Non-Sooting, Low Flame Temperature Mixing-Controlled DI Diesel Combustion

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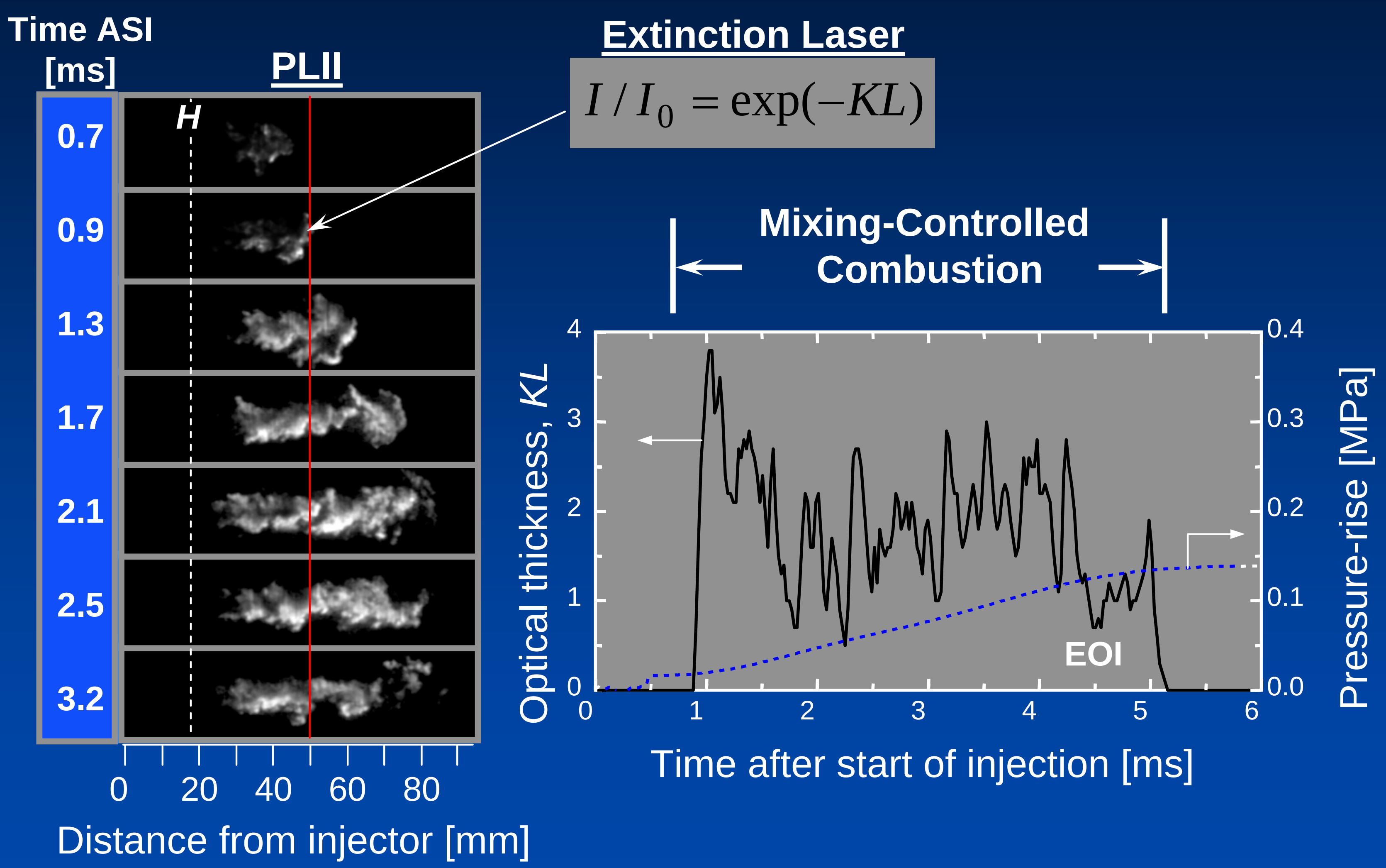
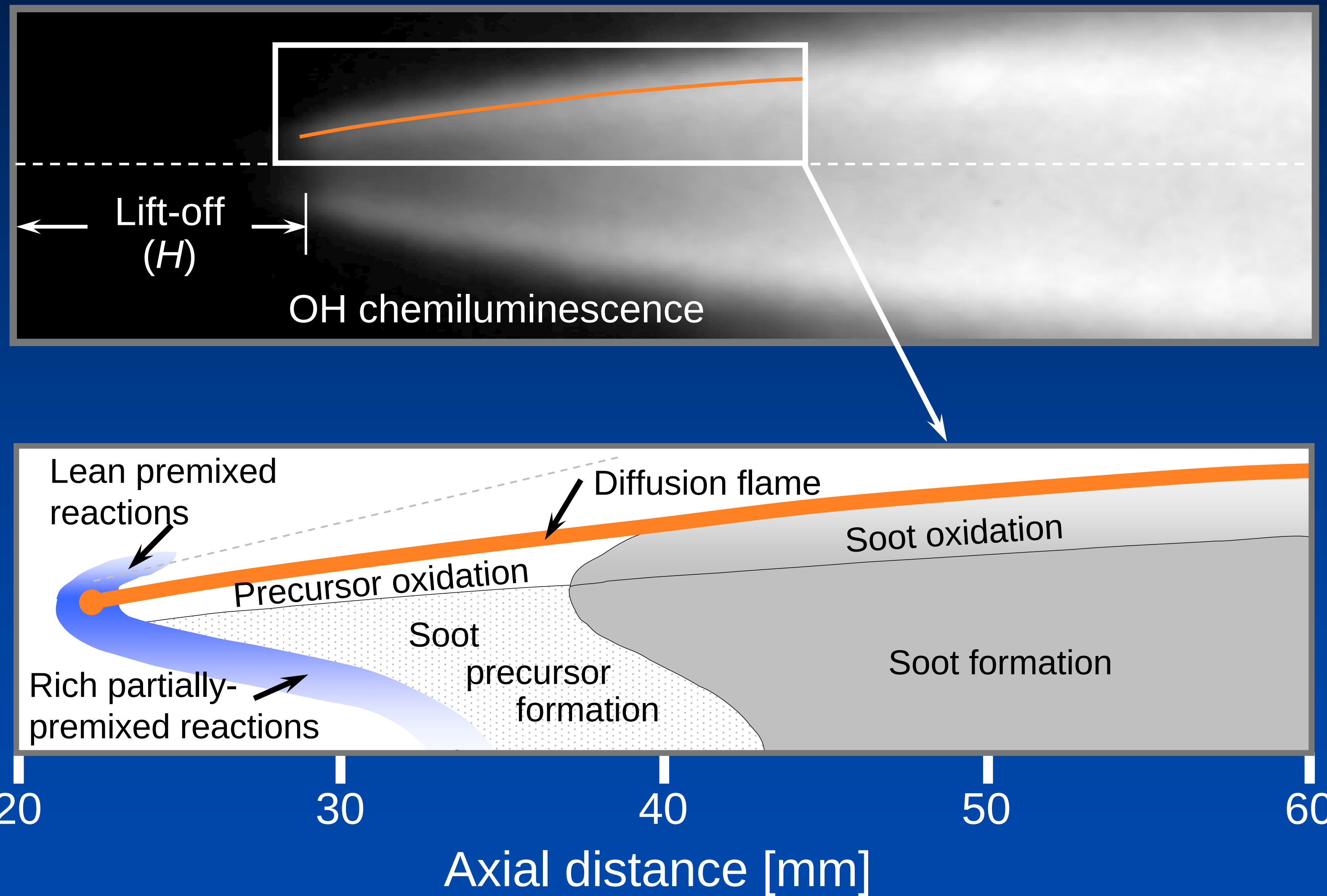
Soot formation during typical diesel combustion:



NOx formation is high during mixing-controlled diesel combustion.

Heat release during mixing-controlled combustion

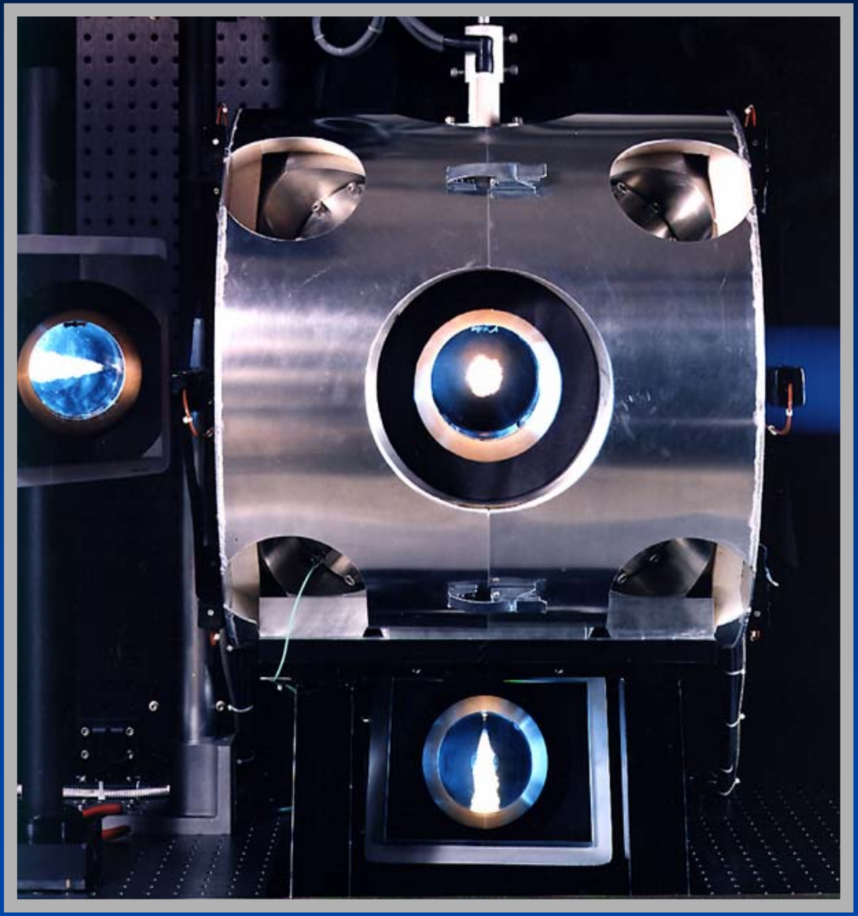


Is mixing-controlled diesel combustion with low emissions possible?

