Laser Induced Incandescence for Jet Engine Exhaust Particle Measurement and Engine Health Monitoring

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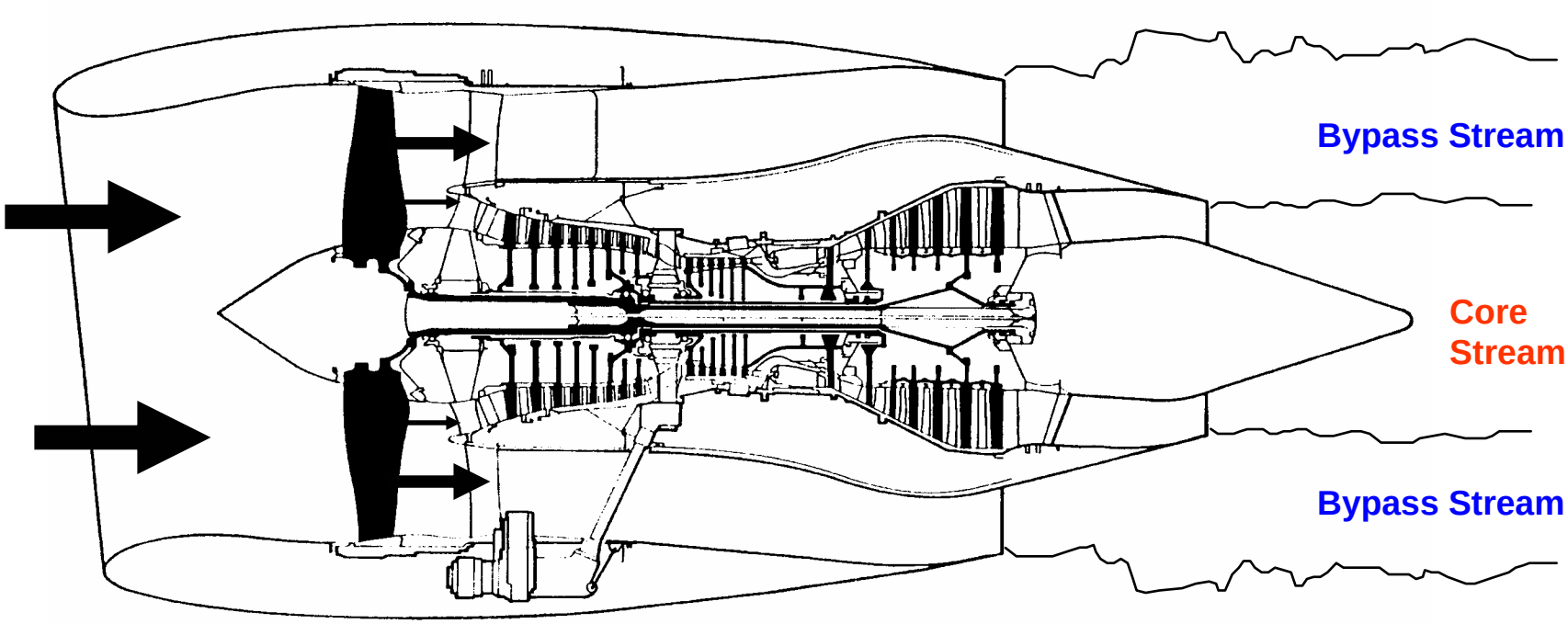
Current Smoke Measurement Methods

- Certification procedures defined by International Civil Aviation Organisation (ICAO)
  - LTO cycle, measurement methods, data handling, etc
- Measurement methods recommended by SAE E-31 committee
  - OEMs, academics, regulators, consultants, etc
- Current smoke measurement method – SAE filter paper
  - Dimensionless ‘Smoke Number’ related to plume visibility

- Optical smoke meters also in use

Typical Flow in Large Modern Civil Engine



Limitations of Current Methods

- Challenge of representative sampling
  - Plume asymmetry and isokinetic flow conditions
- Intrusive
- Expensive – hardware and test duration
  - Long sampling times
- Labour intensive
  - Off-line measurement of filter paper reflectance
- Water cooled probes required
- Poor resolution at low SNs from modern engines
- Large uncertainty: +/-3 SN

