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# Optical Diagnostics for Engine Development


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# Acknowledgements


Collaborators: Dr. Louis-Marie Malbec, IFPEN

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Engine Department Manager: Dr. Paul Miles

Hardware support:

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Injectors:

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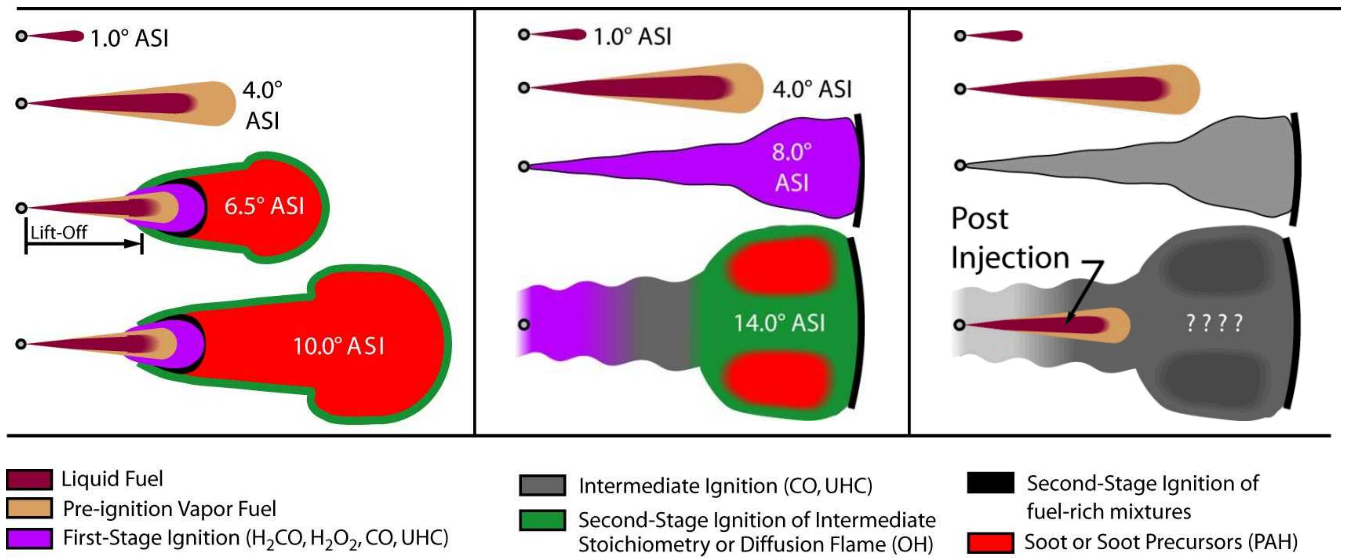
# Relevance/Objectives: Heavy Duty In-cylinder Combustion

## Long-Term Objective

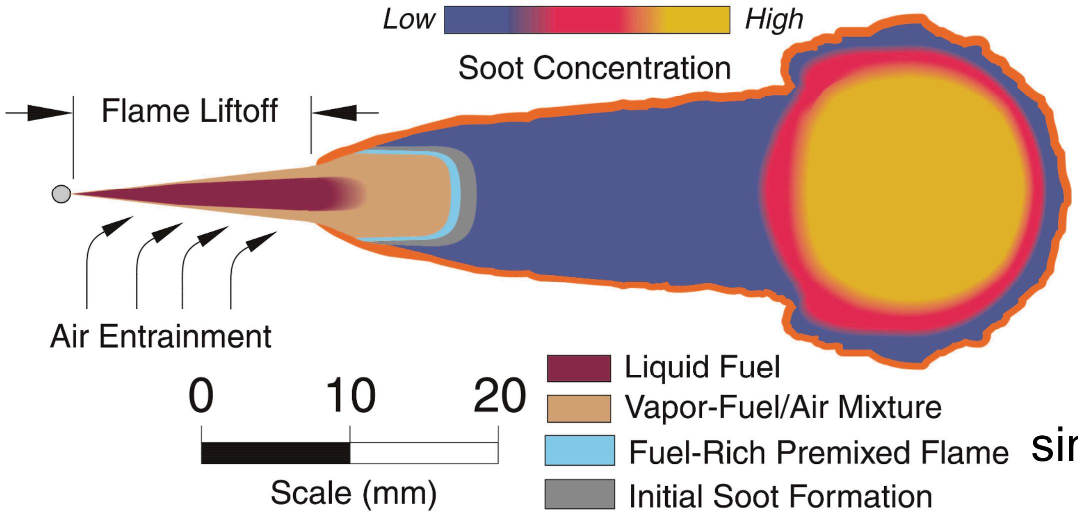
**Develop the science to explain in-cylinder spray, combustion, and pollutant-formation processes for both conventional diesel and LTC that industry needs to design and build cleaner, more efficient engines**

