Diagnostics and Simulation of Sprays for Automotive Applications

Ronald O. Grover, Jr.
Staff Researcher

Tang-Wei Kuo
Lab Group Manager

Propulsion Systems Research Laboratory
General Motors Global Research and Development

Acknowledgement

GM R&D:

Experiment:

- Scott Parrish
- Ronald Zink
- Kevin Peterson
- Jerry Silvas

Modeling:

- Xiaofeng Yang
- Ramachandra Diwakar
- Jian Gao

External University Collaborations:

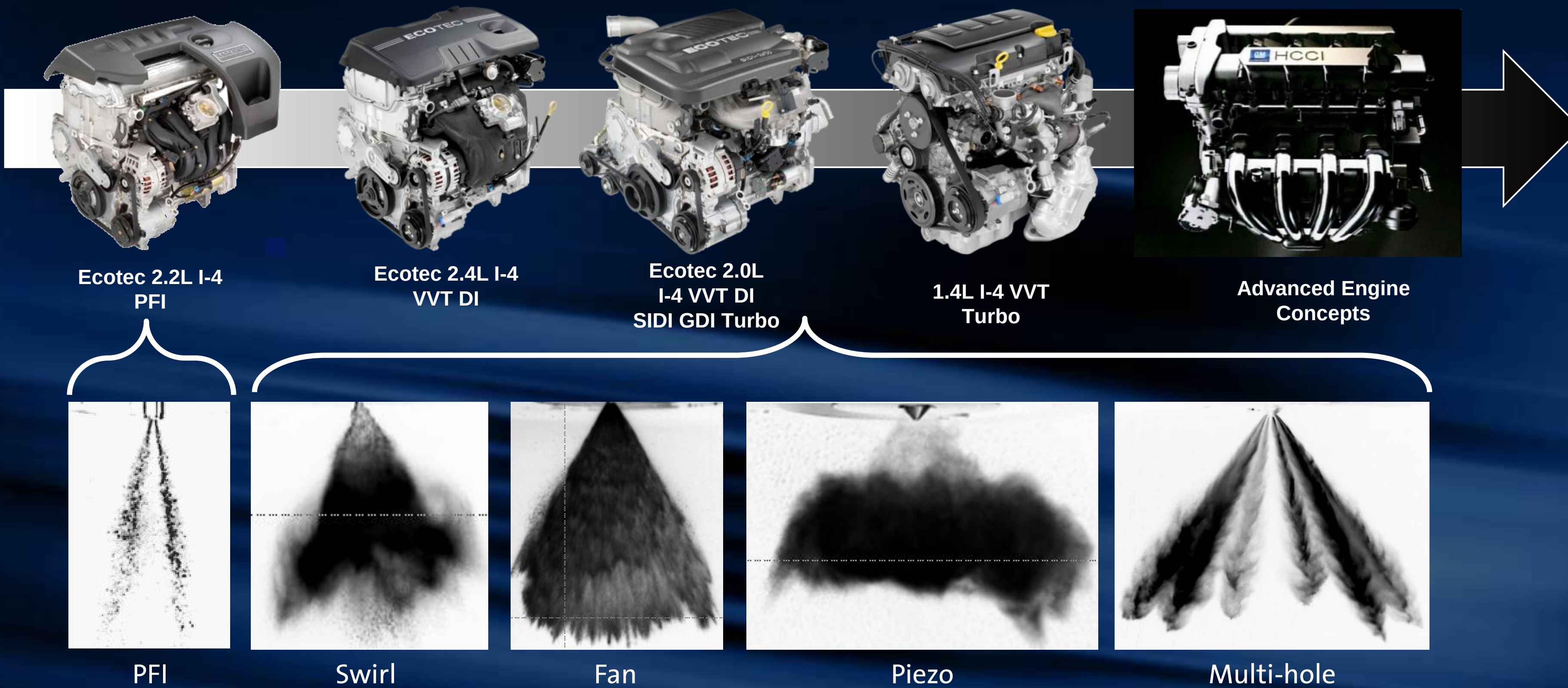
Experiment:

- Profs. Min Xu, David Hung (SJTU)
- Prof. Raul Payri (CMT,Valencia)

Modeling:

- Prof. David Schmidt (Univ. of Massachusetts- Amherst)
- Prof. Rolf Reitz (UW-Madison)
- Prof. Chris Rutland (UW-Madison)

