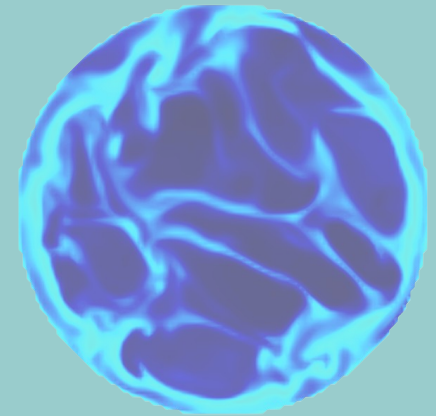




Aalto University
School of Engineering



Computational research methods for increased fuel flexibility

Ville Vuorinen

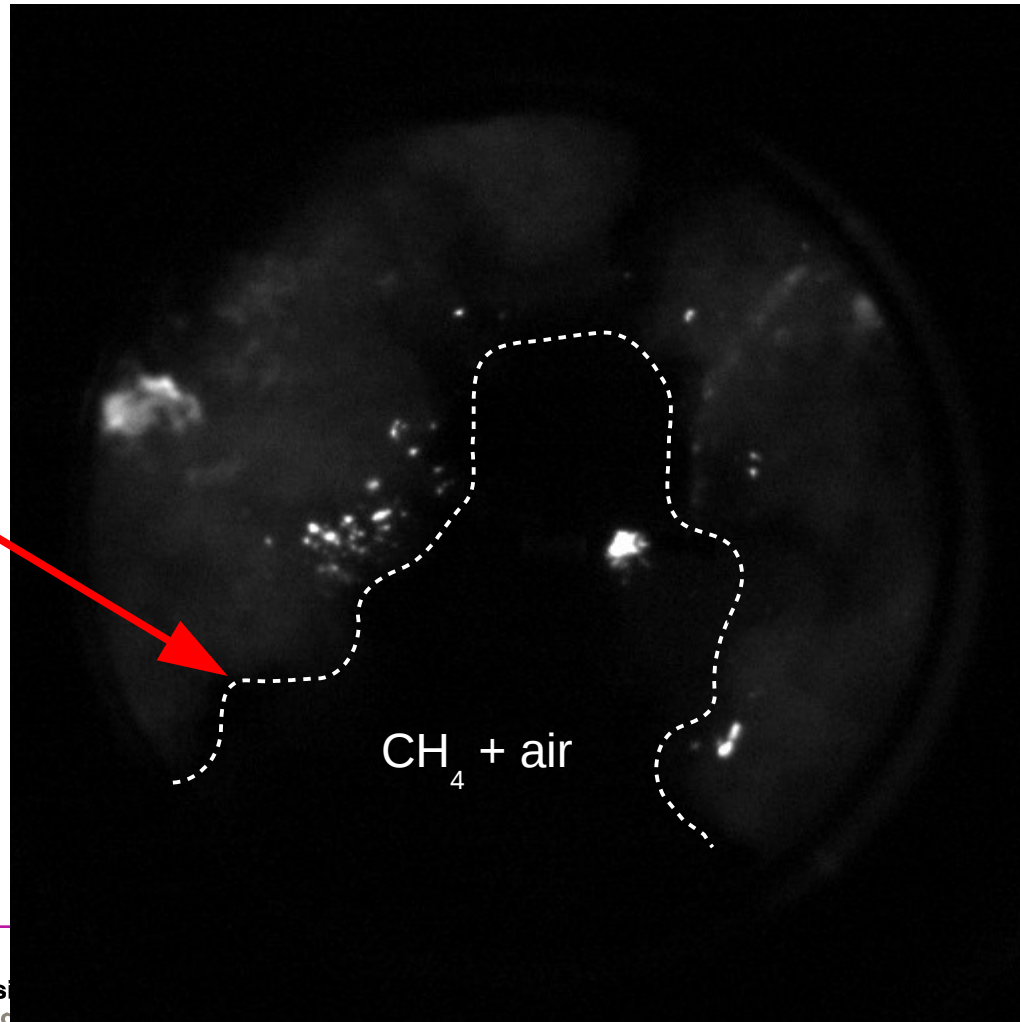
Aalto University School of Engineering

CIMAC Cascades, Helsinki, May 4th - 5th 2017
ville.vuorinen@aalto.fi

News: Optical Engine, Dual-Fuel Combustion Visualization in Prof.Larmi's Team

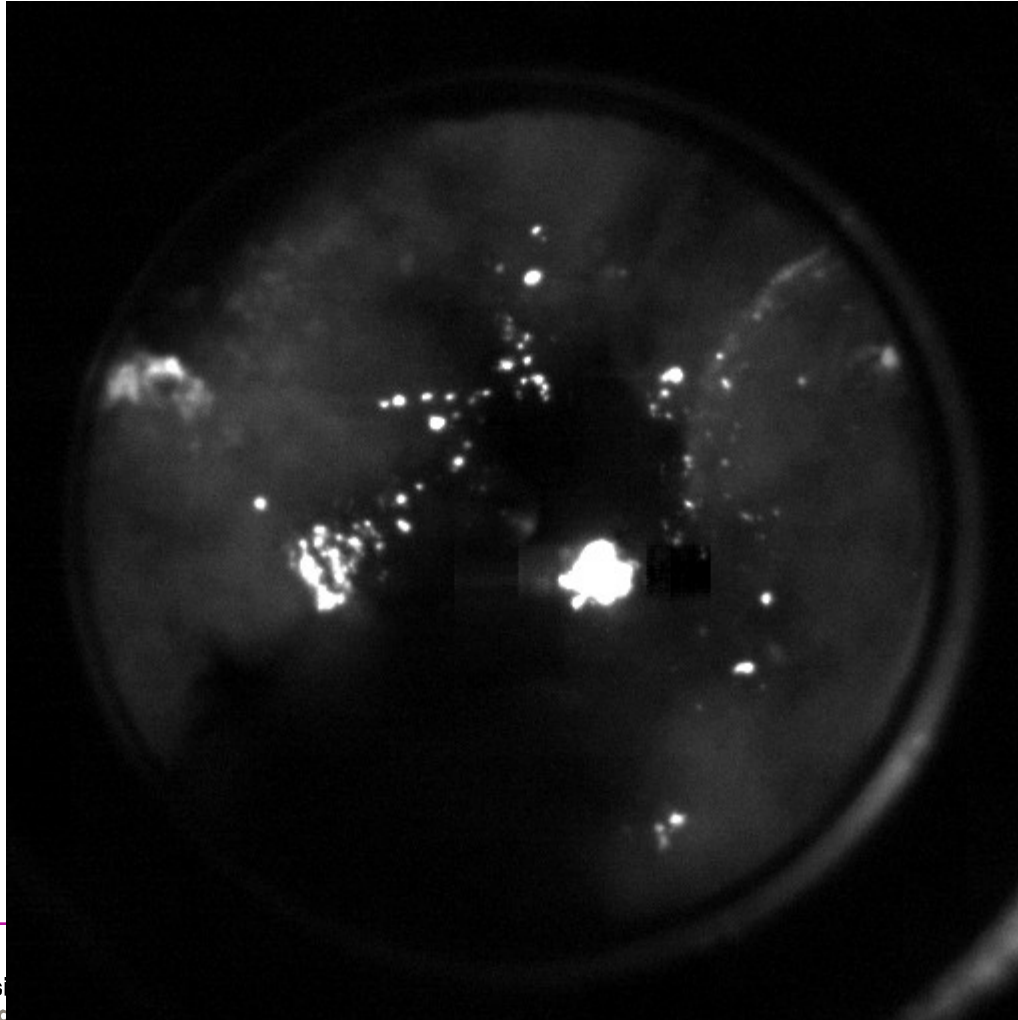
**Project
funded by:**
Academy of
Finland

Premixed
flame front?