| 1997: **Conventional Diesel** (Single Injection) | 2012: **LTC Diesel** (Single Injection) | 2013+: **Multiple Injection** (Conventional & LTC) |
| --- | --- | --- |

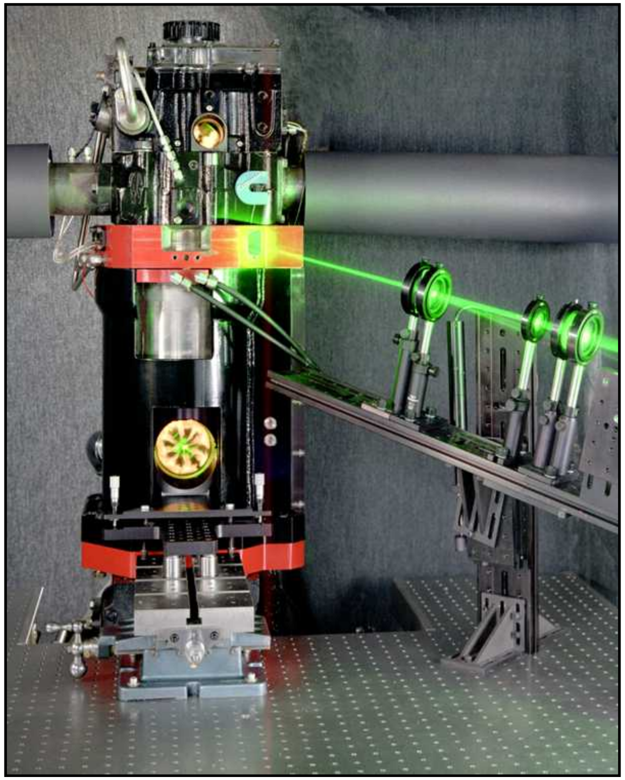


# Sandia heavy-duty LTC optical engine

Background: Since late 1980's, in-cylinder diesel spray, combustion, and pollutant formation has been studied at Sandia with multiple laser/optical diagnostics. Data are the basis of conceptual model of conventional diesel combustion. However, onerous required optical access, design considerations for many such diagnostics.




*From SAE 970873, J. Dec, Conceptual Model of Diesel Combustion*

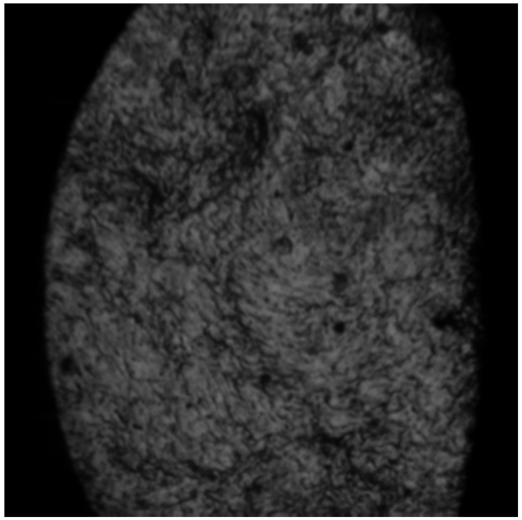


What's Desired?
simple single window optical access,
no lasers, no sapphire optics,
measure multiple sprays simultaneously
Improve spatial and temporal resolution