- Diesel operation with mixing-controlled combustion may be needed/desired:
  - Offers more control of heat release timing.
  - Typically used during high load operation.

- Objective: Investigate soot processes at low flame temperature, mixing-controlled combustion conditions:
  - Low oxygen concentration (EGR) and other low flame temperature operation.
  - Identify non-sooting conditions that also have low flame temperature.

Research was conducted in a unique, optically-accessible combustion vessel.

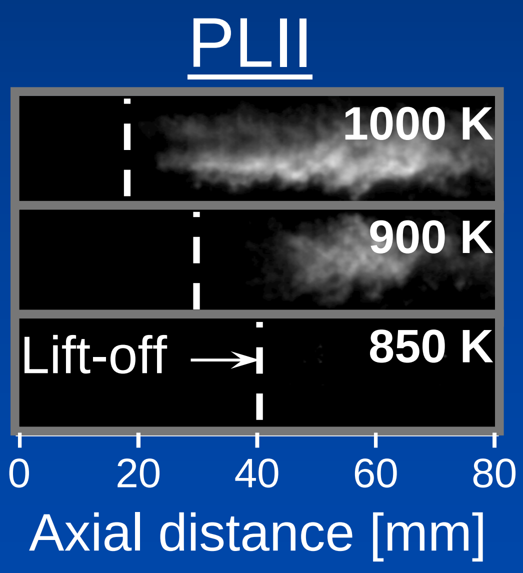


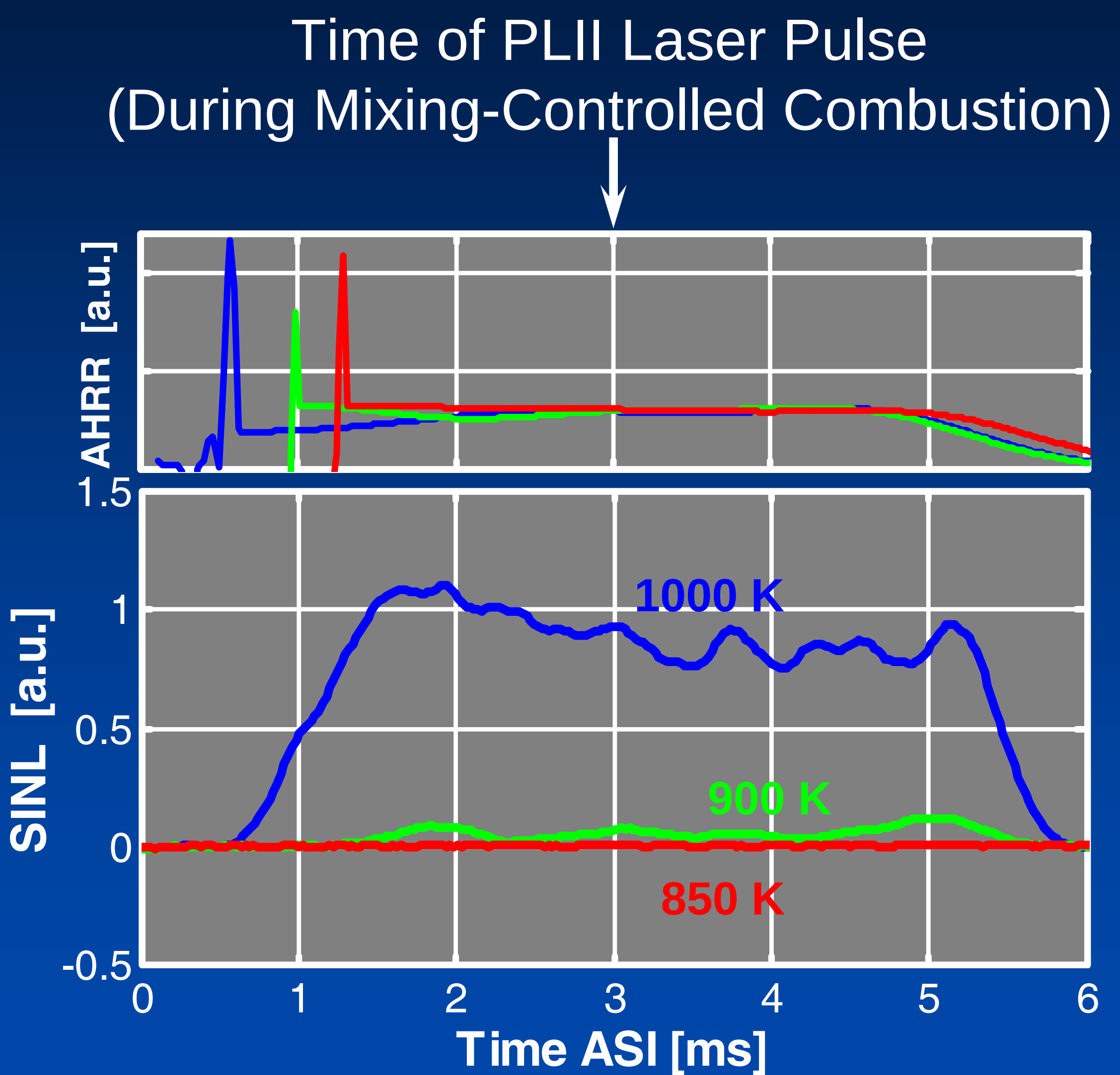
- Ambient gas conditions:
  - 800 - 1300 K.
  - 7 - 60 kg/m^3.
  - O_2 conc.: 10-21% (EGR).
- Common-rail fuel injector:
  - orifice tips from 50 -180 μm.
  - D2 (#2 diesel fuel)
  - T70 (70%-TEOP, 30%-HMN) [21.5 wt% O]
- Measurements performed:
  - soot
  - lift-off length

