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Soot Temperature Distributions in Turbulent Non-Premixed Ethylene and JP-8 Surrogate Jet Flames

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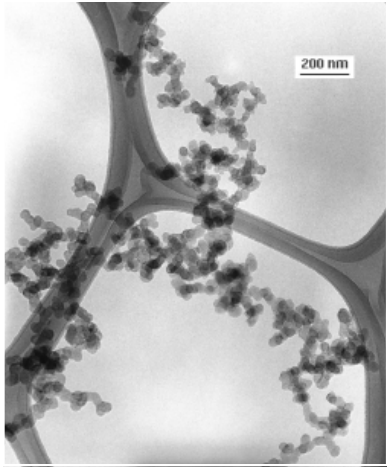
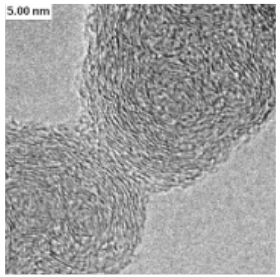
Background and Motivation

- Soot emissions are a health and climate concern, are regulated from ground transport sources, and are an area of concern for aviation
- Soot formation chemistry is very complex & semi-fused aggregate morphology of soot particles makes surface growth and oxidation rates difficult to predict
- *Phenomenological* soot models are tuned to match limited sets of data based on soot concentrations and, in some cases, mobility size distributions from physically probing laminar flat flames

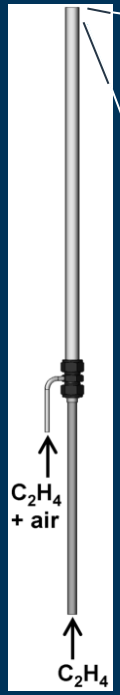


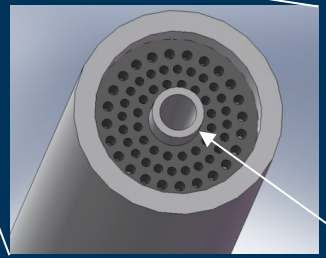


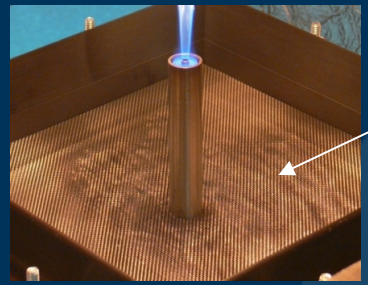
Background and Motivation

- In many applications, the formation of soot impacts the temperature field through its radiant emission and absorption (i.e. it forms a participating media)
- There are few datasets for soot formation in turbulent flames that are conducive to modeling, particularly when there is significant turbulence and sufficient soot to affect the T field
- Previously we have reported on soot concentrations and radiant emission profiles for ethylene and JP-8 fuels – herein focus on soot T distributions in these flames

