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Outline

- Profile
- Research activities (past/current)
    - High fidelity simulations of reacting flows: *Statistics of Local and Global Flame Speed for Highly Turbulent H_2/Air Premixed Flames*
    - Asymptotic analysis of turbulent reacting flows with Computational Singular Perturbation: *Topological and chemical characteristics of turbulent flames at MILD conditions*
- Future research

Profile

Edinburgh Napier UNIVERSITY

Educational background

2016: PhD in Mechanics (NTUA)

Fields of CFD of reacting flows and applied mathematics

2012: MSc in Applied Mechanics (NTUA)

2005: BSc(H) in Aeronautics (Hellenic Air Force Academy)

Work Experience

2020 – now: Lecturer in Mathematics at ENU/SEBE

2019 - 2020: Lecturer in Engineering & Aviation at UHI

Programme Leader for the Aircraft Engineering

2016 - 2019: Postdoc at KAUST/Clean Combust. Res. Center

2005 - 2016: Hellenic Air Force

Research Interests

- High fidelity simulations of reacting flows (hydrogen, ammonia, solar fuels, biofuels)
- Asymptotic analysis of multiscale systems (chemical kinetics, reacting flows, biology, pharmacokinetics, epidemiology, population dynamics etc)
- Model reduction of multiscale systems

Track record

- Funding:
  - RSE, COP26 Climate Change Grant, £10k, 2021 (PI)
  - Edinburgh Napier University, Seed Corn, 2021, £8k (PI)
  - Scottish Funding Council, GCRF, 2021, £20k (co-I)
  - RSE, Research Sabbatical Grant, £65k, 2020 (PI)
- Dissemination: Published 23 papers in peer-reviewed journals, 2 textbook chapters, 4 conference papers.
- Scholar activities: Reviewer for *Combustion and Flame*, *Fuel, Combustion Theory and Modelling, Journal of Energy Engineering, Experimental Thermal and Fluid Science; Grant reviewer for EPSRC*

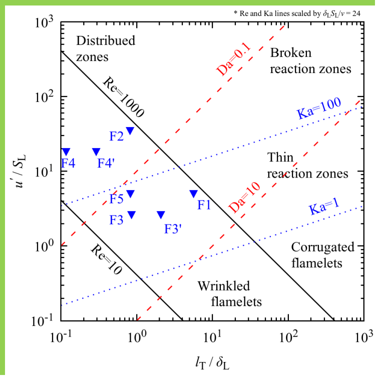
Research activities

Statistics of Local and Global Flame Speed and Structure for Highly Turbulent H2/Air Premixed Flames

Work in progress with KAUST (professor Hong Im)

- Modern combustion devices operate at extreme conditions in pursuit of higher efficiencies.
- Premixed combustion at high Ka has attracted substantial research interest
- However, most previous studies examined:
  - the detailed flame structure in comparison with the reference laminar flames; very few studies on the statistical analysis of the differences in turbulent burning velocity distributions at low and high Ka conditions.
  - the effect of the turbulent intensity (u') on the turbulent flame speed (bending effect); very few studies on the effect of the integral length scale (l_T).

- ✓ DNS data for turbulent hydrogen-air flames propagating into forced turbulent flows in a periodic channel (Ka=14 –1,126).
- ✓ KAUST Adaptive Reacting Flow Solver (KARFS)
- ✓ Fully compressible
- ✓ 8th order central-difference scheme for spatial discretization
- ✓ 4th order explicit Runge–Kutta method for the time integration
- ✓ Nonreflecting Navier–Stokes characteristic boundary conditions (NSCBC)
- ✓ Linear turbulent forcing scheme



Research activities

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Statistics of Local and Global Flame Speed and Structure for Highly Turbulent H2/Air Premixed Flames