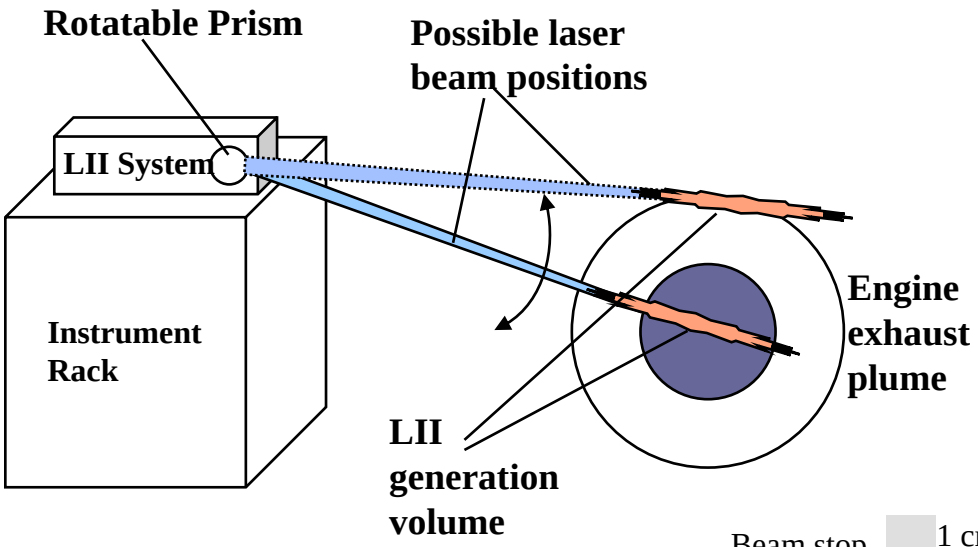
LII for Jet Engine Particle Measurement

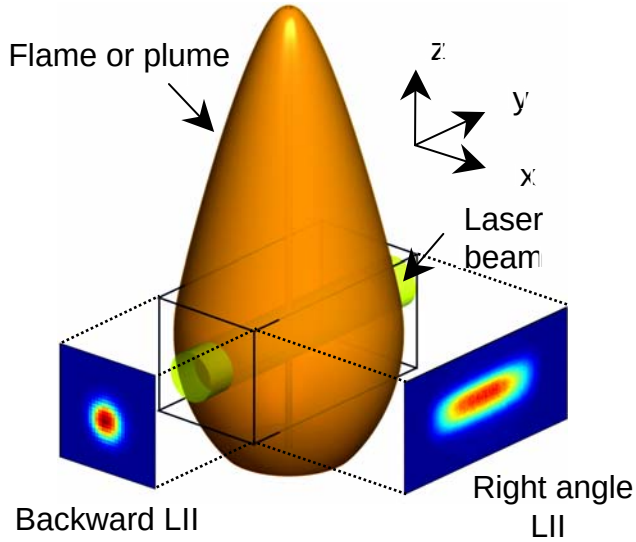
- Method development since ~1996 on collaborative EU funded programmes
  - AEROJET I – 1996
  - AEROJET II – 1998
  - AEROTEST – 2004 – 2007
    - Academic and industrial partners from: UK, Germany, France, Netherlands, Sweden, Greece
- Objective:
  - “Standardise and calibrate LII to the level required by ICAO for use as a non-intrusive method of engine emissions certification. Develop and validate LII as a method for gas turbine engine health monitoring”

