Y_{O_2}(\underline{x},t) - Y^U_{O_2}(\xi)}{Y^B_{O_2}(\xi) - Y^U_{O_2}(\xi)}$

*Ruetsch et al. 1995

Summary

- Kinetics / Ignition
  - CH_4 increases ignition delays.
  - Kinetic effects and dilution effects are important.
  - Ignites at rich mixtures / low dissipation conditions.
- Structure
  - Premixed flame initiated by the lean-branch of a poly-brachial flame structure
- Propagation
  - Marked deviation from laminar flame speed.
  - Model provided for pre-ignition chemistry effects.

Questions:

- Ignition delay time?
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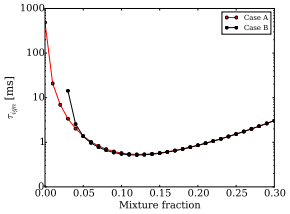

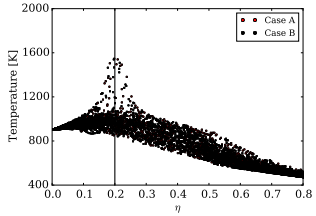

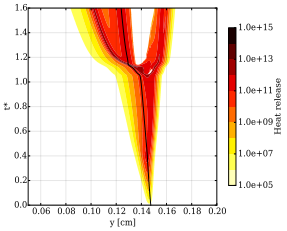

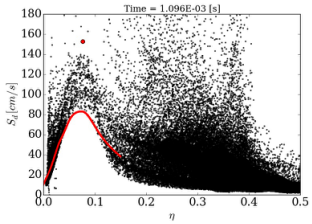

Acknowledgements

CNPq

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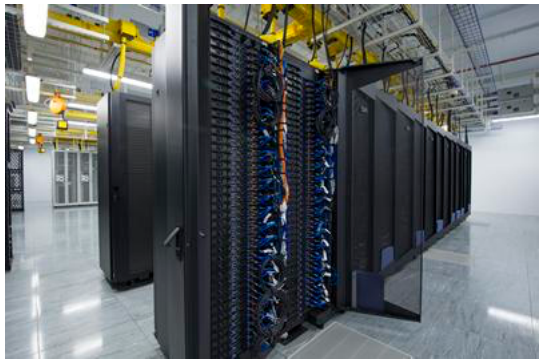

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