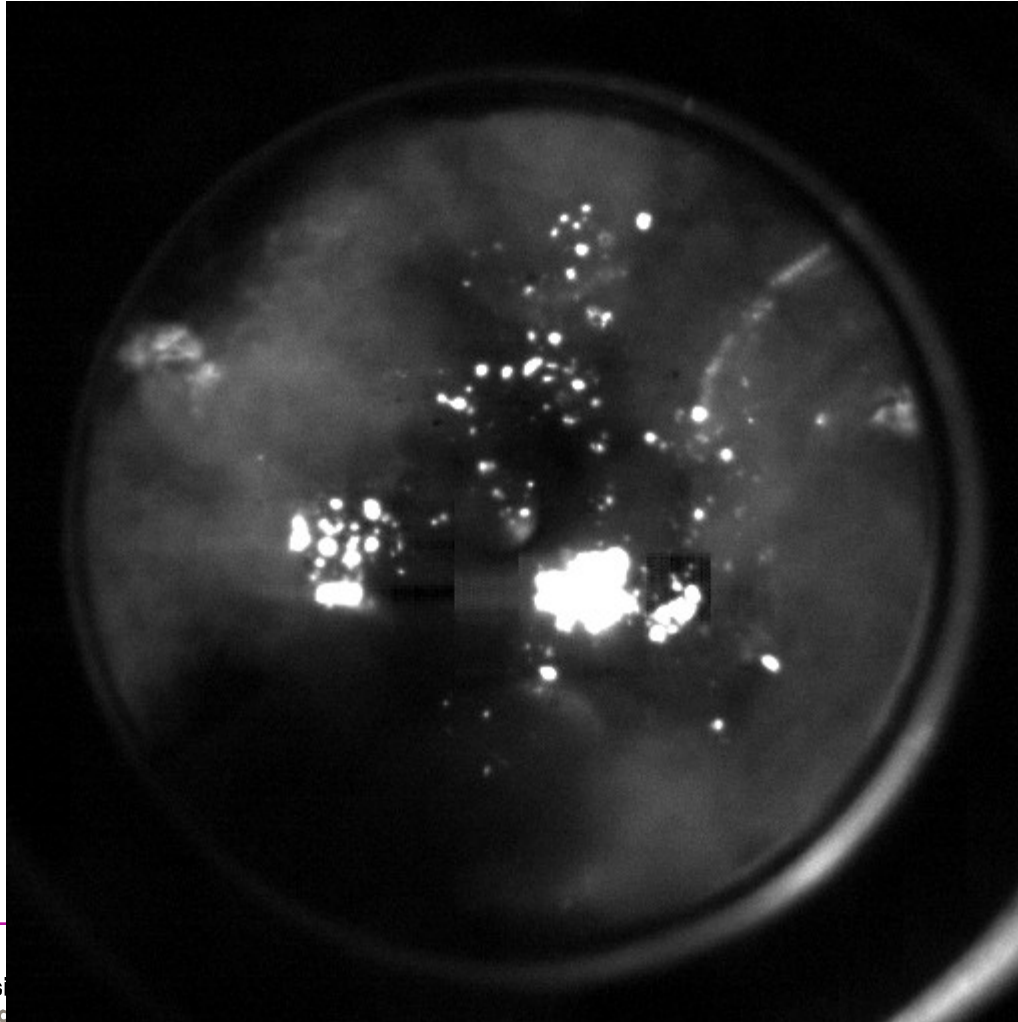


Courtesy of:
O.Ranta
A.Janak
A.Zeeshan
O.Blomstedt

News: Optical Engine, Dual-Fuel Combustion Visualization in Prof.Larmi's Team



News: Optical Engine, Dual-Fuel Combustion Visualization in Prof.Larmi's Team



Computational Team of Prof. Ville Vuorinen

2 post-docs, 7 PhD students



*Prof. V. Vuorinen
Academy of
Finland Research
Fellow 2014-2016*

On-going research projects using LES CFD

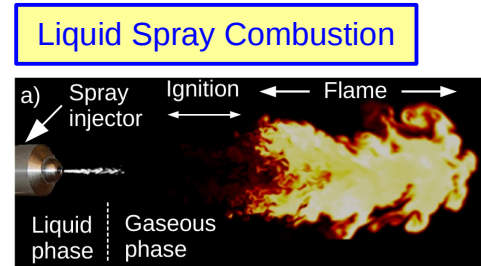
- Turbulence and engine combustion
- Boilers and black liquor sprays
- Applied heat transfer
- Engine sprays

Education and background

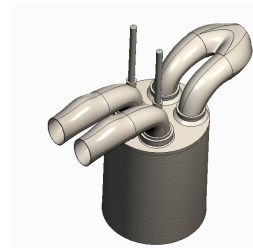
- **M.Sc.(Tech.):** Computational Physics (2004)
- **PhD:** LES of Sprays (2010)
- **Post-doc:** Compressible flow LES (2010-2016)
- **Assistant Professor:** CFD in energy (2014-)

Experience

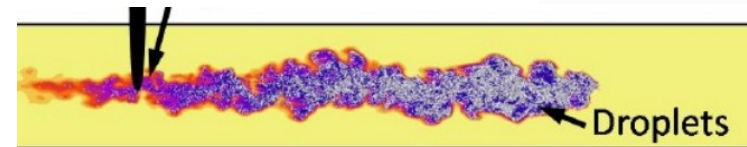
- 35 journal publications
- 2 supervised PhD thesis on engine CFD defended in 2016
- 10+ year experience in CFD/LES methods
- Developer of various LES codes



Wehrfritz et al., Combustion & Flame (2016)

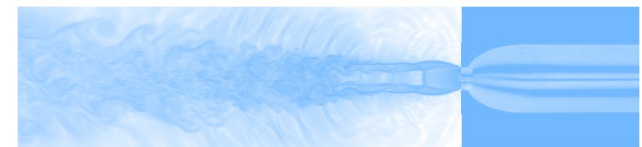


SCR Sprays



Kaario et al., Energy (2017)

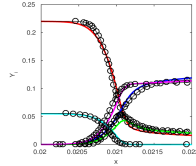
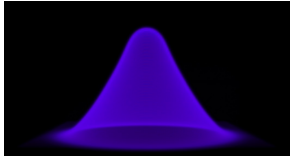
Compressible, high-speed flow



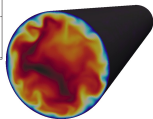
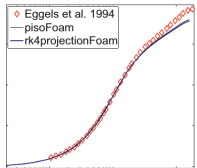
Vuorinen et al., Phys. Fluids (2014)

Challenges in CFD of IC-Engines Tackled at Aalto 2007-2017

Courtesy of H.Kahila (2016)



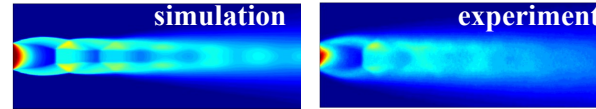
Chemistry: premixed combustion



Vuorinen et al., Adv.Eng.Soft. (2016)

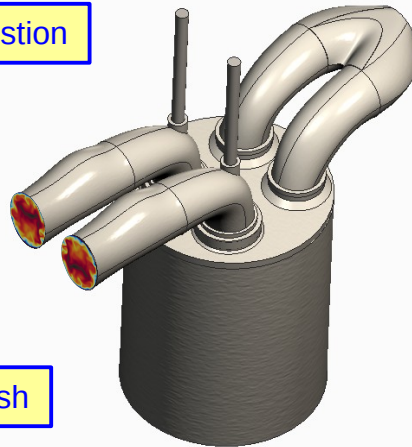
Turbulence: Large-Eddy Simulations

Ignition, Cyclic Variations, Moving Mesh



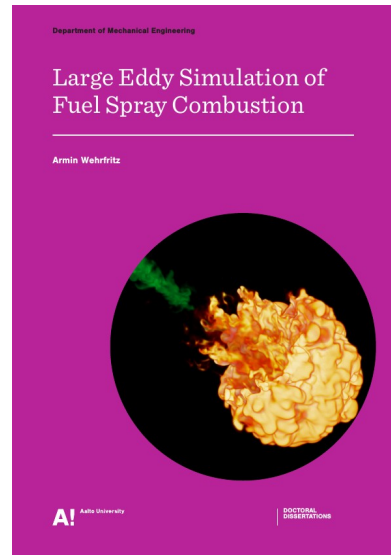
Supersonic flows and Gas DI

Vuorinen et al., Phys. Fluids (2014)
K.Keskinen et al., Energy (2016)

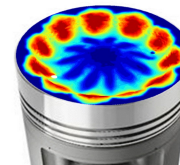
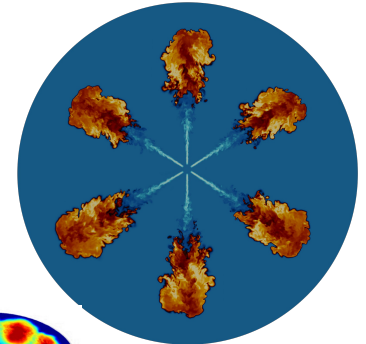


Chemistry: Non-premixed Spray combustion

Wall heat transfer



Phd thesis: Wehrfritz (2016)