Sprays Integral to DI Engine Technology Evolution

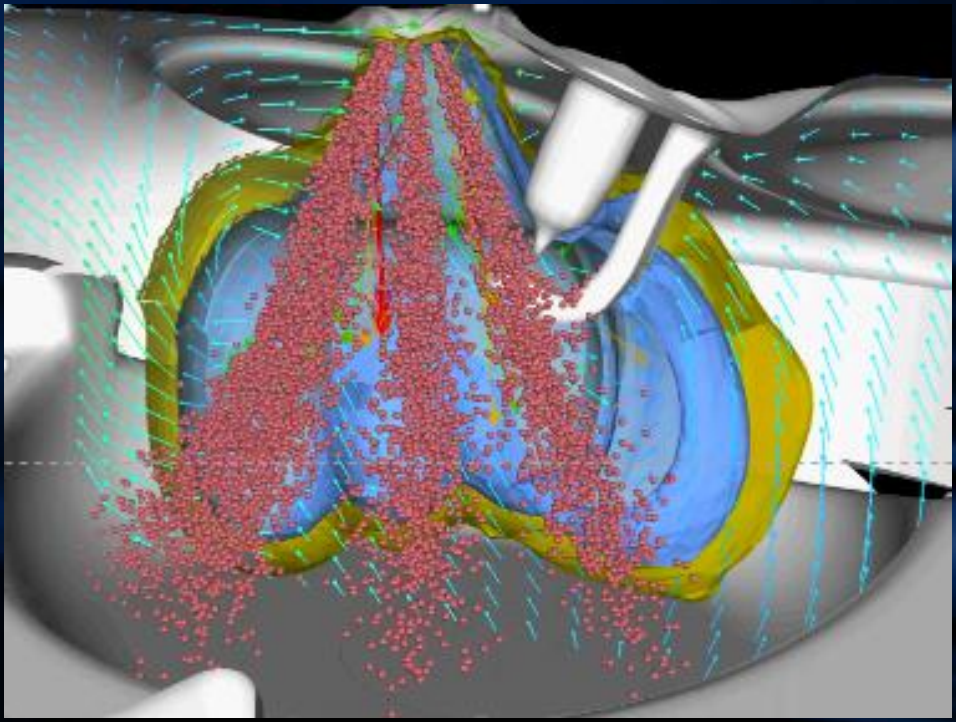


Pathway to advanced combustion strategies

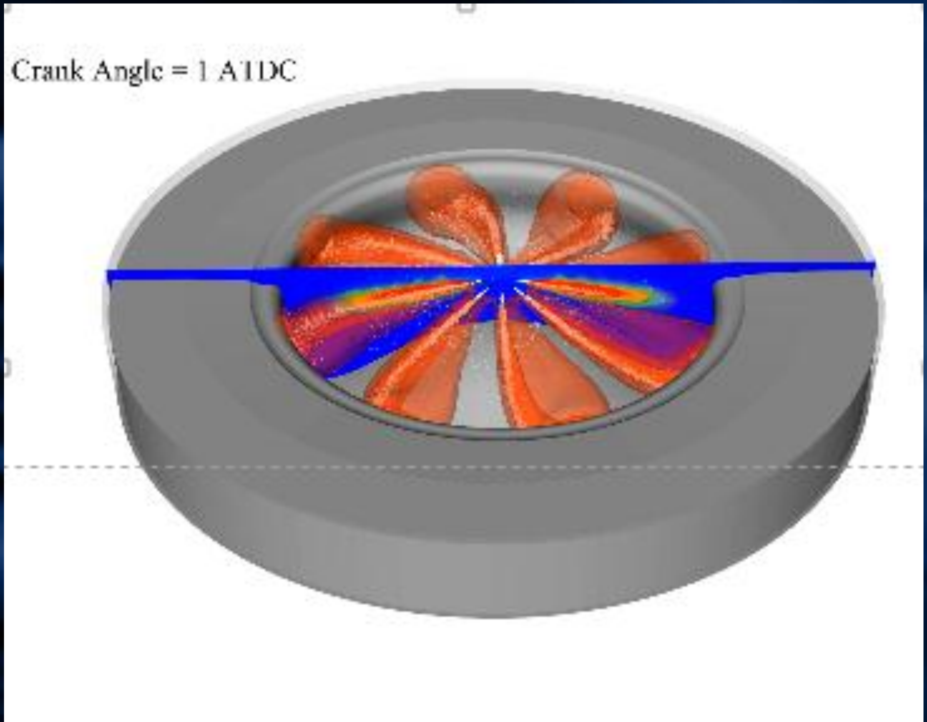
1. High resolution experiments (i.e., optical diagnostics)
2. Validated high-fidelity computational models (i.e., CFD)
3. In-depth understanding of complex physics → engine design

DI Engine Combustion Strategies

Gasoline Spray-Guided Combustion

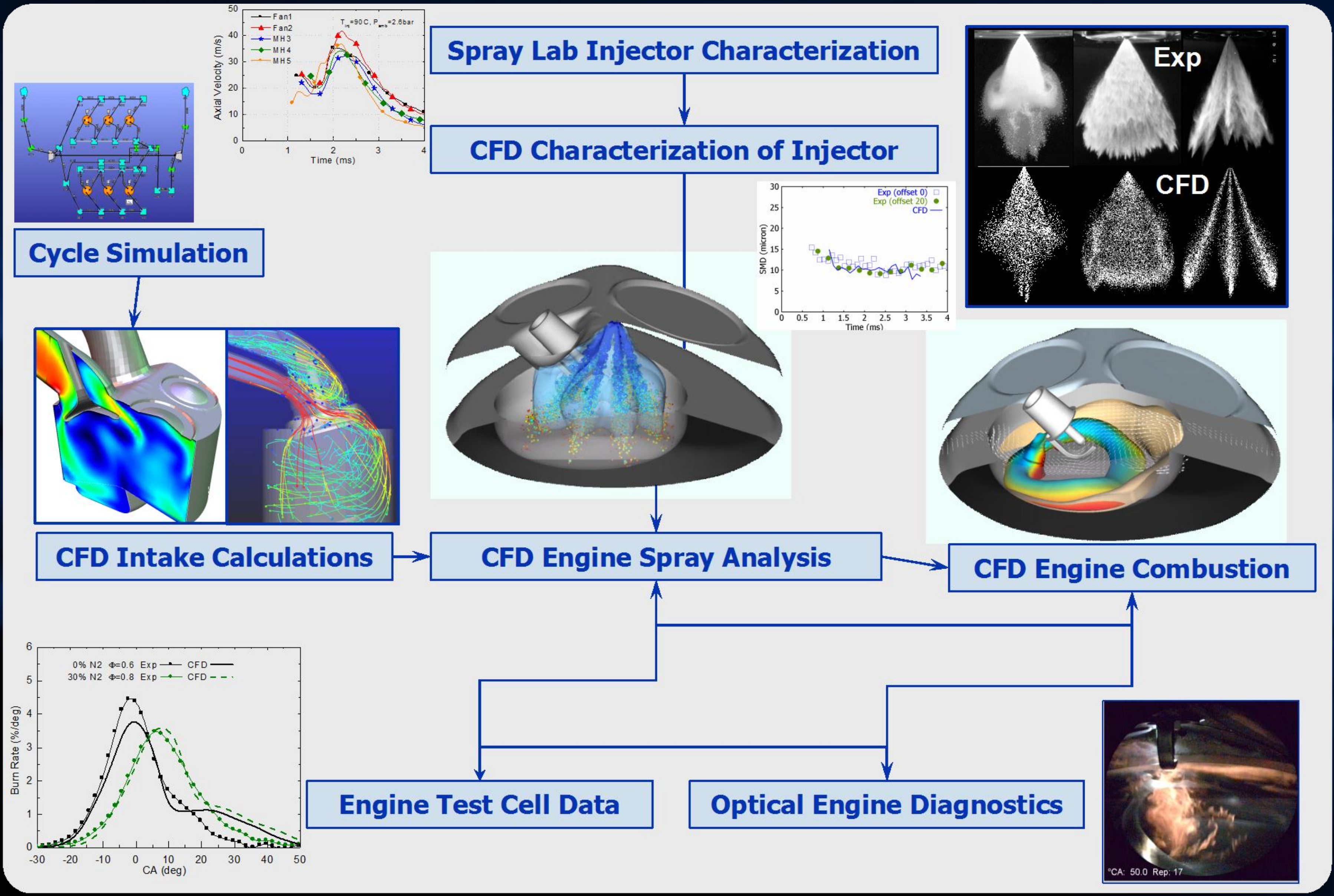


Diesel Combustion



Smyth, et al., FISITA, 2006

Integrated Advanced Engine Development



Smyth, et al., FISITA, 2006

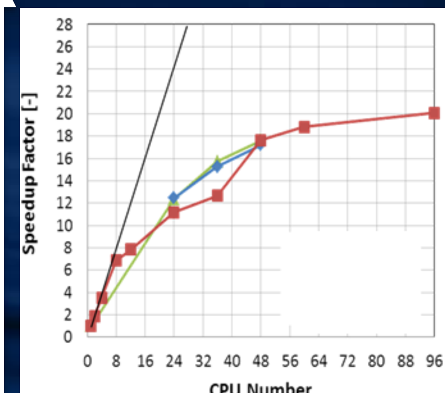
Advancements in HPC for IC Engine Development