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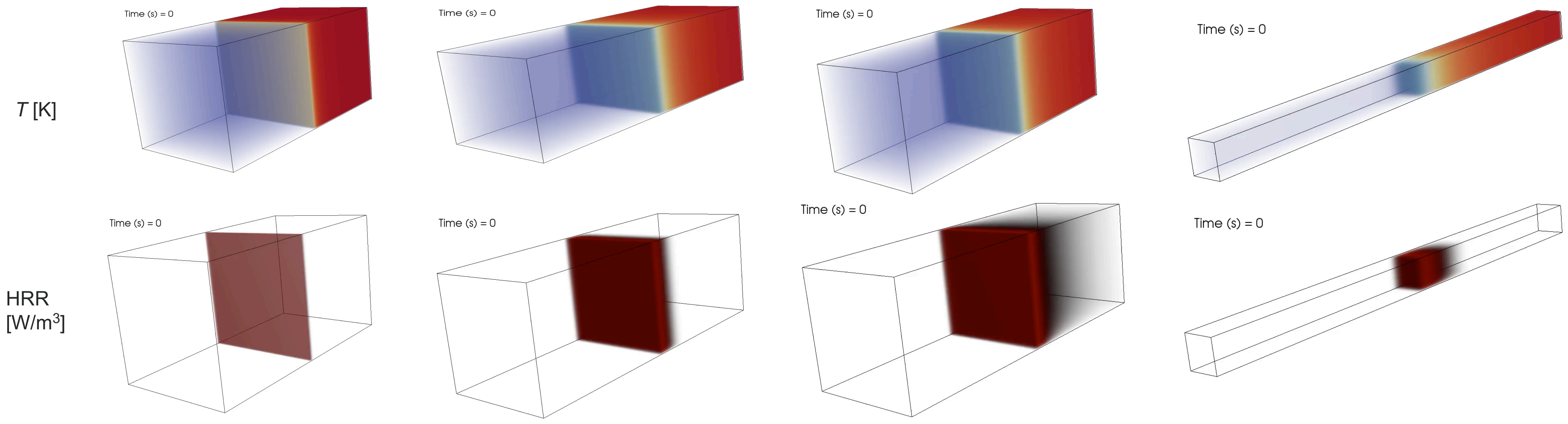
	Case F1 (thin R. zone)	Case F2 (distrib. regime)	Case F3 (thin R. zone)	Case F4 (distrib. regime)
Ka	23	1126	22	1126
Re	686	700	55	52
l_T/δ_f	5.65	0.82	0.86	0.12
u'/S_L	5	35	2.6	18.3