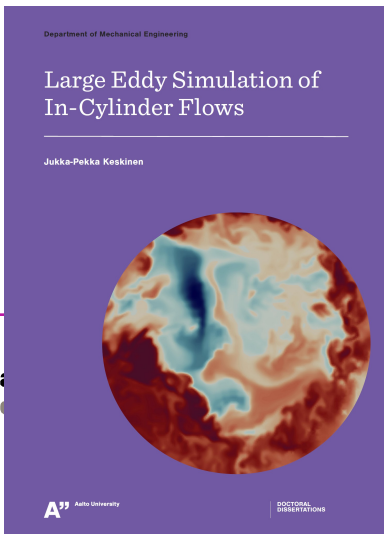


M.Nuutinen et al., J.Eng.Research (2014)

High Performance Computing and Software



CSC: SISUCray XC40



Phd thesis: J.P.Keskinen (2016)



Outline

- 1) Solution to wall heat transfer as computational “bottle-neck”
- 2) New insight to temperature stratification during compression
- 3) Ignition and potential of Large Eddy Simulation for predicting cycle-to-cycle variations

Advanced Wall Heat Transfer Model by Nuutinen et al. (2014) and Extension to LES by K.Keskinen et al. (2017)

Imbalance wall functions with density and material property variation effects applied to engine heat transfer computational fluid dynamics simulations

Mika A Nuutinen, Ossi T Kaario, Ville A Vuorinen, Paul N Nwosu and Martti J Larmi

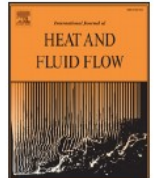
International J of Engine Research
2014, Vol. 15(3) 307–324
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DOI: 10.1177/1468087413481779
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Hybrid LES/RANS with wall treatment in tangential and impinging flow configurations



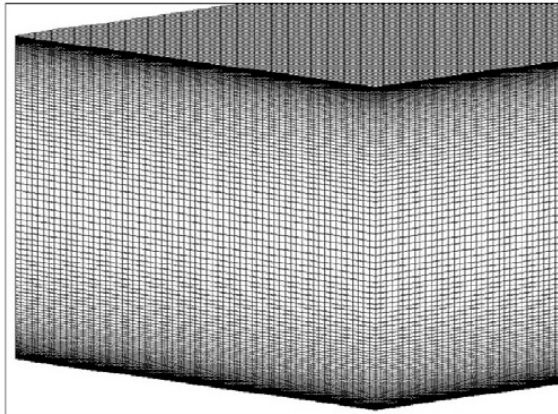
Karri Keskinen^{a,*}, Mika Nuutinen^a, Ossi Kaario^a, Ville Vuorinen^a, Jann Koch^b, Yuri M. Wright^b, Martti Larmi^a, Konstantinos Boulouchos^b

^aAalto University School of Engineering, Department of Mechanical Engineering, Thermodynamics and Combustion Technology Research Group, Puumiehenkuja 5 A, 02150 Espoo, Finland

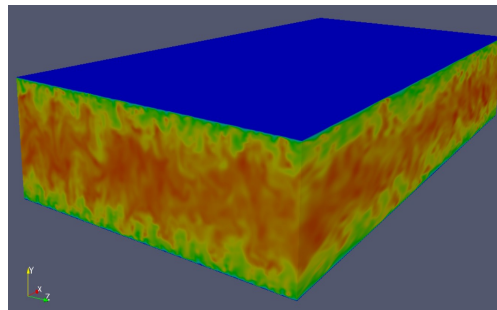
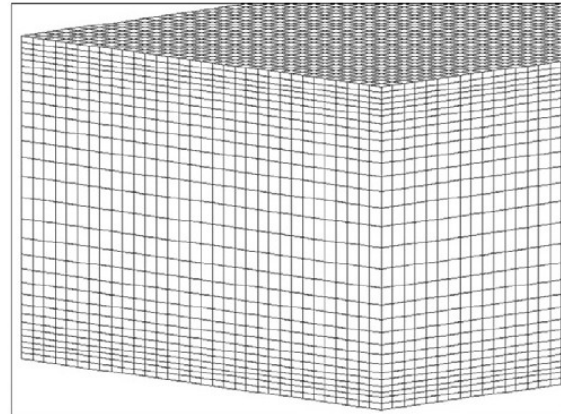
^bETH Zurich, Institute of Energy Technology, Aerothermochemistry and Combustion Systems Laboratory, ML J40, Sonneggstrasse 3, CH-8092 Zurich, Switzerland

Main Objective: Fast, Accurate Simulations on Coarse Resolution

Fine Grid – Long Time



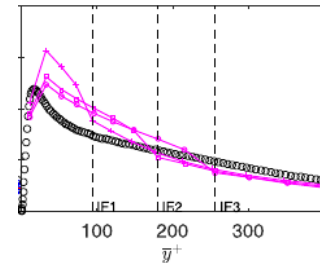
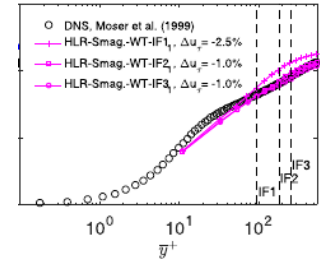
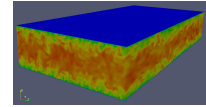
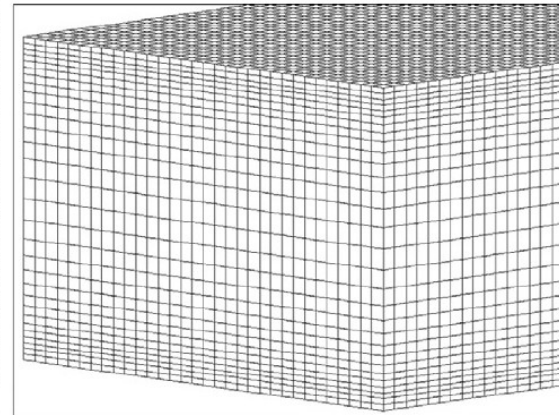
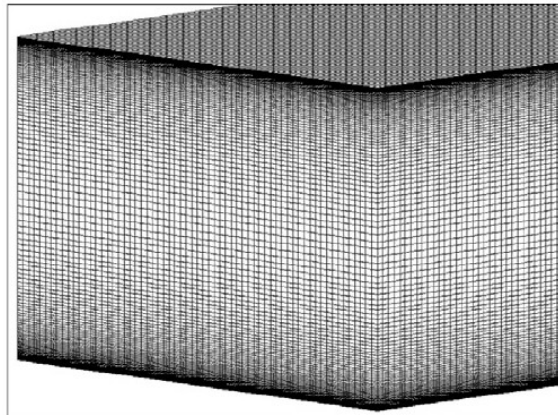
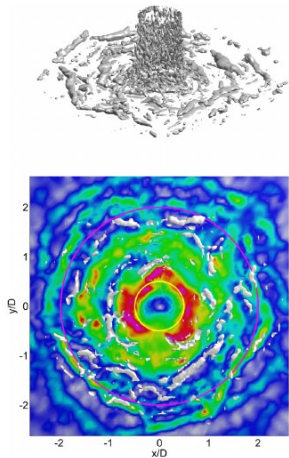
Coarse Grid – Short Time



Main Objective: Fast, Accurate Simulations on Coarse Resolution

Fine Grid – Long Time

Coarse Grid – Short Time



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HEAT AND FLUID FLOW

Hybrid LES/RANS with wall treatment in tangential and impinging flow configurations

Karri Keskinen^{a,*}, Mika Nuutinen^a, Ossi Kaario^a, Ville Vuorinen^a, Jann Koch^b, Yuri M. Wright^b, Martti Larmi^a, Konstantinos Boulouchos^b

^aAalto University School of Engineering, Department of Mechanical Engineering, Thermodynamics and Combustion Technology Research Group, Puimiehenkatu 5 A, 02150 Espoo, Finland

^bETH Zurich, Institute of Energy Technology, Aerothermochemistry and Combustion Systems Laboratory, ML J40, Sonneggstrasse 3, CH-8092 Zurich, Switzerland