Restricted to large number of simultaneous simulations on LCF Platforms

Desired pathway for enhanced solver scalability to enable high-fidelity simulations with acceptable turnaround time

1-2 day turnaround (future roadmap)

Sub-model development



- Single Cycle RANS
- Empirical spray and combustion
- Reduced chemistry
- Extensive trial and error

- Multi-cycle LES, cyclic variability
- Resolution of dense spray region
- Large kinetic mechanisms
- Fast flow & chemistry solvers
- Mesh independence
- Optimization

Desired Roadmap

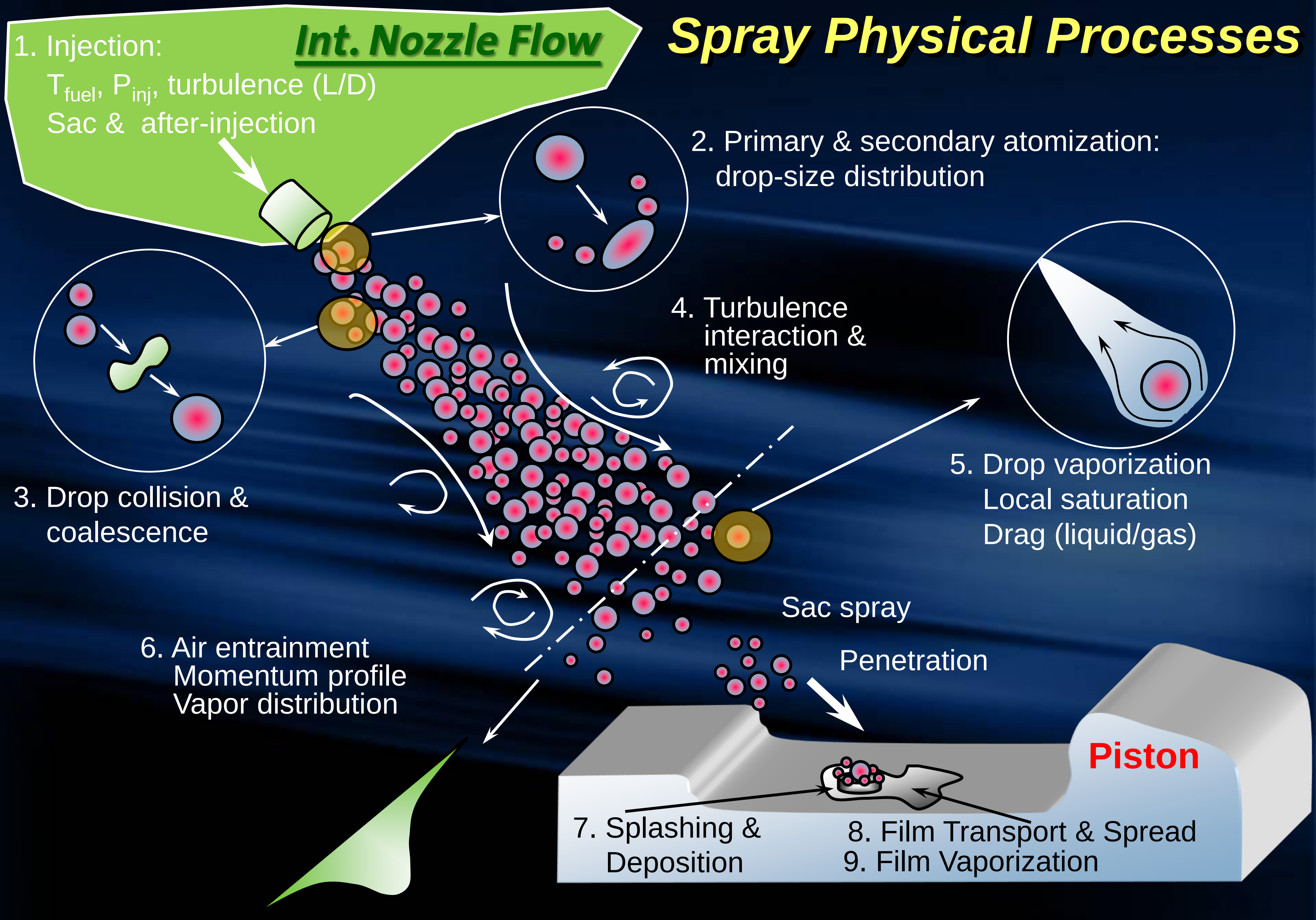
Present status

1cpu | ~10's cpus | ~100's cpus | LCF

Solver Scalability

Significant opportunity for HPC to lead the advancement in predictive IC engine simulations

