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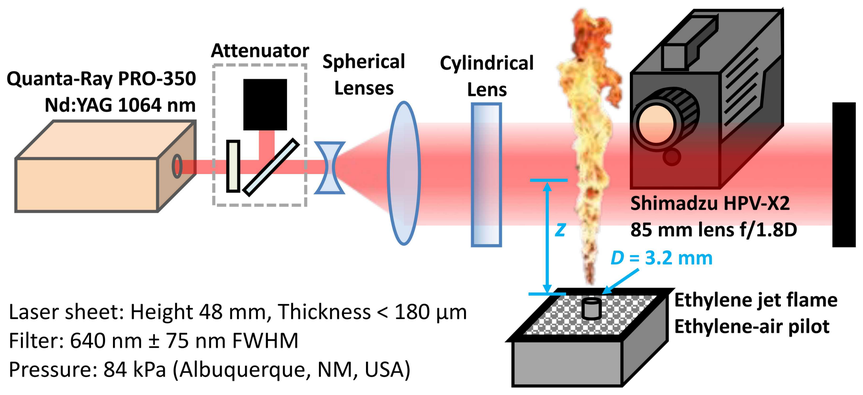
Single-shot Soot Particle Sizing in Turbulent Flames using Ultra-High-Speed Imaging

Ellen Yi Chen Mazumdar[1], Emre Cenker[2], Daniel R. Richardson[3], Sean P. Kearney[3], Benjamin R. Halls[3], Scott A. Skeen[4], Christopher R. Shaddix[4], and Daniel R. Guildenbecher[3]

[1] Georgia Institute of Technology, [2] University of Birmingham, [3] Sandia National Laboratories New Mexico, [4] Sandia National Laboratories California

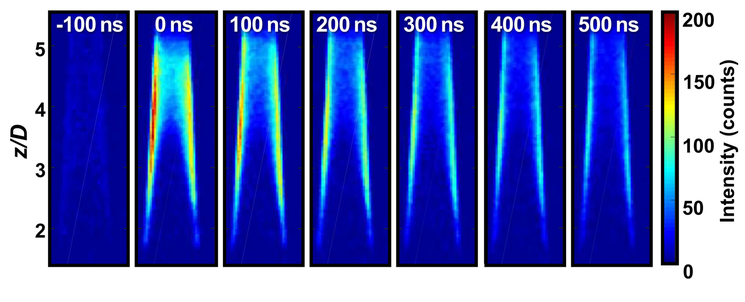
Motivation & Concept

- Time-Resolved Laser Induced Incandescence (TiRe-LII) for soot particle sizing is challenging to apply in turbulent or unsteady flames.
- Previous work has focused on point measurements, statistical averaging with multiple laser shots, or gathering decay data with multiple cameras at various delays (requires image registration).
- We created a novel planar TiRe-LII method using a single laser shot and a single ultra-high-speed camera (10 MHz repetition rate, 50 ns exposure, 10 bit) and no intensifier for soot particle sizing in turbulent flames.



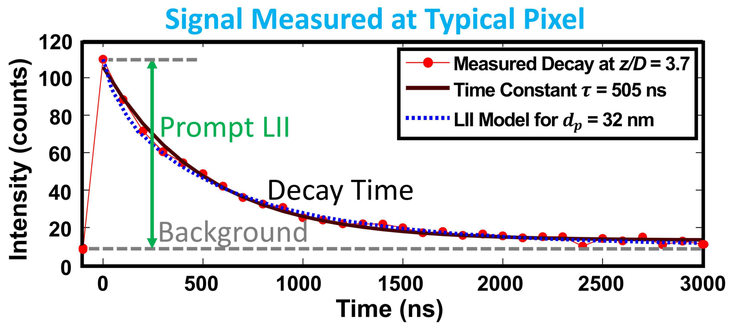
Laser sheet: Height 48 mm, Thickness < 180 µm
Filter: 640 nm ± 75 nm FWHM
Pressure: 84 kPa (Albuquerque, NM, USA)