A “no-soot” condition is obtained when the ambient gas temperature is decreased.

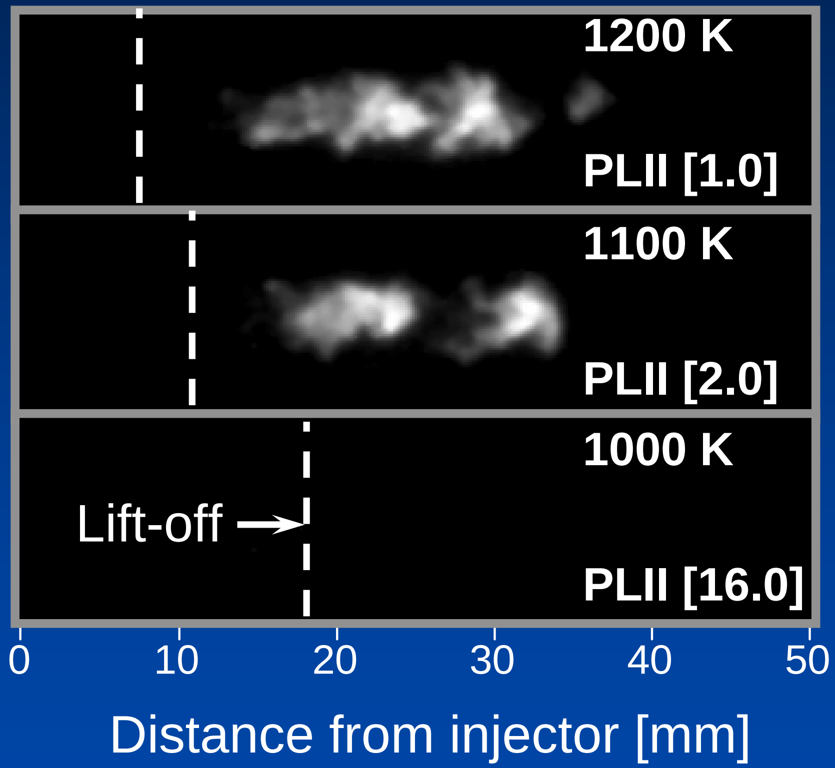
Conditions:

- ρ_a: 14.8 kg/m^3
- ΔP: 138 MPa
- d: 100 μm
- Fuel: D2
- O_2 %: 21%





The temperature at which soot does not form is much higher for a "micro-orifice".