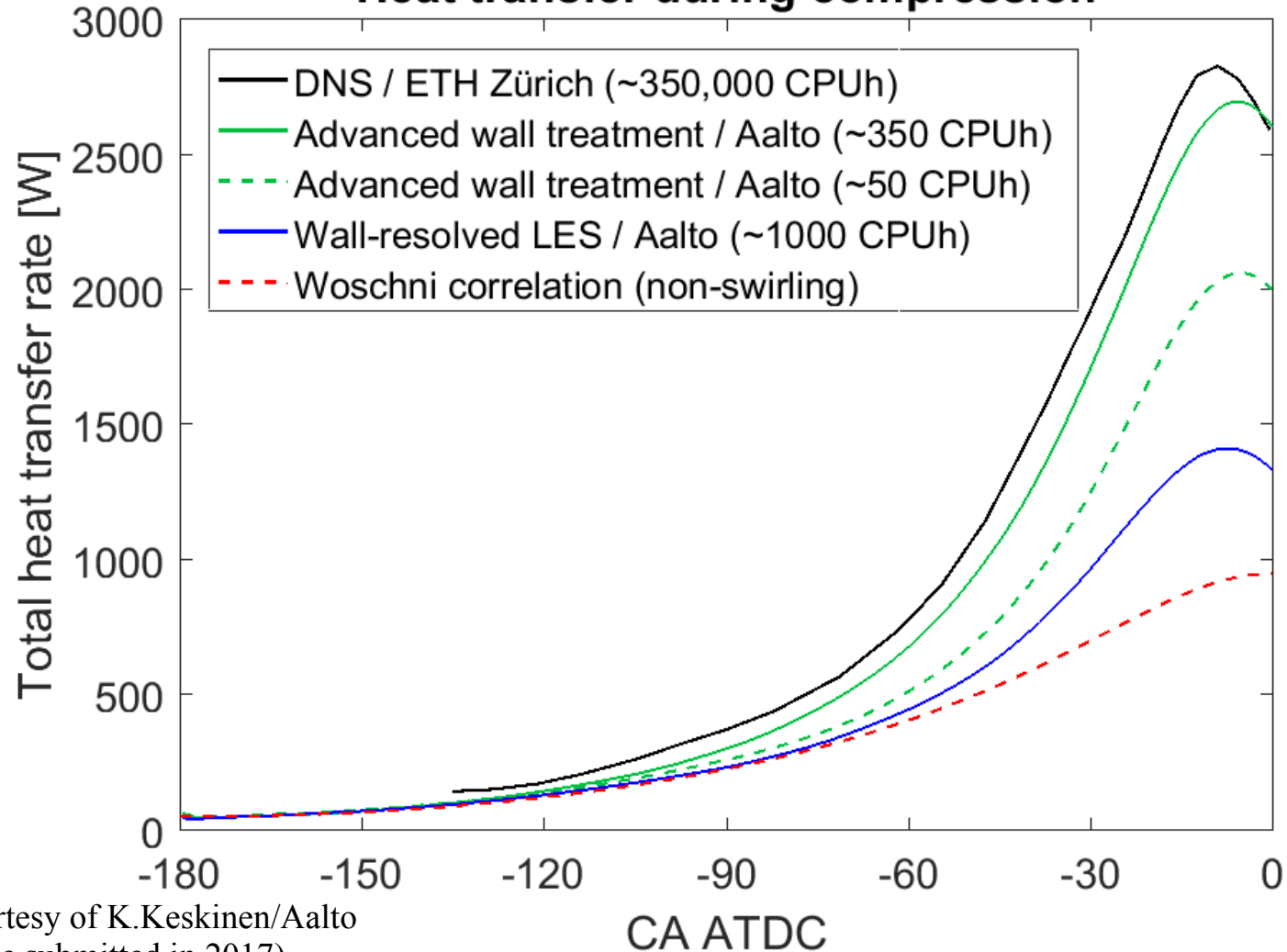
CrossMark



Advanced wall model offers:

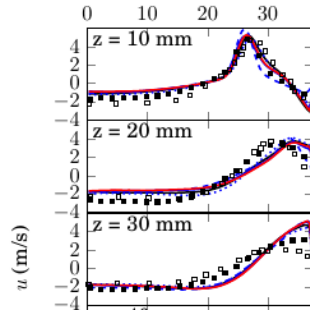
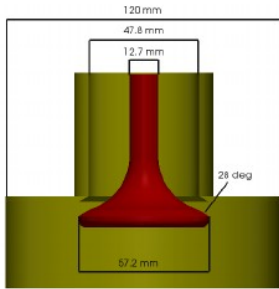
- accurate turbulence statistics on coarse grids
- 100-1000 times faster than DNS

Heat transfer during compression



Courtesy of K.Keskinen/Aalto
(to be submitted in 2017)

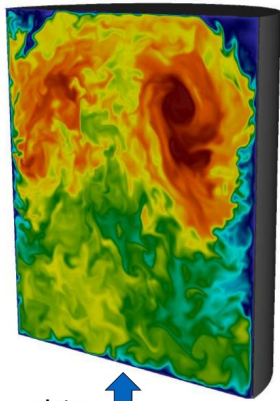
Temperature of Compressing Gas in the Cylinder



Comp.Fluids,
J.P. Keskinen et al. (2015)

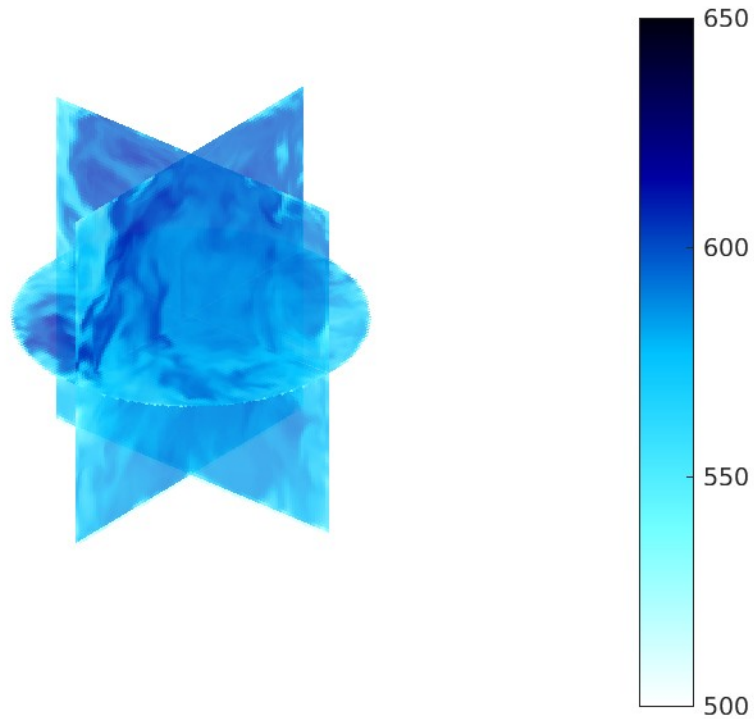


Courtesy of K.Keskinen/Aalto
(to be submitted in 2017)

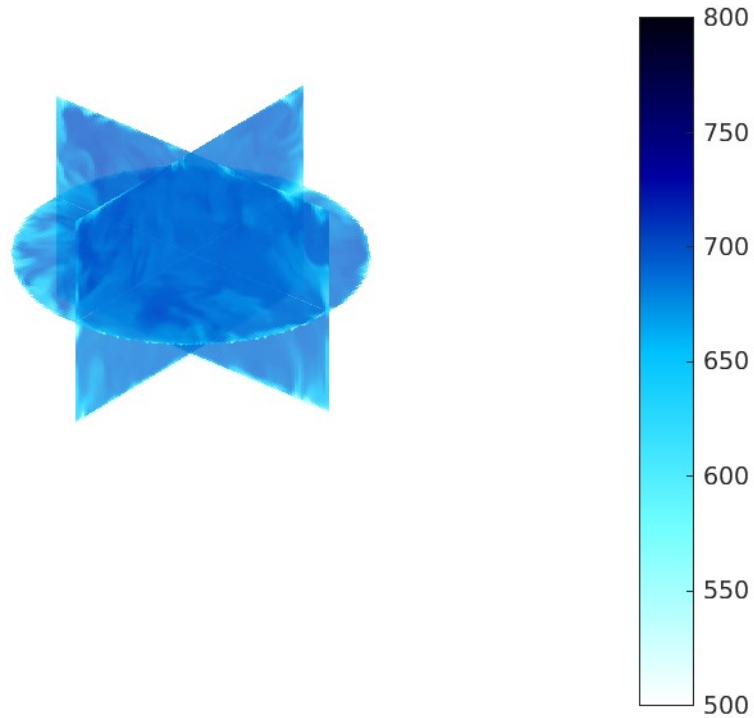


Phys.Fluids, Schmidt et al. (2015)