Spray Physical Processes



Transient Needle Motion with Cavitation

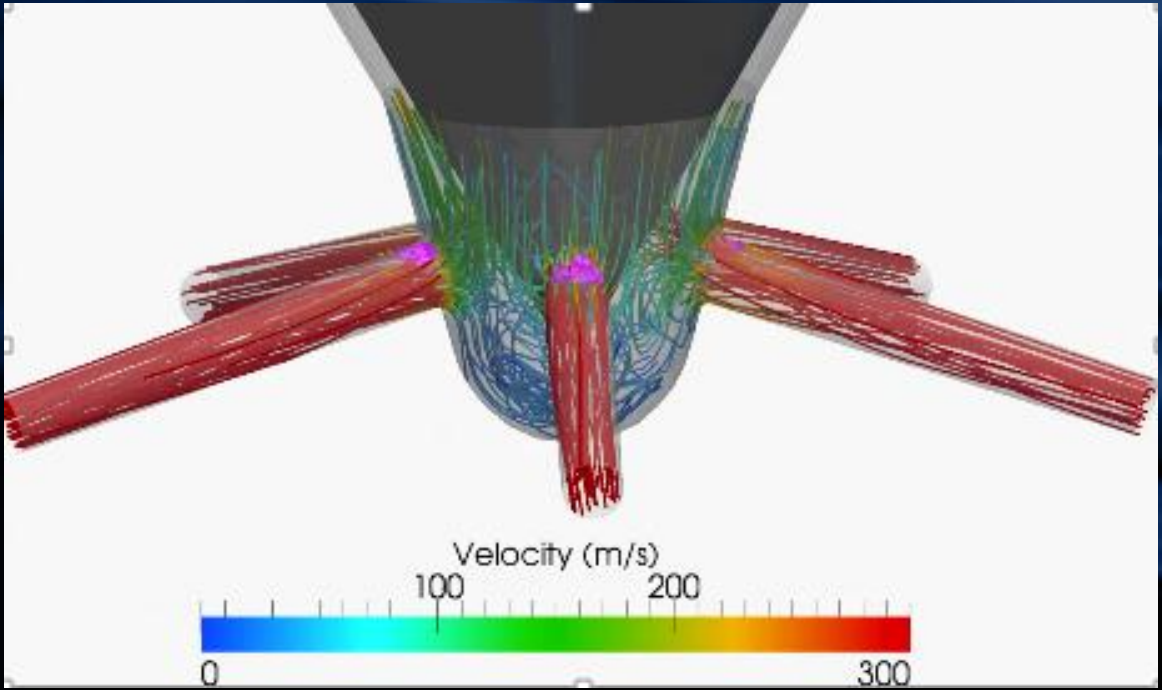
Lower lifts

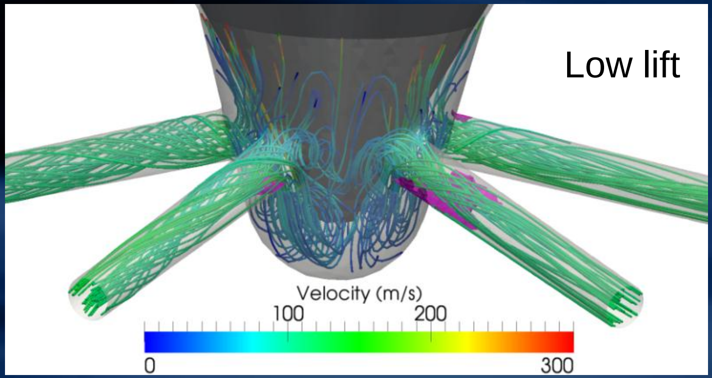
- Swirling flow in nozzle affected by flow in sac
- Transient and asymmetric vapor formation

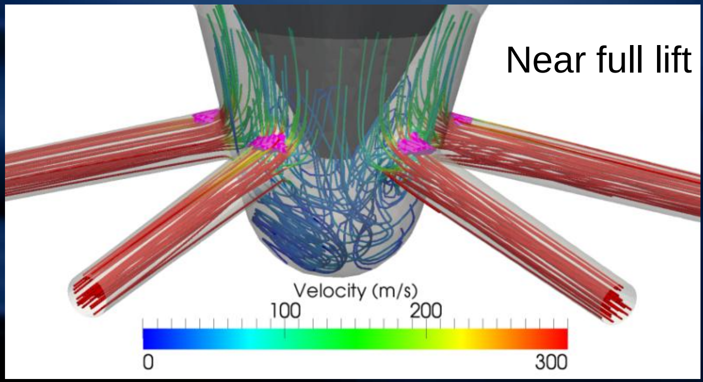
Higher lifts

- Nozzle flow is more ordered with symmetric vapor formation

P_{inj} (bar)	P_{bck} (bar)	Pulse width (ms)
782	20	1





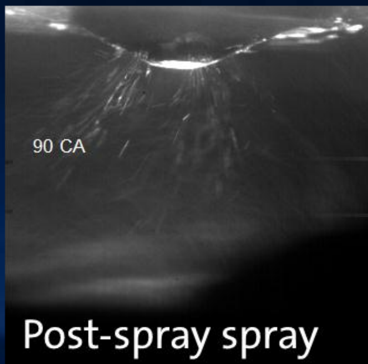


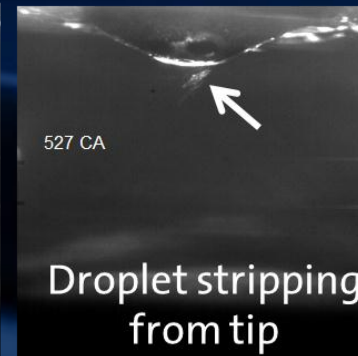
Pink sections near nozzle entrance show vapor

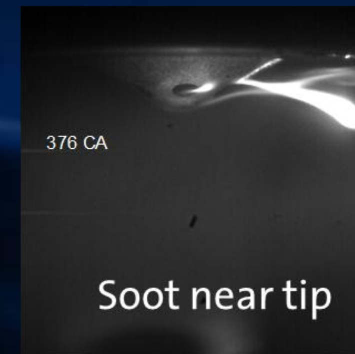
Neroorkar, et al., ILASS, 2012

Influence of Nozzle Internal on the External Spray

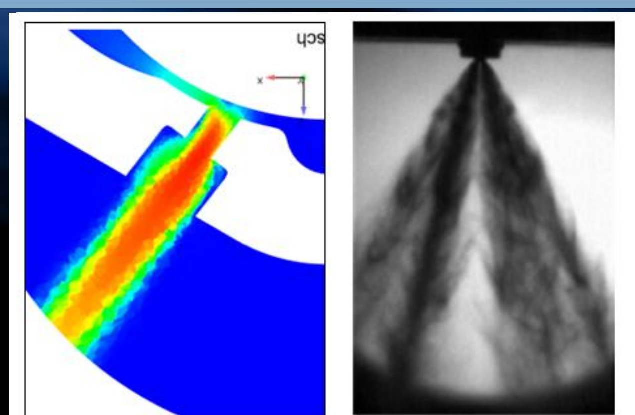
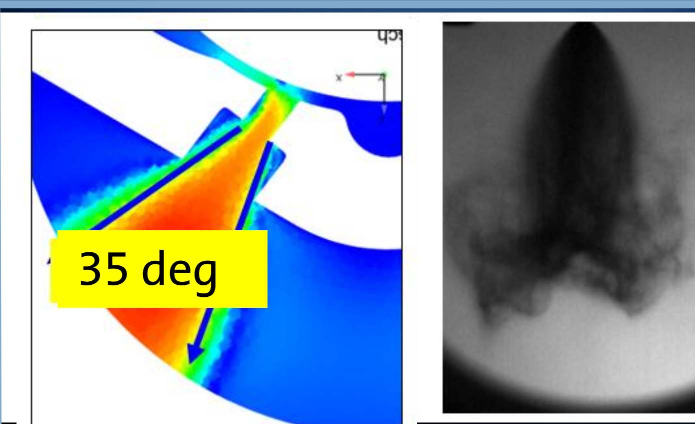
1. Injector Tip Wetting Mechanisms