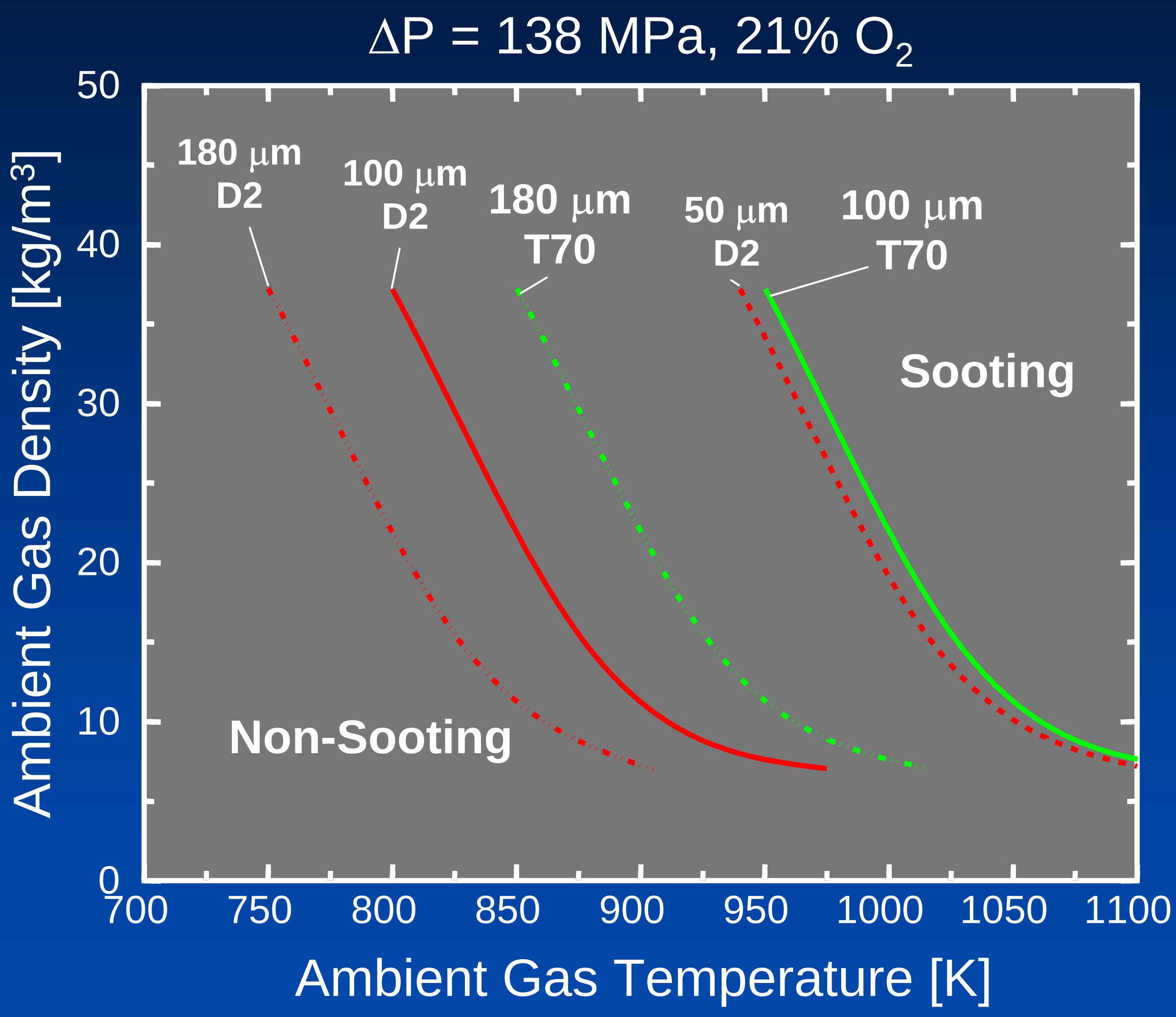


Conditions:

- ρ_a: 14.8 kg/m^3
- ΔP: 138 MPa
- d: 50 μm
- Fuel: D2
- O_2 %: 21%

T_a [K]	H [mm]	$\bar{\phi}(H)$
1200	7.4	4.2
1100	10.9	2.7
1000	18.1	1.6

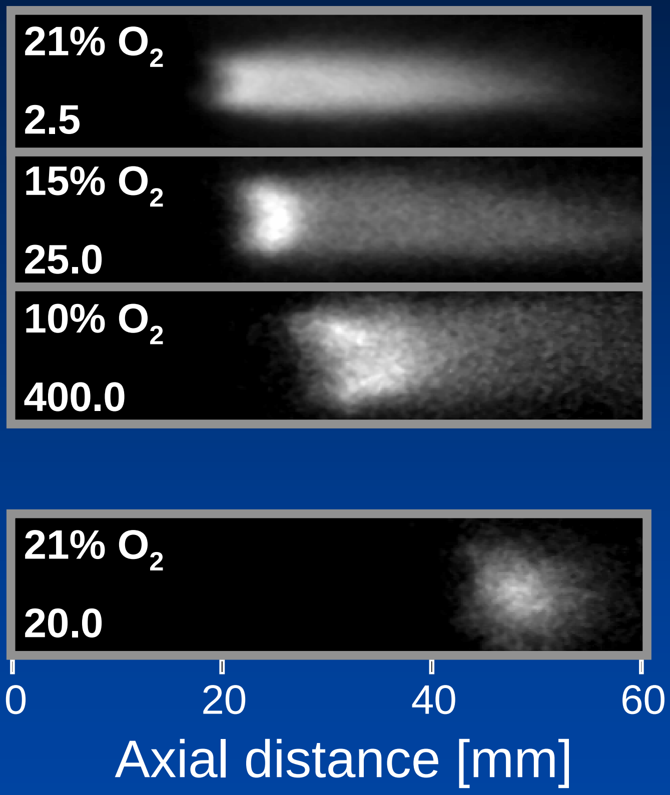
Mixing-controlled, non-sooting operating conditions:



Mixing-controlled, low flame temperature strategies:

- Reduced ambient oxygen concentration (simulating EGR)
  - no soot formation
  - $\phi(H) \approx 2$
  - 10% O_2: T_{ad} = 1940 K
- Reduced ambient temperature
  - Creates a lean-burn steady flame
  - $\phi(H) \approx 0.6$
  - Avoids formation of a diffusion flame
  - T_{ad} = 2040 K

OH Chemiluminescence



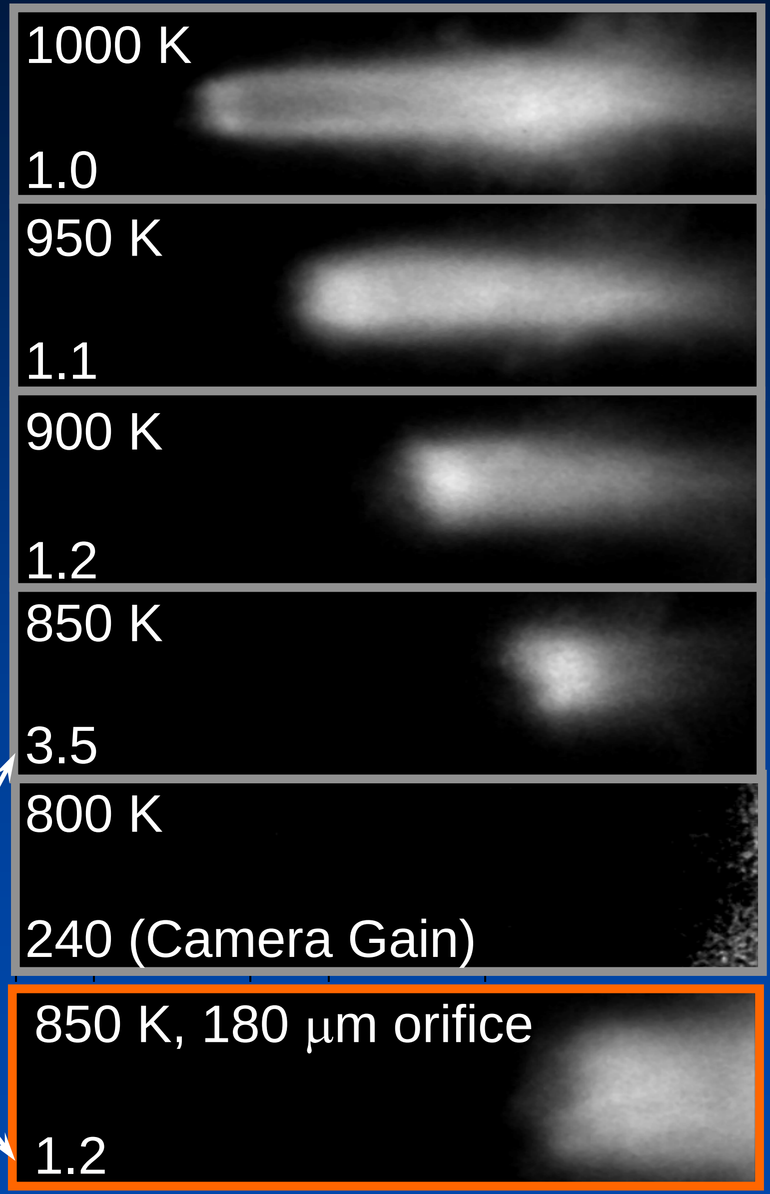
Conditions:

- ρ_a: 14.8 kg/m^3
- T_a: 1000 K
- ΔP: 138 MPa
- d: 50 μm
- Fuel: D2

- T_a: 850 K

Using an oxygenated fuel (T70), lean-burn combustion occurs with a larger orifice:

Conditions
T70 fuel
time-averaged OH*
d = 100 μm
ρ = 14.8 kg/m^3
ΔP = 138 MPa
O_2 % = 21%