Research activities

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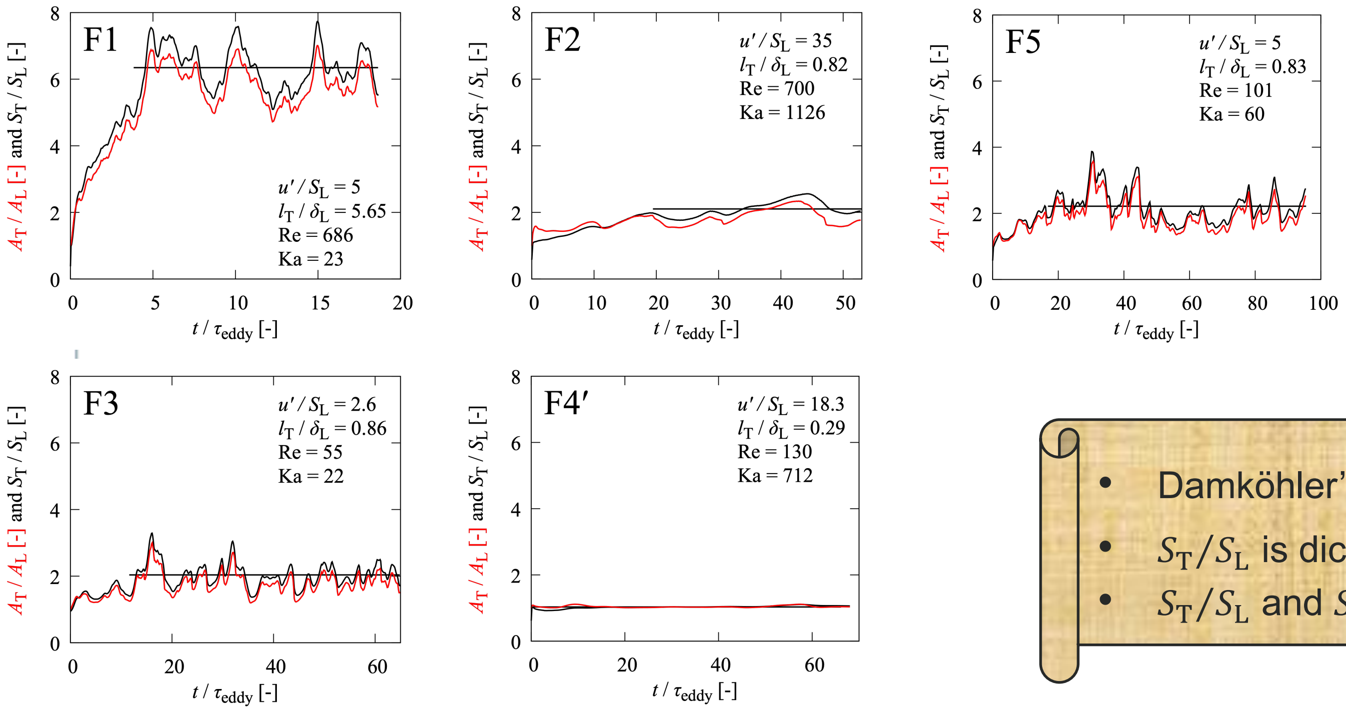
Statistics of Local and Global Flame Speed and Structure for Highly Turbulent H2/Air Premixed Flames

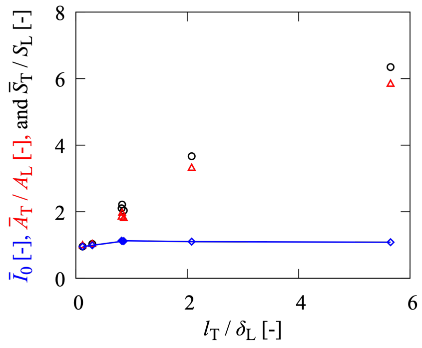
Work in progress with KAUST (professor Hong Im)

Fuel consumption speed (global quantity): $S_T = \frac{1}{\rho_u Y_{u,F} A_0} \int_V \dot{\omega}_F dV$, ***Poinsot et al. (1992) CST***

- Correlation of S_T/S_L vs. A_T/A_L (stretch factor)



- Scaling of the mean turbulent flame speed and surface area



$\overline{I_0} = \frac{\overline{S_T}/S_L}{\overline{A_T}/A_L}$, where $\overline{S_T}$ and $\overline{A_T}$ are temporally averaged

- Damköhler's first hypothesis $\frac{A_T}{A_L} = \frac{S_T}{S_L}$ is valid at Ka > 1,000
- S_T/S_L is dictated by l_T
- S_T/S_L and S_T/S_L strongly correlate proportionally increase with l_T

