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B.M. Franchetti
F. Cavallo Marincola
M. Rabacal
A.M. Kempf | *akempf@uni-due.de*

Large-Eddy Simulation of Pulverised Coal Combustion

IVG Institut für Verbrennung und Gasdynamik
Fluiddynamik

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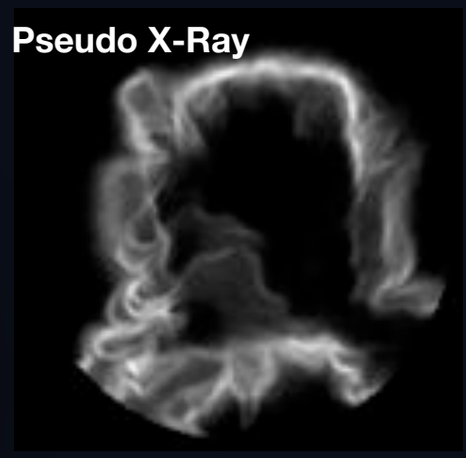
Background: PsiPhi

Inhouse Code, Kempf Group

- We develop C-LES since 1999
- PsiPhi since 2007
- Optimised for LES and DNS
- Massively parallel (2^{15} cores)
- Gas, spray, coal flames
- Nano particle synthesis
- Engine simulations



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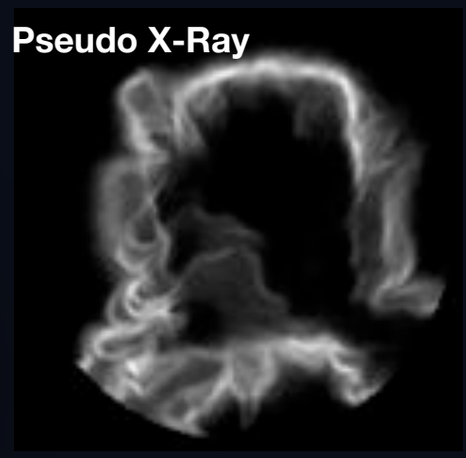

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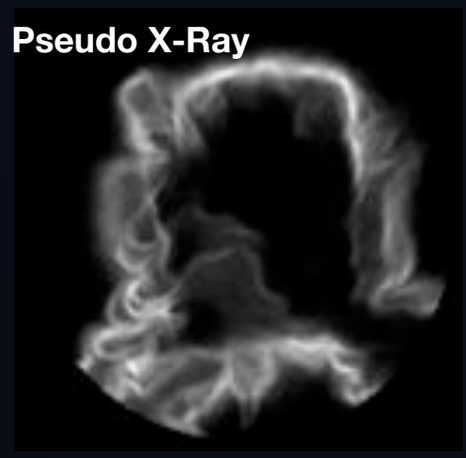

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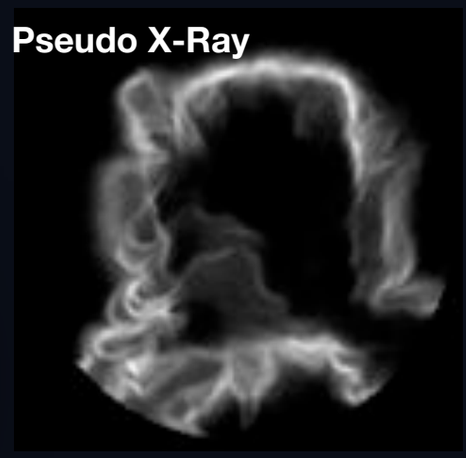

Background: LES

Large-Eddy Simulation vs. RANS (classical CFD)

- **RANS**
- Time-averaged, steady
- *„Photo, long exposure“* ➦
- All turbulent fluctuations must be modelled.
- Correlations of fluctuations must also be modelled! ➦
- Closure models matter!
- Numerics matter little.

- **LES**
- Locally filtered, unsteady
- *„Movie, slightly blurred“*
- Strong fluctuations are calculated.
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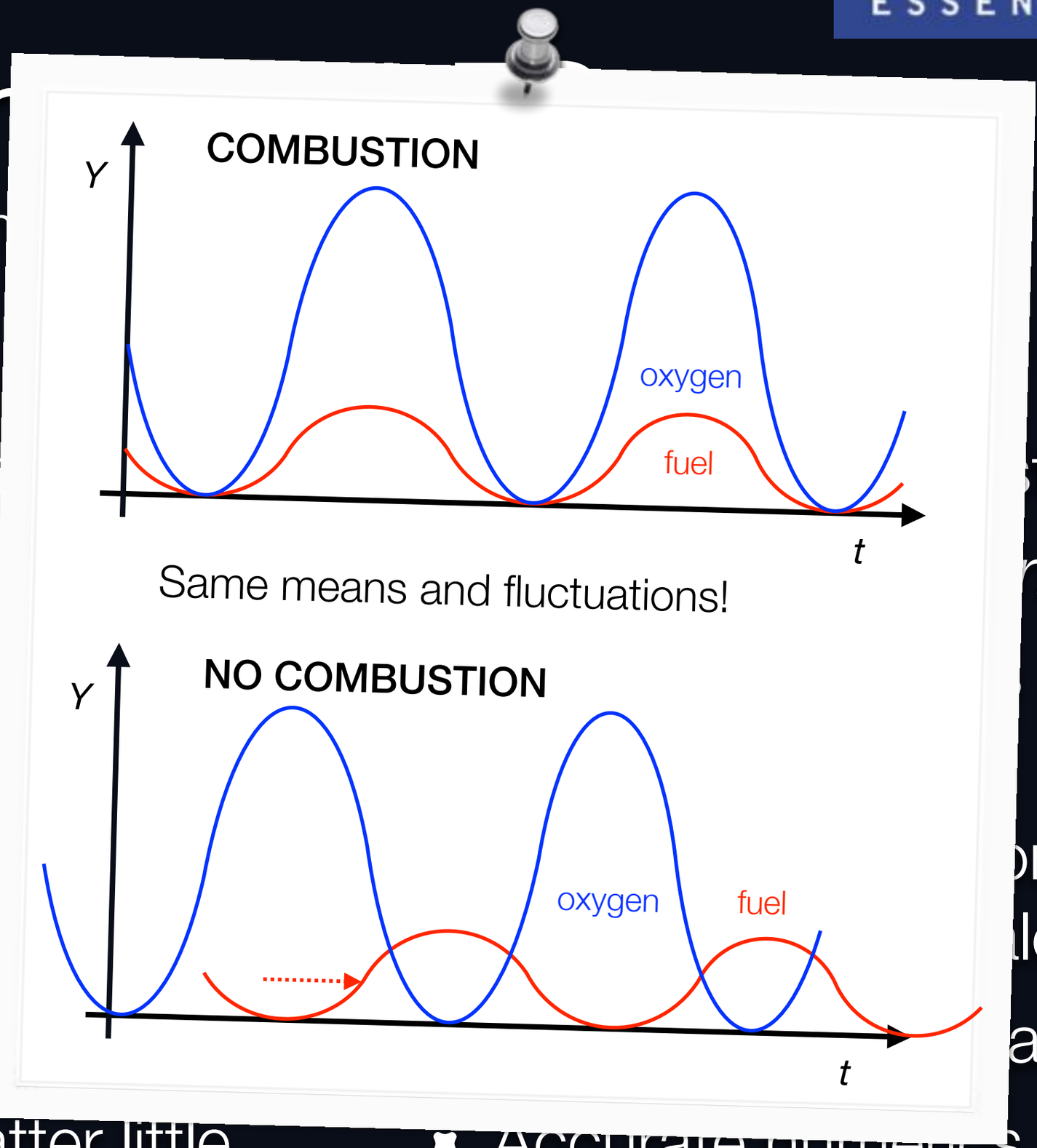

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LES is a different approach (new paradigm), not a different „turbulence model“!

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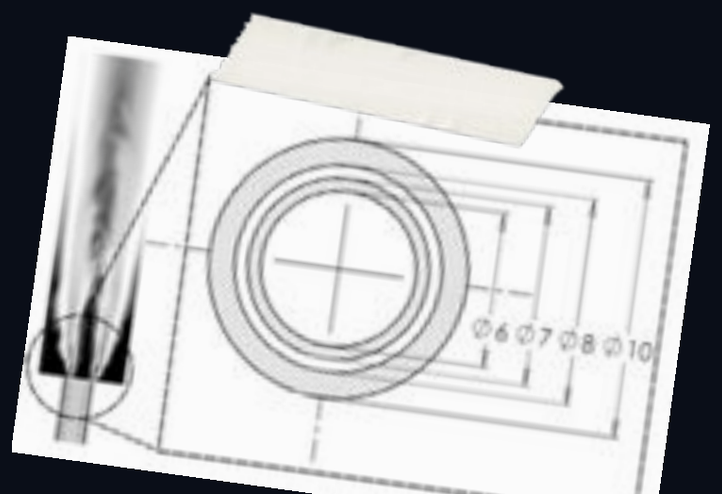
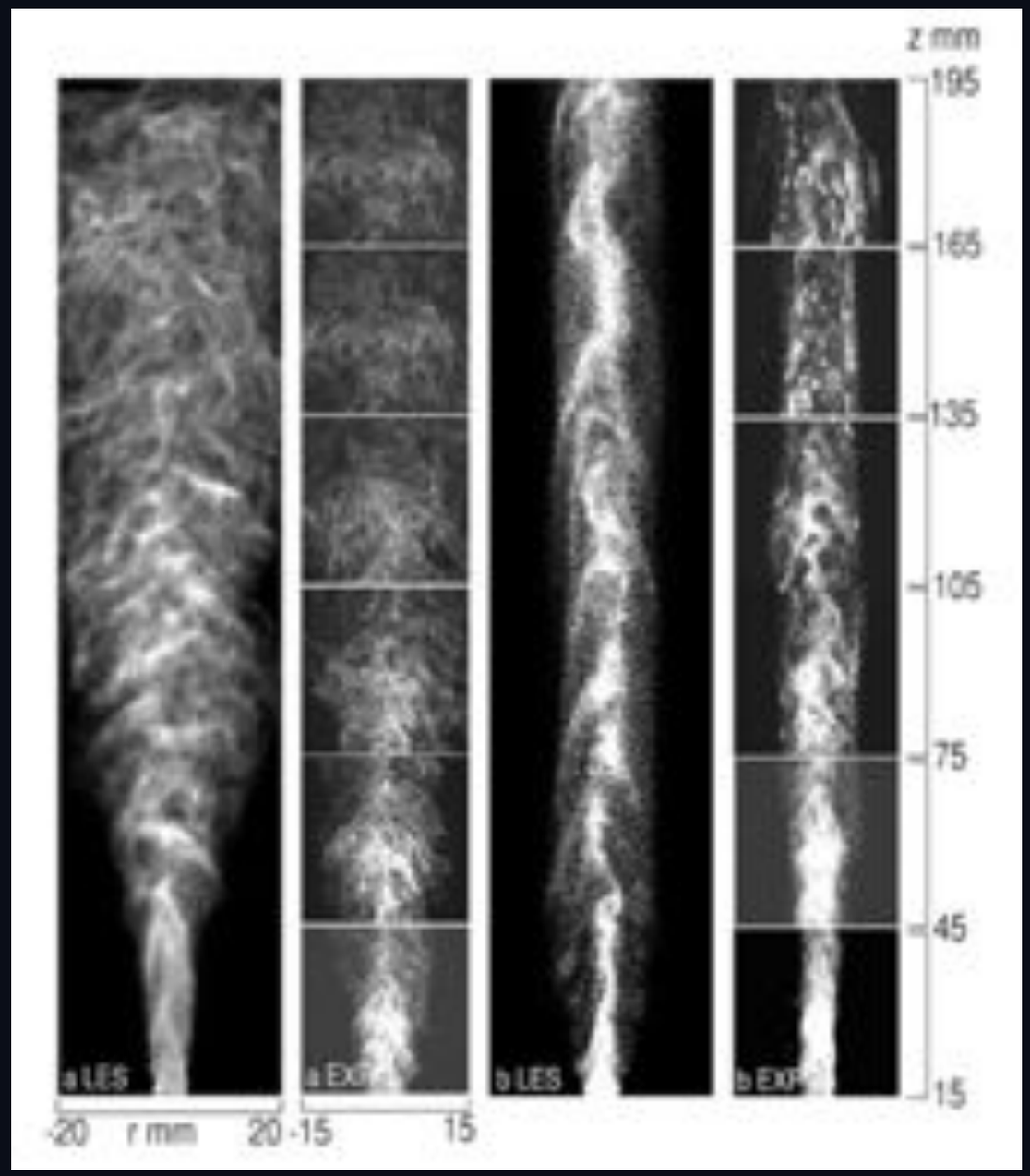
CRIEPI Burner

Franchetti, B.M., Cavallo Marincola, F., Navarro-Martinez, S, Kempf, A.M, Large Eddy Simulation of a Pulverised Coal Jet Flame, Proc. Combust. Inst. 34 (2013) 2419-2426.