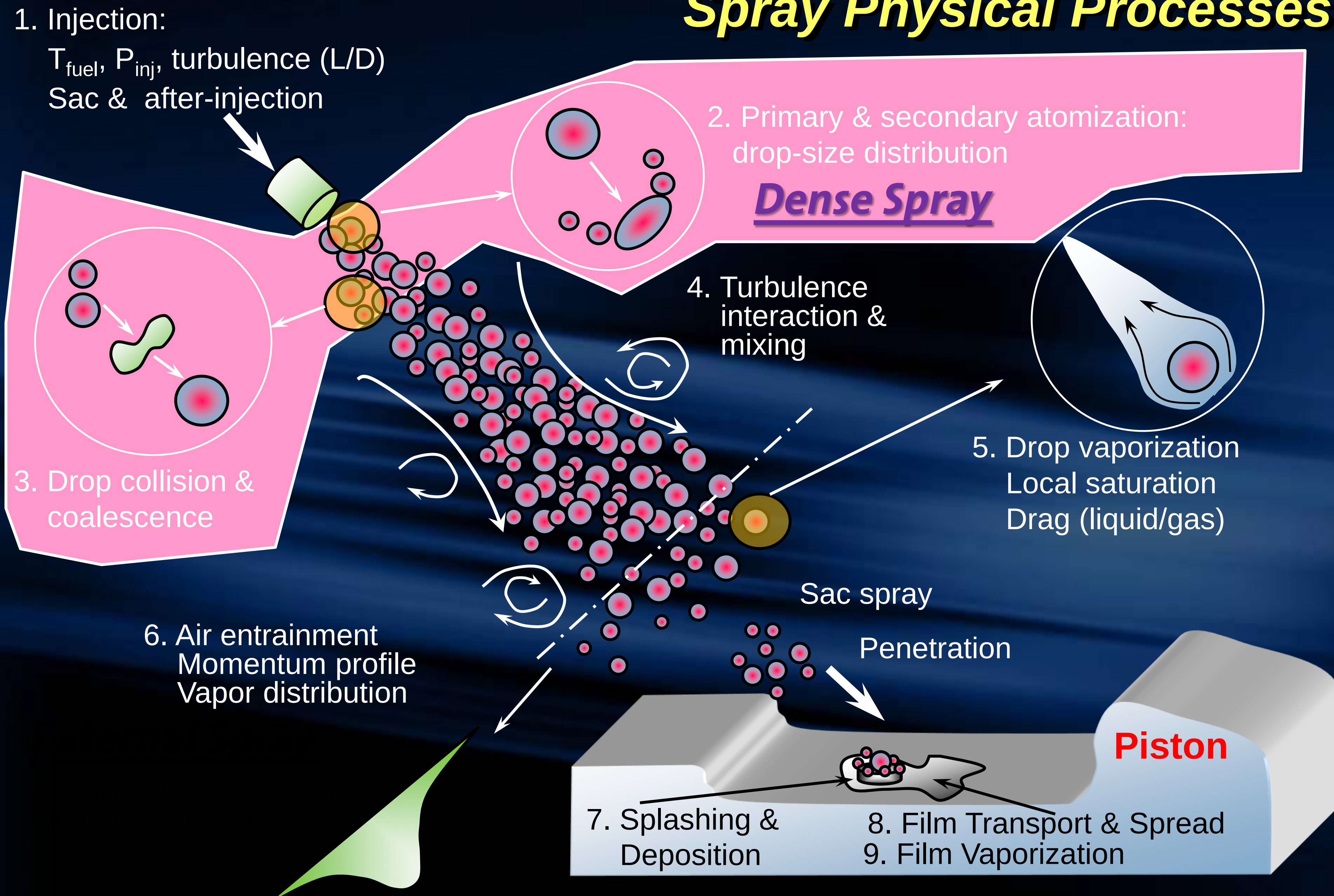


2. Spray Collapse under Flash-Boiling Conditions

	Non flash: 100 KPa/20C	Flash: 40 KPa/90C
		

Peterson, et al., Baden-Baden, 2014

Spray Physical Processes



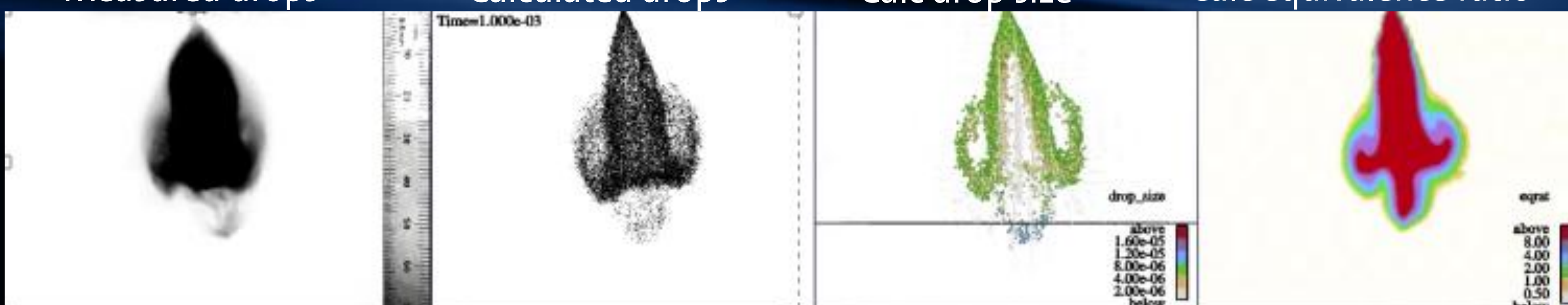
Measured vs Simulated Sprays

Typical spray behavior

Measured drops | Calculated drops | Calc drop size | Calc equivalence ratio

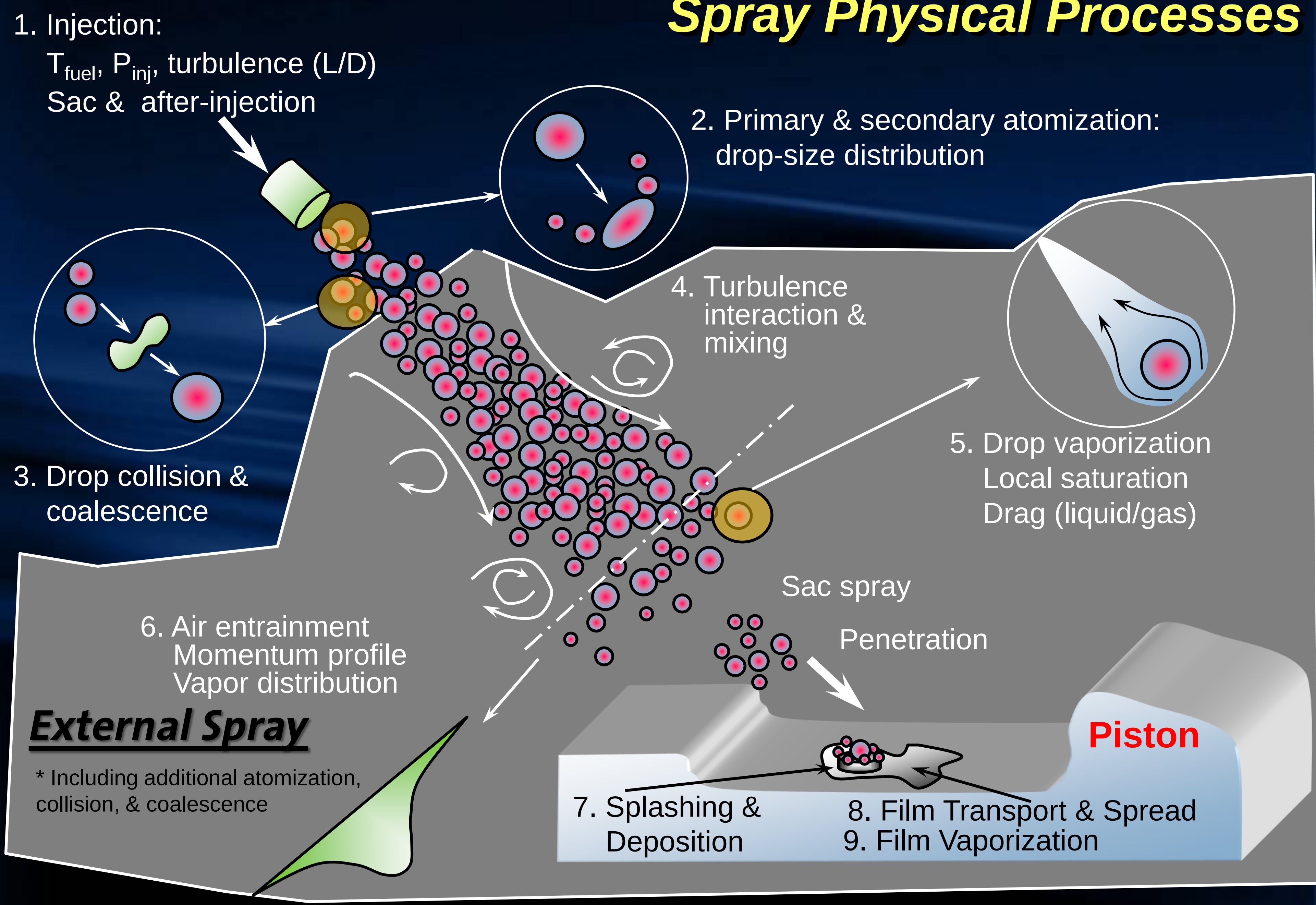
Flash boiling spray behavior