Validation in a Laminar Flame

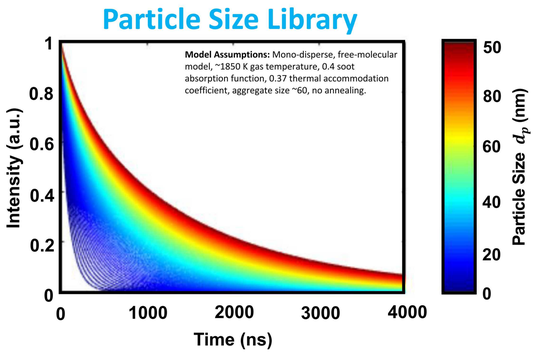


- Validation experiments were conducted in a non-premixed laminar flame (Santoro burner, D = 10.9 mm, ethylene 0.31 SLPM).
- Measurements of the background luminosity, prompt LII signal and decay are obtained.
- LII signal decay near atmospheric pressures is well-matched with the camera max frame rate.

Signal Measured at Typical Pixel

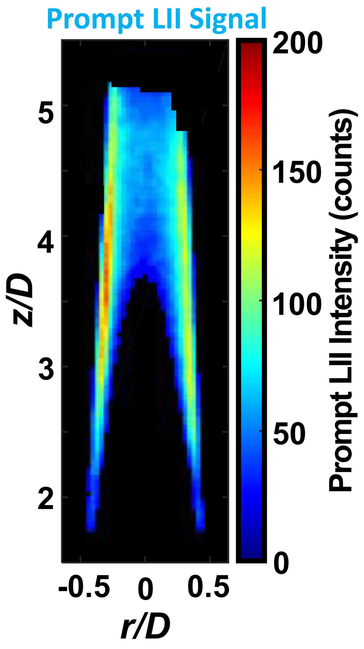


Particle Size Library

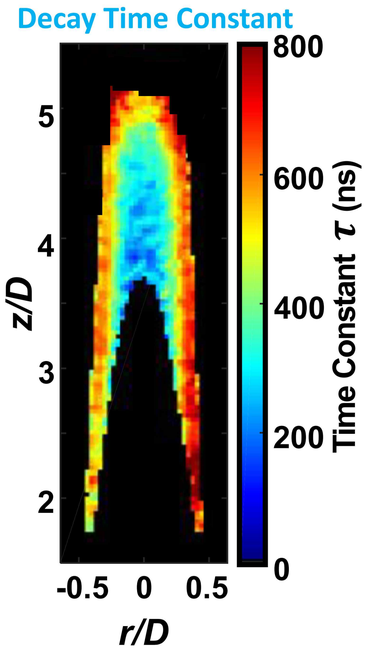


- At low laser fluences, conduction is the dominant soot cooling mechanism. If the particle size is assumed to be monodisperse, the signal can be approximated as an exponential decay.
- A validated LII model was used to generate a particle size library and was fit to the experimental data.