- Small scale jet burner
- Coal: 0.149 g/s
- Methane pilot, 23 cm^3/s
- Re ≈ 2300
- 10^7 computational cells
- Euler-Lagrange LES





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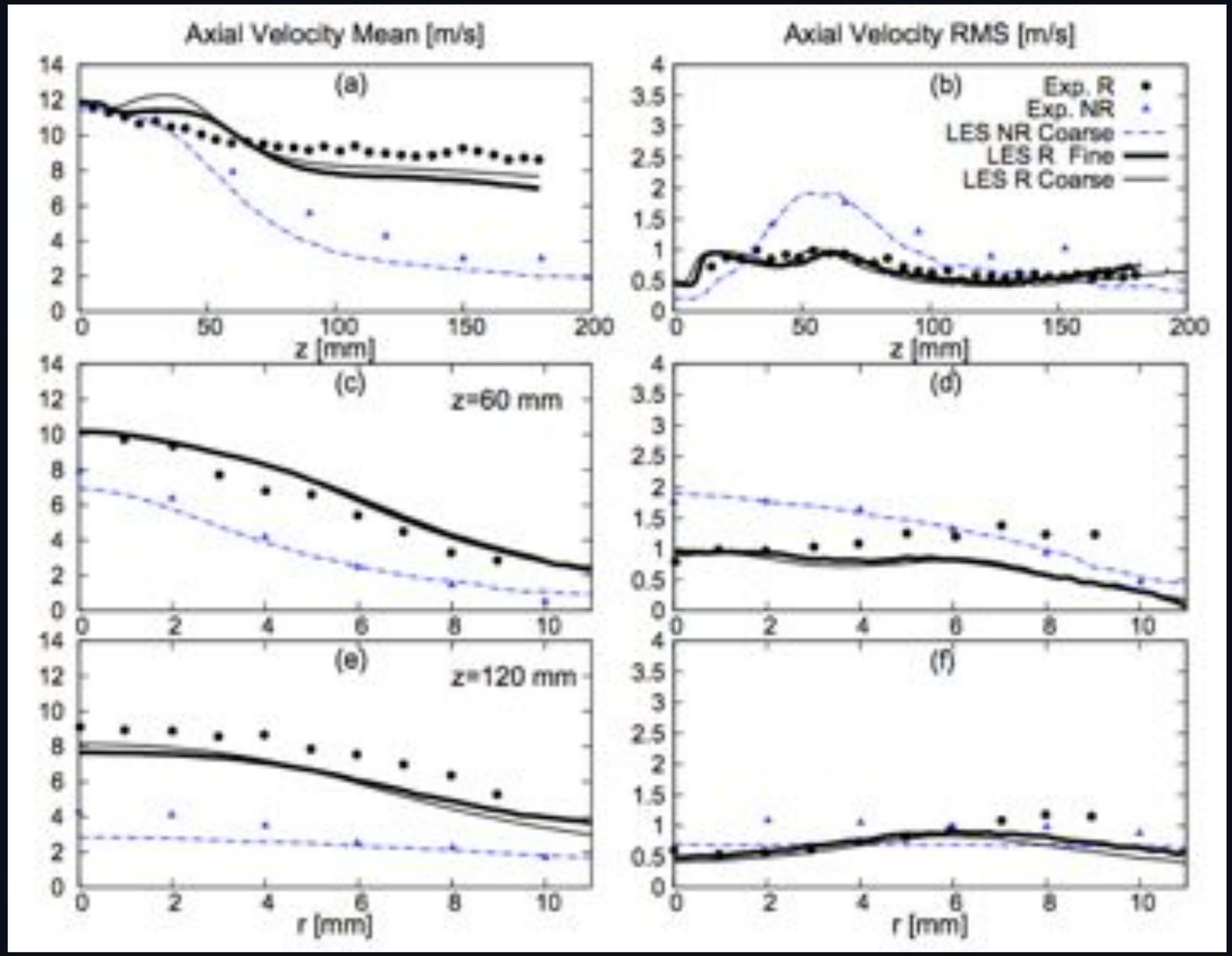

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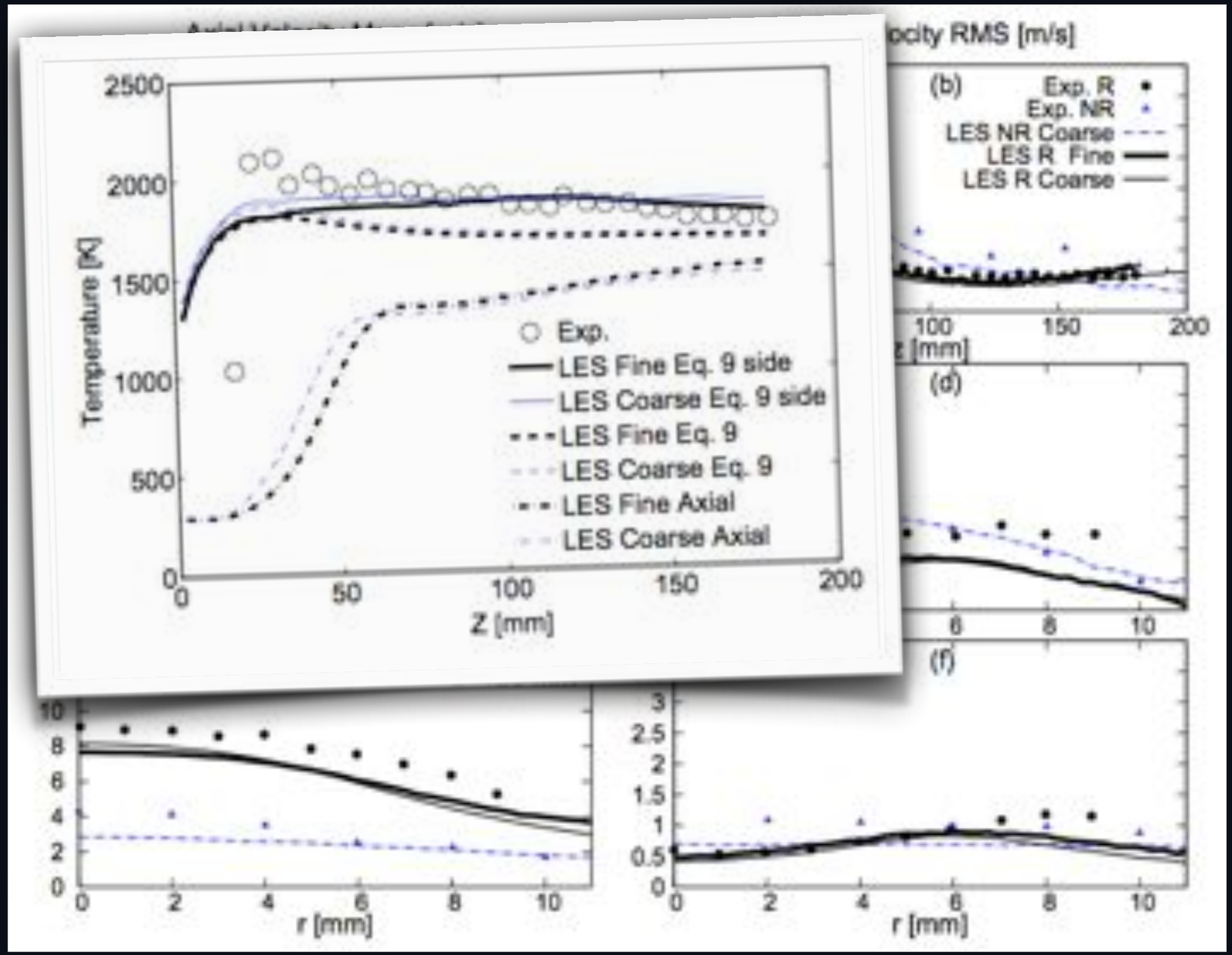

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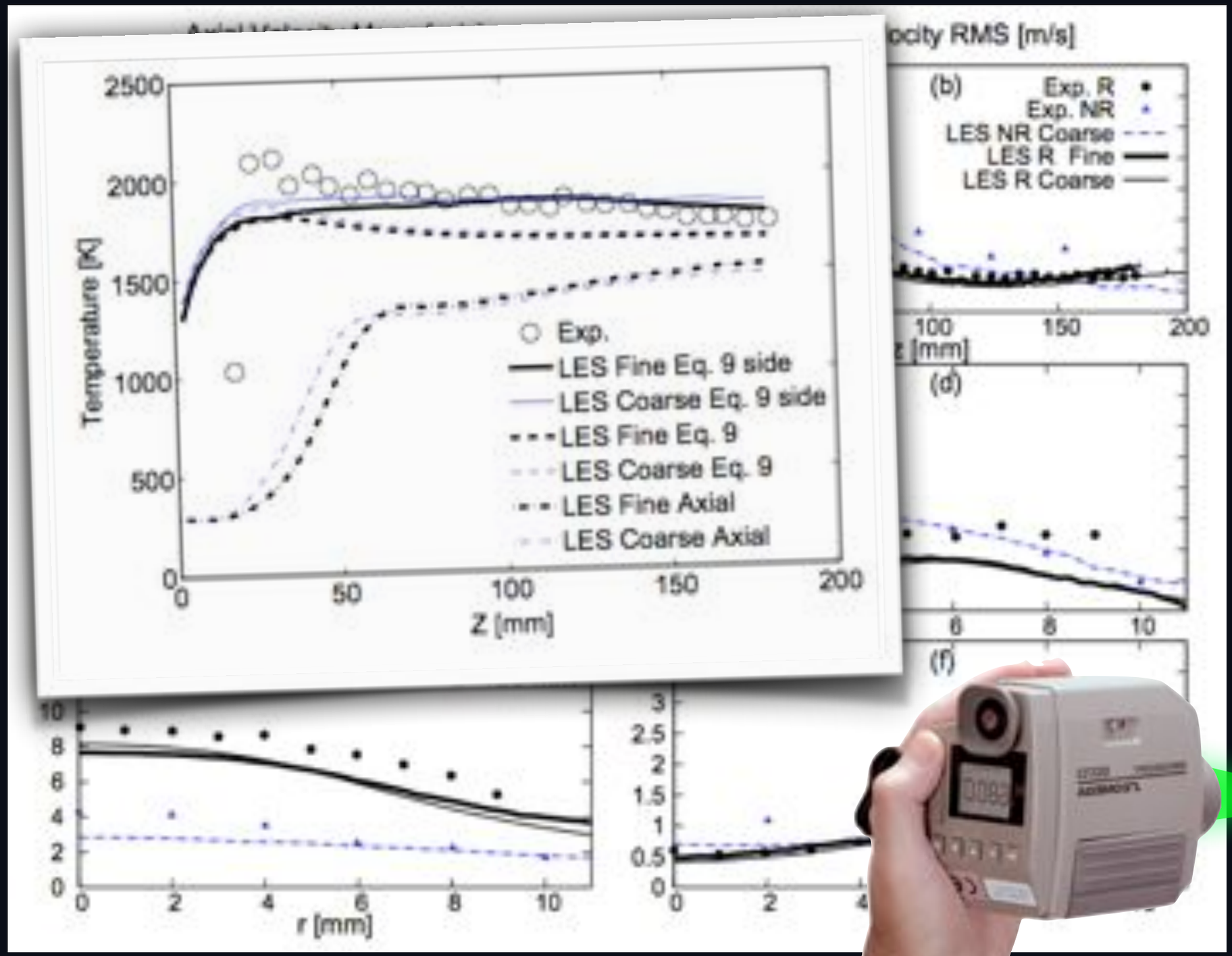

