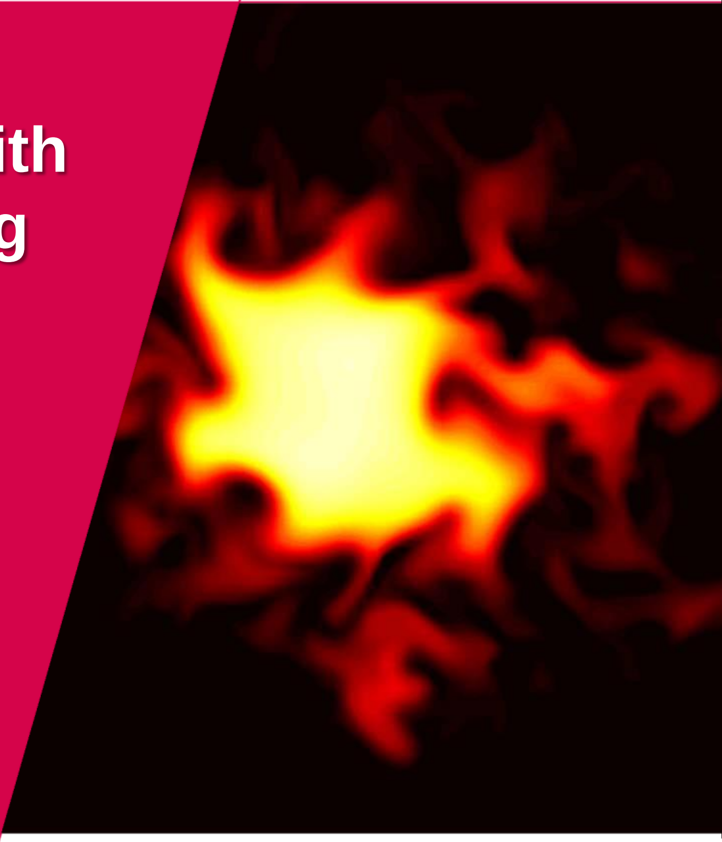
Turbulent Premixed Combustion with Flamelet Generated Manifolds using Comsol Multiphysics



Rob J.M. Bastiaans

COMSOL CONFERENCE ROTTERDAM 2013

Technische Universiteit Eindhoven University of Technology

Where innovation starts

Outline

- Introduction
- Flamelet-Generated Manifolds
- Results?
- Conclusions

Turbulent combustion

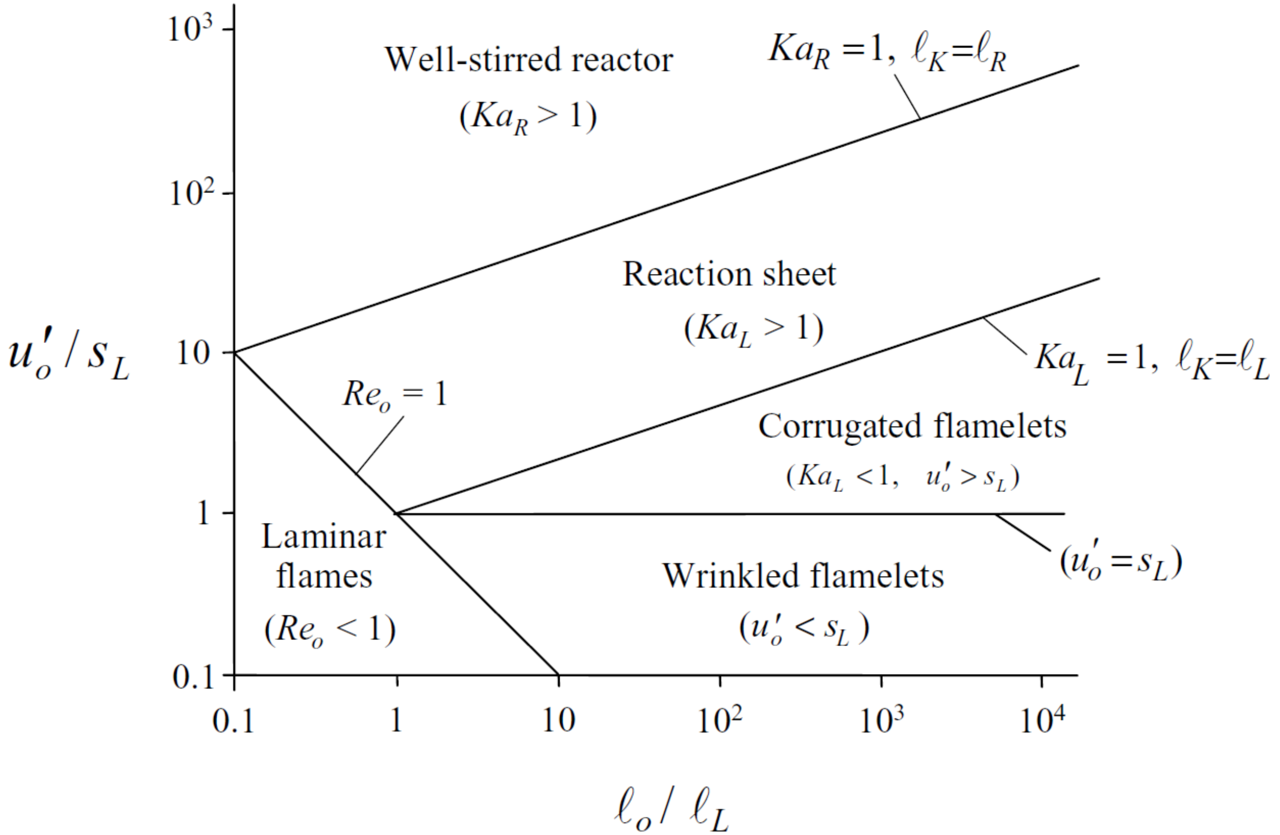
- Turbulence
- Chaos
- Combustion
- Important