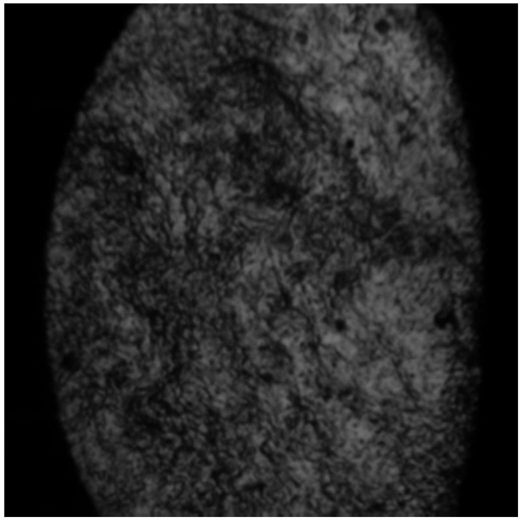
# Objectives of today's presentation

- Infrared hydrocarbon fuel vapor imaging diagnostic
  - Overcomes optical access limitations, reactivity  and oxygen quenching challenges
- Laser-less high-speed PIV technique
  - No laser repetition or Q-switching limitations
- Time-resolved PIV analysis for transient jet flows
  - Jet boundary is defined in a way that is robust to confinement and axial gradients.

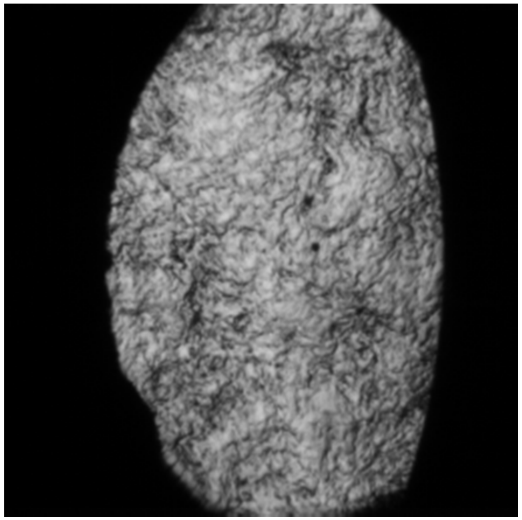
# Low temperature reaction 'softens' schlieren gradients, making vapor detection difficult