Experimental Approach – Sooty Piloted Turbulent Non-Premixed Jet Flames





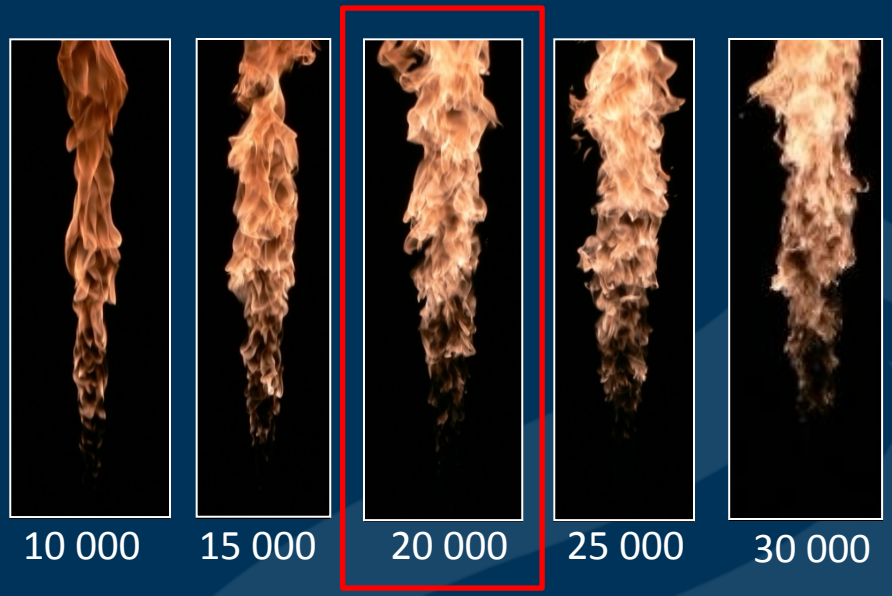


Utilize design knowledge of TNF Workshop flames to produce piloted (attached), fully developed turbulent jet flames with conditioned air coflow surrounding the flame
(pilot = 2% of jet heat release)

Reference Flame: Re = 20,000

Focus on Re = 20,000 flame – minimize buoyancy effects and local extinction events:

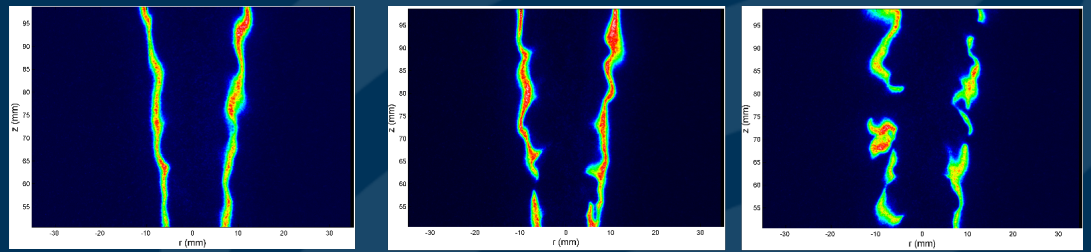
24.0 kW heat release
flame height ~ 870 mm



Re = 10 000 15 000 20 000 25 000 30 000

fast-shutter SLR camera images (ethylene flames)

OH PLIF in high-shear region



Re = 10 000 20 000 30 000

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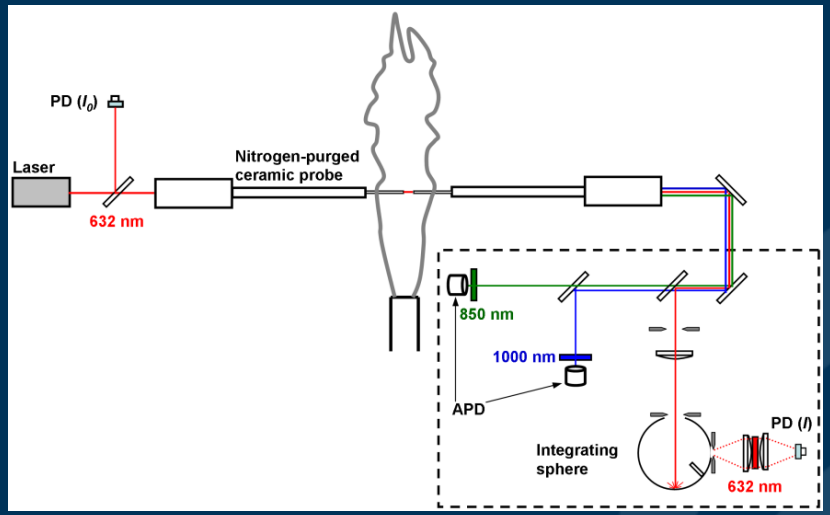
Soot Temperature/Concentration Measurements