- ICE engines
- Furnaces
- Gas-Turbines Aero
- Gas-Turbines Stationary

- Greenhouse
- Emissions

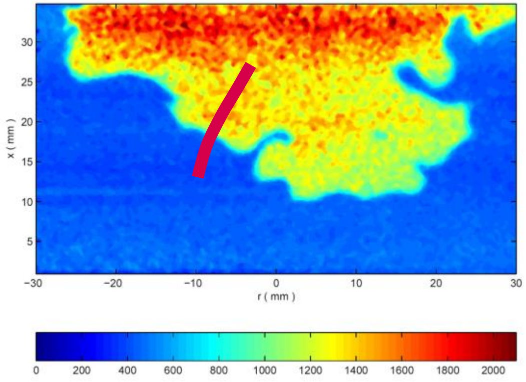
Combustion modes

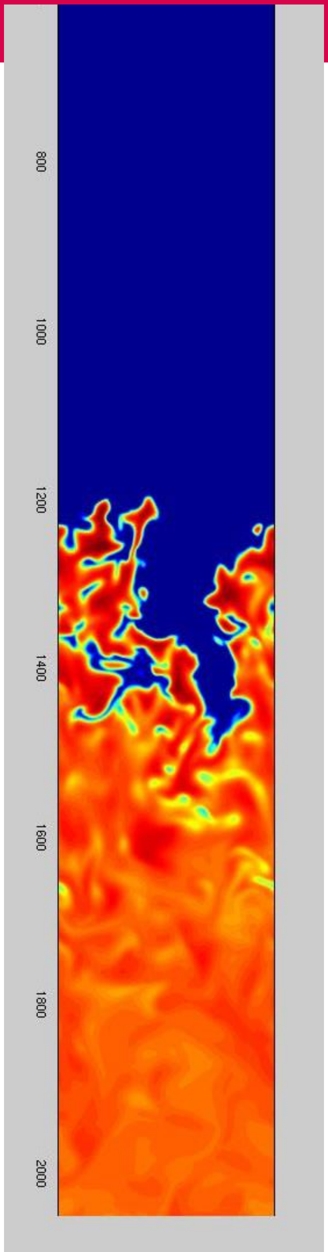
- **Introduction**



Combustion modes

- Thin reaction zones
- DNS
- Experiments





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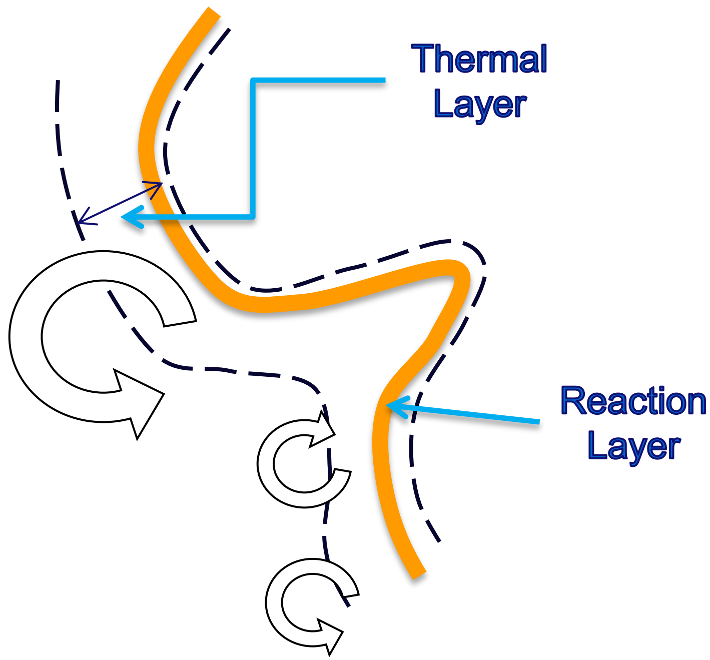
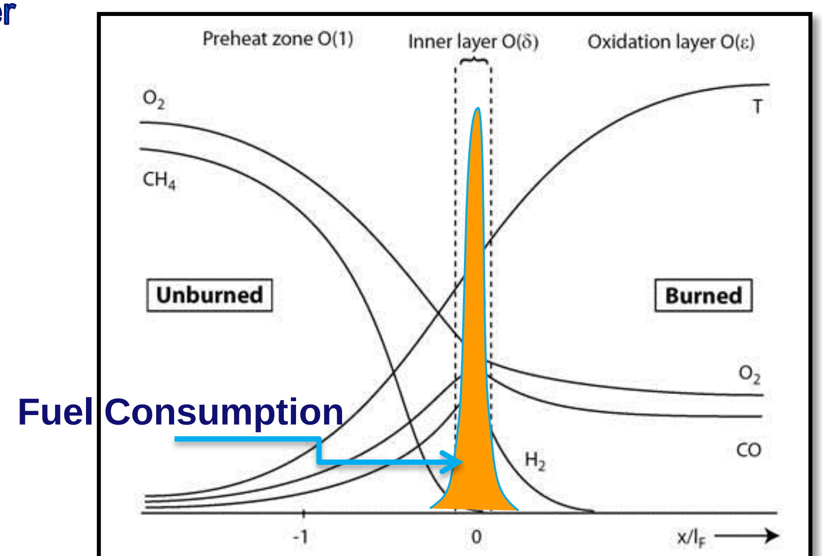
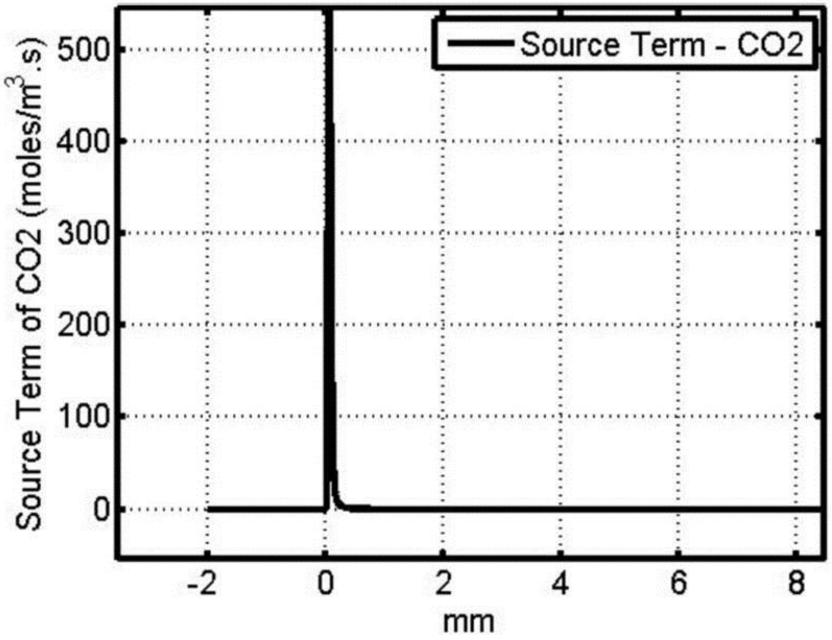
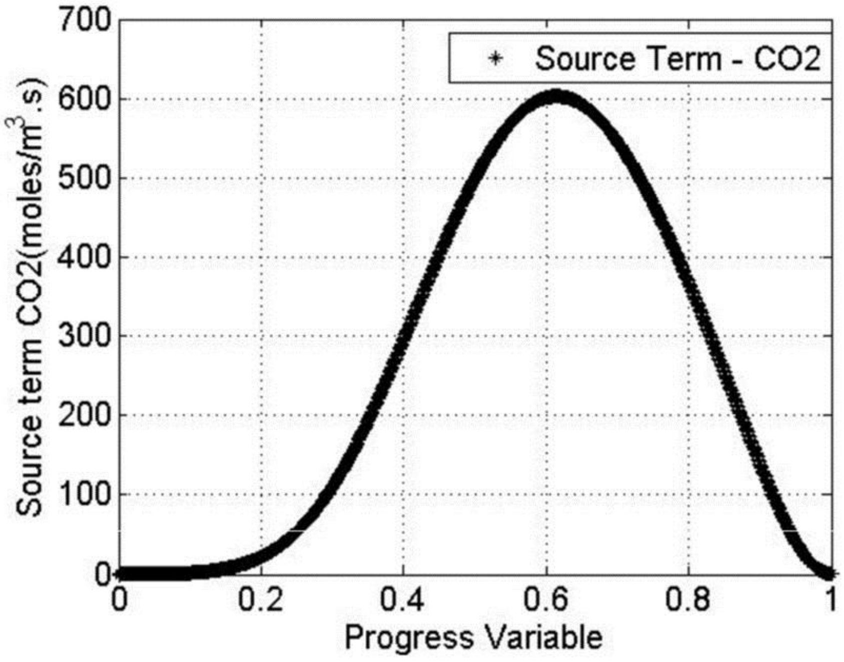
Combustion phase space; FGM