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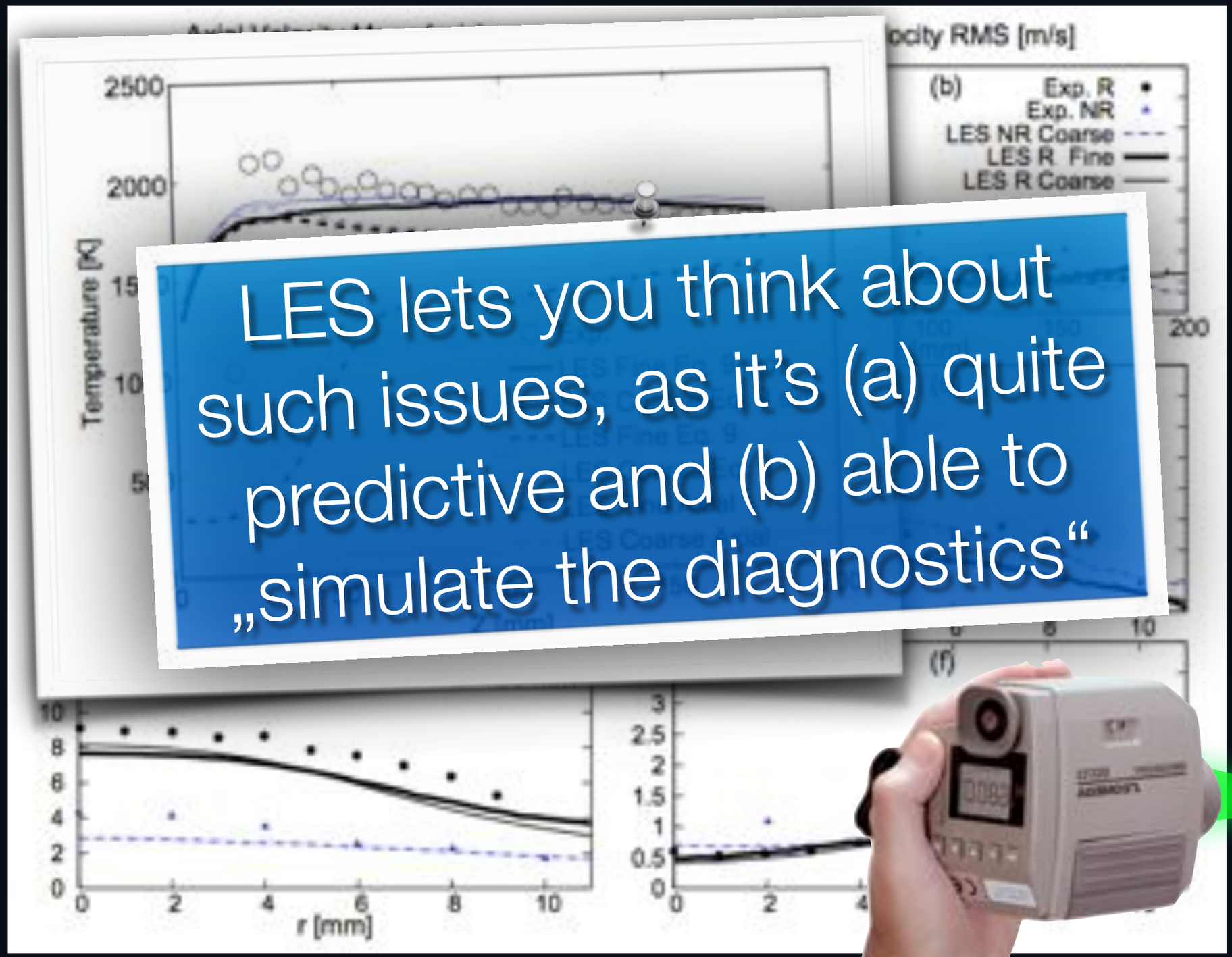

LES lets you think about such issues, as it's (a) quite predictive and (b) able to „simulate the diagnostics“

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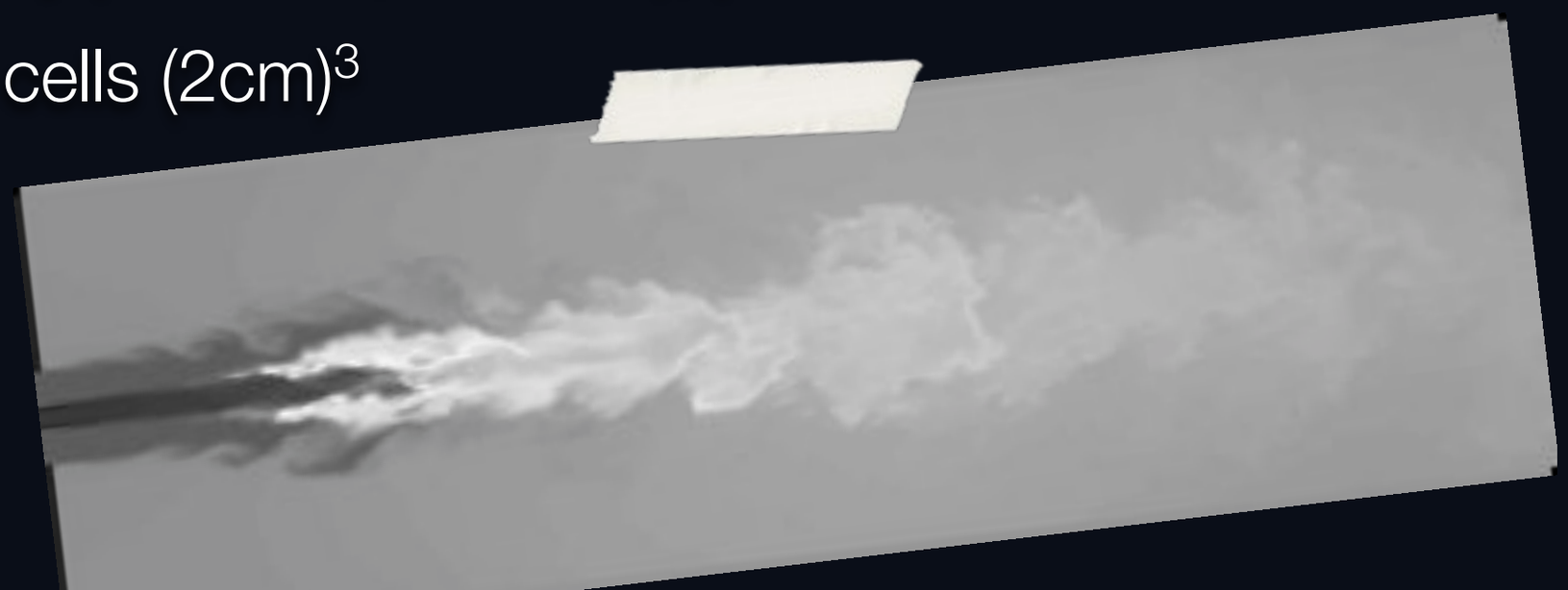
IFRF Flame B1

- Primary: d=0.07m, 40.7m/s, 212kg/h, 463K
- Secondary: d=0.2m, 9.6m/s, 773K
- Turbulence: Smagorinsky
- Postulate substance
- Devolatilisation: First order single rate (Badzioch, Hawksley)
- Char combustion: Intrinsic reacition rate model (Smith)
- Radiation: DOM, (grey products, volatiles), particles scatter
- Mesh: 2.8M / 6.7M cells $(2cm)^3$

Proximate Analysis	[% wt.]
Fixed Carbon	59.5
Volatiles	31
Ash	7.5
Moisture	2

Ultimate Analysis	[% wt.]
C	74.65
H	4.7
O	11.08
N	1.12
S	0.85



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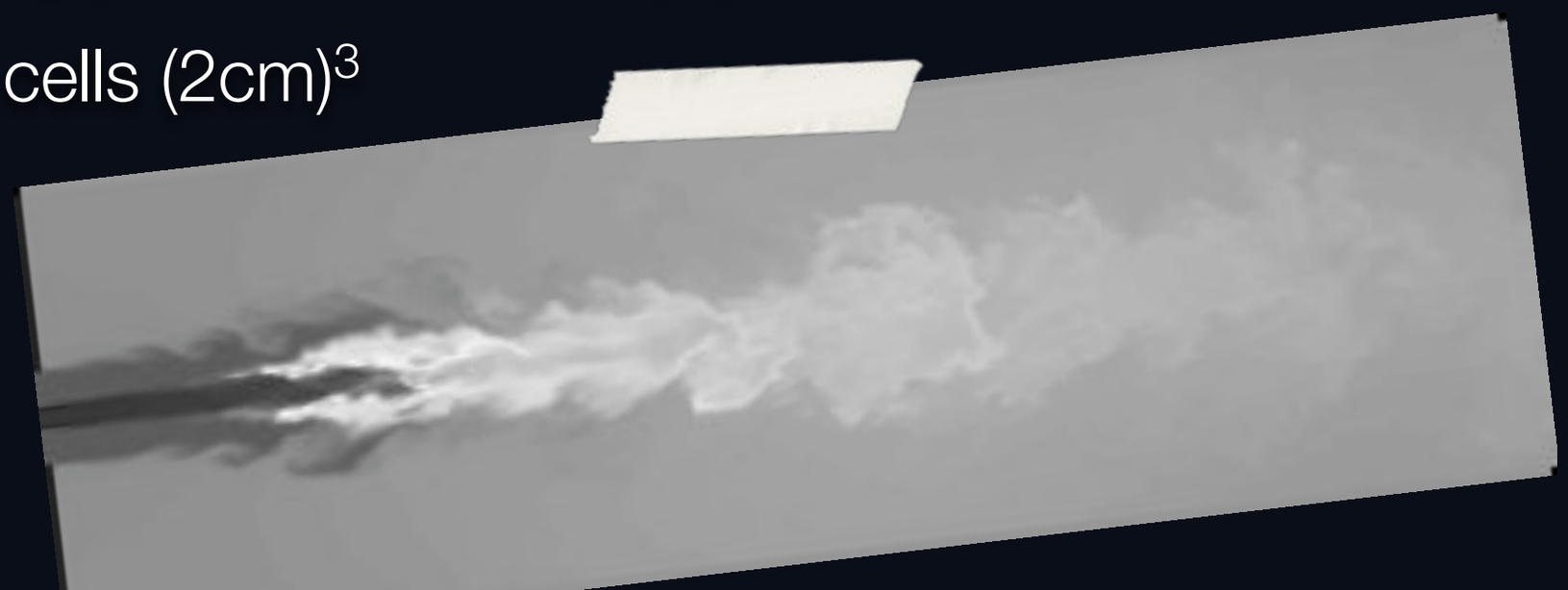