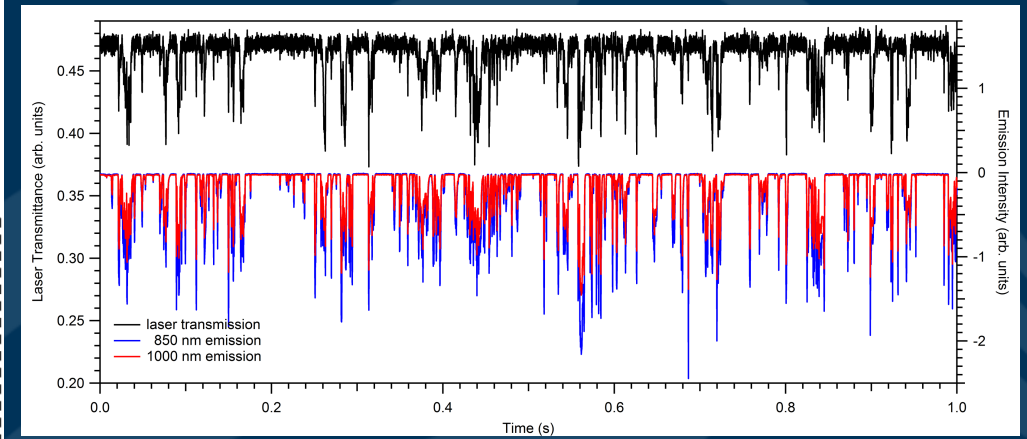
3-line technique, combining soot extinction and 2-color pyrometry