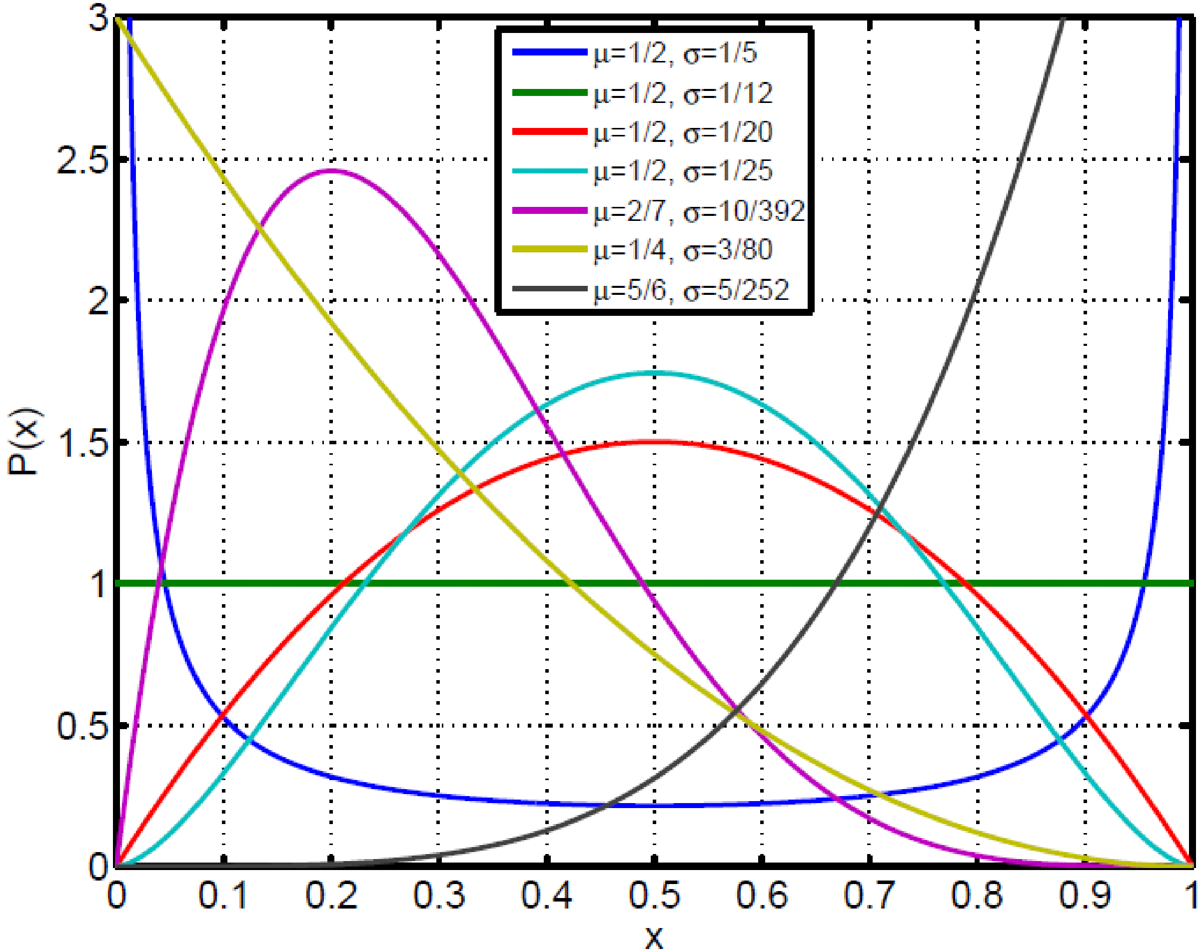
Combustion phase space; FGM





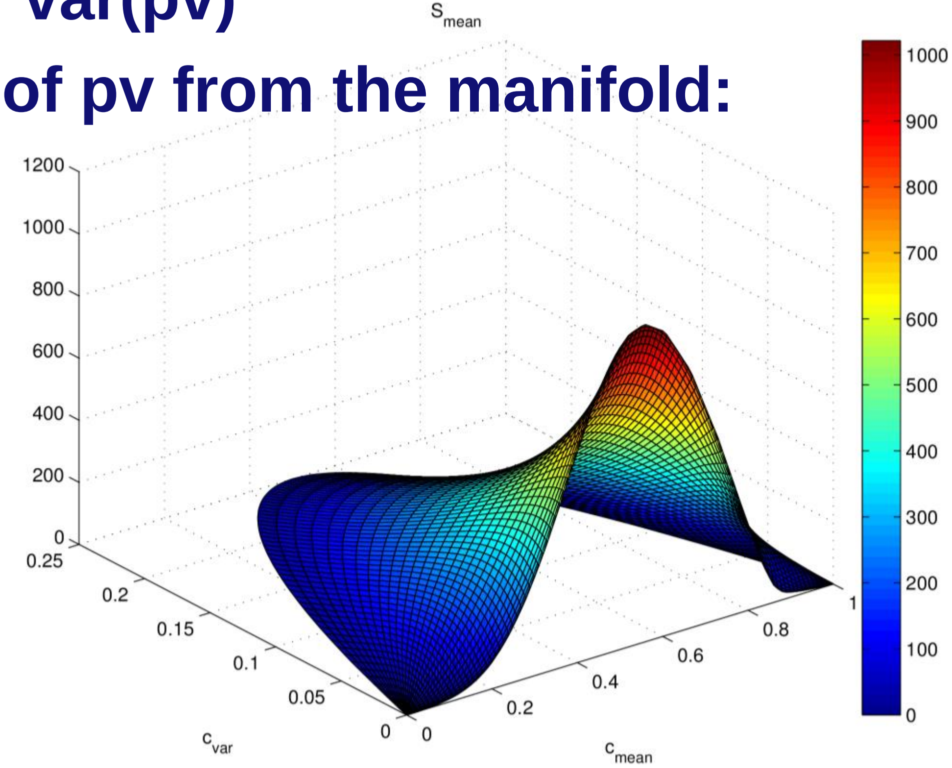
Turbulent Probability Density

- **β-PDF**



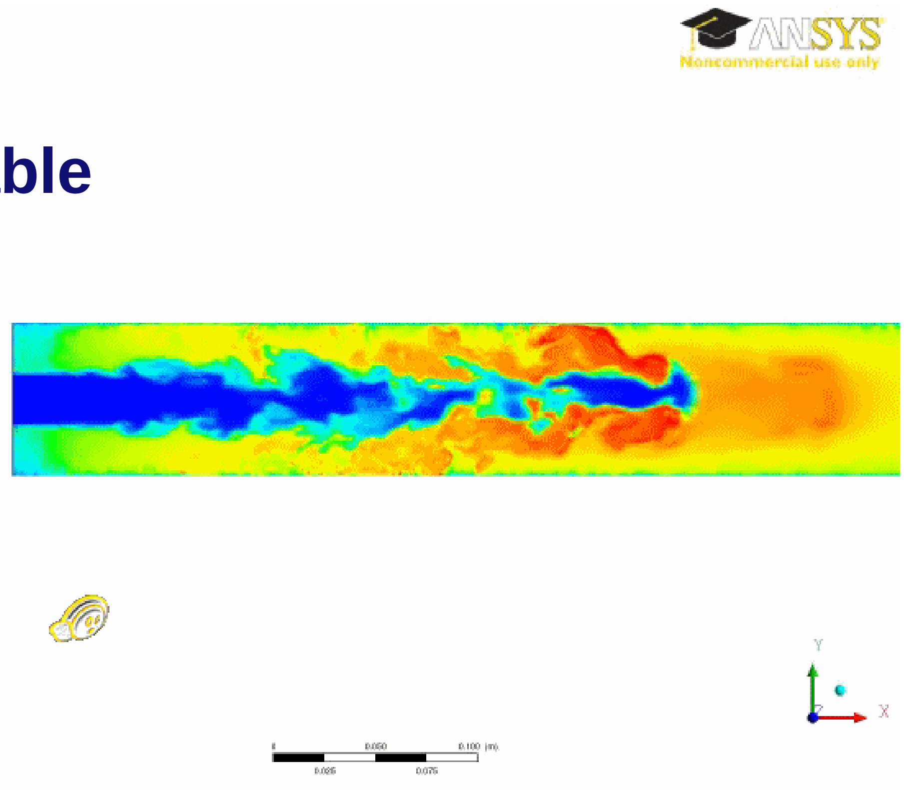
Turbulent Manifold

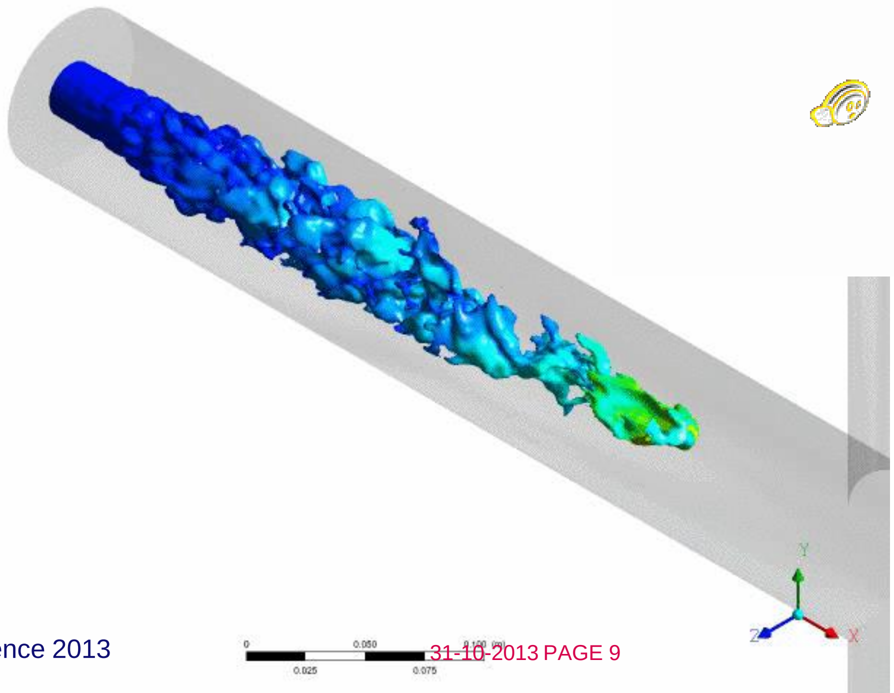
- **Calculate a represtative laminar flamelet**
- **Take the laminar flamelet**
- **Convolute it with the beta-pdf**
- **In CFD add equation for the progress variable, pv**
- **Use an extra equation for var(pv)**
- **Look up the source term of pv from the manifold:**