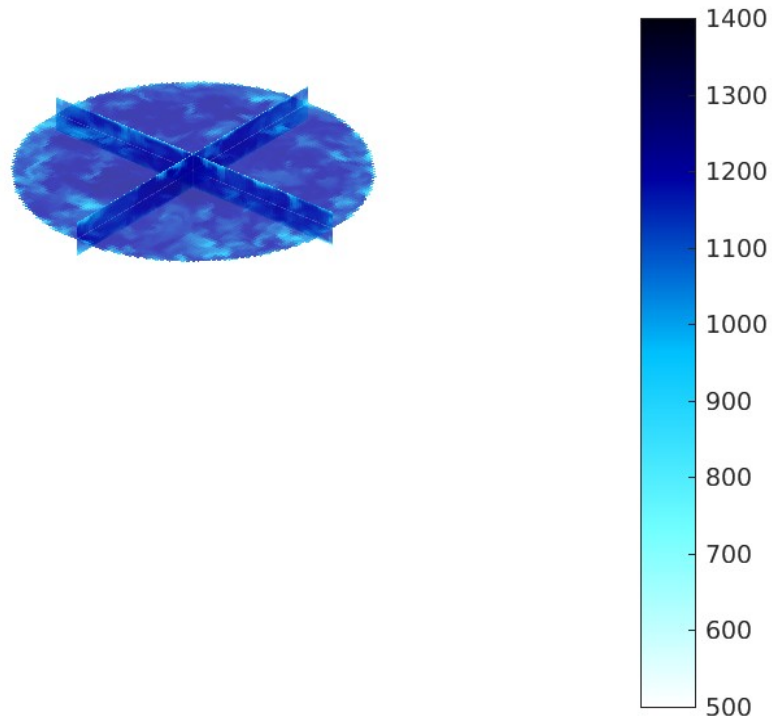
Temperature of Compressing Gas in the Cylinder



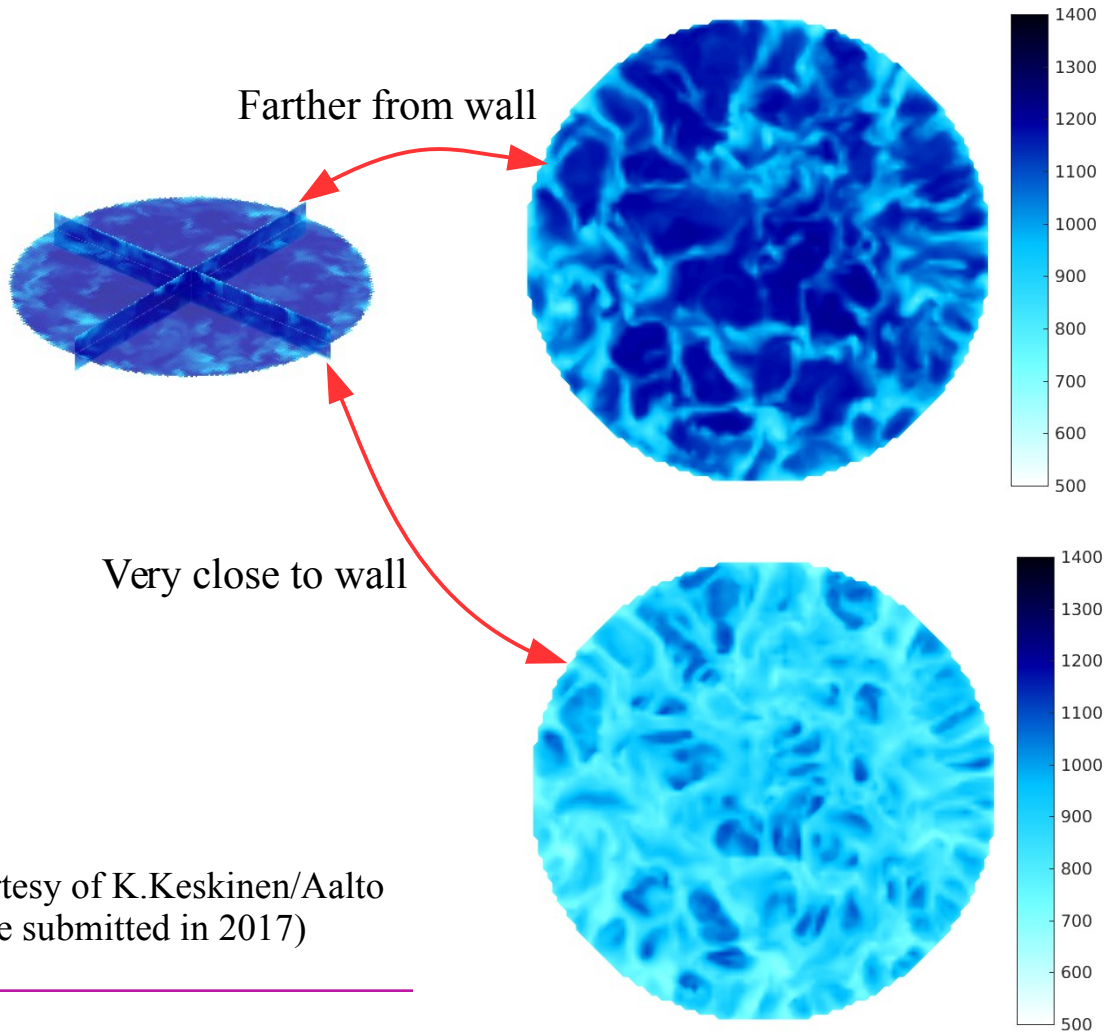
Temperature of Compressing Gas in the Cylinder



Temperature of Compressing Gas in the Cylinder

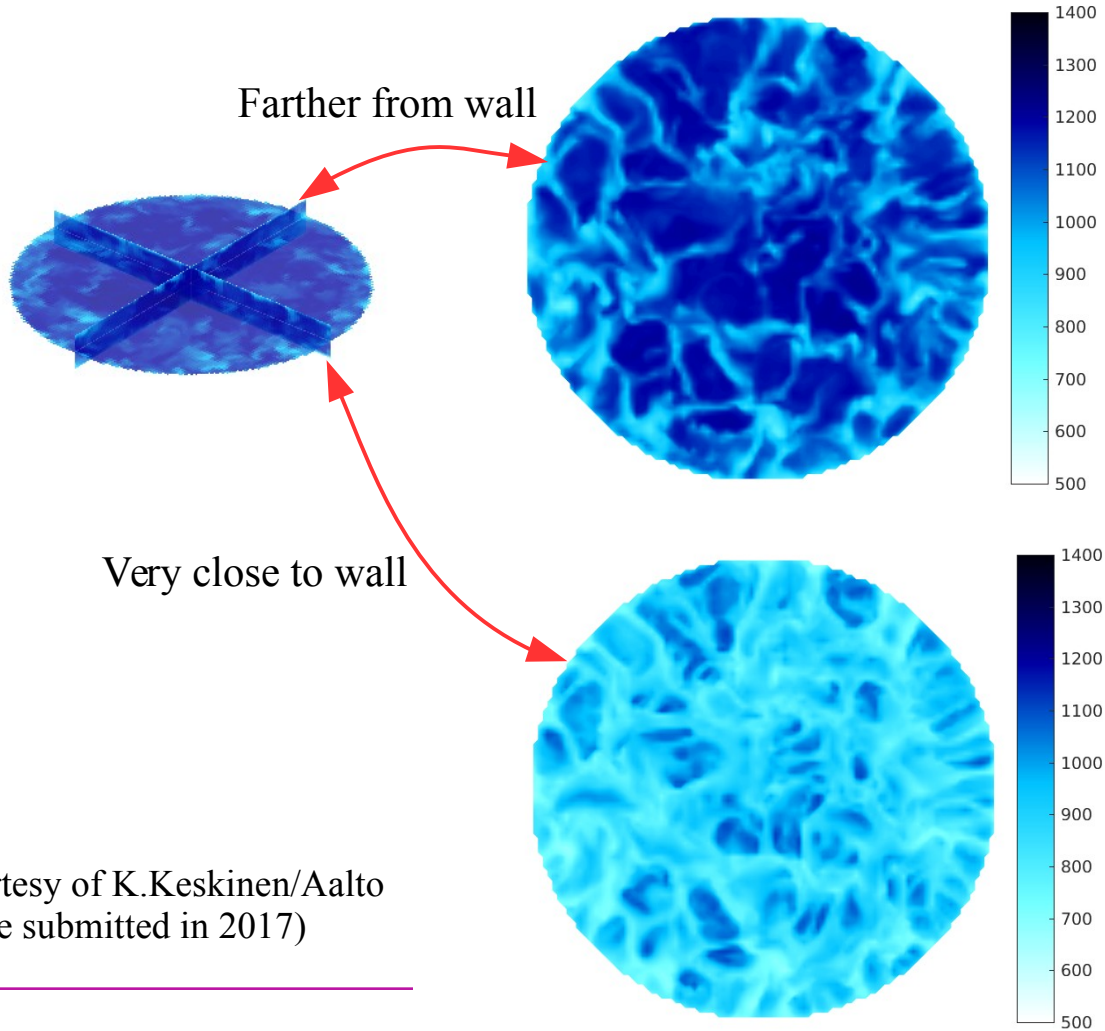


Temperature of Compressing Gas in the Cylinder

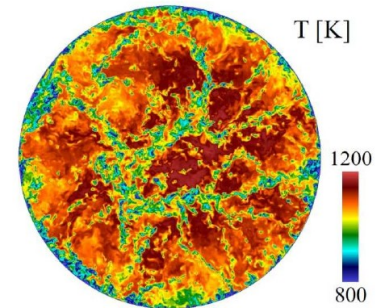


Courtesy of K.Keskinen/Aalto
(to be submitted in 2017)