- ceramic (Al_2O_3) probes (6.35 mm OD) define probe volume: 10 mm long line

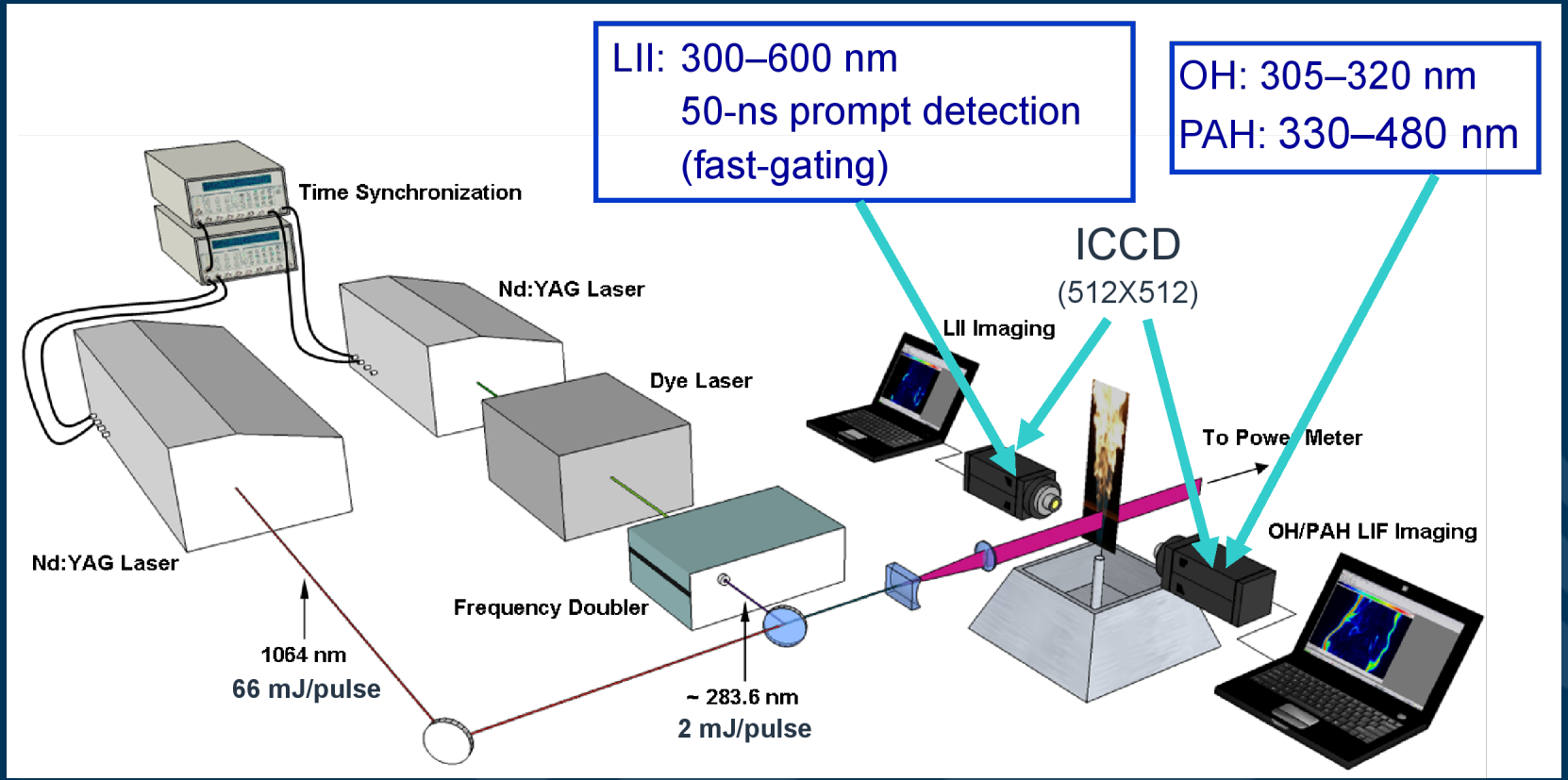
Experimental arrangement



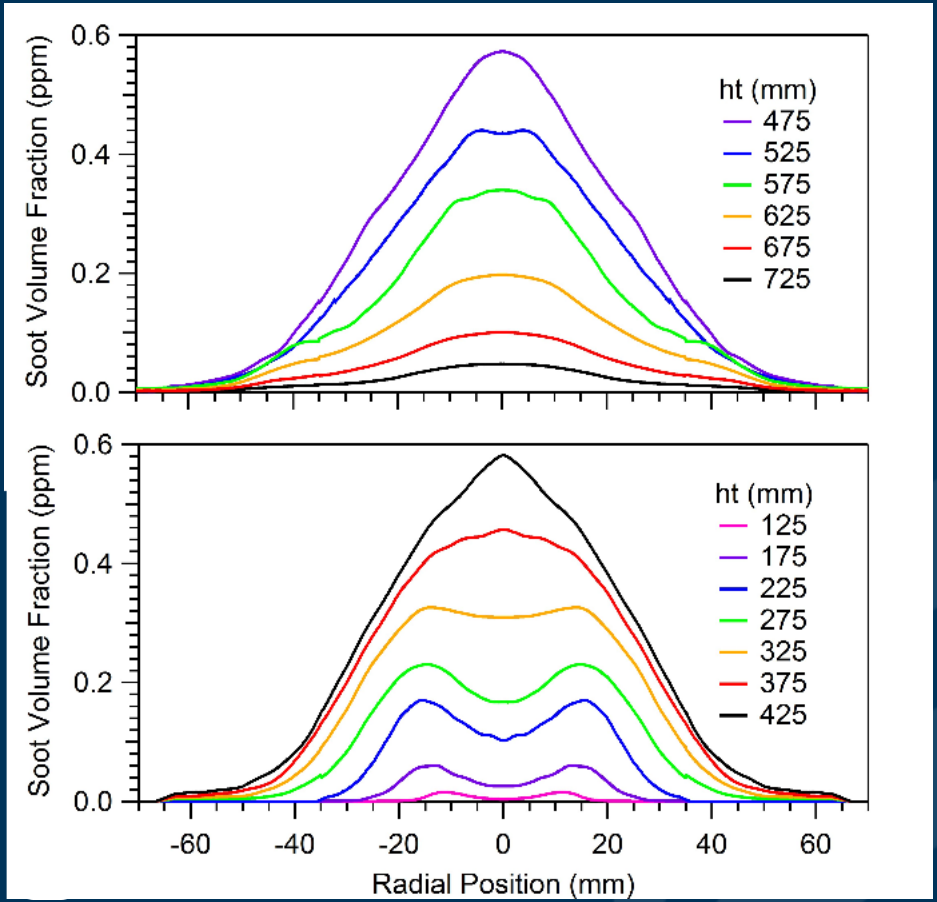
Typical time record



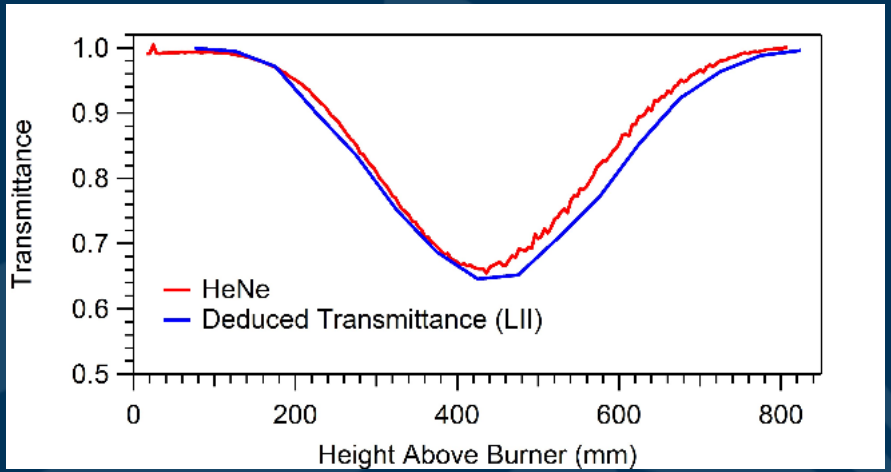
Soot LII and OH PLIF Measurements



Results: LII-Derived Mean Soot Concentrations