0% O2
800K TDC
15.2 kg/m3

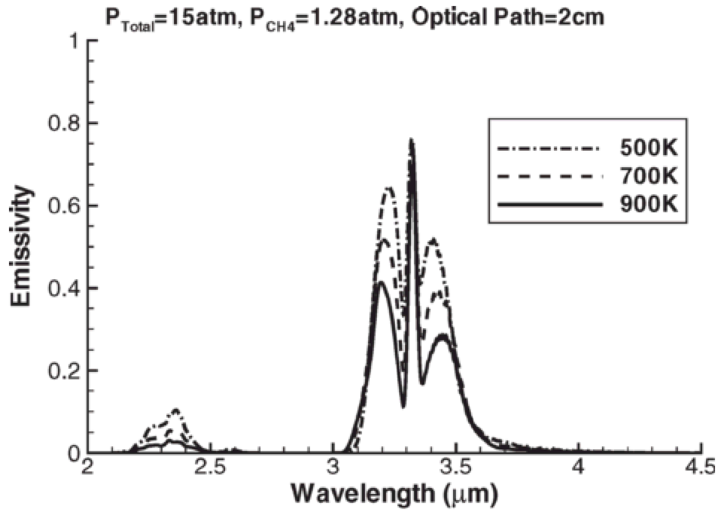


4% O2
825K TDC
22.8 kg/m3

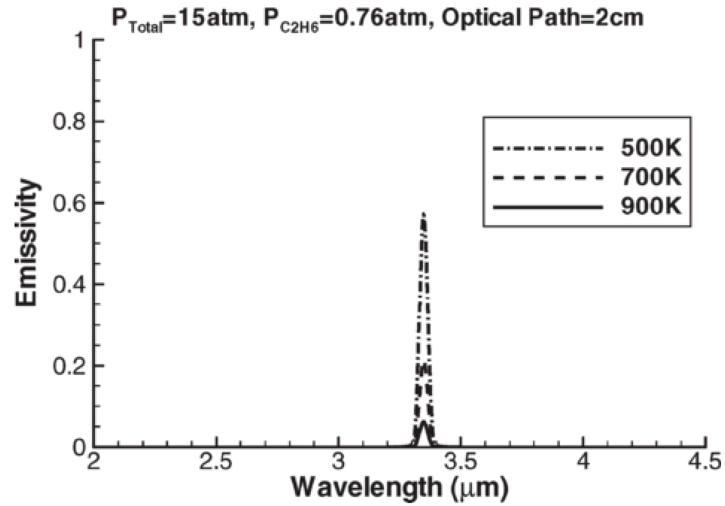


15% O2
800K
15.2 kg/m3

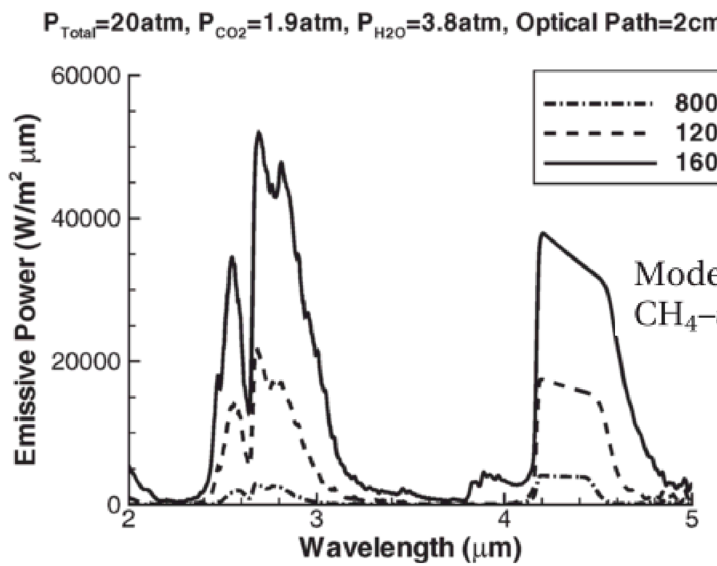
# Spectral models predict emission is strong for fuel, weak for combustion products near 3.4 microns