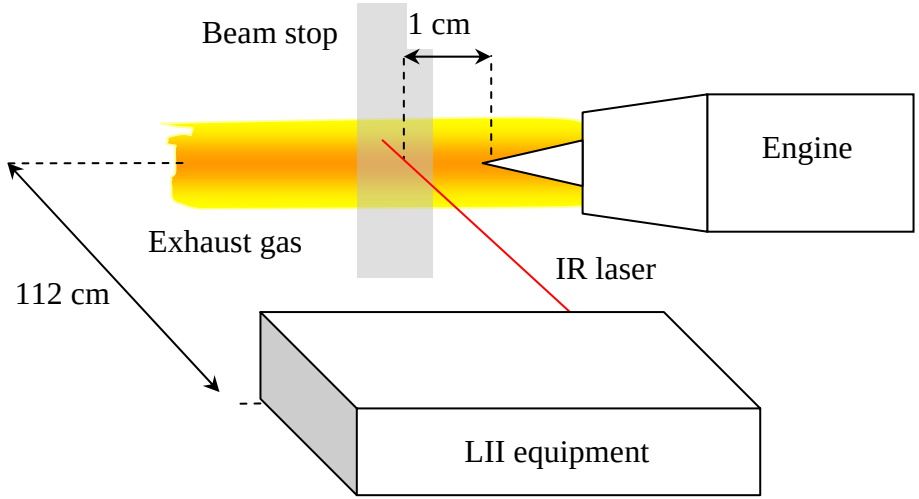
LII Fundamentals

- Particles rapidly heated to incandescence temperature by laser pulse
- Resulting LII images captured on CCD camera
  - Signal proportional to soot volume fraction
- Particle size can be deduced from time decay of LII image intensity
- High laser fluence can lead to particle sublimation
- Calibration procedure requires knowledge of initial soot temperature, laser energy and soot optical properties to convert LII measurements to an absolute scale