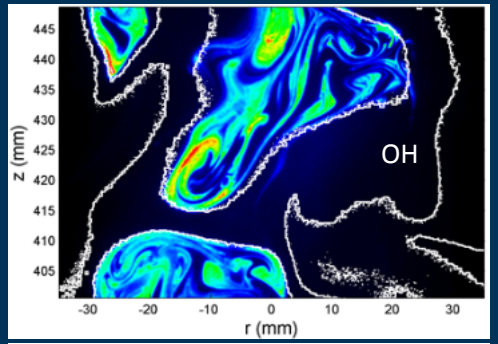


Centerline Transmittance



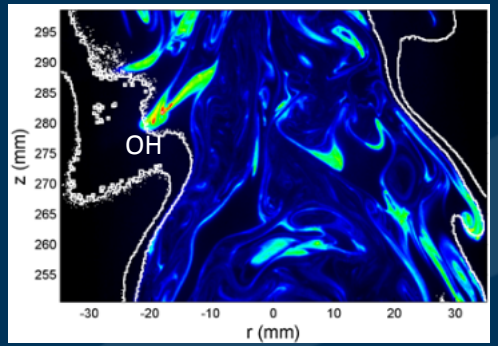
Simultaneous OH PLIF/LII Images Provide Key Insights into Soot T Trends

High



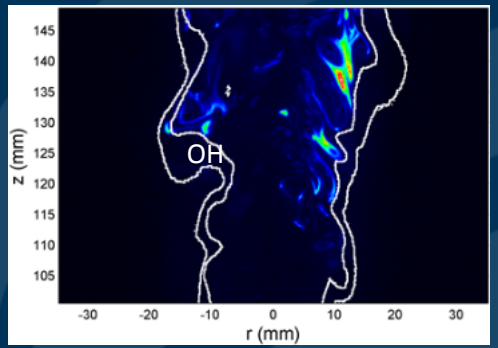
consumption of fuel and vortical motions break apart fuel-rich regions; radiation loss continues