Example

- **Mean progress variable**
- **Variance of progress variable**
- **Enthalpy**
- **High pressure**





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Comsol

- **Simple start**
- **2D quasi steady**
- **RANS flow model**
- **Adding diluted species as progress variable**
- **Use Comsol**
- **Solve flow stationary**
- **Add time integration to stabilize the turbulent flame brush**

Banhawi et al., Comb. & Flame, 1983

- **Backward facing step**

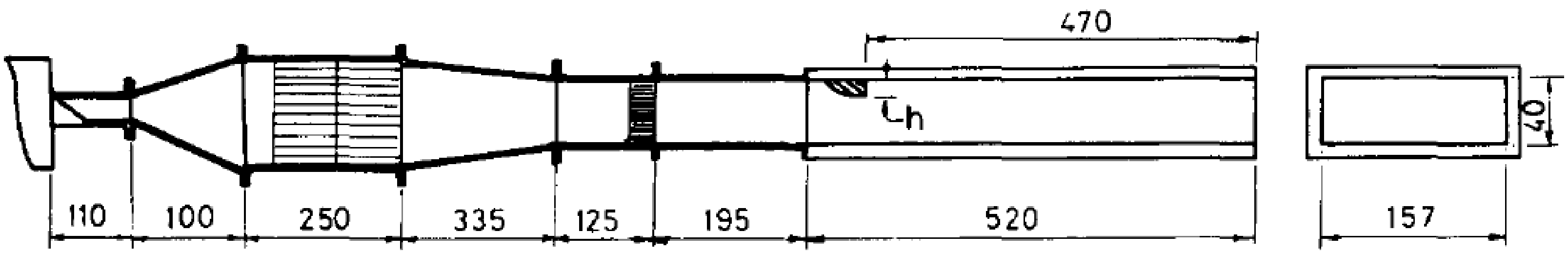

Fig. 1. Flow configuration.