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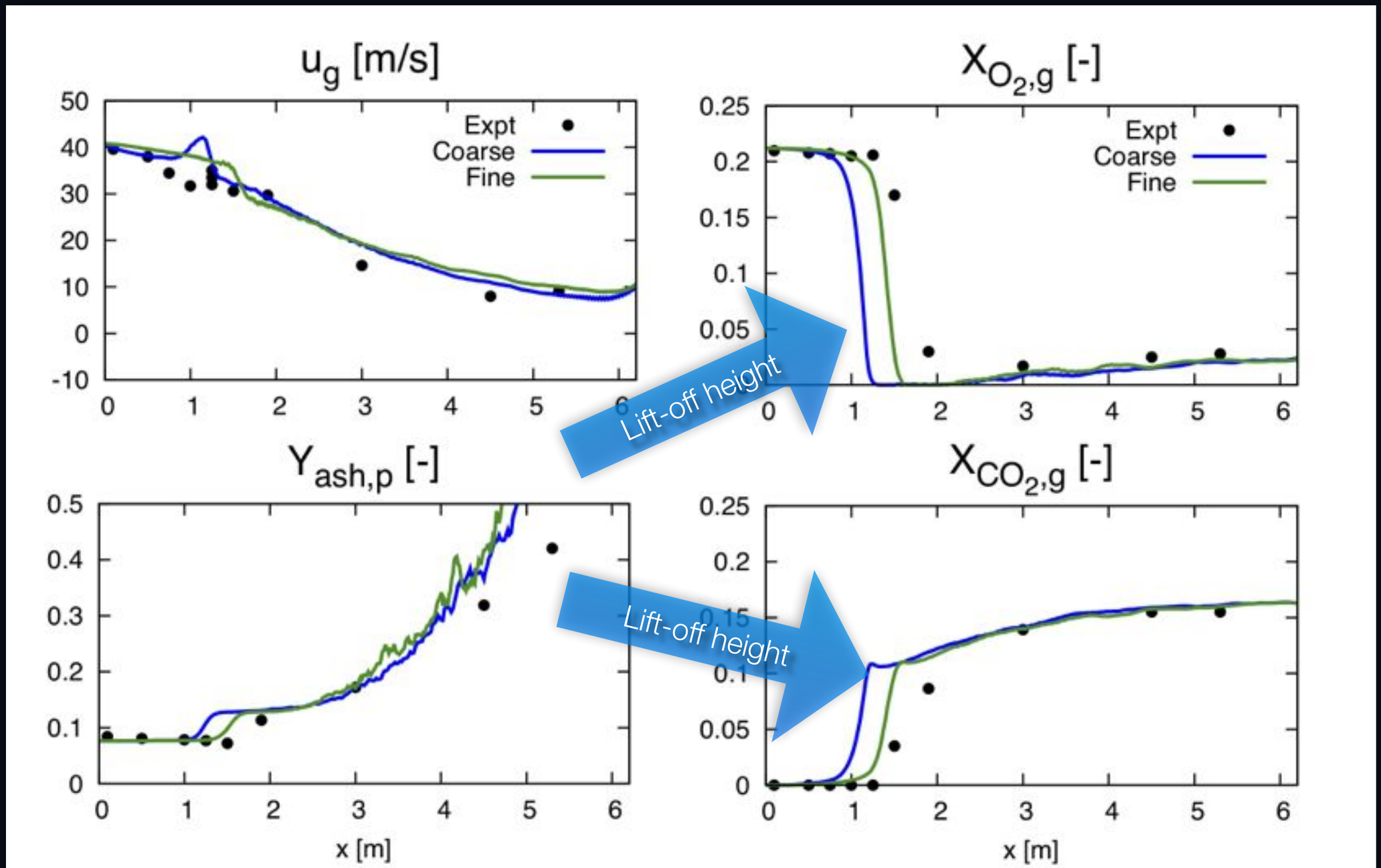

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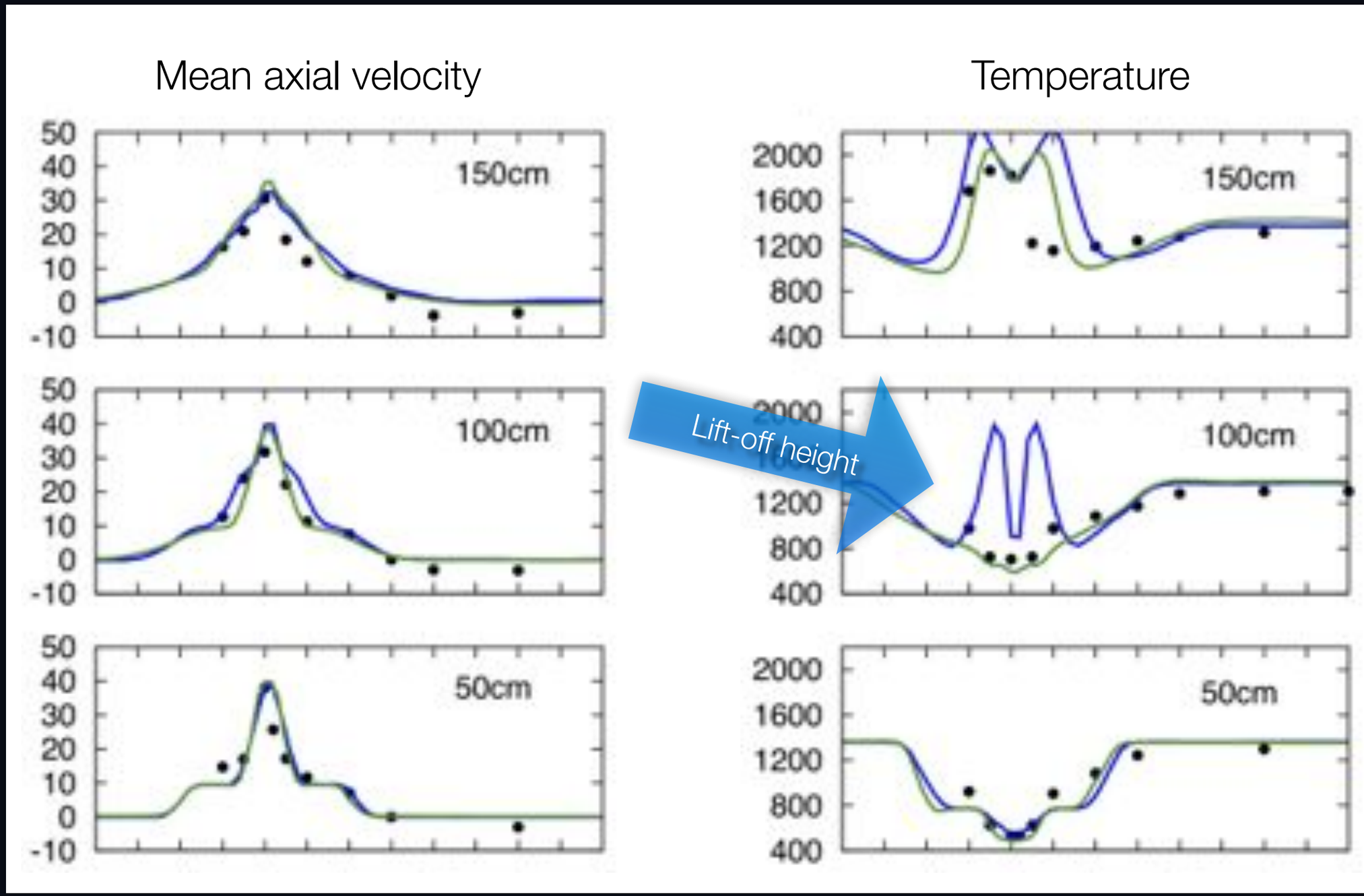

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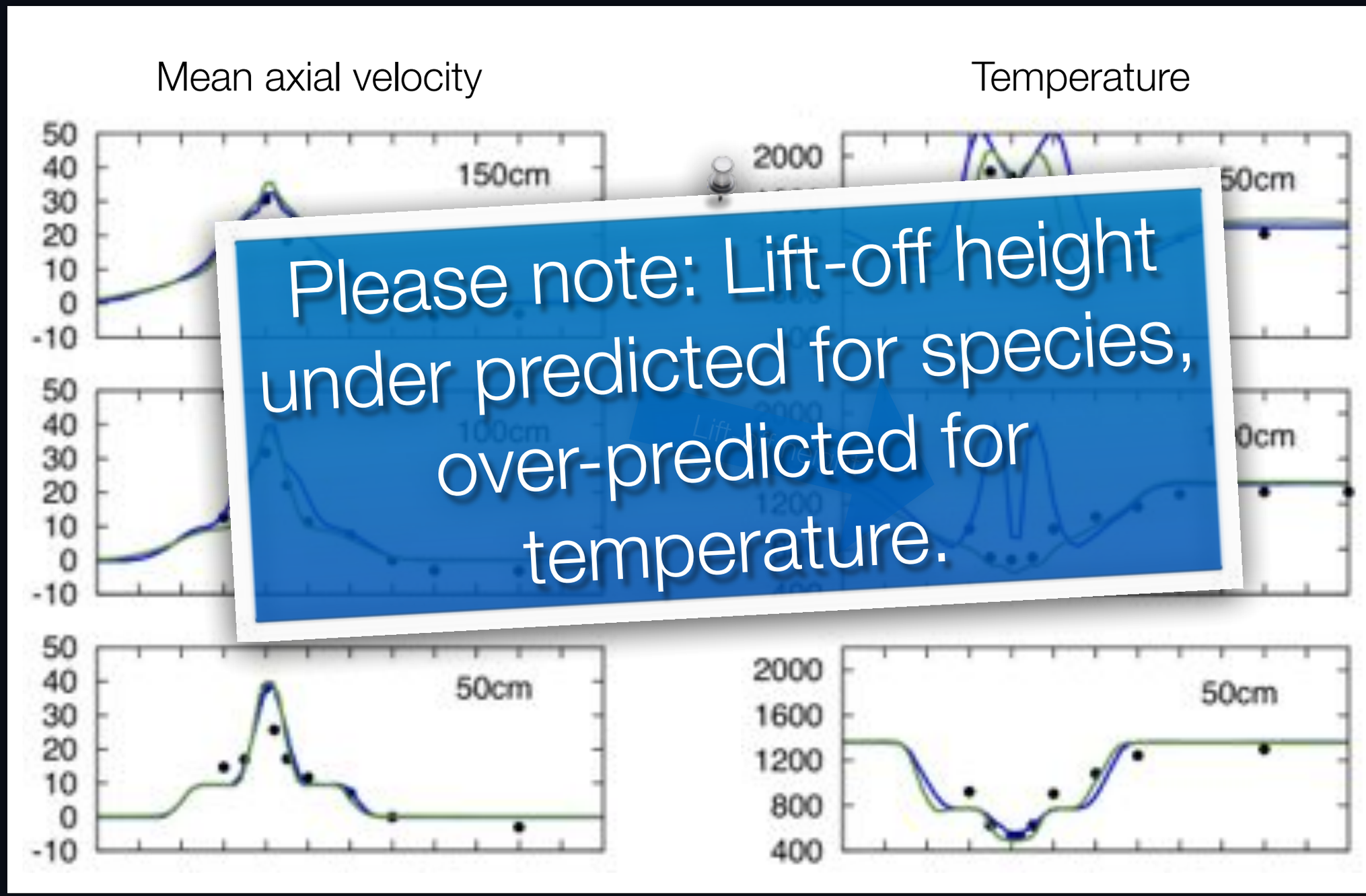