Temperature of Compressing Gas in the Cylinder

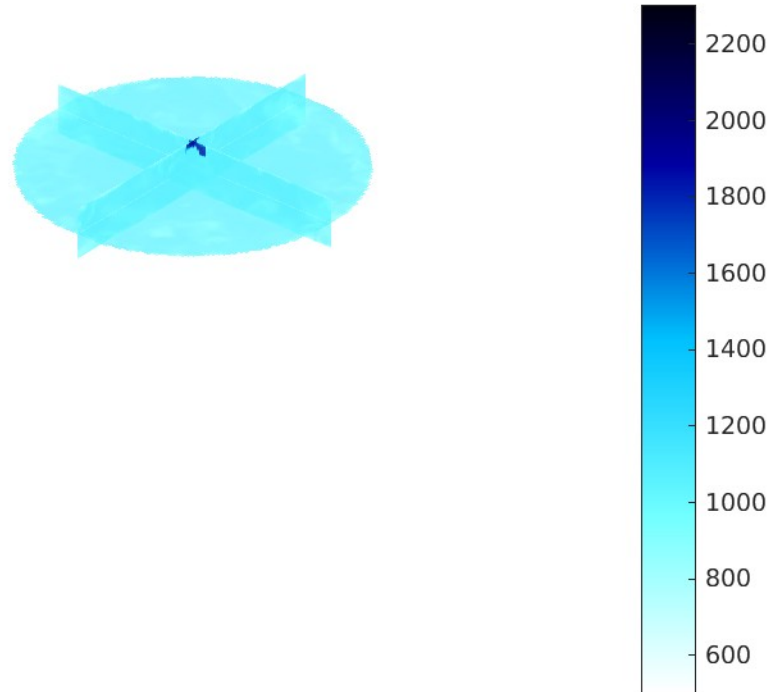


Courtesy of K.Keskinen/Aalto
(to be submitted in 2017)



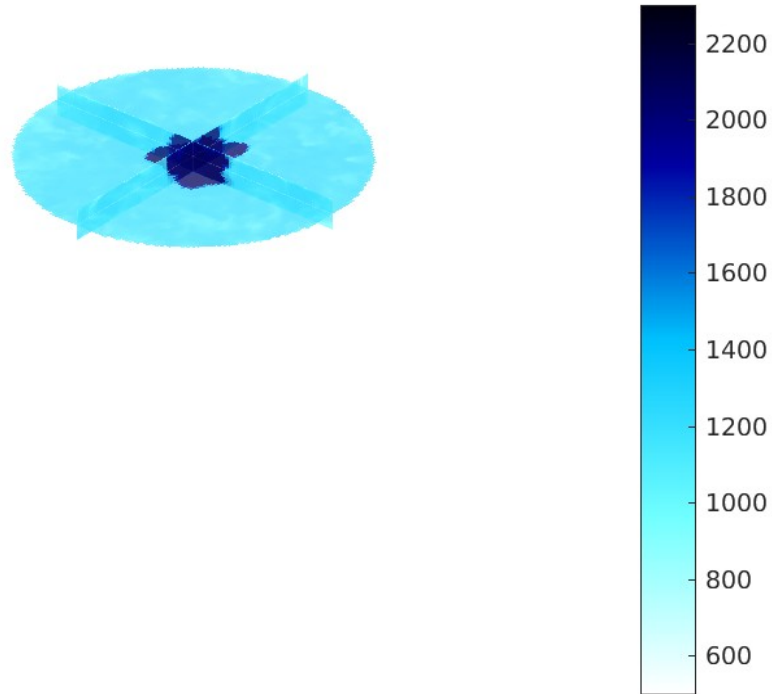
DNS: courtesy of
Schmidt et al.
Proc.Comb.Inst. (2015)

Spark Ignited Lean Methane-Air Mixture



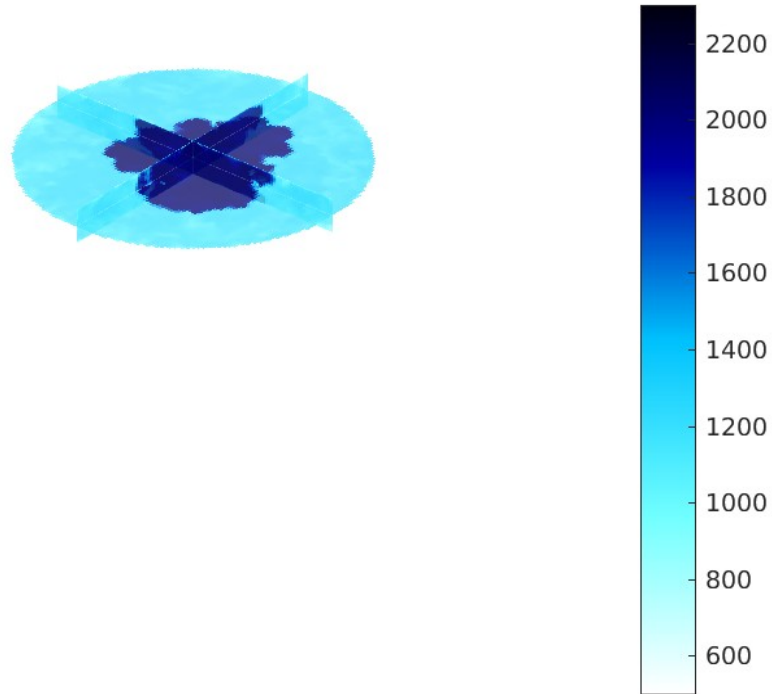
Courtesy of M.Ghaderi-Masouleh/Aalto
(to be submitted in 2017)

Spark Ignited Lean Methane-Air Mixture



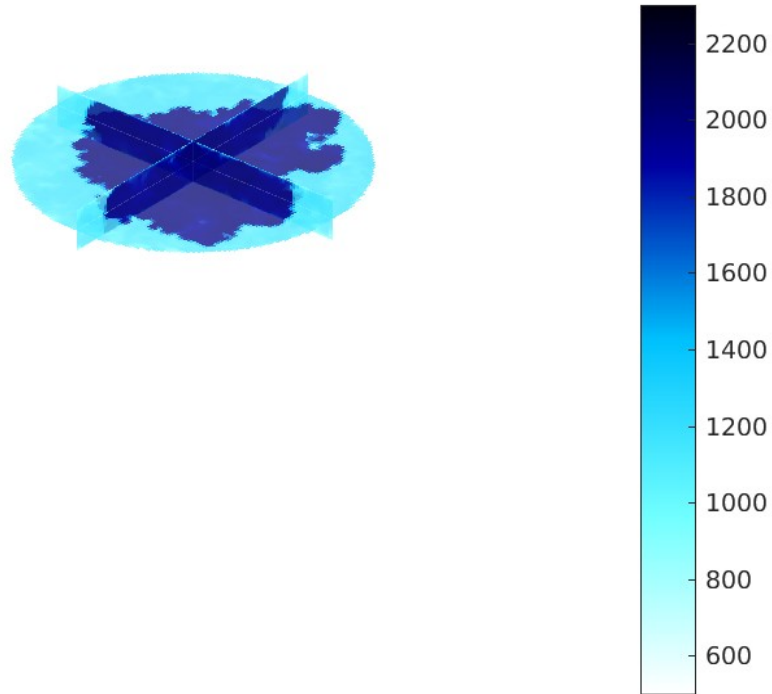
Courtesy of M.Ghaderi-Masouleh/Aalto
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Spark Ignited Lean Methane-Air Mixture