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Want to know the result and how it works?

Come

to my

poster!!!

It

looks like

this:

Turbulent premixed combustion with FGM in Comsol

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Introduction: Solving complex chemistry as in turbulent premixed combustion is hard to do, there are many species and time-scales making problems stiff and memory intesive. We use the correlation of species in a representative flamelet to lookup the source term. This is called flamelet generated manifolds (FGM, [1]. Here it is introduced in Comsol to model a reactive turbulent backward facing step (El Banhawy et al. [2]).

Computational Methods: In this simulation we first solved the turbulent flow with steady k-ε equations. Here the inflow Reynolds number was 10,000 and the mean inflow velocity was 9 m/s. In the next step we solved an unsteady transport equation for the flame **progress variable, c**. With a detailed chemistry code the source term of this progress variable was tabulated. This **source term** was used to continue the integration. In the turbulent case it was convoluted by a β-PDF to include the role of the variance of *c*, that was modelled as an algebraic model. The *c* is taken as CO_2.

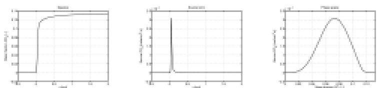

Figure 1. Laminar adiabatic methane flame with ϕ=0,9 species 2 source term, 3 phase space

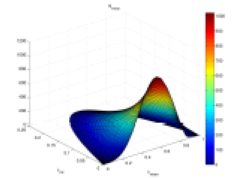

Figure 2. Turbulent manifold, Step 3 convoluted with a β-pdf

Cold flow results: In figure 3 the backward facing step flow is presented. The recirculation length is in agreement with literature.

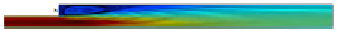

Figure 3. Backward facing step flow with Re=10,000, the recirculation length is l=6.65h

Reactive flow results: A turbulent flame brush is added at the expansion and then a time integration of 0.1 s is performed. This results in a quasi steady flame result, see figure 4 for *c*.

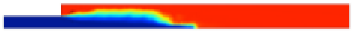

Figure 4. Mean progress variable c at 0.1 s after initiating at the expansion.

Figure 5. Mean value of CO_2 as reported by Al Banhawi et al.

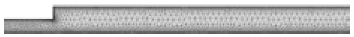

Figure 6. Mesh of the calculation.

Future improvements:

- Include expansion
- Include heat loss
- Expand to 3D
- Application of LES

Conclusions: From the present approach and the resulting solutions it can be concluded that the combination of the Comsol flow solver with the FGM method for describing combustion is a good method to calculate reacting flows. Sufficient resolution is required to keep the the *c* within bounds.

References:

1. J.A. van Oijen & L.P.H. de Goey, Modelling of premixed laminar flames using flamelet-generated manifolds. Comb. Sci. Technol. 161, 113–137, (2000).
2. Y. Al Banhawy, S. Sivasegaram & J.H. Whitelaw, Premixed, Turbulent Combustion of a Sudden Expansion Flow. Comb. & Flame, 50, 153-165, (1983).

Excerpt from the Proceedings of the 2013 COMSOL Conference in Rotterdam

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And ….

- Read the paper
- Sit next to me at the dinner
- Contact me by email

Conclusions

- Physics based turbulent combustion model
- No assumptions
- Good implementation in software
- Usable in RANS, LES and DNS
- Ability to predict emissions
- RANS approach possible in Comsol
- ….

Thank you for your attention

Further information:

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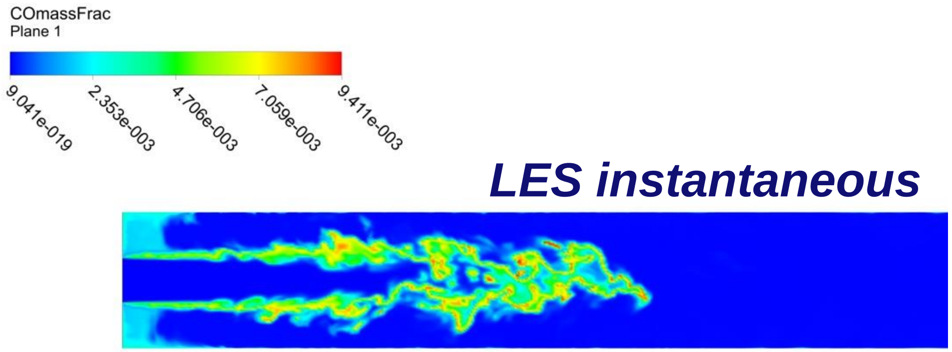
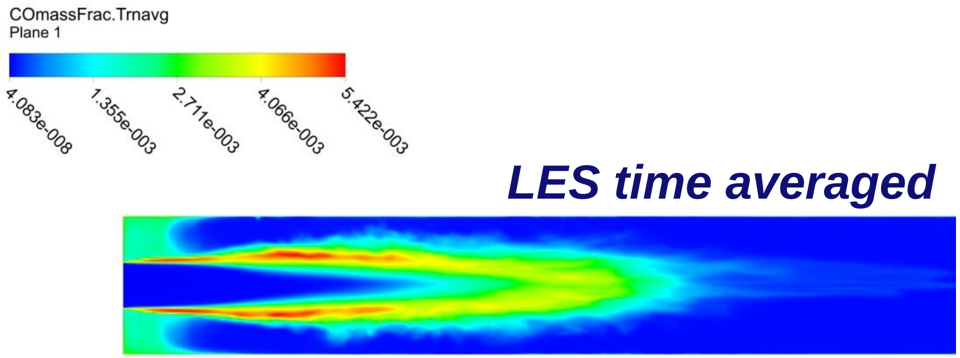
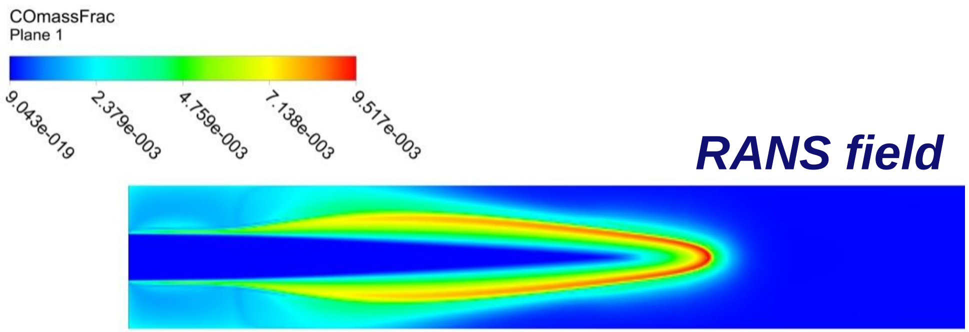
Disclaimer - CO with RANS ??