Research activities

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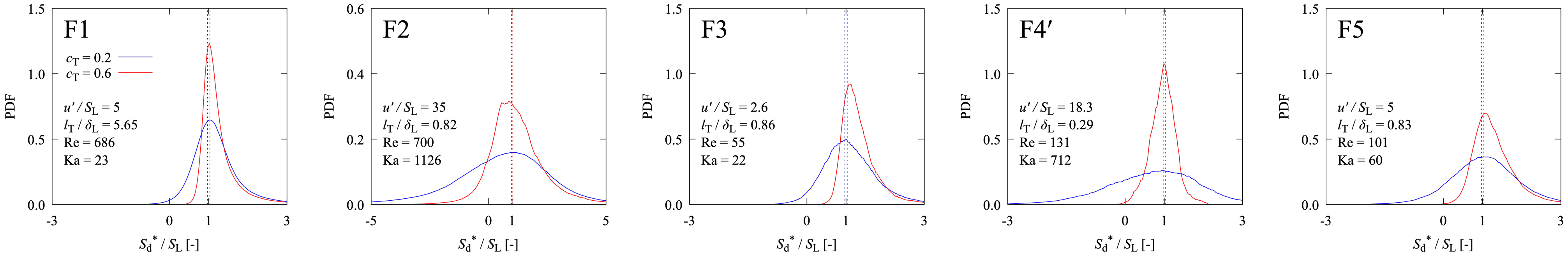
Statistics of Local and Global Flame Speed and Structure for Highly Turbulent H2/Air Premixed Flames

Work in progress with KAUST (professor Hong Im)

Displacement speed (density weighted) (local quantity): $S_d^* = \frac{\rho S_d}{\rho_u} = \frac{1}{\rho \nabla Y_k}[\dot{\omega}_k - \nabla \cdot \mathbf{J}_k]$, ***Im and Chen (1999) CNF***

- Probability density function (PDF) of S_d^*



- For all Ka conditions, the peak of PDF coincides with S_d^* of the laminar flame → Laminar flamelet assumption holds at Ka > 1,000
- S_d^* is dictated by local flame stretch.

Research activities

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Asymptotic analysis of turbulent reacting flows with Computational Singular Perturbation

What is a CSP mode?

It is a mathematical quantity with no physical meaning that results from the projection of the chemical source term on the CSP basis vectors.

How is this helpful?

Because the important modes can be identified. Their importance relies on rigorous mathematics.

Important to what?

It depends on what you are interested: ignition, flame propagation, emissions are some examples

Okay, I found the important mode. Now what?

Now, the physical meaning can be obtained by identifying the processes that compose these modes.

And what is this TSR?

It is a measure of the local rate of stretching of the system's dynamics constructed on the basis of the CSP modes.

Research activities

Asymptotic analysis of turbulent reacting flows

Topological and chemical characteristics of turbulent flames at MILD conditions

Manias et al. CnF 208 (2019) 86-98

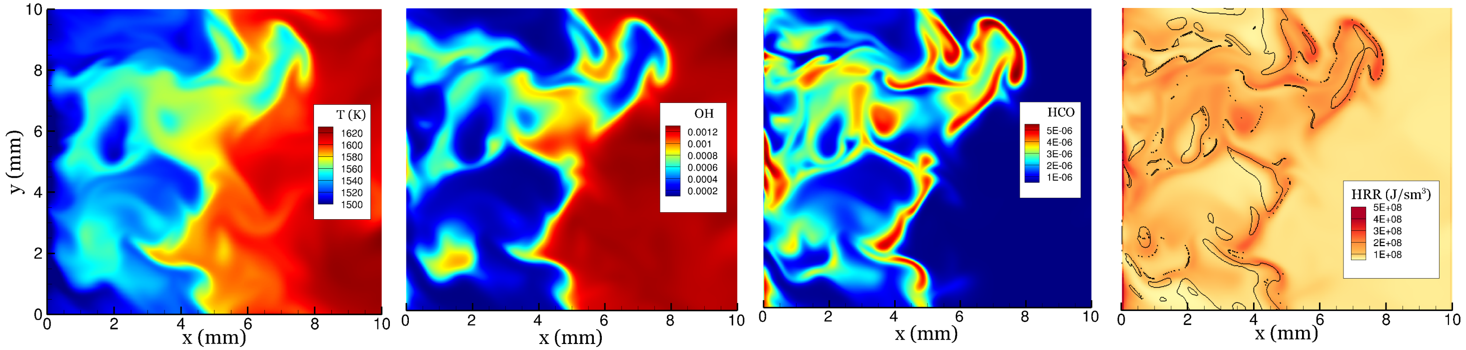
- Processes evolve outside the range of interest of standard combustion processes
- Difficult to identify the dominant physical processes that characterize the combustion.