Middle



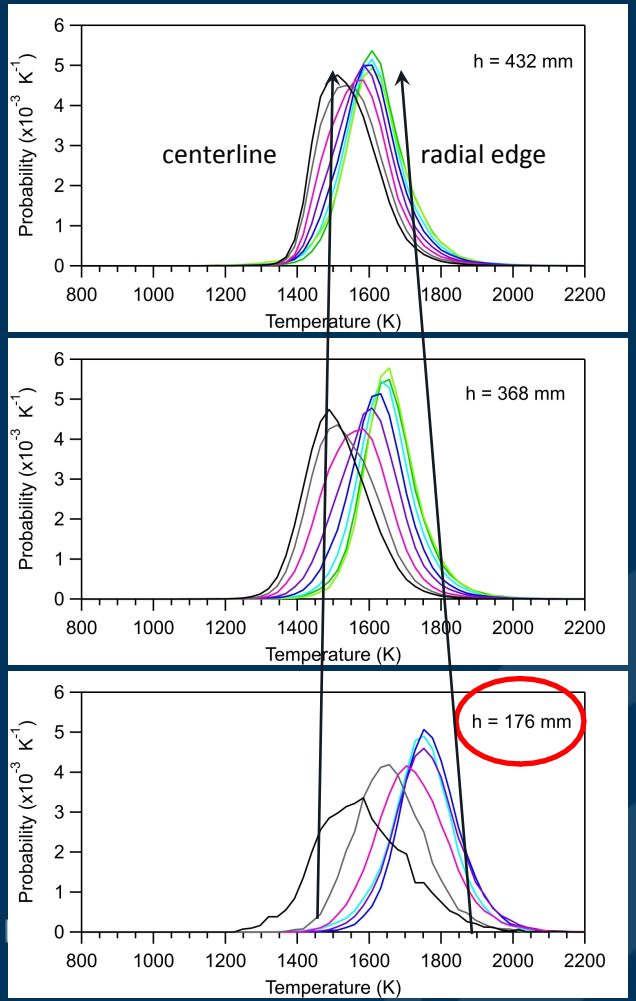
flame is wider, vortical motions distribute soot, radiation loss decreases peak T