Modelled stoichiometric $CH_4$–air mixture emission spectrum



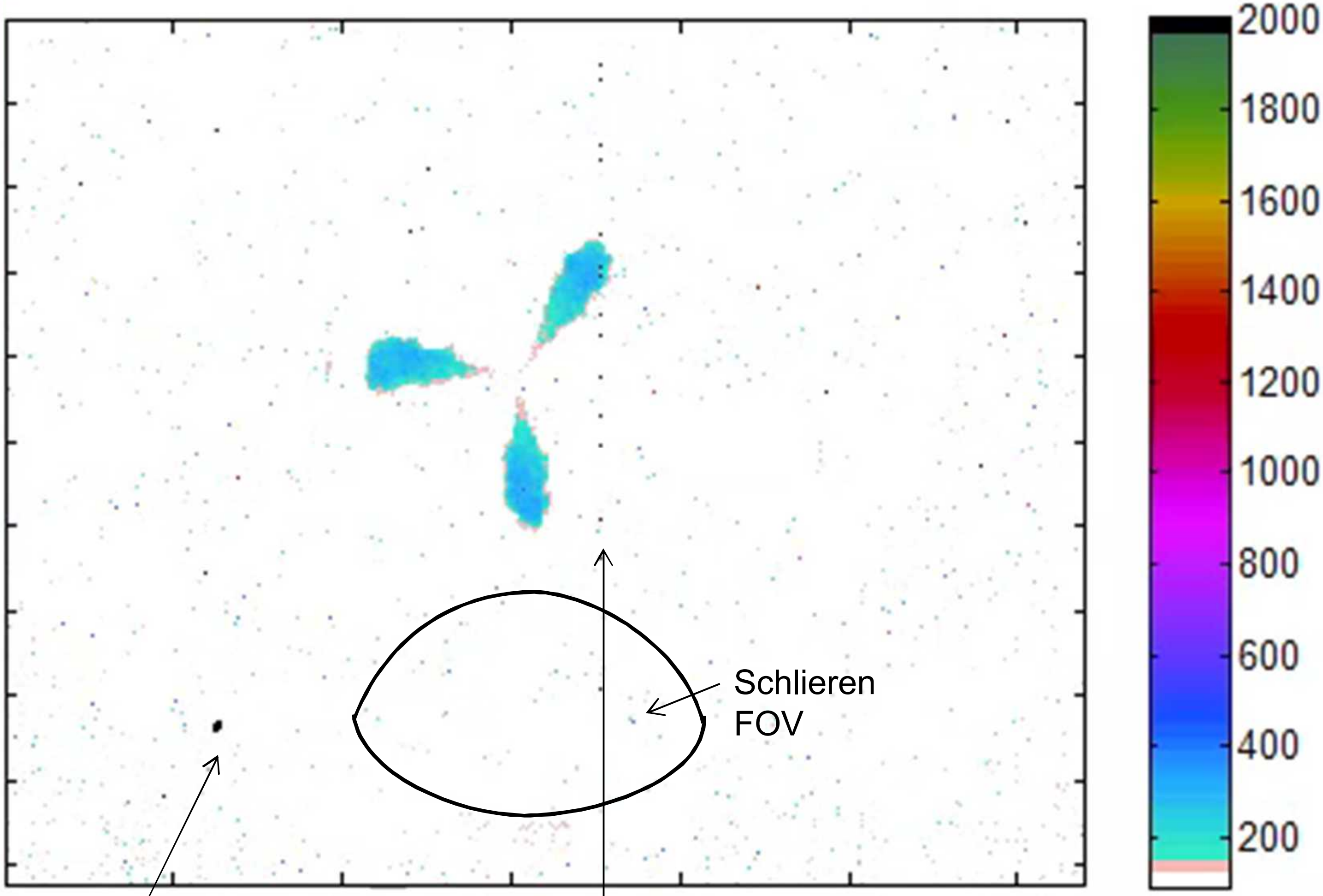

Modelled $C_2H_6$–air mixture emission spectrum



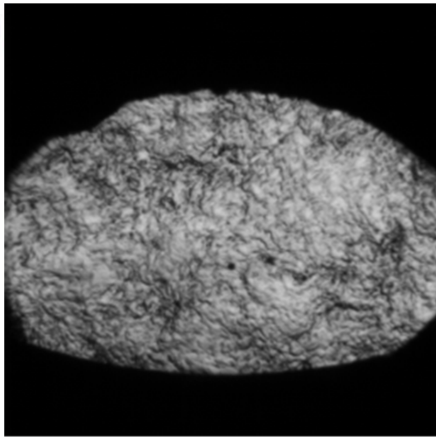

Modelled emissive power of stoichiometric $CH_4$–air combustion product mixture

M. Jansons, S. Lin and K Rhee Infrared spectral analysis of engine preflame emission IJER 2008

# Sample images used for processing




Cycle resolved schlieren



Bad pixel clump

Bad pixel column

Images taken from 2CAD After Start of Injection to 10 CAD ASOI*

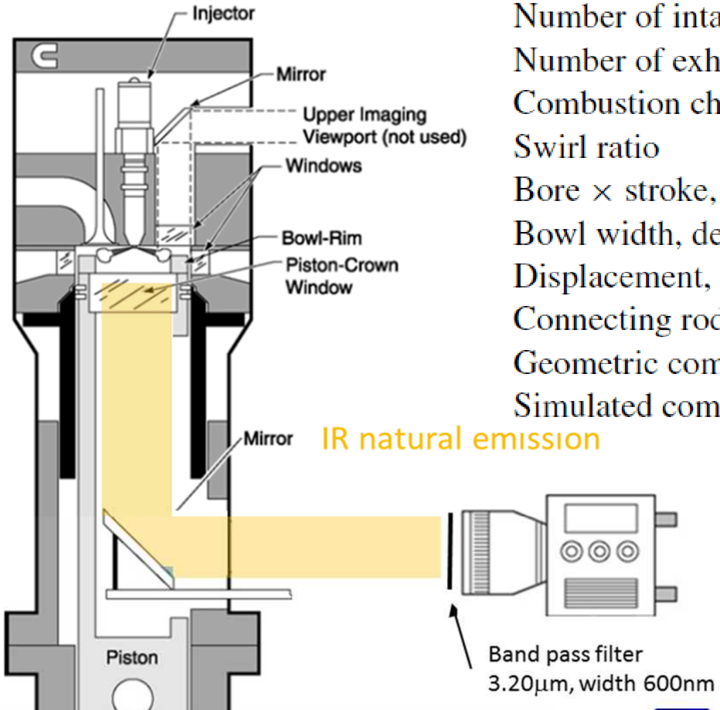
IR Exposure duration freezes motion, but only uses a fraction of the 14bit sensor output range, 16383 counts