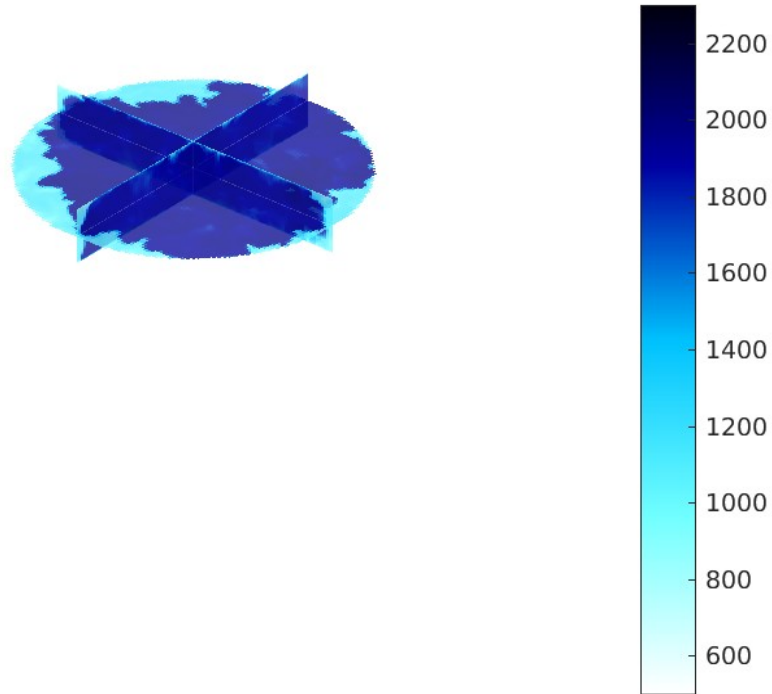
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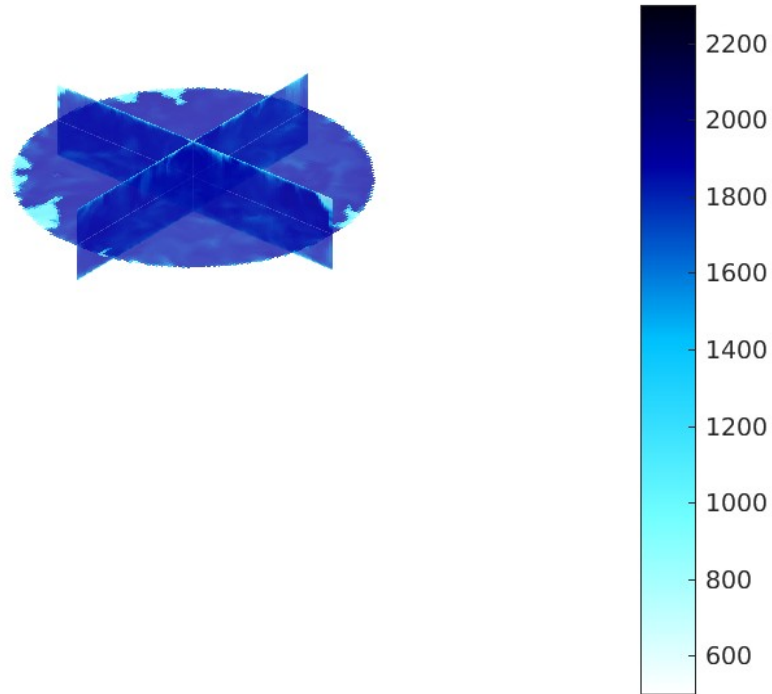
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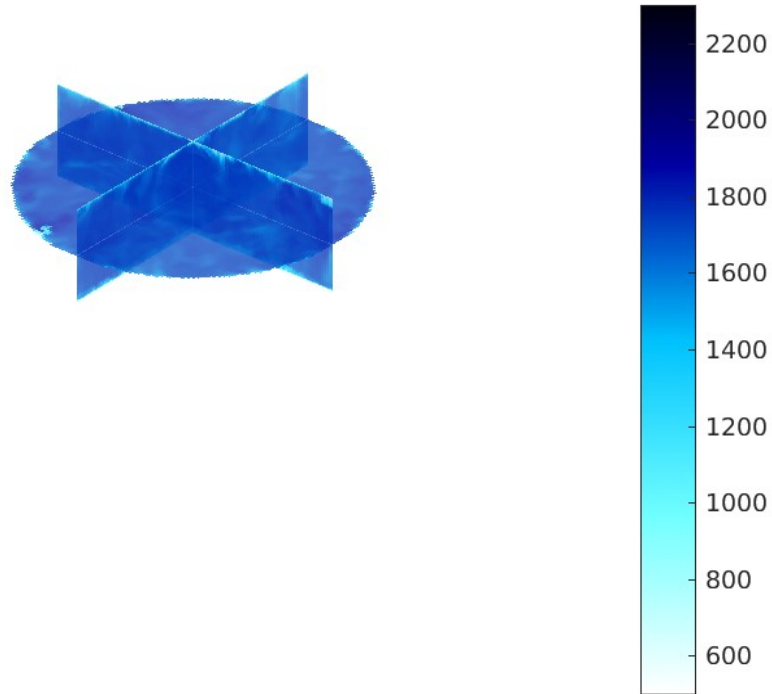
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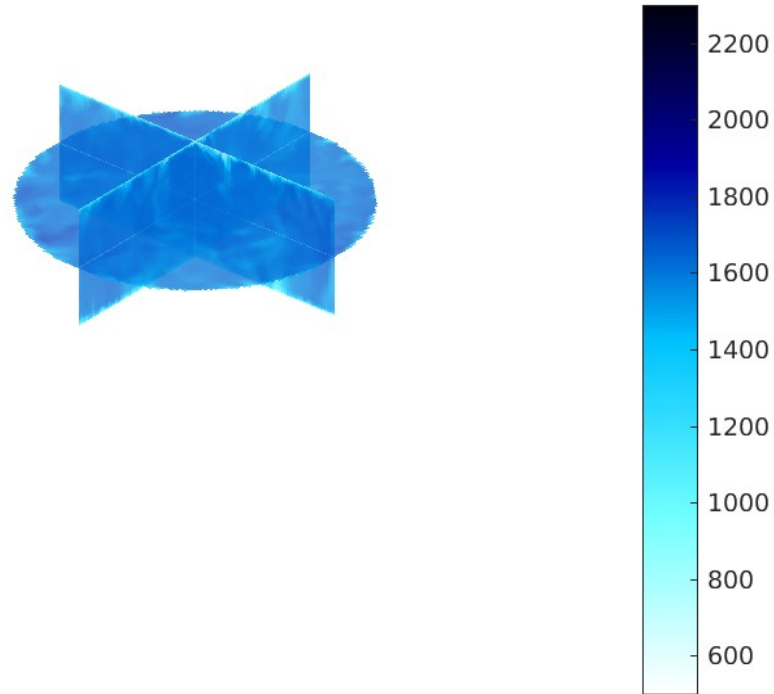
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Spark Ignited Lean Methane-Air Mixture



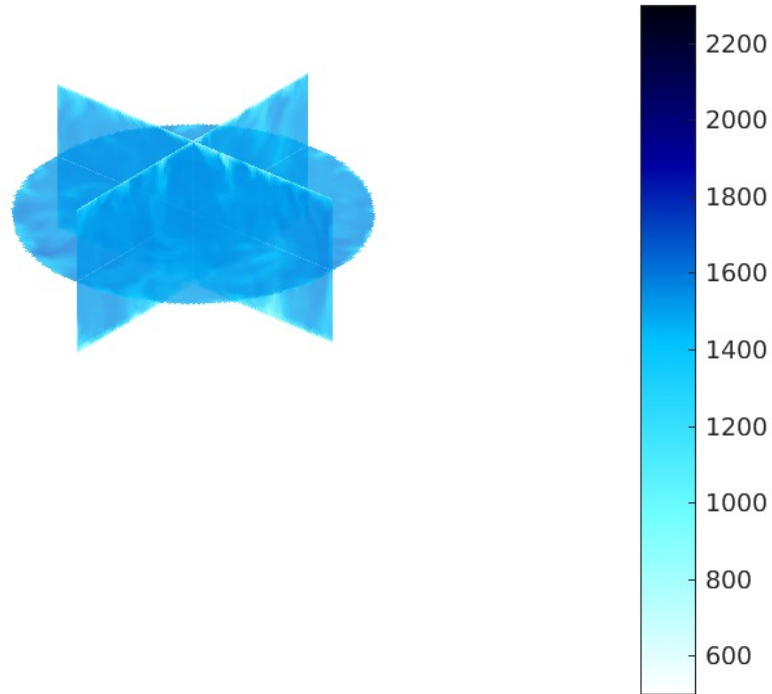
Courtesy of M.Ghaderi-Masouleh/Aalto
(to be submitted in 2017)