LES instantaneous



LES time averaged



RANS field

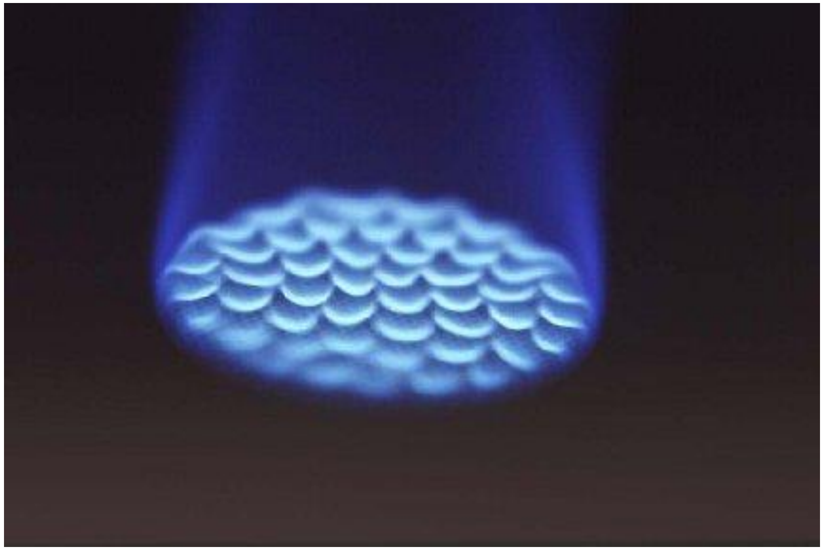
- Consistent difference between LES and RANS
- CO and NO production strongly depend on peaks, not included in RANS
- CO emission is a primary concern during the design of GT combustor
- FGM gives access to all minor species

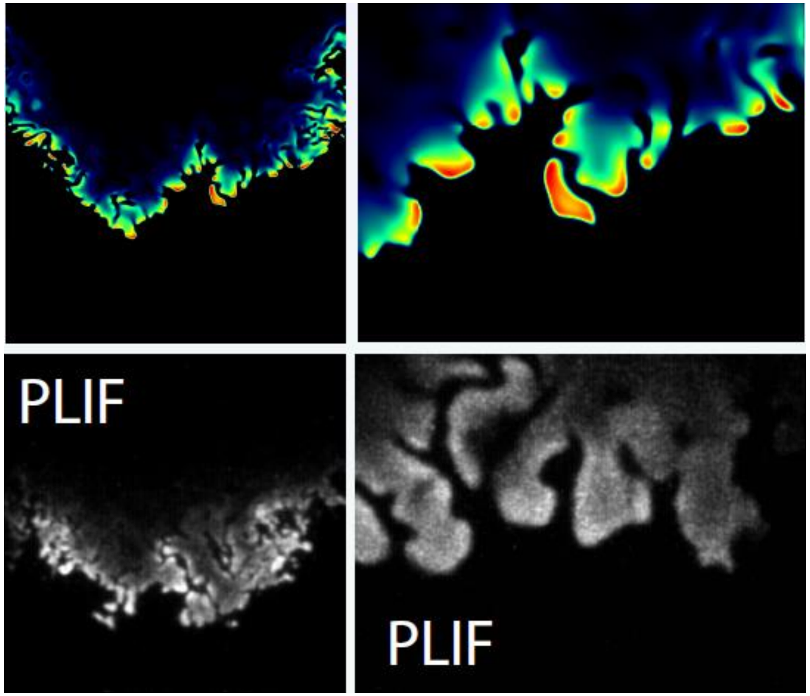
Methane-hydrogen mixtures

- Hydrogen blending with methane recieves a lot of interest
- It allows for leaner operation of premixed turbulent combustion
- It results in reduced emissions and higher efficiencies in engines and turbines

Preferential diffusion effects

- Hydrogen (H_2) is highly diffusive
- Thermo-diffusive instabilities
- Cellular flames