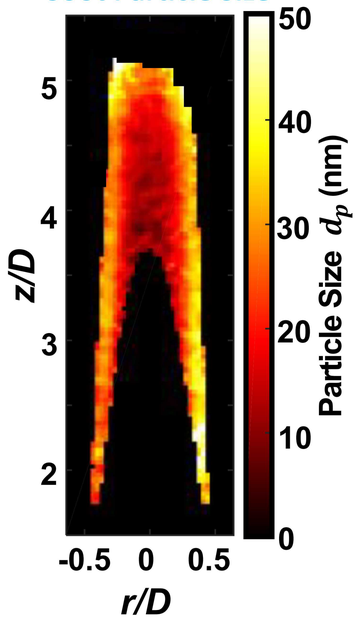
Prompt LII Signal



Decay Time Constant



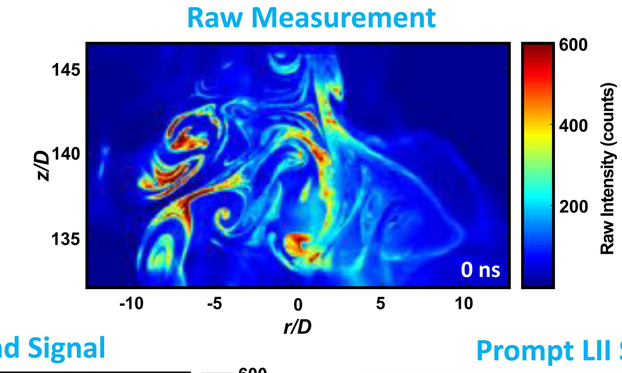
Soot Particle Size



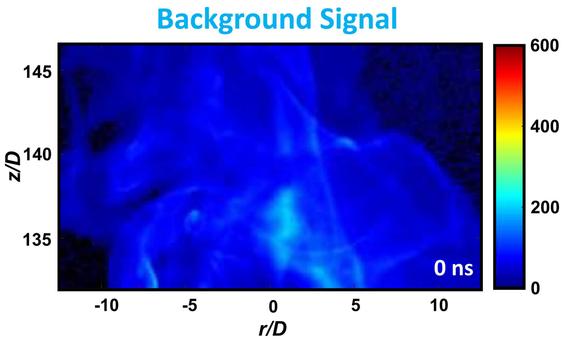
Turbulent Flame Measurements

- A turbulent jet flame was then measured using this technique (Shaddix burner, D = 3.2 mm, air co-flow 200 SLPM, ethylene pilot 0.52 SLPM, air pilot 8.4 SLPM, ethylene jet 26.4 SLPM for Re = 20,000).
- Results in the lower part of the soot growth zone $z/D \approx 70$ (z = 225 mm) were compared with the start of the soot oxidation zone $z/D \approx 140$ (z = 450 mm).