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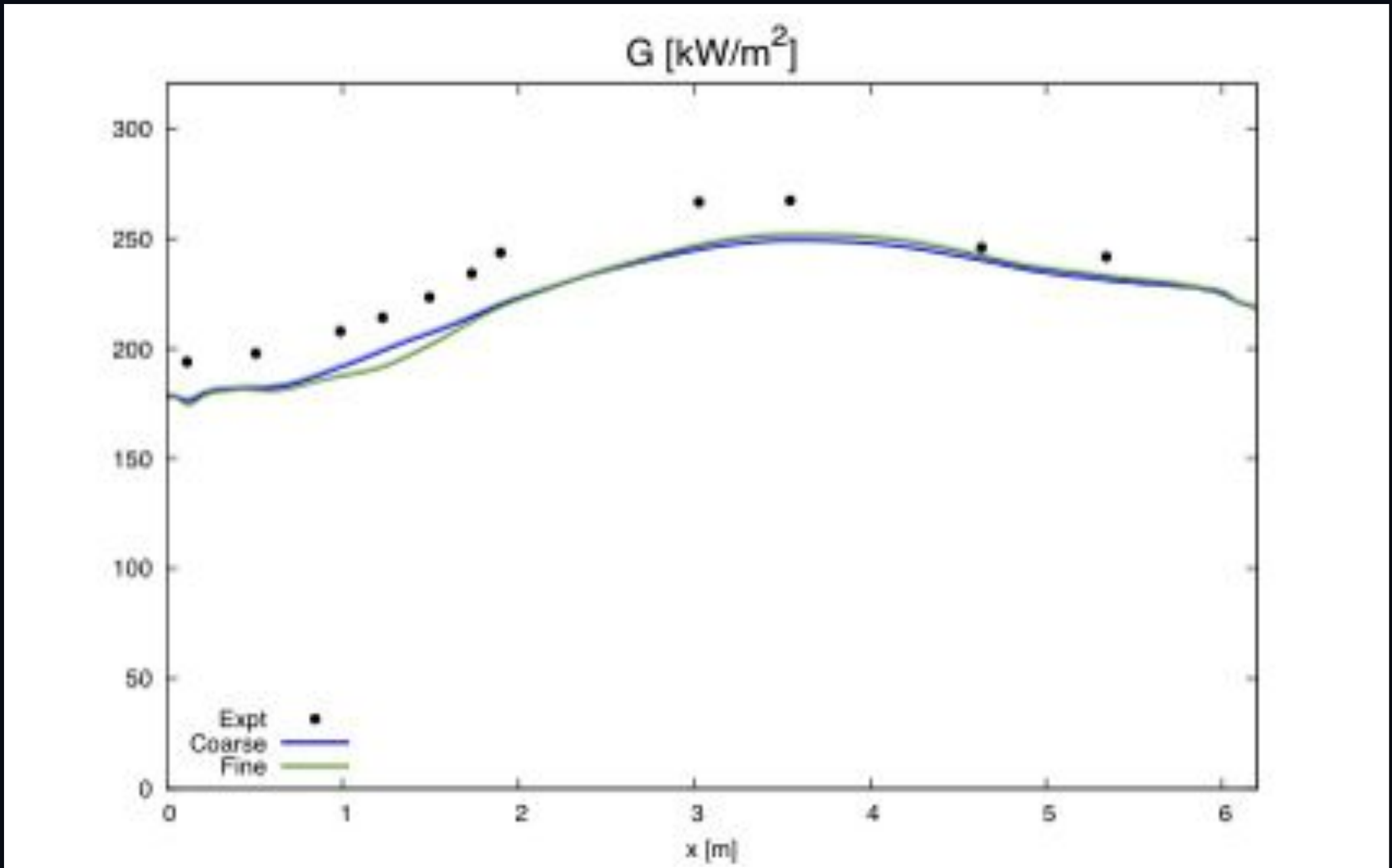

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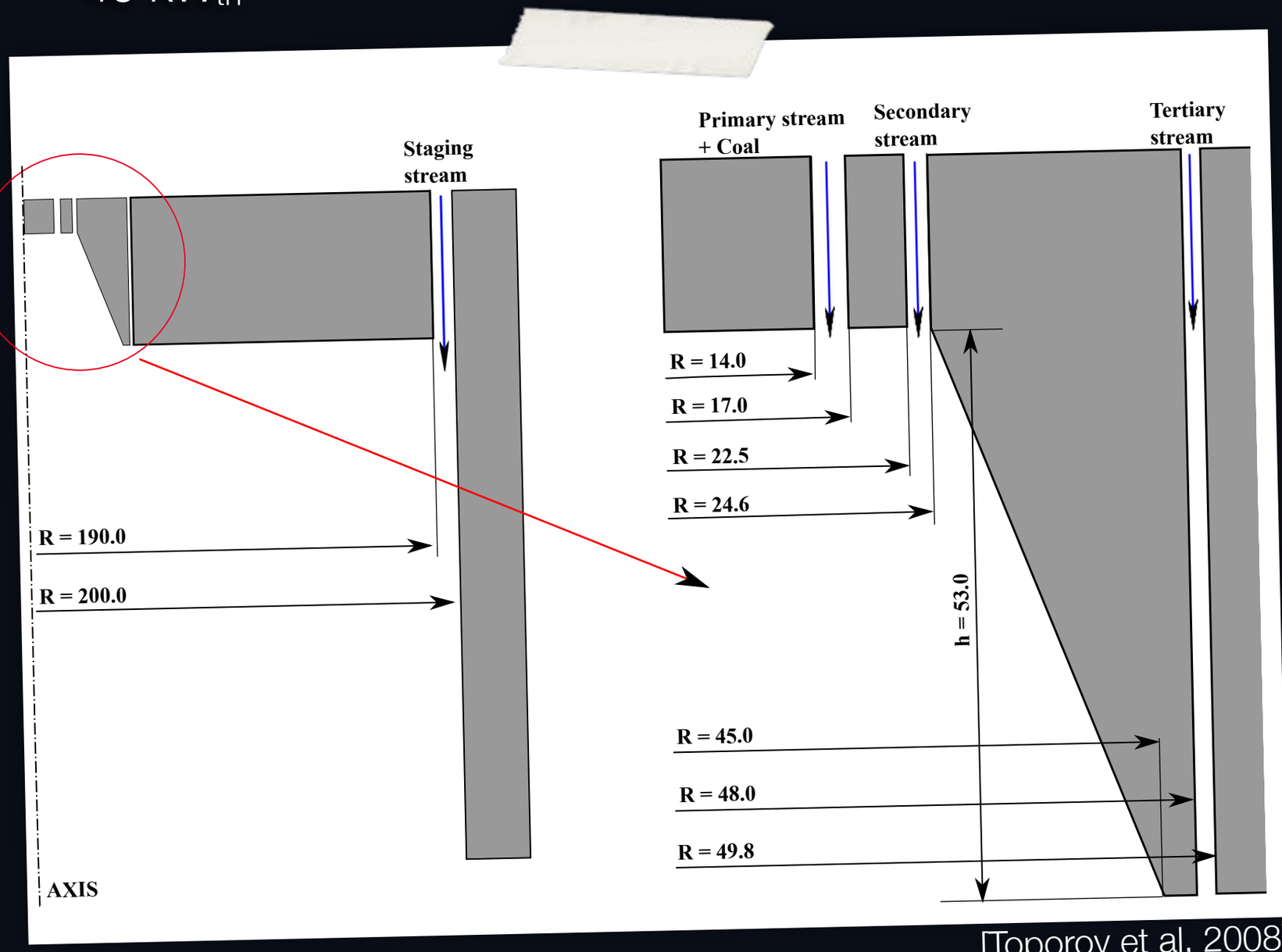
Aachen OXYCOAL-AC furnace

- Realistic swirl burner
- Oxyfuel
- 40 kW_{th}



[Toporov et al, 2008]

	kg/h	O	T
Coal feed	6,5	-	-
Primary	17,6	0.19/	40
Secondary	26,6	0.21/0.79	60
Tertiary	1,5	0.21/0.79	60
Staging	54,9	0.21/0.79	900

Proximate Analysis	[wt %]
Moisture	8,4
Ash	4,1
Volatile Matter	46,6
Fixed Carbon	40,9

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Simulation

- Cartesian grid: 400 x 400 x 800 mm
- Grid: Δ = 1mm, 128 million cells
- 384 cores, 2 weeks (~1000€)
- Ca. 2.5 million numerical particles
- Cray XE6m at Duisburg-Essen & Cluster of Chair

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Mass Fraction Oxygen

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Mass Fraction Oxygen

(a) Mean axial velocity [m/s]

(b) Mean tangential velocity [m/s]

(c) Mean gas temperature [K]

z = 0.025 m

z = 0.025 m

z = 0.05 m

Toporov, EXP, 2008

LES Fine

LES No Rad

LES Coarse

z = 0.05 m

z = 0.05 m

z = 0.1 m

z = 0.2 m

z = 0.2 m

z = 0.2 m

z = 0.3 m

z = 0.3 m

z = 0.3 m

r [m]

r [m]

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z = 0.025 m

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Please note: No signal from staging stream! (no particles!)