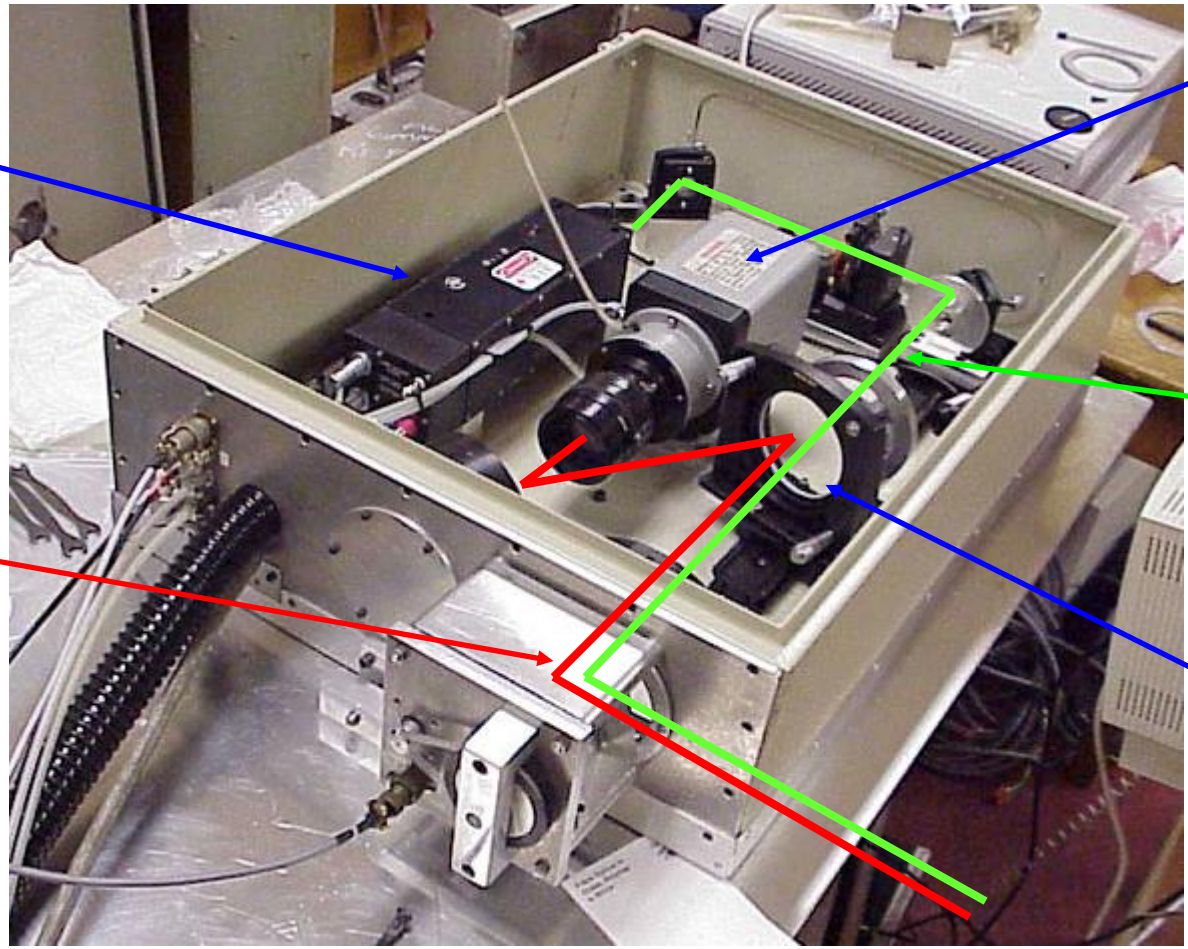
Method of Implementation



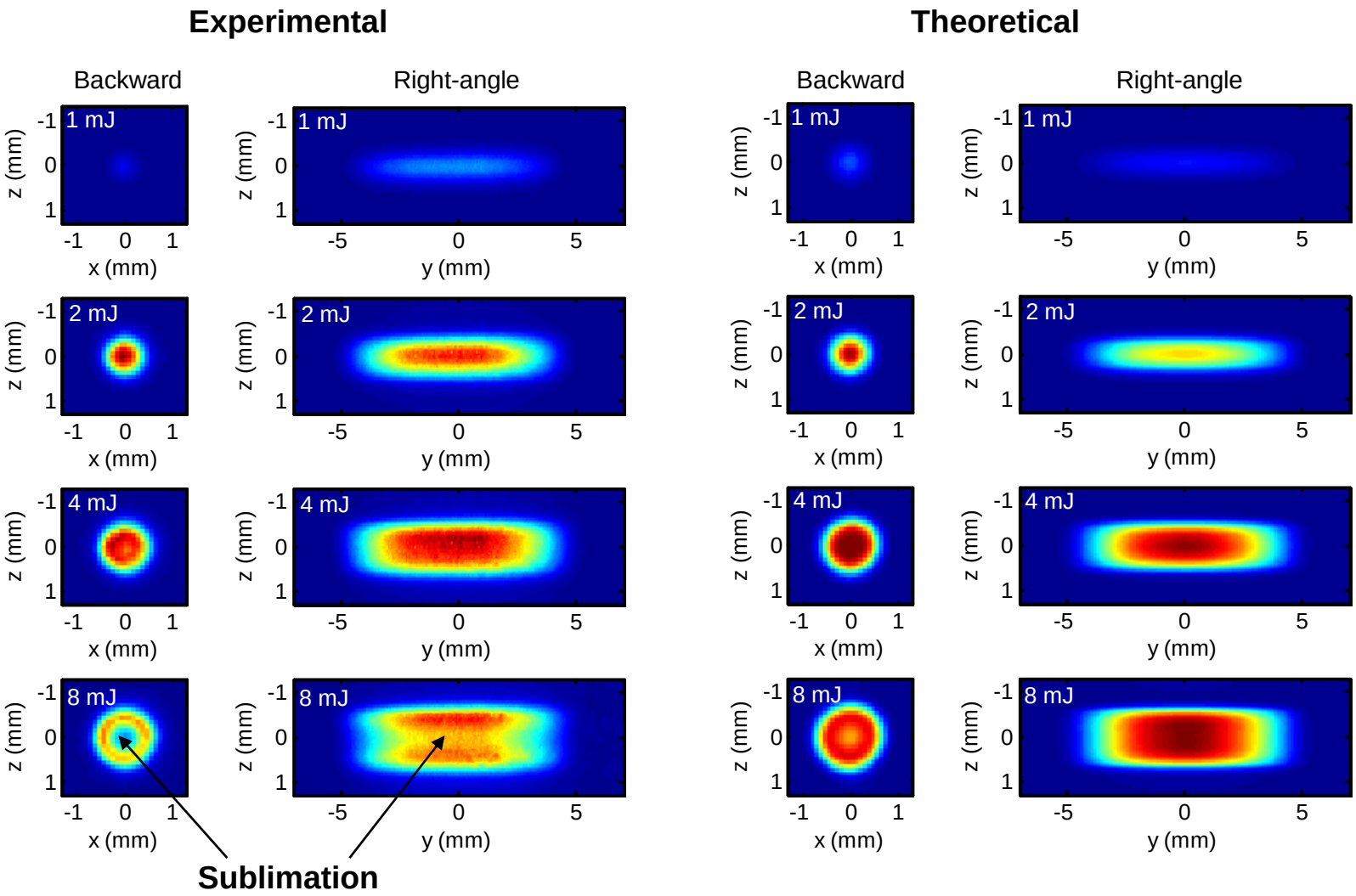




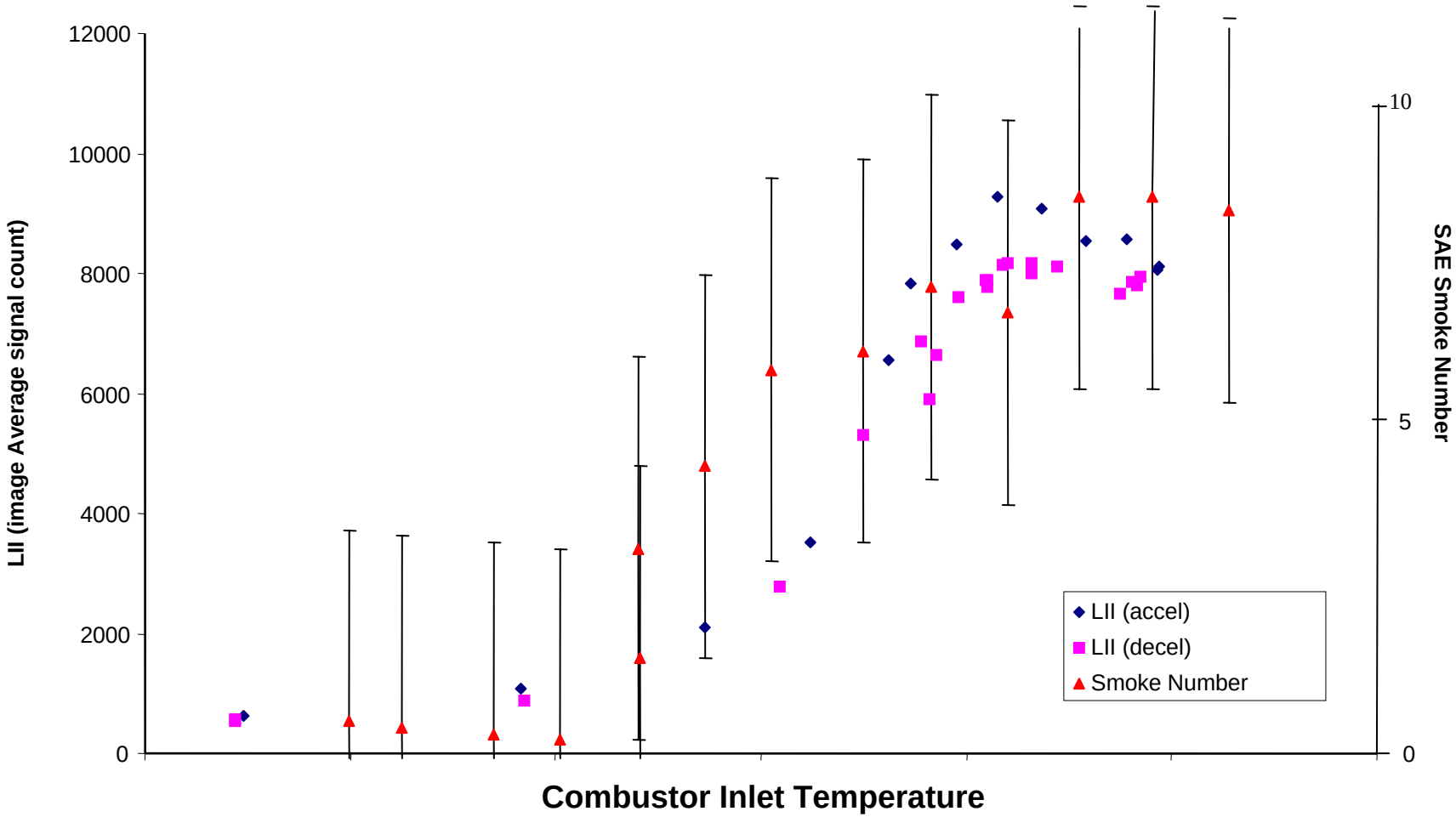
LII Equipment



Sample Results

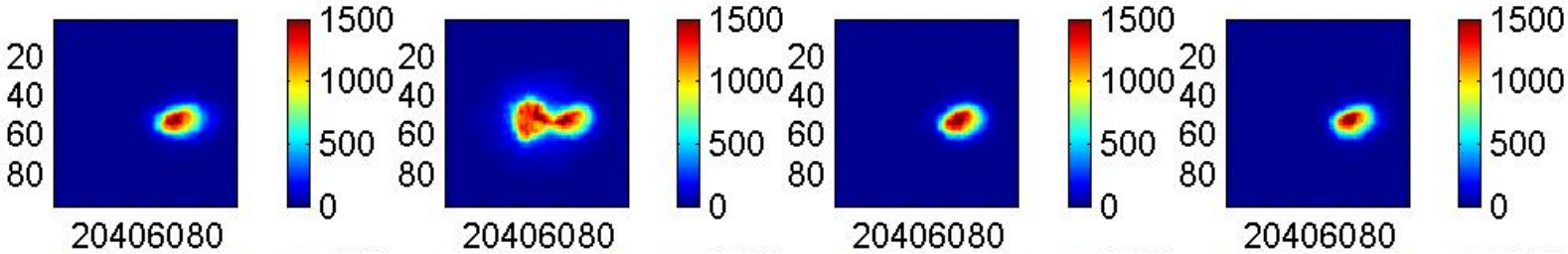


Comparison of LII and SAE Smoke Number