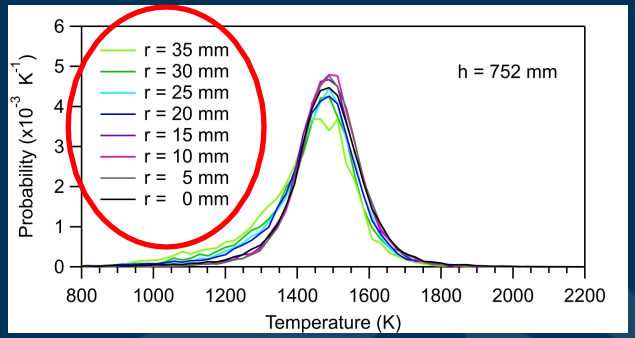
Low

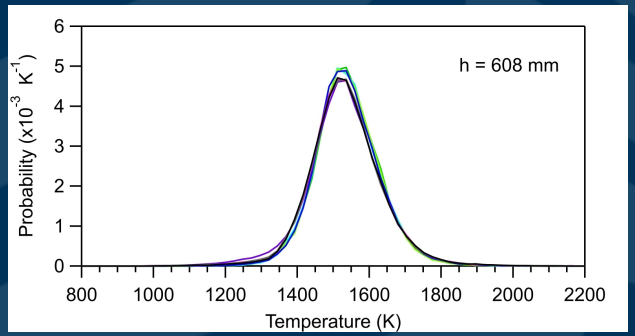


soot rarely forms, and then only in vortices near the flame sheet

Results: PDFs of Soot Temperature in Ethylene Flame







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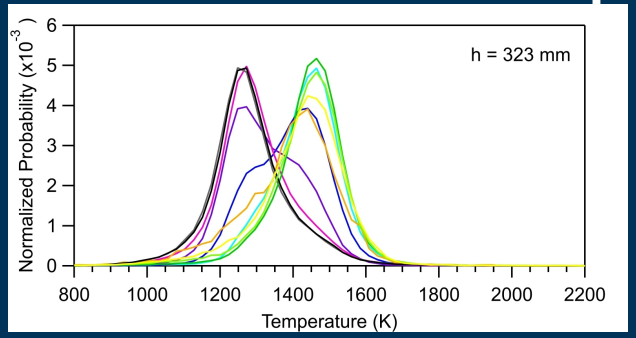
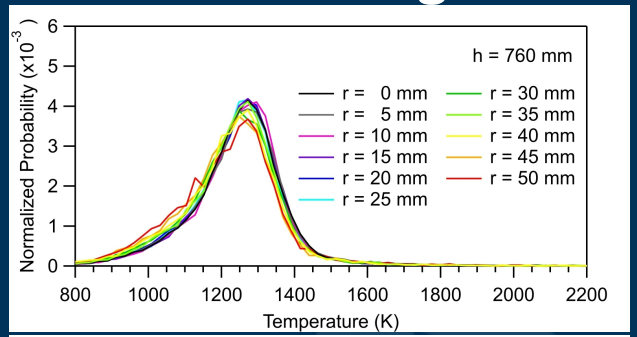
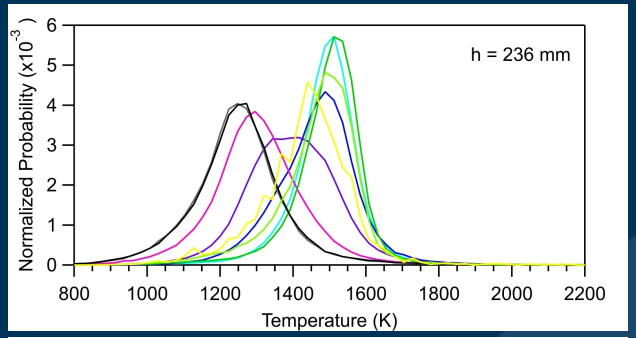
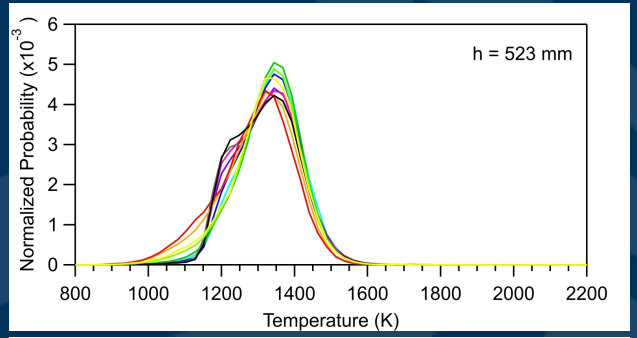
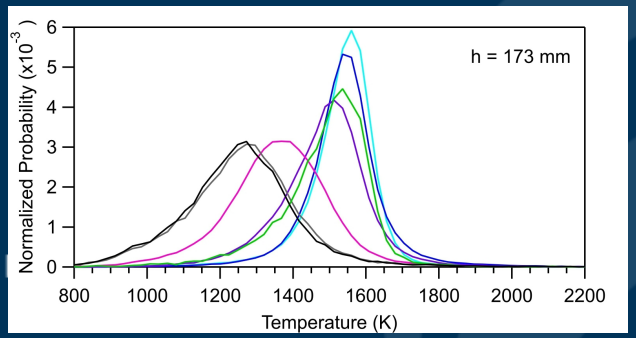
Results: PDFs of Soot Temperature in JP-8 Surrogate Flame

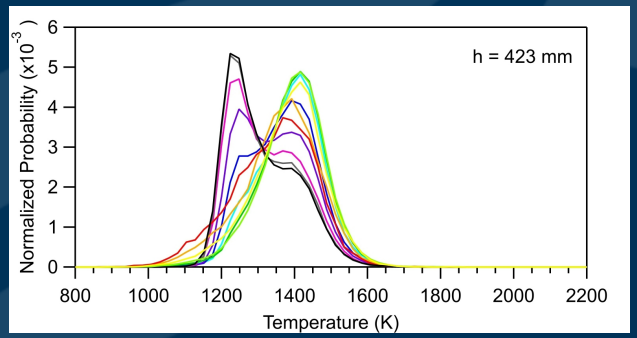












In Summary

- Soot temperatures are highest low and in outer radial positions (towards flame edge) in both ethylene and JP-8 surrogate flames
- Soot temperatures in outer radial positions consistently fall with increasing height, presumably due to radiant losses from flames
- Soot temperatures along centerline decrease shortly after inception, then stay fairly constant with height
- Soot temperatures in the JP-8 surrogate flame are consistently lower than those in the ethylene flame, by approximately 100 K
- This combined data set of soot f_v and T (+ radiation), makes for a challenging target for modelers

Acknowledgment

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Questions?