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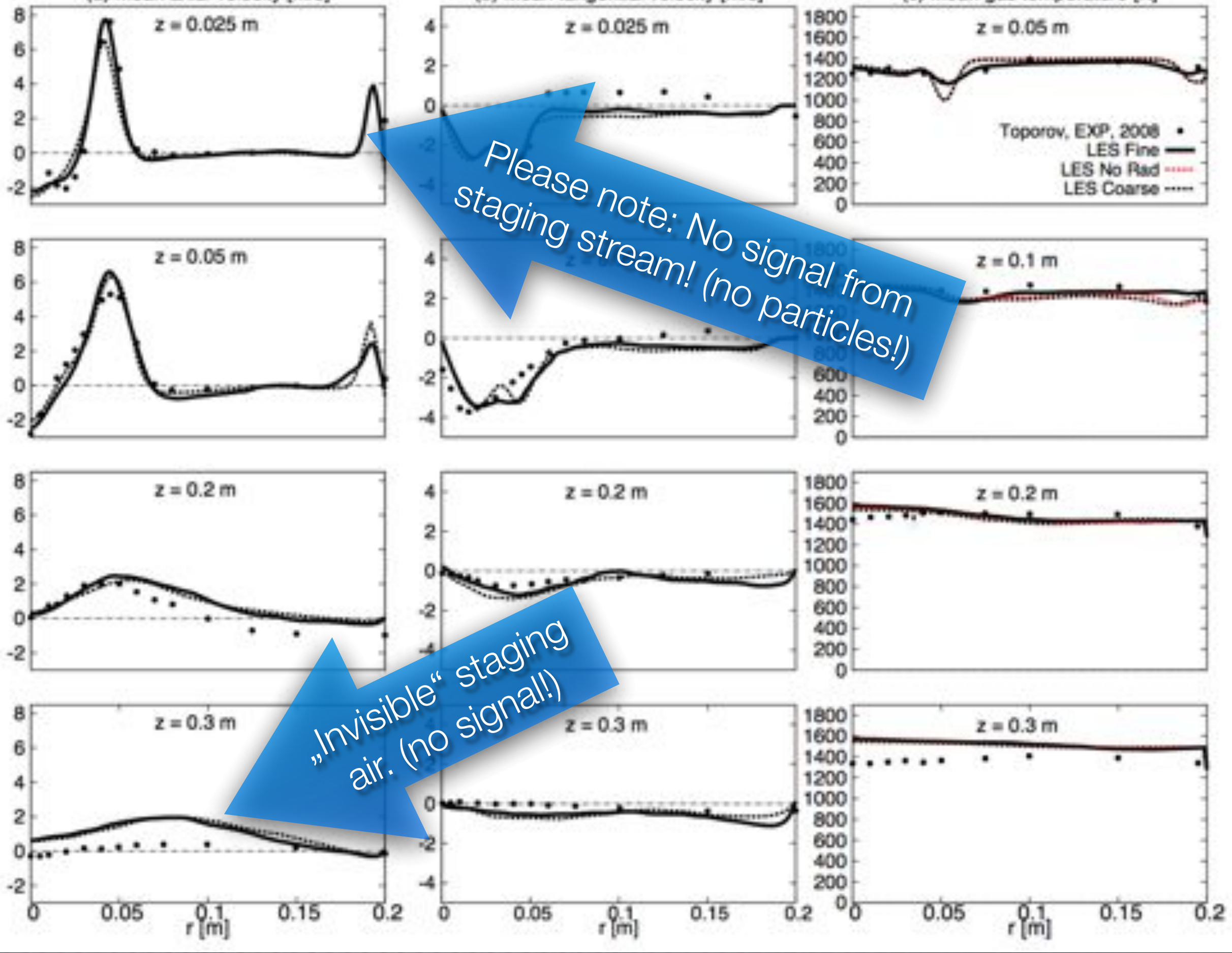
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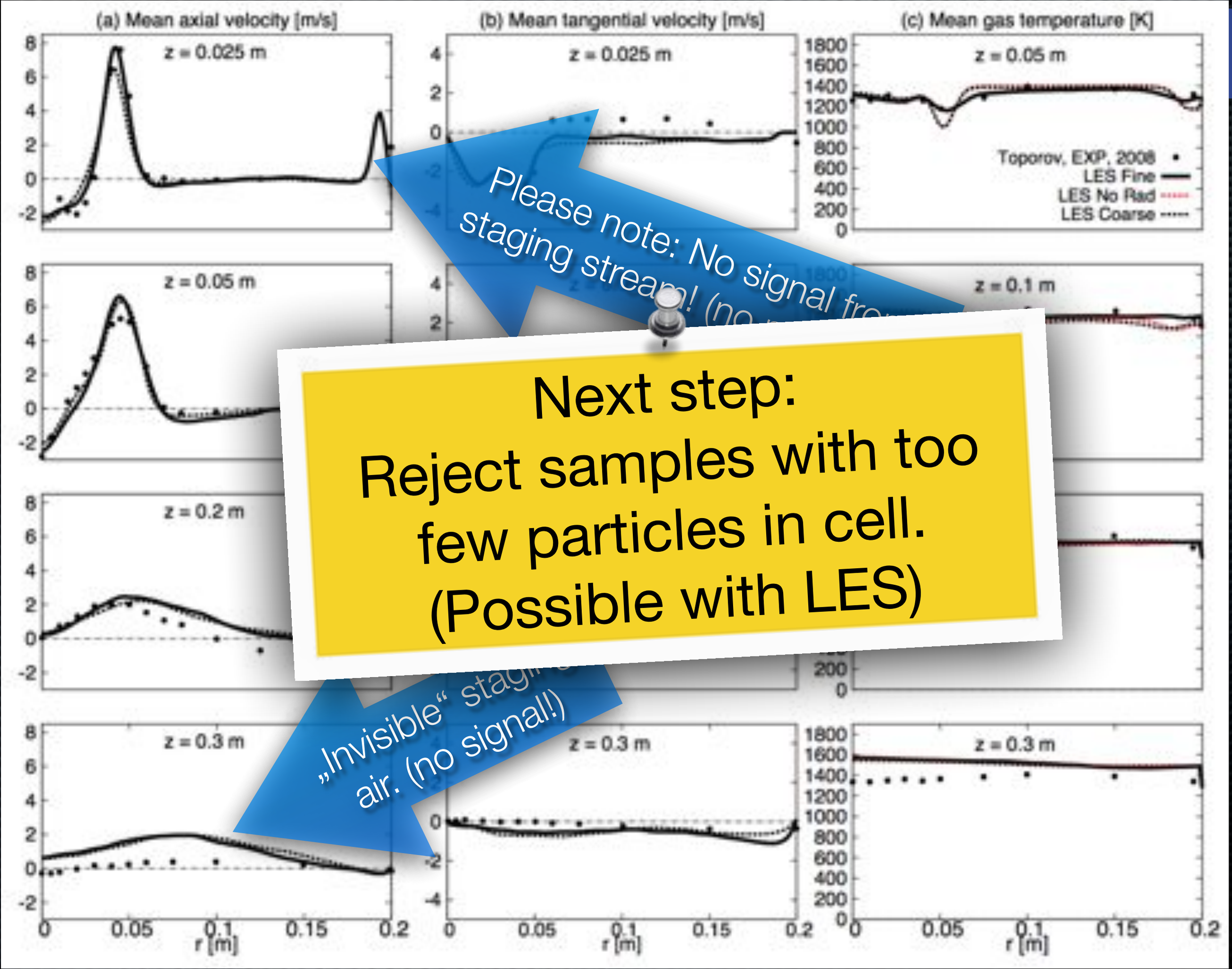
Please note: No signal from staging stream! (no particles!)
„Invisible“ staging air. (no signal!)



Please note: No signal fro… staging strea… (no …

Next step:
Reject samples with too few particles in cell.
(Possible with LES)

„Invisible“ stagn… air. (no signal!)

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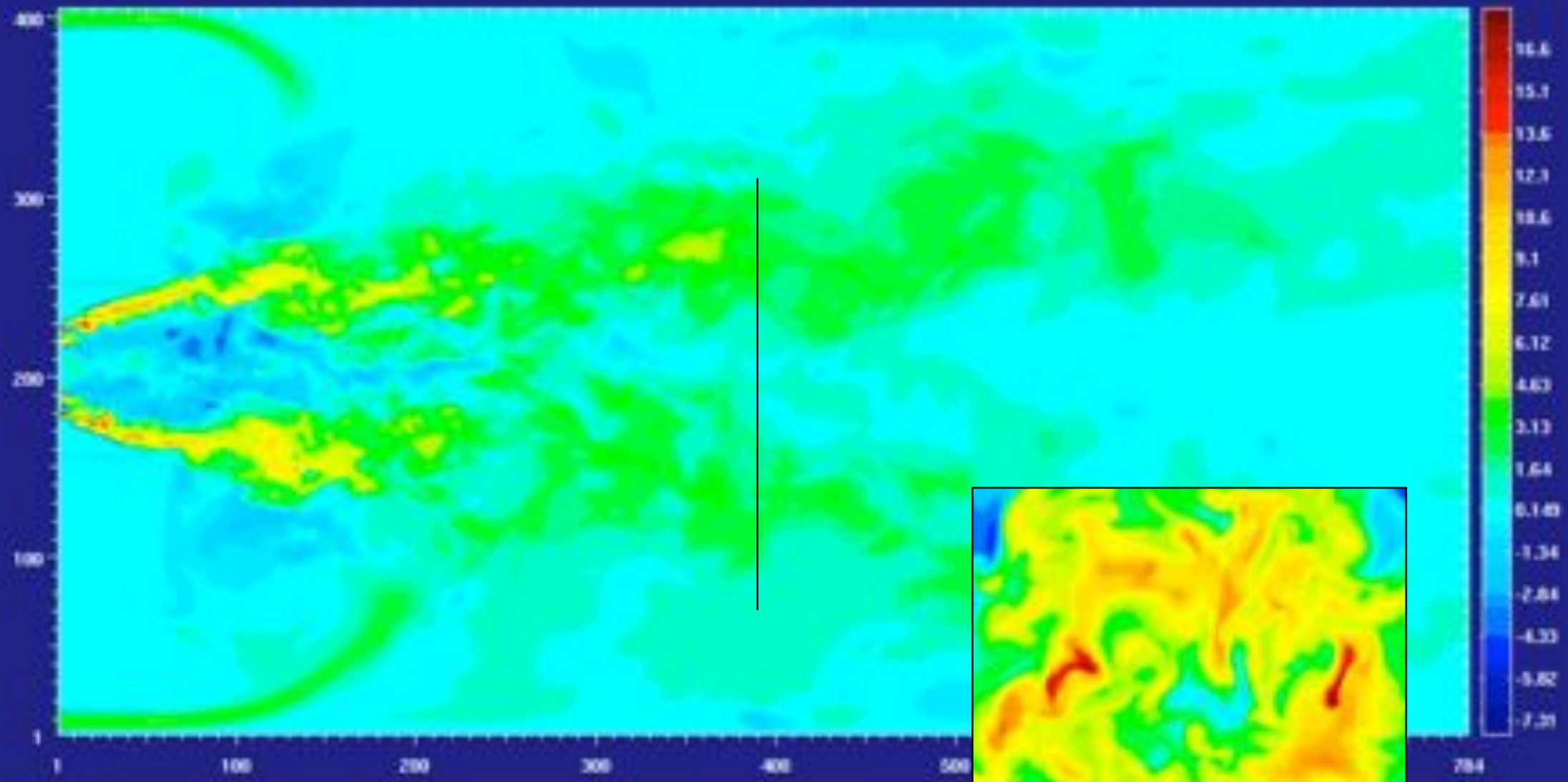
Axial Velocity