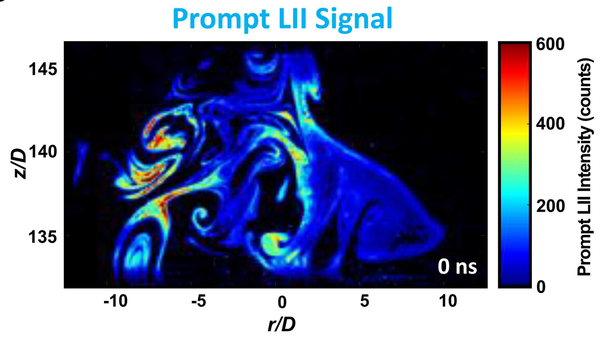
Raw Measurement



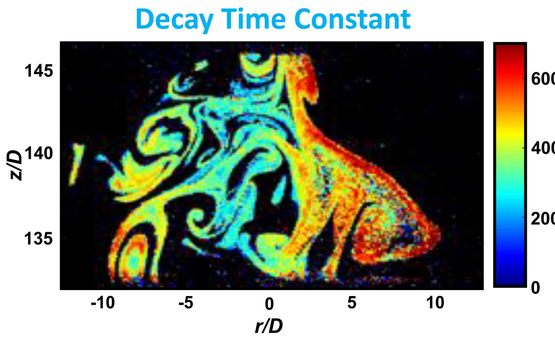
Background Signal



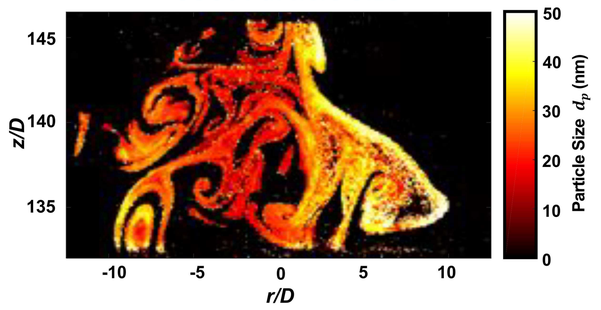
Prompt LII Signal



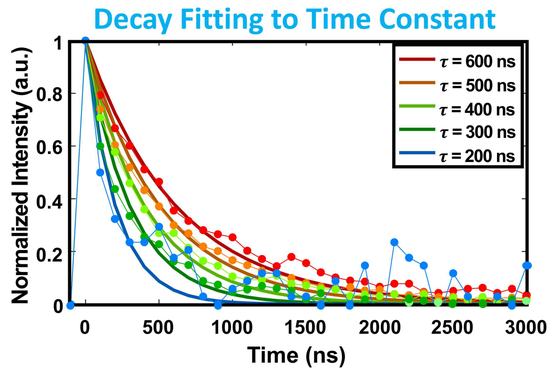
Decay Time Constant



Soot Particle Size

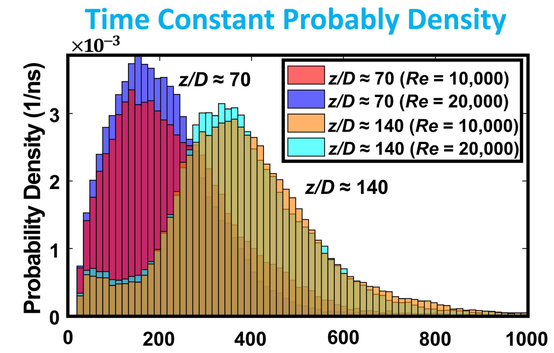


Decay Fitting to Time Constant

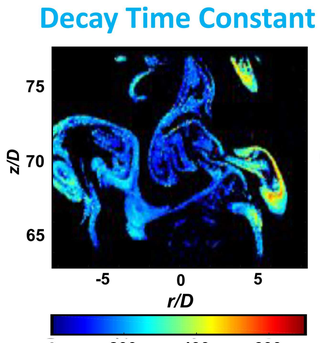


- A turbulent LII model was generated with temperature estimates (1628 K) from CARS measurements.
- Time constants appear to vary with r/D.
- Preliminary probability density results show that soot particle sizes are smaller in the soot growth zone and larger at the start of the soot oxidation zone.

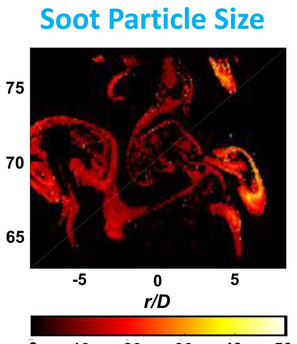
Time Constant Probably Density



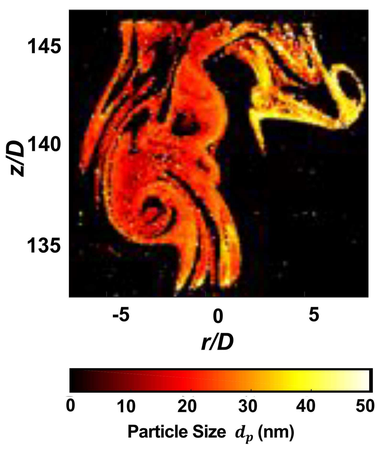
Decay Time Constant



Soot Particle Size



Conclusions & Future Work



- Single-laser-shot, single-camera TiRe-LII is an effective method for measuring soot particle sizes in turbulent and unsteady flames.
- Additional turbulent LII model validation is needed. One method we are pursuing is simultaneous temperature measurements with two-color TiRe-LII using two ultra-high-speed cameras.
- Currently, we are also working on tomographic implementations to illustrate how the technique can be expanded to three-dimensions.

References

- **Y. Chen**, E. Cenker, D. R. Richardson, S. P. Kearney, B. R. Halls, S. A. Skeen, C. R. Shaddix, and D. R. Guildenbecher, "Single-camera, Single-shot, Time-resolved Laser-induced Incandescence Decay Imaging," Optics Letters, vol. 43 (21), pp. 5363-5366, 2018.
- E. Cenker, S. Skeen, **Y. Chen**, D. R. Richardson, C. R. Shaddix and D. R Guildenbecher, "LII Particle-Size Imaging with an Ultra-High-Speed CMOS Camera," 8th International Workshop on Laser-Induced Incandescence, June 10-13, 2018.
- **Y. Chen**, D. R. Richardson, E. Cenker, B. R. Halls, S. Skeen, C. Shaddix and D. R Guildenbecher, "Turbulent Flame LII Particle Sizing via Ultra-High-Speed Imaging," 8th International Workshop on Laser-Induced Incandescence, June 10--13, 2018.

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