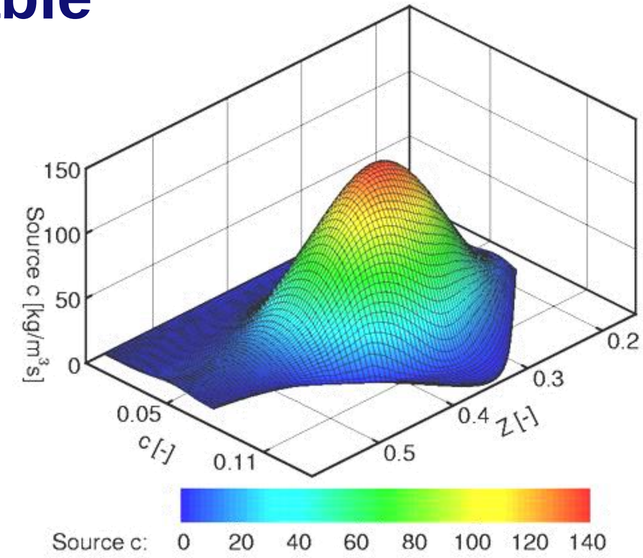




M. Day, Lawrence Berkeley Nat. Lab

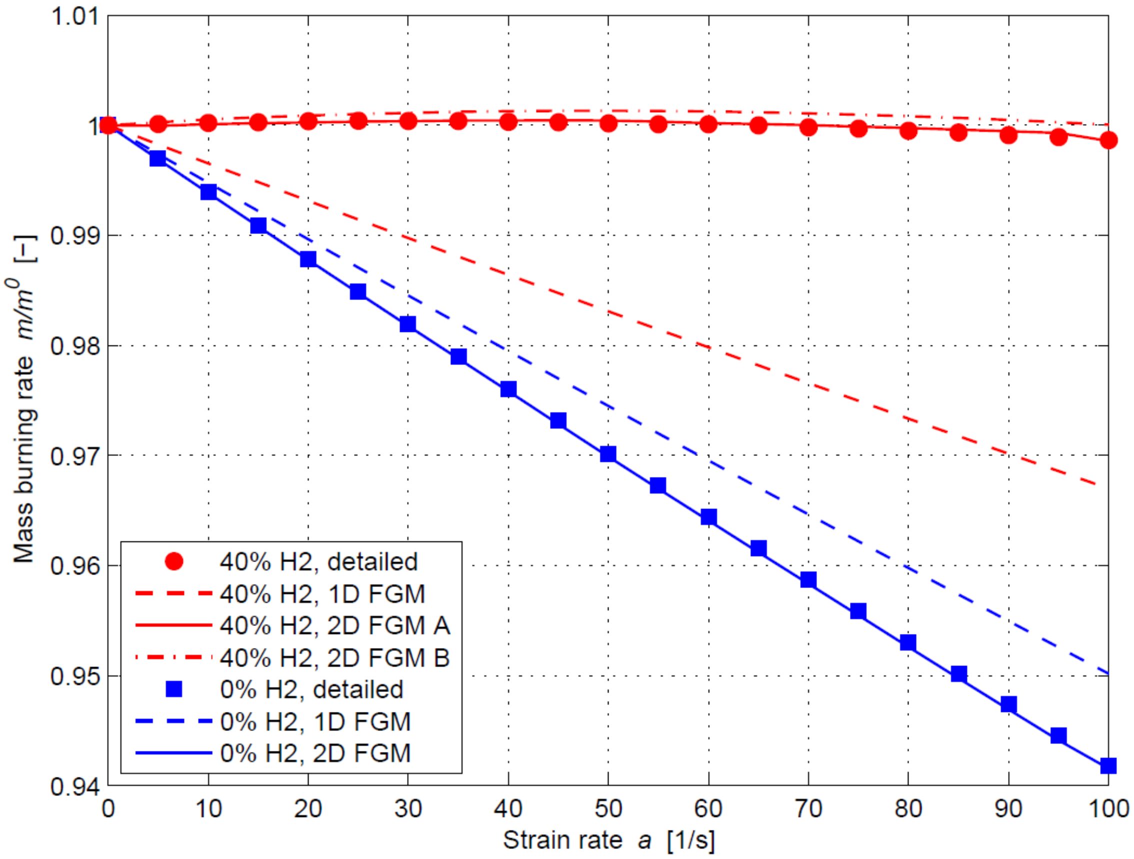
Flamelet-Generated Manifold

- **Rewriting the full 3D transport equations in a flame-adaptive coordinate system results in quasi 1D flamelet equations including the most important transport effects**
- **Solutions of these flamelet equations are used to construct a chemical look-up table**



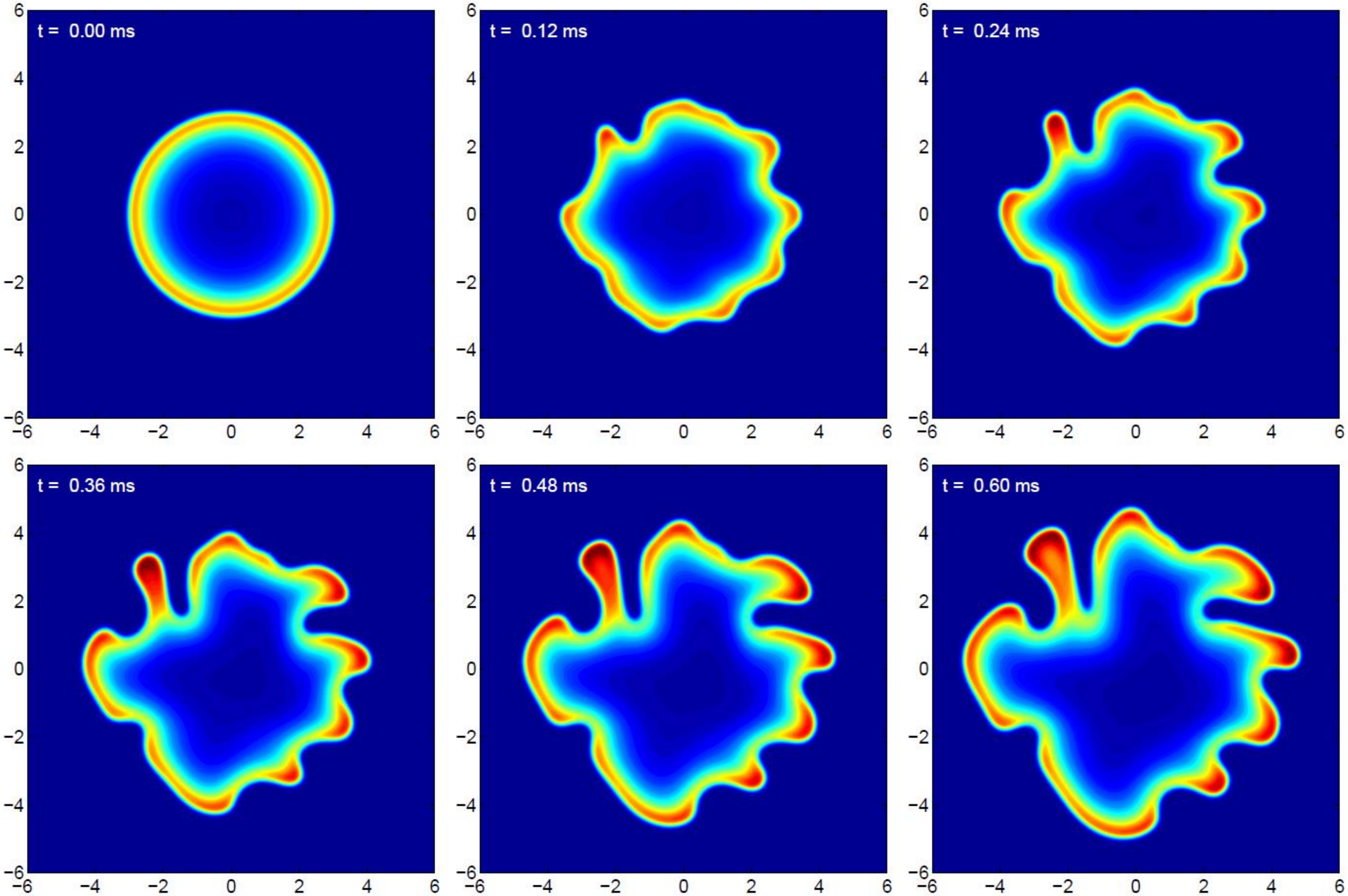
Validation in laminar counterflow flames