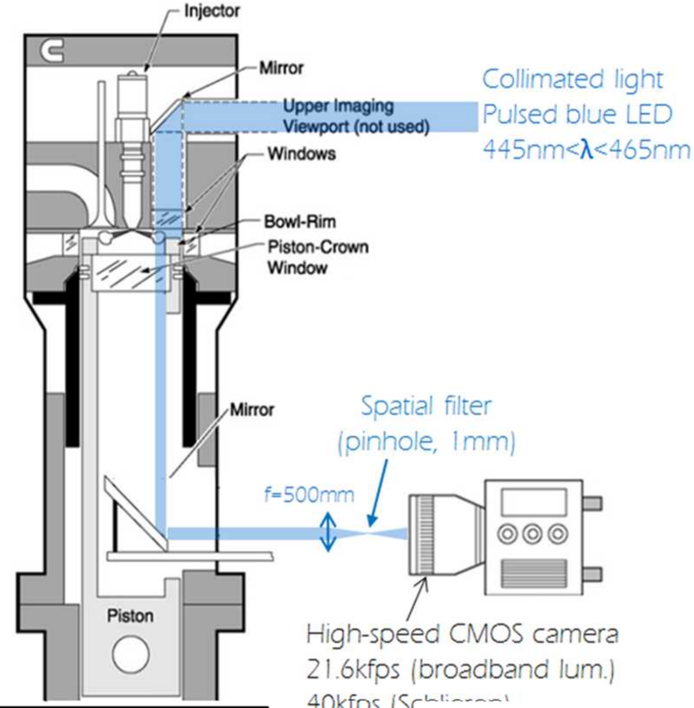


*High resolution IR data shown here for figure clarity, low res stills next page

# IR imaging of hot fuel emission in whole piston bowl, vs schlieren at overlapped flat windows

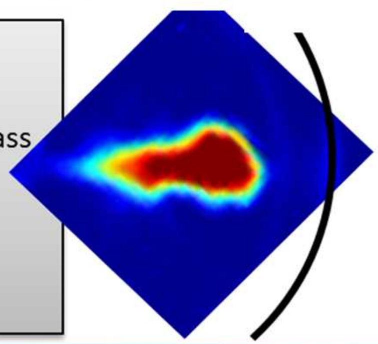
| | |
|---|---|
| Engine base type | Cummins N-14 |
| Number of cylinders | 1 |
| Number of intake valves | 2 |
| Number of exhaust valves | 1[a] |
| Combustion chamber | Quiescent |
| Swirl ratio | 0.5 |
| Bore × stroke, cm | 13.97 × 15.24 |
| Bowl width, depth, cm | 9.78, 1.55 |
| Displacement, L | 2.34 |
| Connecting rod length, cm | 30.48 |
| Geometric compression ratio | 11.2:1 |
| Simulated compression ratio | 16:1 |



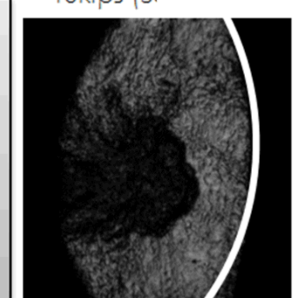

## *Infrared*

- MW-IR (InSb) 3-5µm
- Filter: 3.2±0.6 micron bandpass
- Lens: 50mm IR f/2.4
- Frame rate: 1 image / cycle
- Exposure: 10µs
- Scale: 2.2 or 4.2 pix per mm