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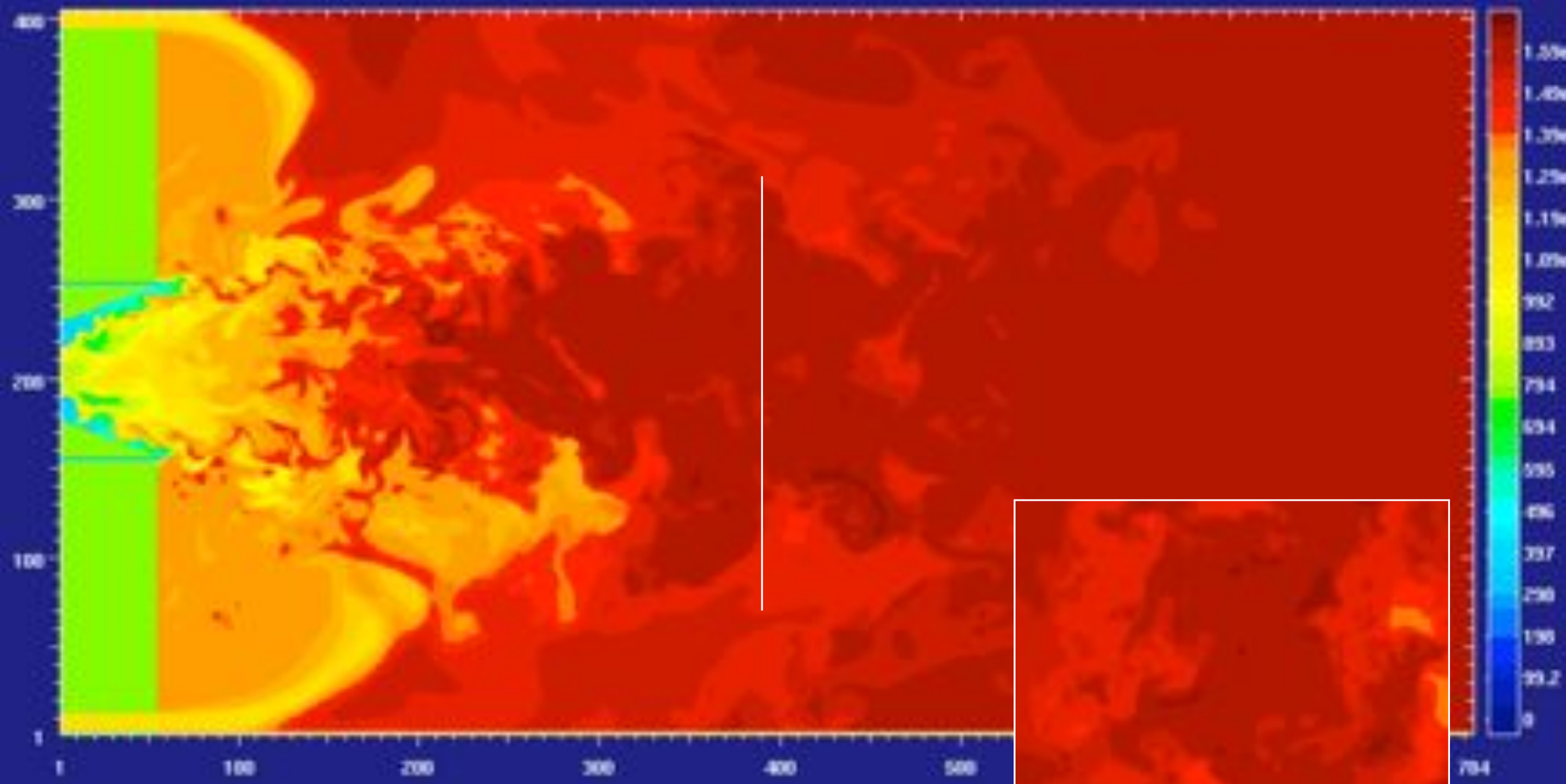
Gas Temperature



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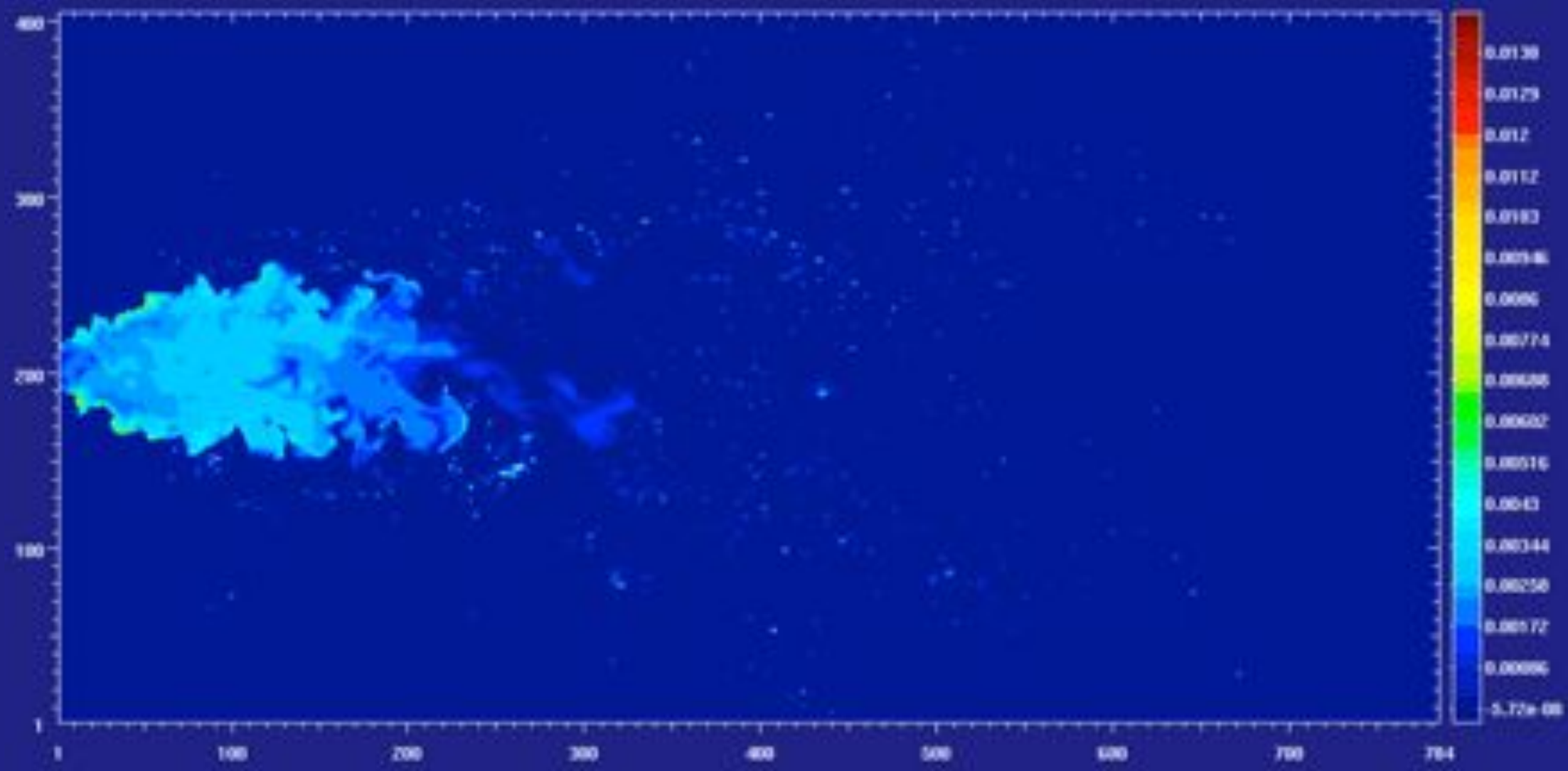
Mass Fraction CO



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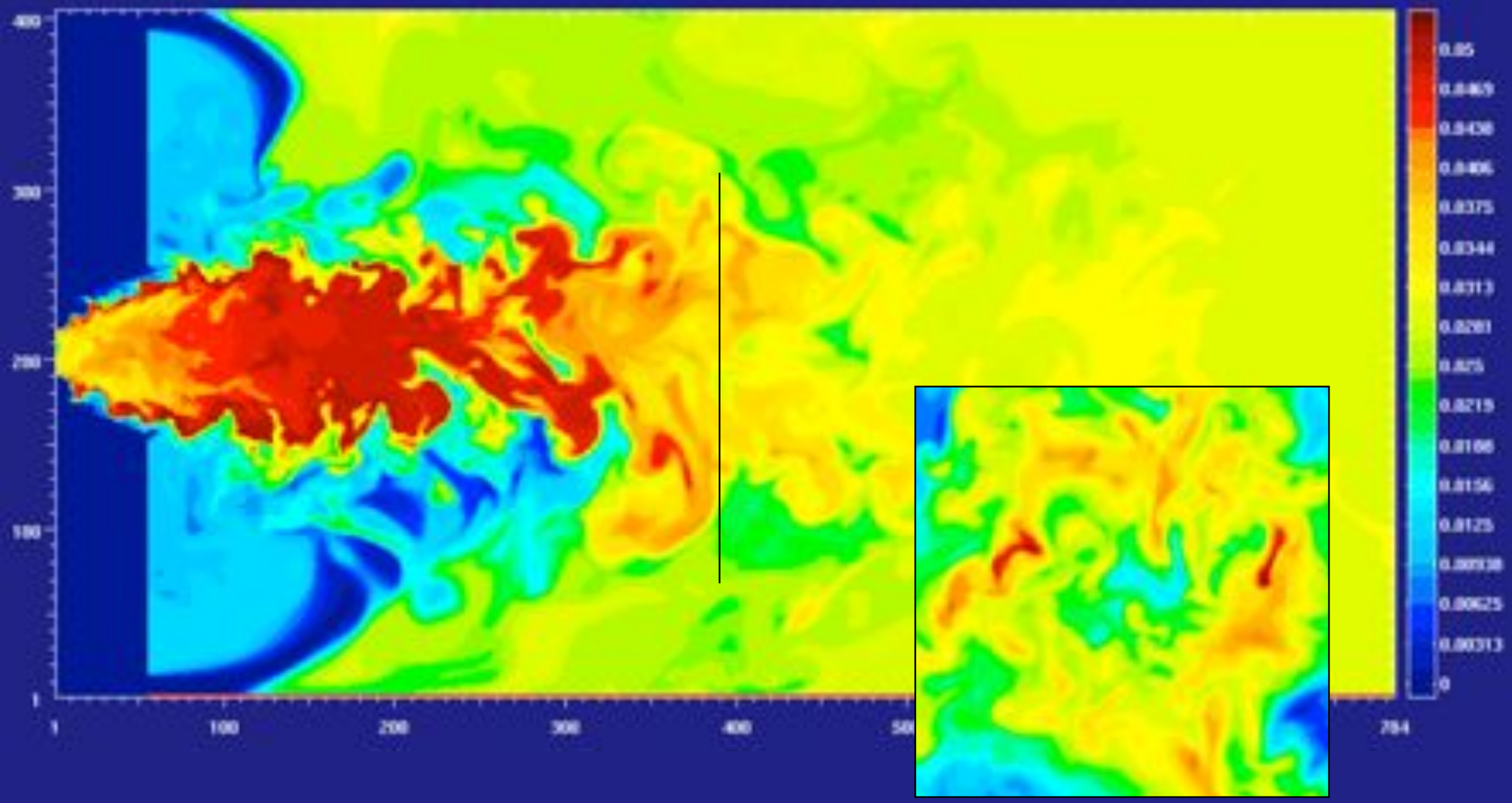
Mass Fraction H_2O