$\bar{\phi}(H) = 2.2$

$\bar{\phi}(H) = 1.5$

$\bar{\phi}(H) = 1.0$

$\bar{\phi}(H) = 0.7$

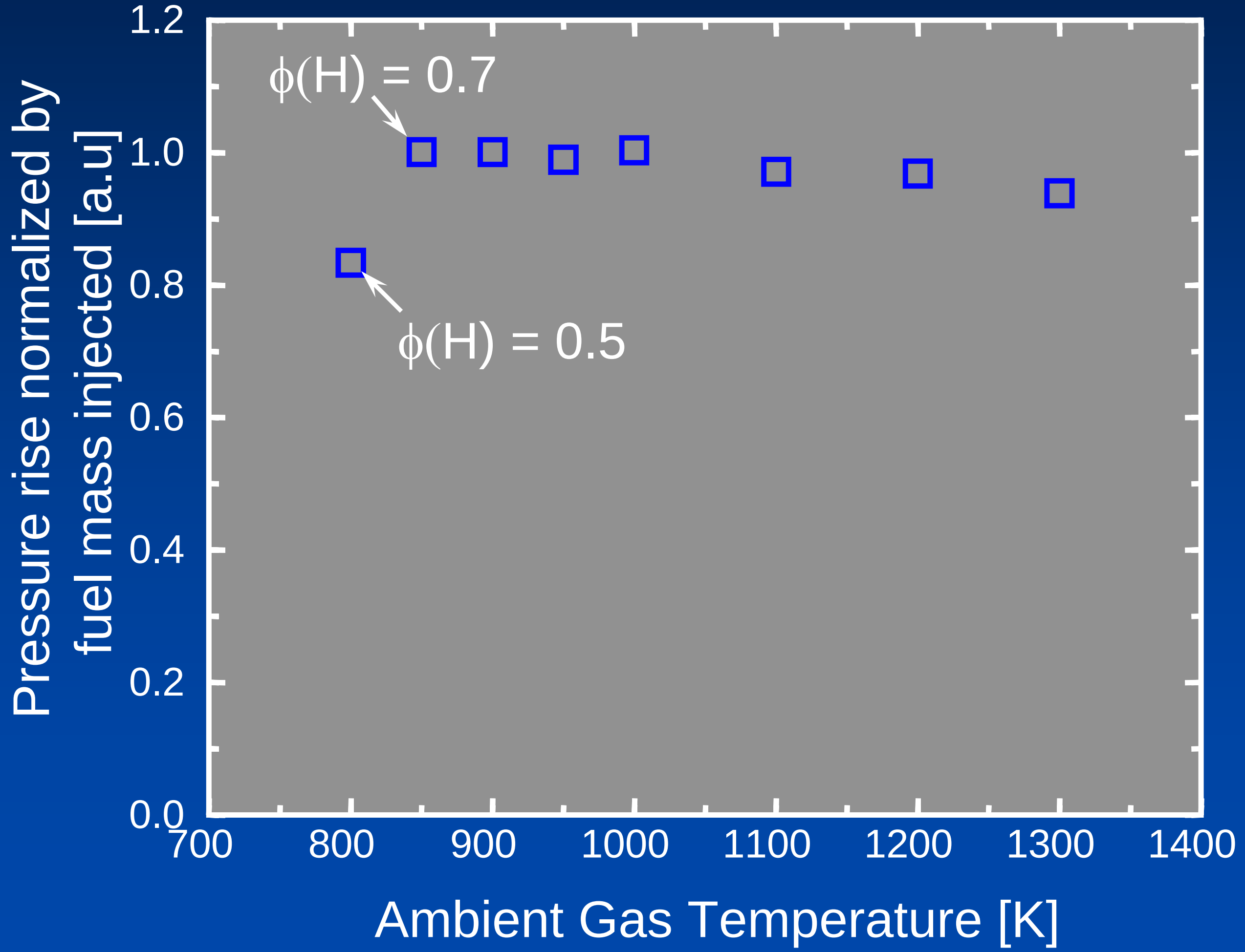
$\bar{\phi}(H) = 0.5$
T_{ad} = 1830 K

$\bar{\phi}(H) = 1.2$

Chemiluminescence is a factor of 3 weaker for fuel-lean combustion indicating lower flame temperature.