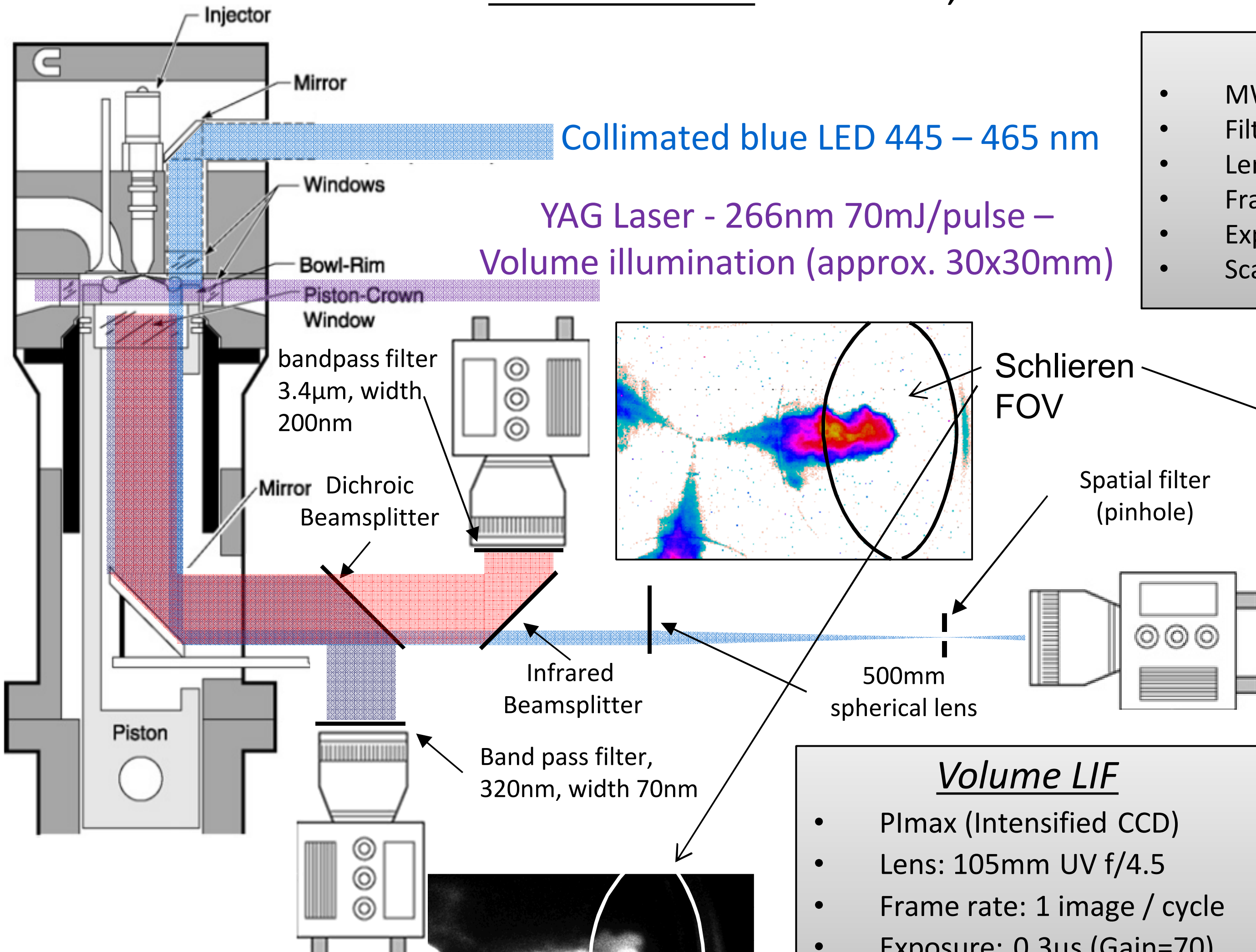
## *Schlieren*

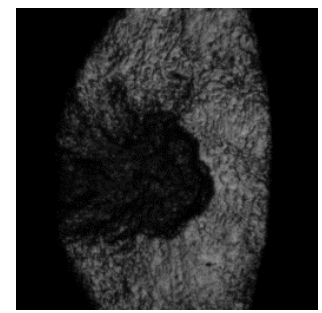
- Phantom v71
- Lens: 50mm f/11
- Frame rate: 25kHz
- Exposure 40µs
- Scale: 9.67 pix/mm