Measured drops | Calculated drops | Calc drop size | Calc equivalence ratio



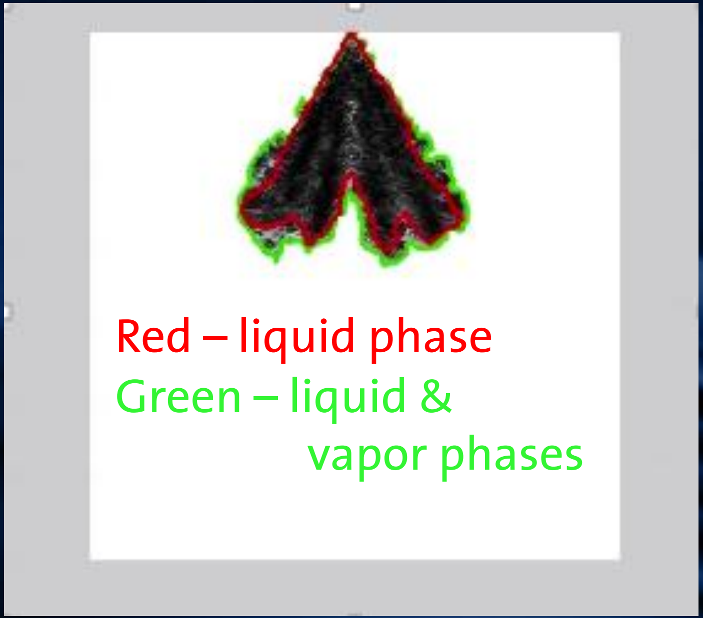
Smyth, et al., FISITA, 2006

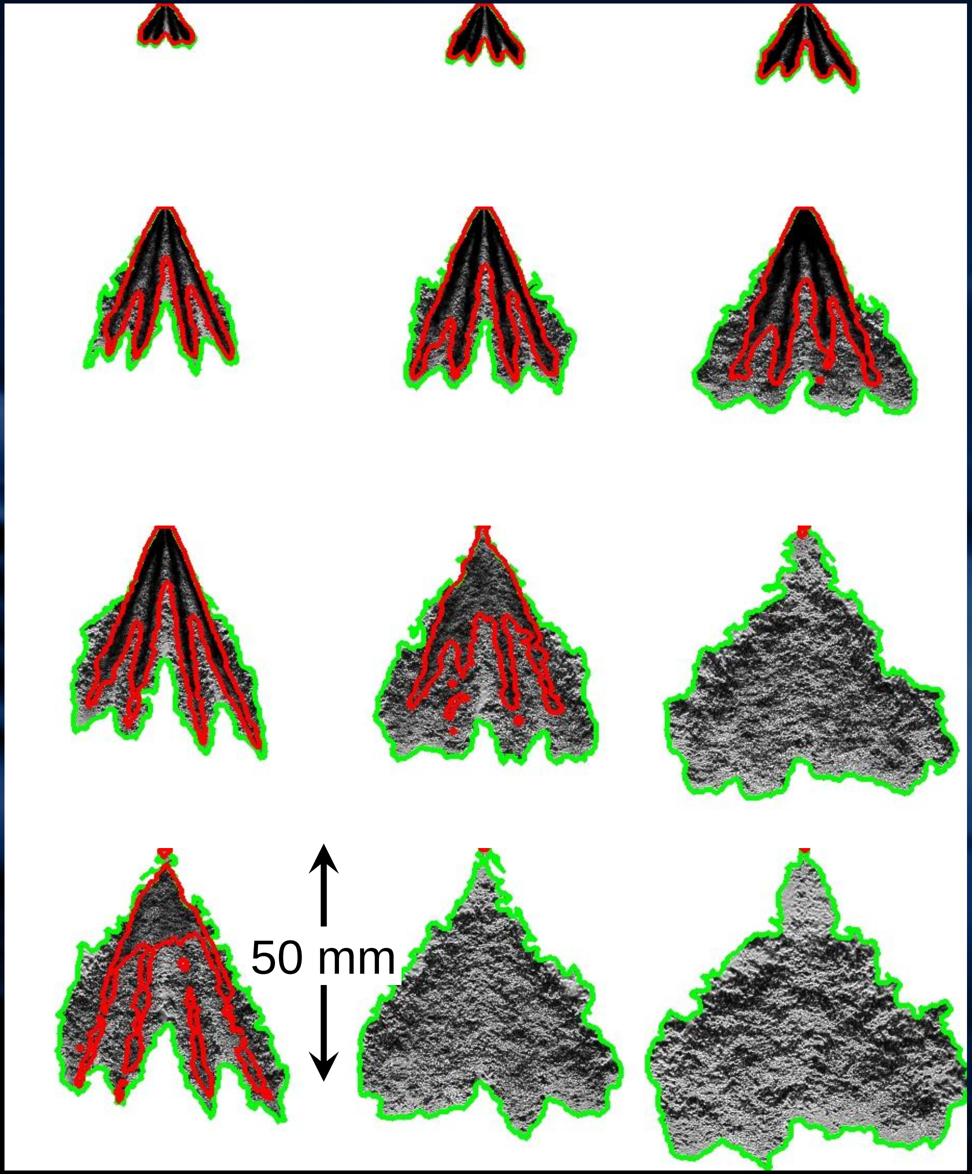
Spray Physical Processes



Near Simultaneous Liquid and Vapor Phase Overlays – Mie Scattering / Schlieren Imaging

P_{inj}=20 MPa





0.5 ms

1.0 ms

1.5 ms

2.0 ms

5 MPa | 10 MPa | 20 MPa

<u>Operating Conditions</u>

- Indolene (multi-component gasoline)
- Injected mass: 10 mg
- Fuel pressures: 5, 10, 20 MPa