Spark Ignited Lean Methane-Air Mixture



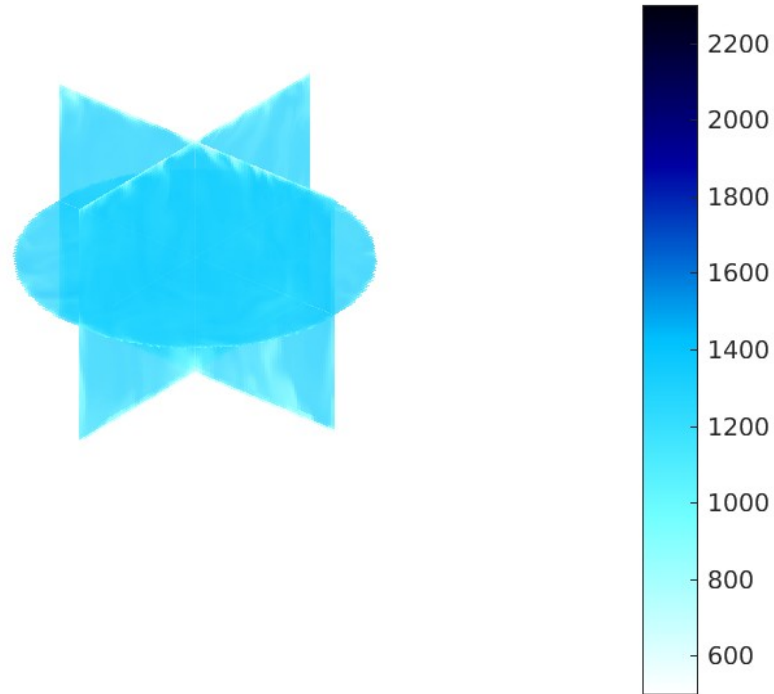
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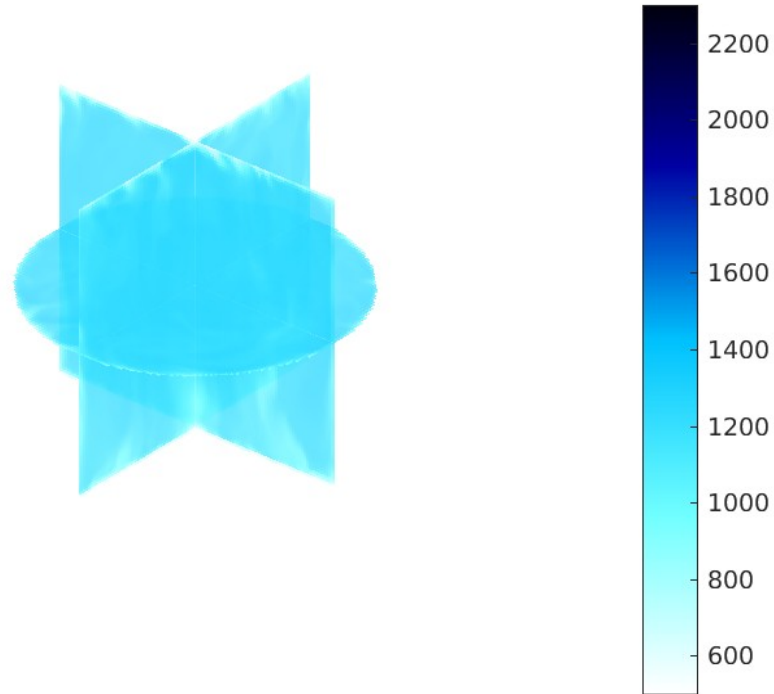
Courtesy of M.Ghaderi-Masouleh/Aalto
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Courtesy of M.Ghaderi-Masouleh/Aalto
(to be submitted in 2017)

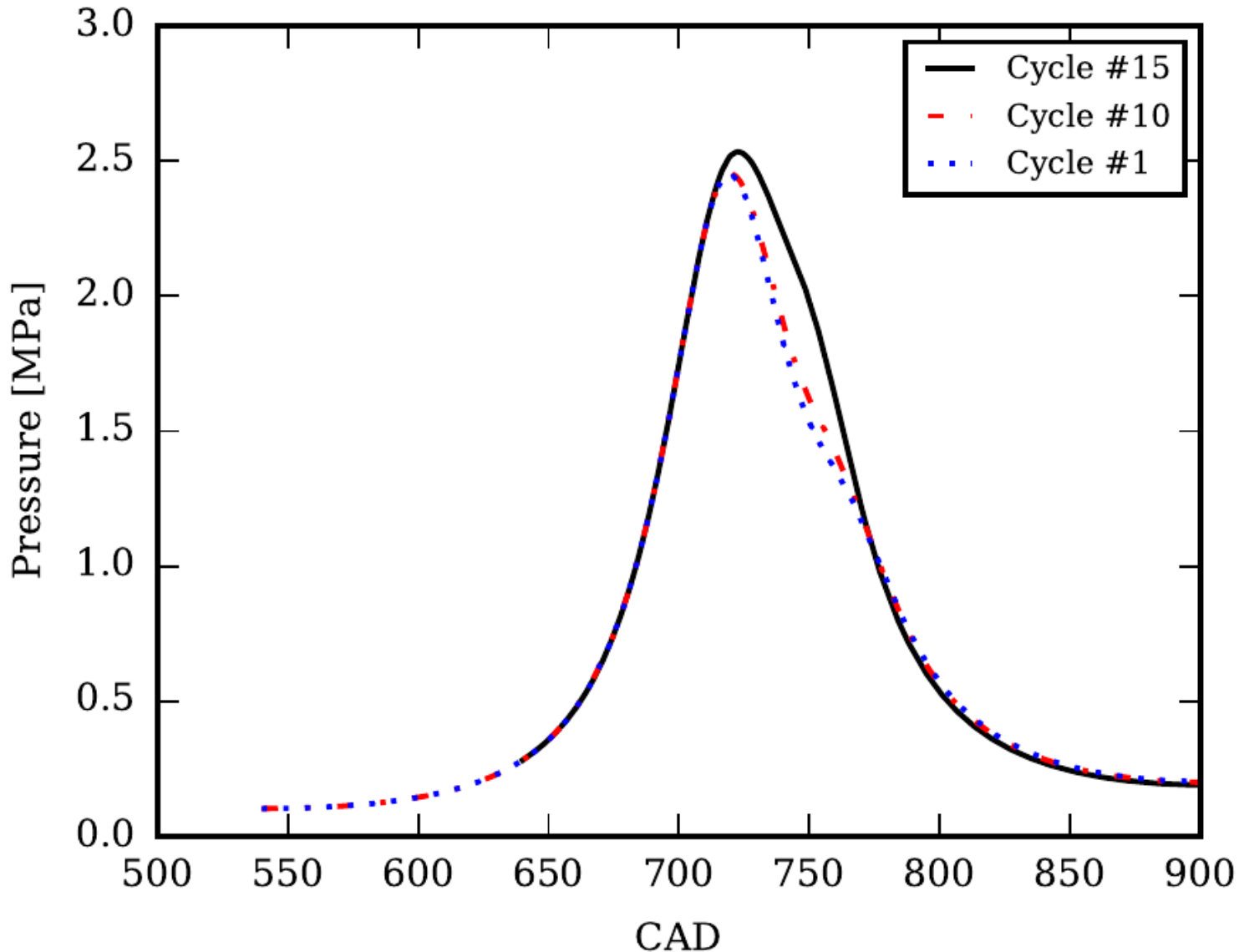
Spark Ignited Lean Methane-Air Mixture



Courtesy of M.Ghaderi-Masouleh/Aalto
(to be submitted in 2017)

Why Are There Cycle-to-Cycle Variations in Pressure Trace?

Courtesy of M.Ghaderi-Masouleh/Aalto
(to be submitted in 2017)



Conclusions

- Wall heat transfer → good models may enable fast LES
- Stratification → significant
- Wall stratification → significant, linkage to methane slip, combustion irregularities
- LES → insight to details

Acknowledgements

- Academy of Finland (grants 268380 and 297248)
- Wärtsilä
- Aalto University Graduate School
- Merenkulun säätiö
- Gasumin säätiö
- Henry Fordin säätiö
- Tekes (Shok Cleen Oy)