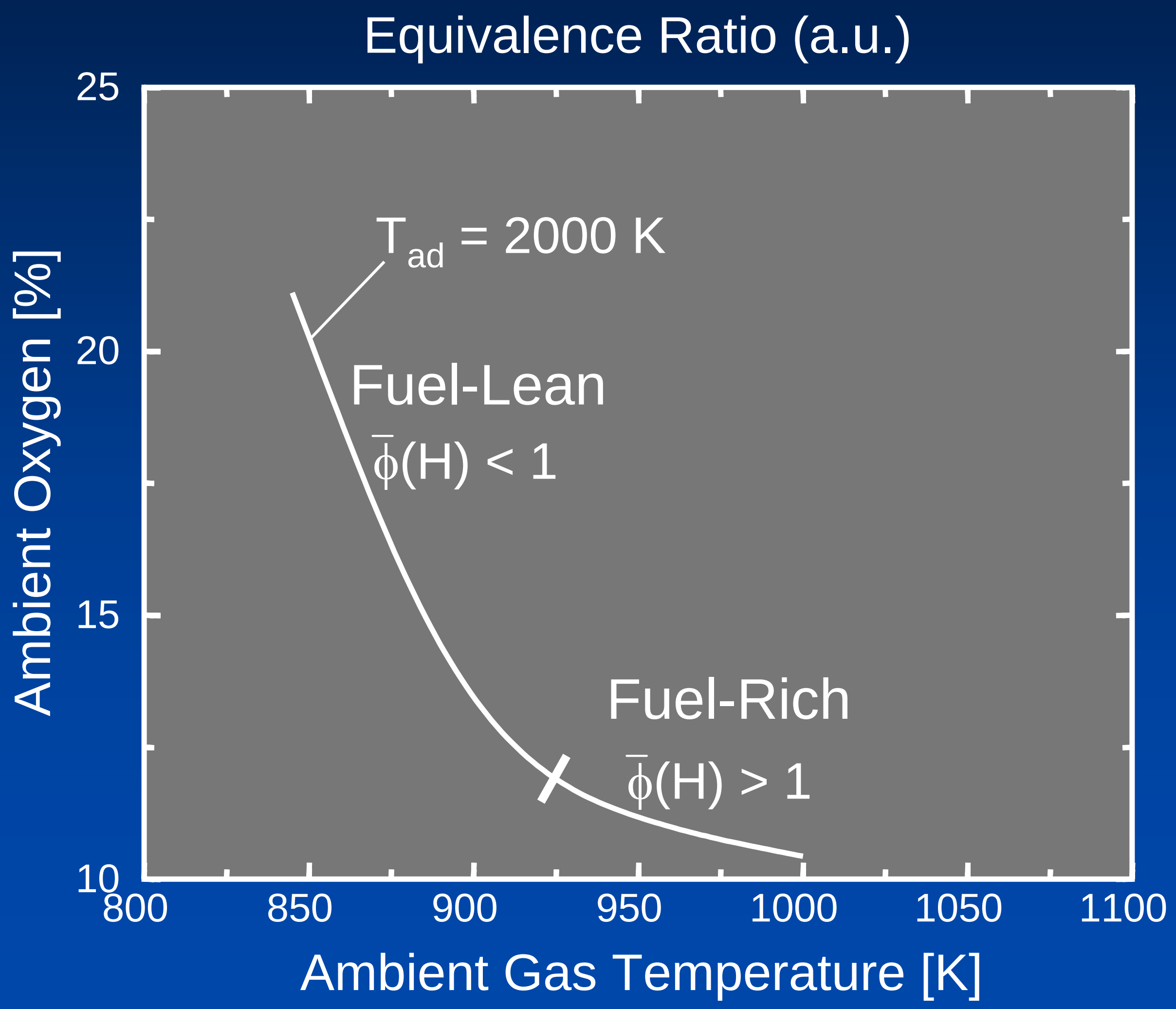
Combustion efficiency appears acceptable for a range of lean-burn conditions.

Conditions: T70 fuel, d = 100 μm, ρ = 14.8 kg/m^3, ΔP = 138 MPa, 21% O_2



Low-temperature, mixing-controlled phase operating conditions:

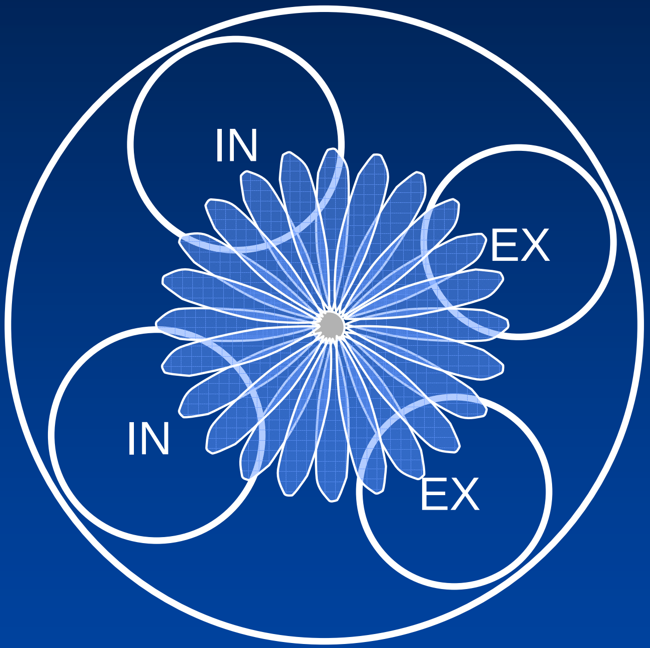
Conditions: D2 fuel, ρ = 14.8 kg/m^3, d = 50 μm, ΔP = 138 MPa



- Soot formation avoided!
- Similar goals and behavior as low flame temperature, low soot production engine strategies.
  - Premixed HCCI
  - MK
  - Smokeless Rich
- However, heat release is closely related to mixing.
- Allows combustion <u>during</u> injection.

Presented results are for single jets--Could micro-orifices be used in an engine?

- In-cylinder air utilization difficulties.
- Large number of orifices are required.
  - Jet-to-jet interactions
  - Multi-injectors?
- Plugging?
- Manufacturing capabilities?



Jet-Jet Interaction in an Engine

Summary and conclusions.

- IN SINGLE ISOLATED FUEL JETS, non-sooting, low flame temperature, mixing-controlled DI diesel combustion is possible.
  - Low ambient oxygen concentration (avoiding soot formation).
  - Lean-burn flames (avoiding high levels of NOx formation) using no EGR.
- Demonstrates limiting-case behavior of single jets.
- With substantial modification to engine hardware, micro-orifices and mixing-controlled diesel combustion MAY have the potential for :
  - Simultaneous engine-out PM and NOx reduction.
  - Higher load operation.
  - More control of heat release timing compared to HCCI.