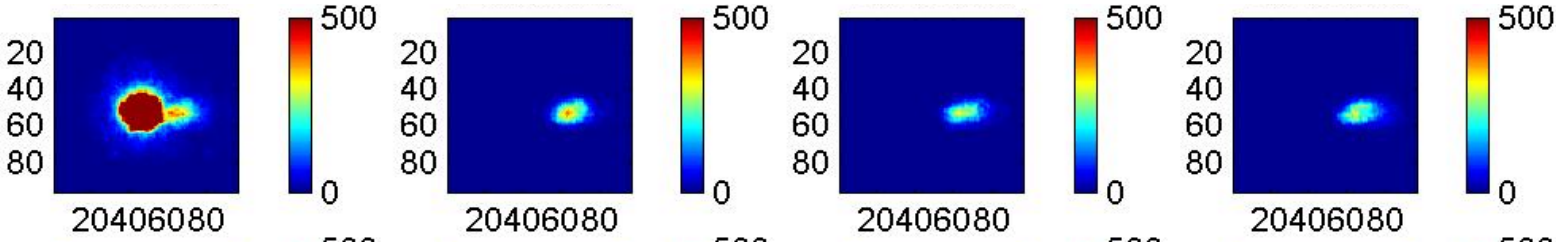


Engine Health Monitoring

- Unique images observed under some operating conditions
  - Transients – unburned fuel ‘spikes’



  - Oil seeded flow – simulated oil leak



Technical Challenges and Next Steps

- Finalise standard method for LII calibration to soot volume fraction
- Determination of soot mass emission rate
- LII signal from carbonaceous particles only – how to account for particulate VOC?
- Equipment installation in production engine test bed at R-R Derby