Computational Singular Perturbation (CSP)

- ✓ DNS data with detailed CH4 chemistry (*Minamoto et al., CNF (2014)*)
- ✓ 2-phase process to achieve MILD combustion:
  - a) preprocessing of inhomogeneous field (Y_i, T, u_i)
  - b) feeding the computational domain as inflowing fields (turbulent MILD combustion)
- ✓ Homogeneous isotropic turbulence (freely decaying turbulence field)

mid-z planes

t = 0.9 ms ≈ $3\tau_D$



Conventional flame markers based on intermediate species isocontours do not work effectively in MILD combustion.

Research activities

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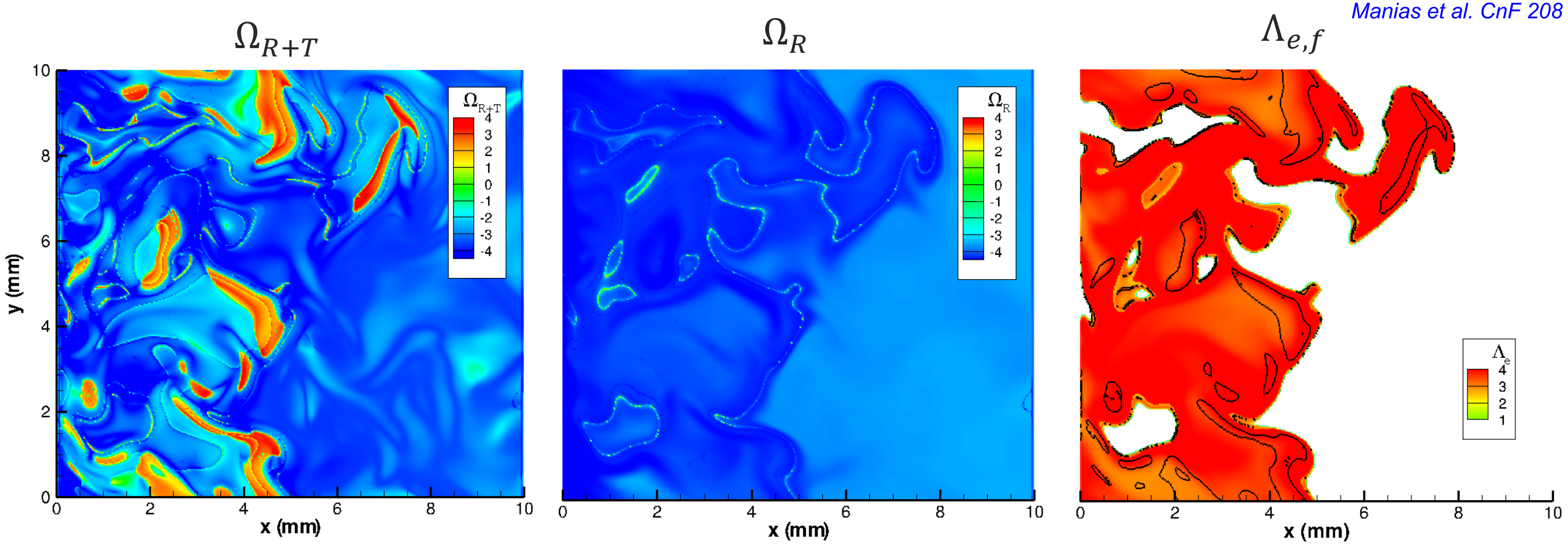

- $\Lambda_{e,f}$ exists in a considerably broader region than Ω_{R+T}
- Ω_R is negative in most part of the domain
- Ω_{R+T} highlights the regions of explosive dynamics
- The system's explosive dynamics is inherently due to transport.