- Fuel temperature: 90º C
- Ambient pressure: 500 kPa
- Ambient temperature: 800º K

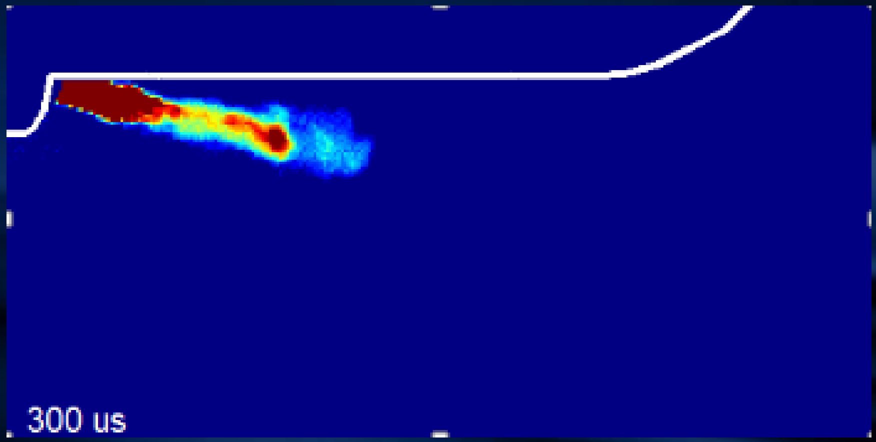
Parrish, Int. Conf. on Eng. & Veh., 2013

High-Speed Mie Scattering & LIF

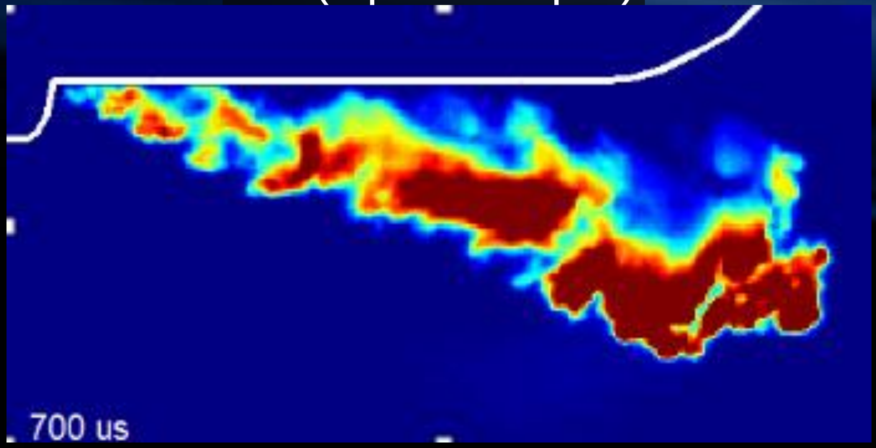
Inj. mass: 3.5 mg, Fuel press: 1500 bar, Fuel temp: 90º C, Ambient press: 60 bar, Ambient temp: 900º K

Individual Cycles

Mie Scattering (liquid only)

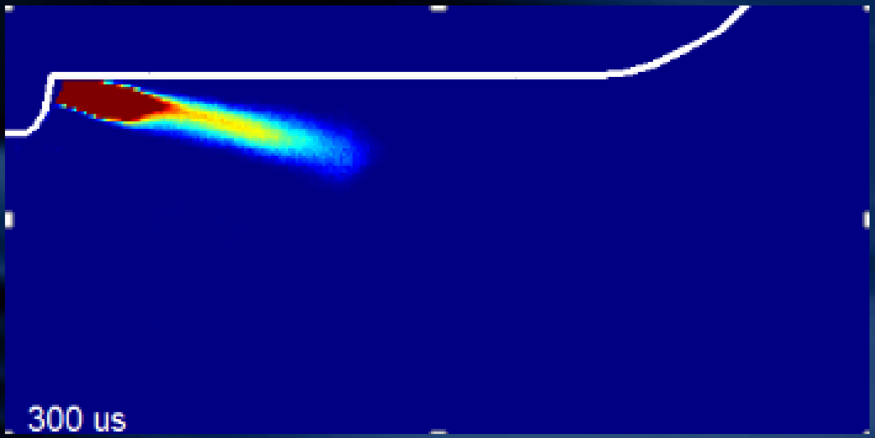


LIF (liquid & vapor)