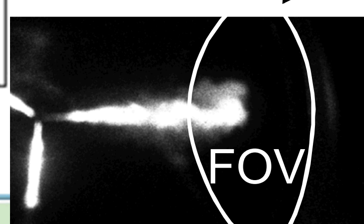


# Future Work – "SchLIFIR"

## Simultaneous Schlieren, LIF and Infrared*






### *Infrared*

- MW-IR (InSb) 3-5μm
- Filter: 3.4±0.2 micron bandpass
- Lens: 50mm IR f/2.3
- Frame rate: 1 image / cycle
- Exposure: 5μs
- Scale: 4.2 pix per mm

### *Volume LIF*

- PImax (Intensified CCD)
- Lens: 105mm UV f/4.5
- Frame rate: 1 image / cycle
- Exposure: 0.3μs (Gain=70)
- Scale: 11.4 pix/mm

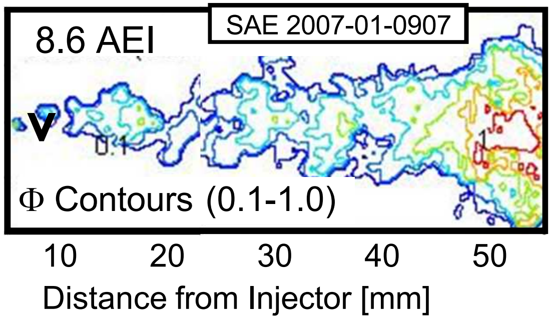
### *Schlieren*

- Phantom v71
- Lens: 50mm f/11
- Frame rate: 14.4kHz
- Exposure 5μs
- Scale: 9.5 pix/mm

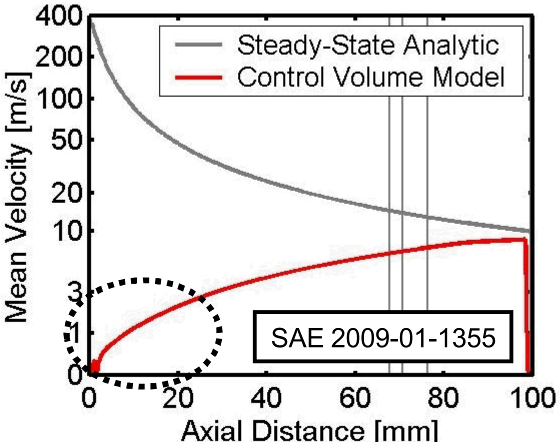
...entational, images shown were not acquired simultaneously (yet)

# LaserLess PIV

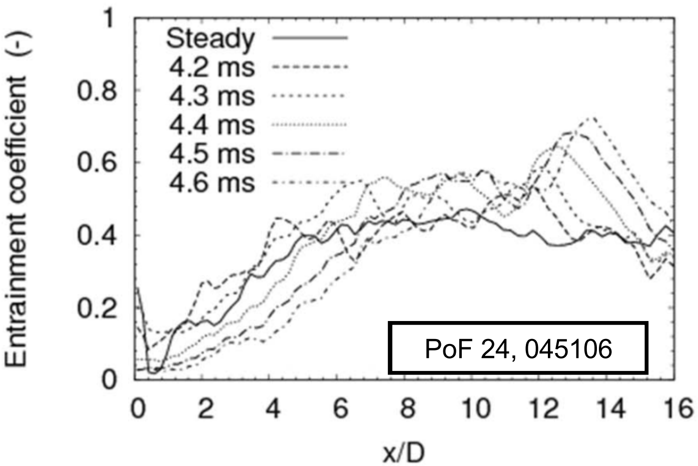
# Motivation for measuring transient entrainment




Fuel lean mixtures after end of injection, may indicate more entrainment




Nearly stagnant axial velocity predicted using 1D model




LES prediction of entrainment increase

No experiments have quantitatively demonstrated end of injection entrainment wave

# PIV Entrainment Analysis