What makes Ω_{R+T} positive and the dynamics there explosive?

Research activities

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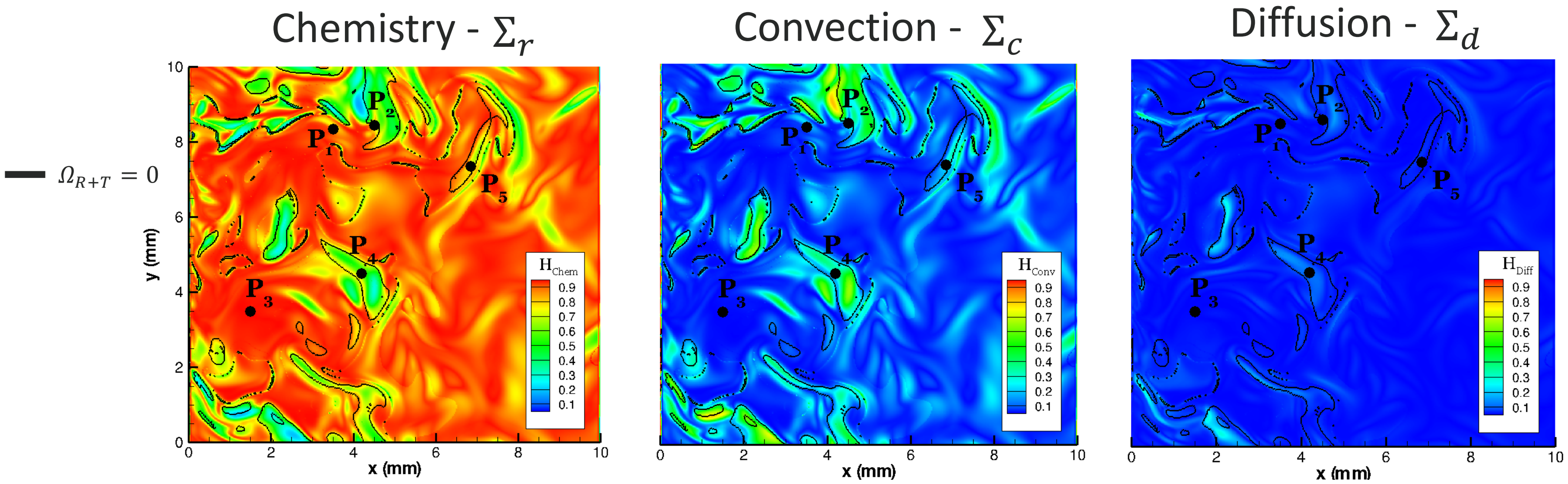

P_1		P_2		P_3		P_4		P_5	
$\omega_{\tilde{\tau}_{R+T}} =$ -166.2		$\omega_{\tilde{\tau}_{R+T}} =$ -46.1		$\omega_{\tilde{\tau}_{R+T}} =$ -3665.73		$\omega_{\tilde{\tau}_{R+T}} =$ 578.4		$\omega_{\tilde{\tau}_{R+T}} =$ 493.9	
c_T=0.2		c_T=0.3		c_T=0.4		c_T=0.3		c_T=0.5	
Mode 1	55%	Mode 10	42%	Mode 1	79%	Mode 10	63%	Mode 10	69%
Mode 10	39%	Mode 1	41%	Mode 10	18%	Mode 1	19%	Mode 1	27%
		Mode 6	13%						

Competition between explosive and dissipative modes

Mode 1 (Dissipative)
- Fastest time scale
- Associated with HCO

Mode 10 (Explosive)
- Largest amplitude
- Associated with H-chemistry
- Enhanced by convective processes

Ongoing/Future Research

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- Hydrogen combustion in compression ignition engines.
- Ammonia use in gas turbines
- CSP analysis of local sensitivity data
- Asymptotic analysis of highly turbulent systems

Thank you