Mass burning rate versus strain rate



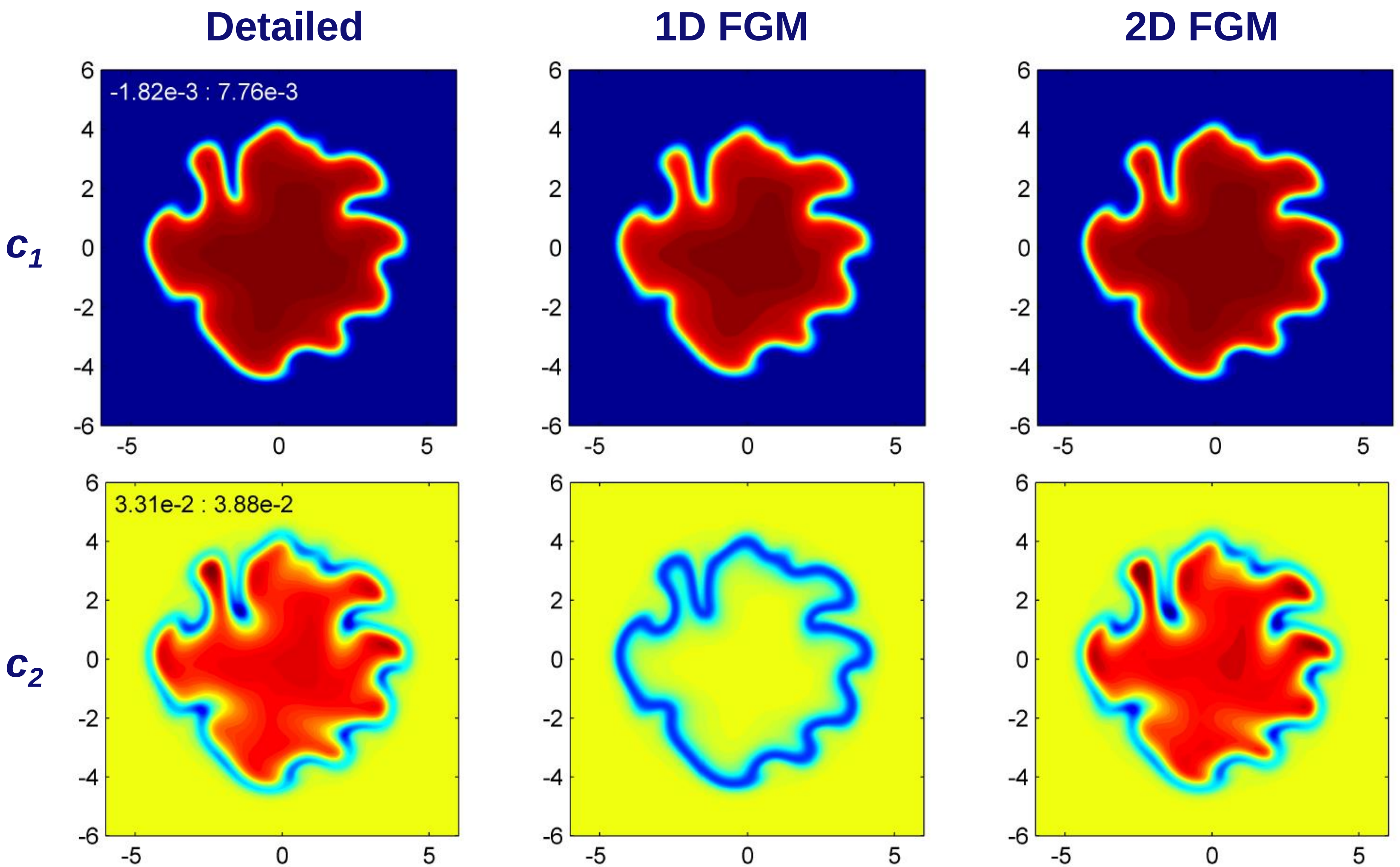
- **1D FGM is fine for 100% methane**
- **2D FGM captures preferential diffusion effects**
- **Not sensitive to the way FGM has been created (constant stretch or stretch derived from constant curvature)**

Results with detailed chemistry



Mass fraction of H radical

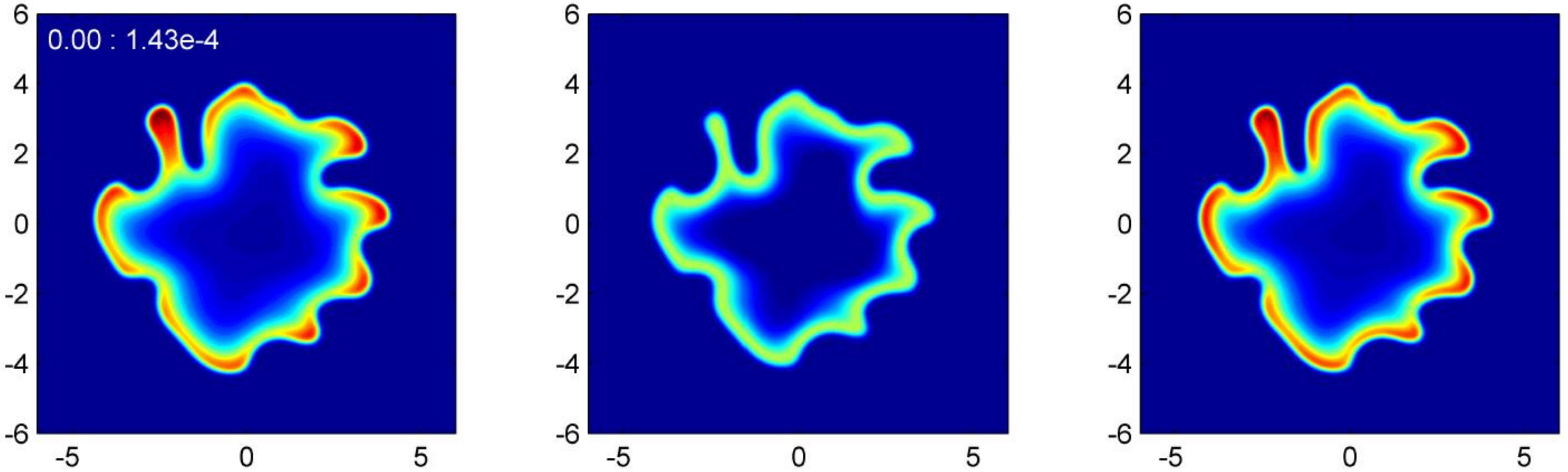
Comparison detailed / FGM



t = 0.36 ms

Comparison detailed / FGM

Mass fraction of H radical



t = 0.36 ms

FGM reduces CPU time by 2 orders of magnitude!

2D FGM has nearly same CPU time as 1D FGM