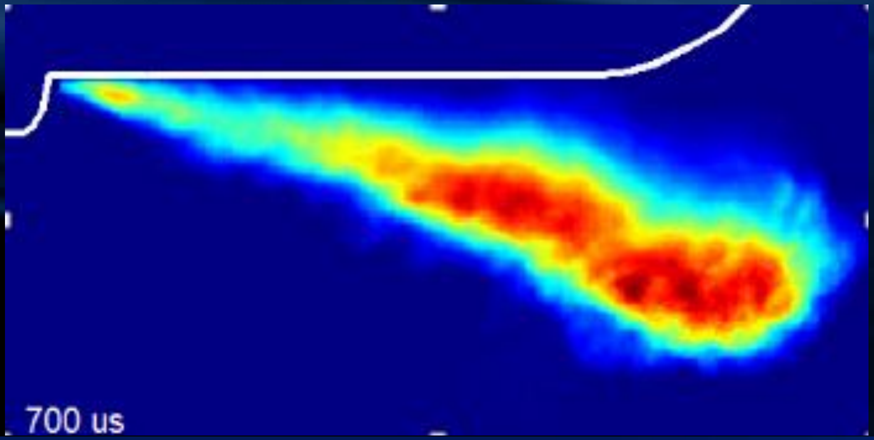


25 cycle Average

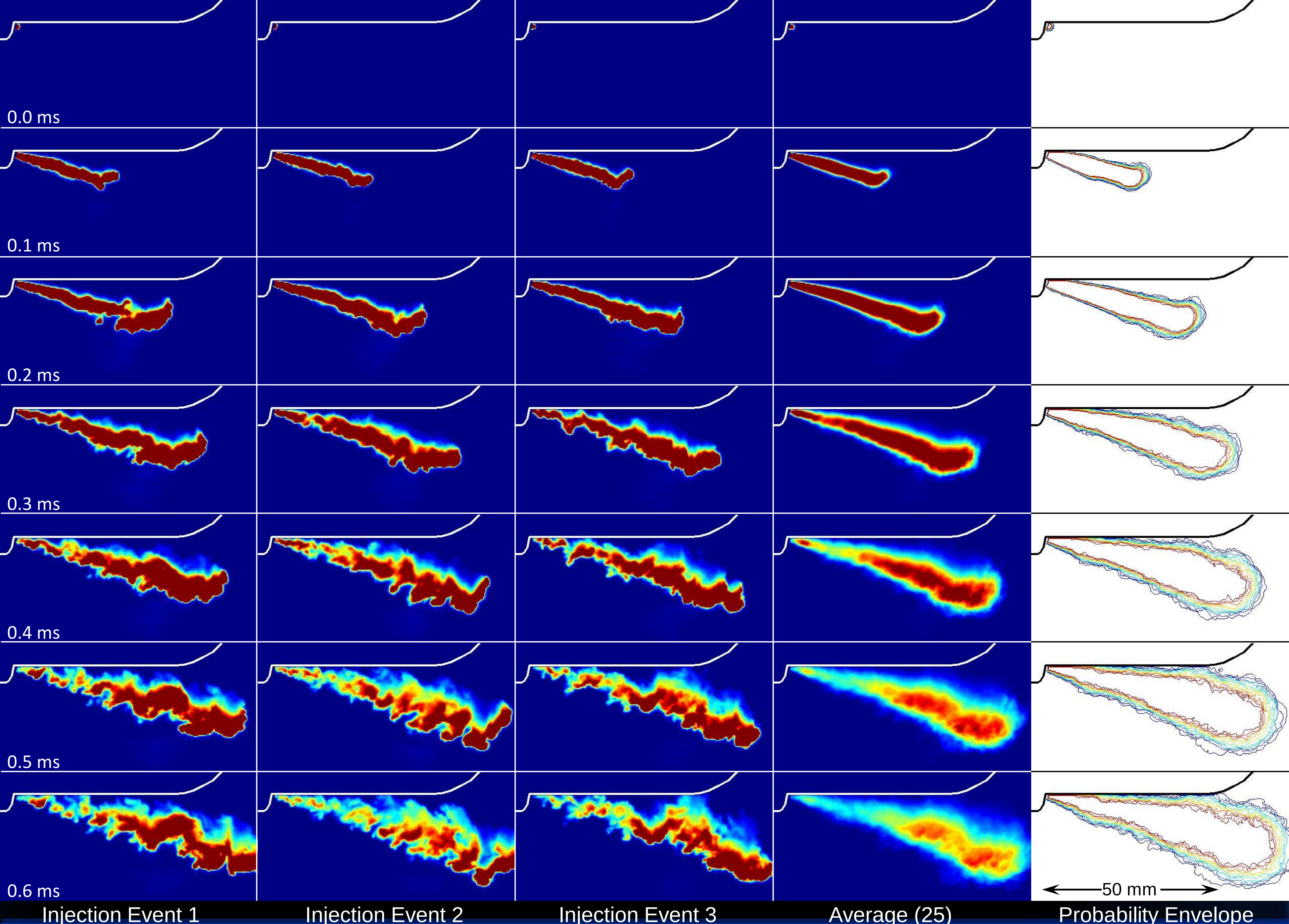
Mie Scattering (liquid only)



LIF (liquid & vapor)



Parrish, ICE 2013 - 11th International Conference on Engines and Vehicles, Capri, Italy, September 15-19 2013



Parrish & Zink, *Meas. Sci. Technol.* 24

Power of Validated Modeling Toolsets

Design Direction

Upfront design & screening of options

Evidence to support hardware & calibration changes in the engine

Physical Insight

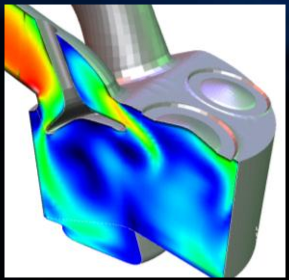
In-depth insight of in-cylinder mixture preparation and combustion drivers (also jointly with experimental testing)

"Out-of-the-Box" Ideas

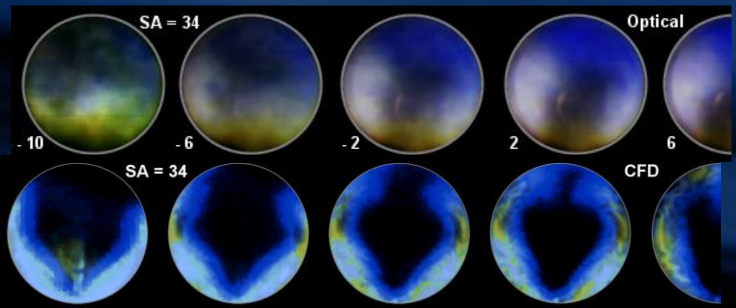
Suggest hardware/calibration options outside of the current matrix that could significantly improve the product

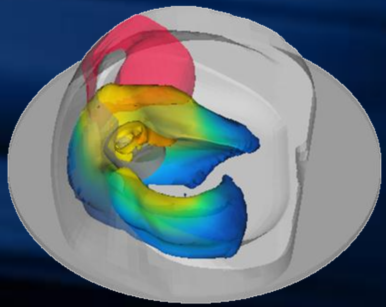
Correlations

Identify CFD "indicators" that provide a relationship between key measured and computed quantities



GM 3.6L
V-6 VVT DI





Thank you
for your attention

GM R&D