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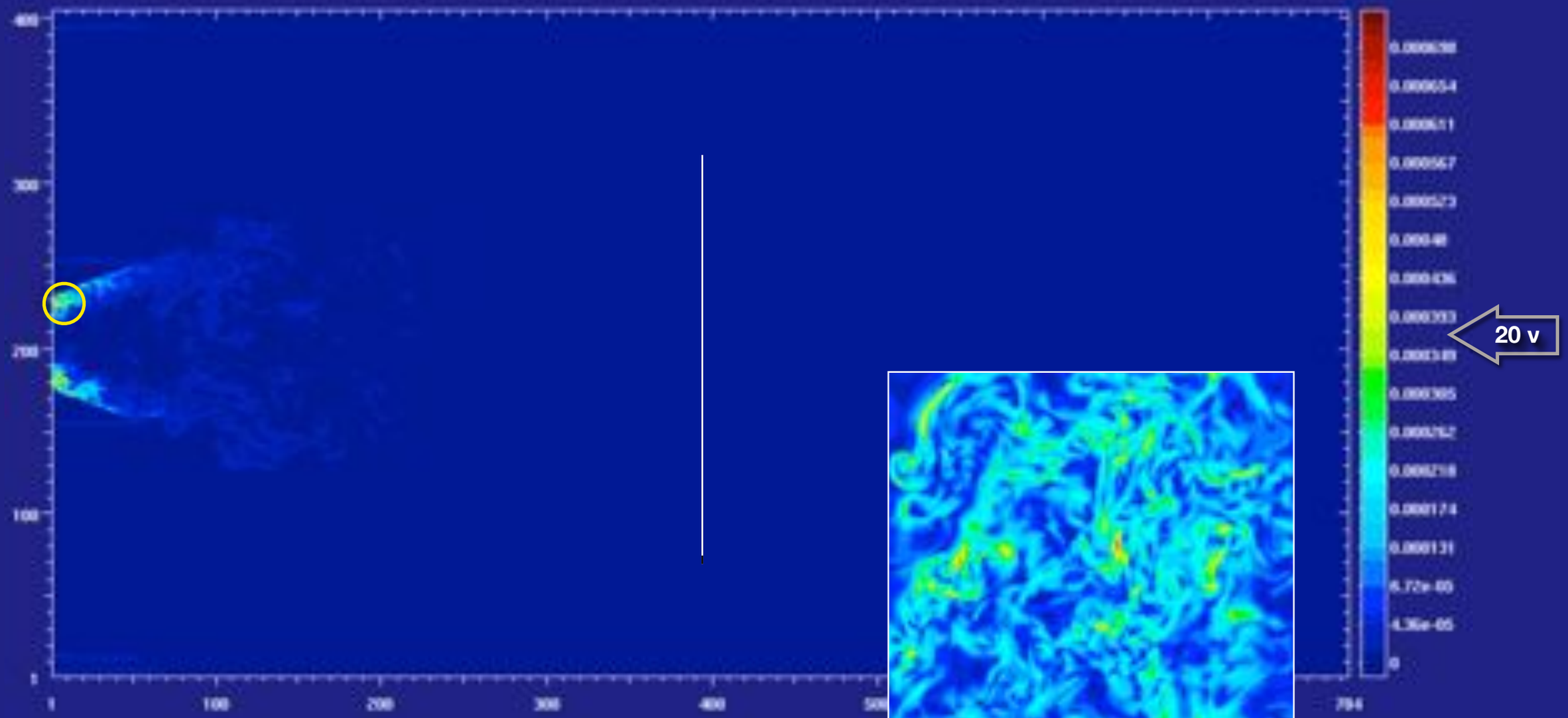
Eddy Viscosity



Symposium 2014

Assessment by a reviewer:

“Oxy-fuel coal combustion systems will not be in operation soon (most probably even never) so the authors should orient their efforts to the air burning of low quality coals…“

separate

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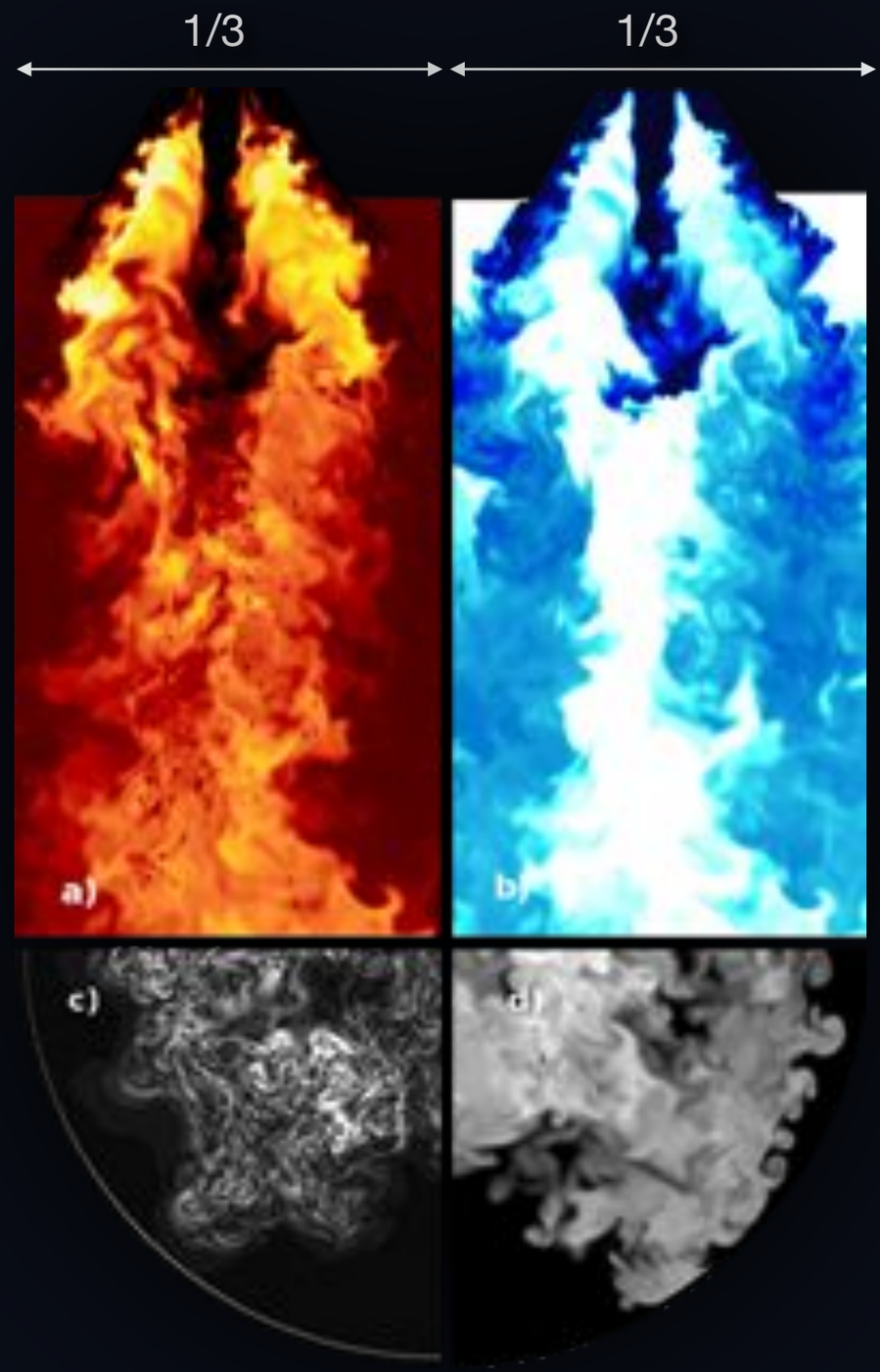
Peak into latest work

- IST Large Scale Lab Furnace, 100kW, D=0.6m
- Work by M. Rabacal, co-supervised by Mario Costa
- 365 M cells of 1mm
- HPC: 8000 cores (PRACE, SuperMUC)

(accepted)



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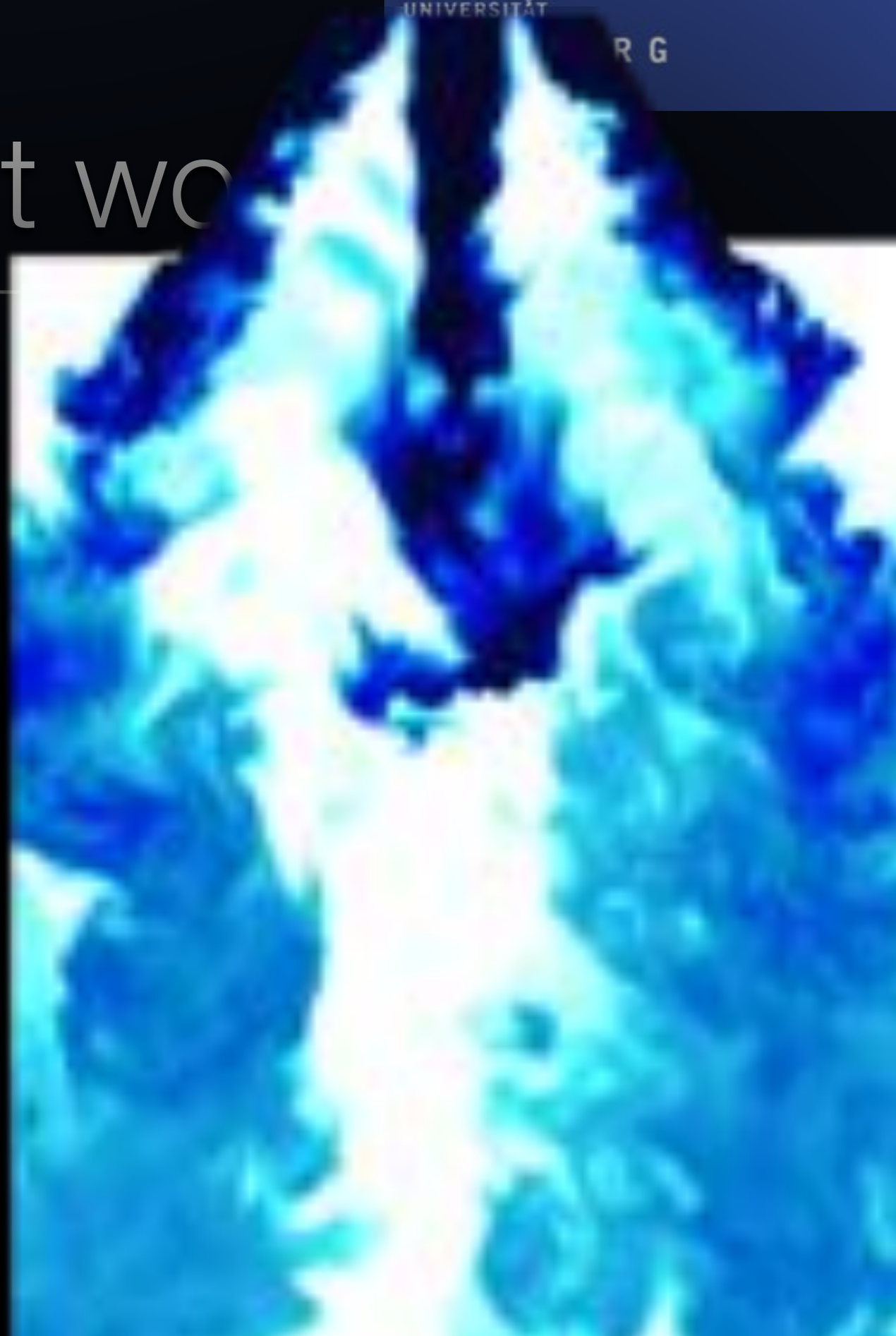

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Summary

- LES of coal combustion is a reality (new paradigm!)
- Pilot-scale combustors can be predicted reasonably
- Now: Time to apply and time to improve sub models
  - Subgrid modelling
  - Devolatilisation Modelling
  - Radiation
- Gas phase combustion (M. Rieth, Duisburg) (Flamelets, DFG Project with Hasse, Kronenburg)
- Biomass combustion (M. Rabacal, Duisburg)

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Acknowledgements

EPSRC OxyCAP, EPSRC China

FCT (Portugal)

Center for Computational Sciences and Simulation (CCSS) of Duisburg-Essen University

PRACE & SuperMUC

Nguyen, Proch, Rittler, Stein, Pettit, Wysocki, Ma, Rieth

Gibbins, Hasse, Costa

Thank you for your attention!

IVG Institut für Verbrennung und Gasdynamik Fluiddynamik

LES